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Research Article

Research on Fire Resistance of Ultra-High-Performance Concrete

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Fire resistance of ultrahigh-performance concrete was measured under different temperatures and loadings. C120 concrete was prepared with 1 kg/m^3 organic fiber and C120 concrete with 2 kg/m^3 organic fiber and tested under loading at 30% ultimate strength when exposed to high temperatures of 200°C, 300°C, and 400°C, respectively.

1. Introduction

At present, the research on the fire resistance of ultra-high-performance concrete equal to or greater than C100 has yet prevailed. However, concrete buildings usually get badly damaged in fire (Figures 1 and 2), causing high life and property losses, let alone environmental pollution [1].

We conducted thorough research on the fire resistancy of ultra-high-performance concrete and fortunately discovered regularity in it and came up with some countermeasures, making agreeable contribution to the study of this issue.

2. Raw Materials

(1) Cement: Nanjing Xiaoyetian P II 52.5.

(2) Microballoon, made in Kunming, average diameter ≦1 μm and superficial area 12000 cm^2/g.

(3) Ganister sand, from Zhunyi, Guizhou; superficial area 20000 cm^2/g [2].

(4) Mineral Powder (ultra fine), from Jiangmen, Guangdong, superficial area 8500 cm^2/g.

(5) Fine aggregate, sea sand from Shenzhen, desalted, FM 2.6~2.8.

(6) Coarse aggregate, macadam from Shenzhen, 5–10, 10–20 mm in diameter.

(7) Water reducer, BASF polycarboxylic acid, solid content: 40%; self-made naphthalene-sulfamate water reducer.

(8) Polypropylene fiber, Grace 19 mm long fiber [3].

3. Mix Proportions of Ultra-High-Performance Concrete

Based on previous test results, we prepared the fire-resistant C120 concrete by proportions found in Table 1.

Finished test pieces were in 3 sizes: 100 × 100 × 300 mm, Φ100 × 150 mm, and Φ100 × 300 mm, as in Figures 3, 4, and 5.

4. Equipment

(1) Heating: we designed 3 heating apparatus and assigned a workshop to manufacture them for us. They came out as in Figures 6, 7, and 8.

(2) Loading: 2000 KN digital press machine.

5. Research Approach

To simulate the situation of ultra-high-performance concrete under pressure in case of fire, we came up with the following research plan.

Table 1: Mix Proportions.

Ratio of water to plastic	Water	Cement	Microballoon + ganister sand + mineral powder	Sea Sand	Coarse aggregate		Additive	Fiber content (kg/m^3)	Steel bars
					5–10	10–20			
0.174	122	550	150	750	285	665	1.3	0	No
0.174	122	550	150	750	285	665	1.4	1	No
0.174	122	550	150	750	285	665	2.17	2	No
0.18	135	500	250	700	300	700	1.3	0	Yes

Figure 1

Figure 2

Figure 3

Figure 4

(1) Take one test piece out of each type, perform axial compressive strength test on them, and write down the numbers.

(2) When the axial compressive strength values of each type of test pieces are obtained, set 30% of each value as the constant loading strength for the certain type.

(3) Put the test pieces onto the press machine and keep adding pressure until the constant loading strength is reached.

(4) While maintaining the pressure, heat the test piece with suitable heating jacket to 200°C, 300°C, and 400°C separately. Keep the heating period within 20 to 30 minutes, once the required temperature is reached, maintain the temperature for 30 to 40 minutes to let the heat spread evenly to every part of the test piece [4].

(5) As soon as the temperature-maintaining time has passed, remove the heating jacket and scrutinize and record any change on the surface. This step must be carried out quickly, for the heat escapes once the heating jacket is removed.

Figure 5

Figure 6: Control cabinet.

Figure 7: Prismatic heating jacket.

Figure 8: Cylindrical heating jacket.

Figure 9

Figure 10

Figure 11

Figure 12

6. Results and Discussion [5]

6.1. Basic Test Piece

(1) Figure 9 features basic test-pieces condition after undergoing constant loading pressure and being heated to 200°C. We could see from the figure that the concrete on the surface, especially the corners, was flaking away; there were minor cracks everywhere, suggesting cracking was the main reason why the concrete flaked away under the influence of pressure and heat.

(2) Figures 10 and 11 feature basic test-pieces condition after undergoing constant loading pressure and being heated to 300°C. During the process, the test piece endured dozens of crackings, which led to massive concrete flaking away on the surface; cylindrical test piece even exploded while pressure mounted and got more seriously damaged.

(3) Figure 12 features basic test-pieces condition after undergoing constant loading pressure and being heated to 400°C. Test piece cracked numerous times during the process of heating, and it exploded while the warmth was being maintained. After all these

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17

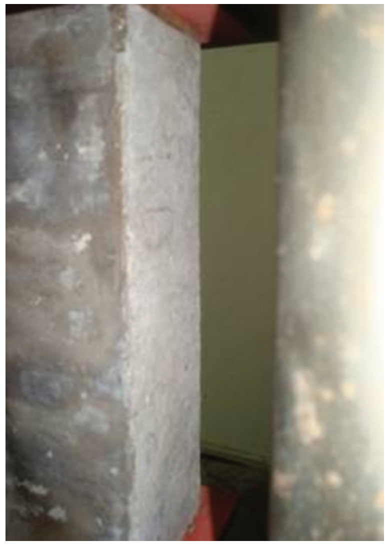

Figure 18

Figure 19

ordeals, the test piece was too wrecked to undertake any pressure.

6.2. Specimen Observations with 1 Kg/m^3 Polypropylene Fiber

(1) Figure 13 features the condition of test piece with 1 Kg/m^3 polypropylene fiber after undergoing loading pressure and being heated to 200°C. It looks quite intact, only few minor cracks can be seen in the figure.

(2) Figures 14 and 15 feature the condition of test piece with 1 Kg/m^3 polypropylene fiber after undergoing loading pressure and being heated to 300°C. Cracks seen in the figures were caused by sudden temperature change after the heating jacket was removed; during heating and loading processes, the test piece was largely intact. Prismatic and cylindrical test pieces showed no difference in this test.

(3) Figure 16 features the condition of test piece with 1 Kg/m^3 polypropylene fiber after undergoing loading pressure and being heated to 400°C. We saw no major cracks but minor ones on the surface of the test piece. In addition, a great number of shallow cracks were also found.

6.3. Specimen Observations with 2 Kg/m^3 Polypropylene Fiber

(1) Figures 17, 18, and 19 feature the condition of test piece with 2 Kg/m^3 polypropylene fiber after undergoing loading pressure and being heated to 200°C and 300°C. After the tests, it appeared nice and sound.

Figure 20

Figure 21

(2) Figure 20 features the condition of test piece with 2 Kg/m^3 polypropylene fiber after undergoing loading pressure and being heated to 400°C. It did not explode in such temperature, but minor cracks still appeared.

6.4. Reinforced Concrete Specimen Observations. Put steel bars into C120 concrete and observe how it changes during the test. Figures 21 and 22 feature the condition of reinforced concrete test-pieces sized $\Phi 100 \times 150$ mm and $\Phi 100 \times 300$ mm after undergoing loading pressure and being heated to 300°C. Test pieces exploded during test, not only the concrete fell off into pieces, but also the steel bars were partly exposed in the air.

7. Analysis

By comparing and analyzing the test results, the research group made the following findings concerning the possible changes of ultra-high-performance concrete in case of fire.

(1) The temperature to which the test pieces were heated has been a main factor in ultra-high-performance concrete changes. This particularly applied to basic test piece, which

Figure 22

cracked many times and more severely at 300°C than at 200°C and eventually exploded at 400°C, forcing the test to get aborted.

(2) At 300°C, reinforced concrete test pieces were more vulnerable to heat than others. Basic test pieces suffered moderate flake-away while reinforced concrete ones broke into pieces, revealing steel bars.

This phenomenon resulted from the fact that steel bars swelled when heated. For basic test pieces, the crackings were caused by the stress released from their own thermal expansion; for reinforced concrete test pieces, they underwent not only stress from its own thermal expansion but also the thermal expansion of the steel bars. It is not hard to explain why the latter broke from the inside out [6].

(3) Certain amount of polypropylene fiber would noticeably enhance ultra high-performance concrete's fire-resistance. Heated to 200∼300°C, test pieces with fiber hardly showed changes; test pieces with 2 kg/m^2 fiber stayed intact at moderately high temperature, even at 400∼500°C, they only chapped a little.

This can be explained this way: the polypropylene fiber mixed into concrete test piece melts in the heat, creating steam vessels throughout the whole test piece. These vessels not only help drain or ventilate the liquid and vapor within the body, but also make room for thermal expansion, which reduces its chance of cracking and exploding [7].

This finding coincides with the popular vapor pressure theory in the explanation of high-performance concrete's cracking and exploding. According to vapor pressure theory, the water in concrete turns into vapor when the temperature goes up (e.g., in fire), if the vapor cannot escape in time, pressure will be created inside the concrete body, when the internal pressure accumulates to some degree, explosion happens [8]. Polypropylene fibers melt in the heat, providing ventilation for liquid and vapor, thus they prevent concrete from cracking and exploding.

8. Conclusions

Ultra-high-performance concrete is an artificially synthesized material low in water-cement ratio and high in strength, density, impermeability, and brittleness. These traits make it easy to crack in case of fire, which results in reduction in strength. Adding polypropylene fibers not only helps enhance concrete's strength and elasticity, but also provides ventilating vessels when the surrounding temperature rises. With these merits, ultra-high-performance concrete with fibers is able to tolerate heat and pressure for a relatively long time without getting seriously damaged, thus making time for firefighters to save people's lives and their properties [9, 10].

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