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EXPERIMENTALINVESTIGATION ON SELF-HEALING CONCRETE USING BACTERIA

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Abstract
Concrete's inherent vulnerability is its irreversible tendency to develop cracks. Through these cracks, water and other salts can seep inside the concrete,further reducing the life of the concrete. The healing of cracks is occurred with bacterial concrete in concrete structures. So, a self-repairing technique that can rectify the cracks and fissures developed in concrete. This technique is highly desirable because the activity of crack remediation is eco-friendly and natural. The paper discusses the plugging of artificial cracks in cement concrete using Bacillus subtilis and the influenceof bacteria on the strength of concrete. Samples of concrete cubes and cylinders were preparedwith replacement 25%, 50%, 75%, and 100% of water with bacillus subtilis for determination of mechanical properties of concretein 28 days after proper curing.Bacillus subtilis has improved the mechanical properties of concrete in compression of conventional concrete.After the healing of concrete, the test result of compressive stress, and split tensile strength is maximum at replacement of water with25% bacterial solution.

Keywords:OPC Concrete, Self–healing, Bacillus Subtilis, Strength of concrete

Introduction

Concrete is the most common material used for all types of construction. Concrete became weakness in tension is the only drawback to using concrete. The likelihood of fractures forming is higher since the concrete is weak in tension. Apart from this, freeze–thaw action and shrinkage also lead to cracking in concrete. The durability of concrete is highly affected due to these cracks and it leads to corrosion of reinforcing bars. So it is very essential to find a suitable repair mechanism for regaining the strength of concrete. In a concrete structure, repair of cracks usually involves applying a cement slurry or mortar which is bonded to the damaged surface. Repairs can particularly be time-consuming and expensive. There are several methods for repairing cracks, including as filling the gaps with epoxy-based fillers. Artificial or synthetic materials that possess the innate capacity to self-heal without the need for human involvement or external problem identification are known as self-healing materials.

The "Bacterial Concrete" is a concrete that can be made by embedding bacteria in the concrete that can constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation. It has been shown that under favourable conditions for instance Bacillus Pasteurian, a common soil bacterium, can continuously precipitate a new highly impermeable calcite layer over the surface of an already existing concrete layer. The favorable conditions do not directly exist in a concrete but have to be created.As a result of the biological reaction of non-reacted limestone a calcium-based nutrient self-healing concrete is formed, and calcium nutrients are called 'Calcium Lactate' a special type of bacteria known as' 'Bacillus'. These products are added to the wet concrete when the mixing is done while preparing of concrete.

Vermeer et al. [2021] Conducted an experimental study of a PHA-based healing agent produced from PHA unsuitable for thermoplastic applications, which induces crack healing in concrete specimens, and consequently, reduces the water permeability of the cracks.Dai et al.[2022] carried out bending the concrete responds linearly at the early loading stage, and observed that the damage starts to accumulate and the formation of microcracks leads to slightly non-linear behavior before the peak load. after the peak, the softening process takes place where the crack growth can be observed.Jeon et al. [2022]

analyzed self-healing test results by SEM/EDS in the case of cracks inducementon 3 days and 7 days and managed in wet conditions for occurring self-healing in the presence of the chemical compositions of binders for all mixtures. Algaifi et al. [2021] conducted the experimental study by using bacterial isolated and identified Uratolytic activity, and determined Urease enzyme bacterial growth activity and Concrete strength for evaluation of bio-based cracks healing.Karimi et al. [2021] used the electrical and thermal conductivity of the asphalt mixture plays a significant role in the induced heating progress, and determined heavier specimens with a higher volume for more energy to reach a specific Temperature and healing level.Cuenca et al. [2021] investigated the mechanical performance and the autogenous self-healing capacity of an ultra-high performance fiber reinforcement cementitious concrete, containing alumina nano-fibre and crystalline admixture as a self-healing stimulator.Singh and Gupta [2019] conducted UPV and self-healing tests on concrete to investigate the self-healing and strength characteristics of all mixes and determined the compression and flexural strength characteristics of the concrete mixes.Smitha et al. (2022) studied self-healing on concrete by determining of mechanical properties compressive strength, tensile strength, and flexural strength of the concrete samples with bacteria culture and Ordinary Portland cement.Rohini and Padmapriya (2021) studied the strength properties of E-Waste concrete to determine bacterial action concrete improved by 2% of normal conventional concrete and obtained the optimum percentage of bacteria to improve about 2% of the properties of concrete at 15% substitution of E-Waste.Xu et al. (2020) studied the behavior of concrete with the addition of steel fibers and microwave healing for a rapid healing process that offers scope for busy airports faced with real problems and found mixtures containing 10% and 15% steel fibers in the mix had lower stiffness and strength recovery after healing in comparison with a mixture containing 5% of fibers.Yoo et al. [2019] studied the self-healing of concrete by using Cement, Silica flume, water, aggregate, short steel fiber, superplasticizer, and admixture, and compared the load when reaching the residual target strain due to its higher flexural strength for different types of samples.Alazhari et al. [2018] studied the self-healing capability of a dual system consisting of bacterial spores and nutrients encapsulated separately and demonstrated based on microscopy and initial surface absorption of water. Sangadj and Schlangen[2013] investigated certainly some variability in the results obtained from the experiments due to the heterogeneous nature of the system and provided visual confirmation of a healed response to a new crack of concrete.Rodriguez et al. [2020] determined the tensile strength and elastic modulus of the interface zone between bacteria-embedded PLA capsules and cement paste for their eventual use as input for mesoscale simulations of the self-healing concrete.

This paper deals with the healing effect of concrete cracks by bacterial precipitation on concrete mix proportion of M25 grade.An experimental study is carried out on concrete with a variation of bacteria used in concrete for M_{25}concrete mix for determination of mechanical properties of concrete

Materials and Methodology

Materials:

Ordinary Portland Cement (OPC) of 53 grade was used for samples of the concrete in this study. The physical and chemical properties of cement are as per IS:1489 part-1. River sand passing through a 4.75 mm IS sieve and confirming to zone-1 of IS:383 (1987) was used as fine aggregate (FA). The specific gravity of FA is found to be 2.66. Crushed stones of maximum size 10mm and 20mm IS sieves are used as coarse aggregates. The specific gravity of coarse aggregates of 10 mm and 20 mm is found to be 2.83 and 2.85 respectively. Fig. 1 shows the sample of fine aggregate and coarse aggregate materials.

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Fig.1: fine & coarse aggregates

Gram-positive bacteria called Bacillus subtilis are found in soil and the gastrointestinal tracts of humans and ruminants. Because of its rod-like shape and ability to produce a hard, protective endospore, Bacillus subtilis is able to withstand harsh environmental conditions. It is historically classified as an obligate aerobe, though evidence exists that it is a facultative anaerobe. Bacillus subtilisis also considered the best-studied Gram-positive bacterium and a model organism to study bacterial chromosome replication and cell differentiation. The concentration of Bacillus subtilis is 10^5 cells per ml of water as shown in Fig. 2.

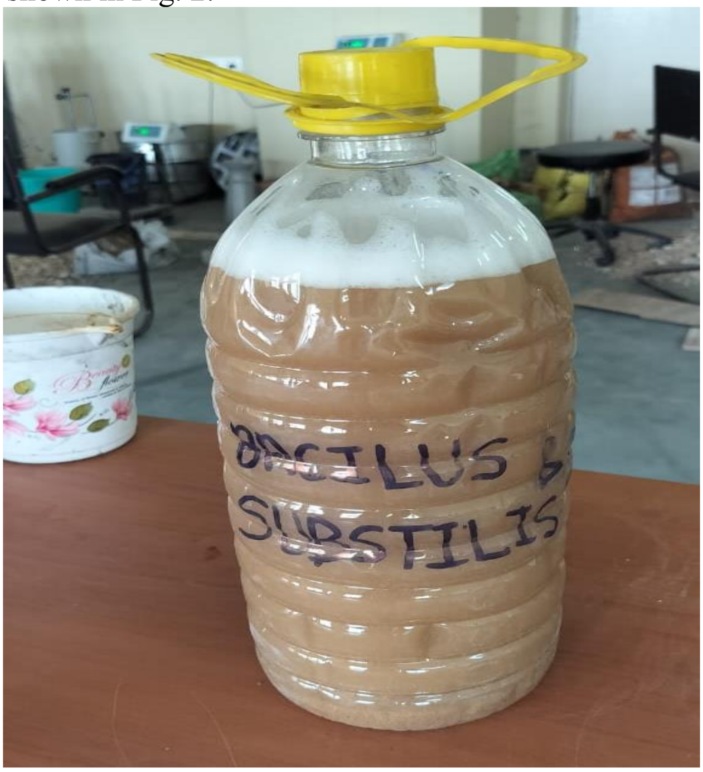

Fig. 2: Bacterial solution (bacillus subtilis)

Methodology

The main aim of our experimental study was to study the effect of Bacillus subtilis on compressive strength and split tensile strength of concrete by partial replacement of water with 0%, 25%, 50%, and 100% of Bacillus subtilis in cultured form. The concrete mix of M25 grade is prepared as per IS10262:2009 having a proportion of 1:1.47:2.6 with a w/c ratio of 0.45 as illustrated in Table 1. To carry out the experimental investigation total of 15 cubes of size 150mm x 150mm x 150mm and 15 cylinders of size 150 mm dia having a height of 300 mm were moulded. The bacterial concrete cube and cylinder specimen were moulded with a bacterial cell concentration of 10^5 cells per ml of mixing water with bacillus subtilis. All the ingredients required for M_{25} concrete were weighed and mixed. Theconcretespecimen 15 cubes and 15cylinders were moulded for 0%, 25%, 50%, 75%, and 100% replacement of water with bacillus subtilis as illustrated in Table 2. From these 12 cubes, some of the cubes and cylinders were tested in a compression testing machine (CTM) and compressive strength and split tensile strength were noted respectively and some of the cubes and cylinders were provided micro-cracks of each specimen of 25%, 50%, 75% and 100% replacement of water with bacillus subtilis by using compressive load on the specimen after 28 days of curing. CTM of 2000kN capacity is used in this study as shown in Fig. 3 was used to determine the total compressive load taken by concrete at 28 days. This ultimate load divided by the cross-sectional area of the cube (150mm x 150mm x 150mm) and the circumference of the cylinder (dia. 150 mm and 300 mm height) yields the compressive strength and split tensile strength of concrete respectively. The cube and cylinder sample for M25 grade containing different percentages of bacteria was loaded through a CTM. The cubes and cylinders were further placed in a water bath for 30 days at room temperature for self-healing. After 30 days, the specimen was removed from the curing tank when the self-healing of the concrete was over and photographs were taken to visualize the healing of the crack. Any presence of white precipitates shows the crack is getting healed. The compressive strength and split tensile strength of concrete were further obtained through a CTM.

Table 1: Material proportions of concrete M_{25} (1 m^3) without using bacteria

Ingredients	Cement	Fine aggregate	Coarse aggregate	water
Quantity (Kg/m^3)	473.5	496.1	1231.1	213.1
Concrete Mix (M)	1	1.47	2.6	0.45

Table 2: Replacement of %water with bacillus subtilis (bacteria) in mix proportion of concrete

Concrete Mix	% water	% bacillus subtilis (bacteria)
M1	100	0
M2	75	25
M3	50	50
M4	25	75
M5	0	100

Fig. 3:Compression Testing Machine

3. Results and discussion:

3.1 Effect of bacterial solution on compressive strength of concrete

An experimental study is performed for a Compressive strength teston concrete cubes of replacement of water25%, 50%, 75 %, and 100% with bacterial solution as shown in Fig. 4. It is observed that the strength of the cube has increased at 0% to 25% replacement of water by bacterial solution and

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obtained the maximum compressive strength of the cube at replacement of 25% water with bacterial solution,then compressive test results are decreased withreplacement of water 50%, 75%, and 100% with bacterial solution in compression to the normal concrete. Hence optimum replacement of water with bacterial solution is found at 25% for compressive strength of the concrete cube. Test results of compressive strength and split tensile strength are illustrated in Table 3.

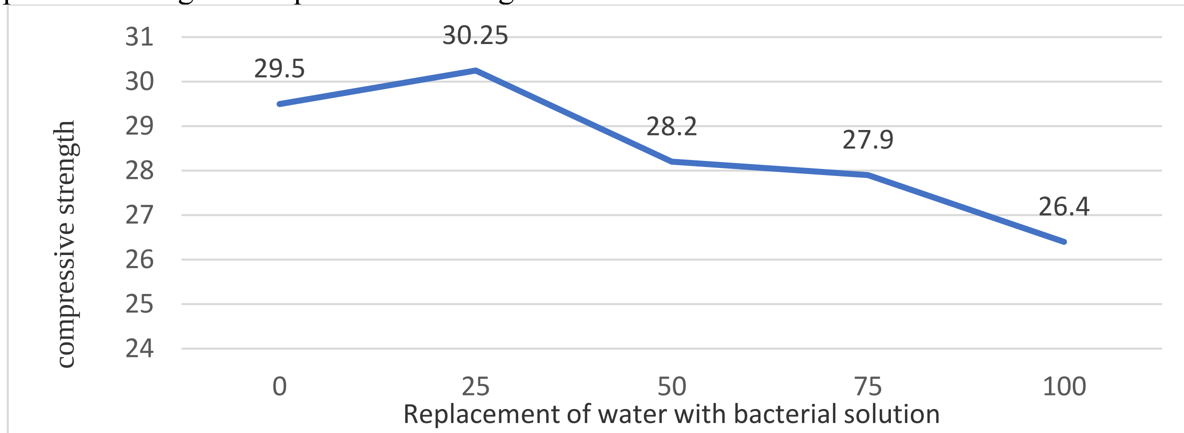

Fig. 4: compressive strength of concrete with replacement of water with bacterial solution

Table 3: Test result of compressive strength and split tensile strength

Concrete Mix	% bacillus subtilis (bacteria)	Split tensile strength (N/mm²)	Compressive strength(N/mm²)
M1	0	2.5	29.5
M2	25	2.4	30.25
M3	50	2.26	28.2
M4	75	2.3	27.9
M5	100	2.21	26.4

Effect of bacterial solution on split tensile strength of concrete

The result of split tensile strength is shown in Fig. 5. It is observed thatthe split tensile strengthof concrete is increased up to 25% replacement of water with bacterial solution the split tensile strength increases after that the split tensile strength decreases with increasing the replacement of water with bacterial solution 50%, 75%, and 100%.

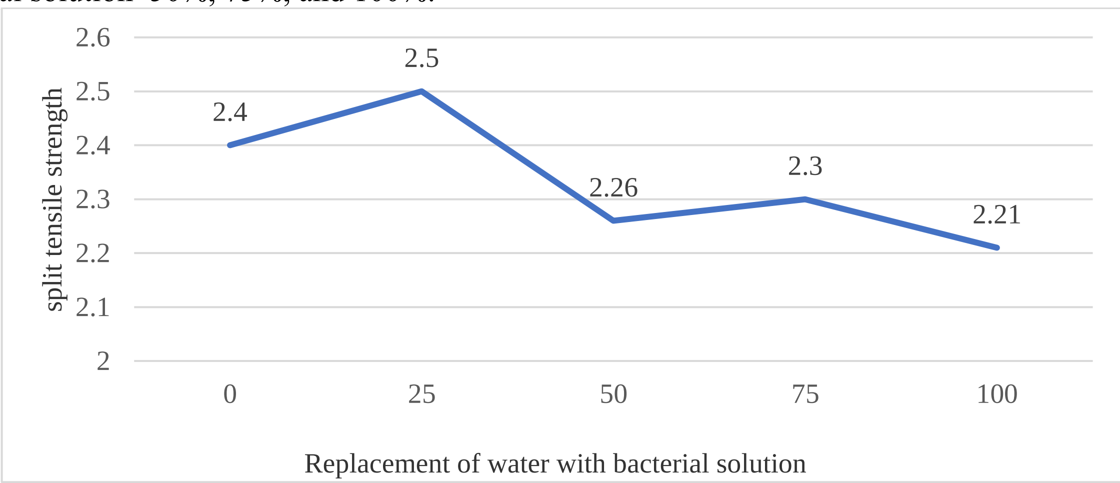

Fig. 5: split tensile strength of concrete with replacement of water with bacterial solution

Effect onproperties of concrete after healing by bacterial solution

After healing,the test result of compressive strength is shown in Fig. 6. The test result of compressive strength is maximum at 25% replacement of water with bacterial solution.When the percentage of bacterial solution is increased thenthe compressivestrengthdecreases. From Table 4, maximum compressive strength is obtained with the replacement of25% water with bacteria.

After healing the concrete samples, the test result for split tensile strength is carried out as shown in Fig. 7 and found that the maximum test result is at replacement of 25%water with bacterial solution.when the percentage of bacterial solution is increased then the split tensile strength of concrete is decreasing.Hence the maximum split tensile strength is found by replacing the bacteria at a maximum limit of up to 25%.

Table 4:Test result of compressive strength and split tensile strength after healing

Concrete Mix	% of bacterial solution	Split tensile strength (N/mm²)	Compressive strength (N/mm²)
M1	0	0.5	12
M2	25	1.5	29
M3	50	1.4	23
M4	75	1.3	20.1
M5	100	1.2	22.82

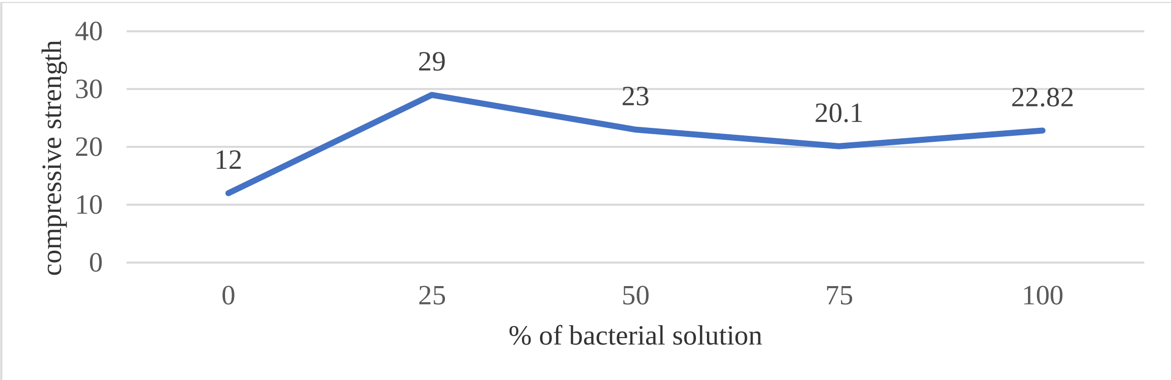

Fig. 6:compressive strength of concrete with replacement of water with bacterial after healing

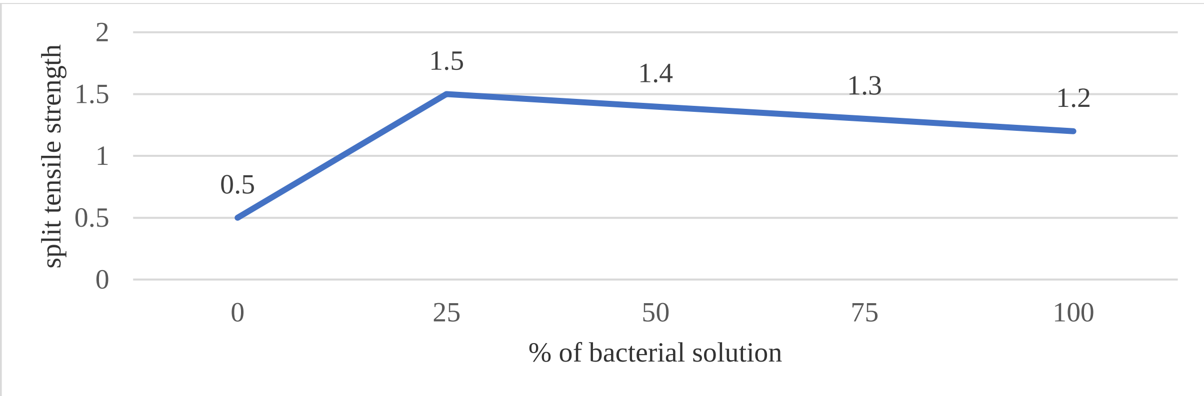

Fig. 7:Split tensile strength of concrete with replacement of water with bacterial after healing

Conclusions

An experimental study is carried out for mechanical properties on concretesamples for replacement of water25%, 50%, 75 %, and 100% with bacterial solution. Based on the test results and discussion, the following conclusions are drawn:

- Self-healing concrete is the best solution for the demand for sustainable concrete due to its ability to self-repair and durability.
- In this study, the maximum mechanical properties of self-healing concrete is obtained at25 %replacement of water with bacterial replacement.

In the future, self-healing concrete is going to play the most important role in concrete technology for micro crack occurred in concrete structures.

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