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LOW VELOCITY DETONATION OF CAST EXPLOSIVE CHARGES

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The problem of initiation of reactions in weak detonation waves produced by low velocity detonation of cast explosive charges is studied. A heating formula is produced.

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Due to the widespread utilization of low speed detonation modes under practical conditions, for example in development of an explosion from an impact [1], a study of their mechanism is of significant interest. The conditions most convenient for investigation are those under which these modes stabilize over significant charge sectors. These conditions have long been defined for plastic, liquid and low-density powdered explosives.

For open charges of cast explosives, modes with detonation propagation velocities less than normal, frequently observed near critical initiation conditions [2], [3], have a clearly expressed unstable nature, and the propagation sector does not exceed two or three charge diameters. Over significantly greater sectors (up to 15 charge diameter), these processes have been observed under conditions of transition of combustion of cast explosives of dina and pentolite to detonation [4], when the explosive was in a strong, closed shell. Stable propagation of detonation at near-sonic speed (about 2km/sec) has been observed with soft initiation of cast charges of trotyl up to 60 charge diameters) as well as with compositions of trotyl plus hexogene and trotyl plus octogene 50/50, placed in thick wall (5-10 mm) steel tubes.

In this work, we will study the process of initiation of reactions in these weak detonation waves.

It is known that the structure of the front during detonation at low and high velocities differs significantly: in the first case, at the leading edge of the wave, the pressure in which is 5-8 kbar, the increase in pressure continues. Further studies have confirmed this. The experiments were performed with charges of cast trotyl and partially with trotyl-hexogene 50/50, in steel pipes. The charge diameter is 10-15 mm, length 200 mm, pipe wall thickness 10-13 mm. Low velocity detonation in experiments with trotyl was initiated by charges of a mixture of finely dispersed hexogene and sodium chloride containing 40 and 50% hexogene (detonation velocity at 1.2-1.3 g/cm^3 density was 4-5 km/sec), and in the experiments with the trotyl-hexogene composition, initiation was by the same charges, containing 20% hexogene (detonation velocity 3 km/sec). The velocity of the process was measured using a high speed type ZhFR-3 photographic recorder with explosions of small charges (5-10 mg of lead azide, placed in radial apertures in the shell. The velocity for trotyl was about 2 km/sec, for the trotyl-hexogene composition -- 2.3 km/sec (the normal detonation velocities under these conditions are 7.4 and 7.6 km/sec respectively).

Information on shock processes propagating in the charge was produced by photography against a bright screen background (ISK-20 flash tube) of the phenomena occurring at the division boundary between the material studied and a transparent inert medium (water or plexiglass) as the detonation front approached.

The photographs thus produced for trotyl and the trotyl-hexogene composition are presented on Fig. 1. High velocity detonation in an aquarium full of water produces one shock wave with high pressure. Low speed detonation produces several successive outgoing waves. Let us study them in the order in which they appear.

The first wave (or more frequently series of waves) arises long before the approach of the detonation front, obviously as a result of shock processes propagating in the shell at the speed of sound (about 5 km/sec). It is assumed that in the case of nitroglycerin these waves leading the detonation front play a significant role in the process of initiation of the reaction. For cast explosives their significance is apparently much less: in a special experiment, a charge of trotyl in a shallow five sectors of steel pipe separated by cardboard inserts 0.2 mm thick detonated at the ordinary speed without any oscillations along the length of the charge.

The second wave is a sharp wave initiating at the charge itself. Behind this wave, the division boundary between the explosive and the inert medium begins to move. The moment of production of this wave in certain experiments corresponded to the approach of a process at a near-sonic velocity, the propagation of which was fixed by the explosion of the charges of lead azide; in many experiments, the lead azide exploded somewhat later. The pressure in this wave is 3-5 kbar, corresponding to the pressure in the wave propagating through trotyl (5-8 kbar). This is apparently a compression wave propagating through the unreacted material. Photography of the flow of the material from the end of the tube into air against a bright screen has shown that it begins at a relatively low velocity (0.3-0.5 k/sec), several times lower than the detonation velocity.

After the departure of the compression wave, the movement of the division boundary continues to accelerate until it reaches a certain maximum speed, approximately 1.5 times the initial speed, which remains constant for sometime. A number of pictures show clearly that this acceleration results from departure of a series of shockwaves into the water (sometimes one stronger wave is seen). It is difficult to estimate the pressure at the leading edge of these waves from the experimental results, but their propagation velocity is apparently higher than the velocity of the wave which develops when the compression waves approach the division boundary; consequently, their pressure is also higher. It might be assumed that this increase in pressure occurs as a result of a chemical reaction developing beyond the compression wave, and that the leading edge of the reaction wave has a more or less clear boundary. Based on the time between the departure of the compression wave and of the wave causing motion of the division boundary at maximum velocity, we can approximately estimate the time of development of the reaction. The estimate for trotyl is 10-20μ sec, for the trotyl-hexogene composition about 10μ sec.

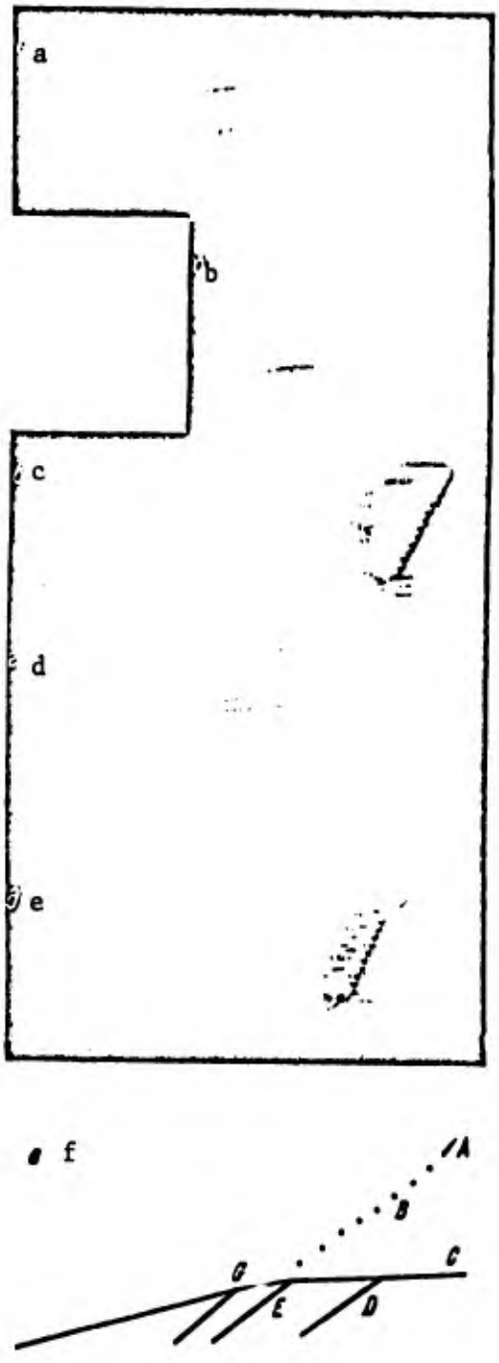

Fig. 1. Photographs of Processes Arising at Division Boundary Between Explosive and Water as Detonation Front Approaches: a, b, Detonation of Trotyl at Low Speed; c, High Speed Detonation of Trotyl; d, Detonation of Trotyl-Hexogene 50/50, Low Speed; e, High Speed Detonation of This Same Composition; f, Diagram of Process: A. Explosion of Supplementary Detonator; B. Explosion of Charges of Lead Azide in Radial Apertures in Shell, C. Division Boundary; D. Departure of Shockwave from Shell; E. Departure of Compression Wave; G. Departure of Wave (or Series of Waves) Resulting from Reaction.

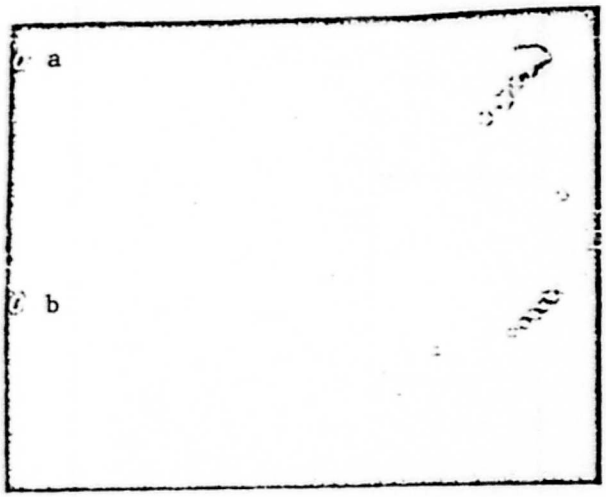

Fig. 2. Attenuation of Low Speed Detonation of Trotyl Charge in Steel Pipe (Internal Diameter of Pipe 15 mm, Wall Thickness 10 mm:) a. Circular Gap of 0.75 mm Between Charge and Pipe Wall, Filled With Layers of Tissue Paper; b. Charge has 6 mm Diameter Central Channel.

This explanation of the processes observed assigns an important role in the initiation of the reaction to the preliminary compression wave. In order to test the correctness of this point of view, two more series of experiments were performed. In the first series, the compression wave was attenuated by various means. Obviously, under the experimental conditions, i. e., with small charge diameters and near-sonic velocity of the process, the lateral rarefaction wave propagates through the entire cross-section of the charge in a time which is less than or in any case comparable to the delay time, or particularly to the time of development of the reaction. Experiments were performed with charges placed in pipes with a circular gap between charge and wall, filled with several layers of tissue paper. With a gap width of 0.5-0.7 mm, the detonation is attenuated (Fig. 2A). It attenuates also in charges with a central channel 6-7 mm in diameter (volume equal to the volume of the circular gap), both when the channel is empty (Fig. 2B) and when wood chips are placed in the channel. When a plexiglass rod of the same diameter is placed in the charge, the detonation propagates stably. Replacement of the steel shell with a brass shell or a decrease in the thickness of the steel shell to 3 mm also causes attenuation of the detonation (the thinner shell is usually ruptured by low speed detonation, whereas the thicker-wall type generally remains whole).

In the second series of experiments, a charge of trotyl 10 mm in diameter was separated by barriers of various materials (Fig. 3), namely a water layer 10 mm thick (Fig. 3A), a plexiglass disc of the same thickness resting on a notch in the pipe channel (Fig. 3B), steel plates 3 and 5 mm thick, firmly fixed in the pipe channel (Fig. 3C and D), a steel piston 10 mm thick, which could move freely in the channel (Fig. 3E). A barrier of low strength material or a moving barrier (water, plexiglass, steel piston) and little influence on the process: if continued beyond the barrier at approximately the same velocity as before it. However, the nonmoving steel plate 5 mm thick fully stopped the process (the plate was not ruptured, but a depression approximately 1 mm deep with diameter equal to the charge diameter was left in it.

The 3 mm plate delayed the process significantly, the process then developing in the lower portion of the charge and propagating at a significantly lower speed, which increased as the detonation continued to propagate in this experiment. A hole was left in the plate with a diameter equal to the charge diameter.

The results of these experiments indicate that during low speed detonation the reaction is initiated by local heating arising as the material is compressed in the compression wave. The reasons for this heating might include, for example, friction of the material for compression of air inclusions. The difference from the mechanism of heating usually used is that due to the high density and homogeneity of cast charges, the reaction occurs with great delay, and stable propagation of the process requires a strong envelope, the reaction attenuating otherwise due to the effects of lateral rarefaction waves. Attenuation of the process also occurs if the flow of the material is stopped behind the compression wave by a nonmoving, strong barrier.

An estimate of the delay time of the reaction ($1 \cdot 10^{-5}$ sec) allows us to calculate the temperature at the center of heating using the equations concluded for a focused thermal explosion. The calculated temperature for trotyl is about 950°K, with a focus size of $3 \cdot 10^{-4}$-$4 \cdot 10^{-4}$ cm. It is interesting to compare these results with the approximate estimate of the temperature of the material produced by friction. Let us use the simplest model of the process: friction arises between the flow of the material filling the spaces between crystals as a result of compaction (initial trotyl charge density 1.57-1.59 g/cm^3) and the nonmoving crystals or the wall of the pipe. The trotyl melts with the friction and the liberation of heat occurs in the melted layer, the thickness of which at the moment of development of the reaction must be equal to the critical focus size. The heating in this case is

$$T - T_0 = \frac{Uk\eta}{\delta^2 c\rho}$$

where U is the rate of flow of the trotyl in air
k is the size of a heterogeneity
η is the viscocity;
ρ is the density of the melt;
c is the heat capacity;
δ is the thickness of melt layer.

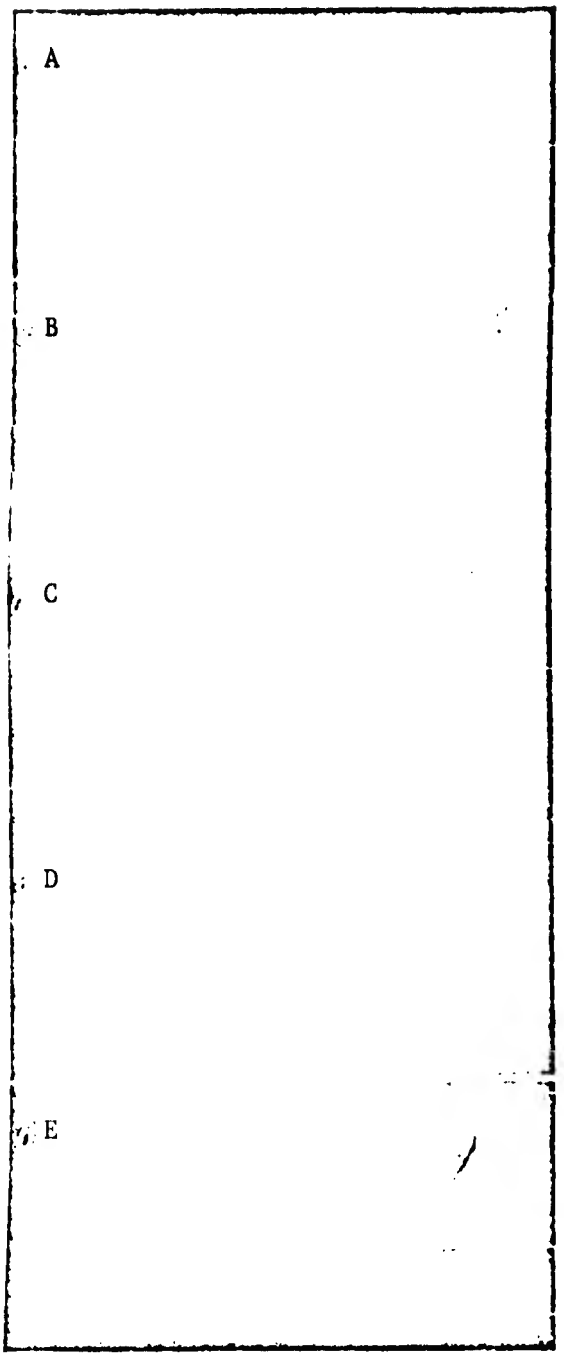

Fig. 3. Transmission of Low Speed Detonation of Trotyl Through Inert Barrier (Charge Diameter 10 mm, Pipe Wall Thickness 13 mm). Point of Placement of Barrier Marked with Horizontal Lines.

Assuming there are calculation, $U=4\cdot10^{-4}$ cm/sec (mean value of initial flow rate of trotyl in air beyond leading edge of compression wave from several experiments), $h=10^{-1}$ cm, $\eta=10^{-1}$ poise, the mean value of δ is equal to 1/2 of the focus size, $c=1.3\cdot10^{-7}$ erg/g·deg, $\rho=1.45$ g/cm^3, we find that T 1000°K.

Consequently, heating as a result of friction is quite sufficient for initiation of the reaction with the delay indicated by the experimental results. Actually, of course, the process is much more complex: the streams of material collide with each other and with the nonmoving material, crystals are ruptured, microcumulative streams are formed, etc. All of these facts can lead in the final analysis to an increase in the temperature of local heated areas.

It must be noted that in the calculation which we have presented, a rather large heterogeneity size figures as one of the conditions required to achieve critical heating. Since the charge includes heterogeneities of various sizes, the reaction will be initiated with various delay times. This is apparently manifested in the fact that following the compression wave, a series of waves frequently appears at the division boundary. This indicates that the less the variation in sizes of heterogeneities in the charge, the more sharply the leading edge of the beginning of the reaction will be expressed. On the other hand, the denser and more homogeneous the charge, the more difficult low speed propagation of detonation will be. This has been qualitatively confirmed in the results of experiments with trotyl, the density of which varied between 1.57 and 1.62 g/cm^3 depending on crystallization conditions, the process clearly attenuating with greater density, in spite of the fact that a decrease in the dimensions of crystals in the cast charge, usually accompanied by an increase in density, is known to facilitate high speed detonation.

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