Performance Analysis of Clay-Steel Slag Powder Grouting Material Stone Body

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Abstract. Through the design of orthogonal experiments, different content of clay, steel slag powder and polycarboxylic acid water-reducing agent were mixed into ordinary Portland cement, and the grout was prepared according to different water-cement ratios. The analysis was conducted under standard curing conditions. Stone rate and compressive strength at different ages. The test results show that with the increase of the clay content, the stone rate of the grout consolidation body increases, and the compressive strength decreases. As the amount of steel slag powder increased, the stone rate and compressive strength of the slurry consolidation body decreased.

1. Introduction
The iron and steel metallurgical industry is the economic foundation of the country. With the continuous development of the iron and steel metallurgical industry, the problems of resource development, energy consumption and pollutant emission have become increasingly serious [1]. Steel slag is one of the main solid wastes in the production process of the iron and steel metallurgical industry, and my country’s annual steel slag emissions are huge. How to realize the comprehensive utilization of large quantities of steel slag is of great significance for the green development of the metallurgical industry. Steel slag powder contains C₂S, C₃S and other components similar to cement clinker in its mineral composition, and has certain gelling activity. The preparation of hydraulic cementitious materials has unique advantages [2]. Expansive soil is mainly composed of strong hydrophilic clay mineral components (montmorillonite and illite). It is a highly plastic clay with strong swelling and shrinkage, multiple cracks and strength attenuation. Clay has good water blocking effect. It is widely used in grouting reinforcement [3]. Qi Fu [4] showed that with the increase of steel slag powder content, the compressive and splitting tensile strength of concrete mixed with steel slag powder first increased and then decreased. Shiran Zhao [5] found that in the steel slag composite cementitious material system, cement and slag can synergistically stimulate the activity of steel slag and improve the activity of the cementing system. Chengjing Zhou [6] conducted uniaxial unconfined compressive strength tests on clay-gypsum cementing materials with different proportions, and found that with the increase of gypsum and clay content, the strength of the cementing material increases, and the initial setting time decreases. The material can It is used in underground engineering, water conservancy and hydropower engineering, and foundation treatment. At present, there have been many researches on steel slag powder and clay, but there are few reports on the research on cement-based grouting materials prepared by the combination of clay and steel slag powder.
Therefore, the effects of clay and steel slag on the stone rate of composite cement paste and the compressive strength of different ages are analyzed and compared, and the working performance of the clay-steel slag powder composite cement paste is initially revealed, which provides a theoretical basis for the further combination of the two in the later period.

2. Test Materials and Test Methods

2.1. Experimental Materials
The clay used is selected from the sodium bentonite produced by Henan Borun Casting Material Co., Ltd.; the steel slag powder is produced from the Lijing mineral processing plant in Lingshou County, Hebei, with a specific surface area of 400m2/kg; ordinary Portland cement is selected from Shandong Shanshui Cement Group Co., Ltd. The PO42.5 grade cement produced by the company; the test water is tap water; the test water reducing agent uses polycarboxylic acid high-efficiency powdered water reducing agent.

2.2. Experiment Method
(1) Determination of stone rate After the grouting material is configured, the grout will solidify into a stone body. Due to the water separation of the slurry, 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 taken as the stone rate. The calculation formula is \( \alpha = \frac{V_1}{V_2} \times 100\% \), where \( V_1 \) and \( V_2 \) are the volume of the stone body and the volume of the original slurry, respectively.

(2) Compressive strength Put the test block in a standard curing box for 3d, 7d, 28d curing. The TYB-2000B pressure testing machine is used. The compressive strength of the stone body is measured according to the "Cement Mortar Strength Test Method GB/T17671-1999".

2.3. Test Plan Design
The orthogonal experiment method can reduce the workload and analyze the influence of various factors. Four levels of factors are selected: clay content, steel slag powder content, water-reducing agent content, and water-cement ratio, and three levels are determined for each group based on the research experience of relevant material ratios. Design the mix ratio according to the orthogonal experiment rule, see Table 1.

| Label | Horizontal combination | A clay/\% | B Steel slag powder/\% | C Water reducing agent/\% | D Water-cement ratio |
|-------|-------------------------|----------|-----------------------|--------------------------|---------------------|
| 1     | A1B1C1D1                | 5        | 10                    | 0.2                      | 0.5                 |
| 2     | A1B2C2D2                | 5        | 20                    | 0.4                      | 0.6                 |
| 3     | A1B3C3D3                | 5        | 30                    | 0.6                      | 0.7                 |
| 4     | A2B1C2D3                | 10       | 10                    | 0.4                      | 0.7                 |
| 5     | A2B2C3D1                | 10       | 20                    | 0.6                      | 0.5                 |
| 6     | A2B3C1D2                | 10       | 30                    | 0.2                      | 0.6                 |
| 7     | A3B1C3D2                | 15       | 10                    | 0.6                      | 0.6                 |
| 8     | A3B2C1D3                | 15       | 20                    | 0.2                      | 0.7                 |
| 9     | A3B3C2D1                | 15       | 30                    | 0.4                      | 0.5                 |
3. Test Results and Analysis

3.1. Test Results

Through the orthogonal test, the stone rate of 9 groups of grouting solutions and the strength of the consolidated bodies of different ages 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     | 97.9          | 12.83           | 18.52          | 30.90               |
| 2     | 91.5          | 4.40            | 6.80           | 19.20               |
| 3     | 82.9          | 4.27            | 5.48           | 15.90               |
| 4     | 96.9          | 3.08            | 3.35           | 15.40               |
| 5     | 97.7          | 8.75            | 12.21          | 21.10               |
| 6     | 92.3          | 3.35            | 5.88           | 16.30               |
| 7     | 99.0          | 6.07            | 8.67           | 15.20               |
| 8     | 94.8          | 1.88            | 2.93           | 8.80                |
| 9     | 97.5          | 4.73            | 7.33           | 13.10               |

3.2. Analysis of the Influence of Grout Stone Rate

The stone rate of the grouting material refers to the stable part of the grout that has strength after coagulation. The higher the stone rate of the grout, the better the grouting effect. If the stone rate is too low, a second grouting is required. Table 3 shows the range analysis of the stone rate of the slurry prepared in the test.

| Test index | Clay | Steel slag powder | Water reducing agent | Water-cement ratio |
|------------|------|-------------------|----------------------|--------------------|
| K1         | 0.91 | 0.98              | 0.95                 | 0.98               |
| K2         | 0.96 | 0.95              | 0.95                 | 0.94               |
| K3         | 0.97 | 0.91              | 0.93                 | 0.92               |
| R          | 0.06 | 0.07              | 0.02                 | 0.06               |
| Influence  | Steel slag powder > Clay = Water reducing agent > Water-cement ratio |

As shown in Table 3, the steel slag powder content has the greatest influence on the stone rate of the slurry. The clay and water-cement ratio have the same effect on the stone rate, and the water reducing agent has a smaller effect on the stone body of the slurry. The influence of various factors on the rate of grout stones is shown in Figure 1.
Analysis of Figure 1 shows that when the amount of steel slag powder increases, the stone rate of the slurry consolidation decreases. The activity of steel slag powder is lower than that of pure cement. When the amount is increased, the consistency of the slurry will decrease, the distance between the molecules of the cementitious material will increase, the consolidation body will separate more water, and the stone rate will decrease. When the clay content increases, the stone rate of the consolidated body increases. Clay mainly plays a filling role in the coagulation process of the slurry. The pozzolanic activity of the clay can react with the cement hydration product Ca(OH)$_2$ to form hydrated calcium silicate and other gels to fill the pores, increasing the stone rate of the slurry consolidation. As the water-cement ratio increases, the stone rate of the slurry consolidation body becomes lower. This is because the water required for hydration of the cementitious material in the slurry is certain. When the water content in the slurry increases, the excess water will precipitate out of the slurry, resulting in a decrease in the stone rate of the consolidated body. With the increase of the amount of water reducing agent, the stone rate of the slurry consolidation body decreases. The water-reducing agent particles can be adsorbed on the surface of the cement slurry, and the cement flocculating particles are dispersed through molecular repulsion, releasing the water contained in the cement particles, and indirectly reducing the stone rate of the consolidated body.

3.3. Analysis of the Influence of the Compressive Strength of the Consolidation

The compressive strength of grout consolidation is an important indicator of the performance of grouting materials. The grouting material must have sufficient compressive strength to ensure the reliability of engineering reinforcement. The range analysis table of the compressive strength of the slurry is shown in Table 4, Table 5 and Table 6.

**Table 4. 3d range analysis table of compressive strength**

| Test index | Clay | Steel slag powder | Water reducing agent | Water-cement ratio |
|------------|------|-------------------|----------------------|-------------------|
| K1         | 7.17 | 7.33              | 6.02                 | 8.77              |
| K2         | 5.06 | 5.01              | 4.07                 | 4.61              |
| K3         | 4.23 | 4.12              | 6.36                 | 3.08              |
| R          | 2.94 | 3.21              | 2.29                 | 5.69              |

**Influence**

- Water-cement ratio > Steel slag powder > Clay > Water reducing agent
Table 5. 7d range analysis table of compressive strength

| Test index | Clay | Steel slag powder | Water reducing agent | Water-cement ratio |
|------------|------|-------------------|----------------------|-------------------|
| K1         | 10.27| 10.18             | 9.11                 | 12.69             |
| K2         | 7.15 | 7.31              | 5.83                 | 7.12              |
| K3         | 6.31 | 6.23              | 8.79                 | 3.92              |
| R          | 3.96 | 3.95              | 3.28                 | 8.77              |
| Influence  |      |                   |                      | Water-cement ratio> Clay > Steel slag powder > Water reducing agent |

Table 6. 28d range analysis table of compressive strength

| Test index | Clay | Steel slag powder | Water reducing agent | Water-cement ratio |
|------------|------|-------------------|----------------------|-------------------|
| K1         | 22.00| 20.50             | 18.67                | 21.70             |
| K2         | 17.60| 16.37             | 15.90                | 16.90             |
| K3         | 12.37| 15.10             | 17.40                | 13.37             |
| R          | 9.63 | 5.40              | 2.77                 | 8.33              |
| Influence  |      |                   |                      | Water-cement ratio> Clay > Steel slag powder > Water reducing agent |

The range analysis shows that the water-cement ratio has the greatest influence on the compressive strength of the consolidated body. In the 3d compressive strength, the influence of the steel slag powder content is greater than the clay content, but in the 7d and 28d ages, the clay content has the greatest influence on the compressive strength of the structure. The water reducing agent has the least influence on the compressive strength of each age. The influence of various factors on the compressive strength of the consolidated body is shown in Figure 2.

Figure 2. The influence curve of each factor's compressive strength

It can be seen from Figure 2 that the compressive strength of each group of slurry consolidation bodies develops slowly in the early stage, but the strength increases significantly in the later stage. It shows that the activity of clay and steel slag powder is lower than that of pure cement, and the reaction mostly occurs in the later stage of hydration. The compressive strength of the consolidated body is inversely proportional to the amount of steel slag powder, the amount of clay, and the water-cement ratio.
ratio, but with the increase of the amount of water reducing agent, the compressive strength first decreases and then increases.

With the increase of clay content, the compressive strength of the consolidated body decreases, but the downward trend of the compressive strength in the early stage is small, and the 28d strength decreases rapidly. Clay mainly plays a filling role, and the increase of its content will reduce the cement content and reduce the strength. However, the gel formed by the reaction of the clay and cement hydration products in the early stage can be filled in the pores of the consolidated body to offset part of the strength loss. As the amount of steel slag powder increases, the strength of the consolidated body decreases. Although unhydrated steel slag plays a filling role and can increase the compactness of the consolidated body, the activity of steel slag powder is much lower than that of cement, and the increased strength of the filling effect is far less than the strength loss caused by the reduction of cement. As the water-cement ratio increases, the water content in the slurry increases, and the surface layer of the slurry that does not participate in the hydration reaction in the slurry rises, which increases the water separation rate of the slurry. As the water-cement ratio increases, the water in the slurry increases, the distance between the molecules of the cementitious material increases, the compactness of the consolidated body decreases, and the strength decreases. The particle molecules of the polycarboxylic acid water reducer can be adsorbed to the surface of cement particles, reducing the thickness of the water layer on the surface of the cementitious material, releasing part of the water, reducing the compressive strength of the consolidated body. As the dosage continues to increase, the water reducing agent The branching effect of the compound appears, improves the dispersion effect of the cementitious material, promotes the hydration reaction, and slightly improves the strength of the consolidated body.

4. Conclusion
Adding clay can increase the stone rate of the grout consolidation, but it will decrease it. Compressive strength of the consolidated body. The increase in the amount of steel slag powder will reduce the solidification rate and strength of the consolidated body.

The water-cement ratio and water-reducing agent will reduce the solidification rate and compressive strength of the slurry consolidation body. The water-cement ratio and the amount of water-reducing agent should be determined according to actual engineering needs.

5. References
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