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Original scientific paper

Experimental Study on Mechanical Properties of Recycled Concrete with Artificial Sand

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Abstract: With the rapid development of the global construction industry, not only a large amount of construction waste has been derived, but also a growing shortage of natural sand resources emerges. Aiming at the above problems, this study uses waste concrete and artificial sand as recycled coarse and fine aggregates to form a new type of recycled concrete. 135 standard cubes and prismatic test blocks were produced. Concrete mixtures were prepared with recycled concrete aggregate and artificial sand to fully replace natural aggregates. This study investigates the mechanical properties of recycled concrete containing artificial sand and polypropylene fibers. Polypropylene fiber content varied from 0-1.5% by mass. Experimental results showed the addition of fibers enhanced the compressive strength and ductility. The optimum fiber dosage was 0.6% for strength gain. However, elastic modulus decreased with increasing fiber content due to increased porosity. The findings demonstrate the feasibility of recycled concrete with artificial sand and polypropylene fibers as an environmentally-friendly construction material.

Keywords: artificial sand; mechanical properties; polypropylene fibre; recycled concrete

1 INTRODUCTION

The recycled coarse aggregate is generated after crushing, washing and manual screening the waste concrete. Recycled aggregate concrete (RAC) refers to the concrete prepared by the recycled coarse aggregate which partially or fully replaces the natural coarse concrete. RAC technology is the fastest, the most direct and effective method to treat a large amount of construction waste, and it is also a hot spot in the current research on building materials [1-3]. Due to the obvious difference in material properties between recycled aggregate and natural aggregate, many scholars have made in-depth and systematic research on RAC. Achtemichuk et al. [4] studied the strength of original concrete, the replacement rate of recycled aggregate, and the mix proportion of recycled concrete by means of tests. The results of relevant papers show that it is feasible to replace natural aggregate with recycled aggregate, but the increase of interface area caused by old cement on the surface of recycled aggregate and the increase of micro-cracks in the aggregate caused by secondary crushing will lead to poor aggregate performance [5-10]. These defects must be paid attention to when studying the performance of recycled concrete. Alexandridou et al. [11] studied the durability of recycled concrete [12-14]; Zegacj et al. [15] studied the high-temperature performance of recycled concrete. In order to improve the performance of recycled concrete, relevant scholars added fiber into recycled concrete to understand the improvement effect of fiber on recycled concrete [16-23]. The research shows that the fiber added to concrete has a certain positive effect, and the effect of improving the tensile strength is obvious compared with the compressive strength, and the fiber concrete has better ductility.

Natural sand, as the main fine aggregate of mixed concrete, also produces huge consumption every year. At present, the mode and method of mining natural sand have caused many environmental problems. Replacing natural sand with artificial sand, a by-product of mining rocks, provides a new idea for the sustainable development of the construction industry and is an effective way to solve the shortage of natural sand resources. Many scholars have actively conducted researches in this field [24-28], and the results show that it is feasible to replace natural sand with artificial sand.

The research on recycled coarse aggregate concrete and artificial sand concrete mentioned above is only a single research on aggregate substitution. With the sustainable development of the construction industry, the combination of recycled coarse aggregate and artificial sand and the full replacement of natural sand and gravel materials can simultaneously solve the two problems that need to be solved urgently, namely, the shortage of construction waste and natural materials. In order to study the working performance and mechanical properties of artificial sand recycled aggregate concrete and further promote the development of green concrete, this paper plans to use recycled coarse aggregate as coarse aggregate and artificial sand as fine aggregate. In the process of mixing concrete, a certain proportion of polypropylene fiber is added to form fiber artificial sand recycled concrete (ARC). 135 test pieces were designed and manufactured for basic mechanical performance test, to study the influence of fiber content on the mechanical properties of artificial sand recycled concrete, which provides a reference for the engineering application of artificial sand recycled concrete.

2 TEST OVERVIEW
2.1 Raw Materials

The waste concrete with a rebound strength of 46 Mpa is broken and sieved into secondary aggregates with a continuous particle size of 5~31.5 mm; the physical performance indicators are shown in Tab. 1. The fine aggregate is made of artificial sand. The content of stone powder of the undisturbed artificial sand is 9%.

Table 1 Physical properties of recycled coarse aggregate

Name	Particle size range/mm	Water absorption / %	Moisture content / %	Performance density / kg·m^{-3}	Bulk density / kg·m^{-3}
Recycled coarse aggregate	5-31.5	3	0.2	2615	1200

Table 2 Basic performance index of artificial sand

Name	Particle size range / mm	Specificiation	Performance density / kg·m^{-3}	Bulk density / kg·m^{-3}	Crush index / %
Artificial sand	0.15～4.75	Medium sand	2702	1581	21.3

The content of stone powder is larger for the artificial sand with larger particle size, the basic performance indicators are shown in Tab. 2. The fineness modulus is 3.02. The monofilament polypropylene fiber with a length of 20 mm is used, and the performance indexes are shown in Tab. 3. The Conch-brand P • O 42.5 ordinary Portland cement is used as the cementing material. The mixing water is tap water.

Table 3 The basic properties of polypropylene fiber

Name	Linear density / Dtex	Equivalent diameter/μm	Elasticity modulus / MPa	Strength of extension / MPa	Stretch limit / %	Melting point / ℃
Polypropylene fiber	4.72	26	3815	560	27	170

2.2 Test Piece Design and Preparation

In this test, the water cement ratio and fiber content are taken as variables, and three groups of water cement ratio, A (0.6), B (0.5) and C (0.4) are set, and each group of water cement ratio is mixed with polypropylene fiber as per five mass percentages, namely, 0 kg/m³, 0.6 kg/m³, 0.9 kg/m³, 1.2 kg/m³ and 1.5 kg/m³ to design and produce 135 test blocks. During the test, for each level, three 150 × 150 × 150 mm standard cube test blocks are used for cube compressive strength test, three 150 × 150 × 300 mm standard prism test blocks are used for axial compressive strength test and three 150 × 150 × 300 mm standard prism test blocks are used for elastic modulus test. Since a large number of old cement stones are attached to the surface of recycled coarse aggregate, additional water shall be added to the test water according to the water absorption. See Tab. 4 for the mix proportion. In order to make the fiber more evenly dispersed in the concrete, the dry mixing method was used to stir the material with a forced mixer. The feeding sequence is as follows: Put recycled coarse aggregate, artificial sand and polypropylene fiber into the mixer for mixing 60 S, add cement for mixing 120 S, and add water for mixing 120 S. After mixing, slump test, pouring molding and indoor resting are carried out. After 24 h, the film was removed and labeled, and the standard maintenance was carried out for 28 days.

Table 4 Mix ratio of polypropylene fiber-artificial sand recycled concrete

Sequence number	Material spending amount / kg·m^{-3}				
	Recycled coarse aggregate	Artificial sand	Cement	Water	Added water
ARCA	1132	755	308	185	33.96
ARCB	1204	648	363	185	36.12
ARCC	1193	588	463	185	35.79

Note: ARC stands for artificial sand recycled concrete, followed by letters representing water cement ratio A (0.6), B (0.5) and C (0.4).

3 TEST METHODS AND RESULTS

The test is conducted according to the provisions of *Standard for Test Methods of Mechanical Properties of Ordinary Concrete* (GB/T50081-2002), and the characteristic values of basic mechanical indexes of concrete made of polypropylene fiber-artificial sand recycled can be measured. See Tab. 5 for the results.

Table 5 Mechanical properties of recycled concrete made of polypropylene fiber sand

Test pieces	Cube compressive strength f_{cu} / MPa	Axial compressive strength f_c / MPa	f_c/f_{cu}	Elasticity modulus E_c / 10^3 MPa
ARCA00	26.7	23.3	0.87	26.7
ARCA06	28.7	25	0.87	25.4
ARCA09	28.2	24.3	0.86	25.1
ARCA12	28.4	23.3	0.82	25.2
ARCA15	30.9	24	0.78	24.3
ARCB00	37.3	32.3	0.87	30.5
ARCB06	38.9	33.9	0.87	29.5
ARCB09	37.3	32.4	0.87	27.8
ARCB12	39.6	32.9	0.83	27.4
ARCB15	38.5	33.5	0.87	26.5
ARCC00	48.7	41.5	0.85	30.9
ARCC06	50	43	0.86	31.1
ARCC09	48.2	42.2	0.88	30.5
ARCC12	48.7	41.2	0.85	28.8
ARCC15	49.7	42.1	0.85	28.1

Note: ARC stands for artificial sand recycled concrete, followed by letters representing water cement ratio A (0.6), B (0.5) and C (0.4), and the last two figures representing fiber content. For example, ARCB06 indicates that the water cement ratio of artificial sand recycled concrete is 0.5, and the fiber content is 0.6 kg·m^{-3}.

4 ANALYSIS OF TEST RESULTS

4.1 Influence of Fibre Content on Compressive Strength of ARC Cube

In order to directly reflect the influence of fiber content on the compressive strength of artificial sand recycled concrete cube, the test results are normalized by taking the test results with fiber content of 0 under unified conditions as the reference value, as shown in Fig. 1.

It can be seen from Fig. 1 that the water cement ratio and fiber content have influence on the compressive strength of artificial sand recycled concrete cube. In the area with high water cement ratio, after fiber is added, the growth rate of cube compressive strength is better than that in the area with low water cement ratio. The reason is that the fine aggregate in this test is artificial sand containing stone powder, and the stone powder has strong water absorption. When the water cement ratio is low, the actual water consumption in the concrete mixture decreases to a larger degree compared with that in the area with high water cement ratio. The uniformity and fullness of cement paste are affected, which increases the interface weak layer of aggregate. The influence of fiber on the cube compressive strength of artificial sand recycled concrete with different water cement ratio is different, but the overall rule is similar, that is, the cube compressive strength increases first, then decreases, and then increases with the increase of fiber content. The optimum fiber content for each water cement ratio strength increase is not consistent, but the fiber can all effectively improve the strength of concrete with different water cement ratio at a low fiber content of 0.6%.

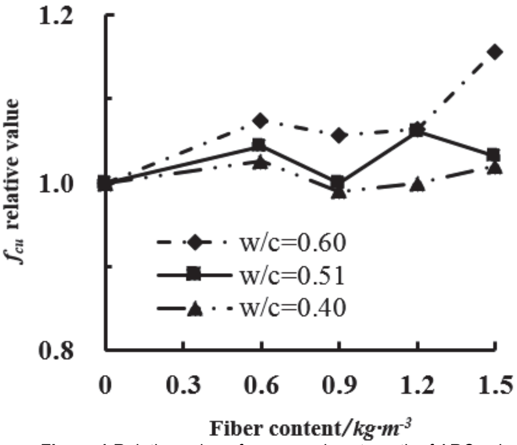

Figure 1 Relative value of compressive strength of ARC cube

4.2 Mechanical Property Index of ARC Prism
4.2.1 Analysis of the Influence of Fiber Content on the Axial Compressive Strength of ARC

The dimensional normalization results of the axial compressive strength of ARC prisms are shown in Fig. 2.

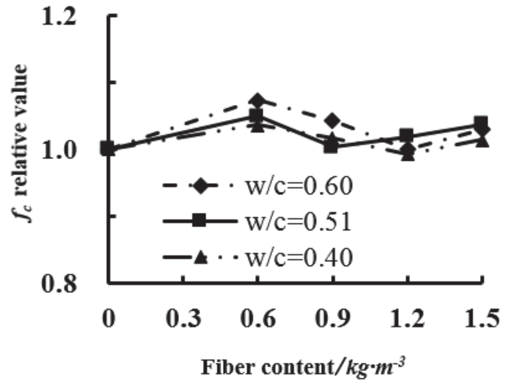

Figure 2 Relative value of ARC axial compressive strength

It can be seen from Fig. 2 that the influence of fiber content on the axial compressive strength of the three concretes with different water cement ratios in this test is similar. With the increase of fiber content, it generally shows a trend of first increasing, then decreasing, and then increasing. The maximum increase occurs when the fiber content is 0.6%, but the maximum increase is only 7%. It can be seen that the role of fiber content in improving the axial compressive strength of artificial sand recycled concrete is limited.

According to the results in Tab. 5, the ratio between the axial compressive strength and the cube compressive strength of fiber artificial sand recycled concrete ranges from 0.78 to 0.88, with an average of 0.85, which is slightly higher than that of ordinary concrete. The reason is that fiber, coarse and fine aggregates, and cement paste jointly play a role in the process of stressing, which enhances the ability of the specimen to resist transverse deformation and improves the performance of the concrete. The compressive strength and axial compressive strength of recycled concrete cube made of fiber artificial sand have been improved, and the axial compressive strength has been improved to a relatively larger degree, so the ratio between the two strengths is higher than that of ordinary concrete.

4.2.2 Analysis of Impact of Fiber Content on Elastic Modulus of ARC Prism

The values of elastic modulus in Tab. 5 are dimensionally normalized, and the result is shown in Fig. 3.

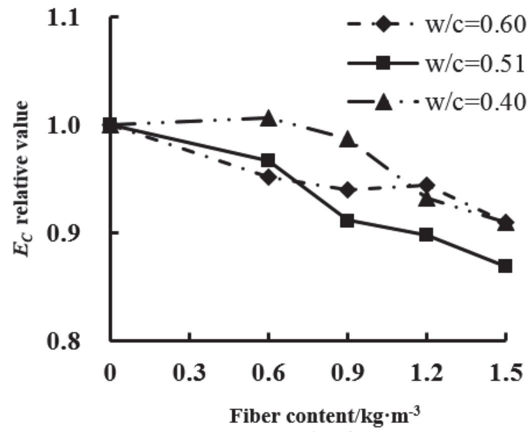

Figure 3 Relative value of ARC elasticity modulus

It can be seen from Fig. 3 that, under different water cement ratios, the elastic modulus of recycled concrete made of fiber and artificial sand generally decreases with the increase of fiber content. The reason is that in the concrete matrix, the fibers are uniformly distributed in random directions, which is equivalent to the formation of countless fine pores in the concrete. Due to the existence of a large number of pores, the effective area of the concrete section under pressure is reduced, resulting in the reduction of the elastic modulus of the concrete. The more fiber is added, the more the effective area of concrete section decreases, and the greater is the loss of elastic modulus.

Relevant research shows that the material properties of recycled coarse aggregate make the elastic modulus of fully recycled concrete lose nearly half compared with ordinary concrete, while the elastic modulus of artificial sand recycled concrete in this test decreases less than this value, because the artificial sand fine aggregate used in this test contains stone powder whose particle size is smaller than or equal to 0.075 mm, which belongs to micro aggregate. After mixing with recycled coarse and fine aggregate, the gap and crack are fully filled, the porosity decreases and the compactness increases, and the stress at the tip of the fine cracks inside the concrete is greatly improved, which is conducive to the relative improvement of the strength and elastic modulus of the concrete. On the other hand, the stone powder also has an activation effect. The calcium hydroxide and aluminate produced during the chemical reaction of cement and water in the concrete react with the calcium carbonate in the stone powder contained in the artificial sand, and the generated hydrated carboaluminate enhances the bond strength between the coarse and fine aggregates of concrete and the hydrated products.

5 CONCLUSIONS

This paper presented an experimental study on the mechanical properties of recycled concrete containing artificial sand and polypropylene fibers. The following conclusions were drawn from the test results.

(1) Polypropylene fiber can improve the compressive strength of recycled concrete with artificial sand, especially for low strength concrete. The optimum fiber content was 0.6% for strength gain.

(2) Polypropylene fiber can improve the axial compressive strength of recycled concrete. At each water cement ratio, the maximum increase in strength is only 7% when the low fiber content is 0.6%. The improvement capacity is limited.

(3) The elastic modulus of reclaimed concrete with three water-cement ratios involved in the test decreases gradually with the increase of fiber incorporation. Artificial sand recycled concrete with low water-cement ratio is the most sensitive to high fiber incorporation and has the largest loss of elastic modulus.

It can be seen from this experiment that recycled aggregate and artificial sand can fully replace natural aggregates to produce an environmentally-friendly concrete. The study supports use of waste materials to advance sustainable construction. Future research should explore the effects of additional parameters like aggregate quality, mixture design, and curing conditions on the properties of this eco-friendly concrete. Microstructural analysis can provide insights into the reinforcing mechanisms of fibers.

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