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Structural-temporal approach and geometry of the fracture zone in spalling

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Abstract

Spalling is one of the main methods of studying the processes taking place in a solid under dynamic stretching. A little explored area is the study of the geometry of the fracture zone formed as a result of impact loading. It has been experimentally established that the qualitative form of the fracture region depends strongly on the parameters of the applied pulse, such as the rate of growth and fall of the load, amplitude, duration. On the basis of the known experimental results it was shown that the observed unstable behavior of the fracture zone formed in the conditions of spalling can be explained by means of the structural-temporal approach based on the concept of the incubation time of failure.

Keywords: dynamic fracture, pulse load, spall, incubation processes

1. Introduction

The phenomenon of spall destruction is the basis for one of the main experimental methods for studying the processes occurring in a solid under conditions of rapid dynamic tension. Spallation occurs in the material as a result of the interaction of a compression wave with a free boundary, when the stress in the original wave changes sign due to reflection. In this case, the total stress at some points of the sample can become tensile, which causes a material rupture. As a rule, with qualitative analysis, the so-called acoustic approximation is used to estimate the parameters

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of the critical pulse, when only the elastic stress fields acting in the spall zone are taken into account. The resulting one-dimensional picture of the spalling process is quite simple and opens up wide possibilities for theoretical calculations and analysis of experimental results.

At present, the dynamic strength is usually associated with the rate of deformation of the material in the splitting section at the moments preceding the fracture, without taking into account other parameters of the temporal loading profile, such as, for example, the total duration, as well as the presence of different stages of the action of the initial pulse. Most of the research in this area is aimed at establishing the so called "rate dependence" for ultimate stresses, which is often interpreted as a function of the material. However, many effects found in the experiments do not fit into the conventional model, which leads to its significant complications. In particular, such are, for example, the effect of "stabilizing" the strength (see Petrov et al., 2010) and the fracture at a strain rate in the cross section near zero (see Petrov et al., 2015).

Also the geometry of the zone formed by impact is little explored. It is established that the qualitative form of the fracture region depends very strongly on the parameters of the applied pulse, such as the rate of growth and fall of the load, amplitude, duration. The geometry of the fracture zone can be affected by the presence of defects (weakened sections) of the real material, i.e. its occurrence is partly statistical in nature. Therefore, to study this phenomenon, it is necessary to carry out a series of tests with identical loads. It was such tests, which showed, in particular, a strong instability of the position of the spall zone, were carried out Kubota et al. 2008. It will be shown below that the effects found there can be explained from a single point of view by means of the structural-temporal approach and the corresponding criterion of incubation time (see Petrov and Utkin 1989, Morozov et al., 1990 and Gruzdkov et al., 2008).

2. Incubation time criterion

We will assume that the initial wave stress pulse propagates in a linear elastic material and when it moves there is no loss. In this case, the stress in the wave reflected from the free boundary changes sign to the opposite one, while its absolute value does not change. The criterion of incubation time in general form was proposed in Petrov and Utkin 1989. In the case of splitting tests produced by longitudinal stress waves, the stress state in the sample is usually taken to depend only on one coordinate. The criterion of destruction in this case takes the form (see Petrov et al., 2010, 2015 and Morozov et al., 1990, 2000):

$$\int_{t-\tau}^{t} \sigma\left(s,x\right) ds < \sigma_c\ \tau \qquad (1)$$

where $\sigma(t,x)$ – stress at the point with the coordinate x at time t, τ – incubation time - independent material characteristic, σ_c – material tensile strength in static.

Time t is counted from the beginning of the moment of reflection of the initial pulse, and the coordinate x specifies the distance to the free boundary. The time of destruction is considered to be the smallest moment at which the criterion condition (1) is violated.

Critical characteristics of failure can be associated with various parameters of the profile of the initial pulse, in particular, with its duration and amplitude. Numerous studies of the process of dynamic fracture within the framework of the structural-temporal approach based on the concept of incubation time have confirmed its effectiveness and predictive power. At present, it has become an effective tool for calculating high-speed dynamic processes, applied by many authors in various fields of science (see Gruzdkov et al., 2008, Petrov et al, 2015 and Morozov et al., 2000). Applying this approach, we'll study the geometry of the fracture zone, formed by pulses of a special shape.

3. Fracture zone in case of trapezoidal impulse

To study the qualitative geometric characteristics of the fracture zone, we consider the initial stress pulse in the form of a trapezium. In many cases, the actual loading during testing can be represented with sufficient accuracy in