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Application of Fiber Reinforced Concrete in Civil Engineering

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Abstract. Fiber-reinforced concrete is one kind of innovative composite material that has received increasing popularity among civil engineers and construction workers. The poor toughness and low strength of traditional concrete have been effectively improved by fiber concrete. The greatest strength of fiber-reinforced concrete is the reinforcement of an ordinary concrete by the inclusion of a certain proportion of fiber material to greatly improve its overall quality. The excellent performance of fiber-reinforced concrete not only significantly extends the service life of construction projects but also reduces maintenance costs. The various types of fiber concrete exhibit different properties in different scenarios. This paper discusses the categorization of fiber-reinforced concrete, explains the performance advantages of this material, introduces its practical applications, investigates its applicability and superiority in engineering applications, and concludes the entire document with a summary of fiber-reinforced concrete as well as discussion of some disadvantages of using fiber-reinforced concrete. It provides reference basis and theoretical foundation for the application in civil engineering.

Keywords: Fiber reinforced concrete, Materials, Civil engineering

1. Introduction

Against the growing demand for construction material for infrastructural construction, more and more concrete is being used. As one of the most common construction materials in civil engineering, due to the inherent disadvantages such as the poor tensile strength, low toughness and crack-prone, fiber reinforced concrete becomes an essential breakthrough in the field.

In civil engineering materials, the addition of different kinds of fibers can mitigate these constraints. When included in concrete, fibers can stop or prevent the formation and progression of micro-cracks inside concrete, substantially strengthening tensile strength, crack resistance, toughness, impact resistance, and durability; how much hybrid fiber-reinforced concrete performs differs based on fiber quantity.

The perfect combination of science & materials technology has led to the application of fiber reinforced concrete. Various types have been put forward by different fields of researchers. Metal fiber reinforced concrete (represented by steel fiber concrete), inorganic non-metallic fiber reinforced concrete (represented by carbon fiber concrete), organic polymer fiber reinforced concrete (represented by polypropylene fiber concrete and polyoxymethylene fiber concrete).

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Natural fibers reinforced concrete such as cellulose fiber reinforced concrete not only improved properties of the composite materials but also possessed beneficial effects [1-5]. Due to the increasing demand for safe, stable and durable structural design and construction in civil engineering, the usage of fiber-reinforced concrete is prevailing and expands continuously on. In addition, for the tunnel engineering, high-performance fiber crack-resistant composite material has been used extensively.

Reinforced concrete and the auxiliary use of new composite waterproof geotextiles as a flexible waterproof layer is applied to construct the lining concrete. In this way, the tunnel's surrounding rock will not be continuously affected by seepage water, and at the same time the entire waterproof problems can be solved in this way [6,7]. Besides that, a set of complete technological methods for long-span bridges in road and bridge engineering were formed through various constructions [8].

Meanwhile, effective strengthening methods have also been explored for long span bridges. Steel fiber concrete can effectively improve the early deformation control ability and has very good durability, greatly improving the integrity and serviceability of long span bridge structure. For bridges constructed with concrete, an appropriate amount of polypropylene fiber in concrete is beneficial to the durability of concrete in bridge engineering and can extend the service life of concrete structure to a great extent; the impermeability, frost resistance and chemical corrosion resistance of fiber reinforced concrete can be fully reflected in hydraulic engineering, which can prolong the service life of hydraulic projects [9,10]. Through this paper, many varieties, performances and application cases about the fiber reinforced concrete are summarized and explained thoroughly, together with evaluation and analysis.

2. Types and performance of fiber reinforced concrete

2.1. Metal fiber reinforced concrete

Metal fiber-reinforced concrete is dominated by steel fibers; therefore, it is the main type of reinforced concrete as it uses the relatively advanced and inexpensive materials (especially in China). It has been classified as carbon steel, stainless steel, or alloy steel according to the materials used. Ordinary carbon steel fiber-reinforced concrete is mainly applied to impact- and crack-resistant areas, because they are relatively inexpensive and have great strength.

General buildings mostly use stainless steel and alloy steel fibers reinforced concrete. In contrast to traditional steel bars, they have good corrosion resistance and high strength, and can be used in chemical plants or places exposed to seawater or salt spray. Adding metal fibers significantly increases the tensile strength of concrete, where the tensile strength of steel fiber concrete could increase by about 50%-100% Compared with ordinary reinforced concrete, metal fiber concrete shows obvious advantages in terms of bending, and impact strength. When subjected to impacts and tension, metal fibers absorb most of the energy to prevent damage to the entire structure, and the utilization of metal fibers enhances the durability of concrete, making it hard for water or chloride ions to penetrate through, and helps extend the life cycle of the concrete structure.

2.2. Inorganic non-metallic fiber reinforced concrete

Inorganic non-metallic fibers usually include carbon fiber and glass fiber. Carbon fiber reinforced concrete, which is referred to as carbon fiber-reinforced concrete, has extraordinary tensile strength, with the tensile strength being 5-10 times that of steel. It's chemically stable, corrosion-resistant, has a long service life, but at the same time it also has less weight than steel fiber concrete, thus saving

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structural weight. However, because of the price problem of carbon fiber, it doesn't have wide application at present. And carbon fiber is a brittle material, without plastic deformation, which has less toughness than steel fiber concrete.

Glass fiber reinforced concrete is the mixture of alkali-resistant glass fiber with cement and sand in combination with other matrices. It consists mainly of inorganic materials and thus has excellent fireproof properties but poor strength characteristics. Since no loading elements can be provided, it is not recommended to construct load-bearing buildings or structures. Another disadvantage is that its toughness and compression strength gradually become worse over time.

2.3. Organic polymer fiber reinforced concrete

Organic polymers such as polypropylene, polyacrylonitrile, polyvinyl alcohol, polyamide, aramid and cellulose fibers, when used in concrete can reduce the plastic shrinkage cracks and increase tensile strength, impact resistance, etc., while glass fibers share similar functions but are in non-load bearing structure. Fibers can be of different types and thus be found in all sorts of concrete projects in the construction industry [11].

2.4. Natural fiber reinforced concrete

Natural fibers originate from different parts of plants and include wood fiber, bast fiber, leaf fiber, seed/fruit fiber and bamboo fiber. Since natural fibers are extracted from renewable plants, they consume low energy, low carbon emission, pollute little to the environment, and are low-cost to produce, as well as reusable using agricultural or industrial waste materials to obtain value. However, the durability of natural fibers is relatively poor: the internal fibers within concrete will easily deteriorate if exposed to humid, corrosive environment.

3. Specific applications of fiber reinforced concrete

Steel fibre reinforced concrete (SFRC) and Organic polymer fiber reinforced concrete (OPFRC) are both utilized in tunnel construction. Steel fiber reinforced concrete is among the most applied and technologically developed materials, used to reinforce concrete in tunnels. Applied as shotcrete, it provides the support structure for tunnels. SFRC strengthens the toughness and strength of concrete and the support layers with shotcretes distribute loads evenly. With the application of these methods to structure loadings, the rock mass can be kept from falling apart, as well as keeping the tunnel free from failure. Moreover, SFRC can be used to replace the steel mesh and avoid the laying of large areas of steel mesh. Therefore, not only does steel fiber reinforced concrete replace the function of meshes, but also saves about half the amount of work as long as there is large amount of steel mesh works on site [12].

Organic polymer fiber reinforced concrete such as Polypropylene fiber concrete can be used as tunnel engineering materials in both shotcrete and cast-in-place forms of concrete, which when set prevent crack formation from shrinkage due to moisture loss or temperature drops, while also imparting high spall resistance once concrete has set. During tunnel fire conditions, Polypropylene fibers will melt at a certain temperature, forming an interconnected micro-pore channel within the concrete. Under high temperature conditions, this channel will provide release of the pressurised water vapour from within the concrete, which prevents spalling [13].

In tunnel engineering, steel fiber reinforced concrete and polypropylene fiber concrete are used jointly to leverage their respective strengths, while also enhancing the performance but leading to

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increased construction costs.

3.1. Application in road and bridge engineering

In road engineering, fiber-reinforced concrete has taken the place of the traditional concrete as well as some of the reinforcement mesh. Paving road surface with steel fiber reinforced concrete structure greatly increases the load-bearing capacity and the impact resistance, effectively avoiding the brittle deformation and fracture of pavement. Under the same loading condition, the thickness of steel fiber reinforced concrete pavement can be reduced.

The relative volume of approximately 30-50% less aggregate means less material is used than in the standard concrete pavement. Steel fibre resists water penetration and prevents the formation of cracks, extending the pavement's lifespan. Steel fiber-reinforced concrete and organic polymer fiber-reinforced concrete accelerates the setting of the repair material and minimizes cracking due to drying shrinkage and temperature changes.

In bridge projects, the utilization of fiber-reinforced concrete has various forms and higher requirements for structural performance and durability. Steel-fiber and organic-polymer-fiber-reinforced-concrete are extensively applied to the roadway pavement to increase crack-resistance and impact-resistance [14], whereas carbon-fiber-reinforced-concrete (CFRC) is widely adopted for the main girders or connections on bridges to further reinforce its loading-carrying capacity and decrease the structural weight. In long-span and high-load projects, such as large-span bridges, the extensive use of fiber-reinforced concrete would help guarantee structural safety and ensure structural stability, which could effectively reduce the construction cost and save energy.

3.2. Application in hydraulic engineering

Hydraulic engineering requires such concrete to possess very high compressive strength, durability and impact resistance levels. It was found that steel fibre and organic polymer fibre reinforced concrete were most commonly used as these were able to withstand erosion due to the high pressure velocity of water without structural failure. The addition of fibres greatly increases the erosion and corrosion resistance while the excellent toughness prevents the concrete from cracking and spalling, thereby prolonging the life of hydraulic projects. In applying fibre reinforced concrete, it can simplify work procedures and reduce maintenance expenses [15].

4. Conclusion

An important composite material, fiber reinforced concrete has been widely applied in construction projects of civil engineering. As various types of fiber reinforced concrete exist in today's market, the selection of suitable fiber materials is essential according to the characteristics of the project and the natural environment. At present, in many infrastructure construction projects, the scope of fiber reinforced concrete application is expanding. Compared with ordinary concrete, fiber reinforced concrete helps overcome the disadvantages of ordinary concrete.

The defects such as poor toughness, crack-prone and short service life can not only be improved but also increase the safety of the whole structure and decrease the maintenance cost. Some fiber materials still have mature technology and price. However, with the continuous progress of engineering technology and material research, more efforts should be made on researching and developing fiber-reinforced concrete.

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