

A MODERN EXPERIMENTAL-THEORETICAL APPROACH TO RATIONALLY DESIGNING NOVEL TECHNOLOGICAL OBJECTS

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Abstract. The paper presents a general methodology for solving problems analyzing strength of dynamically loaded structures, beginning from their development, substantiation and using experimental schemes of obtaining data on dynamic deformation and failure of materials of various physical nature up to the construction of reliable verified defining equations.

1. Introduction

Nowadays the necessity of using numerical modeling at early stages of designing novel technological objects is not questioned. Mathematical modeling, apart from shortening the design time, allows one to optimize substantially the structure being designed, as it becomes possible to analyze a considerably larger number of possible designs (including geometry, materials, coupling methods) and working conditions, as compared with the experimental approach. It is noteworthy that numerical methods and modern computational resources make it possible to analyze accurately enough complex systems of mathematical equations describing processes in a structure under the effect of various factors, to describe the behavior of materials using complex nonlinear mathematical models, as well as to take into account various geometrical and physical singularities. Thus, it can be stated that the accuracy of a numerical solution is mainly determined by the accuracy of the input data, one of the most important components of which being mathematical models of material behavior. To equip and verify phenomenological models of behavior, an ample database on dynamic material properties is required.

There exist practically no standardized testing methods or industrial stands or equipment for dynamically testing materials. Dynamic deformation diagrams are currently constructed using a number of most popular methodologies: pile driver tensile and compression tests, cam plastometer, Kolsky and Tailor methods [1, 2]. Some other methodologies more rarely used to this end are those using ring specimen distribution, Ilyushin and Lensky methodology based on the theory of propagation of one-dimensional elastoplastic waves and distribution of residual stresses along the length of the specimen, etc.

It can be stated that dynamic properties of a number of conventional materials, to say nothing about novel ones, are poorly studied. As a result, the above mentioned critical objects are often designed using static properties (or data on available foreign analogues), leading to irrational design of structures subject to impact loading. In this respect, the development of instrumental and methodological means for dynamic tests, as well as comprehensive study of the dynamic behavior of structural materials under various conditions appears to be a very

where ΔT is increment of temperature of the material, W_p is plastic deformation work, ρ is density, c_p is specific heat of the material, β is part of mechanical energy transformed into heat ($\beta=0.9$ for adiabatic deformation, $\beta=0$ in isothermal case). The transfer from isothermal to adiabatic deformation mode in different materials takes place at different strain rates. However, when analyzing work [6], it can be concluded that, beginning from the strain rate of 10 s^{-1} the material is deformed adiabatically. Mathematical models for coefficient β as a function of strain rate $\beta = f(\dot{\epsilon})$ can also be found in [6].

A natural method of identifying empiric defining relations is the direct method, where experimental data obtained in various loading conditions are described by an analytical model (solving the approximation problem) [7]. However, in case of complex distributions of stress and strain fields in the active area of the specimen, as well as of the history of these values, the identification process can be effected using numerical modeling methods.

5. Verification of defining relations

As in the identification of mathematical models the data of “simple” experiments (homogeneous and uniaxial stressed state, constant strain rate and temperature) is used, it is required to test the effectiveness of defining relations in realistic working conditions of structural units. Due to the complex geometry of such elements and to the wide variety of load distributions and histories, the stressed and strained state in them is neither homogeneous nor uniaxial, whereas the strain rate can vary substantially in the process of loading. To verify the adequacy of models, special test experiments were developed (Fig.2) [7], which, on the one hand, are simple enough and allow for an unambiguous interpretation of the results and numerical representation without any simplifications, and, on the other hand, the stressed state in such tests, as well as the history of loading parameters, differ from those in basic experiments. The presented schemes for registering processes in specimens use the measuring bar technique, which gives additional information for comparing with the results of computational (virtual) experiment.

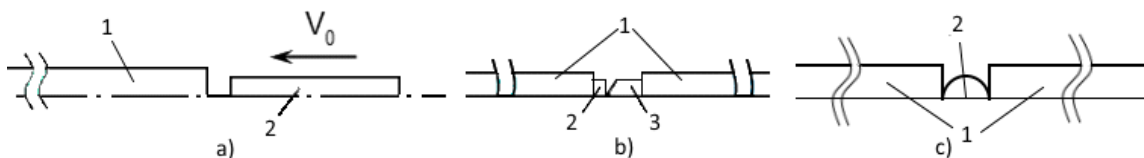


Fig. 2. Schemes of verification experiments: a) modified Taylor test, b) dynamic indentation, c) dynamic diagonal compression of an elastoplastic specimen.

In Fig. 2: 1 are measuring bars, 2 is specimen, 3 is disposable indenter.

6. Conclusions

At present, obtaining reliable mathematical models of materials for predicting the behavior of structures under impact or explosive loading is a highly important issue. Using a complex approach incorporating the development, substantiation and implementation of methodologies of basic tests, obtaining experimental data on high strain-rate deformation and failure of materials, identification of mathematical models, conducting specialized test experiments and verification of mathematical models by comparing the results of realistic and numerical experiments appears to be the most promising way.

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