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Study of Dynamic Tensile Mechanical Properties of Red Sandstone under Dry and Water-filled Conditions

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Abstract

In order to study the effect of water on the mechanical properties of sandstone, a 50 mm diameter split Hopkinson pressure bar (SHPB) device was used to conduct dynamic splitting tensile tests on dry and water saturated red sandstone, and the dynamic splitting tensile mechanical properties of red sandstone under different strain rates were studied. The results show that the dynamic tensile strength of sandstone increases with the increase of average strain rate under different conditions, showing obvious strain rate effect. The strength of dry and saturated sandstone increases approximately as a power function with the increase of strain rate. Under the same strain rate, the strength of saturated sandstone is lower than that of dry sandstone.

Keywords

SHPB; Sandstone; Dynamic Tensile Strength; Brazilian Cleavage; Rate Effect.

1. Introduction

Water is one of the geological conditions of rock mass engineering. With the rapid development of deep rock mass engineering [1-3], deep rocks are often inseparable from the influence of water, and tensile failure occurs under load. Because water has a great influence on the tensile failure of deep rock. Therefore, it is of great significance for deep rock mass engineering to study the tensile and tensile mechanical properties of rock under dry and saturated conditions. Against this background, many scholars at home and abroad have carried out a lot of research on the influence of water on the tensile strength and mechanical properties of rock, and achieved rich results. You Mingqing [4] and others carried out Brazilian splitting tests on four kinds of sandstone discs and rings in dry and water saturated state, and analyzed the influence law and reason of water on the tensile strength of sandstone; B. V á s á rhelyi [5] et al. Found that water weakens the tensile strength of rock, and put forward a calculation method for the weakening of tensile strength of rock by water; Karakul [6] et al. Obtained through the test that the tensile strength of rock decreases with the increase of water saturation, and established different strength prediction equations; Zhu Chaohui [7] et al. Conducted Brazilian splitting test on water saturated dry cyclic sandstone and obtained the deterioration law of water on the tensile strength of sandstone; Mingming [8] et al. Studied sandstone specimens with different water content and found that sandstone has obvious softening phenomenon when encountering water; Wang Chong [9] et al. Studied the influence of temperature and water on rocks and found that strength is related to water content. Liu Yunsi [10] et al. Conducted Brazilian disc splitting test on the lower slate in water saturated state. It was found that the rock mass strength showed water saturated softening and water saturated strengthening under different loading rates. These results have discussed the influence law of water on the dynamic tensile mechanical properties of rock to a certain extent. In this paper, the separated Hopkinson pressure bar (SHPB) device with a diameter of 50mm is proposed to carry out dynamic splitting tests on the Brazilian disc specimens of red sandstone platform under dry and water saturated conditions respectively, so as to reveal the deterioration mechanism of water on the dynamic tensile mechanical properties of fractured rock mass from a mechanical point of view.

2. Test Method

He SHPB system consists of an air cannon, an emission chamber, a spinning cone punch, an incidence rod, a transmission rod, and an absorption rod. The incident rod, transmission rod and absorber rod are 50 mm in diameter and 2.0, 1.5 and 0.5 m in length, respectively, as shown in Figure 1. To ensure that the physical and mechanical properties of the specimens are similar, the materials used in the tests are taken from a complete rock block with good homogeneity. Red sandstone cylinders with a diameter of 50 mm were produced by core drilling, and the specimens were machined into cylinders with a diameter of 50 mm, a length of 25 mm, and an L/D ratio of 0.5. The end surfaces of the specimens were polished and ground to ensure that their end roughness was less than 0.02 mm, and they were dried and saturated separately. As shown in Figure 1.

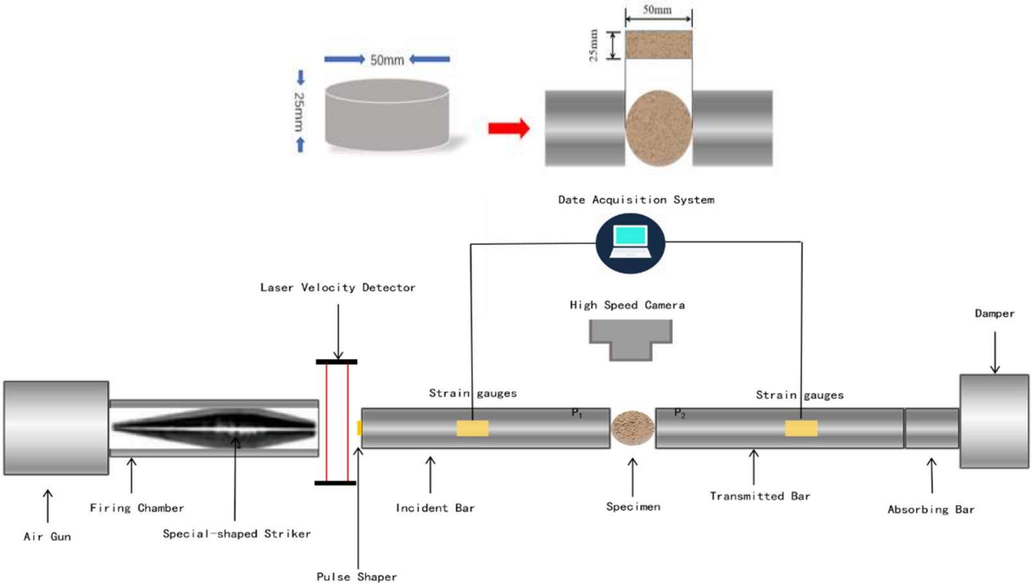


Figure 1. Schematic diagram of sample and SHPB device

3. Stress Balance Verification

For SHPB test, achieving stress balance before rock sample failure is a prerequisite for the effectiveness of experimental results [11]. The stress balance was checked and verified by dynamic stress loading at both ends of the sample. As shown in Figure 2, the curve of the sum of incident wave and reflected wave almost coincides with the curve of transmitted wave, which shows that the loads at both ends of the rock sample are equal before reaching the peak. Ignoring the axial inertia effect of the sample [12,13], it is considered that the sample has reached the stress equilibrium state and the test results are effective. The tensile strength, strain rate and strain of the specimen can be calculated by the following formula [14]:

$$\sigma_t = \frac{E_0 D_0^2}{2DB} \varepsilon_t(t)$$

$$\dot{\varepsilon} = -\frac{2C_0}{D} \varepsilon_r(t)$$

$$\varepsilon = -\frac{2C_0}{D}\int_0^t \varepsilon_r\left(\tau\right)d\tau$$

Where, C_0 is the longitudinal wave velocity of the rod, E_0 is the elastic modulus of the rod, the diameter of the test piece is D, the thickness is B, and the diameter of the rod is D_0. And ε_t, $\varepsilon_r$are the reflected wave and transmitted wave in the rod respectively.

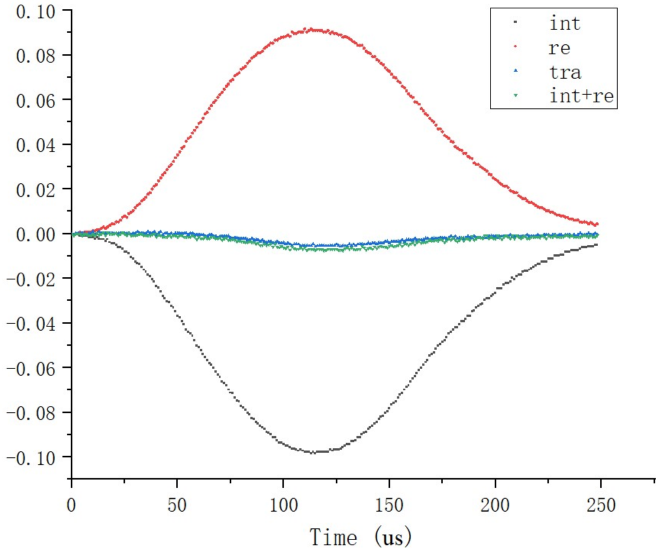
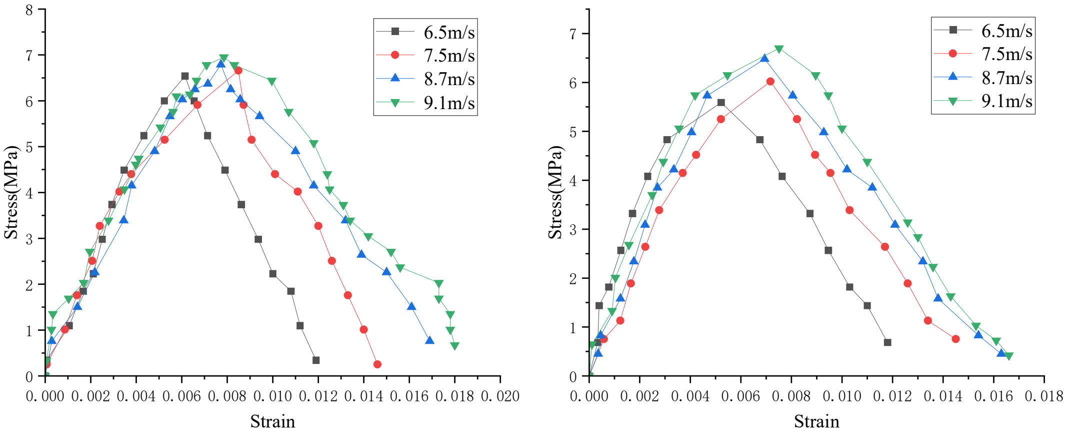


Figure 2. dynamic stress balance verification

4. Test Results and Analysis

4.1 Dynamic Stress-strain Curve



(a) (b)

Figure 3. dynamic stress-strain diagram of red sandstone under different impact velocities (a is dry and b is saturated)

The mechanical properties of the material, such as peak strength and elastic modulus, can be obtained from the characteristics of the stress-strain curve. Fig. 3 shows the stress-strain curves of dry and saturated red sandstone specimens under single impact at different rates. It can be seen from the figure that the characteristics of the stress-strain curves of the two states of sandstone in the dynamic impact splitting test are relatively similar. With the increase of impact speed, the stress-strain curves show a step-by-step growth and change, which can be divided into three stages. The first stage is the elastic stage, the stress increases rapidly in a linear relationship with strain, and the sample absorbs energy for storage for crack propagation and condensation in the next stage, The slope of this stage can be used as the dynamic tensile modulus of the sample. The second stage is the plastic development stage, and the stress gradually slows down with the growth rate of strain, which indicates the characteristics of strain hardening. In this stage, the proportion in the stress-strain curve is small, while the red sandstone in the water saturated state accounts for a large proportion in the stress-strain curve compared with the dry state, and the strain hardening is more slow. In this stage, the internal crack of the sample will expand rapidly and the absorbed energy will reach the tensile stress limit. The third stage is the failure stage. In this stage, the growth of stress and strain decreases sharply, the slope is negative, and the energy absorbed by the sample exceeds the tensile stress limit, resulting in failure. At the same time, in the dynamic impact splitting test of red sandstone in two states, the radial dynamic tensile stress and radial strain increase with the increase of strain rate, showing obvious strain rate effect. In the elastic stage, the slope of the red sandstone sample in the dry state is significantly lower than that in the water saturated state. Due to the action of water, the sandstone has internal chemical reaction, the strength decreases, the sandstone reaches the ultimate tensile stress faster, and the slope is steeper.

4.2 Strain Rate Effect of Sandstone

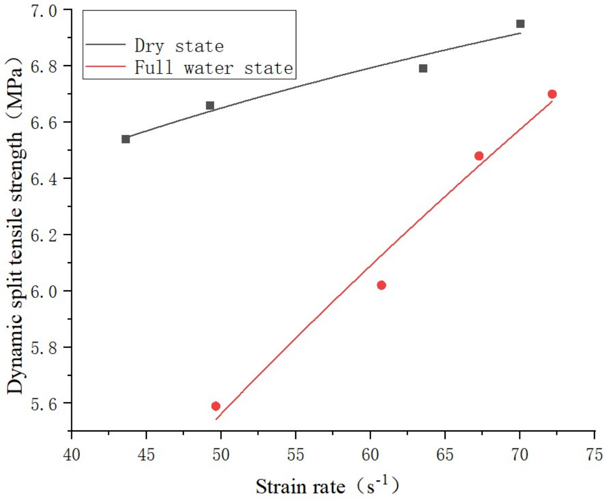


Figure 4. Variation of dynamic tensile strength of dry and saturated sandstone with strain rate

Fig. 4 shows the variation of dynamic tensile strength of red sandstone with strain rate under dry and saturated conditions. As shown in Figure 7, the dynamic tensile strength of sandstone samples in the two states increases with the increase of strain rate, which shows a strong rate correlation. The strength of sandstone samples after water saturation treatment is significantly lower than that in dry state. The reason for this state may be that red sandstone is water sensitive, and the water content causes local deterioration of sandstone samples and greatly reduces the tensile strength. The possible reasons for the strain rate strengthening effect of water saturated sandstone are as follows: with the increase of strain rate, the free water in the specimen cannot immediately fill the new cracks, and the cracks not filled with water will be subject to the surface tension of free water, resulting in the bonding force that hinders the crack propagation [15], inhibiting the crack propagation and improving the tensile strength of rock samples, It is shown in Fig. 3 the dynamic stress-strain diagram of red sandstone under different impact velocities (a is dry state, B is saturated state) and the strain rate strengthening effect under water state. In the dry specimen, the microcracks in the impacted specimen can not expand and connect in time, and the deformation lags behind. With the increase of loading rate, the more obvious the deformation lag is, which shows the strain rate strengthening effect.

In order to describe the relationship between rock dynamic tensile strength and strain rate, the following relationship is used for fitting:

$$\sigma_d = a \cdot \dot{\varepsilon}^b$$

Where: σ_d is the dynamic tensile strength of rock; $\dot{\varepsilon}$ is the average strain rate of rock; And a, b are fitting constants, and the magnitude reflects the rate correlation of intensity. The fitting curve is shown in Figure 4. The minimum correlation coefficient of fitting is 0.9574, which shows that the fitting effect is good. See Table 1 for detailed fitting parameters.

Table 1. fitting parameters of dynamic tensile strength of dry and saturated sandstone with strain rate

Sample state	a	b	R^2
dry	4.2148	0.1166	0.9574
Saturated water	0.7980	0.4964	0.9790

It can be seen from the fitting curve in Figure 4 that the growth trend of rock dynamic tensile strength with strain rate in dry state is slow, while the trend of curve in saturated state is steeper. From the table, it can be seen that the larger the fitting constant a is, the greater the rock dynamic tensile strength is, and the larger the fitting correlation coefficient is, which fully shows that the size of B reflects the rate correlation of strength.

5. Conclusion

The dynamic splitting tensile strength of dry and saturated red sandstone specimens was tested by using a separated SHPB experimental device with a diameter of 50mm. The dynamic mechanical properties of red sandstone in two states are studied. The main conclusions are as follows: (1) the dynamic tensile strength of dry and saturated red sandstone increases approximately exponentially with the increase of strain rate, which has an obvious strain rate effect. The strain rate effect of dry sandstone is lower than that of saturated red sandstone. At the same loading rate, the dynamic tensile strength of dry red sandstone is greater than that of saturated red sandstone. (2) The red sandstone specimen has obvious softening phenomenon in water. At the same rate, the tensile strength of saturated red sandstone is significantly lower than that of dry red sandstone. When the strain rate reaches a certain degree, the strength of saturated red sandstone and dry red sandstone will be close to the same.

Acknowledgments

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