Experimental research on proportioning of similar materials for coal and gas outburst simulation

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Abstract. Coal and gas outburst similar materials are the basis for coal and gas outburst simulation experiments. The study of similar materials helps to more accurately reduce the phenomenon of coal and gas outburst. By using the pulverized coal, sodium humate and river sand as raw materials, through the orthogonal experimental design, outburst coal similar materials are studied, and the physical mechanics such as the uniaxial compressive strength, elastic modulus and density of similar materials under different mixing ratios are obtained. The results show that under the molding pressure of 20MPa, the uniaxial compressive strength range is 1.335 to 2.527 MPa, the elastic modulus range is 117.45 to 302.00 MPa and the density range of similar materials is 1.308 to 1.438 g/cm$^3$. Sodium humate content and pulverized coal ratio are the main influencing factors controlling the uniaxial compressive strength and elastic modulus of similar materials, while river sand content is the main influencing factor controlling the density of similar materials.

1. Introduction
Coal and gas outburst is an extremely complex gas dynamic phenomenon that may occur in the production of coal mine. At present, due to the danger and complexity of coal and gas outburst, the simulation of coal and gas outburst in the laboratory is widely used to explore the mechanism of coal and gas outburst[1-4]. In the laboratory simulation process, the original coal can not meet the requirements of the size of the experimental coal sample, and generally similar materials are used instead. Outburst coal similar materials are the basis for coal and gas outburst simulation experiments. The study of similar materials helps to more accurately reduce the phenomenon of coal and gas outburst. In recent years, domestic and foreign scholars have done a lot of research on similar materials used in coal and gas outburst simulation experiments. In 1999, Jiang Chenglin et al. [5] used pulverized coal with a particle size of less than 1mm to add diesel to produce similar materials. In 2012, Ou Jianchun [6] used pulverized coal with a particle size below 1mm to add coal tar to configure similar materials. In 2015, Wang Hanpeng et al. [7] developed coal powder with a certain particle size distribution (0~1 mm: 1~3 mm=0.76: 0.24) as aggregate, and aqueous sodium humate as cement, then a similar material containing gas coal with a compressive strength of 0.5~2.8MPa was developed. Since 2015, Hu Qianting et al. [8-10] used cement, crushed coal, water, sand, and activated carbon as raw materials to obtain physical and
mechanical indicators such as density, compressive strength, firmness coefficient, elastic modulus, adsorption constant, and initial gas release velocity of similar materials with different ratios. In 2018, Zhang Yanli [11] used river sand, pulverized coal, gypsum, and calcium carbonate as raw materials to study similar materials for coal. The research of coal and gas outburst has promoted the development of coal and gas outburst simulation experiments. At present, in the manufacturing process of similar materials, coal tar, cement, gypsum, sodium humate and so on are selected as the binder. Different bonding agents have different degrees of influence on the strength and gas desorption performance of similar materials when making coal and gas prominent similar materials [12-13]. Therefore, it is necessary to determine suitable binders, carry out research on the ratio of similar materials for outburst coal, and make research to provide a basis for more realistic reduction of coal and gas outburst.

2. Identification of similar material raw materials

The raw materials of similar material are diverse and their performances are different. Selecting different raw materials can be used to prepare similar material suitable for different requirements. The selection of similar material raw materials should comply with the following principles: (1) it is easy to greatly control material performance indicators. (2) it meets the relevant characteristics requirements of prototype materials. (3) the performance of the raw materials is stable. (4) the production process is simple. (5) the materials are safe and free of pollution.

In order to configure the required similar materials, different types and properties of similar material raw materials need to be used, usually composed of aggregate, cement and other accessories. According to the characteristics of the coal and gas outburst simulation experimental model material, aggregate is selected from coal powder of Yuyang Coal Mine M8 coal seam (below 0.178mm and 0.178~0.42mm). Cement is selected from 0.15~0.178mm sodium humate with very strong adsorption, so that it is easy to adjust the adsorption and desorption index of similar materials. The auxiliary material uses 0.425~0.85mm river sand to facilitate the adjustment of the density of similar materials. It is as shown in Table 1.

| Classification | Name          | Parameter                      |
|----------------|---------------|--------------------------------|
| aggregate      | coal powder   | below 0.178mm and 0.178~0.42mm |
| cement         | sodium humate | 0.15~0.178mm                   |
| auxiliary      | river sand    | 0.425~0.85mm                   |

3. Orthogonal experimental design of similar material

The orthogonal experiment method is used for similar material design. The pulverized coal ratio (below 0.178mm and 0.178~0.42mm pulverized coal mass ratio), sodium humate content, and river sand content are used as the three factors in the orthogonal design. Each factor is set at five levels. The specific settings are shown in Table 2 and Table 3.

| Level | Pulverized coal ratio | Sodium humate content(%) | River sand content(%) |
|-------|-----------------------|--------------------------|-----------------------|
| 1     | 0.2                   | 0.5                      | 1                     |
| 2     | 0.4                   | 2.5                      | 3                     |
| 3     | 0.6                   | 4.5                      | 5                     |
| 4     | 0.8                   | 6.5                      | 7                     |
| 5     | 1                     | 8.5                      | 9                     |
4. Experimental results and analysis

4.1. Experimental results

In the pressing process, with using 20 MPa forming pressure, 3-layer pressing and heap maturation are performed to make similar materials. The manufacturing process of similar materials mainly includes: preparing raw materials, material mixing, heap maturation, preparing test molds, filling and tamping, pressing molding, release labeling, natural conservation. The pressed similar materials (Φ50mm×100mm) are shown in Figure 1. Measurements and uniaxial compression experiments are performed on test specimens of different proportions, and the uniaxial compressive strength, elastic modulus, and density of each test specimen are measured as shown in Table 3.

| No. | Pulverized coal ratio | Sodium humate content (%) | River sand content (%) | Uniaxial compressive strength (MPa) | Elastic modulus (MPa) | Density (g/cm³) |
|-----|----------------------|--------------------------|----------------------|-----------------------------------|----------------------|-----------------|
| 1   | 0.2                  | 0.5                      | 1                    | 1.335                             | 117.45               | 1.308           |
| 2   | 0.2                  | 2.5                      | 3                    | 1.485                             | 133.65               | 1.342           |
| 3   | 0.2                  | 4.5                      | 5                    | 1.598                             | 144.05               | 1.364           |
| 4   | 0.2                  | 6.5                      | 7                    | 1.633                             | 162.20               | 1.378           |
| 5   | 0.2                  | 8.5                      | 9                    | 1.599                             | 152.55               | 1.392           |
| 6   | 0.4                  | 0.5                      | 3                    | 1.518                             | 146.15               | 1.344           |
| 7   | 0.4                  | 2.5                      | 5                    | 1.587                             | 148.50               | 1.350           |
| 8   | 0.4                  | 4.5                      | 7                    | 1.655                             | 153.60               | 1.356           |
| 9   | 0.4                  | 6.5                      | 9                    | 1.753                             | 185.05               | 1.386           |
| 10  | 0.4                  | 8.5                      | 1                    | 1.910                             | 192.65               | 1.328           |
| 11  | 0.6                  | 0.5                      | 5                    | 1.698                             | 158.00               | 1.382           |
| 12  | 0.6                  | 2.5                      | 7                    | 1.746                             | 180.10               | 1.390           |
| 13  | 0.6                  | 4.5                      | 9                    | 1.733                             | 173.35               | 1.407           |
| 14  | 0.6                  | 6.5                      | 1                    | 2.085                             | 206.55               | 1.342           |
| 15  | 0.6                  | 8.5                      | 3                    | 1.838                             | 174.45               | 1.412           |
| 16  | 0.8                  | 0.5                      | 7                    | 1.789                             | 172.00               | 1.425           |
| 17  | 0.8                  | 2.5                      | 9                    | 2.201                             | 218.85               | 1.349           |
| 18  | 0.8                  | 4.5                      | 1                    | 1.925                             | 218.85               | 1.366           |
| 19  | 0.8                  | 6.5                      | 3                    | 2.383                             | 272.65               | 1.384           |
| 20  | 0.8                  | 8.5                      | 5                    | 1.867                             | 188.90               | 1.438           |
| 21  | 1                    | 0.5                      | 9                    | 1.963                             | 204.35               | 1.372           |
| 22  | 1                    | 2.5                      | 1                    | 2.197                             | 233.10               | 1.396           |
| 23  | 1                    | 4.5                      | 3                    | 2.527                             | 302.00               | 1.404           |
| 24  | 1                    | 6.5                      | 5                    | 2.459                             | 279.90               | 1.413           |
| 25  | 1                    | 8.5                      | 7                    | 2.459                             | 279.90               | 1.413           |
From the Table 3, under the molding pressure of 20 MPa, the uniaxial compressive strength range is 1.335 to 2.527 MPa, the elastic modulus range is 117.45 to 302.00 MPa and the density range of similar materials is 1.308 to 1.438 g/cm$^3$.

4.2. **Sensitivity analysis of various factors of similar materials**

In order to visually observe the sensitivity of various factors of similar materials, the effect curve diagrams of various factors are drawn, as shown in Figure 2~Figure 4.

![Figure 2. The effective curve of uniaxial compressive strength.](image)
From the Figure 2~Figure 4, the uniaxial compressive strength and elastic modulus of similar materials increase significantly with the increase of pulverized coal ratio and sodium humate content, but does not change significantly with the increase of river sand content. The density of similar materials increases with the increase of river sand content, and increases first and then does not change with the increase of pulverized coal ratio. This shows that the content of sodium humate and the ratio of pulverized coal are the main factors controlling the uniaxial compressive strength and elastic modulus.
of similar materials, while the effect of river sand content is small. River sand content plays a major role in the density of similar materials.

5. Conclusion

(1) Using pulverized coal, sodium humate, and river sand as raw materials, through orthogonal experiment design, under the molding pressure of 20 MPa, the uniaxial compressive strength range is 1.335 to 2.527 MPa, the elastic modulus range is 117.45 to 302.00 MPa and the density range of similar materials is 1.308 to 1.438 g/cm$^3$.

(2) Sodium humate content and pulverized coal ratio are the main influencing factors controlling uniaxial compressive strength and elastic modulus of similar materials, while river sand content is the main influencing factor controlling the density of similar materials.

(3) The research results need to be verified in the next step by combining coal and gas outburst simulation experiment.

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