EXPERIMENTAL INVESTIGATIONS ON BACTERIAL CONCRETE FOR SUSTAINABLE CONSTRUCTION IN INDIA

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Abstract. Bacterial concrete has recently come into use as a repair method for fractures in several types of constructions, including bridges, reinforced cement concrete buildings, reinforced cement concrete pipes, canal linings, pavement, etc. In concrete structures, crack development is a very frequent occurrence that allows water and various types of chemicals to enter the concrete through the cracks and diminishes their strength. This also has an impact on the reinforcement when it reacts with water, carbon dioxide, and other chemicals. Henk Jonkers thus developed bacterial concrete to fix the fractures that emerged in the concrete constructions in order to address this issue. Using bacillus subtilis bacteria and calcium lactate, experimental studies have been conducted in this work to stop concrete fractures. The ability of bacteria to survive in an alkaline environment influences their selection. For M20 and M40 grade concrete with river sand mixes and crushed stone sand mixes as replacements of fine aggregate, Bacillus subtilis bacteria with calcite lactate is utilized in varying percentages, such as 5%, 10%, and 15% of cement weight. The impact of bacteria on the compressive strength, split tensile strength, and flexural strength of concrete was investigated experimentally. A scanning electron microscope was used to check for calcite precipitates in the form of calcium carbonate in bacterial concrete specimens. Energy Dispersive X-ray Analysis and X-ray Diffraction were used to confirm the presence of the calcite precipitates.

Key Words: Bacterial Concrete Bacillus subtilis, Calcium lactate, Crushed stone sand, Scanning Electron Microscope, Energy Dispersive X-ray Analysis, Ultrasonic pulse velocity.

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1. INTRODUCTION

The most popular and effective building material in the world is concrete. It is strong, capable of withstanding high compressive stress, less expensive than most building materials, and moldable into a variety of forms. Despite this, concrete fractures occur as a result of its susceptibility to tension, shrinkage, fatigue stress, and environmental influences. These microcracks can weaken the concrete and make it more porous, which can eventually diminish the material's structural integrity, durability, and lifespan. In that situation, self-healing concrete offers a real remedy.

Concrete that restores its functionality after initial damage is said to be self-healing. It shows a typical cementitious material self-healing. The idea of self-healing in concrete has developed from that of biological living forms, such as plants and animals, which naturally execute self-healing when damage emerges.

When the initial repair is needed, the strength of concrete steadily declines, according to Schlangen and Joseph. Additionally, after 10-15 years, concrete frequently needs a second repair. However, the use of self-healing technology in concrete can significantly lengthen the initial restoration period. With self-healing, materials last longer and do not need to be repaired or maintained.

The most recent research on self-healing in concrete and cement-based materials is presented in this chapter. It talks about this field's limitations and advancements. The idea of self-healing is presented in specific terms and measurement methods in the next part. The chapter then goes over significant advancements in several self-healing concrete fields.

Concrete is the building material most used. It is known to have several constraints despite its versatility in building. It is low in tension, has restricted ductility and little cracking resistance. Different changes were produced from time to time to overcome the deficiencies of cement concrete based on ongoing studies carried out around the globe. Continuous study in the field of concrete technology has led to the growth of unique concrete considering building velocity, concrete strength, concrete durability and eco-friendliness with industrial material such as fly ash, blast furnace slag, silica fume, metakeolin etc[6].

Self-healing concrete that has the potential to mend fractures on its own, autonomously, is said to have self-healing properties. It not only fills up the fractures but also partially or completely restores the structural parts' mechanical qualities. Self-repairing concrete is another name for this type of concrete. Concrete frequently develops surface fractures because, in comparison to other construction materials, it has a weak tensile strength. Due to their capacity to promote the movement of liquids and gases that might contain hazardous substances, these fissures lessen the concrete's durability. Concrete and the steel reinforcement bars will both be vulnerable to assault if microcracks deepen and spread to the reinforcement. Therefore, it is crucial to keep the fracture from getting any wider and to get it fixed as soon as possible. Self-healing concrete would boost the sustainability of the material while also extending the useful life of concrete structures, making them more enduring and ecologically benign.

Given that concrete has natural autogenous healing properties, self-healing is a long-established and well-known phenomenon for the material. The continual hydration of clinker minerals or the carbonation of calcium hydroxide may cause cracks to close over time. Since autogenous healing can only repair little cracks and is only effective in the presence of water, it is challenging to manage. It is difficult to utilize due to this restriction. On the other hand, concrete might be modified to allow for crack self-healing. By adding admixtures, there are several ways to enhance autogenous healing, including mineral additions, crystalline admixtures, and superabsorbent polymers. Concrete can also be changed to have integrated autonomous self-healing mechanisms. The most prevalent kinds of autonomous self-healing strategies include capsule-based self-healing, vascular self-healing, and microbiological self-healing.

Concrete with self-healing characteristics is referred to as self-healing concrete. Concrete's ability to self-heal or self-repair enables crack rectification and repair using either autonomous or autogenous techniques. All these actions are defined by concrete's durability, which is one of its properties. The materialistic quality of durability aids concrete in defending itself against any chemical or physical assaults. There are more opportunities for cracks to form when durability declines.Concrete is still one of the most important construction materials from the time of its invention and will continue in the future also, but most concrete structures are prone to cracking.

Even though most concrete constructions are prone to cracking, concrete is still one of the most significant construction materials today and will remain so in the future. The entire structure is compromised by even a little break in the concrete surface. Water seepage causes the concrete to deteriorate and the steel reinforcing to corrode, drastically lowering a structure's lifespan. Concrete is particularly good at withstanding compressive force, but it struggles to withstand tensile stress. Concrete has steel reinforcing because of this. An excessive tensile tension may cause cracks in many concrete constructions, and they might appear very soon after the building is constructed. Applying a concrete mortar that is adhered to the surface of bonded. Sometimes, for wider crack mortar is required to insert into the existing structure with metal pins to ensure that it does not fall away. Repair or maintenance of any concrete is more time-consuming and it is often very difficult to gain access to the structure to make repairs, especially if they are underground or at a great height.

However, when self-healing concrete element damage or crack and water start seeping through it, the bacteria spores are activated on contact with water and nutrients. These activated bacteria start to feed on the calcium lactate available in concrete. As bacteria consume oxygen and the soluble calcium lactate is converted to insoluble limestone. The limestone gets solidified as encounter the atmosphere, thereby sealing it up. It represents the same process in which fracture in the human body is naturally healed by osteoblast cells that mineralize to re-form the bone.

During the bacterial conversion of calcium lactate to limestone has additional benefits that it consumes oxygen which is a major element in the process of corrosion of steel. As this bacterial activity has consumed all oxygen, it increases the durability of steel-reinforced concrete constructions. While making self-healing concrete two bacterial agents are feed name as the bacterial spores and the calcium lactate-based nutrients are introduced to the concrete as separate clay pallets. These clay pallets ensure that the bacterial agent will not get active before cracking concrete.

This gets activated only when the concrete gets cracked and crack open the pellets and incoming water brings the calcium lactate into contact with the bacteria do these become activated. Self-healing Concrete is a successful test for this process and it is observed that the bacteria germinate and multiply quickly. Self-healing Concrete is a successful test for this process and it is observed that the bacteria germinate and multiply quickly.

Bacterial agent converts the nutrients into limestone within seven days in the laboratory. But in the outside condition, it may take several weeks.

2. LITERATURE REVIEW

Damian Palin et.al. investigated on a self-healing building material composite supported microorganism to be used in marine environments at low temperatures. Through crack water porosity measurements and strength development through compression testing, the composite was tested for its crack-healing capability. The composite showed wonderful crack-healing capability, reducing crack porosity by 95% 0.4 mm wide, and cracks 0.6 metric linear unit wide by 92% when fifty-six days of submersion in artificial H_2O at 8^oC. self-produced precipitation, autonomous bead swelling, magnesium-based mineral precipitation, and calcium-based mineral precipitation in and on were attributed to the healing of cracks. However, mortar specimens incorporated with beads showed lower compressive strengths than plain mortar specimens. This study is that the initial to gift a bacteria-based self-healing cemented composite for application in marine environments at low temperatures, whereas the formation of a bacteria-actuated organic-inorganic composite healing material is associate exciting avenue for concrete self-healing analysis.

H.M. Jonkers investigated on the formation of cracks in many concrete constructions on a typical durability-related phenomenon. In this study, bacteria immobilized in porous expanded clay particles before the addition of a concrete mixture can substantially increase bacterially-mediated self-healing compared to the direct unprotected addition of bacteria to the concrete mixture as per a previous study. The results of this study seem promising as 100% cure (6 out of 6 specimens tested) of cracks induced in 2 months cured bacterial specimens occurred as opposed to 33% cure (2 out of 6 specimens tested) of conventional concrete specimens. Tests also showed that bacterial spore viability increased by adding immobilized (protected) particles inside porous expanded clay compared to direct (unprotected) addition to the concrete mixture from 2 to more than 6 months. Continuous experiments relate to further quantification of crack-healing, i.e., establishing the relationship between added healing agent quantity and effective healing of crack depth and width. It can therefore be concluded from this study that active bacterially mediated mineral precipitation can lead to efficient crack-plugging and concomitant reduction in material permeability. Combined with permeability tests, microscopic techniques revealed that complete crack healing.

Erik Schlangen. et.al investigated on the Self-healing techniques in 3 totally different materials. Bacterium ar used for the primary application to precipitate spar into concrete cracks. This methodology is wont to fill comparatively massive cracks in ferroconcrete. The strategy does not lead to structure strength enhancements; however, the trail to reinforcement is blocked by filling the crack. This stops the entry of liquids and ions beginning to reinforce corrosion and so enhances the structure's sturdiness. Additionally, this methodology is beneficial for structures that retain water. This enables cracks to be stuffed and escape is stopped. It is troublesome or not possible to repair microorganism concrete, particularly in underground structures. During this case Strain hardening composites (SHCC) materials are studied, that because of their tiny crack widths have already got a high potential for self-healing. New additions, like microfibers and super absorbent polymers (SAP), are even any promoting this capability for self-halting. Just in case of asphalt concrete during which the self-healing capability is increased by the employment of encapsulated oil and micro-steel fibers. The latter approach has well-tried to be operating within the laboratory and is being applied within the Netherlands in 2010 on a real road.

Gupta Souradeep .et.al conducted a review on latest self-healing techniques and owed to totally different load and non-load factors, crack formation in concrete structures is inevitable owed to deterioration throughout its service life. To stop cracks from spreading and decreasing the service lifetime of the structures, repair and maintenance operations square measure so required. Accessibility to cracked zone, however, will be difficult; additionally, such operations need capital and labor and contribute to pollution thanks to phylogenesis activities and the use of additional repair materials. Self-healing will be the way of reducing manual intervention. Autonomous crack waterproofing due to carbonate precipitation elicited by microorganism is an environmentally friendly mechanism that several researchers round the world square measure intensively finding out. This review focuses on assessing crack healing by microorganism once it's directly supplementary or supplementary to the concrete when encapsulation into a protecting shell. Four key aspects that verify the effectiveness of microorganism self-healing are highlighted and discussed: capsule material and bio-agent encapsulation, capsule survival throughout concrete intermixture, the impact on concrete properties of adding bio-agents or capsules, and also the ability to seal and recover mechanical and sturdiness properties.

E. Tziviloglou.et.al investigated on the innovative self-healing concrete technology permits the fabric to repair the open micro-cracks that, due to the ingress of gasses and liquids, will cause danger to the structure's sturdiness. Completely different ideas of concrete self-healing are developed with the aim of sick once cracking water tightness. Among these, self-healing concrete supported microorganism has shown promising leads to up the performance of crack waterproofing. The healing agent supported microorganism is incorporated in light-weight aggregates during this study and mixed with recent mortar. This enhances self-produced concrete healing and is capable of sick water tightness once the fabric is cracked. The study focuses on work the impact of the healing agent once incorporated into the mortar matrix and evaluating the recovery of liquid tightness once cracking and exposure through water permeableness tests to two completely different healing regimes (water immersion and wet-dry cycles). It had been found that the presence of the healing agent does not influence the compressive strength of the mortar containing light-weight aggregates. The study reveals that once immersed in water, the recovery of water tightness does not take issue considerably either for specimens with or while not a healing agent. In distinction, once exposed to wet-dry cycles, the recovery of water tightness considerably will increase for specimens containing the healing agent compared to specimens while not it. Measurements of oxygen concentration and microorganism traces on spar formations confirmed the microorganism activity of the healing agent on specimens.

M. Guadalupe Sierra-Beltran.et.al investigated on the mechanical properties, ability to heal all and bonding behavior of a concrete property bio-based mortar repair system. Two completely different mixtures of cement-based strain-hardening composites (SHCC) were used. The additional bio-based agent to the SHCC is created from each microorganism and microorganism food. Measurements of the gas profile, that reveals consumption of O_2 by bacteria-based samples, however not by management samples, monitored the metabolic activity of microorganism. Results show that a SHCC-type material with a bio-based agent meets the compressive and bonding strength needs for a structural repair material. The mortar with bio-based agent shows reduced delamination from the concrete substrate compared to mortar while not the bio-based agent once applied as a repair material. Additionally, once mixtures with bio-based healing agent are cracked and cured, a rather higher recovery of each flexural strength and deflection capability from management mixtures while not a bio-based healing agent is shown. Though measurements of gas indicate that microorganism in bio-based specimens were metabolically active, ascertained amounts of carbonate precipitate didn't seem to dissent considerably from management specimens. The rationale for the apparent uncoupling between metabolic activity and lack of increased precipitation of carbonate is also owing to restricted amounts of feed being applied, and this remains to be processed in unfinished studies.

Virginie Wiktor.et.al investigated on to quantify the crack-healing potential of a particular and novel biochemical self-healing agent of two parts embedded in porous swollen clay particles that act as reservoir particles and replace a part of regular concrete aggregates. Crack ingress water releases the two-component biochemical agent consisting of microorganism spores and salt from the particle when crack formation. Following carbonate formation mediate by microorganism leads to the physical closure of small cracks.That the ascertained doubling of crack-healing potential was if truth be told supported by O_2 profile measurements because of metabolic activity of microorganism that discovered O_2 consumption by microorganism however not by management specimens. This novel bio-chemical self-healing agent has the potential to extend aspects of concrete constructions in wet environments notably in terms of sturdiness.The results prove that the bio-chemical self-healing agent applied in two elements, consisting of a combination of microorganism spores and calcium lactate, will be with success applied to support and develop concrete's self-healing capability because the most healable crack dimension quite doubled. Additionally, oxygen measurements provided proof that concrete incorporating microorganism spores embedded in dilated clay particles and derived active bacterium remains viable and useful once concrete casting for many months. Besides, since the metabolically active bacterium consume oxygen, the healing agent could act as oxygen diffusion obstruction protective against corrosion the steel reinforcement.

Hao Linget.al. investigated on the microbic self-healing concrete be a brand-new technology for repairing cracks, the pat study demonstrated that the precipitated $CaCO_3$ might fill the cracks and lesser the crack constant of permeableness. On this source, the impacts on chloride resistance transmission were studied to evaluate the protecting effects of microbic self-healing cracks through multiple characterization ways like electrochemistry testing, visual examination of the surface of cracks, reinforcement weight-loss quantitative relation and chloride particle content. Additionally, to the strategy of electromigration, chloride transmission was accelerated. The results demonstrated that microorganism self-healing cracks will really stop chloride transmission in cracks and have protecting effects on concrete reinforcements. The results of corrosion current and self-corrosion potential by chemistry check show that the degree of corrosion of reinforcements is lesser once the cracks were recovered by self-healing agent throughout the method of electromigration fast chloride transmission. The visual examination shows less corrosion product abundant from cracks and the lower weight-loss magnitude relation of reinforcements that were removed by destructive check technique from the self-healing specimens. The main cause is that the healed cracks will hamper the chloride type that invades the cracks into the within of the specimens, therefore retardation down the corrosion method of reinforcements. Additionally, chloride content looks at ends up in completely different depths verify that chloride content is lesser within the self-healing specimens once the cracks are healed. It will accurately indicate the lower chloride transmission degree. Through these multiple sorts of characterization strategies, we can accomplish that the microorganism self-healing applied to concrete cracks can impede chloride transmission in cracks that incorporates a directly protecting result on reinforcements.

S. Krishna Rao.et.al investigated on the impact of M-sand on Fly ash Roller Compacted Concrete (FRCC) strength and abrasion resistance. The cement was partly replaced by fly ash at four content levels, i.e., 0%, 20% and 60%. The design of the FRCC mixes incorporates a flexural resistance of five MPa. Fine aggregates of three combinations (Series A, Series B and Series C) were initiated in FRCC mixes, specifically river sand (100%), M-sand (100%) and river sand and M-sand combinations (50% each). All mixes endure strength checking (compression and flexure) and two abrasion resistance testing strategies (Cantabro test and surface abrasion resistance test) at three, seven, twenty-eight- and ninety-days elderly. Experimental findings indicate that in all three series of mixes the loss of Cantabro and weight loss of Surface abrasion has been enhanced with a rise in fly ash content at all ages. In contrast to river sand mixes, however, the rate of rise is reduced with the addition of M-sand in FRCC. Relationships have been created between strength and abrasion resistance for all three sequences of mixes. A model was suggested between the loss of Cantabro and the loss of FRCC surface abrasion weight irrespective of concrete age, type of good aggregate and proportion of fly ash substitute.

V. Wiktor.et.al investigated on the ground performance of the fresh developed bacteria-based concrete renovate system in an exceedingly parking garage. This liquid-based repair system is intended to seal cracks and cut back body because of the assembly of a biomineral supported Calcium. The system combines the advantages of each a standard concrete repair system (fast reaction and short efficiency) and bio-based ways (more property, slow method, and long-run efficiency). The repair system supported bacterium was sprayed on the crack surface and on concrete pavement. Water permeableness and freeze / thaw resistance tests severally evaluated the crack-sealing potency and improvement of frost salt scaling.

The results were terribly promising as solely cracks that the bacteria-based repair system had not been treated were still unseaworthy heavily. What is more, the concrete freeze / thaw resistance treated with the bio-based repair system was above the untreated concrete. These results square measure terribly encouraging for the bacteria-based repair system to be applied in follow. Currently, the system is being optimized to extend its performance to finish crack waterproofing and develop higher resistance to frost salt scaling.

Jiaguang Zhang.et.al reported immobilization is a good approach to self-healing concrete supported microorganism to take care of the high-efficiency mineral-forming capability of incorporated microorganism over time. However, this microorganism carriers comparatively high-cost, native inaccessibility and low surface assimilation capability build them impracticable for potential implementation in large-scale concrete structures. The feasibleness of expanded perlite (EP) as a unique carrier of microorganism on quantifying cracks-healing in concrete through Bacilli cohnii immobilization has been incontestable. Additionally investigated were the results of two different self-healing techniques, i.e., direct microorganism introduction and expanded clay (EC) immobilized microorganism, on crack-healing potency. Experimental results showed that when every healing amount, specimens incorporated with EP-immobilized microorganism showed the foremost effective crack-healing. When twenty-eight days of healing, the values of totally well crack widths were up to 0.79 mm, that is larger than 0.45 millimeter for specimens incorporated with EC-immobilized microorganism. Analysis of emission scanning microscope (FESEM) and X-ray diffraction (XRD) confirmed that spar crystals area unit mineral precipitations on their crack surface.

R. Alghamri .et.al investigated on a method of impregnating potential self-healing agents into light-weight aggregates (LWA) and concrete self-healing performance mixed with fertilized LWA. As a possible self-healing agent, light-weight aggregates with a diameter vary of 4–8-millimeter were fertilized with a sodium silicate solution. Concrete specimens with fertilized LWA and management specimens were pre-cracked at seven days to a crack dimension of up to three hundred µm. Recovery of flexural strength and reduction of water sorptivity are investigated. The specimens containing the fertilized LWA showed 80% recovery of the pre-cracking strength once twenty-eight days of healing in water, that accounts for quite 5 times the recovery of the conventional specimens. additionally, considerably improved was the capillary water absorption; the specimens cured with the fertilized LWA showed a 50% reduction within the sorptivity index compared to the conventional cracked specimens and a awfully similar response to the uncracked management specimens. Sodium silicate contribution to the assembly of additional calcium silicate hydrate gel has been confirmed by characterizing the healing product exploitation diffraction, Fourier remodel spectrum analysis, and microscopy scanning. As a technique for rising the self-healing performance of concrete composites, the impregnation of light-weight aggregates by a liquid self-healing mineral so their encapsulation in an exceedingly polymer-based coating layer was instructed. Concerning strength recovery, water tightness, and crack closure, the practicability and potency of this technique was investigated and verified for the healing product by microstructure analysis. In each crack protection and strength recovery parameters, the SHM specimens showed a good and noteworthy performance compared to conventional specimens. This has been achieved while not forfeiting the concrete specimens expected mechanical properties. The impregnation of LWA particles with water glass, as an example, resulted in a rise in strength by quite 5 times and a decrease in capillary water absorption by nearly half. Compared to several of the antecedently instructed techniques, this means terribly promising results. XRD, FT-IR and SEM techniques area unit terribly helpful in providing info on the chemical compositions of healing materials supporting earlier results on the contribution of sodium silicate to the assembly of additional Calcium silicate hydrate (C–S–H) gel to heal cracks.

3. MATERIALS AND TESTING METHODS

3.1 MATERIALS

3.1.1Cement

Ordinary Portland cement of 53 grade was used and tested for various properties as per IS: 4031-1996 and the physical properties shown in Table

Physical properties of Portland cement

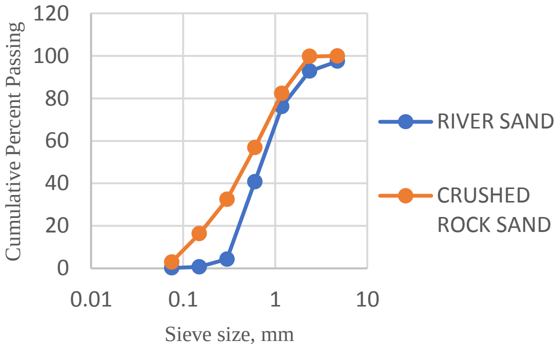
S. No.	Test Property	Result	Requirements as per IS 12269-1987
1	Fineness		
	) Sieve test	2%	Not more than 10%
	) Blaine	285m^2/kg	Min 225 m^2/kg
2	Normal Consistency	31.0%	-
3	Specific Gravity	3.01	-
4	Initial setting time	95minutes	Not less than 30 minutes
5	Final setting time	284minutes	Not more than 600 minutes
6	Compressive strength		
	) 3days	28N/mm^2	27 N/mm^2(Min)
	) 7days	41 N/mm^2	37 N/mm^2(Min)
	) 28days	56N/mm^2	53 N/mm^2(Min)
7	Soundness	2mm	Not more than 10mm

	(Le-Chatlier Exp.)		

3.1.2 Fine aggregates

As fine aggregates, locally accessible river sand and crushed stone sand were employed. The distribution of the gradation curve for the fine aggregate is depicted in Graph. River sand and crushed stone sand have specific gravities of 2.68 and 2.77, respectively.

Grading Curve of Fine aggregate



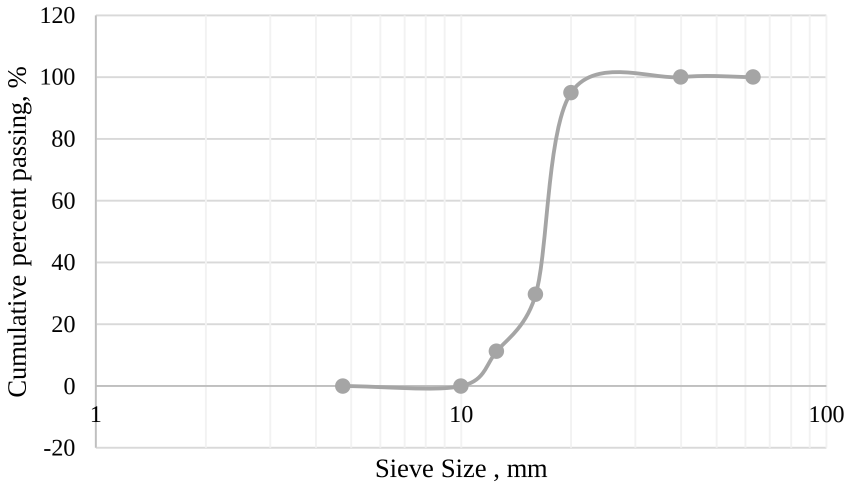
3.1.3 Coarse aggregates

As coarse aggregate, 20mm nominally sized crushed granite broken stone is employed. The coarse aggregate grading curve is depicted in Graph.

Properties of Coarse aggregate

S.No.	Property	Test Value
1	Specific Gravity	2.71
2	Water absorption	0.5%
3	Sieve Analysis Test results	Grading Curve shown in Graph 3.2
4	Aggregate Impact Value, %	21.50
5	Aggregate crushing value, %	20.40
6	Combined Flakiness & Elongation Value, %	21.90

Grading curve of coarse aggregate



3.1.4 Water

Fresh water was used in the manufacturing of concrete.The mixing and curing of concrete were done as per IS: 456-2000.

3.1.5 Casting of Specimens

Prior to pouring concrete, the inside surfaces of the cube, cylinder, and prism cast iron moulds are carefully cleaned and coated with oil. The moulds are filled with the evenly mixed bacterial concrete.

3.2 TESTING OF SPECIMENS

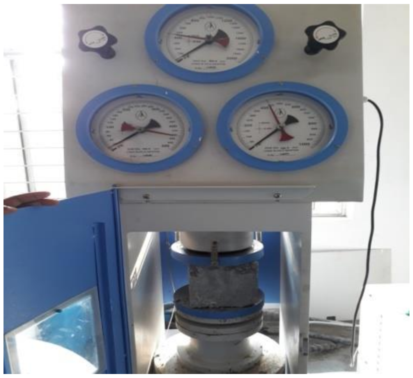
All the specimens are tested for compressive strength, split tensile strength, flexural strength, in the laboratory as per Indian standards and Cantabro loss as per American standards.

3.2.1 Tests on Fresh Concrete

The Slump cone is used to measure how easily bacterial concrete mix sample may be worked. The slump values for various bacterial concrete proportions for M20 and M40 of river sand mixes as well as crushed stone sand mixes.

3.2.2 Compressive Strength of Concrete Specimens

As a means of quality control, this test is the industry standard for assessing the compressive strength of concrete. The test was performed using cubes that were 150x150x150 mm^3. Standard metal moulds were used to cast the cube specimens, and a modified compaction test rammer was used to crush them. On the bacterial concrete specimens, the compression test was conducted in accordance with Indian Standard Specification IS 516-195986.



3.2.3 Flexural Strength Test

Beam specimens of size 100 x 100 x 500 mm^3 were casted for various Bacterial concrete mixes were tested by applying third point loading as per IS 516-1959. Below Figure shows the experimental setup.

The flexural strength of the specimen was calculated using below formula corresponding to the condition “a > 133 mm” where “a” is the distance between the line of fracture and the nearer support.

Flexural Strength (f_r) =$\frac{3Pa}{bd^2}$

When a is less than 133 mm and greater than 110 mm,

Flexural Strength (f_r) =$\frac{PL}{bd^2}$

If a is less than 110 mm discard the results.

Where, P = maximum load at failure in N

L = length of specimen in mm

b = width in mm

d = depth in mm

a= the distance between the line of fracture and the near support in mm

3.2.4 Split tensile strength Test

The specimens 150 mm in diameter and 300 mm long, cast for various Bacterial concrete mixes were tested with the cylinder axis horizontal and applying diametrical compression as per IS : 5816-1996[87]. Figure 4.9 shows the arrangement of split tensile strength test setup. The maximum load applied at failure was noted. The split tensile strength of the Bacterial concrete mix specimen was calculated using the following formula.

Split tensile strength (f_{st}) =$\frac{2P}{\pi Ld}$

Where P – The compressive load on the cylinder specimen N

L – length of the cylinder specimen in mm

d – diameter of the cylinder specimen in mm

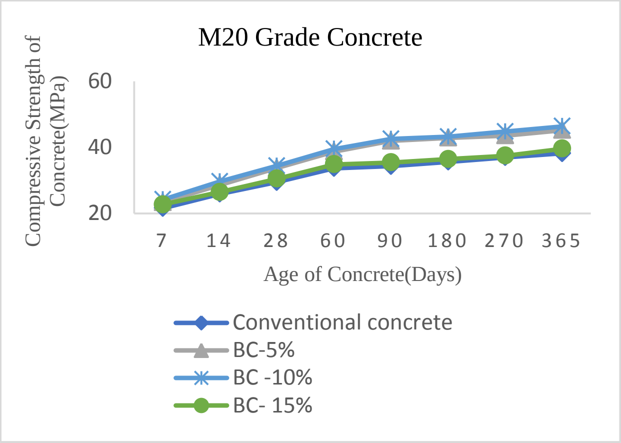
4. RESULTS AND DISCUSSIONS

The concrete mixes are provided for M20 and M40 Grade (1:2.16:3.57 and 1:1.65:3.23) for both regular concrete and bacterial concrete. The mix was specified in accordance with IS: 10262-2009, and bacterial concrete is taken into consideration from two prior studies90,91,92,93. Additionally, the method used to prepare the concrete cubes and the tests conducted on hardened concrete for various samples were shown.

The tests have been done are listed below:

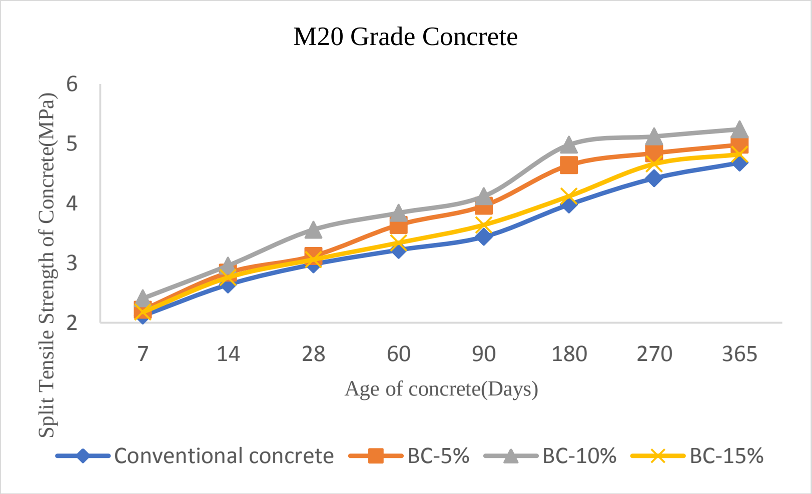
- Compression strength test.
- Split tensile strength test.
- Flexure strength test.

4.1 Variation of compressive strength (M20 Grade Concrete) of bacterial concrete with curing ages for river sand mixes.



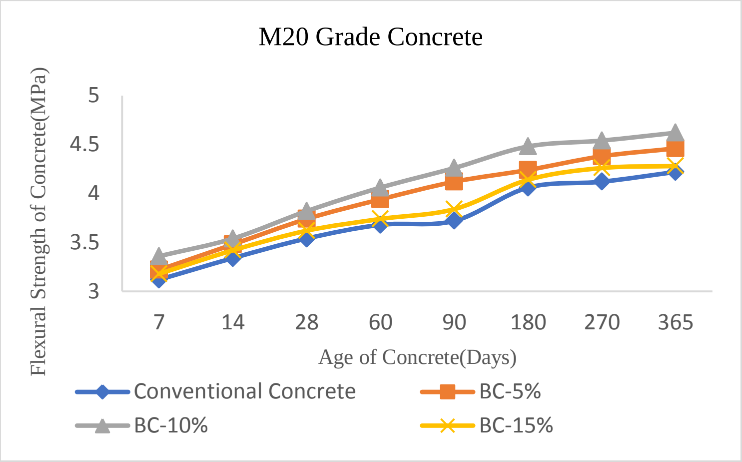
According to Graph, when the curing age rises, the compressive strength of bacterial concrete for M20 grade also increases. However, the percentage increases in compressive strength for BC-5%, BC-10%, and BC-15% at 28 days are 14.5%, 16.8%, and 3.60 %, respectively. In a similar vein, the relative percent increases in compressive strength at 180 days are 20.27%, 21.25%, and 2.27%. In comparison to ordinary concrete, these percentages for BC-5%, BC-10%, and BC-15% at 365 days are 18.34%, 21.48%, and 3.72%, respectively.From the foregoing, the increase in compressive strength at 180 days and 365 days is greater than the increase at 28 days. This is because bacillus subtilis bacteria and calcium lactate play a larger role in compressive strength at ages greater than 28 days.Additionally, it was found that the compressive strength increased as the percentage of bacterial concrete increased from 0% to 10%; however, at 15%, the compressive strength decreased. This is because the hydration products are saturated at this point, and an increase in bacterial solution does not increase strength.

4.2 Variation of split tensile strength (M20 Grade Concrete) of bacterial concrete with curing age for river sand mixes



According to Graph, when the curing age grows, the split tensile strength of bacterial concrete for M20 grade also does. At 28 days, the split tensile strength of M20 grade concrete increased by 4.69%, 19.46%, and 2.68% for BC-5%, BC-10%, and BC-15%, respectively. Like this, the percentage increases in split tensile strength are 16.58%, 25.12%, and 3.51%, respectively, at 180 days. In comparison to ordinary concrete, these percentages at 365 days are 6.41%, 11.96%, and 2.99% for BC-5%, BC-10%, and BC-15%, respectively.From the information above, the increase in split tensile strength at 180 days and 365 days is greater than the increase at 28 days. This is because at ages greater than 28 days, the contribution of the bacteria Bacillus subtilis and the mineral calcium lactate to split tensile strength is more pronounced.It was also noted that the split tensile strength increased as the percentage of bacterial concrete increased from 0% to 10%, but at 15% the split tensile strength decreased. This is because the hydration products are saturated at 10% bacterial solution; therefore, an increase in bacterial solution does not increase strength and the strength decreases.

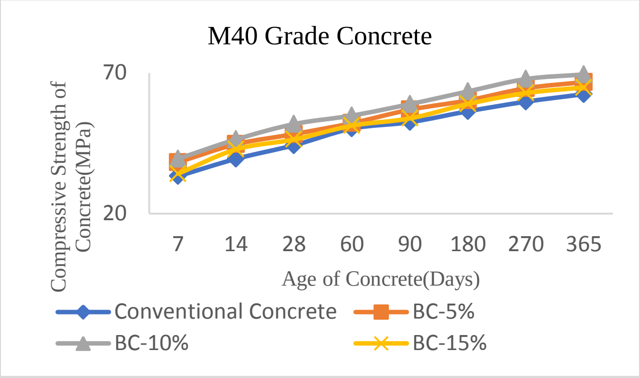
4.3 Variation of flexural strength (M20 Grade Concrete) of bacterial concrete with curing age for river sand mixes.



According to Graph 4.3, when the curing age increases, the flexural strength of bacterial concrete for M20 grade also increases. But for BC-5%, BC-10%, and BC-15% at 28 days, the corresponding percentage increases in flexural strength were 5.64%, 7.9%, and 2.25%. Like this, at 180 days, the percentage increases in flexural strength are 4.43%, 10.34%, and 1.97%, respectively. For BC-5%, BC-10%, and BC-15% at 365 days, these percentages are 5.68%, 9.47%, and 1.42%, respectively, compared to ordinary concrete.According to the information above, the increase in flexural strength at 180 days and 365 days is greater than the increase at 28 days because the contribution of the bacterium Bacillus subtilis and the mineral calcium lactate to flexural strength is more pronounced at ages greater than 28 days. It was also noted that the flexural strength increased as the percentage of bacterial concrete increased from 0% to 10%, but at 15% the flexural strength decreased. This is because the hydration products are saturated at the 10% bacterial solution level; therefore, an increase in bacterial solution does not increase strength and the strength decreases.

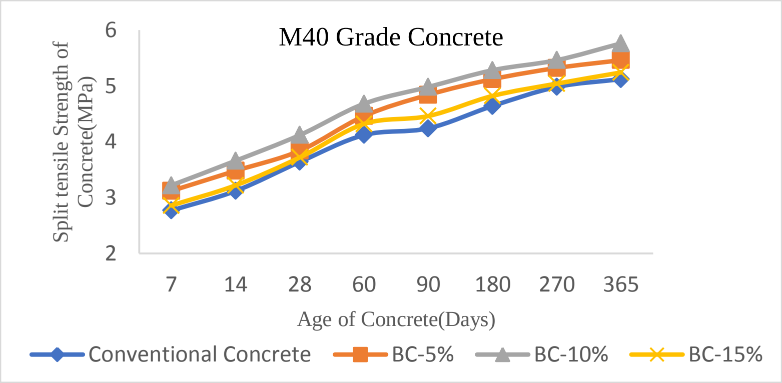
4.4 Variation of compressive strength (M40 Grade Concrete) of bacterial concrete with curing age for river sand mixes.

From Graph, the compressive strength of bacterial concrete for M40 grade increases with increasing curing age.The percent increase in compressive strength of M40 grade concrete at 28 days for BC-5%, BC-10% and BC-15% are 8.98%, 17.02% and 4.65% respectively. Similarly, the percent increase in compressive strength at 180 days are 6.86%, 12.54% and 4.63% respectively. At 365 days these percentages are 6.88%, 11.22% and 3.84% respectively for BC-5%, BC-10% and BC-15% with respect to conventional concrete.



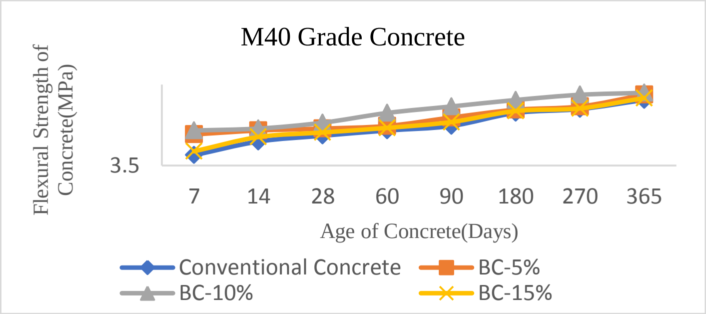
From the above it was observed that the gain in compressive strength at 180 days and 365 days is more than the compressive strength at 28 days since contribution of bacillus subtilis bacteria along with calcium lactate to compressive strength is prominent at ages more than 28 days.It was also observed that as the percentage of bacterial concrete increased from 0% to 10% the compressive strength also increased, but at 15% the compressive strength is reduced, this is because the hydration products are saturated at 10% bacterial solution, with further increase in bacterial solution does not contribute to strength and hence there is reduction in strength

4.5 Variation of split tensile strength (M40 Grade Concrete) of bacterial concrete with curing age for river sand mixes.



According to Graph, when the curing age grows, the split tensile strength of bacterial concrete for M40 grade also does. At 28 days, the split tensile strength of M40 grade concrete increased by 5.49%, 13.18%, and 2.19% for BC-5%, BC-10%, and BC-15%, respectively. Compressive strength also increased by a similar percentage at 180 days, 10.34%, 13.79%, and 3.87%, respectively. For BC-5%, BC-10%, and BC-15% at 365 days, these percentages are 6.64%, 12.5%, and 2.34%, respectively, compared to ordinary concrete.Because bacillus subtilis bacteria and calcium lactate have a larger role in compressive strength at ages greater than 28 days, it may be inferred from the above that the increase in split tensile strength at 180 days and 365 days is greater than the gain in split tensile strength at 28 days.Additionally, it was found that the compressive strength increased as the percentage of bacterial concrete increased from 0% to 10%, but the split tensile strength decreased at 15%. This is because the hydration products are saturated at 10% bacterial solution; therefore, an increase in bacterial solution does not contribute to strength, leading to a reduction in strength.

4.6 Variation of Flexural strength (M40 Grade Concrete) of bacterial concrete with curing age for river sand mixes.



FromGraph, the flexural strength of bacterial concrete for M40 grade increases with increasing curing age. The percent increase in flexural strength of M40 grade concrete at 28 days for BC-5%, BC-10% and BC-15% are 4.97%, 9.04% and 2.26% respectively. Similarly, the percent increase in flexural strength at 180 days are 1.95%, 7.81% and 1.17% respectively. At 365 days these percentages are 2.89%, 3.98% and 1.08% respectively for BC-5%, BC-10% and BC-15% with respect to conventional concrete.It was also observed that as the percentage of bacterial concrete increased from 0% to 10% the flexural strength also increased, but at 15% the flexural strength is reduced, this is due to the fact that the hydration products are saturated at 10% bacterial solution, with further increase in bacterial solution does not contribute to strength and hence there is reduction in strength.

5. CONCLUSION

Due to the formation of calcium lactate in concrete, the compressive strength of bacterial concrete of Grade M40 is increased with an increase in bacterial solution up to 10% for both river sand and crushed stone sand mixes. However, once the bacterial solution is above 10%, the strength is decreased due to the saturation of hydrated products. A similar pattern of results is seen in M20 grade concrete as well. The usage of 10% bacterial solution in concrete applications is therefore concluded.

Similar patterns of increased strength up to 10% bacterial solution at all ages of curing are also seen in the data for flexural strength and split tensile strength.

Due to the cubical particles and increased hardness of crushed stone sand mixes, they outperformed river sand mixes in terms of compressive, flexural, and split tension values. In order to create bacterial concrete for structural usage, crushed stone sand can be utilized.

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