Influence of Expansive minerals on the Self-healing of Cement Paste and Mortar Systems

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ABSTRACT

Expansive minerals have great prospects for improving the self-healing capacity of concrete. Once a crack start propagating, an embedded unhydrated expansive mineral could hydrate and expand hence bridging and healing the cracks. This study investigates the self-healing of Portland Cement (PC) based mortar system using MgO, bentonite clay and quicklime minerals. Firstly, expansive minerals optimum mix proportions for improving the autogenous self-healing capacity of cement paste were investigated. Secondly, expansive minerals were encapsulated within the glass tube capsules and embedded into the mortar prisms for investigating self-healing. The healing efficiency was compared in three different curing conditions (ambient, high humidity, and immersed in water) using mechanical strength recovery, crack sealing percentage, and water absorption through cracks (immersed only). Further microstructural investigation was carried out on self-healing materials for characterising self-healing materials using FT-IR, XRD, and SEM. Promising self-healing performance was found in the samples stored in immersed condition, while limited healing happens in high humidity following by the least performance in the ambient condition. Strength recovery and water tightness were found much higher in the capsule containing samples. Several cracks up to 500 μm had effectively sealed within 7 days in the samples containing optimum self-healing cement mix at immersed healing state. Superficial crack sealing compounds were dominantly calcium carbonate based crystals, although different minerals influenced formation of different types of self-healing materials particularly in the inner crack cross-section.

1. INTRODUCTION

Formation of Cracks in the concrete can cause gradual degradation of its structural functionality much earlier than expected design period. Once it damages the repair and maintenance is highly cost and time concerning issue. Hence, this research involves the expansive minerals encapsulated glass tube systems for improving the self-healing capacity of cracks in the mortar systems for concrete application.

2. MATERIALS AND METHODS

Expansive minerals (magnesium oxide (MgO), quicklime (CaO), and bentonite clay) were used in this experiment. Expansive minerals have been found effectively improve the autogenous self-healing capacity of PC when partially substitute in optimum proportions [1]. Firstly, we have compared autogenous self-healing capacity of self-healing cement mix (SHC) with only PC (CEM 1 52.5N) paste. Secondly, glass tube filled with SHC and MgO minerals were embedded into the PC cement mortar mix. Test series for self-healing evaluation are listed in Table 1 below.

Table 1: Test series used to compare the self-healing glass tube systems.

Code	Minerals (mm)	Encapsulation geometry	Healing conditions		
			Immersed	High-humid	Ambient
CON	---	No tube	√	√	√
MD	MgO	◎	√	√	√
SHC-D	5% MgO, 5% CaO, 2.5% bentonite, 87.5% PC	◎	√	√	√

Glass tube systems were double layer having an internal tube of 5 mm diameter containing water and outer tube of 10mm diameter with minerals (Fig.1a). Tube length was 50mm which was positioned in the middle of mortar prism (50mm X50mm X220mm) at the spacing of 7.5mm from the bottom (Fig. 1b). A 1mm diameter tie wire was pleased at the top of the prism samples (above neutral axis) to avoid the reinforcement impact on crack re-opining allowing possible control of the cracks.

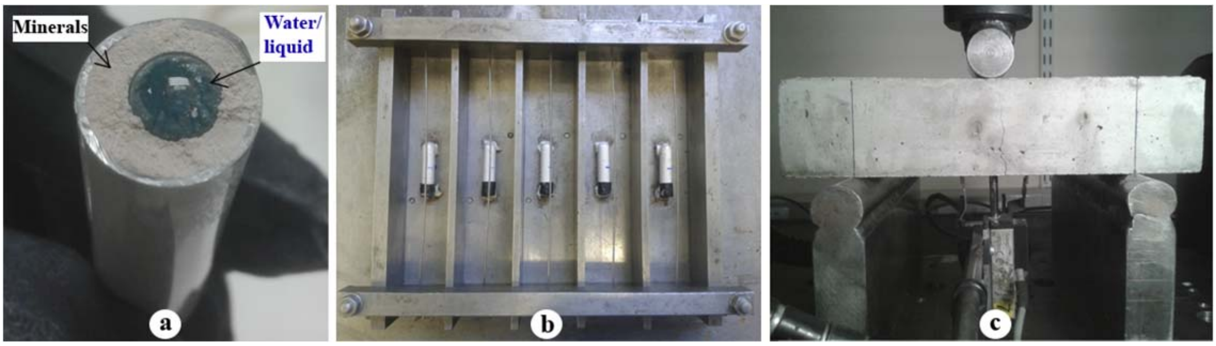

Figure:1 Materials and methods

Mortar (cement to sand ratio of 1:1.5) samples were cured under water for 7 days prior to the formation of cracks under three-point bending (Fig. 1c). Cracks were widened until 600 µm during the test resulting crack width in the range of 300 µm to 500 µm after unloading. Glass tubes were broken releasing minerals into the cracks than samples were healed in three different conditions (Table. 1) for 28 days.

$$R(\%) = \frac{P_{\max,R} - P_{un}}{P_{\max,I} - P_{un}} X100\%......(1); S(\%) = \frac{rec, S_t}{ini, S_0} X100\%.....(2); \frac{Q}{S} = k\sqrt{t}......(3)$$

Mechanical strength recovery [eq.1], crack sealing efficiency [eq.2], and capillary water absorption through crack zone [eq.3] (immersed only samples) were adopted for evaluating self-healing efficiency. In the eq1, $P_{max,I}$ is the initial cracking load, P_{un} is the unloading point of the first test and $P_{max,R}$ is the maximum load after recovery found in the healed sample during the second test. In eq2, rec,S_t and ini,S_o is crack surface area at time t and just after. In the eq3, Q is the absorbed water volume; S is the samples contact surface area with water; k is the slope of water absorption (Q/S) with square root of time (t) plotting [2]. Finally Fourier transform infrared spectroscopy (FTIR), X-ray diffraction analysis (XRD) and scanning electron microscopy (SEM) tests were conducted for characterising self-healing materials.

3. RESULTS

The autogenous self-healing efficiency of SHC cement paste was found around six times more than only PC paste. In the mortar samples, self-healing was found best under immersed curing condition followed by high-humid and ambient condition (Fig.2). This is due to the availability of water for efficient minerals diffusion from glass tube into the crack surface. Although, the hydration of minerals inside the tube causes considerable strength recovery in high-humid condition, crack sealing was fairly pore compared to immersed condition. Typically cracks up to 500 μm were sealed within 7 days in MD, and SHC-D. Absorption coefficient of SHC-D and MD after healing was found 10% and 25% higher compared to control un-cracked (CON-UC) samples where as it was almost 245% for CON cracked samples. Therefore, crack sealing in MD and SHC-D had effectively improves water tightness as evident in the absorption results. Overall, self-healing efficiency was SHC-D>MD>CON.

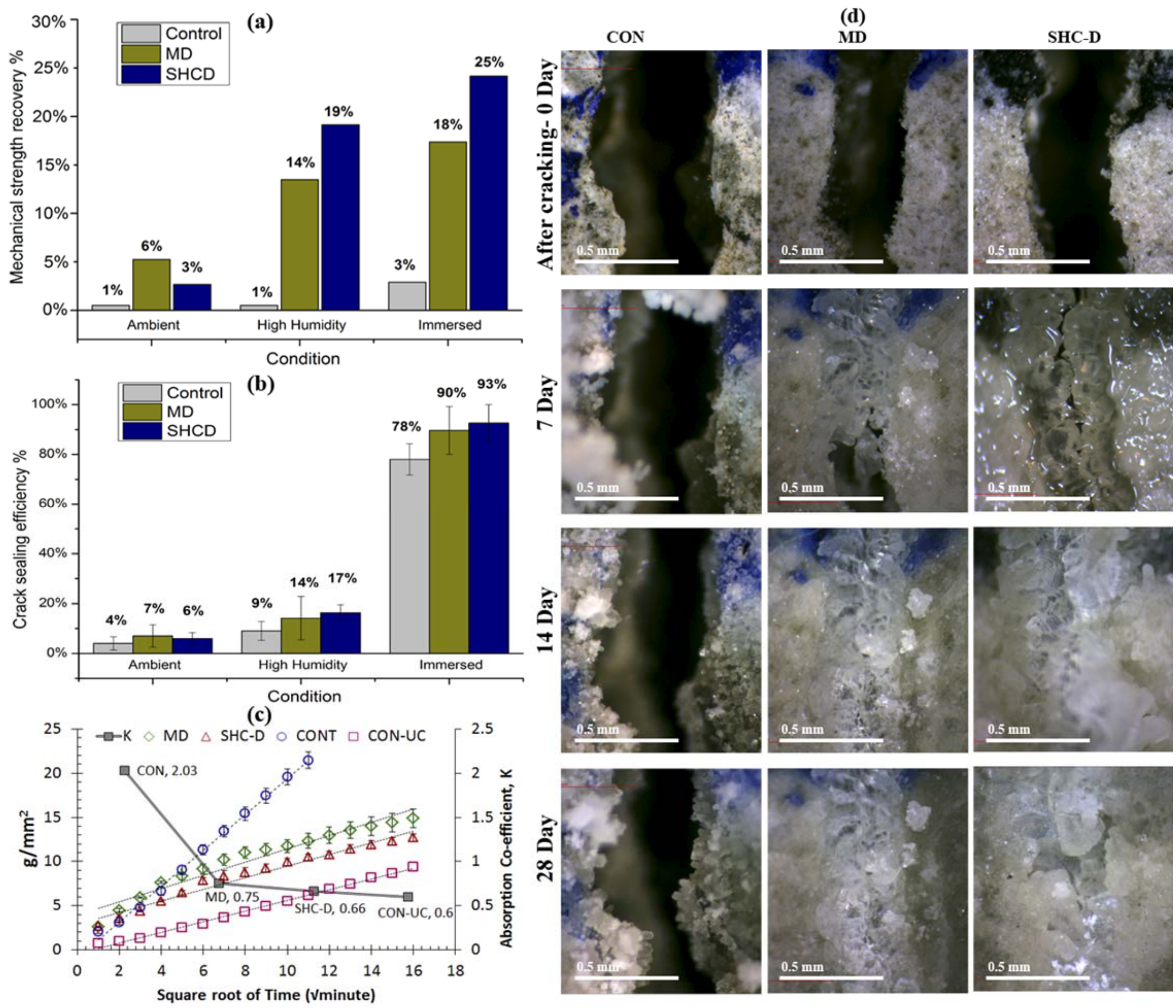

Figure 2: a. Mechanical strength recovery, b. crack sealing efficiency, c. water absorption through crack, and d. typical crack sealing images in immersed condition.

Self-healing materials were mostly calcite, portlandite, and ettringite whereas MD and SHC-D healing materials were also composed of magnesium hydration and carbonation products (Fig. 3). Reactive MgO expansion products such as dypingite/hydromagnesite [3] were produced as it was identified in XRD, FT-IR and SEM of MD and SHC-D. There were also possibilities of the formation of magnesium silicate hydrates alongside with calcium silicate hydrates as silicate and brucite packs were indicated by XRD and FT-IR bends. These re-hydrated expansive compounds of minerals had effectively healed the cracks in the glass tube containing samples.

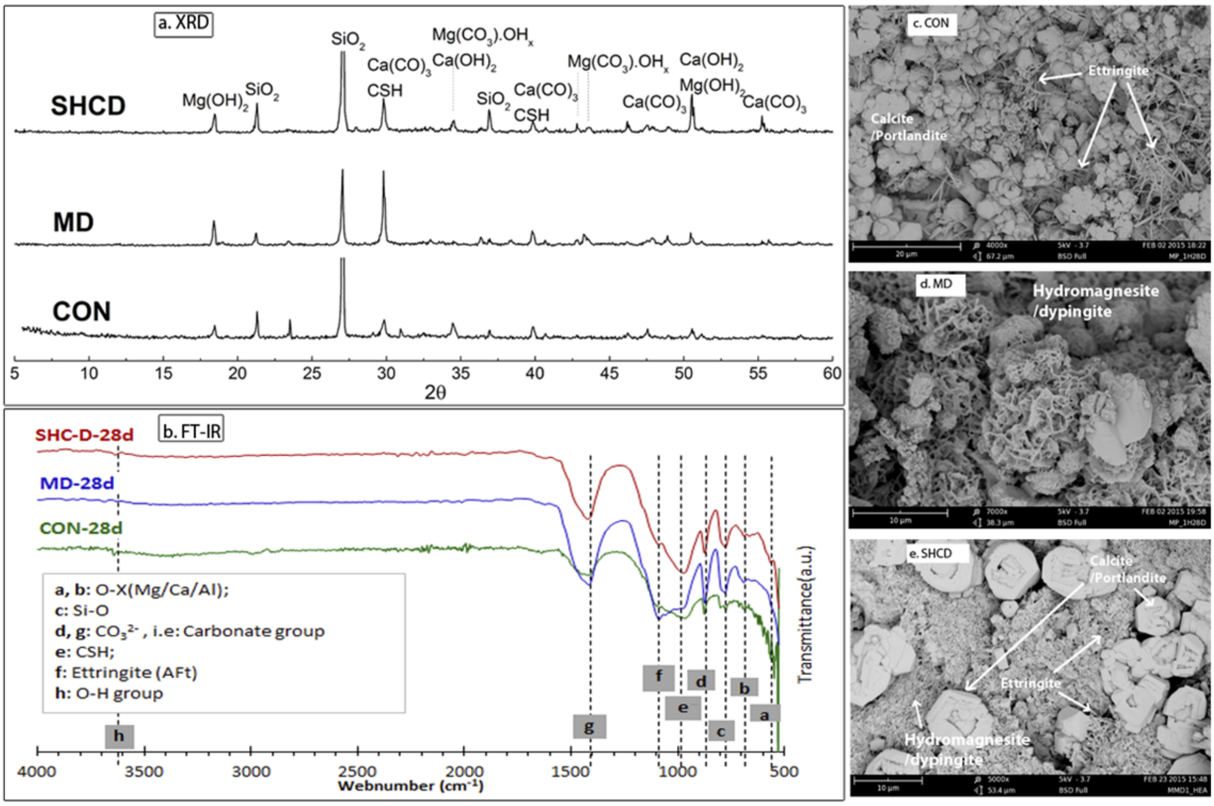

Figure 3: Self-healing materials, a. XRD, b. FT-IR, c,d, and e. SEM images.

4. CONCLUSIONS

Dry minerals have advantages over liquid minerals or superglues in terms of stability and longevity of properties while encapsulated inside concrete. In this experiment, expansive minerals released breaking glass tube had showed considerable self-healing. These minerals expansion in tube systems had improves water tightness by sealing the cracks along with promising mechanical strength recovery.

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