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Research on Sandstone Failure based on Laboratory Test and Numerical Simulation

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Abstract

The mechanical properties of sandstone are of great significance to the establishment of safety protection for underground space excavation. Taking red sandstone as the research object, triaxial compression tests and PFC numerical simulations are used on two sandstones under different confining pressures. The analysis of strength characteristics and failure characteristics aims to reveal the deformation characteristics and force failure mechanism of sandstone under different confining pressures. The results show that confining pressure can increase the peak stress strength of sandstone. At the same time, under low confining pressure, the failure form of sandstone is a typical brittle failure, and the failure form is dilatancy failure, with multiple tensile cracks in addition to the shear failure surface. As the confining pressure increases, the ability of sandstone to resist damage is also significantly improved. The stress required for the specimen to fail from yielding to failure also gradually increases, and the failure mode changes from brittle failure to plastic failure. The PFC software shows the process of sandstone cracks developing to formation under different confining pressures, and the simulation results are highly coupled with the test results.

Keywords

Triaxial Loading Test; Deformation Characteristics; Failure Characteristics; Numerical Simulation.

1. Introduction

Sandstone is the most common rock in underground space excavation, especially in the Sichuan-Chongqing area, most of which are sandstone, so the mechanical properties of sandstone are of great significance to the establishment of safety protection for underground space excavation. Therefore, the research on the mechanical properties of sandstone has received more and more attention from scholars at home and abroad.

For example, Yang Jian et al. [1] carried out systematic mechanical tests on sandstone using a multi-functional rock mechanics test system, and proposed the basic principles that should be followed in sandstone fracturing design. Jia Changgui et al. [2] used the MTS815 rock mechanics testing machine to test the compressive strength of sandstone layers at different angles, and obtained the mechanical parameters and failure mode characteristics. H. Niandou et al. [3] investigated the mechanical behavior of sandstone under triaxial conventional test evidence that sandstone has significant plastic deformation as well as severe failure modes depending on the texture angle limitation and burden under pressure. C.Delle et al. [4] studied the mechanical and anisotropic characteristics of the wave velocity of brine-saturated sandstone, and considered that the anisotropy of elastic behavior should be considered when calculating pore pressure. Heng Shuai et al. [5] conducted uniaxial and triaxial

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compression tests to study the mechanical properties and anisotropy of sandstone failure modes. You Mingqing [6-7] based on the conventional resistance test, as the verification object, proved that the electromagnetic parameter index should be adjusted by the sum of the absolute value of the minimum target deviation value. Most researchers try different loading methods combined with different strength criteria to describe the changing characteristics of sandstone. However, due to the large discrete characteristics of rocks, the test results sometimes have large deviations and cannot be proved. Therefore, the combination of numerical simulation and experiment has more advantages in describing the strength characteristics and failure characteristics of sandstone.

In this paper, physical and mechanical properties experiments and numerical simulations of sandstone are carried out. The sandstone fracture surface obtained by the numerical simulation is compared with the failure results obtained by the laboratory test, which verifies the reliability of the numerical simulation for sandstone failure simulation, and also verifies that the laboratory test data does not have a large deviation, so as to better explain the sandstone confining pressure. damage situation.

2. Sample Preparation And Test Plan

2.1 Sample Preparation

In this test, TFD-2000 microcomputer servo-controlled rock triaxial rheological testing machine was used to conduct triaxial compression test of 0MPa and 20MPa on sandstone (Fig. 1(a)). The test sample is the Longmaxi Formation sandstone drilled and mined in southeastern Chongqing, which is processed into a standard cylindrical sample of Φ50×100mm by the laboratory. Fig 1(b) shows that some sandstone blocks have obvious micro-cracks and bedding.

(a)triaxial rheological machine (b)sandstone sample

Fig. 1 Rock sample analysis and selection

2.2 Test Plan

In order to explore the mechanical properties of sandstone, the laboratory-based triaxial compression test is mainly carried out. The specific operation process of the conventional triaxial test is as follows:

(1) Then fix both ends of the specimen on the loading base with sealing tape, seal with heat shrinkable film, and fasten both sides with iron wire to prevent oil from entering. (2) Install the extensometer, install and fix the specimen on the loading table in the pressure chamber, and then seal the chamber. (3) Fill the pressure tank with oil, control the confining pressure to the target value, and stabilize the confining pressure at the target value. (4) The axial loading method is strain control. First, the specimen is fully contacted with the compression rod, and then axial stress is applied to the rock sample at a rate of 0.05 mm/min until the specimen fails.

The specific test plan is shown in Table 1.

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Table 1. Experimental scheme for sandstone

Sample number	Diameter /mm	Height /mm	Density /Kg.m^{-3}	Confining pressure /MPa	Peak stress /MPa
1	49.6	99.59	2669.5	0	51.6
2	49.66	100.19	2670.1	20	87.3

2.3 Numerical Simulation

PFC2D is a discrete element software, which can well reflect the failure characteristics of rocks. Rocks are composed of mineral particles and cementitious materials. The distribution of the cement or filler and its contact relationship with the crumb particles is called the cement type.

In the PFC2D modeling process, the calculation unit of aggregate is round particles. Due to the heterogeneity of rock materials, according to the actual situation, the radius of rock particles is 0.5-0.75 mm, which is randomly generated, and the number of particles is 2459. Finally, the particles are allowed to equilibrate through repeated and continuous vibrations within a defined range. The model is established as shown in Fig 2.

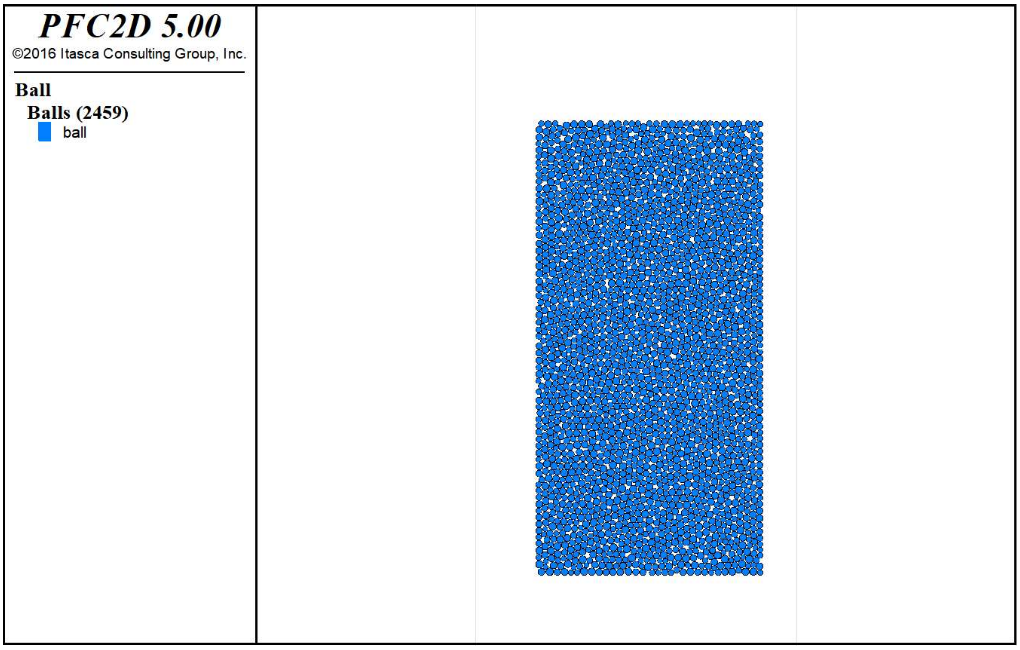

Fig. 2 Model establishment

During the numerical simulation, the meso-parameter settings are shown in Table 2.

Table 2. PFC2D meso-parameters

Bond modulus /GPa	Normal bond strength /MPa	Bond stiffness ratio	Friction factor between particles
1.80	18.00	3.00	0.60

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3. Analysis of Test Results

3.1 Deformation Features

As can be seen from Fig 2, the curve goes through four stages. In the initial compaction stage, the primary pores of the rock sample are greatly compressed. In this stage, the volumetric strain effect is obvious; in the linear elastic stage, the curve grows steadily with a certain slope until the yield stage; in the yield stage, the slope of the curve increases After the rock sample reaches the peak stress, the internal primary fissures and the newly generated fissures gradually merge until the failure surface is formed, and the test is completely destroyed.

It can be seen from Fig 3 that the stress-strain curve of triaxial compression is roughly divided into three stages. In the linear elastic stage, the stress and strain curves show a steady growth trend, showing the elastic characteristics of sandstone. Then, the curve enters the yield stage. With the increase of confining pressure, the ability of sandstone to resist failure is also significantly improved, the stress required for the sample to change from yield to failure also gradually increases, and the failure mode also changes from brittle failure to plastic failure. The final curve enters the failure stage. When the confining pressure is low, the sample is completely sheared and damaged, and as the confining pressure increases, the sample has a local failure surface. This paper takes Figure 3 as an example for specific analysis, and it can be seen that:

The OA segment is a linear elastic stage, and the stress-strain curve maintains a linear relationship and obeys Hooke's law. The original fractures in the sandstone are compacted, and as can be seen from the curve, the volume is continuously compressed.

The AB segment is the yield stage, the slope of the curve gradually decreases, and new cracks are formed in the rock, which gradually develops into a stable state, and the rock gradually becomes a plastic state. As the load continues to increase, slowly entering an unstable phase, the volume of the sandstone changes from compression to expansion.

BC is the failure stage, in which part of the pressure and deformation curve slopes become negative and the rock rests rapidly along the plane before overflowing the stage forms a dramatic drop in the bearing capacity and deformation to complete failure.

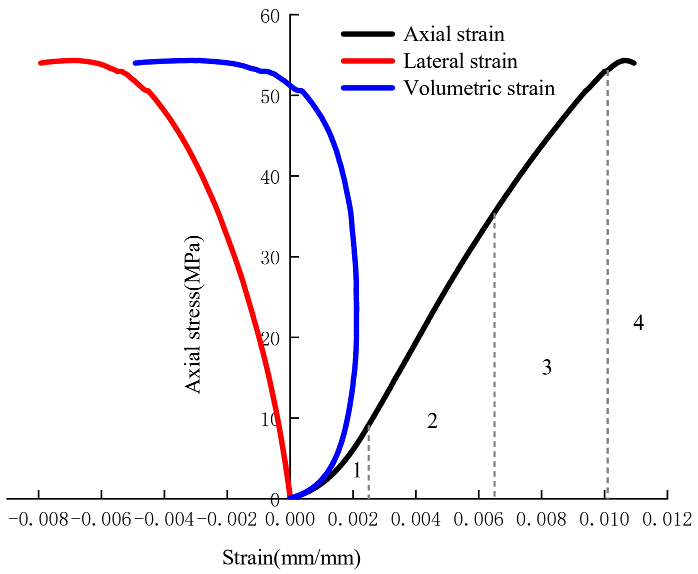

Fig. 3 Uniaxial compression

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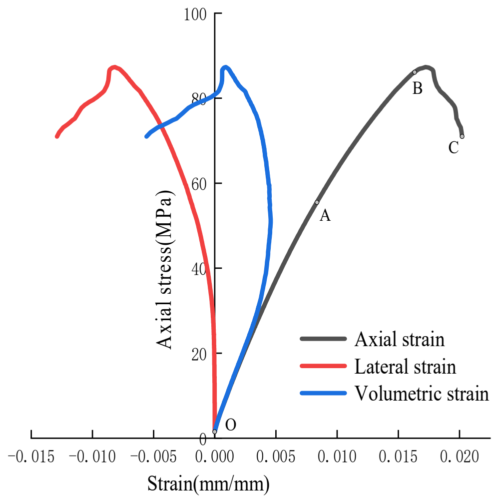

Fig. 4 20MPa

3.2 Destruction Features

The uniaxial compression failure form is a typical single-inclined shear failure, the failure surface forms an included angle of about 45° with the horizontal plane, and the failure crack has no unnecessary extension, showing the typical compression failure characteristics of brittle materials.

Fig 5 shows the compression failure form of sandstone under different confining pressure states. It can be seen that under the condition of low confining pressure of sandstone, the sample undergoes shear slip under the action of triaxial compressive load, and the failure of the sample results in the formation of fractured rock blocks, which leads to an increase in volume and shear dilatation failure, and also occurs in some areas. A number of tensile cracks occurred and tensile failure occurred.

Through the comparison of the figure below, it can be clearly seen that the simulated rupture surface is basically consistent with the actual rupture surface. Micro-cracks were formed in the middle of the specimen and gradually developed and connected to form a whole. The software even simulates the confining pressure effect at the end of the specimen. The confining pressure effect at the end, that is, the local stiffness of the end pressure test equipment is relatively large, and there is friction with the specimen at the same time. Local rupture. However, there is still a certain gap in the correspondence of intensity values. The parameters need to be further optimized and processed to achieve a better effect. In general, PFC2D can better simulate the fracture process of rocks and form a reference with the test. The following mainly shows the failure process diagram and test comparison diagram under uniaxial compression and 20MPa confining pressure.

(a)0MPa

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(b)20MPa

Fig. 5 Damage comparison chart

4. Conclusion

In this paper, through the indoor triaxial compression test, through the experimental results, using PFC2D to carry out numerical simulation, through comparison, the deformation characteristics and failure characteristics of sandstone under 0MPa and 20MPa are analyzed.

(1) According to the analysis, it can be seen that the confining pressure has a significant increase in the peak strength of sandstone. It shows that confining pressure is an important factor to improve the bearing capacity of sandstone. This has important guiding significance for sandstone gas exploitation and roadway support.

(2) Sandstone is mainly damaged by dilatation under low confining pressure, accompanied by some tension cracks. However, with the increase of confining pressure, the fracture surface is mainly the local shear failure surface developed by primary fractures.

(3) The failure surface of the numerical simulation is in good agreement with the laboratory test. The reliability of the numerical simulation is proved. It provides a powerful tool for further research on sandstone mechanical properties.

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