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INFLUENCE OF ALUMINUM PARTICLE SIZE ON HEAT OF EXPLOSION AND ACCELERATION ABILITY OF ALUMINIZED HIGH EXPLOSIVES

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Energetic additives are widely used to increase the power of explosive materials. The most commonly used additive of this kind is the aluminum powder. To date, many reports on the study of mixtures of high explosives (HEs) with aluminum (Al) have been published. The researchers at Semenov Institute of Chemical Physics, Russian Academy of Sciences (ICP RAS), took an active part in investigations of such systems. In particular, the acceleration ability (AA) and the heat of explosion (HoE), were studied.

AA characterizes one of the most important types of HE action. There are many methods to measure AA. In Russia, the end acceleration method, which is known as M-40 (counterpart of M-60 and M-20), has been adopted as a base technique [1]. In this method, a 4-mm-thick steel plate is accelerated from the end of a charge with a height and diameter of 40 mm in the channel of a thick-walled steel shell. A typical measure of AA is the velocity or the kinetic energy of the plate at a distance of 40 mm from the end of a charge.

HoE can also be considered as an important parameter of HEs. HoE characterizes the potential ability of the products of explosion to do work during their expansion. The HoE measurements are commonly performed by the method of the detonation calorimetry with the use of special bombs, in cavities of which the charges of HEs are initiated. The description of the technique used in ICP RAS is given in [2–4]. The specific features of determination of HoE of aluminized mixtures were considered in [4].

The results of a study of AA (M-40) and HoE for aluminized mixtures containing HEs with different elemental composition are presented in [5]. The main data were obtained for HEs: HMX (cyclotetramethylenetetranitramine) with an oxygen balance (OB) equal to –21.6% and bis(trinitroethyl)nitramine (BTNEN, OB = +16.5%). Dispersed Al with varying particle size was used in the compositions. The nanosized aluminum (nAl) with a particle size of 0.1 μm and an activity (unbound metal content) of 86% was prepared by the Gen–Miller condensation-in-flow technique at Talrose Institute for Energy Problems of Chemical Physics, Russian Academy of Sciences (INEPCP RAS) [6]. The compositions were prepared by a long-term mixing of the components under a layer of an inert liquid. The results indicated that, with respect to AA and HoE, the compositions with Al(0.1) (hereinafter the particle size is shown in brackets) didn't have advantages over the compositions containing Al with a particle size of the order of few microns. Analysis of data from other sources, in particular, from foreign publications, confirmed this conclusion [7].

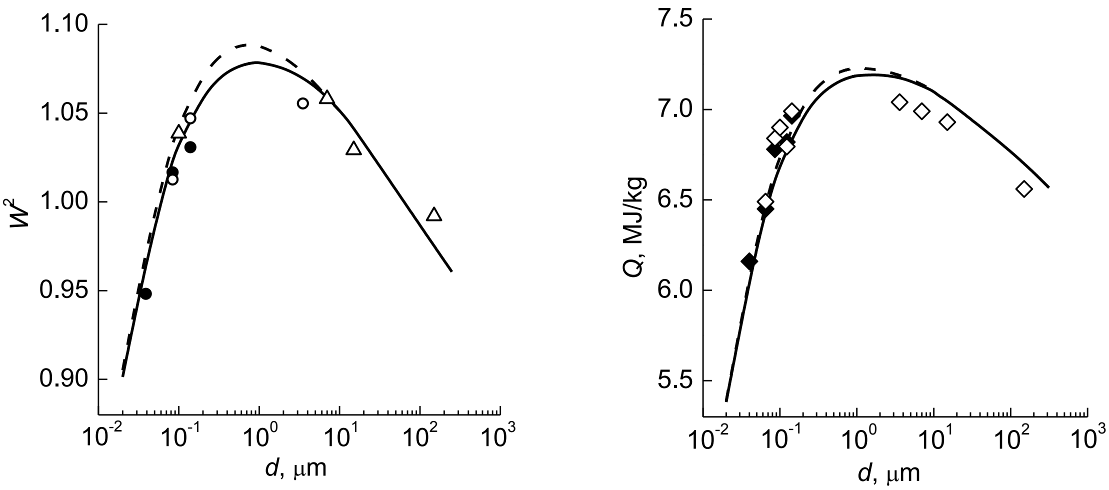
As contrasted to the mechanical mixtures, the aluminized nanocomposites represent the systems with uniform distribution of nAl particles in the HE matrix. Results of a comprehensive study of the parameters of mechanical mixtures and nanocomposites containing HMX and Al in a weight ratio of 85/15 are described in [8]. The nAl powders were prepared at INEPCP RAS; the powders differed in the particle size, particle surface coating, and activity. The average particle size of the nAl powders varied in a range of 38–143 nm with a change in the activity in a range of 60–86%. In addition, mixtures containing Al with a particle size of 3.6 μm were studied. The nanocomposites were prepared by spray drying of a nAl suspension in an HMX solution. This method has been developed at INEPCP RAS [8]. AA was measured by the M-20 method. Contrary to the expectations, the nanocomposite HMX/Al, 85/15, showed no advantages in AA and HoE as compared to the mechanical mixture containing both nAl and Al(3.6).

The paper presented is devoted to the analysis of prospects of enhancement of AA and HoE owing to the formation of aluminized nanocomposites based on HEs with different OB. At first, the data on the investigation of the HMX-based formulations are considered. For generalization, both new results and some previously published data [5, 8] are discussed. In the Figures below, the open and closed symbols represent the experimental results for the mechanical mixtures and nanocomposites respectively. The curves have been constructed using the calculation data.

Figure 1*a* shows the data characterizing the effect of the Al particle size on the relative AA values (M-40) of mechanical mixtures and nanocomposites HMX/Al, 85/15. The kinetic energy of the plate (the velocity squared) was considered as a measure of AA. The HMX charge of the same porosity as the studied sample was selected as a reference. AA was evaluated as described in [9]. In the calculations of the curves, the thickness of the oxide film covering the Al particles was assumed to be 3 nm [10]. The symbols in Figure 1 show the experimental AA values obtained by the M-40 and M-20 methods [5, 8].

The shape of the calculated curves in Figure 1*a* suggests that AA decreases with decreasing nAl particle size. In contrast to this, in the region of micron-sized Al, AA decreases with increasing Al particle size. The curves exhibit a maximum. The calculation suggests that AA of the HMX-based nanocomposites should not significantly exceed AA of the mechanical mixtures. The experimental points lie near the calculated curves; that is, the measurement results obey the same laws as the calculated data.

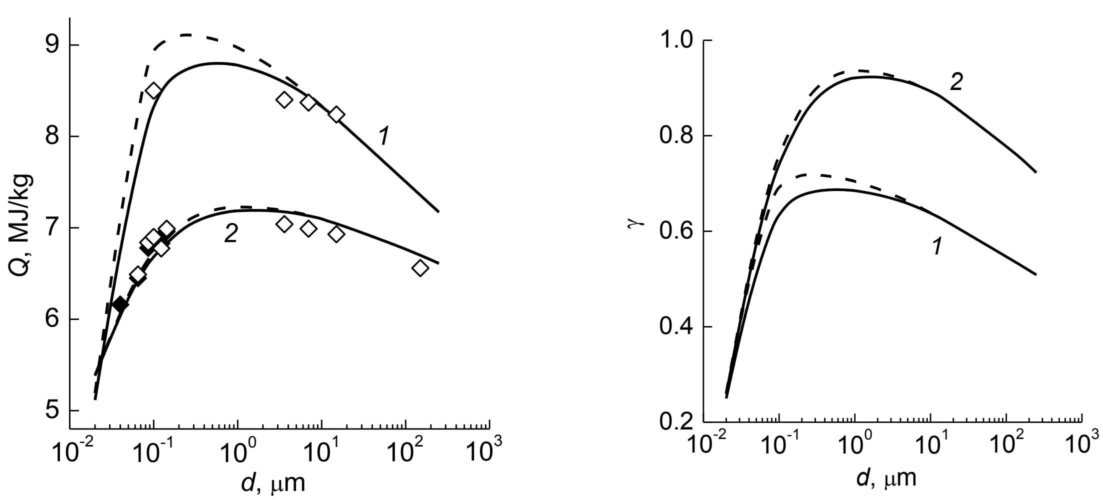
The calculated curves and experimental data on HoE for the same system HMX/Al, 85/15, are shown in Figures 1*b*. The calculation was performed using the method developed earlier [11]. The experimental results are presented in [5, 8]. As in Figure 1*a*, the experimental points lie near the calculated lines. The curves in Figures 1*a* and 1*b* are close in shape. The areas of the optimum sizes of Al particles therewith coincide. However even in the neighborhood of the maximum HoE values, the HoE curves corresponding to the mechanical mixtures and nanocomposites practically merge. The decrease in AA and HoE with decreasing the nAl particle size is attributed to that the smaller is the particle size of nAl, the greater is the initial fraction of oxide film.



(*a*) (*b*)

Figure 1. (*a*) – AA, (*b*) – HoE of the HMX-based compositions versus the Al particle size after the addition of 15% Al; solid lines – mechanical mixtures, dashed lines – nanocomposites; circles – M-20, triangles – M-40, rhombuses – HoE

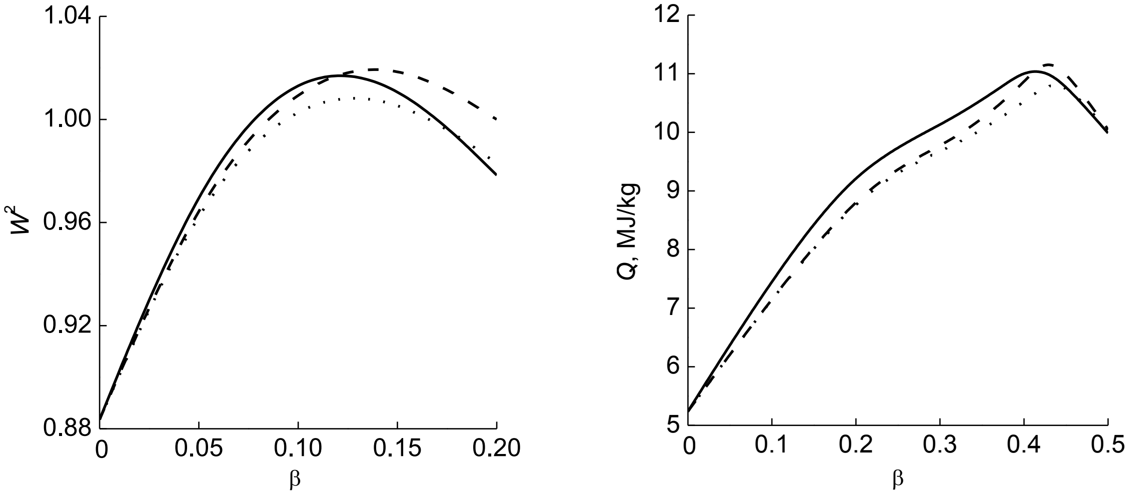
Figure 2*a* shows the calculated curves and the experimental data on HoE for the HMX-based compositions containing 15% and 40% of the Al additive with a variety of particle size. As it follows from Figure 2*a*, the HoE values are greater in the case of 40% of Al. The calculated curves for the degree of Al oxidation, corresponding to the curves in Figures 2*a*, are presented in Figure 2*b*. The curves in Figure 2b merge when the size of nAl particles is small. The reason is that the unbound metal of the nAl additive undergoes practically complete oxidation. In the main range of Al particle size, the degree of Al oxidation is smaller when the content of Al additive is higher. The presence of a reserve in the form of unreacted metal enhances the effect of the mixture structure on HoE, and, as shown by Figures 2a and 2b, the gain in HoE for HMX-based formulations with a high concentration of Al additive (in the case under consideration – 40%) can be obtained by the creation of the aluminized nanocomposite.



(*a*) (*b*)

Figure 2. (*a*) – HoE, (*б*) – the degree of the Al additive oxidation for the HMX-based compositions versus the Al particle size after the addition of 15% (*1*) and 40% (*2*) Al. The designations are the same as in Figure 1

Figures 3 and 4 demonstrate the calculated curves characterizing AA and HoE of the aluminized mixtures based on three HEs with OB, differing from that of HMX. Among these are BTNEN with positive OB (see above), CL-20 (hexanitrohexaazaisowurtzitane) with negative OB (–11%) and TNT (trinitrotoluene) with highly negative OB (–74%).



(*a*) (*b*)

Figure 3. (*a*) – AA, (*б*) – HoE for the BTNEN-based compositions versus the Al concentration; solid lines – mechanical mixtures with Al(7), dotted lines – mechanical mixtures with Al(0.1), dashed lines – nanocomposites with Al(0.1)

The greatest HoE value of compositions corresponds to BTNEN, possessing the excess of oxygen in its molecule. The addition of Al markedly enhances AA of BTNEN. However the mixture is superior in AA to HMX only slightly because of relatively low AA of BTNEN. The creation of the aluminized nanocomposite on a basis of BTNEN can't lead to the additional increase in AA as well as in HoE. CL-20 and its mixtures with Al have the highest AA. The formation of the nanocomposite based on CL-20 can't result in the gain in AA, but can give the additional increase in HoE at the high Al concentration (see Figure 4).

The aluminized formulations based on TNT have low AA and HoE. The reason is that TNT is an oxygen-depleted substance. The nanocomposites therewith can outperform the mechanical mixtures in AA as well as in HoE, and this advantage should be more substantial than it is observed for the other HEs considered. The results obtained for TNT can be explained by the enhancement of the effect of the mixture structure on AA and HoE when the degree of Al oxidation decreases owing to the decrease in OB of HE.

Thus, it follows from the data obtained, that the creation of the nanocomposite on the basis of the mixture of HE with Al can provide the additional gain in AA (M-40) when main HE possesses highly negative OB, and the gain in HoE can be obtained when the Al concentration is high and OB of main HE is negative.

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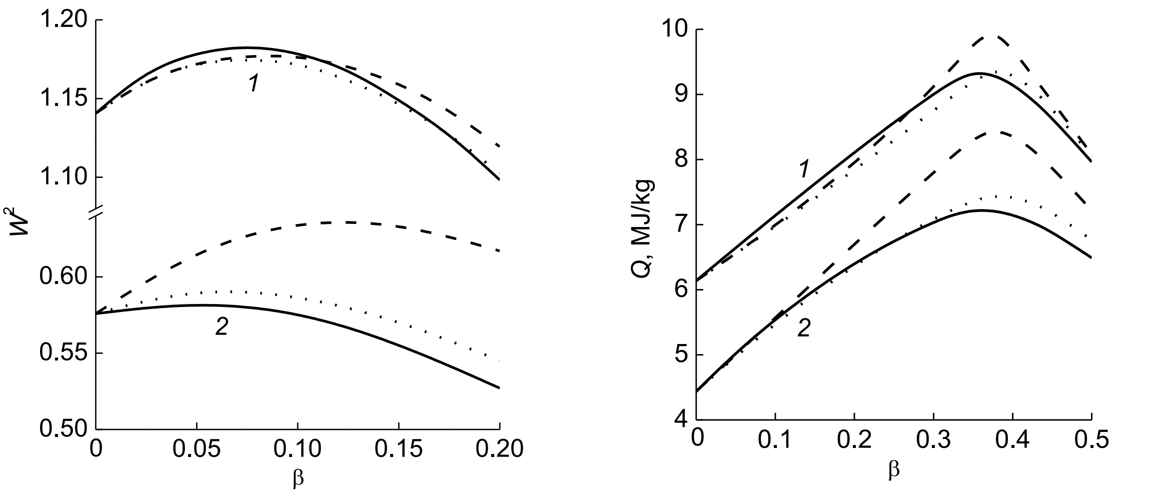

(*a*) (*b*)

Figure 4. (*a*) – AA, (*б*) – HoE for the compositions based on HEs: *1* – CL-20, *2* – TNT versus the Al concentration. The designations are the same as in Figure 3

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