TITLE: RECUPERATION OF CRACKS IN CONCRETE USING MICROBES

Mahir Rather[1], Zeeshan Zahoor[2], Er. Shafaqat Bhat[3]

[1]B.E Student, Civil Engineering Department, SSM College of Engineering, Kashmir, India
[2]B.E Student, Civil Engineering Department, SSM College of Engineering, Kashmir, India
[3]Assistant Professor, Civil Engineering Department, SSM College of Engineering, Kashmir, India

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Abstract: *For the long service life of concrete structures, durability of concrete is very important. But this durability of concrete is greatly influenced by the small cracks which are produced in concrete. Water penetrates through these cracks causing degradation of matrix and finally corrodes the steel reinforced in concrete. So we must make sure that these cracks are filled when they appear. A phenomenon that can fill these cracks automatically is called self healing in concrete. For this purpose, spore forming bacteria with calcium lactate are introduced in concrete which precipitates $CaCO_3$ and finally heal these cracks. Various experiments concluded that Bacillus Subtilis can be used for this phenomenon. This study will investigate the best crack healing technique through changing the quantities of bacteria and carrier compound. This study will further investigate the effect of bacteria on compressive strength of concrete.*

Key Words: *Bacteria, Precursor compound, Curing, Compressive Strength, Cracks and Healing*

1. INTRODUCTION

The most comprehensively used construction material in modern era is concrete. It is cheap, durable, strong and easy to cast in any shape. As compared to its tensile strength, compressive strength of concrete is much higher. But the main limitation of concrete is its brittleness because it is very weak and susceptible in tension. At the very beginning of application of load cracks appear on concrete which further spread throughout the body of concrete due to which concrete finally is not able to give its maximum compressive strength. These cracks pave a way for foreign aggressive chemicals to the reinforcement which is finally vulnerable to chemical reaction in presence of water. As a result this corrosion finally leads to premature failure of concrete. Repair of concrete is a long and inconvenient process. Therefore to counter this problem we opt for sustainable solution like self-healing concrete. In this process the cracks are filled automatically without any human interference. The motive of our research is to investigate self-healing of concrete using bio-influenced techniques. In this method bacteria is used as a healing agent along with precursor compound. This method is suitable for water structures only as water is required to activate the healing process.

2. BACTERIA BASED SELF HEALING

Apart from the microbiological point of view the idea of introducing bacteria in concrete may seem peculiar. Our aim is to create a concrete mix which contains bacteria packed in microcapsules that will activate as soon water enters through cracks. The bacteria will multiply and finally produce limestone and seal the crack before the water can cause any harm. Inducing the bacteria not only seals the cracks but also provide a double layer of protection in preventing steel from the oxygen which is present in crack formation by using it in the reaction. Bacteria based self healing concrete is produced by mixing two components viz spores of bacteria and biochemical healing agent

3. SELECTION AND METHODOLOGY

3.1 Materials used

- Cement-Cement used was TCI 43 grade as it compiles the requirements of IS:8112-2013 for ordinary Portland Cement 43 grade.
- Coarse aggregate-Coarse aggregate of 20mm, specific gravity 2.83 and tested as per IS:2386-1963 was used.
- Fine aggregate-Natural river sand with specific gravity 2.63 and confirming to IS:383 zone 2 was used.
- Water-Local available portable water confirming to standards mentioned in IS:456-2000 was used.
- Microorganisms-Bacillus Subtilis, laboratory cultured bacterium, with a concentration of 108 cells/ml was collected from SKUAST Kashmir.
- Precursor Compound- Calcium Lactate, a white crystalline salt was bought online

3.2 Type of bacteria used

Bacillus Subtilis, a spore forming bacteria was used for self healing due to its ability to survive extreme environmental conditions of temperature and exsiccation. It is an extremely common bacterium which can divide symmetrically to make two daughter cells or asymmetrically to generate a single endospore that can remain feasible for decades and is resistant to unfavorable environmental conditions viz drought, salinity, extreme pH, radiation and solvents.

3.3 Preparation of bacterial solution

Add 12.5g of Nutrient broth to a 500 ml conical flask containing distilled water. Cover it with a thick cotton plug and ensure to make it airtight with paper and rubber band. Now sterilize it using a cooker for about 10-20 minutes. Before the addition of bacteria the solution is orange in color and free from any contaminants. Later 1ml of bacterium is added to sterilized flash and then kept in a shaker at a speed of 150-200 rpm latenight. After 24 hours the bacterial solution was found to be whitish yellow turbid solution.

3.4 Precursor Compound Used

The precursor compound viz Calcium Lactate is necessary to add in the concrete during mixing because the bacteria acts as a catalyst and transforms the precursor compound to a suitable filler material. Calcium Lactate is a white crystalline salt prepared by action of lactic acid on calcium carbonate. It is the chief ingredient used in baking powder.

3.5 Healing phenomenon

When cracks appear on the concrete and water starts to percolate through these cracks, the spores of the bacteria germinate after coming in contact with water and precursor compound. After activation bacteria starts to feed on calcium lactate and oxygen is utilized and the soluble calcium lactate is converted to in soluble limestone. The limestone hardens over the cracked surface and seals it up.

$$Ca(C_3H_5O_2) + 7O_2 \rightarrow CaCO_3 + 5CO_2 + 5H_2O$$

4. PROCUREMENT OF MATERIALS

Coarse and fine aggregates were procured from local markets. As cement tends to lose its strength and starts setting in the bag if exposed to moisture and open atmosphere, therefore we had to procure cement every time one day before casting. Due to unavailability of Calcium Lactate in the local market we had to get this product from e-shopping website Amazon. Procurement of bacteria was very difficult due to limited stock in the valley. The ones which had it was very expensive. Then we procured it from SKUAST Kashmir.

5. INITIAL TESTING

5.1 Sieve Analysis

To analyze the size distribution of aggregates, sieve analysis was performed. The sand was sieved first through 4.75mm sieve to remove particles greater than 4.75mm. Specific gravity of sand used was 2.65.

Table -1: Results of sieve analysis of sand

Sieve Size	Weight of sand Retained [GRAMS]	Percentage Retained	Cumulative% Retained	Percentage Passing
10 mm	0	0	0	0
4.75 mm	12.7	1.27	1.27	98.73
2.36 mm	54.66	5.47	6.74	93.26
1.18 mm	114.59	11.46	18.2	81.8
600 µm	190.9	19.09	37.92	62.71
300 µm	402.9	40.29	77.5	22.42
150 µm	204.35	20.43	98.01	1.99
75 µm	14.43	1.43	99.45	0.55
Pan	5.4	0.54	99.9	0.01

On comparing above results with Table of Zoning IS-383, it was found that the sand belonged to zone 3.

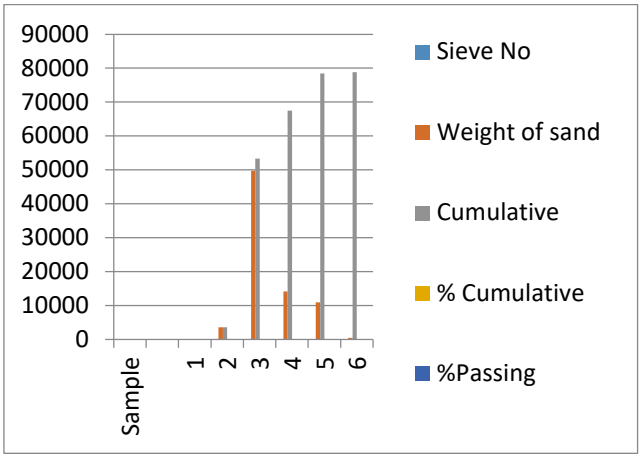

Chart -1: Results of sieve analysis of coarse aggregate

6. CASTING OF SAMPLES

6.1 Types of samples

There were two types of samples viz

- Controlled- The controlled samples were ordinary concrete samples with same mix design as other samples which will be casted in order to compare effect of bacteria on thewiness of concrete.
- Bacterial Samples- To determine the effective quantity of bacteria for providing sufficient healing capability to concrete, three different amounts of bacteria were used. These included

  Bacteria Quantity A = 1% of cement quantity
  Bacteria Quantity B = 1.5% of cement quantity
  Bacteria Quantity C = 2% of cement quantity
  Bacteria Quantity D = 3% of cement quantity

6.2 Types of samples

To check healing capacity and compressive strength of concrete cylinders of diameter 150mm and height 300mm and cubes of size 150mm×150mm×150mm were used.

6.3 Mix Design

Table -2: Mix Design for concrete comprising of two cubes and one cylinder each.

Type	Controlled Sample	Bacteria Sample [A]	Bacteria Sample [B]	Bacteria Sample [C]	Bacteria Sample [D]
Cement [KG]	5.3	5.3	5.3	5.6	5.3
Sand [KG]	7.86	7.86	7.86	7.86	7.86
Coarse Aggregate [KG]	15.77	15.77	15.77	15.77	15.77
Water [L]	2.7	2.7	2.7	2.7	2.7
Calcium Lactate [GM]	0	90	135	180	275
Bacteria [ML]	0	41.08	62.10	82.8	124.2

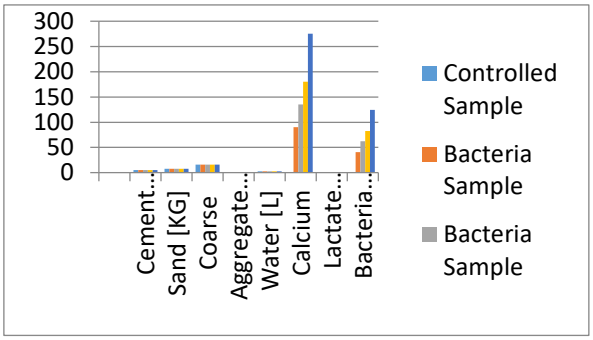

Chart -2: Mix Design for concrete comprising of two cubes and one cylinder each.

6.4 Curing

The samples were placed in curing tank after 24 hours of casting. Half of samples were tested for compressive strength after 7 days and another half after 14 days.

7. CRACK INTRODUCTION AND READING

After the samples were placed in compressive testing machines cracks started to appear on the concrete and the samples were kept under observation for crack measurement. The loading rate was reduced in order to ensure that there shall not be any abrupt change in formation of cracks. Cracks of width less than 0.2mm-0.8mm were studied.

7. RESULTS AND DISCUSSION

7.1 Compressive strength

Table -3: Compressive Strength of different cube samples (kg/cm^2)

Days	Control	Sample A	Sample B
07	117.77	128.85	116.46
28	197.77	201.48	188.62

7.2 Behaviour of casting

- Samples A and B responded in a normal manner after curing of 7 and 28 days but it was found that a fine whitish shade was developed over the irregularities on the surface of samples.
- Samples C and D showed unexpected behavior after initial setting. After placing in curing tank the lost their stability and segregated into raw fragments.
- Compressive strength were affected by the quantity of bacteria and its precursor used.

7.3 Healing Phenomenon

After cracks appeared on concrete the samples were agin placed in curing tank and few samples were placed under normal indoor conditions. It was found that the samples placed in curing tank showed considerable healing as compared to samples placed in indoor conditions.

8. CONCLUSION

After conducting the study of effect on different quantities of bacteria on healing in concrete we concluded that we should opt for Quantity A of bacteria as it has least negative effect on compressive strength of concrete and is economical also. It was also concluded that increase of bacterial quantity, more quantity of precursor material was required which reduced compressive strength of concrete. The use of bio influenced techniques in self healing ensures the concrete to have a higher value of regain as compared to ordinary concrete.

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