Characteristics of Recycled Micro Powder Produced Using Construction Waste

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Abstract. Six different recycled micro powders were prepared by grinding the construction wastes that composed of concrete, tile, brick, and concrete. Experimental researches on their physical and chemical properties, particle size distribution, chemical composition and strength activity index were investigated and compared with the characteristics of cement, slag powder and fly ash. The results suggest that the specific surface area of the recycled micro powder prepared by grinding three types of construction waste for more than 30 min would reach more than 500 m^2/kg. When the specific surface area of the recycled micro powder is $\geq$500 m^2/kg, its density, water demand ratio, and other conventional physical and chemical properties and activities are not affected by fineness. The content of CaO is higher and SiO_2 is lower in the chemical components of the recycled micro powder of waste concrete, while the content of CaO is lower and SiO_2 is higher in the chemical components of recycled micro powder of waste brick and tile. The 28-day activity of the recycled micro powder meets the specification requirements of fly ash.

1 Preface

Recycled micro powder is a kind of fine powder which can be used as mineral admixture of cement concrete, waste brick, and tile after grinding to a certain degree of fineness. It is generally defined that particle size should be less than 0.16 mm [1] in order to induce its filling and activity effects [2]. The recycled aggregate of construction waste is a new way of recycling construction waste, which can significantly improve the economic added values and engineering properties of construction waste. For this study, six different recycled micro powders of construction waste were prepared, and their basic properties were studied. Compared with those of cement, slag powder, and fly ash, the feasibility of using them in cement concrete are presented in this paper.

2 Selection of Raw Materials and Preparation of Regenerated Powder

P.O.42.5 cement of Tang xian Ji dong Cement Co., Ltd., S95 slag powder of Tangshan "Xing wang" brand and class-F class-II fly ash produced by De zhou Power Plant were

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used as test materials. The technical performance indices of these materials met the requirements of relevant specifications [3–5].

The construction wastes included concrete, bricks, and tiles were derived from demolitions of concrete brick and buildings. The construction wastes were broken into recycled aggregates with particle size of 5–10 mm and washed several times to remove substances and debris. The basic performance indices of the recycled aggregates were tested according to the requirements of *Recycled Coarse Aggregate For Concrete* (*GB/T 25177–2010*) [6]. The test results are shown in Table 1.

Table 1. Test results of recycled aggregate raw materials of 5–10 mm waste concrete, and waste brick, and tile mixed construction waste

Test items	Test result	Technical index [6]		
		Class I	Class II	Class III
apparent density (kg/m^3)	2410	>2450	>2350	>2250
Void fraction (%)	48	<47	<50	<53
Crushing index (%)	19.6	<12	<20	<30
Mud content (%)	0.86	<1	<2	<3
Content of needle and flake particles (%)	2.3		<10	
Impurity content (%)	0.2		<1	

Note: mass ratio of recycled aggregates of waste concrete, waste brick, and tile is about 7:3

The recycled aggregates mainly compose of concrete, brick, and tile. SM-500 cement test mill (mill speed: 48 rpm) was used to grind these three kinds of recycled aggregates for 30 min or 1 h. Therefore, the test metric included six kinds of recycled micro powders, which were respectively labeled as 1#–6# recycled micro powders. The main components and grinding times are shown in Table 2.

Table 2. Main components and grinding time of recycled micro powders

Sample name	Composition	Grinding time
1# Recycled micro powder	Waste concrete	30 min
2# Recycled micro powder	Waste concrete	1 h
3# Recycled micro powder	Waste bricks and tiles	30 min
4# Recycled micro powder	Waste bricks and tiles	1 h
5# Recycled micro powder	Mixing waste concrete with waste brick and tile	30 min
6# Recycled micro powder	Mixing waste concrete with waste brick and tile	1 h

3 Test Method

General Portland Cement (GB 175-2007) [3], *Granulated Blast Furnace Slag Powder For Cement And Concrete* (*GB/T 18046-2008*) [4] and *Fly Ash For Cement And Concrete* (*GB/T 1596-2017*) [5] standards and specifications were used to test the conventional physical and chemical properties of the recycled micro powders and other mineral admixtures.

A laser particle size analyzer was used to compare and analyze the particle size distribution of the construction waste recycled micro powders and other mineral admixtures in accordance to the test method of *Particle Size Analysis Laser Diffraction Method* (*GB/T 19077-2016*) [7]. The particle size distribution was measured following the physical phenomenon that particles can cause laser scattering. As shown in Fig. 1, the scattering light I_1 is caused by larger particles, while the scattering light I_2 is caused by smaller particles. The average particle size of a powder is usually expressed by D_{50} and D_{90}. D_{50} is the corresponding particle size when the cumulative percentage on the particle size distribution of a sample reaches 50%. D_{90} is the corresponding particle size when the cumulative percentage on the particle size distribution of a sample reaches 90%.

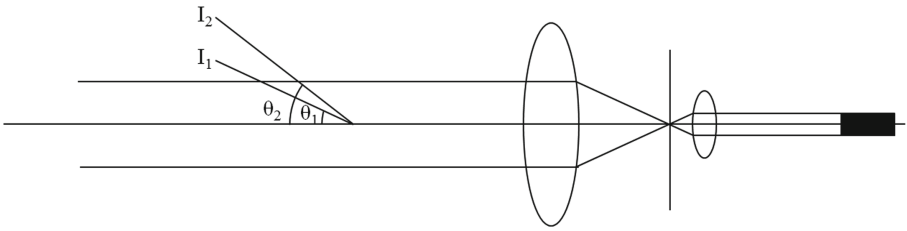

Fig. 1. Schematic diagram of laser particle sizer test

According to the *Classification, Safety Requirements and Test of Portable Tube Excited X-ray Fluorescence Analyzer* (*GB/T 35734-2017*) [8], the chemical composition of a recycled micro powder of the construction waste and other mineral admixtures were analyzed by X-ray fluorescence spectrometer. The X-ray fluorescence spectrometer consists of excitation source (X-ray tube) and detection system. The X-ray tube generates incident X-ray (primary X-ray). Each element in the excited sample emits secondary X-rays, and the secondary x-rays emitted by different elements have specific energy characteristics or wavelength characteristics. The instrument measures the energy and quantity of these emitted secondary X-rays. Then, the software converts the information collected by the instrument into the types and contents of various elements present in the sample.

According to the test method of fly ash strength activity index in Appendix C of *Fly Ash Used In Cement And Concrete* (*GB/T 1596-2017*) [5], the strength activity index tests of the recycled micro powders of the construction waste and other mineral admixtures were carried out, and the results are presented in the subsequent sections.

4 Result Analyses

4.1 Conventional Physical and Chemical Properties

The physical and chemical properties of 1#–6# recycled micro powders, cement, fly ash, and slag powder were studied. The test results are presented in Table 3. These results indicate that:

(1) The specific surface area of recycled micro powder prepared by grinding recycled aggregate for 30 min is more than 500 m^2/kg, which is greater than that of cement, slag powder, and fly ash.
(2) With increasing grinding time, specific surface area, and density, water content and water demand ratio of the recycled micro powder are increased slightly.
(3) The density of recycled micro powder is about 2.6 g/cm^3, which is between fly ash and slag powder.
(4) The water requirement ratio of the recycled micro powders prepared by different components of the recycled aggregates has little difference. However, the ratio is larger than that of fly ash or slag powder. This is due to the large specific surface area and rough particle surface of the recycled micro powder. As a result, the water demand of mixture blended with the recycled micro powder increases [9].
(5) The loss on ignition of the recycled micro powder of the waste concrete and mixed type is greater than that of other mineral admixtures. For the recycled aggregate of the waste brick and tile, the loss on ignition of the recycled micro powder prepared by grinding is smaller because the brick and tile were calcined at high temperature in the forming process.

In conclusion, the physical and chemical performance indices of 1#–6# recycled micro powders basically meet the technical index requirements of grade II fly ash in *Fly Ash For Cement And Concrete* (*GB/T 1596-2017*) [5]. Thus, they meet the requirements to use as a mineral admixture of cement concrete. Therefore, it is feasible to replace grade II fly ash with the recycled micro powders.

Table 3. Test results of physical and chemical properties

Sample name	Fineness (45 μm square hole sieve residue) (%)	Density (g/cm^3)	Comparison table area (m^2/kg)	Moisture content (%)	Loss on ignition (%)	Stability (mm)	Water demand Volume ratio
1# Recycled micro powder	19	2.61	648	0.8	15	1	104
2# Recycled micro powder	/	2.62	883	1	16	1	105

(*continued*)

Table 3. (*continued*)

Sample name	Fineness (45 μm square hole sieve residue) (%)	Density (g/cm^3)	Comparison table area (m^2/kg)	Moisture content (%)	Loss on ignition (%)	Stability (mm)	Water demand Volume ratio
3# Recycled micro powder	20	2.59	545	0.4	1.6	1	104
4# Recycled micro powder	12	2.65	843	0.4	3.5	1	106
5# Recycled micro powder	19	2.6	542	0.2	10	3	106
6# Recycled micro powder	/	2.61	961	0.4	10	3	106
Cement	/	2.99	418	0.1	1	2	/
Fly ash	22	2.35	317	0.3	1	2	98
Slag powder	/	2.84	473	0.2	0.8	/	99
Technical index of grade II fly ash [5]	≤30	≤2.6	/	≤1.0	≤8.0	≤5.0	≤105

4.2 Particle Size Distribution

The particle size analyses of 1#-6# recycled micro powders, cement, fly ash and slag powder were carried out using a laser particle size analyzer. The results are shown in Table 4 and Fig. 2, 3, 4, 5, 6, 7, 8, 9 and Fig. 10.

Table 4. Calculation results of particle size parameters

Sample name	D_{50} (μm)	D_{90} (μm)
1# Recycled micro powder	17	78
2# Recycled micro powder	11	104
3# Recycled micro powder	7.4	55
4# Recycled micro powder	6.9	92
5# Recycled micro powder	15	64
6# Recycled micro powder	9.5	105

(*continued*)

Table 4. (*continued*)

Sample name	D_{50} (μm)	D_{90} (μm)
Cement	12	35
Fly ash	19	82
Slag powder	14	35

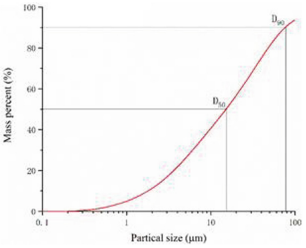

Fig. 2. 1# Recycled micro powder

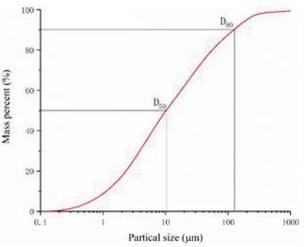

Fig. 3. 2# Recycled micro powder

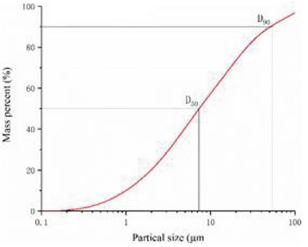

Fig. 4. 3# Recycled micro powder

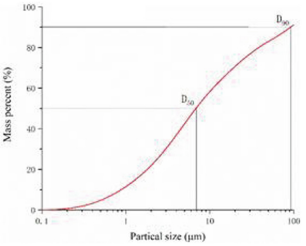

Fig. 5. 4# Recycled micro powder

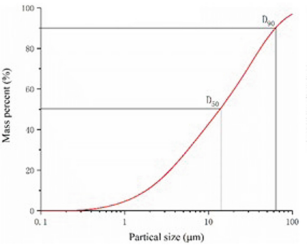

Fig. 6. 5# Recycled micro powder

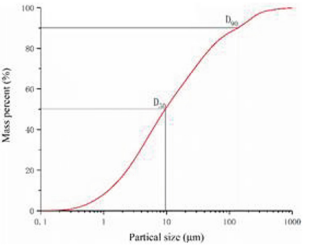

Fig. 7. 6# Recycled micro powder

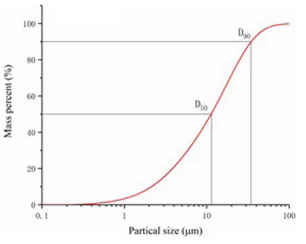

Fig. 8. Cement

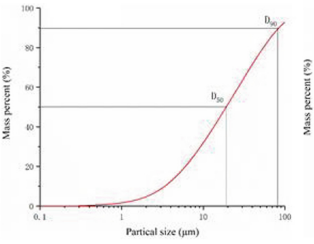

Fig. 9. Fly ash

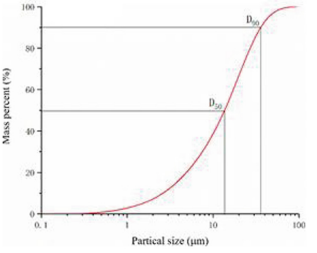

Fig. 10. Slag powder

The experimental results show that:

(1) The average particle size (D_{50}) of the waste concrete and the mixed recycled fine powder is not significantly different from cement, slag powder, and fly ash, while the average particle size (D_{50}) of the waste brick and tile recycled fine powder is significantly smaller than other mineral admixtures. The recycled waste brick and tile aggregates are easier to grind due to their lower hardness. Therefore, the average particle size should be smaller under the same grinding time.
(2) As the grinding time prolonged, the D_{50} of the same type of recycled micro powder decreases, but D_{90} increases. When the recycled fine powders of construction wastes are ground to a certain level (specific surface area $\geq 843 m^2/kg$), more micro-cracks are formed on the surface of the particles. When the diameter distribution is uneven, due to characteristics of polarization between coarse and fine particles, it leads to a decrease in the D_{50} of the regenerated fine powder, but an increase in the D_{90}.

4.3 Chemical Composition

The chemical compositions of 1#–6# recycled micro powders, cement, fly ash, and slag powder were measured by X-ray fluorescence spectrometer. The test results are shown in Table 5.

Table 5. Chemical composition of each admixture

Sample name	Chemical composition content (%)							
	Al_2O_3	SiO_2	CaO	Fe_2O_3	MgO	Na_2O	K_2O	SO_3
1# Recycled micro powder	12.76	46.81	24.26	4.47	5.75	1.86	2.23	/
2# Recycled micro powder	12.45	46.53	23.43	5.50	6.21	1.84	2.25	/
3# Recycled micro powder	16.43	58.60	8.17	7.85	2.77	2.09	2.66	/
4# Recycled micro powder	15.68	57.51	9.27	8.18	3.09	2.16	2.60	/
5# Recycled micro powder	13.93	48.83	21.58	4.43	5.16	1.85	2.35	/
6# Recycled micro powder	13.79	49.99	20.22	4.49	5.26	2.02	2.41	/
Cement	6.81	20.46	59.11	2.94	4.61	/	1.40	3.22
Fly ash	40.82	46.94	3.35	4.40	/	/	/	/
Slag powder	19.20	31.04	32.93	1.25	8.61	/	/	3.63

It can be seen from the data in Table 5 that the main chemical compositions (Al_2O_3, SiO_2, Cao, Fe_2O_3, and MgO) are basically the same, but the relative contents are different.

The relative contents of main chemical components in the cement and slag powder are similar, in which CaO content is the highest, followed by SiO_2. The content of SiO_2 in fly ash is high, but its CaO content is very low.

Comparing the chemical composition of the recycled micro powders of the waste concrete and the waste brick and tile, it can be observed that the content of Cao and SiO_2

in the recycled micro powder of the waste concrete is high, but the content of SiO_2 in the recycled powder of the waste brick and tile is low. This is mainly due to the large use of cement in concrete, and the main raw material for cement production is limestone, and the raw material for firing brick and tile is clay. Therefore, it causes the content of SiO_2 to be high. It can be seen that the type of raw materials has a great influence on the chemical composition of micro powder, which is consistent with the research conclusion in the literature [10].

The main chemical composition content of the mixed recycled micro powder is between the waste concrete and the waste brick and tile. Because of the large proportion of the waste concrete, the main chemical composition content of the mixed recycled micro powder is closer to that of fresh concrete.

The relative content of the main chemical components of the recycled micro powders of the waste concrete is close to that of the cement and slag powder. Their activity characteristics may be similar to that of the cement and slag powder.

4.4 Strength Activity Index

The strength activity indices of 1#–6# recycled micro powders, cement, fly ash and slag powder were tested. The test results are shown in Table 6.

Table 6. Test results of strength activity index

Sample name	7-day strength activity index (%)	28-day intensity activity index (%)
1# Recycled micro powder	46	70
2# Recycled micro powder	50	69
3# Recycled micro powder	51	81
4# Recycled micro powder	55	78
5# Recycled micro powder	47	71
6# Recycled micro powder	51	71
cement	100	100
Fly ash	/	74
Slag powder	88	95
Technical index of fly ash [5]	/	≥70

The experimental results show that:

(1) The 7-day and 28-day activity indices of the six recycled micro powders can basically meet the technical requirements of fly ash. But the activity indices fall short of S95 grade slag powder.
(2) Under the same grinding time, the 7-day and 28-day activity indices of the recycled micro powder of the waste brick and tile are slightly higher than that of waste concrete.

(3) Prolonging the grinding time can improve the 7-day activity indexes of the recycled powder. However, it has no effect on the 28-day activity.

To sum up, the activity indices of the three construction wastes (recycled micro powders) can meet the technical requirements of fly ash. The grinding time has a certain limitation on the improvement of the recycled micro powder. For practical application, the grinding time of the recycled construction waste aggregate should not exceed 30 min.

5 Conclusions

(1) The specific surface areas of recycled micro powder can reach more than 500 m^2/kg by grinding 5–10 mm recycled aggregate of construction wastes for 30 min. The specific surface areas are larger than that of cement, slag powder and fly ash.
(2) With the increase of specific surface areas, the conventional physical and chemical properties changed little, such as density and water demand ratio of the same type of recycled micro powder. For practical application, the grinding time of the recycled construction waste aggregate should not exceed 30 min.
(3) Under the same grinding time, the activity index of recycled micro powder of waste brick and tile is slightly higher than that of waste concrete. When the recycled micro powder was grinded to a certain extent (specific surface area $\geq$843 m^2/kg), the particle agglomeration phenomenon would appear, resulting in uneven distribution of particles.
(4) The relative content of the main chemical components of the recycled powder of waste concrete is similar to that of cement and slag powder.
(5) The results show that the strength indexes of recycled micro power of construction waste basically meet the standard of grade II fly ash. Thus, the recycled micro power is feasible to replace fly ash as mineral admixture of cement concrete

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