Research Status of Mechanical and Fracture Properties of Steel Fiber Reinforced Recycled Aggregate Concrete

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Abstract

A large amount of old mortar is attached to the surface of recycled aggregate, which has a significant deterioration effect on the mechanical and fracture properties of recycled concrete, leading to a decrease in peak load and an increase in brittleness of recycled aggregate concrete. Adding steel fibers to recycled aggregate concrete can effectively improve its own strength, reduce the formation and development of microcracks, and improve toughness.

Keywords

Recycled Aggregate, Mechanical Properties, Fracture Performance, Steel Fiber.

1. RESEARCH STATUS OF RECYCLED AGGREGATE CONCRETE

The strength of recycled aggregate concrete (RAC) is often lower than that of natural concrete [1, 2], due to the fact that the surface of recycled aggregate inside often adheres to old mortar and there are many small cracks inside. The inherent defects of recycled aggregate result in more micro cracks and harmful pores inside RAC, which converge, extend, and expand with pores during the stress process, forming macroscopic cracks [3-5]. Recycled aggregates can form more complex and diverse interface transition zones inside concrete[6,7], which is also one of the main reasons for the deterioration of its mechanical properties. In ordinary concrete, there is only one interface: the transition zone between the aggregate and cement slurry. There are three interfaces in RAC, namely: the old interface between aggregate and old mortar, the new interface between aggregate and new mortar, and the new interface between old mortar and new mortar. Among them, the interface between new and old mortar is the weakest interface.

The current research generally believes that the replacement rate of recycled coarse aggregate less than 30% has little impact on the mechanical properties of concrete [8-10]. Guo Zhanggen et al. [11] showed that when natural sand and gravel are completely replaced by recycled coarse aggregate and recycled sand, the compressive strength of RAC is only 58% -64% of that of natural aggregate concrete; Li Yuefeng et al. [12] showed that the RAC compressive strength of the double mixed recycled coarse and fine aggregates decreased more significantly. When the replacement rate of recycled coarse and fine aggregates was 25%, the maximum compressive strength of the test block reached 37.6 MPa; Hu Qiong[13] et al. conducted experimental research on the basic mechanical properties of RAC and found that the compressive strength and tensile strength of the cube specimens were lower than those of ordinary concrete. Xiao Jianzhuang [14] studied the effect of different replacement rates of recycled coarse aggregate on the compressive strength of RAC, and also proved that when the replacement rates of recycled coarse aggregate are 30%, 70%, and 100%, the compressive strength of RAC at 28 days only reaches 76%, 72%, and 70% of the average strength of ordinary concrete.

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2. RESEARCH PROGRESS ON MECHANICAL PROPERTIES OF STEEL FIBER REINFORCED RECYCLED AGGREGATE CONCRETE

Adding short steel fibers into RAC is called steel fiber reinforced recycled aggregate concrete (SFRRAC). Steel fiber can compensate for the performance degradation of RAC caused by its own aggregate defects, and in some cases, it can bring reinforcement effects beyond natural concrete. Adding fiber materials to concrete materials can significantly improve the toughness of the material, making the damage of fiber reinforced recycled aggregate concrete specimens exhibit continuous cracking. The toughening mechanism of fiber reinforced recycled aggregate concrete is mainly determined by two aspects [15]: firstly, the strength of the fiber itself; The second is the bonding ability between fibers and concrete. The amount, variety, and morphology of fibers will have varying degrees of impact on the performance of recycled aggregate concrete materials.

Erdem S et al. [16] showed that the addition of steel fibers has little effect on the compressive strength of recycled aggregate concrete, and even deteriorates, which is due to the uneven distribution of fibers in the recycled aggregate concrete matrix. Further analysis was conducted on the mechanism by which steel fibers improve the mechanical properties of RAC. Steel fibers increase the initial crack load, initial crack strain, and peak load of RAC, significantly increasing the peak strain and impact strength of RAC, and enhancing energy absorption.

Zong et al. [17] showed through experiments that recycled aggregates and steel fibers have a significant impact on mechanical properties, and internal defects in concrete caused by the use of recycled coarse aggregates can be compensated by adding steel fibers. As the volume fraction of steel fibers increases from 0% to 1.8%, compared to RAC, the tensile strength and peak strain increase by 10.41% -55.90% and 9.70% -48.03%, respectively. In addition, the energy absorption capacity of SFRRAC is 5.71-13.31 times higher than that of RAC.

Sunita Kotwal [18] explored the effects of recycled coarse aggregate as a partial substitute for coarse aggregate and the addition of steel fibers on the performance of self compacting concrete. When different amounts of recycled aggregate from 0% to 50% are used instead of coarse aggregate, the 28 day tensile strength of the concrete mixture increases linearly from 2.84 MPa to 3.31 MPa. As the proportion of steel fibers increases, the splitting tensile strength of all SFRRACs increases.

Lou Zhihui et al. [19] conducted research on SFRRAC, and the results showed that with the increase of steel fiber content, the compressive strength and flexural strength of RAC were significantly enhanced. Steel fiber can effectively strengthen the flexural strength of RAC. By comparing the uniaxial compression tests of SFRRAC under different sizes, it was found that at the same stress level, with the increase of steel fiber diameter, the load displacement curve of SFRRAC under stress showed a trend of first gentle, then steep drop, and then stable. The reason is that compared to natural concrete, with the increase of specimen size, the probability of internal pores and defects in RAC increases; Steel fibers can significantly improve the fracture toughness of RAC, with the cutting type steel fibers having the best strengthening effect and significantly improving the fracture energy of RAC; Compared to pebble concrete, steel fibers have a more significant reinforcement effect on RAC.

Chen Aijiu et al. [20] studied the influence of two parameters on the compressive strength of concrete, namely the replacement rate of recycled aggregate and the amount of steel fiber. Research has shown that with the increase of recycled aggregate and steel fiber content, the slump of the concrete mixture gradually decreases. The compressive strength of RAC decreases with the increase of recycled aggregate proportion, and increases with the increase of steel fiber. The optimal dosage of recycled aggregate and steel fiber is analyzed, and SFRRAC with good

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workability is prepared, which meets the strength requirements and is more economical and reasonable.

Gao Danying et al. [21] conducted SFRRAC compressive strength test research: adding steel fibers to the sample improved the cubic compressive strength of RAC, but the effect was minimal. After ensuring no interference factors, the compressive strength of steel fiber natural concrete remained slightly higher, and the effect of size effect coefficient on the compressive strength of steel fiber concrete and SFRRAC cubic was not significantly different.

Yang Runnian [22] conducted comparative tests on compression, splitting, and four point bending, and found that after adding steel fibers, the bearing capacity of concrete was improved. The performance of SFRRAC is superior to that of steel fiber pebble concrete, with compressive strength, splitting strength, and 4-point bending ultimate strength increased by 26%, 18.1%, and 14.5%, respectively. Plain concrete has stronger brittleness, and when it reaches its ultimate bearing capacity, the test block instantly fails. Steel fiber reinforced concrete exhibits ductile failure, with a longer descent section. After the test piece fails, the overall integrity is good; Compared with ordinary concrete, steel fiber reinforced concrete has better mechanical and durability properties.

3. STUDY ON THE FRACTURE PERFORMANCE OF STEEL FIBER REINFORCED RECYCLED AGGREGATE CONCRETE

By adding steel fibers to RAC in a certain proportion, the tensile improvement effect of steel fibers can be exerted, which can compensate for some defects in recycled aggregates, improve the fracture performance of RAC, and improve the stress structure and deformation performance of RAC. Research has shown that compared to recycled aggregate concrete beams without adding steel fibers, SFRRAC beams have stronger bearing capacity, greater stiffness, smaller deflection, and significantly improved crack resistance [23]. Their various performance can reach the level of natural aggregate concrete beams [24], and the overall cost is lower than ordinary concrete beams [25].

Kong Xiangqing et al. [26,27] tested the mechanical and fracture properties of RAC with single addition of steel fiber, single addition of polypropylene fiber, and fiber mixing. An increase in steel fiber content usually brings significant improvements to the basic mechanical properties of RAC. Compared with ordinary RAC, when the steel fiber content is 117 kg/m3, the strength of hybrid fiber recycled aggregate concrete reaches its highest point, with a 17.68% increase in cubic compressive strength, a 57.88% increase in splitting tensile strength, and a 28.32% increase in flexural strength. It was also found that with the increase of steel fiber content, the splitting tensile stress and elastic modulus of RAC showed a trend of first increasing and then decreasing. Increasing the aspect ratio of steel fibers will improve the mechanical properties of RAC, while the aspect ratio of polypropylene fibers has no significant impact on the strength of fiber reinforced recycled aggregate concrete [28].

From the failure morphology, it can be seen that the incorporation of fibers can significantly enhance the ductility of RAC. In the three-point bending test, regardless of whether the steel fiber and polypropylene fiber are single or co doped, the RAC specimen has been improved to varying degrees in terms of fracture toughness and fracture energy. When the steel fiber content reaches a certain level, the larger the polypropylene fiber content, the higher the peak load and fracture toughness of the specimen, and the higher the fracture energy; However, when the steel fiber content reaches 1.0% and 1.5%, as the polypropylene fiber content increases, the peak load, fracture toughness, and fracture energy of the specimen show a trend of first increasing and then decreasing. When the volume content of steel fiber is 1.5% and the polypropylene fiber content is 0.9%, it is most ideal to improve the RAC fracture performance. Nano SiO2 has a certain improvement effect on the microstructure of cement hydration products, making the

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hydration products wrapped in steel fibers more dense. When the steel fibers are pulled out or pulled out, there will be a greater resistance. As a result, the interfacial bonding strength between steel fibers and nano SiO2 concrete matrix is improved, and the crack resistance, strengthening, and toughening effects of steel fibers are more fully utilized [29].

A similar phenomenon was also observed in Zhu Haitang's fiber reinforced high-strength concrete [30]. Polypropylene fibers and higher amounts of special-shaped steel fibers (cut and shear types) often bring negative hybrid effects, but when mixed with the same proportion of milled steel fibers, it shows an improvement in the fracture performance of the specimen, with a 20.3% increase in fracture energy gain compared to single steel fibers, indicating that polypropylene fibers and milled steel fibers have a better joint effect.

The incorporation of fibers in RAC creates a certain area of fiber bonding in the front of the crack, which increases the crack propagation resistance [31-33]. This results in the need to overcome both the resistance in the main crack plane and the resistance in the non main crack plane caused by fiber extraction during crack propagation, resulting in a significant increase in the fracture energy, fracture toughness, and ductility index of the specimen. However, in the case of excessive fiber content, internal agglomeration occurs, Thus, an unfavorable interface is formed, which affects the mechanical properties and fracture properties of concrete structural mechanics.

Under the action of freeze-thaw cycle, a lot of damage and destruction occurred in the concrete specimen. The free water in the concrete material caused expansion pressure and seepage pressure, which led to the concrete exfoliation damage, the internal structure became loose and deteriorated, which led to the reduction of fracture performance of the specimen. The whole loading process of concrete beams with cracks under freeze-thaw conditions is analyzed by using the theory of fracture mechanics. The fracture energy shows a monotonic decreasing trend with the number of freeze-thaw cycles, and there are a large number of micro cracks inside, which prolongs the time from cracking to failure of the concrete. Therefore, the working ability of the concrete after cracking is improved, and the ductility is improved [34,35]. After experiencing multiple low-temperature freeze-thaw cycles, the frost resistance of the specimen significantly decreases. When concrete is subjected to high temperature treatment, a similar situation occurs [36]. Under the action of high temperature, the internal damage of the concrete occurs, which weakens the load-bearing capacity of the concrete specimen, but on the other hand, the deformation capacity of the concrete specimen is also improved, reflecting the pseudoplastic characteristics.

The content of coarse aggregate in concrete materials has a certain impact on the fracture performance of the specimen. According to the P-CMOD curve, for concrete with a water cement ratio of 0.62 and 0.43, the fracture process is mainly characterized by the detachment of coarse aggregate and cement mortar. The content of coarse aggregate increases from 50% to 60%, and the compressive strength of the specimen increases, resulting in an enhanced bond between the aggregate and mortar [37]. When the volume of aggregate continues to increase to 70%, the spacing between coarse aggregates decreases, and the thinning of the mortar layer is not conducive to anchoring individual aggregates in the matrix. As the particle size of the fine aggregate increases, the interfacial bonding effect increases, and the tensile strength of the sample decreases. When the water cement ratio is 0.3, the strength of the concrete matrix is higher, and the fracture crack passes through the aggregate with a smooth cross-section. At this time, the influence of aggregate content on the P-CMOD curve is not significant.

4. EXISTING PROBLEMS

(1) The strength of RAC will significantly deteriorate with the increase of recycled aggregate content, resulting in a low utilization rate of recycled aggregate in actual construction sites, poor

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recycling efficiency for waste concrete, and relatively limited research on high volume recycled aggregate concrete, lacking experimental data for engineering reference.

(2) Steel fibers can enhance, toughen, and crack resistance concrete materials, making up for the significant negative impact of recycled aggregate on RAC performance. However, it is unclear whether a large amount of recycled aggregate has an inhibitory effect on steel fibers when the replacement rate of recycled aggregate further increases.

(3) There is relatively little research on the fracture performance of steel fiber reinforced recycled aggregate concrete precast crack notched beams. The mechanism of steel fiber strengthening the fracture toughness of RAC needs further research, and the negative impact of recycled aggregate on the reinforcement effect of steel fiber is still unclear.

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