Triaxial test of coal-rock under effective confining pressure

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Abstract. Based on the coal samples from a layer of a block in Xinjiang, the coal-rock triaxial stress test was carried out in 15 groups, and the fracture mechanism and physical properties of coal-rock under low confining pressure, medium confining pressure and high confining pressure were determined. The test shows that under low confining pressure, the elastic modulus of the coal-rock is slowly rising as it is compacted. Under the medium confining pressure, the coal-rock has completed the compaction and turned into an elastic medium, and the elastic modulus has a linear increase trend. Under high confining pressure, the elasticity of coal-rock is destroyed and the resulting elastic modulus will go linearly to change trends. And the larger the confining pressure interval value, the greater the cohesive force and the smaller the friction angle.

1. Introduction
The study of triaxial stress of coal-rock has very important theoretical value for explaining the mechanical behavior of coal seam and its fracture mechanism. It is also of great guiding significance and practicality for the coalbed methane fracturing stimulation project. Triaxial compression test is the basic way to study the deformation and strength characteristics of rock mass under triaxial stress. Li made a quantitative analysis of the fracture mechanism of coal-rock.[1] The characteristics of coal-rock with lower confining pressure and higher confining pressure are found. Liu do the test piece of raw coal taken from the -780 m elevation b10 coal seam in Huainan mining area, through mts815-04 electro-hydraulic servo test system performs the conventional triaxial compression test of raw coal under high stress to study the deformation, strength, parameters and failure characteristics of coal-rock.[2] In 2007, Zhang realized triaxial test under multi-stage confining pressure on rigid servo triaxial test machine by using a single block or a few specimens in a simple control way, and analyzed the test results of sandstone and mudstone. The cohesive force determined by this method is lower than the conventional test value and the internal friction Angle does not change much.[3]

This paper will study the characteristics of coal-rock compressive strength and cohesion under the confining pressure of coal-rock in various sections, and provide data and theoretical support for coal seam gas cracking.

2. Triaxial stress test

2.1 Test design
In order to effectively increase the production of underground resources, we usually need to test the shear strength of underground rock mass to provide data support for fracturing design. The internal friction angle can reflect the amount of friction in the rock. The larger the internal friction angle is, the larger the internal friction is, so it is an important indicator reflecting the mechanical properties of rock fracture.

The triaxial experiment can produce a truly uniform and known stress distribution throughout the sample of the rock sample. Therefore, according to the data obtained from the triaxial experiment of the rock, the molar envelope can be correctly drawn, and the obtained shear strength of the rock is relatively straight. Shear experiments are more reliable. In the triaxial stress test, the formula of the cohesion and friction angle of the rock mass can generally be expressed as:

\[ \sigma_1 = \sigma_c + m \sigma_3 \]

\[ c = \frac{\sigma_c (1 - \sin \varphi)}{2 \cos \varphi} \]

\[ \varphi = \arcsin \frac{m - 1}{m + 1} \]

where, \( c \) is the cohesion of the rock mass, \( \varphi \) is the internal friction angle of the rock mass, \( \sigma_c \) is the stress intercept of the ordinate of the \( \sigma_1 \) and \( \sigma_3 \) relationship curves, and \( m \) is the slope of the \( \sigma_1 \) and \( \sigma_3 \) relationship curves.

We also need to consider the stress triaxiality during the research process, that is, \( \frac{\sigma_m}{\sigma_c} \). Wherein, the hydrostatic pressure is the average value of the three-axis principal stress, that is, \( \sigma_m = \frac{1}{3} (\sigma_1 + \sigma_2 + \sigma_3) \). And the mises equivalent stress is expressed as

\[ \sigma_e = \sqrt{ \frac{1}{2} (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2 } \]

The test was divided into three groups of five samples each. Each sample in each group was tested under effective confining pressure. The three sets of data obtained will be analyzed and interpreted in Section 2.4 to find the fracture mechanism of the coal-rock mass.

2.2 Coal-rock sampling

In order to make the study of the mechanical properties of coal-rock versatile, we adopt the standard cylindrical pattern specified by the International Society of Rock Mechanics. The test sample was taken from a large piece of coal with a solid shape and a hard texture in a horizontal layer of a block in Xinjiang.

In the process of drilling the core, we use a lower speed to reduce the cooling water, and avoid the high speed to destroy the integrity of the core. After taking the sample and grinding it into a standard shape, each sample is packaged in a plastic film and detailed labelled to prevent sample damage and confusion. The core length is 100mm and the diameter is 50mm, as shown in the following figure:
A total of 22 coal cores were obtained, and 15 relatively intact coals were screened and randomly divided into three groups, numbered 1# to 15#.

2.3 Determination of effective confining pressure
In the test, different confining pressures are needed as variables to determine the physical properties of the underground rock mass. In order to meet the reliability of the test results, we need to strictly simulate the force of the underground rock mass. Coal-rock can maintain this property under low confining pressure, but under high confining pressure, coal-rock will become a continuous medium and more resistant to pressure.[4] Therefore, each of our tests should keep the samples in the same physical properties to ensure the accuracy of the experiment. A confining pressure above 15 MPa is referred to as a higher confining pressure, and the test results satisfy this setting. Therefore, we set the effective confining pressure for the three groups of experiments to 1~5MPa, 11~15MPa, 21~25MPa, and take the integer.

2.4 Experimental result
Table 1. Experimental results of triaxial mechanical parameters of coal-rock

| Core number | Confining pressure | Poisson's ratio | Elastic Modulus | Compressive strength | Cohesion | Internal friction angle |
|-------------|---------------------|----------------|-----------------|----------------------|----------|------------------------|
| 1#          | 1                   | 0.313          | 2.33            | 46.2                 |          |                        |
| 2#          | 2                   | 0.324          | 2.48            | 48.8                 |          |                        |
| 3#          | 3                   | 0.236          | 2.62            | 50.9                 |          |                        |
| 4#          | 4                   | 0.248          | 2.73            | 51.6                 |          |                        |
| 5#          | 5                   | 0.264          | 2.81            | 52.2                 |          |                        |
| 11#         | 11                  | 0.237          | 3.45            | 62.79                | 1.28     | 42.78                  |
| 12#         | 12                  | 0.246          | 4.18            | 64.33                |          |                        |
| 13#         | 13                  | 0.239          | 4.97            | 65.76                |          |                        |
| 14#         | 14                  | 0.258          | 5.95            | 67.16                | 3.65     | 31.58                  |
| 15#         | 15                  | 0.264          | 7.95            | 68.38                |          |                        |
| 21#         | 21                  | 0.271          | 7.92            | 87.03                | 12.70    | 24.13                  |
|   |   |   |   |   |
|---|---|---|---|---|
| 22# | 22 | 0.257 | 9.83 | 92.14 |
| 23# | 23 | 0.264 | 9.72 | 97.27 |
| 24# | 24 | 0.268 | 10.14 | 105.44 |
| 25# | 25 | 0.332 | 11.27 | 107.78 |

Based on the above data, we conclude that the compressive strength of the coal and the elastic modulus are positively correlated with the confining pressure, so we perform a polynomial fit on the experimental data.

\[
S = 0.0059P_c^3 - 0.1452P_c^2 + 2.5414P_c + 43.804
\]

We can see that the fitting accuracy between the obtained curve and the data is very high, reaching more than 95%. Therefore, the curve can accurately predict the compressive strength of coal-rock according to the confining pressure, and the result is highly confident. However, when we perform polynomial fitting on the elastic modulus, we find that the fitting effect of the third-order polynomial is not good, but it is unreasonable to require a polynomial of up to sixth order to fit better results. Therefore, it is not appropriate to use a curve to fit the three segments of data. We choose to use a piecewise fitting method to deal with this problem. The following figure shows the third-order polynomial fit of the relationship between elastic modulus and confining pressure:

\[
E = -0.0013P_c^3 + 0.0579P_c^2 - 0.3576P_c + 2.9938
\]

We can find that when the segmentation is performed, the slope of the first segment is very small,
indicating that under low confining pressure and the coal-rock gradually becomes an elastic medium from a multi-space discrete medium. In the section between 10MPa and 15MPa, the elastic modulus and confining pressure have a very significant linear relationship, indicating that the coal-rock is the elastic medium. Therefore, there can be no Determine the relationship between Poisson's ratio and confining pressure.

We found that the cohesion and friction angles were different in the three tests of low confining pressure, medium confining pressure and high confining pressure. As the confining pressure increased, the cohesion increased and the friction angle decreased accordingly. The intrinsic property of coal under high confining pressure has been changed, which may also prove that the coal-rock mentioned in the elastic modulus analysis becomes a rigid material under high confining pressure.

3. Conclusion
The initial compaction of coal-rock has been basically completed in the process of applying low confining pressure. The coal-rock has good elasticity in the normal confining pressure zone. The larger the modulus is, the greater the modulus of elasticity is. Under high confining pressure, the coal-rock loses its elastic characteristics and becomes a completely dense continuous rigid medium. In low confining pressure, medium confining pressure and high confining pressure test, the cohesion and friction angle of coal-rock are different, and there is a tendency to change with the increase of confining pressure. It can be seen that the low confining pressure acts as the initial compaction. The experimental results on cohesion and internal friction angle show that there is a strong hydraulic flushing effect in the coal fracturing process, so the fracturing design should not only consider the conventional elastic deformation, but also must consider the hydraulic flushing effect. At the same time, the coal seam of the three-axis intersection block has poor cementation degree and low strength, and the tangential stress of the fracturing fluid on the weak cementation crack wall will destroy the stability of the crack wall surface, so that the sand particles attached to the crack wall surface change from static to movement. Therefore, the addition of coal powder dispersant to the fracturing fluid is very important for the smooth implementation of fracturing construction.

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