EXPERIMENT STUDY INTO PERMEABILITY OF BROKEN COAL GAUGE

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ABSTRACT

Much attention should be paid to the permeability of broken rocks in goaf for the sake of water-preserving mining and disaster prevention. Using a special device together with the MTS815.02 Rock Mechanics Test System, we tested the permeability of Broken Coal Gangue during its compacting process, getting the relations between the axial stress and the differential seepage pressure and between the pressure gradient and the seepage velocity. The effect of axial stress, grain size, and seepage velocities on the permeability coefficient is analyzed. The result shows that 1) the permeability varies abruptly when the load reaches the compressive strength of rock samples, 2) for a constant seepage velocity, the differential seepage pressure and the axial stress can be expressed by an exponential function, and 3) for a constant axial stress, the pressure gradient and the seepage velocity can be also expressed by an exponential function, and 4) the permeability coefficient of Broken Coal Gangue with different sizes is closely related with its compaction state and will decrease with the increase of axial stress, having a logarithm functional relation between them.

Key words: Rock Mechanics, Broken Coal Gangue, Axial Stress, Seepage Properties, Test.

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INTRODUCTION

During the coal mining, the artificial drainage and the mining induced water conducting fractures may result in natural drainage, seriously destroying the groundwater resource. In addition, the mining production may also pollute the groundwater resource. After mining, with the breaking of the key strata, a cone of depression in this area may be formed, causing the surface subsidence [1–2]. So, the study into the permeability of rocks has attracted a wide attention. Based on experiments and numerical simulations, many scholars have done a lot of researches on the seepage properties of broken rock and on the permeability of rocks and the coupling behavior of stress-seepage during the breaking of rocks [3–8]. Detailed researches into the relation between rock grain size and its stress level has been carried out, which can provide a theoretical base for engineering applications [9–15]. There may be a water-resisting zone formed by compacting soft rocks in the overlying strata. If that is the case, the water line will resume, and the cone of depression will disappear because of the rainwater supply. Its influence on the ground zoology lies on the time interval from the appearance to disappearance of the cone of depression. The lithology of the soft stratum is commonly Coal Gangue and literatures about the permeability of Coal Gangue are rarely seen. So, it is of great importance to study the permeability of Coal Gangue for the water-preserving mining and for the disaster prevention of the mined-out area.

The permeability of Broken Coal Gangue during its compaction was measured on the MTS 815.02 Rock Mechanics Servo Test System. The relations between the axial stress and the differential seepage pressure and between the pressure gradient and the seepage velocity are obtained to analyze the influence of the axial stress of Broken Coal Gangue with different grain size on the permeability coefficient at different seepage velocities.

TEST SYSTEM AND METHOD

The test system is as shown in Figs. 1–2. The additional device for testing the permeability of Broken Coal Gangue is composed of piston (1), cylinder (2), felt (3), porous plate (4), soleplate (6), O-shaped rubber seal rings and some fastening components. The broken rock (5) is confined in the cylinder. Before testing, put the patent device which carry the Broken Coal Gangue samples into the MTS815.02 Rock Mechanics Test System, then apply loads on the Broken Coal Gangue in stages.

First, an axial force loading is designed with some special levels, then for each force level, four seepage velocities are set. According to the seepage velocity and the steady value of pressure gradient, the permeability corresponding to this axial stress level can be obtained. The geometrical sizes of rock samples are as shown in Table 1

Table 1.: Geometrical size of rock samples.

Particle class		Particle size1	Particle size 2	Particle size 3	Particle size 4
Block /mm		20–25	15–20	10–15	10–5
Code	Coal Gangue	g_1	g_2	g_3	g_4

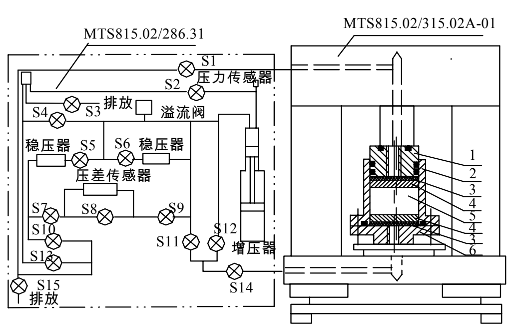

Figure 1.: Test system measuring the seepage properties of broken rock.

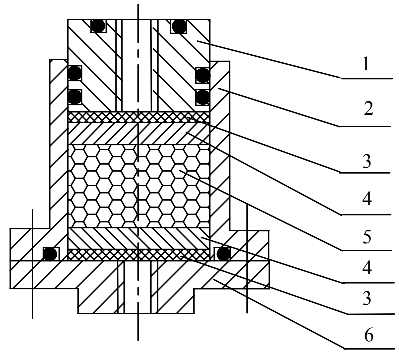

Figure 2.: A patent device measuring seepage properties of broken rock (ZL02219458.4).

EFFECT OF AXIAL STRESS ON PERMEABILITY COEFFICIENT

The curves of the permeability coefficient changing with the axial stress under the different seepage velocities for the rock samples corresponding to different sizes are show in Figure 3.

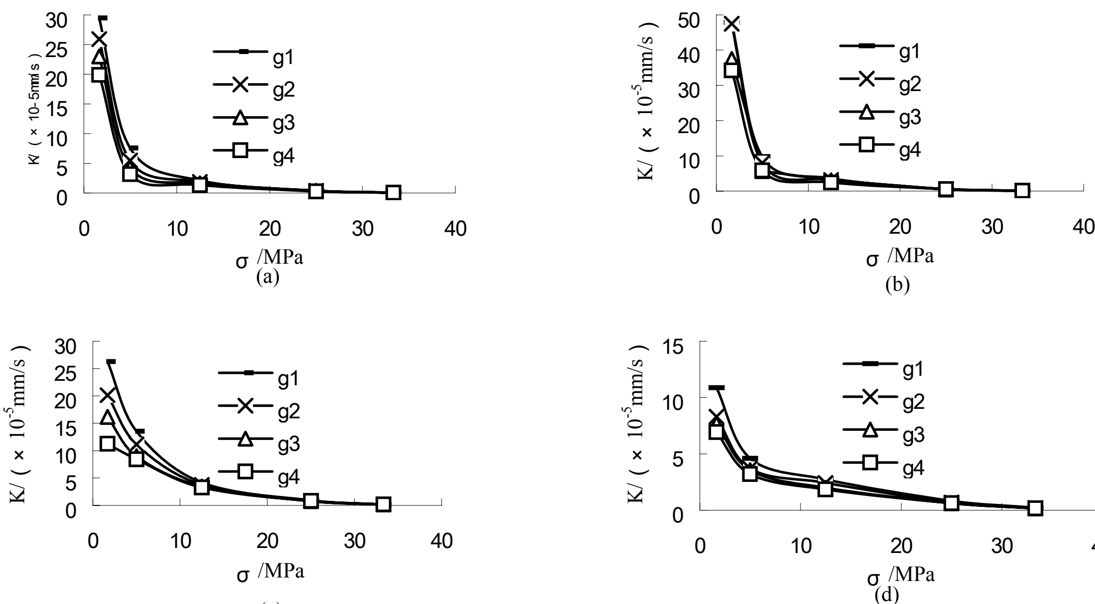

Figure 3.: Curves of permeability coefficient changing with axial stress under the different velocities of the piston. (a) 10/180 /(mm·s^{-1}) (b) 20/180 /(mm·s^{-1}) (c) 40/180 /(mm·s^{-1}) (d) 60/180 /(mm·s^{-1}).

From Fig. 5 we can see that:

1. On the condition of the same axial stress, the smaller the size of rock samples is, the smaller the permeability coefficient is.
2. Under the high axial stress, the permeability coefficient of Broken Coal Gangue is much greater than that of the intact rock(10^{-8} cm/s magnitude).

3. The permeability coefficients of the Broken Coal Gangue corresponding to different sizes are closely related to its compaction state. The permeability coefficient decreases with the increase of axial stress and their relation can be fitted with a logarithm function.
4. The permeability coefficients for the Broken Coal Gangue corresponding to different sizes have a tendency of becoming the same value when their axial stresses increase.

The relation between the permeability coefficient of Broken Coal Gangue and the axial stress can be fitted by a logarithmic function. The function and the correlative coefficient corresponding to rock samples with all kinds of geometrical sizes are shown in Table 2 ($\sigma_0 = 1$ MPa). As a result, the correlative coefficients are all greater than 0.95, which means the parameter have a good relativity in the seepage process.

Table 2.: Relationship of permeability coefficient and axial stress.

V/(mm/s)	Block	Regression equation	Correlative coefficient (r^2)
10/180	g1	$K = -4.564\ln(\frac{\sigma}{\sigma_0}) + 14.525$	0.955
	g2	$K = -3.233\ln(\frac{\sigma}{\sigma_0}) + 10.508$	0.979
	g3	$K = -2.418\ln(\frac{\sigma}{\sigma_0}) + 7.995$	0.985
	g4	$K = -1.795\ln(\frac{\sigma}{\sigma_0}) + 5.995$	0.996
20/180	g1	$K = -5.759\ln(\frac{\sigma}{\sigma_0}) + 18.780$	0.988
	g2	$K = -4.678\ln(\frac{\sigma}{\sigma_0}) + 15.368$	0.993
	g3	$K = -3.241\ln(\frac{\sigma}{\sigma_0}) + 11.042$	0.995
	g4	$K = -3.3332\ln(\frac{\sigma}{\sigma_0}) +$	0.995
40/180	g1	$K = -7.947\ln(\frac{\sigma}{\sigma_0}) + 25.693$	0.963
	g2	$K = -6.534\ln(\frac{\sigma}{\sigma_0}) + 21.252$	0.974
	g3	$K = -5.159\ln(\frac{\sigma}{\sigma_0}) + 17.04$	0.986
	g4	$K = -4.782\ln(\frac{\sigma}{\sigma_0}) + 15.875$	0.985
60/180	g1	$K = -2.312\ln(\frac{\sigma}{\sigma_0}) + 8.534$	0.954
	g2	$K = -1.855\ln(\frac{\sigma}{\sigma_0}) + 6.808$	0.974
	g3	$K = -1.818\ln(\frac{\sigma}{\sigma_0}) + 6.502$	0.998
	g4	$K = -1.603\ln(\frac{\sigma}{\sigma_0}) + 5.827$	0.999

EFFECT OF THE SEEPAGE VELOCITY ON PRESSURE GRADIENT

The curves of the seepage pressure gradient varying with the seepage velocity under different axial compressive stresses for the rock samples with all kinds of geometrical sizes are shown in Figure 4.

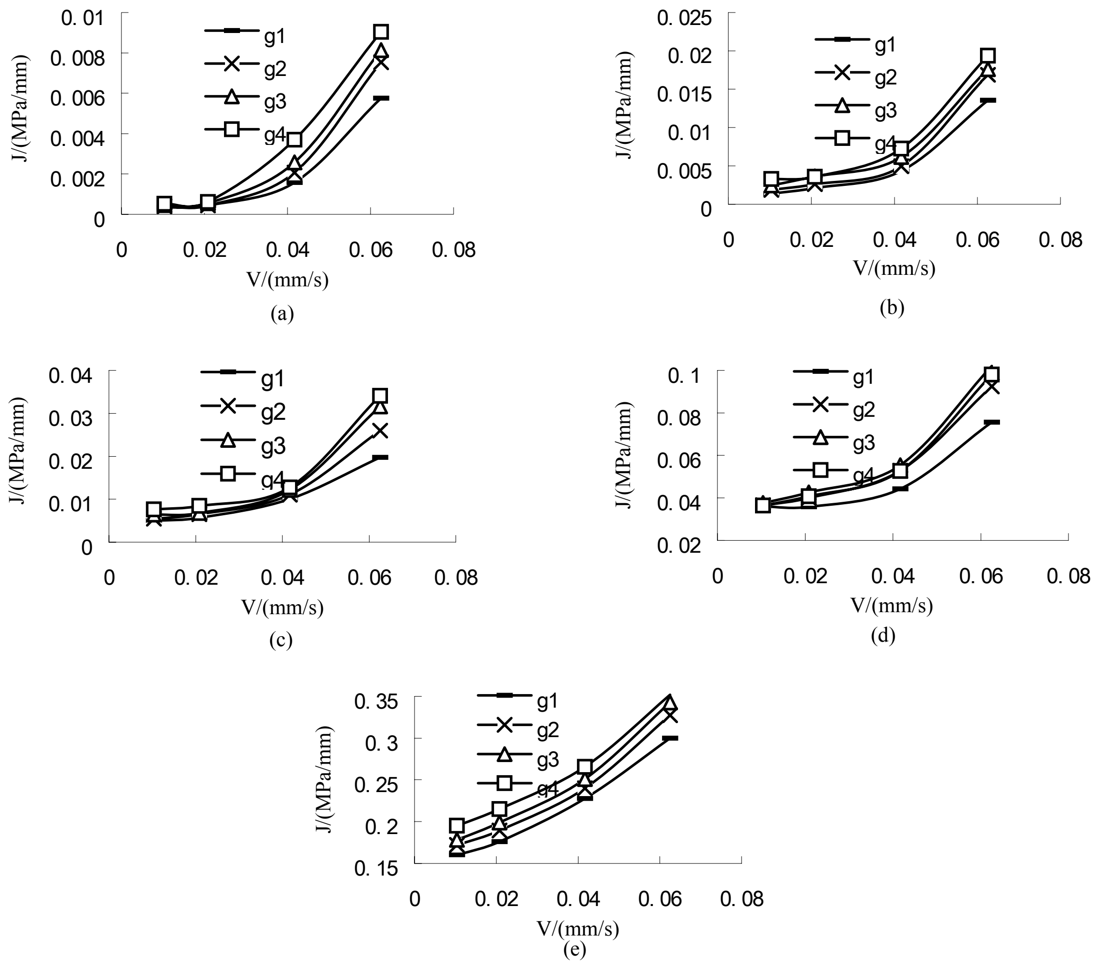

Figure 4.: Curves of the seepage pressure gradient varying with the seepage velocity under different axial compressive stresses.
(a) 1.7 MPa (b) 5.0 MPa (c) 12.5 MPa (d) 25 MPa (e) 33.3 MPa

From Figure 4. we can see that:

1) On the condition of the same axial stress and the same seepage velocity, the smaller the geometrical size of rock samples is, the greater the pressure gradient is.
2) On the condition of the same seepage velocity, the greater the axial stress is, the greater the pressure gradient is.
3) When the axial stress holds invariable, the pressure gradient of Broken Coal Gangue increases with the seepage velocity; when the seepage velocity is small, the

change is slow, but when the velocity achieves a certain value, the pressure gradient rises sharply.

The relation between the pressure gradient and the seepage velocity of Broken Coal Gangue can be fitted by an exponential function. The function and the correlative coefficient corresponding to the rock samples with all kinds of geometrical sizes are shown in Table 3. As a result, the correlative coefficients are all greater than 0.96, which means the parameter have a good relativity in the seepage process.

Table 3.: Relationship between the pressure gradient and seepage velocity

Axial stress /MPa	Block	Regression equation	Correlative coefficient (r^2)
1.667 8	g1	$J = 0.0002e^{55.514V}$	0.995
	g2	$J = 0.0002e^{59.738V}$	0.985
	g3	$J = 0.0002e^{58.517V}$	0.984
	g4	$J = 0.0002e^{59.265V}$	0. 987
5	g1	$J = 0.0008e^{41.315V}$	0.962
	g2	$J = 0.0011e^{39.863V}$	0.995
	g3	$J = 0.0016e^{35.123V}$	0.990
	g4	$J = 0.0019e^{33.036V}$	0.998
12.5	g1	$J = 0.0035e^{26.788V}$	0.994
	g2	$J = 0.0037e^{29.843V}$	0.995
	g3	$J = 0.004e^{31.031V}$	0.996
	g4	$J = 0.0049e^{28.464V}$	0.998
25	g1	$J = 0.0237e^{17.665V}$	0.966
	g2	$J = 0.024e^{20.956V}$	0.979
	g3	$J = 0.023e^{23.016V}$	0.962
	g4	$J = 0.028e^{18.629V}$	0.972
33.3	g1	$J = 0.135e^{12.316V}$	0.999
	g2	$J = 0.150e^{11.597V}$	0.996
	g3	$J = 0.154e^{12.466V}$	0.993
	g4	$J = 0.171e^{11.258V}$	0.993

EFFECT OF AXIAL PRESSURE ON DIFFERENTIAL SEEPAGE PRESSURE

The curves of differential seepage pressure changing with the stress are shown in Figure 5. for the confined rock samples with all kinds of grain sizes during the compaction.

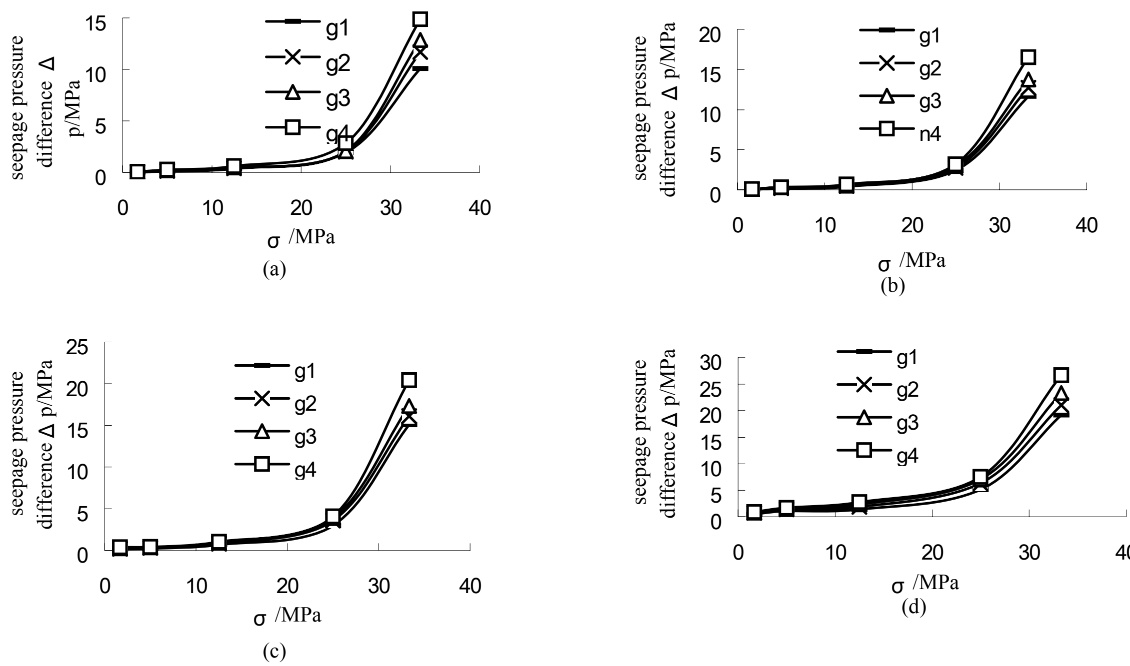

Figure 5.: Relation between differential seepage pressure and stress corresponding to different piston velocities of *v*.
(a) *v* =10/180 mm/s (b) 20/180 mm/s (c) 40/180 mm/s (d) 60/180 mm/s

From Figure 5. we can see that:

1) At the early loading stage, the seepage pressure difference increases slowly, but when the load achieves a certain value (about 25 MPa), the differential seepage pressure increases rapidly.
2) Under the condition of the same axial stress and the same seepage velocity, the smaller the geometrical size of rock samples is, the bigger the differential seepage pressure is.
3) When the seepage velocity keeps a constant value, with the increase of the axial compressive stress, the differential seepage pressure of the Broken Coal Gangue also increases and have an exponential relation between them.
4) The seepage velocity affects the differential seepage pressure. When the axial stress keeps a constant value, the higher the seepage velocity is, the higher the differential seepage pressure is.

The relation between the differential seepage pressure of Broken Coal Gangue and the axial stress can be fitted by an exponential function. The function and the correlative coefficient corresponding to all kinds of geometrical sizes of rock samples are shown in Table 4. As a result, the correlative coefficients are all greater than 0.98, which means the parameter have a good relativity in the seepage process.

Table 4.: Relationship between the seepage pressure difference and the axial stress.

V/(mm/s)	Block	Regression equation	Correlative coefficient (r^2)
10/180	g1	$\Delta p = 0.0345e^{0.169\sigma}$	0.984
	g2	$\Delta p = 0.0445e^{0.164\sigma}$	0.996
	g3	$\Delta p = 0.0562e^{0.159\sigma}$	0.996
	g4	$\Delta p = 0.0722e^{0.158\sigma}$	0.987
20/180	g1	$\Delta p = 0.0463e^{0.165\sigma}$	0.997
	g2	$\Delta p = 0.0546e^{0.163\sigma}$	0.999
	g3	$\Delta p = 0.0727e^{0.156\sigma}$	0.999
	g4	$\Delta p = 0.0809e^{0.157\sigma}$	0.991
40/180	g1	$\Delta p = 0.1136e^{0.141\sigma}$	0.993
	g2	$\Delta p = 0.0546e^{0.164\sigma}$	0.989
	g3	$\Delta p = 0.0727e^{0.157\sigma}$	0.989
	g4	$\Delta p = 0.0809e^{0.158\sigma}$	0.981
60/180	g1	$\Delta p = 0.461e^{0.105\sigma}$	0.999
	g2	$\Delta p = 0.651e^{0.0989\sigma}$	0.997
	g3	$\Delta p = 0.735e^{0.0989\sigma}$	0.993
	g4	$\Delta p = 0.841e^{0.0982\sigma}$	0.998

DISCUSSION

The permeability of Broken Coal Gangue during its compaction are effectively measured on MTS815.02 Rock Mechanics Servo Test System with the help of a special device. The relations between the axial stress and the differential seepage pressure and between the pressure gradient and the seepage velocity were obtained. The influence of the axial stress, grain sizes and seepage velocities on the permeability coefficient was analyzed.

The reasons for the above mentioned characteristics of permeability of Broken Coal Gangue are probably that the Coal Gangue has a tendency of sliming and, under the high compressive stress, it is likely to become sticky when it encounters water. Thus it has a tendency of forming the integrity rock again. With the compressive stress increasing, the Broken Coal Gangue will not only rearrange its particles and compact the fissures, but also become more sticky. The sticky property makes the fissures become denser, resulting in a great increase of pore pressure and a rapid decrease of permeability coefficient. Therefore, the small sized broken rock may easily get a lower permeability coefficient under the compacting action. Because of its sticky property, the small sized rock is more likely to form a relative intact rock under the same compacting action than the large sized rock. The

Coal Gangue is sticky and is low in strength with its edges and corners being quite easy to break. Therefore, the permeability coefficient has already declined to a quite low value at an axial stress of 25 MPa and when axial stress exceeds 25 MPa, the permeability coefficients for all kinds of rock samples become nearly the same.

CONCLUSIONS

1) The permeability coefficient of Broken Coal Gangue with different grain sizes is closely related with its compaction state; the permeability coefficient will decrease as the increase of axial stress; and they can be fitted by a logarithmic function.

2) The differential seepage pressure and the axial stress can be expressed by an exponential function under the same seepage velocity; the pressure gradient and the seepage velocity under the same axial stress can be also expressed by an exponential function .

3) The permeability varies sharply when the load reaches the compressive strength of rock samples.

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