International Journal of Rock Mechanics & Mining Sciences 91 (2017) 72–80

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

Deformation and gas flow characteristics of coal-like materials under triaxial stress conditions

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ARTICLE INFO

Keywords:
Coal and gas outburst
Coal-like materials
Seepage test
Permeability
Triaxial stress

ABSTRACT

The dynamic characteristics of gas flow are often not considered in the simulation test for coal and gas outburst, making coal-like materials hard to meet the required similarity. To solve this issue, based on previous studies on the physical and mechanical properties of coal-like materials and the characteristics of gas adsorption and emission, we investigated the deformation and gas flow characteristics of coal-like materials under triaxial stress conditions using a triaxial servo-controlled seepage equipment for thermo-fluid-solid coupling of coal containing methane. Analysis of the experimental data revealed the relationship of their stress to strain as well as the relationship of their permeability to principal stress difference and strain. In addition, a coal-like material with best seepage dynamic flow characteristics was chosen and its corresponding preparation Scheme 1 was used as the preferable scheme for preparation of class V dangerous seam. The results provide a new idea and research method for further refining preparation of materials similar to coal and gas outburst seam.

1. Introduction

Coal and gas outburst is an extremely complex gas dynamic phenomenon encountered in the production of underground coal mine and characterized as sudden eruption of a large amount of gas and coal from the coal tunnel or stope within a very short period of time.[1] Coal and gas outburst has happened in at least sixteen countries worldwide. China is the one with the most coal and gas outbursts, as nearly half of the coal and gas outbursts occurred in China, causing serious casualties and economic losses.[1,2]

Many factors could affect coal and gas outburst, including ground stress, gas pressure, geological structure, coal properties and mining methods. So far no scientific and rational explanation could well explain its underlying mechanisms.[1,3–7] Moreover, coal seams prone to coal and gas outbursts are highly risky for field trials, therefore simulation test is an effective means to explore the mechanisms of coal and gas outburst.

Since simulation test must use similar materials. In order to improve the reliability of test results, similar materials must be selected to meet the requirements of the simulation test. In the previous simulation tests at home and abroad on coal and gas outburst, specimen are mainly prepared using the following three types of methods.

First, pulverized or smashed coals were directly compressed as samples in the absence of any additives.[8–26] For example, Te conducted a simulation test using CO_2 and the briquette made of outburst-prone Mazurk.[8] Meiners and Miller conducted outburst simulation tests using cylindrical coal samples with diameter of 15 cm.[16] However, the coal briquettes prepared solely relying on pressure in the condition without any additives have very low strength.

Second, the pulverized coals were compressed as samples after mixed with water, diesel or oil.[27–33] Ou[31] prepared samples with different physical and mechanical properties by controlling the ratio of pulverized coal to coal tar. However, such similar materials have low intensity, and adsorption and desorption characteristics highly different from raw coals, thus cannot fully meet the test requirements.

Third, the mixture of sand, lime, gypsum, fly ash and other materials at a certain ratios are compressed as samples.[34–36] Ujihira et al. prepared a 58 cm long pore-like clay sample using mixture of pulverized coal, cement and aerated agent to observe outburst process and monitor gas pressure.[34,35] Because the prepared samples are made of materials without considering their gas adsorption ability such as

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http://dx.doi.org/10.1016/j.ijrmms.2016.11.015
Received 10 March 2016; Received in revised form 11 August 2016; Accepted 15 November 2016
Available online 23 November 2016

ice, cement or rosin, they have quiet different physical and mechanical properties to real coal samples.

Hu et al. launched a systematic study for the first time on the ratio of materials used for similar material simulation, and obtained the effects of different material ratios on the physical and mechanical properties of coal,[37] which has made great progress in the researches on similar materials in coal and gas outburst simulation.

Although the above-mentioned tests on coal-like materials advanced our understanding of outburst mechanisms, the physical and mechanical properties of coal-like materials used in outburst simulation tests are still need to be improved. Moreover, these tests did not consider the impacts of dynamic gas seepage on coal and gas outburst. Thus, the materials for simulation of coal seam are unable to meet the required permeability similarity in the simulation tests. Since gas seepage is an important factor affecting coal and gas outbursts,[1] on the basis of a previous study,[37] in this paper we proposed a method using a dynamic seepage test to verify the similarity accuracy of coal-like materials in outburst simulation experiments, intensively explored the seepage characteristics and deformation features of coal-like materials at triaxial stress conditions, and put forward a more reasonable ratio scheme for preparing coal-like materials.

2. Materials, equipment and methods

2.1. Primary ratio selection of coal-like materials

2.1.1. Selection of coal samples

Coal samples were taken from #N2808 working face of #8 coal seam, the main aquifer of Yuyang coal mine of Songzao Coal Mine Co., Ltd. The coal seam is a type V destructive, soft, middle-thick one with overall average thickness of 2.35 m. It contains 15.08~29.4 m^3/t gas and has gas pressure of 2.24~4.87 MPa and permeability coefficient of 0.013 $m^2/(MPa^2{\cdot}d)$. Coal and gas outbursts have repeatedly occurred in the mine with maximum outburst strength of 695 t and average outburst strength of 162.3 t.

The basic parameters of the coal seam are as follows: coal moisture content of 1.14%, dry ash basis of 15.23%, dry ash free basis of 10.41%, consistent coefficient of 0.21~0.38, porosity of 9.48%, gas adsorption volume constant of 33.68 $m^3\ t^{-1}$, and gas adsorption pressure constant of 1.25 MPa^{-1}.

2.1.2. Coal-like materials and their ratio

Considering that coal-like materials should have certain strength and porous characteristics and their coagulation time should be as short as possible, to avoid the impacts of interactions among raw materials on the characteristics of coal-like materials and make the physical and mechanical properties of coal-like materials basically similar to the parameters of raw coals, raw materials listed in Table 1 were selected to prepare coal-like materials at certain ratios.[37]

Table 1
Coal-like materials and their compositions.

Type	Raw material	Mass ratio /%	Model/ particle size	Note
Aggregate	Crushed coal	70~90	80-40 mesh/ 40-20 mesh, ratio: 1:1	Coal sample from M8 coal seam of Yuyang coal mine
Cementitious material	Cement	2~13	425# ordinary Portland cement	
Auxiliary material	Sand	1~6.5	40-20 mesh	River sand
	Activated carbon	0.7~0.92	Φ5.6 ×5.3 mm^2	Granular sample
	Water	6.5~9.25	–	Ordinary Tap water

Table 2
Coal-like material uniform experimental design (mass ratio,%).

No.	Raw material mass ratio (%)				
	Cement	Sand	Water	Activated carbon	Crushed coal
1	2	3.5	8.25	0.88	85.37
2	3	6.5	7	0.82	82.68
3	4	3	9	0.76	83.24
4	5	6	7.75	0.7	80.55
5	6	2.5	6.5	0.9	84.1
6	7	5.5	8.5	0.84	78.16
7	8	2	7.25	0.78	81.97
8	9	5	9.25	0.72	76.03
9	10	1.5	8	0.92	79.58
10	11	4.5	6.75	0.86	76.89
11	12	1	8.75	0.8	77.45
12	13	4	7.5	0.74	74.76

2.1.3. The primary selection of the ratio of raw materials

Qianting Hu et al. for the first time conducted a systematic research on the ratio of raw materials used to prepare coal-like samples in the outburst simulation tests and used uniform design method to design the ratio of raw materials. They have made great breakthrough on the physical and mechanical properties of outburst-simulation materials and the characteristics of gas adsorption/emission, obtained the compression strength, hardness coefficient, elastic modulus, density, adsorption and desorption index of the coal-like materials listed in Table 2, and summarized the related laws.[36] According to the test on the type III~V outburst-prone coal seams, Zhang et al. concluded that the uniaxial compression strength of type V outburst coal seam is 1 MPa.[38] Based on the above results, the ratios of 3 groups of coal-like materials of type V outburst coal seam that meet the requirement of uniaxial compression strength were selected from Table 2 and are shown in Table 3.

2.2. Testing device

Gas seepage test was conducted using the triaxial servo-controlled seepage equipment for thermo-fluid-solid coupling of coal containing methane (Chongqing University). The device consists five subsystems, namely servo-controlled loading subsystem, triaxial compression chamber, water bath with thermostatic control subsystem, interstitial pressure control subsystem and data measuring subsystem, as shown in Fig. 1. The tested specimens are standard pieces with diameter of 50 mm and length of 100 mm.

The servo-controlled loading subsystem ensures continuity, stability and accuracy of the loading process and loading manner diversification. The triaxial compression chamber is a core component of the seepage device and the important part to place the tested coal (rock) specimens and provides the test-required confining pressure environment. Fig. 2 shows its main structure. The system could provide maximum axial stress of 100 MPa, maximum confining pressure of 10 MPa, maximum axial displacement of 60 mm and maximum radial displacement of 10 mm. The water bath with thermostatic control subsystem can maintain the tested specimens in a highly thermostable environment with maximum temperature of 100 °C and precision of ± 0.1 °C. The interstitial pressure control subsystem could ensure seepage pipe tightness and is able to provide a maximum test gas

Table 3
Primarily selected proportion scheme of coal-like materials.

Proportion scheme	Raw material mass ratio (%)				
	Cement	Sand	Water	Activated carbon	Crushed coal
1	6	2.50	6.50	0.90	84.10
2	7	5.50	8.50	0.84	78.16
3	8	2	7.25	0.78	81.97