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Electrical Conduction of Emulsion Explosives

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Abstract—Results of experiments to obtain a spatial distribution of electrical conduction of emulsion explosives for different content of a sensitizer are presented.

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INTRODUCTION

Emulsion explosives are intensely used in the industry, but the process of their detonation is still not clear enough. Available experimental data show peculiarities not found in other explosives, e.g., nonmonotonic dependence of detonation velocity on the density [1] and weak influence of a charge diameter on the velocity of detonation when the physical sensitizer is present in a large amount [2].

In the present study, we developed a technique for measuring an electrical conduction profile behind the detonation front and applied it to explore emulsion explosives.

EXPERIMENT

An experimental setting and data processing are detailed in [3, 4]. Here, we will only provide a brief description of the experiment. The explosive was placed in a copper coaxial cell (Fig. 1). The external diameter of the coaxial was $b = 8$ mm and the diameter of the internal electrode was $c = 2$ mm. The external electrode was compound, its parts 1 and 2 were tightly joined with thread connection, and the internal copper electrode 3 was inserted in the explosive. The external electrode cavity contained an electrical conduction sensor, that is, toroidal coil 7. The narrow slit connecting the cavity with the cell's measuring volume was filled with dielectric 6 (0.5–0.7 mm Plexiglas). The charge was initiated by hexogen through a 4 mm axial channel in Plexiglas plug 4, and the plug was fixed by copper bolt 5. A capacitor fed the cell by current I via a ballast resistor; the R_s bridge was connected in parallel. The feeding voltage $V(t)$ and the signal at the sensor $U(t)$ were measured. The electrical conduction in the plane of the slit was proportional to the signal from the coil:

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

Here, $x = Dt$ is a distance at which the wavefront has displaced from the slit by the time t; D is the velocity of detonation. The signal adjustment allows for eliminating the distortion $U(t)$, which is due to the sensor inductance, and obtaining the electrical conduction profile behind the front if we assume that the wave is stationary.

Spatial resolution is estimated at quarter-width of insulator 6 to make up about 0.15 mm. To reduce noises, the obtained profiles were averaged over several experiments. We accounted for the dielectric contained in detonation products and recalculated the results using data in Table 2 (see below). The impact is weak, up 10%.

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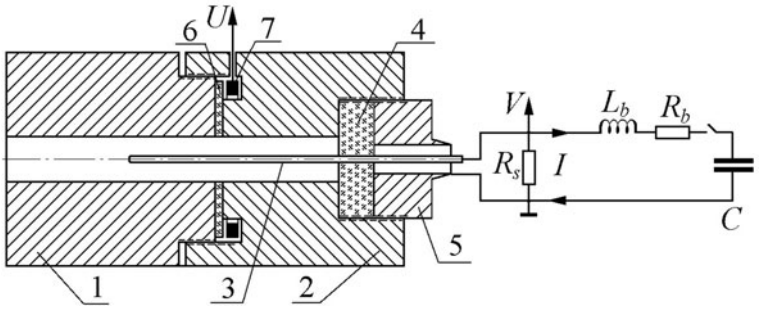

Fig. 1. The electrical circuit and experimental cell.

Table 1.

	Composition 1, %	Composition 2, %
Emulsifier with oil	4	4
Oil I-20	2	3.9
Ammoniac saltpeter	68.25	76.9
Water	15.2	10.55
Sodium nitrate	10.55	

Table 2.

Mass ratio of microspheres, %	Volume share of dielectric	σ/σ_0
6	0.0247	0.963
8	0.031	0.953
20	0.052	0.922
50	0.072	0.895

RESULTS AND DISCUSSION

The experiments were carried out on emulsions whose composition is shown in Table 1. Composition 1 had the oxygen balance 2% and density 1.41 g/cm^3; composition 2 had 12% and 1.35 g/cm^3, respectively. To obtain explosives, hollow glass microspheres playing the role of the sensitizer were added to the emulsion in excess of the mass of the Russia-made emulsion of the MS-V brand. Their share for different experiments was 6–50%. The mean size of a microsphere was 58 μm, and the packed density made up 0.14–0.15 g/cm^3.

Conduction of composition 1 without the sensitizer under normal conditions was studied to find that it was close to zero. Under the shock load, in the absence of a chemical reaction, at the velocity of the shock wave on emulsion being 1.68 km/s, the mixture has a constant electric conduction of 0.0066 Ohm^{-1}·cm^{-1}, which is by one order of magnitude lower than that of the detonation wave.

Figure 2 presents the electric conduction profiles of composition 1 for different percentage of the sensitizer. The plots differ little for 20 and 50% in spite of different volume shares of the reagent, 0.68 and 0.46, respectively; the distribution is wide and has a small drop. For 50%, the distribution has radically changed; a peak about 0.3 μs wide appears (its width is defined by the cusp) and the value for steady-state conductivity after the peak decreases significantly. In previous papers, we have shown that the width of a chemical reaction zone and the zone of increased electrical conduction for condensed explosives are close [3, 4]. This gives grounds to suggest that for emulsion explosive, the increased electric conduction zone correlates with the zone of the chemical reaction. The volume share of the

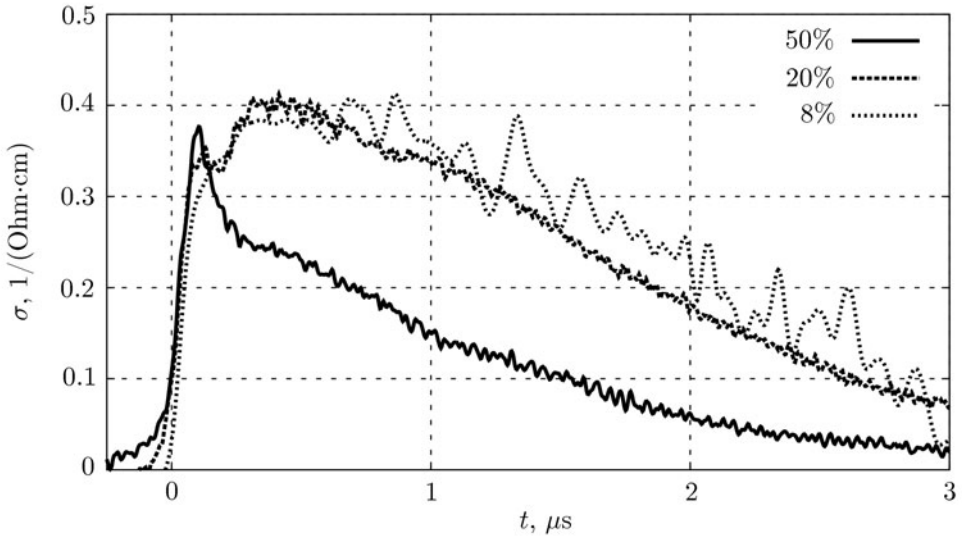

Fig. 2. Influence of the sensitizer content on the electrical conduction profile for composition 1.

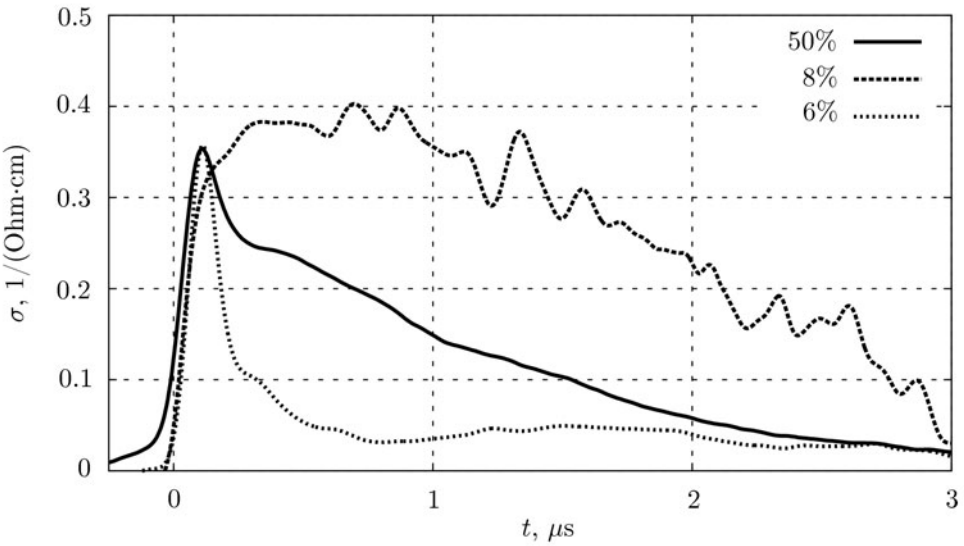

Fig. 3. Demonstration of the role of sodium in the process of conductivity.

reagent is 0.254. In all events, the microspheres are destroyed behind the detonation front; detonation products occupy virtually entire volume so that the volume share of the glass makes up 0.024–0.072 function of experiment (Table 2). The maximum value of electrical conduction does not depend on the presence of the sensitizer and is about 0.38 $\text{Ohm}^{-1}\cdot\text{cm}^{-1}$.

Figure 3 shows the distributions of electrical conduction for 8% and 50% sensitizer content in composition 1, and 6% in composition 2. A comparison of 8 and 6% demonstrates the role of sodium nitrate in emulsion explosives for conductivity: for both explosives, the percentage of the sensitizer is small and the steady-state electrical conduction differs by one order of magnitude. Given the composition of these explosives, one may make a conclusion on sodium dominance among other ionizing products. The steady-state electrical conduction in the detonation products in the presence of sodium is

about 0.35 $\text{Ohm}^{-1}\cdot\text{cm}^{-1}$. If the electrical conduction in the chemical peak for 8 and 20% has the same or lower value, we will not recognize the chemical peak that is hidden by "tailings."

For the 50% microspheres, the detonation products are more diluted by the inert additive, concentration of the emulsion is lower, steady-state conductivity falls to 0.2 $\text{Ohm}^{-1}\cdot\text{cm}^{-1}$, and the chemical peak becomes discernible, the electrical conduction in which is 0.38 $\text{Ohm}^{-1}\cdot\text{cm}^{-1}$. Therefore, sodium is a hindrance; without it, the composition is approximately the same, but the chemical peak is visible. For the 6% composition 2, the amplitude of the signal is the same as for 50% composition 1. This may be related to two competing processes: on the one hand, the amount of the conductive material drops threefold, which leads to decreased conductivity, and on the other hand, the number of hot points surges, which increases the rate of chemical reaction and, hence, the electrical conduction amplitude.

To estimate the contribution of water as a conductive substance in emulsion explosives, one should assess the own conductivity of water under shock load. At a velocity of 4.5 km/s and a density of 1 g/cm^3, the pressure in the wave is 5 GPa (these parameters correspond to the most powerful of the surveyed explosives), at this pressure, electrical conduction of water is under 0.001 $\text{Ohm}^{-1}\cdot\text{cm}^{-1}$ [5, 6].

In [7], with the use of synchrotron emission, the chemical peak duration was obtained to make up about 0.6 μs. Authors of [8] obtained a reaction zone width of 0.4–0.8 μs by the electromagnetic method for emulsion explosives with a 8–35% microsphere content. In these studies, the experimental setting differs in that the sheath of the charge is absent, which leads to reaction zone broadening, compared to our data. Experimental data obtained via different techniques match well.

Numerical Modeling of the Medium with Nonconductive Inclusions

Since the medium is formed behind the detonation wave, which is a mixture of detonation products and a small share of the nonconductive material, numerical modeling of the conductive medium with nonconductive inclusions was carried out to find the true conductivity σ_0 of detonation products of the emulsion explosive. To calculate the electric conduction, it is necessary to solve the system of electrodynamic equations:

$$\frac{\partial \rho}{\partial t} + \operatorname{div}(\vec{j}) = 0, \quad \operatorname{div}(\vec{E}) = 4\pi\rho, \tag{2}$$

where $\vec{E}$ is electric field strength in the medium, $\vec{j} = \sigma\vec{E}$ is current density, and ρ is volume density of the electric charge.

The time of field establishing in the medium at a characteristic value of the explosive charge of ~ 1 cm is no more than 10^{-10} s. Therefore, solving the system of electrodynamic equations describing the current passing in the detonation wave, we may restrict ourselves to a quasi-stationary case. Maxwell's time of relaxation for the medium with graphite conductivity is $\sim \varepsilon_0/\sigma = 10^{-10}$. Then, given $\vec{E} = -\nabla\varphi$, it is sufficient to solve the continuity equation for the current in the following form:

$$\operatorname{div}(\sigma\nabla\varphi) = 0. \tag{3}$$

The conductivity σ depends on the point in the medium. In a cubic mesh, (3) is approximated by the difference equation

$$\sum_{i',j',k'} \sigma_{i',j',k'}\varphi_{i',j',k'} - \varphi_{i,j,k} \sum_{i',j',k'} \sigma_{i',j',k'} = 0, \tag{4}$$

where summation is performed at nodes adjacent to the node (i, j, k), and $\sigma_{i',j',k'}$ is the conductivity of the mesh rib, joining nodes (i, j, k) and (i', j', k'). The problem is thus reduced to the calculation of an electrical potential at mesh nodes proceeding from the system of linear equations (4). The solution was found by the simple iteration method.

The numerical work was carried out for $200 \times 200 \times 200$ meshes. On one of facets of the cubic mesh, the potential $\varphi = 1$ was maintained, and on the opposite one, $\varphi = 0$ (electrodes). On other facets, periodical boundary conditions were applied. The current strength was calculated in the section parallel to the plane of electrodes. To control the calculation precision and convergence, values of the current

were compared in three sections of the mesh: near electrodes and in the mesh central part. In all cases, the relative calculation error was no worse than 10^{-4}.

The calculations of the electrical conduction of the conductive medium with dielectric inclusions were carried out. Some ribs of the calculation mesh were deemed as nonconductive ($\sigma = 0$). A choice of nonconductive ribs was done with the help of the random number generator. Their mean share in the mesh corresponded to the dielectric volume content in the detonation products. The remaining ribs had the relative specific conductivity $\sigma_0 = 1$. Table 2 presents the results of calculations of σ, effective for the medium with the different volume of dielectric inclusions.

CONCLUSIONS

The nature of the electric conduction distribution for emulsion explosives strongly depends on the emulsion composition and the amount of sensitizer, as opposed to the amplitude that is about 0.4 $\text{Ohm}^{-1}\cdot\text{cm}^{-1}$ for all studied emulsion explosives. Sodium compounds predetermine the high steady-state conductivity of emulsion explosive detonation products. The chemical reaction zone is indiscernible against the background of the steady-state conductivity for composition 1 with a small percent content of the microspheres; for 50%, the chemical peak width is below 0.3 μs, as for composition 2, which coincides with data of other authors.

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