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Evaluation of Mechanical and Self-Healing Performance of Bacterial Concrete Using BACTAHEAL-PR and Fly Ash: A Sustainable Approach

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Abstract : Concrete, the backbone of modern infrastructure, suffers from a critical limitation: cracking. These micro- and macro-cracks compromise its integrity, accelerate degradation, and lead to high maintenance costs. Inspired by biomimetic systems and ancient Roman concrete, this study investigates the incorporation of a commercial bacterial healing agent, BACTAHEAL-PR, into M25 grade concrete. This agent comprises Bacillus spores, nutrients, and enzymatic activators that catalyze calcium carbonate (CaCO3) precipitation upon activation by moisture ingress through cracks. Concrete specimens were prepared by partially replacing cement with 1%, 2.5%, and 5% BACTAHEAL-PR. Additionally, 2% fly ash was introduced in select batches to assess its synergistic effects. The research involved a systematic investigation including workability analysis (slump, flow table, and compaction factor), compressive strength testing at 28 days, and visual evaluation of autonomous crack healing over an additional 28-day period. Results revealed that 1% BACTAHEAL-PR with 2% fly ash significantly improved compressive strength (25.63 N/mm²) and enabled full crack closure. In contrast, higher bacterial dosages negatively affected strength due to potential interference with cement hydration. This study demonstrates that optimized bacterial concrete can extend service life, reduce carbon footprint, and support the transition toward sustainable civil engineering materials.
Keywords: Bacterial concrete, self-healing concrete, BACTAHEAL-PR, M25 concrete, compressive strength, calcium carbonate precipitation, fly ash, Bacillus subtilis, sustainable construction.

1. Introduction

Concrete is a brittle material prone to cracking due to its low tensile strength. Cracks can occur in concrete structures due to multiple reasons such as autogenous shrinkage, freeze thaw reactions, mechanical compressive- and tensile forces.(J. Y. Wang, Soens, et al., 2014)

Crack occurrence in reinforced concrete should be minimized for both durability and economic reasons as crack repair is costly. Autogenous repair, or self-healing, of concrete would save a substantial amount of money, as manual inspection and crack repair could be minimized. Thus, a reliable self-healing mechanism for concrete would not only result in more durable structures, but would also be beneficial for the global economy. This study exploited the potential to apply calcite-precipitating bacteria as a crack healing agent in concrete.(Venu et al., 2019)

Concrete is the most extensively used construction material in the world due to its high compressive strength and adaptability. However, its low tensile strength and brittle nature make it highly susceptible to cracking. Micro-cracks, if left untreated, grow and permit the ingress of harmful agents like chloride ions, carbon dioxide, and moisture, leading to corrosion of embedded steel and structural degradation.(Anbu et al., 2016)

Historically, cracks have been repaired using epoxy injection, surface coating, or complete replacement—methods that are labour-intensive, environmentally taxing, and economically inefficient. A paradigm shift is now underway with the development of self-healing concrete, a material capable of autonomous crack repair without human intervention.(Siddique & Chahal, 2011)

This innovation is rooted in biomimicry, where researchers have drawn inspiration from the natural healing mechanisms of biological tissues and the longevity of ancient Roman structures. In particular, Roman marine concrete contained lime clasts that reactivated in the presence of water to form new minerals, thereby naturally sealing cracks over centuries.(Albayrak et al., 2015)

Modern research has introduced bacterial-based self-healing concrete, also known as bio-concrete, which utilizes specific bacterial strains such as *Bacillus subtilis*, *Sporosarcina pasteurii*, and *Bacillus cohnii* to precipitate calcium carbonate ($CaCO_3$) when activated by water and nutrients.(Sreenivasa Rao et al., 2017)

This study investigates the use of a proprietary bacterial healing agent, BACTAHEAL-PR, as a partial cement replacement in M25-grade concrete. The objectives are to evaluate workability, strength, and healing efficacy under varying concentrations, and to identify the optimal dosage that balances performance and sustainability.(J. Y. Wang, Snoeck, et al., 2014)

1.2 HISTORY OF SELF HEALING CONCRETE

Ancient Roman infrastructure can put modern buildings to shame. While today's concrete structures might only last a few decades, some long-lived concrete in Rome has survived for 2,000 years. The Pantheon's unreinforced concrete dome, completed around 125 C.E.(Qiu et al., 2020)

1.2.1 ROMAN CONCRETE

It's fair to say the ancient Romans knew a thing or two about infrastructure. They were among the first to refine the basic elements of lime, shale, clay and aggregate rocks that we call concrete today; then, they poured billions of tons of it to build one of the greatest empires in human history — iconic relics of which still stand across modern Europe.(Ye et al., 2019)

While contemporary infrastructure faces numerous threats due to the crumbling of concrete over decades, or even a few years, many of the structures such as Pantheon and Colosseum ancient Romans built some 2,000 years ago remain standing and stable today. This has led many an expert to wonder: What was their secret?

A new study by researchers from the Massachusetts Institute of Technology (MIT), Harvard University, and laboratories in Italy and Switzerland recently published in Science Advances proposes an answer to that question: the technique of "hot mixing." (Zhang et al., 2014)

Lime is a stabilizing element, a calcium-rich inorganic material that is used to mitigate the erosive effect of water against structures like roads and building foundations. The study analyzes the use of quicklime — a heated and more reactive iteration of lime — along with or instead of slaked lime (which is lime that has been cooled) in Ancient Roman mortar construction, and posits that the lime clasts retained by the hot mixing technique allowed for a process of "self-healing" by holding reactive calcium within their matrix.(Abd Elmoaty, 2013)

Yet there's nothing magic about it, according to the researchers, who describe the clasts as "white chunks" of rock that originate from lime and appear as "small, distinctive, millimeter-scale" features in Roman concrete.(J. Wang et al., 2012)

Roman concrete is one of the most resilient construction materials ever created. It was even capable of setting and hardening underwater, an essential property as it allowed the Romans to build structures such as harbours, breakwaters and pierres out into the sea. It has even been shown to have the ability to self-heal small cracks that appear in the material.

1.7 AIM AND OBJECTIVES

This project focused on the autogenous self-healing of cementitious materials. Due to a lack of confirmed, indisputable, fully understood governing mechanism, the efficiency of the autogenous self-healing process still brings concerns and does not ensure successful full-scale applications. Therefore, the objectives of this study were as follows:

- To understand the mechanisms behind the autogenous self-healing of concrete,
- To use that knowledge to fully control it,
- To develop/design a cementitious material (or a set of materials) having specific chemical composition that under certain environmental conditions will be capable to self-repair, both internally and externally.

2. SELF-HEALING CONCRETE

Self-healing concrete is a product which biologically produces limestone by which cracks on the surface of concrete surface heal. Selected types of the bacteria genus Bacillus, along with calcium-based nutrient known as calcium lactate, and nitrogen and phosphorous are added to the Concrete when it is being mixed. The self-healing agents can lie dormant within the concrete for up to two hundred years. When a concrete structure damages and water starts to penetrate in the cracks present in it the bacteria starts to feed on the calcium lactate consuming oxygen and converts the soluble calcium lactate into insoluble limestone.(Oh et al., 2010) The limestone formed thus sealsthe cracks present. It is similar to the process of how a fractured bone gets naturally healed by osteoblast cells that mineralize to reform bone. Consumption of oxygen in the bacterial conversion has an additional advantage. Oxygen which becomes an essential element for the corrosion of steel to take place is being used in the bacterial conversion. Hence the durability of steel in construction becomes higher. The process of bacterial conversion takes place either in the interior or exterior of the microbial cell or even some distance away within the concrete. Often the bacterial activities trigger a change in the chemical process that leads to over saturation and mineral precipitation. Utilization of concepts of bio mineralogy in concrete lead to invention of a newmaterial termed as Bacterial Concrete. Bacterial concrete refers to a new generation concrete in which selective cementation by microbiologically-induced $CaCO_3$ precipitation has been introduced for remediation of micro-cracks(Monishaa & Nishanthi, n.d.)

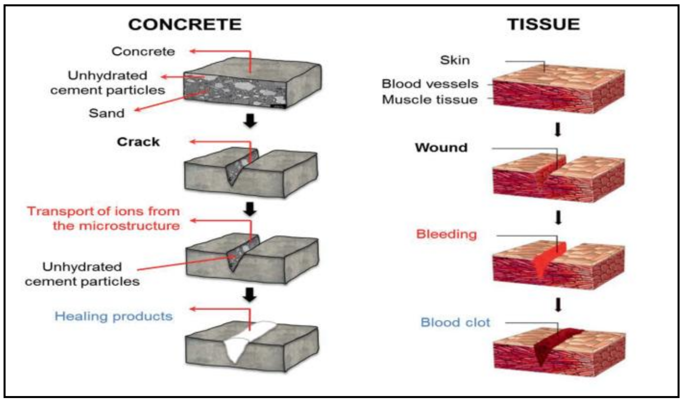

Figure 1 Self-healing of concrete by mimicking tissue healing

2.1 VARIOUS TYPES OF BACTERIA USED IN CONCRETE

Contains a biodegradable polymeric mineral precursor compound and a bio-based enzymatic catalyst (Multi enzymes + Nutrient supplements +Spore forming Bacilli)

1. Sporosarcina pasteurii
2. Bacillus sphaericus
3. Escherichia coli
4. Bacillus subtilis
5. Bacillus cohnii
6. Bacillus balodurans
7. Bacillus pseudofirmus.

2.2 MECHANISM OF THE BACTERIAL SELF-HEALING

Self-healing concrete is a product that will biologically produce limestone to heal cracks that appear on the surface of concrete structures. Specially selected types of the bacteria genus *Bacillus*, along with a calcium-based nutrient known as calcium lactate, and nitrogen(Mahmood et al., 2022) and phosphorus, are added to the ingredients of the concrete when it is being mixed. These self-healing agents can lie dormant within the concrete for up to 200 years. However, when a concrete structure is damaged and water starts to seep through the cracks that appear in the concrete, the spores of the bacteria germinate on contact with the water and nutrients. Having been activated, the bacteria start to feed on the calcium lactate. As the bacteria feeds oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on the cracked surface, thereby sealing it up. It mimics the process by which bone fractures in the human body are naturally healed by osteoblast cells that mineralise to re-form the bone. The consumption of oxygen during the bacterial conversion of calcium lactate to limestone has an additional advantage. Oxygen is an essential element in the process of corrosion of steel and when the bacterial activity has consumed it all it increases the durability of steel reinforced concrete constructions.(Gautam, n.d.)

2.3 PREPARATION OF BACTERIAL CONCRETE

Bacterial concrete can be prepared in two ways,

- By direct application
- By encapsulation in lightweight concrete

In the direct application method, bacterial spores and calcium lactate is added into concrete directly when mixing of concrete is done. The use of this bacteria and calcium lactate doesn't change the normal properties of concrete. When cracks are occurred in the structure due to obvious reasons. The bacteria are exposed to climatic changes. When water comes in contact with this bacteria, they germinate and feed on calcium lactate and produces limestone. Thus sealing the cracks. By encapsulation method the bacteria and its food i.e. calcium lactate, are placed inside treated clay pellets and concrete is prepared. About 6% of the clay pellets are added for making bacterial concrete. When concrete structures are made with bacterial concrete, when the crack occurs in the structure and clay pellets are broken and the bacteria germinate and eat down the calcium lactate and produce limestone, which hardens and thus sealing the crack. Minor cracks about 0.5mm width can be treated by using bacterial concrete.(Biotech, n.d.)

2.4 CHEMICAL PROCESS OF SELF-HEALING OR BACTERIAL CONCRETE

There are two main mechanisms governing bacterial self-healing of concrete, i.e. bacterial metabolic conversion of organic acid and enzymatic ureolysis. The self-healing product that fills the crack is calcium carbonate. In the first process, bacteria act as a catalyst and transform a precursor compound to a suitable filler material. As a result, calcium carbonate-based minerals are produced which act as a type of bio-cement that seals the cracks. One of the calcium precursors, often used in research due to its positive effect on concrete strength, is calcium lactate. In this case, the reaction occurring in the crack can be formulated as follows:(Gautam, n.d.)

$$\mathbf{Ca(C3H5O2)2 + 7O2 \rightarrow CaCO3 + 5CO2 + 5H2O}$$

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In addition to this reaction, the produced CO_2 reacts locally with $Ca(OH)_2$ inside of the crack leading to the production of five more $CaCO_3$ molecules thus making the process six times more effective than the autogenous self-healing. The second mechanism called ureolysis is based on the bacterial production of urease which catalyzes the hydrolysis of urea ($CO(NH_2)_2$) into ammonium (NH^{4+}) and carbonate(CO_3^{2-}) ions. The reactions can be presented as follows:

$CO(NH_2)_2 + H_2O \rightarrow NH_2COOH + NH_3$
$NH2COOH + H_2O \rightarrow NH_3 + H_2CO_3$
$H_2CO_3 \leftrightarrow HCO_3^- + H^+$
$2NH_3 + 2H_2O \leftrightarrow 2NH_4^+ + 2OH^-$
$HCO_3^- + H^+ + 2NH_4^+ + 2OH^- \leftrightarrow CO_3^{2-} + 2NH_4^+ + 2H_2O$

The bacteria surface can serve as a nucleation site due to the cell wall being negatively charged and, therefore, can attract ions from the environment, e.g. Ca^{2+}. Those ions deposited on the surface of the bacteria cell react with CO_3^{2-} and lead to the precipitation of $CaCO_3$:(Abd Majid et al., 2014)

$Ca^{2+} + Cell \rightarrow Cell - Ca^{2+}$
$Cell - Ca^{2+} + CO_3^{2-} \rightarrow Cell - CaCO_3 \downarrow$

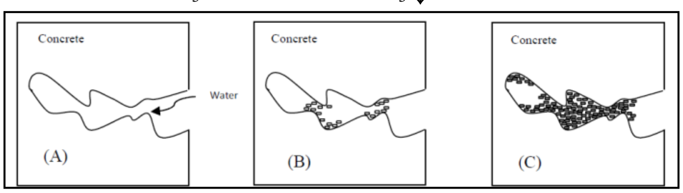

Figure 2 Schematic scenario of crack healing by microorganisms (A) crack is propagating into concrete; (B) Microorganisms is activated into crack; (C) Microorganisms grow and precipitate calcium carbonate around their wall cells and can fill the crack.

MATERIALS USED

2.1 GENERAL

The physical properties of Cement, Sand, Aggregates, Fly ash, BACTAHEAL-PR (Self healing concrete Bacteria) and water used for mix design of M25 grade of concrete was tested in laboratory and the material used are mentioned below.

2.2 CEMENT

Ordinary Portland Cement (OPC) of grade 53 confirming to IS **Code - IS 12269 :** 1987 was used in the present study. The cement is in dry powdery form with the good quality chemical composition and physical characteristics.
Initial Setting Time Of OPC is not less than 30 min
Final Setting Time Of OPC is not less than 600 min

2.3 AGGREGATE

Aggregates are the chief constituents in concrete. They give body to the concrete, decrease shrinkage and achieve economy. One of the most significant factors for producing feasible concrete is good gradation of aggregates. Good grading implies that a sample fractions of aggregates in required proportion such that the sample contains minimum voids. Samples of the well graded aggregate containing minimum voids require minimum paste to fill up the voids in the aggregates. Minimum paste means less quantity of cement and less water, which are further mean increased economy, inferior shrinkage and superior durability In this study, we have used aggregates of maximum nominal size 20 mm.

Fig.3 Aggregate

2.4 BACTAHEAL-PR (SELF HEALING CONCRETE BACTERIA)

BactaHeal-PR Healing Agent is applied in special repair mortars and concrete mixtures. It is composed of a biodegradable granular additive (healing agent) what autonomously seals as water proofs up to 1-mm wide occurring cracks. Permanent sealing occurs due to concrete compatible limestone formation.
Contains a biodegradable polymeric mineral precursor compound and a bio-based enzymatic catalyst (Multi enzymes + Nutrient supplements +Spore forming Bacilli).

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Fig. 4 BACTAHEAL-PR (Self healing concrete Bacteria Powder)

2.5 FLY ASH

Fly ash is finely divided residue resulting from the combustion of powdered coal and transported by flue gases and collected by electrostatic precipitation. Fly ash is most used pozzolonic material all over the world. In recent time, the importance and use of fly ash has grown so much that it has almost become a common ingredient in concrete, particularly in making high strength and high performance concrete. The use of fly ash as concrete admixture not only extends technical advantages but also contributes to the environmental pollution control. Extensive research is being carried out in most part of the world that could be accrued in the utilization of fly ash, which is basically a waste product.

2.6 SAND

Concrete sand is a specific type of sand used as an aggregate in concrete mixtures. Since the surface of concrete sand is coarse, it bonds easier with water, cement, and other aggregates to create strong and durable concrete products. Sand fills up the gap between the building blocks and spreads the binding material, It adds density to the mortar, It also prevents the shrinkage of the cementing material.

Sand of sieve size 2.36 mm was used.

Fig. 5 Sand

2.7 WATER

Potable water has been used for casting concrete specimens. The water is free from oils, acids, and alkalis and has a water-soluble Chloride content of 140 mg/lit. As per IS 456 – 2000, the permissible limit for chloride is 500 mg/lit for reinforced concrete; hence the amount of chloride present is very less than the permissible limit.

2.8 SUMMARY

The principal ingredients that make up the concrete mix are: cement, fine aggregate, coarse aggregate, water, chemical admixtures, and mineral admixtures. Concrete used in construction may also contain reinforcing bars, welded wire fabric (wire mesh), and various reinforcing fibers. The quality of the ingredients, their proportions, and the way they are mixed all affect the strength of the concrete.

EXPERIMENTAL PROCEDURE

3.1 GENERAL

The aim of the present study was to study the mechanism and effect of Self-Healing concrete by partial replacement of cement with 1%, 1.5% and 5% of BACTAHEAL-PR.

The concrete mix of M25 grade was prepared as per IS 10262 : 2009 having mix ratio as 1:1:2 with w/c ratio of 0.5%.

3.2 MATERIAL PREPARATION

3.2.1 SIEVE ANALYSIS

Step - 1

Sieve analysis of aggregate was done by sieve of size 20 mm

3.2.2 CALCULATION OF MATERIAL TO BE USED

- Concrete cubes of 150mm x 150mm x 150mm were casted.
- 8 kg material is required for casting one concrete block.
- M-25 grade concrete was casted with cement, sand and aggregate ratio 1:1:2 with 0.5% water cement ratio.
- For casting one concrete cube 2kg cement, 2kg sand and 4kg aggregate is required with 1 l water.
- Set S-1 of five cubes were casted by replacing cement by 1% of self healing concrete powder and 2% of fly ash.
- 9.700 kg cement, 10 kg sand, 20 kg aggregate, 100g (1%) self healing concrete powder, 200g (2%) fly ash and 5 l water was used for casting Set S-1.

Material were measured by using electronic balance

- Set S-2 of five cubes were casted by replacing cement by 2.5% of self healing concrete powder.
- 9.750 kg cement, 10 kg sand, 20 kg aggregate, 250 g (2.5%) self healing concrete powder and 5 l water was used for casting Set S-2.
- Set S-3 of five cubes were casted by replacing cement by 5% of self healing concrete powder.
- 9.500 kg cement, 10 kg sand, 20 kg aggregate, 500 g (5%) self healing concrete powder and 5 l water was used for casting Set S-3.

3.3 PREPERATION OF CONCRETE MIX

We have prepared the concrete mix by Hand Mixing.

3.3.1 CHARACTERISTICS OF WELL MIXED CONCRETE

- Concrete should be of uniform colour.
- All concrete materials like cement, fine aggregates, coarse aggregates and water should be homogeneously mixed.
- Cement paste should cover all the surface of the aggregate.
- Segregation or bleeding of concrete should not occur after the concrete mixing.

3.3.2 PROCESS OF HAND MIXING OF CONCRETE:

- Hand mixing of concrete is done on a hard, clean and non-porous base made of masonry or flat iron sheet plates.
- The measured quantity of sand is spread on the platform and then the cement is dropped over the sand.
- The sand and cement are mixed thoroughly for several times with the help of shovels in the dry state until the mixture attains an even colour throughout and is free from streaks.
- Next, the measured amount of coarse aggregates is spread out in uniform layer on the above mixture and mixed properly.
- Later, the whole mixture is blended properly like turning over by twist from the centre to the side, then back to the centre and again to the sides several times.
- After that, depression is made at the centre of the mixed materials.
- And, 75% of the required quantity of water is added in the depression and mixed with the help of shovels.
- Lastly, the remaining amount of water is added and the mixing process is continued till a uniform colour and consistency of concrete is obtained. The total time taken for mixing of concrete should not exceed 3 minutes.

3.3.3 PRECAUTION TO BE TAKEN CARE WHILE HAND MIXING OF CONCRETE:

- Base platform must be clean, dirt free and watertight.
- Use a good and clean shovel for the mixing procedure.
- If there are any dirt or debris in the aggregates, wash them before use.
- The personal protective equipment like hand gloves, mask etc. are must to be worn by the labours and masons while mixing and handling the concrete.
- The mixing platform should be cleaned at the end of the day's work.

3.4 ANALYSIS OF CONCRETE

Analysis of properties of concrete such as workability or consistency were done by :-

I. Slump test
II. Flow table test
III. Compaction factor test

3.5 SLUMP TEST:-

Concrete slump test or slump cone test is to determine the workability or consistency of concrete mix prepared at the laboratory or the construction site during the progress of the work. Concrete slump test is carried out from batch to batch to check the uniform quality of concrete during construction.

The slump test is the simplest workability test for concrete, involves low cost and provides immediate results. Due to this fact, it has been widely used for workability tests since 1922. The slump is carried out as per procedures mentioned in **IS: 1199 – 1959 in India**. Generally **concrete slump value** is used to find the workability, which indicates water-cement ratio, but there are various factors including properties of materials, mixing methods, dosage, admixtures etc. also affect the concrete slump value.

3.5.1 EQUIPMENTS REQUIRED FOR CONCRETE SLUMP TEST

- **i.** Mold for slump test i.e. slump cone - It is in the form of the frustum of a cone having height 30 cm, bottom diameter 20 cm and top diameter 10 cm.
- **ii.** Non porous base plate
- **iii.** Measuring scale
- **iv.** Temping rod - The tamping rod is of steel 16 mm diameter and 60cm long and rounded at one end.

3.5.2 PROCEDURE FOR CONCRETE SLUMP CONE TEST

1. Clean the internal surface of the mould and apply oil.
2. Place the mould on a smooth horizontal non- porous base plate.
3. Fill the mould with the prepared concrete mix in 4 approximately equal layers.
4. Tamp each layer with 25 strokes of the rounded end of the tamping rod in a uniform manner over the cross section of the mould. For the subsequent layers, the tamping should penetrate into the underlying layer.
5. Remove the excess concrete and level the surface with a trowel.
6. Clean away the mortar or water leaked out between the mould and the base plate.
7. Raise the mould from the concrete immediately and slowly in vertical direction.
8. Measure the slump as the difference between the height of the mould and that of height point of the specimen being tested.

Slump for the given sample = 170 mm When the slump test is carried out so the concrete was highly workable.

WORKABILITY	*SLUMP (mm)*
Very Low	*0-25*
Low	*25-50*
Medium	*50-100*
High	*100-175*

Table No. 1: Relation between Workability and Slump

3.6 FLOW TABLE TEST

As the name suggests, in this test the fluidity of concrete is determined by examining the flowing property of concrete.

Flow table test of concrete also determines the Quality of Concrete concerning its consistency, cohesiveness and the proneness to segregation.

3.6.1 APPARATUS REQUIRED FOR FLOW TABLE TEST

- i. Flow table – It is made up of metal having thickness 1.5mm and dimensions 750mmx 750mm
- ii. Tamping rod – It is made up of hardwood
- iii. Scoop
- iv. Centimeter Scale
- v. Metal Cone or mould (Lower Dia = 20cm, upper Dia = 13 cm, Height of Cone = 20cm). The middle portion of flow table is marked with a concentric circle of dia 200mm to place a metal cone on it.

3.6.2 PROCEDURE OF FLOW TABLE TEST

1. Prepare concrete as per mix design and place the flow table on a horizontal surface.
2. Clean the dust or other gritty material on Flow table and apply oil on it.
3. Now place the metal cone at the middle portion of the flow table and stand on it.
4. Pour the freshly mixed concrete in the mould comprising two layers; each layer should be tamped with tamping rod for 25times. After tamping the last layer, the overflowed concrete on the cone is struck off using a trowel.
5. Slowly, lift the mould vertically up & let concrete stand on its own without any support.
6. The flow table is raised at the height of 12.5mm and dropped. The same is repeated for 15times in 15secs.
7. Measure the spread of concrete in Diameter using centimetre scale horizontally and vertically. The arithmetic mean of the two diameters shall be the measurement of flow in millimetres.

***3.6.3 Formula for Flow value of concrete**:*

Note the flow of concrete by recording the spread diameter of the concrete.

Spread diameter of the concrete along one edge d_1 = 400 mm

Spread diameter of the concrete along the other edge d_2 = 380 mm

$$Average\ Spread\ Diameter = \frac{d_1 + d_2}{2}\ mm$$

Average Spread Diameter = (400 + 380)/2
= 390mm

Flow = (Spread dia (cm) -25)/25 x100%
Flow = 56%

The flow value of concrete mix ranges from 0-150 %

3.7 COMPACTION FACTOR TEST

Compaction factor test is the workability test for concrete conducted in laboratory. The compaction factor is the ratio of weights of partially compacted to fully compacted concrete. It was developed by Road Research Laboratory in United Kingdom and is used to determine the workability of concrete. The compaction factor test is used for concrete which have low workability for which slump test is not suitable.

3.7.1 Apparatus

I. Trowels
II. Hand scoop (15.2 cm long)
III. A rod of steel or other suitable material (1.6 cm diameter, 61 cm long rounded at one end)
IV. A electronic balance.

Workability	Compaction Factor
Very Low	0.78
Low	0.85
Medium	0.92
High	0.95

3.7.2 Procedure of Compaction Factor Test on Concrete

1. Clean the dust or other gritty material on Flow table and apply oil on it
2. Place the concrete sample gently in the upper hopper to its brim using the hand scoop and level it.
3. Cover the cylinder.
4. Open the trapdoor at the bottom of the upper hopper so that concrete fall into the lower hopper. Push the concrete sticking on its sides gently with the road.
5. Open the trapdoor of the lower hopper and allow the concrete to fall into the cylinder below.
6. Cut of the excess of concrete above the top level of cylinder using trowels and level it.
7. Clean the outside of the cylinder.
8. Weight the cylinder with concrete to the nearest 10 g. This weight is known as the weight of partially compacted concrete (**W1**).
9. Empty the cylinder and then refill it with the same concrete mix in layers approximately 5 cm deep, each layer being heavily rammed to obtain full compaction.
10. Level the top surface.
11. Weigh the cylinder with fully compacted. This weight is known as the weight of fully compacted concrete (**W2**).
12. Find the weight of empty cylinder (**W**)

3.7.3 Calculation of Compaction Factor Value

The compaction factor is defined as the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete. It shall normally to be stated to the nearest second decimal place.
Compaction Factor Value= (W1-W) / (W2-W)

W1 = 22 kg

W2 = 23 kg

W = 3.2 kg

Compaction factor = 0.94
It has high workability.
Table No. 2 Relation between workability and compaction factor

3.8 PREPERATION OF BACTERIAL CONCRETE CUBES

3.8.1 EQUIPMENT

- Sample Tray
- Compaction bar
- Mould of size 150mm X 150mm X 150mm
- Curing tank
- Permanent Marker
- Scoop

3.8.2 SAMPLING OF CUBES FOR TEST

1. Clean the mounds and apply oil
2. The cube mould should be filled with concrete in three layers.
3. Compact each layer with not less than 35 strokes per layer using a tamping rod (steel bar 16mm diameter and 60cm long, bullet-pointed at lower end).
4. Level the top surface and smoothen it with a trowel.
5. Total 5 cubes were casted for each Set i.e S-1 (with 1% bacteria and 2% fly ash), S-2 (with 2.5% bacteria) and S-3 (with 5% bacteria).
6. Now samples were leaved for final setting for 24 hrs.
7. After 24 hrs cube mould is opened and samples are taken out.
8. Now the cubes are marked by using permanent marker

3.8.3 CURING OF CUBES

The specimen must be kept in water for 7 or 14 or 28 days and form every 7 days the water is changed.

3.8.4 CRACK DEVELOPMENT AND COMPRESSIVE STRENGTH TEST

Compressive Strength Definition

Compressive strength is the ability of material or structure to carry the loads on its surface without any crack or deflection. A material under compression tends to reduce the size, while in tension, size elongates.

In this test, the push force applied on the both faces of concrete specimen and the maximum compression that concrete bears without failure is noted.

Compressive strength of Concrete and its importance: -

As we all know that concrete is a mixture of sand, cement, and aggregate. The strength of the concrete depends upon many factors like individual compressive strength of its constituents (Cement, Sand, aggregate), quality of materials used, air entrainment mix proportions, water-cement ratio, curing methods and temperature effects.

Compressive strength gives an idea of the overall strength and above-mentioned factors. Through conducting this test, one can easily judge the concrete strength psi and quality of concrete produced.

3.8.5 Procedure

- Ensure that concrete specimen must be well dried before placing it on the Compression Testing Machine (CTM).
- Weight of samples is noted in order to proceed with testing and it must not be less than 8.1Kg.
- Testing specimens are placed in the space between bearing surfaces.
- The concrete cubes are placed on bearing plate and aligned properly with the centre of thrust in the testing machine plates.
- Due to the constant application of load, the specimen starts cracking at a point & final breakdown of the specimen must be noted.
- After 28 days of curing 3 cubes from each set S-1, S-2 and S-3 were used to find the compressive strength by using CTM machine and remaining 2 cubes from each set were placed in CTM machine for developing cracks.
- After crack generation in the two cubes from each set were placed without any disturbance for self healing process.
- After duration of around 28 days the cracks in the cubes were observed to be healed.

3.9 SUMMARY

Preparation of material for concrete mix was done by following the process of sieve analysis, material calculation and after that concrete was prepared by hand mixing with 1%, 2.5% and 5% of bacterial concentration and analysis of properties of concrete was done by Slump test, Flow table test, Compaction factor test and after that cubes were casted and after 24 hrs of setting they were kept for curing for 28 days.

After 28 days of curing compressive strength test and crack development was done.

3. TEST AND RESULT OF SELF-HEALING OR BACTERIAL CONCRETE AND NORMAL CONCRETE GENERAL

Calculation of compressive strength of cube samples after 28 days of proper curing was done.

3.1 CALCULATION OF COMPRESSIVE STRENGTH OF CUBE SAMPLES

- Compressive strength of the set S-1, S-2 and S-3 cubes were tested on CTM machine.
- Compressive strength of three cubes from each set was recorded after 28 days and their average was taken.

SET OF CUBE	COMPRESSIVE STRENGTH OF SAMPLES (N/mm^2)			
	1	2	3	AVERAGE
S-1	25.5	25.3	26.1	25.63
S-2	21.9	23.5	25.1	23.50
S-3	21	20	21.9	20.96
NORMAL M-25 CUBE	25	24.5	24.2	24.56

Table No. 3 COMPRESSIVE STRENGTH OF SAMPLES

- It was observed that the compressive strength of the concrete decreased when the concentration of bacteria was increased from 1% to 2.5% and 5%.
- Compressive strength decreased rapidly when the concentration of bacteria was increased from 2.5% to 5%.
- So it is confirmed that maximum amount of BACTAHEAL-PR that can be used is around 1 to 1.5 % and less than 2%.
- It is also observed that use of fly ash increases the compressive strength of the cube sample.
- Fly ash also improves the workability of concrete and the strength and durability of hardened concrete.
- Compressive strength of self healing concrete with 1% bacteria concentration was observed to be more than normal M-25 grade mix concrete.

3.2 SELF HEALING OF CONCRETE

After duration of around 28 days the cracks in the cubes were observed to be healed.

Fig. 6 Concrete cubes cracked after 28 days

Fig. 7 crack healed after around 28 days

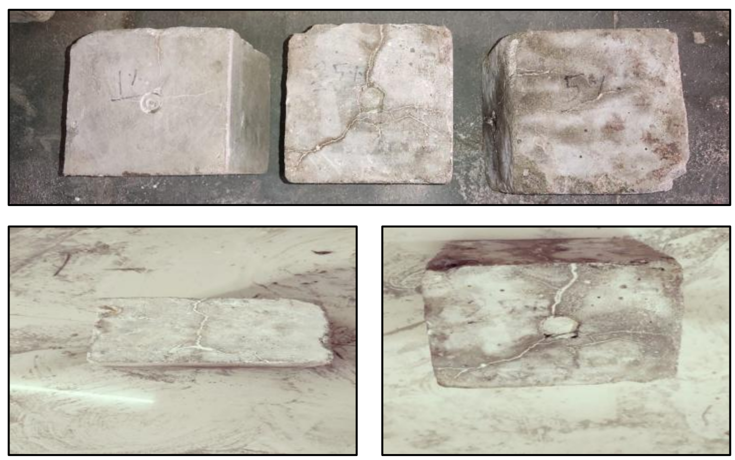

Fig. 8 Concrete blocks after self-healing

3.4 ADVANTAGES OF SELF HEALING CONCRETE

- It can last centuries, it is the biggest advantage of self healing concrete. This ensures that we shall never have to replace concrete surface again during its lifespan.
- Self-healing concrete is eco-friendly.
- Self healing concrete decreases concrete maintenance. In normal concrete cracks have to be repaired and filled but you don’t have to worry about this with self healing concrete.
- Reduces the cost of maintenance.

- Improves compressive strength.
- Reduction in permeability of reinforced concrete.
- Better resistance towards freeze-thaw attack reduction.
- Reduces the corrosion of steel due to the cracks formation and improves the durability of steel reinforced concrete.
- Bacillus bacteria are harmless to human life and hence it can be used effectively.

3.5 DISADVANTAGES OF SELF HEALING CONCRETE

- One of the biggest disadvantages is its initial high cost. It is expensive compared to normal concrete. Maybe in future, the cost will reduce when self healing concrete will become common.
- Growth of bacteria can be affected by various environmental conditions.
- Not many contractors know how to use it yet. Because it is a new product and many people do not have an idea of using it.
- There is no IS code available to standardize the self healing concrete.

4. FUTURE PERSPECTIVES

Currently a fully functional bacteria-based self-healing concrete system using LWA as storage reservoir is available on the laboratory scale. On-going studies in our laboratory investigate the possibility to use this system in practical applications. A next step towards widening application possibilities is the development of a more efficient and economical agent that does not negatively affect concrete strength properties. Possibility for easy application and production on industrial scale at low costs should be considered. Next to healing capacity, long-term behaviour and improvement of durability characteristics of the bacteria-based self-healing concrete material need to be determined, such as resistance to chloride penetration and freeze-thaw cycles. Long-term monitoring of larger scale experiments executed in the outdoors environment may reveal material behaviour in practice. Feasibility of implementing the material in the market should then finally be determined by a full cost-benefit analysis.

The compressive strength of the concrete decreased when the concentration of bacteria was increased from 1% to 2.5% and 5% , so it is confirmed that maximum amount of BACTAHEAL-PR that can be used is around 1 to 1.5 % and less than 2%.It is also observed that use of fly ash increases the compressive strength of the cube sample.

5 CONCLUSIONS

5.1 GENERAL

- Microbial concrete technology has proved to be better than many conventional technologies because of its eco-friendly nature, self-healing abilities and increase in durability of various building materials.
- During self-healing process, when the cracks in bio-concrete come in contact of moisture and air, the bacteria feeds on the calcium lactate, joining the calcium with carbonate to form limestone, and hence fixing the crack.
- The overall development of strength and durability of Self-healing concrete by using Bacillius subtilis bacteria is investigated.
- The more $CaCO_3$ precipitations, the better the self-healing effect will be. The concentrations of bacteria and Ca^{2+} will greater the amount of precipitated $CaCO_3$.
- Self-Healing Concrete improves the impermeability of the specimen thereby increasing the resistance to alkaline, sulphate & freeze-thaw attack.
- All over maintenance cost is minimized.
- Use of fly ash increases the compressive strength of concrete.
- Generally, fly ash benefits fresh concrete by reducing the mixing water requirement and improving the paste flow behavior resulting in good workability.
- Decreases water demand.
- **Reduced permeability** the reduced permeability results in improved long-term durability and resistance to various forms of deterioration.
- Fly ash is also cost effective, when fly ash is added to concrete, the amount of

portland cement may be reduced and hence resulting in overall cost-cutting.

- Use of fly ash decreases the amount of cement and hence reducing the pollution due to cement and promoting the use of industrial waste.

Microbial concrete technology has proved to be better than many conventional technologies because of its eco-friendly nature, self-healing abilities and increase in durability of various building materials.

This report gives the methods for designing self-healing concrete. Introducing the bacteria within the concrete performs extremely useful it improves the attribute of the concrete, which is higher than the conventional concrete. The study reviewed about different types of bacteria that can be used for remedying cracks in concrete. Bacteria repair the cracks in concrete by producing the calcium carbonate crystal which block the cracks and repair it. Many researchers done their work on the self-healing nature of concrete and they had found the following result that bacteria improve the property of conventional concrete such as increase in 13.75% strength increased in 3 days, 14.28% in 7 days and 18.35% in 28 days. As we all know that the repairing and maintenance are costly by the conventional methods than the self-healing concrete. So we have to improve and use these methods for the betterment of concrete structures. This paper gives the ideas and methods for designing the self-healing concrete.

REFERENCES

Abd Elmoaty, A. E. M. (2013). Mechanical properties and corrosion resistance of concrete modified with granite dust. *Construction and Building Materials*, *47*, 743–752. https://doi.org/10.1016/j.conbuildmat.2013.05.054

Abd Majid, M., Ali Fulazzaky, M., & Tin Lee, C. (2014). *A Review of Self-healing Concrete Research Development*.

Albayrak, G., Canbaz, M., & Albayrak, U. (2015). Statistical Analysis of Chemical Admixtures Usage for Concrete: A Survey of Eskisehir city, Turkey. *Procedia Engineering*, *118*, 1236–1241. https://doi.org/10.1016/j.proeng.2015.08.475

Anbu, P., Kang, C.-H., Shin, Y.-J., & So, J.-S. (2016). Formations of calcium carbonate minerals by bacteria and its multiple applications. *SpringerPlus*, *5*(1), 250. https://doi.org/10.1186/s40064-016-1869-2

Biotech, P. (n.d.). *PRODUCT INFORMATION BACTAHEAL-PR (Proven Enzyme, Bacterial and Nutrient formulation for Self healing concrete)*.

Gautam, B. R. (n.d.). *Bacteria Based Self Healing Concrete-A Bacterial Approach*. https://theconstructor.org/concrete/bacterial-concrete-self-healing-concrete/13751/

Mahmood, F., Kashif Ur Rehman, S., Jameel, M., Riaz, N., Javed, M. F., Salmi, A., & Awad, Y. A. (2022). Self-Healing Bio-Concrete Using Bacillus subtilis Encapsulated in Iron Oxide Nanoparticles. *Materials*, *15*(21), 7731. https://doi.org/10.3390/ma15217731

Monishaa, M., & Nishanthi, M. S. (n.d.). *EXPERIMENTAL STUDY ON STRENGTH OF SELF-HEALING CONCRETE*. www.internationaljournalssrg.org

Oh, B. Hwan., Choi, O. Chol., & Chung, Lan. (2010). *Fracture mechanics of concrete and concrete structures : proceedings of the 7th International Conference on Fracture Mechanics of Concrete and Concrete Structures, Jeju, Korea, May 23-28, 2010*. Ia-FraMCos ; Korea Concrete Institute.

Qiu, L., Dong, S., Ashour, A., & Han, B. (2020). Antimicrobial concrete for smart and durable infrastructures: A review. *Construction and Building Materials*, *260*, 120456. https://doi.org/10.1016/j.conbuildmat.2020.120456

Siddique, R., & Chahal, N. K. (2011). Effect of ureolytic bacteria on concrete properties. *Construction and Building Materials*, *25*(10), 3791–3801. https://doi.org/10.1016/j.conbuildmat.2011.04.010

Sreenivasa Rao, K. V., Girisha, K. G., Anjan, S., & Abhilash Sharma, N. (2017). Experimental Investigation of Corrosion Behavior of Plasma Sprayed Cr 2 O 3 Coatings on 410 grade Steel. *Materials Today: Proceedings*, *4*(9), 10254–10258. https://doi.org/10.1016/j.matpr.2017.06.359

Venu, B., BhavyaSwathi, I., Raju, L. S., & Santhanam, G. (2019). A review on Friction Stir Welding of various metals and its variables. *Materials Today: Proceedings*, *18*, 298–302. https://doi.org/10.1016/j.matpr.2019.06.304

Wang, J., Van Tittelboom, K., De Belie, N., & Verstraete, W. (2012). Use of silica gel or polyurethane immobilized bacteria for self-healing concrete. *Construction and Building Materials*, *26*(1), 532–540. https://doi.org/10.1016/j.conbuildmat.2011.06.054

Wang, J. Y., Snoeck, D., Van Vlierberghe, S., Verstraete, W., & De Belie, N. (2014). Application of hydrogel encapsulated carbonate precipitating bacteria for approaching a realistic self-healing in concrete. *Construction and Building Materials*, *68*, 110–119. https://doi.org/10.1016/j.conbuildmat.2014.06.018

Wang, J. Y., Soens, H., Verstraete, W., & De Belie, N. (2014). Self-healing concrete by use of microencapsulated bacterial spores. *Cement and Concrete Research*, *56*, 139–152. https://doi.org/10.1016/j.cemconres.2013.11.009

Ye, H., Wu, C., Liu, D., Wang, T., & Zhang, Q. (2019). Friction and wear behavior of CFRP plate in contact with roughened mould steel under high normal pressure. *Construction and Building Materials*, *220*, 308–319. https://doi.org/10.1016/j.conbuildmat.2019.06.007

Zhang, Z., Provis, J. L., Reid, A., & Wang, H. (2014). Geopolymer foam concrete: An emerging material for sustainable construction. *Construction and Building Materials*, *56*, 113–127. https://doi.org/10.1016/j.conbuildmat.2014.01.081

Abd Elmoaty, A. E. M. (2013). Mechanical properties and corrosion resistance of concrete modified with granite dust. *Construction and Building Materials*, *47*, 743–752. https://doi.org/10.1016/j.conbuildmat.2013.05.054

Abd Majid, M., Ali Fulazzaky, M., & Tin Lee, C. (2014). *A Review of Self-healing Concrete Research Development*.

Albayrak, G., Canbaz, M., & Albayrak, U. (2015). Statistical Analysis of Chemical Admixtures Usage for Concrete: A Survey of Eskisehir city, Turkey. *Procedia Engineering*, *118*, 1236–1241. https://doi.org/10.1016/j.proeng.2015.08.475

Anbu, P., Kang, C.-H., Shin, Y.-J., & So, J.-S. (2016). Formations of calcium carbonate minerals by bacteria and its multiple applications. *SpringerPlus*, *5*(1), 250. https://doi.org/10.1186/s40064-016-1869-2

Biotech, P. (n.d.). *PRODUCT INFORMATION BACTAHEAL-PR (Proven Enzyme, Bacterial and Nutrient formulation for Self healing concrete)*.

Gautam, B. R. (n.d.). *Bacteria Based Self Healing Concrete-A Bacterial Approach*. https://theconstructor.org/concrete/bacterial-concrete-self-healing-concrete/13751/

Mahmood, F., Kashif Ur Rehman, S., Jameel, M., Riaz, N., Javed, M. F., Salmi, A., & Awad, Y. A. (2022). Self-Healing Bio-Concrete Using Bacillus subtilis Encapsulated in Iron Oxide Nanoparticles. *Materials*, *15*(21), 7731. https://doi.org/10.3390/ma15217731

Monishaa, M., & Nishanthi, M. S. (n.d.). *EXPERIMENTAL STUDY ON STRENGTH OF SELF-HEALING CONCRETE*. www.internationaljournalssrg.org

Oh, B. Hwan., Choi, O. Chol., & Chung, Lan. (2010). *Fracture mechanics of concrete and concrete structures : proceedings of the 7th International Conference on Fracture Mechanics of Concrete and Concrete Structures, Jeju, Korea, May 23-28, 2010*. Ia-FraMCos ; Korea Concrete Institute.

Qiu, L., Dong, S., Ashour, A., & Han, B. (2020). Antimicrobial concrete for smart and durable infrastructures: A review. *Construction and Building Materials*, *260*, 120456. https://doi.org/10.1016/j.conbuildmat.2020.120456

Siddique, R., & Chahal, N. K. (2011). Effect of ureolytic bacteria on concrete properties. *Construction and Building Materials*, *25*(10), 3791–3801. https://doi.org/10.1016/j.conbuildmat.2011.04.010

Sreenivasa Rao, K. V., Girisha, K. G., Anjan, S., & Abhilash Sharma, N. (2017). Experimental Investigation of Corrosion Behavior of Plasma Sprayed Cr 2 O 3 Coatings on 410 grade Steel. *Materials Today: Proceedings*, *4*(9), 10254–10258. https://doi.org/10.1016/j.matpr.2017.06.359

Venu, B., BhavyaSwathi, I., Raju, L. S., & Santhanam, G. (2019). A review on Friction Stir Welding of various metals and its variables. *Materials Today: Proceedings*, *18*, 298–302. https://doi.org/10.1016/j.matpr.2019.06.304

Wang, J., Van Tittelboom, K., De Belie, N., & Verstraete, W. (2012). Use of silica gel or polyurethane immobilized bacteria for self-healing concrete. *Construction and Building Materials*, *26*(1), 532–540. https://doi.org/10.1016/j.conbuildmat.2011.06.054

Wang, J. Y., Snoeck, D., Van Vlierberghe, S., Verstraete, W., & De Belie, N. (2014). Application of hydrogel encapsulated carbonate precipitating bacteria for approaching a realistic self-healing in concrete. *Construction and Building Materials*, *68*, 110–119. https://doi.org/10.1016/j.conbuildmat.2014.06.018

Wang, J. Y., Soens, H., Verstraete, W., & De Belie, N. (2014). Self-healing concrete by use of microencapsulated bacterial spores. *Cement and Concrete Research*, *56*, 139–152. https://doi.org/10.1016/j.cemconres.2013.11.009

Ye, H., Wu, C., Liu, D., Wang, T., & Zhang, Q. (2019). Friction and wear behavior of CFRP plate in contact with roughened mould steel under high normal pressure. *Construction and Building Materials*, *220*, 308–319. https://doi.org/10.1016/j.conbuildmat.2019.06.007

Zhang, Z., Provis, J. L., Reid, A., & Wang, H. (2014). Geopolymer foam concrete: An emerging material for sustainable construction. *Construction and Building Materials*, *56*, 113–127. https://doi.org/10.1016/j.conbuildmat.2014.01.081