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Influence of Waste Slurry as Mixing Water on the Properties of C80 Concrete with Different Mineral Admixtures

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ABSTRACT

This paper mainly explores how waste slurry as mixing water affects the properties of C80 concrete. The waste slurry was collected from a mixing station. Two types of C80 concrete were prepared with different mineral admixtures: type I concrete mixed from 15% fly ash and 20% slag powder, and type II concrete mixed from 20% fly ash and 10% silica fume. The properties of the two types of concrete were evaluated in terms of working performance, mechanical properties, and durability. In addition, the influence of waste slurry on microstructure of concrete was analyzed through X-ray diffraction (XRD). The results show that, with the growing content of waste slurry, slump and expansion were declining; the initial and final setting times gradually increased, but the increments were not significant; with the growing content of waste slurry, the 7d compressive strength of type I concrete stayed below that of reference concrete, and gradually decreased, but the later compressive strengths increased rapidly; the 7d compressive strength of type II mineral admixture concrete gradually increased, while the later compressive strengths increased first and then decreased. Besides, the addition of waste slurry enhanced the resistance to chloride ion penetration (CIP), and increased the carbonization depth of concrete. The 7d XRD peak of using tap water as mixing water was slightly higher than that of using waste slurry as mixing water; the 28d XRD peak of the former was slightly lower than that of the latter. The research provides reference for applying waste slurry in concrete production.

1. INTRODUCTION

During the cleaning of concrete transport vehicles and mixing stations, lots of waste slurry and solid wastes are produced. Direct discharge of the waste slurry and solid wastes will seriously pollute water and soil, and even block the municipal pipe network, exerting a great impact on the normal life and work of residents [1].

The waste slurry, which mainly contains water, non-hydrated cement particles, and residual mineral admixtures/additives, is highly alkaline. The potential of hydrogen (pH) of the waste slurry could reach 12 and above. With the growing awareness of environmental protection, it is urgent to recycle and reuse the waste slurry from mixing stations [2].

Mixing water is a vital material for concrete [3]. For a mixing station with an annual output of 500,000m^3, up to 80,000 tons of wastewater is discharged each year. Hence, a mixing station with an annual output of 200,000m^3 can only recycle and treat 60 tons of wastewater per day [4, 5].

Germany started to recycle concrete early in the 1980s, and manages to increase the recycling rate of waste slurry to 95% [6]. In Japan, the solid waste is usually divided into waste aggregate and wastewater, and then recycled in concrete production; during the recycling, the solid content of the mixing water is controlled to less than 10kg/m^3 [7]. In China, about 75% of waste slurry from mixing stations are recovered and reused.

As urbanization picks up speed, there is a growing demand for infrastructure construction. Therefore, the construction industry is in urgent need of high-performance building materials. High-performance concrete provides an ideal construction material, for its good working performance, mechanical properties, and durability. The properties of high-performance concrete depend on the selection of raw materials, admixtures, etc.

At present, the waste slurry produced in mixing stations is mostly processed into low-strength concrete. There is little report on how waste slurry affects the working performance, mechanical properties, and durability of recycled concrete [8]. Moreover, few attempts have been made to prepare high-performance concrete from waste slurry.

In this paper, waste slurry is mixed with tap water, and used as mixing water to produce recycled concrete. The effects of the mixing water on C80 concrete prepared by two mineral admixtures were investigated, in terms of working performance, mechanical properties, and durability. In addition, the influence of waste slurry on microstructure of concrete was analyzed through X-ray diffraction (XRD).

2. TEST RAW MATERIALS

The raw materials of this research are introduced as follows.

2.1 Cement

The cement is P·II52.5 type ordinary Portland cement, whose specific surface area (SSA) is 35m^2/kg, loss on ignition (LOI) is 2.33%, insoluble matter is 0.63%, chloride ion content is 0.023%, 3d compressive strength is 33.4MPa, and 28d compressive strength is 55.3MPa.

2.2 Coarse aggregate

The coarse aggregate is crushed stones with good particle size distribution. The apparent density is 2,800kg/m^3, the stacking density is 1,540kg/m^3, the needle-like content is 4.0%, and the mud content is 0.3%.

2.3 Fine aggregate

The fine aggregate is medium sand, whose fineness modulus is 2.6, mud content is 0.9%, bulk density is 1,460kg/m^3, and apparent density is 2,650kg/m^3.

2.4 Admixtures

Three different admixtures are specified below:

(1) Class F grade I fly ash

The greyish brown fly ash was screened by a 45μm sieve. The fineness is 12%, the water demand ratio is 91%, the LOI is 3.4%, the water content is 0.6%, the density is 1.7g/cm^3, and the strength activity index is 90%.

(2) S95 grade slag powder

For the slag powder, the 3d, 7d, and 38d compressive strengths of cement are 26.6MPa, 36.4MPa and 52.6MPa, respectively; the density is 2.92g/cm^3, the SSA is 405m^2/kg, the 7d active index is 78%, the initial setting time is 131%, the flow ratio is 99%, the chloride ion content is 0.01%, and the LOI is 0.24%.

(3) Silica fume

The silica fume has a greater than 91% SiO_2 content.

2.5 Additives

Two additives were selected, including PCA-1 polycarboxylate superplasticizer (water reduction rate: 30%; solid content: 11.03%; density: 1.03g/cm^3), and BTC functional admixture (density: 1.007g/cm^3; pH: 9.7; chloride ion content: 0.008).

2.6 Water and waste slurry

Tap water (pH: 7.1) is adopted for this research, plus the waste slurry from a mixing station in Hefei, the seat of Anhui Province, China.

3. METHODOLOGY

3.1 Mix ratio design for C80 concrete

After lab trials, the mix ratios of the two types of concretes were determined (Tables 1 and 2). The dosage of cementitious material was set to 600kg/m^3. The slump was designed as 200±20mm. For type I mineral admixture, the fly ash content is 15%, and the slag powder content is 20% of the total cementitious material. For type II mineral admixture, the fly ash content is 20%, and the silica fume content is 10% of the total cementitious material.

Furthermore, the amount of mixing water was designed as follows: 0% waste slurry + 100% tap water; 20% Waste slurry +80% tap water; 40% waste slurry +60% tap water; 60% waste slurry +40% tap water; 80% waste slurry +20% tap water; 100% waste slurry +0% tap water.

3.2 Working performance and durability tests

The working performance of the prepared concretes, including slump, expansion, and setting time, was tested according to *Standard for Test Method of Performance on Ordinary Fresh Concrete* (GB/T50080-2016) [9].

Drawing on *Standard for Test Methods of Mechanical Properties on Ordinary Concrete* (GB/T50081-2002) [10] and *Technical Specification for High-Strength Concrete Structures* (CECS104:99) [11], a total of 9 concrete blocks (100mm×100mm×100mm) of each type of concrete were prepared. Three blocks were used for the test on 7d compressive strength, three for the test on 28d compressive strength, and three for the test on 56d compressive strength.

In addition, the durability of each block was measured as per *Standard for Test Methods of Long-Term Performance and Durability of Ordinary Concrete* (GB/T50082-2009) [12] and CECS104:99.

Table 1. The mix ratios of type I concrete

Mix ratio (%)	Dosage (kg/m^3)							
	Tap water	Waste slurry	Cement	Fly ash	Slag powder	Coarse aggregate	Fine aggregate	Additives
0	0	169	390	90	120	1037	647	11.4
20	33.8	135.2	390	90	120	1037	647	11.4
40	67.6	101.4	390	90	120	1037	647	11.4
60	101.4	67.6	390	90	120	1037	647	11.4
80	135.2	33.8	390	90	120	1037	647	11.4
100	169	0	390	90	120	1037	647	11.4

Table 2. The mix ratios of type II concrete

Mix ratio (%)	Dosage (kg/m^3)							
	Tap water	Waste slurry	Cement	Fly ash	Slag powder	Coarse aggregate	Fine aggregate	Additives
0	0	169	420	120	60	1037	647	11.4
20	33.8	135.2	420	120	60	1037	647	11.4
40	67.6	101.4	420	120	60	1037	647	11.4
60	101.4	67.6	420	120	60	1037	647	11.4
80	135.2	33.8	420	120	60	1037	647	11.4
100	169	0	420	120	60	1037	647	11.4

3.3 XRD tests

The mixing of waste slurry will affect the microstructure of concrete. Moreover, the work performance, properties, and durability of concrete are influenced by the kinds of raw materials, water-binder ratio, and the type of mineral mixture. Hence, a TD-3500 X-ray diffractometer was adopted to study the effects of different mineral admixtures and waste slurry on the microstructure of concrete samples.

Four groups of concrete samples were prepared for XRD tests. The dosage of cementitious material, and the mix ratios of admixture and concrete were the same. The total amount of absorbed water was reduced by proportion. The mixing conditions of the four sample groups are as follows: 100% tap water + 0% waste slurry for Group A of type I concrete; 0% tap water + 100% waste slurry for Group B of type I concrete; 100% tap water + 0% waste slurry for Group A of type II concrete; 0% tap water + 100% waste slurry for Group B of type II concrete.

The samples reaching the curing age were taken out of the curing room and crushed. The 5mm-diameter samples were ground into 80μm powders. Then, the XRD spectra of samples prepared from different mineral admixtures and waste slurry were obtained at 7d and 28d.

4. ANALYSIS OF TEST RESULTS

4.1 Effects of waste slurry on working performance

Figures 1 and 2 present the effects of waste slurry from mixing station on the working performance of C80 concrete prepared with types I and II mineral admixtures, respectively.

The experimental results show that the slump and expansion of C80 concrete gradually decreased with growing content of waste slurry. After the waste slurry content surpassed 60%, type I concrete had faster initial slump and 30min slump losses than type II concrete, and less stable slump change than the latter. Type II concrete exhibited greater slump and expansion than type I concrete. The findings are consistent with Franco's conclusion [6] on how the waste slurry from mixing station affects the working performance of concrete.

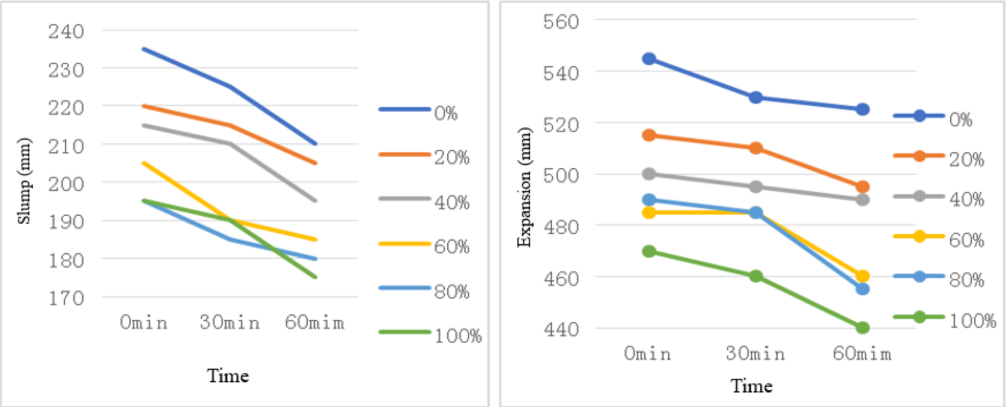

Figure 1. The effects of waste slurry on type I concrete

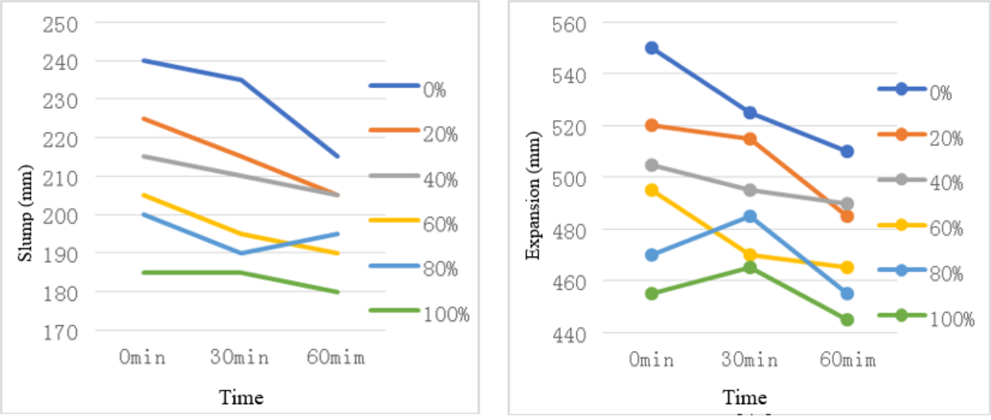

Figure 2. The effects of waste slurry on type II concrete

4.2 Effects of waste slurry on setting time

Tables 3 and 4 display the effects of waste slurry from mixing station on the setting time of C80 concrete prepared with types I and II mineral admixtures, respectively. The experimental results demonstrate the influence of waste slurry on the setting time of C80 concrete prepared from two types of mineral admixtures. With the growing content of waste slurry, the initial and final setting times both gradually increased, but the increments were not significant. This meets the requirements of normal construction. Type II concrete had longer initial and final setting times than type I concrete.

4.3 Effects of waste slurry on mechanical properties

Tables 5 and 6 illustrate the effects of waste slurry from mixing station on the compressive strength of C80 concrete prepared with types I and II mineral admixtures, respectively.

Marco [13] found that the compressive strength of concrete mixed with waste slurry is slightly lower than that of concrete without waste slurry. Li, Xiao and others provided even more experimental results [14-19].

Our experimental results show that, with the growing content of waste slurry, the 7d compressive strength of type I concrete stayed below that of reference concrete, and gradually decreased, but the 28d and 56d compressive strengths increased rapidly. When the waste slurry reached the contents of 20% and 40%, the 28d compressive strength was higher than that of reference concrete.

With the increase of waste slurry content, the 7d compressive strength of type II mineral admixture concrete gradually increased, while the 28d and 56d compressive strengths increased first and then decreased. When the waste slurry reached the contents of 20% and 40%, the later compressive strengths were higher than those of the reference concrete.

In comparison, type II concrete has greater compressive strength than type I concrete. The reason lies in the reaction between waste slurry and the specific mineral admixture of each type of concrete. In type I concrete, pozzolanic acid is not highly active in the early phase, and the waste slurry contains some retarding substances. As a result, the concrete has a lower early compressive strength than the reference concrete. In type II concrete, silica fume has higher pozzolanic activity than slag powder in the early phase, and the residual $Ca\ (OH)_2$ in waste slurry promotes the hydration reaction of silica fume, thereby enhancing the early compressive strength of concrete.

Table 3. The effects of waste slurry on the setting time of type I concrete

	Waste slurry content (%)	**Initial setting time (h; min)**	**Final setting time (h; min)**
1	0	9h 10min	13h 20min
2	20	9h 20min	13h 25min
3	40	9h 25min	13h 30min
4	60	9h 40min	13h 30min
5	80	9h 50min	13h 40min
6	100	10h 05min	13h 55min

Table 4. The effects of waste slurry on the setting time of type II concrete

	Waste slurry content (%)	**Initial setting time (h; min)**	**Final setting time (h; min)**
1	0	9h 50min	15h 30min
2	20	9h 55min	15h 40min
3	40	10h 10min	15h 45min
4	60	10h 25min	15h 45min
5	80	10h 40min	15h 55min
6	100	10h 55min	15h 50min

Table 5. The effects of waste slurry on the compressive strength of type I concrete

Content	**Compressive strength (MPa)**		
	7d	28d	56d
0%	73.6	85.4	92.3
20%	67.2	88.3	96.7
40%	66.4	87.7	98.1
60%	63.1	85.2	97.5
80%	61.8	83.5	96.3
100%	59.9	82.3	96.5

Table 6. The effects of waste slurry on the compressive strength of type II concrete

Content	**Compressive strength (MPa)**		
	7d	28d	56d
0%	70.0	88.4	95.3
20%	71.7	91.2	101.5
40%	73.2	92.7	102.2
60%	73.9	90.6	99.4
80%	75.1	89.3	98.5
100%	77.5	89.5	98.8

4.4 Effects of waste slurry on durability

In general, high-performance concretes are prepared with raw materials of good particle size distribution and a low water-binder ratio, using methods like full vibration to reduce voids. The treatment methods prevent water penetration, making the concrete impermeable. Tables 7 and 8 show the effects of waste slurry from mixing station on the chloride ion penetration (CIP) resistance of C80 concrete prepared with types I and II mineral admixtures, respectively.

The experimental results show that the CIP resistance of C80 concrete was less than 1,000C, which was improved by the addition of waste slurry. Type II concrete had better CIP resistance than type I concrete.

Overall, the solid content of waste slurry has a clear negative impact on the working performance and strength of concrete. But the durability of concrete is not significantly affected, because the solid substances make the concrete more compact.

Table 7. The effects of waste slurry on the CIP resistance of type I concrete

Content (%)	**Electric flux (C)**			Mean (C)
	Group 1	Group 2	Group 3	
0	195.7	207.8	197.7	200.4
20	166.6	165.4	178.9	170.3
40	197.1	197.9	194.5	196.5
60	215.5	209.8	220.9	215.4
80	233.6	226.2	227.8	229.2
100	244.3	247.8	249.2	247.1

Table 8. The effects of waste slurry on the CIP resistance of type II concrete

Content (%)	**Electric flux (C)**			**Mean (C)**
	Group 1	Group 2	Group 3	
0	167.5	177.1	168.1	170.9
20	150.1	149.3	157.8	152.4
40	144.4	143.2	158.5	148.7
60	143.2	157.6	149.8	150.2
80	150.9	153.2	164.8	156.3
100	163.6	161.6	160.9	163.6

4.5 Effects of waste slurry on carbonation resistance

Li [16] called for more research on the influence of waste slurry on the durability of concrete. Xiao [17] found that, with the increase of waste slurry content, the early carbonation depth does not change much, but the later carbonation depth increases to a certain extent.

In our experiments, the carbonization depths of the two types of concretes were zero, indicating that the addition of waste slurry increases the compactness of concrete. This is because the residual fine particles in waste slurry fill the voids of concrete. This finding echoes with the conclusions of Rickert et al. and Chatveera and Lertwattanaruk [20, 21].

4.6 Effects of waste slurry on microstructure

Figures 3 and 4 provide the 7d XRD spectra of type 1 and type 2 concrete samples, respectively. Figures 5 and 6 provide the 28d XRD spectra of type 1 and type 2 concrete samples, respectively.

From Figures 3-6, it can be seen that, for both types of concrete samples, the 7d XRD peak of using tap water as mixing water was slightly higher than that of using waste slurry as mixing water; the 28d XRD peak of the former was slightly lower than that of the latter.

For the concrete samples prepared from fly ash and slag powder, the fly ash is not highly active in the early phase. The pH of tap water is lower than that of waste slurry, owing to the alkaline residual substances in the slurry. The addition of waste slurry inhibits the hydration of cement in the early phase. That is why the XRD peak of using tap water as mixing water was slightly higher than that of using waste slurry as mixing water.

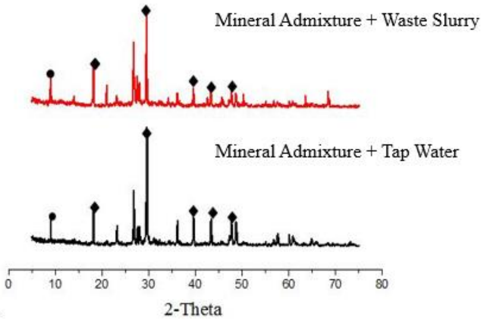

Figure 3. The 7d XRD spectra of type 1 concrete samples

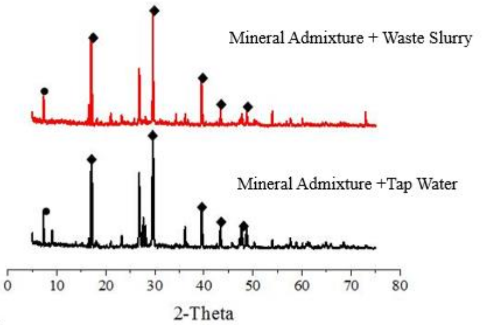

Figure 4. The 7d XRD spectra of type 2 concrete samples

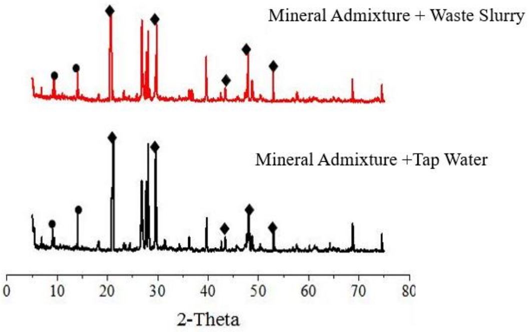

Figure 5. The 28d XRD spectra of type 1 concrete samples

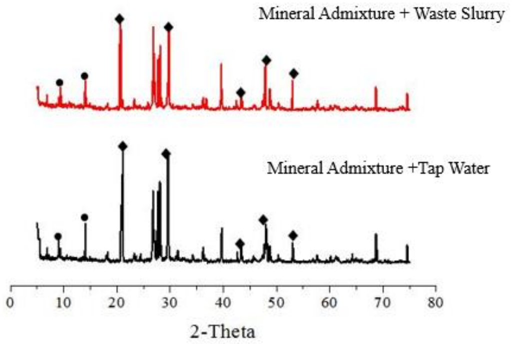

Figure 6. The 28d XRD spectra of type 2 concrete samples

For the concrete samples prepared from fly ash and silica fume, each sample has high early pozzolanic activity, and hydrates faster thanks to the $Ca(OH)_2$ in the waste slurry. As a result, the XRD peak of using tap water as mixing water was slightly lower than that of using waste slurry as mixing water.

Fly ash mixed with slag powder and silica fume help to reduce porosity and improve compactness. The waste slurry is strongly alkaline, which gives play to the later activity of slag powder and produces stable hydration products. Many scholars [18-21] held that the concrete mixed with waste slurry is stronger than that mixed with tap water.

5. CONCLUSION

(1) The slump and expansion of C80 concrete gradually decreased with growing content of waste slurry. After the waste slurry content surpassed 60%, type I concrete had faster initial slump and 30min slump losses than type II concrete, and less stable slump change than the latter.

(2) With the growing content of waste slurry, the initial and final setting times both gradually increased, but the increments were not significant. This meets the requirements of normal construction. Type II concrete had longer initial and final setting times than type I concrete.

(3) With the growing content of waste slurry, the 7d compressive strength of type I concrete stayed below that of reference concrete, and gradually decreased, but the later compressive strengths increased rapidly; the 7d compressive strength of type II mineral admixture concrete gradually increased, while the later compressive strengths increased first and then decreased.

(4) Mixing waste slurry improves the permeability and carbonation resistance of concrete. Type II concrete had better CIP resistance than type I concrete. The carbonization depths of the two types of concretes were zero, indicating that the addition of waste slurry increases the compactness of concrete.

(5) The 7d XRD peak of using tap water as mixing water was slightly higher than that of using waste slurry as mixing water; the 28d XRD peak of the former was slightly lower than that of the latter.

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