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Study on the Influence of Recycled Composite Micro Powder on the Performance of Mortar

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ABSTRACT

In the rapid urbanization process, the extensive development model of China's construction industry has led to excessive consumption of natural resources and intensified environmental. Its resource utilization has become an important topic for the sustainable development of the industry. This study proposes a composite admixture technology path to address the technical bottlene in the application of recycled micro-powder. By constructing a binary composite system of recycled concrete powder (RCP) and recycled brick powder (RBP), the characteristics and multi-age mechanical properties were systematically characterized and tested. The results show that compared with single RAP, the admixture of recycled micro-powder can significantly the mechanical properties of recycled mortar, among which the RCP: RBP = 8:2 group shows the best enhancement effect, with an increase in 2d compressive strength of 23.6% and an increase in flexural strength of 18.4%. The results show that the composite micro-pow system achieves a synergistic effect of micro-aggregate filling and volcanic ash activity through the gradient distribution of particle size, which effectively optimizes the microstructure of cement materials. The composite admixture technology framework established in this study not only improves the amount of recycled micro-powder admixture but also provides a new reference for the-value utilization of construction solid waste.

KEYWORDS

Recycled mortar; Recycled concrete powder; Recycled brick powder; Multi-component optimization; Mechanical properties

1. INTRODUCTION

In recent decades, with the rapid growth of population and rapid economic development, China's real estate industry has experienced a kind of barbaric high growth, and at the same time, it has consumed a large amount of natural resources. According to statistics, about 3 billion tons of concrete are used worldwide each, and the carbon dioxide emissions in the production process account for about 8% of the global total emissions [1]. In the process of construction and demolition after the of the building's life, a large amount of construction waste is generated. According to statistics, the amount of construction waste generated in China in 2022 about 3.5 billion tons, accounting for 40% of the total urban waste, and it is expected to rise to 4 billion tons by 026 [2]. Among them, waste concrete and waste clay bricks account for about 20%-30% of construction waste

Driven by the national strategic goals of “carbon neutrality and carbon peaking” [3], green environmental protection has the main theme of social development. Recycled micro powder, as a sustainable green material, has important research value [4]. Recycled micro powder refers to the particles with a size of less than 150 produced in the process of preparing recycled aggregates from recycled construction solid waste [5], mainly including recycled concrete micro powder (Recycled Powder, RCP) and recycled brick micro powder (Recycled Brick Powder, RBP). According to relevant standards, recycled micro powder can be divided into Grade I Grade II. Recycled concrete micro powder (RCP) mainly comes from the powder produced in the process of recycling construction solid waste, accounting for about 20%-30% of the raw material mass, and has good active potential.

Recycled clay brick micro powder (RBP) is made from waste clay bricks through processes as crushing and grinding [6]. Clay bricks are sintered bricks made from clay as the main raw material, which are formed, dried and fired. There are differences in chemical composition of recycled micro powder from different sources, but the total content of SiO2, Al2O3 and $Ca(OH)_2$ usually exceeds 60% and the main mineral components include quartz, calcium sulfoaluminate, sodium feldspar, calcite and hematite, etc [7].

RCP contains more g and unhydrated cement particles, and the surface is mostly flocculent; while RBP has a higher content of quartz, and the particles are irregularly angularAlthough recycled micro powder has potential application value, its utilization rate is still low. At present, recycled micro powder is mainly used as an admixture in mortar, and is impossible to achieve the effect of partially replacing cement [8]. Compared with ordinary Portland cement, recycled micro powder has problems such as high porosity and increased water absorption of the, especially when the replacement rate exceeds 20%, its mechanical properties decrease significantly [9]. The main reason that limits the activity of RCP is that it contains only a amount of and unhydrated particles in its composition, and $Ca(OH)_2$ the rest of the components are mostly in an inert state [10].

Ma Chuntao [11] showed through experiments that the strength of recycled mortar gradually increases with the increase of the amount of recycled brick powder. When the amount is 10%, its activity index the best, and the strength will decrease significantly when the amount exceeds 10% [12]. In order to improve the activation effect of recycled micro powder and increase the utilization rate recycled micro powder, recycled brick powder and recycled concrete powder are mixed according to different proportions [13], and the replacement rate is 50%. The effects of recycled mortar onity, compressive strength and flexural strength at different ages are evaluated.

2. MATERIALS AND METHODS OF THE EXPERIMENT

2.1. Test Material

The raw materials used in this test include: P•O42.5 ordinary Portland cement, RCP is obtained from the small of waste plain concrete after crushing, and then milled by a ball mill and sieved to obtain powder particles less than 0.016mm. R is obtained from waste clay bricks, which is crushed by a jaw crusher and milled by a ball mill, sand is ISO standard sand. Polycarboxyl superplasticizer, water reduction rate ≥ 30%; hydroxypropyl methylcellulose (HPMC), 100,000 viscosity The cement-sand ratio is 1:1, the water-cement ratio is 0.35, the water reducing agent is 0.5%, the HPMC is 0.08%. It meets the requirements of "Method for Testing the Strength of Cement Mortar (ISO Method)". The mix proportion of composite micro powder is set as RBP: RCP, the mix proportion is 10:0, 8:2, 6:4, 5:5, 4:6, 2:8, 0:10, the replacement rate is 50%, and the number is R (the number is T).

2.1.1. Cement

The cement used in this test is P•O42.5 ordinary Portland cement produced in Jiaozuo City Its apparent density is 3096 kg/m^3, and the chemical composition is shown in Table 2-1.

Table 2-1. Chemical composition of cement.

Oxide	CaO	SiO_2	Al_2O_3	MgO	SO_3	Fe_2O_3
Conten/t %	63.5	21.6	6.1	3.3	2.6	2.9

2.1.2. Fine aggregate

The fine aggregate used in the test was standard sand produced by Xiamen Aisuo Standard Sand Co., Ltd., its physical parameters are shown in Table 2-2.

Table 2-2. Basic physical parameters of standard sand.

	Mohs hardness	bulk density	ash content	porosity	crushing index
	Degree	Kg/m^3	%	%	%
ISO	8.5	1623	0.26	41	2.1

2.1.3. Recycled concrete powder

Recycled concrete powder was obtained by sieving the crushed coarse and fine aggregates of concrete test blocks cast the laboratory.

2.1.4. Recycled clay brick powder

The recycled clay brick powder used in the test was obtained by crushing and grinding the broken clay bricks from the of brick-concrete houses, and then sieving.

2.1.5. Water reducing agent

Poly-carboxylic acid high-efficiency water reducing agent was used, is a high-performance water reducing agent with strong dispersion for cement particles, high water reduction rate, and strong dispersion effect, with a water reduction rate of more than 30%.

2.1.6. HPMC

100,000 viscosity hydroxypropyl methylcellulose (HPMC) produced by Shanghai Chen Chemical Technology Co., Ltd. was used as a viscosity modifier, which can improve the fluidity of the mix without changing the mix proportion.

2.2. Test Method

2.2.1. Flowability

The test was carried out according to the specification of (GB/T 2419—2005 "Method for Determining the Flow Cement Mortar"), the test method is the jumping table test, as shown in Figure 2-1, the jumping table is first jumped empty for a cycle of25 times before use, and after the jumping is completed, the diameter of the mortar bottom in two perpendicular directions is measured, and the average value is taken, the initial flow of the cast-in-place test is tested.

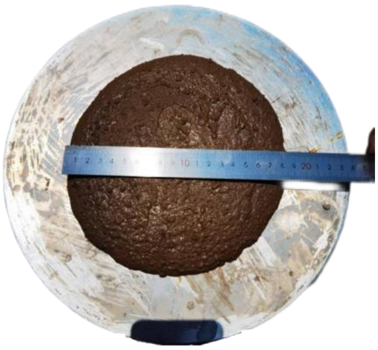


Figure 2-1. Schematic of fluidity test

2.2.2. Mechanical properties

The test was carried out according to the method of "Cement Mortar Strength Test Method (ISO Method)" to make test blocks and carry out mechanical tests. The test equipment used the bending and compression testing machine of the School of Materials of Henan Polytechnic University to test the mechanical properties of the regenerated cement, as shown in Fig. 2-2.

Figure 2-2. Flexural and compressive testing machine

(1) Compressive strength test.

The sample size is 40mm*40mm*40mm, and the load application rate is 2.4KN/S until it.

$$f_c = \frac{F_C}{A} \tag{2-1}$$

Where: f_c is the compressive strength, the unit is MPa, F_c is the failure load of the specimen, the unit is N, is the bearing area of the specimen, the unit is mm2.

(2) Bend strength test

The sample size is 40mm*40mm*160mm, and the load application rate is 50N/S until it.

$$R_f = \frac{1.5 F_f L}{b^3} \tag{2-2}$$

Where: R_f is the flexural strength, the unit is MPa, F_f is the load applied to the prism at the time of breakage, the unit N, L is the span between the supports, the unit is mm, b is the side length of the square cross section of the prism, the unit is mm.

3. RESULTS AND DISCUSSION

3.1. Liquidity

The flowability of each group was tested by the jumping table test, as shown in Fig. 3-1, and the change rule the flowability of the composite recycled mortar with different admixture contents is shown in Fig. 3-2.

At a replacement rate of 50%, the flowability can reach 220mm, and the flowability of the recycled micro powder with different admixture contents is different. The rule is that the flow of the recycled mortar will decrease with the increase of the RBP admixture content, and increase with the increase of the RCP admixture content, showing a linear. The maximum flowability group of RBP: RCP is R7, which is 196mm, and the minimum flowability group is R1 which is 164.5mm.

The reason for the decrease in the flowability of recycled micro powder is that the particle morphology of recycled micro powder is, and the surface is relatively rough. The reason for the evolution rule of its flowability admixture content is that the specific surface area of RBP is greater than of RCP, and its powder morphology has more pore distribution, and the morphology is sawtooth, which makes the demand for surface water and adsorption water ofitious materials increase, so it makes its flowability decrease more.

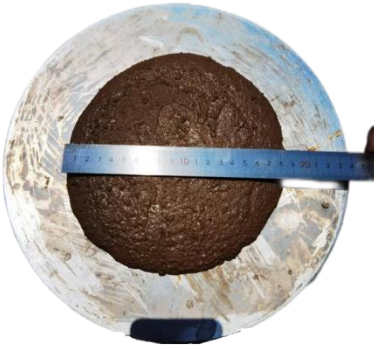


Figure 3-1. Schematic of slump flow measurement

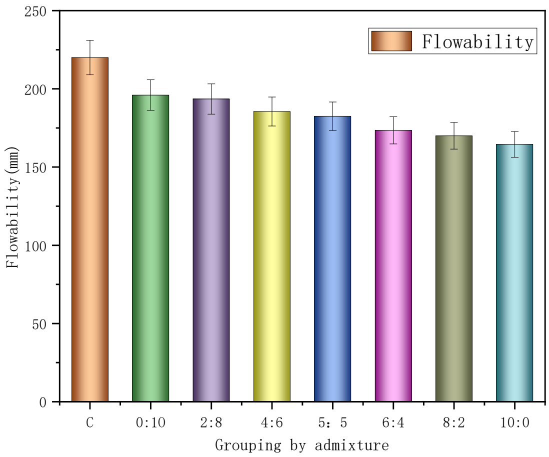


Figure 3-2. Flowability of mortar with admixture

3.2. Compressive Strength

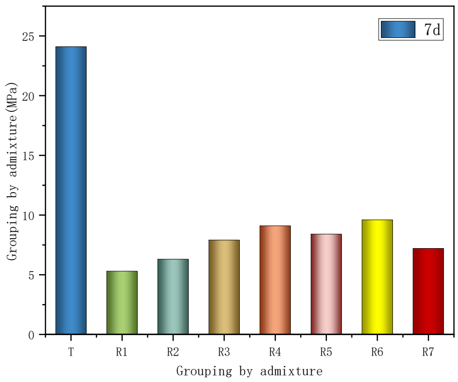
The influence law of the recycled composite micro powder content on the compressive strength is shown in Figure 3-2 Through the compressive strength test of the specimens at different ages (7d, 28d, 56d, 90d), the following characteristics can be observed:

From the perspective of the strength development law, the compressive strength of the specimens shows a typical three-stage evolution characteristic: (1) Early (7d): The strength of each recycled group is only 22%-39.8% of the reference group, among which the R6 group shows best performance of 9.6 MPa, reaching 39.8% of the reference group; (2) Mid-term development stage (28-6d): The strength growth rate is significantly improved, and the R6 group has reached 56% of the reference group at 28d, and continues increase to 56.6% at 56d; (3) Late stable stage (90d): The strength increment tends to be gentle, the strength of each recycled group maintains in the range of 25.8%-57.1% of the reference group, among which the R6 group maintains the highest value of 29.4 MPa, reaching 57.1% of the reference group strength.

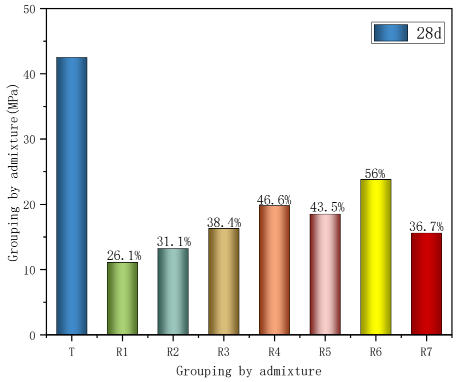
It is worth noting that there are differences in the strength development of different admixture groups. At the age of 28d, the R6 group (23.8 MPa) and R4 group (19.8 MPa) reach the strength level of 56%

and 46.6% of the reference group respectively, forming significant performance gradient. This difference mainly originates from the synergistic mechanism of the composite micro powder: the R6 group can form a dense accumulation structure through optimizing the powder grading, and its high active components continue to participate in the secondary hydration reaction in an alkaline environment, generating C-S-H gel. However, the R4 has a wide particle size distribution of micro powder, which forms a micro aggregate effect in the early stage, but the insufficient active stimulation in the later stage leads to limited growth.

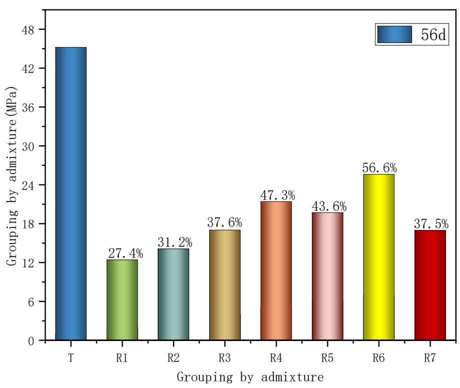
The mechanism analysis of its strength evolution: the compressive strength strength development shows that the early strength of the recycled mortar mainly relies on the physical filling effect of micro powder, and the active components have not been fully stimulated; after 28d, the volcanic ash substances in the micro powder and the cement hydration products occur reaction, and more cementitious products are generated by consuming Ca(OH)2; at 90d, the consumption of active components is close to complete, the strength development is dominated by the interface strengthening of the micro powder-cement matrix. The study also found that the slowdown of the strength increment in the later stage of (the average increment from 56d to 90d is only 3.2%) is related to the phenomenon of pore coarsening caused by deepening of the micro powder carbonation degree, which provides an important direction for the subsequent material modification.



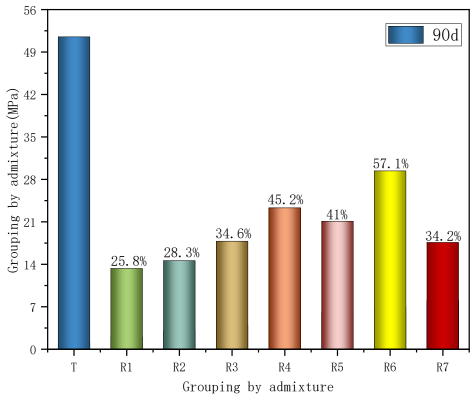
(a) 7d



(b) 28d



(c) 56d



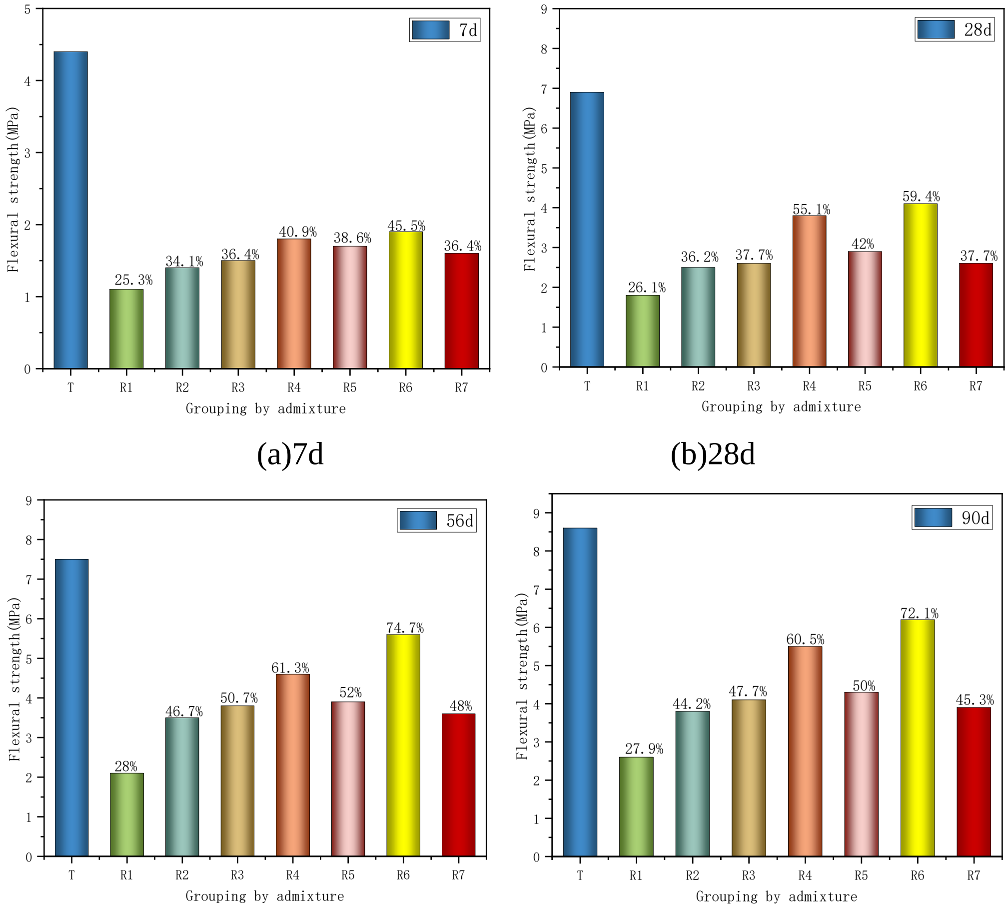
(d) 90d

Figure 3-2. Compressive strength of mortar with admixture

3.3. Flexural Strength

The influence law of the recycled composite micro powder on the flexural strength of mortar is shown in Fig. 3-3. Under the condition of50% replacement rate of RBP and RCP with different mass ratios, the flexural strength of the test piece shows significant time-dependent characteristics and mix proportion sensitivity The strength evolution process can be divided into three characteristic stages:

The influence law of the recycled composite micro powder on the flexural strength of mortar is shown in Fig. 3-3. Under the condition of 50% replacement rate of RBP and RCP with different mass ratios, the flexural strength of the test piece shows significant time-dependent characteristics and mix proportion sensitivity. The strength evolution process can be divided into three characteristic stages:



(a)7d (b)28d

(c)56d (d)90d

Figure 3-3. Flexural strength of mortar with admixture

During the middle strength development stage (28-56d), the strength growth rate showed an exponential increase, with the R6 group reaching5.6 MPa at 56d, which was 74.7% of the control group, significantly better than the 56.6 of the compressive strength at the same period. This phenomenon originated from the sensitivity of flexural strength to the interfacial characteristics of materials: the micro-pow particles effectively enhanced the bonding strength between the cement matrix and the aggregates through the pore refinement effect. Meanwhile, the secondary reaction of unhydrated particles in RCP generated-scale C-S-H gels, which further strengthened the interfacial transition zone.

The strength increment slowed down in the later stage of stable strength (90d), and the R6 group maintained the highest strength value of 62 MPa, reaching 72.1% of the strength of the reference group, but the increment decreased by 2.6% compared to 5d. In this stage, the consumption of micro-powder active components was close to complete, and the strength development turned to the micro-structure reinforcement of carbon products as the dominant mechanism.

It is worth noting that the composite optimization of recycled micro powder can significantly improve the material performance: when the RBP content was increased to 4-50% (i.e., R5 group), the 28d strength reached 3.8-4.6 MPa, which was 7-65% higher than that of the pure RCP group. This was attributed to the synergistic cementitious effect of the kaolinite phase (with a of about 12-18%) in RBP and the calcium component of RCP. In addition, the growth rate of flexural strength was 1%-

20% higher than that of compressive strength, which verified the improvement of the micro powder system on the toughness of the material.

The above research provides a theoretical basis for the application of recycled micro powder in the field of structural repair materials, especially the continuous strength growth characteristics shown the R6 group, with a 90d strength retention rate of more than 95%, indicating that it has the potential to replace 30-4% of cement to prepare high-performance mortar.

4. CONCLUSION

(1) The flowability of the recycled mortar decreased with the increase of RBP content and increased with the increase of RCP content when the recycled micro powder compounded with 50% replacement. The flowability of the group with the closest natural group was RCP: RBP 0: 10, and itsability was 196mm. It shows that RBP has a large specific surface area and a small particle size, and the particle size morphology is serrated which increases the water absorption rate. Overall, the addition of composite RP significantly reduces the flowability of the mortar.

(2) The flowability of the recycled mortar decreased with the increase of RBP content and increased with the increase of RCP content when the recycled micro powder was compounded with 50% replacement. The flowability of the group with the closest natural group was RCP: RBP 0: 10, and its flowability was 196mm. It shows that RBP has a large specific surface area and a small particle size, and the particle size morphology is serrated, which increases the water absorption rate. Overall, the addition of composite RP significantly reduces the flowability of the mortar.

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