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# THE COMPARATIVE ANALYSIS OF THE PROPERTIES OF SELF HEALING CONCRETE USING BACTERIA AND CRYSTALLINE ADMIXTURE

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***Abstract :*** Concrete, a widely used and indispensable construction material, is prone to cracking, which significantly reduces its service life and necessitates costly replacements. Self-healing materials possess the unique ability to autonomously repair minor damages and cracks, thereby preventing member deterioration. Self-healing concrete employs specific constituents to mend cracks without external intervention. This study explores two types of self-healing concrete: one utilizing a crystalline admixture and the other employing the bacteria Bacillus subtilis. A comparison is made between these concretes in terms of their properties and healing capabilities. The crystalline admixture is incorporated into the concrete at percentages of 1%, 2%, and 3%, while Bacillus subtilis bacteria are added at 5%, 10%, and 15%. Among the different proportions, the concrete with 2% crystalline admixture exhibited the highest strength. The research involves conducting tests to evaluate compressive strength, split tensile strength, flexural strength, acid resistance, and water penetration. To assess the healing properties, cracks are intentionally induced in the casted concrete specimens. Ultimately, this study aims to compare the properties of each concrete grade and evaluate the healing capacity of the specimens.

***IndexTerms* - Concrete , self healing concrete , bacterial concrete , bacillus subtilis , crystalline admixture**

## I. INTRODUCTION

Concrete is an essential and indispensable construction material widely used in public infrastructure and buildings. Its effectiveness is greatly enhanced when reinforced with steel rebar since its inherent tensile strength is relatively low compared to its compressive strength. Concrete is also prone to cracking over time due to its brittleness and limited tolerance for strain. Although these cracks do not immediately compromise structural integrity, they expose the steel reinforcement to environmental factors, leading to corrosion, increased maintenance costs, and eventual structural compromise. The wear and tear experienced by concrete over its expected lifespan of several decades further exacerbates these issues. Due to its lack of flexibility and poor strain-handling capabilities, efforts have been made to develop self-healing concrete, which aims to address these flaws and prolong the service life of concrete structures. Self-healing materials commonly utilized include polymers, fibers, and supplementary cementitious materials like fly ash.

Certain bacteria have been found to enhance the self-healing properties of concrete, including Bacillus pasteurizing, Bacillus sphaericus, Escherichia coli, Bacillus subtilis, Bacillus cohnii, and Bacillus balodurans. These bacteria have the ability to produce calcium carbonate, which fills in small cracks and seals pores. In the case of self-healing bacterial concrete, Bacillus subtilis is employed, and the bacterial mixture is added to the concrete along with an activating medium containing calcium lactate. The presence of calcium lactate provides the necessary calcium content, which aids in the development of a calcium carbonate layer by the bacteria, effectively sealing the pores.

Crystalline admixtures are commonly used to reduce permeability in concrete. These commercially available products are added in small amounts to cement-based materials to enhance concrete durability and stimulate the autogenous healing of cracks. Crystalline admixtures possess hydrophilic properties, making them highly reactive with water. Introducing crystalline admixture to concrete improves its self-healing capabilities. The admixture is added as a slurry during the concrete mixing process. In the conducted experiment, the bacterial concrete utilized Bacillus subtilis in the presence of a calcium lactate medium, with bacteria concentrations of 5%, 10%, and 15%. Additionally, crystalline admixture was incorporated into the concrete at concentrations of 1%, 2%, and 3%.

## II. MATERIALS USED

The experimental work involved the use of various materials obtained from different vendors. These materials include cement (OPC), fine aggregate, coarse aggregate, water, superplasticizer, crystalline admixture, and the bacterium Bacillus subtilis. Prior to the experiment, each material underwent testing to determine their properties and ensure their suitability for the investigation. The test results confirmed that all the physical properties of the materials complied with the relevant IS codes of practice.

1. Cement

Ordinary Portland Cement (OPC), specifically 53 grade OPC, was used in the experiment. OPC is a commonly utilized type of cement worldwide, manufactured by blending limestone, argillaceous materials, calcareous materials, and gypsum.

2. Fine aggregate

Fine aggregates play a crucial role in providing workability and uniformity to the concrete mixture. Manufactured sand (M Sand) was employed as the fine aggregate. M Sand is a superior alternative to river sand as it lacks silt, organic impurities, and possesses good grading.

3. Coarse aggregate

Coarse aggregates contribute strength, toughness, and hardness to the concrete. Crushed gravel with a particle size of 20 mm obtained from a local crusher was used as the coarse aggregate.

4. Superplasticizer

A second-generation superplasticizer based on polycarboxylic ether (PCE) polymers was utilized in the experiment. Superplasticizers are added to improve the workability of concrete and reduce water consumption.

5. Crystalline Admixture

Crystalline admixtures (CAs) belong to the category of permeability-reducing admixtures. They mainly consist of OPC, silicon oxide, calcium oxide, alumina, ferric oxide, magnesium oxide, and calcium sulfonate. The crystalline admixture was introduced into the wet concrete mix as a slurry with an equal amount of water. The incorporation ratio was 1%, 2%, and 3% by weight of the cement.

6. Bacillus Subtilis

Bacillus subtilis is a rod-shaped, Gram-positive bacterium capable of forming heat-resistant spores. It is commonly found in soil and is non-pathogenic. In this experiment, Bacillus subtilis was used with nutrient agar as the medium at a temperature of 37ºC. The incubation period lasted for approximately 24 to 48 days. The bacteria were incorporated into the concrete along with a mixture of calcium lactate, which provided an activating environment for the bacteria.

## III. MATERIAL PROPERTIES

Table 3.1 Properties of material

| MATERIAL | PROPERTY | RESULT | ALLOWABLE LIMIT |
|---|---|---|---|
| Cement | Fineness | 9.7% | 10% |
| | Specific gravity | 3.12 | 3.1 – 3.16 |
| | Standard Consistency | 32% | 25 – 35% |
| Fine aggregate | Specific gravity | 2.77 | 2.5 - 3 |
| | Water absorption | 2.9% | 3% |
| Coarse aggregate | Specific gravity | 2.6 | 2.6 – 2.8 |
| | Water absorption | 0.34% | 0.1 - 2% |
| Crystalline admixture | Specific gravity | 2.45 | |
| | Bulk density | 1400Kg/m3 | |

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## IV. MIX PROPORTION

Mix design was done as per IS 10262: 2019. The mix proportion and mix designation are given below.

Table 4.1 Mix designation of M40 grade

| Mix id | Cement (kg/m$^3$) | Crystalline admixture (kg/m$^3$) | Bacteria (kg/m$^3$) | Coarse aggregate (kg/m$^3$) | Fine aggregate (kg/m$^3$) | Water (kg/m$^3$) | Superplasticizer (kg/m$^3$) |
|---|---|---|---|---|---|---|---|
| CA0 | 447 | - | - | 617 | 1173 | 174.4 | 1.788 |
| CA1 | 447 | 4.47 | - | 617 | 1173 | 174.4 | 1.788 |
| CA2 | 447 | 8.94 | - | 617 | 1173 | 174.4 | 1.788 |
| CA3 | 447 | 13.41 | - | 617 | 1173 | 174.4 | 1.788 |
| BS5 | 447 | - | 22.35 | 617 | 1173 | 174.4 | 1.788 |
| BS10 | 447 | - | 44.7 | 617 | 1173 | 174.4 | 1.788 |
| BS15 | 447 | - | 67.05 | 617 | 1173 | 174.4 | 1.788 |

Where
CA0 – Control Mix
CA1- Self healing concrete with 1% crystalline admixture
CA2- Self healing concrete with 2% crystalline admixture
CA3- Self healing concrete with 3% crystalline admixture
BS5- Bacterial concrete with 5% bacillus subtilis bacteria
BS10- Bacterial concrete with 10% bacillus subtilis bacteria
BS15- Bacterial concrete with 15% bacillus subtilis bacteria
CM mix ratio= 1: 1.37: 2.62
Water cement ratio = 0.39
Superplasticizer used was 0.4%

## V. SPECIMEN PREPARATION

Specimens are prepared with different mixes concrete such as addition of crystalline admixture to the mix as 1% , 2% and 3% .Also for self healing concrete using bacteria it is added as 5% ,10% and 15%. The specimens are prepared into cubes , cylinders and beams. The cracking of specimens are done with

## VI. RESULTS AND DISCUSSION

### 6.1 COMPRESSIVE STRENGTH

Table 6.1 Compressive strength test values

| Mix ID | 7 Days (N/mm$^2$) | 28 Day (N/mm$^2$) |
|---|---|---|
| CA0 | 35.2 | 48.3 |
| CA1 | 37.21 | 49.9 |
| CA2 | 41.85 | 52.8 |
| CA3 | 38.5 | 51.69 |
| BS5 | 40.57 | 51.87 |
| BS10 | 38.7 | 50.03 |
| BS15 | 37.95 | 49.45 |

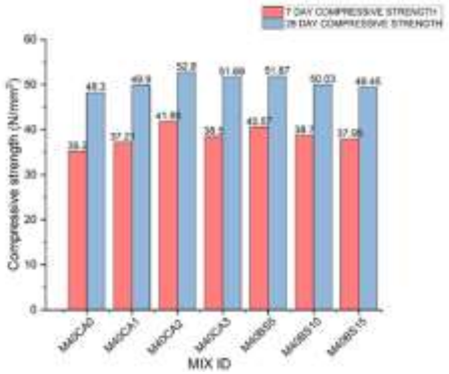


Fig 6.1 Compressive strength results

The 7th day and 28th compressive strength shows that concrete specimen with 2% crystalline admixture has maximum compressive strength i.e. 41.85 N/mm²and 52.8 N/mm². Also bacterial concrete with 5% bacillus subtilis contains more compressive strength i.e 40.57 N/mm²and 51.87 N/mm².

### 6.2 SPLIT TENSILE STRENGTH

Table 6.2 Split tensile strength

| Mix ID | 7 Days (N/mm²) | 28 Day (N/mm²) |
|---|---|---|
| CA0 | 2.81 | 4.83 |
| CA1 | 3.23 | 5.01 |
| CA2 | 3.59 | 5.35 |
| CA3 | 3.19 | 5.22 |
| BS5 | 3.49 | 5.28 |
| BS10 | 3.35 | 5.15 |
| BS15 | 3.21 | 5.05 |

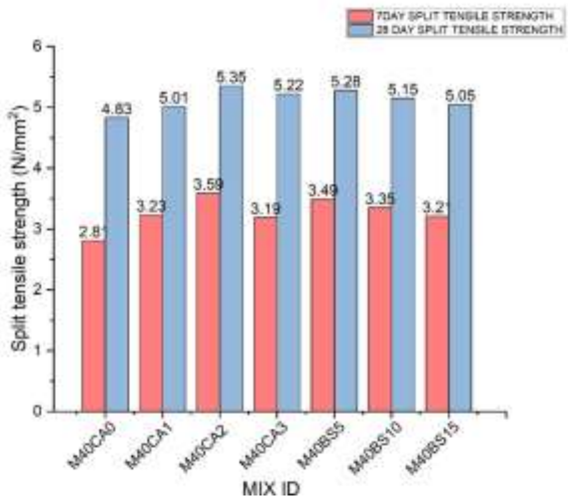


Fig 6.2 Split tensile strength

The results of the split tensile strength test on the 7th day indicate that the concrete specimens with a 2% crystalline admixture exhibited the highest tensile strength, measuring 3.59 N/mm² and 5.35 N/mm². Additionally, the bacterial concrete containing 5% Bacillus subtilis showed greater tensile strength, with values of 3.49 N/mm² and 5.28 N/mm².

### 6.3 FLEXURAL STRENGTH

Table 6.3 Flexural strength

| Mix ID | 28 Day ($N/mm^2$) |
|---|---|
| M40CA0 | 6.65 |
| M40CA1 | 7.17 |
| M40CA2 | 7.69 |
| M40CA3 | 7.22 |
| M40BS5 | 7.36 |
| M40BS10 | 7.19 |
| M40BS15 | 7.06 |

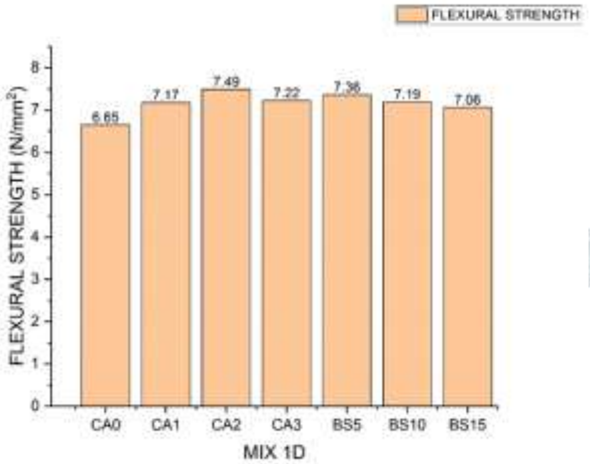


Fig 6.3 Flexural strength

The findings indicate that the self-healing concrete incorporating a 2% crystalline admixture exhibits superior flexural strength, measuring 7.49 N/mm^2, surpassing other mixes. This particular mix demonstrates a noteworthy 12.63% strength enhancement compared to the conventional mix. Similarly, bacterial concrete also exhibits increased strength, specifically a 10.67% improvement when compared to the conventional mix.

### 6.4 ACID RESISTANCE TEST

The effect of acid on concrete was identified in terms of loss in weight and loss in compressive strength at 28 and 56 days of exposure respectively. The visual appearance of the specimen after immersing in 5% of HCl for 56 days revealed that there was some change in the appearance of all the specimens.

Table 6.4.1 Loss in weight due to HCL exposure

| Mix ID | 28 Days (%) | 56 Days (%) |
|---|---|---|
| M40CA0 | 2.71 | 3.12 |
| M40CA1 | 1.56 | 2.36 |
| M40CA2 | 1.05 | 2.01 |
| M40CA3 | 1.45 | 2.35 |
| M40BS5 | 1.27 | 2.15 |
| M40BS10 | 1.12 | 2.22 |
| M40BS15 | 1.3 | 2.34 |

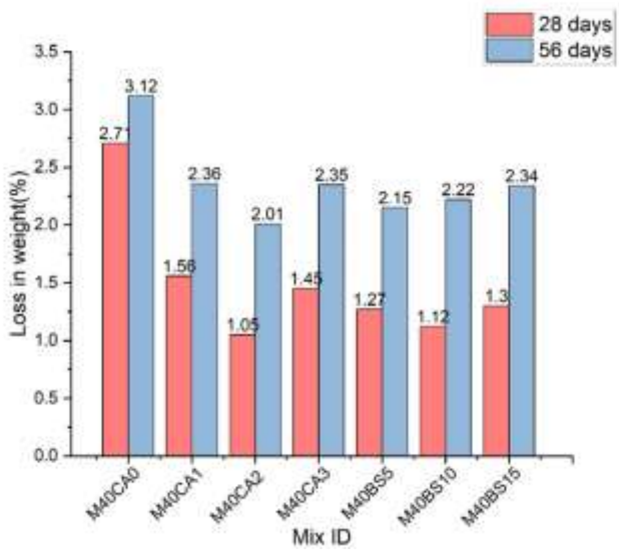


Fig 6.4.1 Loss in weight due to HCL exposure

Table 6.4.2 13 Loss in compressive strength due to HCL exposure

| Mix ID | 28 Days (%) | 56 Days (%) |
|---|---|---|
| M40CA0 | 3.45 | 4.23 |
| M40CA1 | 2.67 | 3.67 |
| M40CA2 | 2.33 | 3.01 |
| M40CA3 | 2.54 | 3.28 |
| M40BS5 | 2.47 | 3.11 |
| M40BS10 | 2.59 | 3.38 |
| M40BS15 | 2.74 | 3.69 |

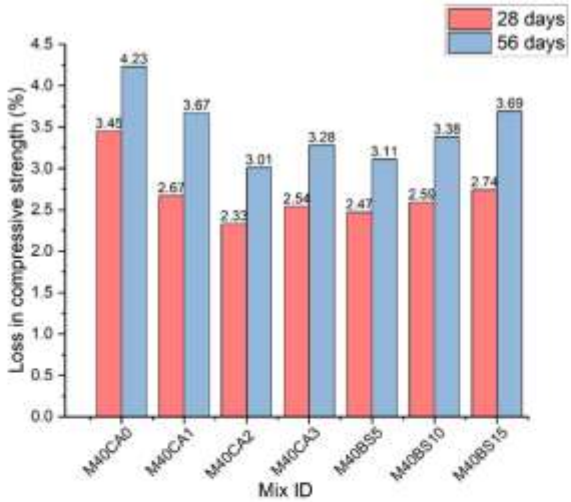


Fig 6.4.2 Loss in compressive strength due to HCL exposure

The results indicate that exposure to acids leads to both weight loss and a decrease in strength. The conventional mix experiences a weight loss of 3.12% and a strength loss of 4.23%. On the other hand, the mix incorporating a 2% crystalline admixture demonstrates a lower weight loss of 2.01% and a reduced compressive strength loss of 3.01%.

In the case of bacterial concrete, the presence of 5% bacteria results in a lesser weight loss of 2.15% and a decreased strength loss of 3.11%. When comparing bacterial concrete and concrete with a crystalline admixture, it becomes evident that the concrete with the crystalline admixture displays superior acid resistance.

**6.5 WATER PENETRATION TEST**

In concrete structures, water penetration can cause internal damage and hasten the deterioration process. Therefore, it is crucial to assess how well concrete can withstand water infiltration. The concrete's permeability; a measure of how easily water may permeate the concrete, can be determined with the use of the water penetration test. It can also be used to assess the concrete's quality, the success of curing, and its durability. Using DIN 1048-part 5, the water penetration test was conducted successfully.

Table 6.5 Water penetration test on specimen

| MIX ID | Observed Depth of Penetration (mm) | Quality Of Concrete |
|---|---|---|
| CA0 | 34 | Moderately permeable concrete |
| CA2 | 21 | Low permeable concrete |
| BS5 | 24 | Low permeable concrete |

**6.6 CRACK HEALING OF CONCRETE**

The specimens were closely monitored to observe the crack healing process, revealing that both self-healing concrete with bacteria and self-healing concrete utilizing a crystalline admixture required approximately 15 to 30 days for complete healing. In the case of small cracks, a white powder formation was observed on both types of specimens. This white powder is believed to be the result of calcium deposits formed as a reaction takes place. However, large cracks remained uncovered, with only small cracks measuring about 2-3 mm exhibiting the presence of white deposits over them. It was noted that approximately 60% of the healing process was completed within the 15-30 day timeframe.

When considering self-healing concrete with a 1% crystalline admixture, a slow healing rate was observed, while specimens with 2% and 3% crystalline admixture exhibited healing with the formation of white deposits on the cracked surfaces.

In the case of self-healing bacterial concrete, specimens containing 5%, 10%, and 15% bacteria displayed healing within the 15-30 day period, accompanied by the formation of white calcium carbonate deposits.

Fig 6.6 Healing of cracks on specimens

### 6.6.1 WATER PENETRATION TEST ON HEALED SPECIMEN

Table 6.6.1 Water penetration test on healed specimen

| MIX ID | Observed Depth of Penetration (mm) | Quality Of Concrete |
|---|---|---|
| CA2 | 29 | Moderately permeable concrete |
| BS5 | 32 | Moderately permeable concrete |

The results indicate that the healed specimens exhibit a moderate level of permeability, with a depth of penetration lower than that of the control mix. This suggests that the cracks in the specimens have undergone healing, resulting in a reduction in the depth of penetration, although it remains within the range of the control mix.

## VII. CONCLUSION

- Self healing concrete with 2% crystalline admixture shows more compressive strength, split tensile strength and flexural strength. Among the bacterial concrete 5% shows an increase compressive strength than that of other bacterial concrete.
- Comparing bacterial concrete and concrete with crystalline admixture, concrete with crystalline admixture (2%) displayed more compressive strength. This is because the crystals formed by the admixture can grow and interlock with the surrounding concrete matrix, creating a stronger and more cohesive material.
- Self healing concrete with crystalline admixture show less weight loss and compressive strength loss than bacterial concrete, in case of acid resistance test.
- The water penetration tests revealed that both self-healing concrete with a crystalline admixture and self-healing concrete with bacteria exhibited significantly lower penetration values compared to the control mix. This can be attributed to the inclusion of a crystalline admixture, which fills any voids present, and the bacteria, which interacts with the pores and voids, occupying all available spaces within the concrete matrix.
- The healing of the cracks induced self healing bacterial concrete and crystalline admixture seems to be required time span of 15-30 days for starting healing of and small cracks are seemed to have a white deposits of calcium carbonate on it.
- For analyzing the healing of the samples , the water penetration of the healed samples shows that they are healed as the penetration of the water are moderately permeable on healed self healing concrete using crystalline admixtures and bacteria.
- From comparing self healing concrete using crystalline admixture and self healing concrete using bacteria, the compressive strength , split tensile strength , flexural strength , durability are more in concrete added with crystalline admixture , while water penetration is low.

### VIII. ACKNOWLEDMENT

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