Impact of Self-Healing Concrete on Precast Construction Technique

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ABSTRACT

India is one of the world's major users of concrete and the world's second-largest cement producer; as a result, the country's carbon footprint is increasing, contributing to global warming and climate change. The ozone layer is being depleted and the air quality is deteriorating as a result of greenhouse gas emissions. As a generation, we face an urgent need to take drastic measures to reduce emissions which is possible by adopting sustainable and eco-friendly techniques to some extent, particularly in the field of construction. The paper helps to understand the technology and material composition of precast construction as well as the mechanism and composition of self-healing concrete. The paper focuses on analyzing a potential alternative to conventional concrete in precast construction with self-healing concrete by laying down the advantages and disadvantages of the material. The study looks upon the cost analysis of conventional and self-healing concrete which is an important factor in proving the argument. The study is based upon factors affecting self-healing concrete, which are crucial in proposing a substantial replacement and it also discusses the potential advantages of fusing precast construction techniques with self-healing concrete. Reducing the usage of conventional concrete would reduce cement output and, in turn, carbon emissions. The research is a compilation of separate research domains of material and technology that helps us explain the need and urgency for a move to sustainable practices, particularly in India.

Keyword: Aggregate, microcracks, bacterial concrete, calcium carbonate, dry volume

I INTRODUCTION

Starting with the early age of mud building, when concrete had not yet been produced and was regarded as an uncommon material, the construction industry has experienced different changes of methods to materials. On the other hand, the same concrete is now a standard and common material, and the globe is striving for greater progress. Our man-made world is constructed on concrete, which is now the second most consumed material on the planet after water by humans. As a result, we see it being utilized in nearly every kind of construction, but we must ask ourselves whether we are harnessing concrete to its maximum potential. At every stage of development, the construction industry has seen a rise in technological advancement i.e., from cast-in-situ to precast, pre-stress, post-tension, etc but there is a significantly lesser development in the material aspect of these technologies. Bisht et al. [1] Every year cement production emits a large amount of carbon dioxide and other harmful gases into the environment, which is a major threat globally and to reduce CO2 emission by 1 million tons by 2030, India surely needs to bring down the emission alone by cement production. This problem requires a unique solution that somehow reduce the demand for concrete or increase the life span of concrete which eventually makes the requirement for cement reduced therefore lesser emission.

K. et al. [2] Self-healing concrete is one of the very new materials which can help in achieving this goal because when exposed to water, self-healing concrete creates calcite, which self-heals fractures in the structure, decreasing infrastructure maintenance costs and greenhouse gas emissions. While on the other hand there is precast construction technique which is very efficient in strength and time as the production of components take place in a controlled environment due to which time of construction is drastically reduced and the desired strength can be achieved instantly. Self-healing concrete mixed with precast construction technology might prove to be significantly more efficient in terms of performance, life duration, carbon emission, and other factors in the future. The research focuses on the components of precast technology and self-healing concrete and how they will eventually replace the traditional way of construction and proceed to a green and sustainable future along with a greater material strength hence getting mankind ready for future natural disasters.

II LITERATURE REVIEW

Gutierrez [3] India is now classified as a developing country, but according to statistics, it will become a powerhouse nation by 2035. This suggests that India would have grown efficient and strong in different industries by then, such as business, automobiles, stock markets, food, and transportation, and that to be a superpower, India would need a solid infrastructure, which is heavily reliant on our building industry. The industry has to develop quickly and experiment with different types of sustainable materials and technologies. Why is it that the United States use a building technology that India has yet to adopt? Why aren't we seeing green concrete or other sustainable materials utilised on-site? This might be due to a lack of knowledge, affordability, structural strength, or other factors. India is the world's third-largest emitter of greenhouse gases, with the construction sector accounting for a significant portion of carbon dioxide emissions from the manufacturing of concrete, cement, and other building materials. So, based on the data, we can infer that we need to begin revolutionising our business, innovate, and encourage the use of environmentally friendly products and procedures. In terms of materials, many sustainable materials are gradually displacing traditional materials such as bricks. Super-thin steel, solar concrete façade cladding, bamboo, hempcrete bricks, and timber crete are just a few examples of sustainable materials. Outside of India, these materials are widely utilised, but not so much in India. Rather than discussing different futuristic materials, the emphasis is on investigating sustainable structural materials in the Indian context. The focus lies particularly with the precast form of construction which is a prime technique for construction of large structures. If there is a change brought in the materiality of the technology by enhancing the life span of the structure then it would become one of the most highly efficient forms of building.

III METHODOLOGY

The research has relied on different primary and secondary sources for data collection. The study aims to discuss the technical details of the construction techniques using various data sources. It is based on a practical approach required to prove the potential of self-healing concrete as an alternative to conventional concrete. The study then talks about the material composition and grade of concrete being used for precast construction which is an important factor to gain knowledge of the current properties of the material used with it. The second stage comprises of detailed study about the composition and mechanism of self-healing concrete using available secondary sources and a study about the various types of bacteria suitable for the concrete. This stage includes cost comparison between 1cum of precast conventional concrete and self-healing concrete, which is a major finding in the research. The third stage is analysing the result of the study and listing out potential advantages of the fusion of these two components.

IV STUDY

(a) About pre-cast construction technology - Council [4] Precast construction technique is a process that involves pouring concrete into a reusable mould or form and treating it in a controlled environment prior to being transported to the project site and hoisted into place. Precast construction technology entails the use of precast components such as walls, beams, slabs, columns, stairs, and landings, as well as some distinctive characteristics, to assure the stability, durability, and structural integrity of the structure. The precast residential building construction process includes design, strategic yard planning, lifting, handling, and shipment of precast sections. This technique may be used to construct high-rise buildings that are capable of withstanding seismic and wind-induced lateral strains in addition to gravity loads. The structure is constructed in such a way that the maximum number of mould repeats is achievable. These components are made under strict quality supervision. The manufacturing is located on or near the site, which reduces costs associated with storage and shipping.

(i) Types of Precast elements

- **Precast reinforced concrete element -** Council [4] Reinforcing bars and/or welded wire meshes are required for structural strength in components such as façade walls, beams, columns, slabs, staircases, and parapet walls.

Table 1
Types of Precast elements

Sr. No	Precast Components	Typical Sizes
1	Wall Panels	Sizes of panels may vary as per requirement
2	Hollow Core Slabs	
3	Beams	
4	Staircase	
5	Columns	

- **Moulds -** Council [4] For precast items, steel and concrete moulds are necessary. When developing the moulds for various components, special attention should be given to the simplicity of de-moulding and assembly of the various portions. The stiffness, strength, and water tightness of the mould are particularly important when considering stresses induced by the pouring of green concrete and vibration.

Table 2
Types of mould

S. No.	Mould type	Uses
1.	Conventional moulds	Ribbed slabs, beams, window panels, box type units and special elements
2.	Tilting moulds	Exterior wall panels where special finishes are required on one face or for sandwich panels
3.	Long line prestressing beds	Double tees, ribbed slabs, piles and beams
4.	Prestressing bed with Extrusion machine	Hollow core slabs andhollow core non load bearing wall

(ii) Precast construction equipment

- Council [4] **For the Production of Hollow Core Slabs**
  - ✓ Extruder Machine - EVO E120 for casting of hollow-core slabs for floor
  - ✓ Extruder Machine - NANO for the casting of partition wall panels and floor slabs
  - ✓ Multifunction bed cleaner machine for bed cleaning, spraying mould release agent, strand laying etc.
  - ✓ Stressing and destressing equipment
  - ✓ Cutting saw machine
  - ✓ Four long line prestressing beds with hydraulic destressing cylinders
- **For Production of Wall, Beam & Column**
  - ✓ Tilting Table for Wall Panels
  - ✓ Magnetic Sides & Shuttering
  - ✓ Beam Mould – Flexible sizing for width, thickness & length
  - ✓ Column Moulds – Flexible sizing for width, thickness, length and corbels.
  - ✓ Stair Mould
- **For Concrete Distribution**
  - ✓ 2 flying buckets & rails
  - ✓ Discharge chutes
  - ✓ Distribution buckets
  - ✓ 4 EOT cranes (Electrical Overhead Travelling cranes)
- **Batching Plant**
  - ✓ Concrete Batching Plant - SP60 Planetary Mixer
  - ✓ Concrete Batching Plant - SP60 Twin-shaft Mixer
  - ✓ 5 silos for storing concrete & fly ash
- **Other Miscellaneous Machinery**
  - ✓ Concrete Buckets (MS)
  - ✓ Bar Bending and Cutting Machine
  - ✓ Power Floater
  - ✓ Water Pressure Machine
  - ✓ Shutter Vibrator
  - ✓ Strand Decoilers
  - ✓ Trampoline Laying Trolley
  - ✓ Weighbridge
  - ✓ Air Compressors
  - ✓ DG Sets
- **Transportation and lifting Machinery**
  - ✓ Element Lifting- Lifting beam with hydraulic clamps.
  - ✓ Lifting beam Mechanical clamps.
  - ✓ EOT Crane – 10 ton (3 nos.) & 15 ton (1 no.)
  - ✓ Pick & Carry Mobile Crane F160 - ACE Make
  - ✓ Backhoe Loader Digimax II - ESCORTS Make
  - ✓ Nylon Lifting Belts Various Capacities
  - ✓ Chain & Pulley Blocks
  - ✓ Chain Slings etc
- **Q.C Machinery and Apparatuses and lifting Machinery**
  - ✓ Compression Testing Machine 3000 KN
  - ✓ Vibrating Table
  - ✓ Pan Mixture
  - ✓ Oven Up to 300oc
  - ✓ Weighing Scales
  - ✓ Flakiness Gauge
  - ✓ Elongation Gauge
  - ✓ Aggregate Crushing Value Apparatus
  - ✓ Aggregate Impact Value Apparatus
  - ✓ Sets of sieve shaker

- ✓ Measuring Flask and Jar
- ✓ Cube Moulds etc

(b) Composition/Mix design in Precast construction - Sir [5] The most common pre-cast concrete mix design is M25 Grade, which has a design mix ratio of 1:1:2 (Cement: Sand: Aggregate) with a compressive strength of 25N/mm^2. The quantity of cement, sand, and aggregate required for 1 cubic metre of M25 concrete is calculated using the following formula-:

(ii) The wet volume of concrete = 1m^3

(iii) Mix ratio for M25 concrete = 1:1:2

(iv) The dry volume of concrete is equal to 1× 1.54 = 1.54 m^3 (cubic meter)

(v) Total mix proportion is equal to 1+1+2 = 4

(vi) Where part of cement is equal to 1/4, part of sand is equal to 1/4 & part of aggregate is equal to 2/4

- **M25 cement requirement (in cubic metre) -** Cement required for 1 cubic metre of M25 concrete in cubic metre = 1/4 × 1.54 m^3 = **0.385 m^3**
- **M25 cement requirement (in Kgs)-** Density of cement = 1440 Kg/m^3 Cement required for 1 cubic metre of M25 concrete in Kgs (kilogram) = 1/4 × 1.54 m^3 × 1440 Kg/m^3 = **554 Kgs**
- **Cement bags required for M25 grade-**1 bag cement weight = 50 kgs Cement bags required for 1 cubic metre of M25 concrete = 554/50 = 11.08 = **11 bags**
- **Sand required for M25 grade (in cubic metre) -** Sand required for 1 cubic metre of M25 concrete in cubic metre = 1/4 × 1.54 = **0.385 m^3**
- **Sand required for M25 grade (in Kgs) -** The density of sand is equal to 1620 Kg/m^3 Sand required for 1 cubic metre of M25 concrete in kgs = 1/4 × 1.54 m^3 × 1620 Kg/m^3 = **624 Kgs**
- **Sand required for M25 grade (in cft) -** 1 cubic metre = 35.3147 cft Sand required for 1 cubic metre of M25 concrete in cubic feet = 1/4 × 1.54 m^3/35.3147 × 1620 Kg/m^3 = **18 cft**
- **Aggregate required for M25 grade (in cubic metre) -** Aggregate required for 1 cubic metre of M25 concrete in cubic metre = 2/4 × 1.54 = **0.77 m^3**
- **Aggregate required for M25 grade (in Kgs) -** The density of aggregate is equal to 1550 Kg/m^3 Aggregate required for 1cubic metre of M25 concrete in Kgs = 2/4 × 1.54 m^3 × 1550 Kg/m^3 = **1194 Kgs**
- **Aggregate required for M25 grade (in cft) -** 1 cubic metre = 35.3147 cft Aggregate required for 1cubic metre of M25 concrete in cft = 2/4 × 1.54 m^3/35.3147 × 1550 Kg/m^3 = **36 cft**

Table 3
Mix quantities of 1 cubic metre of M25 grade concrete with different units

Grade of concrete	bags	Kgs	cft	m3
cement quantity	11	554		0.385
Sand quantity		624	18	0.385
aggregate quantity		1194	36	0.77

Institute [6] Precast concrete sets in 16 hours and reaches 28-day strength in only 16 hours because of the greater curing temperature and regulated atmosphere. Standard [7] The precast concrete component is ready for shipment in only two days, and transportation time after that is extremely specific and varies by location, but on average, two days is a regular completion time.

(c) Cost analysis of Precast construction

Table 4
Rate analysis of 1 cubic metre of M25 grade concrete

Particulars	**Unit**	**Quantity**	**Rate (Rs)**	**Amount (Rs)**
1:1:2 (1 cement: 1 coarse sand: 2 graded stone aggregate of 20mm nominal size) including curing				
Details of the cost of $1m^3$ of M25 concrete				
Materials				
Cement	Bags	11.16	350	3906
Sand	m^3	0.385	1800	697.5
Coarse Aggregate	m^3	0.775	1500	1162.5
Manpower				
Foreman	Each	0.05	800	40
Mason	Each	0.3	700	210
Male Mazdoor	Each	1	500	250
Female Mazdoor	Each	1	400	200
Waterman	Each	0.2	400	80
			Subtotal	**6546**
Tools & Tackles			1%	65.46
Power Consumption			2%	130.92
Add for sundries & contingencies			3%	196.38
Add for overhead & contractor profit			15%	981.9
			Rate per cubic metre	**7921**

(d) About Self-Healing concrete - K. et al. [2] Concrete is the most often used construction material. Fractures are inevitable because concrete is fragile in tension yet strong in compression. When concrete cracks form, the concrete's lifespan may be diminished. Microcracks and pores in concrete are unwelcome because they provide an open route for water and other hazardous elements to enter, resulting in reinforcement corrosion and a decrease in the concrete's strength and durability. A number of techniques may be used to heal the cracks, but they are both expensive and time-consuming. Self-Healing Concrete is a viable method for healing concrete cracks on its own. Because it is bio-based, ecologically friendly, cost-effective, and long-lasting, this bacterial remediation method surpasses others. Because concrete is alkaline, bacteria added to it must be able to withstand the alkaline environment, and most microorganisms die at a pH of 10. Bacteria with a calcium feeding source are added to the concrete at the time of mixing. Bacteria will precipitate calcium carbonate if there are any cracks in the concrete. As a consequence, the fractures will be sealed. The production of urease enzyme by urease positive bacteria has been shown to affect calcium carbonate precipitation (calcite). As a result, the pH of calcite precipitation increases. Fractures bigger than 0.8mm are more difficult to repair, although when bacteria are utilised, fissures may mend with calcite precipitation.

K. et al. [2] Some of the "Urease positive bacterium are – Bacillus megaterium, Bacillus pasteurii, Bacillus sp. CT-5, Bacillus subtilis, Bacillus aerius, Sporosarcina pasteurii, AKKR5, Shewanella Species, Bacillus flexus etc." The bacteria-based self-healing agent is said to be able to hibernate under the concrete for up to 200 years. The microbial activity begins when bacterial spores come into contact with water and oxygen as a consequence of concrete cracks. Self-healing methods have recently demonstrated promising results in mending fractures in the early stages of development. In order to get excellent results, the fractures must not be deeper than 150mm. The following are the three self-healing concrete processes-: (i) natural process (ii) chemical process, (iii) biological process

(i) **Natural Process -** Magaji et al. [8] This process, which is separated into four ways, can substantially repair concrete fractures-:
- Formation of CaC03 or Ca0H (calcium carbonate or calcium hydroxide)
- Crack is obstructed by impurities in the carriage of water
- Crack is further obstructed by hydration of the unreacted cement

- Crack is impeded by the enlargement of hydrated cementitious pattern in the crack loins (such as the lump of calcium silicate hydrate gel)

Magaji et al. [8] The occurrence of more than one of these processes at the same time is known as a multiple event. The majority of these methods may only be able to partly heal the holes of specific fractures, rather than totally closing them. This will help to slow the progression of fractures and prevent the intrusion of caustic chemicals like acids. Calcium carbonate and calcium hydroxide configurations are the most popular and successful solutions for spontaneously mending concrete among the self-healing measures identified in natural processes.

$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + NCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$ (Equation 1)

As a consequence of cement hydration and dissipation, loose calcium ions are discharged into concrete, where they are opposed by NCO_3^- and CO_3^{2-} at cracking surfaces. Calcium carbonate crystals occur as a consequence. Only pH levels higher than or equal to 7.5 may cause reactions 2 and 3. Crystals grow on the fracture surfaces and gradually pervade the region.

$Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_3$ (Equation 2)

$Ca^2 + HCO_3^- \leftrightarrow CaCO_3 + H^+$ (Equation 3)

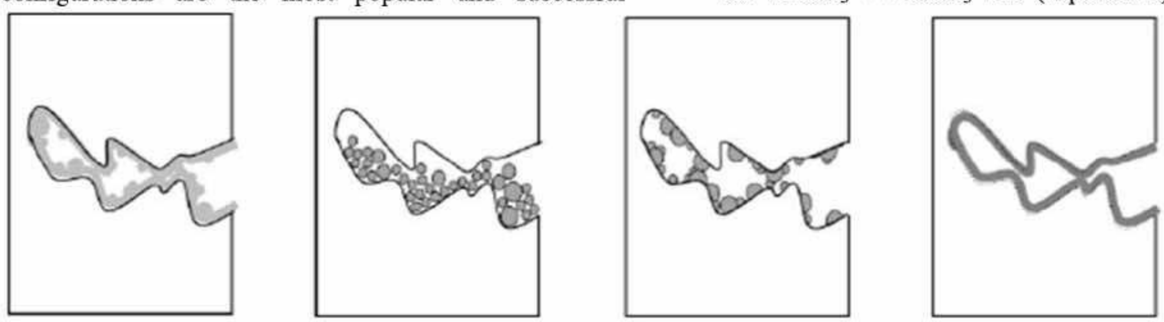

Fig.1 Types of natural processes in self-healing concrete

(ii) **Chemical Self-healing Process -** Magaji et al. [8] Chemical healing is a term that refers to the use of chemical composites in artificial healing. To make self-healing concrete, chemical liquid reagents (glue) are combined with fresh concrete in tiny containers. There are two kinds of chemical processes: a) glue-filled hollow pipettes and vessel networks; and b) encapsulated glue.

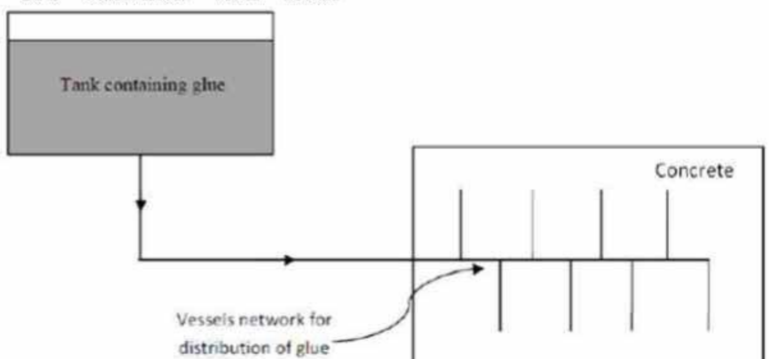

Fig.2 Hollow pipettes and vessel networks containing glue

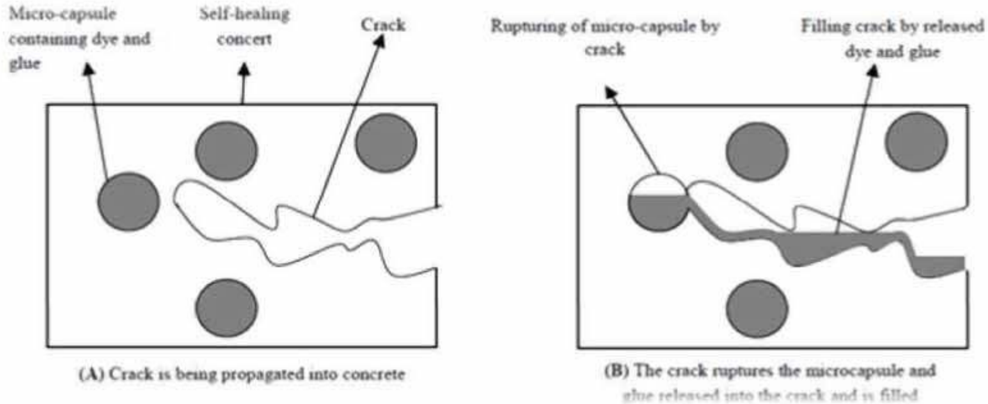

Fig.3 Encapsulated microcapsules Glue

(iii) Biological self-healing process - Magaji et al. [8] Microorganisms may be found in many areas. Water, dirt, oil, acidic hot springs, and industrial waste all contain them. Bacteria, fungi, and viruses are the three most common types of microorganisms. The genetic self-healing concrete is made using these microorganisms. Because certain of these bacteria can produce particular compounds, therefore, they are used in the production of concrete. Two of the most essential mechanisms utilised to design genetic self-healing concretes are the precipitation of polymorphic iron-aluminium-silicate and calcium carbonate. Microorganisms may be included in biological self-healing concrete in a variety of methods. Direct application of microbial brew to new concrete arrangements, as detailed in the chemical technique for sharing microorganisms, is one of them. Concrete's pH, temperature, and moisture content are normally inhospitable to bacterial development. As a consequence, in certain cases, the resistant kind of bacteria (spore) is utilized instead of fresh microbial broth. Microbes that have been encapsulated, on the other hand, maybe utilized to endure the harsh conditions of concrete.

This category includes two biological processes: a) calcium carbonate precipitation and b) polymorphic iron aluminium silicate precipitation. Apart from fungus and bacteria, two kinds of microorganisms, Mesophilic and Thermophilic microorganisms, which are further split into Aerobic and Anaerobic microorganisms, play a vital role in self-healing processes.

(e) Classification of Self-Healing Concrete

(i) Autogenous Self-Healing concrete - Magaji et al. [8] Increased concrete hydration, calcium hydroxide carbonation, and additional binder are required for most of the autogenous self-healing.

- Blocking cracks by waste
- Carbonation of CaOH
- Expansion of the hydrated concrete matrix in crack flanks
- Ongoing hydration of clinker minerals cracks

(ii) Autonomous Self-Healing Concrete - Magaji et al. [8] Autonomous self-healing concrete is fully dependent on a physical process. The phrase "autonomous self-healing" has been used to refer to this phenomenon-:

- the vascular method;
- capsule method;
- the bacterial method;
- the electrodeposition method;
- the shape memory alloy method;
- the microwave method and/or induction energy

(f) The environmental impact of self-healing concrete - Magaji et al. [8] Self-healing concrete reduce the amount of carbon dioxide produced into the environment during the manufacturing process. This is because concrete production uses a lot of energy in a variety of ways, particularly when transportation, mining, and concrete plants are included in it. The construction industry, on the other hand, is India's largest producer of carbon dioxide emissions, accounting for around 8% of total emissions. Self-healing concrete will surely reduce the development of excess concrete, thereby cutting carbon dioxide emissions in our environment, while also improving the lifespan of concrete and minimising maintenance and repairs.

(g) Composition / Mix design - K. et al. [2] An experiment was done based on comparative research between conventional concrete and bacterial concrete of the same grade to better understand the composition and mix design of self-healing concrete. The research was conducted using the following materials:

- Ordinary Portland cement of grade 53 as per IS:12269 (1987b)
- River sand was used, which was determined to be zone-1 of IS:383 (1987a) after passing through a 4.75mm IS sieve. The specific gravity was found to be 2.3.
- Coarse aggregate: On 4.75mm IS sieves, crushed stones up to 20mm in size are retained. The specific gravity was determined to be 3.13
- Potable water for conventional concrete
- Bacterial water - consisting of 10^5 cells of Bacillus megaterium / ml of water
- A thin metal sheet with a thickness of 0.3mm is used to generate an artificial crack in an unhardened concrete specimen up to a depth of 10mm

Table 5
Material and its quantity used for experiment

Ingredients	Cement	Fine aggregate	Coarse aggregate	water
Quantity (Kg/m^3)	340	657.6	1335.94	171.7
Ratio	1	1.93	3.93	0.51

The design mix of M25 was used for traditional and bacterial concrete as per IS:10262 (2009) and IS:456 (2000). The bacterium water substitutes the potable water with the required mix design in bacterial concrete. Now that a suitable bacterium for sustaining the alkali environment of concrete is required, there are several bacteria that may be examined-:

- Bacillus megaterium
- Bacillus pasteurii
- Bacillus sp. CT-5
- Bacillus subtilis
- Bacillus aerius
- Sporosarcina pasteurii
- AKKR5
- Shewanella Species
- Bacillus flexus

Bacillus megaterium may precipitate the most calcite when compared to other urease positive bacteria, resulting in a larger increase in compressive strength and crack-healing efficiency.

(i) Mechanism - K. et al. [2] Bacillus megaterium cells make up 10^5 Bacillus megaterium cells per millilitre of water in bacterial water. And the bacteria are exposed to air and water when cracks emerge in the future, they begin to precipitate calcite crystals. The spores of such bacteria have thick cells that enable them to persist for up to 200 years while waiting to germinate in a favourable environment. Bacteria degrading urea through the bacterial urease enzyme alter calcite precipitation. Urease is produced by bacteria's metabolism, and it catalyses the conversion of urea to ammonia and carbonate. Calcium carbonate is formed when these components hydrolyse into carbonic acid and ammonium chloride (calcite crystal). According to observations, the negatively charged and pH neutral surface of bacteria plays a critical role in calcite precipitation. Calcium ions with a positive charge may interact with bacteria's surface, facilitating nucleation.

$$CO(NH_2)_2 + H_2O \rightarrow NH_2COOH + NH_3 \quad (1)$$

$$NH_2COOH + H_2O \rightarrow NH_3 + H_2CO_3 \quad (2)$$

$$H_2CO_3 \leftrightarrow HCO_3^- + H^+ \quad (3)$$

$$2NH_3 + 2H_2O \leftrightarrow 2NH_4^+ + 2OH^- \quad (4)$$

$$HCO_3^- + H^+ + 2NH_4^+ + 2OH^- \leftrightarrow CO_3^{2-} + 2NH_4^+ + 2H_2O \quad (5)$$

$$Ca^{2+} + Cell \rightarrow cell - Ca^{2+} \quad (6)$$

$$Cell - Ca^{2+} + CO_3^{2-} \rightarrow Cell - CaCO_3 \downarrow \quad (7)$$

Fig. 4 Chemical equations of calcite crystallisation

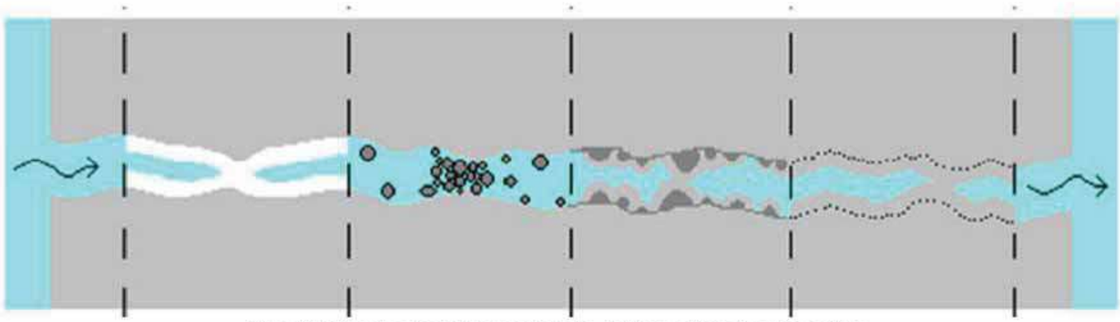

Fig. 5 The bacterial concrete's self-healing mechanism

(ii) Experiment Results

- **Compressive Strength:** K. et al. [2] When it came to compressive strength, it was clear that bacterial concrete surpassed regular concrete by a significant margin. The study discovered that the compressive strength of bacteria concrete was 11.96 per cent greater than the compressive strength of conventional concrete.

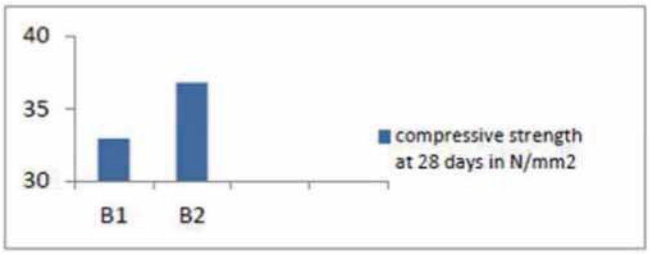

Fig. 6 The compressive strength of conventional concrete [B1] and bacterial concrete [B2] were compared

- **Water Absorption:** Due to the deposition of calcite on the specimen's surface, the bacterial concrete surface absorbs more water than normal concrete. According to reports, water absorption dropped by 0.45 per cent.

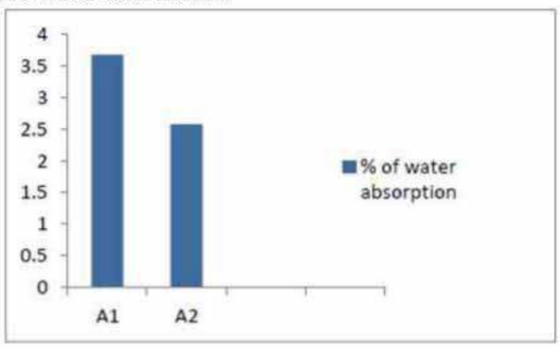

Fig. 7 Water absorption characteristics of conventional concrete [A1] and bacterial concrete [A2]

- **Water Permeability:** Due to the calcite filling of micropores, the depth of water penetration is also decreased in bacterial concrete when compared to conventional concrete.

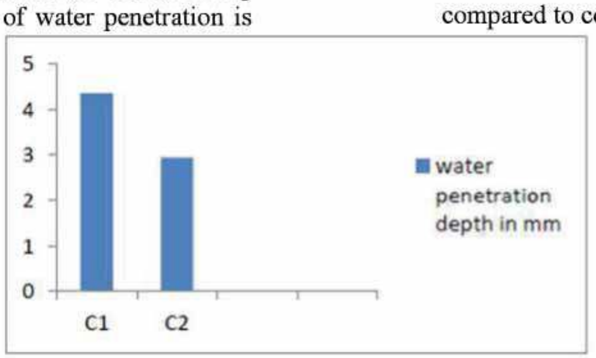

Fig. 8 Water penetration in conventional [C1] and bacterial [C2] concrete

(iii) Other experimentation results - Luhar et al. [9] The compressive strength of the concrete is improved when bacteria are added to it, compared to conventional concrete. The compressive strength of conventional concrete was raised by 14.92 per cent when bacillus subtilis was added. While b. sphaericus enhanced the compressive strength of concrete by 30.76 per cent after three days, 46.15 per cent after seven days, and 32.21 per cent after 28 days as compared to conventional concrete. The ability of a material to withstand a pulling (tensile) force is referred to as tensile strength. Bacterial concrete has better tensile strength than conventional cement, according to the study.

Table 6
Compressive strength of conventional concrete vs bacterial concrete

S.No.	No. of days	Compressive strength of conventional concrete cubes, N/mm^2	Compressive strength of *B.sphaericus* concrete cubes, N/mm^2	% increase in Strength
1.	3	19.24	25.16	30.76
2.	7	23.66	34.58	46.15
3.	28	34.52	45.72	32.21

Table 7
Tensile strength comparison of conventional concrete with bacterial concrete

S.No.	No. of days	Split tensile strength of conventional concrete cylinders, N/mm^2	Split tensile strength *B. sphaericus* concrete cubes, N/mm^2	% increase in Strength
1.	3	3.78	4.30	13.75
2.	7	4.62	5.28	14.28
3.	28	4.85	5.74	18.35

Table 8
Other than Bacillus, bacteria that can thrive in an alkaline environment

S.No.	Application	Types of Bacteria
1.	As a crack healer	B. pasteurii
		Deleya Halophila
		Halomonasrurihalina
		Myxococcus Xanthus
		B. megaterium
2.	For surface treatment	B. sphaericus
3.	B. spharicus	Bacilllussubitilis
		B. sphaericus
		Thiobacillus

Table 9
The compressive strength of different forms of bacteria

S.NO	Bacteria used	Best results	Bacterial concentration
1	Bacillus sp. CT-5	Compressive strength 40% more than the control concrete	5×10^7 cells/mm^3
2	Bacillus megaterium	Maximum rate of strength development was 24% achieved in highest grade of concrete 50 Mpa	30×10^5 cfu/ml
3	Bacillus subtilis	Improvement of 12% in compressive strength as compared to controlled concrete specimens with light weight aggregates	2.8×10^8 cells/ml
4	Bacillus aerius	Increase in compressive strength by 11.8% in bacterial concrete compared to control with 10% dosage of RHA	10^5 cells/ml
5	Sporosarcina pasteurii	Compressive strength 35% more than the control concrete	10^5 cells/ml
6	AKKR5	10% increase in compressive strength as compared to control concrete	10^5 cells/ml
7	Shewanella Species	25% increase in compressive strength of cement mortar compared with the control mortar	100,000 cells/ml

Table 10
Self-healing techniques and measured variable

Approach	Crack depth & width
Micro-encapsulation	Maximum depth of 35 mm crack was filled
Bacteria direct application	Maximum depth of 27.2 mm was filled
Bacteria and Encapsulation	Healing of maximum crack width of 0.970 mm was reported

Table 11
Summary of the contrasts between some techniques

Strategy	Advantage	Disadvantage
Bacteria	1. Biological activities and pollution free and natural way	1. Measures should be taken to protect the bacteria in concrete. Many prerequisites to be met
Encapsulation	1. Healing agent discharge on requirement 2. Potential effectiveness under many damage measures	1. Complexity in casting 2. Possible difficulty of healing agent release

(iv) Factors affecting self-healing of concrete - Huang et al. [10] The five main factors are-:

- **Moisture content:** Water-preserved pilot specimens heal faster on their own.
- **Crack width:** Cracks that are smaller than 0.3 mm in width may be completely repaired. Larger cracks (greater than 0.3 mm) may not heal. Cracks with a width of 0.1 mm are completely repaired after 200 hours. Furthermore, fractures between 0.2 and 0.3 mm in width heal in around 30 days. Cracks that are 0.15 to 0.3 mm wide decrease significantly in 7 days and heal completely in 33 days.
- **Time for hydration:** longer periods of hydration may result in greater self-healing.
- **Pressure applied to cracks:** Cracks may heal quicker if the correct amount of pressure is applied to them.
- **Water-cement ratio:** More unreacted cement particles may be used for further hydration to boost calcium carbonate synthesis when the water-cement ratio is higher.

Furthermore, the fracture interval is substantial. Early breaking concrete has a stronger self-healing potential while maintaining hydration because it contains more unreacted cement particles. Cracks up to 1mm wide may also be filled with adhesive-coated fibres and bacteria or fungus that have been latent in the concrete for hundreds of years and become active when exposed to water or other gases.

(v) Advantages of using Self-healing concrete

- K. et al. [2] When self-healing concrete is used, the strength of the concrete is enhanced.
- It has a lower permeability than traditional concrete.
- It also has a lower rate of water absorption than conventional concrete.
- It has a high resistance to freeze and thaw attacks.
- Corrosion of reinforcement is reduced to a near-zero level.
- It is possible to successfully repair fissures.
- The entire cost of maintaining this concrete is quite low.

(vi) Disadvantages of using Self-healing concrete

- K. et al. [2] The design of microbiological concrete is not mentioned in IS codes or other rules.

- The cost of this concrete is comparable to that of conventional concrete; it is somewhat more costly by around 10% to 30%.
- Bacterial germination does not occur in every kind of bacterium.
- Detecting calcite precipitation requires extensive costly investigation.
- Because bacteria used in concrete are hazardous to human health, they should only be used in construction.

(h) Self-healing concrete vs. conventional concrete cost analysis - The cost of 1 m^3 of concrete as calculated in part (c) above is Rs 7921/cum. Arnold [11] While the cost of producing self-healing concrete is quite high, at 13710 rupees per cubic metre according to Dr Henk Jonkers, this would be a viable product only in specific civil engineering constructions where the cost of concrete is much higher due to its superior quality, such as tunnel linings and maritime structures where safety is a major consideration – or in structures with restricted access for repair and maintenance. The cost increase connected with the adoption of self-healing methods should be tolerable in these cases. Furthermore, it is thought that if self-healing concrete is produced in huge quantities, the cost will be greatly lowered. If the structure's life can be extended by 30%, twice the cost of the concrete itself would still save a substantial amount of money in the long run.

Arnold [11] A second self-healing chemical is being developed, which will be much less expensive and produce much stronger concrete. The calcium lactate, which is currently quite expensive, accounts for the majority of the extra cost. The method of embedding the bacteria and nutrients into the pellets is particularly pricey since it uses vacuum technology. If a sugar-based nutritional component is utilised, the cost of self-healing concrete might be decreased to Rs 7283-7712 per cubic metre. However, unlike calcium lactate, a sugar-based nutrition would not stay intact inside expanding clay pellets. Much of the sugar would dissolve, which would cause the concrete to take longer to set. During the mixing procedure, the new self-healing agent being created would immobilise the sugar-based nutrition. Because it would make up just 3-5 per cent of the total volume, the concrete would be significantly stronger. In addition, it would be a feasible product for the majority of structural concrete applications.

V DISCUSSION

It is evident that self-healing concrete has great potential in the future, but its fusion with the precast alone can revolutionize the construction industry. Though the technology is still under development and requires some more years before it can hit the market on a large scale, it can be one of the most efficient techniques. Their fusion has some great potential advantages such as:

(a) Increased structure life cycle owing to self-healing concrete, which reduces cement and aggregate production, lowering CO2 levels in the environment.
(b) Precast building construction has a low material wastage rate, which means less material is used, less material is created, and the ones that are produced have a longer life duration, establishing an interdependent cycle of a process that contributes to CO2 emission reduction.
(c) Faster development and small-scale low-cost initiatives may assist in achieving the global sustainable objective of providing housing to all people.
(d) Better structural performance and long-term cost savings as compared to conventional techniques.
(e) Job prospects for skilled labour may increase.
(f) By extending the life of concrete, it aids in the avoidance of demolition debris dumps and, as a result, protects our flora and wildlife.
(g) Lowers maintenance and repair cost.
(h) The use of self-healing concrete in certain structures where repair is not feasible will greatly help in securing the building structurally over time.

VI CONCLUSION

It is evident from the above study that we as a generation urgently require a more environmentally friendly building material that can be used as a substitute for traditional concrete construction. It can be seen that conventional concrete is significantly outperformed by self-healing concrete in terms of properties such as compressive strength, workability, and tensile strength. The cost of self-healing concrete is currently a hurdle; owing to the high cost of calcium carbonate, its usage in the industry is not yet viable, but it has a greater number of advantages than disadvantages. It has the potential to be a game-changer in the long term, particularly for huge infrastructure development projects, while researchers and scientists are continuing to transform this concrete into a more significant contributor in the construction business and to make it the next conventional concrete. The globe was just put under lockdown as a result of a pandemic, and this was only the beginning. Nature has just recently begun to reveal its true colours, giving back everything that people have given it, and it is now time to realize that global warming and climate change are slow poisons. India, the world's second-largest cement manufacturer, must cut output and adopt more environmentally friendly building methods. There is a prospect that it will have a positive environmental effect since the usage of bacteria aids in minimising the production of concrete by extending the life-cycle of the structure and preventing landfills. As a result, this material should be utilised more often on construction sites, maybe in smaller quantities for an observatory start, so that we contribute to the environment rather than just exploiting it.

REFERENCES

[1 Bisht, Jitendra; Singhal, Soumya; India's Road to Net-Zero; The Diplomat (2021); Available at: https://thediplomat.com/2021/11/indias-road-to-net-zero/#:~:text=ReachinganonDfossilfuel,below45percentby2030.; Accessed 27 January 2022

[2] K., Kusuma; Rai, Amit Kumar; Kumar, Prashant; K., Harini; M.N, Harshita; Self-Healing Concrete; International Research Journal of Engineering and Technology (IRJET):5(5); PP.3817-3822 (2018)

[3] Gutierrez, Dario; Self-Healing Concrete is the Future of Construction Materials; Smart Bid (2015); Available at: https://smartbid.co/self-healing-concrete-construction materials#:~:text=Self%2DHealing%20Concrete%20is%20the%20Future%20of%20Construction%20Materials&text=When%20a%20concrete%20structure%20cracks,enough%2C%20the%20structure%20can%20collapse.; Accessed 27 January 2022

[4] Council, Building Materials and Technology Promotion; Precast Construction Technology; Building Materials and Technology Promotion Council (2019); Available at: https://bmtpc.org/DataFiles/CMS/file/PDF_Files/61_PAC_Urbaanic_Final.pdf; Accessed 16 December 2021

[5] Sir, Civil; How much cement sand & aggregate required for m25 concrete; Civil sir (2021); Available at: https://civilsir.com/how-much-cement-sand-aggregate-required-for-m25-concrete/; Accessed 16 December 2021

[6] Institute, Canadian Precast/Prestressed Concrete; Curing of High-Performance Precast Concrete technical guide; Canadian Precast/Prestressed Concrete Institute; PP.1 (2014)

[7] Standard, Indian; IS 15916 - Building Design and Erection Using Prefabricated Concrete - Code of Practice; Bureau Indian Standards; PP.1 (2011)

[8] Magaji, Abubakar; Yakubu, Mathias; Wakawa, Yakubu Mamman; A Review Paper on Self-Healing Concrete; The International Journal of Engineering and Science (IJES):8(5); PP.47-54 (2019)

[9] Luhar, Salmabanu; Suthar, Gourav; A review paper on self-healing concrete; Journal of Civil Engineering Research: 5(3); PP.53-58 (2015)

[10] Huang, Xu; Kaewunruen, Sakdirat; Self-healing concrete; New Materials in Civil Engineering; Butterworth-Heinemann; PP.825-856 (2020)

[11] Arnold, Damian; Self-Healing Concrete; Ingenia:1(46); PP. 39-43 (2011)

[12] Vijay, Kunamineni; Murmu, Meena; Deo, Shirish V.; Bacteria based self-healing concrete – A review; Construction and Building Materials; Elsevier; PP. 1008-1014 (2017)

[13] Satheesh; Rate Analysis of Concrete – Explanation; Civil planets (2021); Available at: https://civilplanets.com/rate-analysis-of-concrete/; Accessed 16 December 2021