ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 3, Issue 1, January 2018

Autogenous Healing of Concrete Enhanced by Using Supplementary Cementitious Materials - A Review

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***Abstract:* -- Autogenous healing in concrete occurs when hairline cracks in concrete repairs themselves through reactions in presence of water. This paper presents a review on an enhancement of autogenous healing of concrete using different supplementary cementations materials (SCMs). The supplementary cementations materials such as fly ash and ground-granulated blast-furnace slag (GGBS) react with calcium hydroxide. These materials in terms which delayed reactions, thus being more probable that it remains a reaction capability when a crack appears. In this paper, a review has been carried out on the properties of concrete such as mechanical properties, durability properties and crack closure. From the study, it is concluded that introducing supplementary cementitious materials improves autogenous healing of concrete.**

***Index Terms*— Autogenous healing, Crack, Fly ash, Ground-granulated blast-furnace slag (GGBS).**

I. INTRODUCTION

Concrete cracks can develop in any period of the life because of its low ductility, shrinkage or due to other causes such as excessive loading, harsh environmental exposure etc. These cracks have several harmful effects on the mechanical and durability properties of concrete structures. The advancement of concretes that can frequently recover this loss of properties is extremely necessary. Alongside, self-healing of cracked concrete, commonly known as autogenous healing, is a commonly studied occurrence. Cracks in concrete have the capability to seal themselves, e.g. water flowing through cracked concrete slows over time. In extreme cases, these cracks can be sealed completely. It is usually well-known that the mechanisms which contribute to autogenous healing in concrete in [1] Fig 1, are the precipitation of calcium carbonate (CaCO3), sedimentation of external particles, delayed hydration, swelling of C-S-H.

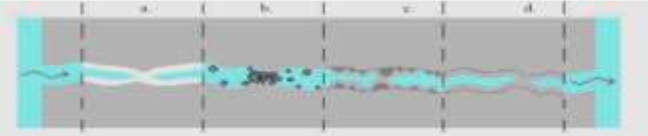

Fig.1: - Possible causes for autogenous healing: (a) carbonation, (b) sedimentation of particles, (c) delayed hydration and (d) swelling of the matrix (ter Heide, 2005).

To quantify self-healing several studies have measured crack width reduction [2], [3]. It is well known that autogenous healing in concrete has got a limited effect. So, there is a strategy in order to enhance autogenous healing of concrete by using supplementary cementitious composites such fly ash and ground granulated blast furnace slag etc.

II. ENHANCEMENT OF AUTOGENOUS HEALING OF CONCRETE

Supplementary cementitious materials (SCMs) that react with calcium hydroxide and have a delayed reaction, thus being more probable that it remains a reaction capability when a crack appears in concrete. These minerals react slower compared to cement, thus more unreacted material was available in the pre-cracking and healing moments. However, SCMs consume calcium hydroxide, which could decrease the ability of carbonation. In this study, a review has been carried out depending on the properties of concrete such as mechanical properties, durability properties, and crack closure.

A. Mechanical properties

Schlangen[4], studied the changes of healing procedure for mechanical properties by using Ordinary Portland Cement (OPC) and a Blast Furnace Slag Cement (BFSC).The pre-cracking the specimens to crack widths of 50 µm by using three-point bending test (before unloading), and also to analyze the strength regain after healing. The specimens pre-cracked at the age of are shown in Fig. 2, where BFSC has got considerably less strength when pre-cracking, as compared with OPC specimens.

And in the case of OPC specimens, they recover their whole initial strength after reloading. Specimen pre-cracked at the age of 15 days in Fig. 3 the strength recoveries are significantly lower than when pre-cracking at 1 day, thus remarking the significance of the hydration degree in autogenous healing. At 15 days there are hardly any differences between BFSC and OPC in pre-cracking or in reloading.

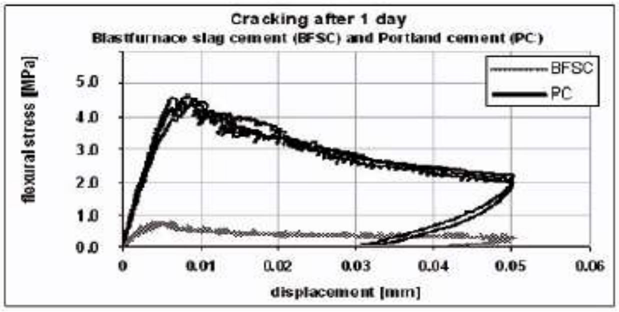

Fig. 2: Flexural stress versus crack opening for pre-cracking age of 1 day (Schlangen, et al., 2006).

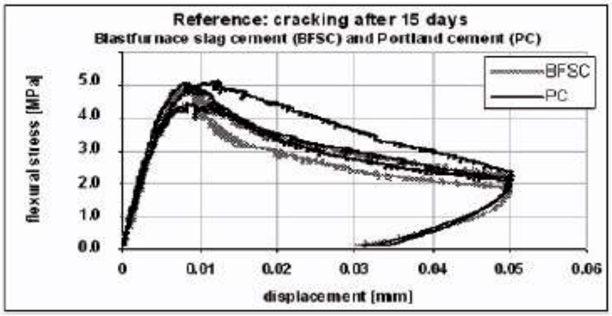

Fig. 3: Flexural stress versus crack opening for pre-cracking age of 15 days (Schlangen, et al., 2006).

In a similar way, van Tittelboom[3] stated that mixtures with OPC, BFS or FA based on the regaining of mechanical properties indicated poor healing capabilities. Termkhajornkit [5], studied a recovery of compressive strength using a 25% of Fly Ash, and also an improvement for durability properties, after letting the fly ash react up to the age of 91 days.

Zhou [6] showed the effect of slag and fly ash content on self-healing by means of compressive strength recovery and SEM observations. They compared the contents of slag and fly ash of 20%, 30%, 40%. Their results show that when the mixing content of slag and fly ash were 30% and 40% the self-healing ability of concrete was maximized.

Na[7] studied the effect of fly ash blended cement with different cement replacement ratios (10%, 20%, and 30% by volume). They used high early strength and low heat Portland cement. Specimens were exposed during 13 weeks to CO_2. The properties of compressive strength, bending strength and dynamic modulus of elasticity for virgin specimens (no cracking) have analysed. The results show a recovery of all the properties after deterioration for most cases, with the higher degree of healing in mortar samples with fly ash (20 and 30% of replacement).

Palin [2], studied that mortar mix having 66-80% GGBS by mass of cement could heal cracks up to 0.41mm when immersed in fresh water.

B. Durability properties

Van Tittelboom [3], analyzed the effect of Blast Furnace Slag and Fly Ash on self-healing. Cracks up to 200 µm could close completely due to $CaCO_3$ precipitation with higher efficiency. From the water permeability test and the calorimetric measurements, a decrease in the W/B ratio of the CEM I mixes from 0.5 to 0.4 and the presence of BFS and FA improved the autogenous crack healing efficiency due to further hydration.

Termkhajornkit [5] studied the self-healing capability of fly ash systems to regain properties on cement paste, which was damaged by shrinkage. When using a 25% of Fly Ash, they showed a regaining of compressive strength. And also they compared the influence of on the carbonation coefficient in the FA mortar samples. Results showed that the carbonation depth after curing in water 20ºC for 1 week was same after deterioration, while specimens cured in water at 40ºC for 4 weeks had carbonation depth lower than 1 mm. Their results Fig.4 show that FA specimens with lower w/c had lower carbonation coefficient and better self-healing performance when healing under water immersion for 4 weeks at 40ºC in Fig. 5.

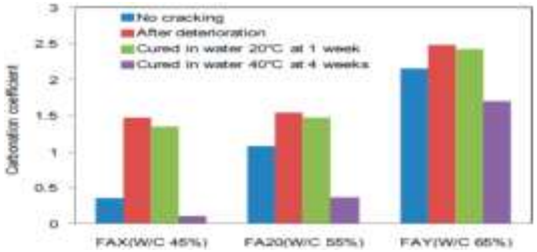

Fig. 4: Change of carbonation coefficient for fly ash mortar samples with different water to cement ratio, exposed to CO_2 for 13 weeks. (Na, 2013)

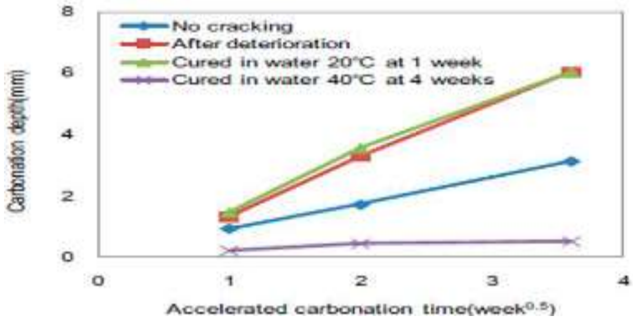

Fig. 5: Change of carbonation depth for specimens with 30% of fly ash after different curing cases (Na, 2013)

Zhang[8] studied the healing behavior was investigated by sorptivity and rapid chloride penetration tests and compared the three ECC mix proportions with different volume of fly ash after healing 30 days under water immersion. Sorptivity test results indicate that specimens with the highest investigated fly ash/cement ratio (4.0 by weight) may have the highest self-healing behavior. According to Neville (2012), as GGBS consumes $Ca(OH)_2$ during hydration, there is no pore-blocking formation of $CaCO_3$ when high proportions are used within the cement mix.

C. Crack Closing

Jaroenratanapirom and Sahamitmongkol [9] compared the effectiveness of the visual closure behavior of several mineral addition such as silica fume (SF), fly ash (FA), limestone powder (LP) and reference OPC. And also they compared with expansive agents and crystalline admixtures, as they are measured a type of autonomous healing. They also analyzed the effect of pre-cracking age (3 and 28 days) and the effect of the crack opening (< 0.05 mm, 0.1- 0.2 mm and 0.2-0.3 mm). The results showed healing processes with different optimal conditions of pre-cracking age and crack width, even for OPC. Silica Fume had the best behaviors for older pre-cracks, and notably good for early cracks of 0.1-0.2 mm. Limestone powder had good results only for early and larger cracks. But, Fly Ash was found to be ineffective to improve self-healing for most cases. Olivier [10] studied the self-healing effect of blast furnace slag cement with a 50% of replacement compared with Portland cement (CEMI 52.5N) in the mortar. And it has exposed 28 days and 42 days to underwater conditions. The results showed that BFS behaves better, mostly because of its delayed reaction.

Sahmaran [11] compared the self-healing behavior of OPC enhanced by using type F and C Fly ash and Slag. The specimen was pre-cracked and exposed to three healing conditions: continuous wet, continuous air, and freeze–thaw cycle, for 2 months. The results showed that self-healing precipitates were observed from the mixture incorporating fly ash and slag, composed of calcite and C-S-H gels, in general, but for slag specimens, only calcite.

Huang [12] studied on the improvement on autogenous healing by blast furnace slag by partial replacement with cement. The results showed that unreacted blast furnace slag in the matrix contributes to self-healing of microcracks when activated by $Ca(OH)_2$ solution. Fig. 6 shows the filling products inside cracks I compared with the original limits of the crack.

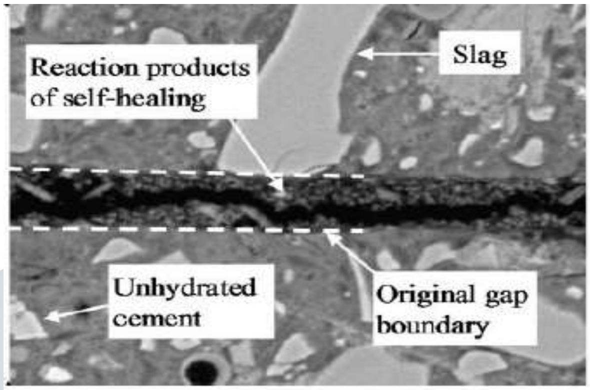

Fig.6: Morphology of products formed in gaps observed perpendicularly to slice surfaces. Healing starts at the age of 28 days of the specimens and healing time is 220 hours (Huang, et al., 2014).

Huang [12] compared the behavior, the filling fraction of microcracks (with openings up to 30 μm) or the air permeability between two main methods. The results showed that a better behavior for slag cement pastes when cured in Ca $(OH)_2$. But it is noted more significantly according to the filling fraction in than by air permeability in Fig. 7.

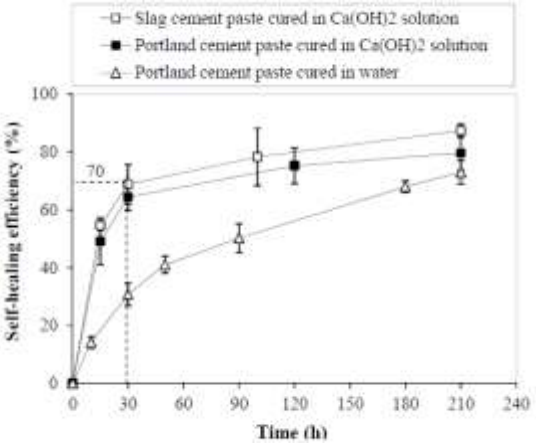

Fig. 7: Comparison between the self-healing behavior of blast furnace slag and ordinary Portland cement by air permeability (Huang, 2014).

III. CONCLUSION

A significant limitation to autogenous healing is the crack width range over which full healing can take place, particularly if the recovery of mechanical strength and stiffness is used as a measurement of self-healing. Blast Furnace Slag has lower autogenous healing effect quoted by some of the authors. While some others quoted that when the percentage of GGBS is around 30-50% by the weight of cement increases the autogenous healing. Some authors say that the fly Ash can improve the autogenous healing effect contents about 15-25% by cement weight. The use of GGBS and FA within concrete has been found to improve the self-healing response, particularly in early-age cracking, due to their slower hydration properties and the improved fine pore structure of the concrete.

REFERENCES

[1] E. Schlangen, N. ter Heide, and K. van Breugel, "Crack Healing of Early Age Cracks in Concrete," Meas. Monit. Model. Concr. Prop., pp. 273–284, 2006.

[2] D. Palin, V. Wiktor, and H. M. Jonkers, "Autogenous healing of marine exposed concrete: Characterization and quantification through visual crack closure," Cem. Concr. Res., vol. 73, no. July 2016, pp. 17–24, 2015.

[3] K. Van Tittelboom, E. Gruyaert, H. Rahier, and N. De Belie, "Influence of mix composition on the extent of autogenous crack healing by continued hydration or calcium carbonate formation," Constr. Build. Mater., vol. 37, pp. 349–359, 2012.

[4] H. M. Jonkers and E. Schlangen, "CRACK REPAIR BY CONCRETE-IMMOBILIZED BACTERIA," no. April, pp. 1–7, 2007.

[5] P. Termkhajornkit, T. Nawa, Y. Yamashiro, and T. Saito, "Self-healing ability of fly ash-cement systems," Cem. Concr. Compos., vol. 31, no. 3, pp. 195–203, 2009.

[6] Z. H. Zhou, Z. Q. Li, D. Y. Xu, and J. H. Yu, "Influence of Slag and Fly Ash on the Self-Healing Ability of Concrete," Adv. Mater. Res., vol. 306–307, pp. 1020–1023, 2011.

[7] S.-H. Na, "Experimental Investigation on Self-Healing Performance of Cementitious Composite Incorporating Fly Ash and Ground GRANULATED BLAST FURNACE SLAG," 2013.

[8] Z. Zhang, S. Qian, and H. Ma, "Investigating mechanical properties and self-healing behavior of micro-cracked ECC with different volume of fly ash," Constr. Build. Mater., vol. 52, pp. 17–23, 2014.

[9] D. Jaroenratanapirom, "Effects of Different Mineral Additives and Cracking Ages on Self-Healing Performance of Mortar," Annu. Concr. Conf. 6, Thail. Concr. Assoc., no. August, pp. 551–556, 2010.

[10] K. Olivier, A. Darquennes, F. Benboudjema, and R. Gagné, "Etude de la sensibilite a la fissuration des matériaux cimentaires avec additions minérales au jeune âge," 31èmes Rencontres de l'AUGC, 2013.

[11] M. Sahmaran, G. Yildirim, and T. K. Erdem, "Cement & Concrete Composites Self-healing capability of cementitious composites incorporating different supplementary cementitious materials," Cem. Concr. Compos., vol. 35, no. 1, pp. 89–101, 2013.

[12] H. Huang, G. Ye, and D. Damidot, "Effect of blast furnace slag on self-healing of microcracks in cementitious materials," Cem. Concr. Res., vol. 60, pp. 68–82, 2014.