Influence of freezing-thawing cycles on strength of fiber recycled concrete column

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Abstract. In order to reduce the influence of freezing-thawing cycle on the recycled concrete and improve the use of recycled concrete in cold regions, this paper systematically explored the influence of different variables such as the mix ratio of recycled aggregate, the content of basalt fiber and freezing-thawing cycle on the mechanical properties of recycled concrete. The results show that adding basalt wire can improve the bearing capacity and ductility of the recycled concrete, but the mechanical properties of the recycled concrete are greatly reduced after the freeze-thaw cycle.

1. Introduction
According to relevant data analysis, the proportion of construction waste in urban garbage is up to 40%, and the proportion of waste concrete blocks is up to over 60% [1-2]. At present, for the recycle of waste concrete has become a major attention focus in the construction industry and the environmental protection industry, but the recycled concrete because of the high porosity, water imbibition is strong, such as large shrinkage creep characteristics [3-5], cause its bearing capacity and durability under the action of freeze-thaw cycle, decrease [6-8], the serious influence the use of recycled concrete in cold region. Therefore, scholars have done a lot of research on improving the freeze-thaw performance of recycled concrete. The relevant research results show that the replacement rate of recycled aggregate has a great impact on the bearing capacity and durability of recycled concrete. The high porosity makes the recycled aggregate more affected by freeze-thaw than the original concrete. The mechanical properties of recycled concrete are also affected by the water-cement ratio, and the resistance of recycled aggregate to freeze-thaw cycle is higher than that of primary aggregate under the same water-cement ratio [9-11]. In terms of the porosity of recycled aggregate, studies have shown that the fiber reinforcement technology can effectively improve the carrying capacity by bridging internal voidage, but the degree of improvement in mechanical properties varies with the fiber types and fiber content [6-7].

In this study, the influence of freezing-thawing cycle on the mechanical energy of specimens was analyzed by adding basalt fiber and the proportion of recycled aggregate, and an optimization scheme was proposed to optimize the freezing-thawing resistance of recycled concrete.
### Table 1. Coarse aggregate material characteristics.

| Aggregate category | Apparent density (kg/m³) | Bulk density (kg/m³) | Moisture content (%) | Crushing index (%) |
|-------------------|--------------------------|----------------------|----------------------|-------------------|
| Native aggregate  | 2347                     | 1382                 | 0.25                 | 11.58             |
| Recycled aggregate| 2172                     | 1219                 | 2.25                 | 13.42             |

### Table 2. Proportion of recycled concrete.

| Substitution rate(%) | Cement | Water | Gravel | Native aggregate | Recycled aggregate |
|----------------------|--------|-------|--------|------------------|---------------------|
| 0                    | 1      | 0.53  | 1.91   | 3.55             | 0                   |
| 50                   | 1      | 0.53  | 1.86   | 1.72             | 1.72                |
| 100                  | 1      | 0.53  | 1.86   | 0                | 3.55                |

### 2. Experimental set-up

#### 2.1. Materials and specimens

The test specimen is a square short column, of which the square short column size is 100mm×100mm×400mm. The primary aggregate of concrete used for pouring was screened according to Technical Requirements and Test Method of Gravel and Crushed Stone for Ordinary Concrete (JGJ53-92), and the aggregate with particle size of 2.36~19mm was taken. The basic performance index of sand crushed stone (or gravel) for ordinary concrete was measured according to Standard for technical requirements and test method of sand crushed stone (or gravel) for ordinary concrete (JGJ-2006). The recycled aggregate is derived from the waste materials of buildings after the earthquake in Dujiangyan, Sichuan Province. It is made by manual screening after the aggregate crusher is broken mechanically. The particle size range is 4.75 ~ 19mm. The fine aggregate was river sand, the apparent density was 1460kg/m³, the sediment content was 1.34%, the fineness modulus was 2.8, and the water was tap water. At the same time, the concrete mixture was mixed with basalt fiber with the volume content of 2kg/m³, the fiber length was 15~19mm and the diameter was 13 mm. Due to the large water absorption rate of recycled aggregate, the water absorption rate of recycled aggregate was determined to be 2.25% after water absorption and saturation treatment before mixing and pouring concrete. The relevant indexes of recycled aggregate and the mix ratio of experimental concrete are shown in Table 1 and Table 2.

In order to determine the mechanical properties of recycled concrete with different replacement rates of recycled concrete aggregate, the configured recycled concrete with different replacement rates was cast into a 150mm×150mm×150mm cube test block to determine its compressive strength and splitting tensile strength. The results are shown in Table 3.

#### 2.2. Experiment scheme

A total of 27 specimens of short square columns of recycled concrete were involved in this experiment, which were divided into 3 groups. Each group was composed of 3 specimens each with the substitution rate of recycled aggregate of 0%, 50% and 100%, and the tail Numbers 1, 2 and 3 were...
used respectively. The B0 group was the basic group, and the influence of the substitution rate of recycled aggregate on the concrete performance was studied. Group B1 is a concrete specimen group with the content of basalt fiber filament of 2kg/m, which is used to compare the improvement degree of basalt fiber filament on the bearing capacity of recycled aggregate. B2 is the freezing-thawing cycle group of fiber regenerated concrete, which is used to compare the influence of freezing-thawing cycle on the performance of fiber regenerated concrete.

2.3. Loading and freeze-thaw scheme

2.3.1. Loading scheme. The static load test was carried out by a 200T press, and the loading scheme of each specimen was the same: the specimen was preloaded before loading, and the method of graded loading was adopted. The loading speed was 0.5kN/s, and the loading rate was 5kN per stage. The load was maintained for 3min. The specific load-time relationship is shown in Figure 1.

2.3.2. Freeze-thaw scheme. The freezing-thawing scheme of this experiment is conducted in strict accordance with the "fast freezing method" for frost resistance performance test in Standard for test method of long-term performance and durability of ordinary concrete (GB/T 50082-2009). Because of the early trials found that plain concrete short column specimen manager after 55 times freeze-thaw cycle has been severely damaged, so the test set the freeze-thaw cycles to 40 times. Each time the cycle time of freezing and thawing is 4 h, used for the melting time accounts for a quarter. In the process of freezing and melting, specimen center temperature control in -18 ± 2 ℃ and 15 ± 2 ℃ range, temperature is not higher than 17 ℃ specimen center at any time and not less than -20 ℃. The temperature-time relationship between the specific freeze-thaw liquid and the specimen is shown in Figure 2.

2.3.3. Deformation and displacement monitoring. Vertical axial and annular strain gauges were arranged from the top of the column to the bottom of the column at 50mm, 200mm and 350mm, respectively. Strain data were collected every 10kN during the loading process to monitor the vertical and annular strain of the specimen. Three displacement meters were used to contact the three angles of the upper part of the specimen to measure the vertical displacement of each Angle during the loading process.

![Figure 1. Load time curve.](image1)

![Figure 2. Freeze-thaw temperature curve.](image2)

3. Results and analysis

3.1. Failure pattern of specimen

3.1.1. Non-freeze-thaw specimen. The change of concrete short column mainly presents three stages: at the initial stage of loading, the load-strain curve of the specimen presents linear transformation, and the specimen surface has no obvious change; With the increase of load, the strain and vertical displacement of concrete gradually increase, and the transverse strain gradually appears in short
columns. When the load increases to 75-85% of the ultimate load, the specimens reach the ultimate tensile strain of concrete due to the large transverse deformation and start to appear tiny cracks, accompanied by the sound of clear concrete splitting. As the load continues to increase, the width of cracks on the column surface increases rapidly and the number of cracks increases, and the cracks continue to expand to both ends. After that, the crack width and displacement of the test short column increase sharply, and the strain gauge value at each measuring point changes sharply or overflows, while the load increases slowly. When the load reaches the limit load, the concrete crack penetrates and the specimen is destroyed. The failure modes of concrete short columns are mainly axial compression failure, splitting failure and baroclinic failure. The failure patterns of the non-freeze-thaw specimens are shown in Figure 3.

![Figure 3. Failure pattern of non-freeze-thaw specimens.](image)

3.1.2. Freeze-thaw specimen. During the loading process of the specimen, there was no obvious phenomenon on the surface of the specimen at the early stage of loading, and when the load increased to a certain extent, the specimen suffered from brittle failure. As can be seen from the figure, after freeze-thaw, the specimen mainly presents the form of splitting failure, and the damage degree of the specimen is relatively serious when it reaches the limit load. The square column is mainly crushed by axial concrete, and the failure position of short concrete column is mainly in the middle and upper end of the column. Compared with the non-freezing-thawing specimens, the concrete fragments were more crushed after the specimens were damaged after freezing-thawing. The specimens were obviously broken into several parts, and there was an obvious separation between aggregate and concrete in the specimens. The failure forms are similar and the different replacement rates of recycled aggregate have no obvious effect on the failure modes of concrete. The failure patterns of freeze-thaw specimens are shown in Figure 4.

![Figure 4. Failure pattern of freeze-thaw specimen.](image)
Table 4. Summary of test results.

| Specimen number | Ultimate load(kN) | Displacement(mm) | Failure modes         |
|-----------------|-------------------|------------------|-----------------------|
| B01             | 195.69            | 1.77             | Axial failure         |
| B02             | 133.71            | 1.74             | Diagonal-compression failure |
| B03             | 116.75            | 1.65             | Diagonal-compression failure |
| B11             | 220.80            | 3.54             | Splitting failure     |
| B12             | 214.37            | 2.34             | Axial failure         |
| B13             | 170.41            | 1.76             | Axial failure         |
| B21             | 158.25            | 1.36             | Splitting failure     |
| B22             | 124.53            | 1.43             | Splitting failure     |
| B23             | 105.42            | 1.46             | Splitting failure     |

3.2. Bearing capacity analysis

The ultimate bearing capacity and ultimate displacement of each specimen are shown in Table 4. The Load-Displacements of each specimen are shown in Figure 5-6.

According to the data in Table 4, the bearing capacity of the specimens B02 and B03 decreased by 31.6% and 40.3% respectively, indicating that the bearing capacity of the specimens gradually decreased with the increase of the replacement rate of the restrained specimens. The bearing capacity of the specimens in group B1 increased by 12.8%, 60.3% and 45.9%, respectively, compared with that in group B0. Among them, the best effect was achieved when the replacement rate was 50% and fiber was added. The bearing capacity of the specimens was fully exerted when the failure type was axial compression failure, while the bearing capacity of the specimens was lower when the failure type was baroclinic failure. Fiber recycled concrete short column after 40 weeks time of freezing and thawing bearing capacity is greatly reduced, B2 specimen relative B1 group specimens bearing capacity to reduce the amplitude decreased respectively 28.3%, 41.9%, 38.1% respectively, the replacement rate of 50% reduction of maximum bearing capacity, the specimens showed that the replacement rate of concrete resistance to freezing and thawing cycle ability is low. The results show that the resistance of recycled aggregate to freezing-thawing cycle is worse than that of primary aggregate, but the suitable mix ratio of recycled aggregate is beneficial to the structural performance of recycled concrete.

From the data in Figure 5, it can be seen that the replacement rate of recycled aggregate has little impact on the ductility of concrete. With the addition of fiber, the ultimate displacement of concrete increased significantly, and the ultimate displacement of specimens with the substitution rate of "0%", "50%" and "100%" increased by 100%, 34.5% and 6.67%, respectively. The load-displacement trend of specimens with the substitution rate of 100 was the steepest, and the strength was the lowest, which was also the earliest to enter the plastic stage. It can be seen from Figure 6 that the performance of recycled concrete has a great change after freeze-thaw. Under different substitution rates, the ultimate displacement decreases by 61.5%, 38.9% and 17.05% respectively under the corresponding substitution rates. The specimen with the substitution rate of "0" develops the most slowly in displacement and the elastic stage is longer, followed by the specimen with the substitution rate of "50" and the substitution rate of "100" is the fastest in displacement development. The higher the substitution rate, the lower the strength of the concrete short column.
4. Conclusion

The test results show that the bearing capacity of recycled concrete can be improved by adding basalt fiber, and the bearing capacity can be increased by up to 60%, and the ductility of recycled concrete can be improved greatly. Under the influence of freezing-thawing cycle environment, the bearing capacity of recycled concrete decreased significantly, and the specimen with the replacement rate of 50% even decreased as much as 41.9%. The reduction rate of ultimate displacement after freezing-thawing decreased with the increase of the replacement rate of recycled aggregate.

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