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Future Development Trend of Fiber Recycled Concrete

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Abstract:

According to existing studies, fibers have a significant effect on improving the tensile and flexural strength of recycled concrete due to their own good tearing properties, and play a good toughening effect, as well as improving and enhancing the shrinkage resistance and impermeability of recycled concrete. This paper outlines the effects of single or mixed several major fibers on the mechanical properties of recycled concrete and the current status of research at home and abroad. Some of the problems that need to be solved in the research, development and utilization of fiber-doped recycled concrete in China are presented.

Keywords **—green recycled resources; fiber recycled coarse aggregates; basic mechanical properties; concrete; tensile strength**

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I. INTRODUCTION

At present, some data show that the total amount of construction waste in China (as shown in Figure 1) has accounted for 30~40% of urban waste, of which 50~60% is waste concrete. Compared with foreign developed countries, the utilization rate of construction waste in China is extremely low, and the vast majority of construction waste is randomly piled up in the open air or landfilled in situ without any treatment. This simple and crude way of disposal will not only occupy a large amount of arable land and increase additional costs such as construction waste removal, but more importantly, it will cause serious waste of resources and environmental pollution. Therefore, the research and utilization of recycled concrete is very necessary. As we all know, the development and application of recycled concrete can, on the one hand, solve the problem of a large amount of waste construction materials that are difficult to dispose of, and can also alleviate a series of problems brought about by the increasing deterioration of the ecological environment; on the other hand, replacing natural aggregates with recycled aggregates (Figure 2) can reduce the mining of natural sand and gravel for construction projects, which can fundamentally solve the increasing scarcity of natural aggregates and the massive sand and gravel mining on the. Currently, recycled concrete, as a new sustainable green concrete, has focused the attention of engineering and academic circles around the world and become one of the hot and frontier issues for domestic experts [1]. However, according to various experiments, the particle size of the recycled coarse aggregate particles increased with the increase of the strength of the virgin concrete, the apparent density and bulk density became larger with the increase of the strength of the virgin concrete, and the crushing index and water absorption decreased with the increase of the strength of the virgin concrete. Therefore, compared with natural aggregates, the apparent density and bulk density of recycled aggregates are reduced, while the water absorption and crushing index of recycled aggregates are

increased [2], so the physical treatment such as crushing and wetting of recycled coarse aggregates alone is unable to meet the requirements of higher strength applications. And fiber as a new material, its superior reinforcement, toughness, crack resistance [3], can significantly improve the splitting of recycled coarse aggregate.The mechanical properties of recycled aggregate such as tensile and compressive, so the recycled concrete prepared by fiber-doped recycled aggregate has a broader space for development. This paper summarizes and analyzes the research results of fiber recycled concrete at the present stage, describes the effects of different types of fibers and different fiber incorporation methods on the basic mechanical properties of recycled concrete and the degree of improvement, and on this basis presents the current deficiencies in this direction and the outlook for the future.

Fig. 1Construction waste

Fig. 2Recycledaggregateconcrete processing site

II. CURRENT STATU

After World War II, the Soviet Union, Japan, Germany and other countries to rebuild their homes, on the issue of waste concrete began to research, develop and use recycled concrete, and has held three international conferences on the theme of regeneration of waste concrete. Nowadays, recycled concrete has become a common research topic in developed countries, and some countries also guarantee and promote its research in the form of legislation. With our government's attention to resources and environmental issues, also began to encourage the research and development of recycled concrete.

A. Japan

Japan is an island country with small area and few resources, but it started early and did well in the research of construction waste recycling. As early as 1997, the Japanese government formulated the "Code of Practice for the Use of Recycled Aggregate and Recycled Concrete" and established construction waste recycling plants in various places. in 1992, the Japanese Ministry of Construction proposed a five-year plan to control construction by-product emissions and develop construction by-product utilization technology, and enacted the "Recycling Resources Law" in October 1996 to promote the reuse of construction by-products and to provide a The "Recycling Resources Law" was enacted in October 1996 to promote the reuse of construction by-products and provide legal and institutional safeguards for the resourceful use of construction waste. Japan has conducted systematic research on the properties of recycled concrete such as water absorption rate, strength, fitting ratio, dry shrinkage rate, and frost resistance. Currently, the recycling rate of construction waste in Japan has reached about 70% [21-22].

B. United States

The U.S. government enacted the Superfund Act, which states that "any enterprise that produces industrial waste must dispose of it properly on its own and must not dump it arbitrarily. The United States not only encourages the use of recycled concrete, but also does systematic research and testing on the performance of recycled concrete. For example, recycled concrete was used on two highways in Michigan, USA. The study showed that the dry shrinkage of recycled concrete is greater than that of natural aggregate concrete. The

use of microwave technology in the United States CYCLEAN can recycle 100% of the road asphalt concrete with the same quality as new asphalt concrete pavement, while reducing the cost by 1/3, while saving on waste removal and disposal costs and greatly reducing environmental pollution in the city [27-29].

C. European countries

Denmark, the Netherlands and some other countries with stone shortage and reliance on imported natural aggregates attach great importance to the recycling of construction waste. Denmark in 1990 generated 12.2 million tons of construction and demolition waste, 8.2 million tons were recycled, a recycling rate of 67.2%. In the Dutch cabinet's environmental policy plan, the recycling rate of construction waste is planned to be as high as 90% in 2000, about 14 million tons. The German state of Lower Saxony now uses recycled concrete primarily for road paving. A double-layer concrete road in Germany using recycled concrete, the total thickness of the concrete pavement is 26cm, the bottom layer of concrete 19cm using recycled concrete, the top layer of 7cm using natural aggregates to formulate concrete. German reinforcement committee in August 1998 proposed a "recycled aggregate in concrete application guidelines", requiring the use of recycled aggregate concrete must fully comply with the national standards for natural aggregate concrete. France also uses crushed concrete blocks and broken bricks to produce masonry concrete blocks, and the concrete blocks produced have been measured to comply with the relevant standards of NBNB 21-001 (1988) for masonry concrete materials [26].

D. Developing Countries

China is a large country among developing countries, and there will not be a shortage of raw materials for concrete aggregates for a certain period of time. However, the environmental pollution caused by construction waste is becoming more and more serious, therefore, our government has started to study the problem of resource utilization of construction waste. Although China's research on recycled concrete started late and is still at the laboratory stage, corresponding results have been achieved, such as Gu Jiaxun's research on construction waste block technology won a national patent; in 2009, Shanghai No. 2 Construction Engineering Company used construction waste from its structural construction phase in two projects in the urban area, "Huating" and "Huolan". Shanghai Construction Component Products Company started to use waste concrete to make concrete hollow blocks in 1997, and its product index fully complies with the Shanghai standard "Concrete Small Hollow Block Engineering and Acceptance Specification" [23-25].

III. THE MANUFACTURING PROCESS OF RECYCLED AGGREGATES

There are several sources of waste concrete used to produce recycled aggregates.

1) Waste concrete blocks are generated when buildings reach the end of their useful life or are demolished due to deterioration, which is the main source of waste concrete blocks.

2) Waste concrete blocks are generated from the relocation of municipal projects and the renovation of major infrastructure.

3) Waste concrete generated from commercial concrete plants.

4) Waste concrete blocks generated from the collapse of buildings caused by earthquakes, typhoons, floods and other accidental causes.

The process of manufacturing recycled aggregates from waste concrete blocks is similar to the process of manufacturing natural aggregates in that it is a production process that combines different crushing equipment, screening equipment and conveying equipment in a rational manner. The actual waste concrete blocks inevitably contain various impurities such as steel, wood, plastic fragments, glass, building gypsum, etc. In order to ensure the quality of recycled concrete, certain measures must be taken to remove these impurities. The recycled aggregate produced during the crushing of the base concrete contains approximately hardened cement mortar, which is mostly independent of the block, with a small

amount attached to the surface of the natural aggregate, while the external forces such as extrusion, impact and grinding of the concrete during the crushing process lead to the accumulation of damage, resulting in a large number of micro-cracks inside the aggregate, which affects and damages the original interface between the aggregate and cement mortar of the base concrete block. The bonding force is reduced. Therefore, compared with natural aggregate, it has high water absorption rate, fast water absorption, low apparent density, low bulk density and large crushing index.

Construction waste has a complex composition of masonry debris, reinforced concrete, iron, wood, plastic, cardboard, cable and sand components, of which masonry debris and concrete debris account for most of the recycled aggregates, which are also recycled resources. The first is to study a set of economical and applicable sorting, crushing, screening, cleaning technology processing methods, followed by research on how to modify the composition and structure of recycled aggregates reinforcement treatment to improve the strength of recycled aggregates, which is the key problem that must be solved. Reinforcement treatment of recycled aggregates, i.e., to solve the problem of low aggregate strength due to the large porosity of recycled aggregates and the presence of some microscopic cracks in the aggregate itself due to the different components of the recycled crushing process. Several chemical slurries of different nature have been envisaged to impregnate, drench and dry the regenerated aggregate, these chemical slurries either fill the pores of the regenerated aggregate directly, or react with certain components in the aggregate such as cement hydration products in the original concrete, $Ca(OH)_2$,3CaO.2 SiO_2.3H_2O, etc. to fill the pores of the regenerated aggregate, or the slurry can bond the regenerated aggregate itself with microscopic cracks, etc. It is undoubtedly feasible to improve the strength of aggregates by improving the pore structure of recycled aggregates, and the key is to select chemical slurry and treatment methods that are less costly and can enter industrial applications through experiments. In the laboratory, the source of recycled aggregate is single, the quality is relatively uniform, and the dispersion of recycled aggregate properties is low, while in the actual production of recycled aggregate, due to its very unstable source and uneven quality, its own random performance and variability is large, which will lead to increased variability in the compressive strength of recycled concrete. Therefore, studying the randomness and coefficient of variation of the properties of the aggregate itself has a great impact on the practical application of recycled aggregates. At this stage, the abandoned concrete is the base concrete with low strength, therefore, the reinforcement of recycled aggregates is of practical significance to improve various properties of recycled concrete, but the existing reinforcement of recycled aggregates has some limitations in terms of economy and feasibility, so further research is needed to improve the performance of recycled aggregates.

IV. STATUS OF RESEARCH ON MECHANICAL PROPERTIES OF FIBER RECYCLED CONCRETE

A. Splitting tensile strength

The tensile strength and deformation of concrete is one of its most important basic properties, which is both the main basis for studying the damage mechanism and strength theory of concrete, and directly affects the cracking, deformation and durability of reinforced concrete structures. Concrete has been considered as a brittle material with low tensile strength, small deformation and sudden damage. Recycled concrete is more pronounced in terms of brittleness due to its unique material origin, therefore fiber incorporation is more in-depth and important when studying the mechanical properties of recycled concrete in terms of tensile strength. In the direction of splitting tensile strength of fiber-doped recycled concrete, the team of Danying Gao [9] proposed a primary structural model for the adhesion stress and slip of steel reinforcement to steel fiber recycled concrete considering the effects of recycled aggregate substitution rate and steel fiber volume rate by establishing the calculation method of the

characteristic parameters of the adhesion stress and slip curve of steel reinforcement to steel fiber recycled concrete. Xiangqing Kong [4] studied the fracture performance of steel-polypropylene hybrid fiber recycled concrete, and the results showed that the incorporation of both steel and polypropylene fibers significantly improved the fracture resistance of the matrix recycled concrete, and the improvement effect of steel fibers was better than that of polypropylene fibers. When the volume admixture of steel fiber was 1.5% and that of polypropylene was 0.9%, the peak load, fracture toughness and fracture energy of the mixed fiber recycled concrete specimens reached the maximum value, and the fracture performance of the recycled concrete was improved most ideally. Li Xiaolu [10] et al. found that:Basalt fibers will reduce the fluidity of recycled concrete, increase the friction between cement matrix, and have a strengthening and toughening effect on the splitting tensile strength of recycled concrete cubes. Chen Aijiu [14] reinforced steel reinforced recycled concrete beams with prestressed carbon fiber cloth can effectively restrain the concrete in the tension zone of the beam, when the beam yielded, the number of transverse cracks in the tension zone of the purely bending section of the beam increased with the increase of prestressed carbon fiber cloth reinforcement and the width was smaller, and the number of cracks decreased and the width increased with the increase of recycled coarse aggregate admixture. Wu [6] et al. found in an experimental study of reinforced recycled concrete with polypropylene fiber and silica fume that the splitting strength of recycled concrete could be increased by 33.3% under the dual action of polypropylene fiber and silica fume, and the effect of polypropylene fiber on the splitting strength of concrete was greater than that of silica fume. Liu C [8] et al. studied mixed steel fiber recycled concrete with different admixture rates and concluded that the admixture of mixed steel fibers significantly improved the splitting strength of recycled concrete, which increased by 20.2% to 124.6% with the increase in the admixture rate of steel fibers. A study by Xiangqing Kong [7] et al. showed that the splitting tensile strength of mixed fiber recycled concrete specimens increased with the increase of temperature and then decreased. When the temperature was 200°C, the splitting tensile strength of mixed fiber recycled concrete specimens increased slightly. The splitting tensile strength of the mixed fiber recycled concrete specimens increased slightly when the temperature exceeded 200°C. When the temperature exceeded 200°C, the damage of splitting tensile strength of recycled concrete was significantly increased by temperature. Under the same temperature conditions, the compressive strength and splitting tensile strength of recycled concrete containing mixed fibers were higher than those of ordinary recycled concrete, with the specimens containing mixed fibers (0.1% for both polypropylene fibers and basalt fibers) having the highest strength under the same temperature conditions. Guo Ruijin [11] et al. showed that under two different fiber incorporation methods, for different fiber incorporation amounts, the compressive strength ratio of the specimens showed a trend of increasing and then decreasing. It was shown that under two different fiber incorporation methods, for different fiber incorporation amounts, the compressive strength ratio of the specimens showed a trend of increasing and then decreasing with the increase of temperature, and the compressive strength ratio reached the maximum value at 200°C; while for the splitting tensile strength, the strength ratio increased with the increase of temperature when the temperature was between 20 and 200°C; for the splitting tensile strength, at 20 to 200°C , the strength ratio did not change with the increase of temperature, and the size difference decreased sharply after 200°C. Hou Min, Dong Jiangfeng, and Yuan Shucheng [12] showed that the tensile strength of fiber recycled concrete with 4 kg/m3 fiber admixture was significantly lower than that of recycled concrete, but the tensile strength gradually increased with the increase of recycled aggregate replacement rate. Jinghai Zhou [13] investigated the splitting tensile strength of recycled concrete mixed with waste fibers, which came from recycled polypropylene carpet, woven from polypropylene fibers, with initial cracks appearing at 70% of the

ultimate bearing capacity. The splitting tensile strength of recycled concrete with waste fibers showed a trend of increasing and then decreasing with the increase of waste fiber admixture, and the splitting tensile strength was maximum at 0.12% of waste fiber admixture.

Conclusion:The addition of fibers has significantly improved the fracture resistance of the matrix recycled concrete and has enhanced and toughened the splitting tensile strength of the recycled concrete cubes.

B. Compressive strength

In terms of the basic mechanical properties of the compressive strength of recycled concrete cubes, many scholars have concluded from experimental studies, such as M.M Tawaan [15], that the addition of steel fibers to concrete caused the concrete to delay the appearance of cracks during the stressing process, while controlling or delaying the spread of microcracks. This resulted in an increase in the compressive strength of the concrete cube. Also, it was found from the experimental results that the cubic compressive strength of recycled concrete basically decreases with the increase of recycled coarse aggregates. The addition of steel fibers in ordinary concrete is basically to improve the cubic compressive strength of ordinary concrete, while in recycled concrete there are discrete types, several main reasons one is that the concrete specimens are not dense enough when cast, the second is related to the source of waste concrete, because different sources of recycled coarse aggregates will have different properties, resulting in strength is affected. Liu [8] mixed steel fibers with different admixtures to effectively improve the compressive strength and elastic modulus of recycled concrete, with the increase of steel fiber admixture, the compressive strength increased by 9.9% to 40.1% and the elastic modulus increased by 12.6% to 38.1%. Wang Sheliang [16] fiber admixture makes the concrete particles crushed when the specimen is damaged appear "cracked but not fallen" phenomenon. The effects of incorporating silica fume or fiber on the deformation capacity of recycled concrete columns were similar, with low admixtures both improving the deformation capacity, and the effect of fiber admixture was particularly significant; however, with the increase in admixture, the deformation capacity instead showed different degrees of reduction. Wu [6] could increase the compressive strength of recycled concrete by 33.7% under the dual action of polypropylene fiber and silica fume , and the effect of silica fume on the compressive strength of concrete was greater than that of polypropylene fiber. Jinghai Zhou [17] waste fibers can significantly improve the axial compressive strength of ordinary recycled concrete. Within the reasonable range of waste fiber admixture, when the length of waste fiber is certain, the peak stress of waste fiber regenerated concrete increases with the increase of waste fiber admixture, and when the length of waste fiber is 19 mm and the volume admixture of waste fiber is 0.16%, the peak stress of waste fiber regenerated concrete increases more significantly. Yao, Lin [18] found that both single and mixed fibers can improve the compressive strength of recycled concrete, and the glass fibers improve significantly more than polypropylene fibers. It was shown that for the axial compressive strength of recycled concrete, the effect was more pronounced when glass fibers were mixed with single fibers than when mixed fibers were used. Both polypropylene fibers and glass fibers showed significant increase in splitting tensile strength of concrete, where the combination of mixed 18 mm glass fibers and 30 mm polypropylene fibers showed good results up to 3.61 MPa. the modulus of elasticity value increased with the increase of glass fiber length. Chen Aiju [14] found through experimental studies that the deformation capacity of polypropylene fibers increased and the elastic modulus decreased after adding polypropylene fibers to glass fiber recycled concrete. According to the assumption of flat section, the height equation of the confining pressure zone for carbon fiber fracture damage and peeling damage in bending of prestressed carbon fiber cloth reinforced reinforced recycled concrete beams was derived, and then the amount of prestressed carbon fiber cloth confining reinforcement for both types of damage was derived. Yuan-Yuan He [19] added basalt fiber yarn can improve the bearing capacity of recycled concrete,

and its bearing capacity can be increased by 35%; the shape of the cross-section has a great influence on the bearing capacity of short columns of recycled concrete, and the bearing capacity of square cross-section is better than that of circular cross-section because the bearing area of square cross-section is larger than that of circular cross-section, but the economy is worse than that of half-pack reinforcement; in half-pack reinforcement, two-layer CFRP reinforcement is better than that of CFRP+BFRP.

Conclusion：The compressive strength and axial compressive strength of concrete decreased with increasing the amount of recycled coarse aggregate admixture, and the changes tended to be consistent. The addition of various appropriate amounts of fibers can significantly improve the compressive strength of recycled concrete and slow down the expansion and development of cracks. However, the existing studies are not more specific and detailed in terms of the number of fibers, their length, and the specific directional location of incorporation into the recycled concrete.

C. Flexural strength

In the performance of mechanical properties of recycled concrete incorporated with fibers, the flexural strength was also significantly improved, and Zhu Hongbing [5] et al. showed that the flexural fatigue life of recycled concrete could be significantly improved with the addition of polypropylene fibers. At the same loading stress level, the fatigue life of recycled concrete with the addition of polypropylene fibers was significantly improved compared with that of ordinary recycled concrete, and the greater the incorporation of polypropylene fibers, the more obvious the improvement of fatigue life. Liu C [8] modified the formula for calculating the flexural strength of steel fiber concrete proposed by Gao Danying and obtained the formula f f=0.776rmft(1+2.32Vfl/d)" rm was taken as 1.024 for steel fibers with different admixtures. Zhu Haitang [20] investigated the effects of steel fiber concrete layer thickness, steel fiber volume fraction and BFRE reinforcement rate on the flexural damage pattern of BFRE-reinforced steel fiber high-strength concrete beams and their bearing capacity and found that the flexural bearing capacity of the test beams gradually increased when the steel fiber concrete layer thickness was increased from 0.30 times the section height to 0.43 and 0.57 times, but the changes were not significant. However, when the thickness of the steel fiber concrete layer increased to 300 mm of the full cross-section, the flexural bearing capacity increased to a larger extent. The increase in volume fraction of steel fibers has a significant enhancement effect on the flexural load capacity of the test beam, and the volume fraction of 0.5%-2.0% steel fibers increases the flexural load capacity of the test beam by 19.2%-30. 71%; increasing the reinforcement rate of BFRE steel bars is an effective method to improve the flexural load capacity of BFRE steel fiber high-strength concrete beam, compared with the test beam with reinforcement rate of 0.56% The flexural load capacity of the test beams with reinforcement ratio of 0.77% to 1.65% was improved by 11.92% to 39.41%.

V. CONCLUSION

Recycled concrete technology can fundamentally solve the problem of waste concrete outlets, not only to reduce the pollution of the environment from waste concrete, but also to save natural aggregate resources, ease the contradiction between aggregate supply and demand, reduce natural resources and energy consumption, with significant social, economic and environmental benefits, in line with the requirements of sustainable development, is one of the main ways to develop green concrete. The study of the practical application of recycled concrete should not only be studied to improve the strength of recycled concrete, but also its durability, such as impermeability, wear resistance and carbonation resistance, so as to gradually achieve high performance of recycled concrete. There are big differences between recycled concrete and ordinary concrete in raw materials, matching ratio and construction process, the existing ordinary concrete standards and regulations are not suitable for recycled concrete, on the other hand, because

there are differences in composition and performance between cement and aggregate used abroad, so the relevant foreign standards cannot be used directly. It is recommended to combine the establishment of recycled aggregate grading standards and develop relevant standards and protocols for recycled concrete suitable for the domestic situation.

The basic mechanical properties of recycled concrete are slightly worse than those of ordinary concrete, as shown by the decrease in cubic compressive strength, axial compressive strength, compressive modulus of elasticity and splitting tensile strength with the increase of recycled coarse aggregate admixture. Fiber incorporation can significantly improve the above basic mechanical properties, the type of fiber, the amount of incorporation, incorporation method, etc. on the basic mechanical properties of recycled concrete improve the role of different. The existing research on fiber-blended recycled concrete is still insufficient, and the research on the mechanical properties of fiber type, incorporation combination type, incorporation method, bending degree, etc. is not in-depth.

VI. DEVELOPMENT DIRECTION

Fiber recycled concrete, as a new environmentally friendly construction material, makes use of the strengthening, crack resistance and toughening effects of fibers to make up for the defects of recycled concrete to a certain extent, and provides a new direction for the recycling of construction waste. This paper discusses and analyzes the advanced research results at home and abroad in recent years in terms of mechanical properties and durability performance of fiber recycled concrete, and proposes the following research directions on this basis：

(1) Recyclable solid construction waste in China mainly consists of waste concrete and waste bricks. Current research is mainly focused on recycled concrete aggregates, while little research on recycled brick aggregates has been reported. It is important to carry out research related to recycled brick aggregate and brick-concrete mixed aggregate concrete.

(2) Further strengthen the research on mechanical properties and durability of non-metallic fiber and mixed fiber recycled concrete to enrich and develop theoretical research and engineering applications of recycled concrete.

(3) At present, recycled concrete is mainly used in low-grade pavement, fiber recycled concrete in this practical engineering applications have more superiority, according to the "Highway Engineering Cement Concrete Test Procedure", should also increase its wear resistance test, flexural elastic modulus test and impact resistance test research.

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