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Test research on the effects of mechanochemically activated iron tailings on the compressive strength of concrete ☆

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HIGHLIGHTS

- High-silicon iron tailings were mechanochemically activated.
- Activated tailings were taken as a supplementary cementing material in concrete.
- The compressive strength of concrete may be as required at some mix proportions.
- The maximum cement substitution rate is 30% in common concrete.
- With a proper admixture, the cement substitution rate can be up to 40%.

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ABSTRACT

High-silicon iron tailings, which have been mechanochemically activated, was used for the preparation of concrete as a supplementary cementing material to substitute cement (by 10%, 20%, 30% and 40% respectively) based on their composition, particle sizes and pozzolanic activity. With the aid of tests, this paper discusses the effects of the tailings on the compressive strength of concrete. Tests show that with an increase in substitution rate of cement in the tailings, the compressive strength of concrete tends to decrease, and when the substitution rate is at 10%, 20% and 30% respectively, the compressive strength of concrete is measured up to the design requirement; if an appropriate amount of water reducing admixture is added while cement is substituted by tailings with a substitution rate of 10%, 20%, 30% and 40% respectively, the compressive strength of concrete is also measured up to the design requirement. The research result demonstrates that as far as the compressive strength concerned, it is feasible to use mechanochemically activated high-silicon iron tailings as a supplementary cementing material to partly substitute cement in concrete.

China is a country rich in mineral resources, and as one of important industrial solid wastes in China, a large amount of tailings are being discharged and deposited. At present, tailings are usually stored within tailings dams, which not only encroaches large amounts of land, causes environmental pollution, but also need large amounts of investment in their management each year, therefore, tailings have already been a heavy burden for mining enterprises. So, how to utilize tailings efficiently is of great significance to the sustainable development of the mining industry. So far, the comprehensive utilization of tailings involves four major aspects: first, reconcentration of tailings, that is, recycling valuable metals or minerals in tailings; second, used as a filler to backfill mined-out areas; third, used in building materials as a raw material; fourth, reclaiming farmland on the tailings dumping ground to plant trees or crops [1].

Tailings are of low-value raw material, so no economic benefit will be presented unless they are used on a large scale [2]. One of efficient approaches is to use them for building materials production [3], and much progress has been made over the years in this field [3–17]. For some types of tailings are rich in silicon, some researchers proposed to use them to prepare cementing materials [18–29]. However, to achieve this purpose, tailings are required to have a certain pozzolanic activity, while in practice, tailings usually have a lower activity, so activating tailings has become the focus of some researches. In literatures [18–20], the potential chemical reactivity of tailings is activated through high temperature

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calcination and rapid cooling; in literatures [21–26], tailings are mixed and ground together with cement clinker, gypsum and other gradients, so that tailings are activated and made into a new cementing material; in literature [28], a combination of high temperature and fine grinding is used to activate tailings; in literature [29], a combination of high temperature and chemical activator is used to activate tailings.

Compared with other types of industrial solid wastes with higher pozzolanic activity, such as fly ash, granulated blast-furnace slag powder and silica fume, etc., tailings, even though rich in silicon, cannot be available as supplementary cementing material for concrete, mainly because of its lower activity. In this research, mechanochemical method, an effective way to activate solid substance, was used to process silicon-rich iron tailings to decrease their particle sizes and raise their activity to a certain level. Literature research reveals that fewer studies published have focused on this area so far.

In consideration of the compositions of this type of tailings, and their particle sizes and chemical activity when they are activated, it is quite possible to use activated tailings as a supplementary cementing material for concrete preparation. This paper relates to the effects of mechanochemical activated iron tailings on the compressive strength of concrete. As we all know, concrete is one of building materials that are consumed largely in civil works, so it will be beneficial for the utilization of tailings as a resource if tailings can be used in concrete as an ingredient.

1. Mechanochemical activation of the tailings

Sampled from a mining enterprise in Liaoning province, China, the tailings present a particle shape as shown in Fig. 1, and the chemical component of the sample is as shown in Table 1, its XRD diffraction pattern as shown in Fig. 2, and its particle size distribution as shown in Fig. 3. As can be seen from Fig. 1, the tailings particles present smooth surface, just like irregular or angular gravels (Fig. 1). The chemical analysis shows (Table 1) that the main chemical composition of the sample is SiO_2, with an average mass fraction as high as 75.23%, and according to literature [30], the tailings are of high-silicon iron tailings; the phase analysis shows (Fig. 2) that the main mineral composition of the sample is quartz, followed by hematite. The particle size analysis shows that the particle size distribution of the tailings ranges from tens of microns to hundreds of microns (as shown in Fig. 3), with a medium value (d_{50}) of 124.727 μm and a specific surface area of 138 m^2/kg.

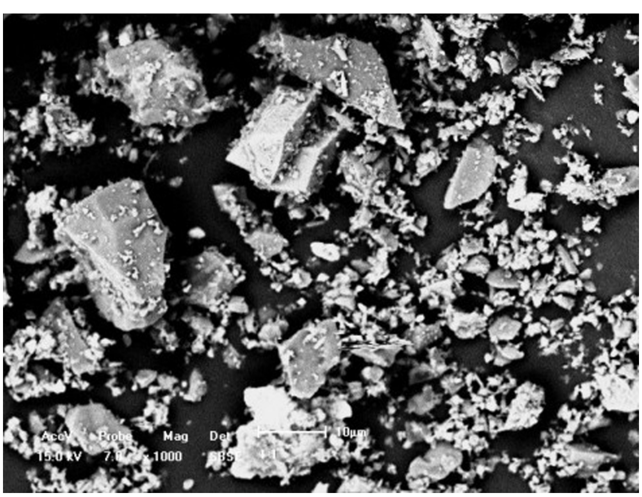

Fig. 1. Particle shape of the tailings (SEM1000×).

A mechanical force can change solid particles physically and chemically, of which their particle sizes may decrease, specific surface area may increase, and the internal structure and physical or chemical properties may change as well [31]. In this course, solid substance is often activated under the action of mechanical forces (such as grinding, impact force and pressure). According to literature [32], when there is no change in chemical compositions or structure, such an activation is called mechanical activation; when there is a change in chemical compositions or structure, such an activation is called mechanochemical activation.

In this research, grinding was adopted as the main means of mechanochemical activation to process the sampled high-silicon iron tailings. The grinding equipment, SYM-Cement Test Ball Mill, is manufactured by Shenyang Jinxin Detection Instrument CO., LTD, which has a cylinder size of φ500 × 500, a capacity of 5 kg and a rotating speed of 48 r/min, with steel balls and steel forging as grinding media.

When the grinding time is within 3.5 h, d_{50} decreases and specific surface area increases gradually over time; when the grinding time reaches 3.5 h, d_{50} is 9.429 μm and specific surface area is 2030 m^2/kg, and the particle size distribution is as shown in Fig. 4. Comparing Fig. 4 with Fig. 3, tailings particles below 10 μm make up an even higher proportion after grinding. As the grinding time reaches 4 h, d_{50} is 21.374 μm and specific surface area is 1400 m^2/kg, and d_{50} begins to rise and specific surface area begins to fall [33], which is because a particle aggregation happens as a result of an increase in surface energy of fine particles when tailings particles are ground to a certain degree. Fig. 5 shows that after grinding, the diffraction peak intensity of SiO_2 in the tailings declines somewhat, and the decline degree increases over time, which manifests that with the proceeding of mechanical grinding, the crystallinity of SiO_2 declines gradually.

Activity tests [34] show that the compressive strength (28d) ratio of cement-tailings mortar (when 30% of cement is substituted by tailings) is 88.9%, and the pozzolanic activity of the tailings is tested to be qualified. However, before grinding, the compressive strength (28d) ratio is 60.1% and the pozzolanic activity is tested not to be qualified. The activity tests were conducted by reference to *Test Method for Activity of Industrial Waste Slag Used as Addition to Cement* (National standard of the People's Republic of China, GB/T 12957-2005) and *Pozzolanic Materials Used for Cement Production* (National standard of the People's Republic of China, GB/T2847-2005). It follows that mechanochemical activation can improve the activity of tailings significantly.

Table 1
Chemical compositions of tailings, wt%.

	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	SO_3	Na_2O	TiO_2
1	75.11	11.26	2.78	2.08	1.42	0.42	0.078	0.49	0.06
2	75.31	11.40	2.53	2.12	1.48	0.39	0.079	0.46	0.04
3	75.26	11.28	2.61	2.09	1.50	0.40	0.075	0.51	0.07
Average	75.23	11.31	2.64	2.10	1.47	0.40	0.08	0.49	0.06