Dimensional Effect at Laser Ignition of Pyrotechnic Structure (Ammonium Perchlorate + Superdisperse Aluminium)

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Abstract – A behavior (values of power thresholds and delays of ignition) of the pressed samples of pyrotechnic composition (PC) of ammonium perchlorate (APC) and superdispersed aluminium (SDA) taken in a stochiometric ratio has experimentally studied depending on spot diameter of an irradiation at influence by a laser pulse with millisecond duration. The strongly expressed dimensional effect is found out. The characteristic size determining border between a wide and narrow beam of the influencing laser pulse is found. Influence of optical properties of these compositions on the course of dimensional dependences is discussed. Connection between the nature of dimensional effect and light-scattering laws in volume of powdered PC is considered.

The dimensional dependences of power thresholds of ignition (PTI) like dependences of threshold density of energy versus beam diameter on a sample surface are found out at laser excitation of explosion of the initiating (heavy metal azides [1, 2]) and secondary (pentaerythritol tetranitrate (PETN) [3]) explosives. Their existence were connected either with the light dispersion laws in volume of transparent explosive powders [1, 2] or with one of fundamental characteristics of explosives – critical diameter of a detonation [3].

In the literature there are no data about dimensional dependences of laser initiation of PC. As follows from [1–3] it is possible to conclude that dimensional effects can be determined both optical and gas-dynamic characteristics of explosives realized in concrete experience. Therefore revelation of the nature of dimensional effect in many respects can be the key moment for understanding of the mechanism of initiation in the whole. In [4] the conclusion about the weak gas-dynamic discharge of the thermal enclosed area during ignition of APC + SDA mix at influence by a wide beam is made. It is possible to expect that it is typical case for areas of the small sizes. At the same time the optical characteristics of mix compositions can be changed over a wide range by injecting of the various reagents or passive absorbing impurity. Affecting on a course of experimental dependences they can give the valuable information about structure and parameters of the centers of ignition. Results of the first experiences in this direction below are presented.

APC + SDA composition prepared by technique in [4] has been studied. The powders by weight ~10 mg were placed in assembly and were pressed with the help of hydraulic press under pressure of $4\cdot10^7$ N/m^2 up to density ~1,5 g/cm^3 (Fig. 1).

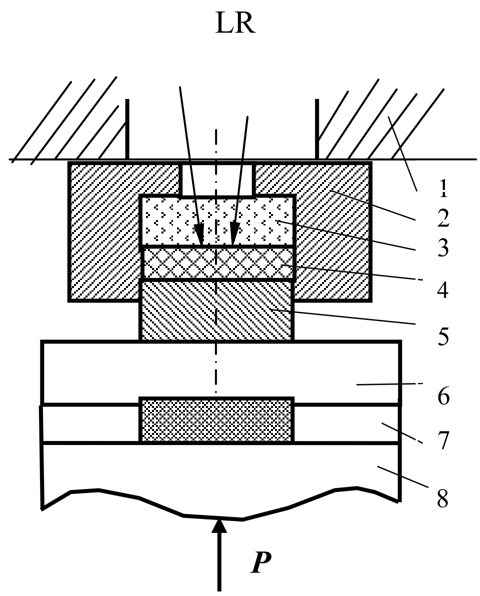

Fig. 1. The circuit of assembly for volumetric compression of a sample.
1 – the top support press; 2 – the case of assembly (45 steel); 3 – an entrance window with thickness of 5 mm and diameter of 5 mm (Plexiglas); 4 – powder; 5 – a bearing; 6 – an entrance window of the pressure sensor; 7 – the high-speed pressure sensor; 8 – the piston of press; LR – laser radiation

The reflection factor of samples was measured with the help of a photometric sphere and has made ~0,35. Radiation of the neodymium laser working in a chaotic free generation mode with the pulses duration about 0,6 ms was used. PTI sizes were determined by a technique described in [4]. Results of measurements were inscribed in the table and shown in Fig. 2, where for comparison the dimensional dependences of lead azide are submitted.

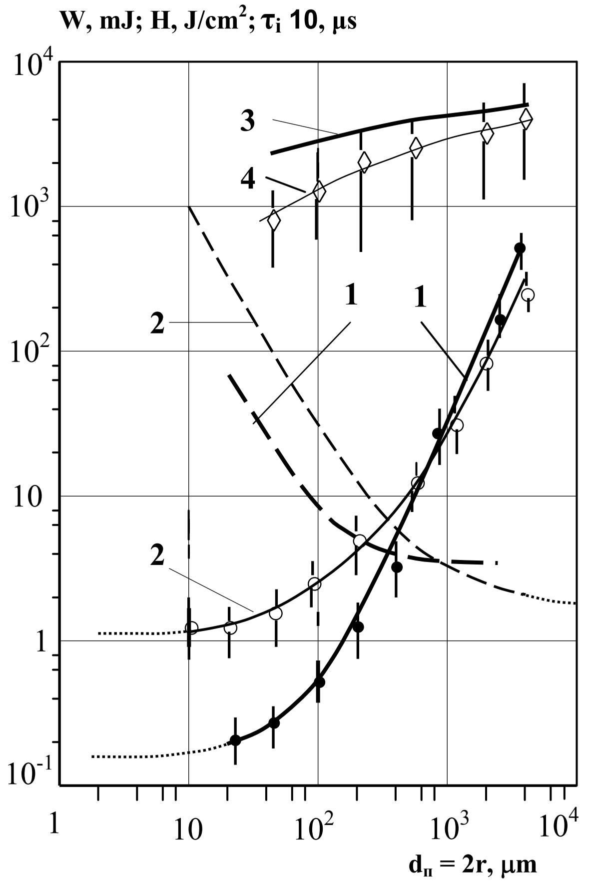

Fig. 2. Dimensional dependences of PTI of cubic compressed APC + SDA at influence by a laser pulse ($\tau_p = 6{\cdot}10^{-4}$ s). 1 – threshold energy of initiation (APC + SDA) (solid lines) and threshold density of energy (dotted curve); 2 – the same for lead azide; 3, 4 – a flash delay of an explosive luminescence of APC + SDA and lead azide accordingly

Table. PTI of APC + SDA composition at initiation by a laser beam with the size d_n

D_n, mm	W_{50}, mJ	E_{50}, J/cm^2
3	297	4,4
2	132	4,4
1	33	4,4
0,8	22	4,4
0,6	13	4,4
0,4	6	4,5
0,2	1,5	5,0
0,1	0,5	6,5
0,05	0,26	13,0
0,025	0,2	40,0

At comparison of dimensional dependences of APC + SDA and lead azide the series of interesting features were became known. First of all it is necessary to note that in the field of influence by a wide beam (d_n> 1 mm) the sensitivity of lead azide approximately is twice higher than sensitivity of APC + SDA. In the range of the small sizes the situation is changed. Here is APC + SDA traditionally considered as the weakly sensible explosives which exceed almost by order of magnitude greater than one of the most sensitive representatives explosives –lead azide. This fact is confirmation of regulations put forward by Afanasyev and Bobylev [5] about possible change of the series of explosives sensitivity at change of conditions of external influenced pulse as applied to a laser way of initiation.

As a whole at initiation of APC + SDA the dimensional effect is less evaluated than in lead azide. More precisely the dimensional curve of power density is as though shifted aside to the small sizes practically by order of magnitude. If we will adhere to the point of view of a determining role of light-scattering process, it is possible to explain this shift by high absorption (about 65 %) in APC + SDA volume and accordingly smaller densities of light-scattering in comparison with such transparent powder as lead azide. Especially this difference is appreciable at dispersion of a narrow beam (Fig. 3).

So in conformity with Fig. 3 in a near-surface layer with depth up to 2 τ at reduction of the size of a laser beam from 50 τ up to 5 τ (on the order of size) the illuminance decreases approximately in 10 times in the case of heavy metal azides. It demands proportional increase in threshold of energy density of a laser pulse for creation of necessary conditions of ignition. The change of illuminance on the given range of diameters does not exceed three times for APC + SDA. The similar situation is observed on experimental curves of energy density of ignition (Fig. 2) in an interval of the beam sizes from 100 μm up to 1000 μm. Conformity between illuminance in a powder volume and a threshold of ignition is observed and on other dimensional ranges.

Since the primal parameter characterizing of dimensional effect is the threshold of energy (flux) density we shall carry out the comparative analysis of the results obtained for various classes of explosives by the magnitude of this parameter. First of all we shall note that a characteristic size of an irradiation zone (for each class of explosives) exists. At its excess the threshold of energy density becomes a constant, i.e. tend to a minimum. We shall pay attention to the circumstance that in transparent powders with high factor of diffuse reflection (lead azide; $\rho_д$ ~0,9) the border between a narrow and wide beams is in range from 1 up to 10 mm. With decreasing of reflection the border is shifted to the left and for APC ($\rho_д$ ~0,35) it is within the limits from 0,2 to 0,4 mm. Such behavior of explosives fully complies with light-scattering laws in diffuse-scattering medium as mentioned above that proves by calculation of dimensional dependences and also estimated criterion of the wide beam executed in [6]. Thus from the optical point of view in the range where the beam can be counted wide *a criterion of initiation* is *the energy density* of an influencing pulse.

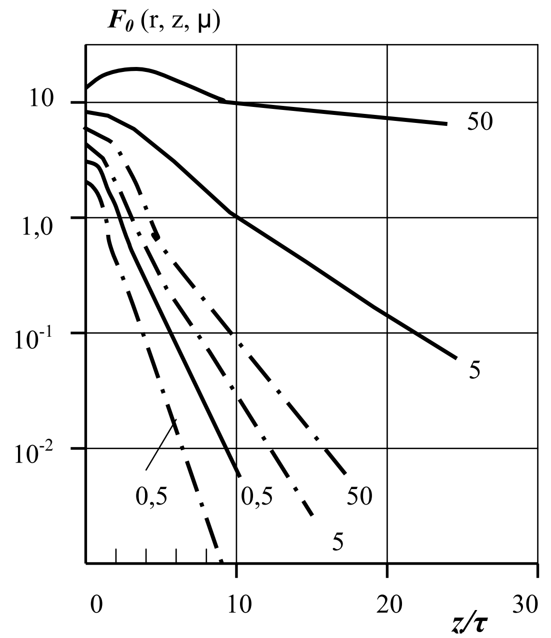

Fig. 3. Connection between spatial illuminance q in depth of object and illuminance q_0 ($q/q_0 = F_0$), created by a laser beam on surface of explosives in mediums with various absorption μ and in conditions of influence by a beam with the various aperture *2r*.

The size of a laser beam on a surface of environment (in terms of r/τ, where τ – optical thickness of environment) are indicated by the numbers. Solid curves correspond to a factor of diffuse reflection from indefinitely thick layer $\rho_\infty = 0{,}8$ (heavy metal azides); dash-dot curves – $\rho_\infty = 0{,}35$ (APC+SDA). Calculation carried out by a Monte Carlo method [6].

In the range of the small sizes of an influencing beam the threshold energy tends to a minimum. In this case *a criterion of initiation* is *energy* of an external pulse. The size characterizing this range is also determined by light-scattering characteristics and decreases with reduction of the diffuse reflection factor of substance, i.e. with increase in absorption. It is illustrated in Fig. 2, curve 1 for lead azide.

The generality in behavior of the dimensional dependences of explosives with various thermalphysic, thermalkinetic and gas-dynamic characteristics defined from light-scattering laws suggests that *dimensional effects* at laser ignition of APC + SDA composition are not connected to *critical diameter of a detonation* and determined by light-scattering processes in a combination of processes of localization of laser beam energy in microvolumes of explosives.

Thus it is possible to assume that light-scattering laws underlie of dimensional effect at APC + SDA ignition from positions of thermal spot models [4]. In this way with reduction of the size of an influencing beam the illuminance of volume falls that demands increase of density of an initiating flux for maintenance of constant temperature of the spot. The constancy of this temperature confirms by independence of an ignition delay versus the beam size (curve 3, Fig. 2).

Acknowledgement

The work was supported by Russian Foundation for Basic Research (grant № 06–03–32724–a).

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