Polypropylene fiber geometry influence on explosive spalling mitigation and correlation between residual properties and UPV of heated high strength concrete

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1. Introduction

Inclusion of polypropylene fibers inside high strength concrete (HSC) was found to be effective in alleviating explosive spalling, a catastrophic failure mechanism inconsistently observed on HSC experiencing elevated temperature condition. Melting of these fibers inside the hardened cement paste at 160-170ºC would generate additional pores thus relieving the buildup of pore pressure. Based on this mitigation mechanism, more addition of fibers into the mixture would be considered favorable to prevent explosive spalling. Nevertheless, deterioration in properties of HSC surviving elevated temperature would correspond with the amount of generated additional pores left upon melting, which was related to initial amount of fibers added into the HSC mixture. In present experimental study, investigation on the effectiveness of polypropylene fiber in mitigating explosive spalling and maintaining HSC properties was focused on fiber geometry instead of fiber volume fraction.

In the aftermath of fire accident, a rigorous method to inspect the residual properties of heated concrete would be favorable. Present experimental study also tried to correlate nondestructive measurement (ultrasonic pulse velocity test) and residual properties of polypropylene fiber-reinforced high-strength concrete after heat exposition.

2. Methodology

Concrete specimens were cast using ordinary portland cement, river sand (FM= 2.9), and crushed limestone (maximum nominal size of 13 mm) with mixture proportions as shown in Table 1. All series had the same W/C of 0.3 and s/a of 50%. Chemical admixtures such as superplasticizer, AE, and bubble cutter agent, were added to obtain targeted workability (slump of 150±25mm) and air content (5±1%) of fresh concrete. Short fibers used in present experimental study consisted of two types of polypropylene fiber (density of 0.9 kg/m^3) as shown in Table 2.

Table 1. Mixture proportions

Series	Water	Cement	Sand	Gravel	Fiber
Plain	170	567	795	780	0
P6-A					0.9
P6-B					

Table 2. Fiber geometry

Type	Length (mm)	d_{eff} (μm)	Aspect ratio	Shape
A	6	310	19	Mesh
B		18	333	Fiibrillated

Upon curing completion, some specimens were then heated inside a computer-controlled electric furnace applying heating rate of 10ºC per minute. The specimen was heated for exactly 2 hours after reaching designated maximum temperature of 200, 400, and 600ºC. It was then let to cool inside the furnace until its temperature coincided with the room temperature. At the same time, some specimens were dried inside drying machine at 105ºC for a few days until the difference in mass losses between measurements was negligible (≤0.1%). All specimens were 100×200 mm cylinders, and ultrasonic pulse velocity (UPV) test was performed in longitudinal direction, before and after heating or drying of the specimens.

Soon, compressive strength and water permeability test were carried out after heating of the specimens. Compressive strength test was performed according to JIS A 1108, setting loading rate at 2 kN/s. As for water permeability test, details about the setup and procedure on this particular test might refer to reference [1].

Keywords HSC, polypropylene fiber, fiber geometry, explosive spalling, elevated temperature
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3. Experimental results

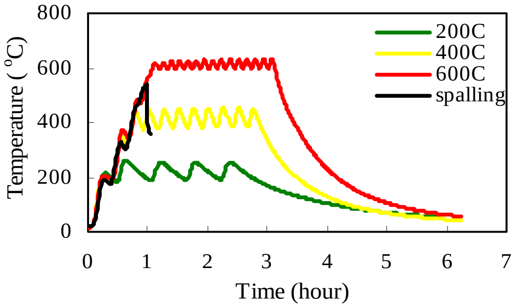

Fig. 1. Spalling temperature

Explosive spalling was observed on all Plain and P6-A specimens that were allocated to be heated at 600°C. Spalling took place during the rising of temperature at about 500-600°C, as shown in Fig. 1. On the contrary, no spalling was observed on all P6-B specimens after heating at 600°C. From this result, it can be noticed that mitigation of explosive spalling is significantly affected by fiber geometry in the case of limited fiber volume fraction inside the HSC mixture. Moisture content of all specimens was in the range of 4-5% prior to heating.

Value of UPV and mass loss of heated specimens are shown in Fig. 2. Up to 200°C, no significant change in UPV value may be observed in all series. However, UPV value dropped to 3.6 and 2.7 km/s (initial of 4.7 km/s) after heating at 400 and 600°C, respectively. In terms of mass loss, vaporization of free moisture in the concrete mass is believed to be the main reason up to 200°C. Further increase in maximum heating temperature would cause dehydration of calcium hydroxide (CH) and calcium silicate hydrate (CSH) leading to increase in mass loss due to the further vaporization of chemically bound water.

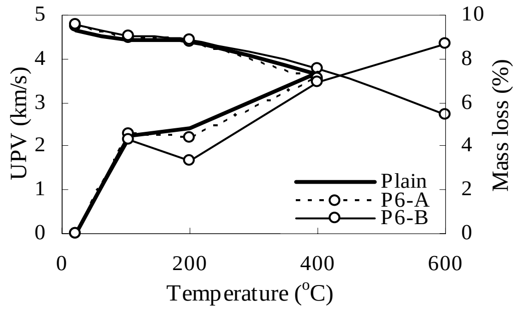

Fig. 2. UPV and mass loss—temperature

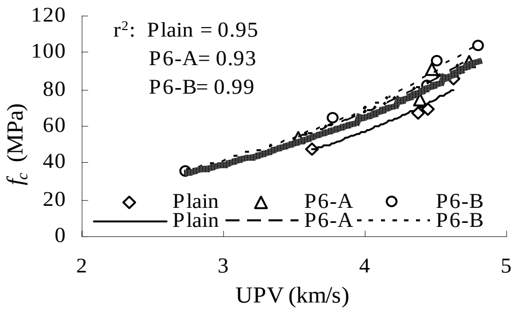

Fig. 3. Compressive strength—UPV

Correlation between properties of heated concrete and UPV is shown in Fig. 3 to Fig. 5. The thickest line inside each figure represents the regression analysis including the data of all series. Correlation between compressive strength—UPV, modulus of elasticity—UPV, and water permeability—UPV is given in Eqs. (1) to (3), respectively.

$$f_c=9e^{0.5v} \qquad r^2=0.90 \qquad (1)$$

$$E=0.7e^{0.87v} \qquad r^2=0.97 \qquad (2)$$

$$k=1.6\times10^{5}e^{-2v} \qquad r^2=0.61 \qquad (3)$$

where: f_c= compressive strength (MPa), E= modulus of elasticity (GPa), k= water permeability coefficient (m/s), and v= UPV (km/s)

Correlation between k—UPV is not as significant as f_c—UPV or E—UPV. This indicates the sensitivity of permeability properties to pores distribution inside the concrete matrix. And, polypropylene fiber geometry greatly affect the outcome of this property as it determines the pore structure of HSC surviving elevated temperature condition.

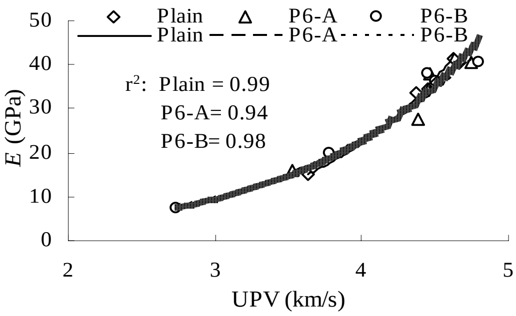

Fig. 4. Modulus of elasticity—UPV

4. Conclusions

1. In case of limited fiber volume fraction, geometry of polypropylene fiber may play a significant role in mitigating explosive spalling.

2. Correlation between residual properties and UPV may serve as a practical tool to assess concrete structure in the aftermath of fire accident.

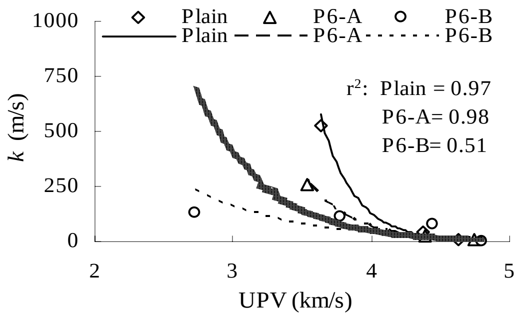

Fig. 5. Water permeability coefficient—UPV

References

1. Suhaendi, S.L. and Horiguchi, T., "Effect of short fibers on residual permeability and mechanical properties of hybrid fibre reinforced high strength concrete after heat exposition, CCR 36 (9) (2006) 1672-1678