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Study on the Mechanical Properties of Recycled Concrete

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Abstract: This paper focuses on recycled concrete, a building material that aligns with the concept of sustainable development, and primarily investigates its mechanical properties, such as compressive strength and flexural strength. Through experimental analysis, the effects of various factors on its performance are examined, and measures to improve its properties are discussed. The aim is to provide a theoretical basis and reference for the rational application of recycled concrete in practical engineering, contributing to the green development of the construction industry.

Keywords: Recycled concrete; mechanical properties; sustainable development

Introduction

The rapid development of the construction industry has led to the demolition of numerous old buildings, generating large quantities of waste concrete. Improper disposal of this waste can severely occupy land and pollute the environment. Against the backdrop of sustainable development, the demand for resource-efficient and environmentally friendly materials in the construction sector has surged. Recycled concrete has emerged as a solution, made from waste concrete through professional processing, achieving both resource recycling and environmental protection. However, the mechanical property differences caused by its unique aggregates limit its application. Therefore, in-depth research into the mechanical properties of recycled concrete is of great significance for promoting its widespread use, addressing construction waste problems, and achieving sustainable development in the construction industry.

1. Raw Materials and Mix Design of Recycled Concrete

1.1 Raw Material Selection

1.1.1 Recycled Aggregates

Recycled aggregates typically come from discarded concrete components of demolished buildings, such as beams, slabs, and columns. The processing of recycled aggregates generally involves a coarse crushing step using a jaw crusher to break large chunks of waste concrete into smaller particles. These particles are then sorted into different particle size ranges using a vibrating screen. Common particle size specifications include 5-10mm, 10-20mm, etc. In terms of physical properties, recycled aggregates exhibit significant differences compared to natural aggregates. Their bulk density is typically lower than that of natural aggregates, primarily due to the presence of internal voids and the old cement mortar adhering to their surface, which results in a relatively loose structure. For instance, the bulk density of natural coarse aggregates generally ranges from 1500-1600 kg/m³, whereas the bulk density of recycled coarse aggregates may only be around 1200-1400 kg/m³. Additionally, recycled aggregates have a higher water absorption rate, in some cases several times higher than that of natural aggregates. This is attributed to the water absorption capacity of the internal pores and the old cement mortar. These characteristics determine that recycled aggregates have a unique effect on the performance of concrete when used in mix designs.

1.1.2 Cementitious Materials

In this study, Ordinary Portland Cement with a strength grade of 42.5 was selected as the cementitious material. Ordinary Portland Cement offers advantages such as moderate setting and hardening speed, high early strength, and good compatibility with various types of aggregates, making it suitable for use in recycled concrete under different construction conditions and service environments. The quality indicators of the cement, including fineness, setting time, stability, and strength, all strictly comply with national standards to ensure the stability and reliability of the recycled concrete.

1.2 Mix Design Method

The mix design of recycled concrete, based on the principles of ordinary concrete mix design, requires appropriate adjustments to fully consider the special properties of recycled aggregates. First, the target strength grade is determined according to the actual engineering requirements and relevant standards. Then, certain parameters such as the sand ratio and the amount of admixtures are fixed, with particular focus on studying the influence of the replacement rate of recycled aggregates on the performance of recycled concrete. Multiple mix designs with different replacement rates of recycled aggregates were prepared, including 0% (ordinary concrete as the control), 30%, 50%, 70%, and 100%. In terms of the water-to-cement ratio selection, a suitable range was chosen through preliminary trials and reference to previous experience, ensuring that the recycled concrete not only has good workability but also meets the expected strength requirements[1]. For instance, in this study, the initial water-to-cement ratio was set between 0.4 and 0.5. As the replacement rate of recycled aggregates increased, the water-to-cement ratio was adjusted as needed based on the state of the concrete mixture to maintain its workability. The amount of cementitious materials was determined comprehensively based on the target strength grade and water-to-cement ratio, ensuring strength while also considering economy and durability. The amounts of sand, coarse aggregates, and other fine aggregates were calculated and allocated according to the selected sand ratio and the replacement rate of recycled aggregates, ensuring a relatively reasonable proportion between the components of the recycled concrete, thus laying a foundation for subsequent performance studies.

2. Mechanical Properties of Recycled Concrete

2.1 Compressive Strength Test

2.1.1 Specimen Preparation and Curing

A release agent is evenly applied to the inside of the mold to prevent damage to the specimen during demolding. The cement, recycled aggregates, and natural sand, accurately weighed according to the mix design, are sequentially poured into the mixer. First, dry mixing is performed for 1-2 minutes to ensure thorough and uniform blending of the raw materials. Next, water containing a water-reducing agent is slowly added to the mixer, and the mixing continues for 2-3 minutes until the concrete mixture is uniform, with consistent color and good workability, without visible segregation or bleeding. After mixing, the concrete mixture is placed in the mold in two layers, each layer being approximately the same height. A tamping rod is used to compact each layer, with the number of tamping operations not less than 12 times per 100 cm^2 of area, according to the standard. The tamping must be evenly distributed across all parts of the mold to ensure that the concrete is densely compacted and free from air bubbles. After tamping, a trowel is used to smooth the surface of the specimen, leveling it with the top of the mold, and key information such as the mix design number and preparation date is marked on the specimen. The prepared specimens are then placed in a standard curing room with a temperature of

20±2 ℃ and a relative humidity of over 95%. During the first 24 hours after specimen molding, the curing room environment is kept undisturbed to prevent any vibrations or disturbances that could affect the normal setting and hardening of the concrete[2]. After 24 hours, the specimens are carefully removed from the molds and continue to be cured in the standard curing room until the specified age. In this study, the curing ages selected are 3, 7, and 28 days.

2.1.2 Testing Method and Procedure

After curing to the specified age, the specimens are taken out of the curing room and placed at the center of the pressure testing machine's platen. Care is taken to ensure that the bearing surface of the specimen is fully in contact with the platen, ensuring uniform distribution of the applied load. The pressure testing machine is then started, and axial pressure is applied to the specimen at a uniform loading rate of 0.3-0.5 MPa/s. During the loading process, the testing machine automatically records the load applied to the specimen until failure occurs. The maximum load at the point of failure is recorded.

2.1.3 Test Results and Analysis

The compressive strength of recycled concrete with different replacement rates of recycled aggregates at various curing ages is calculated using the compressive strength formula (Compressive strength = failure load÷specimen bearing area. For a 150mm cubic specimen, the bearing area is 22,500 mm^2, which is equivalent to 0.0225 m^2). The test results are shown in **Table 1** below.

Table 1. Compressive Strength of Recycled Concrete with Different Replacement Rates of Recycled Aggregates

Replacement Rate of Recycled Aggregates (%)	3d Compressive Strength (MPa)	7d Compressive Strength (MPa)	28d Compressive Strength (MPa)
0 (Ordinary Concrete Control)	20.5	28.3	35.2
30	18.2	25.1	31.5
50	16.3	22.4	28.1
70	14.5	19.8	24.6
100	12.8	17.2	21.3

From the data in **Table 1**, it can be observed that as the replacement rate of recycled aggregates increases, the compressive strength of recycled concrete generally decreases. At the 3-day age, the compressive strength of recycled concrete with a 30% recycled aggregate replacement rate is about 11.2% lower than that of ordinary concrete. By the 28-day age, the compressive strength of recycled concrete with a 100% recycled aggregate replacement rate is approximately 39.5% lower than that of ordinary concrete.

2.2 Flexural Strength Test

2.2.1 Specimen Preparation and Curing

The preparation of the 150mm×150mm×550mm prismatic flexural strength specimens follows a similar procedure to the compressive strength specimens in terms of raw material weighing and mixing. After the concrete mixture is thoroughly blended, it is placed into the prismatic molds in two layers. Each layer is compacted using a tamping rod, starting from one end of the mold and proceeding along the length of the specimen. The number of tamping operations is controlled to not be less than 10 times per 100 cm^2 area, ensuring that the concrete is evenly distributed and well compacted within the mold. After tamping, a trowel is used to smooth the surface of the specimen. The specimen is then marked with relevant information and placed in the standard curing room for curing, with curing conditions and time requirements consistent with those of the compressive strength specimens.

2.2.2 Testing Method and Procedure

After curing to the specified age, the specimens are taken out of the curing room and placed on the supports of the flexural testing machine, with the formed surface facing upward. The distance between the two supports is strictly adjusted to 450mm, in accordance with the standard, and the loading point is positioned at one-third of the span between the supports. The flexural testing machine is then started, and a concentrated load is applied to the specimen at a uniform loading rate of 0.05-0.07 MPa/s. The testing machine records the load in real-time until the specimen breaks, and the maximum load at the point of failure is recorded.

2.2.3 Test Results and Analysis

The flexural strength of recycled concrete with different replacement rates of recycled aggregates at various curing ages is calculated based on the failure load, support span, and the width and height of the specimen. In this study, the specimen width and height are both 150mm, and the support span is 450mm. The results are shown in **Table 2** below.

Table 2. Flexural Strength of Recycled Concrete with Different Replacement Rates of Recycled Aggregates

Replacement Rate of Recycled Aggregates (%)	3d Flexural Strength (MPa)	7d Flexural Strength (MPa)	28d Flexural Strength (MPa)
0 (Ordinary Concrete Control)	3.8	4.6	5.2
30	3.3	4.1	4.7
50	3.0	3.7	4.2
70	2.7	3.3	3.8
100	2.4	3.0	3.4

From the analysis of **Table 2**, it can be observed that the flexural strength of recycled concrete also decreases as the replacement rate of recycled aggregates increases, although the rate of decrease is different from that of compressive strength. This difference is because flexural strength is more dependent on the weak interfaces within the concrete as well as the bonding performance between the aggregates and the matrix. The inherent defects in recycled aggregates, such as microcracks and uneven surfaces, are more likely to lead to stress concentrations at the interface when subjected to bending and tensile loads. This causes the cracks to propagate more rapidly, thus reducing the flexural strength of the recycled concrete.

3 Measures and Recommendations for Improving the Performance of Recycled Concrete

3.1 Optimization of Recycled Aggregate Pretreatment

3.1.1 Physical Reinforcement Technology

Physical reinforcement treatment plays a key role in improving the performance of recycled aggregates. Through mechanical grinding, the old mortar attached to the surface of the aggregates can be effectively removed, reducing microcracks and making the aggregate shape more regular. This increases the bulk density and strength of the aggregates by approximately 10%-15%. Heating treatment, on the other hand, optimizes the internal structure of the aggregates by utilizing high temperatures to eliminate internal stresses and enhance the bonding with the cement paste, thereby improving the overall performance of the concrete[3].

3.1.2 Chemical Modification Strategies

Chemical modification, through surface treatment techniques such as the use of silane coupling agents or polymer emulsions, forms a protective film on the surface of the aggregates, enhancing the bond between the recycled aggregates and the new paste. After treatment with silane coupling agents, the permeability and frost resistance of recycled concrete are improved by approximately 15%-20% and 30-50 freeze-thaw cycles, respectively. This treatment also improves the hydrophilicity of the aggregates, resulting in better homogeneity and workability of the concrete.

3.2 Refined Mix Design

3.2.1 Adjustment of Water-to-Cement Ratio and Cementitious Material

Fine-tuning the water-to-cement ratio and the amount of cementitious material is essential based on performance requirements and construction conditions. Moderately lowering the water-to-cement ratio and increasing the amount of high-performance cement and mineral admixtures (such as fly ash and slag powder) not only reduces costs but also improves the pore structure and increases the density and durability of the concrete through secondary hydration reactions. Specifically, reducing the water-to-cement ratio by 0.05 and increasing the cementitious material by 10%-15% (with 20%-30% fly ash) can enhance the 28-day compressive strength by 8%-12%, significantly improving both permeability and frost resistance.

3.2.2 Aggregate Gradation and Sand Ratio Optimization

Proper aggregate gradation and sand ratio are crucial for the performance of concrete. Using multi-grade recycled aggregates can reduce the void ratio and improve the bulk density. For recycled coarse aggregates with a particle size of 5-20mm, controlling the sand ratio at 35%-40%, along with continuous gradation fine aggregates, can significantly enhance the mechanical properties and durability of recycled concrete, thereby improving its suitability for engineering applications.

3.3 Rational Application of Admixtures

3.3.1 Targeted Selection of Admixture Types

Admixtures should be selected based on the project environment and performance requirements. In cold regions or projects with high frost resistance requirements, air-entraining agents should be prioritized, with the dosage carefully controlled to balance frost resistance and strength. For projects requiring improved toughness and crack resistance, appropriate amounts of fiber materials, such as steel fibers or polypropylene fibers, should be added. The mixing process should be carefully controlled to ensure uniform distribution of the fibers, maximizing their reinforcing effect[4]. In cases where high workability is required, such as for long-distance transport or pumping, high-performance water-reducing agents (such as polycarboxylate-based agents) should be used to ensure the flowability and slump retention of the concrete.

3.3.2 Strict Control of Admixture Dosage and Addition Method

The use of admixtures should adhere to the product specifications and the optimal dosage determined by testing, to avoid overuse or underuse, which could affect performance. The addition method and sequence are also crucial. For example, air-entraining agents should first be prepared into a solution and slowly added to the mixing concrete. The mixing time should be extended to ensure uniform and stable distribution of air bubbles, thereby achieving optimal improvement in frost resistance.

Conclusion

Due to the special properties of recycled aggregates, recycled concrete generally exhibits certain differences in mechanical properties compared to ordinary concrete. Specifically, as the replacement rate of recycled aggregates increases, the mechanical performance indicators show a downward trend. However, by adopting appropriate improvement measures, such as pretreating the recycled aggregates, optimizing the mix design, and rationally selecting and adding admixtures, the performance shortcomings of recycled concrete can be mitigated to a certain extent. This enables recycled concrete to meet the demands of some practical engineering applications, thus playing an active role in resource recycling and environmental protection.

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