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Preventive effect on spalling of UFC using jute fiber at high temperature

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Abstract. In this study, we examined the relationship between spalling behaviour and spalling ratio of UFC with three kinds of short fibers (jute, polypropylene, water-soluble polyvinyl alcohol) at high temperature. The heating temperatures were 400 °C and 600 °C. Although the specimen with jute fiber dosage of 0.19% by volume was occurred explosive spalling, the damage of specimen was slightly small. It appears that the addition of jute fiber to UFC is effective for preventing spalling.

1. INTRODUCTION

Ultra-high strength fiber reinforced concrete (UFC) [1] using steel fiber is a material with specifically advantageous characteristics, resulting in excellent mechanical properties and a very low permeability. Its high strength (>200 MPa in compression and >30 MPa in bending) makes it resistant to severe loading and environmental action. Its dense matrix, leads to the very low permeability, which can improve the durability of UFC members compared to conventional concrete members. Previous studies have clearly shown the advantages to using UFC [2, 3]. However, UFC has been particularly susceptible to spalling in fire. Generally, the addition of synthetic fibers, especially polypropylene (PP) fiber to high-strength concrete is widely used as an effective measure to prevent explosive spalling [4–6]. Authors have investigated the effectiveness of adding jute fiber (natural fiber) to UFC (fc;150MPa with aramid fiber), for preventing spalling at high temperature [7]. However, it should be noted the effectiveness of adding jute fiber to higher strength UFC for preventing spalling at high temperature. In this study, we examined the relationship between spalling behaviour and spalling ratio of UFC (fc:200MPa) with three kinds of short fibers (jute, PP, water-soluble polyvinyl alcohol) at high temperature. The heating temperatures were 400 °C and 600 °C.

2. OUTLINE OF THE EXPERIMENT

2.1 Mixture proportion

Table 1 gives the mix proportions of the mortar matrix used in this study. Pre-mixed cement with silica fume was used. The UFC mix relies on achieving optimum particle packing and reactive powders to develop many of its extraordinary features. The basic premise behind particle packing is to increase the density of the concrete and develop a uniform microstructure by filling the voids around the cement particles.

Table 1. Mix.

Unit weight(kg/m^3)				
Premixed cement	Fine aggregate	Water	Water reducing agent	Steel fiber
1322	932	180	24	157

Table 2. Fibers.

Type of fiber	Length	Diameter	Melting point	Density	note
	mm	μm	°C	g/cm^3	
Jute	12	10 ∼ 30	-	1.3–1.45	Carbonization
WSPVA	4,12	12	220–240	1.3	Water solving
PP	12	42	170	0.91	Melting

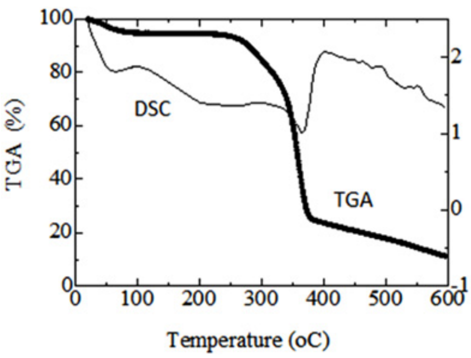


Figure 1. DSC-TGA results (Jute).

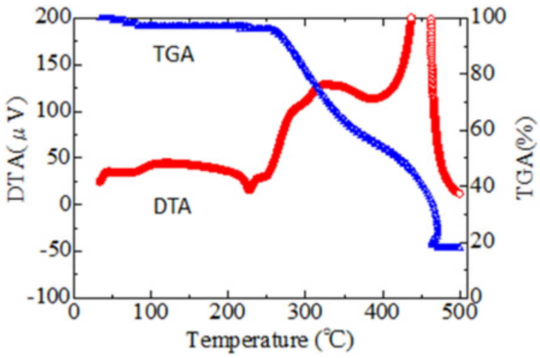


Figure 2. DTA-TGA results (WSPVA).

2.2 Properties of Fibers

The steel fibers used in this study had a diameter of 0.2 mm and a length of 15 mm. Table 2 shows the properties of the natural jute fibers and the synthetic WSPVA and PP fibers used (jute fiber addition ratio: 0.19 vol%; length: 12 mm; WSPVA fiber addition ratio: 0.19 vol%; length: 4 mm and 12 mm; PP fiber addition ratio: 0.19 vol% and 1.0vol%; length: 12 mm) [7]. Photos 1(obtained with a scanning electron microscope (SEM)) show the straw-like structure of the jute fibers. WSPVA fibers have a lower dissolving point (50 °C to 90 °C) than other synthetic types, and also have a lower melting point. These properties have been used for more than 30 years in Japan to improve the permeability of concrete and thereby reduce the likelihood of explosion in castable refractories.

Figure 1 shows the results of thermal analysis of jute fiber using differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA). The exothermic peak (which represents the amount of heat released from the sample) of the DSC curve for such fibers was observed at a maximum temperature of 360 °C. The TGA curve initially exhibits a slight decrease in weight at temperatures below 100 °C due to moisture loss, but both curves begin to show de-composure at 265 °C and 340 °C. The decomposition temperature for the jute fiber sample at 80% weight loss was 390 °C. Figure 2 shows the DSC and TGA results for PP fibers, whose melting, vaporization and burning points were 173 °C, 341 °C and 447 °C, respectively. Higher temperatures reduce their viscosity via the two mechanisms of increased molecular energy and reduced molecular size caused by thermal degradation. Figure 3 shows the DSC and TGA results for WSPVA fibers, whose melting, vaporization and burning points were 227 °C, 246 °C and 470 °C, respectively.

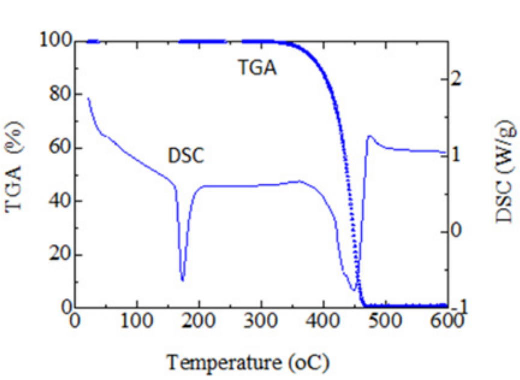


Figure 3. DSC-TGA results (PP).

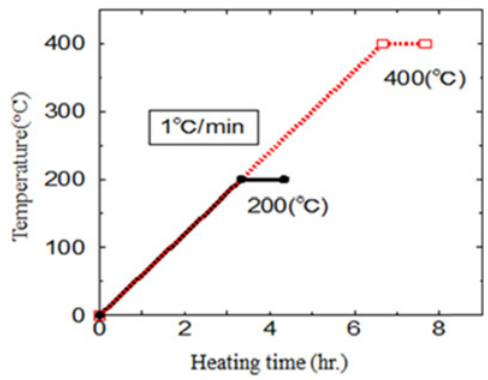


Figure 4. Heating history (Strength test).

2.3 Mixing and flow test

The mortar components were placed into a 10-liter Hobart mixer and agitated. Mixing process is belows:

1) Add pre-mixed cement, pre-mixed sand, mix for 1 minutes.
2) Add water and super plasticizer, mix for 2 minutes, scrape bowl and mix for 5 minutes.
3) Add steel fiber and other fibers mix for 4 minutes.

The flowability of the mortar was evaluated in a flow test using a cone mold with dimensions of 70 mm (top diameter) ×100 mm (bottom diameter) ×60 mm (height). Joggings were not included in the flow test.

2.4 Specimen fabrication and curing

Heating test specimens with 50 mm in diameter and 100 mm in height were used for this study. The concrete was placed in molds and compacted using a table vibrator. The surfaces of the specimens were plastic-wrapped immediately after placement and left for two days in a curing room at 20 °C. After demolding, steam curing was carried out for two days at a temperature of 90 °C.

2.5 Heating tests

Specimens were heated in a muffle furnace with an operating temperature range of 100 °C to 1,150 °C. The unit used was a 2.5 kW iron-chrome wire heater with a 220V power source.

Figure 4 shows the spalling test's heating times and temperatures, which were 400 °C and 30 minutes, 600 °C and 20 minutes. After being heated, the specimens were allowed to cool naturally. Figure 5 shows pre-heating after the compressive strength tests. The heating temperatures were 200 °C and 400 °C. Heating speed was 1 °C /min. After being heated, the specimens were allowed to cool naturally.

3. RESULTS AND DISCUSSION

3.1 Flowability

Figure 6 gives the flow test results. The flow value of each mixture was Control: 293 mm, J-0.19: 265 mm, P-0.19: 280 mm, P-1.0: 135 mm, WS-4: 253 mm and WS-12: 211 mm. The flow value of Control mixture without fiber was 293 mm, which was in the target range, but the high contents of

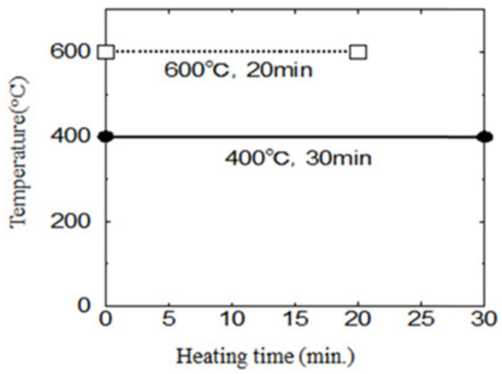


Figure 5. Heating history (spalling test).

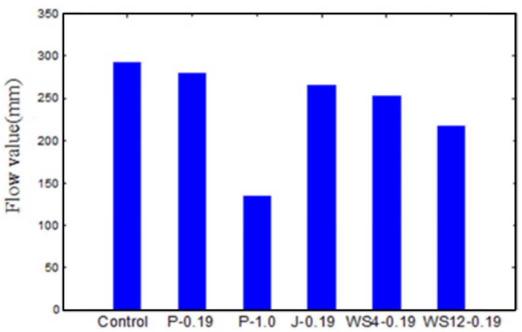


Figure 6. Flow test results.

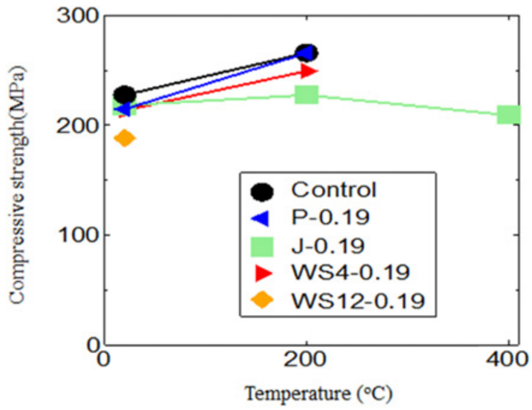


Figure 7. Compressive strength.

fiber notably decreased the flow. Especially, the mixture P- 1.0 had the highest loss of the flow, while the other mixtures with fibers showed relatively better performance.

3.2 Mechanical properties

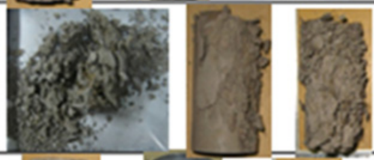
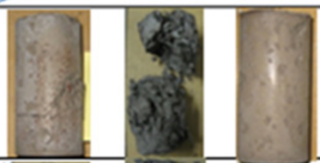
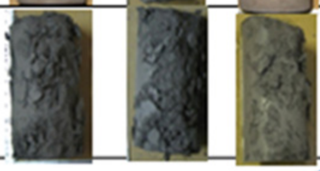
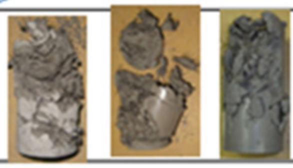
Figures 7 shows the compressive strength of harden UFC of Control, P-0.19, J-0.19, WS4-0.19, WS12-0.19, respectively. The compressive strength of Control specimen without fiber was 228 MPa, which was in the target range. Their results indicate values ranging from 188 MPa to 228 MPa for the specimens before heating test. After heating at 200 °C, their strengths became ranging from 227 MPa to 266 MPa without WS12-0.19. It was clear that strength increased in Conrol, P-0.19, J-0.19, WS4-0.19 specimens. Regarding the improved strength after heating at 200 °C, it was consider to occur additional hydration of cement. After heating at 400 °C, the strength of J-0.19 specimen was 209 MPa.

The strengths could not be measured for other specimens after heating at 400 °C, because these specimens were occured to explosive spalling.

3.3 Extent of spalling

Figure 8 shows the extent of spalling in all specimens after the fire tests. Control specimens were more severely damaged at the temperature 400 °C. In the case of specimens with added fibers, it was clear that

Table 3. Extent of spalling.

Type of Specimens	Heating Temperature(°C) 400	600
Control		
P-0.19		
P-1.0		
J-0.19		
WS4-0.19		
WS12-0.19		

the spalling tendency decreased. With a heating temperature of 400 °C and a heating time of 30 minutes, explosive spalling was observed in Control, P-0.19, WS4-0.19, and WS12-0.19 specimens, but not in the J-0.19 specimen. The extent of spalling in the WS4-0.19 and WS12-0.19 specimens was small. With a heating temperature of 600 °C and a heating time of 20 minutes, explosive spalling was observed in all specimens. P-1.0 and WS12-0.19 specimens were severely damaged, while the extent of spalling in the J-0.19 specimens was small. It appears that the addition of jute fiber to UFC is effective for preventing spalling.

4. CONCLUSION

The results obtained by the experiment can be summarized as follows:

1) Control mixture without fiber addition indicated 293 mm in flow value, which was in the target range, but the high contents of fiber notably decreased the flow. Especially, the mixture containing P- 1.0 had the highest loss of the flow, while the others with fibers showed relatively better performance.

2) Control specimen without fiber addition indicated 228 MPa in the compressive strength, which was in the target range. The compressive strengths were ranging from 188 MPa to 228 MPa for the specimens before heating test. Regarding the improved strength after heating at 200 °C, it was consider to occur additional hydration of cement.
3) For the specimens with added fibers, it was clear that the spalling tendency decreased. With a heating temperature of 400 °C and a heating time of 30 minutes, explosive spalling was observed in Control, P-0.19, WS4-0.19, and WS12-0.19 specimens, but not in the J-0.19 specimen.
4) With a heating temperature of 600 °C and a heating time of 20 minutes, explosive spalling was observed in all specimens. P-1.0 and WS12-0.19 specimens were severely damaged, while the extent of spalling in the J-0.19 specimens was small. It appears that the addition of jute fiber to UFC is effective for preventing spalling.

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