G. T. AFANAS'EV, V. K. BOBOLEV, and L. G. BOLKHOVITINOV

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Abstract

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G. T. AFANAS'EV, V. K. BOBOLEV, and L. G. BOLKHOVITINOV

ON THE THEORY OF THE INITIATION OF EXPLOSION BY IMPACT

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According to modern views, the initiation of an explosive transformation is exclusively thermal in nature. From the theory of thermal explosion it follows that if the temperature of a certain volume of an explosive is raised to some critical level, when the heat released by the chemical reaction can no longer be completely removed, then thermal self-ignition will occur in this volume. In testing solid explosives for impact sensitivity, the temperature rise in the substance occurs as a result of adiabatic compression and heat release due to plastic deformation and chemical reaction. Taking into account the short duration of the impact process and the strong dependence of the reaction rate on temperature, one may neglect the thermal effect of the reaction for subcritical temperatures, i.e., those not exceeding the temperatures calculated by Ridel and Robertson (1) and confirmed experimentally (2). An estimate of the magnitude of the heating of the explosive due to adiabatic compression shows that the heating in this case is small compared with the critical temperatures (3).

Thus, the principal role in creating high-temperature sites is played by plastic deformation of the substance. The intensity of heat release in this process depends on the plastic properties of the substance and on the loading conditions. The load at which the specimen passes into the regime of plastic deformation is subject to the action of a scale factor. V. R. Regel' and G. V. Berezhkova, who studied the dependence of this load on specimen size for several types of plastics, showed that it increases as α decreases, beginning with $\alpha \approx 1.5$ (α is the ratio of the height of the specimen to its diameter) (4). In testing explosives on a copra apparatus, charges less than 1 mm thick with a diameter of 10 mm are usually used. During deformation, the thickness of the layer compressed between the colliding surfaces becomes, as a rule, less than 0.1 mm, i.e., reaches $\alpha = 0.01$. It is evident that the scale effect should play a substantial role in impact on a copra apparatus. L. M. Kachanov (5) considered the problem of compression of a thin homogeneous disk ($\alpha \ll 1$) between the rough end faces of absolutely rigid cylinders. From the solution, which is based on the theory of elastoplastic deformations, one can find those values of the load at which the specimen passes into the plastic state. These values are related to α as follows:

Fig. 1

Figure 1: Fig. 1

$$P = \frac{\sigma_s}{3\sqrt{3\alpha}}, \tag{1}$$

where σ_s is the yield strength.

Thus, the thinner the specimen, the greater the influence exerted by the rigid boundaries of flow, and the more difficult it is to force the specimen into plastic deformation. If the pressure during impact remains less than that given by (1), then no heat release occurs; hence, for each impact energy there exists such a critical value of α below which it is impossible to obtain explosive decomposition.

On the other hand, initiation of a self-accelerating chemical reaction is determined by fulfillment of the Frank-Kamenetskii criterion (^{6}):

$$\frac{d^2 Q E z e^{-E/RT}}{4\varkappa R T^2} = \delta,$$

where Q is the heat effect of the reaction per unit volume, E is the activation energy, z is the pre-exponential factor, $\varkappa$ is the coefficient of thermal conductivity, and $\delta = 3.32$ for a spherical hot spot. Knowing the values of these quantities, one can, for any specified size d, calculate the corresponding critical temperature T. If the calculated value of T proves to be greater than the melting temperature of the substance T_{pl}, then, as was indicated by one of the authors [7], in order to create a hot spot with temperature T, the heating must be accompanied by all-round compression, whose magnitude must be equal to $P = (T - T_{\text{pl}})/\chi$, where χ is the rise of the melting point per atmosphere (for most secondary explosives one may take $\chi = 0.02$ deg/atm). Taking the size of the hot spot to be equal to the height of the compressed specimen, we have:

$$\frac{(\alpha D)^2 Q E z e^{-E/R(T_{\text{pl}}+\chi P)}}{4\varkappa R \left(T_{\text{pl}} + \chi P\right)^2} = \delta, \tag{2}$$

where D is the diameter of the specimen. For local overheatings whose size is smaller than that adopted by us, the required pressure will be greater than that found from (2).

Fig. 1

Thus, the necessary conditions have been obtained for the formation of an effective hot spot under plastic deformation. Condition (1) is the condition for flow of the specimen ($\alpha \ll 1$). For those α where the influence of scale does not appear, this condition consists in the requirement $P = \sigma_s$. Relation (2) gives the condition of critical stresses as a function of the dimensions of the specimen being tested. Initiation of explosion proves impossible if the pressure developed in the process of impact remains less than at least one of the values calculated from the two conditions.

In connection with conditions (1) and (2), it is of interest to consider two sharply differing cases, namely: $T_{\text{vsp}} < T_{\text{pl}}$ and $T_{\text{vsp}} > T_{\text{pl}}$. For a number of initiating explosives, ignition occurs before the appearance of the liquid phase. For them condition (2) drops out, and the necessary condition for explosion is the condition of flow. For most secondary explosives, $T_{\text{vsp}} > T_{\text{pl}}$ and the yield limit is small. Therefore, for them the principal condition fulfilled in explosion will be, as should be expected, the condition of critical stresses.

For each individual experiment, the magnitude of the pressure necessary for formation of a hot spot is determined by the aggregate of quantities entering into conditions (1) and (2). Since α changes during deformation under impact, the role of one or the other condition may prove variable. For illustration let us consider the case shown in Fig. 1, where curve I gives the pressure necessary according to condition (1), and II according to condition (2). We shall confine ourselves here to a model of an ideally plastic body. Then the pressure during deformation changes along curve I, and condition (2) is fulfilled only for $a \leq a_1$ and $a \geq a_2$, where, consequently, the formation of an effective hot center is possible only there.

Institute of Chemical Physics
Academy of Sciences of the USSR

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