Ignition of Ultradisperse Aluminium by Laser Impulse

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Abstract – Features of ignition and coursing of reaction of combustion of ultradisperse aluminum bulk density in an atmosphere of air by laser radiation(λ=1,06 microns) are visually fixed. Measured a threshold and a delay of ignition.

The study of powerful explosives (PE) is one of the most important directions of scientific researches. The processes of combustion of the condensed substances represent significant practical and theoretical interest. It is known, that explosives (PE) under determined conditions are easily enough to flare up and detonate under influence of laser radiation in the field of a spectrum where PE is transparent, namely in conditions of weak absorption. Thus, research of ignition of power substances in which conditions enough strong absorption is realized and, accordingly, conditions of creation of the thermal centers with enough high primary temperature are facilitated represents significant interest. The representatives of such substances are mixture structures on the basis of ammonium perchlorate + Al in which aluminum plays the important role as during localization of energy of laser radiation in volume of a mixture, and during occurrence and spread of a wave of burning. In this connection studying of process of ignition of ultradisperse powder of aluminum in a free condition is important.

In the given work, ignition and process of combustion in an atmosphere of air of ultradisperse aluminum (UDA) bulk density (ρ = 0,27 g/cm^3) by laser radiation (λ = 1, 06 microns) duration of a laser impulse (τ = 4 ms) is experimentally researched and visually registered.

The ultradisperse powder of aluminum is received by electric explosion (voltage 26 κV, the attitude of energy of explosion to energy of sublimation – 1,6) aluminum conductors in diameter 0,35 and length 80 mm in the environment of argon of qualification "o.s.ch." at pressure of 2,5 atmospheres. Average diameter of the particles formed 0,25 microns, the maintenance of active aluminum – no more than 93 % mas., the form of particles spherical, distribution of the particles in the sizes submits to the is normal-logarithmic law [1].

Received powders has the lowered x-ray density which corresponds to density of aluminum, heated on tens degrees. Reactionary ability of such particles can be increased [2].

While definition of a power threshold of ignition UDA the sample in weight of ~ 5 mg, Ø 3 mm and h = 2,5 mm was used. At fixation of process of combustion the sample in weight of ~50 mg was filled on a ceramic substrate in the form of truncated at the basis cone Ø 12 mm and h=2,5 mm. All surface of the sample was irradiated.

The scheme of experimental installation is presented in Fig.1.

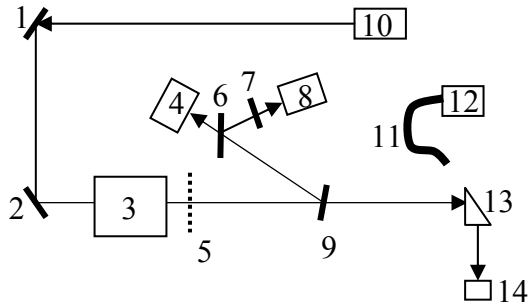

Fig. 1. The scheme of installation of ignition UDA by pulse laser with millisecond duration of an impulse: 1, 2) rotary mirrors; 3) neodymium laser; 4) calorimeter; 5, 7) neutral optical filter; 6, 9) beams splitter; 8) photodetector FEK – 09K; 10) He-Ne laser LGN-109; 11) fiber optical; 12) photodetector; 13) rotary prism; 14) the sample

Energy of laser radiation on installation is adjusted by pumping of lamps of neodymium laser and neutral optical filters. You can find more detailed description of installation [3]. Non-uniformity of illumination of sample surface irradiated on a normal was no more than 20 %.

The threshold of ignition was defined as follows. Firstly likelihood curves of ignitions on an interval from 0 up to 100 % (quantity of ignitions/quantities of experiences) as function from density of energy E of falling radiation were built with at set durations of laser impulses. Each point of a curve is corresponded to statistics from 20 experiences with disorder of indications of a calorimeter no more than 10 % from average value. Values E_{50} were accepted to a threshold of ignition at which 50-th % ignition was realized.

As a result of experiments the power threshold of ignition (PTI) of UDA presented in Table has been revealed.

Along side with definition of PTI of UDA presence of two – stages course of process of combustion of UDA has been revealed at influence of impulse millisecond duration, depending on weight of ignition up sample (Fig. 2).

Table. The value of threshold (E_{50}) and delays of combustion at duration of laser impulse equally τ_i=4 ms

Conditions of an irradiation of a surface	Impulse duration τ_i	E_{50}, J/cm^2	Combustion delay, ms
Opened bulk, ρ =0.16 g/cm^3	4	0,83	4

Results of experiment correspond to representations of [2], according to which combustion occurs in two stages. The temperature of the sample at the first stage does not exceed 1200 °C (a red luminescence). According to the offered mechanism of burning on low temperature stage there is oxidation of UDA up to $\gamma - Al_2O_3$ according to reaction (1):

$$2Al + \frac{3}{2}O_2 = \gamma - Al_2O_3 \qquad (1)$$

With emitting of energy and the products necessary for occurrence of the second, high-temperature stage of burning during which gaseous sub oxides of the aluminium, generated as a result of reaction (2), reacting in a gas stage with

$$4Al + \gamma - Al_2O_3 = 3Al_2O \qquad (2)$$

the nitrogen of air activated by high temperature with formation of a phase of nitride of aluminium (3) which is not oxidized further. The temperature of the burning sample at the second stage reaches 2400 °C. [2]

$$3Al_2O + 3N_2 = 6AlN + \frac{3}{2}O_2 \qquad (3)$$

Visually observable process of burning of samples with equal mass (m=10 mg) was identical and proceeded in two stages, for samples with smaller weight process of burning proceeded in one stage. From a point of local laser initiation the front of burning spread, in mutual opposite directions, gradually forms the "ring" form on periphery of the sample (an orange-red luminescence) with peak brightness of luminescence on 4 second. Further intensity of a luminescence of "ring" decreased; the "ring" form was transformed in 3 characteristic bright "points" (8th second). This points warming a zone of the minimal heat-conducting path, lost intensity of a luminescence. As a result of warming up of a zone of the minimal heat-conducting path on 14.5 second bright flash with a characteristic white luminescence of the sample has been registered. Further intensity decreasing of a luminescence and moving of the center concerning a zone of the minimal warming up, with flash of brightly orange luminescence (20.6 second) were observed. Process of burning on time has formed 21 second (Fig. 2).

At studying of the sample with helps of microscope MBS 9 (×2) three-chromaticity of reacted structure of UDA was revealed: the center of the spot is white with the greatest linear size 2,5 mm with grey and white bordering in diameter of 4 mm and grey color in periphery (Fig. 3).

The mechanism of formation of nitrides while burning of UDA is complex: their special warmphysic and chemical properties, their thermodynamic characteristics influence burning and formation of end-products [2].

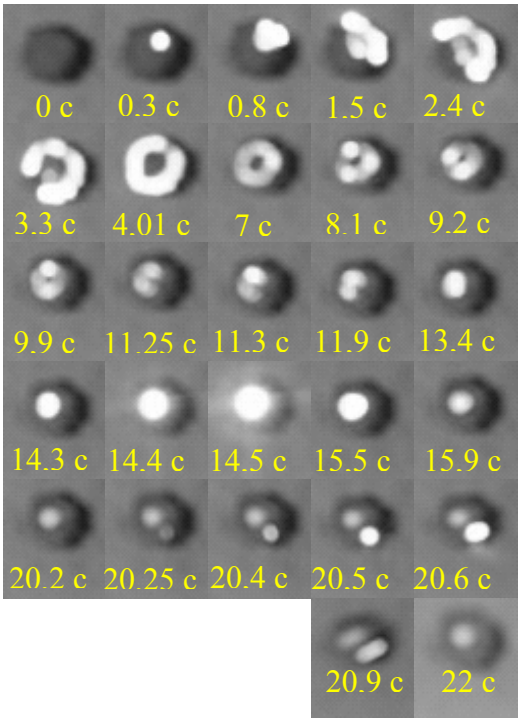

Fig. 2. Process of course of burning UDA

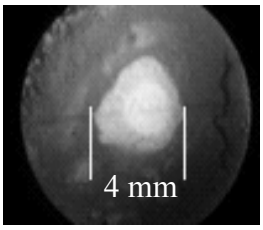

Fig. 3. The sample under microscope MBS 9 (×2)

At the same time the results of the experiments show that the basic laws of process of burning at comparing from traditional ways of ignition with laser are kept.

Presence of two – stages, apparently, is connected with presence of "critical mass" of UDA: with weight less then "critical" the process of burning proceeds in one stage with determined quantities of the bound nitrogen in end-products, and with weight more than "critical weight" in two stages with the significant maintenance of nitride [2].

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