EXPLOSIVE FRACTURE OF CLOSED CYLINDERS

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We present the results of numerical simulation of the process of fracture of thick-walled elastoplastic cylinders with bottoms caused by the explosion of a blasting charge placed inside the cylinders. We show that the influence of the scheme of explosive loading on spalling effects in the walls of the cylinders is significant.

There are numerous experimental works (carried out both in Russia and abroad) devoted to the investigation of the problem of fracture of thick-walled axially symmetric cylinders subjected to various types of explosive loading [1-4]. The most complete investigation of the influence of different schemes of application of explosive loading seems to be [3]; serious attention is given there to the analysis of the morphology of fragments formed as a result of the explosion, and it is shown that there exists a correlation of the growth of microdefects (micropores) and the possibility of spalling with the intensity of the drop of pressure on the contact surface of the explosion products and a cylinder. Experimental data on spalling in cylinders bombarded with thin-walled copper shells (liners) are presented in [2]. In [5], it is demonstrated that, under impact or explosive loading, the zones of brittle cleavage fracture, the spalling zone (or the zone of internal ruptures), and the zone of shear fracture are formed in the cross sections of the walls of a cylinder. The zone of internal ruptures is characterized by the presence of a great number of internal microdefects (pores) whose growth and merging lead to the formation of main cracks which eventually destroy the walls of the cylinders. Experiments aimed at the arrest of shells in different stages of expansion with subsequent metallographic analysis of their cross sections were carried out in [4] and revealed the presence of internal radial cracks, which do not appear on any surface of the shell. This observation corroborates the conclusion that the decisive role in the processes of the formation of main cracks and fragmentation of cylinders is played by the spalling zone [5]. There are a few works devoted to the theoretical analysis of spalling failure and dealing only with some special modes of loading and behavior of thick-walled cylinders [6,7].

In the present work, we make an attempt at numerical simulation of the processes of dynamic deformation of closed cylinders (with bottoms) and study the process of formation of spalling zones in the walls and bottoms for different modes of explosive loading. The investigation of different loading modes allows us to establish the relationship between the degree of damage to the walls of the cylinder and the law of changes in pressure on the boundary of the metal and detonation products.

As a basic model for calculations, we take a thick-walled cylinder with bottoms (Fig. 1). In view of the axial symmetry of the problem, we display only the upper part of the shell. Inside the cylinder (between two thin metallic shells), we place a tubular explosive charge. It can be initiated at any point of the left end of the charge or over the entire end surface. The indicated scheme covers the following special loading modes for cylinders (Fig. 2):

1) explosive charge continuously fills the internal cavity of the cylinder (Fig. 2a);
2) explosive material with cavity along the axis of symmetry (Fig. 2b);
3) charge with facing (Fig. 2c);
4) charge with lining (Fig. 2d);
5) charge with internal bar (Fig. 2e).

One can also indicate some other combinations of facings (shells) and explosive charges, which can be analyzed by the method and software proposed in the present work. However, we restrict ourselves to the above-mentioned schemes as the most typical of various applied problems and technical devices. For all loading modes, the detonation of explosive materials is initiated on the surface of the left end of the charge.
To describe fracture processes in cylinders, we use the model of a damaged (porous) perfectly elastoplastic medium. The basic equations of spatial axially symmetric motion of compressible porous hard elastoplastic media based on the laws of conservation of mass, momentum, and energy can be found in [8,9]. These equations are supplemented with a kinetic equation which describes the growth and compression of spherical pores [9].

As soon as the parameter of porosity reaches its critical value $\alpha = 1.433$ [9], the material is regarded as destroyed at this point. Here, $\alpha = V_p/v$, where $V_p$ is the specific volume of a porous medium and $v$ is the specific volume of the continuous component of the porous medium.

A system of equations which describes the motion of detonation products regarded as an inviscid non-heat-conducting gas can be derived from the equations of elastoplastic media by setting the characteristics of strength equal to zero. In simulating the process of detonation of explosive charges, we use the method suggested in [10].