- получены экспериментальные данные о динамике горения стехиометрической смеси порошков алюминия и оксида меди при разных способах инициирования;

- полученные данные использованы при изготовлении модульного источника света для фотографирования относительно медленных объектов в проходящем или отраженном свете. Модуль прост в изготовлении, а сгорание энергетической смеси Al+CuO не сопровождается разрушением конструкции;

- по совокупности данных определена наиболее оптимальная доза механоактивации смеси микронных порошков Al+CuO. Эта доза составила 8 минут.

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A PULSE LIGHT SOURCE BASED ON THE COMBUSTION OF POWDER MIXTURE Al+CuO

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The results of experimental studies of combustion under different ways of initiation of aluminum and copper oxide powders stoichiometric mixture are given. Some results was used to generate a pulse light source with an aperture 400x400 mm.

By estimations, chemical interaction of the mixture components can occur with the energy release of 4 kJ/g in the case of complete reaction of the components. The rate of energy deposition in the oxidizer - fuel powder mixtures depends on the contact surface between the particles. The mixture of real powders have a finite value of this surface. To increase contact area and reduce energy threshold of the initiation of reaction we carried out the preliminary mechanical activation in a ball vibratory mill. The activation time was 2-20 minutes. Because of activation the activated clusters of source components was formed. As microscopy of the mixture shown (fig. 1), the contact surface of the components in the clusters is in the nature of local spots. Ultimately, this affects the combustion speed and time for test specimen with specified geometric shape.

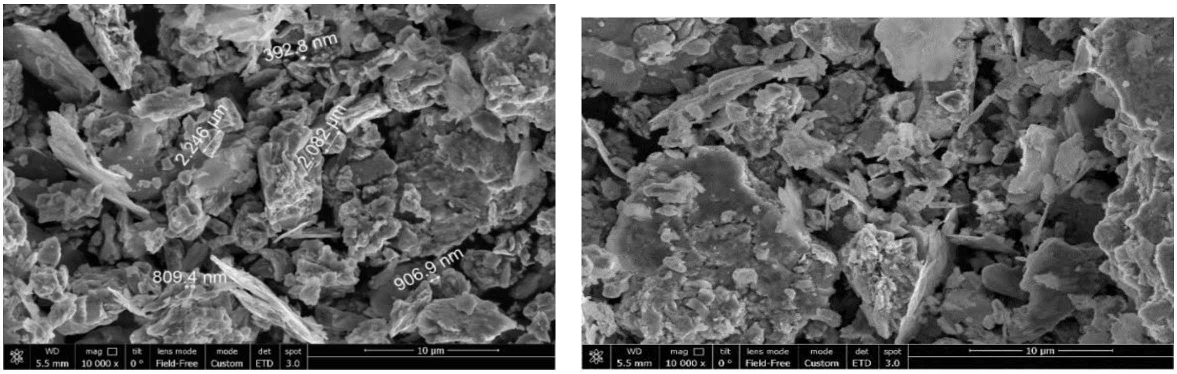


Figure 1. Microscopic photos of Al and CuO powders mixture

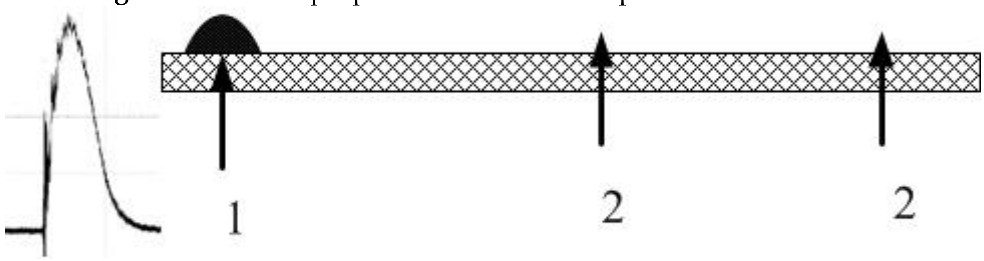
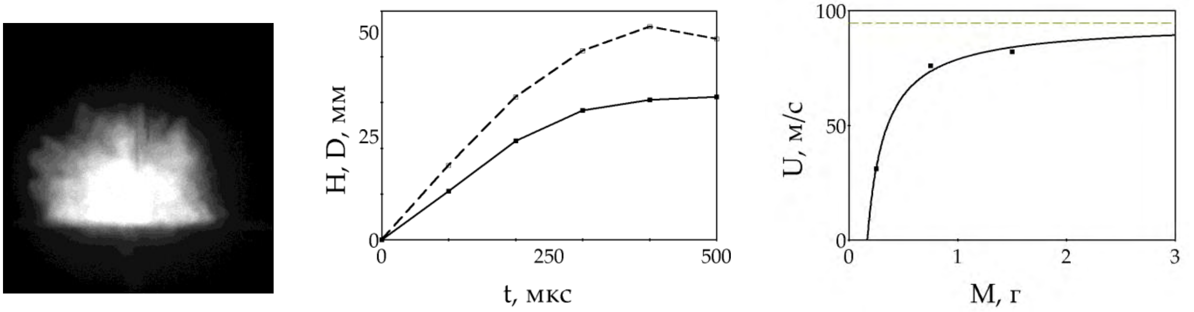


Figure 2. The waveform of spark current and the scheme of experiment with electric-spark initiation. 1 – Current electrodes; 2 – Electric sensors

The mixture combustion is considered as a transition process of a certain mass of a mixture (~1 g) from initial components to final products, because of external influence in the form of heat or pressure pulses. External influence plays a role of a trigger to initiate the chemical reaction. Thermal pulse created by spark discharge with duration of ~1 ms at energy density of ~10^{13} W/m^2. The combustion occurs with natural scattering of substance in the case of placing sample on a flat base (fig. 2).

For the data set from high-speed photography, waveforms from electrocontact sensors and track marks on a thin foils the light emission area (the flame) can be characterized as expanding flow of reacting clusters and cold components in the cloud of radiating plasma of combustion products (fig. 3a). The scattering of reacting clusters with average energy forms the front line of light emission area. For example, the combustion of specimens with mass 0.3 g on a level surface leads to formation of the light emission area up to 2000 mm^2 in section during the ~ 1000 μs.

The moments of closure of contact sensors by combustion products are quite accurately correspond to expansion rate of light emission area. The characteristic expansion rate of combustion products of local mixture portions (0.03 g or above), as well as the rate of combustion of linear mixture tracks (with a linear density of about 0.2 g/cm) is the tens of meters per second (fig. 3b). There is a variability in the expansion rate both due to a scatter in density (while laying the bulk mixture), and natural distribution of clusters in mass and speed. The expansion rate of the light emission area is increased, within certain limits, with increasing the mass of local mixture sample (fig. 3b). Restriction of expansion of combustion products by sidewalls within the height of the mixture line track also increases the speed of combustion.



a b c

Figure 3. a – The photo of light emission area under natural expansion of cold components and reacting clusters (0.3 g) along and across the flat base; b – timing diagram of the diametrically (dotted line) and vertical (solid line) expanding of the light emission area; c – dependence between the vertical velocity of light emission area and the mass of sample

The presence of air gaps between mixture lines does not prevent the spread of combustion. The triggering effect of the most energetic (fast) clusters through the air gaps up to 170 mm was fixed.

The burnout of clusters with low energy in the rear region of light emission area provides the light emission up to 5 ms. I.e., the expansion of light emission area is caused by scattering of mixture clusters and continued release of chemical energy in the whole volume of the mixture. The maximum brightness temperature of the light emission area was determined using a four-channel pyrometer and was 3600 K for 8-minutres activated mixture.

The pressure pulse with duration of ~1 μs and energy density ~10^{12} W/m^2 was carried out under shock and unloading waves consistent passage through the tablet made of a compressed mixture (fig. 4a).

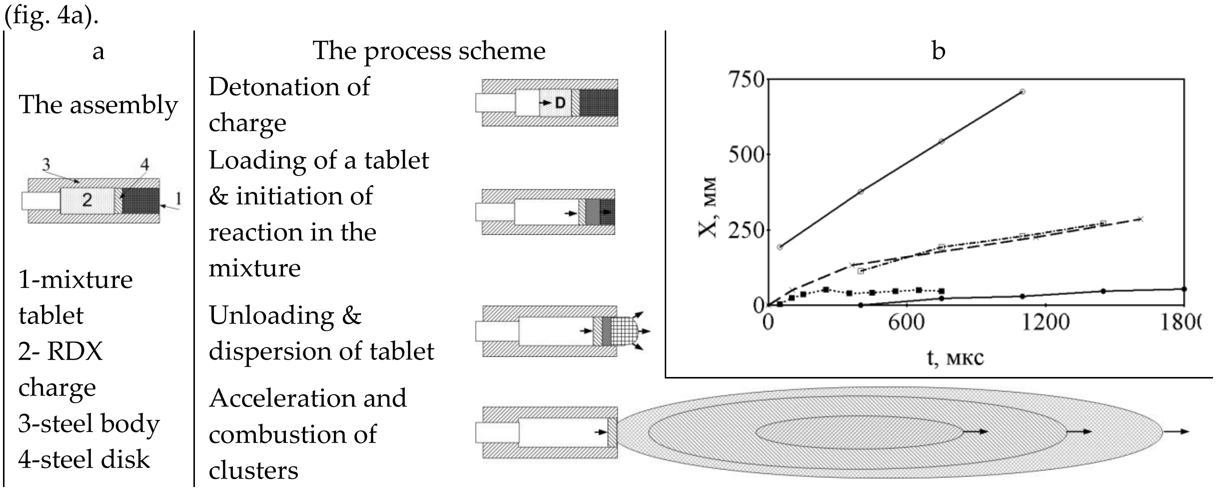


Figure 4. a – A scheme of the experimental assembly and the process of impact loading: 1 – extruded mixture tablet, 2 – RDX charge (1.15 g/cm^3), 3 – intermediate steel disc, b – The time diagrams of different regions of the light emission area: 1 - flow front; 2 - stream center; 3 – plasma front; 4 - the stream radius; 5 – flow rear area

The shock loading of tablet 1 (mass 1g) was carried out under detonation of an explosive charge 2 (RDX 1 g at ~1.15 g/cm^3 density) in a steel tube 3 (the inner and outer diameters of 8 and 14 mm, respectively). For thermal protection of tablet from detonation products an intermediate steel disk 4 with a thickness of 2.5 mm was used. The steel tube was fixed coaxially with nozzle orifice on a steel plate 2.5 mm thick. The intensity of loading was varied by the size of air gap between the explosive charge and the steel disk (0-3 length of charge). The intensity of unloading and the dispersion level was controlled by changing the size of nozzle orifices. With an area less than 0.5 of tablet one, a steel disc stuck in the nozzle and prevent the impact of detonation products on the process of a stream formation from dispersible particles.

The chemical interaction between components was watched in the form of a light across a nozzle orifice under dispersion of substance in a jet stream. Photos of a stream with an exposition of 50 ns confirm a homogeneity of stream radiation in a visible range. The character of conductivity current impulses between potential electrodes allows to assume the great value of electric resistance in the light emission area that can confirm rather low plasma density. The stream dynamics (fig. 3a) of a reacting material was determined at high-speed photography during to 5 ms and by plasma short circuit chronogram of potential electrodes. So, the speed of center of the light emission area increases from ~ 240 to ~ 650 m/s with increasing in diameter of a nozzle orifice. The increasing of longitudinal section of light emission area reaches 35 $mm^2/\mu s$ by the time of 200 μs.

The combustion dynamics of dispersed tablets from mixtures with various mechanical activation level (2-20 min) to the time 500 μs practically doesn't differ, then the longitudinal section of the light emission area begins to decline (especially quickly for tablets with a 6 and 8 minutes activation level). Speed of the front of light emission area doesn't depend on intensity of shock loading within ±10%. Flow speed also doesn't change for tablets with different (15-35%) initial porosity. Apparently, shock loading results in activation effect on chemical reaction at the contact surfaces between metal particles and oxidizer, which exceed the preliminary mechanical activation one.

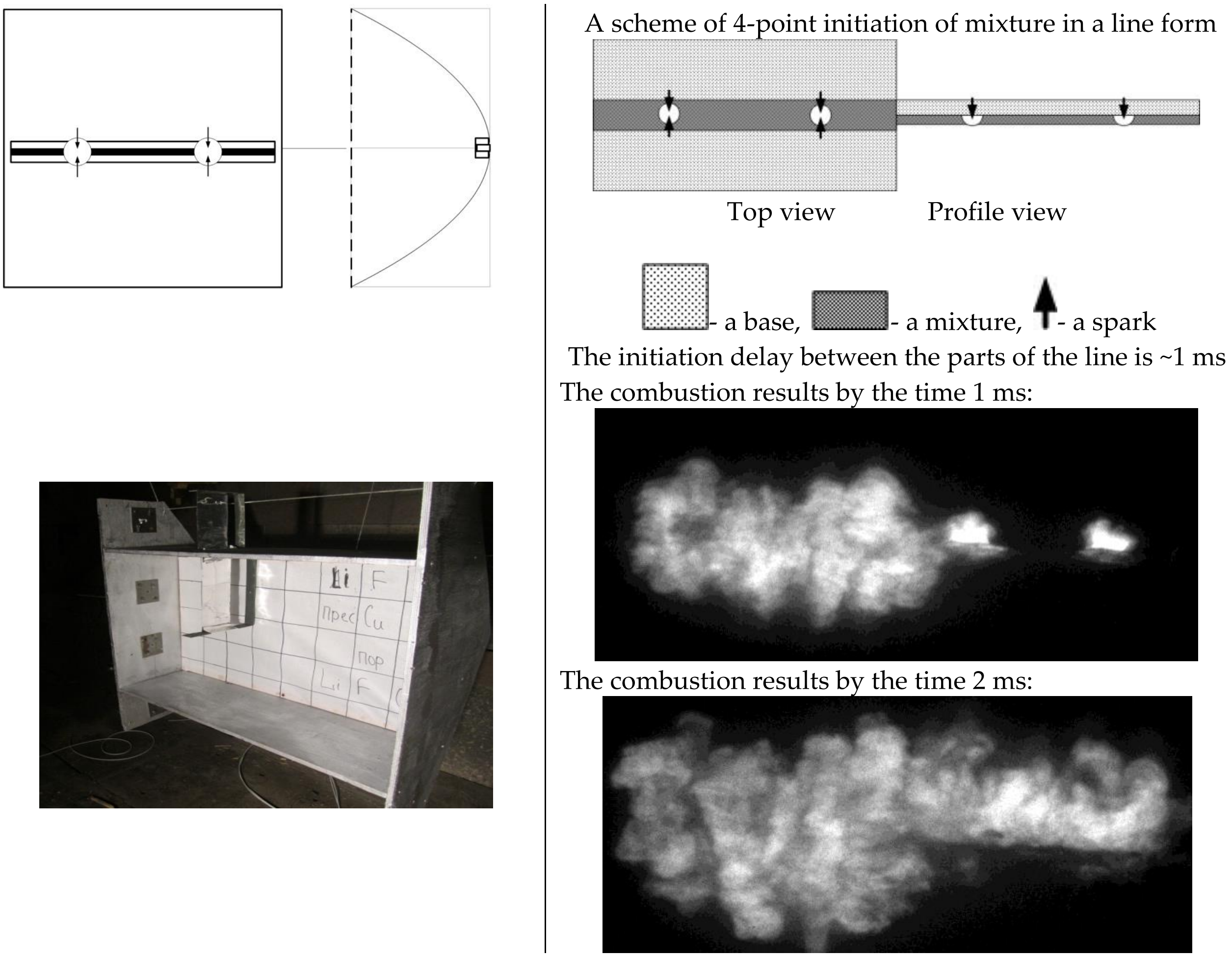
Stated ideas and experimental data were used to manufacture of a simple light source based on the combustion of Al and CuO powders mixture.

The design of light source was based on a module with an aperture 400x400 mm. As the light source a mixture samples in a point form (0.3g) or in a line form (1x10 mm) with a length of 380 mm, with two points of initiation was used. The depth of placement of mixture sample from aperture is 200 mm. The weight of mixture in the case of line form was 9 g. The average value of linear velocity of the mixture combustion was 35 m/s.

The initiation of reaction in a mixture was carried out at 4 points with electric-spark method using the generator GSI-6. To improve the efficiency of light at initial stage of mixture ignition a parabolic reflector was made. The spread of light emission area (fig. 5b) in this construction until the full lighting of the screen is close to 1 ms and the full glow duration is not less than 5 ms. This makes uncritical a time synchronization with other processes.

The module is easy to manufacture and can be used for photographing of moving objects in transmitted or reflected light. In contrast to the sources [1, 2] with HE, the combustion of Al-CuO mixture is not accompanied by destruction of construction. Cleaning the reflector from the reaction products and installation of a new sample allows to use the construction again.

The light source consisted of two modules was used for photographing of the process of formation and movement of dense flow of micro-particles with a velocity ~500 m/s. Photographing was carried out by the camera Cordin 222-16 with exposure of 0.1-1.0 μs.



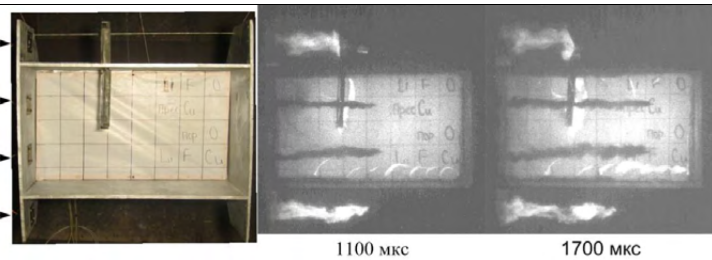
a b

Figure 5. a – A module scheme and a photos of the assembly with two modules with parchment screen on the front. b - A scheme of 4-point initiation of mixture in a line form and a photos of burning fields

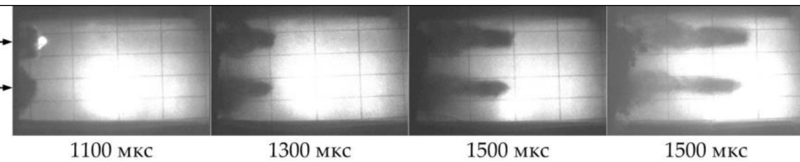
Approximation of X-t diagrams of the front part of the particle flow of non-reacting mixture LiF+CuO, reacting mixture Al+CuO (Fig. 6a, b) and of an inert powder CuO (Fig. 6b), given a values of speed 498 m/s, 491 m/s and 437 m/s, respectively. The proximity of the speed values of these mixtures shows that the release of chemical energy in the particle flow has almost no effect on its speed. The flow rate is determined, in large measure, by total mass of tablet and intermediate steel disc.

- The experimental data on the combustion dynamics of a stoichiometric mixture of Al and CuO powders under different ways of initiation was obtained;
- The obtained data was used to manufacture a modular light source for photographing of slow objects in transmitted or reflected light. The module is easy to manufacture, and combustion of Al+CuO mixture is not lead to destruction of the structure;

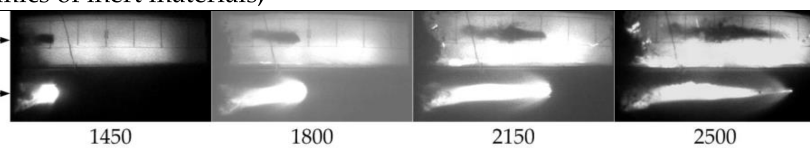
For the data set the optimal mechanical activation level (8 minutes) for micron-sized Al+CuO powders mixture was determined.



a - Mapping the flow dynamics of inert and reactive materials at different initial mixture density;



b - Mapping the flow dynamics of inert materials;



c- Mapping the flow dynamics of inert and reactive materials;

Figure 6. Photos of flows of various powder materials

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ЦИФРОВОЙ ФОТОХРОНОГРАФИЧЕСКИЙ РЕГИСТРАТОР ДЛЯ ИССЛЕДОВАНИЯ БЫСТРОПРОТЕКАЮЩИХ ПРОЦЕССОВ

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Разработка фотохронографов с зеркальной разверткой активно начала развиваться в 50-х годах 20-го века. Разработано несколько десятков моделей и множество модификаций фотокамер, предназначенных для регистрации различных физических процессов. Традиционно, в фотохронографах в качестве чувствительного элемента используется фотопленка. Современным примером такой модификации является установка скоростная фоторегистрирующая УСФ-2, созданная на базе широко известного фоторегистратора СФР [1].

В настоящее время во многих технических устройствах происходит замена фотоплёнки цифровыми устройствами на базе ПЗС- или КМОП-матриц. Применение цифрового устройства регистрации позволяет сократить время извлечения информации и обработки полученных данных, а также уменьшить погрешность измерений.