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Experimental Study on The Influence of Aggregate Strengthening on The Mechanical Properties of Steel Fiber Reinforced Recycled Aggregate Concrete

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Abstract

The influence of the replacement ratio of recycled fine aggregate, the content of steel fiber and the carbonation strengthening of aggregate on the mechanical properties of recycled aggregate concrete is discussed through the cube compression test. The change trend of the basic mechanical properties of recycled aggregate concrete under different replacement rates of recycled aggregate and different amounts of steel fiber is analyzed. The results show that the compressive strength of recycled aggregate concrete is significantly enhanced by steel fiber, and compared with the carbonation of recycled fine aggregate, the carbonation of recycled coarse aggregate can bring more significant improvement to the steel fiber recycled aggregate concrete. The replacement rate of carbonated reinforced recycled coarse aggregate is 50%, the replacement rate of recycled fine aggregate is 20%, and the compressive strength reaches 84.85% of that of natural concrete when the content of steel fiber is 1%. It provides data support for the engineering application of steel fiber reinforced recycled aggregate concrete.

Keywords

Recycled aggregate concrete; Steel fiber; Cube compressive strength.

1. INTRODUCTION

With the rapid development of China's construction industry in recent years, new buildings are being built and old buildings are being abandoned, resulting in increasingly serious problems with the disposal of construction waste, while the exploitation of natural resources such as sand and gravel is a huge burden on the ecological environment. Therefore, the recycling of construction waste and the use of recycled aggregates in construction are of great significance to the construction of green buildings and the realisation of the goal of "double carbon".

Recycled aggregates are made by crushing and sieving waste concrete into recycled aggregates and replacing all or a certain proportion of natural sand and gravel materials to make recycled aggregates concrete (RAC). As the surface of recycled aggregates is often adhered to old mortar, its crushing value, apparent density, water absorption and other performance is inferior to that of natural aggregates [1, 2]， so recycled concrete often shows low strength and poor durability compared to natural concrete [3-5]。The test results of Ding [6] and others showed that the cubic compressive strength of the test blocks decreased with the increase of the amount of recycled fine aggregate when the replacement rate of recycled coarse aggregate was 70%, and when the replacement rate of recycled fine aggregate reached 40%, its strength was 87.4% of that of natural concrete. Xiao [7]varied the amount of recycled fine aggregate admixture to derive the normal distribution probability density curve of compressive strength, and pointed out that the replacement rate of recycled fine aggregate should not be greater than

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30%. In order to solve the various defects of RAC, scholars at home and abroad have used different types of fibres to strengthen RAC[8-11]，The bridging effect of steel fibres can effectively limit the generation and expansion of voids and microcracks inside RAC, which can significantly improve the toughness, ductility and crack resistance of RAC[12-14]。Carbonation strengthening of recycled aggregates can improve their internal structure, resulting in better strength and compactness of recycled concrete [18,19]。

2. TEST OVERVIEW

2.1. Testing raw materials

The cement used for the test was P-O 42.5 grade cement, the natural fine aggregate (NFA) was river sand with a fineness modulus of 2.9, the natural coarse aggregate (NCA) was continuously graded crushed stone, the recycled coarse aggregate (RCA) and recycled fine aggregate (RFA) were taken from waste concrete and made by crushing and screening, the water used for the test was tap water, the carbonation process was carbonation under pressure after soaking in saturated calcium hydroxide solution, the properties of the aggregate and steel fibres are shown in Tables 1 and 2. the water reducing agent was a composite type The above test materials are all from the same batch.

Table 1. Aggregate properties

Type	Gradation/(mm)	Apparent density /(kg/m^3)	Water absorption/(%)	Crushing value/(%)
NCA		2673	1.3	14.77
RCA	4.75~20	2544	8.9	22.8
CRCA		2620	7.5	20.4
NFA		2638	1.16	11.77
RFA	0.15~4.75	2550	8.57	27.65
CRFA		2570	7.33	25.66

CRCA is carbonized recycled coarse aggregate and CRFA is carbonized recycled fine aggregate.

Table 2. Properties of steel fiber

Type	Average length/(mm)	ratio	Density /(kg/m^3)	Tensile strength/(MPa)
Milled corrugated steel fiber	38	42	78.5×10^3	>600

2.2. Test program and ratio design

This paper focuses on the laws of the effects of recycled coarse replacement rate, fine aggregate replacement rate, steel fiber dosing and aggregate reinforcement on the basic mechanical properties of recycled concrete. In the test, three substitution rates of 0%, 20% and 40% were used for recycled fine aggregate, 50% one substitution rate was used for recycled coarse aggregate, and three substitution rates of 0.5%, 1.0% and 1.5% were used for steel fiber admixture. The design of eight test groups including compressive test 100mm × 100mm × 100mm test blocks three groups each, test grouping is shown in Table 3 .

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The concrete ratio design calculation refers to JGJ55-2011 .water-cement ratio of 0.50, sand rate of 34.5%, all test blocks slump control between 30 ~ 180mm, the base ratio is shown in Table 4 .

Table 3. Test groups

number	recycled coarse replacement rate /(%)	fine aggregate replacement rate /(%)	steel fiber dosing /(%)
NC	0	0	0
R50-0-0.5	50	50	0
R50-20-0.5	50	70	0
R50-20-1	50	100	0
R50-20-1.5	70	50	0
R50-40-1	70	70	0
R50-C20-1	70	100	0
RC50-20-1	100	50	0

R50-0-0.5 indicates that the replacement rate of recycled coarse aggregate is 50%, the replacement rate of recycled fine aggregate is 0, and the dosing of steel fiber is 0.5%; R50-C20-1 indicates that the replacement rate of recycled coarse aggregate is 100%, the replacement rate of carbonized recycled fine aggregate is 20%, and the dosing of steel fiber is 1%; RC50-20-1 indicates that the replacement rate of carbonized recycled coarse aggregate is 50%, the replacement rate of recycled fine aggregate is 20%, steel fiber dosing is 1%.

Table 4. Mix design of concrete foundation

Water/(kg/m^3)	Cement/(kg/m^3)	Coarse Aggregate /(kg/m^3)	Fine Aggregate/(kg/ m^3)	Water Reducer/(kg/m^3)
200	398	1177	620	0.86

2.3. Test block production and maintenance

During the test block pouring process, a uniform feeding sequence and mixing time were used, and strict quality control was adopted for the raw materials to ensure the accuracy of the test data. Hydrophobic material was applied inside the mold to ensure the integrity of the test block when it was demolded. After the test blocks were poured, they were left to stand for 24 hours in an indoor environment at 15-25°C, and then demolded and numbered with a marker for record purposes. The maintenance time is 28 days.

2.4. Test equipment and test methods

The test blocks were tested on a maximum 3000kN electro-hydraulic servo universal material testing machine. The test process is carried out with reference to GB/T 50081-2019.

3. TEST RESULTS AND ANALYSIS

3.1. Test procedure and damage pattern

At the initial stage of compressive damage, there is no obvious crack in the natural concrete specimen, when close to the peak load, fine cracks appear on the prongs of the specimen perpendicular to the compressive surface, with the increase of load, the tiny cracks gradually increase and become dense, cracking is more serious and accompanied by the phenomenon of touching and breaking, the tiny cracks cross converge to form a gap and gradually lose bearing capacity, due to the existence of the hoop effect, the final damage form of the specimen often

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show hourglass shape. Due to the bridging effect of steel fibers, the cracks of the specimens mixed with steel fibers are relatively late, mainly concentrated near the main cracks, and the specimens are more complete throughout the process, without the phenomenon of large pieces of spalling, and the overall shape is close to columnar, showing a cracked but not broken form, as shown in Figure 1.

Figure 1. Compression eailure pattern of steel fiber reinforced recycled concre

3.2. Factors influencing the compressive strength of the cube

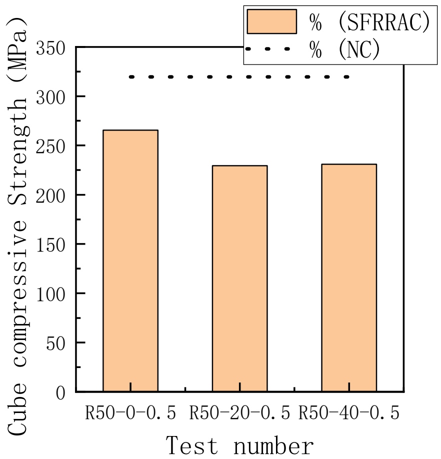

Figure 2. Effect of recycled fine aggregate on cube compressive strength of steel fiber reinforced recycled aggregate concrete

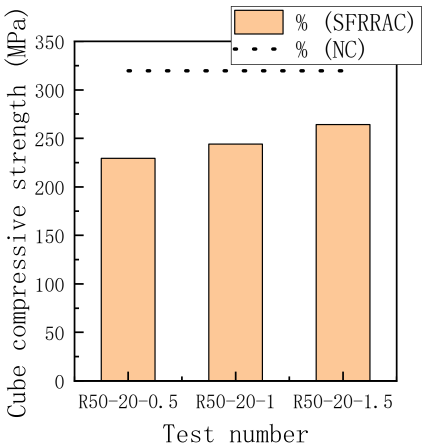

Figure 3. Effect of steel fiber content on cube compressive strength of steel fiber reinforced recycled aggregate concrete

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3.2.1 Recycled Coarse Aggregate

The reason for this situation is mainly because of the old mortar attached to the surface of recycled coarse aggregate, resulting in higher crushing value and water absorption of recycled coarse aggregate compared to crushed stone, and, inevitably, tiny cracks will appear on the surface of recycled coarse aggregate during the production and processing process, which will continuously extend, converge and expand in the process of concrete stressing, eventually forming macro cracks and making concrete lose its bearing capacity. The admixture of recycled coarse aggregate leads to more and more complex interfacial transition zone inside the concrete, and the skeleton formed by the aggregate inside constitutes an uneven strength of the material, which intensifies the stress concentration when stressed and creates more weak links, resulting in the test block being more easily damaged.

3.2.2 Recycled Fine Aggregate

Recycled fine aggregate has many defects compared to natural river sand: 1. Recycled fine aggregate is made of waste concrete crushed particles of 0.15-4.75mm in size, its composition has small particles of gravel, old mortar particles, river sand and old mortar formed particles, gravel and old mortar formed particles, compared to natural river sand, the homogeneity of recycled fine aggregate is worse; 2. Complex, resulting in more types of interface transition zone inside the recycled concrete, the situation is more complex, more likely to form cracks in the process of stress; 3. A large number of old mortar in the recycled fine aggregate makes it higher crushing value and greater water absorption compared to natural river sand, resulting in a decrease in the strength of the new mortar formed by fine aggregate and cement. Inside the concrete structure, as the compressive strength of the mortar decreases, it is more likely to produce tiny cracks during the compression process, and the cracks are rapidly expanded and thus destroyed by the stress concentration (as shown in Figure 2).

3.2.3 Steel fibers

The overall compressive strength of the recycled concrete was improved after the incorporation of steel fibers (Figure 3), which is due to the ability of steel fibers to limit the tiny cracks as well as voids formed by shrinkage during the curing of concrete materials, and also to limit the expansion and extension of cracks, so that the compressive strength of the specimens was improved to a certain extent. As the replacement rate of recycled fine aggregate increases, the negative factors in the concrete matrix accumulate, and the admixture of recycled fine aggregate also changes the bonding environment inside the steel fiber regenerated concrete, which makes the concrete matrix more prone to damage when subjected to load, resulting in the failure of the bond between the steel fiber and the concrete matrix and the loss of bearing capacity of the specimen.

3.2.4 Aggregate Carbonation

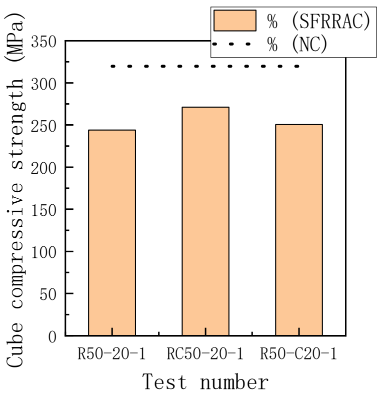

Figure 4. Effect of aggregate carbonization reinforcement on cube compressive strength of steel fiber reinforced recycled aggregate concrete

After carbonation strengthening of recycled coarse and fine aggregates, the cubic compressive strength of the test blocks was increased to different degrees, where the carbonation of recycled coarse aggregates had a greater lifting effect than that of recycled fine aggregates (e.g. Figure 4). The high porosity and high water absorption of the recycled aggregate lead to the formation of connected pores inside the recycled concrete more easily. The carbonation process of concrete is exactly carbon dioxide, dissolved in the water of the capillary, and reacts with each other with calcium hydroxide and hydrated calcium silicate formed by cement hydration, and finally calcium carbonate is formed. Calcium carbonate clogged in the pores, so that has been carbonated concrete denseness and strength slightly increased. The strengthening process is as follows.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

$$C - S - H + CO_2 \rightarrow CaCO_3 + SiO_2 \cdot nH_2O$$

$$3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O + 3CO_2 \rightarrow Al_2O_3 \cdot nH_2O + 3CaCO_3 + 3(CaSO_4 \cdot 2H_2O) + (26 - x)H_2O$$

$$3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 18H_2O + 3CO_2 \rightarrow Al_2O_3 \cdot nH_2O + 3CaCO_3 + CaSO_4 \cdot 2H_2O + (16 - x)H_2O$$

4. CONCLUSION

(1) The replacement of natural sand and gravel materials by recycled coarse aggregate and recycled fine aggregate resulted in a more significant decrease in the basic mechanical properties of the concrete materials, and the greater the decrease with the increase in the replacement rate.

(2) The compressive strength of recycled concrete was significantly improved by adding steel fibers, which increased by 15.17% compared with 0.5% at 1.5%.

(3) Carbonated reinforced recycled coarse aggregate and recycled fine aggregate specimens cubic compressive strength increased, respectively, to 84.85% and 78.34% of natural concrete

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