MECHANICAL CHARACTERIZATION OF FRACTURED GRANITE RESERVOIRS

by

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In this paper, on the basis of laboratory triaxial mechanical experiments, a granite model including different numbers and angles of fractures was established by the Discrete Element Method. Combined with the laboratory triaxial mechanical experiments and PCF simulation results, the effects of the number and angle of fractures on the rock mechanical properties of fractured granite reservoirs were analyzed. The results show that the existence of fractures significantly reduces the strength of the reservoir, but the increase of the fracture angle and the confining pressure will weaken the degree of this reduction, and the fractures are easy to expand and connect during the loading process.

Key words: *Fractured granite reservoirs, Mechanical properties, Discrete Element Method, Fractures*

Introduction

With the continuous growth of the requirement of oil and gas resources as well as the progress of oil and gas exploration technology, unconventional oil and gas resources have become the key field of oil and gas exploration and development, and the continuous discovery of large granite oil and gas reservoirs around the world has proved that its potential for exploration and development is very large, which has attracted more and more attention and concern from petroleum and geological fields [1]. However, the complex internal structure and the development of natural fractures and microfractures and other defects in granite reservoirs result in complex mechanical properties and damage mechanisms, which, if not understood, can cause problems such as well borehole instability and solid-phase production of reservoirs, so it is important to deeply study the mechanical characteristics and damage mechanisms of fractured granite reservoirs [2,3]. In recent years, the mechanical properties and damage mechanism of defective rocks have been one of the hot areas for

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rock mechanics researchers [4]. The PFC simulation method can simulate the mechanical behavior of rocks through the movement and the fracture between particles in the model under different stress conditions, and has a better simulation effect, which has been widely used in the field of rock mechanics [5].

In this paper, on the basis of laboratory triaxial mechanical experiments, a granite model including different numbers and angles of fractures was established by the Discrete Element Method. And the effect of the number and angle of fractures on the mechanical characteristics of fractured granite reservoirs were analyzed by combining the results of the indoor triaxial mechanical experiments and PCF simulation, which can provide reference for the development and production of fractured granite reservoirs.

The indoor triaxial mechanical experiment

The granite sample used in the indoor triaxial experiment is originated from the granite submerged reservoir in Qiongdongnan Basin, with a depth range of 2969.8-3896.5 m. The main mineral component is dominated by feldspar, followed by quartz, containing some hornblende, mica and opaque minerals. The permeability is $<0.050\times10^{-3}$ μm^2 and porosity is <1%. No more obvious fractures were found after CT scanning and acoustic emission testing. And considering that the scale of prefabricated fractures is larger than the microfractures existing in the rock samples themselves, it is considered that the cores sample used in the test are fracture-free granite cores.

The experiments were accomplished by using TAW-1000 microcomputer electro-hydraulic servo-controlled rock triaxial stress tester, which gradually applied axial load at a rate of 1 mm/min until the sample was damaged, and the specific information of the test samples and the test results are shown in Table 1. The density of the rock sample is about 2.60 g/cm^3; the compressive strength is about 143.675 MPa, Young's modulus is about 44.57 Gpa, and Poisson's ratio is about 0.155.

Table 1 The results and information of indoor experiment samples

Number	Diameter, mm	Height, mm	Quantity, g	Density, g/cm^3	Compressive strength, MPa	Young's modulus, GPa	Poisson's ratio
1#	24.50	49.16	59.34	2.56	132.62	40.16	0.175
5#	24.65	48.65	61.40	2.64	154.73	48.98	0.135
Average	-	-	-	2.60	143.675	44.57	0.155

The PFC simulation model

Based on results of indoor triaxial experiments, a PFC simulation model was formulated to simulate and analyse the mechanical characteristics of fractured granite reservoirs. The size of the numerical model is a standard rock sample with radius r=25mm, height h=100mm. The wall was randomly filled with particles with a porosity of 1%, the minimum radius of the filled particles was 0.35 mm, and the ratio of the maximum radius to the minimum radius was 2, resulting in a total number of 6268 particles. The simulated sample density was set to the average density (2600 kg/m^3) of the granite tested by the indoor experiment.

The stress-strain curves and damage patterns of the rocks obtained from indoor experiments are used as references when determining microscopic mechanical parameters, and the microscopic parameters of the model are adjusted using the “trial-and-error method”, so that the simulation results are basically the same as those of the indoor experiments in terms of the stress-strain curves and damage patterns [6]. The specific microscopic parameters selected for the numerical model are shown in Table 2. When performing the calculations, the PFC discrete element is realized by the following two principles as follows. Newton's second law reads $F = ma$. The relationship between force and displacement is given as $s = v_0 t + at^2 / 2$.

Table 2 The specific microscopic parameters for the numerical model

Microscopic parameters	Value	Microscopic parameters	Value
Minimum particle diameter, mm	0.35	Friction coefficient	0.7
Ratio of particle diameter	2	Vertical bonding strength, MPa	50
Porosity, %	1	Tangential bonding strength, MPa	80
Density, kg/m^3	2600	Parallel bonding friction angle, °	43.68
Contact modulus of particles, GPa	10.5	Parallel bonding modulus, Gpa	10.5
Ratio of vertical to tangential stiffness for particles	1.5	Ratio of vertical to tangential stiffness for parallel bonding	1.5

As shown in Figure 1, the model simulation results basically matched with the indoor test results in terms of stress-strain curves and damage patterns, proving the accuracy of the model mechanical parameters.

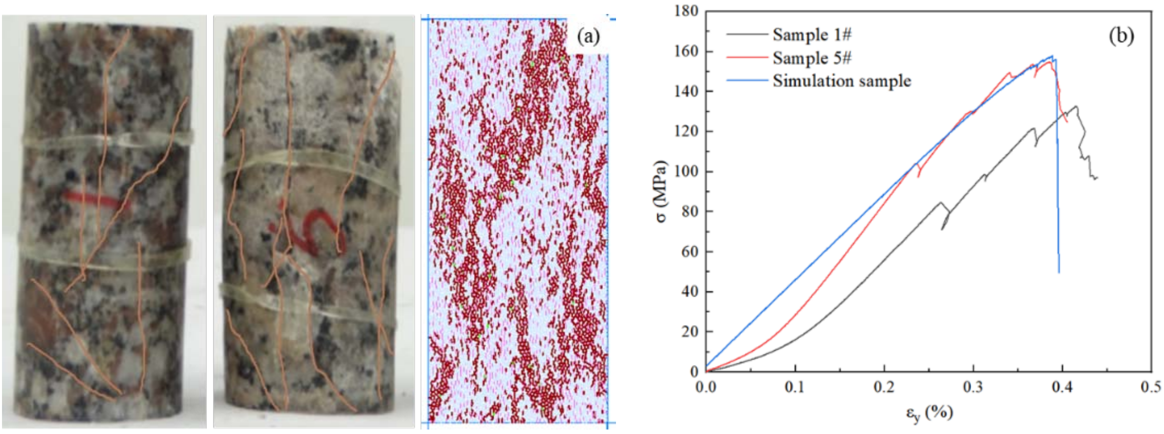
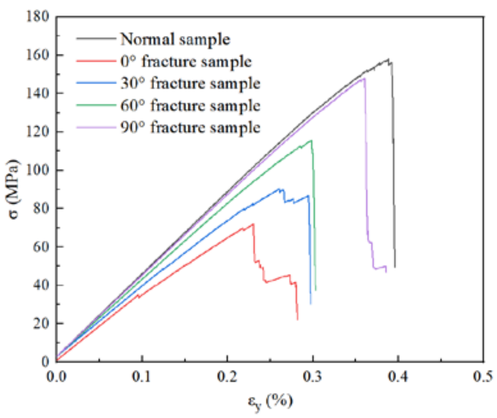


Figure 1 Comparison of simulation results and indoor experimental results

(a) Comparison of damage patterns (b) Comparison of stress-strain curves

Effect of fractures on the mechanical characteristics of granite reservoirs

The effect of fracture angle



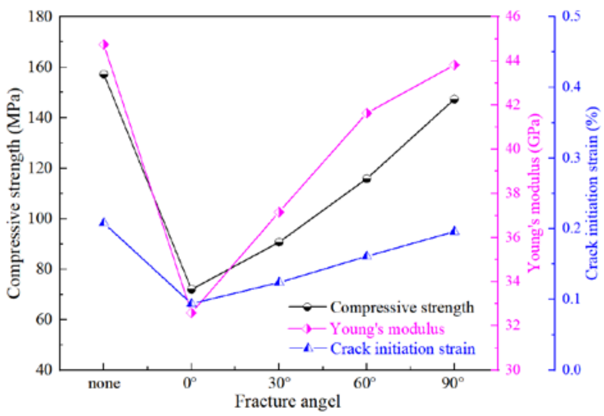


Figure 2 Stress-strain curve of the samples with different angles prefabricated fracture

Figure 3 Effect of prefabricated fracture angle on the mechanical characteristics of the samples

Prefabricated fractures were added to the experimental model with a fracture length of 20 mm and fracture angles of 0°, 30°, 60°, and 90°, respectively, to simulate its uniaxial compressive mechanical behavior, and the results are shown in Figure 2 and Figure 3. The sample without prefabricated fracture started to initiate cracks at a strain of 0.208%, and the axial stress reached a compressive strength of 157.23 MPa at a strain of 0.392%, following which the cracks increased rapidly and the sample was damaged. For the prefabricated fracture samples, the crack initiation strain was earlier, the compressive strength and Young's modulus reduce, and as the angle of the prefabricated fracture increases, the strain at which cracks begin to initiate is delayed and the compressive strength and Young's modulus increase. In addition, as shown in Figure 4, with the increase of prefabricated fracture angle, the number of cracks in the sample damage is increased and the cracks are more easily connected. It indicates that prefabricated fractures significantly reduce the mechanical properties of the samples, and the increase of the fracture angle will weaken this reduction, and the low-angle fracture results in a higher damage degree to the samples.

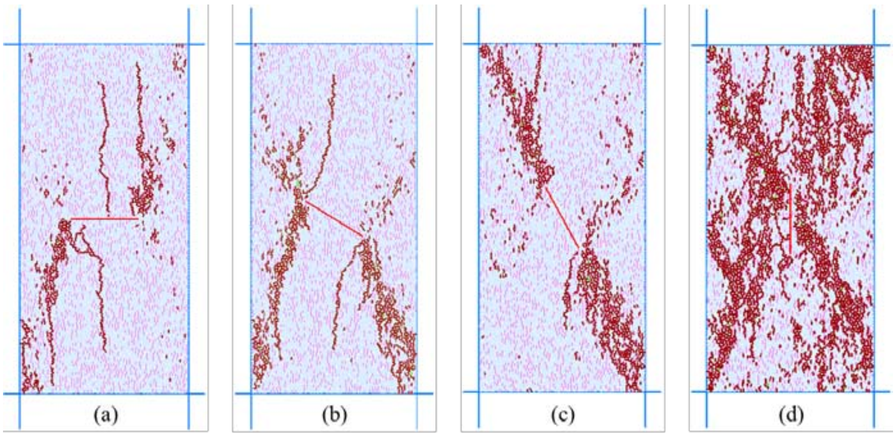


Figure 4 The cracks distribution of samples with different angles prefabricated fracture during damage (a)0°, (b)30°, (c)60°, (d)90°

The effect of fracture number

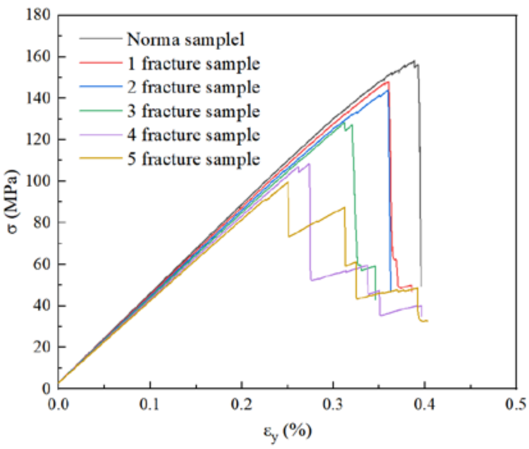


Figure 5 Stress-strain curve of the samples with different numbers prefabricated fractures

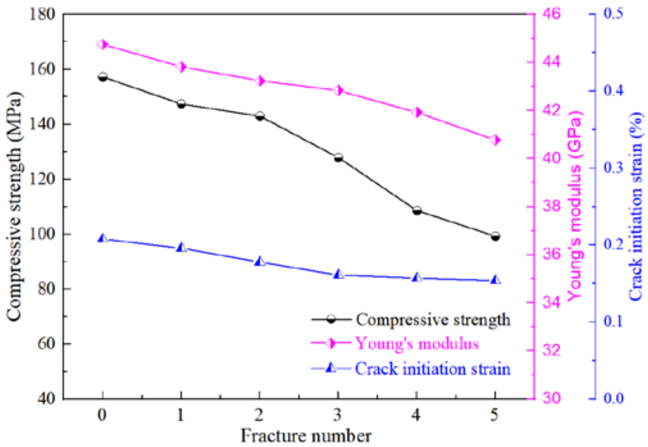


Figure 6 Effect of prefabricated fracture number on the mechanical characteristics of the samples

Multiple prefabricated fractures were added to the simulation model with a fracture length of 20 mm and a fracture angle of 90°, and the simulation results are shown in Figure 5 and Figure 6. With the increase of the number of prefabricated fractures, the compressive strength and Young's modulus of the sample gradually decreased, and the cracks began to initiate strain is earlier, indicating that with the increase of the number of fractures, the mechanical properties of the samples are significantly reduced, and the samples are more easily damaged. Figure 7 shows the distribution of cracks at damage for different numbers of prefabricated fracture samples, from which it can be seen that with the increase in the number of prefabricated fractures, the cracks are mainly concentrated in the region of prefabricated fracture distribution.

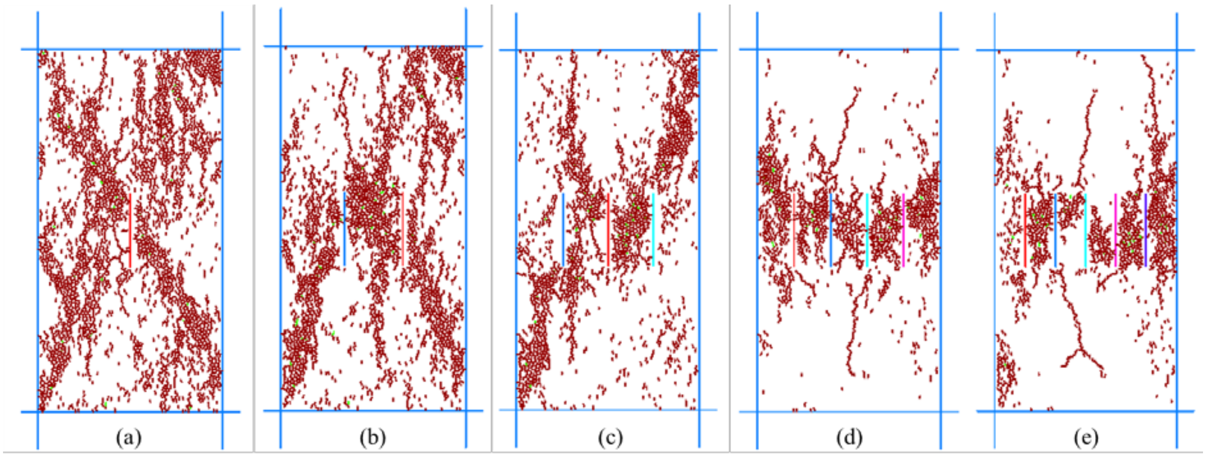


Figure 7 The cracks distribution of samples with different numbers prefabricated fractures during damage (a)1 fracture, (b)2 fractures, (c)3 fractures, (d)4 fractures, (e)5 fractures

The effect of confining pressures

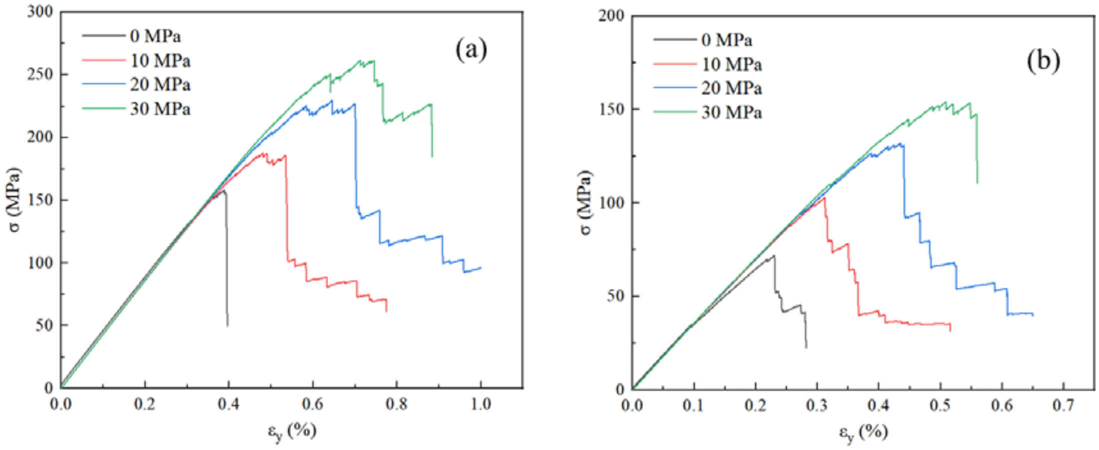


Figure 8 Stress-strain curve of sample under different confining pressure (a) the sample without prefabricated fracture, (b) the sample with 0° prefabricated fracture

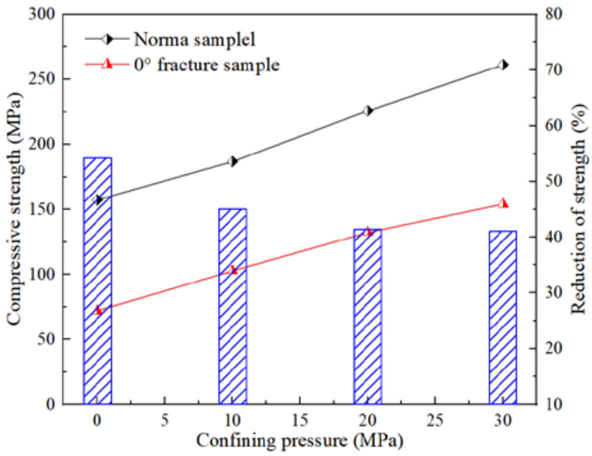


Figure 9 Effect of confining pressure on the compressive strength of samples

The mechanical behaviors of the sample without prefabricated fracture and the sample with 0° prefabricated fracture are simulated under 0MPa, 10MPa, 20MPa and 30MPa confining pressures, respectively, and the results are shown in Figures 8 and 9, which show that the compressive strengths of the sample without prefabricated fracture and the sample with 0° prefabricated fracture are both increased with the increase of the confining pressure. From Figure 9, it can be seen that the compressive strengths of the samples with 0° prefabricated fractures are lower than those of the samples without prefabricated fractures at the same confining pressure, and the degree of reduction gradually decreases with the increase of the confining pressure, which indicates that the confining pressure will inhibit the degree of reduction of the strength of the samples by the prefabricated fractures.

Conclusions

In this paper, on the basis of laboratory triaxial mechanical experiments, a granite model including different numbers and angles of fractures was established by the Discrete Element Method. Combined with the laboratory triaxial mechanical experiments and PCF simulation results, the effects of the number and angle of fractures on the rock mechanical properties of fractured granite reservoirs were analyzed. The prefabricated fractures significantly reduce the compressive strength and Young's modulus of sample, and the crack initiation strain was earlier. Moreover, the increase of the fracture angle and the confining pressure will weaken the degree of this reduction, and the low-angle fracture results in a higher damage degree to the samples.

Acknowledgments

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