ISSN: 1813-4890

A Review on the Performance of Fiber-Reinforced Concrete under Fire Conditions

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Abstract

With the increasing demand for the durability of concrete structures in modern construction, the performance of concrete under high-temperature conditions has become a hot topic of research. This paper reviews the scientific research findings on the improvement of concrete performance under high-temperature conditions by steel fibers and polypropylene fibers (PPF). Steel fibers significantly enhance the mechanical properties of concrete at high temperatures, including residual strength and dynamic compressive performance, by improving its crack resistance and ductility. At the same time, an appropriate amount of steel fiber can effectively enhance the fire resistance of concrete. PPF, as an organic material, forms microcrack channels at high temperatures due to its low melting point characteristic, effectively reducing the risk of concrete explosion and improving its bonding performance and durability. Mechanical studies have shown that PPF concrete exhibits a good retention rate of mechanical properties and bonding-slip behavior after high temperatures. The review in this paper indicates that the rational application of steel fibers and PPF provides new solutions for the application of concrete structures in extreme high-temperature environments and provides a theoretical basis for future research directions and engineering practices.

Keywords

Steel fibers; Polypropylene fibers; High-temperature performance; Concrete; Mechanical properties; Durability.

1. Introduction

In the fields of construction and engineering, concrete, as a widely used structural material, its durability is a key factor in ensuring the safety and lifespan of projects. Extreme high-temperature environments, such as fires or high-temperature industrial environments, pose severe challenges to the durability of concrete structures. Under high temperatures, the evaporation of internal moisture and changes in the microstructure of concrete can lead to a significant reduction in its mechanical properties, thereby affecting the integrity and safety of the structure. Therefore, improving the performance of concrete in high-temperature environments has become an important topic in material science research. In recent years, fiber-reinforced concrete has attracted widespread attention due to its unique performance improvement effects. Steel fibers and polypropylene fibers (PPF), as two typical reinforcing materials, have been proven to effectively enhance the high-temperature performance of concrete. Steel fibers increase the connectivity within the concrete by improving its crack resistance and ductility, thus maintaining better mechanical properties under high-temperature conditions. The low melting point characteristic of PPF makes it form microcrack channels at high temperatures, which helps to release internal pressure, reduce the risk of explosion, and at the same time, improve the bonding performance and durability of concrete.

2. Current Research Status

2.1. Current Status of Steel Fiber Research

In recent years, the performance of steel fiber-reinforced concrete under high-temperature conditions has been deeply discussed. Steel fibers, as an effective reinforcing material, have been proven to play a significant role in improving the mechanical properties of concrete, especially under high-temperature conditions [1]. High temperatures can significantly affect the microstructure and macroscopic performance of concrete, including strength, elastic modulus, and durability. However, the addition of steel fibers brings additional toughness and crack resistance to concrete, thereby improving its performance in high-temperature environments [[2].

Under high-temperature conditions, the evaporation of internal moisture in concrete leads to the formation and expansion of internal pores, which in turn affects its mechanical properties. However, the incorporation of steel fibers can slow down this process, as the presence of fibers increases the connectivity within the concrete, thus enhancing its crack resistance and ductility [3]. In addition, the residual strength and microstructural changes of steel fiber-reinforced concrete at high temperatures have also attracted attention. Research has found that compared with ordinary concrete, steel fiber-reinforced concrete shows better residual strength and less micro damage after high temperatures [4].

In terms of dynamic compressive performance, steel fiber-reinforced concrete under high-temperature conditions has shown improved dynamic compressive performance, which is attributed to the dispersion and bridging effect of steel fibers, helping to enhance the load-bearing capacity of concrete when subjected to impact or vibration [5]. Moreover, the amount of steel fiber also affects the high-temperature performance of concrete. Studies have shown that an appropriate amount of steel fiber can significantly improve the fire resistance of concrete, but an excessive amount may lead to a decrease in performance[6].

In self-compacting concrete, the addition of steel fibers also shows positive effects. Self-compacting concrete, due to its fluidity and filling ability, can form a uniform concrete structure without the need for vibration. The incorporation of steel fibers further enhances the mechanical properties of self-compacting concrete, especially in high-temperature environments, improving its compressive and flexural performance [7].

Overall, the addition of steel fibers significantly improves the mechanical properties and durability of concrete in high-temperature environments. By optimizing the type, content, and incorporation method of steel fibers, the crack resistance and fire resistance of concrete at high temperatures can be further enhanced. Future research should continue to explore the impact of different types and amounts of steel fibers on the high-temperature performance of concrete, as well as how to combine actual engineering needs for the fire-resistant design of steel fiber-reinforced concrete.

2.2. Current Status of Polypropylene Fiber Research.

Under high-temperature environments, the performance and improvement effects of polypropylene fiber (PPF) concrete have become one of the hot topics in the field of building materials research in recent years. Due to its low melting point characteristic, PPF can bring a series of unique advantages to concrete structures under high temperatures. The following review will describe in detail the impact of PPF on the performance of concrete and reference relevant literature for explanation.

Mechanical Property Improvement at Room Temperature

At room temperature, the incorporation of PPF has been proven to improve the mechanical properties of concrete. PPF forms a random distribution network structure, effectively enhancing the crack resistance and toughness of concrete. Studies have shown that the appropriate addition of PPF can significantly reduce the early shrinkage and cracking of concrete, improving its crack resistance [8]. In addition, the incorporation of PPF can also increase the tensile strength of concrete, as the addition of PPF can enhance the concrete's own crack resistance and strengthen its interfacial properties [9].

Bonding Performance at High Temperatures

Under high-temperature environments, the bonding performance of PPF concrete has attracted widespread attention. Studies indicate that the addition of PPF can significantly improve the bonding performance between concrete and steel reinforcement. After exposure to high temperatures, the ultimate bond strength and peak slip of PPF concrete are affected, but concrete with PPF shows better high-temperature resistance and a lower rate of bond strength damage compared to concrete without fibers . Especially when the PPF content is 0.2%, the bonding performance of the specimens is maximized [10].

Degradation of Mechanical Properties after High Temperatures

High-temperature environments have a significant impact on the mechanical properties of PPF concrete. As the temperature rises, the compressive strength, splitting tensile strength, and other properties of PPF concrete will degrade to varying degrees. However, the addition of PPF can slow down this degradation to some extent, especially after high temperatures, the degradation of mechanical properties of PPF concrete is less than that of concrete without fibers [10].

Bond-Slip Constitutive Relationship Model

To better understand and predict the performance of PPF concrete under high temperatures, researchers have established bond-slip constitutive relationship models. These models consider the effects of temperature and PPF content, and through fitting and analysis of experimental data, mathematical models that describe the bonding performance of PPF concrete have been established [10]. These models provide important theoretical support for post-disaster damage assessment and repair of PPF concrete structures.

Thermal Conductivity Performance in Tunnel Lining Structures

In specific structures such as tunnel linings, the thermal conductivity performance of PPF concrete is also valued. Through finite element analysis, the temperature field distribution of PPF concrete with different fiber contents under fire conditions was simulated, and it was found that the incorporation of mixed fibers can significantly improve the internal thermal conductivity performance of concrete, especially when the PPF content is between 2.0kg/m^3 and 3.0kg/m^3, the effect is most significant [11].

In summary, the addition of PPF provides an effective solution for improving the performance of concrete in high-temperature environments. By reasonably controlling the content of PPF, not only can the mechanical properties of concrete be improved, but also its resistance to high temperatures and explosion resistance can be enhanced. Future research can further explore the optimization effects of different types and ratios of mixed fibers on concrete performance, as well as their potential for application in practical engineering.

3. Conclusion

This review has comprehensively analyzed the research findings on the improvement of high-temperature performance of concrete by steel fibers and polypropylene fibers (PPF). Through literature review, we draw the following conclusions:

Significant Enhancement of Mechanical Properties: The incorporation of steel fibers has significantly improved the crack resistance and ductility of concrete, particularly under high-temperature conditions, enhancing the residual strength and dynamic compressive performance of concrete.

Optimization of Fire Resistance: An appropriate amount of steel fiber can effectively enhance the fire resistance of concrete, but further research is needed to determine the optimal amount to avoid a decrease in performance due to an excessive amount.

Improvement of Bonding Performance: The low melting point characteristic of PPF fibers helps to form microcrack channels at high temperatures, improving the bonding performance and durability of concrete, especially in terms of bond-slip behavior.

Enhancement of Environmental Adaptability: PPF fiber-reinforced concrete shows a good retention rate of mechanical properties after high temperatures, indicating its better adaptability to extreme environments.

Potential for Engineering Application: The review results indicate that the application of fiber-reinforced concrete in high-temperature environments has significant engineering importance, providing a new perspective for structural design and material selection.

4. Future Prospects:

Optimization of Fiber Content and Incorporation: Determine the optimal content and method of incorporation for different types of fibers to maximize the performance of concrete.

Study of Aging and Degradation under Long-Term High-Temperature Exposure: Conduct in-depth research on the aging and degradation behavior of fiber-reinforced concrete exposed to long-term high temperatures.

Comprehensive Consideration of Environmental Factors: Take into account the impact of various environmental factors on the performance of fiber-reinforced concrete to enhance its potential for application in complex environments.

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