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Strength Characteristics of Self-Healing Concrete with Crystalline Admixture

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ABSTRACT: In recent times many researchers are taking interest to study the effect of different admixtures on the self-healing properties of concrete. In the present work an effort has been made to study self-healing behaviour of concrete by replacing cement with 1.1% of crystalline Admixture curing under different environmental exposures. The result shows that for all exposures concrete with 1.1% crystalline Admixture regain the compressive strength and split tensile strength same as that of control concrete.

KEYWORDS: Self-healing, Crystalline Admixture.

I. INTRODUCTION

Cracking is considered as an inherent feature of reinforced concrete structures. Cracks can be caused by loading of a structure itself or other mechanisms, e.g. drying shrinkage, thermal effect and freeze- thaw cycles. Cracking is also related to durability of a reinforced concrete structure because cracks act like openings that allow water penetration and ingression of some aggressive chemicals into concrete. They are the main causes of corrosion of reinforcing steels inside the concrete resulting in the decrease of strength and certain serviceability problems.

Concrete cracks were, however, found to be closed autonomously under certain conditions. The most classical experiment of this phenomenon was done by cutting parts of cement-lined pipe with cracks and immersing them in water. It was found that those cracks closed themselves within a certain period of time. Moreover, other researchers performed the durability tests on cracked concrete as well; they indicated the ability of concrete to close its crack.
The concrete specimens were cracked and installed in the special device to measure water flow through crack for 20 week Evidenced by water flow reduction with time, it was concluded that concrete cracks were able to heal themselves. The reduction of chloride migration through cracked concrete was also reported after the specimens were cracked by freeze/thaw and subsequently cured in lime saturated water for 3 months. In addition, some researchers also studied favourable conditions for self-crack closing ability of the concrete. Water was found to be essential in the self-healing process of the concrete. It was also reported that the decrease of flow rate through the cracked concrete depends on crack width and temperature.

Self-crack closing mechanisms can be classified into 2 categories. The first is the artificial autonomic crack repairing in cases where small capsules with adhesive material are embedded in the concrete. The second is the natural ability of hydrates to heal crack over time. In case of the natural crack healing on which this research focuses, the most reliable assumptions are the continuity of hydration process and the formation of calcium carbonate, $CaCO_3$. An ability of self-crack closing of cement mortar has been proved. It was also found that fly ash modifies microstructure and seals the crack after 28 days a capability of the expansive agent to improve the self-crack closing ability of concrete as it provided additional expansion and precipitation of $CaCO_3$ to close the crack was reported.
The main objective of this project is to ability of a material, structure or structural members to contribute positively to the fulfilment of the present needs of human kind with respect to nature, society and humans, without compromising the ability of future generations to meet their needs in a similar manner. For this purpose provide the material an "inborn" capacity to recover its pristine level of performance thus "self-extending" its service life. This can be done preparing self-healing concrete in this work self –healing concrete use of crystalline admixture in concrete used to the strength and stiffness recovery.

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II. LITERATURE REVIEW

In this literature review the thorough study of research papers on the self healing concrete is done. The research papers starting from the year 1997 to 2016 are studied .After analyzing the papers it is observed that a lot of work has been done on to improve the self healing capability in concrete i.e. the use of microencapsulated healing agents, super absorbent polymers (SAPS) ,sealing materials in brittle tubes, shape memory alloys, bacterial concrete and the use of crystalline admixtures.

Ramm and Biscoping (1998) Mechanisms of self-healing can be categorized as follows
(1) further reaction of un-hydrated cement; (2) expansion of the concrete in the crack flanks; (3) crystallization of calcium carbonate; (4) closing of the cracks by solid matters in the water flowing through the crack, in case; (5) closing of the cracks by spalling-off of loose concrete particles upon cracking.
Several variables, besides the presence of water and, in case, of carbon dioxide, may affect the aforementioned mechanisms and phenomena, such as:
1) the mix constituents (Dhir et al., 1973); 2) the stress state along the cracks (Ngab et al., 1971); 3) the temperature of the water (Reinhardt and Joos, 2003); 4) the alternation between water saturated conditions and exposure to air, which reduced "the strength developed by a marked degree" (Lauer and Slate, 1956).

Aldea et al. (2000) The quantitative assessment of crack sealing/healing on the recovery of engineering properties of concrete still needs a much deeper investigation. Most of the surveyed studies (Hearn and Morley, 1997; Hearn, 1998; Edvardsen, 1999) focused on the variation of water permeability and only very few among them (Lauer and Slate, 1956; Dhir et al., 1973) analyzed the effects on recovery of mechanical properties, in case evaluated by means of non-destructive techniques; it was anyway pointed out that recovery in signal transmission was not as spectacular as that in permeability.

Qian et al. (2009) has reported In recent studies, these processes were studied by Hearn (1998), Edvarsen (1999) and ter Heide (2005): all the authors agreed that delayed hydration was the main process in young concrete and carbonation was more relevant for older concrete. Still with reference to the autogenous healing process, the use of different additions (such as fly ash or blast furnace slag) and their increase of the delayed hydration.
Ferrara et al. (2014) a methodology has been proposed and validated to assess and quantify the effects of self healing on the recovery of mechanical properties of normal strength concrete, with and without crystalline admixtures and under different exposure conditions. The proposed ''three-step methodology'' includes pre-cracking of specimens, natural or artificially accelerated environmental conditioning under different exposure conditions and, finally, fracture testing of the same specimens up to complete failure. The effects of self healing are assessed and quantified by means of comparison between mechanical behaviour parameters garnered through pre-cracking and failure tests on the same specimen.

V. Krelani and L.Ferrara (2015) a methodology will be presented to assess the aforementioned capacity, based on three point bending tests on un-cracked and pre-cracked beams, upon exposure to suitable environmental conditions. The paper will focus on the difference between accelerated exposure, in a climate chamber, and "natural conditioning" in air; comparison with immersion in water will also be performed.
From the analyzed results, the following concluding remarks can be drawn:
The self-healing efficiency in concrete increases with the presence crystalline additive Furthermore, as expectable, immersion in water leads to higher self healing capacity, mainly for higher crack widths; accelerated conditioning does not seem, at least with reference to present results, to lead to significant improvements with respect to natural exposure conditionings.

Marta Roig Flores et al. (2015) a study on the self-healing of fibre-reinforced concrete cracked specimens. The analysis has focused on the permeability of the cracked specimens and the measure of crack width. The objective was to quantify the self-healing effectiveness of crystalline admixtures as self-healing agents and to compare the results of concrete specimens with and without the admixture under different environmental exposures.

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III. EXPERIMENTAL PROGRAM AND METHODOLOGY

3.1 Experimental program

In this study, it was decided to maintain the crack width always between 0.3 to 0.4 mm, as we know that 0.3mm is a common threshold for crack width in service state as per IS 456-2000 and it is potentially sealable by Self- healing, according to the available literature. The age of pre-cracking was fixed at 2 days for early age cracks i.e. Most of the cracks due to shrinkage may occur few days after casting time and 28 days for structural cracks i.e. Most of the structural cracks in their service life. Finally the time set for the self-healing process was 42 days according to the available literature; as a matter of fact, in most studies specimens got sealed in a shorter period of time when exposed to water immersion.

The experimental variables which were studied in this study are:
1. Crystalline admixture dosage: 0% (control specimens), 1.1% by the weight of cement (CA specimens).
2. Age of precracking at 2 days for early age cracks and 28 days for structural cracks.
3. Self-healing exposure: water immersion (WI), water contact (WC), wet/dry cycles (WD) and air exposure (AE).

This study includes both a main study of regained mechanical properties due to self healing specimens under different exposures and strength properties control concrete and crystalline admixture concrete specimens. A Total 10 group of specimens were cast, each group consist 3 cubes, 3 cylinders. Two groups are used for improvement of strength characteristics without C.A (Control concrete) and with C.A (Crystalline admixture concrete),four groups are used for early age cracks self-healing study and reaming four groups are used for structural cracks self-healing study under four exposure conditions respectively.

3.2 Materials and mix proportions

It was decided in this study to work with fiber-reinforced concrete. Since the focus of the project was to study the healing effects on pre-cracked specimens, fibers could provide an effective action both in controlling crack width during the pre-cracking process as well as in keeping fixed its value afterwards. The quantity of steel fiber was fixed at 40 kg/m3 according to the criterion of making the crack opening easily controllable while avoiding excessive branching of cracks.
The cement used was OPC 53 Grade the water/ cement ratio used was 0.45 in both types of concrete. a dosage of 1.1% by weight of cement of crystalline admixture (CA) in powdered form was introduced in the C.A concrete whose behavior was whose behavior was compared with control specimens (without crystalline admixture).
The two mix designs are shown in Table 1.

Table 1: Mix proportions of control and CA concrete in (Kg/m$^{3)}$ AS per IS 10262-2009, IS 456-2000

Material	Cement	W/c ratio	Coarse aggregate (20-12.5mm)	Coarse aggregate (12.5-4.75mm)	Sand	Steel fibers (0.51%)	Crystalline admixture (1.1%)	compaction factor
Control concrete	425.5	0.45	599	599	656.5	40	-	0.87
C.A Concrete	420.82	0.45	599	599	656.5	40	4.68	0.87

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3.3 Experimental methodology

The methodology used in this study to evaluate the effects of self-healing consists of four stages:

3.3.1. Determination of mechanical properties of C.C and CCA

Mechanical properties studied in this study are 1.compressive strength 2.split tensile strength.

3.3.2. Creation of control damage in the specimens

Cube (150X150mm) and Cylindrical specimens (150X300 mm) were pre-cracked at the age of 2 days for early age cracks and 28 days for structural cracks, inducing, by means of a compression test and splitting test, a controlled damage this was meant as the width of the crack, which was set to reach a target value, controlled by a loading. The measure of the crack width with the calibration ruler in optical micrometer while performing the compression and splitting test has been meant as good enough to obtain crack widths within a range of 0–0.4 mm.

3.3.3 Exposure simulation

Four environmental exposures created for 42 days after pre-cracking of specimens were studied in order to determine the effect of humidity on the self-healing capability of the cracked specimens

1. Water immersion (WI): Continuous immersion in tap water at laboratory conditions only adding water to compensate for Evaporation. Example: Completely immersed water-reservoirs, irrigation canals.
2. Wet/dry cycles (WD): Water immersion in tap water for 3.5 days and air exposure for others 3.5 days. Example: Partially immersed piles of bridges, dams, water-reservoirs.
3. Water contact (WC): A layer of water of 2 cm on one surface, Additional water was supplied to maintain the water layer. Example: Buried walls under the water table.
4. Air exposure at laboratory conditions (AE): Storage of the specimens in normal atmospheric air conditions. Example: Bridges, buildings, etc. in dry locations.

3.3.4. Evaluation of the regained mechanical properties

Determine the regained mechanical properties after self-healing cracks of concrete specimens and compared with the properties measured in 3.3.1

IV.RESULTS AND DISCUSSION

4.1 Compressive strength

Compressive strength test was carried out on concrete cube of size150X150X150MM using a calibrated compression testing machine of 2000 KN capacity as per IS: 516-1959. The 28 days compressive strength of concrete with crystalline admixture (C.C.A) are 14.57% higher than control concrete (C.C).

The 2nd day pre-cracked specimens are tested after Self- healing of cracks, the regain compressive strength after healing of early age cracks (i.e. 2nd day pre-cracked) under four different exposures as shown in Table 2 and comparison with CC shown in Fig.1. The 28nd day pre-cracked specimens are tested after Self- healing of cracks, the regain compressive strength after healing of structural cracks (i.e. 28nd day pre-cracked) under four different exposures as shown in shown in Table 3 and comparison with CC shown in Fig.2.

Table 2: Regained Compressive strength of C.C.A under four exposures due to self-healing of early age cracks

Mix name	Control concrete (C.C)	Concrete with crystalline admixture (C.C.A)	C.C.A under water immersion (WI_2)	C.C.A under Wet/dry cycles (WD_2)	C.C.A under Water contact (WC_2)	C.C.A under Air exposure (AE_2)
Compressive strength in (MPa)	40.81	46.76	43.4	41.46	42.14	41.93

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Table 3: Regained Compressive strength of C.C.A under four exposures due to self-healing of structural cracks

Mix name	Control concrete (C.C)	Concrete with crystalline admixture (C.C.A)	C.C.A under water immersion (WI_{28})	C.C.A under Wet/dry cycles (WD_{28})	C.C.A under Water contact (WC_{28})	C.C.A under Air exposure (AE_{28})
Compressive strength in (MPa)	40.81	46.76	53.3	50.37	49.18	45.62

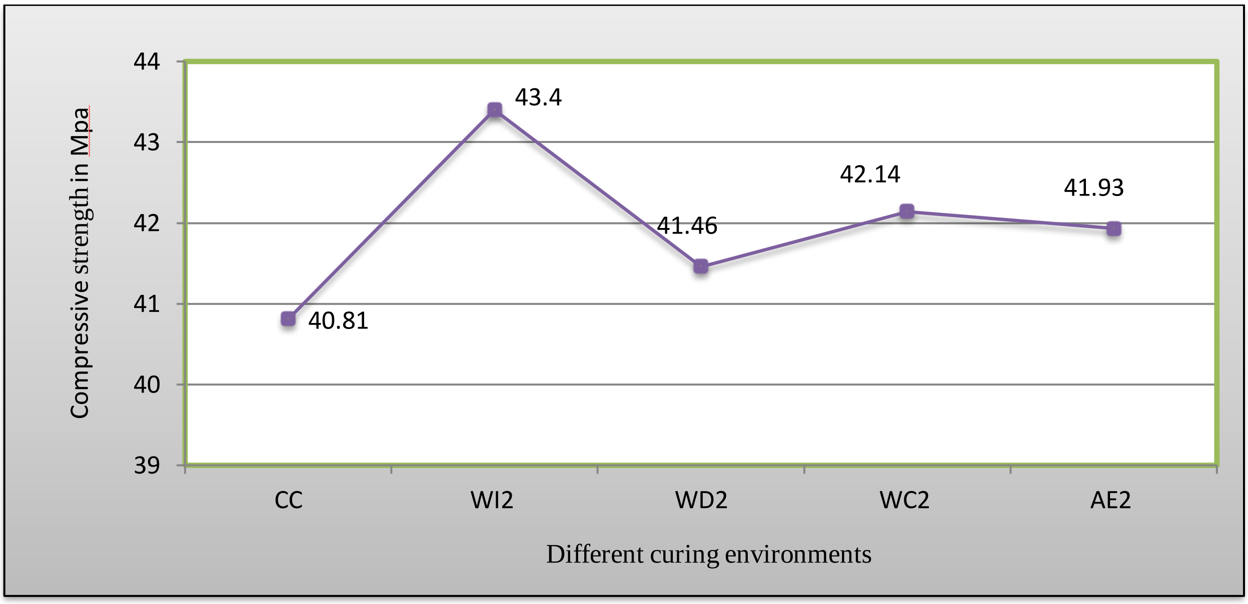

Fig.1. Regain compressive strength due to early age cracks healing under different exposures compared with CC

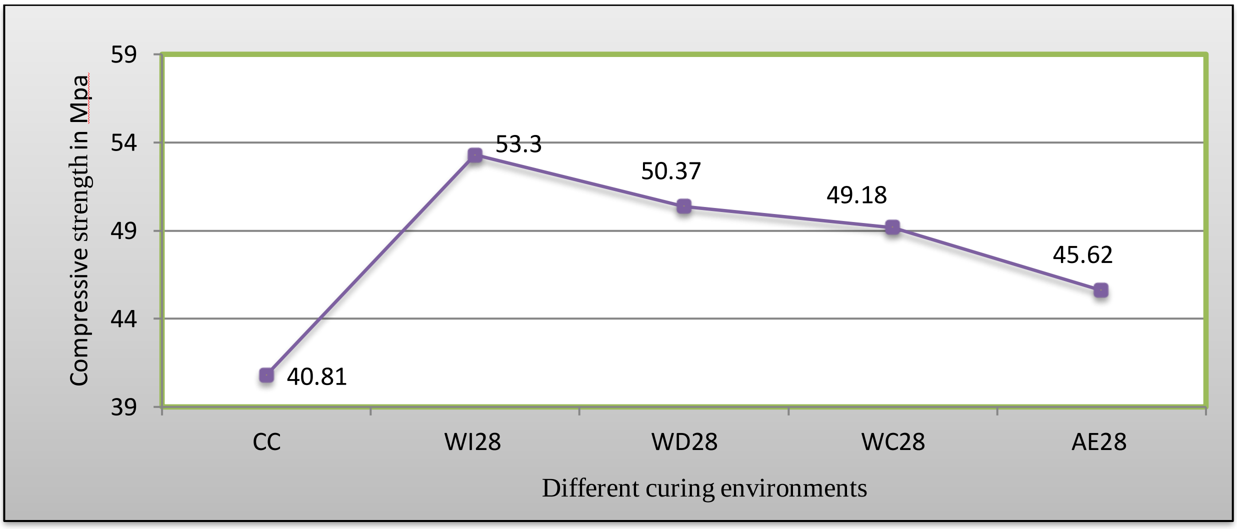

Fig.2. Regain compressive strength due to structural cracks healing under different exposures compared with CC

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4.2 split tensile strength

The split tensile strength of concrete was determined by conducting test on cylinders of diameter 150mm and height 300mm accordance with IS: 5816-1999.The 28 days split tensile strength of concrete with crystalline admixture (C.C.A) are 35% higher than control concrete (C.C).
The 2nd day pre-cracked specimens are tested after Self- healing of cracks; the regain split tensile strength after healing of early age cracks (i.e. 2nd day pre-cracked) under four different exposures as shown in Table 4 and comparison with CC shown in Fig.3. The 28nd day pre-cracked specimens are tested after Self- healing of cracks; the regain split tensile strength after healing of structural cracks (i.e. 28nd day pre-cracked) under four different exposures as shown in shown in Table 5 and comparison with CC shown in Fig.4.

Table 4: Regained split tensile strength of C.C.A under four exposures due to self-healing of early age cracks

Mix name	Control concrete (C.C)	Concrete with crystalline admixture (C.C.A)	C.C.A under water immersion (WI_2)	C.C.A under Wet/dry cycles (WD_2)	C.C.A under Water contact (WC_2)	C.C.A under Air exposure (AE_2)
Split tensile strength in (MPa)	2.82	3.81	3.26	2.82	3.21	3.14

Table 5: Regained split tensile strength of C.C.A under four exposures due to self-healing of structural cracks

Mix name	Control concrete (C.C)	Concrete with crystalline admixture (C.C.A)	C.C.A under water immersion (WI_{28})	C.C.A under Wet/dry cycles (WD_{28})	C.C.A under Water contact (WC_{28})	C.C.A under Air exposure (AE_{28})
Split tensile strength in (MPa)	2.82	3.81	3.92	3.67	3.62	3.28

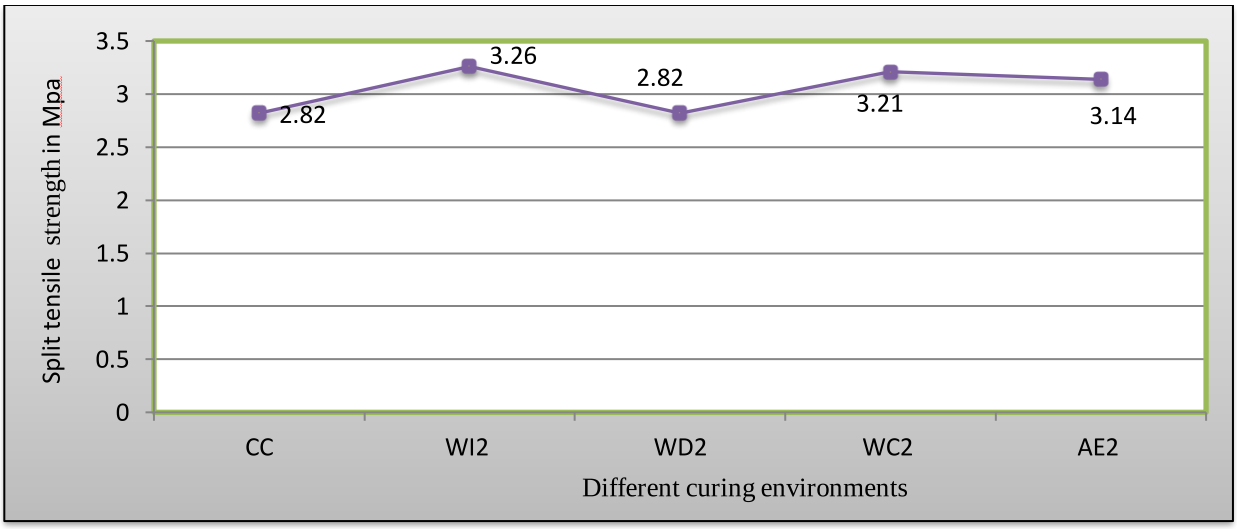

Fig.3. Regain split tensile strength due to early age cracks healing under different exposures compared with C.C

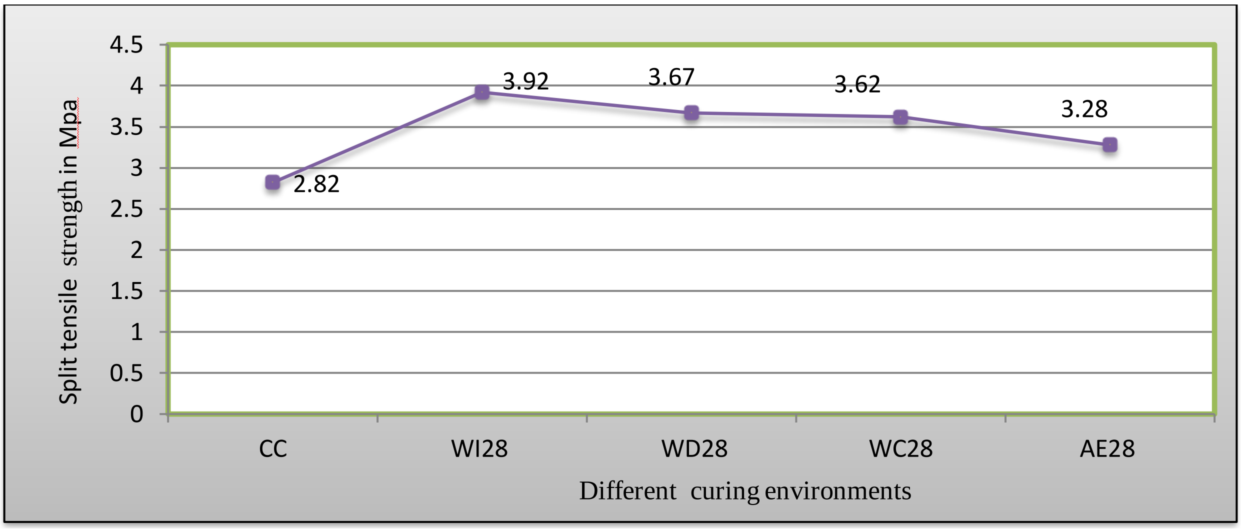

Fig.4. Regain split strength due to structural cracks healing under different exposures compared with C.C

V. CONCLUSIONS

The objective was to quantify the self healing effectiveness of crystalline admixtures as a Self healing agent and compare the results of concrete specimens with and without the admixture under different environment exposure and influence of precracking time on the self healing behaviour.
The following conclusion can be drawn from the results:
1. Concrete with crystalline admixture showed more strength compared to control concrete and the mechanical properties of pre cracked specimens with crystalline admixture exposed to four different curing conditions were regained.
2. Self-healing rate, calculated from the results of the regained mechanical properties of tested specimens are reliable compared to the control concrete specimens.
3. Pre cracking age not affect the healing process the specimen's pre cracked at 2^{nd} day and 28^{th} day healed and regained mechanical properties are same as control concrete. The self-healing process does not depend on age of crack developed it works throughout life of the member.

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