Mechanical Properties of Recycled Concrete with Crushed Brick Coarse Aggregate

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Abstract. In order to study the influence of the characteristics of crushed bricks on recycled concrete, the author took the water-cement ratio (W/C) as the design goal, and crushed bricks as coarse aggregates to prepare five groups of recycled concretes with different W/C. After maintenance under standard conditions, used the YE-2000C Pressure Testing Machine to perform a compressive strength test to calculate the compressive strength value. The results shown that: the increase of W/C ratio will reduce the compressive strength of recycled crushed brick concrete. In this test, the strength of recycled crushed brick concrete can vary between 23.13MPa and 35.43MPa; In order to accurately calculate the amount of raw materials, the regression coefficient of the crushed stone in the regulations is not directly used for calculation. In order to give full play to the role of crushed bricks and cement slurry, recycled crushed brick concrete has a suitable range of water-cement ratio. This conclusion provides a reference for the research and application of crushed bricks in recycled concrete.

1. Introduction

With the acceleration of China's urbanization development process in recent years, the frequent replacement of buildings has led to a large amount of construction waste. How to rationally use construction waste has become an important research topic in the sustainable development of China's construction industry. The recycled crushed brick concrete is the use of sintered ordinary bricks from the demolition of buildings, which are decomposed by a crusher into crushed brick particles of suitable particle size as coarse aggregates. The concrete is prepared with a suitable water-cement ratio and sand ratio. Compared with ordinary concrete, it has the characteristics of low strength and high water absorption [1]. How to improve the strength of recycled concrete is the main research direction at present. For example, 3% sludge ash can increase the compressive strength and tensile strength of ordinary concrete and recycled concrete [2]; the volume of steel fiber and steel The thickness of the fiber concrete layer has a certain impact on the flexural bearing capacity of the BFRP steel fiber recycled concrete beams [3]; the chloride salt has a significant inhibitory effect on the sodium sulfate erosion of the recycled concrete [4]; adding steel fibers can improve the crack resistance of recycled concrete [5]; rubber particles can improve the toughness of concrete [6] and so on. Relevant scholars have also tried to apply recycled concrete to the structure, for example, to solve the problems encountered in the design of the 12-story frame-shear wall structure of Shanghai using recycled concrete [7]. In addition, according to the high water absorption characteristics of crushed bricks, a water-reducing agent is added to recycled concrete to reduce the requirement of water consumption and increase the strength of concrete [8]. Both the quality and height of the capillary water absorption of recycled aggregate permeable concrete (RAPC) change in the form of a power function [9]. However, the research on the characteristics of crushed brick
aggregate and the failure mechanism of recycled concrete is not comprehensive enough. Based on the existing research, this paper prepares five groups of crushed brick recycled concrete with different water-cement ratios to study the influence of crushed bricks on the mechanical properties of recycled concrete, explore the calculation of the regression coefficient of crushed bricks, and explain the failure phenomenon of recycled concrete.

2. Test

2.1. Test materials
Cement: Conch brand PꞏO 32.5, the measured strength is 41.0 MPa.
Coarse aggregate: Discarded sintered ordinary bricks to be artificially crushed into a suitable particle size of 5-31.5 mm.
Fine aggregate: Natural river sand with a fineness modulus of 2.7.
Water for mixing and maintenance: Both use tap water from Nanning City.

2.2. Test method and test equipment
The method of manually mixing concrete is adopted, and the mold is a standard mold of 150x150x150mm³. The equipment used for compressive strength test is YE-2000C pressure testing machine, and the maximum loading load is 2000 kN.

Figure 1 Test block in maintenance.

| Group | Cement (kg) | Sand (kg) | Crushed bricks (kg) | Water (kg) |
|-------|-------------|-----------|---------------------|------------|
| A50   | 10.15       | 14.30     | 26.55               | 5.10       |
| A55   | 9.23        | 14.62     | 27.15               | 5.10       |
| A60   | 8.50        | 15.01     | 28.54               | 5.10       |
| A65   | 5.00        | 8.73      | 16.20               | 3.00       |
| A70   | 4.28        | 9.04      | 16.79               | 3.00       |

2.3. Test design
In order to study the mechanical properties of concrete prepared with crushed bricks completely replacing crushed stones, five groups of experiments with different water-cement ratios were designed. The water-cement ratios were 0.50, 0.55, 0.60, 0.65 and 0.70. According to the ordinary concrete mix ratio design specification [10], the mix ratio design was carried out with the target slump of 75-90 mm. In the mixing process, crushed bricks were directly used to completely replace the crushed stones, and the water consumption and sand rate were adjusted according to the requirements of workability. After measuring the slump to meet the requirements, prepared the concrete standard test block with a 150x150x150 mm³ mold. The final material consumption is shown in table 1. The prepared test block
is shown in Figure 1. It is estimated that the standard compressive strength will be measured after 28 days of standard curing.

3. Test results and discussion

Due to the impact of the Covid 19, the maintenance cycle exceeded the standard maintenance time, and the actual maintenance days were 57 days. According to the general concrete mix design specification [10], under standard maintenance conditions, the development of concrete strength was roughly proportional to the common logarithm of age. The formula is as follows:

\[
\frac{f_n}{f_{28}} = \frac{\lg n}{\lg 28}
\]

Where: 
- \( f_n \) is the compressive strength of concrete (MPa) at \( n \) days; 
- \( f_{28} \) is the compressive strength of concrete at \( 28 \) days (MPa); 
- \( n \) is the conservation age (d).

In the concrete compressive strength test, the formula was used:

\[
f = \frac{F_N}{A}
\]

Where: 
- \( F_N \) is the peak load; 
- \( A \) is the compressive area (150×150 mm²) of the concrete test block.

The YE-2000C Pressure Testing Machine was used to conduct compressive strength tests on the specimens in sequence, and record the peak load when the specimens are broken, as shown in Table 2.

| Group | Specimens 1 | Specimens 2 | Specimens 3 | Average value |
|-------|-------------|-------------|-------------|---------------|
| A50   | 995.14      | 961.68      | 945.82      | 967.55        |
| A55   | 926.85      | 908.00      | 960.89      | 931.91        |
| A60   | 747.37      | 809.40      | 742.56      | 766.44        |
| A65   | 737.40      | 816.02      | 731.03      | 761.48        |
| A70   | 724.56      | 681.23      | 652.75      | 686.18        |

Table 2. Maximum load value of each group of specimens (kN).

The formula 1 and formula 2 were used to convert the load values in Table 2 into corresponding compressive strength values and 28d-age strength values, as shown in Table 3.

| Group | Specimens 1 | Specimens 2 | Specimens 3 | Average value | 28d-age intensity value |
|-------|-------------|-------------|-------------|---------------|-------------------------|
| A50   | 44.23       | 42.74       | 42.04       | 43.00         | 35.43                   |
| A55   | 41.19       | 40.36       | 42.71       | 41.42         | 34.13                   |
| A60   | 33.22       | 35.97       | 33.00       | 34.06         | 28.07                   |
| A65   | 32.77       | 36.27       | 32.49       | 33.84         | 27.89                   |
| A70   | 32.20       | 30.28       | 29.01       | 30.50         | 25.13                   |

Table 3. Maximum load value of each group of specimens (MPa).

It can be seen from Table 3 that although there is a certain deviation in the compressive strength value of each specimen, the compressive strength value of the prepared crushed brick concrete follows the law in the design code of ordinary concrete mix ratio. With the increase of water-cement ratio, the compressive strength of crushed brick concrete shows a decreasing trend. When the water-cement ratio is 0.50 and 0.55, the compressive strength is not much different, but after the water-cement ratio reaches
0.60, the strength change is significantly reduced. Therefore, if we need to prepare recycled concrete with higher strength crushed bricks, we can add a water-reducing agent to reduce the water-cement ratio. At the same time, the maintenance age also affects the strength of concrete.

According to the same mix ratio and the ordinary concrete mix ratio design specification, the relationship between the 28d-age concrete compressive strength \( f_{cu} \) and the actual strength of the cement \( f_{ce} \) and the water-binder ratio conforms to the following formula:

\[
f_{cu} = \alpha_a f_{ce} \left( \frac{C}{W} - \alpha_b \right)
\]  \hspace{1cm} (3)

Where, the actual strength of the cement used in this test is 41 MPa. \( \alpha_a \) and \( \alpha_b \) are regression coefficient of gravel in the regulations, \( \alpha_a = 0.53 \) and \( \alpha_b = 0.20 \).

Calculate the 28d compressive strength of concrete prepared with crushed stone according to the above formula, and compare it with the 28d compressive strength of concrete prepared with crushed bricks.

| Group | Predicted 28d strength of gravel concrete | Measured 28d strength of crushed brick concrete | Comparison value |
|-------|------------------------------------------|---------------------------------------------|-----------------|
| A50   | 39.11                                    | 35.43                                       | -3.68           |
| A55   | 35.16                                    | 34.13                                       | -1.03           |
| A60   | 31.87                                    | 28.07                                       | -3.80           |
| A65   | 29.08                                    | 27.89                                       | -1.19           |
| A70   | 26.70                                    | 25.13                                       | -1.57           |

It can be seen from table 4 that there is a deviation between the compressive strength of concrete prepared with crushed bricks and the compressive strength of concrete calculated with crushed stones, and the value is slightly lower than the calculated strength of crushed stones. It shows that if the cement strength and water-cement ratio are the same, the strength of crushed brick concrete will be lower than that of crushed stone. The reason may be the influence of coarse aggregate on the compressive strength of concrete, and in actual measurement, the strength of crushed bricks is lower than that of crushed stones. At the same time, it can be seen that the deviation value of the compressive strength of the crushed brick concrete and the crushed stone concrete is not proportional. That is, when calculating the standard value of concrete compressive strength, the regression coefficient of crushed brick and the regression coefficient of crushed stone may be different. It is not possible to simply apply the regression coefficient of the crushed stone in the regulations to calculate the strength of the crushed brick concrete. Therefore, in this experiment, the water-cement ratio is the design goal, rather than simply taking the design strength as the design goal to design the mix ratio.

The 28d compressive strength and the corresponding gray-water ratio in the result on the coordinate axis is shown in Figure 2. According to the linear regression model, the calculation results are as follows:

\[
f_{cu} = 18.873 \frac{C}{W} - 1.8025 
\]  \hspace{1cm} (4)

\[
R^2 = 0.925
\]  \hspace{1cm} (5)

Where: \( f_{cu} \) is the compressive strength of recycled concrete with crushed bricks; \( C/W \) is cement-water ratio; \( R \) is variance.
At the same time, J. Bolomy \cite{10} regression coefficient calculation formula is:

\[
f_{cu} = \alpha_a f_{cr} \left( \frac{C}{W} - \alpha_b \right)
\]

(6)

From formula (4) and formula (6), the regression coefficient value of crushed bricks in this test can be calculated, namely \(\alpha_a = 0.46\), \(\alpha_b = 0.10\).

Experiments have proved that the regression coefficient of crushed bricks is different from the regression coefficient of crushed stones. When calculating the amount of recycled concrete materials, it is not possible to directly apply the regression coefficient calculation of the crushed stone in the regulations, so as to avoid the result may be too biased.

Figure 3 shows the internal structure of the test block when it is crushed. It can be seen most of the crushed bricks, a small amount of cement mortar wraps the crushed bricks. This shows that under pressure, the crushed bricks are preferentially destroyed and split, and the internal texture of the crushed bricks can be seen. This can be explained by the fact that the water ash is relatively small, the bonding strength of cement slurry is relatively large, the strength of crushed bricks is low, and the crushed bricks cannot resist the effect of pressure and damage. According to this damage phenomenon, it can be inferred that there should be a proper water-cement ratio when preparing the crushed brick concrete, so that the bonding strength of the cement slurry and the strength of the crushed brick can be maximized at the same time, reducing the input of raw materials, and the preparation meets the application requirements. The crushed brick recycled concrete, such as farmland water conservancy, rural roads and other places that require low strength can be promoted and applied.
4. Conclusion
(1) There are differences in the compressive strength of crushed brick concrete with different water-cement ratios. As the water-cement ratio increases, the compressive strength value of crushed brick concrete shows a decreasing trend.

(2) When calculating the compressive strength value of crushed brick concrete, crushed brick has a regression coefficient value different from that of crushed stone, and the regression coefficient of crushed stone in the regulations cannot be directly used for calculation, otherwise the calculation result will be too biased.

(3) There is a suitable water-cement ratio range when preparing crushed brick concrete, so that the strength of crushed brick and cement mortar can play a maximum role at the same time.

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