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Research Article

Analysis of the Effect of Substitution Rate on the Mechanical Properties of Recycled Concrete Hollow Block

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In this paper, to study the compressive and flexural properties of recycled concrete hollow blocks, the quality substitution rate of recycled fine aggregates is taken as a variable parameter, and four kinds of substitution rates are designed, which are 0%, 30%, 60%, and 100%. At the same time, one kind of recycled coarse and fine aggregates is designed, and the quality substitution rate is 100%. 110 specimens of MU10 and MU7.5 strength grades are tested for compressive and flexural strength. The failure process and morphology of the specimens are observed to obtain compressive and flexural strength. Based on the test data, the relationship between compressive and flexural strength of recycled fine aggregates with different replacement ratios is analyzed in detail. The main findings are that experiment results show the compressive and flexural strength decrease with the increase of substitution rate of recycled fine aggregates under the same other conditions. The work of the paper is a new reform for the source of raw materials for wall materials, and it is a new way for the reuse of concrete garbage and has important environmental protection significance and engineering practical significance for building energy saving.

1. Introduction

With the advancement of urbanization and frequent occurrence of natural disasters such as earthquakes and typhoons, the number of abandoned construction waste increases gradually every year, which seriously pollutes the environment. How to turn waste into treasure has become one of the hotspots of current research. Research on the manufacturing technology of the recycled concrete hollow block plays an important role in the reuse or even multiple use of concrete waste in a demolition site. At present, China has published the national standard recycled coarse aggregate for concrete, recycled fine aggregate for concrete and mortar, and the construction industry standard technical specification for application of recycled aggregate. There are few studies on recycled fine aggregate wall masonry materials, of which some are still under experimental study, while some of them have been studied.

Existing research shows that the strength of recycled concrete is lower than that of original concrete, but it can fully meet the strength requirements of the concrete hollow block. So it is reasonable to use recycled concrete to make the recycled concrete hollow block. Some scholars in domestic and overseas have studied the basic physical and mechanical properties of recycled concrete hollow blocks. Many universities and research institutes in domestic and overseas have carried out a series of research on recycled aggregates and have successively developed recycled concrete technology and basic mechanical properties of recycled coarse and fine aggregate wall masonry materials. Hou et al. [1] of Tongji University produced the recycled aggregate from waste concrete blocks, replaced natural gravel or pebble with the recycled coarse aggregate and natural fine aggregate with recycled aggregate, and replaced natural sand, stone, or recycled fine aggregate with recycled aggregates. The recycled concrete had higher strength and better environmental and economic benefits. Yuan et al. [2] used fly ash as active admixture and demolished broken bricks and mortar as recycled aggregates to make small hollow concrete blocks. It was found that the test strength of concrete can meet the production requirements, the strength of concrete can be significantly improved by properly reducing water-cement ratio, the compactness and durability of small hollow concrete blocks can also be enhanced by properly adding fly ash, and the workability of concrete can be improved. Xiao et al. [3] selected all the experimental materials as recycled aggregates. The effects of recycled fine aggregate content, polypropylene fiber content, and fly ash content on the compressive strength of the recycled concrete hollow block were studied. It was found that the compressive strength of recycled fine aggregate blocks with less than 40% recycled fine aggregate content can be improved, and the production quality of blocks can be better controlled in actual production. It was found that the compressive strength of recycled fine aggregate blocks with less than 40% recycled fine aggregate content can be improved, and the production quality of blocks can be better controlled in actual production. The economic benefit was the best when the content of fly ash was 35%. It was suggested that the optimum content of polypropylene was about 1 kg/m^3 because the crack resistance of the block with the polypropylene fiber was enhanced, but the compressive strength was reduced. Nie et al. [4] enlarged the scale of recycled fine aggregates; the recycled concrete was prepared by high-quality recycled aggregate and focused on the effect of strength grade and recycled fine aggregate replacement rate on the properties of high-quality recycled fine aggregate concrete. Shi et al. [5] studied the mechanical properties and the strength variation against time of recycled aggregate concrete with different recycled aggregate replacement ratios based on mixing design of different recycled aggregate concrete. Kong et al. [6] investigated the effect of steel-polypropylene hybrid fibers on the basic mechanical properties of recycled concrete, and 10 groups of hybrid fiber recycled concrete specimens and one group of recycled concrete specimens were designed and manufactured, and the cube compressive strength, split tensile strength, and flexural strength were tested. Zhang et al. [7] employed the splitting tensile strength experiments of steel fiber-reinforced recycled concrete specimens for researching the influences of four various factors on the splitting tensile performance of recycled concrete, such as the volume fraction of the steel fiber varying from 0.0% to 2.0%, three types of the steel fiber with MF, SF, and BF, respectively, the different pretreatment methods of recycled coarse aggregates, and various specimen sizes. Zheng et al. [8] studied the flexural strength of different replacement percentages of recycled coarse aggregate concrete. 33 specimens were designed for the test, in which replacement percentages of recycled coarse aggregates were 0, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%. According to the experiment, the flexural strength of recycled aggregate concrete and fracture surface picture obtained and the influence of replacement percentages of recycled coarse aggregate were analyzed. Fan et al. [9] experimentally researched the modification of recycled aggregate concrete (RAC) by soaking the recycled coarse aggregate in solution of nano-SiO_2, PVA, water glass, water glass and PVA, and mixing nano-SiO_2 into RAC. Wang et al. [10] studied the effects of different freezing and thawing cycles of regenerated concrete in different concentrations of salinity solution by the freeze-thaw cycle test of recycled concrete in 3.5% NaCl, 3.5% Na_2SO_4, 3.5% NaCl + 3.5% Na_2SO_4, and water. In the research of Zhao et al. [11], coconut fibers recycled concrete was mixed by use of the orthogonal test, the best mix proportion for breaking strength was obtained, comparison was done with the reference concrete which has no coconut fibers added, the stepwise regression equation for breaking strength was found, and micro-analysis for destroyed concrete was done. In the study of Xu et al. [12], the waste concrete collected from three different age sources was converted into recycled coarse aggregates (RA-I, RA-II, and RA-III), the proper proportion of recycled concrete was selected by orthogonal experimental design, and the compressive strength, splitting tensile strength, and flexural strength of recycled aggregate concrete with different replacement rates and service life were studied. In the study of Xiao et al. [13], a comprehensive case study comprising detailed evaluation of properties and carbon footprint of an actual 12-storey twin towers was presented to evaluate the potential carbon emission reductions achievable through adoption of recycled aggregate concrete. In the study of Pedro et al. [14], the durability of high-performance concrete produced with recycled aggregates, fly ash, and densified silica fume was assessed. Xie et al. [15] studied the effects of the addition of silica fume and rubber particles on the compressive behavior of recycled aggregate concrete with steel fibers. El-Tahan et al. [16] investigated the feasibility of using recycled concrete aggregates (RCAs) as a replacement to the natural aggregates in hot mix asphalt, and RCA was collected from two different sources (new concrete cubes used for quality control testing during construction and old demolished building) to investigate the impact of material degeneration on the engineering properties of the mix. Li et al. [17] developed a new generation of planting concrete made from recycled aggregates of demolished concrete to improve the fertilizer retention properties and reduce the cost. Jin et al. [18] focused their research on investigating the effects of recycled aggregates on the material properties of concrete and the structural performance of reinforced concrete beams. In the research of Chaboki et al. [19], the flexural behavior and ductility ratio of reinforced concrete beams made with steel fibers and coarse recycled aggregates were studied. Etman et al. [20] investigated experimentally and analytically the shear performance of recycled concrete beams made of recycled coarse aggregates. The study of Guo et al. [21] explores the possible use of recycled concrete aggregates (RCAs) to produce concrete building blocks; laboratory test and plant trial were carried out to manufacture concrete building blocks incorporating 75% RCAs, and a series of tests were conducted to investigate the mechanical and durability properties of RAC blocks. Fang et al. [22] experimentally studied the mechanical properties of fiber-reinforced recycled aggregate concrete with different types of fibers and various basalt fiber volume fractions. In the study of Xu et al. [23], with the reference of conventional concrete and the scattering-filling natural aggregate concrete, the influences of ratio, type, size, and moisture state of recycled aggregate on mechanical and durable properties of scattering-filling recycled aggregate concrete were investigated. The work of Lima et al. [24] was dedicated to the assessment of the structural performance of a new lightweight block for one-way precast concrete slabs made of short sisal fiber-reinforced concrete containing natural and recycled aggregates. Chan et al. [25] analyzed potential use of fiber-reinforced recycled aggregate concrete for sustainable pavements. Xie et al. [26] studied the effects of combined usage of ground granulated blast furnace slag and fly ash on workability and mechanical properties of alkali-activated geopolymer concrete with recycled aggregates. Jayakody et al. [27] studied the effects of reclaimed asphalt materials on geotechnical characteristics of recycled concrete aggregates as a pavement material. Li et al. [28] studied the liquefaction characteristics of recycled concrete aggregates. Bassani et al. [29] studied the recycled coarse aggregates from pelletized unused concrete for a more sustainable concrete production. Liu et al. [30] carried on the seismic fragility analysis of deteriorating recycled aggregate concrete bridge columns subjected to freeze-thaw cycles.

In this paper, 110 specimens are tested under compressive and flexural loads. And the failure process and morphology of the specimens are observed, and the compressive and flexural strength are obtained. It is hoped that it can provide reference for further scientific research and engineering application of recycled concrete blocks. A new type of masonry with good seismic performance, environmental protection, and energy saving is studied. The recycled fine aggregate is used to produce recycled fine aggregate wall masonry materials. This is a new reform for the source of raw materials for wall materials, and it is a new way for the reuse of concrete garbage and has important environmental protection significance and engineering practical significance for building energy saving.

2. Design and Fabrication of Experiments

The test materials used in this paper are ordinary Portland cement (strength grade 32.5), natural river sand, and recycled fine aggregate. Natural fine aggregate comes from a sand and gravel factory near Yongjiang River. The recycled fine aggregate comes from the demolished brick slag and concrete components, which are crushed by a crusher and manually screened by a square hole sieve (aperture 4.75 mm). Figures 1 and 2 show natural and recycled fine aggregates.

Figure 1: Natural fine aggregate.

Figure 2: Recycled fine aggregate.

4.75–9.5 mm gravel is used. The city drinking water is used as mixing water. The production technology, density, hollow ratio, compressive strength, and flexural strength of concrete hollow blocks with 0%, 30%, 60%, and 100% quality replacement ratio are studied.

2.1. Production Technology of Recycled Concrete Blocks. The forming technology of the recycled concrete block includes manual moulding, concrete vibration ramming, and mass production. Because of the huge quantity of this test, the mass production of the dry and hard concrete machine is selected. The production process consists of three parts. They are concrete mixing technology, concrete hollow block forming technology, and maintenance technology. Recycled concrete hollow block takes a certain time to reach the design strength after forming, and maintenance plays a very important role in this process. This test is made in the concrete hollow block processing plant, so the maintenance conditions are in accordance with the actual outdoor natural maintenance conditions. According to the requirements of the national standards, the specimens should be kept quietly for about 24 hours. During this period, no water is poured, and the water of the mixture itself is used for full hydration and maintenance. This test is made in the concrete hollow block processing plant, so the maintenance conditions are in accordance with the actual outdoor natural maintenance conditions. After that, the recycled concrete hollow blocks are separated from the floor and stacked with uniform

Figure 3: Recycled concrete hollow block in natural outdoor water curing conditions.

watering maintenance. The stacking height does not exceed 1.4–1.6 m, and the specimens are watered more than six times a day, as shown in Figure 3.

2.2. Mix Ratio of Recycled Concrete Hollow Block. In this paper, the quality substitution rates of four kinds of recycled fine aggregates are 0%, 30%, 60%, and 100%. The strength grades of the concrete block are MU10 and MU7.5, the sand percentages of fine aggregate are 75% and 75%, the water-cement ratios are 0.57 and 0.73, and the replacement ratio of benchmark is 0%. The recycled concrete with different aggregate substitution rates is that the dosages of fine aggregate sand composition and reclaimed fine aggregate are changed according to a certain proportion, but the total mass is fixed, the coarse aggregate is fixed by the amount of gravel, and the amount of cement is fixed. That is to say, when the recycled fine aggregate increases, the natural fine aggregate decreases accordingly, and water is adjusted according to the water absorption of the recycled fine aggregate with the addition of the recycled fine aggregate.

The strength grades C20 and C15 of the trial concrete meet the strength requirements of the original concrete hollow block strength grades MU10 and MU7.5, respectively. A group of samples with each replacement rate are made. The size of the specimen (recycled concrete block) is 390 mm × 190 mm × 190 mm double-row hole bottom blind hole. The test block is made, maintained, and tested under the same conditions. Density and void fraction are measured for each group of specimens, compressive strength is measured for 6 specimens, and flexural strength is measured for 5 specimens. Considering that the water absorption of the recycled fine aggregate is 12.36% and that of the natural fine aggregate is 4.80%, the additional water consumption increases step by step with the increase of the replacement rate of recycled fine aggregates to ensure the same workability. The hollow ratio of the recycled concrete hollow block is taken as 40% for the time being. Considering the unavoidable loss in the test process, the consumption of 10.15 m^3 for every 10 m^3 concrete is taken as usual. The mix ratios of concrete and the amount of each material are shown in Tables 1–4.

2.3. Determination of Density of Recycled Concrete Blocks and Hollow Rate. Three blocks of each group are tested for density and void fraction. The method of measuring the density of the recycled concrete block is to put the block in the drying box for 24 hours and then weigh it by electronic weighing and measure the length, width, and height of the block in the middle of each face with tape. The density formula is used to calculate the block density. It is difficult to measure the void fraction of the test by the drainage method prescribed by the code, and the final method is the sand filling method. Using the method that the volume of filled sand equals the volume of the hollow part of the block, the hollow ratio of the block can be measured.

3. Test Loading Device and Test Method

3.1. Compressive Load Strength Test Device and Test Method. The loading device of the test is the YA200A pressure testing machine, as shown in Figure 4.

The range and error of the pressure testing machine should meet the requirements of the national standard. The cement mortar used for leveling is made by mixing one portion of cement with two parts of fine sand and appropriate amount of water. The process of leveling is to first lay the steel plate on the indoor floor, brush a thin layer of oil on the steel plate, and then lay a thin layer of cement mortar, and finally put the concrete hollow block paving surface on the paved mortar. Next, a layer of mortar is paved on the seating surface of the block; then, the glass plate is pressed, and the edge pressing is observed until all the bubbles in the mortar layer are extruded. Finally, the level with a horizontal ruler is adjusted. Compression test is done after 3 days of indoor maintenance. The horizontal ruler is used to measure the length L and width B of the compressive specimens with a minimum scale of 1 mm. The leveling of the specimen is shown in Figure 5.

The specimens are placed on the bearing plate of the testing machine and loaded according to the requirements of the test method for the small concrete hollow blocks until the specimens are destroyed. When the force-measuring pointer of the universal testing machine retreats obviously or the crack of the specimen expands sharply or increases obviously, it indicates that the specimen reaches the failure state and records the maximum failure load P. The fine sand is laid on the upper and lower surfaces to achieve the effect of smoothing on the compression surface, to make the interface between the compression surface of the specimen and the compression plate of the testing machine uniform and compact and to achieve the compression surface uniform. To ensure the accuracy of the test, the number of specimens in each group is 6 blocks for the compression test.

Table 1: Quantity of materials required for the MU10 block experiment.

Number	Replacement rate (%)	Cement (kg)	Water (kg)	Natural coarse aggregate (kg) with continuous gradation of gravel 5–10 mm	Natural fine aggregate (kg)	Recycled fine aggregate (kg)
RCB-10-1	0	48.05	27.46	84.08	252.25	0.00
RCB-10-2	30	48.05	28.52	84.08	176.57	75.68
RCB-10-3	60	48.05	29.58	84.08	100.90	151.35
RCB-10-4	100	48.05	30.64	84.08	0.00	252.25
Total		192.20	116.20	336.32	529.73	479.28

Table 2: Quantity of materials required for the MU7.5 block experiment.

Number	Replacement rate (%)	Cement (kg)	Water (kg)	Natural coarse aggregate (kg) with continuous gradation of gravel 5–10 mm	Natural fine aggregate (kg)	Recycled fine aggregate (kg)
RCB-7.5-1	0	37.75	27.46	86.66	259.97	0.00
RCB-7.5-2	30	37.75	28.55	86.66	181.98	77.99
RCB-7.5-3	60	37.75	29.64	86.66	103.99	155.98
RCB-7.5-4	100	37.75	30.73	86.66	0.00	259.97
Total		151.00	116.38	346.64	545.94	493.94

Table 3: Quantity of materials required for the MU10 block experiment.

Number	Replacement rate (%)	Cement (kg)	Water (kg)	Recycled coarse aggregate (kg) with continuous gradation of gravel 5–10 mm	Natural fine aggregate (kg)	Recycled fine aggregate (kg)
RCB-10-5	100	26.60	19.63	46.64	0.00	139.56
Total		26.60	19.63	46.64	0.00	139.56

Table 4: Quantity of materials required for the MU7.5 block experiment.

Number	Replacement rate (%)	Cement (kg)	Water (kg)	Recycled coarse aggregate (kg) with continuous gradation of gravel 5–10 mm	Natural fine aggregate (kg)	Recycled fine aggregate (kg)
RCB-7.5-5	100	20.90	15.27	47.98	0.00	143.93
Total		20.90	15.27	47.98	0.00	143.93

Figure 4: Specimen of the loading device.

(a)

(b)

Figure 5: Leveling of the specimens.

3.2. Flexural Load Strength Test Device and Test Method. The flexural strength of recycled concrete hollow blocks is tested according to the national standard "Test Methods for the Small Concrete Hollow Blocks." Hydraulic universal testing machine is used. According to the requirements of the national standard, a bending-resistant bearing is designed. The bearing consists of three steel bars and steel plates with a diameter of 35–40 mm and a length of 210 mm. Weld a groove to fix the steel bar on the steel plate so that one of the steel bars can roll freely, as shown in Figure 6. There are 5 blocks in each group. The loading device is shown in Figure 6.

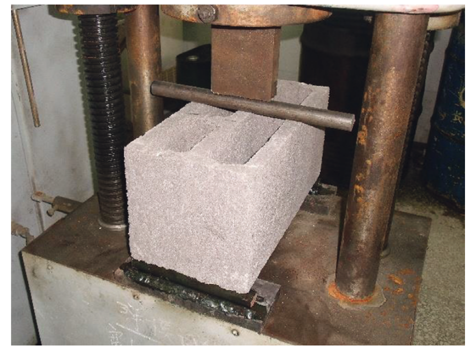

Figure 6: Specimen of the loading device.

4. Data Processing and Result Analysis

4.1. Recording and Processing of Density and Hollowness Test Data of Recycled Concrete Blocks. From Table 5, it is found that the volume density of the recycled fine aggregate concrete hollow block is about 1100–1250 kg/m^3 when the air heart rate is 41–46%. The bulk density of the recycled fine aggregate concrete hollow block is about 1100–1200 kg/m^3 when the air heart rate is 41–46%. The volume density of the recycled fine aggregate concrete hollow block is about 10% smaller than that of the ordinary concrete hollow block because the apparent density of recycled fine aggregates is smaller than that of natural fine aggregates.

Table 5: Comparison of recycled concrete blocks with other blocks.

	Ordinary concrete hollow block	Recycled fine aggregate concrete hollow blocks with different replacement rates	Recycled concrete hollow block
Compressive strength	MU5.0–20.0	MU7.5–10.0	MU7.5–10.0
Bulk density (kg/m^3)	1200–1400	1100–1250	1100–1200

4.2. Recording and Processing of Compressive Strength Test Data

4.2.1. Failure Process of Specimens. Through the compressive strength test of the recycled concrete hollow block, it can be found that the failure mode and shape of the block are basically not affected by the replacement rate of recycled fine aggregates and are basically similar. And the compressive failure process of the recycled concrete hollow block is no different from that of the natural concrete hollow block. In the initial stage of loading, cracks can hardly be observed. With the passage of time and the continuous increase of the vertical load, a few cracks can be observed usually in the corner position. Firstly, on the strip surface, the extension and broadening of cracks are not obvious at the beginning. As the vertical load continues to increase, cracks develop from local to diagonal oblique cracks, some form horizontal cracks in the middle of the strip, and some blocks form vertical cracks when they are destroyed, until the whole block is destroyed, and the surface of the block appears different degrees of the spalling phenomenon in the process of destruction. The failure modes of some blocks are shown in Figure 7.

4.2.2. Recording and Calculation of Compressive Strength Test Data of the Recycled Concrete Hollow Block. The load value of the recycled concrete hollow block is obtained by the measured data, and the compressive strength f of each group of the recycled concrete hollow block is calculated by the following equation:

$$f = \frac{F}{LB}, \tag{1}$$

where the failure load of the recycled concrete hollow block is F and the length and width of the compression surface of the recycled concrete hollow block are B and L, respectively.

The compressive strength test records and calculated values of recycled concrete hollow blocks are shown in Table 6.

Table 7 gives the average compressive strength, coefficient of variation, standard deviation, and minimum compressive strength of recycled concrete block MU10 when the replacement rate of the recycled fine aggregate is 0%, 30%, 60%, and 100% and the replacement rate of the recycled coarse aggregate and fine aggregate is 100%, respectively. The average compressive strength is plotted as Figure 8.

From Table 7 and Figure 8, it is found that the compressive strength of recycled fine aggregate MU10 has little difference when the mass substitution rate of the recycled fine aggregate is 100%. It is compared with that of the recycled coarse aggregate and fine aggregate. All of them are about 6.2 MPa, and the minimum compressive strength of the single block is about 4.7 MPa, which meets the compressive strength standard of concrete block strength grade MU5.0.

This is because the mechanical properties of recycled fine aggregates are not as good as those of natural sand. Through the process of crushing and rescreening of primary concrete, there are cracks in particulate matter due to

(a) (b) (c)

Figure 7: Damage form of specimens under pressure.

Table 6: Compressive strength of recycled concrete hollow block test recording and processing.

Specimen number	Condition	Numerical reading (kN)						Average value (kN)	Average intensity (MPa)
RCB-10-1	Breaking load (kN)	964	750	744	736	738	728	776.67	
	Length L (mm)	390	390	390	390	390	390		
	Width B (mm)	189	188	190	190	190	190		
	Strength (MPa)	13.08	10.23	10.04	9.93	9.96	9.82		10.51
RCB-10-2	Breaking load (kN)	628	602	596	660	654	668	634.67	
	Length L (mm)	391	389	391	390	390	390		
	Width B (mm)	189	189	190	190	190	190		
	Strength (MPa)	8.50	8.19	8.02	8.91	8.83	9.01		8.58
RCB-10-3	Breaking load (kN)	536	520	512	522	516	528	522.33	
	Length L (mm)	390	390	389	389	390	390		
	Width B (mm)	190	189	189	189	190	190		
	Strength (MPa)	7.23	7.05	6.96	7.10	6.96	7.13		7.07
RCB-10-4	Breaking load (kN)	490	556	416	556	350	466	472.33	
	Length L (mm)	390	390	389	390	389	390		
	Width B (mm)	190	190	190	190	189	190		
	Strength (MPa)	6.61	7.50	5.63	7.50	4.76	6.29		6.38
RCB-7.5-1	Breaking load (kN)	638	556	680	540	468	490	562.00	
	Length L (mm)	390	390	390	390	390	390		
	Width B (mm)	190	190	189	190	190	190		
	Strength (MPa)	8.61	7.50	9.23	7.29	6.32	6.61		7.59
RCB-7.5-2	Breaking load (kN)	606	470	496	476	490	456	499.00	
	Length L (mm)	390	390	389	390	390	390		
	Width B (mm)	190	190	190	189	189	189		
	Strength (MPa)	8.18	6.34	6.71	6.46	6.65	6.19		6.75
RCB-7.5-3	Breaking load (kN)	356	404	436	406	412	376	398.33	
	Length L (mm)	390	390	390	390	390	390		
	Width B (mm)	190	190	190	189	189	189		
	Strength (MPa)	4.80	5.45	5.88	5.51	5.59	5.10		5.39
RCB-7.5-4	Breaking load (kN)	488	504	388	272	288	328	378.00	
	Length L (mm)	390	389	389	389	389	388		
	Width B (mm)	190	190	189	189	190	189		
	Strength (MPa)	6.59	6.82	5.28	3.70	3.90	4.47		5.13
RCB-10-5	Breaking load (kN)	470	500	464	416	350	572	462.00	
	Length L (mm)	390	390	390	390	390	390		
	Width B (mm)	190	190	190	189	190	190		
	Strength (MPa)	6.34	6.75	6.26	5.64	4.72	7.72		6.24
RCB-7.5-5	Breaking load (kN)	300	504	206	386	280	400	346.00	
	Length L (mm)	390	390	390	390	390	390		
	Width B (mm)	190	187	190	190	189	190		
	Strength (MPa)	4.05	6.91	2.78	5.21	3.80	5.40		4.69

external force. The surface is rough, the shape is not full, it is often with needle-tip shape, the touch has a prickle feeling, it is containing some particulate matter of cement mortar, and the pore becomes more. The process of discarding raw concrete and recycling aggregate leads to the increase of mud content, which also affects the compressive strength of concrete to a certain extent. The compressive strength of the recycled concrete block MU10

Table 7: Summary of the test results of compressive strength of recycled blocks with different substitution rates of MU10.

Block	RCB-10-1	RCB-10-2	RCB-10-3	RCB-10-4	RCB-10-5
Average compressive strength (MPa)	10.51	8.58	7.07	6.38	6.24
Standard deviation (MPa)	1.2664	0.3115	0.1980	1.0848	1.0006
Coefficient of variation	0.1205	0.0363	0.0280	0.1700	0.1604
Minimum compressive strength of single block (MPa)	9.82	8.02	6.96	4.76	4.72

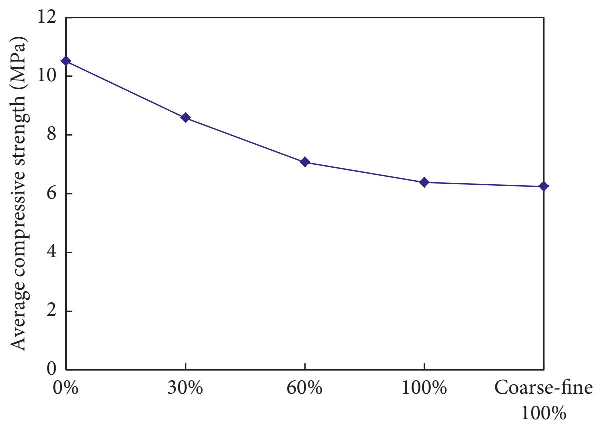

Figure 8: Compressive strength curve of recycled fine aggregates with different substitution ratios.

Table 8: Summary of the test results of compressive strength of recycled blocks with different substitution rates of MU7.5.

Block	RCB-7.5-1	RCB-7.5-2	RCB-7.5-3	RCB-7.5-4	RCB-7.5-5
Average compressive strength (MPa)	7.59	6.75	5.39	5.13	4.69
Standard deviation (MPa)	1.1580	0.7781	0.3528	1.3265	1.4592
Coefficient of variation	0.1526	0.1153	0.0655	0.2586	0.3111
Minimum compressive strength of single block (MPa)	6.32	6.19	4.80	3.70	2.78

is slightly lower than the strength index of the MU7.5 concrete block when the replacement rate of recycled fine aggregates is 60%, but the strength index of the MU7.5 concrete block can be fully met in 30% of cases.

Table 8 gives the average compressive strength, coefficient of variation, standard deviation, and minimum compressive strength of recycled concrete block MU7.5 when the replacement rates of the recycled fine aggregate are 0%, 30%, 60%, and 100% and the replacement rate of the recycled coarse aggregate and fine aggregate is 100%, respectively. The average compressive strength is plotted as Figure 9.

Through Table 8 and Figure 9, it is found that the actual compressive strength of the recycled concrete block with strength grade MU7.5 is 5.13 MPa and 5.39 MPa, respectively, when the replacement rates of the recycled fine aggregate are 100% and 60%, which meet the compressive strength requirements of the concrete hollow block with strength grade MU5.0. When sand and stone aggregates are replaced by recycled materials, the replacement rate of fine and coarse aggregates is 100%, the compressive strength of the recycled concrete block MU7.5 is 4.69 MPa, and the minimum compressive strength of a single block is about

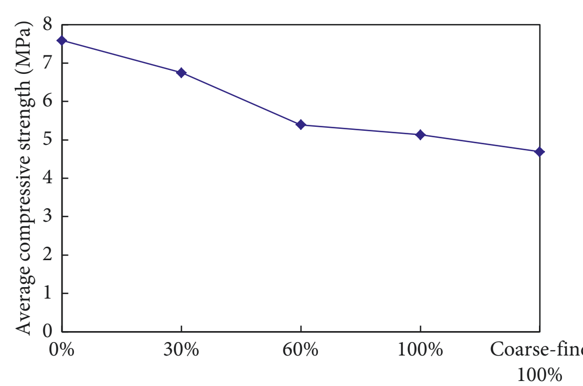

Figure 9: Compressive strength curve of recycled fine aggregates with different replacement rates.

2.8 MPa, which is slightly lower than the compressive strength standard of concrete block strength grade MU5.0, but it meets the compressive strength of MU3.5. When the replacement rate of recycled fine aggregates is 30%, the compressive strength of the recycled concrete block MU7.5 is 6.75, which decreases by about 10%.

4.3. Data Recording and Processing of the Flexural Strength Test

4.3.1. Failure Process of Specimens. Through the flexural strength test of the recycled concrete hollow block, it can be found that the failure modes of the recycled concrete hollow block are basically the same under different fine aggregate replacement rates. At the initial stage of loading, cracks cannot be observed by naked eyes. With the passage of time and the increase of vertical load, the block breaks into two sections when it is damaged. The failure surface generally appears near the middle of the block surface. The failure is relatively sudden, and there is a clear sound, which belongs to brittle failure. A few specimens have diagonal failure surfaces near the corner support. The failure modes of some blocks are shown in Figure 10.

Figure 10: Failure modes of specimens.

4.3.2. Test Recording and Calculation of Flexural Strength of Recycled Concrete Hollow Blocks. The load values of recycled concrete hollow blocks under failure are measured. The flexural strength *f* of each group of recycled concrete hollow blocks is calculated by using the following formula, as shown in Table 9:

$$f_z = \frac{3PL}{2BH^2}, \quad (2)$$

where the failure load of the recycled concrete hollow block is P and the width and height of the recycled concrete hollow block are B and H, respectively. The length of the center line between the flexural supports is $L = 367$ mm.

The test records and calculation of the flexural strength of recycled concrete hollow blocks are shown in Table 9.

Table 10 gives the average flexural strength, coefficient of variation, standard deviation, and minimum compressive strength of recycled concrete block MU10 when the replacement rates of the recycled fine aggregate are 0%, 30%, 60%, and 100% and the replacement rate of the recycled coarse aggregate and fine aggregate is 100%, respectively. The average value of flexural strength is plotted as Figure 11.

At present, there is no uniform standard for the flexural strength grade of recycled concrete hollow blocks. The factors affecting the flexural strength of the concrete hollow block are water-cement ratio, cement slurry volume, shape, and so on. This test is to change the composition of fine aggregates without changing the cement slurry volume, water-cement ratio, and appearance. It is found that the flexural strength decreases with the increase of the replacement rate of recycled fine aggregates. From Table 10 and Figure 11, it can be seen that the flexural strength of recycled concrete block MU10 with a mass substitution rate of 30% and 60% of recycled fine aggregates has little difference, and it decreases by 30%–32% compared with the natural concrete block. When the replacement rate of the recycled fine aggregate is 100%, the flexural strength of the recycled fine aggregate decreases by nearly 50% compared with natural and natural concrete blocks. The flexural strength of recycled coarse and fine aggregates with 100% mass substitution rate is similar to that of recycled fine aggregates with 100% mass substitution rate, but it slightly decreases.

Table 11 gives the average flexural strength, coefficient of variation, standard deviation, and minimum compressive strength of recycled concrete block MU7.5 when the replacement rates of the recycled fine aggregate are 0%, 30%, 60%, and 100% and the replacement rate of the recycled coarse aggregate and fine aggregate is 100%, respectively. The average bending strength is plotted as Figure 12.

This experiment is to change the composition of fine aggregates without changing the volume of cement slurry, water-cement ratio, and appearance. It is found that the flexural strength decreases with the increase of the replacement rate of recycled fine aggregates. From Table 11, the quality replacement rates of recycled fine aggregate MU7.5 for the recycled concrete block are 30% and 60%, and the flexural strength of the recycled fine aggregate is similar to that of the natural concrete block. Compared with the natural concrete block, the quality replacement rate of the recycled fine aggregate decreases by 34%–42%. When the quality replacement rate of the recycled fine aggregate is 100%, the flexural strength decreases by nearly 50% compared with the natural and natural concrete block. The flexural strength of recycled coarse and fine aggregates with 100% mass substitution rate is similar to that of recycled fine aggregates with 100% mass substitution rate, but it slightly decreases.

5. Conclusions

Because the recycled fine aggregate undergoes the process of crushing and rescreening of primary concrete, there are cracks in the particles due to external forces, the surface is rough, the shape is not full, it often with needle-tip shape, the touch has a prickle feeling, it contains some cement mortar particles, and the pore becomes more. The process of primary concrete waste and recycled aggregates leads to increased mud content. With the increase of the replacement rate of the recycled fine aggregate, the compressive strength of the recycled concrete block decreases in general. When the replacement rate of the recycled coarse aggregate and fine aggregate is 100%, the compressive strength index of recycled concrete blocks MU10 and MU7.5 decreases by about two grades. The compressive strength index of recycled concrete blocks MU10 and MU7.5 decreases by about one grade when the replacement rate of the recycled fine aggregate is 60%, but the compressive strength of

Table 9: Computation results of flexural strength of recycled concrete hollow blocks.

Block type	Numerical reading (kN)					Average strength (MPa)	Single block minimum (MPa)
	1	2	3	4	5		
RCB-10-1							
P (kN)	20.7	35.4	37.3	30.4	39.4	2.69	1.73
L (mm)	367	367	367	367	367		
B (mm)	190	190	190	189	189		
H (mm)	186	195	182	186	189		
Strength (MPa)	1.73	2.70	3.26	2.56	3.21		
RCB-10-2							
P (kN)	23.8	22.2	25.4	20.3	21.1	1.87	1.67
L (mm)	367	367	367	367	367		
B (mm)	190	189	190	189	190		
H (mm)	184	186	189	188	190		
Strength (MPa)	2.04	1.87	2.06	1.67	1.69		
RCB-10-3							
P (kN)	19.7	21.2	23.1	24.5	18.1	1.84	1.55
L (mm)	367	367	367	367	367		
B (mm)	190	190	189	191	190		
H (mm)	180	185	186	182	184		
Strength (MPa)	1.76	1.79	1.94	2.13	1.55		
RCB-10-4							
P (kN)	15.2	21.7	13.4	15.8	17.4	1.38	1.1
L (mm)	367	367	367	367	367		
B (mm)	190	188	190	190	190		
H (mm)	185	190	188	187	188		
Strength (MPa)	1.29	1.76	1.10	1.31	1.43		
RCB-7.5-1							
P (kN)	31.5	21.3	32.1	28.4	19.5	2.16	1.6
L (mm)	367	367	367	367	367		
B (mm)	190	190	190	190	190		
H (mm)	191	191	188	187	188		
Strength (MPa)	2.50	1.69	2.63	2.35	1.60		
RCB-7.5-2							
P (kN)	16.3	18.2	18.4	16.1	17.2	1.42	1.33
L (mm)	367	367	367	367	367		
B (mm)	189	189	190	190	190		
H (mm)	188	187	188	187	188		
Strength (MPa)	1.34	1.52	1.51	1.33	1.41		
RCB-7.5-3							
P (kN)	15	15.4	13.4	16.1	15.9	1.25	1.09
L (mm)	367	367	367	367	367		
B (mm)	189	189	190	190	190		
H (mm)	185	190	189	188	187		
Strength (MPa)	1.28	1.24	1.09	1.32	1.32		
RCB-7.5-4							
P (kN)	13.3	11.7	12.3	13.8	11.4	1.03	0.92
L (mm)	367	367	367	367	367		
B (mm)	189	188	190	190	190		
H (mm)	190	183	189	187	189		
Strength (MPa)	1.07	1.02	1.00	1.14	0.92		
RCB-10-5							
P (kN)	13.4	15.8	14.4	14.6	15.3	1.21	1.14
L (mm)	367	367	367	367	367		
B (mm)	189	189	190	190	190		
H (mm)	185	190	189	188	187		
Strength (MPa)	1.14	1.27	1.17	1.20	1.27		
RCB-7.5-5							
P (kN)	15.2	11.7	13.6	12	11.2	1.06	0.91
L (mm)	367	367	367	367	367		
B (mm)	190	190	190	190	190		
H (mm)	181	189	187	189	189		
Strength (MPa)	1.34	0.95	1.13	0.97	0.91		

Table 10: Summary of the test results of flexural strength of recycled blocks with different substitution rates of MU10.

Block	RCB-10-1	RCB-10-2	RCB-10-3	RCB-10-4	RCB-10-5
Average flexural strength (MPa)	2.69	1.87	1.84	1.38	1.21
Standard deviation (MPa)	0.6300	0.1251	0.1385	0.2295	0.0587
Coefficient of variation	0.2342	0.0669	0.0753	0.1663	0.0485
Minimum flexural strength of single block (MPa)	1.73	1.67	1.55	1.1	1.14

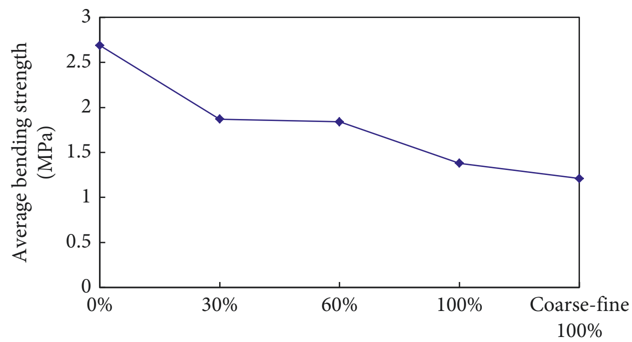

Figure 11: Flexural strength curve of the recycled fine aggregate with different substitution ratios.

Table 11: Summary of the test results of flexural strength of recycled blocks with different substitution rates of MU7.5.

Block	RCB-7.5-1	RCB-7.5-2	RCB-7.5-3	RCB-7.5-4	RCB-7.5-5
Average flexural strength (MPa)	2.16	1.42	1.25	1.03	1.06
Standard deviation (MPa)	0.4409	0.1236	0.0954	0.0819	0.1775
Coefficient of variation	0.2041	0.0870	0.0763	0.0795	0.1675
Minimum flexural strength of single block (MPa)	1.6	1.33	1.09	0.92	0.91

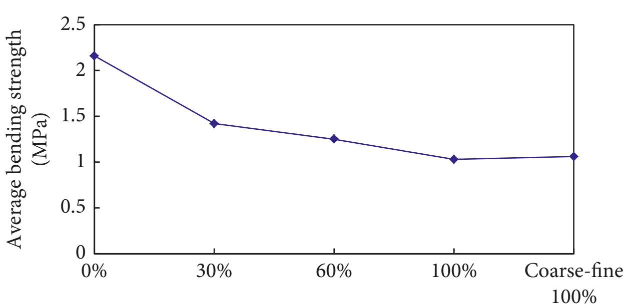

Figure 12: Flexural strength curve of the recycled fine aggregate with different substitution ratios.

recycled concrete blocks MU10 and MU7.5 decreases by about 10% when the replacement rate of the recycled fine aggregate is 30%.

On the premise of only changing the composition of fine aggregates in the influencing factors of flexural strength, the flexural strength decreases with the increasing replacement rate of recycled fine aggregates. However, almost all specimens have the same fracture morphology and process. The substitution rates are 30% and 60%, and the flexural strength of the recycled concrete block is not different. Compared with the natural concrete block, the flexural strength decreases by 30%–42%. The flexural strength of the recycled concrete block is less discrete and easy to control in quality. When the replacement rate is 100%, the flexural strength decreases by nearly 50% compared with natural and natural concrete blocks.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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