Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 6 (12): 2647-2651, 2006
ISSN 1812-5654

Testing Research on the Coal Specimen Permeability

Peide Sun
Department of Environmental Engineering, Zhejiang Gongshang University, Hangzhou, 310035, China

Abstract: The three-dimensional compression tests to coal specimen containing methane gas were carried out with various confining pressures and pore pressures in this study. The rule for three-dimensional compression deformation on the gas permeability of the coal specimens was systematically studied by the tests. The new empiric equations for the gas permeability of the coal specimens were formulated by the numerical fit of the test data and they were successfully used in the visual numerical simulations for coupled coal seam deformation and methane gas leak flow in parallel coal seams and the visual simulation result for the gas drainage from the coal mining goaf was close to reality.

Key words: Testing research, permeability, coal specimen, methane gas flow, mining engineering

INTRODUCTION

The gas permeability of a coal seam is a physical parameter for the flow ability of methane gas flowing through coal seam and also an important index of the possibility of gas pre-drainage and coal-gas outburst in coal seam. So the study on the measurement method of the coal-seam permeability is the key technology for rock mechanics and mining sciences. It is one of the issues of rock mechanics, which are researched by the following predecessors with Somerton *et al*. (1975), Walsh (1981) and Halpalani and Mopherson (1984). Zhou (1984) put forward bore flow rate method which was calculating the coal-seam permeability using the increasing curve of gas pressure in a borehole based on the principle of similitude. Lin and Zhou (1987) discussed the stress effect on the coal specimen permeability. In the 1990s', Sun (1990, 1991a, b, 1996) deduced the analytic formula for the coal-seam permeability and coal physical-parameters, gas flowing parameters and pore pressure based on the formula for the radial distribution of pore pressure around a borehole in a coal seam. Xu and Xian (1993), they discussed the effect of many factors such as the stress, pore pressure, temperature as well as the earth electricity field parameters on coal specimen permeability. Zhao (1994) and Liang *et al*. (1995) presented the testing relation for coal specimen permeability, stress and pore pressure under the action of the triaxial compression. To investigate into the numerical simulation of coupled models between coal or rock deformation and gas leak flow in the multi-coal-seam, it is necessary to study on the testing empiric equations for coal specimen permeability, stress and pore pressure under the action of triaxial compression tests by Sun (1998, 2000), Sun and Xian (1999), which is the foundation of numerical simulations of the model coupled gas leak flow and coal/rock deformation in multi-coal-seams (Sun, 2004a, b, 2005; Sun and Wan, 2004). Therefore, this study will discuss mostly for the testing empiric equation of the coal specimen permeability under the action of 3-dimensional compression.

MATERIALS AND METHODS

The homogenous coal specimen preparation: Coal specimen was collected from the 6th, 7th, 8th coal seam and intercalation of Shongzhao coal mining district in Chongqing, China according to the research aim. In the experiment, the moulding specimen was adopted. In the process of moulding coal specimen, firstly, the selected coal specimen was grinded and the coal powder whose size is 40~80 mu (diameter is 0.1~0.2 mm) was selected. Then the coal powder was compressed and moulded under 100 Mpa, the size of moulding coal specimen was $\phi 50\times 95$ mm ± 0.25 mm and immediately put the specimen into a oven and dried under 80°C, it made the moisture in the specimen be equal to the moisture content in the coal seam. Finally the resistance strain sensor was plastered on the cylinder of the specimen on the base of request and the specimen was put into the plastic bag in time in order to the testing.

The test equipment and method: The test equipment was made up of DLY-10 test machine as a loading on base of the rigid test machine and the triaxial permeability cell that was made up of triaxial cell and measurement meters. The test equipment was showed Fig. 1. The axial pressure of the coal specimen was given by the machine of triaxial compression tests and the surrounding pressure was given by the oil pump; the coal specimen was separated from the oil route system and gas route system by silicon rubber. The methane gas was penetrated into the top

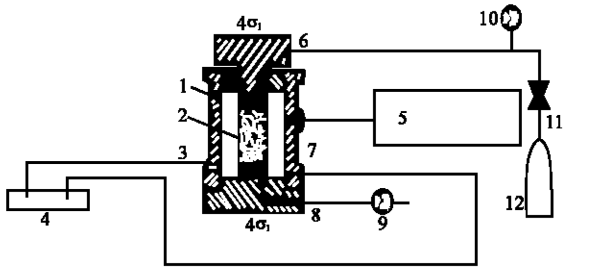

Fig. 1: Sketch of experimental equipment, 1- traixial compression equipments, 2- coal specimen, 3- oil flow out pipe, 4- oil pump, 5- strain-determining instrument, 6- gas flow in pipe, 7- oil flow in pipe, 8- gas flow out pipe, 9- gas flow rate meter, 10- pressure meter, 11- gas pressure reductor, 12- steel bottle containing methane gas

ingoing hole of the triaxial permeability cell, which contains the specimen, from the high-pressure gas steel-bottle (the concentration of CH_4 is 99%) by triaxial compression chamber. It was flowed into the flow meter of the pipe from the outgoing hole in the bottom of the specimen and it was flowed out. The pore pressure in the coal specimen can be adjusted to the value we needed by the reductor. The high precision meter was used to measure the pore pressure and the surrounding pressure. The axial and the transverse strain of the coal specimen were measured by the static and dynamic resistance-strain-instrument in the whole compression process.

The test was carried out step-by-step according to the following. Firstly, the axial pressure was added a little and the specimen was fasten, then the surrounding pressure and the pore pressure was increased stepwise and the surrounding pressure was not small than the pore pressure, which was kept in order to avoid that the methane gas was overflowed because of higher pore pressures. Secondarily, in the test, the sorption of the coal specimen for methane gas must be saturation, at this time, we could, respectively measure the axial and cross direction strain value as well as the gas flow rate and so on. After measurement, the pore pressure of next level was added. Thirdly, after the surrounding pressure and the pore pressure both were adjusted equal to the value we needed, the next level axial pressure was thrown by the test machine. In the whole process, the loading rate was kept about 0.2 Mpa/s in order to keep the static loading.

TEST RESULTS

According to Darcy's law, we could get the calculating equation for the gas permeability of homogeneous coal specimen as following.

$$K = 2P_nQ_nLu/F\,(P_1^2 - P_2^2) \quad (1)$$

where, K is the permeability; P_1 is the pressure of the ingoing end of the specimen; P_2 is the pressure of the outgoing end; P_n is a atmosphere pressure; μ is the dynamic viscosity of methane; F is the cross square of the specimen; L is the length of the specimen; Q_n is the gas flow rate under a atmosphere pressure and temperature is 20°C. According to the test equipment and the size of the specimen, the specimen average was: F = 20.589 cm^2, L = 9.882 cm, $\mu = 1.087 \times 10^{-4}$ cPa, $P_1 = P_n = 1$ kg cm^{-2}. The following Eq. 2 can be obtained by substituting above parameters into Eq. 1.

$$K = 0.1042Q_n\,(P_1^2 - 1) \quad (2)$$

Where, K is the permeability of coal specimen (mD); Q_n is the methane gas flow rate under an atmosphere pressure (cm^3 s^{-1}); P_1 is the pressure of specimen ingoing end (kg cm^{-2}). On the base of the Eq. 2, the test results of the 7th, 8th of coal seam in Shongzhao was showed Table 1 and 2, the typical K-Θ, K-P curve was, respectively showed in the Fig. 2-5.

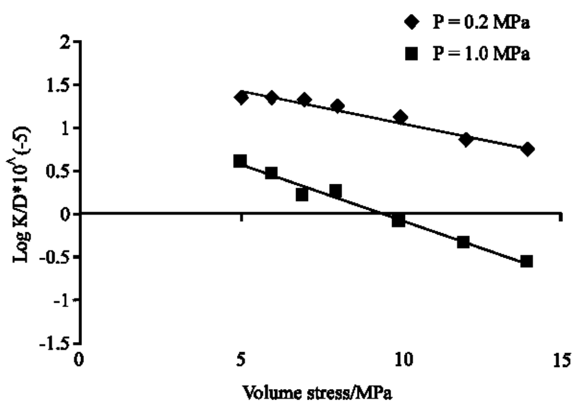

Fig. 2: Relations for K-Θ of coal specimen

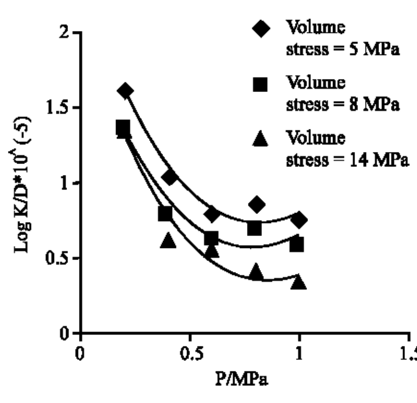

Fig. 3: Relations for K-P of coal specimen

Table 1: Permeability of coal seam 7 in shongzhao of China

Axial pressure (MPa)	Volume stress (MPa)	Confining pressure (Mpa)	The permeability of the coal specimen K (Darcy×10^{-5}) The pore pressure (Mpa) 0.2	0.4	0.6	0.8	1.0
2.0	5.0	1.5	3.882	2.179	1.863	1.987	1.805
3.0	6.0	1.5	3.794	2.040	1.748	1.526	1.580
	7.0	2.0	3.751	1.965	1.537	1.347	1.208
4.0	8.0	2.0	3.477	1.599	1.391	1.242	1.264
	10.0	3.0	3.071	1.298	1.118	0.993	0.903
6.0	12.0	3.0	2.318	0.927	0.815	0.762	0.702
	14.0	4.0	2.086	0.869	0.685	0.634	0.562

Note: No.7-7 coal specimen

Table 2: Permeability of coal seam 8 in shongzhao of China

Axial pressure (MPa)	Volume stress (MPa)	Confining pressure (Mpa)	The permeability of the coal specimen K (Darcy × 10^{-5}) The pore pressure (Mpa) 0.2	0.4	0.6	0.8	1.0
2.0	5.0	1.5	7.880	5.215	3.576	3.311	3.161
3.0	6.0	1.5	6.952	4.172	3.561	3.301	2.528
	7.0	2.0	6.780	3.210	2.553	2.483	2.107
4.0	8.0	2.0	6.489	3.210	2.531	2.470	2.086
	10.0	3.0	4.867	2.781	2.528	1.987	1.805
6.0	12.0	3.0	5.215	2.608	2.525	2.460	2.511

Note: No.8-6 coal specimen

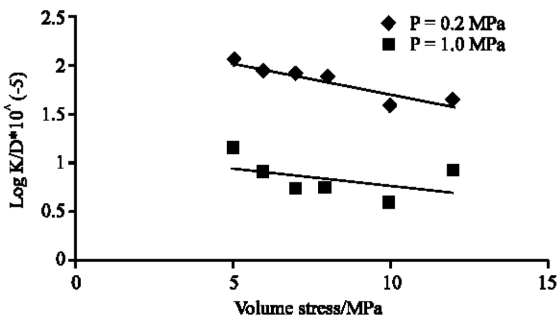

Fig. 4: Relations for K-Θ of coal specimen

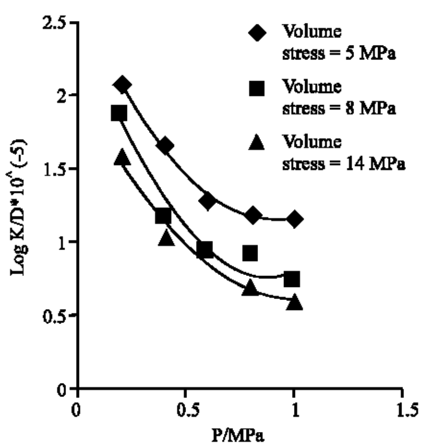

Fig. 5: Relations for K-P of coal specimen

THE PERMEABILITY ANALYSIS

The curve fit of coal specimen permeability: From the tables and figures, it is manifest that it is the negative exponential relation between the coal specimen permeability and volume stress. And in a way of the logarithmic coordinate, it is manifest that it is the parabola relation between the permeability and pore pressure. On the base of the Table 1 and 2, the empiric relational expression of coal specimen permeability was given in Table 3 by data fit.

Analysis of the coal specimen permeability: The variety for coal specimen permeability was very complex; it was correlative with many factors, so it was difficult to be expressed correctly. The key of numerical analysis on coupled for stress field and gas flow field was based on understanding the permeability variety. Through this study we could draw the following conclusions on base of the results for the permeability test of the coal seam 7 and 8 under 3-dimensional compression.

- When the pore pressure was constant relatively, the permeability decreased by negative exponential with the increasing of the effective volume stress.
- The permeability decreased by the parabola under the logarithmic coordinate with the increasing of the pore pressure when the effective volume stress was constant relatively. It is to say that the coal specimen permeability varied by the compound function of the exponential curve and parabola curve with the variety of the pore pressure when the effective volume stress was constant relatively.
- When the ratio of the pore pressure to volume stress was the small, the permeability decreased by the pore pressure increasing; when the pore pressure

Table 3: The empiric relational expression of the coal specimen permeability

The coal specimen mark	Empiric relation	Fit error
Coal seam 7	$k = 0.14419 \exp 0.49739\,\Theta + 2.88375\,p - 0.6493\,\Theta\,p)$	<15%
Coal seam 8	$k = 0.28392 \exp (0.50286\,\Theta + 2.29107\,p - 0.56691\,\Theta\,p)$	<15%

Note: k is the coal specimen permeability, is the effective volume stress, p is the pore pressure. From the table 3, the fit error is good

increased to a infinitesimal point, $P_{min} = a_3\Theta/2a^2$, the permeability decreased to the minimum along the left branch of the parabola. The decreasing range of the permeability increased with the increasing of the effective volume stress. The smaller the pore pressure, the smaller the effective stress coefficient was. It means that the action of the pore pressure for the solid skeleton deformation and the tension degree between crack and pore is very small, the effective stress action to the solid skeleton was mostly with the total stress. In this way, with the increasing of the thickness of gas molecule lay on the pore and crack surface, it made the effective seepage route decreased, it is showed that the resistance for gas molecule movement augmented and the speed of gas flow was slow. This phenomenon was called Klinkenberg effect. In this test, when the volume stress is more than 5 MPa and the pore pressure is less than 0.4 MPa, there was notable Klinkenberg effect.

- When the ratio of the pore pressure to volume stress was more than a constant, the permeability increased with the increasing of the pore pressure. It is to say that the permeability increased by the increasing of the right branch of parabola when the pore pressure increased to an infinitesimal point $P>P_{min}$. At this time, the effective stress coefficient (α) increased rapidly with the increasing of the pore pressure. It means that the contribution of the pore pressure to the effective stress increased. Namely, in this way, the action of the pore pressure for solid skeleton and the tension degree of crack and pore increased. With the increasing of the pore pressure, the contribution was large step by step; which lead to the dynamic balance for the contribution to effective stress between the pore pressure and total stress action to the solid skeleton. At this time, the solid skeleton took place notable deformation and it made the effective tension degree of both crack and pore increase. When $\alpha \rightarrow 1$, the pore and crack of the solid were joined up; The solid skeleton was situation of cracked and the permeability was increased notably. Meanwhile, Klinkenberg effect disappeared with the increasing of the pore pressure and it made the effective transportation route of gas molecule increase so as to speed up gas flow through the coal specimen.

CONCLUSIONS

- The three-dimensional compression tests to the coal specimen containing methane gas were carried out with various compression and pore pressure in this study. The rule for three-dimensional compression deformation on the gas permeability of the coal specimens was systematically studied by the tests. The new formula for gas permeability of the coal specimens were formulated by the numerical fit of test data and they were successfully used in the numerical simulation of the coupled model for coal seam deformation and methane gas leak flow in the parallel coal seams and the numerical simulation result for the gas drainage from coal mining goaf was closer to reality.
- The permeability decreased by the parabola under the logarithmic coordinate with the increasing of the pore pressure when the effective volume stress was constant relatively. It has been proposed that the coal specimen permeability varied by the compound function of the exponential curve and parabola curve with the variety of the pore pressure when the effective volume stress was constant relatively.
- The solid-gas coupled model can be applied in the issues related gas leak flow including mining engineering, gas drainage engineering and mining safety engineering, the prediction of the mining safety range using a protection layer mining due to coal and gas outburst can be efficiently carried out.

ACKNOWLEDGMENTS

This study is supported by Visiting Scholar Foundation of Key Laboratory In University of China. The author would give the grateful to Prof. Xuefu Xian, Prof. Guangzhi Yin and Daijun Zhang and Ph. D. Longjun Xu with Chongqing University for their helpful comments.

REFERENCES

Halpalani, S. and M.J. Mopherson, 1984. The effect of gas evacuation on coal permeability test specimens. Intl. J. Rock Mech. Min. Sci. Geomech. Abstr., pp: 361-364.

Liang, B., M.T. Zhang and Y.S. Pan *et al.*, 1995. The experimental research on the effect of gas on mechanical properties and mechanical response of coal. Chinese J. Geotech. Eng. (In Chinese, with English Abstract), pp: 12-18.

Lin, B.Q. and S.N. Zhou, 1987. Experimental study of permeability of coal specimens containing gas. J. China Inst. Min. Techno. (In Chinese, with English Abstract), pp: 21-28.

Somerton, W.H. *et al.*, 1975. Effect of stress on permeability of coal. Intl. J. Rock Mech. Min. Sci. Geomech. Abstr., pp: 151-158.

Sun, P.D., 1990. A new method for calculating the gas permeability of a coal seam. Intl. J. Rock Mech. Min. Sci. Geomech. Abstr., pp: 325-327.

Sun, P.D., 1991a. A new method for rational arrangement of gas drainage boreholes. Min. Sci. Techno., pp: 105-111.

Sun, P.D., 1991b. Distributions of gas pressure in radial flow fields. Min. Sci. Techno., pp: 409-415.

Sun, P.D., X.F. Xian and D.J. Zhang, 1996. Dynamics of coal gas seepage and its applications. J. Coal Sci. Eng., pp: 67-71.

Sun, P.D., 1998. A study on the interaction mechanics for coal seam deformation, gas leak flow and its numerical simulations. University of Chongqing, Ph.D Thesis, (In Chinese, with English Abstract).

Sun, P.D. and X.F. Xian, 1999. Coupled models for coal seam deformation-gas leakage and its applications. J. China Coal Soc., (in Chinese, with English Abstract), pp: 60-64.

Sun, P.D., 2000. Solid-gas interaction modeling for mining safety range and numerical simulations. J. Coal Sci. Eng., pp: 41-46.

Sun, P.D., 2004a. Numerical simulations for coupled rock deformation and gas leak flow in parallel coal seams. Geotech. Geolog. Engng., pp: 1-17.

Sun, P.D., 2004b. A numerical approach for coupled gas leak flow and coal/rock deformation in parallel coal seams. Intl. J. Rock Mech. Min. Sci., pp: 440-440.

Sun, P.D. and H.G. Wan, 2004. A coupled model for solid deformation and gas leak flow. Intl. J. Numer. Anal. Methods Geomech., pp: 1083-1104.

Sun, P.D., 2005. Advances in Coupled Modeling in Geomechanics. Beijing: China Environmental Science Press.

Walsh, J.B., 1981. Effect of pore pressure and confining pressure on fracture permeability. Intl. J. Rock Mech. Min. Sci. Geomech. Abstr., pp: 429-439.

Xu, J. and X.F. Xian, 1993. Experimental analysis of mechanical-properties for coal containing gas. J. Chongqing Univ. (in Chinese, with English Abstract), pp: 26-32.

Zhao, Y.S., 1994. Rock Fluid Mechanics in Mine. Beijing: China Coal Industry Press. (in Chinese, with English Abstract)

Zhou, S.N., 1984. The result of checking two methods for measuring the permeability of coal seams with a computer. J. China Inst. Min. Technol. (in Chinese, with English Abstract), pp: 38-47.