Performance Evaluation of Recycled Aggregates Prepared from Waste Concrete

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Abstract: This study investigates recycled aggregates for high-performance concrete, derived mainly from construction demolition waste and concrete production residues. Their performance is influenced by original concrete quality, crushing techniques, and impurity content. Using standardized tests for water absorption, crushing value, apparent density, and packing properties, results indicate that recycled aggregates exhibit higher water absorption, greater crushing value, and lower apparent density compared to natural aggregates. By optimizing screening processes and mix design, the surface structure of recycled aggregate concrete can be improved to meet high-performance application requirements. This performance evaluation supports the resource utilization of construction waste.

Keywords: Recycled aggregate, High-performance concrete, Construction waste, Performance evaluation, Resource utilization

INTRODUCTION

With accelerated urbanization and industrialization in China, the urbanization rate has now surpassed 60% [1], leading to increased energy consumption and environmental degradation. In 2025, the national commercial concrete output is projected to reach 2.55 billion m³, a 14.5% year-on-year increase [2]. The rising demand for concrete exacerbates resource scarcity and pollution issues. To promote sustainability, utilizing construction waste and waste tire rubber as recycled aggregates in concrete production offers a viable solution. Recycled aggregates, processed from waste concrete, often exhibit high water absorption and lower strength compared to natural aggregates, resulting in a weaker interfacial transition zone (ITZ) with higher porosity, which compromises mechanical performance and durability [3–5]. The failure mechanism of recycled concrete is characterized by microcrack initiation and propagation along the ITZ and at the interfaces between adhered old mortar and new paste [6], and the heterogeneity of recycled aggregates further leads to inconsistent concrete properties [7]. Therefore, enhancing the ITZ and reducing matrix porosity are essential for improving recycled concrete performance.

This study outlines the properties and preparation methods of recycled aggregates for high-performance concrete, including tests on water absorption, crushing value, density, and porosity. A comparative analysis highlights performance gaps between recycled and natural aggregates, providing foundational data for their application in sustainable construction.

MATERIALS AND METHODS

1. Sources and Characteristics of Recycled Aggregates in High-Performance Concrete

The experiment utilized waste concrete specimens from Hubei University of Technology. These specimens featured varied mix proportions, strengths, and curing conditions, representing the complexity of actual construction waste while aligning with resource recycling principles. The waste concrete was processed into 5–20 mm recycled coarse aggregate, which was washed and screened to remove impurities before testing to ensure result reliability. Figure 1 shows natural aggregate, Figure 2 presents the processed recycled coarse aggregate, and Figure 3 illustrates the microstructure of a recycled aggregate particle.

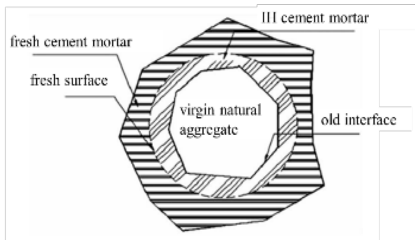

Figure 1 Natural coarse aggregate
Figure 2 Recycled Coarse Aggregate
Figure 3 Schematic Diagram of the Structure of Recycled Aggregate grain

2.Performance Evaluation Methods of Recycled Aggregate and Natural Aggregate

The recycled coarse aggregate and natural coarse aggregate used in the tests were measured for water absorption rate, crushing value, apparent density, dense packing density, dense packing porosity. testing methods followed jgj-52-2006, 'standards for quality and inspection methods of sand and stone for ordinary concrete' [8].

To preserve the methodological scope of this chapter, no measurement results or discussion are reported here. all quantitative data and computed results are presented and interpreted in results.

2.1 Water Absorption Rate

According to Section 7.5 of the standard, the aggregates are tested in two groups. The calculation formula is:

$$\omega = \frac{m_1 - m_2}{m_2} \times 100\% \quad (1)$$

In the formula: ω —— Water absorption rate (%);

m_1 —— Mass of specimen in saturated surface-dry condition before drying (g);

m_2 —— Mass of specimen after drying (g).

2.2 Crushing value

According to Section 7.13 of the standard, the aggregates are tested in three groups. The calculation formula is:

$$\delta = \frac{m_0 - m_1}{m_0} \times 100\% \quad (2)$$

In the formula, δ — crushing value (%);

m_0 — aggregate mass (g);

m_1 — sieve residue mass (g).

2.3 Apparent Density Measurement

Take 2 kg of aggregates with a particle size less than 26.5 mm. According to the standard immersion method (see Figure 4), measure as follows:

a. Fill a wide-mouth bottle with water, cover it with a glass plate, remove air bubbles, and dry it before weighing (precision 1g);

b. Put the saturated aggregates into the bottle, add water, and cover it again to remove air bubbles;

c. Fill the bottle with water again and cover it to ensure no air bubbles. Dry it and weigh the total weight (precision 1g).

d) Pour the aggregates into the tray, dry them in a 105 ± 5°C oven, and then cool them to room temperature before weighing (with an accuracy of 1g). See Figure 4.

(a) (b) (c)

(a).First weighing: bottle + water + glass plate; bubbles removed; outer wall wiped.
(b).Add SSD specimen, refill, remove bubbles.
(c).Second weighing: bottle + water + glass plate + specimen; outer wall wiped.

Figure 4 Specimen placed in the drying oven

The apparent density of the final coarse aggregate is calculated using the following formula, accurate to 10 kg/m³.

$$\rho_b=\left[\frac{G_0}{(G_0+G_2-G_1)}\right]\times 100\% \quad (3)$$

Where: ρ_b — Apparent density, kg/m³; G_0 — Mass of the dried specimen, kg; G_1 — Mass of the wide-mouth bottle, specimen, water, and glass sheet, kg; G_2 — Mass of the wide-mouth bottle, water, and glass sheet, kg.

2.4 Method for determining the Dense Packing Density of Coarse Aggregate

The specimen is loaded into the bucket in three portions. After each loading, a steel bar is placed at the bottom of the bucket, and the bucket is shaken 25 times left and right along two perpendicular directions. Finally, the bucket is filled to the brim and leveled. Specific results are presented in Table 3. The dense packing density of the coarse aggregate is calculated by the following formula:

$$\rho_G=\frac{m_2-m_1}{v} \quad (4)$$

Where: ρ_G —Dense packing density of coarse aggregate, kg·m^{-3}.; m_2 —Total mass of the bucket and specimen, kg; m_1 —Mass of the bucket, kg; v —Volume of the bucket, L. In accordance with Eq. (4), the dense packing densities of the two aggregates are summarized in Table 4.

2.5 Method for Determining Dense Packing Porosity of Coarse Aggregate

Reference to the standard, the porosity of the coarse aggregate is tested by the volumetric mass method. Specific results are reported in Section 3.5 (Table 5). The dense packing porosity of coarse aggregate is calculated by Eq. (5):

$$\gamma_C=\left(1-\frac{\rho_G}{\rho_b}\right)\times 100\% \quad (5)$$

Where: γ_C —Dense packing porosity of coarse aggregate, %; ρ_G —Dense packing density of coarse aggregate, $kg\cdot m^{-3}$.; ρ_b —Apparent density of coarse aggregate, $kg\cdot m^{-3}$.

RESULTS

3.1 Water Absorption Rate

After the saturated surface-dry treatment and drying of recycled coarse aggregate (RCA) and natural coarse aggregate (NA), the water absorption rates of the two groups of RCA were measured to be 5.67% and 5.34% respectively, with an average of 5.50%; while the two groups of NA were both 0.52% and 0.53% respectively, with an average of 0.53%. The water absorption rate of RCA was as high as 10.4 times that of NA (absolute difference 4.97%), mainly due to the old mortar and micro-cracks attached to the surface of RCA, which increased the porosity.

3.2 Crushing Value

After crushing and sieving the 3000g standard sample, the crushing values of the RCA group were 15.67%, 15.57%, and 15.87%, with an average of 15.70%; the crushing values of the NA group were 12.79%, 12.81%, and 13.10%, with an average of 12.90%. The crushing value of RCA was 2.80% higher than that of NA (a relative increase of 22%), and it also had good repeatability (the RCA range was 0.30%, and the NA range was 0.31%).

3.3 Apparent Density

The apparent density of NA was measured to be 2850 kg/m^3 using the beaker method (with an accuracy of 1g), and that of RCA was 2535 kg/m^3. The density of RCA was 315 kg/m^3 lower than that of NA (a decrease of 11.1%), indicating that its effective solid content is lower and is related to the adhesion of the old mortar and internal cracks.

3.4 Compact Density

After being compacted by three layers (with each layer being vibrated vertically 25 times), the compact density of NA was 1730 kg/m^3, and that of RCA was 1520 kg/m^3. The density of RCA was 210 kg/m^3 lower than that of NA (a decrease of 12.1%), indicating that the packing of RCA particles was looser under the same compaction conditions.

3.5 Dense packing porosity

Dense packing porosity (γ_C) was computed strictly by Eq. (5), using the dense packing density ρ_G from Eq. (4) and the apparent density ρ_b from Section 2.3, both expressed in $kg\cdot m^{-3}$. Substituting the measured values, for NA we use ρ_G = 1730 and ρ_b= 2850, which gives γ_C = (1 − 1730/2850) × 100% = 39.3%. For RCA we use ρ_G = 1520 and ρ_b= 2535, which gives γ_C = (1 − 1520/2535) × 100% = 40.0%. The porosity of RCA is 0.7% higher than that of NA, which is consistent with its lower ρ_a (-11.1%) and ρ□ (-12.1%). This verifies that RCA has a more porous packing structure and higher water absorption properties. In engineering applications, it is necessary to strengthen the control of the material's moisture content and adjust the admixtures to ensure workability.

CONCLUSION

This study reveals that recycled coarse aggregate (RCA) has significantly higher water absorption (5.50% vs 0.53%), crushing value (15.70% vs 12.90%), apparent density (2535 vs 2850 kg/m^3), and bulk density (1520 vs 1730 kg/m^3) compared to natural aggregate (NA), while its porosity is slightly higher (40.0% vs 39.3%). Its microstructure is porous and the aggregate is loosely packed, mainly due to the adhesion of mortar and microcracks. In engineering applications, it is necessary to strengthen the control of aggregate moisture and adjust the admixtures to ensure workability and promote the resource utilization of construction waste.

REFERENCES

[1] Wang K., Lin C., Wu C. Trends and Planning Options Following the 60% Urbanization Rate in China // Urban Planning. — 2020. — T. 44, № 12. — C. 9–17.

[2] Shi C. The Impact of the New Technological Revolution and Industrial Transformation on Talent Demand in the Building Materials Industry // China Building Materials. — 2020. — № 10. — C. 97–100.

[3] Ignjatović I. S., Marinković S., Mišković Z. M., et al. Flexural behavior of reinforced recycled aggregate concrete beams under short-term loading // Materials and Structures. — 2013. — T. 46. — C. 1045–1059.

[4] Poon C. S., Shui Z. H., Lam L. Effect of microstructure of ITZ on compressive strength of concrete prepared with recycled aggregates // Construction and Building Materials. — 2004. — T. 18. — C. 461–468.

[5] Abhijit M., Sriman K., Navdeep D., et al. Petrographic investigation on recycled coarse aggregate and identification the reason behind the inferior performance // Construction and Building Materials. — 2019. — T. 221. — C. 399–408.

[6] Liu Q., Xiao J., Sun Z. Experimental study on the failure mechanism of recycled concrete // Cement and Concrete Research. — 2011. — T. 41, № 10. — C. 1050–1057.

[7] Xiao J. Z., Li W. G., Corr D. J., et al. Effects of interfacial transition zones on the stress-strain behavior of modeled recycled aggregate concrete // Cement and Concrete Research. — 2013. — T. 52. — C. 82–99.

[8] Industry Standards of the People’s Republic of China. JGJ 52–2006: Standard for Quality and Test Methods of Sand and Stone for Ordinary Concrete [S]. — Beijing: China Architecture & Building Press, 2007.