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Effect of Temperature on Dynamic Fracture Toughness of Rock†

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In order to study the effect of temperature on fracture properties of rock materials, the stress impulse are controlled to achieve the relationship of average load, time and temperature by changing the testing temperature. According to the basic test method for fracture toughness of specimen, we test the specimens on split Hopkinson pressure bar system and calculate the fracture toughness. The test results indicated that when the temperature increases from 10 to 100 ºC, the fracture toughness of rocks reduce steadily.

Keywords: Dynamic fracture toughness, Central cracked circular disk, Split Hopkinson pressure bar, Temperature.

INTRODUCTION

The dynamic fracture toughness of rock are closely related to loading condition and environment temperature[1]. Different environment temperatures correspond to different fracture modes for rock material in engineering practice. When the surrounding rock was kept in a state of heating for long time, temperature effects dynamic fracture toughness of rock in nuclear waste repository. Wang *et al*.[2,3] got the dynamic fracture toughness of center-cracked Brazilian disc by split Hopkinson pressure bar technique in impact experiments. Based on split Hopkinson pressure bar technique, Gao *et al*.[4,5] also calculated the dynamic fracture toughness of the specimens by granite specimen impact experiments and extending the quasi-static formula of the stress intensity factor. However, the most researchers don't involve the research on the effect of temperature on dynamic fracture toughness of rock due to the instinct traits of rock and experimental technical difficulties.

In this article, I fracture mode of granite rock in one loading rate and four different environment temperature was tested on split Hopkinson pressure bar system and the effect of temperature on dynamic fracture toughness was also carried out for rock studies.

Principle of split Hopkinson pressure bar experiment system: The schematic diagram of split Hopkinson pressure bar device is shown in Fig. 1. Based on one-dimensional wave theory[6], the left side load $P_L(t)$ and the right side load $P_R(t)$ of the specimen are:

$$P_L(t) = EA[\varepsilon_i(t) + \varepsilon_r(t)] \quad (1)$$

$$P_R = EA\varepsilon_t(t) \quad (2)$$

In these equations, E stands for elastic modulus of the incident bar and transmission bar; A stands for the cross sectional area of the incident bar and transmission bar (the two bar have the same diameter).

The average load of the two side of the specimen can be obtained by using $P_L(t)$ and $P_R(t)$.

$$\bar{P}(t) = \frac{P_L(t) + P_R(t)}{2} = \frac{EA}{2}[\varepsilon_i(t) + \varepsilon_r(t) + \varepsilon_t(t)] \quad (3)$$

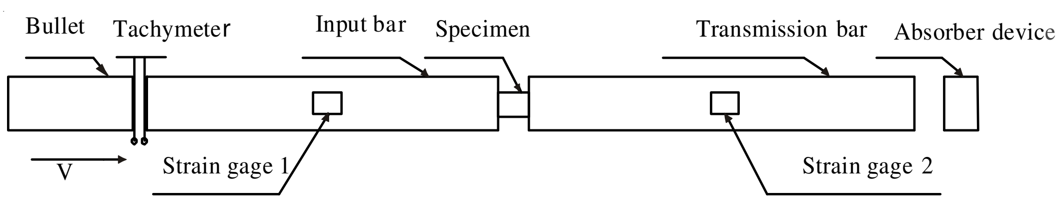

Fig. 1. Principle of Hopkison bar

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EXPERIMENTAL

The test was carried out on the split Hopkinson pressure bar system at the dynamics impact laboratory, Anhui University of Science and Technology. The diameter of the aluminum bar is 37mm and the other parameters refer to Fig. 2 and Table-1.

Fig. 2. Split Hopkinson pressure bar system

TABLE-1
SHPB TEST EQUIPMENT PARAMETERS

Diameter of bar (mm)	Length of incident bar (mm)	Length of transmission bar (mm)	Elastic modulus (Gpa)	Density (kg/m^3)	Poissons' ratio (μ)
37	2000	2000	70	2700	0.3

The rock used in this work obtained from Ya'an in Sichuan province. The elastic modulus of the rock is 21.8 GPa, density is 2520 kg/m^3 and poisson ratios is 0.3. The center crack of the specimen was produced by water-jet cutting,and the hair-line crack (Fig. 3) was obtaned through grinding the crack tip by diamond wire. The test result would not be effected by local stress concentration for symmetrically producing a plane on each load end. Specimen's thickness is 13 mm, diameter is 50 mm and crack relative length (α) is 0.5.

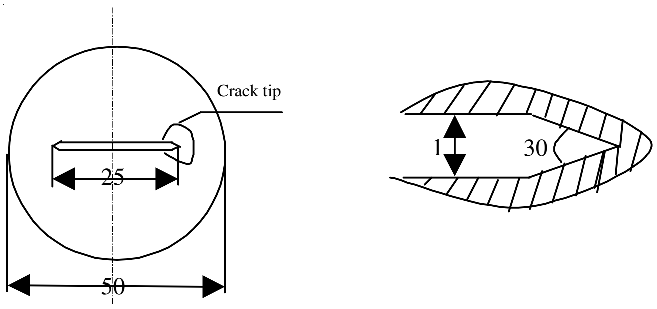

Fig. 3. Central sharp-notched circular disk specimen

The specimens were divided into four groups which consist of 5 each, the test temperature for each group was 10, 50, 80 and 100 ºC. The specimens were heated to the setting temperature and kept for 1 h, the impact test was implemented quickly on split Hopkinson pressure bar experiment system.

RESULTS AND DISCUSSION

Based on the basic principle of fracture dynamics[7], the maximum load is the instability point for the dynamic fracture toughnes. $\overline{P}_{max}$, as the the maximum value of average load on both ends of the specimen, was taken into the extending quasi-static dynamic formula of the stress intensity factor to calculate the dynamic fracture toughness K_{Id} of the specimens[8,9]. That is:

$$K_{Id} = \sigma\sqrt{\pi a}F_I = \frac{\overline{P}_{max}}{\pi BR}\sqrt{\pi a}F_I \quad (4)$$

In equation (4): B stands for the thickness of the specimen; R stands for the radius of the specimen; a stands for the half crack length; F_I stands for the dimensionless stress intensity factor[9]; $\overline{P}_{max}$ stands for the average maximum value load of the two side of the specimen.

The loading rate is:

$$\dot{K}_I = \frac{K_{Id}}{t_f} \quad (5)$$

There, t_f is the time corresponding to the maximum load of the specimen.

Fig. 4 shows the average load $\overline{P}$ of the two sides of the specimen changs with time. As can be seen from the Fig. 4, the curve is smooth.

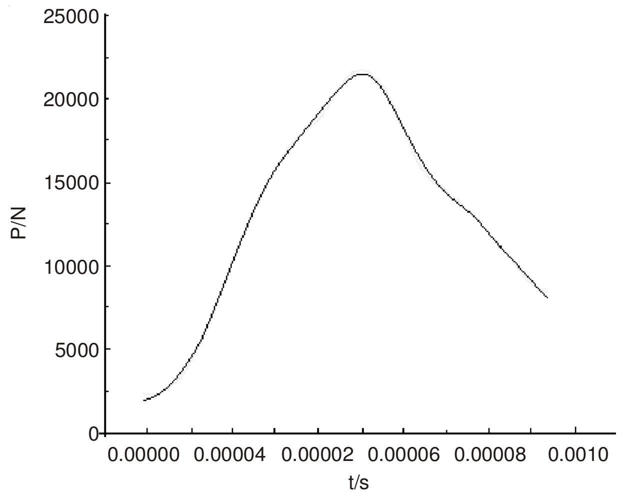

Fig. 4. Relationship between average load and time

Table-2 lists the dynamic fracture toughness K_{Id} under different temperature. It can be seen from Table-2, the loading rates are close in dynamic fracture though the environment temperature is different. The dynamic fracture toughness decreased in linear relationship as the temperature increased gradually (Fig. 5).

TABLE-2
EXPERIMENTAL RESULTS

Test temperature (ºC)	Loading rates $\dot{K}_I$ (Mpa m$^{1/2}$ s^{-1})	Fracture toughness K_{Id} (Mpa m$^{1/2}$)
10	144230	7.9
50	142560	7.5
80	142420	7.2
100	141950	6.87

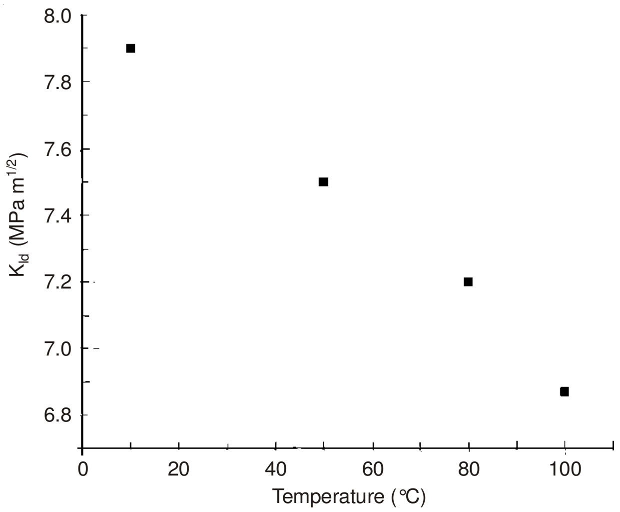

Fig. 5. Relationship between K_{Id} and temperature

Conclusion

Based on split Hopkinson pressure bar system, the dynamic fracture toughness of rock was tested in one loading rate and four different environment temperature and the effect of temperature on dynamic fracture toughness of rock was also carried out. The test results showed that when the loading rate is kept in 142000 and temperature changes from 10-100 ºC, the dynamic fracture toughness declines steadily in linear relationship as temperature increases gradually.

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