Experimental Study on Shear Capacity of Waste Fiber Recycled Concrete Shear Wall

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Abstract. In this paper, the shear capacity of waste fiber recycled concrete shear wall (FCSW) is studied by cyclic loading tests on 9 specimens. The failure of the specimens under low cycle cyclic loading is analyzed. The influence of waste fiber content, recycled aggregate content and axial compression ratio on the shear capacity of shear wall is studied. The results show that: the larger the volume ratio of waste fiber is, the higher the shear bearing capacity of shear wall is; the addition of recycled coarse aggregate will reduce the shear capacity of shear wall; the shear capacity of shear wall increases with the increase of axial pressure. On the basis of relevant specifications, the calculation formula of in-plane shear capacity of waste fiber recycled concrete shear wall is proposed considering the influence of waste fiber on shear capacity. By comparing with the test results, it can be found that the two formulas are in good agreement. The conclusion of the study can provide reference for the design of waste fiber recycled concrete shear wall.

1 Introduction

With the rapid development of Chinese urbanization, a large number of waste buildings have been demolished. It resulted in more and more construction waste such as waste concrete. At present, there are serious waste of land resources and environmental pollution in the treatment of construction waste in China[1]. In order to make full use of waste concrete and other construction waste, domestic and foreign scholars began to use waste fiber concrete to replace part or all of the concrete coarse aggregate to make recycled concrete, and studied its mechanical properties and components [2~5]. Due to the decrease of strength, toughness and crack resistance of recycled aggregate concrete, its application in practical engineering is limited. According to the research results at home and abroad, the incorporation of fiber can improve the mechanical properties of recycled aggregate concrete [6~8]. The recycled waste fiber is processed, manufactured and mixed into recycled aggregate concrete for reuse, which not only solves the problems of resource waste and environmental pollution, but also produces better economic and social benefits.

At present, many scholars at home and abroad began to study the waste fiber recycled concrete, mainly focusing on the material and structural performance. Zhou[9~12] studied the constitutive problems such as splitting tensile strength and compression damage of waste fiber recycled concrete, and the flexural performance of waste fiber recycled concrete beam. The test results show that the splitting tensile strength of concrete can be improved to a certain extent by adding appropriate amount of waste fiber; the uniaxial compression damage test of prism specimen is carried

out. In the test, with the increase of strain, the damage variable of waste fiber recycled concrete also increases. In the bending process of waste fiber recycled concrete beam, the ductility and bearing capacity of the beam are improved. Wang[13] studied the seismic performance of fiber reinforced recycled concrete frame joints, and the results show that: the incorporation of fiber improves the bearing capacity and seismic performance of frame joints. Wang[14] studied the carbonation performance of waste fiber recycled concrete through rapid carbonation test. The results show that: the addition of waste fiber can reduce the carbonation depth. At present, the research on the waste fiber recycled concrete shear wall is still relatively few at home and abroad. In this paper, the shear capacity of waste fiber recycled concrete shear wall under low cycle cyclic load is obtained through theoretical analysis and test. The shear bearing capacity formula of waste fiber recycled concrete shear wall is proposed by theoretical analysis method. The research results can provide reference for the design of waste fiber recycled concrete shear wall, and lay the foundation for the future application of waste fiber recycled concrete shear wall in practical engineering.

2 General situation of constitutive test

Recycled coarse aggregate takes concrete with original strength of C40 as raw material. The concrete is artificially crushed and then made into continuously graded coarse aggregate with a maximum diameter of 25 mm. The waste fiber is made from waste fabric as shown in Figure 1.

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Figure 1. Coarse aggregate and waste fiber

The test scheme of concrete test block is determined according to the type of shear wall. Three cubes with dimensions of 150 mm × 150 mm × 150 mm, 3 prism blocks with dimensions of 150 mm × 150 mm × 300 mm and 3 tensile test blocks with dimensions of 100 mm × 100 mm × 370 mm are made for each type of

concrete specimens. The strength, uniaxial tensile stress-strain curve and uniaxial compression stress-strain curve of concrete were measured. The test loading device is shown in Figure. 2. The values of measured test data after processing are shown in Table 1.

Figure. 2 Test device for compressive strength and tensile strength of concrete

Table 1. Test strength values of waste fiber recycled concrete

Num ber	Concrete strength	Volume ratio of waste fiber/%	Replacement rate of regenerated coarse aggregate/%	Cubic compressive strength/MPa	Tensile strength/ MPa	Elastic modulus /kN/mm ²
1	C40	0	0	40.47	4.08	32.51
2	C40	0	50	39.12	3.73	26.81
3	C40	0.08	50	41.68	3.87	27.65
4	C40	0.12	50	43.98	4.36	27.98
5	C40	0.16	50	40.82	4.48	28.62
6	C40	0.08	0	40.36	4.12	32.68
7	C40	0.08	100	37.96	3.56	25.66

3 Scheme design

3.1. Specimen design

In this paper, nine specimens of waste fiber recycled concrete shear wall are designed. Taking the common

C40 reinforced concrete shear wall as a reference, the influence of waste fiber volume ratio, recycled aggregate volume ratio and axial compression ratio on the shear capacity of shear wall is studied. The test parameters are shown in Table 2.

Table 2. Parameter design of FCSW

Number	Strength grade of concrete	volume ratio of waste fiber/%	Recycled aggregate replacement ratio / %	Axial compression ratio	Vertical load / N
FCSW1	C40	0	0	0.2	390390
FCSW2	C40	0	50	0.2	390390
FCSW3	C40	0.08	50	0.2	390390

FCSW4	C40	0.12	50	0.2	390390
FCSW5	C40	0.16	50	0.2	390390
FCSW6	C40	0.08	0	0.2	390390
FCSW7	C40	0.08	100	0.2	390390
FCSW8	C40	0.12	50	0.3	585585
FCSW9	C40	0.12	50	0.4	780780

The reinforcement is HRB335, the diameter of longitudinal reinforcement is 16mm, and the diameter of stirrup is 8mm. The shear wall specimens are mainly composed of loading beam, shear wall and foundation. The size of the loading beam (length $\times$ width $\times$ height) is 1000mm $\times$ 230mm $\times$ 200mm, the size of shear wall is

1000mm $\times$ 130mm $\times$ 1900mm, and the size of foundation is 2000mm $\times$ 500mm $\times$ 500mm. In order to compare and study the changes of various factors, the size and reinforcement of each specimen are the same, as shown in Figure 3.

Figure 3 Specimen size and reinforcement drawing (unit: mm)

3.2. Experimental test.

In the experiment, the electro-hydraulic servo loader

online system was used to carry out low cycle cyclic loading on specimens of FCSW. The loading diagram of the test device is shown in Figure 4.

- 1 - Frame beam 2 - Reaction wall 3 - Vertical hydraulic jack
- 4 - Horizontal actuator 5 - Distribution beam 6 - Loading beam
- 7 - Shear wall 8 - Foundation beam 9 - Ground anchor bolt 10 - Hand Jack

Figure 4. Loading diagram of test device

4 Experimental phenomena and failure modes

The low cycle cyclic loading test of FCSW specimens is similar, which can be roughly divided into four stages: elastic stage, crack development stage, yield stage and failure stage. The crack development and failure mode of shear wall specimens are shown in Figure 5.

Figure 5. Distribution and failure mode of wall cracks

Elastic stage: the wall is basically in elastic state without obvious phenomenon.

Crack development stage: with the increase of load, cracks first appear at the root of the wall tensile zone and continue to develop. When the loading continues, the inclined cracks appear at the position near the top of the foundation and extend to the middle of the wall.

Yield stage: the cracks in the corner concrete become wider, and the fibers in the concrete begin to play a role. But under the same load, the displacement variable increases. The specimens yield obviously. The yield phenomenon of shear wall specimens without waste fiber is not obvious.

Failure stage: the corner concrete is crushed by large blocks, and the fiber is broken. The reinforcement at the corner of the wall yielded and the bearing capacity of the wall decreased sharply.

It can be seen from Figure 5 that when the shear failure occurs in the shear wall specimen FCSW6, the number of inclined cracks is more, and the through cracks are relatively short. When the shear wall bottom is damaged, the concrete spalling is serious and the failure is ductile; the distribution of cracks in the shear wall specimen FCSW1 is relatively sparse, but the through cracks are relatively long. Through comparison, it can be found that the incorporation of waste fiber can prevent the formation of cracks to a certain extent.

5 Analysis of shear capacity of FCSW

5.1. Influence of various factors on shear capacity of FCSW

Based on the test results of specimens FCSW2, FCSW3, FCSW4 and FCSW5, Figure 6 (a) shows the change of shear capacity of shear wall specimens with volume fraction of waste fiber when the replacement rate of recycled aggregate is 50%. It can be seen from the figure that the more the waste fiber volume content, the greater the shear bearing capacity of the shear wall specimen.

Comparing the test results of FCSW6, FCSW3 and FCSW7, Figure 6 (b) shows the change of shear capacity of shear wall specimens with recycled coarse aggregate content when the volume ratio of waste fiber is 0.08%. It can be seen from the figure that when the content of recycled aggregate increases from 0% to 50%, the shear capacity of shear wall specimen decreases by 4.85%; when the content of recycled aggregate increases from 50%, the shear bearing capacity of shear wall specimen decreases by 3.69%.

Comparing the test results of FCSW4, FCSW8 and FCSW9, Figure 6 (c) shows the variation of shear capacity of shear wall specimens with axial compression ratio. It can be seen from the figure that the shear bearing capacity of shear wall specimens increases with the increase of axial compression ratio. When the axial compression ratio changes from 0.2 to 0.3, the shear capacity increases by 10.4%; when the axial compression ratio changes from 0.2 to 0.3, the shear bearing capacity increases by 13.5%.

Figure 6. Influence of various factors on shear capacity

5.2. Calculation of shear capacity of FCSW

The incorporation of waste fiber and replacement of natural coarse aggregate with recycled fiber make the material performance of recycled concrete with waste fiber different from that of ordinary reinforced concrete. Therefore, the structural performance of FCSW is different from that of ordinary reinforced concrete shear wall. According to the provisions of code for design of concrete structures (GB 50010-2010) and technical specification for fiber reinforced concrete structures (CECS 38:2004), and considering the influence of waste fiber and recycled concrete on shear capacity of shear wall, the shear capacity of FCSW V_u can be divided into two parts: Shear capacity of concrete V_c and horizontal reinforcement concrete resistance V_s . The concrete strength is the recycled aggregate concrete strength considering the recycled aggregate content and multiplied by the influence coefficient of waste fiber. Therefore, the shear capacity of shear wall can be calculated according to the following formula:

$$V_u = V_c + V_s \quad (1)$$

$$V_c = \frac{1}{\lambda - 0.5} (0.5 f_t b h_{w0} + 0.13 N \frac{A_w}{A}) \quad (2)$$

$$V_s = f_{yh} \frac{A_{sh}}{s} h_{w0} \quad (3)$$

Where λ is shear span ratio, $\lambda = M / V h_{w0}$, (λ is 1.5 when λ is less than 1.5, λ is 2.2 when λ is greater than 2.2), f_t is design value of axial tensile strength of concrete, b is Section width, h_{w0} is effective height of

section, A_w is Area of shear wall Web (When the cross-section is rectangular $A_w = A$), f_{yh} is the yield strength of horizontal stirrups, A_{sh} is the section area of horizontal stirrup at the same section of wall limb, s is spacing of horizontal stirrups, N is axial force (When $N > 0.2 f_t b h$, take $N = 0.2 f_t b h$).

According to the test data [15], it can be found that the ultimate shear capacity increases with the increase of waste fiber volume content in a certain range. Therefore, the influence coefficient of waste fiber on shear capacity of inclined section β_v is introduced. The formula of influence coefficient is obtained by fitting test data and applied to the design of recycled concrete shear wall. The shear capacity of FCSW can be expressed by formula (4):

$$V_u = \frac{1}{\lambda - 0.5} [0.5 f_t b h_{w0} (1 + \beta_v) + 0.13 N \frac{A_w}{A}] + f_{yh} \frac{A_{sh}}{s} h_{w0} \quad (4)$$

$$\beta_v = 25 \rho_f$$

Where β_v is the influence coefficient of waste fiber on shear capacity of inclined section, ρ_f is volume ratio of waste fiber, and $\rho_f = 0 \sim 0.16\%$.

5.3. Comparison of calculated and measured shear capacity

The calculated and measured values of each specimen of waste fiber recycled concrete shear wall are shown in Table 3.

Table 3 Comparison of calculated and measured values of each specimen

Number	Measured values / kN	Calculated values / kN	Measured value / Calculated value
RCS1	354.99	314.15	1.13
RCS2	322.95	288.35	1.12

RCS3	307.86	293.2	1.05
RCS4	374.96	337.8	1.11
RCS5	394.09	348.75	1.13
RCS6	344.57	319.05	1.08
RCS7	315.76	281.93	1.12
RCS8	413.86	394.15	1.05
RCS9	469.87	419.53	1.12

It can be seen from table 3 that the average value of the ratio between the measured value and the calculated value of the waste fiber recycled concrete shear wall is 1.101, and the calculated value is conservative.

6 Conclusion

In this paper, nine FCSW specimens are tested under low cyclic loading test, and the method of theoretical analysis is used to study the calculation of shear capacity of FCSW. The following conclusions can be drawn.

(1) The influence of various factors on the shear capacity of FCSW: waste fiber delays the development of cracks to a certain extent, the shear capacity increases with the increase of waste fiber volume ratio, and decreases with the increase of recycled aggregate volume ratio.

(2) Based on the code for design of concrete structures, combined with the influence of volume ratio of waste fiber on shear capacity, the calculation formula of shear capacity of FCSW is proposed. By comparing with the test results, it can be found that the two formulas are in good agreement.

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References

1. ZHANG D.(2012)The flexural properties' study of waste fiber recycled concrete beam [D]. Shenyang Jianzhu University.
2. GENG Y, WANG Q, Yuyin Wang etc. (2109)Influence of service time of recycled coarse aggregate on the mechanical properties of recycled aggregate concrete[J].Materials and Structures, Vol.52 (5), pp.1-16.
3. HANG F X, CAO X Y, et al. Influence of admixture on compressive strength and splitting tensile strength of C30 recycled coarse aggregate self compacting concrete[J]. Concrete, (08) : 82-87.
4. WANG J Q.(2015) Testing Study on the Strength and Permeable Performance of R ecycled

- Aggregate Pervious Concrete. Structural engineers,31(04):167-171.
5. Mohammad S,Long S,Amir S, et al. (2019)Recycled concrete aggregate mixed with crumb rubber under elevated temperature[J]. Construction and Building Materials,222.119-129.
6. Wang Y , Zureick A H , Cho B S , et al. (1994)Properties of Fiber Reinforced Concrete Using Recycled Fibers from Carpet Industrial Waste[J]. Journal of Materials Science,29(16):4191-4199.
7. ZHU H B, YAO C, ZHAO B L, et al. (2017)Experimental research on the effects of polypropylene fiber content on recycled concrete flexural fatigue performance[J]. Sichuan Building Science, 43(05):104-107.
8. YUAN F C, LI S.(2018)Review of fiber reinforced recycled aggregate concrete[J]. Concrete, (09):31-39.
9. ZHOU J H, LIU Z H, LI T, et al. (2013)Experimental Study on Splitting Tensile Strength of Waste Fiber Recycled Concrete[J].Journal of Shenyang Jianzhu University (Natural Science),29(5):796-802.
10. ZHOU J H, ZHAO W L, LIU D, et al. (2014)Damage analysis of waste fiber recycled concrete[J]. Concrete,(4):40-43.
11. ZHOU J H, LIU D, DONG J F.(2013)Constitutive relation of waste fiber recycled concrete[J]. Concrete,(2):54-58.
12. ZHOU J H, ZHANG D, YANG Y S.(2013)Test Study on Flexural Properties of Waste Fiber Recycled Concrete Beams[J]. Journal of Shenyang Jianzhu University (Natural Science), 29(2):290-296.
13. WANG D L, LU Y L, YANG T.(2017)Experimental study on seismic behavior of recycled concrete frame joints with hybrid fibers[J]. WORLD EARTHQUAKE ENGINEERING, 33(01):117-121.
14. WANG J C, ZHOU J H, WANG X D, et al.(2018)Experimental study of the carbonation depth prediction model for waste fiber recycled concrete[J]. Industrial Construction, 28(3):17-20.
15. ZHANG W L. (2014)Experimental study on mechanical properties of waste fiber recycled concrete beam[D]. Shenyang Jianzhu University.