Effect of the Density of an Emulsion Explosive on the Reaction Zone Width

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Abstract: This paper presents experimental dependences of the width of the reaction zone and detonation critical diameter on the initial density with a variation in the density of an emulsion high explosive from 0.5 to 1.33 g/cm$^3$. Glass microballoons were used as a sensitizer. The emulsion explosive is characterized by a U-shaped dependence of the critical diameter on the density, and the reaction time and the width the reaction zone increase monotonically with the density of the explosive. The detonation pressure of the studied compositions varies in the range of 0.6–12 GPa.

Keywords: emulsion explosives, width of reaction zone, critical detonation diameter, effect of density, Khariton relation.

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INTRODUCTION

Variation in the width of the reaction zone for emulsion explosives (EMX) over a wide range of initial densities $\rho_0$ is of interest, at least, for two reasons. First, there is a nonmonotonic dependence of the detonation velocity $D$ on the density of the explosive $\rho_0$, which is due to the presumed increase in the width of the reaction zone with increasing density of explosives [1, 2]. However, direct experimental evidence of this statement is not available. Available data [3–8] indicate that the reaction time $t_R$ and the width of the reaction zone at $a_R$ increase monotonically with increasing density. However, these results were obtained for EMXs of different compositions, with uncontrolled degree of dispersion of the emulsion, using a variety of techniques (from electromagnetic gauges to proton radiography), and as a rule, for one density value [3–5, 8], except in [6, 7]. All techniques used to solve this problem seek to find a chemical spike on the time profile of the parameter determined behind the detonation wave front (particle velocity, pressure or density), and to estimate the duration $t_R$ and width of the reaction zone $a_R$.

Second, EMXs with a sensitizer in the form of hollow glass microspheres are characterized by a U-shaped dependence of the critical thickness [9] and critical detonation diameter $d_{cr}$ [10] on the initial density of the composition. This dependence allows a qualitative verification of the well-known Khariton relation, which played a significant role in studies of problems related to the critical detonation diameter of powerful explosives:

$$d_{cr} \approx 2a_R.$$ (1)

According to (1), the critical diameter is mainly due to the energy losses of the detonation wave during unloading of explosion products from the lateral surface of a cylindrical explosive charge and the finite rate of the chemical reaction behind the detonation wave, which, in turn, determines the finite width of the reaction zone [11]. In the formulation of (1), restrictions on its validity and type of explosive were not imposed. A logical consequence of relation (1) is the assumption that with a change in the initial density of the explosive, the behavior of the critical diameter and the width of the reaction zone should be qualitatively similar. For individual monomolecular explosives, this proportionality is indeed the case. However, a quantitative mismatch between relation (1) and experimental data has been noted repeatedly, for example, the well-known examples with cast and pressed TNT: with the same density of the
explosives, the widths of their reaction zones in steady detonation are almost identical, whereas their critical diameters differ by a factor of 3–10 [12, 13]. This fact has been associated with the effect exerted on the critical diameter by the physical structure of the explosive, which determines the number of hotspots affecting the initiation of the reaction behind the front of the leading shock wave and the formation of a stationary reaction zone at the detonation front.

Therefore, the purpose of this study was to measure the width of the reaction zone of EMXs with variation in their initial density over a maximally wide range subject to the following conditions: one emulsion, one degree of dispersion of the matrix, one sensitizer, one method, and a unified approach to determining the inflection point on the profile of the measured parameters behind the detonation front.

**EXPERIMENT AND RESULTS**

A composition based on a highly dispersed emulsion with oxidizer drops no more than 1–2 μm was investigated. The emulsion matrix contained 94% (wt.) oxidizer consisting of an aqueous solution of ammonium and sodium nitrates and 6% (wt.) fuel consisting of a mixture of industrial oil, paraffin, and emulsifier [10]. The density of the emulsion matrix was 1.41 g/cm³. MS-V hollow glass microspheres with a bulk density of 0.15 g/cm³ were used as a physical sensitizer. The typical size of the microbubbles was 60 μm. The density of the EMXs was varied from 0.5 to 1.37 g/cm³ by changing the amount of the sensitizer μ added to the emulsion, μ = 50–0.5% over the weight of the matrix. In this case, the porosity of the composition was varied, but its physical structure was the same.

To measure the reaction time on the axis of the charge (t_R), we determined the particle velocity u(t) behind the detonation front at the interface between the EMX and the optical window made of Plexiglas 25 mm thick using a VMBV-04 type VALYN VISAR laser Doppler interferometer with a constant of 450 to 1934 m/s per one interference fringe [14]. The laser radiation was focused along the axis of the assembly in a ≈1 mm area, reflected from a mirror made of a brushed aluminum foil 7 μm thick located near this interface, and passed through an optical sensor with a focal length of 30 mm to the input of the interferometer.

The diameter of the EMX charges was d = 6–48 mm and their length was not less than L ≥ 8d. In some experiments, the charge diameter was increased to 90 and 115 mm with L ≈ 4d and 2d. The charges were in cylindrical casings made of polypropylene or octahedron steel. Typically, the charge diameter exceeded the critical diameter of the EMX by a factor of 2–2.5 (for the given densities of the explosive and casing material). All charges were initiated with a primer of a 5% of EMX (μ = 5%), which was initiated by an electric blasting cap.

A series of contact sensors was used to measure the detonation velocity D and control its steadiness within 1–2%. The detonation velocity was varied from 1.9 to 6 km/s, and the critical diameter of the compositions from 5 to 40 mm by varying the amount of the sensitizer. The lowest value of D is close to the velocity of sound in the emulsion without the sensitizer 1.6–1.8 km/s. The dependence D(ρ_0) is described by a straight line $D = -0.59 + 4.96\rho_0$ (Fig. 1) with coefficients typical of EMXs [15].

The U-shaped nature of the dependence d_{cr}(ρ_0) was confirmed over a wider range of initial densities of EMXs confirmed (see Fig. 5 below). According to [10], the critical diameter varies from 13 mm at $\rho_0 = 0.5 \text{ g/cm}^3$ (μ = 50%), reaches a minimum ($\approx 5 \text{ mm}$) at $\rho_0 \approx 1.0–1.05 \text{ g/cm}^3$ (μ = 8–10%), and increases to 7–8 mm for $\rho_0 = 1.12 \text{ g/cm}^3$ (μ = 5%). In this study, values $d_{cr} = 17 \text{ mm for } \rho_0 \approx 1.28 \text{ g/cm}^3$ (μ = 2%) and $d_{cr} = 38 \text{ mm for } \rho_0 \approx 1.33 \text{ g/cm}^3$ (μ = 1%) were determined using the method of cylindrical charges. The critical detonation velocity was 2.7 and 2.9–3.0 km/s, respectively, and it was constant on the last 240 mm at a charge length L = 360 mm.

Figure 2 shows typical particle velocity profiles versus time. All the profiles have a region of high velocities, a chemical spike predicted by the Zel’dovich–Neumann–Döring theory [12], followed by a gradual decline in the...