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ON POSSIBILITY OF DETONATION PRODUCTS TEMPERATURE MEASUREMENTS OF EMULSION EXPLOSIVES

MOŻLIWOŚCI POMIARU TEMPERATURY PRODUKTÓW DETONACJI EMULSYJNYCH MATERIAŁÓW WYBUCHOWYCH

The new view on the structure of the radiance signal recorded by optical pyrometer and the preliminary results of brightness detonation temperature of the emulsion explosive are presented. The structure of an optical signal observed is typical for the heterogeneous explosives. First, there is the short temperature spike to 2500÷3300 K connecting with a formation of "hot spots" assembly that fire the matrix capable of exothermal reaction. Then the relaxation of radiance to equilibrium level is observed that corresponds to brightness temperature 1840÷2260 K of explosion products at detonation pressure 1÷11 GPa. Experimental results are compared with the calculations of other authors. The detonation temperature of the investigated explosive is measured for the first time.

Keywords: optical measurements, emulsion explosive, detonation temperature

Przedstawiono nowy sposób analizy struktury promieniowania rejestrowanego przy użyciu pirometru optycznego oraz wstępne wyniki pomiaru temperatury promieniowania w procesie detonacji emulsyjnego materiału wybuchowego. zaobserwowano, że struktura rejestrowanego sygnału optycznego jest typowa dla niejednorodnych materiałów wybuchowych. Początkowo obserwuje się krótkotrwały pik temperaturowy o wartości 2500÷3300 K, związany z formowaniem się „gorących punktów", które zapalają matrycę zdolną do reakcji egzotermicznej. Następnie, obserwuje się relaksację promieniowania do poziomu równowagi, które odpowiada temperaturze produktów eksplozji o wartości 1840÷2260 K, przy ciśnieniu detonacji 1÷11 GPa. Wyniki pomiarów uzyskane w niniejszej pracy (po raz pierwszy prezentowane w literaturze) porównano z wynikami obliczeń innych autorów.

1. Introduction

Emulsion explosives (EMX) having the detonation velocity 2÷3 km/s, critical diameter up to 5 mm and critical thickness up to 2 mm are applied in the Institute of Hydrodynamics to realize the delicate explosive welding regimes in various geometries with small quantity of explosive [1, 2]. So far the detonation temperature of these explosives was not measured though the heat exchange between hot explosion products and throwing plate may be important at acceleration of thin foils by explosive. It is important during using low-melting-point metals as cladding coatings, for instance, made of tin-and-aluminum alloy [3].

The reason is that the problem of detonation temperature measurement of condensed explosives by optical methods has no the universally recognized solution. This is connected with the effects that occur on the interface of the explosive/transparent window [4]. Detonation temperature is often estimated using maximum value of the optical signal. In this work the other view on the structure of spectral radiance signals registered and the initial results of brightness temperature measurement of explosion products of EMX are presented. The experimental estimate of the detonation temperature of emulsion explosive is obtained for the first time.

2. Experimental setup and results

The composition of laboratory-made emulsion matrix is follows: the oxidizer is the water solution of the ammonium (AN) and sodium nitrates (SN), 94 wt. %; the fuel is the mixture of hydrocarbons and emulsifier, 6 wt. % (AN/SN emulsion). Hollow glass microspheres having 60 μm in mean size and the bulk density of 0.15 g/cc are used as sensitizer. The explosive density ρ_0 is varied from 0.5 up to 1.3 g/cc by the quantity of microballoons from 1 up to 50 wt. % above the weight of pure emulsion. The critical diameter of investigated explosives was in the range 5÷38 mm, the detonation velocity 2÷6 km/s [1, 5].

Experimental setup is shown in Fig. 1. Diameters of tested charges are 55 and 105 mm, charges length – 165 and 400 mm respectively. Plexiglas (PMMA) plate 10 mm thick is used as an optical window. The detonation velocity is measured in each shot on the 50 mm base. The moment of the detonation wave arrival to the EMX – PMMA interface is registered by Dynasen's PVF2-4 gage mounted on the window. The detona-

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tion pressure p_D is measured by this gage or calculated using the initial density of explosives according to expression $p_D = 4.53\rho_0^{3.25}$ approximating the experimental data [5].

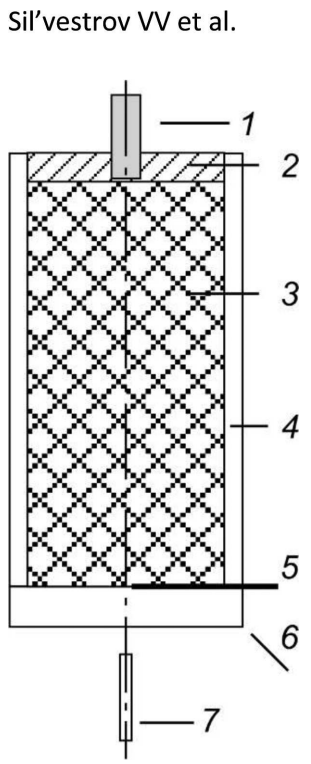

Fig. 1. Experimental arrangements. *1* – detonator, *2* – 5% EMX primer, *3* – emulsion explosive investigated, *4* – polypropylene tube, *5* – PVF2 gauge, *6* – Plexiglas window, *7* – optical fiber (to pyrometer)

The "optical window" technique and the self-made, time-resolved, four-channel optical pyrometer are used to estimate a detonation temperature T_D. The detailed description of the pyrometer, the calibrating procedure, and the treatment procedure of the radiance signal are described in [6]. Brightness temperature measurements are performed at wave lengths of 620 (20) and 660 (120) nm (in parenthesis – bandwidth of the interference filter). We supposed that the radiance of the detonation front was uniform, and spectral emissivity was equal 1. Instrumental error of the temperature measurement was about 8%, or ±160 K.

The spectral radiance profiles of the EMX are typical for heterogeneous explosives (Fig. 2). First of all, there is the radiance spike and the associated temperature spike connecting with a formation of "hot spots" that fire the matrix capable to exothermal reaction. Then the relaxation of radiance to equilibrium level is observed. Emission from the detonation front passes through strongly diffusing and at the same time absorbing medium that is EMX, so as the detonation front comes to EMX/window interface the radiance signal grows accordingly to the Bouguer-Lambert-Beer law. Hence we infer that to match the pyrometer signal (Fig. 2, dash curve *1*) with the temperature of hot detonation products (Fig. 2, solid curve *2*) it is correct to begin from the moment $t = t_1$. At this very moment the hot detonation products come into contact with the optical window that is transparent or partially-transparent upon these pressures. Vertical arrow t_2 in Fig. 2 points the time that possibly corresponds to Chapman-Jouguet surface on the pressure and particle velocity profiles behind the detonation wave.

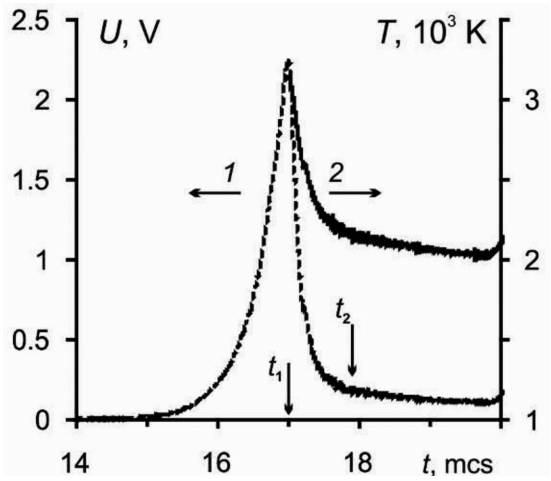

Fig. 2. Profiles of spectral brightness (*1* – dash line) and temperature (*2* – solid line) at detonation pressure 4.4 GPa

The series of special tests were performed to analyze the structure of the pyrometer signal upon EMX detonation. The monolayer of glass microballoons embedded into the epoxy resin was shock-compressed up to 9÷29 GPa, and the amplitude – time characteristics of radiance signal were measured [7]. The microballoons used in these experiments were just like that of added into emulsion explosives. It was shown that the presence of artificial pore's monolayer leads to short duration temperature spike up to 3200÷3500 K whereas the temperature of shocked matrix without pores was only 1000÷1440 K.

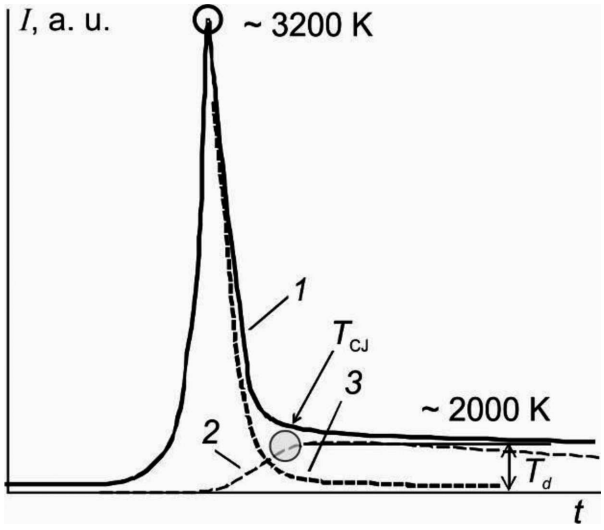

Fig. 3. Structure of the light intensity record at EMX detonation. *1* – profile of brightness signal, *2* – equilibrium profile corresponding to the temperature in reaction zone, *3* – "hot spots" spike. The temperature can be measured at point marked T_{CJ}

Based on these results, the conclusion was formulated that the registered radiance signal (curve *1*, Fig. 3) is the superposition of two temperature profiles. The first profile is the temperature spike (curve *3*) associated with the formation of the "hot spots" layer near the EMX/window interface behind

the shock leading the detonation. The spike duration is about 0.3÷1.0 μs, and it increases as the detonation pressure decreases. The second profile (curve *2*) is connected with the increase of detonation products temperature in reaction zone in accordance with the ZND theory as the reaction degree increases. The detonation products temperature runs up to maximum at the end of reaction zone, near the proposed Chapman–Jouguet surface. It follows that estimation of the detonation temperature should be performed using the point on the radiance signal 0.5÷1.0 μs after maximum, on the trailing edge of the signal (Fig. 2, 3).

The convincing proof of this statement is obtained at superposition of profiles of temperature, pressure and particle velocity behind the detonation front that were registered at the EMX/Plexiglas interface using optical pyrometer, PVF2 pressure gage, and Valyn Visar interferometer, respectively. Good correlation of these profiles for three different techniques of the reaction zone structure determination may be seen in Fig. 4. The pressure profile (curve *2*) was recorded on the EMX/Plexiglas interface. In this particular case the detonation pressure calculated from the pressure profile is about 0.7 GPa [5], and the estimation of the temperature was performed at the profile's point distanced by 0.6 μs from the moment of the detonation wave arrival to the interface EMX/window. Similar comparison for other pressures allows to find the points for measuring the detonation products temperature near the end of the reaction zone.

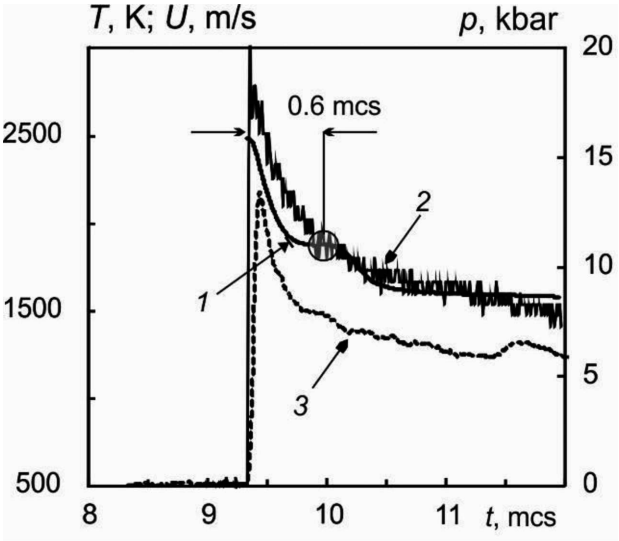

Fig. 4. Reaction zone structure for 0.5 g/cc EMX. *1* – temperature (pyrometer), *2* – pressure (PVF2 gauge), *3* – particle velocity u (laser interferometer), it's drawn $U = 500 + 2.9u$

The experimental results of detonation temperature measuring are presented in Fig. 5. The detonation temperatures of emulsion explosives (T_d) are not high, i.e. about 1.5÷2 times lower in comparison with detonation temperatures of the ordinary explosives (≈ 3200÷4500 K). Detonation temperature changes slightly when pressure varies from 0.7 to 11 GPa and is equal 1840÷2260 K. Temperature of "hot spots" (T_{hs}) is essentially higher and achieves 2500÷3300 K in pressure range investigated and grows as pressure increases.

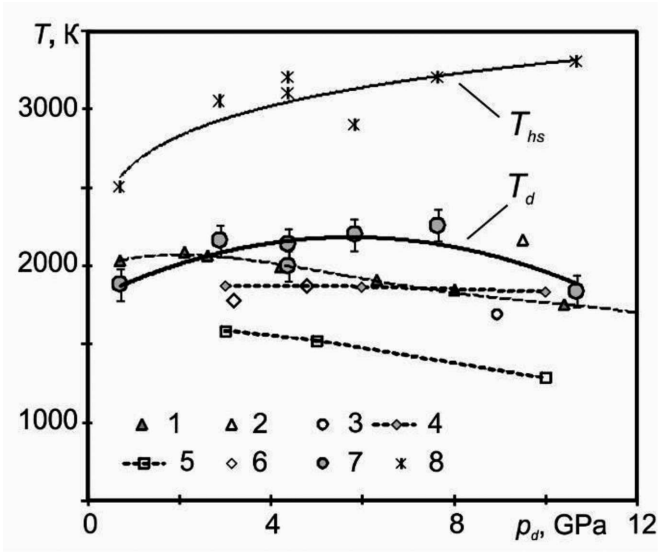

Fig. 5. Detonation temperature of EMX based on AN/SN emulsion versus detonation pressure. Calculations: 1 – [8], 2 – AN emulsion [11], 3 – [12], 4, 5 – AN emulsion [9], 6 – [10]. Experiments, our data: 7, 8 – detonation and "hot spots" temperatures; 8% accuracy is given

The difference in the compressibility of EMX explosion products and the window material is not considered. Moreover, it is impossible technically to select the window material that matches the impedance of explosion products of low-density EMX. The comparison on the $p - u$ plane the Hugoniot of the PMMA and the calculated relationship $p_{CJ} = f(u_{CJ})$ reported in [8] shows that after the interaction of the detonation wave with the PMMA window (under the EMX density lower then 1.2 g/cc or the detonation pressure below 8 GPa) the shock wave is reflected. Behind this shock the temperature of detonation products increases. At higher pressures the rarefaction wave moves through detonation products and their temperature decreases. Correction of these effects is possible. However, it is necessary to build up the wide-range EOS of explosion products, and this equation should take into account all energetic and radiance losses connecting with the large variable quantity of physical sensitizer.

Satisfactory qualitative and quantitative correspondence of our experimental data and calculation results [8] obtained using the Kihara-Hikita-Tanaka EOS (marker *1* in Fig. 5) is observed. As the EMX initial density increases (at decrease of the microballoons number or number of "hot spots" consequently) the detonation temperature decreases to 1840 K though the detonation pressure rises up to 11 GPa. Such behavior differs qualitatively from the similar detonation temperature – pressure dependence for high explosives such as RDX, TNT and etc. The obtained data allow to choose and to correct the EOS form and its parameters for EMX's. Note, that at decrease of the detonation pressure to 0.7 GPa the detonation temperature remains enough high in accordance with the calculations [8].

The calculated detonation temperatures of EMX [8-12] are shown in Fig. 5. These calculations give results that differ from 200 up to 500 K and depend not only on the choice of the EOS of detonation products, but on the choice of the set of constitutive parameters too. Therefore the difference about 200÷400 K between experimental data and curves calculated

using Kihara-Hikita-Tanaka EOS [8, 12] or BKW-RR EOS [9, 10] (symbols *4* and *6* in Fig. 5) may be considered as unessential.

Hence experimental data on the detonation temperatures of EMX are necessary for analysis of the correctness of thermodynamics calculations: for example, it is clear now that BKW-RDX EOS [9] (symbols *5* in Fig. 5) does not conform to description of the EMX detonation temperatures.

3. Conclusion

The alternative view on the structure of the spectral radiance signal recorded at detonation of an emulsion explosive with embedded glass microballoons is presented. Moreover, the choice of the profile's point that should be selected for estimating the detonation temperature is suggested. The location of this point is defined by the comparison of pressure, particle velocity and temperature profiles behind the detonation front. Qualitative and quantitative accordance of our experimental results and calculated data reported in [8] is observed. In the range of detonation pressures from 1 to 11 GPa the detonation temperature of EMX is about 1840÷2260 K, and has non-monotonous behavior on pressure.

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