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Research progress of basic mechanics property and durability of fiber reinforced concrete

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Abstract: This paper presents an overview of the development of fiber reinforced concrete (FRC) and analyzes the current research status of its basic mechanical properties and durability. Specifically, the study focuses on both single FRC and hybrid fiber reinforced concrete (HFRC). The analysis of basic mechanical properties includes the study of compressive strength, tensile strength, flexural strength, and impact resistance. The durability aspects cover topics such as freeze-thaw resistance, chloride ion penetration resistance, and carbonation resistance. Based on the research findings, the paper provides practical recommendations suitable for engineering applications. These recommendations aim to optimize the use of FRC and HFRC in construction projects, considering factors such as material selection, mix design, and construction practices. Overall, the paper contributes to the understanding of FRC and HFRC by providing a comprehensive analysis of their mechanical properties and durability. The suggested recommendations can serve as valuable guidelines for engineers and researchers working in the field of concrete technology, helping to enhance the performance and durability of concrete structures.

1. A brief history of the development of fiber reinforced concrete

Fiber reinforced concrete is a composite concrete material composed of cement slurry, mortar or concrete as the matrix and added with fibers, which is referred to as “Fiber Reinforced Concrete” (also known as FRC)[1].

The history of fiber reinforced concrete can be traced back more than 100 years. H.F.P in the United States first proposed the concept of “rigid fiber concrete” in 1910 and obtained a patent. Subsequently, the United States, Britain, France, and Germany began to study fiber reinforced concrete, and came to the corresponding conclusions. In 1963, J.P.Romualdi and J.B.Batson proposed the “fiber spacing theory”, which made steel fiber reinforced concrete make great progress. In 1879, “asbestos fiber cement” came out. Subsequently, asbestos cement production reached its peak. Later, it was found that asbestos dust was a carcinogenic hazard, so many developed countries began to develop synthetic fiber concrete such as glass fiber, polypropylene fiber and polyethylene.

In the 1950s, my country began to study the theory and application of “steel fiber reinforced concrete”. In the 1970s, fiber reinforced concrete technology was introduced into my country; many

colleges and universities, scientific research institutions and construction units began to study the use of synthetic fibers in concrete. In the 1980s, steel fibers have been widely used in many concrete projects such as roads, bridges, and tunnels. Many standards and specifications have also been issued accordingly, such as “Technical Regulations for Fiber Concrete Structures” (CECS 38:2004), “Synthetic Fibers for Cement Concrete and Mortar” (GB/T 21120--2007), “Short Fibers for Cement Concrete and Mortar” Cutting Steel Fiber” (GB/T 23265--2009), “Technical Specification for Fiber Concrete Application” (JGJ/T 221-2010), etc. So far, synthetic fiber reinforced concrete has been widely used in the plastering of walls, slabs, floors and other components in housing construction projects; dams, reservoirs, canals, thin-walled water pipes in water conservancy projects, etc.; road and bridge engineering pavements, bridges surface, etc.; tunnels; military engineering; port engineering, etc. Significant economic benefits have been achieved.

2. Research status of single-mixed fiber reinforced concrete and its durability

Single-mixed fiber reinforced concrete refers to fiber reinforced concrete composed of adding a fiber with the same properties to the concrete as the matrix. Incorporating a certain amount of a single fiber into the concrete will greatly improve the performance of the concrete matrix in a certain phase, a certain structure, and a certain level. A large number of relevant studies at home and abroad have shown[2, 3] that adding a single fiber into concrete can improve the mechanical properties of concrete, inhibit the early plastic cracking of concrete, effectively control the expansion of cracks, and improve the durability of concrete such as impermeability and frost resistance, also has a great promotion effect. At present, the single fiber research is mostly steel fiber reinforced concrete, carbon fiber reinforced concrete, glass fiber reinforced concrete, steel fiber reinforced concrete, synthetic fiber reinforced concrete, etc. Steel fiber reinforced concrete (SFRC) is a new type of multiphase composite material formed by adding steel fibers into ordinary concrete. Steel fibers can not only effectively hinder the expansion of micro-cracks in concrete, but also prevent the formation of macro-cracks, significantly improving the tensile strength, fatigue resistance, toughness, bending resistance, wear resistance, impact resistance, crack resistance and resistance of concrete. Burst performance. At present, steel fiber reinforced concrete has been widely used in construction, water conservancy and other engineering fields. Carbon fiber reinforced concrete (CFRC) is a composite material that incorporates carbon fibers into a concrete matrix. Because carbon fiber itself has the advantages of high tensile strength, good electrical conductivity, stable chemical properties, and high temperature resistance; therefore, adding a certain amount of carbon fiber to the concrete matrix can improve the mechanical properties of concrete, improve the shock absorption capacity of concrete, and improve wear resistance. performance, improve the bond strength between old and new concrete, prevent the spread of cracks in the matrix concrete, can significantly improve the conductivity of the matrix, etc. Glass fiber reinforced concrete (GFRC) is a composite material prepared by uniformly mixing alkali-resistant glass fibers with a large elastic modulus into a concrete substrate. Because glass fiber has the advantages of high tensile strength, good insulation, strong heat resistance, good corrosion resistance, and good workability, the glass fiber reinforced concrete has the advantages of light weight, high strength and high toughness. Synthetic fiber concrete refers to a composite concrete material made by incorporating synthetic fibers into the concrete matrix. Mainly include: polyvinyl alcohol fiber concrete, polypropylene fiber concrete, polypropylene fine fiber concrete, polyamide fiber concrete, aramid fiber concrete, etc. A large number of studies have shown [4] that the impact resistance, frost resistance and crack resistance of synthetic fibers on the matrix concrete are greatly improved.

3. Research status of hybrid fiber reinforced concrete and its durability

Hybrid fiber reinforced concrete (HFRC) refers to fiber reinforced concrete composed of two or more different fibers or the same variety of fibers with different geometric properties in the concrete as the matrix. The hybrid forms can be divided into three specific types [5]: one is the hybrid of two kinds of fibers with different qualities and different geometric properties, such as the hybrid of high elastic modulus and low elastic modulus fibers. The other is the hybrid of the same variety of fibers with different geometric properties. The third is multi-fiber mixed, that is, a variety of fibers mixed. In a word, hybrid fiber reinforced concrete is developed on the basis of single-mixed fiber reinforced concrete. Different varieties of fibers or fibers with different characteristics are mixed into concrete in a certain proportion, so that they can learn from each other and make use of their respective advantages. The performance of concrete matrix can be improved in multi-phase, multi-structure and multi-level. At present, the research on hybrid fiber concrete at home and abroad is still in the initial stage. Many scholars at home and abroad have done a lot of research in this direction, mainly focusing on the mechanical properties and durability of the hybrid fiber on the concrete matrix. Valuable achievements include:

Sorelli L.G et al.[6] pointed out that the geometric properties of fibers can improve the toughness of the matrix concrete; when fibers of different lengths are mixed, the long fibers can inhibit the development of macroscopic cracks in concrete, and the short fibers can improve the initial crack strength of concrete. Kobayashi K et al.[7] studied the flexural properties of steel fiber and polyethylene fiber hybrid concrete, and the results show that the hybrid fiber has better toughening effect on concrete. Through experimental research, Walton[8] found that two kinds of fibers with different properties were mixed and mixed into the concrete matrix, and it was concluded that under the combined action of the two fibers, the tensile performance and impact resistance of the concrete matrix were improved. Komlos K et al.[9,10] studied the reinforcement mechanism and failure mechanism of hybrid fiber reinforced concrete. Chandra Sekhar Das et al.[11] found that the mixing ratio of coarse and fine polypropylene fibers has an impact on the mechanical properties and durability of the matrix concrete, mainly on the splitting tensile strength but not on the tensile strength. The performance of chloride ion permeability and carbonization resistance has been improved. Sun Wei, Qian Hongping et al.[12] studied the high elastic modulus steel fiber, polyvinyl alcohol fiber and low elastic modulus polypropylene fiber binary and ternary hybrid fiber concrete with different mixing ratios through experiments. The flexural strength of 0.25% polypropylene fiber and 1.0% volume ratio of steel fiber and 0.25% polyvinyl alcohol fiber is mixed into the concrete matrix, and its flexural strength is higher than that of the same type of steel fiber concrete with the same volume ratio. Strength increased by 17%. Zhong-Xian Li et al. [13] studied the mechanical properties of carbon-steel fibers, carbon-polypropylene fibers, and steel-polypropylene hybrid fibers at a low content of 0.5%, and obtained the hybrid types of fibers, fiber types, The mixing ratio and addition amount have a great influence on the compressive strength and elastic modulus of the matrix concrete, and the elastic modulus and compressive strength of the matrix by carbon-steel fiber mixing are increased by 32.9% and 31.4%, respectively. The steel-polypropylene fiber mixture has little effect on the matrix properties. Wang Chengqi et al.[14] conducted an experimental study on the flexural strength of polypropylene fibers, vinylon fibers, and steel fibers mixed into the matrix by ternary hybridization. The structure shows that the hybrid fiber reinforced concrete has excellent mechanical properties. Wang Kai, Zhang Yishun, etc. [15] studied the mechanical properties of single-doped polypropylene fiber, steel fiber and steel-polypropylene hybrid fiber concrete with volume ratios of 0.3%, 0.6%, and 0.9%, respectively. The results show that the mechanical properties of fiber reinforced concrete are stronger than those of plain concrete, and the mechanical properties of hybrid fiber reinforced concrete are stronger than those of a single fiber reinforced concrete. Hua Yuan's research results[16,17] showed that the aspect ratio of carbon fiber, polypropylene fiber, glass fiber and polyethylene fiber has relatively little effect on the compressive strength of the matrix concrete, but has a great influence on the flexural strength. The durability of hybrid fiber reinforced concrete

also experimentally studied. The results show that carbon-polypropylene hybrid fiber and steel-polypropylene hybrid fiber can improve the impermeability of matrix concrete, and the resistance of matrix increases with the increase of fiber content. The penetration performance has been improved.

4. Research status of steel fiber and polypropylene fiber concrete

Polypropylene fiber (Polypropylene Fiber or PPF), commonly known as polypropylene fiber, is a kind of macromolecule hydrocarbon, the raw material is monomer C3H6, white, translucent, in the form of bundled monofilament structure or mesh, with simple synthesis process and moderate price, chemical stability and other advantages. In foreign countries, the research on polypropylene fiber concrete began in the 1960s[18]. At that time, polypropylene fibers were mainly incorporated into the concrete matrix to improve the mechanical properties of concrete. In the 1980s, Japan, South Korea, etc. also successively carried out research on polypropylene fiber reinforced concrete. In China, it was not until the 1970s that the research on polypropylene fiber reinforced concrete began. In the 1990s, China Textile University, Dalian University of Technology, etc.[19,20] have carried out experimental research on the mechanism of polypropylene fiber improving the mechanical properties of concrete. At present, polypropylene fibers have been commercialized and developed on a large scale at home and abroad. Subsequently, polypropylene fiber reinforced concrete is also widely used in military, transportation, water conservancy and other engineering fields. Adding a certain amount of polypropylene fibers into the concrete matrix can greatly improve the mechanical properties and physical properties of the matrix concrete. It is mainly manifested in the following aspects[21-23]: First, it prevents the plastic shrinkage of the matrix concrete. Adding a certain amount of fine polypropylene fibers into the concrete matrix can make the internal stress field of the matrix concrete more continuous and uniform, and prevent the cracks caused by the early plastic shrinkage of the concrete matrix and improve the tensile strength of the early concrete. Second, it has a significant impact on the tensile strength of the matrix concrete. Polypropylene fiber itself is a low elastic modulus fiber, which is only 1/10~1/12 of the base concrete. It has little effect on the compressive strength of the base concrete, but improves the tensile strength. When it is added in a volume ratio of 0.05% to 0.5%, its tensile strength is about 15% higher than that of the matrix. Third, it can improve the durability of concrete matrix. The improvement of the durability of the base concrete by the polypropylene fiber is mainly manifested in its impermeability, frost resistance, wear resistance and corrosion resistance; the impermeability of low-volume polypropylene fiber concrete is increased by 40%, and the wear resistance is increased by 30% to 60%; It has good stability and has a certain inhibitory effect on the chloride ion corrosion resistance, sulfate corrosion resistance and alkali orthopaedic reaction of the matrix concrete itself.

Steel fiber[24] (CBF or BF) is an inorganic fiber material. It is made of pure natural volcanic extrusive rock as raw material, melted at a high temperature of 1450~1500 degrees and then quickly drawn into fibers, golden brown and filamentous. Relevant studies have shown[25,26]: steel fiber has superior bending toughness, fracture toughness, tensile resistance, fatigue resistance and other mechanical properties. Steel fiber is a typical silicate fiber, which is easy to disperse in concrete matrix and has good workability. At the same time, it also has excellent comprehensive properties such as strong acid and alkali resistance, strong low temperature and high temperature resistance, good thermal insulation, high tensile strength, good elongation, and good aging resistance. Therefore, steel fiber reinforced concrete is widely used in engineering fields such as housing construction, seaport terminals, roads and bridges, seaport nuclear power, subway tunnels, etc.; respectively, to enhance the mechanical properties of concrete and improve the durability of concrete. The research of steel fiber at home and abroad began in the 1960s. In 1911, Graham found out how the strength and stability of ordinary reinforced concrete could be improved by adding steel fibers into it, in the following decades, the research of steel fiber reinforced concrete has been developed rapidly and has been applied in engineering [27]. In recent years, the United States, Japan, China, etc. have successively carried out research on steel fiber, and the United States has now reached a production

scale of 1500t per year. In my country, the “Steel Continuous Fiber and Its Composite Materials” project has been included in the National 863 Program, the National Torch Program, and the National Science and Technology Small and Medium Enterprise Innovation Fund. Now Shanghai and Heilongjiang have successively invested in the production of steel fiber. At present, the main representatives of steel fiber reinforced concrete research at home and abroad are: Tian Wenling et al. [28] studied the size effect of bending strength of cement mortar, misaligned steel fiber reinforced cement mortar and directional steel fiber reinforced cement mortar. Chang Honglei et al [29] studied the effects of organic imitation steel fibers on the compressive strength, fracture toughness and crack resistance of high-performance concrete were studied. The results show that the addition of organic imitation steel fiber has little effect on the compressive strength of high-performance concrete, but it can significantly improve its fracture toughness and crack resistance, and the effect becomes more and more significant with the increase of the dosage. The research of Zhang Cang [30] shows the steel fiber addition volume rate is 0.5% and 1%, the tensile strength of concrete splitting was increased by 14% and 27% respectively, and the corresponding compressive strength and tensile strength of steel fiber concrete specimens were better. Liu Yanjie et al[31] pointed out through experimental research that the impact compressive strength of steel fiber on matrix concrete has been improved, and the improvement of impact compressive strength is closely related to the fiber content. Feng Zhongren et al[32] carried out the fatigue test of steel fiber concrete by the electro-hydraulic servo machine, the results show that the fatigue performance of steel fiber concrete is significantly higher than that of ordinary concrete, and its fatigue strength is increased about 20% compared with ordinary concrete. Wang Haitao etal[33] mixed steel fiber into the concrete matrix at the dosage of 0, 0.5, 1.0, 1.5, 2.0, and 2.5 kg/m3, respectively, to form different types of fiber concrete. The effect of steel fiber on the compressive strength of the matrix is not very significant, but its toughness, flexural strength and impact resistance are greatly improved compared to plain concrete.

5. Conclusion

From many ways (such as fiber kinds, crack resistance, volume ratio,) this paper analyze the research status of basic mechanics properties and durability of single FRC and hybrid fiber reinforced concrete. Some advices were suggested. They were suitable for many kinds of engineerings.

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