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Fiber Concrete Components Under High Temperatures: A Research Overview

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Abstract

With the increasing demands for structural safety and durability in the construction industry, hybrid fiber-reinforced concrete (HFRC) has garnered widespread attention due to its superior mechanical properties and fire resistance. This paper reviews the current state of research on HFRC at home and abroad, focusing on the impact of different fiber types, dosages, reinforcement methods, and the performance of concrete under high-temperature conditions. Studies have shown that hybrid fibers can effectively enhance the compressive strength, flexural strength, shear strength, and impact resistance of concrete, while also improving its ductility and toughness. Under high-temperature effects, HFRC demonstrates better fire resistance and residual strength retention compared to ordinary concrete. Moreover, this paper also explores the application potential and challenges of HFRC in practical engineering, providing a theoretical basis and technical support for future research directions and engineering practices.

Keywords

Steel fibers, Polypropylene fibers, Mechanical properties.

1. Introduction

Concrete, as one of the most widely used structural materials in modern construction, is directly related to the safety and durability of structural performance. However, traditional reinforced concrete structures often experience a sharp decline in performance under extreme conditions such as high temperatures and impacts. To address this issue, researchers have begun to explore the use of fibers to improve the performance of concrete. In particular, in recent years, HFRC has become a hot topic of research due to its significant advantages in mechanical and fire-resistant properties. HFRC refers to a composite material that incorporates two or more different types of fibers in concrete simultaneously. These fibers can be steel fibers, polypropylene fibers, carbon fibers, etc., which work together through different mechanisms to enhance the overall performance of concrete. However, despite existing research providing a certain theoretical basis for the application of HFRC, there are still many issues that need further exploration. For example, the specific impact mechanisms of different fiber types and dosages on concrete performance, the long-term performance of HFRC under high-temperature conditions, and how to apply HFRC more effectively in practical engineering, etc. This paper aims to review relevant domestic and foreign research, analyze the performance characteristics and application prospects of HFRC, and provide references for future research and engineering applications.

2. Current Research Status

2.1. Domestic Research Status

Yang Juan and Peng Gai Fei [1] in their study, evaluated the residual compressive strength and splitting tensile strength of Ultra-High Performance Concrete (UHPC) after exposure to high temperatures through experiments. Specifically, they explored the contribution of steel fibers and hybrid fibers in improving the high-temperature spalling behavior of UHPC. The experimental results showed that the introduction of hybrid fibers significantly enhanced the material's anti-spalling performance.

Xu Yu Ye, Wu Bo, and others [2] conducted a series of static tests to deeply analyze the impact of fire exposure time, shear-span ratio, and stirrup ratio on the residual shear and bending performance of reinforced concrete simply supported beams. The study found that as the fire exposure time increased, the deflection of the beams increased, and the reasonable arrangement of stirrups could effectively improve their shear carrying capacity and bending carrying capacity under high-temperature conditions, while reducing deformation.

Yi Wei Jian and Lv Yan Mei [3] revealed the positive effect of longitudinally distributed reinforcement on the shear ductility and shear carrying capacity of beams through shear failure tests on reinforced concrete simply supported beams with a shear-span ratio of 3. In addition, Ding Xin Bang [4] confirmed the significant effect of hybrid fibers on improving the ultimate shear strength, ductility, stiffness, and toughness of concrete beams through the anti-shear strength test of simply supported concrete beams with four-point loading.

Yang Zhi Nian, Qi Jian Quan, and others [5] assessed the impact of different concrete cover thicknesses and shear-span ratios on the fire resistance of reinforced concrete beams through standard fire tests. The results pointed out that increasing the cover thickness can significantly improve the beam's shear performance, and reducing the shear-span ratio helps to enhance the beam's fire resistance limit, although this may be accompanied by more obvious brittle fracture characteristics.

Ding Yi Ning, Da Bu Xi La Tu, You Zhi Guo [6] used hybrid fiber-reinforced self-compacting concrete beams to study the impact of fiber types, dosages, and stirrup ratios on the shear force performance of the beam's oblique section. The experiment found that an appropriate amount of steel fibers and hybrid fibers could partially replace the stirrups in the concrete beams, improving the failure mode of the concrete beams, thus transforming from brittle shear failure to more ductile bending failure.

Zhou Yun Long [7] by pouring beams of different shapes, compared and analyzed the impact of fiber content, stirrup ratio, and flange size on the shear carrying capacity of concrete beams. The study pointed out that in T-beams, hybrid fibers can partially replace the stirrups and longitudinal reinforcement, increasing the spacing of the stirrups and reducing the amount of longitudinal reinforcement, while also playing a good role in restricting crack development.

Shao Lian Fen [8-9] focused on the mechanical performance changes of ordinary concrete, polypropylene fiber concrete, steel fiber concrete, and hybrid fiber concrete after high temperature. The experimental results showed that both steel fibers and polypropylene fibers can effectively enhance the high-temperature post-compressive strength of concrete. However, when the temperature exceeds 400°C, the melting point of polypropylene fibers limits their performance improvement effect.

Wang Yue Hua [10-11] showed that below 400°C, hybrid fibers can significantly improve the pre- and post-high temperature compressive strength of concrete. Although polypropylene fibers introduce weak interfaces when improving fire resistance, this can be compensated by adding steel fibers, as they have a higher melting point and complement the polypropylene fibers, jointly enhancing the overall performance of concrete.

Shan Liang and others [12-13] found through the bond failure test of steel-polypropylene hybrid fiber concrete and deformed steel reinforcement that compared with single steel fiber or polypropylene fiber, the ultimate bond strength of hybrid fiber concrete increased by nearly 1/4. Hybrid fibers not only enhance the tensile strength of concrete around the reinforcement but also provide lateral restraint throughout the steel pulling-out process.

Mei Guo Dong [14] pointed out that the research on hybrid fiber concrete is still in its infancy and systematically studied the tensile performance and axial tension constitutive relationship of steel-polypropylene hybrid fiber concrete, finding that increasing the dosage of steel fibers and polypropylene fibers can effectively improve the initial crack tensile strength of concrete.

Cui Kai and others [15] showed through the uniaxial cyclic compression fatigue deformation test that under the action of compression fatigue, steel-polypropylene hybrid fiber concrete shows a multi-level, step-by-step crack blocking characteristic and exhibits good ductility.

These research results provide a solid theoretical basis for the application of hybrid fiber concrete and point the way for further research and engineering practice.

2.2. International Research Status

Varona et al. [16-17] systematically explored the effects of temperature on the compressive strength, tensile strength, and dynamic elastic modulus of hybrid fiber-reinforced concrete (HFRC) by pouring standard cubic test blocks and pull-out test blocks. The study revealed that as the temperature rises, the mechanical properties of HFRC show a downward trend, but compared with ordinary concrete, the rate of performance decay is slower, showing better thermal stability.

Soulioti et al. [18] compared the mechanical behavior of steel fiber-reinforced concrete (SFRC) with plain concrete, focusing on the effects of the geometric size and volume content of steel fibers on the compressive, bending performance, and toughness of SFRC. The results showed that the addition of steel fibers significantly improved the mechanical properties of concrete, especially with the increase in the volume content of steel fibers, the residual strength and bending toughness of concrete were significantly enhanced.

Vandewalle [19] conducted in-depth research on the hybrid effect of fibers of different scales and found that short fibers hindered the crack formation process at the micro-crack stage, while longer fibers provided better ductility at larger deformation stages, revealing the synergistic mechanism of hybrid fibers at the microscopic level.

Fernanda et al. [20] in 2021 investigated the impact of hybrid fibers on the bond performance between steel reinforcement and concrete, finding that the addition of hybrid fibers reduced the maximum bond strength of concrete compared to plain concrete, and noted that the excessive addition of fibers did not further improve bond performance, emphasizing the importance of optimizing fiber dosage.

Guo et al. [21] studied the toughening effect of the hybrid combination of steel and polypropylene fibers on high-strength concrete through bending and dynamic splitting tensile tests. The results showed that the appropriate addition of steel and polypropylene fibers significantly increased the bending strength and toughness of high-strength concrete.

Kodur et al. [22] used thermocouple temperature measurement methods to study the thermal conductivity of HFRC under high-temperature environments, finding that the thermal conductivity of concrete did not significantly decrease below 600°C, with steel fibers contributing the most to heat conduction. Sanchayan et al. [23] further pointed out that as the temperature rises, the mass loss rate of HFRC gradually increases, and the fiber dosage significantly affects the mechanical performance of concrete after high temperature, with an optimal dosage critical value.

Chen and Liu [24] studied the spalling behavior of HFRC containing synthetic fibers under high temperature through simulated fire experiments, showing that compared with ordinary concrete, HFRC did not spall under high-temperature action, maintaining a relatively intact surface.

BANGI [25] has recently studied the impact of hybrid fibers on the internal steam pressure of high-strength concrete, finding that steel fibers can effectively reduce the internal steam pressure of high-strength concrete, with the porous weak zone (interfacial transition zone) on the surface of steel fibers potentially serving as a channel for releasing steam pressure, and the hybrid effect of steel fibers with synthetic fibers is better than that of single steel fibers or synthetic fibers.

M.B. Dwaikat and V.K.R. Kodur [26] conducted experimental research on the shear carrying capacity of reinforced concrete beams under the action of fire, finding that beams under bending are more likely to undergo bending failure rather than shear failure under the action of fire, providing important references for the shear design of concrete structures under fire.

García et al. [27] in 2023 conducted in-depth analysis on the shear performance of precast concrete T-beams with an in-situ slab on top, testing composite specimens with different T-sections and concrete qualities, confirming the positive effect of the in-situ slab on improving the shear strength of composite beams, and pointing out that the compressive strength of precast beams significantly affects the shear performance.

3. Conclusion

As the construction industry's demands for structural safety and durability increase, hybrid fiber-reinforced concrete has attracted widespread attention due to its excellent mechanical properties and fire resistance. This paper reviews the current state of research on HFRC at home and abroad, focusing on the impact of different fiber types, dosages, reinforcement methods, and the performance of concrete under high-temperature conditions. Studies have shown that hybrid fibers can effectively enhance the compressive strength, flexural strength, shear strength, and impact resistance of concrete, while also improving its ductility and toughness. Under high-temperature effects, HFRC demonstrates better fire resistance and residual strength retention compared to ordinary concrete. Moreover, this paper also explores the application potential and challenges of HFRC in practical engineering, providing a theoretical basis and technical support for future research directions and engineering practices.

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