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Experimental Study of the Crack Control of Concrete by Self-healing of Synthetic Fiber Reinforced Cementitious Composites Synthetic Fiber

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Abstract

In this study, it is possible to disperse effectively cracked using synthetic fiber, an examination of the most suitable self-healing conditions was performed on the above crack width 0.1mm. As a result, effective crack dispersion using polyvinyl alcohol (PVA) fibers with polar OH^- groups, as well as improved self-healing for cracks that are larger than 0.1 mm in width, posing concerns of CO_2 gas and Cl^- penetration, were observed. Also, CO_3^{2-} reacts with Ca^{2+} in the concrete crack, resulting in the precipitation of a carbonate compound, $CaCO_3$. Based on this, it is deemed possible for the recovery of effective watertightness to be made from cracks that are larger than 0.1 mm in width. In addition, it was determined that, as for the most suitable self-healing conditions in the inside and surface of the cracks, calcium hydroxide ($Ca(OH)_2$) solution with CO_2 micro-bubble was more effective in promoting the self-healing capability than water with CO_2 micro-bubble.

Keywords: micro crack, PVA, CO_2 micro-bubble, self-healing, $Ca(OH)_2$, $CaCO_3$

1. Introduction

Although concrete is one of the most widely used construction materials, it is characterized by substantially low tensile strength in comparison to its compression strength, and occurrence of cracks is unavoidable. In addition, cracks progress due to environmental conditions including damage by freezing, neutralization and salt damage, etc. Moreover, detrimental damages can occur in concrete structures due to the permeation of deteriorating elements such as Cl^- and CO_2, etc. Meanwhile, under an environment in which moisture is being supplied, if the width of the crack is small, a phenomenon of self-healing in which the portion of the crack is filled in due to the rehydration of the cement particles and precipitation of $CaCO_3$ has been confirmed. As for the self-healing mechanism of concrete, the reaction between Ca^{2+} in concrete and CO_3^{2-} dissolved in water produces $CaCO_3$, a carbonate compound that does not easily dissolve in water. This phenomenon leads to the filling and closing of cracks [1]. The calcite crystal reactions are shown in Equations [1-3]

$$H_2O + CO_2 \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_{3^-} \Leftrightarrow 2H^+ + CO_3^{2-} \tag{1}$$

$$Ca^{2+} + CO_3^{2-} \Leftrightarrow CaCO_3 \{pH_{water} > 8\} \tag{2}$$

$$Ca^{2+} + HCO_3^- \Leftrightarrow CaCO_3 + H^+ \{7.5 < pH_{water} < 8\} \tag{3}$$

Therefore, this study effectively disperses the cracks in the cracks in the cementitious composite materials by using synthetic fiber, and, for the cracks with a width of more than 0.1mm, executed the review of the optimal

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self-healing conditions along with the review of a diverse range of self-healing performance.

2. Experimental Overview

The mixture proportions of the mortar are summarized in Table 1. Portland cement (C, density: 3.16 g/cm^3, mean diameter: 10 μm), quartz sand as the fine aggregate (S, surface-dry density: 2.61 g/cm^3, mean diameter: 180 μm), and a high-performance water reducing agent as an admixture (SP, density: 1.05 g/cm^3, main constituent: polycarboxylate-based superplasticizer) were used. As for the synthetic fibers, PVA (fiber diameter: 40 μm, fiber length: 12 mm, density: 1.3 g/cm^3) and polyethylene (PE) (fiber diameter: 12 μm, fiber length: 12 mm, density: 0.97 g/cm^3) and polypropylene (PP) (fiber diameter: 65 μm, fiber length: 12 mm, density: 0.91 g/cm^3) were used.

Table 1Mixture proportions of the mortar

Type	S/C (Wt.%)	W/C (Wt.%)	SP/C (Wt.%)	Fiber (vol.%)
PVA	0.4	0.3	0.4	1.2
PE			0.45	
PP			0.3	

Table 2 Experimental factors and conditions

Experimental factors		Conditions
Fiber		PVA, PE, PP
Self-healing	Water + Micro-bubble	pH 6.0
	$Ca(OH)_2$ + Micro-bubble	pH 8.5
Temperature		20℃
Crack (Target of crack width: 0.3mm)		Tensile load
Period of self-healing		7 Days

As the Experimental procedure, in STEP A, an analysis of the permeability coefficient immediately following the introduction of the cracks by the tensile loading test (prior to self-healing), and an analysis of the types of the hydrates prior to self-healing by using the Raman spectroscopy were executed. In STEP B, a comparison and evaluation were made by using the method applied in STEP A in order to evaluate the changes in the permeability of each of the specimens due to self-healing, changes in the structure within the cracks and a quantitative evaluation the self-healing precipitated substances. The experimental factors and conditions are summarized in Table 2.

3. Results and Discussion

3.1. Permeability Coefficient

As the results of the experiment, W+MB in STEP B, when compared with that in STEP A, displayed the trend of an increase in the resistance to permeability by about 40 folds for PVA, 3.5 folds for PE and 1.5 folds for PP(Fig 1). Meanwhile, Ca+MB in STEP B, when compared with that in STEP A, displayed the trend of an increase in the resistance to permeability by about 460 folds for PVA, 60 folds for PE and 6.0 folds for PP(Fig 2). In addition, in the comparison of the permeability coefficient following self-healing, Ca+MB, in comparison to W+MB, displayed the trend of improvement in the resistance to permeability by approximately 15 folds for PVA, 17 folds for PE and 4.0 folds for PP (Fig 3). From the aforementioned results, it can be discerned that the resistance to permeability is improved in the order of PVA>PE>PP, regardless of the conditions of self-healing. In particular, PVA with OH-radical displays a more effective self-healing performance [2], and, it was confirmed that the conditions of Ca+MB are more advantageous than the conditions of W+MB for the promotion of self-healing performance. Therefore, for the micro cracks with a width of more than 0.1mm for which substantial permeation of deteriorating elements from the external into the internal aspects of the concrete is anticipated, it is deemed that the generation and precipitation of the self-healing substances were promoted due to the mixing of the PVA fiber with the OH^- radical along with the introduction of the conditions of self-healing of the saturated $Ca(OH)_2$ solution (Ca^{2+}) that contains CO_2 micro bubbles (CO_3^{2-}).

3.2. Review of the Crack Section Due to Self-healing

Fig 4 shows the experimental results of Raman spectroscopy. Here, the locations of the occurrence of the peak of a wave generated by a laser at the crack section to which the white colored precipitated substance of PVA specimen is attached and that at the sections without cracks were compared. As the results of the experiment, with the peak of the wave of $CaCO_3$powder as the subject of comparison, there was almost no occurrence of the peak in the wave of the sections without cracks that coincides with that of the $CaCO_3$. However, the peak of the wave in the crack section accurately coincides with the peak of the wave of $CaCO_3$ powder. Accordingly, it is concluded that the majority of the white colored precipitated substance was generated following self-healing due to $CaCO_3$.

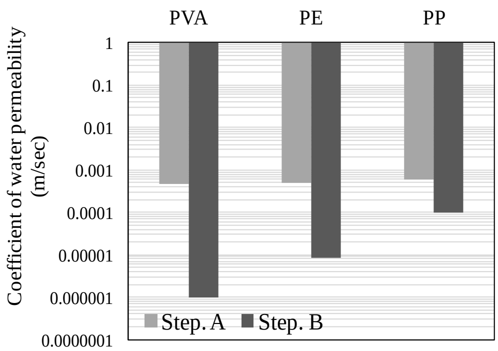

Fig. 1 Permeability coefficient of Water + Micro bubble (W + MB).

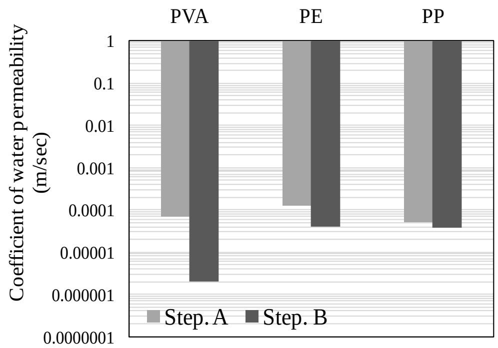

Fig. 2 Permeability coefficient of $Ca(OH)_2$ + Micro-bubble (Ca + MB).

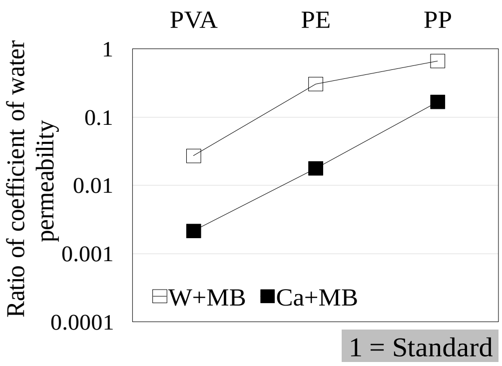

Fig. 3 Comparison of permeability coefficient ratio

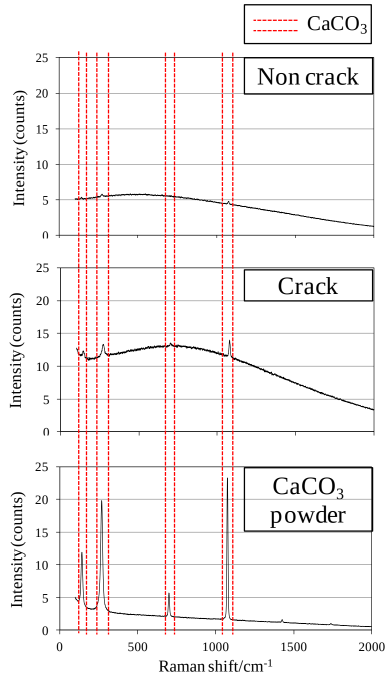

Fig. 4 Precipitated substances of self-healing

4. Conclusions

In this paper, it was confirmed that the effective restoration of water tightness and the majority of the self-healing products was due to $CaCO_3$ by using synthetic fiber with polarity, along with the effect of inducing a multiple number of hairline cracks. In addition, it was confirmed that the self-healing conditions of the saturated $Ca(OH)_2$ solution, which supplied the CO_2 micro-bubble, displayed the most effective self-healing performance in the surface and internal sections of the cracks.

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