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ScienceDirect

Procedia Engineering 197 (2017) 244 – 251

Procedia Engineering

www.elsevier.com/locate/procedia

DYMAT 23rd Technical Meeting

Dynamic Fracture of Ductile Materials

On the issue of determining parameters in models and criteria of dynamic spallation fracture

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Abstract

The issue of determining material parameters and scalar functions in models and criteria of dynamic spallation fracture is discussed. An experimental-theoretical methodology to obtain them for the dynamics of failing elastoplastic media is presented, which consists in analyzing inverse problems. The methodology involves testing specimens of the studied material, using special regimes of dynamic loading, followed by analyzing a number of numerical modeling problems. For models and criteria of dynamic spallation fracture, the methodology is based on minimizing the quadratic deviation between experimental and analytical data containing information on the kinetics of the spallation fracture process. The reliability and unambiguity of the determined material parameters is demonstrated by comparing the experimental and analytical data.

Peer-review under responsibility of the scientific committee of the International Conference on Dynamic Fracture of Ductile Materials

Keywords: dynamic deformation, spallation, stress waves, models and criteria of dynamic failure, modeling, material parameters, methodology of determining, mathematical nonlinear programming, minimization of quadratic deviation.

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Peer-review under responsibility of the scientific committee of the International Conference on Dynamic Fracture of Ductile Materials
doi:10.1016/j.proeng.2017.08.101

1. Introduction

Experimentally determined material parameters and scalar functions of defining relations of the dynamics of failing elastoplastic media play an important role in formulating models and criteria of dynamic spallation fracture. To determine values of parameters or groups of parameters, experiments, which are called “basic experiments”, are used. A basic experiment is related with a particular physical effect. This makes it possible to determine values of parameters of a mathematical model. With such a formulation of the problem, the number of determined parameters is of no importance, which allows one to determine very different in their physical nature parameters of the dynamics of failing elastoplastic media. Traditionally, uniaxial strain or uniaxial stressed state conditions are provided in basic experiments. In the first case, loading is effected with an impacting plate or by exploding an explosive charge secured on the surface of the tested specimen. Changing the geometrical sizes of the specimen and of the explosive charge in the vicinity of the axis of symmetry of a cylindrical specimen, one can obtain a stressed state corresponding to a plane stress wave. The second case is characteristic of experiments using the Kolsky methodology of the Hopkinson split bar. Thus, the main experimental scheme for studying processes of dynamic spallation fracture of solids is a plane wave generator using explosion or impacting plates. Free surface displacement velocity of specimens, velocities of elastoplastic waves and mass velocity of particles are measured most reliably in such experiments [1–6]. Investigations in the conditions of uniaxial strain are in many cases the only way to obtain quantitative strength characteristics of materials. The study of dynamic failure characteristics of materials in the case of complex (multiaxial) stressed-strained state in most cases is only of a qualitative character.

Information on the kinetics of the process of dynamic spallation fracture is obtained in the following main ways: using metallographic analysis of remaining partially damaged specimens [1–3]; by processing the experimentally registered free surface displacement velocity in the specimen when it is loaded with a compression pulse and a “spallation” pulse [1–5]; by computing the stress along the material – material interface, based on the lowest acoustic stiffness [6]. These methods, except the first one, provide indirect information on the kinetics of the spallation fracture process and the accompanying stresses. This is connected with the fact that along with the propagation of stress waves, various strain and stress process also take place in the different cross-sections of the specimen [7]. It is difficult here to conduct experiments with controlled stressed state, strain and loading time. Still more difficult is to determine tensile stresses, strains, particle velocities, quantitative characteristics of microstructural changes determining failure processes in solids under dynamic effects, at the same point of a specimen (in particular, in the fracture plane). That is why, at present, it is impossible to obtain a history of tensile stresses in the fracture plane from dynamic experiments without introducing certain apriori assigned relations or using calculations based on the mathematical model of the experiment. Moreover, the calculated stress functions do not guarantee the reliability of the used relation or mathematical model: a tensile stress history in the reference cross-section of the specimen is required. It is conventional to judge about the adequacy of the chosen relation or model based on various effects [7].

Using experimental data with continuous registration of a number of parameters in the process of deformation and failure of materials in combination with numerical experiment and a good choice of the model of material behavior makes it possible to obtain information about parameters and functions characterizing the kinetics of the dynamic failure process. That is why determining material parameters and scalar functions for equipping models of spallation fracture of solids, based on dynamic experiments, is a vital issue of the dynamics of failing elastoplastic media. In [1–3], an experimental-theoretical methodology for determining material parameters in NAG (nucleation, growth and merging of microdefects of various forms) models is introduced, which is based on the interpretation of results of metallographic analysis of damaged, partially failed specimens. In Russia, an analogous approach to the issues of determining such parameters is described in [8]. Unfortunately, these approaches to determining material parameters require a specialized experimental basis and a large number of tests. This limits the scope of its practical application.

Work [9] presents two theoretical-experimental methodologies of determining material parameters for the integral criteria of spallation fracture based on standard experimental data on determining the thickness of the spallation disc and the displacement velocity of its back surface. The methodologies are based on determining constants from the numerical analysis of the problem of plane impact of plates, using the semi-inverse method. A considerable drawback of the approach is a strictly limited number of determined parameters: not more than two.