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LOADING OF OBSTACLES BY EXPLOSION OF A LOW-DENSITY SHEET EXPLOSIVE

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The dependence of the detonation velocity of a NIL-1 *low-density sheet explosive on density is found in the range of charge densities* 0.1–0.3 g/cm^3. *The equation of state of the* NIL-1 *detonation products with a linear dependence of the effective isentropic exponent of unloading on the density of an explosive that is acceptable for applied calculations is proposed. Calculated estimates of the mechanical action of an* NIL-1 *explosion on obstacles from several powerful explosive compositions are given.*

For loading of large curvilinear surfaces, special high-explosives (HE) have been developed. Depending on the purpose, these are either powerful brisant sheet plastic HE, for example, TP-83 [1], or NIL-type low-density sheet HE. If the first class of HE, which is widely used for solving military-technical problems, has been examined quite adequately, the second class of HE, which is used mainly for industrial technological operations, has been examined to a lesser degree, and their application to the solution of particular problems should be preceded by examination of their properties.

In connection with weapons conversion, the problems of dismantling and utilization of diverse conventional and nuclear ammunition are of primary importance. The development of the technology of dismantling showed that for fracture of strong adhesive junctions and a number of structural units of ammunition and for grinding of large-sized charges extracted from ammunition, it is expedient to employ remote methods of pulse mechanical loading. The simplest and most efficient implementation of similar methods is possible only with the use of explosion energy. The restrictions on the loading intensity, which are due to the great amount of HE in the ammunition and the necessity of loading large curvilinear surfaces, have led to the choice of low-density sheet NIL-1, which meets the above requirements, as a basic loading reactant. The goal of this study is to determine the detonation properties of this HE and to estimate numerically the pulse mechanical action of a NIL-1 explosion on obstacles with a view to ward applying it to the solution of applied problems.

The low-density sheet high-explosive NIL is produced in the form of polyurethane-foam sheets with PETN (NIL-1) or RDX (NIL-2) crystals inside the pores. For NIL-1 production, the PETN powder with a specific surface area of 1500–8000 cm^2/g and a mass fraction of moisture no more than 0.5% is used. Similar HE are characterized by the charge density, i.e., the effective density of PETN power in the polyurethane-foam skeleton. For a charge density of $\rho_e \approx 0.2$ g/cm^3, 10-mm-thick polyurethane-foam sheets are used, and for a greater density (up to $\rho_e = 0.4$ g/cm^3) sheets of thickness 10 and 5 mm are used. Preliminary detonation results for these grades of HE showed that NIL-1 detonates more stably in a broad range of ρ_e ($\rho_e \geqslant 0.1$ g/cm^3 for a 10-mm-thick sheet); therefore, NIL-1 was chosen to study and perform the operations of dismantling and utilization of the ammunition. We note that the detonation of sheet HE and the action of an explosion on a loaded obstacle are considered in a simplified manner, disregarding the effect of the carrying polyurethane-foam skeleton.

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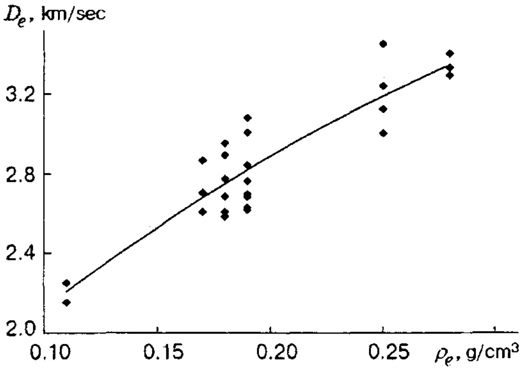

Fig. 1

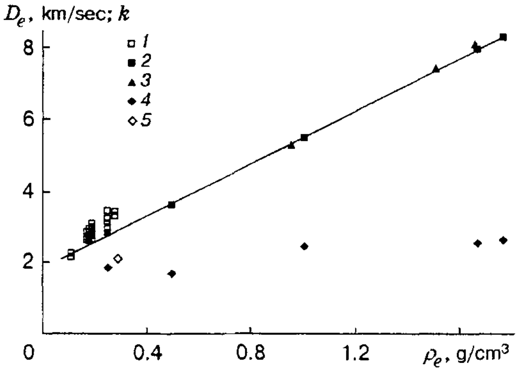

Fig. 2

Fig. 1. Detonation velocity of NIL-1 sheet charges of thickness 10 mm vs. density.

Fig. 2. Detonation velocities (1–3) and the isentropic exponent of detonation-product unloading (4 and 5) vs. density: points 1 and 5 refer to the data of the present work, points 2 and 4 to the data of [2], and points 3 to the data of [3].

To study the effect of the NIL-1 density on the detonation velocity D_e, electrocontact and photochronographic recording methods were used. The test samples were cut from 10-mm-thick sheets in the form of bands whose width was not smaller than 50 mm. The measurements were performed on a 100-mm basis. The results are given in Fig. 1. This figure also shows the approximating dependence obtained by the least-squares method:

$$D_e = 1.16 + 10.7\rho_e - 10.2\rho_e^2. \tag{1}$$

The quality of the approximation can be characterized by the value of the correlation coefficient $R = 0.914$ and the standard deviation of the points from the resulting dependence $s = 0.14$ km/sec. For $\rho_e < 0.11$ g/cm^3, the HE detonation becomes unstable: initiation is hindered and cases of detonation damping in the bands or partial detonation of the sheets occur. A significant scatter of the experimental points, which is identical for the specimens from different sheets and one sheet, is observed. This scatter is caused by the unavoidable heterogeneity of filling of the polyurethane-foam skeleton with a PETN powder.

The dependence $D_e(\rho_e)$ for sheet NIL-1 in Fig. 2 is compared with known results for PETN. The approximating dependence $D_e = 1.85 + 3.65\rho_e$ in Fig. 2 is constructed with the use of five points from [2] which are in the range of densities 0.25–1.77 g/cm^3. The results for NIL-1 agree well with the data for porous PETN, and the exceeding of the detonation velocity is, apparently, due to the effect of the polyurethane-foam skeleton on the detonation.

For the five points, the values of the isentropic exponent of PETN detonation products k at the Chapman–Jouguet point are presented in [2]. These data are also given in Fig. 2 for comparison with the value of k estimated in [4] for sheet NIL-1 of density 0.29 g/cm^3 on the basis of pressure recording upon explosive loading of the obstacle. In this study, the estimate was obtained under the assumption that the isentropic detonation-product curve has the form

$$p = A\rho^k \tag{2}$$

and describes the compression of detonation products if the detonation wave reflects from quite a rigid obstacle. In the experiment of [4], a sample of OTK-90 explosive composition was subjected to a normal detonation wave in a NIL-1 charge of thickness 20 mm which consisted of two HE layers of density 0.29 g/cm^3. Loading was registered by a manganin pressure gauge located on the sample surface. The maximum pressure in a loading mechanical pulse was 2.06 GPa. As a result of the combined solution of the equations for the

TABLE 1

Obstacle material	ρ_0, g/cm^3	c_0, km/sec	λ
OTK-90	1.86	2.74	2.06
GTK-70	1.72	2.37	2.12
OF-8	1.89	2.52	2.21

isentropic detonation-product expansion dependence and the shock adiabatic curve of the sample material, the parameter k was obtained to be equal to 2.09; this value is shown in Fig. 2.

It was noted in [5] that, for porous RDX, the dependence of k on the HE density can be represented in the form of the relation

$$k = a + b\rho_e, \tag{3}$$

where $a = 1.33$. Assuming that $a = 1.33$ for PETN as well and using the values of k obtained from the experimental data for a NIL-1 of density 0.29 g/cm^3 and a porous PETN of density 0.25 g/cm^3, we obtain $b = 2.41$. On the basis of (1) and (3) and known relations for the detonation wave, one can estimate the NIL-1 parameters such as pressure, mass rate, velocity of sound, and density behind the detonation-wave front.

To measure the mechanical pulse applied to a steel obstacle subjected to sliding detonation of a NIL-1 layer of density 0.21 g/cm^3, a ballistic pendulum was used. Five 100 × 100-mm specimens were cut from each of two HE sheets 10 mm thick. This allowed us to estimate the possible scatter of the results for both one sheet and different sheets. The specific mechanical pulse for two sheets is equal to (3.65 ± 0.21) and (3.74 ± 0.17) GPa $\cdot$ μsec.

The numerical calculation of the effect of detonation products of the NIL-1 layer on the obstacle upon sliding incidence of the detonation wave was performed by the method of characteristics. The method is briefly described in [1], where a similar problem of an obstacle subjected to sliding detonation of a layer of TP-83 plastic HE was considered. The loading scheme can be presented as follows. A plane detonation front, perpendicular to the HE–obstacle interface, propagates over an HE layer with velocity D_e. The detonation-product flow is considered in the coordinate system related to the detonation front. According to the Chapman–Jouguet condition, the detonation products outflow from the detonation front with the velocity of sound. The subsequent supersonic flow of detonation products occurs in the zone where two rarefaction waves interact. With the equation of an isentrope of detonation products used in the form (2), the equations of gas dynamics for a two-dimensional steady-state isentropic flow take the following form [6]:

(a) $Q - \theta = 2\xi$ along the characteristic C^+ $[dy/dx = \tan(\theta + \alpha)]$;

(b) $Q + \theta = 2\eta$ along the characteristic C^- $[dy/dx = \tan(\theta - \alpha)]$.

Here ξ and η remain constant along the individual characteristics, θ is the angle of flow, α is the Mach angle, and Q is determined by the expression

$$Q = \arcsin\frac{1}{\mathrm{M}} + \sqrt{\frac{k+1}{k-1}}\arctan\sqrt{\frac{k-1}{k+1}(\mathrm{M}^2 - 1)},$$

where M is the Mach number. The pressure is determined by the formula

$$p = B\Big(\frac{k-1}{2}\mathrm{M}^2 + 1\Big)^{-k/(k-1)}, \tag{4}$$

where the constant B is determined by the HE properties. As the boundary conditions from the side of the obstacle, the conditions of equality of the angles of flow and the pressure at the boundaries of the detonation products and the obstacle material are used. These conditions are determined at each step by the combined solution of the equation

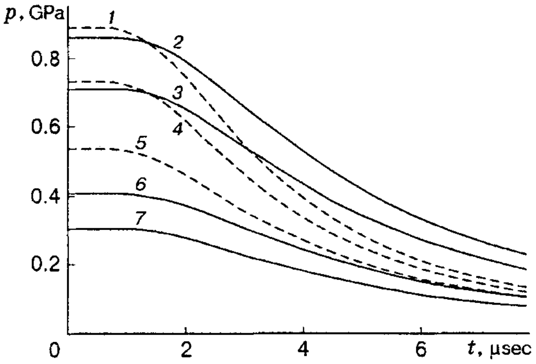

Fig. 3. Pressure profiles on obstacles from the GTK-70 (solid curves) and OTK-90 (dashed curves) compounds subjected to the sliding detonation of NIL-1 charges 10 mm thick for $\rho_e = 0.3$ (1 and 2), 0.26 (3 and 4), 0.21 (5), 0.18 (6), and 0.15 g/cm^3 (curve 7).

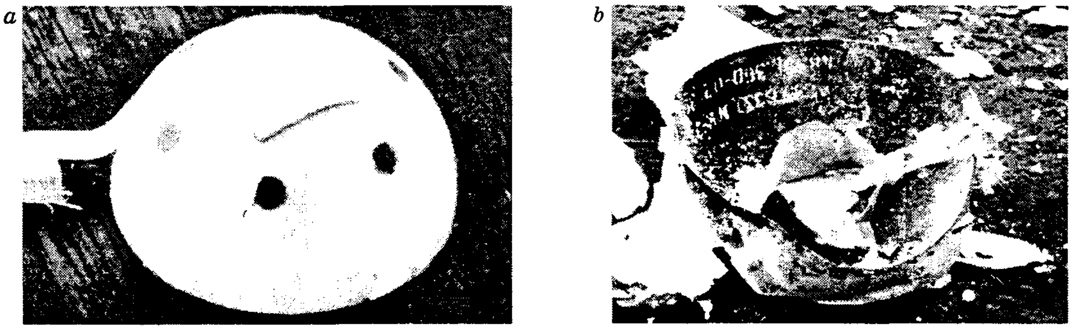

Fig. 4. Loading of a hemispherical explosive shell with a boron carbide shell stuck in it by an explosion of a 100 × 100 × 5 mm NIL-1 charge of density 0.28 g/cm^3: photo of the assembly before the experiment (a) and after the experiment (b).

$$p = \rho_0(c_0 + \lambda D_e \sin\theta) D_e \sin\theta,$$

where c_0 is the volumetric velocity of sound and λ is the shock-adiabat coefficient, and Eq. (4), into which the expression for M on an appropriate (C^-) characteristic is substituted.

The pressure profiles upon sliding detonation of NIL-1 of different densities were calculated for obstacles from several high-power explosive compounds; the shock-adiabat parameters are given in Table 1. The values of the NIL-1 detonation velocities and the isentropic exponents of detonation-product expansion as a function of density were found from formulas (1) and (3). Calculation results are shown in Fig. 3. Here the curves are limiting in the sense of the occurrence of a steady-state shock-wave loading regime of corresponding obstacles. A further decrease in NIL-1 density results in the calculated value of the shock-wave velocity of the obstacle becoming greater than the detonation velocity of the loading HE. For the third, OF-8 composition, the dependences $p(t)$ are approximately 1% lower than for the OTK-90 composition, and the limiting shock-wave loading regime occurs at an HE density equal to 0.18 g/cm^3.

Figure 4 shows an example of the use of the loading method described above. Reliably stuck into a hemispherical explosive shell, the boron carbide shell is easily extracted, for subsequent treatment, after loading by explosion of a small NIL-1 charge.

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