



# Effect of Iron Tailings and Slag Powders on Workability and Mechanical Properties of Concrete

Wu Ruidong<sup>1,2</sup>, Shen Yu<sup>3</sup>, Liu Juanhong<sup>1,2\*</sup>, Cheng Linian<sup>1,2</sup>, Zhang Guangtian<sup>4</sup> and Zhang Yueyue<sup>1,2</sup>

<sup>1</sup>School of Civil and Resource Engineering, University of Science and Technology Beijing, Beijing, China, <sup>2</sup>Beijing Key Laboratory of Urban Underground Space Engineering, University of Science and Technology Beijing, Beijing, China, <sup>3</sup>CCCC-SHEC Third Highway Engineering Co., Ltd., Xi'an, China, <sup>4</sup>Hebei Academy of Building Research, Shijiazhuang, China

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### \*Correspondence:

Liu Juanhong  
liujuanhong66@126.com

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Tailings are one of the largest solid wastes in stock at present. In order to improve the comprehensive utilization rate of tailings, especially to solve the problems of fine-grained tailings treatment, the concrete composite admixture was prepared by using iron tailings powder and slag powder. In order to study the influence of iron tailings powder on the workability and long-term mechanical properties of concrete, C30 and C50 concrete with different iron tailings powder dosages were prepared, and the slump, expansion, flexural strength, splitting tensile strength, and compressive strength of concrete at different ages were tested. The results showed that the proper addition of iron tailing powder is beneficial to the working performance of concrete and can effectively reduce the time-loss of concrete fluidity. When the content of iron tailings powder in the composite admixture is 50%, the 1080d long age strength of C30 and C50 concrete can reach 50.3 and 80.7 MPa. Based on the 28d compressive strength, the relative strength-age prediction model of iron tailings powder concrete was established. The calculation and experimental results show that the model can accurately predict the compressive strength of micro-powder concrete of iron tailings at long age, and the error rate is less than 1%. The results lay a theoretical foundation for the utilization of iron tailings in concrete.

**Keywords:** iron tailings powder, slag, mechanical properties, workability, prediction model

## INTRODUCTION

With the continuous development of mineral resources, a large number of tailings have been formed after mineral dressing, and tailings is one of the most abundant solid wastes. The accumulation of tailings in tailings ponds not only pollutes groundwater and the surrounding environment but also threatens the safety of surrounding people and buildings (Pedro et al., 2019; Liu et al., 2020). Limited by science and technology, the overall utilization rate of tailings is not high at present; nearly 78% of the tailings are piled on the surface, resulting in a considerable waste of resources. The main use of tailings is to prepare filling materials and building materials, especially coarse-grained iron tailings can be used as an aggregate to prepare filling materials and concrete, iron tailings can be used as a kind of machine-made aggregate, and the performance of filling materials and concrete is good (Lv et al., 2019; Qi and Fourie, 2019; Protasio et al., 2020; Karthikeyan et al., 2021; Leong, 2021). Some tailings are used to prepare the concrete of mine pillars; the concrete has good mechanical properties by means of fiber reinforcement (Cao et al., 2020; Cao et al., 2021a; Cao et al., 2021b). However, with the continuous development of mineral processing technology, tailings become finer and finer, and

the fine-grained tailings below 75  $\mu\text{m}$  can reach more than 80% (Wu et al., 2020). Fine-grade tailings will lead to the increase of cementitious substances in filling materials and cannot be used as a concrete fine aggregate, which greatly increases the difficulty of tailings utilization. The fine-grained tailings need to be classified, and a large number of fine-grained tailings cannot be used, which results in a considerable waste of resources, reduces the overall utilization rate of tailings, and increases the treatment cost. To solve the problem of fine tailings treatment is the bottleneck to improve the comprehensive utilization rate of tailings.

On the other hand, a huge amount of concrete is consumed in infrastructure construction. The production and preparation of concrete lead to the shortage of many resources, especially high-quality mineral admixtures. Mineral admixtures are essential raw materials for the modern green high-performance concrete. Under the background of low carbon and environmental protection, more and more admixtures will replace cement in concrete, which will help reduce carbon emissions and form an environment-friendly cementitious material system (Miller, 2018; Li et al., 2020a; Li et al., 2020b; Habert et al., 2020). In some areas, there is a scarcity of high-quality mineral admixtures, such as fly ash and slag powder (Granulated blast furnace slag, S95 and S105). Therefore, it is imperative to make a rational and efficient use of all kinds of resources, especially waste resources. In order to supplement the shortage of traditional admixture resources such as fly ash and slag and to make a wider use of industrial solid waste, reuse of iron tailings powder as a mineral admixture of concrete should be considered. The content of fine powder below 75  $\mu\text{m}$  in iron tailings is increasing. Because the iron tailings powder is mainly composed of  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and other chemical components, it can be used as a kind of concrete admixture. At present, the research of iron tailings powder as a mineral admixture in concrete is mainly focused on the influence of iron tailings powder on the strength of concrete, as well as the activation and hydration of iron tailings powder. Research shows that when iron tailings powder is mixed with slag powder, concrete has relatively good mechanical properties (Wu and Liu, 2018; Han et al., 2019), and its hydration rate is very slow, which can effectively reduce the hydration heat of cement concrete (Han et al., 2017). It is found that the fineness of iron tailings powder has an important impact on the performance of concrete. Some scholars believe that iron tailings powder can promote the performance of concrete

through effective activation and further grinding (Hou et al., 2019; Liu et al., 2019; Yang and Mao, 2020). Through the study on the influence of iron tailings powder as a concrete admixture on mechanical properties and microstructure, iron tailings powder can be completely used as a mineral admixture to prepare concrete materials (Song and Liu, 2017; Song et al., 2019; Wu et al., 2019; Song and Chen, 2020).

However, as an inactive mineral admixture of concrete, iron tailings powder needs to be mixed with highly active slag powder to become a compound admixture. The influence law of iron tailings powder and slag powder on concrete strength, especially the development law of long age strength, is urgently needed to be explored. In this article, different proportions of iron tailings powder and slag powder composite admixtures are designed to prepare two common grades of concrete, C30 and C50. The compressive strength, flexural strength, and splitting tensile strength of concrete are tested, and the long-term strength prediction model is established and verified. This study can fill the research blank of iron tailings powder concrete long-term mechanical properties, which provides a theoretical basis for the application of fine-grained tailings.

## RAW MATERIALS AND MIX PROPORTION

### Raw Materials

Iron tailings powder comes from Fujian, China. Iron tailings are collected from mines and become iron tailings powder after drying, dehydration, and grinding. Its specific performance indexes are shown in **Table 1**.

The main chemical composition of iron tailings powder is silica, which comprises metal elements such as iron, copper, and zinc, and the main chemical composition is shown in **Table 2**. Iron tailings are a kind of mineral rich in silica, so it can be used as a mineral admixture of concrete.

**Figure 1** is the X-ray diffraction pattern of iron tailings powder, which is mainly composed of quartz,  $\text{SiO}_2$ , and a small amount of calcite, mica, and other minerals.

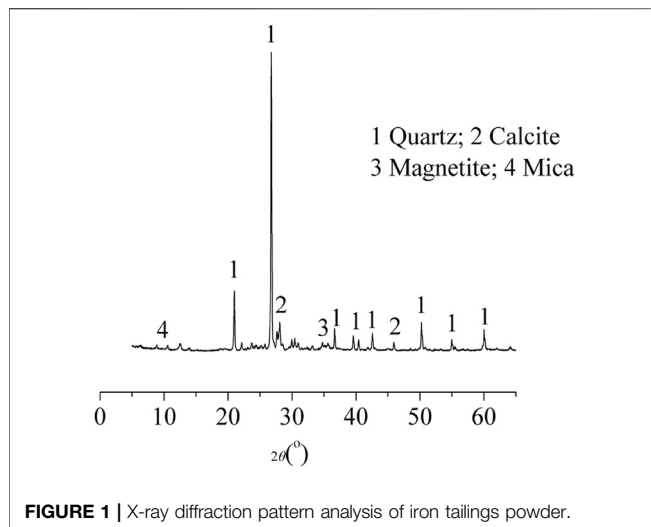
In order to eliminate the influence of other mineral admixtures in cement, the standard cement produced by the China Building Materials Institute, namely, pure Portland cement P.I 42.5, is selected for the test, and its basic performance indexes are shown in **Table 3**.

**TABLE 1** | Technical indexes of iron tailings powder and slag powder.

	Density/g·cm <sup>-3</sup>	45 $\mu\text{m}$ sieve residue/%	Water requirement ratio/%	Specific surface area/m <sup>2</sup> ·kg <sup>-1</sup>
Iron tailings	2.82	6.45	90	450
Slag	2.80	6.20	96.2	485

**TABLE 2** | Main chemical components of iron tailings powder (%).

Chemical composition	$\text{SiO}_2$	$\text{CaO}$	$\text{Fe}_2\text{O}_3$	$\text{Al}_2\text{O}_3$	$\text{MgO}$	$\text{CuO}$	$\text{ZnO}$
Mass fraction	67.59	4.02	10.88	4.57	1.18	0.23	0.11



**FIGURE 1** | X-ray diffraction pattern analysis of iron tailings powder.

Water quenched slag powder is an important mineral admixture for concrete. S95 slag powder produced by a factory in Hebei Province is adopted in the test. The basic performance indexes are shown in **Table 1**.

The coarse aggregate and fine aggregate used are in line with the national standard. In coarse aggregate, the particle size of large stone is 10–20 mm and that of small stone is 5–10 mm. The mass ratio of large stone and small stone is 8:2. The fine aggregate used in the test belongs to the medium sand of II area. It meets the grade I aggregate requirements of JG/T568-2019 “High performance concrete aggregate”. See **Table 4** for specific indicators.

Ordinary tap water is used to meet the requirements of mixing water. Polycarboxylate superplasticizer is used as a superplasticizer, and the solid content is about 20%.

## Mix Proportion

This article designs C30 and C50, two kinds of commonly used concrete. Due to environmental protection, concrete cementitious materials introduce solid waste, so the cement

content should not be high. A low cement system is used in this experiment, and cement only accounts for 30 and 40% of the whole cementitious material system, respectively. After the preliminary test, the iron tailings powder belongs to an inactive admixture, so the water-binder is lower than that of concrete with common mineral admixtures. The water-binder ratio of C30 concrete is 0.40 and that of C50 concrete is 0.29. The composite admixture of iron tailings powder and slag powder is adopted, and the proportion of iron tailings powder in the composite admixture is 0, 30, 50, 70, and 100%, respectively. The influence of different proportion of iron tailings powder on the mechanical properties of concrete is studied. With the increase of iron tailings powder content, the water-binder ratio of concrete decreases to ensure that the strength can meet the requirements. Specific coordination is shown in **Table 5**.

In order to verify the relationship model between phase compressive strength and age of iron tailings micro-powder concrete, the verification group of concrete was prepared. The content of reference cement in C30 and C50 concrete accounted for 40 and 50% of the total cementing material, respectively, and the mixing ratio was shown in **Table 6**.

## RESULTS AND DISCUSSION

### Influence of Iron Tailings Powder on Concrete Performance

C30 and C50 concrete with different iron tailings powder contents were prepared according to the mix ratio, and the slump and dilatancy of each group of concrete at the time of discharge and 1 h after discharge were tested, respectively. The specific data are shown in **Table 7**.

The slump and expansion of C30 and C50 concrete mixed with iron tailings powder are greater than that of concrete mixed with slag powder alone. With the increase of iron tailings powder content, the slump and expansion of concrete first increase and then decrease. When iron tailings powder accounts for 70% of mineral admixtures (iron tailings powder and slag powder), the slump and expansion of concrete are the largest, with C30

**TABLE 3** | Property indexes of reference cement.

Compressive strength/MPa		Flexural strength/MPa		Setting time/min		Specific surface area/m <sup>2</sup> ·kg <sup>-1</sup>	Fineness/mm	Water requirement of normal consistency/%	Stability
3d	28d	3d	28d	Initial	Final				
28.3	53.2	5.5	10.3	155	215	347	0.5	27.2	Qualified

**TABLE 4** | Technical indexes of coarse and aggregate.

	Fineness modulus	Apparent density/kg·m <sup>-3</sup>	Bulk density/kg·m <sup>-3</sup>	Porosity/%	Mud content/%	Crushing index/%	Needle and flake content/%
Coarse	-	2,743	1,569	42.8	1.0	5.2	5.5
Fine	2.7	2,595	1,534	39.0	1.6	-	-

**TABLE 5** | Mix proportion of iron tailings powder concrete ( $\text{kg}\cdot\text{m}^{-3}$ ).

		Cement	Iron tailings powder	Slag powder	Sand	Stone	Water	W/B	PC
C30	A0	113	0	264	840	1,018	151	0.40	3.4
	A30	113	79	185	840	1,018	147	0.39	3.4
	A50	113	132	132	840	1,018	143	0.38	3.4
	A70	113	185	79	840	1,018	140	0.37	3.4
	A100	113	264	0	840	1,018	136	0.36	3.4
C50	B0	191	0	287	725	1,071	139	0.29	6.7
	B30	191	86	201	725	1,071	134	0.28	6.7
	B50	191	144	144	725	1,071	129	0.27	6.7
	B70	191	201	86	725	1,071	124	0.26	6.7
	B100	191	287	0	725	1,071	119	0.25	6.7

W/B: Water–binder ratio, mass ratio of water to cementitious material.

**TABLE 6** | Mix proportion of verification concrete ( $\text{kg}\cdot\text{m}^{-3}$ ).

		Cement	Iron tailings powder	Slag powder	Sand	Stone	Water	W/B	PC
C30	E0	151	0	226	840	1,018	151	0.40	3.4
	E30	151	68	158	840	1,018	147	0.39	3.4
	E50	151	113	113	840	1,018	143	0.38	3.4
	E70	151	158	68	840	1,018	140	0.37	3.4
	E100	151	226	0	840	1,018	136	0.36	3.4
C50	F0	239	0	239	725	1,071	139	0.29	6.7
	F30	239	72	167	725	1,071	134	0.28	6.7
	F50	239	120	120	725	1,071	129	0.27	6.7
	F70	239	167	72	725	1,071	124	0.26	6.7
	F100	239	239	0	725	1,071	119	0.25	6.7

W/B: Water–binder ratio, mass ratio of water to cementitious material.

**TABLE 7** | Slump and dispersion of concrete (mm).

Group	Slump		Dispersion		Group	Slump		Dispersion	
	Initial	After 1 h	Initial	After 1 h		Initial	After 1 h	Initial	After 1 h
A0	215	155	450	300	B0	200	160	445	375
A30	220	170	500	390	B30	210	170	525	405
A50	230	180	515	420	B50	225	185	550	440
A70	230	190	525	450	B70	230	200	550	470
A100	225	170	510	410	B100	215	180	510	435

concrete reaching 230 and 525 mm, and C50 concrete reaching 230 and 550 mm.

The slump and expansion of C30 and C50 concrete decreased in different degrees after 1 h out of the mixer. The slump and expansion of C50 concrete are higher than that of C30 concrete after 1 h. This is due to the low water–binder ratio and high viscosity of C50 concrete. With the passage of time, the concrete has a good water retention performance, while the water–binder ratio of C30 concrete is larger, and there is more free water in the concrete. The concrete will lose water with time, and even the phenomenon of mortar bone separation appears. Therefore, the working performance of C30 concrete is not as good as that of C50 concrete after 1 h. The slump loss rate and expansion loss

rate of concrete with slag powder are the largest, and the loss rate of C30 concrete can reach 27.9 and 20.0%, respectively. The addition of iron tailing powder can effectively reduce the loss rate of slump and expansion of concrete after 1 h. When iron tailing powder accounts for 70% of mineral admixtures, the loss rate of slump and expansion is the lowest. Taking C30 as an example, it is 17.4 and 13.0%, respectively, which is 10.5 and 7.0% lower than that of concrete with slag powder alone.

In conclusion, the appropriate addition of iron tailings powder can effectively improve the particle size distribution of cement slag powder cementitious material system and make the particle distribution more uniform, thus increasing the workability of concrete. At the same time, it reduces the time loss of concrete

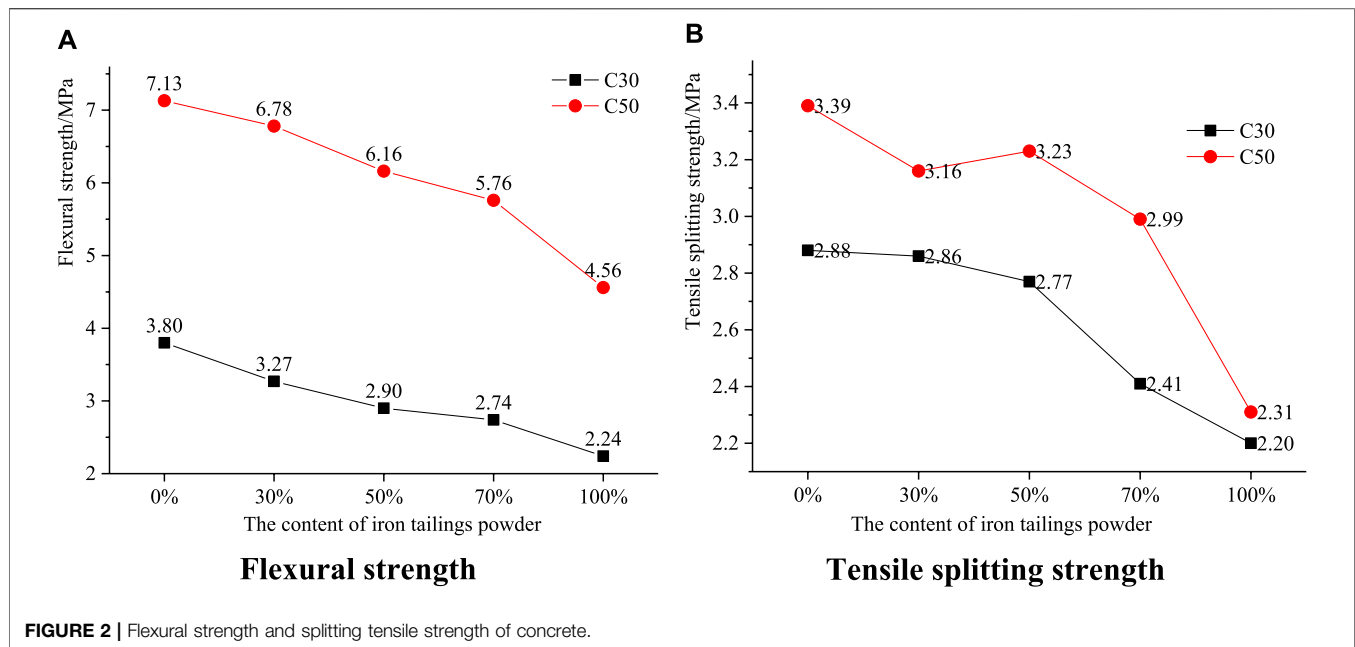


FIGURE 2 | Flexural strength and splitting tensile strength of concrete.

slump and expansion, has good working performance, and ensures the smooth pumping and construction of concrete.

### Flexural Strength and Splitting Tensile Strength of Concrete

The flexural strength and splitting tensile strength of concrete after standard curing for 28d were respectively tested, and the results are shown in Figure 2.

The results show that the flexural strength and splitting tensile strength of concrete decrease with the increase of iron tailings powder content. The flexural strength and splitting tensile strength of A0 and B0 concrete with slag powder are the largest, which are 3.80, 7.13, 2.88, and 3.39 MPa, respectively. The A100 and B100 concrete with iron tailings powder is not suitable for single mixing. The bending strength and splitting tensile strength of A100 and B100 concrete with iron tailings powder is low, which is only 58–76% of that of concrete with single slag powder. When the ratio of iron tailings powder and slag powder is not more than 5:5, the flexural strength and splitting tensile strength of concrete are similar to those of concrete with slag powder alone. For example, when the proportion of iron tailings powder in a mineral admixture is 30%, the splitting tensile strength of C30 and C50 concrete is only 0.69 and 6.7% lower than that of concrete with single slag powder. In low-strength concrete (C30), the effect of iron tailings powder on flexural strength is greater, and the splitting tensile strength is less. In high-strength concrete (C50), the adverse effect of iron tailings powder on flexural strength is less than that of low-strength concrete, and the adverse effect on splitting tensile strength is greater than that of low-strength concrete. On the whole, the effect of iron tailings powder on the flexural strength of concrete is much greater than that on the tensile strength of concrete.

### Long-Term Compressive Strength Law of Concrete

In order to explore the influence law of iron tailings powder on the long-term compressive strength of concrete, the 3, 7, 28, 90, 180, 270, 360, 540, 720, and 1080d compressive strength of C30 and C50 concrete were tested, respectively. The development law of concrete strength with age is shown in Table 8.

The results show that the strength of C30 and C50 concrete decreases with the increase of the iron tailings powder content. Iron tailings powder is a kind of non-active admixture, a very small amount of which can participate in the hydration reaction and produce less hydration products. Slag powder is a kind of mineral admixture with higher activity, which has a faster hydration reaction and can produce more hydration products, so it has higher strength. When the ratio of iron tailings powder to mineral admixtures (slag powder and iron tailings powder) is less than 50%, the compressive strength of concrete with different ages has little difference from that with single slag powder. The maximum reduction of compressive strength of C30 and C50 concrete at 28d was only 2.0 and 10.2% compared with that of the concrete with slag powder. When the proportion of iron tailings powder in a mineral admixture is more than 50%, the compressive strength of concrete at different ages decreases greatly compared with concrete mixed with slag powder alone. The maximum reduction ranges of 28d compressive strength are 19.4 and 33.8% compared with that of slag powder concrete. The content of iron tailing powder in concrete should not exceed 50% of the whole mineral admixture.

The influence of iron tailings powder on the strength of high-strength concrete (C50) is greater than that of low-strength concrete (C30). The reason is that high-strength concrete needs more cementitious materials, and the water–binder ratio is also relatively low. Although the addition of non-active

**TABLE 8** | Compressive strength of iron tailings powder concrete (MPa).

Group	Iron tailing powder content/%	3d	7d	28d	90d	180d	360d	540d	720d	1080d
A0	0	14.4	28.7	35.5	45.5	46.3	47.2	48.1	50.5	52.1
A30	30	11.3	26.8	36.3	43.8	45.1	47.8	48.6	49.2	50.5
A50	50	9.6	23.9	34.8	42.9	43.6	44.1	45.5	48.1	50.3
A70	70	6.9	19.1	32.9	34.2	34.7	38.6	40.2	42.1	43.5
A100	100	4.2	17.4	28.6	30.4	31	35.5	35.9	36.4	37.3
B0	0	24.9	50.2	71.4	75.1	78.3	85.6	88.2	90.5	91.1
B30	30	22.1	48.7	64.4	77.0	79.3	82.5	83.4	85.6	88.2
B50	50	19.8	44.9	64.1	71.5	72.2	78.4	79.1	79.9	80.7
B70	70	15.7	34.5	53.8	58.4	60.6	62.8	66.6	67	67.5
B100	100	8.1	29.9	47.3	50.2	53.3	53.8	53.5	55.2	56.1

The content of iron tailing powder is the mass percentage of iron tailing powder in mineral admixture.

**TABLE 9** | Relative compressive strength of iron tailing powder concrete.

Group	Iron tailing powder content/%	3d	7d	28d	90d	180d	360d	540d	720d	1080d
A0	0	0.41	0.81	1.00	1.28	1.30	1.33	1.35	1.42	1.47
A30	30	0.31	0.74	1.00	1.21	1.24	1.32	1.34	1.36	1.39
A50	50	0.28	0.69	1.00	1.23	1.25	1.27	1.31	1.38	1.45
A70	70	0.21	0.58	1.00	1.04	1.05	1.17	1.22	1.28	1.32
A100	100	0.15	0.61	1.00	1.06	1.08	1.24	1.26	1.27	1.30
B0	0	0.35	0.70	1.00	1.05	1.10	1.20	1.24	1.27	1.28
B30	30	0.34	0.76	1.00	1.20	1.23	1.28	1.30	1.33	1.37
B50	50	0.31	0.70	1.00	1.12	1.13	1.22	1.23	1.25	1.26
B70	70	0.29	0.64	1.00	1.09	1.13	1.17	1.24	1.25	1.25
B100	100	0.17	0.63	1.00	1.06	1.13	1.14	1.13	1.17	1.19

The content of iron tailing powder is the mass percentage of iron tailing powder in mineral admixture.

admixtures can change the particle size distribution of cementitious materials to a certain extent, and the microaggregate effect can improve the performance of concrete, its effect is not as good as the hydration reaction of active admixtures. Therefore, the adverse effect of iron tailings powder on the strength of low-strength concrete is small, and the adverse effect of iron tailings powder on the strength of high-strength concrete is obvious. Therefore, in the design mix proportion of high-strength concrete, the amount of iron tailings powder should be reduced appropriately under the low clinker system. For example, when the proportion of iron tailings powder to a mineral admixture is 30%, the compressive strength of group B30 concrete is equivalent to that of group B0 concrete, even if at some age exceeds the strength of group B0. At the same time, the compressive strength of concrete can not only be based on the 28d compressive strength as the standard system in the case of introducing the non-active admixture iron tailings powder. The curing age should be extended so that the non-active admixture can give full play to its effect. For example, when the age reaches 90 days, the strength of concrete with iron tailings powder accounting for less than 50% of the mineral admixture is very close to that of concrete with slag powder alone; it is more

suitable to evaluate the mechanical properties of concrete with inactive admixtures by the strength of longer age.

## Relative Compressive Strength and the Age Prediction Model

The 28d strength of concrete in each group was taken as the reference value 1, and the strength of other ages was divided by the 28d compressive strength to calculate the relative compressive strength of concrete at different ages, as shown in **Table 9**.

The addition of iron tailings powder is not conducive to the early strength of concrete, but the appropriate addition of iron tailings powder (30%) is conducive to the growth of long-term strength of concrete. From the point of view of long age, after 360 days, the strength development law of concrete with appropriate amount of iron tailings powder is similar to that of concrete with slag powder only. Taking 1080d strength as an example, the compressive strength of A50 group increased by 45% compared with 28d compressive strength.

In order to study the relationship between compressive strength and age, the development model of compressive strength and age was established, which can provide

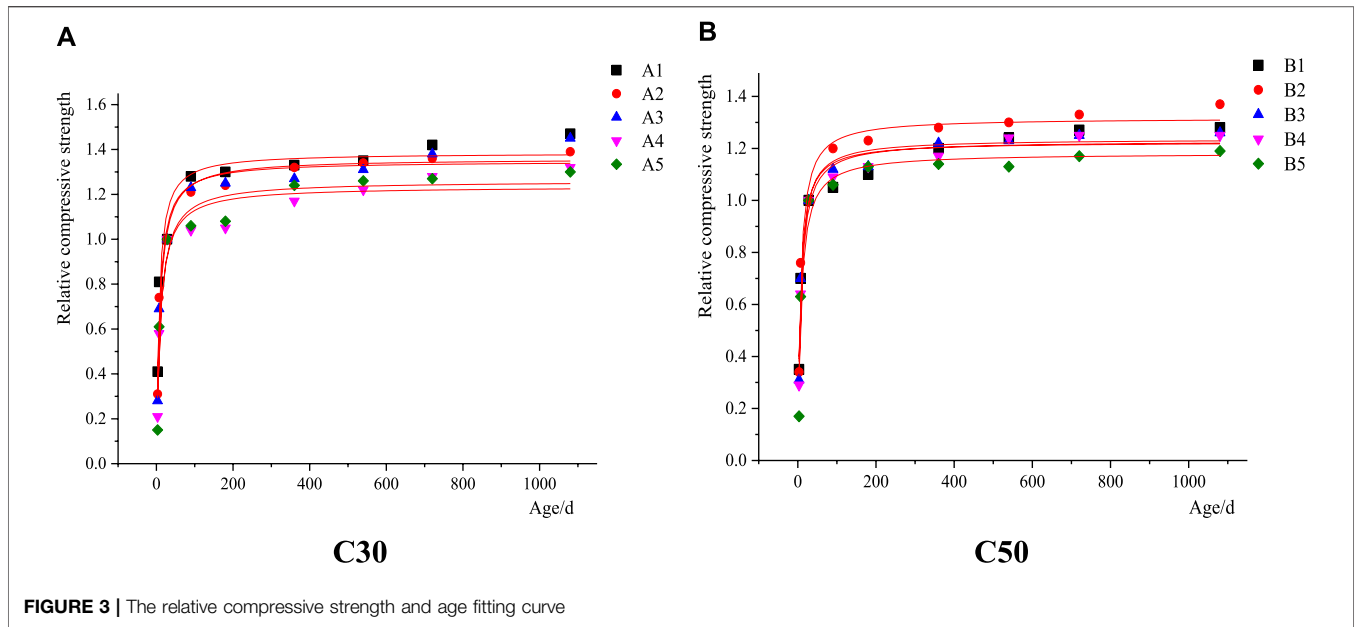


FIGURE 3 | The relative compressive strength and age fitting curve

TABLE 10 | Relative compressive strength and age fitting parameters.

Group	Content of iron tailings powder/%	A	B	C	Correlation coefficient R <sup>2</sup>
A0	0	1.26	5.54	0.911	0.948
A30	30	1.19	6.37	0.879	0.969
A50	50	1.22	7.42	0.898	0.964
A70	70	0.878	6.22	0.711	0.934
A100	100	0.729	5.28	0.579	0.937
B0	0	1.11	5.33	0.906	0.950
B30	30	1.15	5.51	0.871	0.967
B50	50	1.02	5.10	0.826	0.973
B70	70	0.932	5.21	0.758	0.977
B100	100	1.01	6.30	0.852	0.945

The content of iron tailing powder is the mass percentage of iron tailing powder in mineral admixtures, and the coefficients retain three significant figures.

theoretical basis for the prediction of long-term compressive strength of iron tailings powder concrete. By using the software to fit the curve of compressive strength and age of C30 and C50 concrete with different iron tailings powder contents, it is found that the regularity of single compressive strength and age is not strong, but the better regularity is found by using the relative compressive strength and age fitting of each age to 28d strength. The fitting curve is shown in Figure 3.

In order to more accurately determine the relationship between reaction intensity and age, three parameter equation is chosen as the fitting formula, and the fitting reliability is high. The formula is as follows:

$$f_t = At \ln \left( 1 + \frac{1}{B + Ct} \right)$$

In the formula, the fitting parameters of different concrete groups are shown in Table 10.

TABLE 11 | Model calculation value and the real value of concrete compressive strength (MPa).

Group		28d	90d	180d	360d	540d	720d	1080d
E0	Real	45.3	56.7	59.2	60.1	61.0	61.8	62.5
	Calculated	-	58.3	60.4	61.5	61.9	62.1	62.3
E30	Real	43.3	53.6	56.5	57.3	58.2	58.5	58.7
	Calculated	-	53.9	56.2	57.4	57.8	58.0	58.2
E50	Real	40.9	49.8	53.5	54.3	54.8	55.1	55.5
	Calculated	-	50.6	53.0	54.2	54.7	54.9	55.1
E70	Real	36.0	41.6	42.9	43.5	43.8	44.0	44.4
	Calculated	-	40.2	42.2	43.3	43.7	43.9	44.1
E100	Real	30.5	34.2	36.9	37.5	37.8	38.2	38.2
	Calculated	-	34.6	36.4	37.4	37.7	37.9	38.0
F0	Real	65.4	79.5	87.1	88.4	89.6	91.1	91.5
	Calculated	-	74.8	77.4	78.7	79.2	79.4	79.7
F30	Real	69.7	83.1	88.5	90.1	90.5	90.8	91.3
	Calculated	-	85.5	88.6	90.3	90.9	91.2	91.4
F50	Real	63.4	73.2	75.5	76.7	77.5	78.1	78.5
	Calculated	-	72.8	75.4	76.8	77.3	77.6	77.8
F70	Real	58.3	65.8	67.8	69.4	70.3	70.8	71.5
	Calculated	-	66.1	68.8	70.2	70.7	70.9	71.2
F100	Real	52.4	56.8	58.9	60.1	60.8	61.1	61.3
	Calculated	-	57.1	59.5	60.8	61.2	61.4	61.7

It can be seen from Table 10 that the range of parameters A, B, and C in the model of relative compressive strength and age relationship of iron tailings powder concrete is relatively concentrated, and the fitting correlation coefficient is also very high, all above 0.930, with a strong correlation, indicating that the model selection is more appropriate. Parameter A is related to the content of iron tailings powder. Parameter A increases with the increase of iron tailings powder contents. The A value of C30 concrete is between 0.7 and 1.3. The A value of group A5 with iron tailings powder is smaller and the dispersion is larger than that of the other four groups. The A value of C50 concrete is

**TABLE 12** | Error rate of model calculation value and experiment measured value (%).

Group	Content of iron tailings powder/%	90d	180d	360d	540d	720d	1080d
E0	0	2.82	2.03	2.33	1.48	0.49	0.32
E30	30	0.56	0.53	0.17	0.69	0.85	0.85
E50	50	1.61	0.93	0.18	0.18	0.36	0.72
E70	70	3.37	1.63	0.46	0.23	0.23	0.68
E100	100	1.17	1.36	0.27	0.26	0.79	0.52
F0	0	5.91	11.1	10.9	11.6	12.8	12.9
F30	30	2.89	0.11	0.22	0.44	0.44	0.11
F50	50	0.55	0.13	0.13	0.26	0.64	0.89
F70	70	0.46	1.47	1.15	0.57	0.14	0.42
F100	100	0.53	1.02	1.16	0.66	0.49	0.65

relatively concentrated, ranging from 0.9 to 1.2. It shows that the influence factor (parameter a) of non-active admixtures on the strength of iron tailings under the condition of low water–binder ratio is much smaller than that under the condition of high water binder ratio. The range of B value and C value in the model is relatively concentrated, except for the points with large individual dispersion, B value ranges from 5.10 to 6.30, and C value ranges from 0.711 to 0.911.

To verify the correctness of the prediction model, 30% of the original C30 concrete cement is increased to 40%, the original C50 concrete 40% cement content is increased to 50%, and the concrete is prepared according to the mix proportion shown in **Table 9**. Based on the measured value of 28d compressive strength, the compressive strength of different age is calculated according to the model, and compared with the measured value of the same age. The results are shown in **Table 11**.

In order to intuitively show the reliability of the relative compressive strength and age model, based on the experiment data of each age, the difference between the calculated value of the model and the real value is divided by the real value, and the error rate of strength predicted model is calculated, as shown in **Table 12**.

It can be seen from the above table that the prediction error of the relative compressive strength and age prediction model for E0 and F0 groups with single slag powder is relatively large, which indicates that the prediction effect of the concrete without iron tailings powder is general. However, the model has a good prediction effect on the strength of concrete mixed with iron tailings, and the prediction error of different proportion of iron tailings is relatively small. When the age is over 90 days, the error between the predicted value and the measured value is very small, and the error rate is basically within 1%. It shows that the model can effectively predict the long-term service strength of concrete based on the 28 days compressive strength, and the model has a

good prediction effect on the long-term service performance of concrete.

This study has found out the influence of iron tailings powder and slag powder on the workability and long-term mechanical properties of concrete. The appropriate proportion of tailings powder and slag powder can increase the workability of concrete and contribute to the long-term strength. In the future research, we should pay attention to the long-term hydration mechanism of iron tailings powder and explore the hydration process of composite admixtures.

## CONCLUSION

- 1) Appropriate addition of iron tailings powder is beneficial to the working performance of concrete and can effectively reduce the time loss of concrete fluidity.
- 2) When the content of iron tailings powder in the compound admixture is 50% or less, the mechanical properties of concrete are equivalent to that of the single slag powder concrete. The long-term strength of 1080d in C30 and C50 concrete can reach 50.3 and 80.7 MPa.
- 3) Based on the 28d compressive strength, the relative strength and age prediction model of iron tailings powder concrete is established. The calculation and experimental results show that the model can accurately predict the long-term compressive strength, and the error rate is less than 1%.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## AUTHOR CONTRIBUTIONS

LJ and WR conceived and designed the experiments; WR, CL, ZG, and ZY performed the experiments; SY contributed materials; WR and LJ wrote the article. All authors read and approved the manuscript.

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The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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