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Incubation time criterion analysis of rock materials under dynamic loadings

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Abstract

Analysis of tensile strength properties of rocks under dynamic loading on the basis of the structural-temporal approach is given. The possible values of incubation times of granites and marbles for different dynamic tests (split Hopkinson bar test, a drop weight test, Brazilian test) are presented. Obtained results show that a statistical dispersion of incubation times for granite is less than for marble. An influence of anisotropy of rocks on the incubation time is presented.

Keywords: incubation time; dynamic tensile strength; granite; marble

1. Introduction

The behaviour of rock materials strength represents a significant interest for environmental and civil engineering, dam and canal making, railway embankment construction, mining and seismic works and geodynamic modeling. It is well known that rock mechanical properties vary in wide range of strain rate because of its inhomogeneous structure influenced by pore space geometry, grain sizes and etc. and notable anisotropy. In addition one is rate dependent and its strength properties quickly increase with growth of stress rate or strain rate (Zhang et al. (2013a, 2013b), Dai et al. (2010a, 2010b, 2010c), Dai and Xia (2010), Bragov et al. (2012, 2013, 2015)).

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We focus on tensile strength of rock materials in this work. Several experimental techniques can be used for this reason under intermediate and dynamic loadings (Zhang et al. (2013a, 2013b), Zhao and Li (2000), Cai et al.(2007), Cho et al. (2003), Huang et al. (2010), Howe et al. (1974), Goldsmith et al. (1976), Wang et al. (2009), Cadoni et al. (2010), Aspron et al. (2009), Kubota et al. (2008), Bragov et al. (2015)). The dynamic tensile strength can be obtained directly or indirectly by means of different experimental methods based on drop weight machines, split Hopkinson pressure bar, gas gun, etc. The direct measurement of the dynamic tensile strength should be preferred because the measurement should be simple enough without introducing complexities such as a superposition of waves or inertia effects.

For the goal to describe the material behavior under high rate loadings some semi-empirical criterion were proposed (for example Lu,Wang and others 2017). Every such equation represents correlation between stress or strain rate and observed tensile strength data and doesn't take into account incident wave parameters which may affects the experiment results. This work is dedicated to quasi-static and dynamic strength test results analysis published in literature based on incubation time criterion approach which supposes new material parameters to explain high rate behavior features (Petrov and Utkin (1989), Petrov (1991), Petrov and Morozov (1994), Morozov and Petrov (2000), Petrov (2004)). It demonstrates well agreement with experimental results for wide range of materials like rocks, composite concretes, steels and etc.

2. Incubation time criterion

The presented fracture criterion (Petrov and Utkin (1989), Petrov (1991), Petrov and Morozov (1994), Morozov and Petrov (2000), Petrov (2004)) is very effective tool to describe temporal effects in fracture mechanics (Bratov et al. (2004)) and to solve of different problems of mechanics of extreme states in continua (Petrov et al. (2012), Volkov et al. (2011)). In particularly, observed effects of unstable behavior of material strength under dynamic loading in many experiments can be predicted using the incubation time criterion. For wide class of problems the criterion can be represented by the inequality:

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

Here, $\sigma(t)$ is the temporal dependence of the tensile stress in the specimen, σ_{st} is the static strength of material, and τ is the incubation time associated with the dynamics of the relaxation processes preceding the macro-fracture event. It actually characterizes an incubation process, which backs the stress/strain rate sensitivity phenomenon of the material. The fracture time t_* is defined as the earliest time at which an equality sign is reached in the condition Eq. (1). The parameter α characterizes the sensitivity of the material to the level (amplitude) of the local force field causing the destruction. In this paper $\alpha = 1$ is taken, as that value provides good agreement with experimental data for all materials investigated further.

Let us briefly consider a physical meaning of the incubation time τ. According to the classical theory of strength, the local force field in the moment of material (sample) fracture is instantaneously drops to 0 straight after achievement of a critical value σ_{st}. Considering the real process, associated with macro-fracture event, in terms of the micro-scale level kinetics, we interpret the macro-fracture event as a temporal process of transition from a conditionally defect-free state of the continuum subjected to tensile stress σ_{st} to a completely broken state that occurs at the moment of fracture t_*. The incubation time is related to the relaxation process of growth of microdefects in the structure of material, which provides its non-reversible deformation and failure. In this case the characteristic time of relaxation can be considered as the incubation time (Petrov (1991), Morozov and Petrov (2000)). Thus, the incubation time is a constant of material, unrelated with the geometry of the test specimen, the way the applied loading and characterized dynamic effects of the fracture process on a given scale level.