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Experimental Study on The Influence of Effective Stress on Stress Sensitivity of Coal Permeability

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ABSTRACT

In order to study the influence of effective stress on the sensitivity of coal permeability stress, three groups of low permeability dense coal samples were selected in the range of confining pressure of 2 MPa ~ 4 MPa. Under the influence of single factor of effective stress, the cross-contrast seepage experiment of coal samples under different effective stress conditions was carried out by using steady seepage method, and the variation characteristics of effective stress sensitivity of coal samples were systematically analyzed by using permeability damage rate and permeability curvature. The results show that: (1) under various confining pressures, with the increase of effective stress, the damage rate of coal permeability decreases according to the law of negative exponential function, and the greater the effective stress, the greater the damage rate of coal permeability; (2) The effective stress is constant, the smaller the confining pressure is, the greater the curvature of permeability is, the greater the influence of effective stress on coal seam permeability is, and the stronger the sensitivity is.

KEYWORDS

Coal; Effective stress; Permeability damage rate; Permeability curvature.

1. INTRODUCTION

At present, scholars at home and abroad have conducted extensive research on the permeability variation law of coal and rock, including considering the influence of slippage effect, stress sensitivity, matrix shrinkage and other influencing factors on permeability. Among them, most scholars think that stress sensitivity is the main factor that causes the change of dynamic permeability. It can be seen that it is of great significance to systematically study and consider the influence of effective stress on the permeability stress sensitivity of coal and rock.

Ren Shaokui [1] and others derived the functional model of effective stress and coal permeability based on sensitivity coefficient. Zhao Mingkai [2] established a prediction model of fracture permeability considering stress sensitivity, and studied the correlation between fracture permeability and rock mass lithology under effective stress. Zhang Tianjun et al. [3] analyzed the mechanism of effective stress on coal seepage with porous structure. Wang Yi [4] and others have found that the apparent permeability has a completely opposite trend with the change of effective stress in different pore pressure intervals. Xie Yuhua [5] and others found that the permeability of No.3 coal seam in Xinjing Mine is extremely sensitive to effective stress, and the permeability of coal seam decreases with the increase of effective stress, and there is a good negative exponential power function relationship between them. Liu Shuaishuai [6] and others analyzed the variation law of bedding permeability and vertical permeability under different effective stress conditions and the relationship between them, and concluded that the stress sensitivity of permeability increased with the increase of effective stress difference; Zhao Yanlong [7] and others studied the stress-sensitive mechanism of coal and rock permeability in eastern Yunnan and western Guizhou under effective stress; Li Kang [8] and others systematically studied the evolution law and influencing factors of permeability, and concluded that the permeability of coal and rock decreased in the form of power function with the increase of effective stress, and the decline rate gradually decreased, showing high stress sensitivity. Zhu Jie [9] and others studied the change characteristics of gas phase (helium) permeability under the condition of effective stress change.

Based on this, on the basis of predecessors' research, this experiment plans to take effective stress as the breakthrough point, and use a biaxial infiltration device to carry out infiltration experiments, and further study the influence law of effective stress on the permeability stress sensitivity of coal samples by changing the water pressure and confining pressure respectively.

2. EXPERIMENTAL MATERIALS AND SCHEME DESIGN

2.1. Experimental materials

The briquette is homogeneous in texture and has the average permeability of coal. The experiment with briquette can better show the permeability evolution law of coal samples. In order to avoid the influence of heterogeneity and difference of natural coal samples on the experimental results as much as possible, the standard briquette of Qianjin Coal Mine was directly used in this experiment, which was sealed and brought to the laboratory for biaxial seepage experiment. The basic physical parameters of coal samples used in the test are shown in Table 1.

Table 1. Basic physical parameters of experimental coal samples

Test coal sample	Number	radius /cm	high/cm	quality/g	densityg/cm3
	A1	2.455	9.987	287.93	1.55
A	A2	2.45	9.887	279.95	1.53
	A3	2.46	9.933	255.56	1.37
	B1	2.455	10	290	1.55
B	B2	2.46	9.72	277.75	1.52
	B3	2.46	9.977	273.56	1.46
	C1	2.455	9.937	287.37	1.55
C	C2	2.4515	9.697	274.41	1.52
	C3	2.46	10.033	282.8	1.5

2.2. Scheme design

In order to explore the response law of coal permeability to effective stress, the confining pressure is set to be constant at 2MPa-4MPa, and the water pressure is set to be kept in a low range. At the same time, in order to prevent the coal from soaking in oil, the water pressure value is always kept less than the confining pressure value during loading, as shown in Table 2. According to Karl Terzaghi's effective stress principle, in the actual experiment process, the effective stress is equal to half of the sum of confining pressure minus inlet and outlet water pressure.

Table 2. Design values of confining pressure and water pressure in seepage test

confining pressure /MPa	water pressure /MPa
2	0.4、0.8、1.2、1.6、2.0
3	0.4、0.8、1.2、1.6、2.0、2.4、2.8
4	0.4、0.8、1.2、1.6、2.0、2.4、2.8、3.2、3.6、4.0

2.3. Experimental procedure

1) Place coal samples. The measured coal sample is put into the special coal rubber sleeve of the infiltration device, the rubber sleeve and the fixed ends of the coal bodies on both sides are tightly sealed with iron wires, the water-saturated coal sample is connected with the upper and lower permeable plates by rubber sleeves, so that it fits the top seat, the sample and the base, and finally it is put into the pressure chamber to complete the installation of the confining pressure and water pressure sensors.

2) Air tightness inspection. First, load the confining pressure of 1MPa, and at the same time, load the water pressure until there is water flowing out of the outlet end. Observe whether the water flow at the outlet end is stable, whether there is oil leakage, and whether there are bubbles in the outlet pipe. If there is stable water flowing out, no oil leakage and no bubbles, it proves that the water system and the wall of the specimen have good air tightness.

3) Carry out the coal sample cross water penetration experiment. When the constant confining pressure is 2, 3 and 4 MPa, the water injection permeability of coal bodies with water pressures of 0.4, 0.8, 1.2, 1.6, 2.0, 2.4, 2.8, 3.2, 3.6 and 4.0MPa are measured respectively. For the convenience of analysis, the inlet pressure is set as the set water pressure, and the outlet pressure is set as the atmospheric pressure of 0.101MPa.

4) Measure the seepage flow. Connect the water pressure outlet to the graduated cylinder with a thin tube, and measure the flow and record the data after the water flow is stable; The permeability test time under each gradient is set to 1h;

5) Loading water pressure and confining pressure to the next test point, and repeating step 4).

6) After the test of group 6)A1 is finished, replace the sample specimen, repeat steps 1) ~ 5), and carry out group A2, A3, B1, B2, B3, C1, C2 and C3 tests in turn, and finish the test after measurement.

3. EXPERIMENTAL RESULT

Table 3. Calculation results of coal permeability damage rate

effective stress/MPa	Permeability damage rate/%								
	A1	A2	A3	B1	B2	B3	C1	C2	C3
1.7495	0.449	0.532	0.571	0.675	0.692	0.649	0.675	0.492	0.615
1.5495	0.713	0.764	0.764	0.847	0.853	0.822	0.852	0.767	0.833
1.3495	0.867	0.879	0.902	0.91	0.91	0.894	0.935	0.907	0.93
1.1495	0.929	0.94	0.945	0.956	0.953	0.95	0.972	0.953	0.964
0.9495	-	-	-	-	-	-	-	-	-
2.7495	0.191	0.354	0.523	0.533	0.751	0.807	0.61	0.766	0.666
2.5495	0.793	0.771	0.801	0.79	0.91	0.893	0.853	0.885	0.853
2.3495	0.91	0.888	0.902	0.916	0.948	0.927	0.939	0.928	0.942
2.1495	0.965	0.929	0.957	0.967	0.974	0.967	0.977	0.971	0.978
1.9495	0.977	0.964	0.97	0.983	0.987	0.984	0.99	0.988	0.99
1.7495	0.979	0.969	0.974	0.987	0.99	0.987	0.992	0.99	0.993
1.5495	-	-	-	-	-	-	-	-	-
3.7495	0.61	0.766	0.61	0.767	0.767	0.844	0.765	0.941	0.883
3.5495	0.939	0.963	0.934	0.976	0.963	0.969	0.969	0.963	0.974
3.3495	0.972	0.982	0.97	0.98	0.982	0.981	0.987	0.983	0.986
3.1495	0.986	0.991	0.985	0.991	0.991	0.99	0.993	0.993	0.993
2.9495	0.993	0.996	0.993	0.993	0.996	0.994	0.996	0.996	0.996
2.7495	0.996	0.997	0.995	0.997	0.997	0.997	0.997	0.997	0.997
2.5495	0.997	0.998	0.996	0.998	0.998	0.998	0.998	0.998	0.998
2.3495	0.998	0.998	0.998	0.999	0.998	0.999	0.999	0.999	0.999
2.1495	0.998	0.999	0.998	0.999	0.999	0.999	0.999	0.999	0.999
1.9495	-	-	-	-	-	-	-	-	-

Table 4. Calculation Results of Coal Permeability Curvature

effective stress /MPa	Permeability curvature /%								
	A1	A2	A3	B1	B2	B3	C1	C2	C3
1.7495	27.37	21.78	19.53	10.97	10.62	13.11	5.45	8.11	6.58
1.5495	9.08	8.52	8.32	6.18	6.32	6.84	3.07	2.92	3.12
1.3495	7.06	6.84	6.12	5.3	5.35	5.45	2.72	2.58	2.92
1.1495	8.16	7.18	7.93	4.87	4.72	4.94	3.36	3.45	3.76
0.9495	9.53	9.02	8.83	6.16	5.55	6.46	4.85	4.26	4.52
2.7495	9.86	12.64	11.51	4.39	3.4	4.15	2.18	2.13	1.75
2.5495	2.23	3.58	4.42	1.72	2.49	3.93	1.02	1.67	0.96
2.3495	3.53	4.08	4.28	1.55	2.78	2.86	1.1	1.38	0.88
2.1495	4.35	4.49	4.67	2.09	2.61	2.25	1.42	1.19	1.2
1.9495	7	4.4	6.59	3.25	3.2	3.08	2.38	1.83	1.98
1.7495	7.11	5.9	6.45	4.46	4.46	4.52	3.81	2.89	2.94
1.5495	5.88	4.97	5.36	4.02	4	4.05	3.29	2.73	2.89
3.7495	1.1	0.65	1.09	0.44	0.64	0.44	0.22	0.21	0.22
3.5495	0.51	0.51	0.51	0.34	0.5	0.51	0.17	0.67	0.34
3.3495	1.32	1.32	1.22	1.33	1.28	1.06	0.53	0.43	0.62
3.1495	1.57	1.47	1.45	0.87	1.43	0.94	0.69	0.51	0.64
2.9495	1.88	1.74	1.78	1.19	1.7	1.09	0.77	0.77	0.73
2.7495	2.8	2.54	2.59	1.13	2.48	1.15	0.86	0.87	0.84
2.5495	3.23	2.66	2.83	1.66	2.6	1.75	0.96	1.02	0.92
2.3495	3.44	2.74	2.85	2.12	2.67	2.23	1.21	1.28	1.18
2.1495	3.5	3.07	3.2	2.41	3	2.45	1.51	1.56	1.5
1.9495	3.04	2.8	2.89	2.2	2.73	2.2	1.4	1.46	1.41

4. EXPERIMENTAL ANALYSIS

In this experiment, the effective stress sensitivity of coal permeability is comprehensively evaluated by permeability damage rate and permeability curvature.

4.1. Permeability damage rate

According to Table 3, the fitting curve of effective stress-permeability damage rate of test coal samples (Figure 1) is exported, and combined with the standard SY/T5358-2010 stress sensitivity evaluation index, it can be seen that:

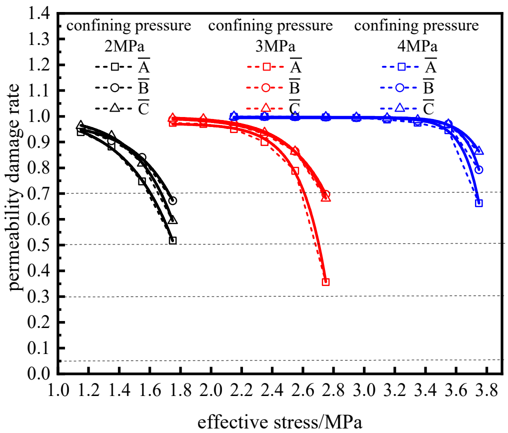


Figure 1. Curve of effective stress-coal permeability damage rate

(1) When the confining pressure is 2MPa and the effective stress is 1.1495MPa-1.5495MPa, the effective stress sensitivity of coal samples in groups A, B and C is very strong, and when the effective stress is 1.5495-1.7495MPa, the effective stress sensitivity of coal samples in groups A, B and C is moderately strong;

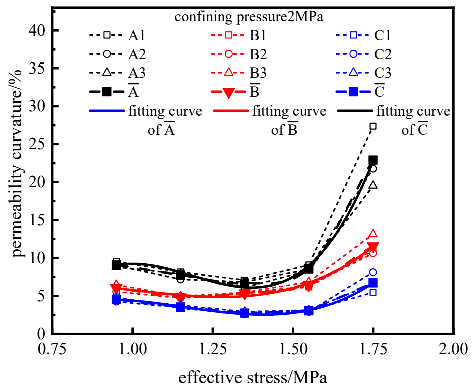
(2) When the confining pressure is 3MPa and the effective stress is between 1.7495 MPa and 2.5495 MPa, the effective stress sensitivity of coal samples in groups A, B and C is strong; when the effective stress is between 2.5495 MPa and 2.7495 MPa, the effective stress sensitivity of coal samples in group A is moderately weak, and that of coal samples in groups B and C is moderately strong;

(3) When the confining pressure is 4MPa and the effective stress is between 2.1495 MPa and 3.7495 MPa, the effective stress sensitivity of coal samples in groups B and C is strong; When the confining pressure is 4MPa and the effective stress is 2.1495MPa-3.5495MPa, the effective stress sensitivity of group A coal samples is strong. When the effective stress is 3.5495-3.7495MPa, the sensitivity of effective stress of coal samples in group A is moderate and strong.

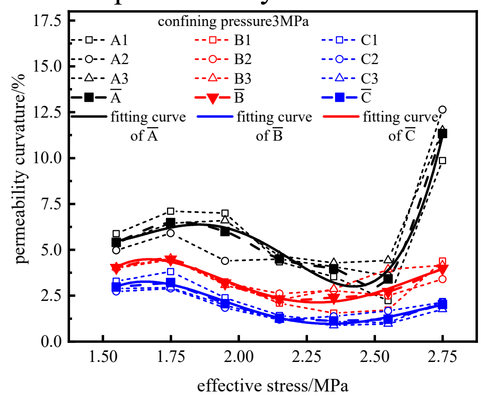
(4) Under the same confining pressure, the greater the effective stress, the greater the permeability reduction and the smaller the permeability damage rate.

4.2. Permeability curvature

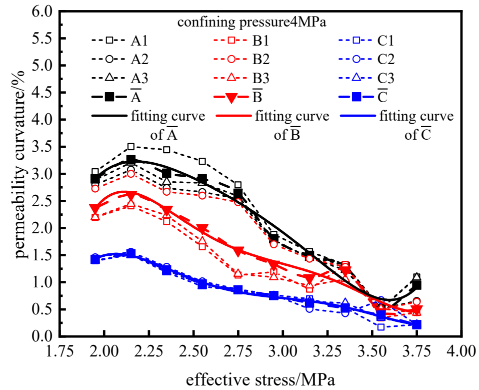
The relationship between permeability curvature and effective stress is shown in Figure 2.



(a) Curve of effective stress-coal permeability curvature under confining pressure of 2 MPa



(b) Curve of effective stress-coal permeability curvature under confining pressure of 3 MPa



(c) Curve of effective stress-coal permeability curvature under confining pressure of 4 MPa

Figure 2. Curve of effective stress-coal permeability curvature

As can be seen from Figure 2:

(1) Within the range of confining pressure of 2MPa and effective stress of 0.9495-1.7495MPa, the permeability curvature of three groups of coal samples shows a trend of slowly decreasing-rapidly increasing with effective stress. It shows that under the confining pressure of 2MPa, with the increase of effective stress, the influence of effective stress on the permeability of three groups of coal samples first decreases and then increases, and the sensitivity first weakens and then increases.

The permeability curvature of coal samples in group A decreased from 9.12% to 6.67% when the effective stress was 0.9495 MPa-1.3495 MPa, and increased from 6.67% to 22.90% when the effective stress was 1.3495 MPa. In group B, the permeability curvature decreased from 6.05% to 4.84% when the effective stress was 0.9495-1.1495MPa, and increased from 4.84% to 11.57% when the effective stress was 1.1495-1.7495MPa. In group C, the permeability curvature decreased from 4.54% to 2.74% when the effective stress was 0.9495-1.3495MPa, and increased from 2.74% to 6.72% when the effective stress was 1.3495-1.7495MPa.

(2) Within the range of confining pressure of 3MPa and effective stress of 1.5 495-2.7495MPa, the permeability curvatures of the three groups of coal samples show a trend of slowly increasing-rapidly decreasing-rapidly increasing with the effective stress. It shows that under the confining pressure of 3MPa, with the increase of effective stress, the influence degree of effective stress on the permeability of three groups of coal samples first increases, then decreases and then increases, and the sensitivity first becomes stronger, then weakens and then becomes stronger.

The permeability curvature of coal samples in group A increased from 5.40% to 6.49% when the effective stress was 1.5495-1.7495MPa, decreased from 6.49% to 3.41% when the effective stress was 1.7495-2.5495MPa, and increased from 3.41% to 11.34 when the effective stress was 2.5495-2.7495MPa. In group B, the permeability curvature increased from 4.02% to 4.48% when the effective stress was 1.5495-1.7495MPa, decreased from 4.48% to 2.32% when the effective stress was 1.7495-2.1495MPa, and increased from 2.32% to 3.98% when the effective stress was 2.1495-2.7495MPa. In group C, the permeability curvature increased from 2.97% to 3.21% when the effective stress was 1.5495-1.7495MPa, decreased from 3.21% to 1.12% when the effective stress was 1.7495-2.3495MPa, and increased from 1.12% to 2.02% when the effective stress was 2.3495-2.7495MPa.

(3) Within the range of confining pressure of 4MPa and effective stress of 1.9495-3.7495MPa, the permeability curvatures of the three groups of coal samples show a trend of slowly increasing-rapidly decreasing-rapidly increasing with the effective stress. It shows that under the confining pressure of 4MPa, with the increase of effective stress, the influence degree of effective stress on the permeability of three groups of coal samples first increases, then decreases and then increases, and the sensitivity first becomes stronger, then becomes weaker and stronger.

The permeability curvature of coal samples in group A increased from 2.91% to 3.01% when the effective stress was 1.9495-2.3495MPa, decreased from 3.01% to 0.51% when the effective stress was 1.9495-3.5495MPa, and increased from 0.51% to 0.95 when the effective stress was 3.5495-3.7495MPa. In group B, the permeability curvature increased from 2.37% to 2.62% when the effective stress was 1.9495-2.1495MPa, decreased from 2.62% to 0.45% when the effective stress was 2.1495-3.5495MPa, and increased from 0.45% to 0.50% when the effective stress was 3.5495-3.7495MPa. In group C, the permeability curvature increased from 1.42% to 1.52% when the effective stress was 1.9495-2.1495MPa, and decreased from 1.52% to 0.22% when the effective stress was 2.1495-3.7495MPa.

On the whole, the smaller the constant effective stress and confining pressure, the greater the curvature of permeability, the greater the influence of effective stress on coal seam permeability and the stronger the sensitivity.

5. SUMMARY

(1) Within the range of confining pressure of 2MPa-4MPa and water pressure of 0.4MPa-4MPa, with the increase of effective stress, the permeability damage rate of coal decreases gradually, and the greater the effective stress, the faster the permeability damage rate decreases.

(2) Within the range of confining pressure of 2MPa-4MPa and water pressure of 0.4MPa-2MPa, with the increase of effective stress, the effective stress-permeability curvature is a differential multiple function.

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