Electrical Conductivity Profiles in Detonating Low-Density Explosives of Various Grain Sizes

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Abstract. Electrical conductivity profiles behind the detonation wave front were measured in PETN, RDX and HMX. To preserve the initial particle-size distribution, the charge densities were close to the loose-packed ones. Each explosive was tested in both the common commercial coarse-grained state (grain size of a few hundred μm) and the fine-grained state (about 10 μm). The conductivity peaks were found to be certainly shorter in fine-grained materials, indicating faster chemical reaction.
The results may be understood within the framework of A.N. Dremin's concept about two parallel reaction mechanisms.

Introduction

The chemical reaction in solid explosives is usually suggested to proceed through the hot spots mechanism. However, the characteristics of these ignition sites such as their concentration, initial size, etc. are not known in detail. The kinetic models currently in use do not operate with the explicitly specified hot spots. Rather, they are treated indirectly as a justification of incorporating certain terms in the reaction rate law.

Fine-grained explosives are likely to contain more hot spots than coarse-grained ones, and one might expect that grain size should influence the kinetics. Indeed, the dispersion does affect the shock sensitivity. However, no definite evidence was found that the reaction time in a stationary detonation wave depends on explosive particle size. On the contrary, early electromagnetic data presumably demonstrated that the reaction zones were virtually the same regardless of explosive dispersion.[1]

Since the resolution of these experiments was rather poor (about 100 ns), independent tests are desirable. More refined methods were developed later. Nevertheless, no explicit grain size effect in a stationary detonation was detected. One reason for this paradox may be that in dense explosives, which attract the main interest, the structure defects, i.e. hot spots precursors, are more or less unified in the course of compaction, regardless of the initial particle size. Low-density explosives, in which the initial grains are preserved, are more complex to study by the conventional methods because their strong non-uniformity produces quite noisy records.[2]

Recently an improved time-resolved electrical diagnostics was used to study the structure of the detonation waves.[3] The output information of this technique is the electrical conductivity profile behind the detonation wave front. The method does not employ any moving marker which allows one to avoid the gas-dynamical disturbances. The explosive fills the coaxial cell which provides

natural averaging in the direction perpendicular to the front. This makes the noise level lower.

Previous studies[3,4] showed that in dense PETN, RDX and HMX, the conductivity peaks correlated with the conventionally measured reaction zones, and the grain size had no influence on the conductivity profiles. In present work, the initial densities of the same explosives were but slightly higher than those of the loose-packed ones. A moderate compression was needed to obtain the material which was uniform enough. The charges prepared in that way preserved the initial particles' size distributions, in contrast to high-density specimens.

Experimental

The coaxial cell used is shown in Figure 1. An explosive charge with a diameter b = 8 mm was placed in an axial channel of the copper cylinder (40 mm outer diameter) made of two sections (1 and 2) threaded together. A copper electrode 3 (c = 2 mm in diameter) was mounted along the charge axis in the PMMA plug 4, and was supported by the bolt 5.

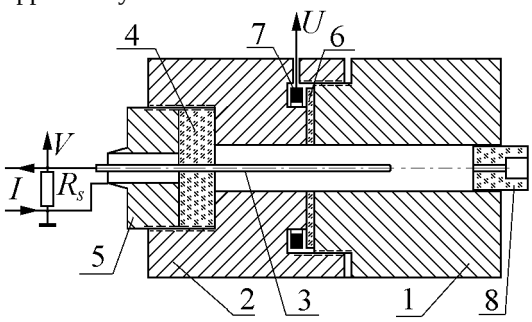

Fig. 1. Experimental cell.

The conductivity gauge 7, a small Rogovsky coil, was inserted into a special chamber within the outer electrode. A thin slit connected the gauge chamber and the coaxial cell volume. The slit width was fixed by the dielectric layer 6. The mutual inductance M between the gauge and the chamber contour was 10 – 15 nH. The explosive was initiated through a 2.4 mm axial opening drilled in a PMMA stopper 8 to maintain the cylindrical symmetry. The external source produced a nearly constant feeding current I (usually 30 A), which was distributed between the cell and the shunt resistor R_S.

The cell becomes conductive as the detonation wave reaches the central electrode. The cell current flows around the gauge chamber. A magnetic flux change across the coil produces an output voltage pulse U. This first pulse was utilized for real-time gauge calibration. As the wave passes by the slit, the current around the gauge decreases, as does the magnetic flux, and the second pulse $U(t)$ of an inverse polarity is generated. This second pulse represents the electrical conductivity σ in the slit plane:

$$\sigma(x) = \frac{\ln(b/c)}{2\pi DM}\frac{U(t)}{V} \qquad (1)$$

Here, D is the detonation velocity, V is the feeding voltage across the cell, and $x = Dt$ is the distance between the detonation front and the slit at a time t. The relation (1) assumes that the wave is stationary as well as the moving conductivity distribution. Actually somewhat smoothed signal U_{in} is observed due to the coil inductance $L \approx 1$ μH, and the corrected voltage in Eq. (1) is $U = U_{in} + (L/R)\frac{dU_{in}}{dt}$. Here R = 50 Ohm is the input oscilloscope impedance.

The measuring volume is defined by the slit 6. The spatial resolution was estimated to be about a quarter of the slit width.[4] Because of low explosive density, in present experiments the cell operated in rather mild conditions, which allowed us to use thin slits attaining about 50 μm spatial resolution (or ≈10 ns time resolution).

Each explosive was tested in common coarse-grained state (grain size of some hundreds μm) and fine-grained state (about 10 μm). The fine-grained materials were prepared by mixing instantly their solutions in warm acetone with cold water. Then the powders were washed in water and dried. Microscopic inspection showed distinct difference between fine and coarse materials though the latter contained certain fraction of fine grains. Average particle sizes are shown in Table 1.

For each explosive, six tests were done, three for coarse-grained sort and three for fine-grained one. Explosive was pressed into the cell by 5 mm

increments. At low density, several percent above the loose-packed one, rather small pressing force was needed, though it was higher for fine-grained charges. The compaction degree was adjusted to get the samples which were uniform enough. The actual charge density ρ was determined from the directly measured detonation velocity D using $D(\rho)$ correlations[5].

Results

Examples of the experimental profiles for coarse and fine PETN are shown in Figure 2. In all cases a distinct peak behind the detonation front was observed followed by a "tail" of lower and slowly decreasing conductivity. The transition point was defined as an intersection of fitting straight lines drawn through the rear part of the peak and through the tail. The peak duration found in this manner was supposed to represent the characteristic reaction time. One can see that in the fine-grained PETN the peak is distinctly shorter.

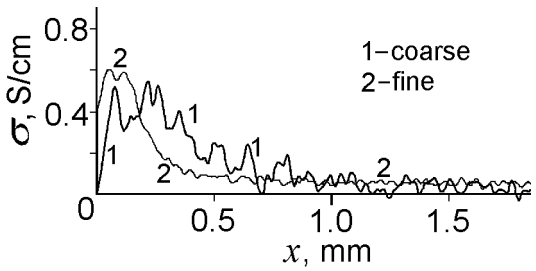

Fig. 2. Conductivity profiles in low-density PETN. S (Siemens) is Ohm^{-1}.

The results of all experiments are summarized in Table 1. For each explosive averaged values are presented. A distinct grain size effect is evident: in fine-grained charges the peak durations were about a half of those in coarse-grained explosives. Note that the greater is the difference in particle size, the more pronounced is the contrast in the peak duration.

Due to experimental scattering, among all 18 shots two cases were found in which the narrowest "coarse" peak was not broader than the widest "fine" one for the same explosive. However, all tests may be arranged into pairs in which the "fine" peak is definitely shorter. To estimate a possibility that such a proportion might be produced by the coincidence, all measured times were normalized by dividing each actual time by an average value obtained for each coarse-grained explosive. The standard statistic calculations gave a value of about 3.7×10^{-5} for the significance level of the null hypothesis. So, the grain size indeed affects the peak duration. On the contrary, both the peak and tail conductivity appear to be not dependent on the grain size.

Table 1. ρ is the initial density, σ_{max} is the maximal peak conductivity, τ is the peak duration.

Explosive, *d*, μm	**ρ, g/cc**	**σ_{max}, S/cm**	**τ, ns**
PETN, 80	1.09	0.62	57
PETN, 260		0.59	92
RDX, 11	1.18	1.7	31
RDX, 160		1.8	56
HMX, 21	1.32	3.6	34
HMX, 430		2.8	69

In coarse-grained explosives the noise is visible (see Figure 2). The spatial scale of these fluctuations was about one grain size, so they are caused by the meso-scale density contrast between grains and pores. Nevertheless, the main signal can be recognized since the coaxial cell averages the non-uniformities around the axis. When the grains are smaller, larger number of the grains and pores take part in this averaging, so the signal is smoother.

Some experiments, especially at small grain sizes, approached the resolution limit, thus the corresponding peaks may be somewhat distorted. However, since the same data handling procedure was used throughout the experiments, the grain size effect on the peak width is reliably demonstrated.

Discussion

The shapes of conductivity profiles lead to suggestion that the peaks are produced by the chemical reaction. Our results show that the conductivity peak in the fine-grained low density explosive is shorter than in the coarse-grained one.

Moreover, it may be narrower than in the same explosive pressed to almost theoretical maximum density (TMD).[3,4]

These findings can be explained using the reaction rate concept introduced by Dremin et al.[6] Two main processes are supposed to proceed in parallel, namely the hot spot mechanism and the homogeneous decomposition. The hot spots govern the low-pressure domain while the homogeneous reaction prevails at pressures higher than about half of Chapman–Jouguet pressure at TMD. This explains why the grain size does not matter in a stationary wave at high initial density, and is in agreement with our conductivity data.[3,4]

At low pressures, the relative contribution of hot spots mechanism increases and grain size becomes important. For example, shock sensitivity certainly depends on grain size. In present experiments, the conductivity peaks become distinctly narrower in fine-grained materials. With sufficiently small grains, the effective reaction rate can exceed even that at high density, which presumably leads to narrow conductivity peaks. Such an effect should be most pronounced for loose packed explosives.

Acknowledgements

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References

1. Dremin, A.N., Savrov, S.D., Trofimov, V.S. and Shvedov, K.K., "Detonation Waves in Condensed Media", pp. 1-164, Nauka, Moscow, 1970.

2. Fedorov, A.V., "Neumann Peak Parameters and Detonation Wave Front Structure in Condensed Explosives" *Khimicheskaya Fizika*, Vol. 24, No. 10, pp. 13-21, 2005.

3. Ershov, A.P. Satonkina, N.P. and Ivanov, G.M., "Reaction Zones and Conductive Zones in Dense Explosives" *Proceedings of the 13th International Detonation Symposium*, pp. 79-88, Norfolk, VA, July 2006.

4. Ershov, A.P., Satonkina, N.P. and Ivanov, G.M., "Electroconductivity profiles in dense high explosives" *Russian Journal of Physical Chemistry B.* Vol. 1, pp. 588-599, 2007.

5. Al'tshuler, L.V., Doronin, G.S. and Zhuchenko, V.S. "Detonation regimes and Jouguet parameters of condensed explosives" Combust. Explos. Shock Waves Vol. 25, No. 2, pp. 209-224, 1989.

6. Dremin, A.N., "Toward detonation theory", pp. 1-165, New York, Springer, 1999.

Discussion

James Kennedy

HERE

Does the relaxation time of the conductivity curve correspond to the reaction time or to the expansion process?

Reply by A.P. Ershov

To our opinion, in the explosives studied in this work, the fast relaxation of the peaks marks the end of the reaction zone, while subsequent slower relaxation of conductivity tails is governed by the expansion. To the contrary, in explosives like TNT, which release solid carbon in large quantities, the carbon-produced conductivity is too high to observe the peak by our method, and the conductivity falls down mainly due to expansion.