number; $\bar{x} = x/2R$; x, r, φ, cylindrical coordinates; w_x, w_φ, w_Σ, axial, tangential, and total velocities; $\bar{x}_I$, $\bar{x}_{Io}$, lengths of hydrodynamic initial section with swirl and without it; τ_{wx}, $\tau_{\varphi w}$, $\tau_{\Sigma w}$, tangential stresses at wall; $\tan\varphi_{_N} = \tau_{\varphi w}/\tau_{xw}$; $\varphi_\Sigma = w_\Sigma/v_\Sigma^*$; $\eta_\Sigma = yv_\Sigma^*/\nu$; $v_\Sigma^* = \sqrt{\tau_{\Sigma w}/\rho}$; φ, angle of swirl; φ_I, n, eddy-generator parameters; $\Omega = M\sqrt{\rho}/G\sqrt{K_\Sigma}$; $\xi_i = -\Delta E_i/0.5Gu^2$; $\xi_1^* = -\Delta E_1/0.5G_{01}w_{01}^2$; $\overline{\rho_{01}w_{01}}$, mean mass-flow-rate density in eddy-generator cross section; Δ, difference. Indices: s, swirl; eg, eddy generator; in, inlet; w, wall; 00, channel axis; I, initial; 0, maximum.

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STATISTICAL CHARACTERISTICS OF MASS LOST IN

THERMAL DESTRUCTION

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It is shown that there are characteristic pulsations of the concentration of condensed particles in the high-temperature destruction of solids in the absence of gasdynamic pressure.

The thermostability of materials under the action of a high-enthalpy flow is one of the main factors determining the efficiency of operation of much modern thermal equipment. However, many aspects of the thermal destruction of solids remain unclear; in particular, the disperse characteristics of the material produced have been inadequately studied. In calculating the efficiency of thermoprotective coatings the mass lost in the form of disperse phase is often ignored, which leads to significant errors [1, 2]. In considering ablation it is usually assumed [1, 3] that the destruction of a thermoprotective coating in a high-enthalpy flow occurs with the formation, at the surface, of a molten layer, which is then
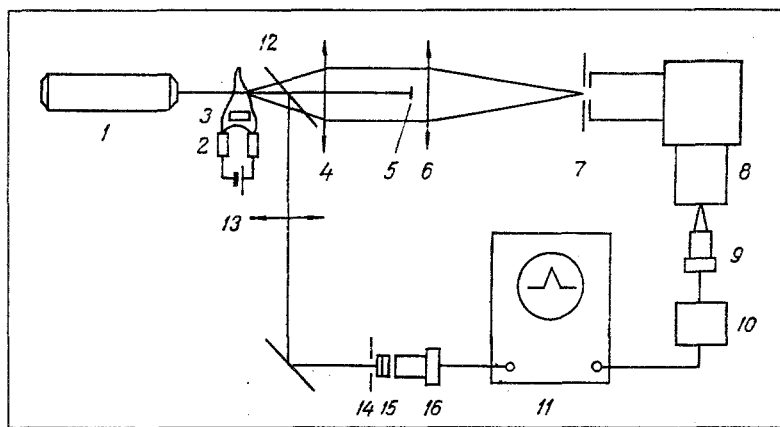
Fig. 1. Schematic diagram of measuring equipment.

drawn away and broken into drops by the flow. However, another possible mechanism is that thermal destruction (pyrolysis) occurs throughout the coating and that the escaping gas carries away particles of condensed phase. The two mechanisms may evidently operate simultaneously.

The present work investigates low-frequency pulsations in the concentration of disperse-phase particles in the ablation flare formed in the thermal destruction (ablation) of solids in a relatively slow flow, when aerodynamic separation of particles from the molten layer is practically absent. The samples were placed in the flare of a dc arc burning freely in air between vertical parallel carbon electrodes. The arc current was 20 A and the electrode diameter 6 mm. The temperature of the flare close to the sample surface was determined pyrometrically and held at 2500°K. The velocity of the convective flows was estimated from the particle trajectories by the transit-time method. Velocity pulsations were practically absent. Preliminary investigations were made of the temperature distribution and electron concentration in the arc flare [4].

The instantaneous values of the particle concentration close to the surface during its destruction were determined from scattering and simultaneously from the absorption of laser radiation.

A diagram of the experimental apparatus is given in Fig. 1. Radiation from an He—Ne laser 1 is passed above the surface of the sample 3 in the flare of a dc arc 2 and is focused by the lens 4 onto the absorbing plate 5 of width 1.5 mm. Light scattered on particles of the suspension in the range $0.05 \leq \beta \leq 0.1$ rad is focused by lenses 4 and 6 onto the inlet slit 7 of a monochromator 8, where a magnified image of the ablation flare is produced. The size of slit 7 is determined by the volume of the apparatus (the longitudinal — with respect to the laser beam — dimension of the object is given by the specimen thickness).

The working volume is 1.2 mm³. The monochromator 8 is used to eliminate the characteristic plasma radiation. The signal from the photoelectron multiplier 9 is fed to the dc amplifier 10 and then recorded by a high-frequency (f = 2 kHz) 12-channel N-700 instrument 11.

Simultaneously, the fluctuations of the absorption are measured. A part of the radiation is separated after passing through the flare using the glass plate 12. Lens 13 produces a magnified image of the ablation flare at the slit 14. The size and position of slit 14 are chosen so that the volumes of both parts of the diagram are the same. Behind slit 14 there is an interference filter 15 and a photomultiplier 16, the signal from which is fed to a vibrator with characteristic frequency 400 Hz of the N-700 recorder.

The radiation intensity scattered by polydisperse ensembles of particles in the range of angles between β_{min} and β_{max} may be written in the form [5]

$$I_{scat} = I_0 \pi N L \int_0^\infty f(r) \int_{\beta_{min}}^{\beta_{max}} \Gamma(r, \beta) \, dr \, d\beta. \tag{1}$$

Earlier [6], under the same conditions, instantaneous distribution functions of the particle size in the ablation flare were measured. It was shown experimentally that the function f(r) varies relatively little with time. Therefore, applying the theorem on the mean to Eq. (1) gives
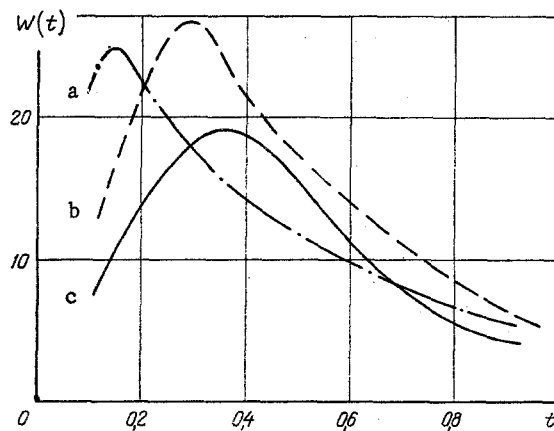
Fig. 2. Probability density of statistical fluc-
tuations of particle concentration in ablation
flare: a) fluoroplastic; b) viniplast (polyvinyl
chloride plastic); c) glass-fiber laminate; t (sec)
is the duration of the pauses between packets of
scattered-light pulses; w(t) is the number of pack-
ets; the time of measurement was 10 sec.

$$I_{scat} \sim N. \tag{2}$$

The value of N is determined from the absorption of radiation in the flare [5]

$$I_{tr} = I_0 \exp\left[-\pi N L \int_0^\infty K(r) f(r) r^2 dr \right]. \tag{3}$$

Hence

$$N = \frac{\ln \dfrac{I_0}{I_{tr}}}{2\pi \int_0^\infty f(r) r^2 dr}; \quad K(r) = 2. \tag{4}$$

The value

$$\frac{1}{2} \ln \frac{I_0}{I_{tr}} = \pi N \int_0^\infty f(r) r^2 dr \tag{5}$$

determined directly from experiment is the total cross section of the particles.

The experimental results indicate that the admission of disperse phase into the volume
of the flare is nonuniform. The signal corresponding to the radiation scattered from the
particles takes the form of characteristic "packets" of pulses alternating with pauses of up
to 1 sec. Against the background of these packets, a higher-frequency structure with a char-
acteristic period of the order of milliseconds is visible.

The curves in Fig. 2 show the probability density of the appearance of packets in the
ablation of various materials during the first 10 sec (the length of the pauses between suc-
cessive packets is plotted along the abscissa).

The scattering peak on the oscillogram corresponds to a particle concentration of the
order of 10^8 cm^{-3}.

Graphical interpretation of the absorption function shows that, on average, the total
number of particles in the volume investigated is close to $5 \cdot 10^2$. Statistical fluctuations
in this case do not exceed 4% and cannot account for the pulsations observed. The fluctua-
tions of the particle concentration in the ablation flare are evidently associated with the
nonuniformity of the destruction of the materials investigated (the presence of inhomogene-
ities, microexplosions, etc.).

The dispersion coefficient K_d, i.e., the ratio between the mass of disperse phase m_d and
the mass loss m, may be determined from the following relations:

$$K_{\mathrm{d}} = \frac{m_{\mathrm{d}}}{m} = \frac{m_{\mathrm{d}}}{m_0 - m_t},$$

$$m_{\mathrm{d}} = d \cdot \frac{4}{3}\, \pi N L v t \int\limits_0^\infty f(r)\, r^3 dr.$$

(6)

The particle velocity is determined using two photomultipliers fed from optical systems at two points of the flare, situated 2 mm apart in the light field; the pulses of light scattered by the particles are recorded using a two-beam oscillograph with memory. The time shift between the pulses allows the particle velocity to be determined (of the order of 2 m/sec).

Because of the variation in physicochemical properties of the surface, the value of K_{d} depends significantly on the duration of ablation.

The values of K_{d} for the first 10 sec of ablation given by Eq. (6) for different materials are as follows: 0.12 for fluoroplastic; 0.60 for viniplast; and 0.35 for glass-fiber laminate.

The experiments allow the following conclusions to be made.

1. The dispersion of particles in the ablation of solids in the absence of gasdynamic pressure is extremely nonuniform; the characteristic frequency of pulsations of the condensed-phase concentration is in the range 2-10 Hz.

2. For the materials investigated, a considerable part (up to 60%) of the mass lost in ablation is in the form of coarsely disperse particles of condensed phase.

NOTATION

I_0; I_{scat}, I_{tr}, intensities of incident, scattered, and transmitted radiation; N, total number of particles per cm^3; L, path length of beam in medium; r, particle radius; f(r), density of particle size distribution; β, scattering angle; β_{min}, β_{max}, minimum and maximum scattering angles; $\Gamma(r, \beta)$, scattering index; K(r), coefficient of effective particle cross section [for $r \geq 1\ \mu$, K(r) = 2]; K_{d}, dispersion coefficient; m_{d}, disperse-phase mass; m, mass lost in ablation; v, particle velocity; d, specific gravity of disperse-phase material; m_0, initial mass of sample; m_t, mass of sample after t sec; t, time of ablation.

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