Discussion on determination method of characteristic stress of Jinping marble under confining pressure condition

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Abstract

The characteristic stress is coincident well with the internal crack propagation in brittle rock. The characteristic stress are separately called closure stress, cracking stress, damaging stress and peak stress according to the internal crack state in loading. The propagation and damage extent in brittle rock can be reflected. Limited by loading testing equipment, the characteristic stress in confining pressure condition cannot be determined in China. In order to confirm the stress, the strain curves under different confining pressure condition are used to analysis the problem. The results show that the closure stress, cracking stress and damaging stress can be accurately confirmed by this method. The characteristic stress relates to the confining pressure, and the relationship is approximately linear.

Keywords: brittle rock, characteristic stress, marble, confining pressure

1 Introduction

The deformation characteristics and failure mechanism of brittle rock has received widespread attention. After decades of development, in particular the progress of testing technology, gaining a new awareness of the cracking character in brittle rock [1-4]. According to different state of compaction, propagation, connection and perforation of crack rock under different stress levels, the stress-strain curve of rock can generally be divided into four stages: I Compaction stage; II Linear elastic stage; III The stable crack development stage; IV The unstable crack development stage Figure 1.

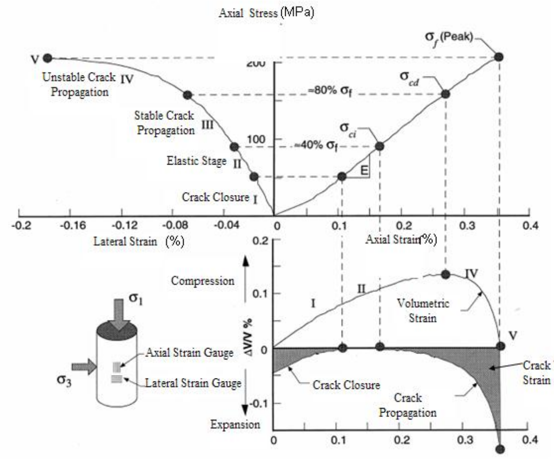

FIGURE 1 Schematic diagram of each stage in the process of uniaxial compression for granite [1]

(1) Compaction stage. Rock crack (including the crack of original and unloading) is compacted under axial compression. Stress-strain curve shows concave upward and nonlinear deformation. Axial pressure σcc corresponds to the minimum pressure of the crack with completely compaction.

(2) Elastic stage. The axial stress and axial strain is approximately linear. Deformation is mainly for the elastic deformation, but also contains a small amount of unrecoverable plastic deformation. The stress-strain relationship approximately obeys Hooke's law. In this stage, the diastrophism between micro fractures can be restrained by friction between closed fractures. Therefore, deformation is mainly elastic.

(3) The stable crack development stage. After The axial stress reaching the splitting strength σci, internal rock began to appear micro cracks, namely, began to appear rupture phenomenon. At this level of stress is about 40% of the peak intensity of rock.

(4) The unstable crack development stage. Axial pressure continues to increase to the intensity of damage σcd (about 80% of the uniaxial compressive strength of rock).Crack propagation way of rock starts into the unstable stage. The corresponding stress level is called damage strength. In this stage, the volume of crack formation and propagation formation is over the elastic deformation formed by compressive stress. Then the dilatancy began to appear.

Thus, it can be seen, the characteristic stress of brittle rock are closely linked with their internal crack propagation. In the whole process, volumetric strain, crack volumetric strain and sound emission divided the

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whole stress-strain curve into different stages. And these stages has a great significance in indicating the rupture process. However, due to the limit of current experimental technology and theory, currently China does not have the monitoring technology of sound emission under the condition of confining pressure, generally direct fixing the sound emission probe on the push rod of MTS. However, the effect is not good. Results of sound emission signals are rare. And it cannot correspond to the stress-strain curve well. Therefore, this paper tries to analyse the changing law of the rock stress-strain curve under different confining pressure to determine the characteristic stress under confining pressure

2 Closure stress and cracking stress

According to the existing research results, subtracting the elastic volumetric strain εev from the volumetric strain εv can get the crack volumetric strain εcv curve which could reflect the process of crack closure and crack opening in the process of loading. For testing of volumetric strain of rock specimen cannot be measured directly. However, the rock specimen is generally cylindrical, according to the assumption of small strain, volumetric strain can be calculated according to following formula:

$$\varepsilon_v = \frac{\Delta V}{V} = \varepsilon_1 + 2\varepsilon_2 \ , \tag{1}$$

where ε1 is axial strain, ε_2 is lateral strain, ε_v is the total volumetric strain.

Using formula (2) calculates crack volumetric strain:

$$\varepsilon_{cv} = \varepsilon_v - \varepsilon_{ev} \, , \tag{2}$$

where εev is elastic volumetric strain, $\varepsilon_{ev} = \frac{1-2\nu}{E}(\sigma_1 + 2\sigma_3)$.

In the first phase, the opening crack is gradually compacted and crack volumetric strain gradually increases. In the end of first phase, crack volumetric strain reaches the maximum, as the most crack is airtight closing. In this case, the corresponding axial stress is the closure stress. In elastic stage, as the compacted cracks have not yet appeared relative sliding and the new cracks have not yet been generated. Therefore, in this stage the total volume strain increment is equal to the elastic volume strain increment. Crack volumetric strain remains the same and the curve remains level standard. After the rock specimen entering into the stable crack development stage, because of the existing crack propagation and new crack generation, the total volume strain increment is less than the elastic volume strain increment. It leads the curve offsetting to the negative direction. Whereupon, there must be a point of inflection between the elastic stage and the crack propagation stage that the curve represents. This point of inflection corresponded to the axial stress is the cracking stress. Under no circumstances with sound emission, the research of changing law of closure stress and cracking stress under different confining pressure that can use the above method to analyse compacted testing results of triaxial test. Try to arrange triaxial test data using the above method, as shown in Figure 2.

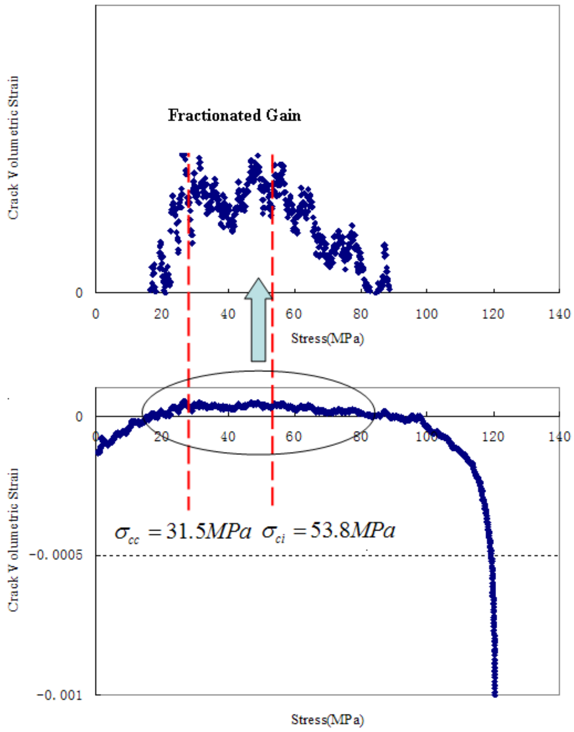


FIGURE 2 The closure stress and cracking stress under D12-28MPa confining pressure

3 Damaging stress

Damaging stress σcd corresponds to the stress that volume strain just began to recover. Therefore, the key to determine σcd is to accurately determine the recovering point of volumetric strain. Figure 5 shows the volumetric strain-axial strain curve. If this curve is used directly, the point is determined with greater randomness. In order to accurately determine the volume strain recovering point, Eberhard [5] proposed to use the relative volumetric strain stiffness method, in which the zero point corresponds to volume stiffness point is the volumetric strain recovering point. Volume stiffness is defined in Figure 3 and the specific steps are as follows: (1) The calculation shows that relative volume stiffness curve can accurately reflect the variation trend of volumetric strain curve when the number of data points between A1 and A2 are between 5% to 10% of the total number of data points.

(2) The least square method is used to fit the data (ε1, ε2) between A1 and A2 and the slope of the resulting line is the relative volume stiffness value corresponding to point A.

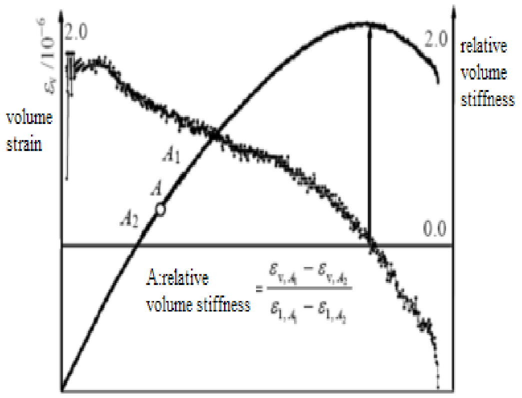


FIGURE 3 Schematic diagram of determining the volume strain recovery points

(3) Relative volume stiffness can be gained by calculating each point based on step (2). When the relative volume stiffness is zero, that point is the volumetric strain recovering point.

Following the steps above, this method can be applied to determine the damaging stress under 8MPa confining pressure. The final result is shown in Figure 4.When the damaging stress reaches 102MPa, the peak strength is 120MPa. The ratio between damaging stress and peak strength is about 85%.

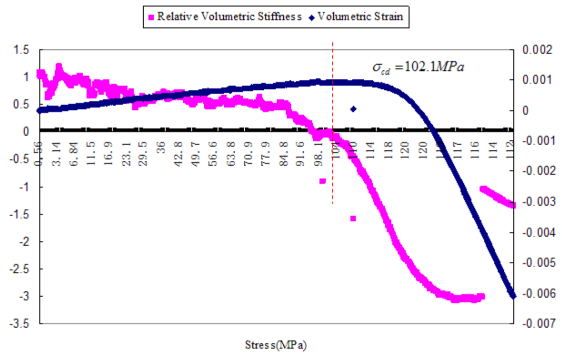


FIGURE 4 Damaging stress under the condition of 8MPa confining pressure

4 Characteristic stress under different confining pressure

Characteristic stress under different confining pressure shown in table 1 can be gained by the experiment curve combining with the method above. The result shows that σcc/σf under homotaxial condition is greater than σcc/σf under triaxial condition. Probably because the peak strength is affected by confining pressure and the crack is closed under confining pressure, the closure crack tends to be small. Significant linear relationship between each characteristic stress and confining pressure can be seen in Figure 5.

Figure 6 shows the fitting of each characteristic stress value based on Hoek-Brown criterion. The experimental data curve is moving closer to the Hoek-Brown curve with the transition from closure strength to cracking strength to damage strength to the peak strength. That is the Hoek-Brown failure criterion can be used to forecast the stress failure condition of rock. However, the development process of damage, which is the development stage of the crack, cannot be judged with Hoek-Brown criterion.

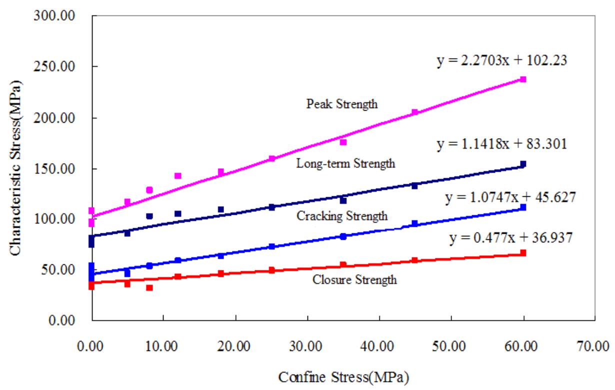
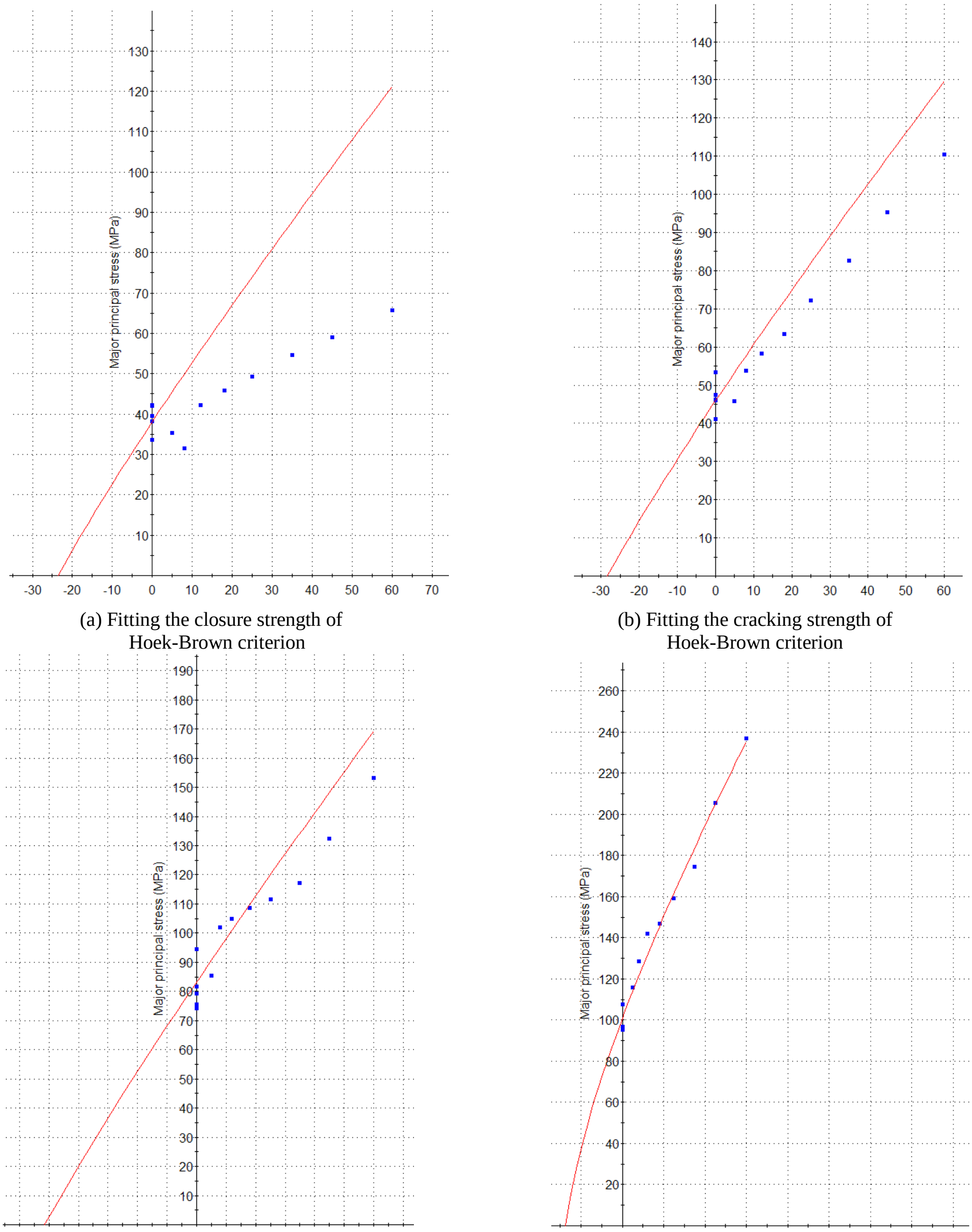


FIGURE 5 Characteristic stress with changing curve under confining pressure

TABLE 1 Characteristic stress under different confining pressure

Rock specimen number	σ3	σf	σcc	σci	σcd	σcc / σf	σci / σf	σcd / σf
D25	0.00	95.20	33.60	41.20	75.50	0.35	0.43	0.79
D28	0.00	107.60	39.50	53.40	94.50	0.37	0.50	0.88
D30	0.00	96.50	42.30	47.50	74.20	0.44	0.49	0.77
D31	0.00	95.80	42.00	46.10	81.60	0.44	0.48	0.85
D35	0.00	96.90	38.20	46.30	79.20	0.39	0.48	0.82
D12-1	5.00	115.90	35.40	45.90	85.50	0.31	0.40	0.74
D12-2	8.00	128.50	31.50	53.80	102.10	0.25	0.42	0.79
D14-1	12.00	142.10	42.20	58.20	104.90	0.30	0.41	0.74
D18-1	18.00	146.70	45.80	63.50	108.70	0.31	0.43	0.74
D17-2	25.00	159.10	49.30	72.30	111.50	0.31	0.45	0.70
D18-3	35.00	174.60	54.70	82.60	117.10	0.31	0.47	0.67
D17-3	45.00	205.40	59.10	95.40	132.30	0.29	0.46	0.64
D18-2	60.00	236.90	65.80	110.50	153.30	0.28	0.47	0.65



(a) Fitting the closure strength of Hoek-Brown criterion

(b) Fitting the cracking strength of Hoek-Brown criterion

(c) Fitting the damaging strength of Hoek-Brown criterion

(d) Fitting the peak strength of Hoek-Brown criterion

FIGURE 6 Fitting the characteristic strength of Hoek-Brown criterion

5 Conclusion

Characteristic stress can reflect damage degree inside the rock. Based on the triaxial compression testing curve of Jinping marble, four characteristic stress that is closure stress, cracking stress, damaging stress and peak stress can be defined to reflect the extended state of rock internal cracks according to the internal cracks extending state of rock specimen in the loading process, where closure stress, cracking stress, damaging stress and peak stress can be obtained by stress-strain curve combining with regression technology. The results are well consistent with the existing test results.

Acknowledgments

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