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The comparative analysis of the strength of self healing concrete using bacteria and crystalline admixture.

El análisis comparativo de la resistencia del hormigón autorreparable utilizando bacterias y aditivos cristalinos.

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ABSTRACT

One of the most popular and indispensable building materials is concrete. It often develops microscopic fissures that could eventually grow larger. Members start to deteriorate as a result of this. By including specific components, self-healing concrete can be utilised to repair cracks on its own. The two forms of self-healing concrete used in this study. One is prepared with crystalline admixture and other made with Bacillus subtilis bacteria. Properties of the two concrete are compared, and their compressive and split tensile strength are assessed. 1% ,2% and 3% of crystalline admixture are added to the specimens whereas 5%, 10% and 20% bacteria bacillus subtilis are added to the bacterial concrete.

Keywords: self healing concrete, bacterial concrete, crystalline admixture, *Bacillus subtilis.*

RESUMEN

Uno de los materiales de construcción más populares e indispensables es el hormigón. A menudo desarrolla fisuras microscópicas que eventualmente podrían crecer. Los miembros comienzan a deteriorarse como resultado de esto. Al incluir componentes específicos, el hormigón autorreparable se puede utilizar para reparar grietas por sí solo. Las dos formas de hormigón autorreparable utilizadas en este estudio. Uno se prepara con una mezcla cristalina y otro con la bacteria *Bacillus subtilis*. Se comparan las propiedades de los dos hormigones y se evalúa su resistencia a la compresión y a la tracción dividida. Se agregan 1%, 2% y 3% de mezcla cristalina a las muestras, mientras que se agregan 5%, 10% y 20% de bacterias bacillus subtilis al concreto bacteriano.

Palabras clave: hormigón autorreparable, hormigón bacteriano, aditivo cristalino, *Bacillus subtilis*.

INTRODUCTION

Concrete is a vital building material that is an absolutely essential component of public infrastructure and most buildings. It is most effective when reinforced by steel rebar, mainly because its tensile strength without reinforcement is considerably low relative to its compressive strength. It is also a very brittle material with low tolerance for strain, so it is commonly expected to crack with time. These cracks, while not compromising structural integrity immediately, do expose the steel reinforcement to the elements, leading to corrosion which heightens maintenance costs and compromises structural integrity over long periods of time. It cracks and suffers serious wear and tear over the decades of its expected term of service. It is not flexible and cannot handle significant amounts of strain. Self-healing concrete in general seeks to rectify these flaws in order to extend the service life of any given concrete structure. Self healing materials commonly used are polymers, fibres, supplementary cementitious materials such as fly ash etc.

There are certain bacteria which can improve the self healing property of concrete Bacillus pasteurizing, Bacillus sphaericus, Escherichia coli, Bacillus subtilis , Bacillus cohnii, Bacillus balodurans etc. The bacterial concrete will also close the small pores by producing calcium carbonate filling the small cracks. Here bacteria bacillus subtilis is used to prepare the self healing bacterial concrete .The bacterial mix is added to the concrete in the presence of an activating medium of calcium lactate which provide calcium content which helps in developing the calcium carbonate layer on the pores by the bacteria.

Crystalline admixture is generally used as permeability reducing admixture. They are commercial products employed in low contents in cement-based materials either to improve concrete durability or to stimulate autogenous healing of cracks .These materials are hydrophilic, and this makes them to react easily with water. But adding crystalline admixture on concrete will improve the self healing ability of concrete. Crystalline admixture is added as a slurry during the mixing of concrete. In this experiment the Bacteria used in presence Calcium lactate medium and the bacteria is added to the concrete as 5%, 10%, 15%.Crystalline admixture is added to the concrete as 1%, 2% and 3%.

MATERIALS AND METHODS

The materials used in the experimental work are, cement (OPC), fine aggregate, coarse aggregate, water, super plasticizer, crystalline admixture and bacteria bacillus subtilis. Each material was acquired from different vendors. Various test was done on material to find out the material properties and to determine that all the material are suitable for the experiment. All the tests done and the values of all physical properties of materials used for investigation are confirming to relevant IS codes of practice.

Cement - Ordinary Portland Cement (OPC) are the commonly used cement in the world. It is manufactured by mixing limestone and other raw materials which consist of argillaceous, calcareous and gypsum. In this experiment 53 grade OPC is used.

Fine aggregate - The most important function of fine aggregates is to assist in providing workability and uniformity in mixture Manufactured sand (M Sand) is used as fine aggregate. It is a better substitute to river sand, as it have no silt, organic impurities and mostly well graded.

Coarse aggregate - Coarse aggregates provide strength, toughness and hardness to concrete. Crushed gravel of size 20 mm downgraded from a local crusher is used as coarse aggregate.

Superplasticizer - Superplasticizer used here is a second-generation superplasticizer of polycarboxylic ether (PCE) based polymers. These are added to improve the workability of the concrete and also reduce the water consumption.

Crystalline Admixture - Crystalline admixtures (CAs), categorized as permeability- reducing admixtures, ,mainly consists of OPC, silicon oxide , calcium oxide, alumina , ferric oxide, magnesium oxide, calcium sulphonate . It is introduced to the wet mix by making a slurry of this crystalline admixture with same amount of water. It is incorporated as 1% ,2% and 3%of weight of cement.

Bacillus Subtilis – Bacillus subtilis is a Gram-positive, rod-shaped bacterium that forms heat-resistant spores. It is commonly found in the soil. It is non-pathogenic. It is used on waste composts .Here the medium used is nutrient agar at temperature 37ºc. The incubation days are about 24 to 48 days. They are incorporated to the concrete with mix of calcium lactate which provide an activation state to the bacteria.

Table 1 Properties of material

MATERIAL	PROPERTY	RESULT	ALLOWABLE LIMIT
Cement	Fineness	9.70%	10.00 %
	Specific gravity	3.12	3.10–3.16
	Standard Consistency	32.00%	25.00–35.00 %
Fine aggregate	Specific gravity	2.77	2.50-3.00
	Water absorption	2.90%	3.00 %
	Specific gravity	2.60	2.60 –2.80
Coarse aggregate	Water absorption	0.34%	0.10-2.00 %

MIX PROPORTION

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

Table 2 Mix proportion

MixID	Cement $kg//m^3$	Crystalline Admixture kg/m^3	Bacteria kg/m^3	Fine kg/m^3	Coarse kg/m^3	Water kg/m^3
CA0	396	-	-	583	1231	142
CA1	396	3.96	-	583	1231	142
CA2	396	7.92	-	583	1231	142
CA3	396	11.88	-	583	1231	142
BS5	396	-	19.8	583	1231	142
BS10	396	-	39.6	583	1231	142
BS15	396	-	59.9	583	1231	142

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: 1.85 : .4

Water cement ratio = 0.42

Superplasticizer used was 0.4%

The test conducted on concrete of different mix where test, compression strength test slump and split tensile strength test to obtain fresh and hardened properties of concrete. All the test was done confirming to relevant IS codes of practice.

A. Compressive strength test: The cube specimens of standard size were casted and tested for compression strength in accordance with the IS 516:1956 (reaffirmed 2011). Compressive strength of concrete was calculated by crushing to failure of the test cubes by means of compression testing machine.

B. Split tensile strength test: The cylinder specimen for split tensile strength were casted and tested in in accordance with the IS 516:1956 (reaffirmed 2011). Split tensile strength of concrete was calculated by crushing to failure of the test cylinder by means of compression testing machine in the axial direction of the cylinder.

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%.

RESULTS AND DISCUSSION

A. Compressive strength

Compressive strength test was conducted on the prepared cubes and the load at failure of each cube was noted. The cubes after 7- day and 28-day curing were tested and their average value is reported. Table 3 shows the compressive strength of mix.

Table 3 Compressive strength

Mix ID	7th day compressive strength (N/mm^2)	28th compressive strength (N/mm^2)
CA0	24	38.4
CA1	25	40.5
CA2	31	46.9
CA3	26	43.1
BS5	25	39.7
BS10	28	44.6
BS15	27	41.2

The observed 7 and 28-day compressive strength of hardened concrete specimen shows that there is an increase in compressive strength of concrete with crystalline admixture and bacterial concrete than that of control mix. This increase in strength of concrete that form the calcium silica hydrate (C-S-H) gel and also calcite content. It is observed that at 2% addition of crystalline admixture shows maximum compressive strength then after that the for higher percentage strength reduces. This due to the CSH formation is completed and there is no further component left for reaction. In self haling concrete using bacteria, the compressive strength is more than that of control mix but less than that of self healing concrete with crystalline admixture. 10% of addition bacteria shows maximum compressive strength in self healing bacterial concrete.

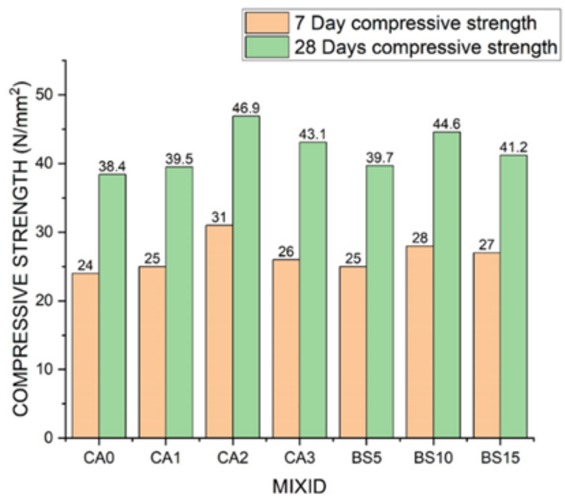

Fig.1 Variation in compressive strength of all the mixes

B. Split tensile strength

Split tensile test was conducted and the load at failure of each cylinder was noted. The cylinder after 7-day and 28-day curing were tested and their average value is reported. Table 5 shows the split tensile strength of specimens.

Table 4 Split tensile strength values

MixID	7thday split tensile strength (N/mm^2)	28th split tensile strength (N/mm^2)
CA0	2.1	3.25
CA1	2.3	3.5
CA2	2.7	4.15
CA3	2.4	3.85
BS5	2.2	3.64
BS10	2.5	3.98
BS15	2.35	3.86

The result observed for 7 and 28-day split tensile strength of hardened concrete specimen displays a result similar to that of compressive strength which was observed above. The concrete with 2% crystalline admixture displays a maximum Split tensile strength than any other specimen.

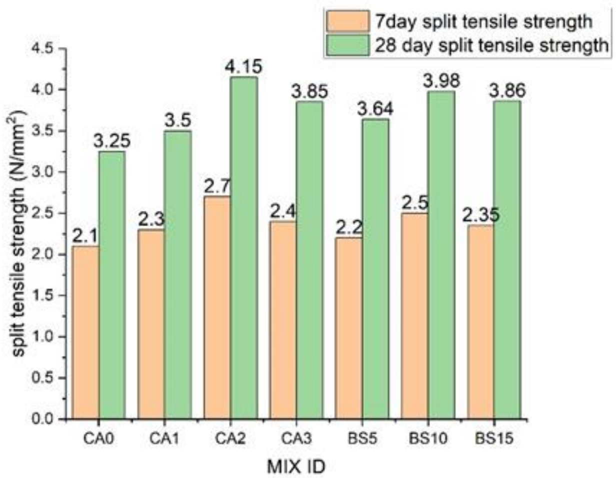

Fig.2 Variation in split strength of all the mixes

CONCLUSION

For the experiment, M30 grade concrete mix design was chosen and was carried out with the help of guidelines given in IS 10262:2019

It is observed that compared to control mix,specimen with 2% crystalline admixture have more compressive strength in 7 day testing and 28 day testing with 31N/mm^2 and 46.9N/mm^2. Addition of bacteria bacillus subtilis also displayed an improvement in compressive strength compared to control mix .With 10% addition of bacillus subtilis bacteria attained more strength among tested bacterial concrete i.e 28N/mm^2 and 44.6$N/mm^2$for 7th day and 28th day respectively. In 7 day and 28 day testing, concrete with crystalline admixture have more split tensile strength of 2.7 N/mm^2 and 4.15N/mm^2respectively. Comparing bacterial concrete and concrete with crystalline admixture, concrete with crystalline admixture (2%) displayed more compressive strength and split tensile strength. This is due to the formation of CSH gel and also the unreacted particles fills the pores.

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