Study on the effect of iron tailings manufactured sand powder content on cement Hydration

Guo Jun-hua¹, Li Gong-zhou², Gao Chun-yong¹

¹ China Building Materials Academy, No.1 Guan Zhuang Dong Li, Chaoyang District, Beijing, China;
² Beijing China Coal Mine Engineering Co., Ltd, No.5 Qing Nian Gou Road, Heping Li, Chaoyang District, Beijing, China

Abstract. In this paper, the effects of different stone powder content (5%, 10%, 15%, 20%, 25%) of iron tailings manufactured sand on the work ability and mechanical properties of cement were studied. The results show that the strength of hardened paste can be improved by adding appropriate amount of stone powder. When the content of stone powder is 5%, the compressive strength reached 34.4MPa. The results of XRD show that the hydration products of cementitious materials mixed with stone powder are mainly ettringite, Ca(OH)₂, hydrocalcium, calcium silicate hydrate and quartz. The results of SEM show that proper amount of stone powder can effectively improve the porosity of composite cementitious materials, but the content of stone powder increases, the bond between stone powder and hydration products is not close enough, and the paste structure becomes loose.

1. Introduction
Concrete is the most widely used constituent material in modern society, and sand is one of the components of concrete aggregate, natural sand can no longer meet the production needs of concrete enterprises. At the same time, a large number of waste tailings have been produced in our mineral resources, resulting in a great pressure of environmental pollution. In view of this situation, it is of great practical significance to study the feasibility of tailings recycling. The effect of stone powder on the performance of manufactured sand concrete is the core content of the research. Zhang Lihua [1] studied the effect of different stone powder content on the workability and mechanical properties of low grade strength concrete. The results show that for C30 concrete, the content of stone powder should not exceed 15%, and when the content of stone powder is about 5%, the workability and mechanical properties of concrete reach the optimum value. Chen Xiaoshuan [2] studied the influence of the stone powder content on the workability properties of concrete. The results show that the content of stone powder of low strength concrete should be controlled at 10%~15%, and the content of stone powder of high strength concrete should not exceed 7%~10%. Hudson [3] studied that the stone powder in the manufactured sand can improve the effective accumulation of aggregate, prevent the formation of capillary pores in the hydration process of cement, and thus improve the impermeability of concrete. V.Bonavetti [4-6] studied that the stone powder does not have pozzolanic effect, it reacts with aluminum phase to form hydrated single carbon calcium aluminate to form AFm.

The above studies are all the effects of the content of calcium carbonate stone powder on the workability and mechanical properties of concrete. In this paper, the influence of stone powder content
in iron tailings manufactured sand on the workability and mechanical properties of cement and the hydration products of cement are discussed.

2. Experimental details
Cement: 42.5 grade ordinary Portland cement of Shandong Luchen cement. The physical and mechanical properties are shown in Table 1; Stone powder: iron tailings manufactured sand with a particle size of less than 75 μm. The microstructure of the stone powder is shown in Fig.1. It can be seen from Fig.1 that the main minerals in iron tailings are quartz, hematite, and a small amount of plagioclase and amphibole. According to chemical composition analysis, most of them belong to high silicon and low sulfur containing a small amount of iron phase, and more than 70% of SiO$_2$ are mainly in the form of inactive silicon quartz. Sand: iron tailings manufactured sand with fineness modulus 2.8.

| Cement type | Standard consistency water consumption (%) | Density (g/cm$^3$) | Specific area (m$^2$/kg) | Setting time (min) | Compressive strength (MPa) | Flexural strength (MPa) |
|-------------|-------------------------------------------|-------------------|---------------------------|-------------------|---------------------------|------------------------|
| P.O 42.5    | 28                                        | 3.08              | 365                       | 170               | 25.9                      | 5.1                    |
|             |                                           |                   |                           | 225               | 48.6                      | 8.5                    |

Table 1. Physical properties of cement

![SEM](image1.png)

(a) SEM
![XRD](image2.png)

(b) XRD

Figure 1. SEM and XRD of the stone powder in iron tailings manufactured sand

3. Test results and discussion

3.1 Effect of the stone powder content on the standard consistency water consumption of cement
Fig.2 shows the effect of different stone powder content of iron tailings manufactured sand on the standard consistency water consumption of cement. As can be seen from figure 2, the standard consistency water consumption of the cement is 25.6%. When the content of stone powder is 5%, the standard consistency water consumption of cement reaches the maximum 27.3%. The main reason is that the cement is replaced by the same content of stone powder, the specific surface area is increased, and the standard consistency water consumption of cement is increased. However, when the content of stone powder increases from 5% to 25%, the standard consistency water consumption of cement decreases 1.0%, because the overall specific surface area decrease is the dominant factor, the standard consistency water consumption of cement decreases.
3.2 Effect of the Stone Powder content on the standard consistency water consumption of cement

Fig. 2 shows the effect of different stone powder content on the standard consistency water consumption of cement. As can be seen from figure 2, the standard consistency water consumption is higher when the stone powder content is lower. This is because the stone powder can absorb water, thus reducing the water consumption.

3.3 Effect of the Stone Powder content on the setting time of cement

Fig. 3 shows the effect of different stone powder content on the setting time of cement. As can be seen from figure 3, the initial setting time and final setting time of cement are 152 min and 225 min. When the stone powder content is less than 25%, the initial setting time of cement gradually advances with the increase of the content of stone powder. The main reason is that the induction period of hydration is shortened with the increase of the content of stone powder. Increasing the content of stone powder can increase the concentration of calcium ion in the solution and shorten the time to reach the critical value. When the content of stone powder is more than 10%, the final setting time is gradually delayed with the increase of the content of stone powder, due to the addition of a large amount of stone powder, the cement clinker is relatively reduced, and the setting time of the sample is prolonged under the same hydration degree. Therefore, a certain range of stone powder accelerated the hydration process.

3.4 Effect of the Stone Powder content on Mechanical Properties of cement

Fig. 4 shows the effect of different stone powder content on the compressive strength of cement. As can be seen from figure 4, when the age is 3 days, the compressive strength of cement is 26.2 MPa. When the stone powder content is 5%, the compressive strength is 34.42 MPa. When the content of stone powder increased from 5% to 20%, the compressive strength decreased 6.86%, but it is higher than that of blank group. When the content of stone powder is 25%, the compressive strength is 4.33% lower than that of the blank group. The main reason is that the filling effect of iron tailing powder in cementitious material system, the paste structure of cementitious material is denser, the pore structure is improved, and the strength of paste is improved. However, if the content of stone powder is too high, a large number of stone powder will produce agglomeration which is not conducive to the dispersion of water, resulting in insufficient hydration products and an increase in the proportion of large...
diameter pores produced by free water. Therefore, the addition of appropriate amount of stone powder can optimize the gradation of cementitious material particles, improve the pore size distribution, reduce the proportion of harmful holes in the sample of slurry, and improve the compactness of hardened paste. Thus improve the mechanical properties of cementitious materials.

Figure 4. Effect of the stone powder content on the compressive strength of cement

3.4 Effect of the stone powder content on hydration products of cement

The cement was replaced by 5%, 10%, 15%, 20% and 25% of the stone powder. The hydration products of the cement paste were analyzed after 3 days and 28 days. The cement samples with different content of stone powder were ground into powder for XRD analysis. Analysis of cement samples containing 15% and 20% stone powder by SEM. The test results of each sample were shown in Fig.5~Fig.6. As can be seen from figure 5, when the hydration age is 3 days, the hydration products of the cementitious materials are mainly Ca(OH)$_2$, ettringite, hydro calcium and calcium silicate hydrate, as well as some quartz characteristic peaks. These quartz characteristic peaks come from the stone powder, and with the increase of the amount of admixture, the quartz characteristic peak also becomes more and more obvious. In addition, the characteristic peaks of ettringite in 5% and 10% of stone powder are obvious, indicating that the content of ettringite is relatively high. As the amount of Ca(OH)$_2$ decreases, the amount of ettringite increases, indicating the chemical reaction in the continuous process:

$$6Ca^{2+}+2Al^{3+}+3SO_4^{2-}+12(OH)^-+26H_2O=3CaO·Al_2O_3·CaSO_4·32H_2O$$ \hspace{1cm} (1)

The Ca(OH)$_2$ and desulphurization gypsum in the system are consumed and the ettringite content is increasing. When the hydration age is 28 days, the hydration products of cementitious materials are mainly ettringite, calcium silicate hydrate and Hydro Calcium, and the characteristic peak of Ca(OH)$_2$ decreases, which indicates that Ca(OH)$_2$ is gradually consumed to form ettringite during hydration. The characteristics of hydration products are the same as those of 3 days. The more stone powder content is, the more obvious the characteristic peak of quartz is. The formation of ettringite is actually promoting the formation of C-S-H or hydrated silica-aluminum network, thus increasing the strength of the sample.

As can be seen from figure 6, there are many relatively large holes in the test block with 15% stone powder content, while those with 20% stone powder content are relatively small. Stone powder particles are closely linked to hydration products, forming a relatively dense structure. A large number of rod-shaped and needle-like crystals are alternately grown in a space, and the crystal and the C-S-H form a network framework structure. The filling of fine particles increases the compactness and is beneficial to the improvement the strength of hardened paste. However, the stone powder content is too large, which makes the combination of hydration products not close enough and the paste structure becomes loose.
4. Conclusions

(1) When the content of stone powder is less than 25%, the initial setting time of cement gradually advances with the increase of stone powder content, and the final setting time of cement gradually delays with the increase of stone powder content when the content of stone powder is more than 10%. Therefore, the hydration process can be accelerated when the content of stone powder is less than 10%.

(2) The strength of slurry can be improved by adding appropriate amount of stone powder. When the content of stone powder is 5%, the maximum compressive strength is 34.4MPa. When the content of stone powder is 25%, the compressive strength is 4.33% lower than that of blank group.

(3) The hydration products of cementitious materials mixed with stone powder are mainly composed of Ca(OH)₂, ettringite, hydro calcium, calcium silicate hydrate and quartz. Adding appropriate amount of stone powder can effectively improve the porosity of composite cementitious materials and reduce the proportion of macropores in pore size distribution, but the addition of stone powder is too large, which makes the combination of hydration products not close enough, and the paste structure becomes loose.

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