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The structural temporal approach to dynamic and quasi-static strength of rocks and concrete

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Abstract

This work presents results of an experimental and theoretical study on dynamic and quasi-static failure of rocks and concrete. The results of dynamic compression and splitting of rocks (gabbro, granite, marble), as well as dry, water-saturated and frozen limestone and concrete are discussed. The tests were conducted using the Split-Hopkinson pressure bar with the diameter of 20 mm. It is shown that one material (or its condition) can have a lower dynamic strength for a higher static strength compared to the other material (or its condition). Also, it is shown a dependence of the threshold limit stress on the stress pulse duration. An unified interpretation of the experimental results, based on the structural–temporal approach is presented.

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Keywords: dynamic effects of failure; quasi brittle failure; rock; concrete; SHPB; structural–temporal approach.

1. Introduction

Intense short-term loads lead to effects of material strength, which are important to understand and take into account in the transition from slow to dynamic load. The experimental results (Abrosimov et al., 2012) and the theoretical calculations (Petrov et al., 2010) show that the strain rate dependence of spall strength may depend on duration of an impact pulse. The experimental results (Grote et al., 2001) and the theoretical calculations (Petrov et

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al., 2013) show that one material may have a greater quasi-static strength than other material, but the second material can withstand more high dynamic loads than the first. The experimental results (Abrosimov et al., 2012; Grote et al., 2001) were obtained for impact durations less than 5 microseconds. Moreover, the dependence of threshold limit stresses on the impact duration was obtained for metals (Abrosimov et al., 2012). In this paper, we consider these two effects for the case of longer pulses and quasi-brittle materials like rocks and concrete. Interpretation and calculation of the obtained effects is carried out on the basis of the structural-temporal approach proposed by Petrov and Utkin (1989).

2. Experimental procedures

In the experiments the setup based on the Split-Hopkinson pressure bar (SHPB) was employed. For the uniaxial compression tests, the classical Kolsky scheme was used. For the tensile testing, the Brazilian test scheme was used. The details of the SHPB modifications and application can be found in the review prepared by Zhang and Zhao (2014).

In the setup, aluminium rods (D16) with the diameter of 20 mm were used. To vary the length of a stress pulse, aluminium projectiles of different lengths (100 and 300 mm for compression tests; 75 and 250 mm for splitting tests) were used. The threshold (minimum breaking) speed of the projectile was determined by sequentially decreasing speeds up the case when the sample remained intact after the impact.

An analysis of implementation of requirements to experiments on the used SHPB setup and dimensions of the used samples was considered in detail in the papers of Bragov et al. (2013) and Petrov et al. (2017).

The experimental results include the testing of different rocks (granite, gabbro-diabase, limestone, marble) and fine concrete. The samples were in the form of a cylinder with a diameter of 20 mm and a height of 15 mm. Limestone and concrete were tested in three states: dry, water-saturated or frozen. To prepare the water saturated samples, the dry samples were half-submerged in water to become saturated through the capillary effect. After that, they were kept fully submerged during several days. The part of the saturated samples was placed in a freezer at -15°C for two days.

Quasi-static tests were carried out using standard equipment with a capturing speed of 1 mm/min.

The limit stress σ^* and the failure time t^* were determined by the first stress maximum in the timing diagram of stress. For example, typical diagrams of compression stress for the different impact speeds of the projectile (i.e. strain rates) are shown in Fig. 1. Initial parts of the graphs correspond to the growth of stresses and deformations. When stress in the sample reaches the critical value σ^*, the sample quickly starts to break due to the formation of micro and macro cracks, which leads to significant reduction of stresses and further increase of deformation.

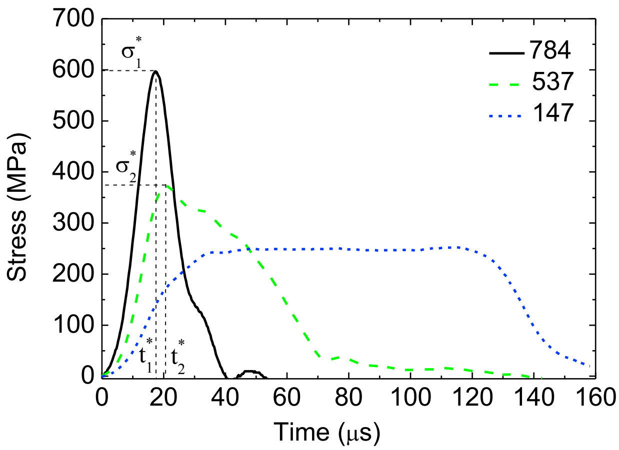

Fig. 1. Stress profiles during dynamic compression of gabbro-diabase for different strain rates. σ_i^* is the limit stress; t_i^* is the failure time. The strain rate of 147 1/s corresponds to the sample without visible damage.