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STRUCTURAL-TEMPORAL APPROACH FOR DYNAMIC STRENGTH CHARACTERIZATION OF ROCK

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Abstract. Test results of rock obtained by split Hopkinson bar apparatus and his modifications. A uniform interpretation of fracture rate effects of the tested marble samples is given on the basis of the incubation time approach based on a set of fixed material constants. Time dependences of both compressive and tensile strengths are calculated using the incubation time fracture criterion.

1. Introduction

The understanding of dynamic behaviour of rock materials under high strain rate is essential in the design of dams and canals, roads and other structures in seismic areas subjected to impact or impulsive loadings. Rocks materials are rate-dependent. And for better understanding of the dynamic behavior of rocks we should solved many problems for determination of material parameters.

It is well known that the properties of rock under dynamic loadings are different to the corresponding static values. The dynamic fracture process is much more complicated than the static one due to the inertia effects and the stress wave propagation. Usually rocks show a significant increase of the mechanical characteristics as tensile and compression strength with increasing strain-rate.

Moreover, various heterogeneity and impurity content can lead to various dynamic effects of fracture of rocks. One of such effects is the change of the dominant strength between the two rock materials. A material, which has a lower strength compared to another material in quasi-static tests, can have greater strength under dynamic loading [1].

In this paper we consider such "strength inversion effect" of two rock materials. The theoretical analysis is based on the structural-temporal approach to fracture process [2-5]. This approach is based on the incubation time notion and provides a possibility to describe the correct transition between quasi-static and dynamic loadings.

2. Materials and experimental techniques

Progress in this area associated with the split Hopkinson bar (SHB). Experimental method originally proposed by Kolsky [6] is today one of the most thoroughly developed and verified methods for obtaining the dynamic strain curves for materials within the strain rate range of ~ 10^3 s^{-1}. In what follows we shall describe an experimental complex of software and hardware means for dynamically testing materials within the strain rate range of $5x10^2$- $5x10^3$ s^{-1} for different types of the stressed and strained states, based on the Kolsky method. In the last decades many efforts were undertaken to develop experimental studies and new set-ups in order to analyse dynamic behaviour of different materials. For example in work performed by Goldsmith and Sackman [7] Kolsky method was used for some rock. In this work we show good compliance experimental method and theoretical investigation.

Dynamic compressive and splitting tests were performed at the Laboratory of Dynamic Investigation of Materials in Nizhny Novgorod by means of a SHPB shown in Fig. 1.

Fig. 1. Experimental apparatus realizing SHPB for compressive and splitting tests.

The experimental set-up consists of a compact gas gun (1), incident (2) and transmitter (5) steel (or duralumin) pressure bars with the specimen (3) sandwiched between them. Power supply and calibration of strain gauges was produced by an original scheme (4). In order to record the electrical signals from strain gauges, a multichannel digital oscilloscope (6) was used. Diameters of striker as well as pressure bar are 20 mm. The incident bar length was 1 m, whereas the length of transmitter bar was 3 m in order to provide correct registration of possible additional cycles of loading during the experiment [8].

Splitting test of disks, also called 'Brazilian tests', is one of the available methods to measure the tensile strength of brittle materials [9]. Due to the stress-state of the disk, the failure is caused by tension when tensile stresses reach the tensile strength of the material on the diametric loading plane.

Test specimens in the form of rectangular parallelepipeds were sawn diamond cutting discs from flat slabs of marble "Koelga" and "Pervouralskiy" 20 mm thick and length dimensions 20x20x10 mm, 20x20x20 mm, 20x20x30 mm, 30x30x20 mm. Samples of the first two sizes are used for high-speed tests on a simple compression and splitting under compression (Brazilian test). Samples with size 20x20x30 mm are mainly used for static testing in compression. Samples with size 30x30x20 mm - for dynamic tests with compression and splitting under compression in the quasi-static and dynamic tests.

3. The concept of incubation time

Considering phenomena such as brittle failure of a defect free specimen, fracture of specimen with macro-defect (crack), we deal with strength properties of the materials. These very different processes exhibit some important common features. In the case of slowly applied load there exists the threshold value of load amplitude. In the case of very short durations the strength characteristics of materials are considerably different from those obtained in the case of quasi-static testing. This can be explained by the circumstance that the time of loading is of the same order as the typical time of certain processes on the micro-level. The above-mentioned time can be described by virtue of the material constant and will be referred to as "incubation time". An efficient criterion for the analysis of brittle fracture of rocks can be formulated in the following form [4, 10, 11]:

$$\frac{1}{\tau}\int_{t-\tau}^{t} \sigma(s)ds \le \sigma_{st}, \qquad (1)$$

where τ is the incubation time, σ_{st} is a tensile strength for quasi-static loading and $\sigma(t)$ is the applied stress which for $t < 0$ is supposed to be zero. The instant of fracture t^* corresponds to the earliest realization of equality in Equation (1) or, in the general case, violation of this condition.

For our tasks (uniaxial extension) take stress $\sigma(t)$ in this form

$$\sigma(t) = \dot{\sigma} t H(t), \tag{2}$$

where $H(t)$ is a Heaviside function, $\dot{\sigma}$ is a stress rate (supposed to be constant).

The general concept of incubation time works in both compressive and tensile cases, but the set material constants must be determined for compression and tension separately.

4. Results

Experiments for tension was completed like a model “Brazilian tests”, but samples were in the form of rectangular parallelepipeds. Experimental schemes is demonstrated in Fig. 2.

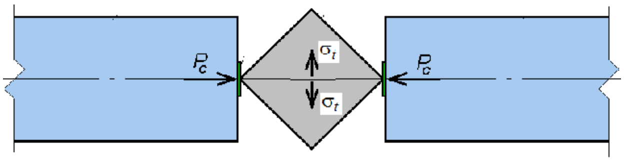

Fig. 2. Experimental scheme for splitting tests.

For tensile stress formula has the form:

$$\sigma_t = 0.5187 \frac{P_c}{b h}, \tag{3}$$

where b and h are the dimensions of the sample, P_c is a longitudinal force in the gauging rods, determined by indications on the support rod. The maximum value of the tensile stress is the required tensile strength of stone.

Figure 3 demonstrates the effect of the dynamic tensile strength. Points show the experimental data. Curves show the theoretical line constructed by the formula (1) with parameters τ = 1 μs, σ_{st}=5.5 MPa for "Koelga" and τ = 1.7 μs, σ_{st}=4.5 MPa for "Pervouralsk". We can see good compliance theoretical approach and experimental data. Parameter σ_{st} is a static tensile stress. It is determines the horizontal section on theoretical curve. Parameter τ can move theoretical curve to the right or to the left. Theoretical curve was built as a middle line of experimental data.

It is clear from the picture that carrying capacity of both materials increases with the growth of loading rate. However although "Koelga" has a higher quasi-static split strength than that of "Pervouralsk", its dynamic carrying capacity in splitting is lower at high strain rates.

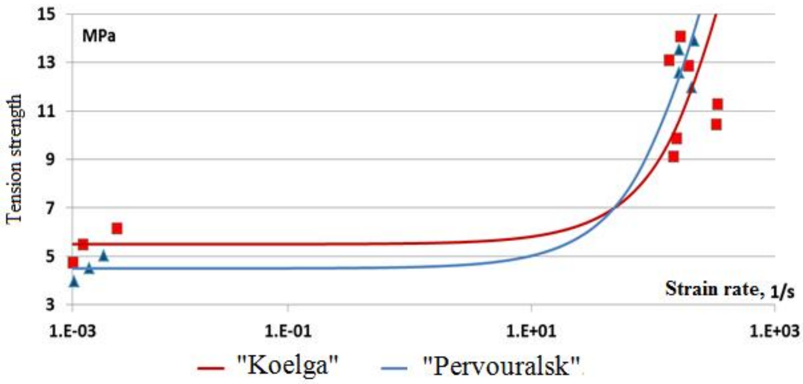

Fig. 3. Tension strength.

For compression tests were carried out standard experiments. Figure 4 demonstrates the effect of the dynamic compression strength. Points show the experimental data. Curves show the theoretical line constructed by the formula (1) with parameters τ = 2.8 μs, σ_{st} =45 MPa for "Koelga" and τ = 3.9 μs, σ_{st} =25 MPa for "Pervouralsk". We can see also good compliance theoretical approach and experimental data.

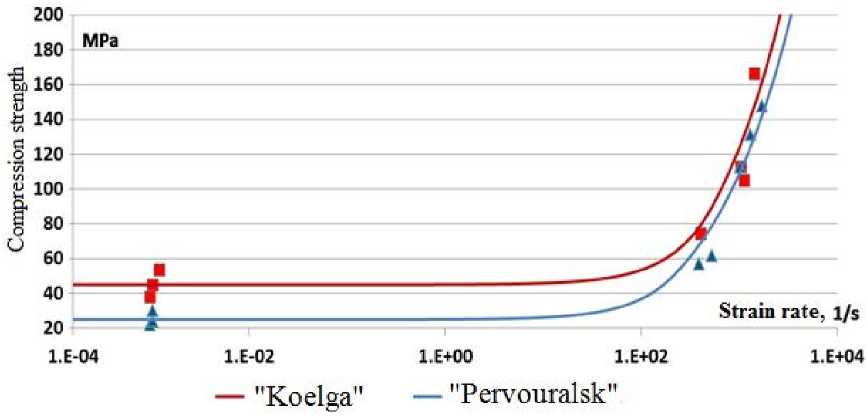

Fig. 4. Compression strength.

5. Conclusion

Rock tensile and compression strength is strain rate dependent. It has been verified that also for the marble "Koelga" and "Pervouralskiy" this strength increases with the strain rate increasing within the wide strain rate range. The results show non-linear relationships between strength and strain rates.

For different kind of marble we can see "strength inversion effect" of load-carrying capacity of materials at different strain rate under the compression. The strength inversion effect means that in spite of the fact that static strength of one material is smaller than that of another one, its dynamic strength measured in terms of incubation time can be essentially higher.

The analysis was conducted based on the incubation time approach, which allows one to separate static strength and dynamic strength. As the incubation time is a material parameter we can estimate and compare load-carrying capacity of materials in a wide range of loading rates.

Thus, one of the main problems in testing of dynamic strength properties of rocks can be connected with measurements of the incubation time parameter. Studies of strain rate features using incubation time approach provide an effective opportunity to examine the fracture process that is important for predicting critical parameters of external action in a wide range of loading conditions.

Acknowledgements

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