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A Review on Self-Healing Concrete Using Crystalline Admixture

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Abstract- Cracks in concrete structures are inevitable as they deteriorate throughout their lifetime due to different factors. Self-healing of concrete is thus a new approach, which repairs cracks and increases concrete's durability. One of the self-healing method such as autonomous healing in which chemical agent such as crystalline admixture, which enhances concrete healing capacity. Crystalline admixtures (CA) are hydrophilic in nature that reacts easily with water. These are the products, which are formed by chemical active substances of cement and sand. The crystalline admixture is a permeability reducing admixtures under hydrostatic conditions (PRAHs) as stated by the ACI Committee 212. The chemical reaction between crystalline admixture along with cement and water forms crack blocking deposits. Due to this crack blocking deposits, it increases the density of Calcium Silicate Hydrate (CSH) and the resistance to water penetration in the concrete. This study presents the self-healing effects of the crystalline admixture on various characteristics of concrete with different percentages of crystalline admixtures. The literature shows a different healing behavior of crystalline admixture on the different exposure condition and the presence of water is necessary for the healing reactions.

Keywords: concrete; crystalline admixture; micro-cracks; recovery; self-healing; water permeability test.

1. Introduction

The phenomenon in concrete that repairs cracked concrete is self-healing [1]. Concrete has some self-healing capacity which fills the crack when a crack occurs in concrete. Around 20-30% of cement particles are generally anhydrous in concrete which reacts with water or moisture, producing hydration materials which contribute to the closing of the crack due to self-healing capacity[2],[3],[4]. The self-healing materials are used to increase the durability of structures and reduce maintenance and repair costs. It also prevents the structures from difficult repairs throughout their life [5]. Autogenous healing in a concrete is an intrinsic healing capacity, which is common in ordinary concrete but its capacity is limited. It was also later observed by Neville in 1981[6] and Abrams[7]. Further unhydrated cement particles and calcium carbonate precipitation were the main reasons for the autogenous healing [8],[9]. Due to the lack of feasibility for autogenous healing, autonomous healing has been studied. In order to improve the self-healing capacity of the concrete, engineered healing has been developed and

several self-healing ideas have been employed, such as the use of crystalline admixture[10], microencapsulating healing agents[11],[12], and bacterial concrete[11][14].

2. Self-healing approach by using crystalline admixture in concrete:

Crystalline admixtures (CA), as indicated by the ACI Committee 212, are permeability-reducing admixtures (PRAs)[15]. Especially, crystalline admixtures are hydrophilic in nature due to this they react easily with water. These products are made of cement and sand active chemicals. Together with cement and water, crystalline admixture form water based insoluble deposits of crack blockage that increase CSH density and water penetration. According to the ACI Committee 212 report [15]the cement compounds which reacts with crystalline admixture are tricalcium silicates in the presence of water, While others[13] indicate the reactivity of calcium hydroxide. The general process is followed by Eq(1), which, according to the ACI report 212, reacts in the process of producing modified calcium silicate hydrates and an insoluble pores blocking system with an crystalline promoter M_XR_X.

$$3CaO\text{-}SiO_2 + M_xR_x + H_2O \rightarrow Ca_x\, Si_x\, O_x\, R - (H_2O)_x + M_xCaR_x\text{-}(H_20)_x \quad (1)$$

(calcium silicate + crystalline promoter + water →modified calcium silicate hydrate + pore-blocking precipitate)

Jaroenratanapirom & Sahamitmongkol[16]studied and compared the different admixtures, containing crystalline admixtures for visual closure. Crystalline Admixture showed their good results for small and early age cracks (< 0.1 mm and 3 days) but they were not effective in case of larger cracks (around 0.3 mm) as compared with OPC mortars. For cracks of up to 150 μm that were immersed in water for thirty days Sisomphon has achieved [17] the self-healing capacity of crystalline admixture. Ferrara [18],studied the influence of adding CA of 1% by the weight of cement on the strength recovery of ultra-high performance concrete and the specimens were initially pre-cracked at crack width as 130μm and 270μm and specimens have kept in wet/dry cycles during 4 weeks. Crystalline admixture specimens recovered around 80% of the crack width; therefore the addition of CA improved a 14% the self-healing properties of concrete while reference specimens were healed up to 70%. Marta Roig Flores [19]focused on the cracked specimens of self-healing of fibre-reinforced concrete by measure its permeability and crack width.

3. Influence of crystalline admixture on properties of concrete

3.1 Compressive strength

The compressive strength of concrete has increased by 3% Admix C significantly and gives the best results compared to control concrete in the moist cured environment. Though this addition changed the aggregate to cement ration, and due to this modulus of elasticity is decreased [20]. The concrete's compressive strength was

almost equal to the crystalline mixture in Table 1, which after 28 days was added at 2% and without it [21]. It has found that concrete density does not change by addition of admixture at the same time, it significantly increases the compressive strength which is up to 47 %[22]. The compressive strength of concrete is 14.57% higher in case of crystalline admixture than control concrete after 28 days. The test was carried out as per IS:516-1959 on a concrete cube of size 150X150X150 mm using 2000Kn capacity of compression testing machine [23]. The maximum compressive strength of 88.10 N / mm^2 for mix S10CA is 3.12% higher than the control mix (CA) for 28 curing days [24].

Table 1: Results for compressive strength test (Jiri et.al 2016)

Crystalline admixture	Compressive strength (N / mm^2)			
	Mixes			Average
	1	2	3	
Penetron Admix	35.6	35.8	37.1	36.2
Xypex Admix	37.2	35.7	36.1	36.3
Without admixture	37.6	36.9	36.0	36.8

3.2 Water permeability

The healing rate which is a constant indicator of durability recovery from the results of the modified permeability test (Fig 1). And by using image analysis, the crack width is evaluated which has the samerelationto the results of water flow[19][20].

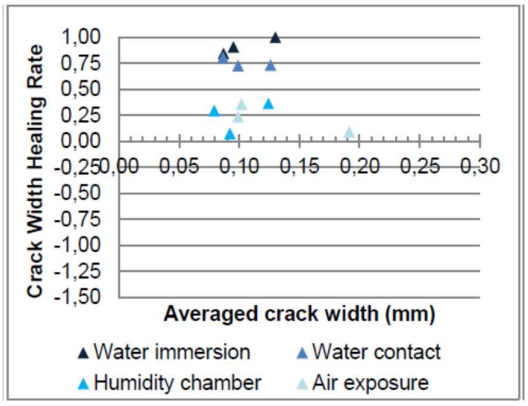

Fig 1: Crack width healing rate for crystalline admixture concrete (CAC) for the four exposures (Marta Roig-Flores et.al 2015)

For the cracks up to 0.30mm, the crystalline admixture in concrete, which presented the better, results in healing of cracks. The concrete with crystalline admixture showed the highest healing rates with values about 95 % which is stored under water immersion exposure at 15 and 30ºC[25]. The water vapour permeability of concrete has reduced by using crystalline admixture by 20% Penetron and 16 % Xypex [21]. The hydro insulating admixture in fibre concrete compositions showed the reduction in water penetration depth up to 75 % compared with reference composition[22]. The crystalline admixture in concrete immersed in water at 15^0C and 30^0C, with low standard deviation, yielded healing ratios, by reduces dispersion and thus increases healing reliability [25].The addition of crystalline admixture showed a reduction of water penetration depth and thus reducing water permeability coefficient [26].

3.3 Three-point bending test

A normal concrete intrinsically has certain autogenous healing ability underwater immersion, as showed the recovery of bending stiffness and load bearing capacity that was measured by three-point bending test and by visual observation. By adding crystalline admixtures and associated mechanical properties to the air exposure, the crack healing process was increased [18]. In reference to NSC and HPFRCC, the influence of crystalline admixtures on self-healing was investigated in concrete. A methodology was studied and validated for quantification of the influences of concrete healing for various mechanical features of concrete such as load carrying capacity, rigidity, and deformity. It was also based on specimen pre-cracked to the prescribed crack width and exposed to proper exposure condition. In addition, after that, specimen tested again until failure [27]. The methodology is proposed here is allows giving a quantification of crack closing due to self-healing ability of concrete. The addition of crystalline admixture in concrete increases the efficiency of self-healing of concrete. The self-healing capacity is higher in water immersion is expected mainly for large cracks widths[28].The cracked concrete specimen is seal the cracks completely or partially and similarly recover of the mechanical properties under two different exposure conditions [27].

4. Conclusion

Introducing the crystalline admixture (CA) into the concrete makes it very beneficial it improves the properties of the concrete that is more than the conventional concrete. This study is important for understanding the influence of CA on a concrete's healing capacity. The study examined the effect of crystalline admixtures on different concrete properties. Based on the study, crystalline admixture has shown good self-healing capacity in water

immersion and water contact. The addition of crystalline admixture into concrete showed a positive effect on mechanical properties recovery through three-point bending tests such as load recovery index, index damage recovery and indices of crack healing as well as the recovery of durability properties such as water penetration reduction. In addition, for further research, this study recommends that the use of crystalline admixture with other admixture or mineral admixture should be studied to increase their healing ability.

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