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Abstract

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PHYSICS

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CALCULATION OF THE LOWER LIMIT OF THE EXPLOSION-FREQUENCY CURVE

(Presented by Academician V. N. Kondrat' ev, July 7, 1958)

The peculiarity of any drop-weight test in studying the sensitivity of explosives to impact is that, as a result of the experiments, we obtain the so-called explosion-frequency curve. It has been shown both experimentally and by calculation ([1]) that, although the size of the initial decomposition source (which may arise for various reasons) is large on a molecular scale, it is nevertheless very small in comparison with the dimensions of the entire charge subjected to impact. It has been experimentally proved that the minimum size of a hot spot sufficient to initiate an explosion is 10^{-5} cm.

Assuming, as N. A. Kholevo does, that the heating of the substance is caused by plastic deformation of the explosive, we shall calculate the lower limit of the explosion-frequency curve for one specific case—for tests in the stamp apparatus proposed by N. A. Kholevo, in which free flow of the substance takes place. Let us assume that the explosion occurs at the beginning of the collision, when the deformation of the charge is small. (This agrees with the experimental fact that the time from the beginning of the impact to the explosion is 60—100 μsec, while the total impact time is about 500 μsec.)

For a sufficiently large mass of the load, we may neglect the change in its energy during deformation of the substance at the initial stage of the impact and may consider the velocity of the load to be constant.

Let us calculate the heating of a volume of substance of size l^3 that has undergone deformation. To do this, we solve the equation

$$l^3 c\rho \frac{dT}{dt} = -kl^2(T - T_0) + Q, \qquad (1)$$

where k is the heat-transfer coefficient, c is the heat capacity of the substance, ρ is its density, and Q is the heat release due to external work. The initial condition will be: at $t = 0$, $T = T_0$. The radial velocity of flow of the substance is

$$v_r = -\frac{3ur}{h^3}\, z(z-h),$$

where u is the velocity of the upper roller, h is the thickness of the charge, and z and r are the coordinates of the particle (in a cylindrical coordinate system whose origin coincides with the center of the lower roller).

For an approximate calculation of the heat release per unit time in a volume element, it is sufficient to restrict ourselves to the component $\partial v_r/\partial z$. Then the heat release in the volume under consideration per unit time is

$$Q = \frac{l^3\eta}{2}\left(\frac{3ur}{h^3}\right)^2 (h-2z)^2.$$

(Since the volume of substance considered by us is small, it may be assumed that in it $\partial v_r/\partial z = \text{const.}$)

As a consequence of the assumption that the loading rate and the layer thickness are constant, the heat release is also constant, and equation (1) gives

$$T = T_0 + \frac{Q}{kl^2}\left[1 - \exp\left(-\frac{kl^2}{l^2 c\rho}\, t\right)\right], \tag{2}$$

or, substituting the value of Q and replacing t by δ/u (where δ is the deformation of the specimen before explosion):

$$T = T_0 + \frac{9\eta l u^2}{2kh^4}\, r^2 \left(1 - 2\frac{z}{h}\right)^2 \left[1 - \exp\left(-\frac{k\delta}{c\rho u l}\right)\right]. \tag{3}$$

Expanding the exponential in a series and retaining only the first term, we obtain

$$T = T_0 + \frac{9\eta R^2 \delta u}{2c\rho h^4}\, r^2 \left(1 - 2\frac{z}{h}\right)^2. \tag{4}$$

Since heat release occurs most intensely at the periphery of the deforming specimen, near the surface of the rollers, putting $T = T_{\text{cr}}$, $r = R$, and $z = 0$, we obtain an expression for the minimum loading rate at which the probability of explosion becomes nonzero:

$$u_{\text{cr}} = \frac{2c\rho h^4}{9\eta R^2 \delta}\left(T_{\text{cr}} - T_0\right). \tag{5}$$

Riddell and Robertson calculated, for certain substances, the critical temperature of initial hot spots of different sizes. According to their data, the critical temperature of a hot spot of size 10^{-5} cm for PETN, hexogen, and tetryl is respectively 835, 895, and 1085°K ([1]).

Substituting into (5) the values of the quantities for standard rollers and for a certain hypothetical explosive close in properties to tetryl: $c = 0.3$ cal/g · deg, $\rho = 1.6$ g/cm^3, $h = 0.05$ cm, $R = 0.5$ cm, $\delta = 0.02$ cm, $T_0 = 290$°K, $T_{cr} = 1085$°K (tetryl at $l = 10^{-5}$ cm), $\eta = 5 \cdot 10^7$ g/cm · sec, we obtain $u_{cr} \simeq 10$ cm/sec, which corresponds to a drop height of the load of approximately 5 cm. The value of the viscosity coefficient has been taken as approximately equal to the viscosity coefficient of such organic compounds as glucose, pitch, etc., near their melting points. The resulting value of the lower limit of the frequency curve agrees well with numerous experimental data for such substances as PETN, hexogen, and tetryl.

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CITED LITERATURE

1. F. R. Bowden, A. D. Yoffe, *Initiation and Growth of Explosion in Solids and Liquids*, IL, 1955.

Note: Figure translations are in progress. See original paper for figures.