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The dynamic strength of concrete and macroscopic temporal parameter characterized in fracture process

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Abstract

The structural-temporal approach based on the notion of incubation time is used for interpretation of strength behaviour of concrete in the fracture process. Temporal dependences of concrete under influence of steel spiral fiber, water, a scale level of fracture are evaluated by the incubation time criterion. Effect of more significant increase of strength in dynamic condition than static at growth percentage of fiber is explained by behaviour of the incubation time related with presence of defect in specimen. Numerical simulation of dynamic strength with different percentage of spiral fibers is given. Both size effect and scale effect for concrete samples subjected to impact loading are considered. Statistical nature of a size effect contrasts to a scale effect that is related to the definition of a spatio-temporal representative volume determining the fracture event on the given scale level.

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Keywords: fracture stress; strain rate; fiber; fracture scale level

1. Introduction

The strength characteristics of concrete under dynamic loading are widely applied in fracture mechanics, construction and civil engineering fields. Nowadays, an actual problem is a reinforcing by the discrete addition of fibers with different geometry, percentage of fibers and material (Hao and Hao (2013), Kruszka et al. (2015)). The rupture stress in comparison with a volume ratio of fiber gives a good result in increment of the strength properties. However, some experiments (Song and Hwang (2004), Yet et al. (2012), Kruszka et al. (2015)) show a decrease of

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the fracture stress of reinforcing concrete with a certain volume ratio of fiber. General physical explanations of the increase effect of strength in impact experiments for the modified concrete (the reinforcing of fibers, a saturation of water, and homogeneity of structure) are usually conducted using different interpretations related with dynamic processes (Hao et al. (2013)): the lateral inertia confinement, the contribution of aggregates, the end friction confinement and others. The numerical variations of the fracture stress for modified materials similarly by the strength under quasi-static loading are difficultly explained (Grote et al. (2001), Reinhardt et al. (1990), Bragov et al. (2015), Smirnov et al. (2014)). Thus, the consideration of a clearly stated parameter of dynamic processes is essential for characterization of fracture in a generalized sense on structural level.

In this paper, we consider the structural-temporal approach for quasi-brittle and defect-free material based on the incubation time concept, proposed in Petrov (1991), Petrov and Morozov (1994), Morozov and Petrov (2000), Petrov (2004), Morozov and Petrov (2006). Physical meaning of incubation period as the preparation time of an inner structure of the material in the fracture moment allow interpret effect of increase of rupture stress as a growth incubation period. It is noted, that the incubation time is a constant parameter of material and is sensitive to changes in the material structure. Moreover, given concept is described the rupture process in terms of upper and lower boundaries of the characteristic linear size of fracture with certain incubation period (spatio-temporal representative volume). According to scale level concept (Petrov et al. (2005), Petrov et al. (2012a), Petrov et al. (2012b)) is discover new possibilities of the increase of dynamic strength of concrete (scale effect) in dependence on definition of a fracture event (Petrov and Selyutina (2015)).

This work is analyzed the different impact experiments for concrete and is established a straight relation between the incubation time and the fracture stress. The effects of dynamic behaviour of concrete strength are explained based on the structural-time approach. The advantages of understanding of dynamic process by the incubation time on practice are discussed.

2. Incubation time approach

For description of the fracture process in dynamic loading for quasi-brittle material, we consider the structural-temporal criterion, proposed in (Petrov (1991), Petrov and Morozov (1994), Morozov and Petrov (2000), Petrov (2004), Morozov and Petrov (2006)). On the basis of the incubation time concept, the given approach, in contrast to classical criterions, qualitatively explains the dynamic effects of unstable behaviour of strength characteristics of the material observed in experiments on the fracture of solids. Particularly, well-known effect of the increase of static strength in several times at high strain rates for initially a defect-free specimen of rocks and concrete is modelled using discussed approach in Petrov (1991), Petrov et al. (2003), Petrov et al. (2013). The incubation time criterion is identified by the fracture condition in the following general form:

$$\frac{1}{\tau}\int_{t-\tau}^{t}\left(\frac{F(s)}{F_c}\right)^{\alpha} ds \le 1 . \qquad (1)$$

Here, $F(t)$ is the intensity of the local force field causing the fracture of the medium, F_c is the static limit of the local force field, and τ is the incubation time associated with the dynamics of the relaxation processes preparing the break. It actually characterizes the strain (stress) rate sensitivity of the material. The fracture time is defined as the time at which the equality sign is reached in Eq. (1). The parameter α characterizes the sensitivity of a material to the intensity level (amplitude) of the force field causing the fracture (or structural transformation). Condition $\alpha \ge 1$ is performed for solid material. The cases of tension and compression are considered as two independent formulations of criterion (1) with different characteristics of fracture.

Let us detailed examined the physical meaning of the incubation time. According to the classical theory of strength, the local force field in the moment of material (sample) fracture is instantaneously decreased before 0 straight after achievement of a critical value F_c. Considering described process, related with macro-fracture event, in terms of the micro-scale level kinetics, we interpret one as a temporal process of transition from a conditionally defect-free state to a completely broken state at the moment of fracture. The macro-parameter of fracture process, identified as an incubation time, is equal to the duration of known temporal process on the given scale level (the