Characteristics of rock damage variable under cyclic loading

Yunfeng Wu
School of Civil and Resource Engineering, University of science and technology Beijing, Beijing, China

*Corresponding author e-mail: g20188106@xs.ustb.edu.cn

Abstract. In order to study the mechanical characteristics of rock under dynamic load, shock and P-wave velocities were measured by split Hopkinson (SHPB) testing system and NM-4b non-metallic ultrasonic testing analyser. In the test, the specimens were subjected to single impact with different air pressure and cyclic impact with the same air pressure. Acoustic velocity was measured before and after impact to observe the morphological characteristics of rock samples after impact. The results show that: under different air pressure, the rock fracture morphology is closely related to the air pressure. The higher the air pressure, the greater the peak strength of the sample, the more concentrated the damage range to the center of the sample; The results show that the peak stress decreases, the cumulative damage increases and the wave velocity decreases with the increase of cyclic impact times.

Key words: Hopkinson pressure bar; cyclic shock; P-wave velocity; damage.

1. Introduction
When the engineering rock mass is subjected to cyclic dynamic loads such as blasting and mechanical drilling, it has already borne static loads from in-situ stress and tectonic stress. Through theoretical calculation and experimental research, Jin Jiefang et al. [1] It is concluded that the change of rock wave impedance can be used to define the damage variable in the process of cyclic impact. Li XB et al. [2] conducted repeated impact tests on granite without axial compression and confining pressure by using SHPB with a rod diameter of 75 mm. It is considered that when the peak impact stress is less than 60% - 70% of its static uniaxial strength, the cyclic impact can hardly increase the internal damage of rock. Lin Daneng et al. [3] conducted multiple impact tests on rocks under different confining pressures by using the device of approximate drop hammer, and obtained the correlation between impact damage degree and confining pressure, load impulse and impact times. Lv XiaoCong et al. [4] carried out cyclic impact test on rocks with different confining pressures, and obtained the relationship between Young's modulus, yield stress and yield strain with the number of cyclic impact, and studied the relationship between specific energy absorption value of rock specimen and confining pressure in the process of cyclic impact. Wang Zhiliang et al. [5] analyzed the relationship between peak stress, strain, average strain rate, damage value and impact times of granite under constant amplitude cyclic impact, as well as the influence of axial pressure on total cyclic impact times of samples. Based on the above knowledge, the impact test is divided into different groups, and the influence of impact load change on rock damage and rock sample shock P-wave velocity is discussed.
2. Experimental details

2.1. Experiment system design
The SHPB pressure bar device used in this test is divided into three main parts: pneumatic driving system, pressure bar device system and data signal receiving and collecting system. The Hopkinson test system and sample used in this paper are shown in Fig 1. The length and diameter of the incident rod and transmission rod are 1800mm and 50mm respectively. The elastic modulus is 240GPa and the density is 7800kg / m³.

The data acquisition and receiving system is LK2400 high speed data collector and LK2109A ultra dynamic strain gauge. Before the test, empty rod impact should be carried out first to observe whether the waveform diagram meets the experimental requirements. After debugging, it can meet the test requirements, and then carry out the follow-up test. When the test block and other devices are set up, the air pressure bar is pressurized to the pressure required by the design experiment. The release speed should be fast. Try to give the bullet a stable initial speed to reduce the error. The bullet speed is measured by laser velocimeter. In order to reduce the dispersion effect of the test, T2 copper sheet is used as the waveform shaper in the test because the bullet is cylindrical.

![Fig. 1 Hopkinson test system and sample](image_url)

2.2. SHPB test process
During the test, in order to determine the maximum impact strength of the specimen and avoid the specimen being damaged at one time, the pre impact test is carried out on the specimen first, so as to achieve the effect of subsequent test cycle impact. After four specimens were impacted by different air pressures, the state of the specimens after impact was observed. According to the critical failure state of the corresponding air pressure value when there was no debris falling off, the critical pressure was determined to be 0.07MPa.

After determining the critical pressure of rock sample failure, six groups of tests were set up. The first group was three samples, which were subjected to cyclic impact with 0.04MPa air pressure until failure or block falling. The second and third groups were subjected to cyclic impact test in the same way as 0.05MPa and 0.06MPa respectively; the fourth, fifth groups were subjected to single impact test with 0.07MPa, 0.08MPa respectively.

3. Experiment results and discussion

3.1. Stress strain curve
The stress-strain curve corresponding to a single test. The stress-strain curves of each cycle number under different air pressures are shown in Fig 2.
It can be seen from (b), (c) and (d) in Fig. 2 that the stress-strain curve of the same specimen rises linearly at the initial stage, and maintains roughly the same slope rise, which means that the internal pores of the rock sample are in the compaction stage in a short period of time when the load is impacted, and there are not enough new cracks generated, which is similar to the elastic stage, showing the strength and toughness of the rock. With the increase of stress, the trend of tangent slope of each specimen in the figure has a gradually decreasing trend, and the side reflects that the dynamic modulus of elasticity is decreasing at this stage. From the microscopic properties of rock materials, it is due to the continuous increase of stress that leads to the stress concentration of the original crack in the rock sample, which absorbs the kinetic energy of impact transformation, and makes the internal crack extend and expand rapidly. With the increase of the number of impact cycles, the strain corresponding to the yield point of the specimen gradually moves back, and the peak stress decreases gradually.

The trend of stress-strain curves in figures (e) and (f) in the early stage is similar to that in the first three kinds of cyclic impact tests under different air pressures. In the later stage, the stress gradually decreases, but the strain increases gradually, i.e. "rebound" phenomenon will not occur. This is because the incident rod still works on the specimen in the process of stress drop, resulting in the continuous expansion of the fracture surface of the specimen and the reduction of the residual strength of the rock sample. At this time, the impact strength of the incident bar is far greater than the bearing capacity of the specimen, so the strain will continue to increase.

3.2. Damage mode
The research on the failure mode of strongly disturbed rock under impact load is of guiding significance to the analysis of failure mode in engineering rock mass and disturbance prevention. Fig. 3 shows the four failure modes of rock in 0.05MPa pneumatic cyclic impact test.
It can be seen from Figure 3 that: before the third impact, the appearance of the specimen is basically intact; after the second impact, an axial crack with a length of 2cm appears; after the fourth impact, the surface crack is widened, and there is a through crack, and the crack also begins to develop and extend in the radial direction; after the fifth test, the specimen is fractured and damaged to a large degree.

In Fig. 4, with the increasing of impact pressure, the sample is broken first by large pieces splitting. Due to the gradual increase of strain rate, the failure of the sample develops from large to small and even comminuted, and the scope of damage also transits from the edge part of the sample to the central position. At this time, the failure forms are mainly tensile failure and compression shear failure.

3.3. Velocity variation of P-wave

The damage measurement of materials can be measured from the micro and macro directions, and the micro is mainly judged by the crack density of the materials, and the ultrasonic velocity measurement method is a commonly used macroscopic method to identify the rock damage. After rock is damaged by impact, its physical and mechanical properties will change, and the generation of cracks and fissures will reduce the amplitude and speed of acoustic wave. Acoustic signal has the function of transmitting information. According to its wave characteristics, it can reflect some physical characteristics of rock, so as to distinguish the internal integrity of rock.

When the wave velocity encounters obstacles or the propagation medium changes, there will be velocity change, reflection and scattering. When acoustic wave meets different structural planes, it will change its propagation path. After reflection superposition, according to the nature of acoustic wave carrying information, acoustic wave can be used to reflect the damage degree of rock. Due to the large amount of measured acoustic data, Fig. 5 only lists the P-wave velocity before and after 0.05MPa air pressure cyclic impact. The wave velocities after cyclic impact are 5435km / s, 5000km / s, 4808km / s.
and 4630km / s respectively. It can be seen that the wave speed of sound wave decreases with the increase of impact times.

![Images showing longitudinal wave velocity of specimen before and after impact under 0.05Mpa air pressure]

**Fig. 5** Longitudinal wave velocity of specimen before and after impact under 0.05Mpa air pressure

### 4. Conclusion

In this paper, SHPB pressure bar is used to carry out impact test on the sample and granite, and the failure mode of rock sample under different air pressure is analyzed. With the increase of air pressure, the peak strength of rock sample is proportional to it. The size of rock sample failure block gradually accumulates from the circumference to the center. Under the condition of cyclic impact on a single specimen, the peak strength of the specimen gradually increases with the increase of impact times. Under cyclic impact load, the internal structure of rock sample changes, and its longitudinal wave velocity decreases with the impact times.

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### References

[1] Jin Jiefang, Li Xibing, Yin Zhiqiang, et al. Study on rock damage variable defined by wave impedance under cyclic impact [J]. Geotechnical mechanics, 2011, 32 (5): 1385-1393.

[2] Li X B, Lok T S, Zhao J. Dynamic characteristics of granite subjec ted to intermediate loading rate [J]. Rock Mech. Rock Eng., 2005, 38(1):21-39.

[3] Lin Daneng, Chen Shouru. Experimental study on rock damage law under cyclic impact load [J]. Journal of rock mechanics and engineering, 2005, 24 (22): 4094-4098.

[4] Lv XiaoCong, Xu Jinyu, Ge Honghai, et al. Influence of confining pressure on dynamic impact mechanical properties of sandstone [J]. Journal of rock mechanics and engineering, 2010, 29 (1): 193-201.

[5] Wang Zhiliang, Yang Hui, Tian nocheng. Mechanical properties and damage evolution mechanism of granite under uniaxial cyclic impact [J]. Journal of Harbin Institute of technology, 2020, 52 (2): 59-66.