A COMPARATIVE STUDY OF DYNAMIC ROCK TENSILE STRENGTHS OBTAINED FROM DIFFERENT MEASUREMENT METHODS

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Summary Tensile strength is an important material parameter for rocks. Similar to the static tensile strength study, there are various methods proposed to measure the dynamic tensile strength of rocks. Here we examine dynamic tensile strength values measured from three methods: dynamic direct tension, dynamic Brazil test, and dynamic semi-circular bend. We found that the dynamic tensile strength from direct tension has the lowest value, and the dynamic semi-circular bend gives the highest strength at a given loading rate. Because we believe that dynamic direct tension gives the intrinsic rock tensile strength, we thus have to reconcile the difference between the direct tension and the other two methods. We interpret the difference between the dynamic Brazilian disc results and the direct tension result by noticing the overload and internal friction phenomena in Brazil tests. The difference between the dynamic semi-circular bend results and the direct tension results can be understood by invoking the non-local failure theory.

INTRODUCTION

The dynamic BD test using split Hopkinson pressure bar (SHPB) was recently used to study the loading rate dependence of rock tensile strength [1] and rock tensile strength anisotropy [2]. Furthermore, a dynamic semi-circular bending (SCB) method was used in combination with SHPB to measure the flexural tensile strength of rocks [3]. There is still a need to validate the dynamic BD tests using the direct tension tests, due to the same reason as for the static case [4]. Motivated by the foregoing issues, we developed a split Hopkinson tension bar (SHTB) system to measure the dynamic direct tensile strength of Laurentian granite [5]. We first overview the three dynamic tensile strength measurement methods: dynamic BD, dynamic SCB and dynamic direct tension. The values of dynamic tensile strength for the same rock (Laurentian granite) obtained from these three methods are then compared and the differences are interpreted.

THREE DYNAMIC TENSILE MEASUREMENT METHODS

Split Hopkinson pressure bar (SHPB)

Split Hopkinson pressure bar (SHPB) is used in this study to apply dynamic load to the rock sample. SHPB is composed of three bars: a striker bar, an incident bar, and a transmitted bar [6]. Denoting the incident wave by ε_i, the transmitted wave by ε_r, and the reflected wave ε_t, the dynamic forces on the incident end (P_1) and the transmitted end (P_2) of the specimen are [7, 8]: $P_1 = AE(\varepsilon_i + \varepsilon_r)$, $P_2 = AE\varepsilon_t$ .Here E is the Young's modulus and A is the cross-section area of the bars. Split Hopkinson tension bar (SHTB) works in a similar way as SHPB, the only difference is that the nature of the load is tensile through special design of the striking mechanism. The tensile strength is then obtained as the maximum value of the dynamic stress experienced by the sample [5].

Dynamic Brazilian disc (BD) and dynamic semi-circular bend (SCB) methods

A close-view of the dynamic BD test in the SHPB system is schematically shown in Fig. 1a, where the disc sample is sandwiched between the incident bar and the transmitted bar. The tensile stress in the central of the disc along the loading direction is $\sigma = P/(\pi BD)$. Here P is the load, D and B are the diameter and the thickness of the disc. It is usually believed that at the peak load, the corresponding tensile stress is the material tensile strength σt. In the dynamic case, the load is P_1 (= P_2) obtained using Equations above. The loading rate is the pre-peak slope of the stress curve [1].

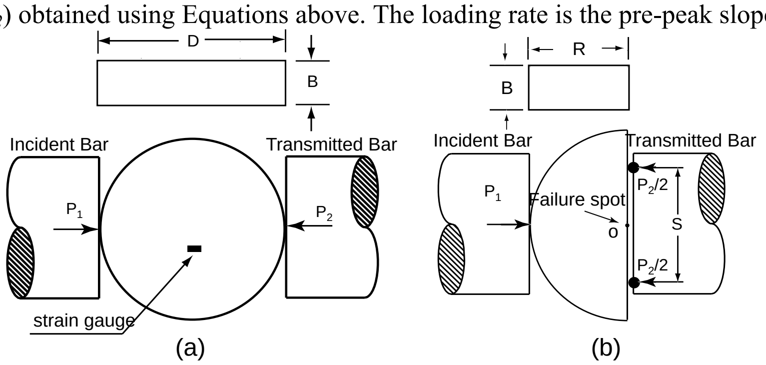

Fig.1. Schematics of (a) a BD sample and (b) a semi-circular bend sample in an SHPB system.

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The SCB method can be viewed as an integration of BD method and three-point bend (TPB) method (Fig. 1b). As shown in the figure, *R* is the radius of the half disk, *B* is the thickness of the rock disc, and the span between two supporting pins is *S*. Upon loading, failure will be initiated at the failure spot *O* on the specimen due to bending. Using a dimensional argument, the equation for calculating the tensile stress at *O* is [3]: $\sigma = P/(\pi BR)\cdot Y(S/2R)$. Here *P* is the time-varying load recorded in the test. The dimensionless stress *Y*(*S/2R*) is a function of dimensionless distance *S/2R*, and this function can be calibrated using finite element analysis. The (flexural) tensile strength is taken as the maximum tensile stress in the history of σ and the corresponding loading rate is measured from the slope of the pre-peak linear portion of the σ curve [3].

RESULTS AND DISCUSSION

The tensile strength obtained from the three dynamic testing methods is plotted against the loading rate (Fig. 2). It is clear that for a given loading rate, the tensile strength obtained from BD test higher than that from direct tension, while the SCB test gives the highest tensile strength. Because the tensile strength from direct tension is the true tensile strength, it is thus necessary to understand the difference between the BD results, SCB results and direct tension results.

To understand the difference between the dynamic direct tension strength and the dynamic BD tensile strength, we proposed two mechanisms for the strength over-estimation of the dynamic BD method: the overload effect and the internal friction effect. We conducted dynamic BD tests using SHPB to illustrate the overload effect and the frictional effect was qualitatively derived based on the micromechanical failure mechanism of rocks. After corrections based on these mechanisms, the dynamic BD tensile strength can be reduced to the dynamic direct tensile strength (Fig. 2a). The differences between the dynamic flexural tensile strength and the dynamic direct tensile strength were explained by invoking a non-local failure theory (Fig. 2b).

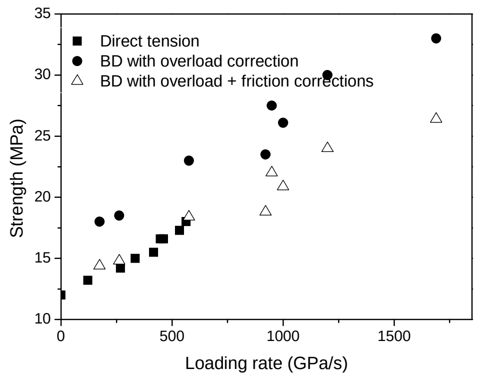

Fig.2a. Strengths from direct tension & BD tests.

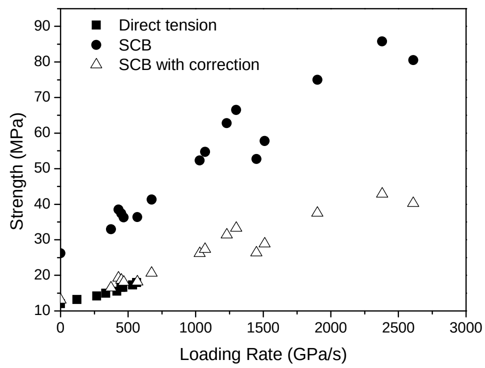

Fig.2b. Strengths from direct tension & SCB tests.

CONCLUSIONS

In this work, we first overviewed the three dynamic tensile strength measurement methods: dynamic BD, dynamic SCB and dynamic direct tension. The values of dynamic tensile strength for the same rock (Laurentian granite) obtained from these three methods were then compared. It is found that the dynamic direct tensile strength is consistently lower than the dynamic BD tensile strength, and the dynamic BD tensile strength is consistently lower than the dynamic flexural tensile strength obtained using the dynamic SCB test. We explained the differences and showed the dynamic strength values obtained using various dynamic indirect tensile tests are more meaningful that we expected. By carrying out proper corrections, we can obtain the intrinsic rock dynamic strengths from these indirect tensile results.

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