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Research Article

Experimental Study on the Fine Iron Ore Tailing Containing Gypsum as Backfill Material

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The strength of the filling body is largely affected by the properties of the binder, mineral composition, fineness, and slurry concentration of tailing. In this paper, the rheological test was conducted to determine the slurry concentration of iron ore tailing containing gypsum. Then, the samples made from slurry and three binders, Portland cement, filling plant binder, and Huazhong binder, were tested, respectively. The effects of curing time, binder-tailing ratio by mass (b/t), and slurry concentration on compression strength were investigated. The sample made from Huazhong binder and iron ore tailing presented the largest compression strength.

1. Introduction

Tailings are produced as a lot of by-product in the mining industry. Large amount of open area is needed for the waste, and it has an important effect on the environment. However, voids occur after mined. Landslide may happen in the goaf zone. It is necessary to develop paste backfill technology to reuse waste and increase stability of land. About 60% of the waste will be reduced by the backfill.

The tailing is used as the raw material of the filling body. The physical and chemical properties of tailing, as a kind of artificial sandy soil, mainly depend on mineral composition and grade. Generally, due to quartz of high content, tailing particle of hard ore rock after mineral processing is hard. Instead, due to the ore of high content, the tailings of soft and fractured rock or oxidized ore usually are tiny and viscous. While sometimes ore is mixed with much soil, the average particle size also decreases. In the mine-tailing-filled engineering, the physical and chemical properties of different tailings are complicated and changeable. When using different binder materials, the mechanical property of filling body is diverse. Huang et al. [1] had found that the bind type had an observable influence on the mode I fracture toughness of backfill structure. The backfill material is always pumped in a pipe into the site, so an appropriate rheological property is needed. Zhang et al. [2] had found that the mineral admixture type and dosage affect the rheological and mechanical properties of cemented foam backfill. The strength of the filling body not only depends on the properties of tail but also depends on the type, content, and fineness of the binder [3, 4]. Jabulani et al. [5] investigated the effect of fly ash on the behavior of paste backfill produced by brine. The fly ash seems play a significant role than brine. Fall and Benzaazoua [6] studied the influence of Portland cement, fly ash cement, and slag cement on high sulfur tailings' paste filling strength. It turned out that Portland cement had a better effect than fly ash cement and slag cement on the paste filling body. Furthermore, the chemical composition of the mixed water played a certain role in the strength properties of the cemented backfill. Other researchers [7–9] studied the strength characteristics of sulfur tailings' backfill under different conditions. Cihangir et al. [10] and Yilmaz et al. [11] investigated the microstructure of the paste filling body and discussed the influence of the microstructure on mechanical properties and strength development. Some researchers [12–18] analyzed the coupling effect of temperature, water, and force on the strength of the filling body. They also evaluated various mechanical properties of backfill under other similar complex environments. Fall et al. [19] and Abdul-Hussain et al. [20, 21] analyzed the water pressure characteristics of cemented backfill. Moreover, they investigated the permeability of cemented backfill and cemented paste backfill under saturated and unsaturated conditions.

In this paper, the rheological behaviors of slurry were investigated to determine the concentration of tailing. Because there is some gypsum in iron ore tailing of chenchao, the usually used binder materials are unbefitting. Then, three binders, Portland cement 325# (PC), filling plant binder (FP), and Huazhong binder (HZ), were, respectively, used as the binder to make backfill samples. The compressive strength of backfill samples with different binder-tailing ratio by mass (*b/t*), slurry concentration, and curing time was compared.

2. Preparation of Raw Materials

The iron ore tailing of chenchao and three binders, PC, FP, and HZ, were used. The physical properties of three binders are shown in Table 1.

In order to obtain the representative and uniform tailings, a rectangular material-receiving tank was dug at a tailing dam. Antiseepage color cloth was laid in the tank, and then, the tailing pumped from the mineral processing plant was drained into it by using a 4-inch white plastic tube, as shown in Figure 1. The tail paste will be settled naturally and water above the tailing mortar will be discharged. The physical properties of tailing were measured and shown in Table 1.

The particle size distribution of tailings was measured by a MASTERSIZER 2000 Laser diffraction particle size analyzer and shown in Figure 2.

The chemical composition of the tailing is shown in Table 2. It contains about 22% $CaSO_4$.

3. Experiment

3.1. Rheological Test of Slurry. The filling process is downwards, so the viscosity of slurry should not be too small to prevent separation. The filling distance is long, and the viscosity should be not too large to guarantee flow under self-gravity. The viscosity is largely dependent on the slurry concentration of the tailing. The slump test is usually conducted to describe the flow performance of slurry [22, 23]. Therefore, slurries with 7 different concentrations were prepared, and their mix proportions are shown in Table 3. A slump test were conducted, as shown in Figure 3. The slump values are shown in Figure 4. With the advance of concentration, the slump increases.

Meanwhile, a rheometer was used to measure the yield strength and plastic viscosity of slurry, and the results are shown in Table 4. With the decrease of slurry concentration, the yield strength and plastic viscosity decrease. When the concentration is 74~72%, the flow characteristics of slurry is bad and the slump is 20.0~23.5 cm, making it difficult to flow under self-gravity. When the concentration is 70%, the slurry has a certain fluidity and the viscosity is large. When the concentration decreases to 68~64%, the slump is 25.5~27 cm. At this time, the fluidity of slurry is obviously improved. When the concentration is below 62%, the water-retaining property of slurry declines, and the bleeding phenomenon is obvious. Combining with rheological parameters and slump value, we determined the slurry concentration is 64%–68%.

3.2. Production of the Filling Sample. 36 series filling samples with 3 different *b/t*, 4 types of tailing concentrations, and 3 types of binders were prepared. The mix proportion is shown in Table 5.

The tailing and binder were firstly poured into the mixer and mixed for 3 min. Then, water was added and mixed for another 3 min. After the filling paste was prepared, it was poured into the mold. After one day, we removed the molds and put them into the curing room. The cubic filling sample with an edge length of 70.7 mm was fabricated.

4. Experimental Results and Discussion

A uniaxial compression test was conducted to measure the uniaxial compression strength of every series after curing time of 3, 7, 28, and 60 days. The load was applied at a constant loading rate of 0.5 MPa/s until the sample was broken. For every series, the average UCS of 3 samples was calculated.

4.1. Effect of Curing Time on UCS. The effect of curing time on UCS of the sample with 66% tailing concentration is shown in Figure 5. Although the UCS of all samples of three binders increases with curing time, the increase rate is different.

When the curing time is 3 days and *b/t* is 1 : 4 (Figure .5(a)), the UCS of HZ is slightly larger than others, but for the other 3 series, their UCS is almost the same. When the curing time is 7 days and the dosage of binder is surplus (Figures 5(a) and 5(b)), the UCS of HZ is the largest and the UCS of PC is the lowest, but when the dosage of the binder decreases (Figures 5(c) and 5(d)), the UCS of FP is larger than others. However, after 60 days curing time, regardless of *b*/*t*, the UCS of HZ used sample is largely higher than others.

4.2. Effect of b/t on UCS. The effect of *b/t* on UCS of the sample with 66% tailing concentration is shown in Figure 6. Regardless of curing time, the UCS of HZ increases with the increase of *b/t*. However, for PC and FP, the *b/t* has no obvious effect. The UCS of PC and FP at all curing ages is less than 2 MPa. There are two reasons: On one hand, the size of iron tailing of chenchao is small, so its specific surface area (SSA) is large. The SSA of HZ is larger than the others, so the increase of contact area leads to the increase of reaction rate. On the other hand, the iron tailing of chenchao has only 27.8% SiO_2, but the contents of $CaSO_4$ and MgO exceeds

Table 1: Physical properties of the backfill material.

Material	Specific gravity	Loose bulk density (t/m³)	Compacted bulk density (t/m³)	Porosity (%)	Rest angle (°)
Tailing	2.772	1.290	1.590	42.60	33.73
PC	3.106	1.252	1.687	45.68	32.65
FP	2.985	1.367	1.703	42.95	34.28
HZ	3.262	1.389	1.792	45.06	33.32

(a)

(b)

Figure 1: The tailings sampling.

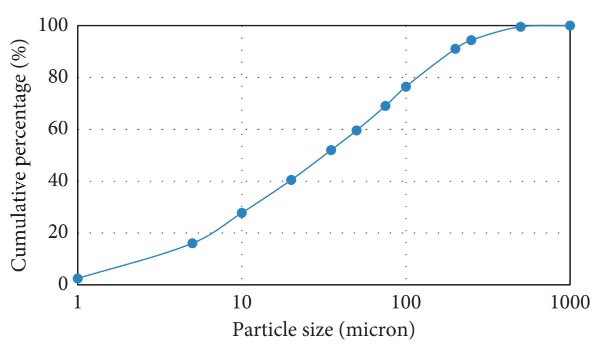


Figure 2: Particle size distribution of tailings.

Table 2: Chemical composition of tailings.

Chemical composition	TFe	SiO_2	Al_2O_3	MgO	Cu	S	*P*	$CaSO_4$	Other
Content (%)	8.74	27.80	5.96	7.35	0.034	5.30	0.09	22.09	22.64

Table 3: Mix proportion of slurry.

Series no.	Concentration (%)	Water (kg/m³)	Tailing (kg/m³)
1	74	493	1404
2	72	519	1334
3	70	543	1267
4	68	566	1203
5	66	588	1142
6	64	609	1083
7	62	629	1027

24% and 7%. The flocculation of Ca+ has a negative effect on the strength of cementitious material.

4.3. Effect of Slurry Concentration on UCS. The effect of slurry concentration on UCS of the sample with *b/t* of 1 : 4 is shown in Figure 7. In spite of curing time, the UCS of HZ increases with the increase of slurry concentration. The UCS of HZ is the largest, and the UCS of PC is the lowest. Nevertheless, the

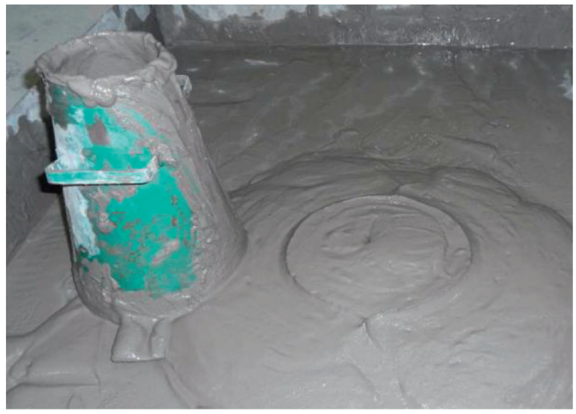


Figure 3: Slump test of slurry.

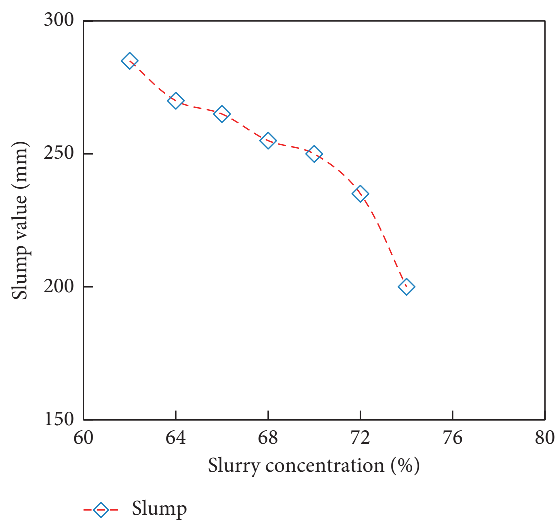


Figure 4: The slump-value-slurry-concentration curve.

Table 4: Rheological parameters of slurry.

Concentration (%)	74	72	70	68	66	64	62
Yield strength (Pa)	102.6	29.5	18.0	15.4	12.9	10.4	5.8
Plastic viscosity (Pa˙s)	486.0	15.1	0.5	0.23	0.18	0.16	0.14

Table 5: Mix proportion of the filling paste.

Series no.	*b*/*t*	Concentration (%)	Water (kg/m^3)	Tailing (kg/m^3)	Binder		
					PC (kg/m^3)	FP (kg/m^3)	HZ (kg/m^3)
1		64	614	874	218		
2	1 : 4	66	593	921	230		
3		68	571	971	243		
4		64	613	934	156		
5	1 : 6	66	592	985	164		
6		68	570	1038	173		
7		64	612	967	121	—	—
8	1 : 8	66	591	1020	127		
9		68	569	1075	134		
10		64	612	988	99		
11	1 : 10	66	590	1042	104		
12		68	568	1098	110		

Table 5: Continued.

Series no.	b/t	Concentration (%)	Water (kg/m^3)	Tailing (kg/m^3)	Binder		
					PC (kg/m^3)	FP (kg/m^3)	HZ (kg/m^3)
13		64	613	871		218	
14	1 : 4	66	592	919		230	
15		68	570	968		242	
16		64	612	932		155	
17	1 : 6	66	591	983		164	
18		68	569	1036		173	
19		64	611	966	—	121	—
20	1 : 8	66	590	1018		127	
21		68	568	1073		134	
22		64	611	987		99	
23	1 : 10	66	590	1041		104	
24		68	568	1097		110	
25		64	617	877			219
26	1 : 4	66	596	925			231
27		68	574	975			244
28		64	614	936			156
29	1 : 6	66	593	987			165
30		68	571	1041			173
31		64	613	969	—	—	121
32	1 : 8	66	592	1022			128
33		68	570	1077			135
34		64	613	990			99
35	1 : 10	66	592	1044			104
36		68	569	1100			110

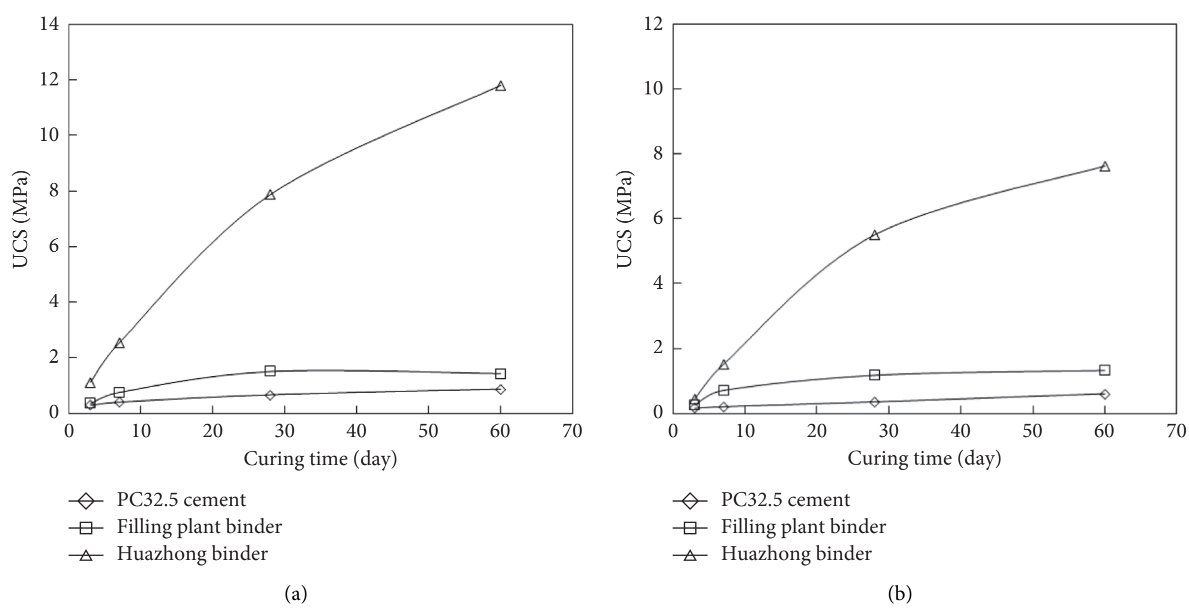
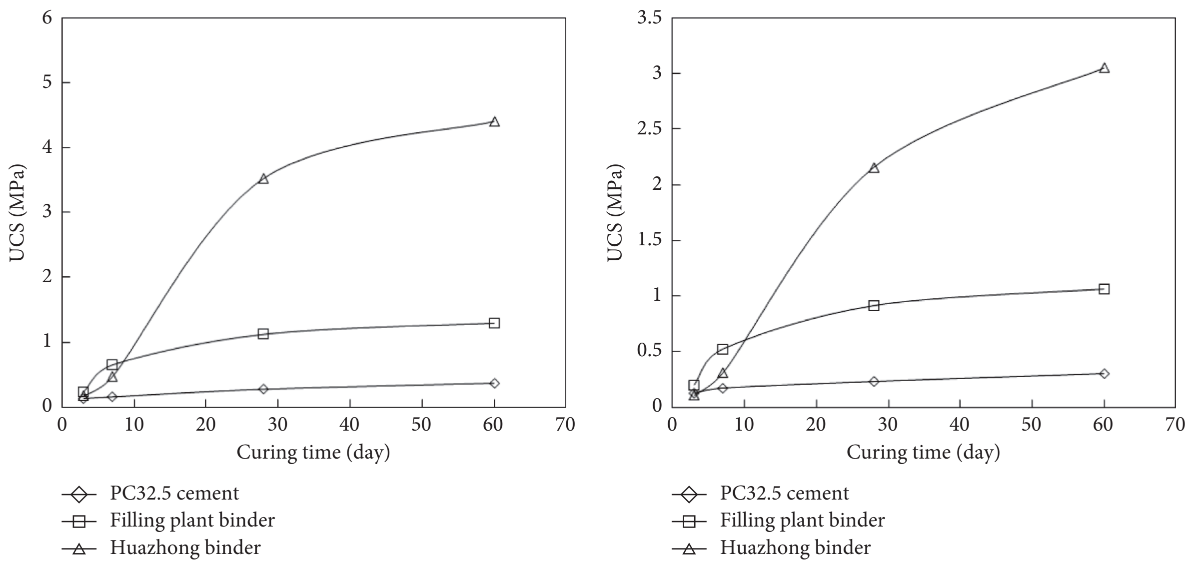
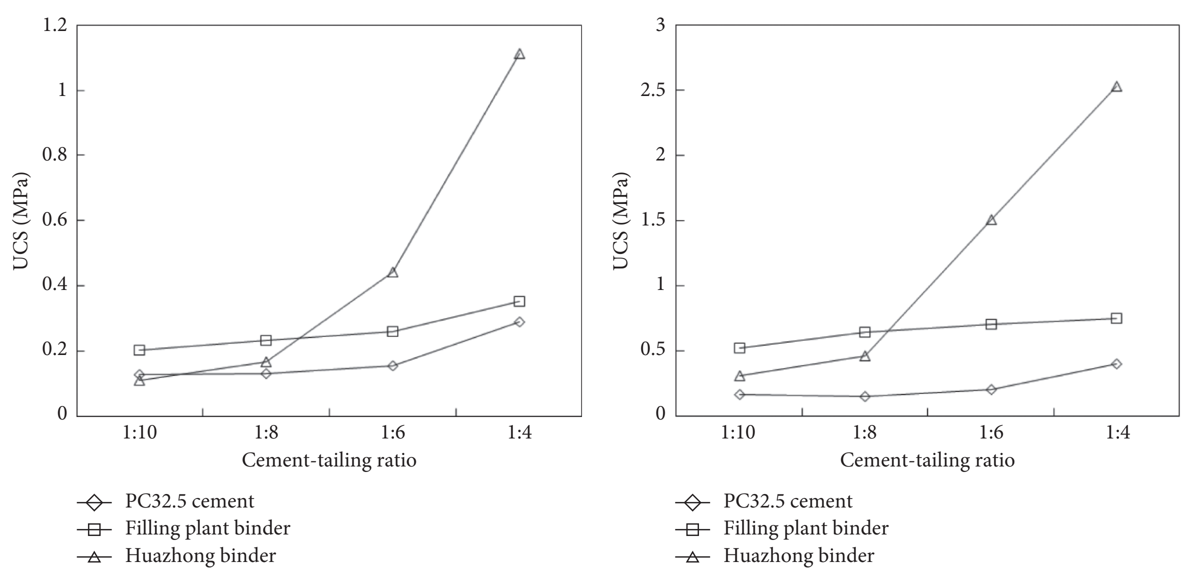


Figure 5: Continued.



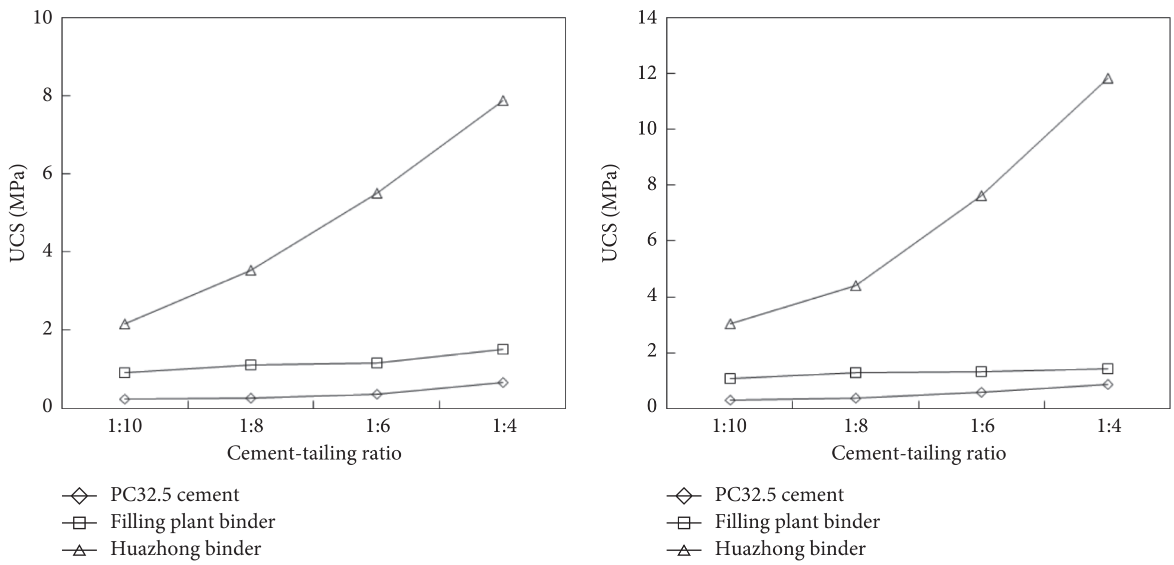
(c) (d)

Figure 5: Variation of UCS with curing time at different *b/t*. (a) *b/t* is 1 : 4. (b) *b/t* is 1 : 6. (c) *b/t* is 1 : 8. (d) *b/t* is 1 : 10.



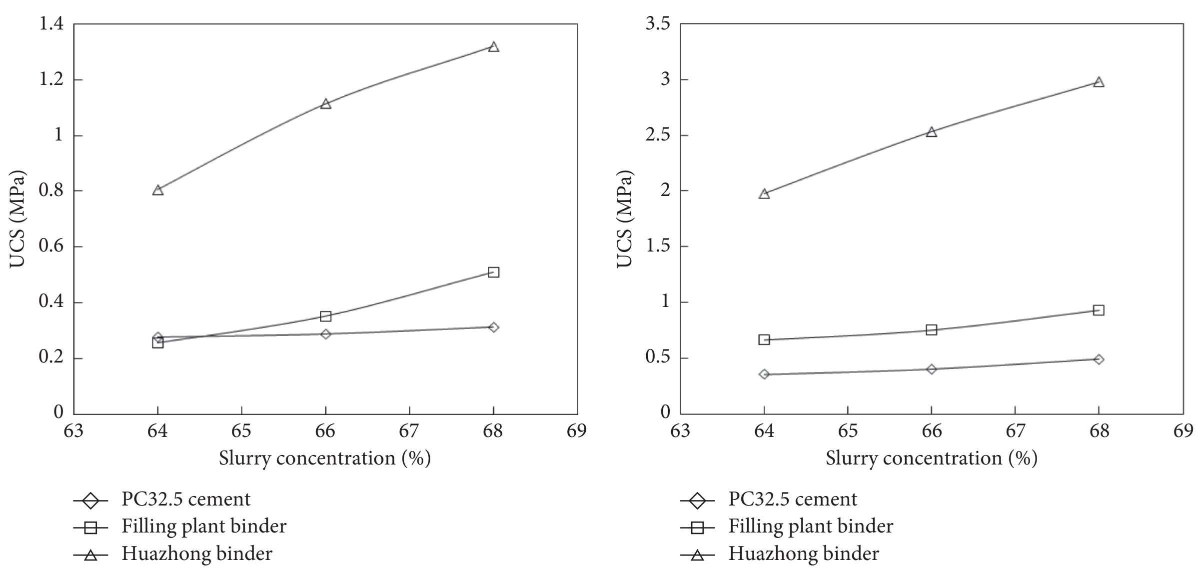
(a) (b)

Figure 6: Continued.



(c) (d)

Figure 6: Variation of UCS with *b/t*. (a) 3 d curing time. (b) 7 d curing time. (c) 28 d curing time. (d) 60 d curing time.



(a) (b)

Figure 7: Continued.

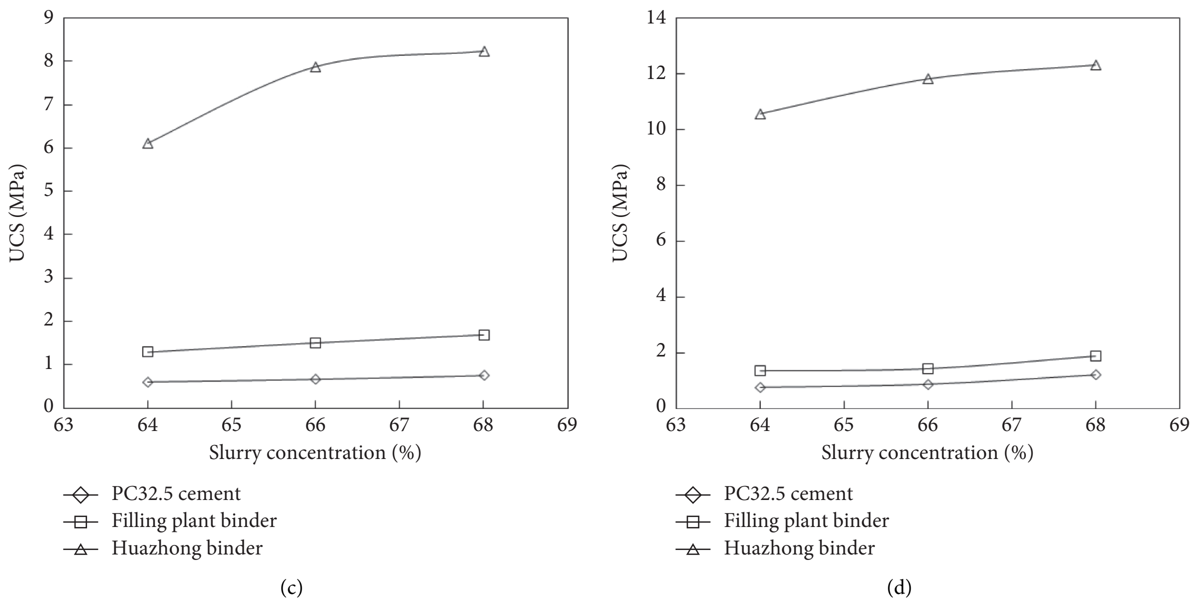


Figure 7: Variation of UCS with slurry concentration. (a) 3 d curing time. (b) 7 d curing time. (c) 28 d curing time. (d) 60 d curing time.

UCS of PC and FP has no obvious change with the increase of slurry concentration.

5. Conclusions

36 series samples were conducted. The effects of curing time, *b/t,* and slurry concentration were investigated. The following conclusions were obtained:

(1) Regardless of curing time, *b/t*, and slurry concentration, the UCS of HZ is larger than the others
(2) The UCS of all samples increases with the curing time
(3) The UCS of HZ increases with the increase of *b/t* and slurry concentration, but the UCS of PC and FP has no obvious variation

HZ is a new kind of mine tailing filling material, which is made of blast furnace slag powder and some additives. Compared with PC and HZ, it has the advantages of early strength increasing quickly, late strength stability and reliability, and small dosage. At the same level of filling body strength, HZ dosage is just about 30~60% of PC. Hence, for iron tailing with gypsum of high content, the HZ is a more suitable binder.

Data Availability

The [DATA TYPE] data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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