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Test study on permeability properties of the sandstone specimen under triaxial stress condition

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Abstract

During the formation of mining space, the stress of rock within the scope of disturbance of mining redistributes, and a range of rock in front of and on the both sides of tunnel is damaged under concentration stress. Due to the change of the stress, some of cracks in damaged rock open and the others close, which greatly affects the flow of gas in rock. The change and development of cracks in rock and the unusual flow of gas are two main reasons that cause all kinds of gas accidents to happen in roadways. Based on this fact, a water seepage test was conducted in a sandstone specimen under triaxial stress condition by using MTS815.02 Electro-Hydraulic Servo-controlled Rock Mechanics Testing System. During the test, the deformation parameters and permeability of the specimen at twelve testing points were measured. Through the analysis of experimental results from a macroscopic perspective, the laws that the permeability changed respectively with axial strain, hoop strain and volumetric strain in the completely stress-strain process of the sandstone specimen were obtained. By comparison of influences of axial strain and hoop strain on the permeability in the completely stress-strain process of the sandstone specimen, it was concluded that hoop strain dominated the change of permeability at elastic stage and plastic stage of rock deformation under triaxial stress.

Keywords: the completely stress-strain; circumferential deformation; volumetric deformation; permeability

1. Introduction

In China, Most of coal resources are deeply buried, and 95% of the coal resources need to be mined underground[1-2]. In the early period of coal mining, large numbers of tunnels must be prepared before
mining coal, but in the course of preparing roadways, all kinds of gas accidents often occur, coal and gas outburst has also become a major accident in high gas mines and coal and gas outburst mines. There are two reasons for causing a variety of gas accidents in roadways, one reason is that mining roadways makes the original pressure balance of the mine destroyed, and drives the original pressure disturbance of the mine within the scope of mining redistribute, which brings about the change of the permeability of the rocks; the other reason is that due to the disturbance of mining, the original gas dynamic pressure balance in coal seam is ruined, a large number of adsorbent gas desorbs with the change of external conditions, which leads to the gas pressure inside coal increases. Based on the above fact, the study of change of permeability of rock in the completely stress–strain process has an important practical significance to guide safe mining.

At present, the main researches in this field are as follows: in 2000, Peng SP et al [3] conducted seepage tests in different rocks in the completely stress–strain process, and a general curve that the permeability of rock varied with the axial strain was obtained; in 2007, Yang YJ [4,5] did seepage test in coal, and the experimental results showed that the trend of the curve of the permeability varied with the strain keep the same with that of the curve of stress varied with strain, but the maximum permeability fell behind the peak of stress, the experimental results also indicated that confining pressure had a more significant impact on coal than other rocks. According to the previous research, it can be seen that the previous studies mainly focused on the relationship of permeability and axial deformation of rock, there were a little research on the impact of circumferential deformation and volumetric deformation on the permeability. To better understand the law of the changes of the permeability in the completely stress-strain process of rock, this paper will study the changes of permeability with circumferential deformation and volumetric deformation in the completely stress-strain process of rock.

2. Experimental system and principles

The test uses MTS815.02 Electro-Hydraulic Servo-controlled Rock Mechanics Testing System. The system consists of three separate closed-loop servo-control systems, they are axial compression loading system (Axial load ≤ 1700kN), the confining pressure loading system (Confining pressure ≤ 45MPa) and the pore water pressure loading System (Pore water pressure ≤ 45MPa).

The selected specimen used in the test is the sandstone of 8 # roof in Zhuxianzhuang coal mine. And it is Cylindrical, height 107.5mm, diameter 53.2mm, and uniaxial compressive strength 57.5MPa. Based on the curve of stress and strain of the sandstone, which obtained from the stress-strain test, the twelve testing points are designed, which are at twelve axial displacements of the sandstone, they are 0.07mm, 0.17mm, 0.41mm, 0.64mm, 0.85mm, 1.18mm, 1.38mm, 1.41mm, 1.50mm, 1.62mm, 1.73mm, 1.83mm. When the rock is loaded into the twelve points respectively, water seepage tests are conducted.

The principles of the water seepage test are shown in Figure 1. P1 is axis pressure, P2 the confining pressure, P3 water pressure on the top of the rock, P4 water pressure on the bottom of the rock. In order to make water pressure evenly acting on the both ends of the rock sample, there are two steel plates with uniform distribution of holes respectively placed on the upper and bottom ends of the rock specimen. The upper pressure head is on the top of the upper steel plate, and the bottom pressure head is under the bottom plate, the upper and bottom pressure head both have a vertical hole in their centers to achieve water seepage of rock specimen. The plastic materials are used to seal the specimen, so that the water can flow through the specimen without overflow.
3. Experimental data process

Currently, there are two ways to measure the rock permeability in laboratory. One is the steady method, it is suitable for the rock with high permeability, when using this method, the seepage test require a long time. The steps of the test in this method are as follows: first, set a different constant pore pressure on each end of the rock and keep the pressure difference on both ends of the rock constant, then, measure fluid flow through the rock, finally, calculate the permeability of rock using the pressure difference and fluid flow from Darcy's law. Compared with the steady method, the transient method is the other way to measure rock permeability, it is applied to the rock with low permeability, and it requires a short time to finish the test, when water is used as liquid medium of seepage test, the transient method is more perfect than the steady method. The process of the test in transient method is as follows: provide a pressure pulse on one end of the specimen and then measure the values of osmotic pressure differences at different time points to calculate indirectly the permeability. According to the comparison above, this test should use the transient method to measure the rock permeability in the completely stress-strain process of the rock.

The formula of rock permeability \( k \) in Transient method can be expressed as:

\[
k = \frac{1}{5} \sum_{i=1}^{n} 526 \times 10^{-6} \times \lg \left( \frac{\Delta p(i - 1)}{\Delta p(i)} \right)
\]

Where, \( k \) is the rock permeability; \( n \) is the number of rows of data collections; \( \Delta p(i-1) \) is the osmotic pressure difference in the first \((i-1)\) row of data collections; \( \Delta p(i) \) is the osmotic pressure difference in the first \(i\) row of data collections.

According to the values of the osmotic pressure difference automatically collected by the computer during the test, the values of the permeability of the specimen in different testing points can be calculated from formula (1).
4. Results and analysis

From the test, the main results obtained are shown in Table 1, Fig.1, Fig.2, Fig.3, Fig.4 and Fig.5. Table 1 indicates deformation parameter and the permeability of sandstone, Figure 2 indicates curve of the changes of the stress and hoop strain of sandstone with the axial strain, Figure 3 indicates curve of the changes of the permeability of sandstone and circumferential strain with axial strain, Figure 4 indicates the curve of the changes of stress and volumetric strain of sandstone with the axial strain, Figure 5 indicates the curve of the changes of the volumetric strain and permeability of sandstone with the axial strain.

Table.1 deformation parameter and the permeability of sandstone table

<table>
<thead>
<tr>
<th>X/mm</th>
<th>stress σ/MPa</th>
<th>Axial strain ε1/%</th>
<th>Hoop strain ε2/%</th>
<th>Volumetric strain ε%/</th>
<th>permeability k/×10^-3md</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.07</td>
<td>15.10177</td>
<td>0.06378</td>
<td>0.01314</td>
<td>0.0375</td>
<td>0.085521</td>
</tr>
<tr>
<td>0.17</td>
<td>32.20355</td>
<td>0.16095</td>
<td>0.00651</td>
<td>0.14793</td>
<td>0.005521</td>
</tr>
<tr>
<td>0.41</td>
<td>76.65791</td>
<td>0.38595</td>
<td>0.02072</td>
<td>0.34451</td>
<td>0.026564</td>
</tr>
<tr>
<td>0.64</td>
<td>116.8746</td>
<td>0.59477</td>
<td>0.0425</td>
<td>0.50977</td>
<td>0.075689</td>
</tr>
<tr>
<td>0.85</td>
<td>155.7781</td>
<td>0.79525</td>
<td>0.07187</td>
<td>0.65151</td>
<td>0.053218</td>
</tr>
<tr>
<td>1.18</td>
<td>211.0965</td>
<td>1.09782</td>
<td>0.15901</td>
<td>0.7798</td>
<td>0.136783</td>
</tr>
<tr>
<td>1.38</td>
<td>227.3473</td>
<td>1.28652</td>
<td>0.6408</td>
<td>0.00492</td>
<td>0.276512</td>
</tr>
<tr>
<td>1.41</td>
<td>136.9009</td>
<td>1.31121</td>
<td>1.26637</td>
<td>-1.22153</td>
<td>0.367117</td>
</tr>
<tr>
<td>1.5</td>
<td>131.9009</td>
<td>1.39386</td>
<td>1.45514</td>
<td>-1.51642</td>
<td>0.578185</td>
</tr>
<tr>
<td>1.62</td>
<td>130.6632</td>
<td>1.50872</td>
<td>1.78086</td>
<td>-2.053</td>
<td>0.535135</td>
</tr>
<tr>
<td>1.73</td>
<td>113.0992</td>
<td>1.60747</td>
<td>2.19659</td>
<td>-2.78571</td>
<td>0.306371</td>
</tr>
<tr>
<td>1.83</td>
<td>105.5483</td>
<td>1.70623</td>
<td>2.37942</td>
<td>-3.05261</td>
<td>0.338134</td>
</tr>
</tbody>
</table>

Fig2 the curve of the change of stress and circumferential strain with the axial strain

Fig.3 the curve of the change of circumferential strain and permeability with the axial strain
As shown in Figure 2 and 3, at the stage of elastic deformation of the rock, the axial strain is much larger than the circumferential strain, axial deformation dominates the change of rock permeability, and the permeability of the rock rise slowly at this stage. When the rock go into the stage of plastic deformation, the speed of circumferential deformation increases, the experimental results show that the growth rate of the permeability at this stage was significantly greater than that at the elastic stage; at the softening stage, the speed of circumferential deformation dramatically increase, and the circumferential strain exceed the axial strain. the circumferential strain is dominant, and the permeability of the rock rise to the peak; at residual strength stage, the axial and circumferential deformation both have a greater speed than before, but at this stage the permeability was in downward trend.

Make the Orientation of compression positive, so a positive value of volumetric deformation indicates compression, and a negative value indicates expansion. As shown in Figure 4, the volumetric deformation of sandstone can be divided into three stages, at the first stage, the volume of the sandstone decrease due to compression; at the second stage, the volume of rock specimen expand, and gradually recovered to the initial volume; at the third stage, the volume of rock specimen become larger and larger.

The changes of permeability can be analyzed from the three stages of the volumetric strain of rock specimen. As shown in Figure 5, at the first stage, the rock specimen is compressed into a smaller size, the permeability decreases at first and then increases slowly. The lowest penetration rate emerge at this stage; at the second stage, the volume of the specimen starts to swell, the penetration rate has a rapid growth; at the third stage, the volume of rock samples abruptly grow, permeability first increase and then decrease, and the maximum of the permeability lags behind the mutation of volumetric strain.

5. Conclusion

(1) The permeability of the rock increases with the circumferential deformation and axial deformation of rock before the softening stage of the rock. Compared with axial deformation, the circumferential deformation of the rock Play a leading role in taking control of the change of rock permeability at elastic stage and plastic stage.

(2) the rock has different permeability in a certain size that keeps the same in the condition of compression and expansion of the rock, which means that there is no simple linear relationship between the permeability and the volumetric deformation of the rock.
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References


