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Study on the effect and mechanism of fiber on the anti-bursting property of fiber reinforced concrete after fire

Yuhao Wu, Yuhan Miao, Dong Lv, Mingzhe Guo, Xinming Wang

School of North China University of Science and Technology, College of Civil and Architectural Engineering, Hebei 063000, China;

2393461360@qq.com

Abstract

Fiber concrete is a new type of composite material that is widely used in the construction industry. However, due to the destructive effects of high-temperature environments on concrete structures, it is important to study the fire resistance of fiber concrete at high temperatures. In this paper, the internal and external temperature changes and bursting of fiber concrete with ceramic fibers, copper-plated steel fibers, ceramic-copper-plated steel fibers, and ceramic-polypropylene fibers were investigated at different admixtures after being subjected to high temperatures by open fire. The test results show that: copper-plated steel fibers have good thermal conductivity, and can be in the concrete specimen inside the better conductive temperature; ceramic fiber thermal conductivity is low, and the specific heat is small, ceramic fiber concrete specimen inside the temperature rises slowly; polypropylene fibers with a low melting point, thermal conductivity is weak, by the fire in the concrete inside the formation of holes, can not be conductive temperature. Single mixed with ceramic fiber and mixed with ceramic-polypropylene fiber concrete are a serious bursting phenomenon, copper-plated steel fiber in improving the lightweight aggregate concrete burst resistance is better than ceramic fiber.

Keywords

Fiber concrete, polypropylene fibers, ceramic fibers, copper-plated steel fibers, bursting.

1. Introduction

Fire has been the world's most frequent, causing the most serious loss of life and property disasters, of which building fires accounted for more than 80% of the total number of fires[1]. The frequency of fires in high-rise buildings is increasing day by day, and once these high-rise and ultra-high-rise buildings catch fire, it is very difficult to get effective control of the fire, which seriously jeopardizes the safety of people's lives and property. High-rise building fire frequency is a fact that can not be ignored, how to solve the problem of fire safety in China's buildings will be the future development of the direction of the building.

High-strength concrete as a kind of low permeability, low porosity, and small water content of brittle material, compared with traditional ordinary concrete, its characteristics in fire at high temperatures, but may form a negative effect, once the building fire, high-performance concrete inside the dense structure will lead to a large number of buildings can not be completely out of water vapor and heat, and ultimately will cause the component protective layer of bursting spalling[2]. The protective layer of the component will eventually cause cracking and spalling. This kind of cracking spalling is in the absence of any warning in the case of random occurrence[3]. This kind of bursting and spalling occurs randomly without any warning and can bring great damage to concrete members or structures. It usually occurs at 300 ℃ or more, and bursting will be accompanied by a violent sound[4] The specimen is broken into pieces of varying size in a very short time, and the concrete surface of the naked eye discernible obvious "crater", a serious burst depth of up to 75mm[5]. This weakness greatly limits the ability of high-strength concrete to be used in a variety of ways. This weakness greatly restricts the advantages of high-strength concrete to give full play to. Therefore, the development of concrete materials with excellent fire resistance is very important. Studies have shown that the fiber mixed in the concrete can be very good in improving the toughness of the concrete and better than ordinary concrete has a better resistance to high-temperature performance.

Harmathy[6] first discovered and reported the phenomenon of concrete cracking at high temperatures in 1965, so people began to conduct in-depth research on the high-temperature cracking of concrete

Li Qiang[7] found that the internal pores of the aggregate and the bonding surface of the contact surface of the concrete slurry began to appear brittle cracking rapidly, a large amount of calcium hydroxide would be rapidly corroded and decomposed, and the internal strength of the concrete specimen showed a sharp and linear decline in the compressive strength of the structural failure body.

To further enhance the high-temperature resistance and other properties of light aggregate concrete and improve its high-temperature burst resistance, Yining[8] has studied the improvement measures. At present, the modification methods mainly include adding polypropylene fiber, changing cementing materials, and using different aggregate types.

Li Mengnan [9] found out after the test that the appropriate addition of polypropylene fiber in concrete can greatly reduce the burst after local high-temperature deformation of reinforced concrete members with high-temperature self-compaction in a short period.

Wenzhong Zheng's research[10] showed that polypropylene fiber reinforcement exhibited better anti-explosive spalling properties than normal strength concrete. Explosive spalling of concrete could be prevented when polypropylene fibers were added at 2.73 kg/m3 due to the melting of PP fibers, which created supplementary holes and small channels in the RPC.

Wang Guan et al.[11] carried out a fire test study on fiber concrete columns. The results show that when the load ratio and axial constraint stiffness are large, the initial bursting of high-strength concrete specimens is more serious; and polypropylene fibers can limit the occurrence of early bursting, but also inhibit the late bursting, thus improving its fire resistance limit; in addition, the concrete column will produce axial force and thus affect the bursting time when the concrete column is subjected to thermal expansion. PP fibers melt before the existence of the role of the bridge link, which restricts the high-strength concrete's early bursting Before the PP fiber melting, due to the existence of bridging, limiting the occurrence of early bursting of high-strength concrete, the formation of pores after melting, the release of vapor pressure, inhibiting the occurrence of late bursting, so that the fire-resistant limit of high-strength fiber concrete has been greatly improved.

This thesis analyzes the effect of different fibers on concrete after fire by studying some changes in microstructure and apparent characteristics of concrete after adding different fibers, different dosages, and different fire time, including mass loss, degree of bursting, etc., and concludes the relationship between bursting of concrete after fire and fire time, different fibers, and fiber dosage. According to the results of different fiber mixing specimens after the fire data and the apparent characteristics, comparative analysis to select the optimal fiber and fiber mixing of the comprehensive fire resistance performance. Finally, combined with the characteristics of various fibers and the existing research results, analyze the role of fiber on the post-fire fiber lightweight aggregate concrete mechanism.

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2. Fire test preparation

(1) In order to study the effect of different fiber conditions on the internal temperature change of the specimen, the size of the concrete specimen of 100 × 100 × 400mm, to be punched to arrange the thermocouple. Measurement point arrangement as shown in Figure 1, the use of electric drills in the 100 × 100mm face is centered, drilling depth of 50mm, buried thermocouple wires and grout injected into the concrete pores and then sealed with high-temperature mastic on the drilled holes. The thermocouple wire was wrapped in rockwool and then secured with binding wire on the outside of the rockwool. A pyrometer was utilized to measure the temperature at the point of measurement during the warming and thermoregulation process.

(2) In the process of being subjected to fire, there are 10 fire-breathing ports in the furnace chamber. Ensure that each piece of test block is heated evenly, and as close as possible in the middle part of the hearth, in the test block under the pile of a certain number of refractory bricks, the test block in a certain order, the spacing of 350mm or so, uniformly arranged in the hearth of the flat furnace, as shown in Figure 2.

(3) Before the high-temperature test, each thermocouple is checked for availability. One end of the thermocouple wire is fixed in the concrete test block, and the other end is connected to a connecting wire that is transmitted to the temperature collector. By sensing the temperature of the thermocouple in the receiving fire, the temperature in the chamber and the temperature of the test block can be displayed on the monitor.

The data from the tests were recorded and the phenomena of the concrete specimens at different times of fire were observed.

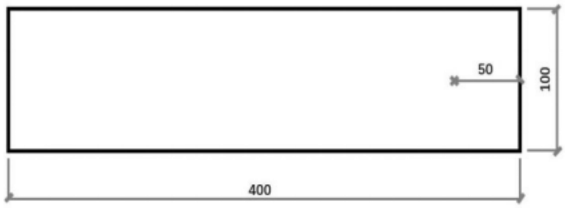

Fig. 1 Thermocouple arrangement position

Fig. 2 Specimen arrangement

3. Fire test methods and fire equipment

3.1. Warming system

Adopt the international standard ISO834 standard fire temperature-time curve. When the fire time reaches the target time, the heating is stopped.

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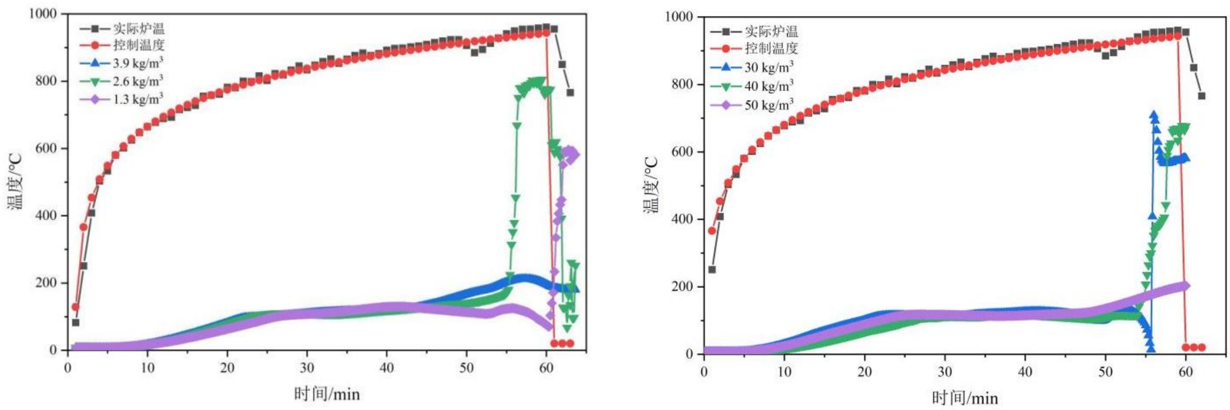
3.2. Cooling method

Cooling mode for the natural cooling of the furnace, to 200 ℃, open the furnace cover cooling to 100 ℃ and then take out the specimen placed in the room, and then indoor static 1 day after the mechanical properties of the test.

The test equipment was a fire flat furnace with a net width of 3.6 m, a net length of 6 m, a net height of 1.76 m, and 10 burners purchased by the North China University of Science and Technology (NCTU), as shown in Fig. 3.

Fig. 3 Fire leveling furnace

4. Internal temperature profile of specimen under fire

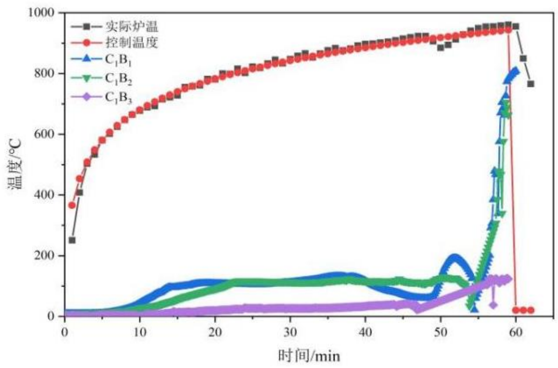


(a) Single-mixed ceramic fiber concrete

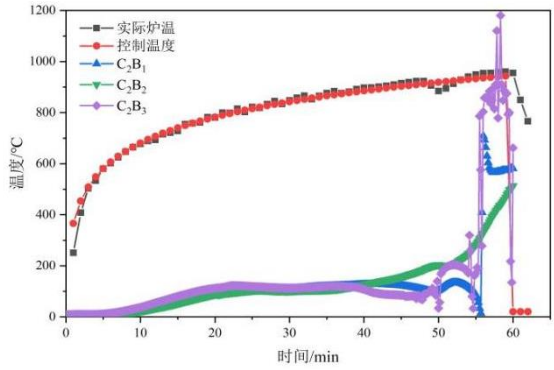
(b) Concrete with copper-plated steel fibers alone

Fig. 4 (a) (b) Temperature versus time for different admixtures of ceramic fiber concrete alone and copper-plated steel fiber concrete alone

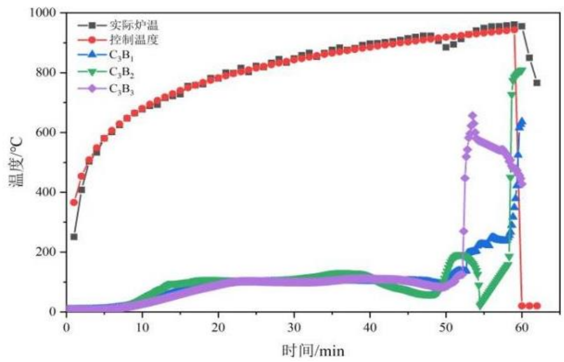
Although the ceramic fiber concrete burst seriously, but still collected ceramic fiber concrete specimen internal temperature data. In the fire 55min before, the ceramic fiber concrete and copper-plated steel fiber concrete internal temperature curve is approximately the same, in the fire specimen for about 20min, the specimen internal temperature curve inflection point, the copper-plated steel fiber concrete specimen internal temperature than the ceramic fiber concrete specimen internal temperature rise slightly larger, in 55min after the beginning of the phenomenon of sudden increase and decrease.



(a) Ceramic-copper-plated steel fiber concrete with different dosages, Group I.



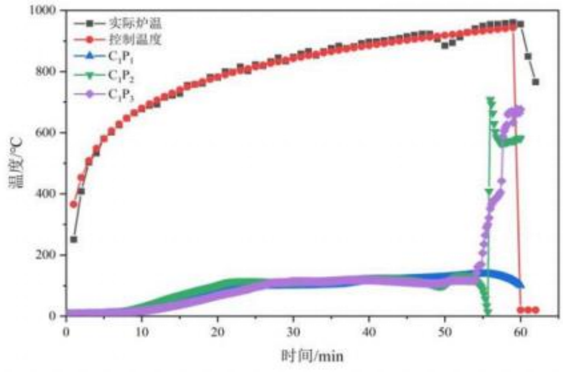
(b) Ceramic-copper-plated steel fiber concrete with different dosages, Group II



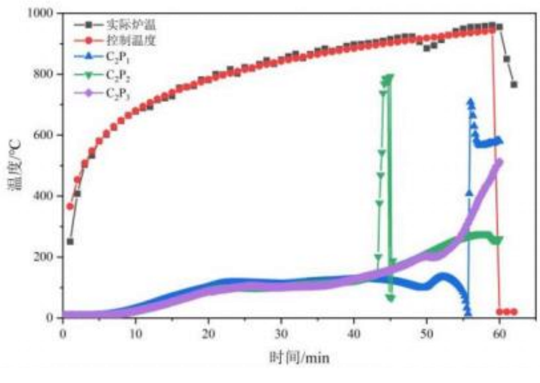
(c) Ceramic-copper-plated steel fiber concrete with different dosage, Group III

Fig. 5 (a) (b) (c) Temperature versus time for concrete with different admixtures of ceramic-copper-coated steel fibers

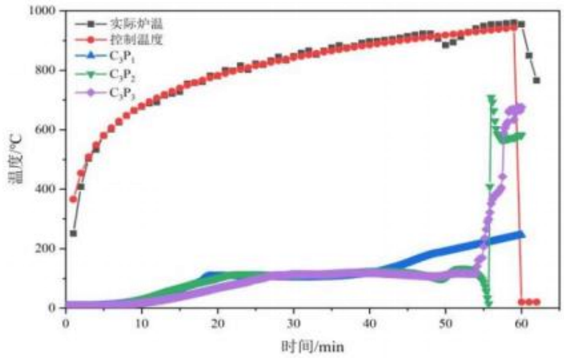
C1B3 (ceramic fiber dosage of 1.3kg/m^3 and copper-plated steel fiber dosage of 50kg/m^3 hybrid fiber) fiber concrete specimen temperature curve growth is small, did not appear normal upward trend, analysis of the reasons, maybe a few minutes of the specimen fire, the specimen appears to be damaged, resulting in thermocouple measurement of the temperature anomaly. For the rest of the different dosages of ceramic-copper-plated steel fiber hybrid fiber in the fire time of 50min, the temperature rise law is similar, in the fire time of 15min to 20min or so, the specimen internal temperature curve inflection point, in the fire time of 50min later, began to appear the phenomenon of sudden increase and decrease.



(a) Ceramic-Polypropylene Fiber Concrete, Group I



(b) Ceramic-polypropylene fiber concrete, group II



(c) Ceramic-Polypropylene Fiber Concrete, Group III

Fig. 6 (a) (b) (c) Temperature versus time for concrete with different admixtures of ceramic polypropylene fibers

Ceramic-polypropylene hybrid fiber concrete with different dosages of ceramic-polypropylene hybrid fiber concrete was subjected to fire specimen for about 20min, the specimen internal temperature curve appeared inflection point. After 40 minutes of fire time, a sudden increase and decrease phenomenon began to occur.

5. Bursting of fiber concrete specimens after fire

5.1. Indicators for evaluating concrete bursting under fire

Concrete burst is the temperature from low to high changes in the process, the cement stone contraction and deformation and thermal expansion of the aggregate, the two thermal mismatch caused by the matrix internal strain, resulting in the formation of interfacial transition zone cut surface, in the concrete internal vapor pressure, thermal stress and other factors under the joint influence of the concrete, the surface layer of the concrete without warning and the separation of the matrix, broken into small pieces of the rapid outward projection of the process. High-performance concrete is more likely to burst than ordinary concrete. Caused by bursting is divided into internal and external causes, internal causes include the size of the water-cement ratio, type of admixture, type of aggregate, moisture content, and other factors, external causes include the environmental warming rate of fast and slow, temperature-stress trends and load size and other factors. The possible spalling are edge bursting, edge spalling, split bursting, gradual spalling, and post-cooling spalling. The spalling involved in this test are edge corner spalling, edge corner bursting and split bursting as shown in Fig. 7.

(1) Edge bursting

Edge bursting is the separation of large or small pieces of concrete from the concrete edges where this type of spalling is caused by pore pressures and thermal gradients, and the degree of internal crack opening also affects this bursting process.

(2) Edge peeling

Corner spalling indicates a location where the concrete has fractured. This difference in deformation causes stresses in the concrete resulting in splitting cracks that lead to corner breaks in columns and slabs.

(3) Splitting and bursting

Explosive spalling is the result of a combination of a rise in pore pressure and a thermal gradient within the section. At the beginning of the temperature rise, a "water blockage" (region of high pore pressure) is created within the concrete. As a result of the pressure gradient created by the blockage, some of the water is pushed further into the lower-temperature region of the concrete. If the heated surface is compressed due to the thermal gradient, the entire

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heated surface may crack with a loud bang. The huge bursting impact causes the specimen to burst open from the inside and the concrete in the center of the specimen separates from the rest.

(4) Gradual flaking

Gradual spalling is spalling caused by loss of strength due to internal cracking and chemical deterioration of the cement paste. This spalling phenomenon is related to the temperature at which the concrete arrives, not the rate of heating. If the concrete is heated to a very high temperature, the strength will be reduced, due to its weight, causing small pieces of concrete to fall without much sound.

(5) Post-cooling flaking

Post-cooling spalling occurs after the fire has cooled down at the end of the fire, or even during fire suppression. After cooling moisture reappears on the surface of the concrete and CaO becomes $Ca(OH)_2$ in contact with water. The expansion due to rehydration leads to severe internal cracking and thus loss of concrete strength. As long as there is water to rehydrate the calcium oxide in the dewatering zone, a piece of concrete will continue to fall off.

Fig. 7 Bursting after fire

5.2. Fiber reinforced concrete bursting phenomena and analysis under fire

Admixture of ceramic fiber concrete, after 20 minutes of fire, the edges and corners of the concrete are spalling, aggregate exposure; after 30 minutes of fire, the fiber concrete edges and corners of the bursting are more obvious. The corners of the concrete specimens are spalling, aggregate exposure, and ceramic fiber concrete specimens from the middle part of the disconnection; after 60 minutes of fire, the concrete splitting burst, no complete specimens.

Adding copper-plated steel fiber concrete, after 20min of fire, the surface is smooth and flat without cracks, the integrity is intact, with no fine spalling, or peeling phenomenon; after 30min of fire, the surface of the concrete has fine lines visible to the naked eye, and slight powder particles; after 60min of fire, the color of the specimen becomes grayish-white, the width of the cracks increases, the length of the cracks increase, and there are powder particles on the surface.

After being subjected to fire for 60 min, the ceramic-copper-plated fiber-steel concrete partially burst and disconnected from the middle part of the specimen. The unbroken specimen was loose and powdery particles appeared on the surface.

After 60min of fire, most of the ceramic - polypropylene VSG concrete burst, did not burst ceramic - polypropylene fiber concrete specimen admixture combination is only one, namely: 3.9kg/m^3 dosage of ceramic fibers and 1.4kg/m^3 dosage of polypropylene fibers, knocking the specimen, the sound of the cavity is more pronounced and the specimen is significantly lighter.

Table 1 Statistics on the number of bursts and bursts of fiber concrete after fire

fire duration	fibroid	Number of test blocks	Number of complete units remaining	Number of bursts and bursts
20min	ceramics	18	0	13 Edge peeling 5 Split Burst
	copper-plated steel	18	18	not have
30min	ceramics	18	0	6 Edge bursting 13 Edge peeling 7 Split Burst
	copper-plated steel	18	18	not have
60min	ceramics	18	0	9 Edge bursting 9 Split Burst
	copper-plated steel	18	18	not have
	Ceramic-copper plated steel	54	36	9 Edge bursting 9 Split Burst
	Ceramic-Polypropylene	54	6	27 Edge bursting 21 Split Burst

According to Table 1, concrete specimens doped with ceramic fiber are bursting seriously. As the fast rate of warming will affect the concrete bursting, this test uses the ISO834 standard fire temperature-time curve, the rate of warming is faster, while the concrete is a thermally inert material, with low thermal conductivity, the specimen externally close to the source of high temperature, the temperature rises quickly. The inside of the specimen due to the low thermal conductivity of ceramic fiber, small specific heat, and low tensile capacity, can not transfer heat to the inside of the specimen promptly, resulting in a lower temperature in the core area, resulting in a temperature gradient, resulting in a gradual decrease in temperature stress from the outside to the inside, resulting in stress between the inside and outside. So the concrete mixed with ceramic fiber is more likely to burst.

Lightweight aggregate concrete with copper-plated steel fibers had the highest number of remaining specimens intact after the fire because the incorporation of copper-plated steel fibers increased its own tensile and thermal conductivity, which had a significant inhibiting effect on bursting.

Concrete with copper-plated steel and ceramic fibers had bursting in some specimens, due to the low thermal conductivity and small specific heat of ceramic fibers, which generate stress and are prone to bursting, but the copper-plated steel fibers inhibited bursting in some of the specimens due to good thermal conductivity and reduction of bursting phenomenon.

Concrete with polypropylene and ceramic fibers, only 3.9kg/m^3 dosage of ceramic fibers and 1.4kg/m^3 dosage of polypropylene fibers mixed fiber concrete without bursting, and the rest of them have bursting. Adding polypropylene fibers can alleviate the steam pressure on concrete at high temperatures, polypropylene fibers melt and form continuous channels inside the concrete, the steam diffuses through these pores, and the internal pressure becomes smaller, which greatly reduces the bursting of concrete, but the high-temperature bursting prevention of polypropylene was not reflected in this test. The reason may be, polypropylene fiber thermal conductivity is weak, in the rapid rise in temperature outside the specimen, the concrete specimen inside the polypropylene fiber did not have time to melt, and can not be timely to the specimen's internal temperature transfer, resulting in thermal stress. Or less polypropylene doping, resulting in holes failing to evacuate more vapor pressure, resulting in bursting. Ceramic fiber with low thermal conductivity, small specific heat, and low tensile capacity, resulting in stress, but also prone to bursting, the two fibers together, so that the concrete specimen failed to resist bursting, resulting in concrete specimen bursting.

6. Summary and outlook

This paper focuses on some changes in the apparent characteristics of fiber concrete after fire, including mass loss, degree of bursting, etc., and analyzes the effects of different fibers on concrete after fire, as well as the effects of different fiber admixtures on concrete with the same fire time.

(1) Copper-plated steel fibers can conduct the temperature better inside the concrete specimen due to their good thermal conductivity. The temperature rise inside the ceramic-copper-plated steel hybrid fiber concrete specimen is slightly smaller, and the copper-plated steel fibers play a major role in raising the temperature. Due to the low thermal conductivity and small specific heat of ceramic fibers, the internal temperature of ceramic fiber concrete specimens rises more slowly. Polypropylene fiber melting point is low, thermal conductivity is weak, by fire in the concrete internal formation of holes, can not conduct temperature. So ceramic-polypropylene hybrid fiber concrete specimen internal temperature rises more slowly.

(2) The placement of the specimen affects the proximity of the high-temperature source to the specimen, resulting in stress between the inside and outside, causing damage to the fiber concrete specimen. The rock wool wrapped around the thermocouple will provide some protection to the fiber concrete specimen.

(3) For single-mixed copper-plated steel fiber concrete, different copper-plated steel fiber mixes do not make a significant difference in the mass loss rate when the fire time is short. When the fire time is longer, the larger the amount of copper-plated steel fiber, the smaller the quality loss rate. For ceramic-copper-plated steel hybrid fiber concrete, both copper-plated steel fibers and ceramic fibers have a positive effect on the mass loss rate under the same fire time of 60 min.

(4) single-mixed ceramic fiber concrete, first, due to the rapid rate of temperature rise resulting in concrete burst; second, the poor tensile properties of the concrete, more prone to bursting; third, the low thermal conductivity of ceramic fibers, small specific heat, and low tensile capacity, the internal thermal stresses, resulting in a single-mixed ceramic fiber concrete is more prone to bursting after the fire.

(5) Mixed concrete with copper-plated steel and ceramic fibers is prone to bursting due to the low thermal conductivity and small specific heat of ceramic fibers, which generates stress, but the copper-plated steel fibers inhibit the bursting of a part of specimens due to good thermal conductivity and reduction of the bursting phenomenon.

(6) mixed concrete with polypropylene and ceramic fiber, only 3.9kg/m3 dosage of ceramic fiber and 1.4kg/m3 dosage of polypropylene fiber mixed fiber concrete without bursting, the rest of the specimens are bursting seriously, one is due to the weak thermal conductivity of polypropylene fiber, in the specimen outside the rapid temperature rise, can not be timely to the specimen temperature transfer to the interior, resulting in thermal stress. Secondly, less polypropylene doping, resulting in holes not forming a continuous channel, failing to evacuate more steam pressure, resulting in bursting. At the same time ceramic fiber thermal conductivity is caused by weak higher thermal stress, so the concrete specimen failed to resist bursting. So leads to ceramic-polypropylene fiber concrete specimens bursting seriously.

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