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Study on the Influence of Crack Geometry Characteristics on Macroscopic Mechanical Properties of Roadway Surrounding Rock

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Abstract: Granite, although generally low in porosity, often contains numerous microcracks or microfractures that significantly constrain its mechanical strength. This study focuses on the mechanical properties of deteriorated rocks due to joints and cracks in granite, using the Mesozoic Sanjiazi granite in the Liaodong Uplift, Dandong City as a case study. A discrete element model based on particle flow was established using a trial-and-error approach to iteratively calibrate microscopic parameters until they matched actual conditions. Different fractured rock masses underwent uniaxial compression tests and orthogonal discrete element numerical simulations involving a 4-factor, 4-level experimental design. A multivariate linear regression analysis assessed the impact of the four factors on granite's mechanical properties, while numerical experiments investigated the influence of individual factors on its macroscopic mechanical characteristics. Results indicate that the geometric characteristics of cracks exert a greater influence on granite's peak strength than on its elastic modulus. Specifically, the sequence of crack geometric parameters affecting peak strength is crack Y-axis position component > crack X-axis position component > crack length > crack inclination angle. Similarly, the sequence of their impact on elastic modulus is crack X-axis position component > crack Y-axis position component > crack length > crack inclination angle. As the angle increases, the crack initiation point gradually moves towards both ends of the crack, with the specimen primarily experiencing tensile cracking and localized shear failure at the crack tips. Longer cracks correlate with lower peak strength and thus poorer stability in granite. Changes in the position of primary microcracks in granite significantly alter its peak strength and stress-strain state post-peak, albeit without a pronounced effect on elastic modulus. This research contributes valuable insights for predicting the mechanical properties of fractured granite.

Keywords: Rock Mechanics Microcracks; Peak Strength; Faulted Granite; Mechanical Property.

1. Introduction

In natural rock masses, in addition to containing pores, there are typically various sizes of natural cracks or fissures (such as faults, joints, microcracks, etc.). The presence of these discontinuities leads to varying degrees of deterioration in the mechanical properties of rocks. Many failures in geotechnical engineering are caused by the propagation of cracks/fissures within rocks, and the fracture characteristics and mechanical properties of fissured rocks typically determine the peak strength and failure modes of rock masses. Therefore, studying the geometric characteristics of cracks within rocks, their propagation patterns under loading conditions, and their relationship with the macroscopic strength of rock masses is of significant engineering importance.

Numerous scholars worldwide have conducted extensive uniaxial and triaxial compression experiments on natural rock masses with fissures of different rock types or similar materials, accumulating abundant results in the aspects of fissure propagation and rock failure in fissured rock masses. Zhang Guokai et al. [1] used high-strength gypsum-based materials to create specimens with single fissures, conducting uniaxial compression tests using an MTS rock mechanics testing machine. They employed methods such as acoustic emission, ultrasonic waves, and video monitoring to determine that the initiation pressure and peak strength exhibit a consistent trend with fissure inclination angles, showing an initial decrease followed by an increase. Xiao Taoli et al. [2] used high-strength silica mortar to create specimens and conducted triaxial loading tests under different confining pressures, demonstrating that the peak strength of rock masses gradually decreases with increasing length of single fissures. Zhou Hui et al. [3] utilized cement mortar-like rock materials with pre-existing joints for direct shear tests, finding that longer joint fissures result in lower shear strength and cohesion of rocks. They also observed significant differences in the impact on rock strength depending on the location of the joint fissure within the specimen; minimum shear strength and cohesion occurred when the joint was positioned in the middle of the specimen, while maximum peak shear strength and cohesion were observed when the joint fissure was located at the rear of the specimen. Liu Hongyan [4] conducted uniaxial compression tests on simulated jointed rock masses, concluding that as the number of parallel joint sets increased, the peak strength of specimens gradually decreased. Ke Zhiqiang et al. [5] created columnar jointed rock mass models with different column inclinations and lateral joint distributions using cement mortar and conducted uniaxial compression tests to study the effects of column inclination and lateral joints on the anisotropic mechanical properties and failure mechanisms of rocks. Studying crack propagation and failure modes of rocks using materials similar in mechanical properties and nature to natural rock masses holds scientific value. However, due to variations in ingredient proportions and experimental errors, experiments using similar materials often yield results with significant uncertainties. Therefore, many scholars conduct experimental studies on rock mechanics characteristics using naturally fissured rock masses. Guo Qifeng et al. [6] utilized a GAW2000 rigid testing machine to conduct uniaxial compression tests on granite specimens with pre-existing single fissures, determining that the compressive strength of rocks is highest when the fissure orientation is parallel to the loading direction, decreasing as the angle between the crack orientation and loading direction increases. Yin Qian et al. [7], using a YNS2000 universal servo pressure machine, conducted uniaxial compression tests on sandstone specimens with longitudinal fissures, studying the strength degradation effect of sandstone. They found that with increasing offset of pre-existing fissures, the load capacity of specimens initially increased, then decreased, and subsequently increased again, indicating that the position of fissures has a significant impact on the rock failure mode.

With the development of computer numerical simulation technology, combining numerical simulation software with laboratory experiments is an effective method for analyzing failure modes of fissured rock masses. Previous studies on crack propagation and its impact on rock failure modes in fissured rock masses have mainly focused on individual variables, with relatively fewer comprehensive variable analyses concerning the influence on rock failure modes. Wang Guoyan et al. [8] used the RFPA numerical simulation software for rock fracture processes to study the influence of initial crack length on the evolution of crack propagation under specific stress conditions.

2. Establishment of Numerical Models of Crack Propagation and Instability Failure in Fractured Granite

2.1. Macroscopic Mechanical Experiments of Granite

The rock samples were taken from the granite quarry of Sanjiuliu rock mass in Sanjiuliu Village, Dandong City, Liaoning Province. The granite was formed in the Mesozoic era, and its main mineral components are quartz, alkaline feldspar, plagioclase, and a small amount of biotite. The rock is not weathered, the appearance is gray and dense, and the surface has no obvious cracks, but the permeability test shows that it contains many cracks inside.

The granite samples used in the test were cut into the rock mechanics standard size of Φ25 mm×50 mm, as shown in Figure 1. The MTS815.03 triaxial rock testing machine was used to carry out triaxial compression experiments on three rock samples under several different confining pressures (5 MPa, 10 MPa and 20 MPa). After the axial loading pressure was continuously increased to cause rock instability and failure, the peak stress (i.e., the compressive strength of the rock 1) was recorded. The elastic modulus, cohesion force and internal friction Angle of the rock are obtained according to relevant calculations (see Table 1).

Table 1. Mechanical properties of granite samples obtained from Dandong city

Sample number	E/(GPa)	σ_1/(MPa)	σ_3/(MPa)	Cohesive force (MPa)	Angle of internal friction (o)
1	23.465	242.5473	5	19.65	62.68
2	23.5692	339.0023	10		
3	26.06	498.9676	20		

2.2. Construction of Numerical Model

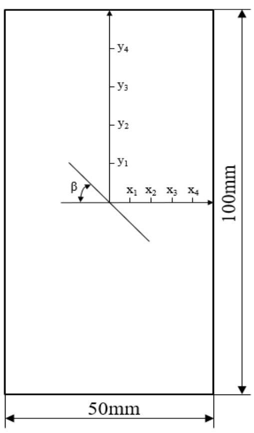


Fig 1. Geometric parameters of single cracked specimen

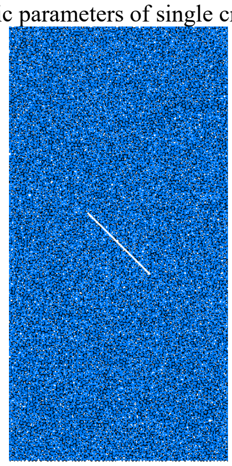


Fig 2. PFC2D simulation of granite particle arrangement

In order to intuitively observe the propagation and evolution of internal cracks and the instability failure process of rock in fractured granite under external load, and to establish the correlation between the crack geometry characteristics and the macroscopic mechanical properties of rock samples, this paper uses particle flow numerical simulation software PFC2D to carry out relevant numerical tests. PFC2D is a numerical simulation software developed by ITASCA based on the principle of discrete element stress analysis, which is commonly used to simulate the instability and failure process of rock, and can be applied to both micro and macro damage of rock materials. Based on the physical and mechanical properties of granite, scholars at home and abroad generally use the bonding model to study the failure process of granite. The bond model is divided into contact bond model and parallel bond model. The parallel bond model can transmit force and moment [9], and is suitable for materials with cement inside rocks, and the cemented part of which can also simulate the birth and expansion of cracks. So, the parallel bonding model is suitable for granite crack study. In this paper, the parallel bonding model is used as the constitutive model to study the expansion process of new cracks and the instability failure of rock samples in granite with primary cracks under load. The two-dimensional geometric model of the standard rock sample in this paper is set to be 100 mm long and 50 mm wide, and the uniaxial compression model is determined by removing the "walls" on both sides.

2.3. Mesoscopic Parameters of Parallel Bonding Model

In the parallel bonding model, the macro-mechanical properties of rocks (peak strength, Poisson's ratio, elastic modulus) are mainly affected by granular contact modulus, particle stiffness ratio, particle size, normal strength, tangential strength, parallel bonding contact modulus, parallel bonding stiffness ratio and other microscopic parameters [10]. In order to reduce the difficulty of calibration, some assumptions are generally made to reduce the number of mesoscopic parameters in parallel bonding models. The calibration of microscopic parameters is based on many laboratory tests, and the results are in good agreement with the macroscopic mechanical properties.

When determining the mesoscopic parameters of the parallel bonding model, the following assumptions are followed [11-16]:

1. The uniaxial compressive strength is less than the shear strength, that is, $\sigma<\tau=c+\sigma\tan\varphi$, to obtain a suitable uniaxial tensile compression ratio.
2. $\gamma=1.0$
3. $R_{max}/R_{min}=1.66$
4. $\rho=2830$ kg/m3
5. $\mu=0.5$
6. $E_p=E_c$, $k_n/k_s= k_n/ k_s$

Uniaxial compression test was carried out by particle flow numerical simulation software PFC2D. By comparing the macroscopic parameters of the laboratory test and modifying the microscopic parameters repeatedly by using the "trial and error method", the error of the macroscopic mechanical parameters obtained by the numerical simulation test of uniaxial compression and the laboratory test was finally within 5%. The final mesoscopic parameters of the parallel bonding model are shown in Table 2.

Table 2. PFC2D simulation meso parameters

Model height L/mm	Model width W/mm	Minimum particle radius Rmin/mm	Particle radius ratio Rmax/Rmin	Particle density ρ/(kg/m3)	Particle contact modulus Ec/GPa	Particle stiffness ratio kn/ks	Particle friction factor μ	Bonding radius coefficient λ	Parallel bond modulus Ep/GPa	Parallel bond stiffness ratiokn/ks	Parallel bond normal stress σ p/MPa	Parallel bonding tangential stress τ p/MPa
100	50	3	1.66	2830	15	2.5	0.5	1	15	2.5	15	15

3. Orthogonal Model Tests for Particle Flow Simulation of Mechanical Characteristics of Fractured Granite

3.1. Orthogonal Simulation Test Scheme Design

According to experience, orthogonal experiments can choose uniform discrete levels and representative factors to design experiments, which can greatly reduce the test workload. In addition, variance analysis can also be used to analyze the influence degree of different factors on the dependent variables, so the orthogonal test is adopted in this paper to study the influence of single crack geometric characteristics on the macro-mechanical properties of granite.

In the orthogonal test of crack geometric characteristic parameters, we adopted a design scheme of 4 horizontal grades and 4 factors (see Table 3). 4 factors are the geometric characteristic parameters of the crack, and 4 levels are the average discrete distribution values of each geometric parameter. The geometric characteristics of the primary crack include: (1) crack inclination x1, (2) crack length x2, (3) crack X-axis position component x3, (4) crack Y-axis position component x4; The macroscopic mechanical parameters of rock samples include (1) peak strength y1 and (2) elastic modulus y2.

When conducting the particle flow numerical simulation test, the correlation between the four factors was not considered, and the specific test scheme of four factors and four levels was obtained by using the orthogonal table (see Table 4). The primary crack inclination Angle (that is, the Angle between crack strike and X-axis direction) was set as 0, 30, 60 and 90, respectively. Considering the influence of sample length, width and boundary mechanical effect, the crack length is set to 5, 10, 15 and 20 mm respectively. Considering that the sample under uniaxial compression has axial symmetry, a rectangular coordinate system is established at the center of the sample, which is divided into five parts on average from the origin of X and Y axes to the boundary of the sample, and the four coordinate points in the middle are respectively taken as the values of the four levels of X and Y axes, as shown in Table 4. Table 4 also lists the simulation results of macroscopic mechanical parameters (peak strength, elastic modulus) of each test.

Table 3. Orthogonal test level design table

factor / level	Angle x_1 (°)	Crack length x_2 (mm)	X-axis component x_3 (mm)	Y-axis component x_4 (mm)
1	0	5	5	10
2	30	10	10	20
3	60	15	15	30
4	90	20	20	40

3.2. Multiple Linear Regression Equations of Primary Crack Geometric Parameters and Mechanical Properties Were Established

According to the numerical simulation results, a model can be established in which the macroscopic mechanical parameters affect the crack geometric characteristics and the macroscopic mechanical parameters are affected by the crack geometric characteristics. For the NTH orthogonal test, the geometric characteristic parameter of the primary crack is set as {xnm}, and the corresponding macro-mechanical parameter is set as {yn}. {yn} and {xnm} constitute a multiple linear regression equation:

$$\{y_n\} = \beta_0 + \beta_1 + \beta_2 + \ldots + \{\beta_m x_{nm}\} + \varepsilon_n \quad (1)$$

Table 4. Granite particle flow orthogonal simulation test plan

Crack geometric characteristic parameters				Macroscopic mechanical parameter	
Angle x_1 (°)	Crack length x_2 (mm)	X-axis component x_3 (mm)	Y-axis component x_4 (mm)	Peak intensity y_1 (MPa)	Modulus of elasticity y_2 (MPa)
0	5	5	10	48.5	30.1
0	10	20	30	37	28
0	15	10	40	30.7	26.7
0	20	15	20	29.7	22.2
30	5	15	30	41.1	29.1
30	10	10	10	40.2	27.2
30	15	20	20	38.8	27.4
30	20	5	40	29.8	23.5
60	5	20	40	39.6	28.1
60	10	5	20	47.9	29.8
60	15	15	10	37.2	26.4
60	20	10	30	32.6	28.1
90	5	10	20	51.2	31.2
90	10	15	40	50.9	31.1
90	15	5	30	50.8	30.8
90	20	20	10	50.3	30.9

Where: β0 is a constant; β1, β2 and β3 are regression coefficients, which represent the influence of crack inclination, crack length, crack X-axis position component and crack Y-axis position component on peak strength and elastic modulus. n is the number of orthogonal trials, n= 1,2,... ; m is the number of crack geometric characteristic parameters; εn is the random error at the NTH orthogonal test.

In order to establish the relationship between the geometric characteristics of the primary crack in granite and its macro-mechanical parameters, four main crack geometric characteristics parameters, namely crack inclination, length, crack X-axis position component and crack Y-axis position component, are considered in this paper, and two main macro-mechanical property parameters of rock, namely peak strength and elastic modulus, are selected. The crack geometric characteristic parameter in the table is taken as the dependent variable {xnm}, and the macro mechanical parameter is taken as the independent variable {yn}. Using the multiple linear regression equation (1), the relationship between the macro mechanical parameter and the crack geometric characteristic parameter can be obtained:

$$x1 = 2.8384y1+1.4237y2-110.9025 \quad (2a)$$

$$x2 = 0.0073y1-1.1410y2+44.2932 \quad (2b)$$

$$x3 = -0.0003y1+0.0011y2-0.0071 \quad (2c)$$

$$x4 = -0.0014y1+0.0036y2-0.0183 \quad (2d)$$

Similarly, by taking the macroscopic mechanical parameters in the table as the dependent variable {yn} and the crack geometric characteristic parameters as the independent variable {xnm}, it can be concluded that the crack geometric characteristic parameters affect the macroscopic mechanical parameter relationship:

$$y1 = 0.1604x1-0.5905x2-46.6517x3-171.2753x4+45.8467 \quad (3a)$$

$$y2 = 0.0502x1-0.2101x2+22.9663x3-15.5056x4+28.5946 \quad (3b)$$

Where x1, x2, x3 and x4 represent crack inclination, length (mm), crack X-axis position component and crack Y-axis position component, respectively. y1 and y2 are the peak strength (MPa) and elastic modulus (GPa) of the sample respectively.

According to the analysis formula (3a), the crack Angle is positively correlated with the peak strength, indicating that the greater the crack Angle is, the higher the peak strength is. The crack length, crack X-axis position component and crack Y-axis position component are negatively correlated with the peak strength, indicating that the longer the crack length and the farther the crack is from the center of the specimen along the X-axis and Y-axis, the lower the peak strength of the rock is. According to the regression coefficient absolute value 171.2753 (β1) > 46.6517 (β2) > 0.5905 (β3) > 0.1604 (β4), the effect of crack geometric characteristic parameters on the peak strength is as follows: crack Y axis position component > crack X axis position component > crack length > crack inclination Angle. The influence of the crack location offset along the loading axis on the peak strength is much greater than that of the crack location offset along the loading axis normal direction, and the influence of the crack location offset (X, Y axis) on the peak strength is also much greater than that of the crack length and inclination Angle.

According to the analytical formula (3b), crack inclination and crack position on the X-axis are positively correlated with the elastic modulus of the rock, but the regression coefficient of the crack inclination is only 0.05, indicating that the effect of crack inclination on the elastic modulus can be negligible. The farther the crack is from the center of the specimen along the X-axis, the greater the elastic modulus is. The crack length and the crack Y-axis position component are negatively correlated with the elastic modulus, indicating that the longer the crack length and the farther the crack is from the Y-axis, the lower the elastic modulus is. According to the regression coefficient absolute value 22.9663 (β1) > 15.5056 (β2) > 0.2101 (β3) > 0.0502 (β4), the influence degree of crack geometric characteristic parameters on rock elastic modulus is as follows: crack location in X axis > crack location in Y axis > crack length > crack inclination Angle. The influence of crack position offset along the normal direction of the loading axis on the elastic modulus is slightly greater than that along the loading axis, and the influence of crack position offset along the X and Y axis on the elastic modulus is much greater than that of crack length and inclination.

The goodness of fit R2 of equations (2a)~ (2d) are 0.5596, 0.2737, 0.0586 and 0.1790, respectively, and the goodness of fit R2 of equations (3a) and (3b) are 0.7750 and 0.6918, respectively. It is concluded that the effect of crack geometry on rock peak strength is greater than that on rock elastic modulus. Therefore, this paper mainly explores the effect of crack geometry on rock peak strength.

4. Mechanical Characteristics of Fissured Granite under the Influence of Single Factors

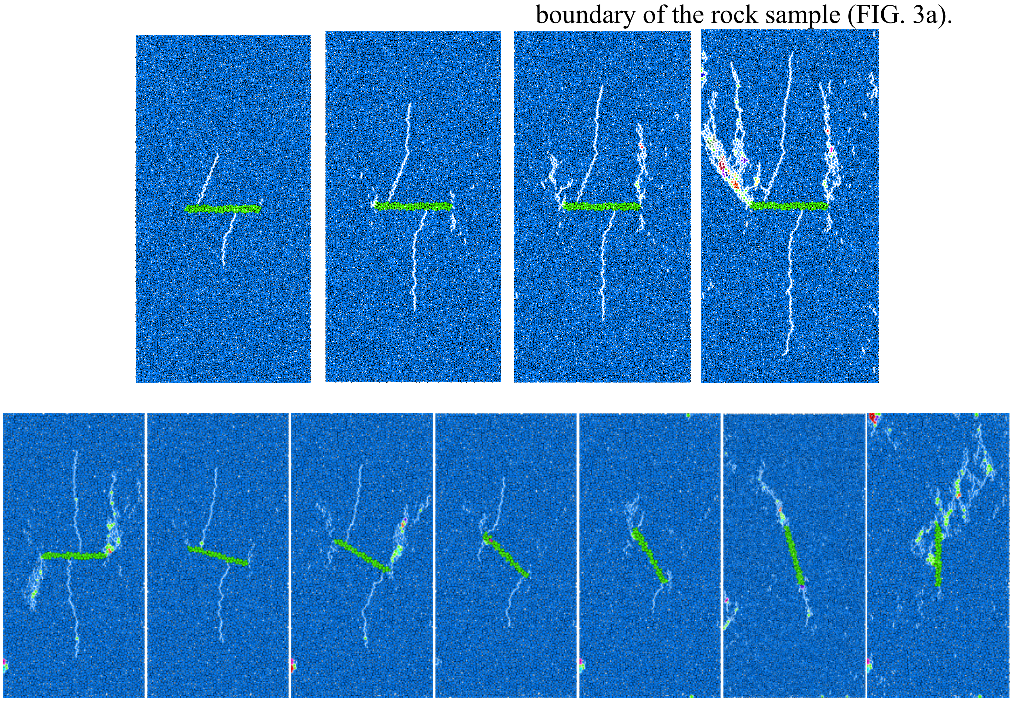
4.1. Experimental Design

The effect of the crack geometry characteristics on the macroscopic mechanical properties of the granite was studied from a single factor (such as length, inclination and location). The test was divided into three groups. (1) The crack was located in the center of the specimen and the crack length was 20 mm. The angles between crack strike and X-axis were set as 0, 15, 30, 45, 60, 75 and 90, respectively. (2) The crack was located in the center of the specimen, and the Angle between the crack trend and the X-axis was 0, 15, 30, 45, 60, 75, and 90. The changed crack lengths were 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, and 35mm, respectively. (3) The Angle between crack strike and X-axis is 45, the crack length is 15 mm, and four locations are set as the crack center point, respectively. In order to avoid the adverse influence of boundary effect on rock fracture, cracks are arranged within a reasonable size range [17].

4.2. Effect of Crack Angle on Rock Strength

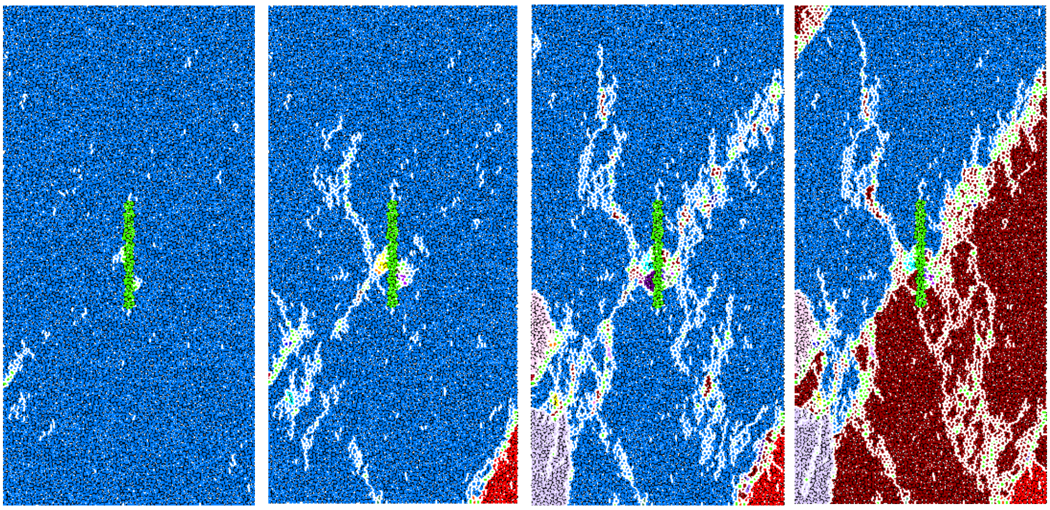
Crack inclination Angle has a significant influence on the initiation position and failure form of nascent cracks. FIG. 3 shows the generation and growth of nascent cracks caused by uniaxial compression of simulated granite under different crack inclination angles at a certain number of calculated steps. As can be seen from the figure, when the crack inclination is 0, the crack starts in the middle of the prefabricated crack. With the progress of axial loading, the nascent crack starts in the middle and expands to both ends of the specimen along the direction of external load (that is, the direction of maximum principal stress). The specimen is mainly dominated by tension cracks, and the crack tip is accompanied by local shear crack failure.

With the increase of crack inclination, the initiation position of the new crack gradually shifts from the middle of the primary crack to the crack tip. When the inclination Angle of the primary crack is 15, the initiation position is about 1/2 from the middle of the crack to both ends of the specimen. The new crack is dominated by tension and extends to both ends of the specimen along the direction of external load. When the inclination Angle of the primary crack is 30, the initiation position is located at 2/3 of the middle of the primary crack, and the shear failure of the tip also increases gradually. When the inclination Angle of the primary crack is 45, the initiation position of the nascent crack shifts to the tip of the primary crack, and the tension failure and local shear failure cross each other. When the inclination Angle of the primary crack is 60, the specimen is mainly dominated by shear failure cracks at the beginning, and accompanied by local tension failure, the nascent cracks gradually expand along the tangential direction of the primary crack. When the inclination Angle of the primary crack is 75, an inclined shear crack runs through the specimen along the direction of the primary crack and finally forms a fracture plane, which is a typical shear failure mode. When the inclination of the primary crack is 90, a series of shear cracks are formed at the tip of the primary crack under the influence of shear stress, and the cracks gradually expand until they penetrate the boundary of the rock sample (FIG. 3a).



β=0° β=15° β=30° β=45° β=60° β=75° β=90°

Fig 3. PFC2D simulation results



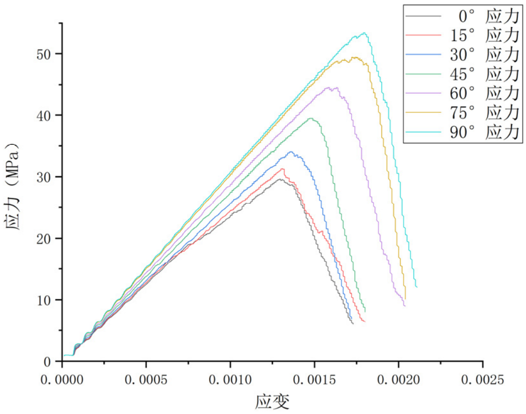


Fig 4. Stress-strain curves of specimens with cracks at different inclination angles

FIG. 4 shows the stress-strain curves of rock induced by uniaxial compression under different primary crack inclination angles. It can be found that the uniaxial compressive strength of the rock increases with the increase of the inclination Angle of the primary crack. When the primary crack inclination is 0, the uniaxial compressive strength is the smallest, which is 29.6 MPa. Before the primary crack Angle increases to 30, the upward trend of the peak value is relatively gentle. When the inclination increases to 45, the peak value increases to 39.5 MPa, and the peak strength increases by 15.8% compared with that of 30. When the inclination of primary crack increases from 45 to 90, the peak strength increases to 53.4MPa, which increases by 35.2% compared with that at the inclination of primary crack 45. Compared with that at the inclination of primary crack 45, the peak strength increases significantly. Compared with that from 0 to 45, 45 is the boundary point of the rise rate of the peak strength. The peak strength of the rock rises gently, and after the primary crack inclination reaches 45, the peak strength of the rock rises rapidly, which is consistent with other scholars. **Influence of** Primary Crack Length **and** Inclination **Angle on** Rock Strength

FIG. 5 shows the uniaxial compressive strength curves of primary cracked rock samples with different inclination angles and lengths. As can be seen from the figure, under the condition that the inclination of the primary crack remains unchanged, the peak strength of the rock sample basically shows a trend of decreasing with the increase of the primary crack length, except for the case that the inclination of the primary crack is 90. For example, when the inclination of the primary crack is 0 and the primary crack length is 35 mm, the peak strength of the rock sample is reduced by 81.2% compared with that when the crack length is 10 mm. However, when the primary crack inclination is 90, that is, when the crack trend is consistent with the direction of force loading, the peak strength of the rock sample has little change with the increase of crack length. There is a positive correlation between the primary crack dip Angle and the peak strength of rock samples. The greater the crack dip Angle, the higher the peak strength of rock samples. When the primary crack length is 10 mm, the peak strength of rock sample is 38 MPa when the crack inclination is 0, and 55 MPa when the crack inclination is 0 with the same crack length. It can be seen that the inclination Angle and length of the primary crack in the rock sample have great influence on the peak strength of the rock sample. The smaller the inclination Angle and the longer the length of the crack, the lower the peak strength of the rock sample.

4.3. Effect of Crack Location on Peak Strength of Rock

Due to the axial symmetry of uniaxial compression test, numerical simulation experiments of rock sample failure evolution under uniaxial compression under four different locations of primary cracks were designed in this paper (FIG. 6), that is, the midpoint coordinates of primary cracks were located at points 1 (x4, y2), 2 (x2, y2), 3 (x4, y4), and 4 (x2, y4) respectively.

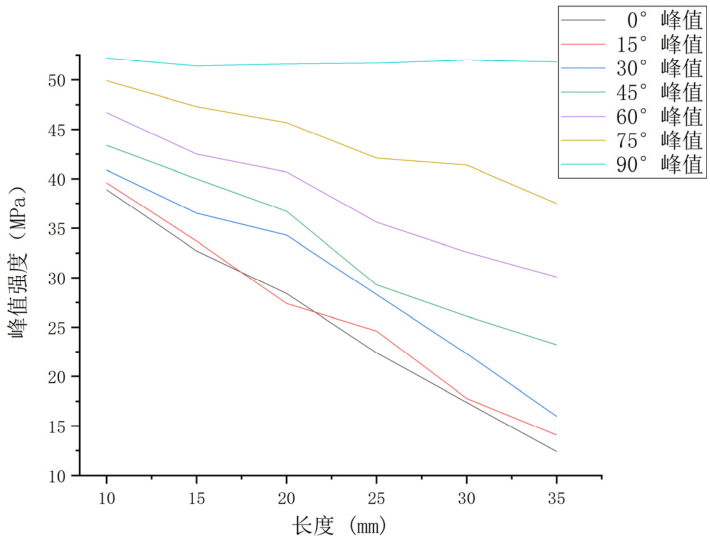


Fig 5. Variation curve of peak strength of specimen under cracks with different inclination angles and lengths

Figure 7 shows the peak strength of the rock sample when the primary crack is located at four different locations, and the difference between them is relatively small, ranging from 2-4 MPa. Compared with the peak strength of relatively intact rocks, the peak strength decreases between 23%-31%, and the peak strength generally shows a trend of high in the middle and low in the surrounding. From the view of the failure form of the rock sample, when the primary crack is close to the edge of the rock sample (point 3), the crack is easier to penetrate to the boundary, resulting in a significant decrease in the peak strength of the rock sample.

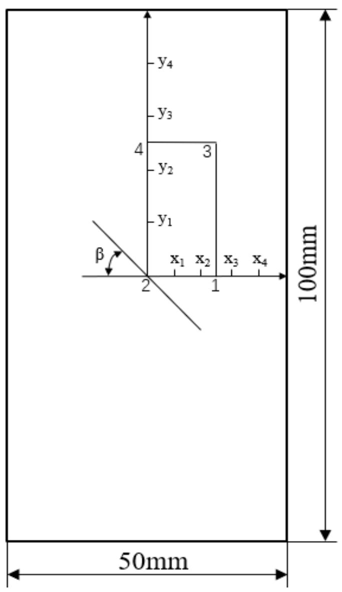


Fig 6. Schematic diagram of crack center position distribution

FIG. 8 shows the influence of the location of the primary crack on the stress-strain relationship of the rock sample in the uniaxial compression experiment. It can be seen that the location of the primary crack mainly changes the peak strength and post-peak stress-strain state of the rock sample, but has no obvious effect on the elastic modulus of the rock sample (that is, the slope of the straight-line segment of the stress-strain relationship curve).

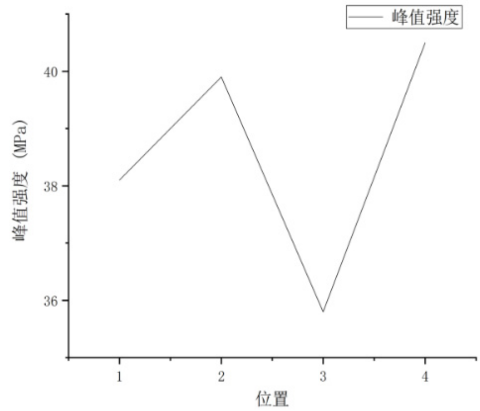


Fig 7. Peak intensity changes curves at different positions

The characteristics of the stress-strain relationship curve are as follows: 1) When the primary crack is located in the middle of the rock sample (i.e., at points 2 and 4), there is only one peak strength, and the post-peak stress of the rock sample quickly falls back, which is consistent with the classic stress-strain relationship curve of general rock; 2) When the primary crack is located at the edge of the sample (such as point 3), the post-peak stress of the sample is slow to fall, and after the stress reaches the first peak strength (i.e. uniaxial compressive strength), the post-peak stress has a large fall and then a small rise. 3) When the primary crack is located at the mid-lateral boundary of the rock sample (such as point 1), after the stress reaches its peak value for the first time, it does not fall back rapidly, but with the continuous fluctuation of stress, a larger peak strength appears than that in the linear elastic stage, and the second peak strength is the uniaxial compressive strength.

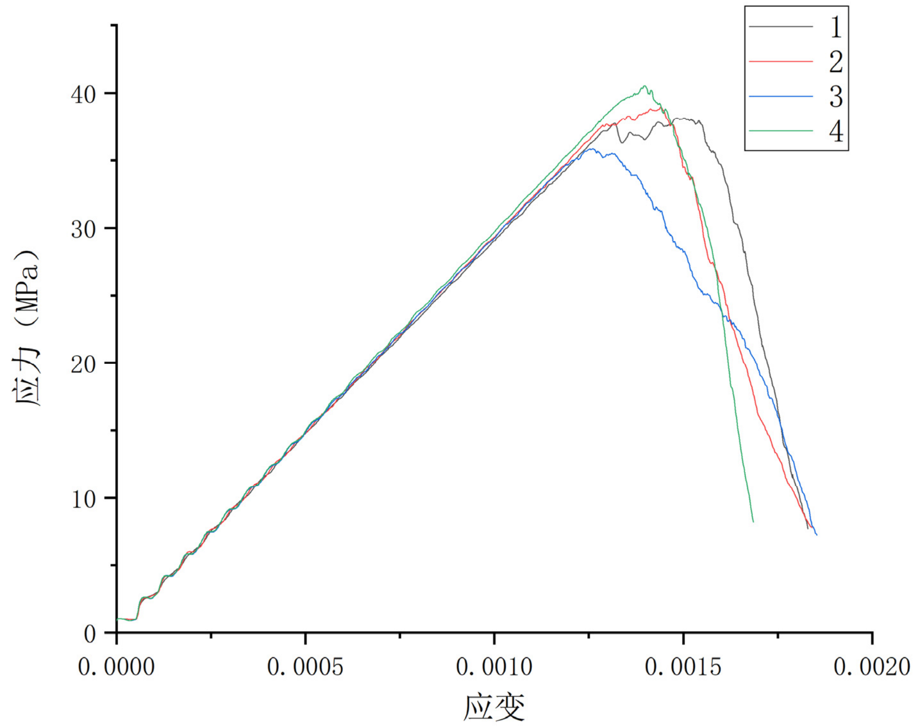


Fig 8. Stress-strain curves of specimens at different positions

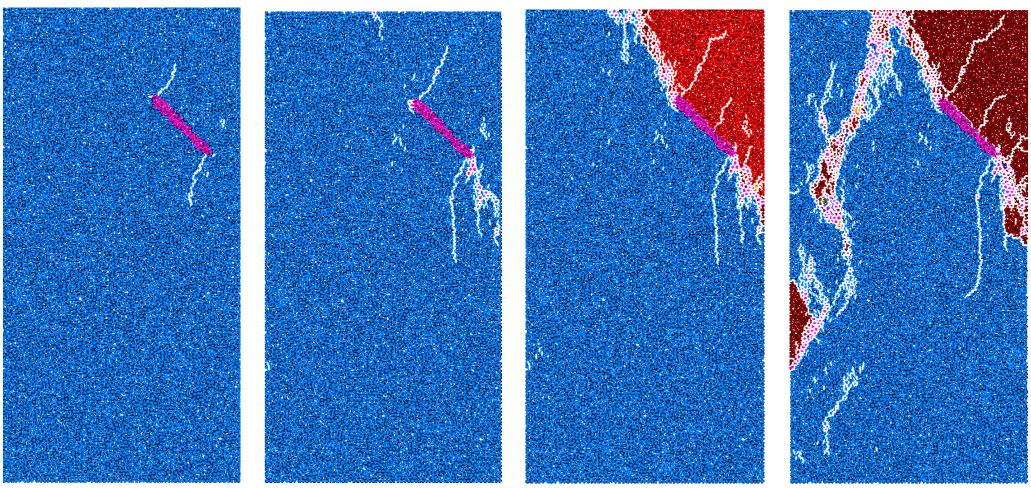


Fig 9. The fracture process of fractured rock at the same location

The following figure shows the growth of nascent cracks when the rock sample reaches peak strength under four different primary crack locations

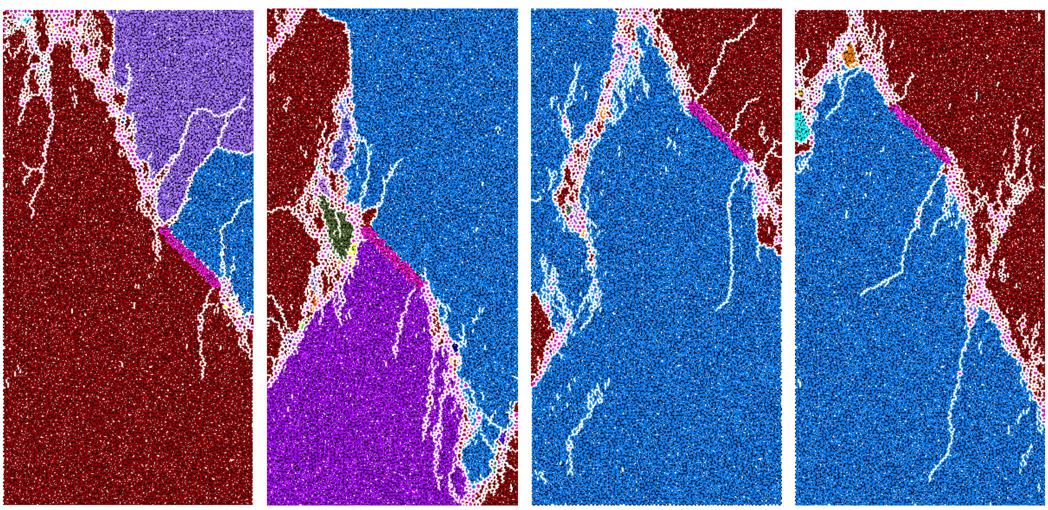


Fig 10. The growth of nascent cracks when the rock sample reaches peak strength under four different primary crack locations

5. Conclusion

1) When the crack inclination is 0, the crack starts in the middle of the prefabricated crack, and gradually moves to both ends of the crack with the increase of the Angle. With continuous loading, the crack starts in the middle and expands to both ends of the specimen along the direction of external load. The specimen is mainly dominated by tension cracks, and the crack tip is accompanied by local shear cracks. The longer the crack length, the lower the peak strength. The worse the stability; The change of crack location mainly changes the peak strength and post-peak stress-strain state of the rock sample, but has no obvious effect on the elastic modulus.

2) The influence degree of crack geometric characteristic parameters on the peak strength is in the order of crack Y axis position component > crack X axis position component > crack length > crack inclination Angle. The influence of crack position offset along the loading axis on the peak strength is much greater than that along the normal direction of the loading axis. The influence of crack deflection along X and Y axis on the peak strength is much greater than that of crack length and crack inclination.

3) The degree of influence of crack geometric characteristic parameters on the elastic modulus is as follows: crack X-axis position component > crack Y-axis position component > crack length > crack inclination Angle. The influence of crack location offset along the loading axis normal direction on the elastic modulus is slightly greater than that along the loading axis. The influence of the crack deflection along the X and Y axes on the elastic modulus is much greater than that of the crack length and crack inclination.

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