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Research Status of Mechanical Properties of Steel-Polypropylene Hybrid Fiber Reinforced Concrete

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Abstract

Incorporating two or more types of fibers into concrete in a rational manner, leveraging the advantages of different fibers to complement each other and work in synergy, can achieve a positive hybrid effect where 1+1 is greater than 2. This is referred to as hybrid fiber concrete. The following text introduces the current research status of steel fibers and polypropylene fibers, and provides a general overview of the performance of steel-polypropylene fiber reinforced concrete, as well as an exploration of the application of steel-polypropylene in practical engineering.

Keywords

Steel-Polypropylene Hybrid Fiber; Crack Resistance; Tensile Strength; Hybrid Fiber.

1. Introduction

The addition of fibers to concrete has rapidly developed in recent years as an important means of modifying concrete. Fibers widely used in concrete can be divided into high modulus fibers such as steel fibers and low modulus fibers such as polypropylene fibers according to the level of their elastic modulus. The former can significantly improve the tensile, bending, and shear ultimate strengths of concrete while enhancing the fracture toughness of concrete, thereby significantly improving the seismic performance of this brittle material. The latter can significantly reduce the early shrinkage cracks of concrete, improve the impermeability and durability of concrete, and also have a certain effect on improving the brittleness of concrete. Based on the respective advantages of the above fibers in improving the performance of concrete, hybrid fiber concrete (such as steel-polypropylene hybrid fiber concrete) has emerged in recent years, which involves adding multiple types of fibers to concrete to work in synergy and comprehensively improve the performance of concrete.

2. Research status

2.1. Research Status of Mechanical Properties of Steel Fibers:

A reasonable amount of steel fiber can reduce the number of original pores and cracks, making the structure more compact and effectively preventing the generation and development of micro-cracks in concrete[1]. Li et al. used acoustic emission (AE) technology to locate the source of sound, finding that the total number of sound sources increased with the increase of steel fiber volume fraction, which is caused by the slip and pull-out of steel fibers; they also found that as the fiber volume fraction increased, the new cracks in the concrete specimens changed from tensile cracks to shear cracks[2]. Yue Jianguang et al. also obtained similar results in the three-point bending notched beam experiment, and also found that the fracture energy of steel fiber concrete is approximately linearly related to the volume fraction of steel fiber[3]. Literature also found that the fracture energy increases with the increase of the volume fraction of steel fiber[4]. Lee et al.'s experimental results showed that the effect of steel fiber reinforcement on shear capacity varies with the amount of longitudinal reinforcement, which means that the same volume fraction of steel fiber may undergo different types of failure under different longitudinal reinforcement[5].

Han et al. found that the length of steel fibers has little effect on compressive strength and initial fracture toughness, but the splitting tensile strength and bending strength both increase with the length of the fibers; Steel Fiber Reinforced Concrete (SFRC) with a combination of large grain size coarse aggregate and long steel fibers exhibits good mechanical properties[6]. Ying Wenzong by comparing ordinary steel fibers (25mm in length) with ultra-short and ultra-fine steel fibers (6mm in length), discovered that the volume fraction of ultra-short and ultra-fine steel fibers in concrete can reach up to 7.0%, and these fibers can significantly enhance the compressive strength of the concrete[7].

2.2. Research Status of Mechanical Properties of Polypropylene Fibers:

Zhang Yue conducted cubic compression strength tests on polypropylene concrete specimens with fiber contents of 0kg/m^3, 0.6kg/m^3, 0.9kg/m^3, and 1.2kg/m^3. The test results showed that as the fiber content increased, the compressive strength of polypropylene fiber concrete first increased and then decreased, and the compressive strength of polypropylene concrete began to decrease when the fiber content exceeded 0.9kg/m^3[8]. Wang Qianxi et al. found that the increase in compressive strength of polypropylene fiber concrete was about 3.0% to 5.3%, and the increase in anti-splitting and bending strength was about 14.2% to 17.5%[9]. Ede et al. conducted destructive and non-destructive compression strength tests and destructive bending strength tests on concrete specimens with polypropylene fiber content of 0.25%, 0.5%, 0.75%, and 1%, and carried out standard curing for 7 days, 14 days, 21 days, and 28 days for different groups of concrete specimens. The test results showed that polypropylene fibers can increase the 28-day cubic compression strength of concrete by about 9%, and the optimal ratio of polypropylene fibers is between 0.25% and 0.5%, with the best effect of polypropylene fiber reinforcement on concrete when the fiber content is 0.25%, with an increase in bending strength of about 65%[10].

Xu Lihua et al. conducted mechanical property tests on polypropylene fiber-reinforced concrete specimens with different aspect ratios and fiber contents. The test results indicated that for concrete specimens with an aspect ratio of 167 and polypropylene fiber contents of 0.05%, 1.0%, 1.5%, and 2.0%, the compressive strength increased by 2.12%, 12.12%, 15.84%, and 18.55% respectively, compared to ordinary concrete. For specimens with a polypropylene fiber content of 1.0% and aspect ratios of 167, 280, and 369, the compressive strength increased by 12.12%, 14.80%, and 5.41% respectively, compared to ordinary concrete[11]. Yu Chun measured the splitting tensile strength of polypropylene fiber-reinforced concrete with different fiber contents through splitting tensile tests. The study found that the splitting tensile strength of fiber concrete with polypropylene fiber contents of 0.5kg/m^3, 1.0kg/m^3, 1.5kg/m^3, and 2.0kg/m^3 were 5.24Mpa, 5.58Mpa, 5.68Mpa, and 5.65Mpa respectively. Due to the role of polypropylene fibers in bearing part of the tensile load when the concrete is under tensile stress, the splitting tensile strength of polypropylene fiber-reinforced concrete increases with the increase of fiber content. The test results show that the addition of polypropylene fibers to concrete can effectively improve the fatigue strength and service life of the concrete, achieving a composite reinforcement effect on the interface transition zone of cement mortar. However, when too many fibers are added, the fatigue strength of the concrete is reduced instead, and under a constant stress level, a higher loading frequency makes the reduction in fatigue strength more significant[12].

A comprehensive analysis of the above research results reveals that the incorporation of polypropylene fibers can effectively improve the internal defects of concrete, enhance the performance of concrete, and suppress crack generation. Polypropylene fibers mitigate plastic shrinkage and early drying shrinkage by improving the tensile performance and bridging cracks in concrete. Polypropylene fibers have a lower Young's modulus, so they cannot prevent the formation and expansion of cracks under high stress levels, but they can bridge larger cracks. An increase in the volume fraction of polypropylene fiber content can improve the mechanical properties of concrete, increasing its ductility and toughness; as the polypropylene fiber content continues to increase, the mechanical properties of the concrete reach a peak and then decrease.

2.3. Research Status of Mechanical Properties of Steel-Polypropylene Hybrid Fibers:

Concrete is a non-homogeneous and multiphase material, and the addition of a single type of fiber can only improve or strengthen one aspect of its performance. In recent years, to make comprehensive use of the different effects of different fibers in improving the performance of concrete, hybrid fiber concrete, which is based on single fiber concrete, has emerged. The selection of hybrid fibers is usually based on the following three considerations: (based on the consideration of the constitutive relationship of fiber materials, using relatively high-strength, high-hardness fibers to improve the cracking strength and peak strength of concrete, and using relatively low-hardness but flexible fibers to suppress the development of native cracks in concrete and enhance the toughness and deformation capacity of cracking; (based on the consideration of fiber size, using fine fibers to bridge micro-cracks in the concrete matrix, improving the tensile strength of concrete, using coarse fibers to suppress the expansion of macro-cracks in the matrix, and improving the toughness after concrete cracking; (based on the consideration of fiber function, one type of fiber is used to alleviate the early temperature stress and plastic shrinkage of concrete, reducing the native cracks of concrete, and one type of fiber is used to improve the mechanical properties of concrete.

Due to the current immaturity in the research on hybrid fiber concrete, there is no universally accepted conclusion on many aspects. The following text only lists representative research findings on the material properties of steel-polypropylene hybrid fiber concrete.

For hybrid fiber-reinforced cementitious composites with different scales and properties, different fibers suppress the initiation and propagation of cracks at different structural levels, reducing and narrowing the scale and quantity of crack sources. At the same time, they complement each other at the level of fiber performance, exhibiting a significant synergistic effect. For example, when the total amount is fixed, the reinforcing effect of steel-polypropylene hybrid fibers on the matrix concrete is greater than that of single fibers (especially in terms of tensile strength, peak strain, elasticity, shrinkage limitation, impermeability, and the suppression of temperature crack generation) [13].

3. Conclusion

Under the condition of a fixed total volume fraction, the appropriate addition of polypropylene fiber content in steel-polypropylene hybrid fiber concrete can effectively enhance the impact resistance of concrete before and after experiencing fatigue load, and hybrid fibers have better post-crack performance compared to single steel or polypropylene fibers.

We can observe that currently, both domestic and international scholars have not conducted extensive research on concrete with two types of mixed fibers or multi-scale fiber concrete. Moreover, existing research primarily explores the impact of single factors, but in actual engineering applications, situations influenced by single factors are relatively rare. Therefore, in future research efforts, the focus should be on the changes in the mechanical properties of hybrid fiber concrete under the influence of multiple factors. We can determine the basic mechanical properties of hybrid fiber concrete through mechanical property tests, analyze the stress-strain curves obtained from the experiments, and perform corresponding numerical simulations using finite difference simulation software. By fitting the polypropylene fiber concrete constitutive model in conjunction with the stress-strain curves, the experimental results obtained will be more reflective of actual engineering conditions, and the experimental data will be more valuable.

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