Study on Effectiveness of Self-Healing Technique for Self Compacting Concrete

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Abstract

This study presents the self-healing capacity of sodium silicate (Na_2SiO_3) and polyurethane in self-compacting concrete (SCC) inserted by the pharmaceutical capsule and cementitious hollow tubes. M20 grade SCC was designed based on the recommendations available in the literature. The effectiveness of self-healing agents was found by comparing the result of modulus of elasticity and recovery indices found by testing of 78 specimens after healing. It is observed that the modulus of elasticity of specimens having healing agents in various percentages, was reduced according to the increase in the volume of the healing agent but the target strength is always achieved. From interpreting the result of the study after 28 days of testing we can conclude that the optimum dosage of the healing agent is 4% and polyurethane is more effective as we can see from the difference in modulus of elasticity and recovery indexes. Also, the cementitious hollow tubes show higher modulus of elasticity and recovery indexes.

Keywords: *sodium silicate, self-healing, SCC, cementitious hollow tubes, polyurethane, modulus of elasticity.*

1. Introduction

Concrete is the most used construction material on Earth but it is susceptible to crack formation due to its limited tensile strength. Moreover, damage repair tends to be difficult when cracks are not visible or not easily accessible. Striving for larger and more complicated structures, a variety of engineered materials with high-grade properties have become available. These materials are almost always designed along the 'damage prevention principle'. This means that strength and stiffness properties of these materials are optimized in order to prevent the occurrence of damage. Nowadays there are other approaches than the autogenous healing of concrete previously described self-healing with mineral additives, self-healing by means of bacteria and self-healing based on encapsulated adhesives.

In various researches, several healing agents such as sodium silicate (Na2 Si O3)[1], Potassium silicate (K2 Si O3), polyurethane[3], Dicyclopentadiene [5] and several methods such as pharmaceutical capsules [1], cementitious hollow tubes [4], and glass tubes are used to insert healing agents into the concrete are discussed. Among those self-healing agents, sodium silicate (Na2Si O3) and polyurethane are low cost and easily available in the market. The various study suggests cementitious hollow tubes and pharmaceutical capsules as effective methods to insert self-healing agents but the comparison is not studied by anyone and both are low-cost methods so in this study those methods are used. From various studies, it can be concluded that the use of healing agents is effective to reduce crack and to increase durability.

2. Scope and Objectives

Cracks are the main problem faced by the construction industry which affects the aesthetics of the building and needs costly repairs. By the use of self-healing concrete by adding self-healing agents will heal the cracks by it and also decreases the porosity by calcium precipitation will increase the durability of structures. Many researchers have studied the properties of self-healing concrete for strength and effectiveness of healing capacity. No studies have been mentioned the optimum dosage of self-healing agent used to attain the maximum strength. Many self-healing agents are used in concrete for strength improvement and to increase self-healing capacity. Here sodium silicate and polyurethane were used since it's easily available in the market. Also, several methods are adapted to insert self-healing agents into the concrete such as ceramic tubes, glass tubes, and capsules. Here pharmaceutical capsules and cementitious hollow tubes are used.

The objectives of investigation are discussed below

- To study the effect of self healing agents on the mechanical properties of SCC.
- To find effectiveness of the sodium silicate and polyurethane as self healing agent and to find the optimum dosage
- To compare the healing property of sodium silicate and polyurethane
- To find effective method to insert self healing agent in concrete
- To find the behavior of concrete under fracture after self healing.

3. Methodology

The cement, fine aggregate, and coarse aggregate used for concrete preparation satisfy the IS specifications and good for use.

Mix designs done based on the material property found by studying the materials in the lab as per IS specification.

Experiments were conducted to compare the properties of self-healing agents in SCC and to find the optimum dosage of the self-healing agents to attain maximum strength. For this 2%, 4%, 6% dosage of the self-healing agent was added to the SCC. The specimens were tested to find modulus of elasticity and load recovery indexes after curing and 28 days of primary tests.

The results obtained from the modulus of elasticity and CMOD test of healed specimens were compared with the ordinary SCC.

4. Properties of Materials

The materials used for self-compacting concrete are cement, Fine aggregate, Coarse aggregate, water, fly ash and super plasticizer (CERAPLAST 300) and their properties are summarized in the table 1.

Table 1: Properties of Materials

S.No	Material	Property	Value
1	Cement (O.P.C 53)	Specific Gravity	3
2	Fly ash	Specific Gravity	2.63
3	CERAPLAST 300	Specific Gravity	1.2
4	Coarse Aggregate	Specific Gravity	2.85
5	Fine Aggregate	Specific Gravity	2.7

In this study sodium silicate (Na_2SiO_3) and polyurethane are used as the self-healing agents and pharmaceutical capsule (PC) having Size 13 with capacity of 3ml and Cementitious hollow tubes (CHT) which have an inner radius of 10 mm, outer radius 12.5 mm and a length of 5 cm are used to insert those self-healing agents were shown in Fig.1.

Fig. 1 Pharmaceutical tablets

Fig. 2 Cementitious hollow tubes

5. Mix Design

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, durability and workability as economically as possible. The mix proportioning has to be done to achieve specified characteristics at a specified age, workability of fresh concrete and durability requirements. The grade of concrete adopted for this study is M20 and the target strength is 26.6 N/mm2.The maximum size of aggregate taken is 20mm. The mix proportion of M20 grade SCC is shown in table 2 [5]. Details of specimens and the mix designation of each specimen are shown in table 3.

Table 2: Mix Proportion

CEMENT (kg/m^3)	Fine Aggregate (kg/m^3)	Course Aggregate (kg/m^3)	FLY ASH (kg/m^3)	WATER(lit)	Super Plasticizer (lit)
330	895	605	158.93	234.93	3.91

Table 3: Details of Specimen

Mix designation	Healing agent (%)	Healing agent inserting method	Healing agent
0HA	0%	-	-
SSCHT2	2%	Cementitious hollow tubes	Sodium Silicate
SSPC2	2%	Pharmaceutical capsules	Sodium Silicate
PCHT2	2%	Cementitious hollow tubes	Polyurethane
PPC2	2%	Pharmaceutical capsules	Polyurethane
SSCHT4	4%	Cementitious hollow tubes	Sodium Silicate
SSPC4	4%	Pharmaceutical capsules	Sodium Silicate
PCHT4	4%	Cementitious hollow tubes	Polyurethane
PCHT4	4%	Pharmaceutical capsules	Polyurethane
SSCHT6	6%	Cementitious hollow tubes	Sodium Silicate
SSPC6	6%	Pharmaceutical capsules	Sodium Silicate
PCHT6	6%	Cementitious hollow tubes	Polyurethane
PCHT6	6%	Pharmaceutical capsules	Polyurethane

6. Experimental Programs

The methods employed in preparing the test specimens including casting, curing are described. The following molds were used to cast the concrete specimen for various studies. 500mm x 100mm x 100 mm moulds were used to cast beams to determine the load recovery index and flexural strength of SCC and 300 mm x 150 mm molds were used to cast cylinders to determine the modulus of elasticity. Flow test and Vee Bee Consist meter test was conducted for determining the fresh properties of concrete.

For determining the mechanical properties, the test specimens were removed from water bath and surface-water was removed using dry cloth, immediately before testing. This was to ensure that the test specimens were tested at a saturated-surface dry condition (SSD) condition. Various tests to be carried out on hard concrete are:

1. Three Point Bending Test
2. Flexural Strength Test
3. Compression test

The tests on specimens were conducted after curing and the specimen were kept in environmental condition and those testes where also conducted after 28 days of testing to find the effect of self-healing agents and technique used to insert those agents.

6.1 Three Point Bending Test

After curing time, samples were removed from the water and subjected to three-point bending (TPB) test in order to analyze the behavior to fracture and repair effectiveness. Before the mechanical tests, 10 mm deep U-shaped notches were made on the samples, in order to control the cracking's start of the specimen. TPB test were carried out for each mortar notched specimen, by using a UTM with a load cell capacity of 400 kN. The Crack Mouth Opening Displacement was found by attaching an angled section to the specimen and using dial gauge (Figure 3). The samples were loaded until the failure, and were maintained in normal environment for 28 days, before the repetition of the test and the subsequent evaluation repair.

$$\text{LRI (\%)} = \frac{Pr - Pu}{Pp - Pu} \qquad (1)$$

Where Pr is the peak load obtained during the reloading stage, Pp is the peak load reached during the pre-loading stage (i.e. during crack creation in the intact material, corresponding to the material maximum strength), and P_u is the residual load obtained at the moment of unloading preceding the re-loading stage. In addition, a stiffness recovery index (SRI) was calculated as

$$\text{SRI (\%)} = \frac{Sr}{Sp} \times 100 \qquad (2)$$

Where again S_r is the stiffness of the specimen during the re-loading stage and Sp is the stiffness of the intact specimen (i.e. the stiffness recorded in the pre-loading stage, prior to crack creation).

Fig. 6. Test setup for three point bending

6.2 Flexural Strength Test

This test method covers the determination of the flexural strength of concrete using a simple beam with third-point loading. The results were calculated and reported as the modulus of rupture (f_b).

$$f_b = \frac{P \text{ X } L}{bd^2} \quad (3)$$

Where,

P - Maximum applied load
d - Depth of the specimen at failure
L- Length of the span
b - Width of the specimen

6.3 Modulus of Elasticity

Test Procedure

- Place the specimen with compressometer in the compression testing machine and center it.
- Apply load continuously without stock at a rate of 140kg/cm2/minute until a stress of(c+5)kg/cm2 is reached where c is the one third of average compressive strength of cubes calculated to the nearest 5kg/cm2(a load of 12.4T).
- Maintain the load at this stress for at least one minute and reduce gradually to an average stress of 1.5kg/cm2 (a load of 0.3T)
- Apply the load again at the same rate until an average stress of (c+1.5) kg/cm2 is reached(a load of 11.8T).Note the compressometer reading at this load.
- Reduce the load gradually and take readings at an interval of 1T up to0.3T (11.8T, 10.8T, 9.8T, 8.8T, 7.8T… 1.8T, 0.3T).
- Apply the load third time and note the compressometer readings at an interval of 1T.

Fig. 5 Test setup for finding modulus of elasticity

7. Results and Discussions

The properties of normal self-compacting concrete is listed in table 4

Table.4. Properties of Normal Self Compacting Concrete

Property	Value
Flow percent	144%
Vee-Bee seconds	1.9 Seconds
Compressive Strength of Concrete Cubes	29.82 N/mm^2
Splitting Tensile Strength of Cylinders	2.8N/mm^2

As we can see the obtained Flow percent was 144%, and the obtained Vee-Bee seconds was 1.9 seconds which seems to be the normal M20 grade concrete have high

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workability. Also the target strength is 26.6 N/mm^2 the compressive strength obtained after 28 days was 29.82 N/mm^2 which is greater than target strength. The hardened concrete properties such as compressive strength, split tensile strength were tested in the laboratory of M20 self compacting concrete having healing agents after 28 days of curing and those specimen were kept in environmental condition to heal by the agents. Below graphs shows the variation in flexural strength and load recovery index of specimen after 28 days of curing and testing.

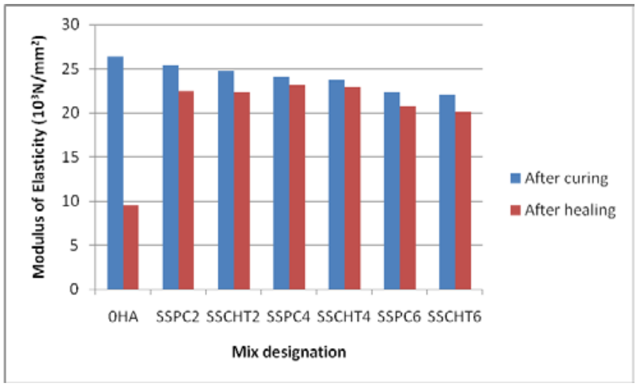

Fig. 5. Variation of modulus of elasticity at 28 days of curing and after healing of specimen having sodium silicate as healing agent

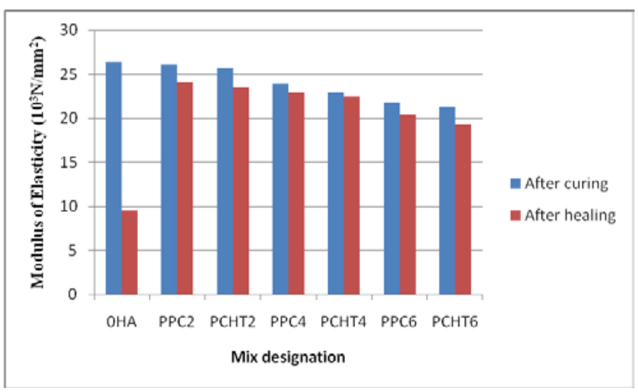

Fig. 6. Variation of modulus of elasticity at 28 days of curing and after healing of specimen having polyurethane as healing agent

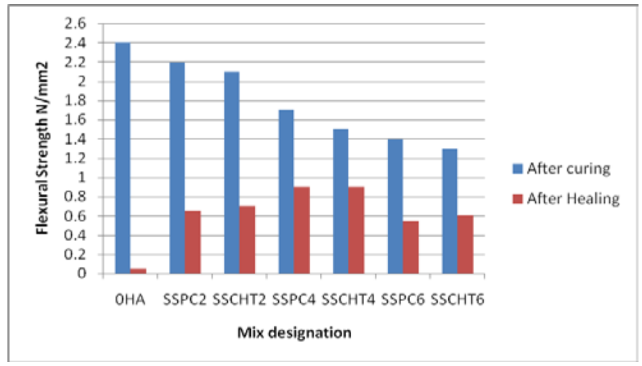

Fig. 7. Variation of flexural strength at 28 days of curing and after healing of specimen having sodium silicate as healing agent

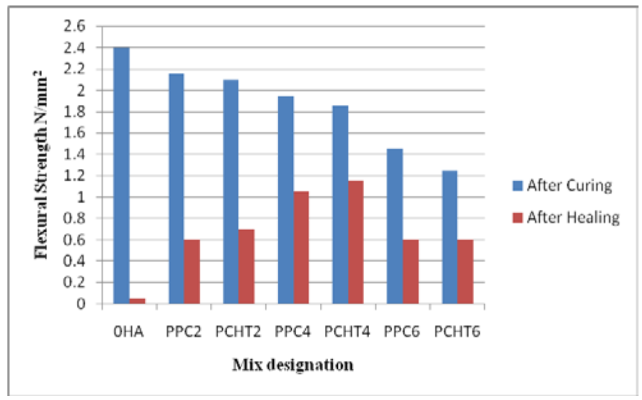

Fig. 8.Variation of flexural strength at 28 days of curing and after healing of specimen having polyurethane as healing agent

From the graphs showing modulus of elasticity and flexural strength at 28 days of curing we can see that there is a decrease in the modulus of elasticity and flexural strength according to the increase in the percentage of self-healing agents but all the specimens have archived target strength. And we can observe a slightly higher value for pharmaceutical capsules since the volume occupied by the capsule is fewer effects on the strength than the volume occupied by cementitious hollow tubes. Also from the graphs showing modulus of elasticity and flexural strength strength after healing, we can observe that PCHT4 gives a better result in both cases. Also, the values were increasing at 4% volume of healing agent and polyurethane has higher strength than specimen having sodium silicate as the healing agent. The CHT gives more results than PC as inserting methods. The results of the experimental studies were described below in table 5&6 by tabulating the result of three point bending test in terms of load and stiffness recovery indexes.

Table 5: The load recovery index (LRI) of specimens

Mix designation	LRI (%)
0HA	0
SSPC2	16.22
SSCHT2	24.32
SSPC4	40.74
SSCHT4	50
SSPC6	26.09
SSCHT6	33.33
PPC2	20.51
PCHT2	24.32
PPC4	45.45
PCHT4	58.82
PPC6	29.17
PCHT6	35

Table 6: The stiffness recovery index (SRI) of specimen

Mix designation	SRI (%)
0HA	1.84
SSPC2	17.24
SSCHT2	19.06
SSPC4	36.27
SSCHT4	43.19
SSPC6	22.9
SSCHT6	26.93
PPC2	18.06
PCHT2	21.58
PPC4	43.59
PCHT4	55.25
PPC6	24.82
PCHT6	28.24

From the tables showing LRI and SRI after healing, we can observe that PCHT4 gives a better result in both cases. Also, the values were increasing at 4% volume of healing agent and polyurethane has higher recovery index than specimen having sodium silicate as the healing agent. The CHT gives more good results than PC as inserting methods.

8. Conclusions

In this study sodium silicate (Na_2SiO_3) and polyurethane were used as the self-healing agents and pharmaceutical capsule and Cementitious hollow tubes were used to insert those self-healing agents. The properties of the specimen having sodium silicate (Na_2SiO_3) and polyurethane in pharmaceutical capsules and cementitious hollow tubes were compared to find the effectiveness of self-healing agents and inserting method.

1. From the experimental results, we can conclude that self-healing ability of SCC can be effectively increased using self-healing agents such as sodium silicate and polyurethane.
2. The modulus of elasticity and flexural strength of specimens having healing agents in various percentages was reduced according to the increase in the volume of the healing agent.
3. The modulus of elasticity and flexural strength after curing were higher for specimens having pharmaceutical capsules as inserting method compared to cementitious hollow tubes.
4. The reduction in modulus of elasticity and flexural strength of specimen having healing agents kept in environmental condition after 28 days of testing are varying from 11.59% to 2.09% and 70.45% to 37.84%
5. The LRI and SRI is also varying from 16.22% to 58.82% and 17.24% to 55.25%
6. The optimum content is 4% since the modulus of elasticity and flexural strength was less than 5% and 50% respectively. Also the SRI and LRI are higher for specimen having 4% of healing agent.
7. The polyurethane and cementitious hollow tubes are the effective self-healing agent and inserting method since both shows less reduction in the modulus of elasticity and flexural strength also both have higher SRI and LRI.

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