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Surface Protection Bio-Mortar

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Abstract: It's a well-known fact that concrete structures are susceptible to cracking which allows gases and water to enter and degrade the concrete, reducing the performance of the structure requiring expensive maintenance and repairs. Cracking in the surface layer of concrete mainly reduces its durability, since cracks are responsible for the transport of liquids and gasses which contain potentially deleterious substances. When micro cracks growth reaches the reinforcement, not only the concrete itself may be damaged, but also corrosion occurs in the reinforcement due to exposure to water and oxygen. Micro- cracks are therefore the main downside to structural health. In the project 'Surface Protection Bio-Mortar' we are incorporating a calcite precipitating bacteria namely Bacillus Subtilis with a source, Calcium Lactate which is mainly the supplemental substance used at bacterial food to promote the self-healing mechanism. The bacteria utilizes the supplemental material and gives out precipitates of limestone. To start with, we did literature review of several similar projects and research papers respectively, from which we worked certain values of the bacterial solution and calcium lactate which can lead us to the best possible results. We used a mortar mix of 1:4 which consisted of 1 part of 53 grade Ordinary Portland Cement (OPC) and 4 parts of crushed sand (m-sand). We also formally worked out the mix design where we, based on the reviews of various literatures, decided that we shall make 4 batches of trials with varying content of bacterial culture and the calcium source specifically, 0% of OPC, 7.5% of OPC, 15% of OPC, 22.5% of OPC. The reason behind doing 4 trials is to determine the most optimum dosage and the fastest time period wherein we can achieve the best crack healing. On the day of casting, we prepared 2 plasters, casted 6 cubes for compression testing and 1 cuboidal prism for capillary test. On the plaster samples, we made 2 groves approximately 2 mm thick each of different depths. We also conducted slump test which gave us satisfactory results confirming that the workability is not affected. The compression tests were conducted at 7 days and 28 respectively which also gave expected results which indicate that the bacterial impregnation has actually enhanced the strength of the sample. According to the research papers, we had to observe the plaster sample for at least 40 days under normal environmental conditions which is considered to be optimum to confirm that the self-healing mechanism is active and the cracked or the grooved portion of limestone precipitation which seals the crack making it practically impermeable giving a perfectly alkaline environment for the concrete and the reinforcement halting any further damage caused by corrosion activity, restoring the strength of the surface. Hence it can be averred that such a practice with conventional mortar can be very helpful for maintaining the structural health which in turn can help save a large amount of money.This document gives formatting instructions for authors preparing papers for publication in the Proceedings of an International Journal. The authors must follow the instructions given in the document for the papers to be published. You can use this document as both an instruction set and as a template into which you can type your own text.

Keywords: Subtilis; self-healing; Calcium Lactate**.**

I. INTRODUCTION

Concrete in all the structures, is designed to crack in order to let the steel reinforcement take over tensile stresses. Crack formation is also a typical phenomenon related to durability. Such cracks may lead to leakage problems or penetration of liquids containing harmful chemicals, which can cause deterioration of the concrete body or corrode the reinforcement. Durability can be maintained by preventing further penetration of water and other chemicals and gases. Self-healing mechanism is characterized by the restoration of the structural performance after a crack occurs. Restoration targeted in bacteria-based self- healing mortar particularly relates to increased durability, leakage prevention and extending service life of concrete structures. Jonkers, in (2007) introduced a two-component healing mechanism to be added to the concrete mix, which consists of a calcite precipitating bacterium and a mineral supplemental compound mainly of calcium. Upon cracking the system is activated by introduction of moisture and oxygen. Bacteria, convert the mineral supplemental compound into the mineral calcium carbonate, also known as limestone. Precipitation of the limestone in the crack cavity leads to sealing and plugging of the cracks, making the structure less accessible to water and other deleterious materials. A fully active bacterium based self-healing system exists, which will be explained in this paper.

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II. LITERATURE REVIEW

1)"Healing and Self-Healing of concrete" by Dr. Fixit Institute of Structural Protection and Rehabilitation, Vol. 4, No. 4 (Oct- Dec 2010), A quarterly Newsletter, Reports that Crack repair with a biological treatment in which a Bacillus subtilis culture is incorporated in a gel matrix is most effective. Silica gel can be used to protect the bacteria against the high pH in concrete. This helps to decrease in water permeability. Precipitation of these crystals inside the gel matrix also enhances the durability of this repair material.

2) Chunxiang et al, in their paper published, Nov 2015, aver that the self-healing potential of early age cracks in cement-based materials incorporating the bacteria which can produce carbonic anhydrase. Cement-based materials specimens were pre-cracked at the age of 7, 14, 28, 60 days to study the repair ability influenced by cracking time, the width of cracks were between 0.1 and 1.0mm to study the healing rate influenced by width of cracks. The experimental results indicated that the bacteria showed excellent repairing ability to small cracks formed at early age of 7 days, cracks below 0.4mm was almost completely closed. The repair effect reduced with the increasing of cracking age. Cracks width influenced self-healing effectiveness significantly.

3) H. Jonkers et al, in their paper, facture mechanics of concrete and concrete structures, published in December 2011. Report that, the bacteria are mixed with the concrete that can precipitate calcite in a crack with that make concrete structures water tight and durable.

III. EXPERIMENTAL PROGRAM

The experimental program in this study of our was to use the same Self-Healing mechanism in conventional cement mortar mix (1:4) as according to various literature reviews it is established that the type, shape and size of aggregates does not affect the mechanism as it solely depends on the cement and its basic chemical properties. We also determined the most optimum dosage of bacterial culture and the supplemental bacterial food, to bolster the crack healing mechanism.

MATERIALS REQUIRED

Cement: Ordinary Portland cement of 53 grade having specific gravity of 3.15 was used. The Cement used has been tested for various proportions as per IS 4031-1988 and found to be confirming to various specifications of 12269-1987. Fine Aggregates: The locally available crushed sand also called the m-sand (manufactured sand), is used as fine aggregates in the present study. The sand is free from clay, silt, and organic impurities. The sand is tested for various properties like specific gravity, water absorption and fineness modulus of fine aggregate were found to be less than 4.75 mm down confirms to IS : 383- 1970,(Zone: II). Bacteria: The bacteria used for the experiment is Bacillus subtilis also known as B-subtilis which is commonly used for various agricultural practices. The bacterial count used for the study by us is 20 billion (20 X 108) per gram of the powder. The powder was then cultured in nutrient agar and stored at -5o C. for 24 hours this whole process of culturing the bacteria was carried out at Patchem micro biology Lab, Andheri.

Calcium Lactate: Calcium Lactate which is the supplemental product used to bolster the self-healing mechanism which on combination with B-Subtilis results in the formation of limestone was obtained from amazon.

Mix Proportion.

The mix proportion consist of the conventional mix of 1:4 mortar. Please refer the table page 4 for the same.

Mixing, Casting, Curing & Testing of Specimen

Mixing: The mixing procedure was carried out in a baby mixer combining all the components. First the dry mix of cement and sand was carried out followed by water and bacterial solution mixed in accordance with the water cement ratio after subtracting the amount of bacterial solution from content of water. 4 mix proportions were prepared which differed in bacterial content by 7.5%, starting from 0% to 22.5% of OPC. Casting of specimen: For casting the cubes standard cast iron metal moulds of size 70mm have been used. The moulds have been cleaned and greased. Thoroughly mixed mortar was mixed layer by layer to cast the specimen. The specimen was prepared by hand compaction, finished smooth and kept under curing for 24hrs. Same procedure was carried out for capillary test samples with an exception that they were casted as cuboidal prism 50X50X120 mm. 2 batches each the same proportions were been casted in the form of wall plaster, in which the grooves were made to observe the self-healing.

Curing the specimen: After casting the moulded specimen are stored in the laboratory free from vibrations in moist air at the room temperature for 24hrs. The specimen was cured for 28 days. Testing of specimen: The specimen cured as explained are tested as per Indian Standard 516-1959.

Cube compression test: For the cube compression testing of mortar, 70 mm cube was employed. All the cubes were tested in saturated conditions, after wiping out the surface moisture. For each trial mix combination, 3 cubes were tested at the age of 7 and 28 days of curing. Test was conducted as per IS 516-1959 standard test method. A cube was subjected to a concentrated compressive force where failure under compression was expected to occur.

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Capillary Test: A capillary rise test method is specified by RILEM in a tentative recommendation CPC13. Capillary absorption tests are specified by the Belgian Standards Institute, (NBN B15–217), the Deutches Institute fur Normung (DIN 52617) and the Scandinavians in a Nordtest. Which consisted of placing the cuboidal prism casted of mortar with one of its surface in contact with water for at least 5 hours and later testing the weight gained due to water absorption.

IV. OBSERVATIONS AND DISCUSSION.

Workability: The workability was found to be unaffected even after the addition of the bacterial culture and calcium lactate. So it can be safe to assume that the addition of bacteria along with calcium lactate does not in any way affect the workability which comes out to similar to that of conventional concrete.

Compression Strength: The compression strength was found to have been increased subsequently as the quantity of bacteria increased. The compression test results of 7 days and 28 days justify the same the results of the test carried out are recorded in the table no. 1 on page no. 5.

Capillary Test: The capillary test of the test specimen prepared of all the different batches made of different bacterial compositions was carried out and the result were found out to be satisfactorily convincing that the bacteria are flourishing in the test specimen and the comparison was done based on the readings shown in the table no. 2 on page 6.

The figures below (Fig. No. 1.1 and Fig. No. 1.2) indicate the before and after images of the groves at the time of casting and later the time of testing. Figure No. clearly indicates that the grove on the left which is approximately 4mm in depth and 3mm wide if almost 80% healed.

Figure No. 1.1 (before)

1) The figure below (Fig. No. 1) shows the healed grove (circled red), approximately 4mm in depth and 3 mm wide.

Figure No. 1.2 (after)

V. CONCLUSION

From the study carried as described in this paper and observing the results as shown, we arrive to the following conclusions:

- The workability of fresh mortar is not affected if not increased after the introduction of B-subtilis and calcium lactate with varying proportions in the mortar mix.
- The compression strength of the mortar sample increased significantly and the results of both the 7th day and 28th day reflect the same.
- The capillary test results indicate that the bacterial content is active and flourishing as the retention of water was found to increase with the increase in the bacterial content in the samples. The 60 day observation clearly show the

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formation of limestone deposits in the groves of the plaster samples made artificially which support the claim the the self healing process in actively carried out.

- Experimental studies indicate that such a fussion of biologically active media with conventional mortar, concrete or any such cementatious product can be very effective in situations when microcracks are formed due to internal or external factors.
- The sealing of such cracks, (refer figure no. 1) due to such biologically active media can be very efficient and cost effective saving a subsequent amout of money spent in maintenance of structures and can give a longer life expectancy to the structure.

MIX DESIGN SUMMARY

Trial No.	Trial Ref.	No of Batches	Batch Size	Target Strength	Mortar (Cement : Sand) Ratio	Mixing	Target Flow Initial	Customer	Project	OPC 53 Cement (Kg)	Crushed Sand (SSD) - (Kg)	Crushed Sand (Actual)	Bacillus Subtilis - Solution % of OPC 53	Bacillus Subtilis - Solution Kg / m3	Calcium Lactate - Food % of OPC	Extra Water	Design Free Water	Actual Water	Design Volume	Design Density	W / C
											Water Absorption	Moisture Content									
Date	13/10/2017									Bharthi	3.00%	1.00%									
Batch Size	1.0								Specific Gravity	3.15	2.700%										
Mix Design Volume = 1m3																					
1	TM-001A	-	1.000	7.5MPa	1 : 4	Micro Mixer	Hand Consistency	VCET	R & D	400	1600	1569	0.00%	0	0.00%	-31	227.5	259	0.947	2228	0.57
2	TM-001B	-	1.000	7.5MPa	1 : 4	Micro Mixer	Hand Consistency	VCET	R & D	400	1600	1569	7.50%	30	0.75%	-1	227.5	229	0.947	2228	0.57
3	TM-001C	-	1.000	7.5MPa	1 : 4	Micro Mixer	Hand Consistency	VCET	R & D	400	1600	1569	15.00%	60	1.50%	29	227.5	199	0.947	2228	0.57
4	TM-001D	-	1.000	7.5MPa	1 : 4	Micro Mixer	Hand Consistency	VCET	R & D	400	1600	1569	22.50%	90	2.25%	59	227.5	169	0.947	2228	0.57
Mix Design Volume for Lab Trials																					
1	TM-001A	3.000	0.003	7.5MPa @ 28 Days		Micro Mixer	Hand Consistency	VCET	R & D	1.20		4.71		0.000	0.0000			0.776			
1	TM-001B	3.000	0.003	7.5MPa @ 28 Days		Micro Mixer	Hand Consistency	VCET	R & D	1.20		4.71		0.090	0.0090			0.686			

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1	TM-001C	3.000	0.003	7.5MPa @ 28 Days		Micro Mixer	Hand Consistency	VCET	R & D	1.20		4.71		0.180	0.0180			0.596			
1	TM-001D	3.000	0.003	7.5MPa @ 28 Days		Micro Mixer	Hand Consistency	VCET	R & D	1.20		4.71		0.270	0.0270			0.506			

Nuvoco Vistas Corp Ltd

(formerly Lafarge India Ltd)

Construction Development & Innovation Center (CDIC)

Report Title	Evaluation of Self Healing Mortar with Bacillus Subtilis as Bacteria and Calcium Lactate as Food					
Project	R & D					
Stake Holders	Vidyavardhini College of Engineering and Technology and CDIC					
	Age (Days)	Date	TM 001 B	TM 001 C	TM 001 B	TM 001 C
Cement Name			Bharthi	Bharthi	Bharthi	Bharthi
Cement Content (Kg/m3)			OPC 53 : 400	OPC 53 : 400	OPC 53 : 400	OPC 53 : 400
Sand Source			UltraMod	UltraMod	UltraMod	UltraMod
Sand Type			Crush Stone Sand	Crush Stone Sand	Crush Stone Sand	Crush Stone Sand
			VSI - Plaster Sand	VSI - Plaster Sand	VSI - Plaster Sand	VSI - Plaster Sand
Mortar - Cement : Sand Ratio			1 : 4	1 : 4	1 : 4	1 : 4
Design Free Water (l/m3)			227.5	227.5	227.5	227.5
Self Healing Bacteria			Bacillus Subtilis	Bacillus Subtilis	Bacillus Subtilis	Bacillus Subtilis
Self Healing Bacteria Concrete Addition Method			Diluted - Cultured Solution	Diluted - Cultured Solution	Diluted - Cultured Solution	Diluted - Cultured Solut
Self Healing Bacteria Count / ml Before Additon to Concrete			160 * 10^6 Bacteria / ml	160 * 10^6 Bacteria / ml	160 * 10^6 Bacteria / ml	160 * 10^6 Bacteria /
Self Healing Bacteria Diluted - Cultured Solution Dosage (% of OPC)			0.00%	7.50%	15.00%	22.50%
Bacteria Food			Calcium Lactate	Calcium Lactate	Calcium Lactate	Calcium Lactate
Self Healing Bacteria Concrete Addition Method			Powder	Powder	Powder	Powder
Bacteria Food Dosage (% of OPC)			0.00%	0.75%	1.50%	2.25%
Trial Date			14/10/2017	14/10/2017	14/10/2017	14/10/2017
Batch Size (m3)			0.003 * 3 Batches	0.003 * 3 Batches	0.003 * 3 Batches	0.003 * 3 Batches
Batch Time			13:30	14:15	15:30	16:00
Initial Mini Slump	0		25	35	27	35
Hand Consistency for Mortar Application			Yes	Yes	Yes	Yes
Hardend Cube - Density & Strength Results						
Density (Kg/m3)						
Curing			Water Curing	Water Curing	Water Curing	Water Curing
Density	7		2410	2435	2478	2413
Density	7		2410	2444	2458	2433
Average Density	**7**		**2410**	**2440**	**2468**	**2423**
Strength (Mpa)						
Compressive Strength	7		30.39	38.02	31.99	35.06
Compressive Strength	7		23.12	34.14	32.75	36.17
Average Compressive Strength	**7**		**26.76**	**36.08**	**32.37**	**35.62**

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Table NO. 2

Construction Development & Innovation Center (CDIC)

Self Healing Concrete - Capillary Water Rise Test - BS EN 480 - 5

Sample Weight (Gms)				
Time	TM01-A (% Increase from Initial)	TM01-B (% Increase from Initial)	TM01-C (% Increase from Initial)	TM01-D (% Increase from Initial)
3 HRS.	0.69%	0.75%	0.71%	0.63%
6 HRS.	0.76%	0.82%	0.89%	0.89%
24 HRS.	1.02%	1.10%	1.32%	1.41%
27 HRS.	1.02%	1.10%	1.32%	1.45%
30 HRS.	1.02%	1.14%	1.32%	1.49%
48 HRS.	1.05%	1.14%	1.39%	1.67%
51 HRS.	1.05%	1.14%	1.39%	1.67%
54 HRS.	1.05%	1.17%	1.43%	1.71%
72 HRS.	1.05%	1.17%	1.39%	1.75%
75 HRS.	1.02%	1.14%	1.43%	1.75%
78 HRS.	1.02%	1.14%	1.43%	1.75%
96 HRS.	1.05%	1.17%	1.43%	1.79%
99 HRS.	1.05%	1.17%	1.36%	1.71%
102 HRS.	1.05%	1.17%	1.36%	1.71%
120 HRS.	1.02%	1.14%	1.39%	1.75%
123 HRS.	0.92%	1.17%	1.39%	1.75%
126 HRS.	0.92%	1.17%	1.39%	1.75%
144 HRS.	0.92%	1.17%	1.36%	1.67%

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147 HRS.	0.89%	1.17%	1.36%	1.67%
150 HRS.	0.89%	1.17%	1.36%	1.67%

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