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Experimental research on coal seam similar material proportion and its application

Cheng Weimin [a,b], Sun Lulu [a,b,*], Wang Gang [a,b], Du Wenzhou [b], Qu Hongyuan [c]

[a] Key Laboratory of Ministry of Education for Mine Disaster Prevention and Control, Shandong University of Science & Technology, Qingdao 266590, China
[b] College of Mining & Safety Engineering, Shandong University of Science & Technology, Qingdao 266590, China
[c] Department of Mining Engineering, Colorado School of Mines, CO 80402, USA

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ABSTRACT

In this paper, the optimization design of the low strength mechanical test and orthogonal test have been analyzed in order to simulate the mechanical properties of thick and extra-thick coal seam accurately in a similar material simulation test. The results show that the specimen can reach a wider range of strength when cement has been used compared to that of gypsum, suggesting that cement is more suitable for making coal seam in similar material simulation tests. The uniaxial compressive strength is more sensitive to cement than coal or sand. The proportion of coal and sand do not play a decisive role in uniaxial compressive strength. The uniaxial compressive strength and specimen density decrease as the mass percent of coal and aggregate–binder ratio rise. There is a positive correlation between uniaxial compressive strength and density. The No. 5 proportion (cement: sand: water: activated carbon: coal = 6:6:7:1.1:79.9) was chosen to be used in the similar material simulation test of steeply dipping and extra-thick coal seam with a density of 0.913 g/cm^3 and an uniaxial compressive strength of 0.076 MPa which are in accordance with the similarity theory. The phenomenon of overburden stratum movement, fracture development and floor pressure relief were obtained during the similar material simulation test by using the proportion.

1. Introduction

Within the realm of overburden stratum movement law under mining research, a similar material simulation test can intuitively show the process of overburden stratum movement as well as its failure mode as an important research method for rock mechanics. Scholars at home and abroad have used the similar material simulation method to carry out extensive research regarding strata movement, surface subsidence and mining stress [1–6].

Since the ratio of similar materials directly affects the accuracy and reliability of the test phenomena and data, a large number of scholars have studied the similar material proportion of rock [7–12]. However, in the similar material simulation test system, the mechanical property of coal seam has a significant influence on the experimental results and thus scholars also study the similar material proportion of coal. Using the raw coal specimen made by press-forming is the main research method. The similar material simulation test of coal has been researched by Kong et al. [13]. Chu et al. created the engineering classification for coal and completed selective tests on different classifications [14]. Kang et al. selected coal and sand as aggregates, cement and gypsum as cementing agents, and analyzed the strength influence factors of a raw coal specimen [15]. Xu et al. obtained the seepage properties of a briquette specimen and a raw coal specimen with different mass percentages of cement, confirming briquette's similar material proportion and mechanical property to those of raw coal [16].

Actually, coal seams in similar material simulation test are not made through press-forming. Since coal seams are mainly made by artificial works, the strength should be calculated by the similarity theory and actual argument. Accordingly, studies considering the proportion low strength coal specimen are of vital significance, and some scholars have begun to pay attention to this aspect. Liu et al. tested low strength similar material using an orthogonal test to study a sand aggregate combined with fly-ash and gypsum as the cementing agents [17]. Li et al. developed materials that can satisfy the mechanical property of coal and rock with a combination of sand, calcium carbonate and gypsum [18].

Existing similar material of coal seam generally use sand as the aggregate and can only simulate the law of movement and failure form. The laws of gas pressure relief and movement are different depending on the coal mining technology and coal mining method

* Corresponding author. Tel.: +86 18678933326.
E-mail address: sunsdust@126.com (L. Sun).

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used when the thick coal seam are mined. It is the research principle and basis for the relief and movement of gas pressure to use coal while making the coal seam in similar material simulation test. The gas desorption–adsorption property of coal seam can be adjusted by adding activated carbon.

The aim of this work is to improve the accuracy of the similar material simulation test. A strength similar material orthogonal test is adopted as the method to optimize the similar material proportion of coal seam while using coal as the aggregate. The similar material proportion is used in the steeply dipping and extra-thick coal seam similar material orthogonal test.

2. Optimization design of low strength specimen fabrication process and strength test based on error analysis

The similar material simulation experiment is a way to study macroscopic phenomena and laws, as well as factors leading to errors existing in the production phase, maintenance phase and test phase in the process of making a similar material model [19,20]. Design optimization is completed in order to test the mechanical properties of the specimens made by various proportions and ultimately reduce the error as much as possible.

2.1. Production phase

Raw material for laboratory test purpose should be preserved under the natural or similar environment in order to minimize the error due to different water absorption rates of the raw material.

Different raw materials should be weighed in a dry clean glass beaker at the amount of 10 specimens on weight. The specimen should be made by 3–5 people as soon as the raw material is weighed to minimize the effects of hydration reaction and initial setting time.

Material B should be weighed after weighing material A in the same glass beaker and then mixed before adding the next material.

In order to reduce error caused by compactness of the coal seam or strata, the compactness coefficient S is defined as the volume ratio of initial volume and compacted volume. Fixed materials with the quality of M and volume of N (M is about 1/6–1/10 times for a single specimen quality) is loaded into the mould and compressed into volume for $N \times S$. A specimen can be made after 6–10 repetitions of this step.

Tough treatment should be done on the surface of specimen during the last step to provide a good contact area for the next loading.

2.2. Maintenance phase

Generally speaking, it is difficult to carry out a large similar material model test under constant temperature and humidity conditions. As a result, the specimen should be kept in the similar material simulation test laboratory while approaching the real conditions of the model. The temperature and humidity of the laboratory should remain relatively stable during the maintenance phase.

2.3. Test phase

Specimens with a smooth face are selected and used in the uniaxial compressive strength test under a constant loading rate to reduce the influence of face roughness and loading rate. A reasonable pre-stress measurement should be confirmed after several tentative experiments.

3. Low strength similar material orthogonal test of coal seam

3.1. Primary election of proportion test scheme

Throughout the existing proportion of coal seam in similar material test research, the aggregate is mainly comprised of sand and coal using a cementing agent consisting of mainly cement and gypsum. The auxiliary materials are relatively flexible, containing calcium carbonate, borax, mica, sawdust, activated carbon, etc. [13–18,21]. In order to choose the more reasonable proportion scheme, coal, sand and activated carbon are selected as the aggregate, while cement and gypsum are selected as cementing agents. The strength of cement and gypsum are tested first, and the orthogonal test is carried out after optimizing the cementing agents. The inner diameter of the mould is 50.1 mm, and has a height of 110 mm.

3.2. Low strength similar material orthogonal test and optimal selection of schemes

3.2.1. Optimization of cementing agent

The results of the optimal selection test, resulting in choosing cement or gypsum as the cementing agent, are shown in Table 1. The results are listed as the average value of valid data from each multi-group.

Test specimens include a wide range of aggregate–binder ratios to analyze their respective strength. The aggregate–binder ratio is defined as the mass ratio of the aggregate (coal, sand, activated carbon) and cementing agent (cement or gypsum). The coal–sand ratio is defined as the mass ratio of coal and sand.

It can be seen in Table 1 that the strength of specimens is at a low level, which satisfies the need of the similar material simulation test. The strength range of specimens using a gypsum cementing agent is 85.4–117.8 kPa, while the strength range of specimens using a cementing agent made of cement is 113.8–456 kPa. The results show that the strength control effect of cement is more significant than that of gypsum.

This means that the strength range of specimens is larger under the situation that: (1) the aggregate is mainly constituted by coal, and (2) the cement works as the cementing agent. Since the similarity ratio and original strength of coal seam varies between different similar material simulation tests, the applicability of cement is more obvious when compared to gypsum. Accordingly, cement was selected as the cementing agent for this study.

3.2.2. Low strength similar material orthogonal test

This orthogonal test uses a test table with five orthorhombic factors and four levels (factors are cement, sand, water and activated carbon, respectively; the fourth factor is empty, and the proportion of coal is determined by the total mass of the other four factors). Test results are shown in Table 2.

3.2.3. Analysis of test results

3.2.3.1. Sensitivity analysis of uniaxial compressive strength influence factors.

3.2.3.1.1. Orthorhombic factors. The average value and range calculation results of uniaxial compressive strength are shown in Table 3 and Fig. 1.

As seen in Table 3 and Fig. 1, the range of cement, water, activated carbon and sand decreases in sequence. This means that the uniaxial compressive strength is much more sensitive to cement, followed by water and activated carbon, and it is not sensitive to sand.

The uniaxial compressive strength of specimens rises as the mass percents of cement and water increase. When compared with

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