LOW-VELOCITY PROPAGATION OF AN EXPLOSION IN SOLIDS

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It is now clear [1] that if sufficiently large hot spots (10^{-3}-10^{-5} cm) form in an explosive, the development of the reaction may lead, first, to combustion, and then to detonation at low or high velocity. The hot spot temperature necessary for initiating an explosion is approximately 500°C and the duration of heating varies from 10^{-4} to 10^{-6} sec.

This paper describes the propagation of an explosion in thin layers of secondary explosives densely compressed between two cylinders, one of which was metal and the other plexiglas; the process of propagation of the explosion was photographed through the plexiglas cylinder using a ZhFR high-speed photorecorder. The maximum pressures which could be attained on the apparatus and which were withstood by the lower plexiglas cylinder did not exceed 2000 kg/cm². The experiments were conducted at pressures of 1200-1500 kg/cm². Figure 1 is a diagram of the apparatus.

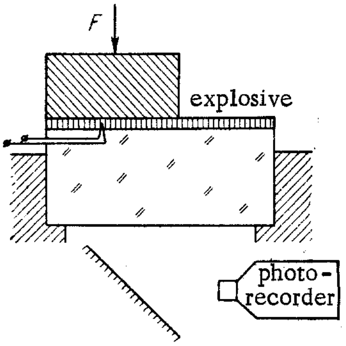


Fig. 1

The explosion was initiated by introducing into the substance a thin (diam. 0.15 mm) nichrome wire which was heated to a temperature of about 1000°C by current pulse of duration 10^{-5} sec obtained by discharging a condenser. A small folded part of the wire, in contact with the explosive at one point, simulated a hot spot from which the explosion propagated radially. Usually, an explosion begins as relatively slow combustion (tens of m/sec), which is accelerated rapidly due to an increase of pressure beyond the flame zone as a result of a strong increase of the volume of decomposition products in comparison with the volume of starting material. As propagation continues, the profile of the plane flame front becomes curved, which leads to an increase in combustion surface and an increase in the rate of the process.

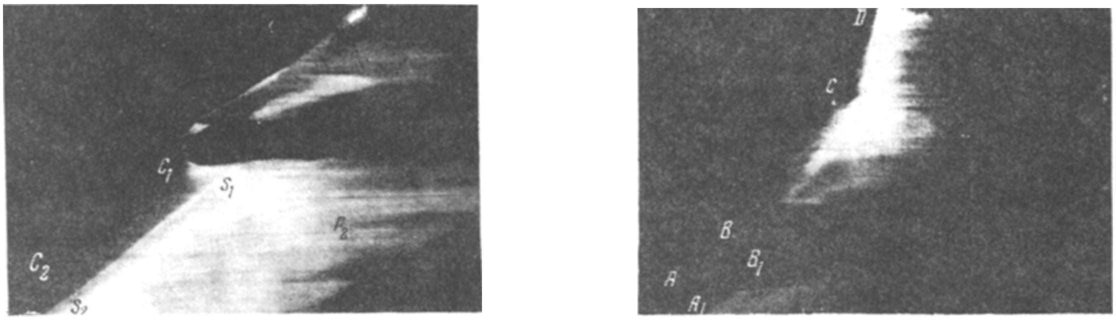
Accelerating to several hundred m/sec, the flame, acting like an accelerated piston, creates in front of it a preliminary compression wave which propagates approximately with the speed of sound in the starting material.

At velocities of several hundred m/sec, the process becomes stabilized; below we present the ordinary regimes of propagation of an explosion under the experimental conditions considered above.

Explosive	ρ, g/cm³	D, m/sec
PETN	1.68	700—800
RDX	1.67	700
Dynamite	—	550
Tetryl	1.63	300

Figure 2a is a typical photorecord of the propagation of an explosion in PETN, showing the characteristic features of the mentioned regimes. The very faint luminescence in the zone C_2S_2 beyond the compression wave C_1C_2 is apparently caused by the scattering of light from the detonating charge at the numerous inhomogeneities (zones of weakness, cracks) formed in the initial solid charge during its disintegration in the preliminary wave C_1C_2. The weak low-velocity detonation wave S_1S_2, which follows the preliminary wave, easily excites a rapid chemical reaction in the mentioned inhomogeneities, which then proceeds by the mechanism of explosive combustion. In many cases, in the faintly luminescent zone in front of the explosive combustion front S_1S_2 it is possible to observe brighter flares of reaction centers. In the upper part of the figure, at the point C_1, it is possible to see the explosion of a small charge of lead azide, compressed into the investigated explosive, due to the preliminary compression wave. The photograph shows that the detonation wave S_1S_2 is followed by the products of explosion of the starting material moving in the same direction (along the trajectory S_2P_2) with velocities ~ 200-300 m/sec. An estimate of the pressures, using the formula $p = \rho_0 Du$, gives values of about 3800 atm for PETN and 3000 atm for RDX. The photorecord shows that the motion of the explosive products gradually slows down, and that, finally, they begin to move in the direction opposite to the direction of propagation of the explosion.

Figure 3 is a magnified frame-by-frame time resolution of the propagation of an explosion in an explosive charge. It can be seen that the curved front of the low-velocity detonation has nonuniform luminescence, individual bright tongues being ejected slightly ahead. In the case of explosive combustion, the curved combustion front, breaking down into a large number of individual microjets, apparently does not completely entrain the existing explosive surface, leaving burning grains far behind it; therefore the chemical reaction zone is greatly elongated and may exceed by ten times the reaction zone of a normal detonation. The presence of an extended zone of chemical conversion leads to considerable losses of the energy released during the decomposition reaction.



a

b

Fig. 2

Upon destruction of the plexiglas cylinder the rarefaction waves penetrate into the conversion zone and intensive expansion of the explosive products begins before the chemical reaction is complete. In addition, heat losses to the wall, leading to cooling of the explosive products and the appearance of a rarefaction wave behind the flame front, attenuate the detonation wave.

Fig. 3

If we make a rough estimate of the heat of the explosion in the mentioned regime on the basis of hydrodynamic theory, using the dependence Q ~ D^2 as a point of departure, we reach the conclusion that the energy release in the wave is negligible (about 1%). This confirms to some extent the conclusion that chemical conversion is incomplete and gasdynamical and heat losses high. We note that after the propagation of an explosion with a stationary velocity of about 700 m/sec, fused grains of unreacted substance frequently remain on the surfaces of the cylinders, between which the investigated explosive is compressed; these grains will burn if ignited. However, no matter how great the energy losses, even a slight contribution of heat to the wave is sufficient to produce a stationary low-velocity detonation process, whose propagation is dependent on the balance between the release of energy due to the chemical reaction and the losses associated with the mentioned process.

The following explanation may be given for this phenomenon. In Fig. 4 curve 1 is the Hugoniot adiabatic curve of the initial explosive; the point a on this curve designates the state into which the material compressed by the shock wave is carried. A given stationary propagation velocity corresponds to the point of tangency b of the straight line oa with some curve 3, the adiabat of the incompletely reacted substance, rather than to the point of tangency with the adiabat 2 of the completely reacted explosive products.

However, the above-mentioned stationary propagation is apparently pseudostable [2], because possible disturbance of the balance and decrease in the energy losses in the layer affected by the compression wave, in which a rapid reaction was initiated, may lead to thermal self-acceleration of the process and explosion of the layer in question with the formation of a strong shock wave that excites normal detonation of the starting material. Figure 5 is a photorecord of the corresponding phenomenon in PETN.

Initiation occurred at point A. A low-velocity regime BC developed at point B after an acceleration interval AB. Normal detonation CF of the starting material occurred at point C; DE is the retonation wave. The scale in Fig. 5b is enlarged 1.5 times in comparison with Fig. 5a. The considerable size CD of the exploding layer should be noted (linear dimension about 6 mm); the persistent post-luminescence of the explosive products, observed in the low-velocity process, is completely absent from the normal detonation process. Note that such transitions were observed under our conditions only for PETN.

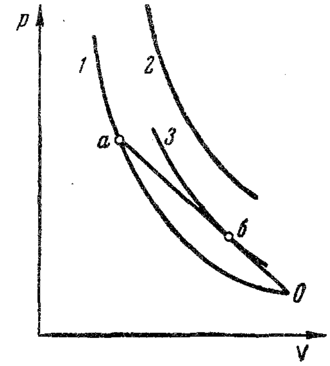


Fig. 4

The formation of a normal detonation regime was recorded in an experiment in which the low-velocity regime emerged from the zone of explosives compressed between solid surfaces and entered the zone of unconsolidated material free of pressure (Fig. 1). Usually, there is transition to a high detonation velocity (Fig. 2b) accompanied by a gradual increase in shock wave velocity until the normal process develops. The line AB is the trajectory of the low-velocity wave through the compressed explosive. The point B is the edge of the compressed zone, BC is shock wave acceleration, and CD is normal detonation in the uncompressed zone. The phenomenon described is not observed for dynamite and tetryl, apparently owing to the insufficient momentum of the shock wave which excites the chemical reaction in the starting material. In this case detonation does not occur: the material damps out, burning slowly in the uncompressed zone.

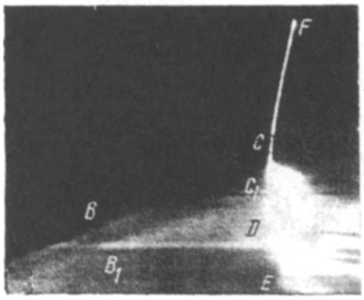


Fig. 5a

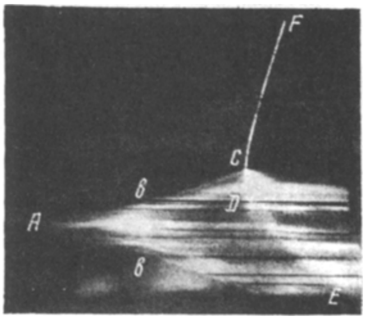


Fig. 5b

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2. N. Griffiths, R. M. Laidler, and S. T. Spooner, "Some aspects of the shock initiation of condensed explosives," Combustion and Flame, vol. 7, no. 4, 1963.

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