

Experimental Study on Self-Healing Concrete Using Bacterial Additives

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Abstract- The durability and service life of conventional concrete structures are significantly compromised by the formation of microcracks, which facilitate the ingress of water and aggressive agents. This experimental study investigates the feasibility and performance of self-healing concrete incorporating bacterial additives as a sustainable crack remediation technique. A ureolytic bacterial strain capable of inducing calcium carbonate precipitation was introduced into concrete mixes using a suitable carrier medium. The self-healing efficiency was evaluated through controlled crack induction followed by curing under favorable environmental conditions. Mechanical properties, including compressive strength, split tensile strength, and flexural strength, were assessed and compared with those of conventional concrete. Crack healing performance was examined using visual inspection, water permeability tests, and microscopic analysis. The results indicate a notable enhancement in crack closure and a significant reduction in water permeability in bacterial concrete specimens. Additionally, bacterial incorporation contributed to improved long-term mechanical strength due to bio-mineralization and pore refinement. The study demonstrates that bacterial self-healing concrete offers an effective, eco-friendly solution for improving structural durability, reducing maintenance requirements, and extending the service life of concrete infrastructure. The findings highlight the potential of bio-based materials as a promising advancement toward sustainable construction practices.

Keywords: Ride Height, Vehicle Dynamics, Ground Clearance, Suspension performance.

I. INTRODUCTION

Concrete has undergone constant evolution since it was first used as a structural material in the 1800s in response to changing field application needs. For instance, the strength of concrete in the early 1950s was normally in the 30–40 MPa range, and it has since significantly grown. Concrete used in the Water Tower Plaza in Chicago in 1974 has a compressive strength of roughly 65 MPa, whereas the Two Union Square Building built in Seattle in 1989 has a compressive strength of more than 130 MPa. In general, the need to create larger structures - longer span bridges and taller buildings - and to build them faster was the driving force behind the strength growth of concrete. Initially, cement of increasing fineness was used to achieve this.

Later, the availability of microsilica and superplasticizer accelerated the trend of increasing concrete strength, resulting in concrete with a larger

gel/space ratio while keeping good workability. By the 1990s, it was evident that increasing strength alone was insufficient to raise the standard of infrastructure. Instead, a more expansive definition of high performance was adopted in response to the global need to address the premature deterioration of concrete infrastructure. High performance concrete is frequently used to refer to concrete that has improved durability, which is typically achieved by densifying concrete and is indicated by a low water permeability as tested in the lab (in the uncracked state). In Japan, a shortage of qualified workers in the industry was linked to concerns over the quality of concrete.

The solution to this problem was the creation of a different kind of high performance concrete in the late 1990s called self-consolidating or self-compacting concrete, which did away with the requirement for skill-dependent vibration of fresh concrete in the field. Despite being more expensive,

self-consolidating concrete provides a benefit that has been demonstrated by the growth in its use across the globe. Since about 2000, the practice in the building industry and its material suppliers has been impacted by the widespread desire for sustainable development, which is linked to the increased awareness of climate change. As a result, the sector undertook a number of carbon and energy reduction initiatives that are still in place today. These initiatives include increasing the effectiveness of the kilns used to make cement, combining portland cement with other pozzolans made from waste streams from other sectors, creating green or ecological cements, using recycled concrete as aggregates, and others. Future concrete development to meet societal requirements is anticipated to go much more quickly. While improvements in concrete's strength, durability, and greenness each address specific pressing issues, the use of new concrete technologies also highlights the shortcomings of conventional methods.

II. MATERIALS USED

1. Cement

Ordinary Portland Cement (OPC) of 53 grade conforming to IS 12269:2013 was used as the primary binder in this experimental investigation. The cement exhibited good fineness, normal consistency, and satisfactory setting characteristics. The selection of OPC 53 grade ensured adequate early-age and long-term strength development, which is essential for evaluating the effectiveness of bacterial self-healing mechanisms.

2. Fine Aggregate

Natural river sand conforming to Zone II as per IS 383:2016 was used as fine aggregate. The sand was clean, free from organic impurities, and well-graded. Proper grading of fine aggregate contributed to improved workability, reduced void content, and enhanced matrix compactness, which supports bacterial mineral precipitation within microcracks.

3. Coarse Aggregate

Crushed angular coarse aggregate of maximum nominal size 20 mm conforming to IS 383:2016 was used. The aggregates possessed adequate strength,

toughness, and abrasion resistance. A well-graded combination of 20 mm and 10 mm aggregates was adopted to achieve dense packing and minimize pore connectivity in the hardened concrete.

4. Water

Potable water free from organic matter, oils, acids, and salts was used for mixing and curing of concrete, conforming to IS 456:2000. Clean water is essential for proper cement hydration and bacterial metabolic activity.

5. Bacterial Strain

A ureolytic bacterial strain, *Bacillus* species (commonly *Bacillus subtilis* or *Bacillus sphaericus*), was used due to its ability to survive in alkaline environments and induce microbiologically induced calcium carbonate precipitation (MICP). The bacteria were selected based on their spore-forming capability, which enables long-term viability within the concrete matrix.

6. Bacterial Culture Medium

The bacterial spores were cultivated in a nutrient medium containing urea, calcium source, and essential nutrients to promote metabolic activity. The medium supports bacterial growth and enhances calcium carbonate precipitation when activated by moisture ingress through cracks.

7. Carrier Material for Bacteria

To protect bacterial spores from harsh concrete conditions and to ensure sustained viability, bacteria were encapsulated using a suitable carrier material such as lightweight aggregates, silica gel, or porous ceramic particles. The carrier acts as a protective reservoir and releases bacteria upon crack formation and water penetration.

8. Calcium Source

A soluble calcium source such as calcium lactate or calcium chloride was incorporated to facilitate calcium carbonate precipitation during bacterial metabolic activity. The availability of calcium ions is critical for effective crack sealing through calcite formation.

9. Chemical Admixture

A polycarboxylate ether-based superplasticizer conforming to IS 9103:1999 was used to achieve desired workability without increasing the water-cement ratio. The admixture ensured uniform dispersion of bacterial additives and improved the fresh concrete properties.

III. METHODOLOGY

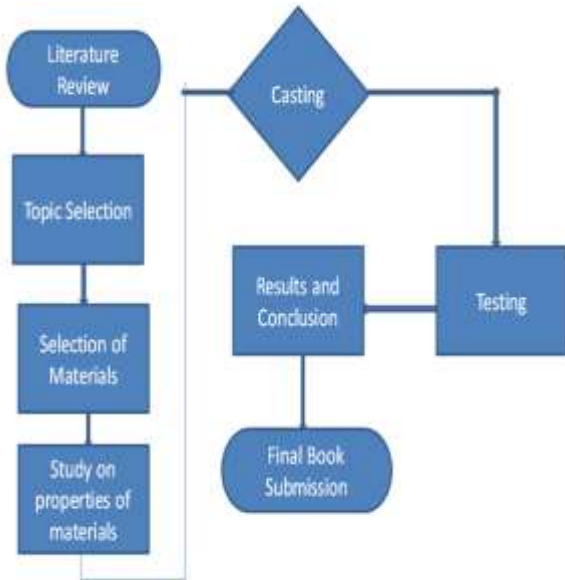


Table 1 a) Mix ratios of ECC

	Cement	Mineral admixture	Chemical admixture	Sand	Water	Fibre
Ratio	1.0	1.2	0.0012	0.8	0.56	0.02

Table 4.1 b) Mix ratios of ECC

Mix ID	Cement	Fly ash	GGB S	Silica fume	sand	water	HRWR	PVA Fibre	PP Fibre
ECC M1	1	0.8	0.4	—	0.8	0.56	0.012	2	—
ECC M2	1	0.4	0.4	0.4	0.8	0.56	0.012	1.5	0.5

IV. TESTS



Figure 1 a) Casting



Figure 1 b) Casting

Compressive strength

ECC has a compressive strength range of 30 to 90 MPa. Due to the lack of coarse particles, it often has a lower elastic modulus than concrete (about 20–25 GPa). ECC has a little greater compressive strain capacity, anywhere between 0.45 and 0.65%. The testing in this case uses 100mm*100mm*100mm cubes.

Compressive force

ECC has a compressive strength range of 30 to 90 MPa. Due to the lack of coarse particles, it often has a lower elastic modulus than concrete (about 20–25 GPa). ECC has a little greater compressive strain capacity, anywhere between 0.45 and 0.65%. Testing is done using these 100mm*100mm*100mm cubes.

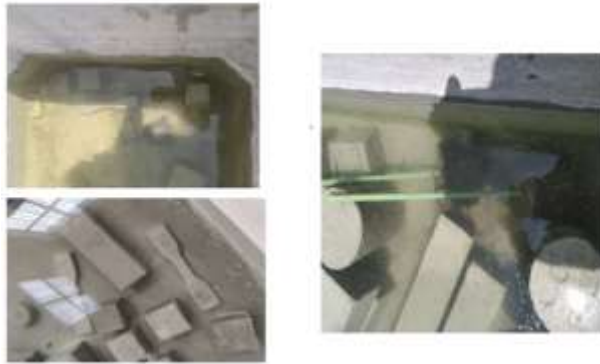


Figure 2 Curing

Fineness Test

The fineness of cement can be defined as the measure of size of particles of cement or in simple form "Specific Surface of Cement". This test is usually carried out using IS sieve no.9 or 90 microns



Figure 3 Fineness of cement



Figure 4 Set of Sieves

Setting Time Test

When cement and water are combined, a chemical reaction occurs that causes the mixture to progressively become harder over time. Initial Setting Time (IST) and Final Setting Time (FST) are the two different cement setting times. Vicat's apparatus is used to test it. For Portland Cement, for example, IST is around 30 minutes and FST is roughly 600 minutes.

Initial Setting Time Test

Underneath the rod containing the needle, place the test block. Gently lower the needle to make touch with the cement paste's surface, and then rapidly let go to allow it to pierce the test block. Continue until the test block cannot be pierced by the needle at a position 5.0 0.5mm measured from the mold's base. The first setting time is the amount of time that passes between adding water to the cement and the test block failing to penetrate the needle by 5.0 0.5mm when measured from the mould's base.

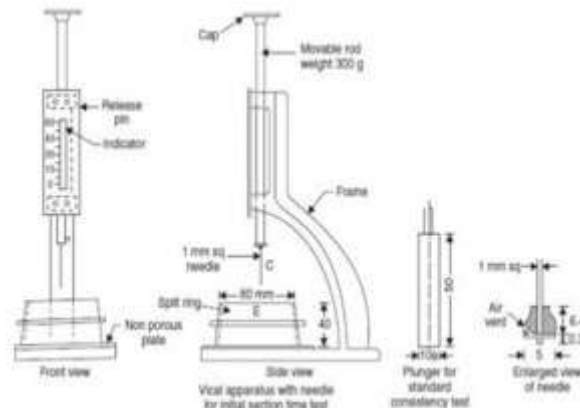


Figure 5 Le-chatelier Apparatus

Final Setting Time Test

Substitute the needle with the annular attachment for the one above. When the attachment fails to leave an impression on the test block's surface after gently pressing the needle against it, the cement is regarded to have fully set. The final setting time is the amount of time that passes between adding water to the cement and the moment the needle produces an impression on the test block's surface but the attachment doesn't.



Figure 6 Test set up

Strength Test

Cement strength is measured in MPa or N/mm². Strength should reach 33 MPa for Portland cement grade 33 after 28 days. The strength of cement is tested using a compression test.



Figure 7 cube moulds



Figure 8 Preparation of cube moulds



Figure 9 Universal Testing Machine

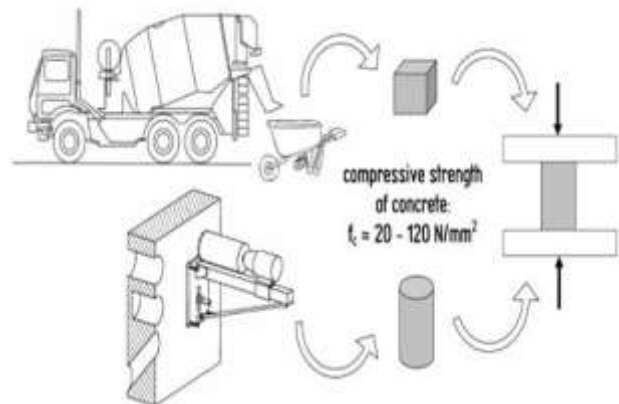


Figure 10 Compressive Strength Test procedure

Heat of hydration Test

The heat of hydration is the heat released from cement paste as a result of the interaction between water and cement. Thermos flasks are typically used for this test.



Figure 11 Heat of Hydration apparatus

Fine Aggregate

- Sand sieve analysis

To maintain the appropriate grading of the sand that is to be utilized, the sand sieve analysis is performed as frequently as is necessary. A typical sample of dry sand is run through a sequence of BS sieves Nos. 7, 14, 25, 52, and 100 (or local equivalent standard), commencing with the biggest sieve, to determine the grading of a sand aggregate for Ferrocement. A record of the outcome should be kept, and it should be compared to the necessary acceptable envelope.

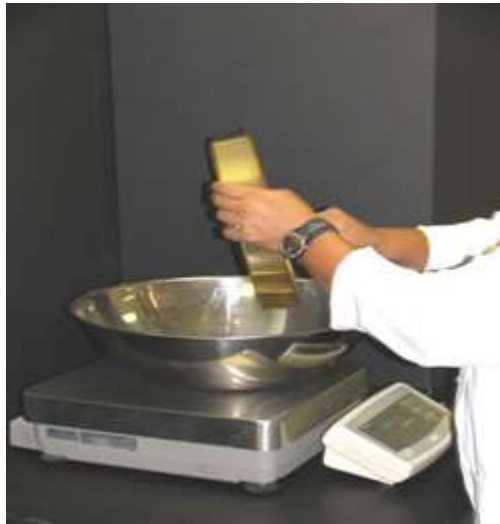


Figure 12 weighing Balance



Figure 12 Set of Sieves

Bulking of sand

Sand is presumed to be dry when combinations are given by volume. However, the amount of sand might vary depending on its moisture content. Equal weights of dry and submerged sand occupy roughly the same volume, however the same weight of moist sand might take up a volume that is up to 40% more. 'Bulking' is the term used to describe this behavior. You may show it by adding dry sand to a gauge box. The level will somewhat sink if the sand is submerged in water, but not much. The level decrease will be significantly larger when the box is similarly filled with wet sand and the surface is flooded.

If you batch by volume without taking bulking into account, your mortar could not have enough sand. This is one of the causes for choosing weight-based measuring. Fine sands bulk up much more often



Figure 13 Bulking of sand

Compressive strength

Sand is presumed to be dry when combinations are given by volume. ECC has a compressive strength range of 30 to 90 MPa. Due to the lack of coarse particles, it often has a lower elastic modulus than concrete (about 20–25 GPa). ECC has a little greater compressive strain capacity, anywhere between 0.45 and 0.65%. The testing in this case uses 100mm*100mm*100mm cubes.



Figure 14 Compressive strength setup



Figure 15 Compressive strength testing

Tensile strength

A dog bone specimen with dimensions of 330 mm x 60 mm x 30 mm, a gauge length of 80 mm, and a cross section of 30 mm x 30 mm was used to assess the direct tensile strength of ECC mixtures. Tests are conducted 7 days, 14 days, and 28 days after cure. The direct tensile strength test is conducted using a universal testing equipment with a 100 kN capability.

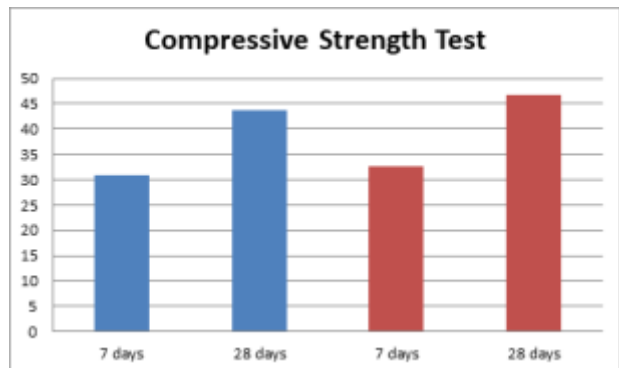
Pull out test

The strength of the frictional binding is assessed using a pull-out test with a 4 mm embedding length. The influence of micromechanical parameters in general and frictional bond strength in particular is taken into account in an equation that is proposed to assess the ultimate flexural strength of ECC.



Figure 16 Pull out test apparatus

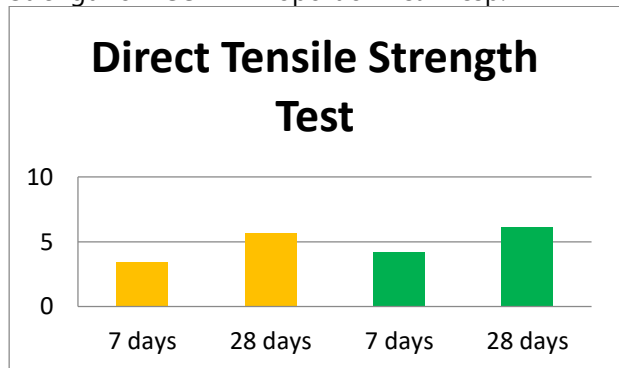
V. RESULTS



Graph 2 Compressive Strength Test

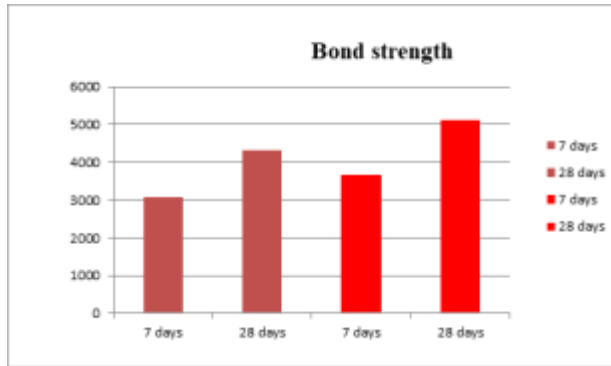
Tensile strength

The graphical representation of Direct Tensile Strength of ECC Mix Proportion 1&2 Resp.



Graph 3 Direct Tensile Strength Test

Pull out test



Graph 4 Bond Strength Test

Durability

Given the relatively recent invention of this material, the long-term performance of ECC in full-scale structures has not been completely demonstrated. However, there is some evidence to support the claim that ECC can be resilient in real-world field situations from at least two field demonstration tests. In one research (Rokugo et al., 2005), ECC was used to repair an alkalisilica reaction (ASR)-damaged concrete gravity earth-retaining wall that was 18 meters wide and 5 meters tall. The necessity to stop substrate concrete fractures from reflecting onto the repair layer led to the choice to utilize ECC for the 50–70 mm thick repair overlay.

Given the ongoing ASR growth, such reflection would have been expected if regular concrete had been utilized in this repair. The wall was separated into 9 repair blocks for demonstrative purposes, leaving one block (block 10) undamaged. Two different kinds of ECC, one with 1.5% hybrid PVA and PE fibers (blocks 1-4), and the other with 2.1% PVA fibers (blocks 5-8), were applied to the repaired blocks. Either expanded metal reinforcement, welded wire mesh reinforcement, or no reinforcement was employed in each block. On block 9, a repair mortar with welded wire mesh reinforcement was used for control. This wall has been under constant observation ever since the 2003 restoration. While the blocks restored with regular mortar showed visible cracking within one month after repair, the overlay did not show any signs of cracking until seven months following restoration by ECC. At 10 and 24 months, the crack widths in the

ECC repair blocks were less than 50 μ m and 120 μ m, respectively.

The typical repair mortar block, on the other hand, had crack widths of 200 μ m and 300 μ m at 10 and 24 months, respectively. Figure 26 depicts the fracture patterns at 12 months and 24 months. A modest ECC patch repair that was applied to the bridge deck of Curtis Road over M-14 in Southern Michigan in 2002 in cooperation with the Michigan Department of Transportation provides another opportunity for long-term performance evaluation. Li and Lepech (2004) have provided a thorough description of this study. During this project, a segment of a bridge deck that had been degraded was restored using ECC, and the remaining area was fixed using a commercial concrete patching compound that was frequently utilized by MDOT.

VI. CONCLUSION

ECC has several attractive features. Most unique is the hundredfold high tensile ductility of concrete while maintaining the compressive strengths similar to concrete or high-strength concrete. ECC's metal-like behavior is accomplished without high fiber content, breaking the conventional wisdom of the need for high-volume fiber fraction to achieve high product efficiency. The moderate fiber content (2% or less per volume) makes ECC easy to adapt to field construction project execution or prefabrication of structural elements from plants. In fact, ECC has shown flexibility in processing routes, including on-site self-consolidating casting and spraying, as well as precasting and extrusion off-site. It is obviously important to maintain a moderately low fiber content, also for economic reasons.

ECC's large tensile ductility enables compatible deformation and creates a synergistic load sharing capacity in structural members with steel reinforcement. This improves the use of steel reinforcements in R / ECC members to improve structural performance. At the same time, ECC's narrow crack width protects steel reinforcement from conventional corrosive methods, resulting in increased longevity of the structure. A number of full-scale ECC implementations have been carried

out in different countries in recent years. Among these is the use of ECC in prefabricated R / ECC coupling beams at the heart of Japan's two high rises. (Ali, Soliman et al. 2017) This technology utilizes R / ECC's high energy absorption ability to assist such tall buildings in seismic resistance. Sustainable infrastructure in developed and developing countries is key to sustainable economic growth. Technological advances in materials will contribute to this global effort.

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