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ACTION OF A RECTANGULAR PULSE OF A NEODYMIUM LASER ON POROUS METAL TARGETS

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By the method of laser probing the erosion products of porous metal targets of Al and W under the action of a rectangular radiation pulse of a neodymium laser are investigated. The diameters of metal particles in the erosion flame measured using an electron microscope and using laser probing are fairly close, which indicates the reliability of control of particle sizes in real time by the laser probing method. The possibility of decreasing the particle sizes by reevaporating them is shown.

The process of reevaporation of particles in a laser radiation field may serve as one of the methods of decreasing the particle sizes of finely dispersed powders. On the other hand, in experimental investigations problems in producing two-phase flows consisting of plasma and liquid-drop or solid particles as model media often arise. These processes can be realized under the action of laser radiation on targets produced by the method of powder compaction.

In the present work investigations on the action of pulse neodymium laser radiation on porous metal targets produced by compacting aluminum and tungsten powders are carried out. The neodymium laser enabled us to produce radiation pulses of approximately rectangular shape (Fig. 1) with a duration of 400-500 μsec and an energy up to 400 J. The production of these pulses is described in detail in [1]. Tablets of aluminum powder, tungsten powder, and a powder mixture of 30% W and 70% Al by weight produced with the aid of a mechanical press served as targets.

Since with this production method the targets were porous, their destruction differed from that of a target of monolithic metal. When acting on a porous target the heated gas, sharply increasing in volume, separates the particles and in the destruction products the major portion is comprised of the initial particles of the precompacted powder.

The destruction products were investigated using transverse probing of the erosion flame by radiation from an auxiliary ruby laser. The ruby laser generated in the regime of regular pulses of duration 10^{-6} sec each. The total time of generation was 2.6×10^{-3} sec. The ruby laser power density in the probing zone did not exceed 10^4 W/cm^2 lest the probed medium be disturbed. The target was placed in an integrating sphere, as a result of which we manage to simultaneously control the transmission coefficient of the erosion flame $K_{\mathrm{tr}}(t)$, the scattering coefficient $K_{\mathrm{scat}}(t)$, and the absorption coefficient $K_{\mathrm{ab}}(t)$ in the experiment. This method is described in detail in [2]. Collection of information and its storage and processing are automated. In [3] one can find a description of how this is realized concretely.

Experiments on the action of neodymium laser radiation on targets of the tungsten and aluminum powder mixture showed that once a certain laser radiation power density is attained, selective evaporation of the target particles occurs in the erosion flame. The aluminum particles, by reevaporating, form the basic vapor and plasma medium in the flame and the tungsten particles remain unchanged. Figure 2 gives the time variations $K_{\mathrm{ab}}(t)$ and $K_{\mathrm{scat}}(t)$ in probing at different distances h from the surface for a target of aluminum and tungsten, the power density of the acting radiation being 2×10^6 W/cm^2. We point out that the start of the neodymium laser pulse is taken as the reference point.

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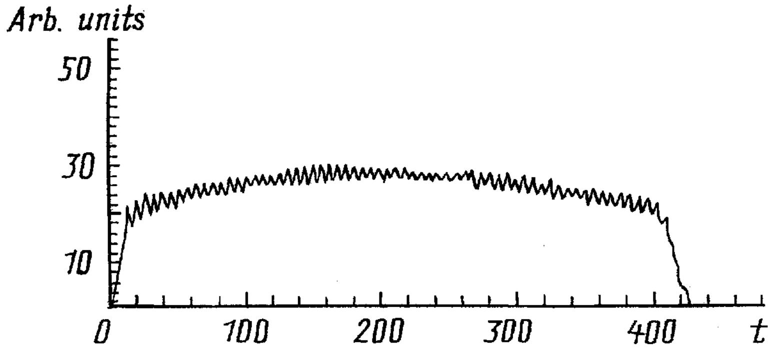

Fig. 1. Shape of the neodymium laser pulse. t, μsec.

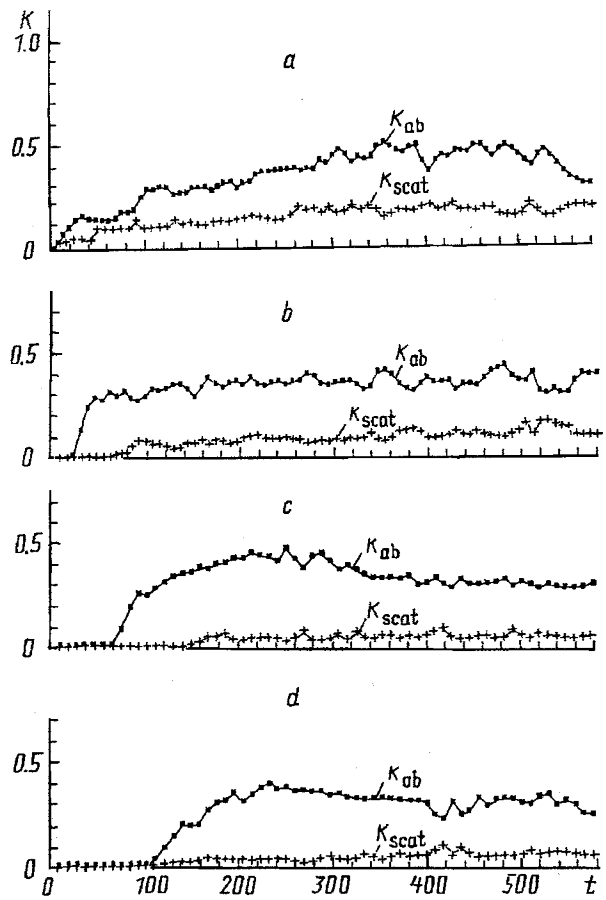

Fig. 2. Time variation of the scattering and absorption coefficients at different probing heights: a) $h = 5$ mm; b) 10; c) 20; d) 30.

As can be seen from Fig. 2, the scattered component of the probing ruby laser decreases with distance from the target, which indicates a decrease in the average size of particles in their motion toward the laser beam. Since the boiling point for aluminum is much lower than that for tungsten, the vapor phase must be comprised mainly of aluminum, and the tungsten particles must not undergo drastic changes. To elucidate this matter, experiments were performed on the action of laser radiation on targets compacted from aluminum powder alone and tungsten powder alone.

To control the size of the tungsten target particles, use was made of a procedure based on experimental ratios of the scattering and absorption coefficients of the probing radiation and the theoretical dependence of this ratio on particle size [4].

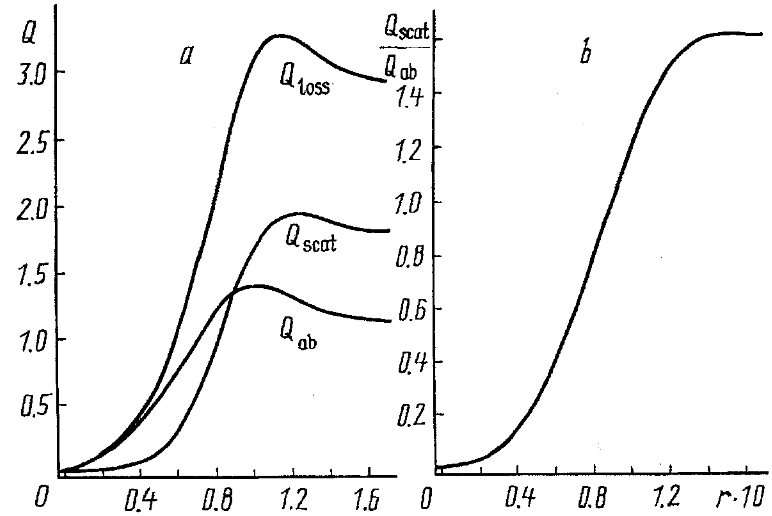

Fig. 3. Theoretical dependences of Q_{loss}, Q_{scat}, and Q_{ab} (a) and Q_{scat}/Q_{ab} (b) on the tungsten particle size. r, μm.

Scattering and absorption of electromagnetic waves are calculated by the Mie theory under the assumption of homogeneity and sphericity of the particles, which is well substantiated in the present experiment. According to this theory, the scattering σ_{scat} and absorption σ_{ab} cross sections are represented as infinite series of complex coefficients:

$$\sigma_{scat} = \pi r^2 Q_{scat}, \quad Q_{scat} = \frac{2}{x^2} \sum_{n=1}^{\infty} (2n+1)(|a_n|^2 + |b_n|^2);$$

$$\sigma_{ab} = \pi r^2 Q_{ab}, \quad Q_{ab} = \frac{2}{x^2} \sum_{n=1}^{\infty} (2n+1)\,\mathrm{Re}\,(a_n + b_n); \tag{1}$$

$$\sigma_{loss} = \sigma_{scat} + \sigma_{ab}, \quad Q_{loss} = Q_{scat} + Q_{ab},$$

where r is the particle radius; $x = 2\pi r/\lambda$ is the diffraction parameter; λ is the incident (probing) radiation wavelength; Q_{loss}, Q_{scat}, and Q_{ab} are the loss, scattering, and absorption factors; Re denotes the real part of the complex expression. The coefficients a_n and b_n are expressed in terms of Riccati-Bessel functions of the first ψ_n and third ξ_n kind and their derivatives [5]:

$$a_n = \frac{m\,\psi_n(mx)\,\psi_n'(x) - \psi_n(x)\,\psi_n'(mx)}{m\psi_n(mx)\,\xi_n'(x) - \xi_n(x)\,\psi_n'(mx)},$$

$$b_n = \frac{\psi_n(mx)\,\psi_n'(x) - m\,\psi_n(x)\,\psi_n'(mx)}{\psi_n(mx)\,\xi_n'(x) - m\,\xi_n(x)\,\psi_n'(mx)}, \quad \xi_n(x) = \psi_n(x) - i\chi_n(x), \tag{2}$$

where $m = m_1/m_0$ is the relative refraction index; $m_1 = m_1' + im_1$ and m_0 are the refraction indices of the particle material and the ambient medium; χ_n are Riccati-Bessel functions of the second kind.

Results of calculations for tungsten are given in Fig. 3. Using the results for the experimental ratio K_{scat}/K_{ab}, and taking into account that $K_{scat}/K_{ab} \approx Q_{scat}/Q_{ab}$ in our case due to insignificant losses of probing radiation, the particle diameter $d = 2r$ is found from the dependence of Fig. 3b.

The sizes of tungsten powder particles were previously determined from the results of numerous measurements by an electron microscope. The size distribution function $F(d)$ of the particles is obtained using these measurements (Fig. 4).

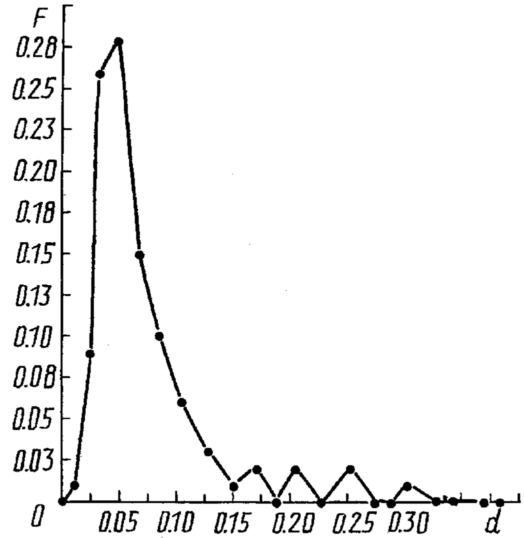

Fig. 4. Tungsten particle size distribution function. d, μm.

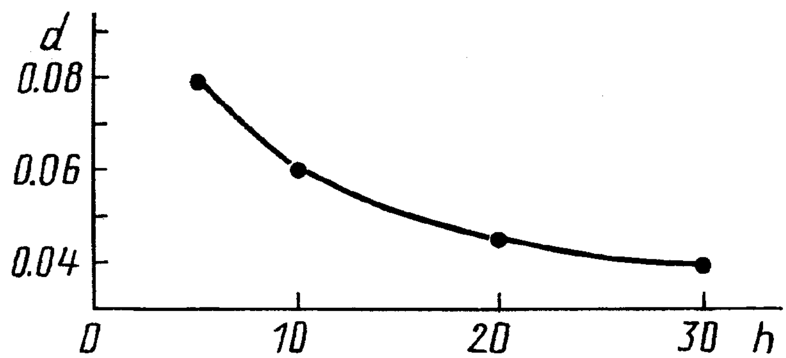

Fig. 5. Variation in the aluminum particle size along the erosion flame. h, μm.

Relations (1) are written for scattering and absorption on one particle. In the case where the particle size distribution function $f(r)$ is known, the average radius of the particles r_{av} is determined by the relation

$$r_{av} = \int_{r_{min}}^{r_{max}} f(r)\, r dr \Big/ \int_{r_{min}}^{r_{max}} f(r)\, dr, \tag{3}$$

where r_{min}, r_{max} are the minimum and maximum radii of the particles; $\int_{r_{min}}^{r_{max}} f(r) dr = n$ is the total number of particles.

Then the effective scattering σ_{scat}^{ef} and absorption σ_{ab}^{ef} cross sections are determined as:

$$\sigma_{scat}^{ef} = \int_{r_{min}}^{r_{max}} f(r)\, Q_{scat}(r)\, \pi r^2 dr \Big/ \int_{r_{min}}^{r_{max}} f(r)\, dr,$$

$$\sigma_{ab}^{ef} = \int_{r_{min}}^{r_{max}} f(r)\, Q_{ab}(r)\, \pi r^2 dr \Big/ \int_{r_{min}}^{r_{max}} f(r)\, dr. \tag{4}$$

Experiments on probing the erosion laser flame of a tungsten target with various power densities of a plasma-forming laser located at various distances from the target surface showed that the destruction products, initially arriving as particles, do not change their size with time in the process of their motion toward the laser beam up to an acting laser power density of 2.7×10^6 W/cm^2. The particle size determined experimentally by the described procedure using probing by ruby laser radiation (λ = 0.69 μm) was d_{ef} = 0.082 μm. Based on the actual size distribution of the particles (see Fig. 4), using relations (3) and (4) the average particle size d_{av} and the effective scattering d_{ef}^{scat} and absorption d_{ef}^{ab} sizes were calculated. They were found to be as follows: d_{av} = 0.075 μm; d_{ef}^{scat} = 0.092 μm; d_{ef}^{ab} = 0.086 μm. The results of measurements by the two procedures are fairly close, which indicates their reliability. Although the measurements using the electron microscope are more detailed, they are very cumbersome and do not enable us to control particle sizes dynamically. Measuring particle sizes by laser probing enables us to control the particles during their motion in real time.

Similar experiments on laser probing of erosion products of targets produced by compaction of pure aluminum powder were performed. At an acting laser power density of 2×10^6 W/cm^2 particle sizes were measured during exposure at different distances to the target surface. The experiments showed that the aluminum particle sizes become smaller with distance from the target, i.e., they reevaporate, forming a vapor medium around themselves (see Fig. 5).

Thus, the action of laser radiation on a target of a mixture of tungsten and aluminum powders at a certain power density leads to selective reevaporation of the particles in the erosion products and enables us to control the qualitative composition of a two-phase flow. This can be very useful when performing some model experiments on studying both erosion products and two-phase flows in general. The investigation showed that a procedure of control of particle size in flows based on laser probing is fairly reliable and enables us to perform measurements in real time.

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