ISSN: 2710-0588

Study on the Rock Mechanical Properties under Different Preloading Values

Yifan Wang, Lingzhi Huang, Shuai Wang*

School of Civil Engineering and Architecture, Wuhan Engineering University, Wuhan 430070, China

*Correspondence Author

Abstract

In order to study the influence of different preloading values on rock mechanical properties, uniaxial and triaxial compression tests were carried out to analyze rock failure forms, deformation characteristics and strength changes. The results show that the failure of rock mainly consists of compaction stage, elastic stage, plastic stage and fracture stage. In the triaxial compression test, the strength of the rock decreases with the increase of the preload value.

Keywords

Rock mechanics, Preloading, Single-axis and Triaxial Tests, Confining Pressure.

1. Introduction

With the current rapid economic development, geotechnical mechanics and related engineering projects have gradually begun to develop in depth [1]. Rocks have relatively complex structures inside, and the natural environment of deep rocks is relatively complex, which leads to different changes and damages in rocks under different external conditions. The large number of microstructures inside rocks causes rocks to behave differently under different stress conditions. Therefore, it is necessary to attach different conditions to the rock, observe the corresponding performance of the rock, and obtain corresponding data, so as to explain the different damage forms of the rock. [2]

The distribution of complex microscopic structures inside rocks (crack length, crack inclination, etc.) has an important impact on the peak strength, threshold, deformation and damage of rocks. Huang Mingli et al. [3] conducted uniaxial compression tests and used scanning electron microscopy to observe rock cracks during uniaxial compression loading in real time. The entire process from generation, extension to rock failure provides a reference for subsequent research on the internal microstructure deformation of rocks; Yang Shengqi [4] et al. conducted uniaxial compression tests on marble with intermittent prefabricated cracks and analyzed the rock bridge inclination angle, crack spacing, crack length, crack number, and crack length. The influence of gap inclination angle on rock deformation and strength characteristics provides understanding of the deformation and failure characteristics of discontinuous jointed rocks. At the same time, Yang Shengqi et al. only focused on uniaxial compression in this article, but rocks are in a triaxial compression state in most cases; while Huang Yanhua et al. [5] focused on discontinuous jointed rocks. Triaxial compression tests were conducted on rocks. By observing the stress-strain curves of complete rock samples and intermittent cracks under different confining pressures, the strength, deformation and other characteristics of the rock samples were analyzed, which provided certain help in understanding the different mechanical properties of rocks. Zeng Sheng et al. [6] carried out experiments on different rock samples in dry and saturated states. Uniaxial compression tests under cyclic conditions showed that water has a significant impact on rock deformation characteristics; Meng Qingbin et al. [7] revealed

ISSN: 2710-0588

the rock energy evolution process and distribution law of rock samples under cyclic loading and unloading conditions by conducting unloading axial compression tests under constant confining pressure; Yao Wei et al. [8] conducted cyclic loading and unloading confining pressure. The combined perturbation test showed the evolution rules of red sandstone damage and permeability under different conditions; Huang Da et al. [9] conducted a peak confining pressure release test on marble under high stress conditions. By analyzing the characteristics of rock sample energy conversion and other processes, they revealed the strain energy conversion mechanism in the rock sample damage and fracture evolution process. Li Simon et al. [10] conducted uniaxial graded cyclic loading and unloading tests on sandstone, analyzed the rock fatigue damage evolution process, and established a relevant theoretical model; Feng Shi et al. [11] conducted cyclic loading tests on sandstone with different crack angles. The results showed that as the number of cycles increases, the uniaxial The compressive strength did not decrease but increased, and the strength tended to be stable after reaching 30 times. Zhou Jijun et al. [12] conducted a uniaxial unloading test to compare the stress-strain curves of damaged rock samples with different degrees and intact rock samples. It showed that the strength of damaged rock samples changed due to different unloading points before unloading before the peak.

In summary, there have been a lot of studies on conventional uniaxial and triaxial compression tests, which has made great progress in the field of geotechnical engineering. This article conducts uniaxial and triaxial compression tests on rock samples under different preload values to study their deformation characteristics and strength characteristics under different degrees of damage. This provides a reference for the mining of rock samples under loading and unloading conditions in subsequent projects and provides a basis for engineering safety.

2. Test Plan

Specimen numbering convention: single-axis: rock sample + group + state + preload value + specimen number of this group; triaxial: rock sample + group + state + confining pressure + preload value + specimen number of this group, for example, H1A0-1: The first rock sample is the first rock sample when the preload value is 0 in the dry state of the granite group. Similarly, G3B30-30-2 is the second rock sample when the confining pressure is 30 and the preload value is 30% in the third group of limestone saturated state.

Table 1. Test piece number

Group number	Test piece number
0%	1A0-1, 1A0-2, 1B0-1, 1B0-2
30%	3A15-30-1, 3A15-30-2, 3A30-30-1, 3A30-30-2, 3B15-30-1, 3B15-30-2, 3B30-30-1, 3B30-30-2
60%	3A15-60-1, 3A15-60-2, 3A30-60-1, 3A30-60-2, 3B15-60-1, 3B15-60-2, 3B30-60-1, 3B30-60-2
90%	3A15-90-1, 3A15-90-2, 3A30-90-1, 3A30-90-2, 3B15-90-1, 3B15-90-2, 3B30-90-1, 3B30-90-2

The test conducted conventional uniaxial and triaxial compression tests on three rock samples in dry and saturated states, providing a comparison for the subsequent triaxial compression tests on rock samples with different preloading values. For the triaxial compression tests, the preloading values were set at 30%, 60%, and 90% times the uniaxial average compressive strength, and the corresponding stress-strain curves were observed and compared respectively. Combined with the failure mode of rock samples, a deeper understanding has been gained of the mechanical properties of different rock samples under different preloading values.

ISSN: 2710-0588

2.1. Sample Condition

The samples were granite, sandstone, and limestone retrieved from the Kangyu Tunnel of the Sichuan-Tibet Railway. They were produced in a processing plant and made into 50 mm × 100 mm International Society of Rock Mechanics standard rock samples in accordance with the requirements of the "Engineering Rock Mass Test Method Standard" (GB/T 50266-2013). There are 260 sample blocks in total, including 100 blocks of granite and limestone, and 60 blocks of sandstone. Different rock samples have different mining heights and locations, and different rock sample characteristics. The rock samples themselves have already undergone preliminary damage during mining, so the rock samples contain natural fissures. The rock sample is shown in Fig. 1:Ø

Limestone granite sandstone

Fig. 1 Three rock samples

2.2. Test Device

Fig. 2 Single-axis device

The uniaxial compression test uses a multifunctional rock mass structural surface cyclic shear instrument. Cui Zhen et al. [13] developed special "top-clamping configuration" and other technologies to conduct multiple mechanical tests on rock mass structural surface samples, including structural surface normal cyclic loading and unloading tests, structural surface monotonic shear tests, structural surface cyclic shear tests, etc. The triaxial compression test was carried out using the stress-seepage coupling test system independently developed by the Wuhan Institute of Geomechanics, Chinese Academy of Sciences [14]. The system mainly consists of a self-balancing triaxial pressure chamber, a high-pressure servo pump, a deformation measurement system, a motor and a loading control system. , can carry out uniaxial and triaxial compression tests and stress-seepage coupling tests, in which the maximum confining pressure can be increased to 100Mpa, and the maximum stroke of the axial piston is 20mm. The deformation measurement system is used to monitor the hoop and axial deformation of the rock sample.

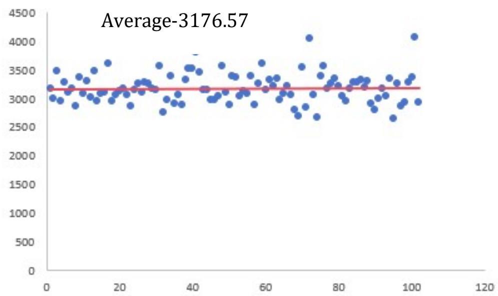
ISSN: 2710-0588

2.3. Uniaxial Compression Test Plan

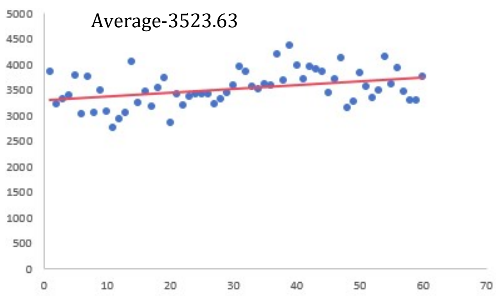
According to TB 10115-2014 the provisions of the railway engineering rock testing procedures, the displacement of the growth is 0.06 mm/min, growth rate of 0.5 kN/s, basic conditions for sample, load damage to sample, the strength of the measured parameters, will be used as subsequent trials average rock strength. Meanwhile, dry and saturated water were set as the control groups. During the loading process, axial stress and axial strain are simultaneously detected, and photos of all the specimens after the tests are taken. The specimen numbers should be reflected as much as possible in the photos. The sample preparation method for saturated samples is to soak them in clear water for more than 48 hours according to the free water absorption method. 2.4 triaxial compression test scheme for triaxial test, when the confining pressure load flow pressure flow to choose 10 to 15 ml, close to the target when the confining pressure, flow pressure modulation 1-2 ml, easy to control. When performing axial compression loading, the flow rate is selected at 1-2ml to make the obtained data more accurate. The triaxial compression mechanics of rocks under damage conditions will test the triaxial deformation and strength characteristics of rocks of different lithologies under different damage conditions in dry/saturated states. Among them, the damage conditions are considered as 0.3, 0.6, and 0.9 times the average uniaxial compressive strength, and the confining pressure conditions are considered as 15 and 30Mpa. During the loading process, axial stress, axial strain and lateral strain are simultaneously detected. Photos of all the specimens after the tests are taken, and the specimen numbers should be reflected as much as possible in the photos. When conducting triaxial compression tests under different damage conditions, the rock samples are first loaded to the specified strength according to the average strength value calculated from conventional uniaxial compression. Then, the confining pressure and axial pressure are simultaneously unloaded to 0. During this period, the samples are not removed. Finally, the samples are loaded again until failure. Meanwhile, record the relevant data synchronously.

3. Test results and analysis

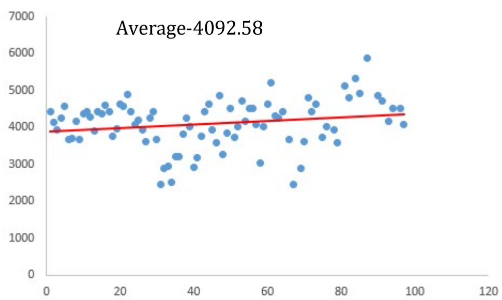
3.1. Relationship between Wave Speed and Intensity



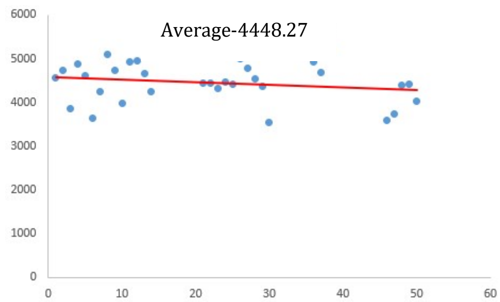
Before preloading the granite



After the granite is preloaded

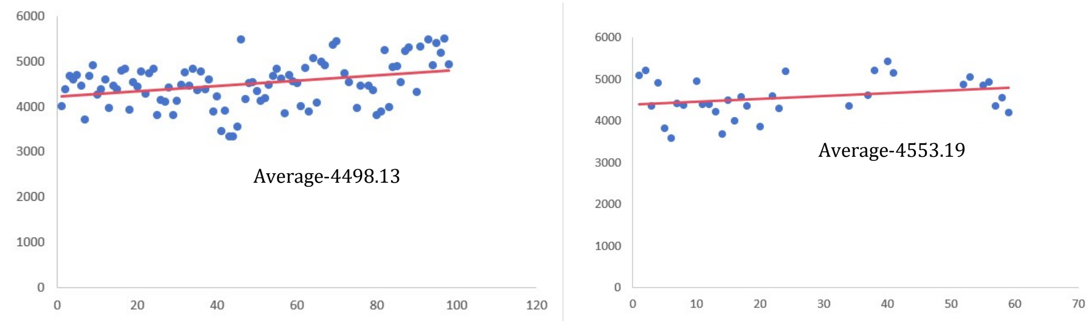


Before preloading the sandstone



After the sandstone is preloaded

ISSN: 2710-0588



Before preloading the limestone After preloading the limestone

Fig. 3 Wave velocity of three rock samples

As shown in Fig. 3, the wave speed of the three rock samples before reaching the preload value and the wave speed after reaching the preload value can be concluded from the wave speed diagram of the three rock samples. The longitudinal wave speed of the granite before preloading ranges from 2650.53 to 4072.26m/s, with an average value of 3176.6 m/s. After preloading, the wave speed ranges from 2751.3 to 4354.75m/s, with an average value of 3523.6 m/s; the longitudinal wave speed range of sandstone before preloading is 2463.05~561.16m/s, with an average value of 4113.85 m/s, and the wave speed range after preloading is 3544.81~5173.6m/s, with an average value of 4448.27 m/s; before preloading, the longitudinal wave speed of limestone ranges from 3333.33 to 5503.84m/s, with an average wave speed of 4450.64 m/s. After preloading, the wave speed ranges from 3432.89 to 5374.12m/s, with an average of 4553.19. The results show that the average wave speed of the three rock samples after preloading has increased to varying degrees. Wu Yanqing et al.[15] Using a scanning electron microscope to observe the deformation of rock before the peak strength and during the damage process, it was found that the rock initially undergoes a compaction process, which causes stress concentration in certain areas, resulting in some micro-cracks inside the rock and causing density changes at the damaged site.

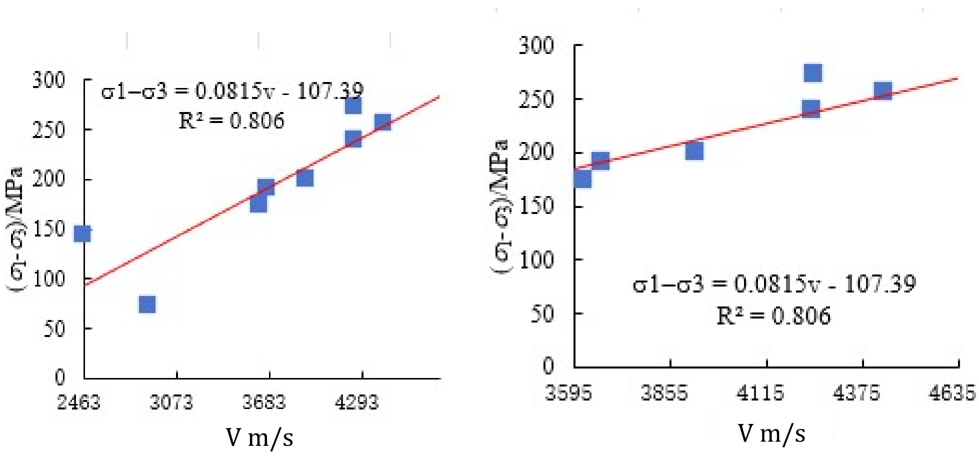


Fig. 4 Wave velocity and corresponding intensity

Select some representative relationship diagrams between wave speed and strain from three types of rocks. The diagram shows the relationship between wave speed and corresponding intensity in the dry state and saturated state when the triaxial compression confining pressure of sandstone is 15Mpa. From Fig. 4, it can be seen that there is an exponential relationship between rock wave speed and strength. As the wave speed increases, the peak intensity also increases. This is consistent with Wang Rujiang et al. [16] who studied rock wave speed. Consistent with the correlation findings of strength parameters, there is a significant positive

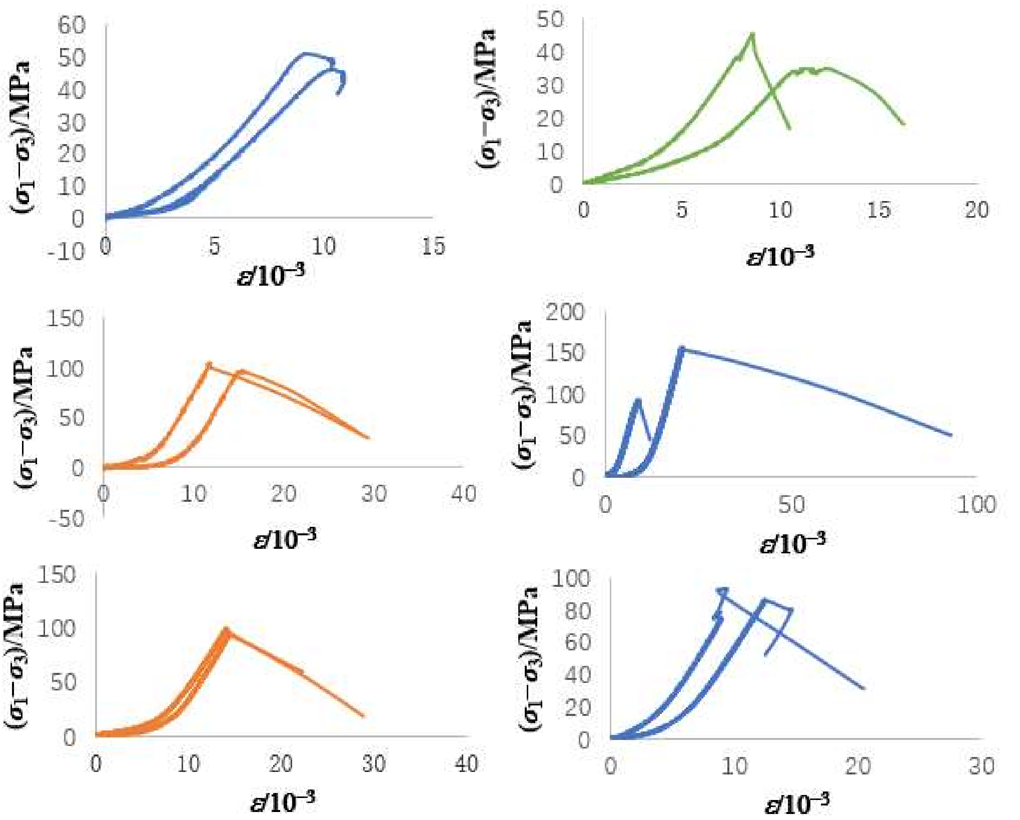
ISSN: 2710-0588

correlation between the compressive strength of different rocks and wave speed. As the compressive strength increases, the wave speed also increases. Different rock types have different characteristics. Granite, sandstone, and limestone are all hard rocks. Due to different burial depths and different natural environments, there is a certain overlap in the range of wave speed changes, but there are obvious differences. Since the degree of internal damage cannot be visually observed, the test wave speed is used to comprehensively reflect the degree of internal damage of the rock [17], achieving the macro-mechanical effect of using wave speed to define rock cracks.

3.2. Uniaxial Compression Test

From the stress-strain curves of the uniaxial compression test of the three rock samples, it can be found that the deformation stages of the three rock samples are relatively similar. Zeng et al. [18] mentioned in rock concrete under dry and saturated conditions that the deformation stages are divided into compaction stage, elastic stage, plastic stage and fracture failure stage.

Fig. 5 Uniaxial compression failure of three rock samples

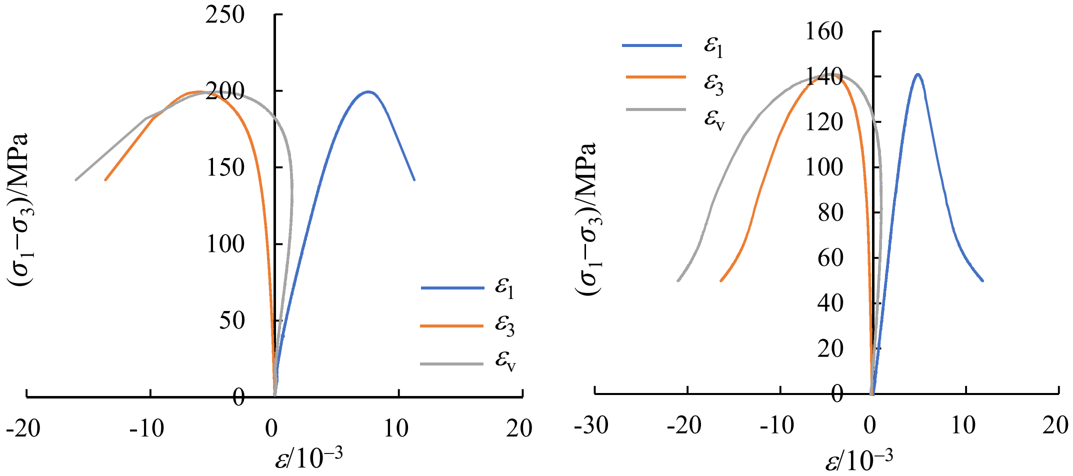


a b

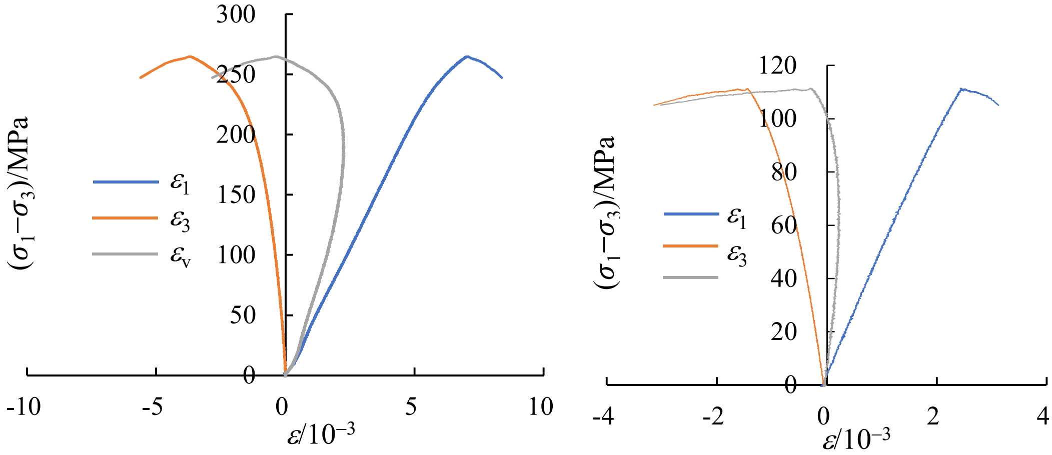
Fig. 6 Uniaxial compressive stress-strain curves of three rock samples

Fig. 5 shows the uniaxial compressive stress-strain curves of granite, test, and limestone samples in dry and saturated states respectively. It can be seen from Fig. 5 that the peak strength of granite and limestone in the saturated state is slightly lower than the peak strength in the dry state. The sandstone sample is in the saturated state. The peak intensities in the dry state are higher than those in the dry state. The peak intensities of the dry state of granite are 50.7 and 45.78Mpa respectively, and the peak intensities in the saturated state are 45.06 and 34.59Mpa respectively. In contrast, the peak intensities in the saturated state are The peak intensities in the dry state were reduced by 12.2% and 32.2% respectively; the peak intensities in the dry state of sandstone were 94.95 and 103.03Mpa respectively, and the peak intensities in the saturated state were 91.73 and 154.11Mpa respectively. Under the conditions, the peak strengths in the saturated state decreased by 3.5% and increased by 49.5% respectively; the peak strengths in the dry state of limestone were 93.66 and 99.2Mpa respectively, and the peak strengths in the saturated state were 86.02 and 93.16Mpa respectively. This compares with decreases of 8.3% and 6.4% respectively. The results show that the strength of granite rock samples in the saturated state decreases significantly, showing the "softening" effect of water on the rock samples; the increase in the strength of the sandstone in the saturated state is due to the different internal structures of the rock, which causes the rock to produce different results when facing the same external conditions.

3.3. Triaxial Compression Test



15Mpa confining pressure



a Dry b Saturated

30Mpa confining pressure

Fig. 7 Stress-strain relationship under different confining pressures

ISSN: 2710-0588

The triaxial compressive stress-strain curves of granite under different confining pressures were selected as representatives for analysis. It can be seen from the figure that in the early stage of loading, various strains under different confining pressures have a certain linear relationship, and the whole is in the elastic stage. As the axial pressure gradually increases and approaches the peak strength, the slope of the curve continues to decrease. When rock pressure conditions are high, internal cracks appear and continue to grow, causing local damage, resulting in a reduction in the rock's ability to resist deformation. [19] By observing the stress-strain curves under different confining pressures, it can also be found that the higher the confining pressure, the greater the peak strength and yield stress at the time of failure. There is a linear relationship between confining pressure and compressive strength. Within the test range, the failure of the three rock samples conforms to the Coulomb strength criterion, among which granite has a confining pressure of 15Mpa. When the confining pressure is 30Mpa, the peak difference value can reach about 25%, the sandstone difference value can reach 0.3%, and the limestone difference value is 0.6%. This has a great relationship with the inhomogeneity of the internal materials of the rock. The internal material strength of the rock is different, resulting in large discreteness when doing relevant tests, which is a normal phenomenon. [20] At the same time, conventional triaxial compression tests also provide comparison for subsequent triaxial compression tests under different preload values.

It can be seen from Fig.7 that the overall stress-strain curves of different preload values in the initial stage and elastic deformation stage are relatively similar to the curves when the intact rock sample fails. As the confining pressure increases, the strength of the rock sample when it fails also increases, which is the same as the results of conventional triaxial rock damage tests. It can be seen from the trend line in the figure that as the preload value increases, the overall strength of the rock sample will decrease. The analysis may be because: brittle rocks are more sensitive to cracks. As the preload value increases, the cracks within the rock will also expand, causing internal damage to the rock. Once the rock is damaged, the stress-strain curve will show a sharp decrease in the stress curve.

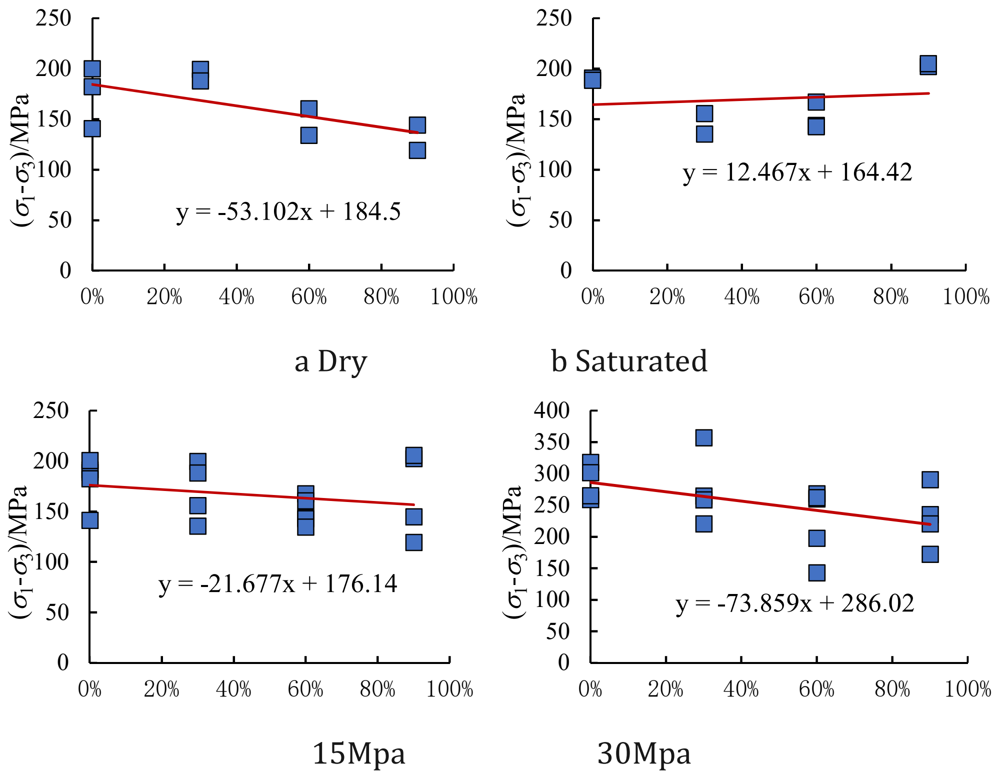


Fig. 8 Relationship between different preloading values and corresponding stresses

ISSN: 2710-0588

3.4. Analysis of Damage Morphology

As shown in the figure below, photos of the damage of rock samples after uniaxial compression and triaxial compression (confining pressures are 15 and 30Mpa respectively) were selected from the rock samples. It can be seen from the figure that the cracks in the rock samples are basically parallel to the longitudinal direction during uniaxial compression. , and accompanied by multiple fine cracks; the rock sample under triaxial compression does not have particularly violent damage characteristics, but there are obvious fine cracks. As the confining pressure increases, the angle of the rock sample gradually transforms from parallel tensile cracks to shear failure cracks. The failure form of sandstone is different from that of granite. As the confining pressure increases, the failure angle gradually becomes smaller. In general, the failure modes of rock samples can be roughly divided into: tension failure and shear failure.

The vertical cracks parallel to the loading direction that appear during the failure of the specimen are macroscopic cracks during the loading process. During the loading process, stress concentration occurs due to the compression of the specimen at both ends, resulting in invisible micro-cracks inside the rock sample, which merge with the original cracks inside the rock to form multiple shear failure surfaces. [21] After the rock sample is destroyed, new secondary cracks are derived from the primary cracks, and the two combine with each other to form the macroscopic fracture surface of the rock sample. From the perspective of the overall damage of the rock sample, uniaxial compression makes the rock sample damage more significant and accompanied by debris. In the triaxial compression test, as the confining pressure increases, the inclination angle tends to decrease and the compressive strength of the rock sample increases [22-24].

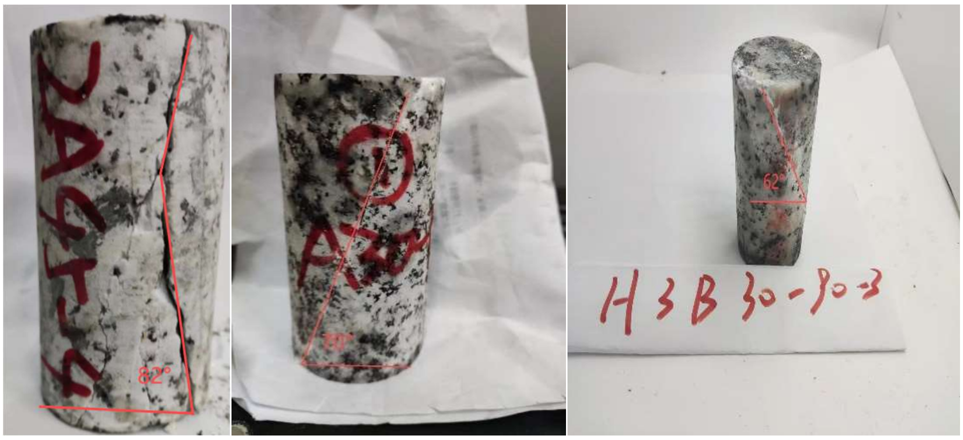


Fig. 9 Destruction diagram of granite sample

Fig. 10 Destruction diagram of sandstone sample

4. Conclusion

By conducting uniaxial compression and triaxial compression tests on different rock samples, the following conclusions can be drawn:

ISSN: 2710-0588

(1) It is essentially a one-cycle loading and unloading process. The disadvantage is that the number of cycles is too small to see very obvious damage phenomena. The hysteresis loop is generated in the compaction stage during the unloading process. Xiao Fukun et al. can see from the uniaxial compression cycle loading and unloading test that the area of the hysteresis loop grows slowly in the first three cycles. Each cycle will cause more cracks than the previous one, and the irreversible plastic deformation will also increase. When the rock sample is close to failure, the irreversible plastic deformation will reach the maximum value;

(2) In the uniaxial compression test, there are four main stages: compression stage, elastic stage, pre-peak yielding, and post-peak elasticity;

(3) In the triaxial compression test, as the preload value increases, the compressive strength of the rock samples decreases to varying degrees; as the confining pressure increases, the inclination angle of the rock samples decreases to varying degrees. When the inclination angle of the fracture is large and nearly parallel to the direction of compression, there are more rock fragments and the degree of rock sample damage is relatively large; when the inclination angle is close to 60°, the rock sample failure is shear failure and there are less rock fragments.

References

[1] Qiao Tong, Zhang Guang, Hu Shaohua, et al. Research on constitutive model of microcrack compaction section of brittle rock [J]. China Production Safety Science and Technology, 2017, 13(10): 128-135.

[2] Zhou Jiawen, Yang Xingguo, Fu Wenxi, et al. Research on uniaxial cyclic loading and unloading tests and fracture damage mechanical characteristics of brittle rocks [J]. Journal of Rock Mechanics and Engineering, 2010, 29(6): 1172-1183.

[3] Huang Mingli, Tang Chunan, Zhu Wancheng. SEM real-time study of rock failure and instability process under uniaxial compression [J]. Journal of Northeastern University (Natural Science Edition), 1999, 20(4): 426-429.

[4] Yang Shengqi, Dai Yonghao, Han Lijun, et al. Uniaxial compression test study on deformation and failure characteristics of brittle marble with intermittent prefabricated cracks [J]. Chinese Journal of Rock Mechanics and Engineering, 2009, 28(12): 2391-2404.

[5] Huang Yanhua, Yang Shengqi, Ju Yang, et al. Experimental study on triaxial compression mechanical properties of discontinuous fractured rock materials [J]. Chinese Journal of Geotechnical Engineering, 2016, 38(07): 1212-1220.

[6] Zeng Sheng, Zhang Ni, Sun Bing, et al. Experimental study on the stress characteristics of rock concrete integrated two-media under dry and saturated conditions [J]. Bulletin of Silicates, 2018, 37(7): 2206-2209, 2213.

[7] Meng Qingbin, Wang Congkai, Huang Bingxiang, et al. Rock energy evolution and distribution rules under triaxial cyclic loading and unloading conditions [J]. Journal of Rock Mechanics and Engineering, 2020, 39(10): 2047-2059.

[8] Yao Wei, Yu Jin, Zhou Xianqi, et al. Damage fracture and permeability characteristics of red sandstone under the combined disturbance of cyclic loading and confining pressure relief [J]. Chinese Journal of Geotechnical Engineering, 2024: 1-9.

[9] Huang Da, Tan Qing, Huang Runqiu. Research on the strain energy conversion process mechanism of marble damage and fracture under high stress and strong unloading conditions [J]. Chinese Journal of Rock Mechanics and Engineering, 2012, 31(12): 2483-2493.

[10] Li Simon, Liu Changyou, Speng Syd, et al. Research on fatigue deformation characteristics and damage model of sandstone under uniaxial graded cyclic loading [J]. Journal of China University of Mining and Technology, 2017(1): 8-17.

[11] Feng Shi, Sheng Hua, Zhang Haijun, et al. Research on the influence of cyclic loading on the mechanical properties of green sandstone with different crack angles [J]. Mining Technology, 2022, 22(03): 45-50.

ISSN: 2710-0588

[12] Zhou Jijun, Shan Renliang, Wang Hui, et al. Research on the strength of damaged and destroyed rocks [J]. Mining Research and Development, 2010, 30(3): 30-33, 108.

[13] Cui Z, Sheng Q, Zhang M, Cao J, Mei X, Luo Q. A New Direct Shear Apparatus for Rock Joints Specialized in Cyclic Loading[J]. Rock Mechanics and Rock Engineering, 2021, 54(8): 4321-4327.

[14] Chang Liuming. Experimental and discrete element simulation research on mechanical properties of the entire failure process of different types of rocks_Chang Liuming (1)[J]. Anhui University of Science and Technology, 2023.

[15] Wu Yanqing, Ding Weihua, Pu Yibin, et al. CT dynamic observation of rock density damage increment under compression conditions [J]. Progress in Natural Science, 2000, 10(9): 830-835.

[16] Wang Rujiang, Ren Meng, Liu Jinsong, etc. Research on the correlation between rock wave speed and strength parameters [J]. Mining Research and Development, 2021, 41(9): 87-91.

[17] Zhao Mingjie, Xu Rong. Research on rock damage characteristics and strength using ultrasonic wave velocity [J]. Chinese Journal of Geotechnical Engineering, 2000(06): 720-722.

[18] Zeng Sheng, Zhang Ni, Sun Bing, et al. Experimental study on the stress characteristics of rock concrete integrated two-media under dry and saturated conditions [J]. Bulletin of Silicate, 2018, 37(7): 2206-2209, 2213.

[19] Zhang Zhiliang, Xu Weiya, Wang Wei, et al. Research on conventional triaxial compression tests and deformation and damage evolution rules of ductile rocks [J]. Chinese Journal of Rock Mechanics and Engineering, 2011(S2): 3857-3862.

[20] Yang Shengqi, Xu Weiya, Su Chengdong. Research on triaxial compression deformation failure and energy characteristics of marble [J]. Engineering Mechanics, 2007, 24(1): 136-142.

[21] Niu Liang, Mu Rui, Chen Jun. Experimental study on mechanical properties of rocks containing natural micro-cracks [J]. Proceedings of the Yangtze Academy of Sciences, 2020, 37(2): 141-146.

[22] Zhang Peisen, Xu Daqiang, Yan Wei, et al. Research on the effects of cyclic addition and removal of confining pressure on rock deterioration and seepage characteristics under different initial damage degrees [J]. Journal of Rock Mechanics and Engineering, 2023, 42(9): 2109-2124.

[23] Qiu Shili, Feng Xiating, Zhang Chuanqing, et al. Experimental study on the unloading mechanical characteristics of deeply buried marble under different confining pressure relief rates [J]. Journal of Rock Mechanics and Engineering, 2010, 29(9): 1807-1817.

[24] Wang Chunping, Wang Lu, Liu Jianfeng, et al. Mechanical properties and failure characteristics of single-cracked granite under uniaxial compression [J]. Journal of Southwest Jiaotong University, 2024, 59(2): 369-376, 446.