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Optimization of Mix Proportion for Similar Materials of Deep Iron Ore

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Abstract

Since most iron ores are buried underground and costly, similar materials play an important role in model tests. To meet the demand for similar materials in simulation tests such as iron ore mining, similar materials for iron ore were prepared using quartz sand and iron powder as aggregates, and cement and gypsum as binders. The orthogonal test design method was adopted, with four influencing factors selected: cement content, quartz sand content, iron powder content and gypsum content, and each factor was set at four levels. Through weighing and uniaxial compression tests under 16 different mix proportions, three physical and mechanical property indexes of the materials under different mix proportions, namely density, compressive strength and longitudinal wave velocity, were obtained, which satisfy the simulation requirements of iron ore in similar model tests.

Keywords

Density, Compressive Strength, Longitudinal Wave Velocity.

1. Introduction

With the gradual depletion of shallow mineral resources in China, the exploitation of deep mineral resources has become a necessity. The preparation and selection of rock simulative materials form the foundation of engineering geological model tests. Scholars have conducted extensive research on the development of rock simulative materials. In the early 21st century, a new type of iron-crystal sand cemented geotechnical simulative material was developed using iron ore powder, barite powder, quartz sand, gypsum powder, and rosin-alcohol solution as raw materials. In recent studies, Peng Sun et al. used coal powder as aggregate, sodium humate as a binder, and river sand as an auxiliary material for similarity simulation experiments. They applied range analysis to determine the sensitivity of various factors on test specimens and proposed a comprehensive method for determining the mix proportion model for outburst coal simulative materials. Wang and Li, Yang et al., and Xi et al. developed similar materials with different raw materials and proportions, all of which were proven to meet the physical or mechanical properties of soft rock[1] . In recent years, an increasing variety of simulative materials have been used in model tests, with cement-gypsum-sand being the most commonly employed Cheng et al,Sun et al ,analyzed low-strength mechanical tests and the optimal design of orthogonal experiments to simulate the mechanical characteristics of thick and extra-thick coal seams, obtaining the degree of influence of each component on uniaxial compressive strength[2-3].

Regarding sensitivity analysis methods, many scholars have used variance and range analyses to examine the sensitivity of various factors to the physical and mechanical parameters of materials. For instance, Piao Chunde et al. selected river sand as aggregate, lime and gypsum as binders, iron sand as a densifying agent, glycerin as a plasticizer, and a mixed solution of borax and water as a bonding material. Through range analysis and variance analysis of experimental results, they designed an optimal mix proportion scheme for soft rock simulative materials. Lin

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Sun et al. studied the mix proportion scheme for coal measure rock-like materials, analyzing four factors: aggregate-binder ratio, heavy calcium carbonate content, cement-gypsum ratio, and water content. They used range and variance analyses separately to determine the sensitivity of each factor. Wen Caoxuan and Lianghuan Yan applied range analysis to assess sensitivity and found that various factors controlled the density, compressive strength, elastic modulus, and tensile strength of test specimens. For regression analysis, Zhou Weiyang, Zhang Yanli et al. used regression functions to perform regression analysis on models, deriving relationships between different factors and parameters such as compressive strength, tensile strength, and density based on regression equations. Building on this, Wang Junshun et al. used SPSS software to construct a mathematical model, obtaining multiple linear regression equations for various physical and mechanical parameters of simulative materials for mudstone, thereby determining the optimal mix proportion for mudstone simulative materials

2. Optimization of Proportioning for Iron Ore Similar Materials under Orthogonal Design

Table 1. Target parameters of prototype and model

Parameter	Density	Strength	P-wave Velocity
Original Parameters	3.3	140	5400
Target Parameters	2.2	14	2700

2.1. Screening and Characteristic Characterization of Similar Materials

For the similar material simulation, on-site samples were collected from an iron ore mine in Liaoning Province, and corresponding physical and mechanical tests were conducted to obtain the physical parameters of the original samples. Based on the similarity principle, a density similarity ratio of 1:1.5 and a strength similarity ratio of 1:10 were derived, and the target parameters for the test were further determined as shown in Table 2 below:

Table 2. Target parameters of prototype and model

Material	Property	Specification	Main Component
Quartz Sand	White Powder	20-40 Mesh	Silicon Dioxide
Iron Powder	Black Powder	250 Mesh	Iron Tetroxide
Gypsum	White Powder	1500 Mesh	Calcium Carbonate
Cement	Gray Powder	PO42.5	Calcium Oxide

3. Design of Similar Material Proportioning

3.1. Selection of Similar Materials

Based on previous studies, the selection of appropriate sandstone-like materials for physical model tests must adhere to the following three principles:(1) The physical and mechanical properties of the sandstone analog should be similar to those of natural sandstone.(2) The raw materials of the same type of materials should be widely available, low in cost, non-toxic and harmless, and have stable physical and mechanical properties.(3) The physical and mechanical properties of the sandstone analog can be adjusted to a large extent by modifying the proportioning scheme.

Therefore, river sand, barite powder, gypsum, and cement are selected as the similar materials. Ordinary Portland cement is currently a widely used cementing material for adjusting the strength of test specimens. Barite and river sand have relatively high densities, so adjusting their content in the aggregate can adjust the density of the similar materials. Gypsum serves as a cementing material, and water is used as a solvent. Specifically, river sand + barite powder is

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used as the aggregate, and cement + gypsum as the cementing material. Meanwhile, to avoid errors caused by differences in test materials, all similar materials used are of the same specification and batch. The specific parameters of the similar materials are shown in Table 1.

3.2. Design of Factors and Levels

Four factors, namely cement content, quartz sand content, iron powder content, and gypsum content, were selected as the influencing factors of the experiment, with four levels set for each factor. The interaction between the factors was ignored during the analysis process. The specific factor-level settings were determined after pre-experiment mixing, as shown in Table 3.

When designing the orthogonal array for the experiment, it is necessary to select an orthogonal array with the same number of levels and a number of columns not less than the number of factors as a reference. Therefore, an orthogonal design scheme L16 (4 factors, 4 levels) was adopted in this experiment. The specific combinations of each group are shown in Table 4.

Table 3. Orthogonal design level of similar materials

Level	Factor A /%	Factor B /%	Factor C /%
1	35	15	15
2	40	20	20
3	45	25	25
4	50	30	30

Table 4. Orthogonal test results of similar material mix ratios

Serial No.	Cement Content	Quartz Sand Content	Iron Powder Content	Gypsum Content
1	35	30	25	10
2	40	25	30	5
3	45	20	20	15
4	50	15	15	20
5	35	25	30	10
6	40	20	25	15
7	45	15	20	20
8	50	30	15	5
9	35	20	25	20
10	40	15	30	15
11	45	30	20	5
12	50	25	15	10
13	35	15	30	20
14	40	30	25	5
15	45	25	15	15
16	50	20	20	10

4. Sample Preparation and Measurement

4.1. Preparation

According to the orthogonal design combination table, the raw materials were uniformly mixed and then placed into standard molds. A vibration table was used to eliminate air bubbles inside the specimens. After the initial setting of the specimens, they were demolded and cured in a constant temperature and humidity chamber with a temperature of 20℃ and a humidity of 95% for 28 days. Finally, the specimens were numbered and classified.

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4.2. Measurement

- **Density measurement:** The samples were weighed using an electronic balance, and the density was calculated based on the weight.
- **P-wave velocity measurement:** A concrete ultrasonic detector was used, with a measurement range of 0-99999 s and a repeatability error of 0.1 s.
- **Uniaxial compression test:** A rock mechanics testing machine was adopted, and the test was conducted using the displacement loading method with a loading rate of 0.01 mm/s.
- **Acoustic emission monitoring:** A DS5-16 acoustic emission system was used, equipped with an RS-2A probe. The preamplifier was set to 40 dB, and the external parameter sampling frequency was 60 kHz, as shown in Figure 2.

5. Test Results

The physical and mechanical property indicators (density, uniaxial compressive strength, and P-wave velocity) of materials with different proportions were calculated using relevant formulas. The specific results are shown in Table 4. To intuitively observe the variation trend of the material's physical and mechanical properties with each factor, the formulations and mechanical parameters of the 16 groups of materials were visualized, as shown in Table 5.

Table 5. results of similar material mix ratios

Serial No.	Density	Compressive Strength	P-wave Velocity
1	2.1	9.02	2512
2	2.18	8.33	2402
3	2.3	14.02	2989
4	2.1	13.85	2658
5	2.15	8.76	2608
6	2.23	14.21	2677
7	2.14	13.26	2582
8	2.1	18.84	2839
9	2.15	8.56	2521
10	2.11	11.96	2318
11	2.25	15.53	2746
12	2.07	10.06	2637
13	2.05	6.05	2267
14	2.23	9.97	2581
15	2.11	10.38	2634
16	2.11	15.93	2648

6. Conclusion

(1) The physical and mechanical parameters of the ore similar material prepared with cement, quartz sand, iron powder and gypsum as raw materials have a wide adjustable range. The orthogonal design test method was adopted, with cement content, quartz sand content, iron powder content and gypsum content set as the four control factors, each of which was designed with four levels, thus establishing a 4-factor and 4-level orthogonal test scheme. The test results show that when the cement content is 50%, quartz sand content 15%, iron powder content 15% and gypsum content 20%, the material meets the target parameters.

(2) Through the tests, it is obtained that under the 16 groups of mix proportion schemes, the density of the similar material ranges from 2.07 to 2.3 g/cm^3, the strength ranges from 6.05 to

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18.84 MPa, and the longitudinal wave velocity ranges from 2402 to 2839 m/s. Meanwhile, along with the different stages of uniaxial loading, the acoustic emission activity presents a variation trend of "stable transition followed by a sharp rise", which is consistent with the mechanical process of internal damage accumulation and instability of rocks.

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