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THEORETICAL MODELS OF DETONATION OF A FLAT LAYER OF CONDENSED EXPLOSIVE WITH DIMINISHING DENSITY

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We have obtained in [1] the numerical nonself-similar solution of the problem of denotation wave (DW) propagation in a flat layer of a condensed explosive (EX) whose density ρ_0 diminishes according to a power law:

$$\rho_0 = \rho_{00}(1 - x/L_0)^\delta, \ \delta > 0. \tag{1}$$

Here, x is the present coordinate, ρ_{00} is the initial EX density at the x = 0 section, adjacent to an absolutely rigid wall, L_0 is the relative length over which ρ_0 formally vanishes, and δ is the exponent, which varies over the 0...2 range. The distribution of caloricity, i.e., of the specific energy release Q_0 per unit mass in the direction of thickness of the EX layer, was used in two limiting forms [2-4]:

$$Q_0 = Q_{00}(\rho_0/\rho_{00})^2; \tag{2}$$
$$Q_0 \equiv Q_{00} = \text{const}, \tag{3}$$

corresponding to either the purely elastic or the purely thermal character of the intrinsic energy of detonation products (DP) for a polytropic equation of state with the polytropic exponent k = 3 (Q_{00} is the caloricity corresponding to the density ρ_{00}). The DW behavior

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was investigated by using the solution of the problem involving disruption of the explosion under initial conditions, which occurs at the instant of time $t = 0$ in a thin EX layer adjacent to the rigid wall. We have established that the compression and the mass velocity of DP increase at the front of the supercompressed DW as it propagates. We have found that the coefficient of transformation of the chemical energy of an EX layer with diminishing density into the kinetic energy of the DP flow and of the flung incompressible plate is larger than in the case of normal detonation of an EX with constant density.

We shall consider here the detonation of a flat EX layer whose parameters vary according to the (1)-(3) laws by using analytical methods unconnected with studies of explosion disruption.

Assume that a shock wave from a heavy, inert backing arrives at the instant of time $t = 0$ at the EX layer on the side of its maximum density ρ_{00} and immediately causes detonation at the $x = 0$ section. Subsequently (at $t > 0$), the backing is considered as an absolutely rigid wall. By analogy with the problem of a strong point detonation [2], we assume that the pressure p_1 at the DW front is of the same order of magnitude as the mean energy per unit volume of the detonated part of the EX layer:

$$p_1 \sim KE(X_1)/X_1 = K \int_0^{X_1} \rho_0(x)\, Q_0(x)\, dx/X_1. \tag{4}$$

Here, X_1 is the coordinate of the DW front, K is the proportionality coefficient, which, on the basis of dimensionality considerations, is independent of X_1. In correspondence with standard laws of conservation [2] of the mass, momentum, and energy of matter at the DW front and the distributions (1)-(4), we obtain the following expressions for the DP mass velocity u_1 at the front, the pressure p_1, and the front velocity D_1:

$$u_1 = D_1\left[1 + \sqrt{1 - 16Q_0/D_1^2}\right]/4;$$

for $Q_0 \sim \rho_0{}^2$,

$$\begin{gathered} p_1 \sim K\rho_{00}Q_{00}\left[1 - (1 - X_1/L_0)^{3\delta+1}\right]/(3\delta + 1)X_1/L_0, \\ \frac{16Q_{00}}{D_1^2} \sim 2(3\delta + 1)\frac{(1 - X_1/L_0)^{\delta}\, X_1/L_0}{1 - (1 - X_1/L_0)^{3\delta+1}} - (3\delta + 1)^2\,\frac{(1 - X_1/L_0)^{4\delta}\,(X_1/L_0)^2}{\left[1 - (1 - X_1/L_0)^{3\delta+1}\right]^2}; \end{gathered} \tag{5}$$

for $Q_0 \equiv Q_{00}$,

$$\begin{gathered} p_1 \sim K\rho_{00}Q_{00}\left[1 - (1 - X_1/L_0)^{\delta+1}\right]/(\delta + 1)X_1/L_0, \\ \frac{16Q_{00}}{D_1^2} \sim 2(\delta + 1)\frac{(1 - X_1/L_0)^{\delta}\, X_1/L_0}{1 - (1 - X_1/L_0)^{\delta+1}} - (\delta + 1)^2\,\frac{(1 - X_1/L_0)^{2\delta}\,(X_1/L_0)^2}{\left[1 - (1 - X_1/L_0)^{\delta+1}\right]^2}. \end{gathered} \tag{6}$$

The value of K is found from the condition $t = 0$, and p_1 is equal to the pressure at the wave front of a normal Chapman–Jouguet detonation: $p_1(X_1 = 0) = p_{10} = 4\rho_{00}Q_{00}$. Expanding expressions (5) and (6) in series with respect to powers of the variable X_1/L_0, and letting X_1/L_0 tend to zero, we obtain $K = 4$.

After defining the total energy of the detonated part of the EX layer as the product between the mass $m = \int_0^{X_1} \rho_0(x)\, dx$ and the sum of the specific kinetic and intrinsic DP energies at the DW front and the function $\alpha(X_1)$, which accounts for the nonself-similarity of the process, we arrive at approximate expressions for the integrals of the kinetic T_1 and the intrinsic W_1 energies of the DP flow:

$$\begin{gathered} T_1(X_1) \sim \int_0^{X_1} \rho_0(x)\, Q_0(x)\, dx/\left[1 + c_1^2(X_1)/u_1^2(X_1)\right], \\ W_1(X_1) \sim \int_0^{X_1} \rho_0(x)\, Q_0(x)\, dx/\left[1 + u_1^2(X_1)/c_1^2(X_1)\right] \end{gathered}$$

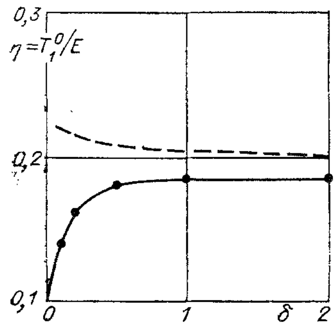

Fig. 1

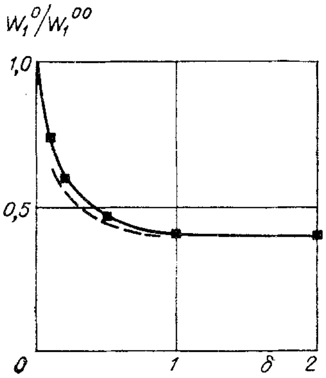

Fig. 2

where ($c_1 = \sqrt{3p_1/\rho_1}$ is the velocity of sound in DP at the DW front and $\rho_1 = \rho_0 D_1/(D_1 - u_1)$ is the DP density at the DW front.

Calculations show that, in the analytical approximation under consideration, the behavior of the DW front is qualitatively the same as in the numerical model [1]. The integral energy characteristics of the DP flow, determined analytically and numerically, are given in Figs. 1 and 2 as functions of the exponent δ ($\eta = T_1{}^0/E$ is the coefficient of transformation of the chemical energy of EX into the kinetic energy of the DP flow, and $W_1{}^{00}$ is the intrinsic energy of the DP flow in normal detonation of an EX layer with the constant maximum density ρ_{00}). It is assumed that the density between the initial ($x = 0$) and final ($x = X_1{}^0$) sections of the EX layer diminishes by one half, while the caloricity distribution is assigned by (2). The dashed curves represent analytical estimates, while the solid curves with points correspond to numerical calculations [1]. It is evident that the agreement between the values is quite satisfactory for $\delta > 0.5$. A similar agreement between the theoretical results occurs for $Q_0 \equiv Q_{00}$.

Consequently, the integral relationship (4) can be used for investigating qualitatively the DW behavior in the system under consideration and for estimating the integral energy characteristics of the DP flow for a relatively sharp decrease in ρ_0.

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