

## Experimental study on compressive properties of mixed fiber concrete after fire

Xiaoqiang Chen, Zechang Wang

North China University of Science and Technology, Tangshan, China

### Abstract

In recent years, the application of high performance self-compacting concrete with high strength, high durability and high workability has become more and more widespread, and has gradually become the main building material. However, high-performance self-compacting concrete increases brittleness while increasing strength, and at the same time, explosion resistance and fire resistance are significantly reduced. With the development of cities, natural gas and intelligent electrical equipment are becoming more and more popular, but people's awareness of fire safety has not been improved, making the incidence of fire in buildings on the rise. In recent years, the development of hybrid fiber self-compacting concrete (HFRSCC), which combines the high workability of self-compacting concrete (SCC) and the high toughness and high crack-resistant properties of fiber concrete (FRC), giving full play to the fiber's anti-cracking, reinforcing and toughening effect, and after the fire and high temperature effect, the components of the use of hybrid fiber self-compacting concrete to maintain a certain degree of residual load-bearing capacity. The introduction of fibers for reinforcement and toughening, to improve the mechanical properties of concrete materials, blast resistance and fire resistance performance points to a direction.

### Keywords

Blended fibers; High-performance concrete; High-temperature properties; Compressive properties.

### 1. Research background

Fire usually causes high-temperature bursting of concrete structures and materials, reducing their durability and safety. In recent years, it has been found that the incorporation of single fiber has certain limitations on the improvement of high-temperature resistance of concrete, so more and more experts and scholars have turned their attention to the study of high-temperature mechanical properties of hybrid fiber concrete. Yang Juan and Zhang Daoling on the hybrid fiber high-performance concrete residual strength and high temperature bursting performance research, the results show that: hybrid fiber concrete high temperature bursting after the residual compressive strength, flexural strength and splitting tensile strength have been improved to varying degrees, mixed fibers can be part of the ultra-high-performance concrete specimens to avoid bursting. Varona et al. results show that at different temperatures (200 °C, Varona et al. showed that at different temperatures (200 °C, 450 °C, 650 °C, 825 °C), the compressive strength, tensile strength and dynamic modulus of elasticity of hybrid fiber concrete showed a tendency to decrease with the increase in temperature, but at a slower rate than that of ordinary concrete. Chen and Liu's research results showed that the hybrid fiber high-strength concrete with synthetic fibers did not occur any bursting. Kodur et al. studied the thermal conductivity of hybrid fiber concrete at high temperatures, and the results showed that some ultra-high performance concrete specimens avoided bursting. Kodur et al. studied the thermal conductivity of hybrid fiber concrete at high temperatures, the results show that: the thermal conductivity of fiber concrete will be reduced only after 600 °C, in which the steel fibers

contribute the most. Sanchayan et al. showed that the rate of mass loss of hybrid fiber concrete will gradually increase with the increase in temperature and fiber mixing on the trend of the mechanical properties of hybrid fiber concrete at high temperatures have a greater impact. BANGI In recent years, and the effect of hybrid fibers on the steam pressure of high-strength concrete. The effect of vapour pressure on high-strength concrete, it was found that steel fibers can also effectively reduce the vapour pressure inside the high-strength concrete, and the porous weak zone on the surface of the steel fibers (interfacial transition zone) may be a potential channel for releasing the vapour pressure, and the mixing effect of steel fibers with synthetic fibers is better than that of single-mixed steel fibers or synthetic fibers.

Therefore, this project will use low melting point ceramic fibers and high melting point copper-plated steel fiber mix, based on the high temperature bursting mechanism - steam pressure theory to optimize the design of mixed-fiber self-compacting concrete ratio, in order to meet the requirements of self-compacting concrete working performance indicators, improve the fire resistance of high-performance concrete, and provide a new building material for the reinforced concrete structure. The new building materials for reinforced concrete structures are provided.

## 2. Pilot program

### 2.1. Research methodology, steps and key technologies

(1) Review the latest literature at home and abroad to grasp the latest development of this research.

(2) With reference to the foreign advanced test methods (J-ring, L-trough, U-tube, rheometer), carry out the analysis of the influence of different mixing amounts (30+1.3, 30+2.6, 30+3.9, 40+1.3, 40+2.6, 40+3.9, 50+1.3, 50+2.6, 50+3.9 kg/m<sup>3</sup>) of hybrid fibers on the working performance of self-compacting concrete to determine the The highest and optimal amount of hybrid fibers (one of the key technologies).

Table 1 Concrete mixing ratio (kg/m<sup>3</sup>)

water to binder ratio	Cement	Water	Water reducing agent	Sands	Lytag	Silica fume	Fly ash
0.39	357	200	2.55	693	605	51	102

(3) Production and curing of mixed fiber self-compacting concrete specimens

The specimens of this test are shaped by steel mold plate and mixed by forced mixer. Attention should be paid to lead the lead wires of thermocouples to the outer edge of the formwork, and at the same time protect the pre-buried thermocouples, lead wires, and especially the numbered markings of the wires during the filling process. When pouring concrete, enter the mold quickly to avoid water evaporation. Move the specimen to a level site after pouring and molding. To prevent the concrete moisture from dissipating, cover the specimen with a plastic sheet. The mold was removed after 24 hours. The specimens were cured under natural conditions until the test stage. All the accompanying specimens were cured under the same conditions so that the accompanying specimens and the test beams would have the same strength.



Fig. 1 Well-conserved fiber concrete specimens

## 2.2. Open flame high temperature test

After 28 days of standard maintenance conditions, it was placed in a dry and ventilated place for 2-3 days and dried naturally for fire experiments. Tests using the North China University of Science and Technology Fire Laboratory 3600mm × 6000mm × 1760mm horizontal furnace, in accordance with international standards ISO834 standard heating curve for fire heating experiments. When heated to a predetermined time to stop heating, natural cooling cooling to room temperature, open the furnace cover, observe the test block bursting, measure the mass loss and residual compressive strength of the test block.



Figure. 2 Fire test furnace

## 2.3. Cubic compression test after high temperature

According to the "Fiber Concrete Test Method Standard", lightweight cubic specimens with different dosage of 100mm side length were used to add different scales of fibers, three specimens in each group, and the specimens were wiped clean after taking out the specimens, measuring the dimensions and checking their appearance. Place the specimen on the lower pressure plate of the testing machine, and the pressure surface of the specimen is perpendicular to the top surface of the molding. The center of the test piece should be aligned with the center of the lower platen. Start the testing machine, when the upper platen and the specimen close, adjust the ball seat, so that the contact is balanced. When the specimen is close to destruction and begins to deform rapidly, stop adjusting the test machine throttle until the specimen is destroyed. Then record the destructive load.

## 3. Experimental results

### 3.1. Experimental phenomena

#### 3.1.1. Post-fire situation

When the fire time reaches 60min, you can see the data on the temperature collector of the flat furnace, the temperature of the furnace chamber reaches about 900 °C, the specimen connected to the thermocouple collector data part of the phenomenon of sudden increase or decrease. When the furnace temperature reaches about 100 °C, open the lid and found that most of the specimens specimen burst, a few specimens intact, the specific situation is shown in Figure 3.



Fig. 3 Test phenomenon after 60 min of exposure to fire

After being subjected to fire the concrete specimen partially fractured in the center and had a good temperature profile with no breaks occurring. The reason for the analysis is that the high temperature effect will inevitably appear from the inside to the outside of the gradient, the surface temperature of the specimen close to the source of high temperature is the highest, and the temperature at the center of the specimen is the lowest. This temperature gradient leads to a gradual decrease in temperature stress from the outside to the inside, resulting in stresses between the inside and outside, which eventually shows concrete shear damage. Therefore, the specimen placement also affects the damage of fiber concrete specimens subjected to fire.

From the position of the specimen arrangement, the fire spout is ejected from the two ends of the specimen, and the outer end of the specimen is close to the high temperature source, which leads to the uneven heating of the specimen and the generation of stresses. In addition to this, the complete temperature profile shows that the rock wool wrapped around the thermocouple is also at the outer end of the specimen, which provides some protection to the end of the specimen with the thermocouple under fire.

**3.1.2. Quality, apparent characteristics of fiber lightweight aggregate concrete after a fire**

Mixed ceramic concrete and ceramic-polypropylene hybrid fiber concrete burst and crushed severely after 60 min of fire.



Fig. 4 Apparent characteristics after being subjected to fire for 60 min

Statistics of the remaining intact specimen fiber admixture found that copper-plated steel fiber lightweight aggregate concrete at high temperatures the remaining intact number is higher, the fiber admixture of bursting resistance improved, steel fiber volume admixture of 40kg/m<sup>3</sup> or 50kg/m<sup>3</sup>, polypropylene fibers volume admixture of 1.3kg/m<sup>3</sup>, can effectively prevent the occurrence of bursting damage.

Table 2 Complete statistics after 60 min of exposure to fire

Fire duration	Fiber Type	Number of test blocks	Number of complete units remaining
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	ceramics	18	0
60min	copper-plated steel	18	18
	Ceramic-copper-plated steel	54	36
	Ceramic-Polypropylene	54	0

As can be seen from Table 2, mixed with ceramic - copper-plated steel fiber lightweight aggregate concrete after 60min of fire, there are large cracks around and a large number of small holes, part of the test block occurred in the corner burst phenomenon. Mixed with ceramic fiber lightweight aggregate concrete specimens, all serious bursting phenomenon, no complete specimen; fire 60min, mixed with steel fiber lightweight aggregate concrete specimens did not occur bursting phenomenon, while mixed with ceramic - copper-plated steel fiber lightweight aggregate concrete part of the corner bursting phenomenon.

### 3.2. Test results of compressive performance of fiber-reinforced concrete after fire

With the increase of temperature, the internal structure of concrete gradually deteriorates, and each mechanical property index is attenuated to different degrees. The law of change of compressive strength residual rate of fiber concrete is that, in the process of fire time increase, the compressive strength residual rate of fiber concrete gradually becomes smaller. For mixed fiber, in the same fire time, with the increase of copper-plated steel fiber dosage compressive strength residual rate gradually increased.

Table 3 Residual rate of cubic compressive strength after 60 min of fire

Number	Ceramic fiber/kg·m <sup>-3</sup>	Copper Plated Steel Fiber/kg·m <sup>-3</sup>	Fire time/min	Compressive strength/MPa	Residual compressive strength/%
C1B1T2	1.3	30	60	6.95	0.178
C1B2T2	1.3	40	60	6.49	0.159
C1B3T2	1.3	50	60	6.42	0.151
C2B1T2	2.6	30	60	6.75	0.178
C2B2T2	2.6	40	60	6.10	0.156
C2B3T2	2.6	50	60	6.84	0.167
C3B1T2	3.9	30	60	7.00	0.185
C3B2T2	3.9	40	60	7.20	0.178
C3B3T2	3.9	50	60	7.21	0.177

As shown in Table 3, the residual compressive strength of lightweight aggregate concrete with copper-plated steel fibers mixed with 30kg/m<sup>3</sup>, 40kg/m<sup>3</sup> and 50kg/m<sup>3</sup> after 60min of fire is similar, which is 15.8%, 16.5% and 16.7%. The compressive strength of lightweight aggregate concrete mixed with 1.3kg/m<sup>3</sup>, 2.6kg/m<sup>3</sup> and 3.9kg/m<sup>3</sup> of ceramic fibers is lower than that of lightweight aggregate concrete mixed with copper-plated steel fibers alone after 60min of fire; when the amount of copper-plated steel fibers remains unchanged, the compressive strength of lightweight aggregate concrete after fire increases with the increase of ceramic fibers. When the dosage of copper-plated steel fiber is 50kg/m<sup>3</sup>, the compressive strength of lightweight aggregate concrete mixed with 3.9kg/m<sup>3</sup> ceramic fiber is higher than that of lightweight aggregate concrete mixed with copper-plated steel fiber alone. The compressive strength residual rate of copper-plated steel fiber lightweight aggregate concrete mixed with 1.3kg/m<sup>3</sup>, 2.6kg/m<sup>3</sup>, 3.9kg/m<sup>3</sup> ceramic fibers is higher than that of lightweight aggregate concrete mixed with copper-plated steel fibers, and with the increase of ceramic fiber mixing, the residual rate of compressive strength is gradually increased; among them, the copper-plated steel fiber

mixed with  $1.3\text{kg}/\text{m}^3$  lightweight aggregate concrete mixed with  $1.3\text{kg}/\text{m}^3$ ,  $2.6\text{kg}/\text{m}^3$  and  $3.9\text{kg}/\text{m}^3$  ceramic fibers is higher than that of lightweight aggregate concrete mixed with copper-plated steel fibers alone. Concrete mixed with  $1.3\text{kg}/\text{m}^3$ ,  $2.6\text{kg}/\text{m}^3$ ,  $3.9\text{kg}/\text{m}^3$  ceramic fiber compressive strength residual rate of the best effect, respectively increased by 0.2%, 0.9%, 2.9%.

#### 4. Conclusion

(1) Copper coated steel fibers have anti-popping effect on concrete specimens, ceramic fibers have poor anti-popping effect and polypropylene fibers do not have good anti-popping effect on concrete. The integrity of the concrete mixed with ceramic fibers after fire is lower, mixed with copper-plated steel fiber concrete integrity is higher.

(2) The same fire time (60min) and the same amount of copper-plated steel fibers in light aggregate concrete, with the increase of ceramic fiber mixing, the rate of mass loss showed a gradual decline in the trend of compressive strength and compressive strength of the residual rate of gradual increase.

(3) After 60min of fire, the mixing effect of ceramic fiber with the dosage of  $3.9\text{kg}/\text{m}^3$  is the best, the mass loss rate is only 10%, and the compressive strength residual rate increases by 3% compared with that of lightweight aggregate concrete with copper-plated steel fibers with the dosage of  $50\text{kg}/\text{m}^3$  alone.

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