Study on Durability of Recycled Large Aggregate Concrete

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Abstract: In this paper, natural large aggregate concrete (NAC) and recycled large aggregate concrete (RAC) are prepared. The impermeability, carbonation resistance, chloride ion penetration resistance, early crack resistance and dry shrinkage of the two kinds of concrete are compared and studied. The results show that, compared with NAC, when cured to the same age (28d), the water seepage height of RAC increased by 23.11%, and its relative permeability coefficient increased by 40.81%; carbonization depth increased by 14.63%; 6h chloride ion electric flux increased by 24.85%, chloride ion diffusion coefficient increased by 24.90%; the number of cracks per unit area increased by 68.88%, and the total crack area per unit area increased by 37.80%. The dry shrinkage rate increased by 50.46%. Although RAC’s durability is worse than NAC, RAC prepared by reasonable technology has the same performance as NAC and can be used instead of NAC to some extent.

1. Introduction
Concrete is the most widely used building material in the world. China ranks first in the world in concrete usage and plays a vital role in adapting to the rapid economic development. However, with the acceleration of urbanization and the arrival of the service life of old buildings, the amount of abandoned concrete removed every year in China is very large and is on the rise year by year. Recycled aggregate concrete, as an important way of recycling construction waste, is not only conducive to solving the problem of construction waste disposal and landfill, but also conducive to reducing the ecological damage of the origin of aggregates caused by uncontrolled mining of natural sandstone aggregates [1]. Therefore, the research on recycled aggregate and recycled aggregate concrete is imperative.

Recycled concrete aggregate is the aggregate formed by crushing, grading and mixing waste concrete blocks according to a certain proportion, which is called recycled aggregate or recycled concrete aggregate [2]. Compared with natural aggregate, recycled aggregate has rough and uneven surface, many edges and corners and high mud content [3]; low apparent density and bulk density, high water absorption rate and large mass loss rate affect the durability of aggregates [4,5]. Recycled concrete refers to concrete made by crushing, cleaning and grading waste concrete blocks and mixing them with gradation according to a certain proportion to partially or completely replace natural aggregate. Durability of concrete is greatly affected by test conditions: the carbonization rate of specimens under standard curing conditions is lower than that under high-temperature autoclaved curing conditions [6]. The deformation of recycled concrete varies with the amount of coarse aggregate, water absorption rate, strength, mortar attach rate and proportioning method: under the...
same proportioning, the amount of recycled aggregate has limited influence on the dry shrinkage of concrete [7]; the larger the aggregate mortar attach rate, the greater the autogenous shrinkage of the concrete prepared [8].

According to the Recycled Coarse Aggregate for Concrete (GB/T 25177-2010), the recycled aggregate whose particle size is greater than 4.75mm is called recycled coarse aggregate. The research on recycled coarse aggregate is mostly concentrated below 40mm. Compared with conventional recycled coarse aggregate, recycled large aggregate with particle size over 40mm has the advantages of simple crushing, low energy consumption and easy acquisition, but there are few related researches. Yingjie Li, Jianzhuang Xiao, Kang Li and other scholars [9-11] respectively studied the durability of various recycled concrete, including various recycled concrete with different strength grades of primary concrete as recycled coarse aggregate.

In this paper, recycled aggregate concrete is prepared by using aggregates with a particle diameter of more than 40mm and a maximum particle diameter of 80mm. The durability of the two kinds of concrete is studied, including impermeability, carbonation resistance, chloride ion permeability resistance, early crack resistance and dry shrinkage.

2. Material and Methods

2.1. Raw Materials
Cement: the cement is PꞏO 42.5 ordinary portland cement with density of 3100kg/m³, water consumption of standard consistency of 27.2%, qualified stability, initial setting time of 190min, final setting time of 250min, 28d flexural strength and compressive strength are 8.2MPa and 47.6MPa respectively;

Fine aggregate: fine aggregate is locally produced river sand, fineness modulus is 2.6, apparent density is 2640kg/m³, saturated surface dry water absorption rate is 3.15%, bulk density is 1600kg/m³;

Coarse aggregate: coarse aggregate includes natural limestone macadam with continuous gradation of 5-80mm and recycled coarse aggregate with particle size in the range of 5-80mm. The apparent density of natural coarse aggregate is 2720kg/m³, bulk density is 1600kg/m³, water absorption rate is 0.22%, silt content is 1.44%, crushing value is 11%, apparent density of recycled coarse aggregate is 2490kg/m³, bulk density is 1240kg/m³, water absorption rate is 4.48%, silt content is 5.32%, crushing value is 15.7%.

2.2. Test Mix Proportion
The test set the mass ratio of NAC as m (water): m (cement): m (sand): m (stone) = 136: 317: 645: 1370; the mass ratio of RAC was m (water): m (cement): m (sand): m (stone) = 134: 344: 577: 1226.

2.3. Test Methods
This test will study the durability of two kinds of concrete. The test methods refer to the Hydraulic Concrete Test Code (SL352-2006).

(1) Impermeability: the specimen of concrete impermeability was a cone with an upper opening φ175mm, a lower opening φ185mm and a height of 150mm. After the specimen was formed, it was cured to the specified age (28d), placed in an anti-permeability meter, sealed and pressurized to the specified pressure. After the test, split the specimen, measured the water seepage height and calculated the relative permeability coefficient.

(2) Anti-carbonation Performance: the concrete anti-carbonation performance test piece was a 150mm×150mm×550mm prismatic test piece. After the test piece was formed, it was cured for 28 days and moved to the carbonation box for testing. The temperature, humidity and carbon dioxide concentration of the carbonation box were set to 20.2°C, 72% and 20% respectively. After reaching the predetermined age, the test piece was split and phenolphthalein ethanol indicator was sprayed to measure the carbonation depth of the corresponding age.
(3) Resistance to chloride ion penetration: tested the 6-hour electric flux and chloride ion diffusion coefficient of concrete. Among them, the required specimen size for 6h electric flux of chloride ion was φ95mm×51mm cylindrical specimen, and the required specimen for chloride ion diffusion coefficient was φ100mm×50mm cylindrical specimen. All required specimens were cut from cube specimens. After the chloride ion diffusion coefficient test was completed, the specimen shall be split and AgNO₃ indicator shall be sprayed to measure the chloride ion diffusion depth so as to calculate the chloride ion diffusion coefficient.

(4) Early crack resistance: the early crack resistance of concrete was formed by flat plate method. The specimen size was 600mm×600mm×50mm. The specimen was covered with plastic film immediately after pouring. The ambient temperature was kept at 30°C and the relative humidity was 60%. After 2 hours, the plastic film was taken off, and the concrete surface was blown with a fan. The length, width and quantity of cracks on the surface of the flat plate were measured to evaluate the early crack resistance of the two kinds of concrete.

(5) Dry Shrinkage Performance: the concrete dry shrinkage performance test piece was a 150mm×150mm×550mm prism type test piece. After the test piece was formed for 48 hours, the mold was removed, and the test piece was put into a dry shrinkage laboratory, and a dial indicator was set up to measure the dry shrinkage changes of the two kinds of concrete at different ages. The laboratory temperature was 20°C, keeping constant temperature and humidity.

3. Results and Analysis

3.1. Impermeability

Two kinds of concrete specimens are tested for impermeability. The experimental process is shown in figure 1. The water seepage after splitting the specimens is shown in figure 2. The test results are shown in Table 1.

![Figure 1. Impermeability test of concrete](image1)

![Figure 2. Red line of seepage height of concrete](image2)

| Type | Seepage height (mm) | Relative seepage height (%) | Relative permeability coefficient (cm/h) |
|------|---------------------|----------------------------|----------------------------------------|
| NAC  | 84.2                | 56.1                       | 5.44×10⁻⁶                              |
| RAC  | 109.5               | 73.0                       | 9.19×10⁻⁶                              |

According to the results in Table 1, under the same strength grade, the water seepage height of RAC increased by 23.11% compared with NAC, and the relative permeability coefficient increased by 40.81%. The main reason is that recycled aggregate hydraulic concrete is prepared with recycled aggregate, which has many surface defects, cracks, voids and so on. In addition, the water absorption rate of recycled aggregate is higher than that of natural aggregate, resulting in pores and non-compactness in RAC, which makes water easy to penetrate into and causes water seepage height higher than NAC. Therefore, RAC is inferior to NAC in terms of impermeability.
3.2. Carbonation Resistance

The carbonation resistance tests of the two kinds of concrete specimens are carried out, and the carbonation depth results of 3d, 7d, 14d, 28d, 56d and 90d are shown in figure 3, and the carbonation test process is shown in figure 4.

As can be seen from figure 3, the carbonization depth of RAC at each age is higher than that of NAC. The carbonization depth of RAC at each age is increased by 5.86%, 12.03%, 17.75%, 14.63%, 16.08% and 16.58% respectively. Because RAC has uneven surface and internal pores and is not dense, carbon dioxide is easier to enter the concrete, while NAC has relatively flat surface and high internal density, and carbon dioxide gas is not easy to enter the concrete, which indicates that NAC has better carbonation resistance than RAC.

3.3. Resistance to Chloride Ion Penetration

The chloride ion penetration resistance test is carried out on two kinds of concrete specimens. The test process is shown in figures 5-8, and the test results are shown in Table 2.
Figure 7. Determination of chloride ion diffusion coefficient of concrete

Figure 8. Color reaction of two kinds of concrete after dropping AgNO3 color developing agent

Table 2 Chloride Penetration Resistance of NAC and RAC (28d)

| Type | 6h chloride ion electric flux (C) | Chloride diffusion coefficient (m²/s) |
|------|---------------------------------|-------------------------------------|
| NAC  | 3538                            | $10.6 \times 10^{-12}$              |
| RAC  | 4708                            | $14.5 \times 10^{-12}$              |

From the results in Table 2, under the same test conditions, RAC’s 6-hour chloride ion conductivity is 24.85% higher than NAC’s, and the chloride ion diffusion coefficient is 24.90% higher. The results of anti-chloride ion penetration are similar to those of anti-carbonation. RAC has rough and uneven surface, internal pores and non-compactness, which make chloride ion easier to enter the concrete, thus increasing the electric flux and chloride ion diffusion depth. However, NAC has a relatively flat surface and a relatively high degree of internal compactness. Cl⁻ is not easy to enter the concrete, and there are less chloride ions in the concrete, resulting in lower electric flux and diffusion depth than RAC. Therefore, RAC is slightly inferior to NAC in chloride ion permeability resistance.

3.4. Early Crack Resistance

The early crack resistance tests of the two concrete specimens are carried out. The test process is shown in figures 9-12, and the test results are shown in Table 3.
According to the results in Table 3, the average crack area of each crack in RAC is lower than NAC, but the number of cracks per unit area and the total crack area per unit area are higher than NAC, which are 68.88% and 37.80% higher respectively, and the crack width on RAC surface is larger than NAC by measuring the crack width. During the test, the wind speed has certain influence on the test results. Due to the low wind speed of the fan and the high distance from the surface of the test piece, the early cracking effect on the surface of the test piece is not obvious. Although there are certain cracks, they are all very small and need to be observed with professional instruments and equipment. However, on the whole, the early cracking macroscopic performance on the surface of the test piece is not obvious, but it can also be proved that the early cracking resistance of recycled large aggregate hydraulic concrete is slightly inferior to that of natural large aggregate hydraulic concrete.

3.5. Dry Shrinkage Performance

The dry shrinkage performance tests of the two concrete specimens are carried out, and the dry shrinkage results at 3d, 7d, 14d, 28d, 56d and 90d are shown in figure 13, and the dry shrinkage test process is shown in figures 14-15.

As can be seen from figure 13, the dry shrinkage rate of RAC is higher than that of NAC at all ages, with the smallest increase in the dry shrinkage rate at 7d, the dry shrinkage rate of RAC is 29.24% higher than that of NAC, the dry shrinkage rate at 28d is 50.46% higher, and the dry shrinkage rate at 56d is the largest increase, the dry shrinkage rate of RAC is 54.25% higher than that of NAC, indicating that the increase in the dry shrinkage rate of RAC is larger than that of NAC with the
increase of ages. Due to the water absorption of aggregates, the water absorption of recycled aggregates is far greater than that of natural aggregates. This makes RAC have a larger change in dry shrinkage under the same test conditions, and the dry shrinkage change of natural large aggregate hydraulic concrete tends to be stable with the growth of age. However, there is still a certain change in dry shrinkage of recycled large aggregate hydraulic concrete. It can be seen that the aggregate performance has a greater impact on the dry shrinkage of concrete.

4. Conclusion
This paper tests the durability of NAC and RAC under the same strength grade, and studies the influence of the two aggregates on the durability of the prepared concrete. The conclusions are as follows: compared with NAC, when cured to the same age (28d), the water seepage height of RAC increased by 23.11% and the relative permeability coefficient increased by 40.81%; the carbonization depth at each age increased by 5.86%, 12.03%, 17.75%, 14.63%, 16.08%, 16.58% respectively. 6h chloride ion electric flux increased by 24.85%, chloride ion diffusion coefficient increased by 24.90%; the number of cracks per unit area of RAC increased by 68.88%, and the total crack area per unit area increased by 37.80%. The dry shrinkage rate at each age increased by 36.30%, 29.24%, 43.93%, 50.46%, 54.25%, 52.46% respectively. Although RAC's durability is worse than NAC, RAC prepared by reasonable technology has the same performance as NAC and can be used instead of NAC to some extent.

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