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Experimental Study on Mechanical Properties of Self-Compacting Recycled Concrete

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Abstract: The application of self-compacting recycled concrete can solve the problem of environmental pollution caused by construction waste but its mechanical properties have not been unified and need further study. The strength of recycled concrete is unstable, and its performance still needs further study. The combination of fixed sand and stone volume method and free water cement ratio method is used to determine the mix ratio of self-compacting recycled concrete. 24 sets of slump expansion tests and 24 sets of cube axial compression tests were carried out to study the effect of recycled aggregate replacement rate on the flow performance and axial compressive strength of self-compacting recycled concrete, and the performance conversion formula of self-compacting recycled concrete was given. The results show that with the increase of the regenerated coarse aggregate substitution rate, the fluidity and filling property of the self-compacting regenerated concrete mix decreased. The failure of self-compacting recycled concrete is mainly due to the failure of strength between old mortar and new mixture. As the substitution rate increases from 0 to 100%, the axial compressive strength decreases by 15.2%.

Keywords: Self-compacting recycled aggregate concrete; Axial compression test; Mechanical property; Substitution rate

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1. Introduction

With the continuous advancement of urbanization, infrastructure construction is in a stage of steady development, and the shortage of natural resources is not difficult to foresee [1]. Additionally, the demolition of waste infrastructure, the dumping of test waste and construction leftovers have led to a sudden increase in construction waste, which not only occupies a large amount of land resources but also causes serious pollution to the ecological environment [2]. Therefore, the solution to the construction waste pollution problem is imminent. The application of recycled concrete can not only effectively solve the environmental pollution problem caused by construction waste, but also conform to the environmental protection concept of sustainable development in China and help to solve the problem of lack of natural resources [3]. At present, the research on self-compacting concrete has been relatively mature. Zhang Yong *et al.* used the slump expansion test to test the static stability of self-compacting concrete and found that there was a good correlation between the basic working performance of self-compacting concrete and its static stability [4]. Fernando *et al.* studied the flow and mechanical properties of self-compacting concrete by adding metakaolin and fly ash (binary and ternary mixed cement) [5]. The results show that when metakaolin and fly ash are used to add minerals, the working performance of self-compacting concrete can be ensured while the cement dosage can be reduced. Abdalhmid *et al.* studied the performance and hardening state of self-compacting concrete with different fly ash replacement rates and water-binder ratios [6]. The results show that the addition of fly ash can significantly improve the working performance of self-compacting concrete, but has negative effects on its compressive strength, flexural strength and hydration rate. Mahmoud *et al.* studied the working performance and mechanical properties of self-compacting recycled concrete containing air entraining agent and silica fume [7]. It was found that air entraining agent and silica fume played an important role in stabilizing the freshness of the mixture. Sasanipour *et al.* studied the effect of adding recycled aggregate on the physical properties (including mechanical properties and durability) of self-compacting concrete with the substitution rate of coarse and fine aggregate as the parameter [8]. The results show that the coarse-fine aggregate has significant influence on the compressive properties of self-compacting concrete but little influence on its tensile properties. With the increase in replacement rate, its durability decreased slightly. Silva *et al.* studied the working performance and physical properties of self-compacting recycled concrete by taking masonry slag and concrete waste as substitutes and found that recycled aggregate negatively impacted the working performance of self-compacting concrete, but it could meet the standard requirements [9]. The laws of its mechanical properties are similar to those studied in literature [8]. Wu Chunyang *et al.* studied the effect of non-continuous graded recycled coarse aggregate on the performance of self-compacting concrete, and the results showed that non-continuous graded recycled aggregate could be used for the preparation of self-compacting recycled concrete [10,11]. The elastic modulus is higher than that of continuous graded recycled concrete, but it is lower than that of ordinary concrete.

To sum up, domestic and foreign scholars have conducted a lot of experiments and theoretical analyses on self-compacting concrete and recycled concrete but there are few studies on self-compacting recycled concrete. Currently, there are different conclusions about the axial compressive properties of recycled concrete which needs to be further studied. In this paper, slump expansion test and cube axial compression test of self-compacting recycled concrete are carried out, and the influence of substitution rate on its working and mechanical properties is analyzed. The formula for calculating the cube compressive strength of self-compacting recycled concrete with respect to the substitution rate is modified.

2. Mix ratio design of self-compacting recycled concrete

According to the Technical Regulations for the Application of High-strength Concrete, this paper designs 60 MPa and 80 MPa self-compacting recompacted concrete with replacement rates of 0, 50%, 75% and 100% [10]. In this paper, the working performance was taken as the preliminary judgment criterion in the process of trial mixing, and axial compression tests were carried out on the 7-day and 28-day concrete cube test blocks respectively. The test mix ratio meeting the performance was finally adjusted and optimized, as shown in **Table 1**. It is worth noting that the self-compacting recycled concrete with a water-binder ratio of 0.33 produced a large segregation phenomenon.

Table 1. Mix ratio of self-compacting reclaimed coarse aggregate concrete

Number	Cement	Coarse aggregate		Machine-made sand	Water		Water reducer	Fly ash	Swelling agent	Silica fume	Water-binder ratio
		Natural	Regeneration		Mixing water	Additional water					
S60-0	334	848	0	808	166	0	13	127	42	27	0.31
S60-1	334	424	424	808	166	8	13	127	42	27	0.31
S60-2	334	212	636	808	166	11	13	127	42	27	0.31
S60-3	334	0	848	808	166	15	13	127	42	27	0.31
S80-0	378	848	0	808	141	0	14	144	48	30	0.23
S80-1	378	424	424	808	141	8	14	144	48	30	0.23
S80-2	378	212	636	808	141	11	14	144	48	30	0.23
S80-3	378	0	848	808	141	15	14	144	48	30	0.23

3. Performance of self-compacting recycled concrete

In this paper, according to the requirements of "Technical Regulations for Application of Self-compacting Concrete", slump expansion and expansion time T500 of its working performance test indexes are taken as the basis for the research and judgment of self-compacting recycled concrete's working performance and its anti-segregation ability is also observed to assist the judgment [12]. The slump spread and spread time T500 test must be carried out quickly after the completion of mixing, and the instrument uses the laboratory standard slump cylinder. The test results show that the working performance of the self-compacting recycled concrete in this paper meets the requirements of secondary self-compacting recycled concrete. The working performance indexes of self-compacting recycled concrete with different replacement rates are shown in the table, and the slump expansion test is shown in **Figure 1**.

Table 2. Working performance of self-compacting recycled concrete

Number	Slump spread (mm)	Spread timeT_{500} (s)	Segregation resistance
S60-0	635	3.5	Good
S60-1	595	3.9	Good
S60-2	580	4.1	Good
S60-3	585	4.2	Good
S80-0	610	3.2	Good
S80-1	600	3.6	Good
S80-2	585	3.9	Good
S80-3	570	4	Good

(a) Slump expansion test with strength of 60 MPa (b) Slump expansion test with strength of 80 MPa

Figure 1. Slump expansion test of self-compacting recycled concrete

4. Mechanical properties of self-compacting recycled concrete

4.1. Compressive strength of cube

The compressive strength of concrete cube is an important index of concrete strength. In this paper, according to the requirements of "Test Method for Mechanical Properties of Ordinary Concrete", a standard cube test block of 150 mm × 150 mm is made and maintained in a standard curing room for 28 d to test the strength of the standard cube test block. The test instrument adopts an electro-hydraulic servo pressure testing machine, and the loading and final failure patterns are shown in **Figure 2**.

(a) Cube test block test instrument

(b) Failure pattern of S60-0 test block

(c) Failure pattern of S80-0 test block

Figure 2. Failure patterns of part of the test block

As seen from the figure, the failure form of the self-compacting recycled concrete cube test block is basically similar to that of ordinary concrete, both of which are manifested as brittle failure caused by insufficient bearing capacity. However, with the increase of the replacement rate of recycled coarse aggregate, it means that there is more old mortar inside the concrete, resulting in a greater possibility of shear failure on the contact surface between old mortar and coarse aggregate inside the concrete, which advances the failure time of concrete to a certain extent and reduces its strength. By comparing **Figure 2 (b)** and **Figure 2 (c)**, it can be seen that the failure modes of 60 MPa and 80 MPa concrete test blocks are completely different. The concrete test blocks with lower strength give off a "muffling sound" when they are damaged, and the degree of breakage is small, while the self-compacting recycled concrete with higher strength makes a violent "popping sound" when they are damaged, and the degree of damage is greater. The compressive strength of the self-compacting recycled concrete cubes with different numbers is shown in **Table 3**.

Table 3. Compressive strength of self-compacting recycled concrete cube

Number	Compressive strength of cube (MPa)	Axial compressive strength (MPa)
S60-0	82.5	66.4
S60-1	77.6	63.0
S60-2	73.0	59.5
S60-3	70.5	57.9
S80-0	100.3	80.5
S80-1	95.8	77.8
S80-2	92.4	75.5
S80-3	89.5	74.0

In order to visually analyze the influence of the substitution rate on the strength of self-compacting recycled concrete, the data in **Table 3** are drawn as shown in **Figure 3**:

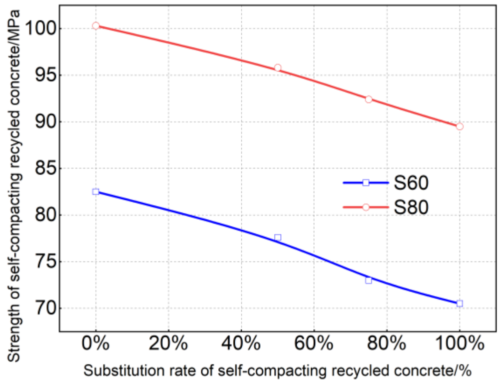

Figure 3. Strength of self-compacting recycled concrete

As shown in **Figure 3**, the cube compressive strength of self-compacting recycled concrete decreases monotonically with the increase of the substitution rate. When the design strength is 60 MPa, the cube compressive strength of self-compacting recycled concrete with 100% substitution rate decreases by 14.5% compared with that of ordinary concrete, while when the substitution rate is 50%, the strength only decreases by 5.9%. When the design strength is 80 MPa, the strength of self-compacting recycled concrete with 100% replacement rate is reduced by 10.8% compared with ordinary concrete, while the strength of self-compacting concrete with 50% replacement rate is reduced by 4.5% compared with ordinary concrete. It can be seen that the influence of recycled coarse aggregate on the compressive strength of self-compacting recycled concrete will become weak with the increase of its design strength and when the replacement rate of recycled coarse aggregate is about 50%, its strength is close to that of ordinary concrete.

In order to describe the relationship between the axial compressive strength of self-compacting recycled concrete and its regenerated coarse aggregate replacement rate, regression analysis was carried out on the test results of this paper and the test data in literature [13,14]. The regression curve is shown in **Figure 4** and the calculation expression is shown in the following equation:

$$f_{c(\rho)} = (1 - 0.131r) f_c$$

In the formula: $f_{c(\rho)}$—Axial compressive strength of self-compacting recycled concrete, MPa.

f_c—Axial compressive strength of self-compacting recycled concrete when the replacement rate is 0%, MPa.

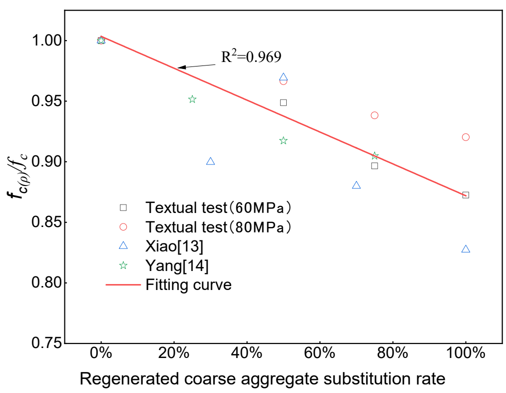

Figure 4. Fitting curve of axial compressive strength of self-compacting recycled concrete

5. Conclusion

In this paper, a suitable high-strength self-compacting recycled concrete was prepared. The flow performance and compressive strength were studied and analyzed through cube axial compression test and slump expansion test, and the following conclusions were obtained:

(1) The various mix ratio design methods of self-compactness recycled concrete are essentially different, and this paper suggests that the fixed sand and stone volume method combined with free water-cement ratio method in the code should be used. With the decrease of water-cement ratio, the slump spreading degree decreases, and the spreading time increases. With the increase of regenerated coarse aggregate substitution rate, slump expansion loss is serious.

(2) The axial compressive strength of high-strength self-compacting recycled concrete decreases significantly with the increase of the replacement rate of recycled coarse aggregate. The replacement rate increases from 0 to 50%, the axial compressive strength of 60 MPa and 80 MPa test blocks decreases by 5.9% and 4.5%, and when the replacement rate becomes 100%, the strength decreases by 14.5% and 10.8%. Furthermore, the expression between the axial compressive strength of self-compacting recycled concrete and its substitution rate is obtained by fitting regression based on the test data.

Disclosure statement

The author declares no conflict of interest.

References

[1] Deng S, Zhang X, Luo Y, 2006, Current Situation Analysis and Research Prospect of Waste Concrete Recycling. Concrete, 2006(11): 20–24.

[2] Xiang X, 2017, Study on Axial and Partial Mechanical Behavior of Steel Tube Self-Compacting Recycled Concrete Short Columns, thesis, Southwest Jiaotong University.

[3] Niu J, Xu Y, Xie C, 2020, Analysis of Bond Strength Between Rebar and Recycled Concrete Based on Statistical Regression. Journal of Yangtze River Scientific Research Institute, 37(06): 156–159.

[4] Zhang Y, Zhao Q, Li H, et al., 2016, Relationship Between Basic Working Performance and Static Stability of Self-Compacting Concrete. Journal of the Chinese Ceramics, 44(02): 261–267.

[5] Fernando P, Alexandre V, Adriano MB, 2018, Efficient Self-Compacting Concrete with Low Cement Consumption. Journal of Cleaner Production, 2018(175): 324–332. https://doi.org/10.1016/j.jclepro.2017.12.084

[6] Abdalhmid JM, Ashour AF, Sheehan T, 2019, Long-Term Drying Shrinkage of Self-Compacting Concrete: Experimental and Analytical Investigations. Construction and Building Materials, 2019(202): 825–837.

[7] Nili M, Sasanipour H, Aslani F, 2019, The Effect of Fine and Coarse Recycled Aggregates on Fresh and Mechanical Properties of Self-Compacting Concrete. Materials, 12(7): 1120.

[8] Sasanipour H, Aslani F, 2020, Durability Properties Evaluation of Self-Compacting Concrete Prepared With Waste Fine and Coarse Recycled Concrete Aggregates. Construction and Building Materials, 2020(236): 117540.

[9] Silva YF, Delvasto S, Izquierdo S, et al., 2021, Short and Long-Term Physical and Mechanical Characterization of Self-Compacting Concrete Made with Masonry and Concrete Residue. Construction and Building Materials, 2021(312): 125382.

[10] Wu C, Ma J, Pan Z, et al., 2015, Experimental Study on Basic Mechanical Properties of Self-Compacting Concrete with Discontinuous Graded Recycled Coarse Aggregate. Architectural Structures, 45(10): 69–73.

[11] Wu Ch, Ma J, Pan Z, 2014, Experimental Study on Work Performance of Self-Compacting Concrete with a Discontinuous Gradation of Recycled Coarse Aggregate. Concrete, 2014(10): 109–113.

[12] China Construction Industry Press, 2012, Technical Specification for Application of Self-Compacting Concrete, JGJ/T 283-2012.

[13] Xiao J, Yang J, Huang Y, et al., 2011, Axial Compression Test of Recycled Concrete Restrained by Steel Tube. Journal of Building Structures, 32(6): 92–98.

[14] Yang Y, Ma G, 2013, Bending Properties of Recycled Concrete for Stainless Steel Tubes. Journal of Dalian University of Technology, 2013(004): 572–578.