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The effect of self-healing additive on the durability of cracked concrete

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Abstract

Self-healing techniques are presented in three different ways: The first application is the use of bacteria to calcite in concrete cracks. In this way, relatively large cracks can be filled in reinforced concrete. This method does not improve the strength of the structure, but by filling the crack, the reinforcement path is blocked. This stops the entry of liquids and ions that start to corrode the reinforcement and thus increase the compressive strength but decrease the electrical resistivity of the structure. With this method, cracks can be filled and leakage can be prevented. In designs that use a self-healing additive such as Mix designation 7, the time interval obtained from the accelerated corrosion test between the cracked and intact specimens is reduced. Compressive strength in cracked and intact specimens in these designs is higher than in other designs. The use of more superplasticizers and more Silica fume are effective in these amounts. Its low electrical resistance can lead to increased corrosion intensity thus more superplasticizers in Plan 7 is not preferable to Plan 4. Low electrical resistance can lead to increased corrosion intensity thus Plan 4 is preferable to Plan 7.

Keywords: Nanotechnology, Compressive strength, Self-healing, Silica fume, electrical resistance
2020 MSC: 82D80

1 Introduction

One of the main concerns in any concrete structure is to control and prevent cross-sectional cracking. Cracking in concrete may be caused internally by the constituents of the concrete itself or by external factors and environments such as corrosive chemical environments containing sulfate and chloride, the penetration of salts and acids, atmospheric and environmental effects, severe changes Temperature, shocks and loads on the concrete to be created. Not only such cracks but also even microscopic cracks in the tensile zone of concrete, which is taken for granted, may in some cases disrupt the performance of the concrete structure. So far, a lot of research has been done to control and repair cracks and protect against corrosion of reinforced concrete members. At present, methods such as repairing damaged limbs, various chemical coatings and the use of crack fillers, traditional and conventional methods are used to repair visible cracks in a concrete structure. The introduction of nanotechnology into the concrete industry with the advent of self-repairing composites is associated with the construction of intelligent structures with the detection of failure

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and automatic repair. This technology is being developed by modeling and inspiring the repair mechanism in the body of living organisms and its simulation in concrete. A solution to the repair effect of failure, reinforcement of materials by adding various elements to the mixture is investigated.

The main phases are the ability of natural repair, swelling and hydration of cement paste, which continue with the deposition of calcium carbonate (CaCO3) and ultimately block the flow paths and deposition of water impurities or the movement of some concrete particles separated during the cracking process.

Researchers' efforts to increase the strength and useful life of concrete have led to the concept of self-healing concrete making its way into the construction industry. There are two main areas of research for this type of concrete; One is the natural hydrate-based way to seal cracks over time and the other is the artificial way to seal cracks that require human intervention. The main purpose of this work is to increase the durability of concrete, which will have a great positive impact on the environment and the economy.

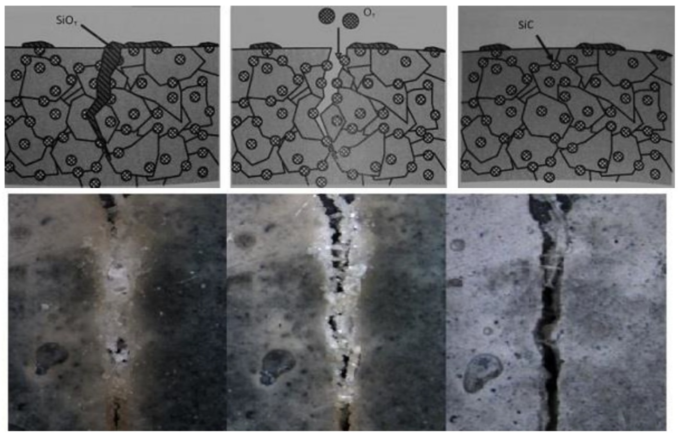

Figure 1: Self healing in concrete [13]. the main phases are the ability of natural repair, swelling and hydration of cement paste, which continue with the deposition of calcium carbonate (CaCO3) and ultimately block the flow paths and deposition of water impurities or the movement of some concrete particles separated during the cracking process.

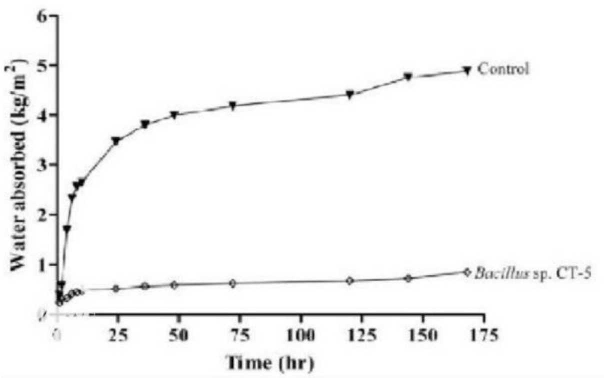

Figure 2: Self-healing in concrete by using of a special type of bacteria [11].

The figure 2 shows the effect of bacterial self-healing over a period of 168 hours to absorb water about 6 times that of the control sample. This is for the formation of calcium deposits in the presence of bacteria. At times of more than 10 hours for bacterial specimens, the rate of optimal water uptake is increased. This indicates the high effect of the formation of even a layer of calcite against the amount of water absorption.

Concrete is a very heterogeneous material produced by a combination of cement powder and aggregate of different sizes and water, with natural physical, mechanical and chemical properties [10]. The reaction between cement and water produces calcium hydrate silicate, which causes the strength of concrete and other mechanical properties of concrete, as well as some by-products such as calcium hydroxide CH, gel pores, and so on. Despite hydrated cement and by-products everywhere in concrete, it is difficult to control the reaction in concrete after molding and hardening, and this is a major problem in the concrete industry. The important issue, in the fresh and hard state of concrete, is the cracks and the resulting problems. Cracks in concrete structures and premature erosion occur due to alkaline silica reactions, which is a chemical reaction. Apart from the above, the permeability of gases through pores and micro-cracks in concrete has led to the problem of corrosion, which in concrete repairs causes further deterioration. In addition to the expansion and contraction of concrete, which causes cracks in concrete at older ages, sulfate attack causes the concrete to decompose and leach chemicals, both of which are due to excess calcium hydroxide CH [10]. The by-product during cement hydration is according to the following equation:

$$2C3S + 6H \longrightarrow C3S2H3 + 3CH$$

$$2C2S + 4H \longrightarrow C3S2H3 + CH$$

$C =$ Cement, $S = SiO_2$ and $H = H_2O$

According to the above equation, CSH is the resistance phase, while the CH by-product has no cementitious properties and is easily washed away by chemical attack. By adding suitable siliceous or aluminum cementitious materials to the cement which react with CH. Production of excess CSH and replacement with CH improves the pore structure, reduces the permeability of gases and water in concrete. Reducing the amount of CH during hydration of cement reduces the chance of sulfate attack and leaching with chemicals. Will cope to some extent. To solve the above problem, various methods such as pozzolanic reaction of cement using cementitious materials for chemical reaction with lateral CH to obtain the amount of excess CSH or the use of cementitious materials such as abrasive fly ash, pozzolanic granules to fill pores to reduce CH and gain extra CSH has been investigated. Addition of cementitious materials in concrete not only improves the mechanical properties of concrete, but also affects its efficiency, changing the formability time and its durability [10].

The white masses in the electron microscope images are the same as the calcium hydroxide crystals. According to Figure 3, it can be said that the addition of silica fume and nanosilica to the combination of cement and water in the cement paste can reduce The amount and size of calcium hydroxide crystals in the transition area between the dough and the aggregate and thus strengthen this area [10].

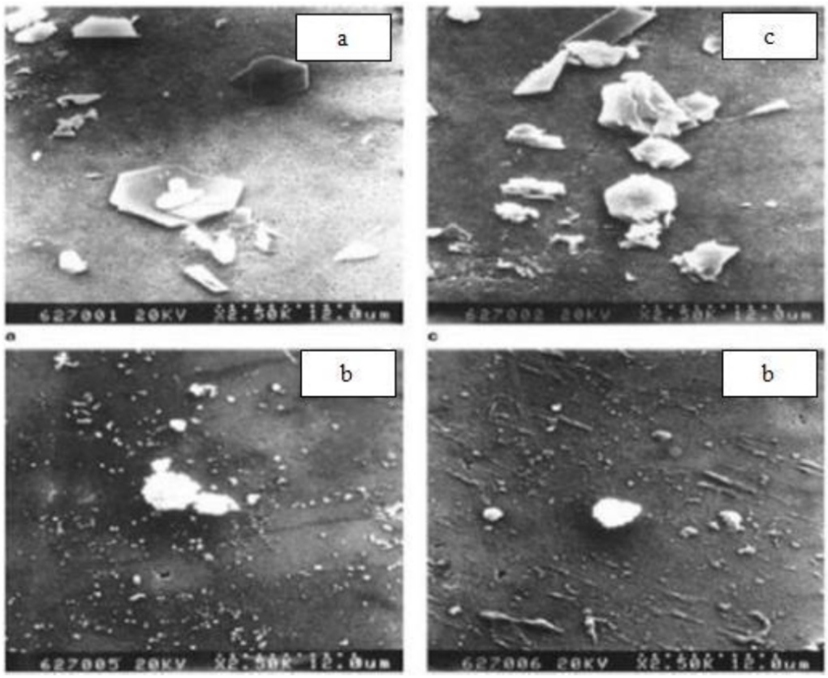

Figure 3: SEM images of calcium hydroxide crystals in 28-day aggregate and cement paste area a) without the use of nanosilica b) using 3% nanosilica c) using 3% microsilica [10].

Edwardsen 1999 investigated the percentage of water penetration in concrete and self-healing of cracks in concrete [5]. Jonkers et al. (2010) introduced bacterial self-healing concrete [7].

Li et al. (1998) studied about the passive intelligent self-healing cement composite [8]. They showed S-M1-4 is best potential for passive intelligent self-healing according to figure 4.

Table 1: mix design of passive intelligent self-healing [8].

Specimens	No. of specimens	No. of SAC fibers	No. glass fiber w/ink	Amount of SA (ml)
N-M1	1	–	–	–
N-M2	5	–	–	–
N-M1-4	2	–	–	–
I-M1	2	–	10	–
S-M1	2	20	–	1.0
S-M2	6	20	–	1.0
S-M1-4	1	32*	8*	3.2

SA, sealing agent (Superglue)
*200 mm length and 100 µl capacity glass fibers with the same cross-section specified in the ''Passive Smart Self-healing Concept: Implementation'' section

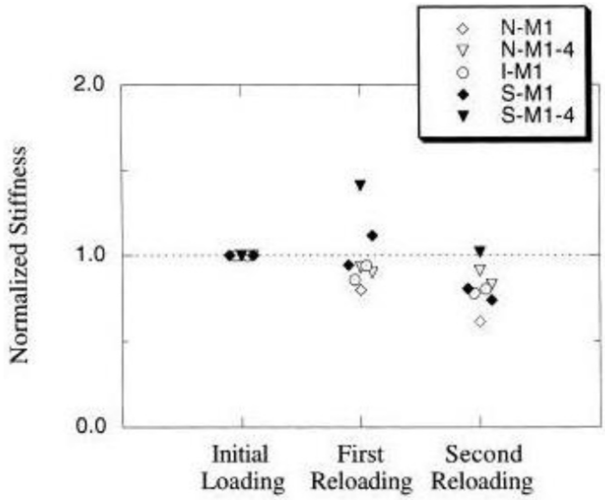

Figure 4: comparison of stiffness in flexural beam [8].

Schlangen et al. (2010) presented in their article on self-healing techniques in three different ways [12]: The first use of bacteria was for the deposition of calcite in concrete cracks. Bacterial concrete has a great future, especially in underground structures that are difficult or impossible to repair.

A number of studies have reported that concrete structures have a specific capacity to repair cracks. Therefore, the use of alternative options such as bacterial concrete has been considered [1, 14].

In this new method, for the structural modification of damaged structures, a microbial process is used in which metabolic activities lead to the deposition of calcium carbonate in the form of calcite, which will repair cracks and reduce the permeability of concrete. This phenomenon is called bacterial-stimulated calcite deposition or microbial calcium carbonate (MICP) [9].

1.1 New aspect and innovation in research

Investigating the effect of the role of using self-healing additive and silica fume and superplasticizer in concrete after cracking is an innovative aspect of this research.

These couple equations are the necessary relationships for damage and restoration variables in each area. The first balance equation is as follows [6]:

$$D^{\pm} = \frac{1}{1-H^{\pm}} - \frac{\frac{1}{1-H^{\pm}} + \frac{B_0^{\pm}}{K_d^{\pm}}}{1 + \frac{E^{\pm}(1-H^{\pm})^2}{K_d^{\pm}}(\varepsilon^{\pm})^2}$$

$$H^{\pm} = 1 - \frac{1}{D^{\pm}} - \frac{1 - \frac{1}{D^{\pm}} + \frac{G_0^{\pm}}{K_h^{\pm}}}{1 + \frac{E^{\pm}(D^{\pm})^2}{K_h^{\pm}}(\varepsilon^{\pm})^2}$$

$$b\rho \int E\varepsilon(1 - D(1-H))^2 d\varepsilon = 0$$

$D^{\pm}$ and $H^{\pm}$ are damage and restoration tensors, respectively. E^{-} and E^{+} are Young's modulus is compressive and tensile. ε^{-} and ε^{+} are according to compressive and tensile strains in line with the height of the beam.

2 Experimental study

Cement type I-42.5 in accordaning to (ASTM)-C150 [3] was used. Silica fume in according to ASTM-C1240 [4] was used. Chemical composition of silica fume and cement are presented in Tab. 1. Polycarboxylate based superplasticizer is according to with the standard specifications of ASTM-C494 [2].

With the help of laboratory method, the effect of using silica fume, lubricant and self-healing additive instead of a percentage of cement in increasing or decreasing the compressive strength and the self-healing property of concrete will be investigated. Eight mixing schemes were proposed to compare the effect of the use of silica fume and lubricant and self-healing additive on the self-healing properties of concrete based on previous studies that were reviewed and are presented in Tab. 2. To evaluate the self-healing property, the compressive strength and electrical resistance of the samples were measured according to ASTM standards. Tab. 2 shows the mix proportion designs of this study.

Table 2: Mix designs

Mix designation	Ratios					cutie (kg/m3)						
	Cement content (kg/m3)	Silica fume/ cement	Self-healing additives	Water/ cement	superplasticizer/ cement	cement	Silica fume	Self-healing additives	Water	superplasticizer	Gravel	Sand
1	400	0	0	0.4	0.003	400	0	0	160	1.2	1037	849
2	400	0.05	0	0.4	0.004	380	20	0	160	1.6	1033	846
3	400	0.1	0	0.4	0.005	360	40	0	160	2	1030	842
4	400	0.1	0.0005	0.4	0.005	360	40	0.2	160	2	1030	842
5	400	0.1	0	0.4	0.005	360	40	0	160	2	1030	842
6	400	0.1	0	0.4	0.006	360	40	0	160	2.4	1030	842
7	400	0.1	0.0005	0.4	0.006	360	40	0.2	160	2.4	1030	842
8	400	0.05	0.0005	0.4	0.005	380	20	0.2	160	2	1030	846

After performing corrosion acceleration test on 8 concrete mixing designs, the measured results of corrosion current density were recorded. The trend of changes in corrosion current density with respect to the duration of the affected flow is shown in Tab 3.

Non-cracked samples that were tested directly at the age of 28 days and cracked samples were loaded after leaving the mold to crack and were processed and tested until the age of 28 days.

Table 3: Experimental results

Mix designation	Compressive Strength (MPa)		Electrical resistivity (kohm.cm)		ACT		
	kgf	28 days	I(mA)	28 days	Con.	I(mA)	t(h)
1	57100	58.20591	18.3	16.39344262	Cracked	351	111
	56800	57.9001	19.1	15.70680628	Intact	332	143
	57500	58.61366	19.9	15.07537688			
2	62300	63.50663	12.8	23.4375	Cracked	161	166
	61400	62.58919	13.6	22.05882353	Intact	152	187
	62100	63.30275	13.1	22.90076336			
3	64900	66.15698	7.9	37.97468354	Cracked	110	193
	65200	66.46279	7.2	41.66666667	Intact	96	213
	66100	67.38022	8.1	37.03703704			
4	58600	59.73496	7.2	41.66666667	Cracked	119	173
	59400	60.55046	7.3	41.09589041	Intact	101	195
	57500	58.61366	7.9	37.97468354			
5	70400	71.76351	15.9	18.86792453	Cracked	144	164
	70800	72.17125	16.4	18.29268293	Intact	132	190
	68300	69.62283	16.1	18.63354037			
6	75000	76.4526	25.6	11.71875	Cracked	176	146
	73500	74.92355	24.9	12.04819277	Intact	164	160
	74900	76.35066	26.5	11.32075472			
7	75500	76.96228	24.6	12.19512195	Cracked	167	154
	73900	75.33129	23.9	12.55230126	Intact	158	168
	75000	76.4526	23.8	12.60504202			
8	64700	65.95311	22.9	13.10043668	Cracked	161	177
	62600	63.81244	22.6	13.27433628	Intact	144	191
	68400	69.72477	23	13.04347826			

3 Conclusions

Self-healing techniques are presented in three different ways. In designs that use a self-healing additive such as Mix designation 7, the time interval obtained from the accelerated corrosion test between the cracked and intact specimens is reduced.

Compressive strength in cracked and intact specimens in these designs is higher than other designs. The use of more superplasticizers and more Silica fume are effective in these amounts. Its low electrical resistance can lead to increased corrosion intensity thus Plan 4 is preferable to Plan 7. Low electrical resistance can lead to increased corrosion intensity thus Plan 4 is preferable to Plan 7.

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