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Experimental Research on Coal Rock Creep Deformation-seepage Coupling Law

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Abstract

Coal rock creep is an inevitable phenomenon in coal mining, fluid seepage is involved in coal rock creep in coal mine, and coal rock creep and fluid flow interact. To determine the coal rock creep–seepage law, in this paper, CSCG-160-type gravity hydraulic constant load creep seepage test system developed by China University of Mining & Technology (Beijing) is used to carry out creep seepage test with step loaded axle load in certain condition of confining pressure for raw coal rock sample; in the test, coal rock-related deformation (axial strain, volumetric strain) in the creep process is measured and seepage is recorded. By analysis of the test result, the creep deformation–seepage law during coal rock creep seepage is obtained. The study result of very important practical guiding significance for dynamic disaster and water damage prevention and control of gas in coal mine.

Keywords: coal rock creep deformation; seepage; coupling; permeability; experimental research

Coal is the primary energy of China, in the primary energy consumption structure in China in recent years, the proportion of coal has remained at around 70%. At the same time, coal mining is always an industry prone to production safety accident in China. Among the top five disasters in coal mine, gas and water disaster accidents cause the most serious hazards, and they both involve seepage problem of fluid medium in the coal rock. As the underground coal mining causes the change in stress state of coal rock, the deformation of coal rock will also occur, and the deformation is a creep process \cite{1, 2, 3}; the process has an important impact on fluid seepage \cite{4}, such as resulting increased gas emission and increased water flow. The presence of these fluid media also has some impact on creep process. Therefore, it has a very important theoretical and practical significance to carry out study on coal rock creep seepage for mine disaster prevention and control.

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1. Introduction of Test System

CSCG-160-type gravity hydraulic constant load creep seepage test system independently developed by China University of Mining & Technology (Beijing) is adopted in the test. The test system primarily consists of three parts, including loading system, measuring system and gas (liquid) supply system. The schematic diagram of test system structure is shown in Figure 1. The loading system consists of gravity hydraulic constant load energy storage device, static pressure change device, holder and triaxial creep seepage device; the measuring system consists of displacement sensor, pressure sensor and gas flowmeter; gas (liquid) supply system consists of high pressure gas cylinder, constant pressure and constant velocity pump, pressure maintaining valve, pressure reducing valve, etc.

The static pressure change device of the test system has 14 pressure cylinders with seven different pressure ratios, including 1:1, 1:1.189, 1:1.384, 1:1.682, 1:2, 1:4, 1:8; there are two for each ratio. By opening and closing the valves, the pressure cylinders can connect in any combination to achieve different pressure ratios. The pressure cylinder realize pressurization by different cross-sectional areas at both ends of the piston within it; when pressure applies on the end with larger cross-sectional area, the pressure on the end with smaller cross-sectional area is larger. The operating principle of gravity hydraulic constant load device is to apply the steady pressure provided by gravity hydraulic constant load energy storage device to the static pressure change device, and then change the connection mode of the pressure cylinder by controlling its valve to get different constant pressures. The test system can provide axial pressure with range of 0~160 MPa, and confining pressure with range of 0~80 MPa.

The coal rock samples used in the test are taken from 9#, 10# coal seams in a coal mine of Shanxi Fenxi Mining Group, and the sampling is made according to sampling specification. The large lump of coal rock mass is processed into cylindrical specimens with height/diameter ratio of 2:1 in accordance with international standard and with dimensions of $\phi 50 \times 100$mm and $\phi 25 \times 50$mm, three specimens of each dimension.

![Fig. 1. Schematic Diagram of Test System Structure](image-url)
2. Introduction of Test System

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2.1. Preparation before test

(1) Vacuumizing equipment. Open the vacuum pump and corresponding valves, and vacuumize the pipeline and pressurizer.

(2) Pressure test. Put the metal standard specimens into each holder, and apply different axial pressure and confining pressure to the specimens, to test the stability of the pressure and ensure constant axial pressure and confining pressure.

(3) Adjustment of equipment state. Check the piston of each pressurizer to see check to see whether they are at the initial state; if not, adjust the manual pump to restore it to the initial state; install the displacement sensor correctly; observe the pressure gauges to see if they are at the initial zero position; if not, open/close relevant valve for pressure relief to return the pressure gauge to zero.

(4) Installation of specimens. Close all the valves, put the specimens into appropriate holders, jack the core plugs, and fix and lock the holder.

2.2. Preparation before test

(1) After gravity hydraulic constant load device is equipped with the appropriate amount of weight block, first apply equal confining pressure and axial pressure to the coal specimens to ensure that specimens will not deviate, then apply the confining pressure to the test value of 4MPa, and then apply axial pressure to the required value of the test in order. The test adopts step loading of axial load test to increase the axial pressure to the predetermined maximum creep load value. After loading of each step of axial pressure, observe the creep displacement; when the creep rate is small, that is, when the creep basically tend to be stable, begin to apply a higher step of load.

After the first step of axial pressure is applied, maintain the confining pressure and axial pressure unchanged, open the high-pressure nitrogen cylinder of the gas supply system (maximum outlet pressure of 5MPa) and relevant valves, and maintain the gas outlet pressure unchanged, inject nitrogen slowly into the coal specimen, and gradually achieve the required gas pressure value; after the gas pressure is stable, measure the permeability of the coal specimen. With the confining pressure kept unchanged, apply axial pressure step by step, and measure the permeability of the coal specimen at the fixed gas pressure value for each step of axial pressure.

(2) Put the rock sample into the holder, and apply confining pressure and axial pressure on the rock sample; considering that the triaxial creep test will last for a long period and the rock samples are limited in quantity, step loading test method is adopted for triaxial creep test. Loaded stress is in three steps. Determine the stress of each step by conventional triaxial compression test. In making creep test, keep the entire test process is in the environment of constant temperature and humidity with thermostatic and constant humidity apparatus.

(3) Test data collection. Start computer collection software of the test system, fill in the basic parameters, calibrate the displacement sensor, and collect test data. The main parameters measured during
the test include time, creep load, axial strain, volumetric strain, inlet and outlet gas pressures, instantaneous flow rate at the gas outlet and other parameters.

3. Test Data Analysis

3.1. Creep deformation properties of coal rock

Perform creep seepage test on the coal rock specimens and inject helium into the coal rock body according to test procedure.

Based on the time, axial strain and volumetric strain measured at the measurement point in the coal rock specimen step loading creep process, draw the coal rock creep test curve, and volumetric strain versus time curve respectively, as shown in Figure 2 and Figure 3. Based on the test data, draw the relation curve of volumetric strain and axial strain, as shown in Figure 4.

![Figure 2 Coal rock Creep Test Curve of Step loading of Different Creep Loads](image1)

![Figure 3 Volumetric Strain-Time Curve](image2)

![Figure 4 Volumetric Strain-Axial Strain Curve](image3)

It can be seen from Figure 2 that the coal rock has obvious creep characteristics in step loading of different creep loads; under low creep load, the coal rock shows attenuating creep characteristics; when creep is stable, the deformation increases with the increase of load level; the lower the creep load is, the less time is taken for the coal rock to enter into creep stability stage; when the creep load (23.5MPa) is higher than long-time strength of coal rock, the coal rock has a typical three-stage creep. It can be seen from Figure 3 that the change law of the volumetric strain of the coal rock varying with time is contrary
to the change trend of the creep test curve of coal rock, that is, the volume deformation decreases with increase of the load and becomes negative.

It can be seen from Figure 4 that the volumetric strain of coal rock specimen increases and then decreases with the increase of axial strain, when the axial strain reaches 1.5, the corresponding volumetric strain decreases rapidly.

3.2. Seepage property of coal rock

Based on the test data obtained, draw permeability-time curve (Figure 5), and permeability-axial strain curve (Figure 6). Figure 5 Permeability-Time Curve shows that, coal rock permeability increases with the increase of creep load level. Figure 6 Permeability-Axial Strain Curve shows that the permeability in the coal rock creep process of coal rock increases with the increase of axial strain, and the increase rate also increases with the increase of axial strain.

During creep deformation of the coal rock, it is inevitable that new cracks or extension of original cracks will occur inside it; as the axial strain of the coal rock increases, more and more fissures occur inside it, and further, the fissure inside the coal rock is the main channel for seepage of fluid, and the number of fissures has large impact on coal rock permeability. Therefore, the coal rock increases with the axial strain; before the macro-breakage, its internal part shows evolution of the fissure initiation; the more the fissures are, the more proportion of the interconnected fissures is, and thus the permeability of the coal rock is larger.

![Figure 5 Permeability-Time Curve](image1)

![Figure 6 Permeability-Axial Strain Curve](image2)

4. Conclusion

To study the creep deformation law of the coal rock under the effect of different seepage media and the change of seepage law of seepage media in creep process, this paper describes the nitrogen seepage creep test with the self-made gravity constant load creep seepage test system, using step constant loading method to obtain the creep law of coal specimen and nitrogen seepage law. Creep and seepage under the low pressure are relatively gentle, but when loading reaches to a certain pressure, creep will become accelerating creep and the permeability of coal specimen also increases dramatically, and the specimen enters breakage stage.
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