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# Research Status and Outlook on High Temperature Performance of Fiber Concrete

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## Abstract

**Fiber concrete is a novel composite material that has widespread use in the construction industry. However, high-temperature environments can cause severe damage to concrete structures. Therefore, it is essential to study the refractory properties and microscopic changes of fiber concrete under such conditions. This paper reviews the current research status of steel fiber concrete, polypropylene fiber concrete, and hybrid fiber concrete, which are commonly used in practical engineering, and summarizes their respective roles in concrete by combining theory and practice. The review also looks forward to future research directions and development trends to provide a reference for related research. Studies have demonstrated that adding a suitable amount of fibers can significantly enhance the high-temperature performance of concrete. However, different fiber types have varying effects on concrete. The high-temperature performance of fiber concrete is also influenced by various factors, including concrete mix ratio, fiber type, and admixture. Future research should focus on investigating the mechanism and microscopic changes in the high-temperature performance of fiber concrete, developing new fiber materials, optimizing concrete mixing ratios, and exploring the application of fiber concrete in practical engineering.**

## Keywords

**Reinforced Concrete; Steel Fibers; Polypropylene Fibers; Hybrid Fibers; High Temperature Performance; Bursting.**

## 1. Introduction

Fire has been the world's most frequent, causing the most severe loss of people's lives and property disasters, of which building fires accounted for more than 80 percent of the total number of fires [1], especially high-rise building fires are occurring more and more often every day, these high-rise and ultra-high-rise buildings once a fire, the fire is tough to get effective control, a danger to the people's lives and property safety.

These high-rise buildings often use high-performance concrete, due to its good fluidity will leads to it generally having a high degree of compactness; this characteristic is conducive to improving the durability of the building but inhibits the fire performance of the building, once the building fire, the high-performance concrete internal dense structure will lead to a large number of water vapor and heat inside the building can not be completely discharged, and ultimately will cause the components of the protective layer of the cracks Spalling. This kind of bursting and spalling occurs randomly without warning and will damage the concrete component or structure [2]. The three main aspects are as follows [3]: reduction of the cross-sectional area and reduction of the load-bearing capacity of the member, and the high temperature in the concrete destroys the hydrates of the cement paste. This damage implies a weakness in the material due to deterioration of its mechanical properties [4]; some of the reinforcement will be exposed to the high temperatures of the fire due to the loss of the protection of the concrete and will soften rapidly due to the heat, resulting in a drastic reduction in the load-bearing capacity of the members and thus affecting the safety of the structure.

Generally speaking, ordinary concrete materials have weak tensile strength and strain capacity, poor high-temperature resistance, and are typical brittle materials. At the same time, under high fire temperatures, a series of complex physicochemical reactions, such as hydration and decomposition, occur continuously within the concrete, and its microstructure and mechanical properties are changed accordingly. Therefore, it has been a significant concern in the research field to investigate the causes of high-temperature damage and prevent it from occurring. Domestic and foreign researchers also hope to clarify the mechanism of high-temperature burst damage based on a large number of attempts to enhance the method, in which the randomly distributed discontinuous fibers into the concrete to make fiber concrete, is an effective method[5,6], to further promote high-performance concrete in the actual engineering of large-scale promotion and application.

The high-temperature performance of materials is the basis for the study of structural fire resistance, but the high-temperature resistance of fiber concrete is a very complex problem because of the different thermal properties of the components of fiber concrete, and the performance of each component has a great relationship with moisture and pore structure[7,8]. Many researchers have expressed their opinions and conclusions on the microstructural changes, damage mechanisms, mechanical properties, and strain laws of fiber concrete after subjecting it to high temperatures in fires. Jin-Cheng Liu [9] believes that even if fibers are added to the concrete, high temperatures will still lead to a decrease in the strength of the concrete and the creation of cracks, which will lead to the collapse of the structure. Heyang Wu [10] has considered the influence of various factors, including fiber type, fiber shape, fiber dosage, water binder ratio, moisture content, and chemical composition, etc., to establish a thermal damage constitutive model to simulate the behavior of high-performance concrete under fire conditions, and finally verified the validity and accuracy of the proposed model by comparing the simulation results with the test data in the literature. He also proposed empirical equations to predict the compressive strength, tensile strength, and Poisson's ratio of SFRC under high temperatures to predict the temperature-dependent compressive strength, tensile strength, and Poisson's ratio of SFRC with the correctly selected empirical equations for modulus of elasticity, and peak stress-strain. By introducing the temperature-dependent coefficient for the fracture strain, the model can ensure the accuracy of SFRC prediction at high temperatures [11].

## 2. Current Status of Research on the High Temperature Properties of Fiber Concretes

### 2.1. Steel fiber Concrete

Ordinary high-performance concrete exhibits significant brittleness in flexural damage, whereas high-performance concrete with steel fibers not only exhibits significant ductility [12] but also increases its shear strength [13] in case of damage, even after exposure to specific high temperatures. Therefore, researchers usually add steel fibers to concrete to improve its high-temperature resistance.

Shanshan Chang [14] believes that for single-mixed copper-plated steel fiber concrete, different copper-plated steel fiber dosages do not significantly affect the rate of mass loss when the fire time is short. When the fire time is longer, the more significant the amount of copper-plated steel fiber, the smaller the quality loss rate. Zhou Yunlong analyzed the effects of different fiber types and dosages on the bursting, mass loss rate, compressive strength, and compressive strength residual rate of lightweight aggregate concrete after 20, 30, and 60 min of an open fire. The test results show that the lightweight aggregate concrete with different copper-plated steel fiber dosages has only slight bursting, indicating that copper-plated steel fiber is better than ceramic fiber in improving the bursting resistance of lightweight aggregate concrete.

Zhu Ming [15] found that the mass loss rate of SFRSCC specimens increased gradually with the increase of temperature, with the fastest weight loss of 5.72% from 25 to 200 ℃, and the slowest weight loss from 600 to 800 ℃, with the mass loss rate only increasing from 10.65% at 600 ℃ to 11.69% at 800 ℃. In addition, with the increase in temperature, the static compressive strength showed a tendency to increase and then decrease. It reached a maximum value of 66.9 MPa at 200 ℃, which was enhanced by 11.3% compared with that at ambient temperature (25 ℃). The static compressive strengths of SFRSCC at 400, 600, and 800 ℃ were decreased by 25.5%, 49.4%, and 84.7% compared with that at ambient temperature (25 ℃), which illustrated that high temperature had not only a weak effect on the static compressive strength of SFRSCC but also an essential role in the development of SFRSCC. The static compressive strength of SFRSCC is not only weakened but also strengthened. Under the same impact velocity, the dynamic compressive strength of the specimens showed a tendency to increase and then decrease with the increase in temperature. The dynamic compressive strength reached maximum when the temperature level was 200℃.

Lau A [16] found that the strength of concrete decreases as the maximum heating temperature increases and the initial percentage of saturation before firing increases, but refractoriness and cracking improved when 1% steel fibers were incorporated.

Olivito [17] found that the ductility and toughness of steel fiber concrete increased when the fiber content increased, and the ductility and toughness of SFRC increased when the fiber length was increased for the same fiber content. This phenomenon is due to the higher deformability and energy absorption of SFRC during the cracking stage, as well as higher flexural stiffness and unused cracking pattern compared to normal concrete. This study also showed that plasticity, initial cracking strength, and flexural strength increased with the increase in the volume content of steel fibers. However, there was no significant change in compressive strength.

Zhou Heng's research [18] shows that the admixture of steel fibers can substantially improve the high-temperature impermeability of concrete, and when the fiber admixture is the same, the higher the temperature, the stronger the high-temperature impermeability of fiber concrete. The reason is that the steel fiber has good thermal conductivity, in the warming and cooling process reduces the temperature gradient inside the concrete due to the temperature stress, inhibiting the internal cracking of the concrete, at the same time, due to the reinforcing effect of steel fiber on the concrete also makes the expansion of the cracks is restrained, thus increasing the amount of steel fiber can improve the high-temperature impermeability of concrete.

Soner [19] investigated the variation of mass loss, residual strength, and toughness properties of 3D, 4D, and 5D steel fiber reinforced concrete with temperature values and found that the mass loss, residual strength, and toughness of the specimens do not change significantly after 300℃, but decrease significantly after 500℃ and 800℃. In addition, 5D fibers had higher residual strength and toughness. In contrast, 5D fibers contributed more effectively than 3D and 4D steel fibers in reducing mass loss in plain concrete, which was attributed to the superior end geometry and higher tensile strength of 5D steel fibers, resulting in better adhesion to the concrete matrix.

Jihwan Kim [20] investigated the mechanical tensile properties of concrete with twisted or hooked steel fibers at different temperatures, aspect ratios, and fiber contents and found that the specimens' residual compressive strength, DPT tensile strength, and rupture energy decreased with increasing temperature. The relative loss of tensile strength was higher than that of compressive strength when SFRC was exposed to elevated temperatures, but the relative loss of rupture energy was relatively low. The fibers' volume fraction and length-to-diameter ratio affected the properties more than their shape.

Through his research, Fike [21] found that the use of steel fiber concrete (SFRC) instead of plain concrete in floor slabs significantly improved the fire resistance of beam-slab assemblies and enabled them to withstand spaced fires in most fire conditions, due to the improved tensile strength and ductility of SFRC compared to plain concrete. Also, a completely unprotected secondary steel beam can be realized by using SFRC instead of plain concrete in the combined beam-slab assembly.

Danying Gao [22] investigated the splitting properties of reinforced ground granulated blast furnace slag concrete incorporated with steel fibers at elevated temperatures. With the increase of steel fibers, the residual splitting strength increases accordingly. When subjected to fire, the presence of steel fibers will allow more heat to flow into the interior of the concrete, lowering the temperature gradient and thus reducing cracking. This favors the fire resistance of concrete to some extent. However, when excessive amounts of steel fibers are added to the concrete mix, the splitting tensile strength will strongly depend on the reinforcing effect of the steel fibers. When subjected to high temperatures, the bond between the steel fibers and the calcium silicate hydrate (CSH) breaks down more severely than the bond between the coarse aggregate and the CSH due to the significant difference in thermal properties, resulting in more strength loss. In order to take full advantage of the reinforcing effect of steel fibers, a balance should be maintained to achieve the optimum dosage. Danying Gao found that 1.0% steel fiber admixture had the highest relative residual splitting strength and, therefore, proposed that in terms of relative splitting strength, 1.0% steel fiber appeared to be the optimum concrete dosage for the concrete used in this study.

Jinping Zhuang [23] found that the toughness index of SFRSCC increased after high temperature compared to room temperature. When the volume fraction of steel fibers was 1.5%, the strain rate was about 55s-1, and the toughness indices of SFRSCC increased by 24.07% (300℃), 24.64% (600℃), and 22.35% (900℃), respectively, compared with room temperature.

Oğuz Düğenci [24] found that the incorporation of steel fibers can be beneficial to the residual compressive strength of concrete after high temperatures when the temperature does not exceed 1000℃. C.S. Poon [25] found that the incorporation of 1% steel fibers in concrete with a cubic standard compressive strength of 79~105 MPa prevents bursting at high temperatures. However, it has also been shown that [17] steel fibers have a high melting point and melt only at relatively high temperatures and, therefore, cannot significantly improve the spalling resistance of HFRC.

Sideris K [26] showed that 380 ~ 580 ℃ is a high-performance concrete prone to bursting temperature range; steel fibers can't prevent the occurrence of bursting but can increase the initial bursting temperature.

Dong Xiangjun [12] found that the intensification of the thermal movement of atoms in the steel fibers and the reduction of the binding force between each other is the root cause of the reduction in the strength of steel fibers after high temperatures when the concrete is subjected to temperatures of less than 600 ℃, almost all the steel fibers on the damaged cross-section of the beams are pulled out, and the damage is ductile, as the temperature rises further, it begins to appear that the steel fibers are being pulled out and after a high temperature of 900 ℃, the steel fibers on the damaged cross-section Almost all of them were pulled out, and the destruction of both beams and fibers showed obvious brittleness.

The above studies have shown that the addition of steel fibers enables the concrete to undergo predetermined ductile damage when subjected to specific high temperatures and improves the concrete's bursting resistance, residual strength, and toughness. The admixture of steel fibers significantly impacts the high-temperature resistance of concrete, and the optimum admixture is about 1%. The admixture of steel fibers can transfer the heat inside the concrete well, reduce the temperature stress due to the temperature gradient, and inhibit the internal cracking of the concrete.

## 2.2. Polypropylene Fiber Concrete

Concrete cracking is the cause of high-performance concrete internal overpressure. Vapor pressure far exceeds the expansion strength of concrete, resulting in concrete being unable to withstand this excessive internal pressure and easy explosive damage. Mixed fibers in high-performance concrete, due to the low melting point of polypropylene fibers, when the temperature is 180 ℃, the fibers have melted, the concrete is still in the stage of self-steaming internal pressure is not large, the fibers volatilized after the formation of a multitude of tiny pores for the evaporation of internal water in the concrete to provide a conducive channel, but also alleviate the pressure due to the formation of water expansion, so that the internal pressure is significantly reduced, thereby preventing the bursting of concrete. Prevent the generation of cracking[5,27-33]. In addition, the addition of polypropylene fibers in concrete is an effective way to improve the shrinkage and cracking characteristics, toughness, and impact resistance of concrete materials. The use of polypropylene fibers has been recommended by many researchers at home and abroad to reduce and eliminate the risk of explosive spalling of high-strength concrete at high temperatures [34].

Pierre Kalifa [35] has concluded that adding polypropylene fibers is an effective solution to the problem of high-temperature bursting of high-strength, high-performance concrete. Adding polypropylene fibers to concrete can reduce the vapor pressure by melting the polypropylene fibers at high temperatures to form more open pores inside the concrete. Xiaoda He [36] found that the melting point of polypropylene fibers is about 170 ℃. High-temperature polypropylene fibers in concrete polypropylene fibers have all melted; the melting of the formation of holes for the discharge of high-pressure vapors inside the concrete to build several channels can effectively prevent the generation of cracking. Xiong [37] found that the cubic standard compressive strength of 76 MPa of concrete, mixed with 0.6% of PP fibers, can be used to prevent high-temperature cracking. Prevent high-temperature bursting.

Muyu Liu [38] investigated the changes in the surface physical characteristics of high-performance concrete with polypropylene fibers after exposure to high temperatures and showed that the color of the concrete specimens would gradually change from greenish grey at the beginning at room temperature to slightly brownish, then to greyish brown and finally to brownish red. As the temperature rises, the phenomena of peeling, loosening, and missing corners become more and more serious, and one can roughly estimate the fire temperature based on these physical characteristics. Unadulterated polypropylene fiber high-performance concrete specimens exploded at 400 ℃, while the polypropylene fiber-adulterated high-performance concrete did not explode; the anti-explosion effect is noticeable, indicating that the polypropylene fiber admixture is conducive to high-performance concrete anti-explosion cracking performance improvement. Polypropylene fiber admixture on the compressive strength and splitting tensile strength has a specific effect; the loss of 1.5 kg/m3 polypropylene admixture strength is minimal.

Yuan Chengfang [39] found that polypropylene fiber concrete subjected to high temperatures after the loss of concrete quality rate increases with the increase in temperature, which can be divided into three stages. 20 ℃ ~ 200 ℃ when the loss of faster because of this stage of the concrete inside the loss of capillary water and cementitious water faster; 200 ℃ ~ 600 ℃ when the loss of the rate of reduction; 600 ℃ ~ 800 ℃ when the loss of the rate of increase again, due to the 600 ℃ above the high temperature will make the calcium aggregate and polypropylene fiber inside the concrete begin to decompose, causing the quality of concrete to decrease again. In addition, the quality loss of concrete is also different when the fiber dosage is different. The quality loss rate under the same temperature will be reduced with the increase of fiber dosage, i.e., when the fiber dosage is larger, the damage caused by the high temperature to the concrete interior is relatively small. The quality loss rate caused by this is also relatively low.

Wenzhong Zheng [40] conducted compressive and tensile strength tests at 20 to 800℃. The experimental results showed that polypropylene fiber-reinforced concrete's compressive and tensile strengths decreased with increasing temperature. Reinforced polypropylene fiber showed better mechanical properties than normal-strength concrete. When polypropylene fibers were added at 2.73 kg/m3, it prevented explosive spalling of the concrete and significantly increased its compressive and tensile strengths at elevated temperatures. Chen Mingyang [41] also found that as the compressive strength of concrete increases, the amount of anti-explosive PP fibers required increases accordingly, and there is a linear relationship between the two.

Youkun's study [42] found that when the polypropylene fiber admixture of more than 1.18% suffered a 600 ℃ high-temperature effect of 1h, high-strength concrete bursting chances will be reduced from 83% of the unadulterated fiber to 17%, bursting degree from the unadulterated fiber of 3.65% reduced to 0.07%. It is well proven that polypropylene fiber admixture is beneficial in improving the high-temperature resistance of concrete. At the same time, Youkun also pointed out that the amount of polypropylene fiber only after the dosage reaches a specific value, the connecting melting aperture of the effective concrete at high temperature will be formed, and the high-strength concrete specimens can be protected from the hazards of bursting and coarsening of the capillary aperture.

Behnood [43] found that different dosages of PP fibers could not significantly affect the relative residual compressive strength at 100℃, whereas they significantly increased the residual compressive strength of concrete at 200℃, 300℃, and 600℃. The addition of PP fibers at 2 kg/m3 significantly promotes the residual mechanical properties of HSC during heating, which is the optimum amount of PP fibers for concrete, and lower and higher dosages of fibers usually show poorer performance due to more deterioration and more voids. Sideris investigated self-compacting concretes spiked with 6 mm and 12 mm long polypropylene fibers and found that after high temperatures, Both residual compressive strength and residual tensile strength decreased significantly after 300℃.

Feijian Wang [44] conducted an experimental study on the variation rules of apparent density, thermal conductivity, and thermal conductivity coefficient of ordinary high-strength concrete and high-strength concrete doped with polypropylene fiber after high temperatures, respectively. The results show that the apparent density, thermal conductivity, and thermal conductivity of ordinary high-strength concrete and high-strength concrete doped with polypropylene fibers after high-temperature decrease with the temperature increase. After mixing polypropylene fiber high-strength concrete than ordinary concrete, the apparent density is small, thermal conductivity and thermal conductivity coefficient are large, the difference between the two thermal conductivity coefficients is about 4% ~ 34%, the difference between the coefficient of thermal conductivity of about 6% ~ 34%, and its coefficient of thermal conductivity and coefficient of thermal conductivity with the temperature of the law of change is more significant.

Pierre Kalifa [30] found that the microstructural changes of polypropylene fiber concrete materials after 400℃ were due to the decomposition reaction of the solid phase hydration products and the continuous expansion of microscopic cracks inside the material. At the same time, the increase of microscopic cracks inside the concrete is affected by the pore pressure inside the concrete, and the channels after the melting of the fibers make the initially closed pores inside the material form a connection, which is conducive to the emission of water vapor from the inside of the material. Therefore, the internal pore pressure of concrete with polypropylene fibers is smaller than that of concrete without fibers, and the damage to the concrete material itself is reduced accordingly.

Bilodeau [45] investigated the effect of different polypropylene crude fibers in different dosages on the performance of lightweight concrete subjected to hydrocarbon fires and derived the optimum dosage. Nearly 3.5 kg of 20 mm polypropylene fibers per cubic meter of concrete were required to prevent the spalling of lightweight concrete with a low water-cement ratio exposed to hydrocarbon fires. For the finer 12.5 mm fibers, which are more effective than the 20 mm fibers in preventing spalling of fire-exposed concrete, a dosage of 1.5 kg of polypropylene fibers per cubic meter of concrete is sufficient.

Niu Xujing [46] found that polypropylene coarse fibers adversely affected the flexural strength of HSC after high temperatures, with the mixing of coarse and fine fibers having the least adverse effect. There is a synergistic effect of the two, polypropylene crude fiber melting channel as a trunk road and fine fibers as a branch, through each other to form a connecting vein system, which is more effective in mitigating high-temperature damage, thereby reducing the loss of strength.

Liu Xian [47] explored the mechanism of polypropylene fiber action at high temperatures and concluded that the melting of fibers did not increase the porosity of concrete but improved the pore connectivity and, therefore, the fire resistance of concrete. The melting point of polypropylene fibers is about 171 ℃. The effect of fiber content on the material's microstructure is not apparent at this temperature. However, at this time, the fiber content of the material plays a significant role in the air permeability properties. With the continuous increase of fiber content, this role is increasingly apparent.

Ping Wang [48] found that within 300 ℃, polypropylene fiber participation is conducive to the improvement of compressive strength of concrete after high temperature, but will reduce the flexural strength and flexural modulus of elasticity, and the degree of reduction of flexural modulus of elasticity is more influential. Above 300 ℃, polypropylene fibers will gradually melt due to high temperature, which is conducive to the bursting performance of high-strength concrete compressive strength and flexural strength enhancement. In contrast, for medium-strength concrete, the participation of polypropylene fibers has little effect on the performance of concrete after high temperatures.

Hao Xiaoyu [49] found that at room temperature, the interfacial bond between aggregate and cement paste is better after 300℃ due to the intensification of hydration, resulting in a closer bond between aggregate and paste after 500℃, the cement paste will gradually shrink, but the aggregate will gradually expand, which will lead to cracks between aggregate and cement paste.

Aslani [50] established the ontological relationships of normal and high-strength polypropylene fiber reinforced concrete at elevated temperatures, which were used to accurately model and specify the fire performance criteria of the concrete structures, including compressive and tensile strengths, modulus of elasticity, modulus of rupture, peak stress-strain, and compressive stress-strain relationships at elevated temperatures. Li Bing [51] found that after high temperatures, the mass loss rate of polypropylene fiber concrete is related to the length and admixture of polypropylene fibers. The longer the fiber length and the higher the admixture, the lower the mass loss rate; the reason is that the increase of fiber length and admixture will make the dispersion of polypropylene fiber concrete worse, which is not conducive to the spillage of water, resulting in the reduction of mass loss. The peak stress of polypropylene concrete decreases continuously with the increase in the length of polypropylene fibers due to the poor dispersion, and the enhancement of polypropylene fibers does not play a significant role. The maximum peak stress was observed at a PPF length of 3 mm and dosage of 1.0 kg/m3. After the high temperature, the best performance was achieved when the PPF length was 9 mm, and the dosage was 0.5 kg/m3.

Based on the experimental data, Ríos [52] determined the relationship between the macroscopic behavior (mechanical and fracture behavior) and the microstructure (pore size, number, and distribution). The results showed that incorporating PP fibers significantly increased the maximum pore size and the total porosity slightly. In addition, the partial melting of polypropylene fibers at 300℃ resulted in an increase in porosity and a reduction in thermal damage.

Resende [53] found that adding polypropylene fibers to the cement matrix at 100-200℃ (polypropylene fiber dosing of 2 kg/m3 ) increases the tensile strength of HSC, and the increase in tensile strength is more significant at the latter (at 200 ℃ ), above 400 ℃ , doping polypropylene fibers in HSC decreases its tensile strength; below 400℃, doping polypropylene fibers is beneficial to increase the compressive strength of HSC, and above 400℃, the doping of polypropylene fibers decreases the compressive strength of HSC.

The above studies show that polypropylene fibers can connect the pores within the concrete and release the vapor pressure by melting at high temperatures, thus reducing the damage caused by high temperatures to the interior of the concrete, inhibiting the bursting of the concrete, reducing the loss of quality and increasing the compressive strength.

## 2.3. Mixed Fiber Concrete

Mixed fiber concrete is a new composite building material formed by mixing several fibers of different sizes and properties in a particular proportion in the concrete [54]. This way of producing the fiber concrete can not only promote complementary synergies between different fibers, showing superior performance than their respective single-mixed fiber concrete [55] at different levels and stages to play a "positive mixing effect"[56,57] to improve the overall performance of the concrete at the same time can also be used at the same time to replace some of the costly synthetic fibers expensive metal fibers, saving material costs. At the same time, it can also use economical synthetic fibers to replace some of the expensive metal fibers, saving material costs. With the increasing frequency of building fires in China, the use of hybrid fiber concrete can effectively solve the problem of poor fire resistance of concrete components.

You Zhiguo [58] found that blended fibers effectively improved the self-compacting concrete matrix's flexural strength and toughness. The beams mixed with steel and synthetic fibers showed better flexural strength and flexural toughness than those mixed with steel fibers alone, and the two blends showed an excellent positive blending effect. In addition, the hybrid fibers also significantly improved the shear strength, shear toughness, split tensile strength, and split tensile toughness of self-compacting concrete. Dong Xiangjun [12] also found that the hybrid fibers showed better post-temperature reinforcement and toughening effects than the corresponding steel fibers.

Yan Wang [59] found that the concrete components will be subjected to high temperatures due to uneven heating, resulting in the formation of an uneven temperature field within the concrete components, resulting in deterioration of the concrete components, and severe cases, even bursting and, ultimately the loss of structural load bearing capacity, but in the concrete mixed with an appropriate amount of fiber can effectively solve the problem of high temperature-induced deterioration of the concrete components.

Li Han [60] found that adding polypropylene fibers with a fiber volume rate of 0.1% and steel fibers with a fiber volume rate of 0.1% to concrete improved the compressive strength of mixed-fiber concrete after high temperatures. Its compressive strength showed a decreasing

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trend below 200℃, an increasing trend from 200℃ to 400℃, and a more significant decrease after 400℃.

Gao Danying [61] found that at 600 ℃, unadulterated fiber high-strength concrete occurred bursting, and mixed-fiber concrete until 800 ℃ did not occur, indicating that the mixing of mixed fibers can effectively solve the problem of high-temperature bursting of high-strength concrete. The quality loss of hybrid fibers will increase with the increase in temperature. At the same time, their compressive strength and flexural strength will decrease with the increase in temperature, and the decrease is more evident after 400 ℃.

Yanlan [62] found that the splitting tensile strength of hybrid fiber concrete was significantly higher than that of ordinary concrete. When the temperature was 400℃, the maximum splitting tensile strength of hybrid fiber concrete was 4.57 MPa, which was 1.67 times higher than that of ordinary concrete at the same temperature. Although the splitting tensile strength of hybrid fiber concrete decreases gradually with the increase in temperature, it always maintains high splitting resistance. At 800℃, the splitting tensile strength of hybrid fiber concrete is 4.5 times higher than that of ordinary concrete at the same temperature, although it is only 30.71% of that at room temperature.

Du Yong [63] found that for the standard compressive strength of 116-143 MPa of ultra-high-strength concrete when only 1% of the volume fraction of ultra-fine steel fibers in which the mix, high temperature is easy to burst. In contrast, the mixing of volume fraction of 0.15% of polypropylene fibers and 0.5% of the ultra-fine steel fibers can effectively inhibit high-temperature bursting of components, indicating that the mixing of fibers to inhibit high-temperature concrete bursting plays a significant role in the inhibition of high-temperature bursting of concrete.

Afroughsabet [64] found that combining different volume fractions of steel and polypropylene fibers achieved the optimum reinforcement by blending 0.85% steel fibers and 0.15% polypropylene fibers by volume.

Sadrmomtazi [65] found that the polypropylene fibers were melted entirely when the concrete was heated to 300℃. However, due to the high melting point of the steel fibers, the unmelted steel fibers could exert their tensile and bonding effects. When the temperature reaches 450 ℃, although the steel fibers and the bond between the concrete is reduced by more than 20%, to a certain extent, it can still inhibit the generation and development of internal cracks in the concrete, which makes the concrete after high temperature is still able to maintain good integrity, and the strength of the reduction of the magnitude of the hybrid fibers effectively enhance the residual strength of the concrete after high temperature.

Tong Zhang [66] conceptually illustrated the mechanism of action of hybrid fiber concrete with polypropylene and steel fibers based on microstructural analysis. Due to the weak dispersion of the polypropylene fibers, as the fiber geometry decreases, the polypropylene fibers are aligned more tightly in the cement matrix, which in turn has an inhibitory effect on the bonding of the fibers to the matrix. In contrast, the steel fibers were uniformly distributed, and the bond between the steel fibers and the concrete matrix was better. When the polypropylene and steel fibers were incorporated, the hybrid fibers were inevitably closely aligned to a certain extent, considering the differences in diameter and bending stiffness between the hybrid fibers, which facilitated heat conduction. At high temperatures, the thermal expansion and phase change of polypropylene fibers induce microcracks on the fibers, and the incompatibility of steel fibers with the cement matrix enriches microcracks in the hybrid fiber concrete. Therefore, changes in microstructure and porosity lead to alterations in the thermal conductivity of hybrid fiber concrete at elevated temperatures.

Chen Jing [67] found that the compressive, split tensile, and flexural strengths of mixed ceramic and copper-plated steel fiber concrete were significantly higher than those of fiber concrete mixed with ceramic alone or copper-plated steel alone, and their maximum compressive strengths were increased by 47% and 2.8% compared to ceramic fiber concrete and copper-plated steel fiber concrete, respectively; their maximum split tensile strengths were increased by 68% and 6.5% compared to compressive strengths by 116% and 6.7%, respectively; the mechanical properties of this hybrid fiber concrete were mainly dependent on copper-plated steel fibers and ceramic lightweight aggregate, while the role of ceramic fibers was not significant. In this study, the microanalysis of the damaged specimens of hybrid fiber concrete also revealed that the ceramic fibers were randomly distributed around the copper-plated steel fibers, and both of them inhibited the development of concrete cracks from different scales, significantly improving the mechanical properties of the concrete.

The above research shows that under certain high-temperature conditions, the reasonable use of fiber mixing ratio can effectively improve the high-temperature performance of high-performance concrete through the combination of different types of fibers not only can effectively improve the phenomenon of bursting damage after the concrete suffers from high temperature, and at the same time, can also improve the tensile, flexural, shear and other mechanical properties of concrete after high temperature. At the same time, the type of fiber and the amount of mixing play a decisive role in these properties; however, the compressive strength is mainly determined by the strength class of concrete.

## 3. Summary and Outlook

Combined with the domestic and international research results in recent years, the current research status of steel fiber concrete, polypropylene fiber concrete, and mixed fiber concrete, which are more prevalent in the research field, is summarized, and their respective advantages and disadvantages are analyzed. From the level of the combination of theory and practice to summarize their respective roles in concrete, as well as the changes in their apparent phenomena, microstructure, and mechanical properties after high temperature, a detailed discussion of the fiber types, shapes, admixture, mixing ratios, and the effect of temperature on the fiber concrete, and according to the different methods of preparation to give the optimal amount of fiber admixture under the corresponding high-temperature conditions.

Current research on the high-temperature performance of fiber-concrete focuses on a single factor, which differs from the complex environment in which actual buildings are often located. Researchers simulate the high-temperature heating method as mostly the type of resistance furnace heating, which is different from the rapid heating of the fire scene or the instantaneous high temperature caused by the explosion. Fiber concrete belongs to the composite material; its high-temperature damage involves physical and chemical changes; its high temperature after the microscopic evolution of the law and high-temperature bursting mechanism needs further study with the help of instrumentation.

Research on the high-temperature resistance of fiber concrete has progressed, but there are still some problems and challenges. Future research should strengthen the selection of fiber materials and the application of additives, explore the application of fiber concrete in high-temperature environments, and further improve the performance evaluation methods of fiber concrete. Meanwhile, exploring the introduction of new fiber materials and the study of the relationship between concrete process and fiber efficacy, as well as the combination of fiber concrete and structural fire-resistant design, will provide new ideas and methods for the application of fiber concrete in high-temperature environments. In the future, with the continuous development of science and technology, further breakthroughs will be made in the research of fiber concrete in high-temperature fire-resistant performance, which will provide more reliable theoretical and technical support for engineering practice.

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