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Short communication

Investigation into the characteristics of rock damage caused by ultrasonic vibration

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1. Introduction

Rocks characterized by high density, high strength, strong abrasiveness and large fracture energy are highly difficult to break, and this difficulty presents a major technical problem in today's drilling fields. It is inferred that the strength of a rock can be reduced by vibration.[1,2] The traditional methods of crushing rock by vibration can be divided into single impact drilling, low frequency impact drilling and sonic drilling. The principle of single impact drilling and low frequency impact drilling is to use the impact to crush cavities within the rock and subsequently combine with rotary shearing to break rock during drilling. However, this method has certain disadvantages, such as short bit life and poor drilling efficiency because of an unintuitive decrease in rock strength. Sonic drilling also does not work well for hard rock drilling because of the high impact loss during transmission from the vibrator installed on the rig through the long drill pipe to the drill bit. Therefore, it is necessary to identify a new technical method of drilling hard rock.

The natural frequency of complete, high-density hard rock is commonly in the range of 20–38 kHz. When rock resonates reasonably well, the strength will drop sharply and quickly. In this situation, rock will be easily broken and drilling speed and bit life will also be improved substantially.

At present, the mechanism of rock crushing by vibration has been investigated deeply. Bagde et al.[3,4] considered that the dynamic fatigue strength, dynamic axial stiffness and dynamic modulus of rock are associated with the frequency and amplitude of load. Cho et al.[5] identified the inhomogeneity of the microstructural strength of rock as a contributing factor to the difference between the static and dynamic tensile strengths. The inhomogeneity had an effect on the strain-rate dependency of the dynamic tensile strength. Davison and Stevens [6] proposed a compound-damage-accumulation model of rock and observed a threshold value in the model. These researchers found that whether damage of rock material develops is primarily related to external load and the size of the threshold value. Whittles [7] investigated the relationship among strain rate, impact energy, the degree of fragmentation and the energy efficiency of fragmentation using laboratory test methods combined with numerical simulation methods. It was found that a greater amount of energy was required for breakage with increasing strain rate, and samples broken at higher strain rates tended to produce much more fragmentation. In other words, the dynamic uniaxial compressive strength is considerably higher than the static strength. Tay [8] simulated the internal crack propagation of rock under the action of impact using the maximum hoop stress criterion and the maximum principal stress criterion, respectively.

However, the vibration frequency involved in all of the research mentioned above is relatively low, and investigations on crushing rock with high frequency vibration close to the natural frequency have not been reported. Thus, it is necessary to investigate the formation of rock cracks and the decrease of rock strength under

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ultrasonic vibration in order to provide theoretical guidance for ultrasonic vibration drilling. This paper investigated the relationship among the preloading level, the duration of vibration, the compressive strength of the rock and the development of cracks using a uniaxial static-dynamic loading pattern.

2. Static-dynamic loading rock crushing test

2.1. Description of test specimens

The test samples were granite with an average compressive strength of 94.18 MPa. The samples were 40 mm in diameter and 80 mm tall, as is common when testing rock mechanical properties. Both sides of the sample were ground before the test.

2.2. Testing apparatus

The test was completed with a special ZJS-2000 ultrasonic vibration device, which consisted of a vibration generator, driving power and bracket (Fig. 1). A vertical static load was exerted at the top of the bracket, while a 20 kHz ultrasonic dynamic load were exerted by vibration generator. The ZJS-2000 ultrasonic vibration device had the following performance parameters: working frequency and limited static load were 20 kHz and 600 N, respectively, working current was less than 2 A, and the power could be regulated between 0 W and 1600 W.

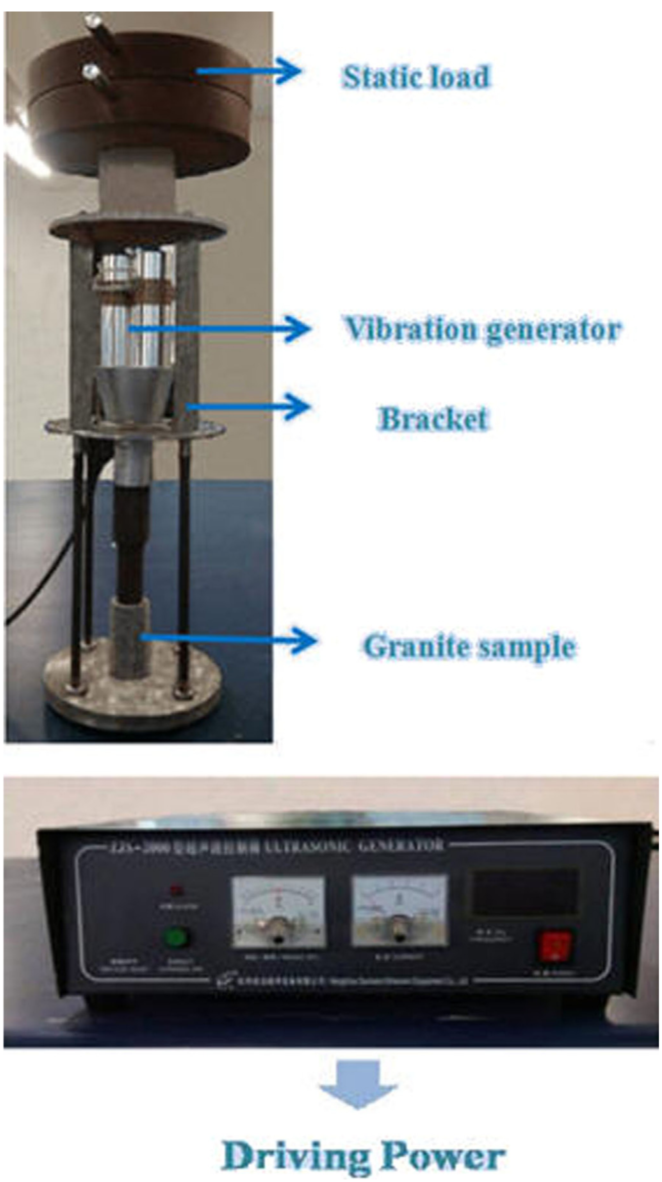

Fig. 1. Photographs of the special ZJS-2000 ultrasonic vibration device.

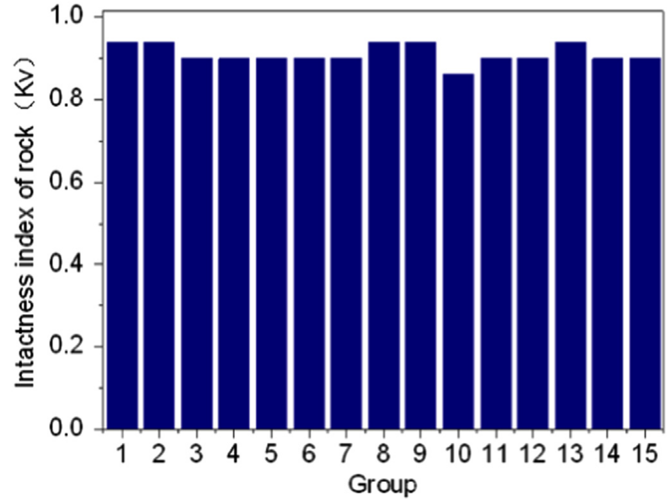

Fig. 2. The average value of intactness index of rock of each group.

2.3. Testing schedule

The test was divided into fifteen groups according to the preloading level and the duration of vibration. Each set contained five samples. The vibration duration was either 5, 10 or 15 min while the preloading values were 100, 200, 300, 400 and 500 N. Rock is a type of composite material which contains micro defects, such as microcracks and micropores. [9,10] To reduce the effects of rock anisotropy and integrity on the test results, the intactness index of each sample was measured before the test. The average intactness index of each group is shown in Fig. 2. Each sample was processed by the ZJS-2000 ultrasonic vibration device, and the compressive strength of these processed samples was subsequently measured to observe the change in strength after ultrasonic vibration using a WEW-1000D hydraulic universal testing machine. The average compressive strengths of each group have been detailed in Table 1.

Table 1
Summary of text results.

Serial number	Duration of vibration (min)	Preloading (N)	Compressive strength (MPa)
1	5	100	87.44
2	5	200	90.11
3	5	300	79.61
4	5	400	77.31
5	5	500	78.37
6	10	100	94.03
7	10	200	95.08
8	10	300	78.11
9	10	400	76.96
10	10	500	77.73
11	15	100	89.64
12	15	200	95.80
13	15	300	77.04
14	15	400	76.50
15	15	500	76.82