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DETERMINATION OF THE DECOMPOSITION TIME OF HEXOGEN UNDER THE EFFECT OF SHOCK WAVES

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I. M. Voskoboinikov, V. M. Bogomolov, A. D. Margolin,
and A. Ia. Apin

ABSTRACT

A method for determining the decomposition delay after the action of a plane, flat-topped shock wave upon hexogen is described. A layer of hexogen was set on one surface of a polished metal plate with precisely parallel surfaces. The other surface of the plate was mounted on the end of a booster charge. The thickness of the metal plate was chosen so that a shock wave entering the hexogen would have uniform pressure over a given time interval. When the shock wave ran through the hexogen layer and reached the free surface, a rarefaction wave (characterized by decreasing pressure and temperature) formed and ran in the opposite direction. If the delay in initiation was longer than the time required for circulation of shock and rarefaction waves (back and forth) through the hexogen, an explosion did not occur. The critical thicknesses, h_{crit}, of the hexogen layers in which explosions occur, were determined. Shock waves of various intensities were applied. The delay time was determined by

$$\tau \approx \left[h_{crit}/D\right] (D + C - U)/C \quad ,$$

where C is the velocity of sound in compressed matter, D is the velocity of the shock wave, and U is the mass flow velocity behind the shock wave. Determination of decomposition delay in explosive mixtures (under the action of pressures greater than 100 kbar) was based on analysis of the dependence of the detonation rate upon the cartridge diameter. Experimental results obtained for compressed and crystallized hexogen initiated by shock waves with intensities of 120 to 205 kbar are presented and discussed.

Resolution of many important questions about the theory of detonation of condensed explosives depends on an understanding of the decomposition processes of explosives at shock-wave pressures from tens to hundreds of kilobars. The temperature in shock waves at such pressures exceeds those usually encountered in studies of thermal decomposition by a factor of two of three.

The proposed method utilizing hexogen attempts to elucidate some obscure facets of this problem.

I. A method for measuring delay times in the decomposition of explosives under the effect of plane shock waves is presented schematically in Fig. 1. The (single crystal of the)* explosive to be studied was mounted on the polished surface of a plane-parallel metal attenuator plate which, in turn, was mounted on a donor explosive charge. A constant pressure was maintained in the test explosive by proper selection of the metal thick-

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*From the description, one of the editors believes that single crystals were used, but this is not specifically stated in the original.

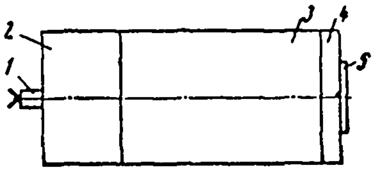

Fig. 1. Test setup for measuring decomposition time of explosives in shock waves. 1. percussion cap, 2. lens for shaping plane front, 3. explosive charge, 4. metal plate, 5. hexogen layer.

ness. The shock wave traversed the explosive to the free surface, then a rarefaction propagated backwards, reducing the pressure and temperature in the explosive. If a reaction had not developed in the test explosive before the shock wave hit the free surface, the rarefaction wave significantly decreased the decomposition rate, and detonation did not occur. The reaction process, identified as a detectable light flash upon detonation of the explosive, was recorded by a streak camera. If no flash was observed, it was assumed that the reaction time was greater than the reverberation time of the wave through the layer of explosive (passage of the shock wave and return of the rarefaction wave). The critical thickness, h_{crit}, at which the explosive still detonated was determined for several shock pressures.

Very small delays in sample decomposition can be measured by this method. The maximum sample thickness (and, consequently, the delay time) was limited by the charge dimensions and the speed of lateral rarefactions. In these tests, the sample diameter was significantly greater that its thickness. Some overestimate of the critical thickness is possible when it exceeds 3 mm because the pressure at the back boundary can decrease by 5%.

The graph (Fig. 2) of the propagation of the shock wave through the sample shows that the relationship between the decomposition time, τ, and h_{crit} is

$$\tau = \frac{h_{crit}}{D}\,\frac{(D + C - U)}{C} ,$$

where D is the shock velocity, C is the sound velocity in the compressed material, and U is the particle velocity behind the shock front.

Without increasing the error by more than 5%, we will assume that D = C. The relationship can

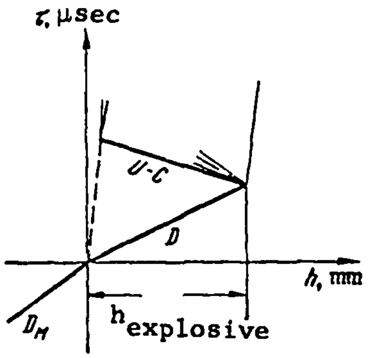

Fig. 2. Propagation of shock waves through a hexogen sample. D_M is the velocity of the shock wave in metal.

then be simplified to

$$\tau = \frac{h_{crit}}{D}\left(2 - \frac{U}{D}\right).$$

Figure 3 shows the experimentally measured relationship between τ and the initial pressure for both crystalline (single-crystal?) hexogen and hexogen pressed to a density of 1.80 g/cm^3.[1,2]

The significant divergence of the curves below 180 kbar indicates that the temperature rise in the single-crystal material is due only to adiabatic heating, while in the pressed material reaction can occur in the inhomogeneities, causing a reduction in τ at low pressures.

II. The model used for measuring the delay time in decomposition of an explosive at pressures above 100 kbar is based on an analysis of the de-

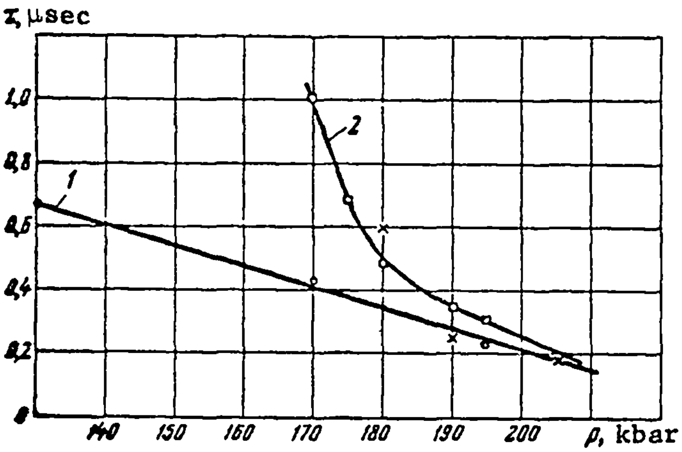

Fig. 3. Dependence of hexogen decomposition time on intensity (p) of shock wave. 1. for pressed hexogen, 2. for hexogen crystals, ○, □ - first method, x - second method.

pendence of the detonation velocity, D, on the charge diameter for mixed explosives. It has been observed for a number of mixed explosives that the detonation velocity is independent of charge diameter over a limited diameter range. This velocity is called the "pseudo-ideal" detonation velocity, and is related to a stepwise progress of the reaction within the detonation wave. The delay time for a particular step is characterized by the charge diameter, d_1, at which the detonation velocity begins to increase rapidly with increasing charge diameter (e.g., decomposition of one of the components or a slow step in the decomposition of one of the fuel oxidizer mixtures).

Apin[3] determined the dependence of detonation velocity on the charge diameter for 1.0- to 1.6-mm hexogen particles suspended in a solution of varying amounts of Plexiglas (polymethyl methacrylate), tetranitromethane, and nitrobenzene. As Apin reported, the diameter at which the detonation velocity begins to increase depends upon the detonation pressure of the liquid phase. When an inert salt was substituted for the hexogen, the pseudo-ideal velocity for the liquid phase was obtained, indicating that the increase in velocity was caused by the energy contributed by the hexogen.

The rapid settling of coarse particles, which created difficulties in the preparation of suspensions, was circumvented by first pouring the powdered explosive (particle size 2.5 to 5.4 mm) into the charge assembly and then flooding with the liquid phase.

The dependence of the detonation velocity, D, on the charge diameter, d, obtained for these systems is given in Fig. 4. Figure 5 shows Apin's[3] results. The detonation pressure of the liquid explosive is shown on each curve.

By comparing the graphs, one can conclude that the charge diameter, d_1, for coarse crystalline hexogen depends exclusively on the detonation pressure of the liquid explosive, not on the hexogen content. This conclusion is acceptable only when the hexogen grains are flooded with liquid explosive having a small failure diameter.

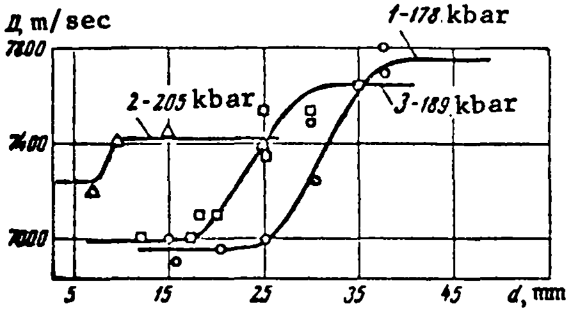

Fig. 4. Dependence of detonation rate on charge diameter of mixed explosives.
1 - 2.5- to 5.8-mm hexogen grains and a 35/65 mixture of tetranitromethane with TNT; 2 - 88/12 mixture of tetranitromethane with nitrobenzene; 3 - 92/8 mixture of tetranitromethane with nitrobenzene.

If one assumes that the pressure decay behind the detonation wave is the same for two explosives with the same initial densities and detonation velocities, and that decomposition of hexogen is a monotonic function of pressure above some critical point, the following can be noted: The delays in decomposition of hexogen in the liquid explosives studied are in the ratios of 8:3:2 for detonation pressures of 180, 190, and 205 kbar. For pressures above 220 kbar, no pseudo-ideal velocity corresponding to the delay in hexogen decomposition was observed.

The delay in decomposition of hexogen in a detonation wave is determined not only by the detonation pressure of the liquid explosive but also by the drop in pressure behind the detonation front. Therefore, the observed ratios cannot be used to determine an accurate single value for the pressure. However, the ratios can be considered approximately correct by taking into account the strong dependence of τ on pressure, and the fact that the pressure drop behind the detonation wave

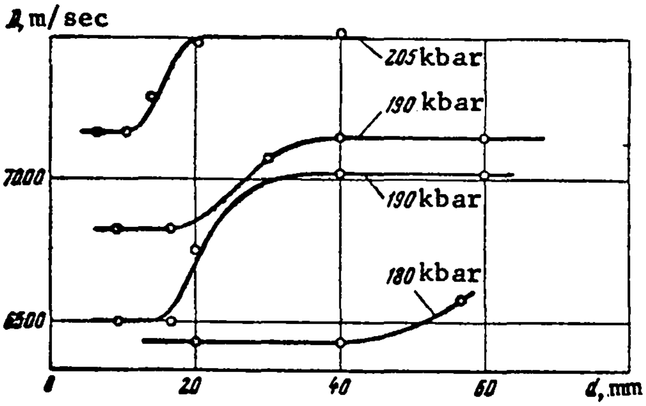

Fig. 5. Dependence of mixed explosive detonation rate on charge diameter.

depends primarily on the charge diameter. Also note the extremely small dependence of the value of d_1 (within experimental limits) on the material and thickness of the container for the mixtures examined. This confirms the assumptions of quenching of the hexogen decomposition reaction within the grain volume when a very small pressure reduction occurs behind the detonation front of a liquid explosive.

It is interesting to compare the critical time results obtained by the two methods.* For comparison, we will assume that the values of τ determined by the two methods coincide at a pressure of 205 kbar, as the second method provides only the relative time of the delays (see Fig. 3). Note that the pressure range is small. The delays at pressures above 210 kbar are small, and at pressures below 180 to 170 kbar the delay increases rapidly; i.e., the difference between the two methods is insignificant. Both methods show that there is a strong dependence between the decomposition time of crystalline hexogen and the applied pressure.

Our results indicate that for a pressure of 180 kbar and a decomposition time of 0.5 μsec, the charge diameter should be 40 mm to permit the decomposition of hexogen. Using the ratio $d_1/2D$ to calculate the reaction time for a charge of critical diameter, Iu. B. Khariton reports a value of 3 μsec, i.e., of a different order from our results for decomposition under the effect of shock waves. Apparently, the calculation of reaction times based on Khariton's theory, using values of d_1 and d_{crit} should be assumed erroneous.[4]

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*(Ed. note. At this point the author wants to compare the results obtained by observing the initiation as described in Part I to the results obtained in Part II. The results of Part II are not absolute, but must be compared by scaling).

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