Performance analysis of steel slag powder-coal gangue grouting material

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Abstract. In this paper, coal gangue soil, steel slag powder and polycarboxylic acid superplasticizer with different dosages were combined into ordinary Portland cement. Grouting solution was prepared according to different water-cement ratios and solidified under standard conditions. Through orthogonal experiments, the influence of different dosages on the rate of grout stones and the compressive strength of stones in different ages was studied. The experimental results show that the increase in the amount of coal gangue will lead to the decrease of the slurry stone first and then increase, and the compressive strength will decrease. The increase in the amount of steel slag powder reduces the stone rate and compressive strength of the slurry.

1. Introduction
Steel slag is a solid waste produced during crude iron steelmaking. In recent years, China's crude steel output has approached 1 billion tons, and this process has also produced a large amount of steel slag \cite{1}. The chemical composition and mineral composition of steel slag are similar to Portland cement clinker. Grinding steel slag to stimulate its mineral activity and preparing steel slag mineral admixture to replace part of the cement is the main technical way to realize the high value-added application of steel slag \cite{2}. Coal gangue is the solid waste discharged in the coal mining process and coal washing process. As a solid waste, coal gangue has low nutrient content and contains more heavy metal elements \cite{3}. Because the price is low and the long-term stacking will cause serious damage to the surface structure and ecological environment, it is widely used as mining subsidence land filling material. Yang \cite{4} prepared ultra-fine steel slag powder with median particle size of 5.0 microns and 3.3 microns, respectively, and explored the influence of the particle size and content of ultra-fine steel slag powder on the rheological properties of cement paste. The results show that the blending of ultra-fine steel slag significantly reduces the fluidity of the ultra-fine steel slag-cement composite system. Zheng \cite{5} used steel slag to prepare mineral admixtures, and used steel slag powder instead of mineral powder to prepare C30 concrete, and studied the effect of steel slag powder on the mechanical properties, volume stability and durability of concrete. The results show that the incorporation of steel slag powder can reduce the total heat of hydration of the cementitious material system, but the saturation point of the admixture and the loss rate over time have a greater impact. Zhang \cite{6} mixed the ground coal gangue into concrete to prepare coal gangue foamed concrete. The study found that when the water-to-material ratio is 0.27, the volume density of the gangue foamed concrete decreases with the increase of the amount of coal gangue powder. Increase after small. The compressive strength of foamed concrete decreases with the increase of the water-to-batter ratio of the material and the amount of coal gangue. At present, there have been many researches on fly ash and coal gangue, and a lot of progress has been made, but there are few reports on...
the research on the preparation of cement-based grouting materials by mixing steel slag powder and coal gangue.
Therefore, by preparing composite grout of steel slag powder and coal gangue, and analyzing and comparing the stone rate and compressive strength of cement slurry at different ages, the mechanical properties of composite cement slurry are preliminarily demonstrated, which provides a theoretical basis for the further combined use of the two in the later stage.

2. Test materials and test methods

2.1. Experimental Materials
The steel slag powder used in the test was produced from Lijing Mineral Products Processing Plant in Lingshou County, Hebei Province, with a specific surface area of 400m²/kg. The coal gangue is taken from Yiran Mineral Processing Plant of Lingshou County, Hebei Province, in which the content of Al₂O₃ is 43.1%, the content of SiO₂ is 42% and the particle size is 150 mesh. PO 42.5 grade cement produced by Shandong Shanshui Cement Group Co., Ltd is used for ordinary Portland cement. The experimental water is laboratory tap water. The superplasticizer used polycarboxylic acid powder superplasticizer.

2.2. Experiment method
(1) Determination of stone rate. After the preparation and mixing of grouting materials is completed, the grout will solidify into a stone body with certain strength after setting time. Since the water in the slurry cannot be completely hydrated, the slurry will precipitate some water in the process of coagulation and hardening, so the stone body is often smaller than the volume of the slurry, and the ratio of the volume of the stone body to the volume of the original slurry is the stone rate. The calculation formula is \( \xi = \left( \frac{V_1}{V_2} \right) \times 100\% \), where \( V_1 \) and \( V_2 \) are the volume of stone and the volume of original slurry respectively.

(2) The compressive strength of stone body was determined according to "Test Method for Strength of Cement Mortar GB/T17671-1999". The condensed test block will be put into the standard curing box for 3d, 7d and 28d, using the TYB-2000B pressure testing machine, the ballast speed is not more than 1kN/s.

2.3. Test mix ratio design
Adopt the orthogonal test method, reduce the number of tests, and can analyze the influence of various factors on the performance of the slurry under the condition of mixing at the same time. Fly ash content, coal gangue content, polycarboxylic acid water reducer content and water cement ratio were selected as four level factors, and three levels were determined for each group according to the performance of relevant grouting materials. In order to make the serous stones more cohesive and strong, 0.3% polypropylene fiber was added into the serous fluid in each group. The design of orthogonal test rules is shown in Table 1.

| Label | Horizontal combination | A Coal gangue/% | B Steel slag powder/% | C Water reducing agent/% | D Water-cement ratio | polypropylene fiber |
|-------|------------------------|-----------------|-----------------------|------------------------|---------------------|-------------------|
| 1     | A1B1C1D1               | 10              | 10                    | 0.1                    | 0.5                 | 0.3%              |
| 2     | A2B2C2D1               | 15              | 15                    | 0.2                    | 0.5                 | 0.3%              |
| 3     | A3B3C3D1               | 20              | 20                    | 0.3                    | 0.5                 | 0.3%              |
| 4     | A2B3C3D2               | 15              | 20                    | 0.1                    | 0.55                | 0.3%              |
| 5     | A3B1C2D2               | 20              | 10                    | 0.2                    | 0.55                | 0.3%              |
| 6     | A1B2C2D2               | 10              | 15                    | 0.3                    | 0.55                | 0.3%              |
| 7     | A3B2C2D3               | 20              | 15                    | 0.1                    | 0.6                 | 0.3%              |
3. Test results and analysis

3.1. Test results

Through orthogonal test, the stone rate and the stone strength of different ages of the 9 groups were obtained. The test results are shown in Table 2.

| Label   | Stone rate (%) | 3d compressive strength (MPa) | 7d compressive strength (MPa) | 28d compressive strength (MPa) |
|---------|----------------|-------------------------------|-------------------------------|-------------------------------|
| 1       | 98.26          | 9.1                           | 12.17                         | 19.76                         |
| 2       | 97.83          | 6.2                           | 7.76                          | 14.92                         |
| 3       | 98.96          | 4.0                           | 6.15                          | 10.10                         |
| 4       | 97.36          | 3.7                           | 6.46                          | 11.23                         |
| 5       | 99.77          | 4.3                           | 6.25                          | 11.53                         |
| 6       | 96.79          | 4.3                           | 7.60                          | 10.97                         |
| 7       | 97.97          | 2.5                           | 3.84                          | 7.23                          |
| 8       | 98.11          | 2.9                           | 5.19                          | 7.45                          |
| 9       | 97.36          | 2.9                           | 4.60                          | 7.74                          |

3.2. Analysis of influence of serous stone rate

The stone rate of the serous fluid reflects the ability of the serous fluid to coagulate and harden. The higher the stone rate, the better the ability of the serous fluid to develop strength. The range analysis of the stone rate of the slurry prepared in the test is shown in Table 3.

| Test index | Coal gangue | Steel slag powder | Water reducing agent | Water-cement ratio |
|------------|-------------|-------------------|----------------------|--------------------|
| K1         | 0.9772      | 0.9846            | 0.9786               | 0.9835             |
| K2         | 0.9752      | 0.9753            | 0.9857               | 0.9797             |
| K3         | 0.9890      | 0.9814            | 0.9770               | 0.9781             |
| R          | 0.0138      | 0.0093            | 0.0087               | 0.0054             |

As shown in Table 3, the content of coal gangue has the greatest influence on the stone rate of the grout. Steel slag powder and water reducer have little difference on the stone rate. Steel slag powder is slightly higher than water reducer, and the change of water cement ratio has little influence on the stone body of the grout. The influence of various factors on the serous stone rate is shown in Figure 1.
It can be seen from the analysis of Figure 1 that with the increase of gangue content, the calculi of grout injection firstly decreased and then increased. The particle size of coal gangue is larger than that of Portland cement, and it contains less cementitious activation components. Therefore, when the dosage of coal gangue increases at the beginning, the stone rate of the grout decreases slightly. However, with the continuous increase of its content, coal gangue plays the role of coarse aggregate in the grout, and the stone volume of the grout is filled, and the stone rate of the grout increases again. The cementitious activity of steel slag powder is also less than that of cement, so the increase of steel slag powder content leads to the decrease of cement content, and the stone rate of slurry decreases accordingly. However, with the increase of its content, the hydration of steel slag powder in the grout began to highlight, and its hydration products filled the pores of the stone body, and the stone rate of the grout rose again. With the increase of dosage of water reducing agent, slurry concretion reduced after the first to rise, this is because the polycarboxylic acid water reducing agent particles can be adsorbed on the surface of the cement slurry, using molecular repulsive force will not hydration gelled material dispersion of flocculation on the surface of the product, wrap cement particle release moisture, to a certain extent promoted the hydration reaction, slurry concretion rate rise. However, with the continuous increase of the content of the slurry, the free water in the slurry increases, and the water that needs hydration is certain, so the grain setting rate of the slurry decreases. The increase of water-cement ratio directly leads to the decrease of the grout stone rate. After meeting the water required for the hydration of cementitious materials, the excess water will precipitate out of the grout, thus leading to the decrease of the grout stone rate.

3.3. Analysis of the influence of the compressive strength of the consolidation

The compressive strength of the grout stone body is an important indicator of the performance of the grouting material, and the higher compressive strength ensures the reliability of the grouting project. The range analysis table of the compressive strength of the slurry is shown in Table 4, Table 5 and Table 6.

| Test index | Coal gangue | Steel slag powder | Water reducing agent | Water-cement ratio |
|------------|-------------|-------------------|----------------------|-------------------|
| K1         | 5.4333      | 5.4333            | 5.1000               | 6.4333            |
| K2         | 4.2667      | 4.3333            | 4.4667               | 4.1000            |
| K3         | 3.6000      | 3.5333            | 3.7333               | 2.7667            |
| R          | 1.8333      | 1.9000            | 1.3667               | 3.6667            |
| Influence  | Water-cement ratio > Steel slag powder > Coal gangue > Water reducing agent |

Figure 1. The influences curve of each factor on stone rate
### Table 5. 7d range analysis table of compressive strength

| Test index | Coal gangue | Steel slag powder | Water reducing agent | Water-cement ratio |
|------------|-------------|-------------------|----------------------|-------------------|
| K1         | 8.3167      | 7.6727            | 7.4913               | 8.6907            |
| K2         | 6.2727      | 6.3973            | 6.3967               | 6.7680            |
| K3         | 5.4120      | 5.9313            | 6.1133               | 4.5427            |
| R          | 2.9047      | 1.7413            | 1.3780               | 4.1480            |

Influence: Water-cement ratio > Coal gangue > Steel slag powder > Water reducing agent

### Table 6. 28d range analysis table of compressive strength

| Test index | Coal gangue | Steel slag powder | Water reducing agent | Water-cement ratio |
|------------|-------------|-------------------|----------------------|-------------------|
| K1         | 12.7267     | 13.0100           | 12.7400              | 14.9267           |
| K2         | 11.2967     | 11.0400           | 11.3000              | 11.2433           |
| K3         | 9.6200      | 9.5933            | 9.6033               | 7.4733            |
| R          | 3.1067      | 3.4167            | 3.1367               | 7.4533            |

Influence: Water-cement ratio > Steel slag powder > Water reducing agent > Coal gangue

It can be seen from the range analysis table that the water-cement ratio has the greatest impact on the compressive strength of the grout stone body. In the 3d compressive strength, the steel slag powder content is greater than the coal gangue content on the compressive strength of the stone body. During the period, the impact of coal gangue content on the compressive strength of the stone body is greater than that of steel slag powder, and the water reducing agent has the least impact on the compressive strength of 3d and 7d age. The 28d compressive strength of the stone body is least affected by coal gangue, and the influence of various factors on the compressive strength of the stone body is shown in Figure 2.

![Figure 2. The influence curve of each factor's compressive strength](image-url)
It can be seen from Figure 2 that the compressive strength of the calculus body at different ages decreases with the increase of the admixture. The water-cement ratio has a greater impact on the 28d compressive strength of the stone body. With the increase of the water-cement ratio, the compressive strength of the stone body decreases significantly.

When the amount of coal gangue in the slurry increases, the compressive strength of the slurry stone bodies at different ages decreases. Although coal gangue has a certain strength, its gelling activity is lower than that of Portland cement. In the slurry, except for a few hydration reactions, most of them play a filling role. In addition, the strength of the crystals formed by the reaction of coal gangue is small, and its strength increases far. It is lower than the strength loss caused by the decrease in cement content, so the strength is reduced. With the increase of the steel slag powder content, the compressive strength of the slurry stone body decreases. The activity of steel slag powder is directly proportional to the particle size, but the overall activity is less than that of pure cement. Although the unhydrated steel slag powder particles can be filled in the stone body to increase the compactness of the stone body, overall, the increase in its content still makes Decrease in the strength of the stone body.

When the water-cement ratio becomes larger, the water content in the slurry is increased. When the water required for the hydration of the cementing material in the slurry is saturated, the excess water will be free in the slurry, and the slurry will be precipitated as the setting time increases. In addition, the excessive water in the slurry increases the distance between the molecules of the cementing material and reduces the compactness of the stone body, so the compressive strength of the stone body at each age decreases. The particle molecules of the polycarboxylic acid water-reducing agent can break up the flocculation structure of cement particles, reduce the thickness of the water layer on the surface of the cementitious material, release part of the water wrapped by the cementitious particles, and help increase the fluidity of the slurry. However, the increase of its content makes more free water precipitated in the slurry, which indirectly leads to the decrease of the compressive strength of the stone body.

4. Conclusion
Increasing the amount of coal gangue can increase the stone rate of the slurry, but it will reduce the compressive strength of the stone body. The increase in the amount of steel slag powder will reduce the solidity and strength of the stone body. If the activity of coal gangue and steel slag powder can be stimulated, the strength of the slurry stone body may increase.

The water-cement ratio and water-reducing agent will reduce the solidification rate and compressive strength of the grout. In actual engineering, a smaller water-cement ratio should be selected while ensuring the performance of the grout.

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