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SELF-HEALING BEHAVIOUR OF CRACKS IN CEMENT-BASED MATERIALS EXPOSED TO CYCLIC TEMPERATURE AND RELATIVE HUMIDITY

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Abstract: Pervious studies on self-healing behaviour of concrete have mainly focused on crack self-healing when concrete is fully submerged in water. However, field experience with civil RC structures exposed to sulphates or chlorides has often shown that concrete can suffer serious damage under cyclic relative humidity. In addition, in the presence of micro-cracks, the damage could significantly be propagated. Therefore, in the current study, crack self-healing behaviour of cement mortar incorporating metakaolin, bentonite, and calcium carbonate microfiller was investigated under cyclic temperature and relative humidity. The results should open new research directions for improving the self-healing capacity of concrete.

1 INTRODUCTION

Several studies have reported the healing of surface cracks in concrete (e.g. Şahmaran et al., 2013; Suleiman and Nehdi, 2017 & 2018; Wu et al., 2012; Snoeck and De Belie, 2015; Tang et al., 2015; Ferrara et al., 2014; Kempl and Çopuro, 2016; Huang et al., 2013 & 2014; Jonkers et al., 2010; Wiktor and Jonkers, 2011; Van Tittelboom et al., 2012; Wang et al., 2014). For instance, Sisomphon et al. (2012) reported that using expansive and crystalline additives in pre-cracked concrete specimens submerged in water can promote self-healing of cracks. Gagné and Argouges (2012) investigated the natural self-healing of cement mortars using air-flow measurements. Mortar specimens were cracked and stored in a fog room at 23°C and 100% RH. Experimental results showed evidence of complete self-healing of surface cracks. Similar findings were reported by Jiang et al. (2015) who reported that using mineral additives including silica-based, chemical expansive, swelling, and crystalline minerals improved the self-healing behaviour of pre-cracked cement mortar submerged in water. Wiktor and Jonkers (2011) found that applying two-component bio-chemical self-healing agent into concrete could improve the self-healing of surface cracks.

In previous studies, crack width change due to self-healing was essentially evaluated in concrete submerged in water. The effects of varying the environmental exposure conditions remain largely unexplored. Therefore, in this study, the influence of variable environmental exposure conditions on the change in crack width owing to self-healing is investigated.

2 RESEARCH SIGNIFICANCE

Previous research generally reported self-healing without capturing the dominant effect of environmental exposure. In the present study, techniques including MIP and optical microscopy have been mobilized to investigate crack self-healing in cracked cement mortar incorporating various minerals. The results should stimulate a new critical look into the state-of-the-art of self-healing testing protocols and highlight the need for capturing the dominant effects of environmental exposure.

3 EXPERIMENTAL PROCEDURES

3.1 Materials and Specimen Preparation

Mortar specimens were made with ordinary portland cement (OPC) compliant with requirements of CSA A3001 and ASTM C150. Water-to-cementitious materials ratio (w/cm) of 0.35 and sand-to-cementitious materials mass ratio (s/c) of 2 were used. Three different mineral additions including high-reactivity metakaolin (MK), granular bentonite (BN), and fine calcium carbonate powder (CC) were used. Physical and chemical properties of the OPC, MK, BN, and CC are summarized in Table 1. The mixture design of mortars is demonstrated in Table 2. A polycarboxylate-based high-range water reducing admixture (HRWRA) as per ASTM C494 was used to adjust workability. PVA fiber at a dosage of 1% by volume fraction was added to the mortar mixtures. Disk specimens (50 mm diameter and 25 mm height) were prepared and cured for 28-d in a moist room at RH ≥ 95% and T = 21 ± 1°C as per ASTM C511 (Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes). Crack was created at the age of 28 days using a screw jack (Fig. 1), like previous study by Wang et al. (2014). Similarly, the crack width was controlled during the screwing process via a calibration ruler. For each environmental exposure, three groups of specimens with three different values of crack width were tested. The first group consisted of three specimens with an average crack width in the range of 50 – 150 µm. For the second and third groups, the average crack widths were 150 – 300 µm and 300 – 500 µm, respectively.

Table 1: Physical and chemical properties of materials used

Components /Property	OPC	MK	BN	CC
Assay percent range (%)	-	-	-	>99
Montmorillonite (%)	-	-	85.0	-
Quartz (%)	-	-	5.0	-
Calcium oxide (CaO) (%)	61.50	0.20	-	-
Calcium	-	-	1	-
Fledspars (%)	-	-	5.0	-
Silicon oxide (SiO2) (%)	19.6	53.50	-	-
Cristobalite (%)	-	-	2.0	-
Aluminum oxide (Al2O3) (%)	4.8	42.50	-	-
Ferric oxide (Fe2O3) (%)	3.3	1.90	-	-
Magnesium oxide (MgO) (%)	3.0	-	-	-
Sulfur trioxide (SO3) (%)	3.50	0.05	-	-
Loss on ignition (%)	1.90	0.50	-	-
Insoluble residue (%)	0.44	-	-	-
Equivalent alkalis (%)	0.7	-	-	-
Tricalcium silicate (C3S) (%)	55	-	-	-
Dicalcium silicate (C2S) (%)	15	-	-	-
Tricalcium aluminate (C3A) (%)	7	-	-	-
Tetracalcium aluminoferrite (C4AF) (%)	10	-	-	-
Specific gravity	3.15	2.60	2.50	2.70
Surface area (m2/kg)	371	15000	-	-

Table 2: Mixture design of mortars by mass ratio

Mix	Description	PC	MK	BN	CC	Sand	Water
1	OPC	100	-	-	-	200	35
2	MK15	85	15	-	-	200	35
3	BN8	92	-	8	-	200	35
4	CC8	92	-	-	8	200	35

Figure 1: Cracking of specimens using screw jack

3.2 Environmental Exposure

The effect of environmental exposure on the development of self-healing in mortar specimens was investigated. Cracked specimens were placed inside a walk-in environmental chamber and exposed to cyclic temperature ranging from 10°C to 40°C and relative humidity in the range of 20% to 90%, as shown in the Table 3.

3.3 Optical Microscopy

The change in surface crack width of mortar specimens owing to self-healing was monitored using a Carton 40x microscope. For each environmental exposure, the width of surface cracks was measured over a period of one year.

3.4 Mercury Intrusion Porosimetry (MIP)

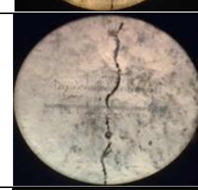
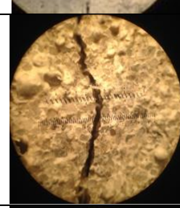
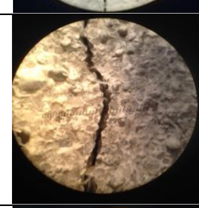
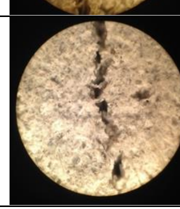
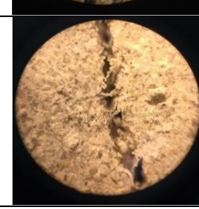
The pore size distribution for each specimen was tested using a Micrometrics AutoPore IV 9500 Series porosimeter allowing a range of pressures from 0 to 414 MPa. The assumed surface tension of mercury was 0.484 N/m at 25°C according to ASTM D4404 (Standard Test Method for Determination of Pore Volume and Pore Volume Distribution of Soil and Rock by Mercury Intrusion Porosimetry).

4 EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Optical Microscopy

Table 4 shows surface cracks before and after exposure to cyclic T and RH. Surface cracks of mortar specimens prior to and after the self-healing process were investigated using optical microscopy at 40x magnification. No significant self-healing could be identified in cement-based mortar specimens exposed to cyclic T and RH. This suggests that self-healing of a cementitious material primarily depends on the surrounding environment. For example, previous study by Jiang et al. (2015) reported that mortar specimens exposed to still water curing exhibited a larger decrease in crack width compared to that of identical specimens cured in flowing water. Wang et al. (2014) reported that the self-healing efficiency of cracks in a bacteria-based concrete depended primarily on the exposed environment. Similarly, studies by Sahmaran et al. (2013), Zhang and Zhang (2017), Zhu et al. (2012), and Qian et al. (2010) showed that the self-healing ability of engineered cementitious composites (ECC) highly depended on the surrounding environment. Therefore, in the current study, cracked specimens exposed to cyclic T and RH exhibited no self-healing, which further reinforces the argument that the presence of water in a liquid state in cracks is an essential factor for promoting self-healing of cement-based materials.

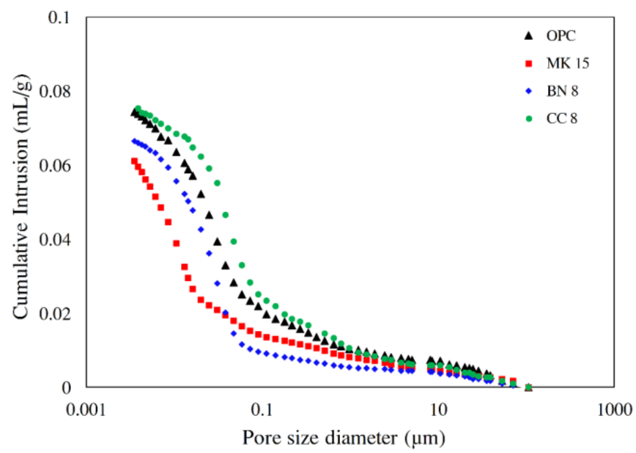
Table 3: Mixture design of mortars by mass ratio

Specimen Type	Before	After
OPC		
MK 15		
CC		
BN8		

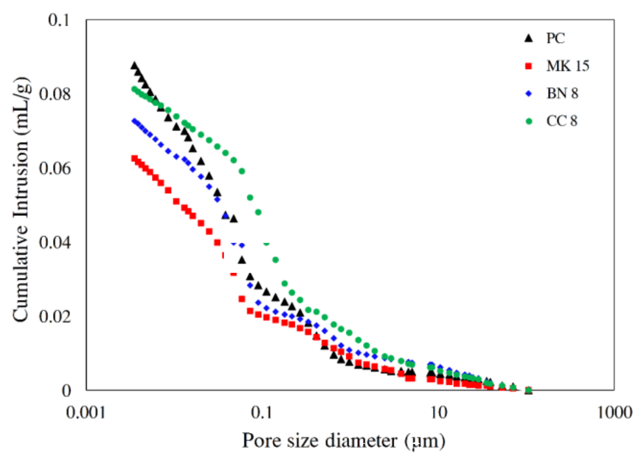
4.2 MIP Results and Pore Structure

The evolution of pore structure with time was investigated using MIP. Figure 2 displays the cumulative mercury intrusion curves as a function of the pore diameter for cracked mortar specimens before and after exposing to cyclic T and RH. All cracked specimens exhibited slight increase in porosity. The increase in porosity may be related to the formation of microcracks. This could be due to the formation of microcracks due to the cyclic exposure to different T and RH. Previous study by Roig-Flores et al. (2015) investigated different healing behavior depending on the exposure and the presence of the crystalline admixture and found that the presence of water is necessary for the healing reactions.

It can be also observed that the MK15 specimens showed the least crack self-healing after one year of water submersion, they exhibited the highest reduction in porosity compared to that of other specimens, even those that exhibited better crack self-healing. This is likely due to the ongoing pozzolanic reaction of metakaolin.



(a)



(b)

Figure 2: Cumulative intruded pore volume vs. pore diameter for cracked specimens (a) at 28 days, and (b) one year after cyclic T and RH

5 CONCLUSION

In the present study, the self-healing of cracks in cement-based materials incorporating various minerals (i.e., metakaolin as a pozzolanic material, bentonite as a swelling agent, and limestone microfiller) was explored. Results showed that no significant self-healing could be identified in cement-based mortar specimens exposed to cyclic T and RH.

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