Journal of Engineering Physics and Thermophysics, Vol. 66, No. 5, 1994

INTERACTION OF LASER RADIATION WITH METALS ENTERING INTO THE COMPOSITION OF IRON-BASED ALLOYS

V. K. Goncharov, V. L. Kontsovoi, and M. V. Puzyrev

UDC 536.33:621.375.826

Optical characteristics of V, Cr, Mn, Fe, Co, and Ni erosion flames were investigated in laser probing of them; quantitative results on dimensions of particles are given and the conditions of their appearance in laser erosion products are determined.

In laser cutting of metals or piercing of holes in them with a certain power density of the laser radiation the erosion products can contain particles of a liquid drop phase that absorb the incident radiation and defocus it [1]. The latter leads to an increase in the cut width or in the diameter of pierced holes. These issues are the most topical in laser treatment of hard steel alloys. To elucidate the physical picture of formation of the liquid drop phase of steel targets of complex composition, it makes sense to study these phenomena on pure metals that enter into the composition of the steels.

The present work is concerned with a quantitative study of the optical characteristics of erosion laser flames in which a finely divided liquid drop phase of the target material forms by volume vapor formation and also with quantitative investigations of the dimensions of the particles and the conditions of their appearance in laser erosion products of targets of vanadium, chromium, manganese, iron, cobalt, and nickel. For this purpose we carried out experiments on probing, by an auxiliary ruby laser, an erosion flame formed under the action of neodymium laser radiation on the targets. The neodymium laser radiation pulse is of near-rectangular shape with a duration of 400-500 μsec. The acting radiation power density was varied within 0.1-10 MW/cm^2 in the experiments. The irradiation spot diameter on the target surface was ~0.9 cm. The power density of the auxiliary ruby laser did not exceed 10 KW/cm^2 so as not to disturb the medium being probed. The ruby laser operated in the regime of generation of regular pulses with a duration of $\sim 10^{-6}$ sec. The total generation time of the ruby laser was ~2 msec. The probing was performed perpendicularly to the erosion flame axis at a distance of 1.5 mm from the target surface. The target of the investigated metal was placed in a integrating sphere, which enabled us to control simultaneously the scattering coefficient K_{sc} and the absorption coefficient K_{ab} of the ruby laser probing radiation. In performing the experiments we obtained and processed information using an automated multichannel recorder and a personal computer. One can obtain more details on the experimental procedure from [1, 2].

As the experiments showed, formation of liquid drop phase particles by volume vapor formartion and hence the appearance of absorption and scattering of probing radiation on them differ rather strongly both in the energy threshold of the onset of formation and in the intensity of the process of volume vapor formation for different target materials. A typical time shape of the acting radiation of the neodymium laser is given in Fig. 1. Figure 2 compares curves of variation of the absorption and scattering coefficients of the probing radiation for erosion flames of the metals in question with the power density of the acting radiation equal to 2.5 MW/cm^2. It is pertinent to note that the start of these curves coincides with the onset of generation of the neodymium laser.

As is well known [3], for particles whose dimension as small compared to the probing radiation wavelength ($d \ll \lambda$) the relation

A. N. Sevchenko Research Institute of Applied Physical Problems, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 66, No. 5, pp. 585-589, May, 1994. Original article submitted December 28, 1992.

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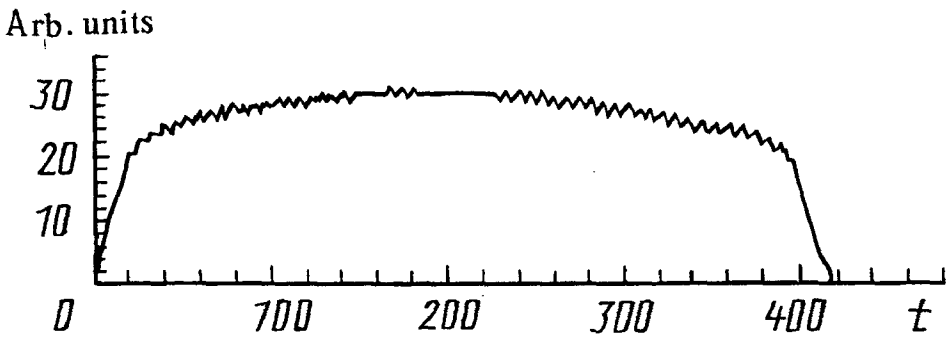

Fig. 1. Time shape of the acting laser pulse. t, μsec.

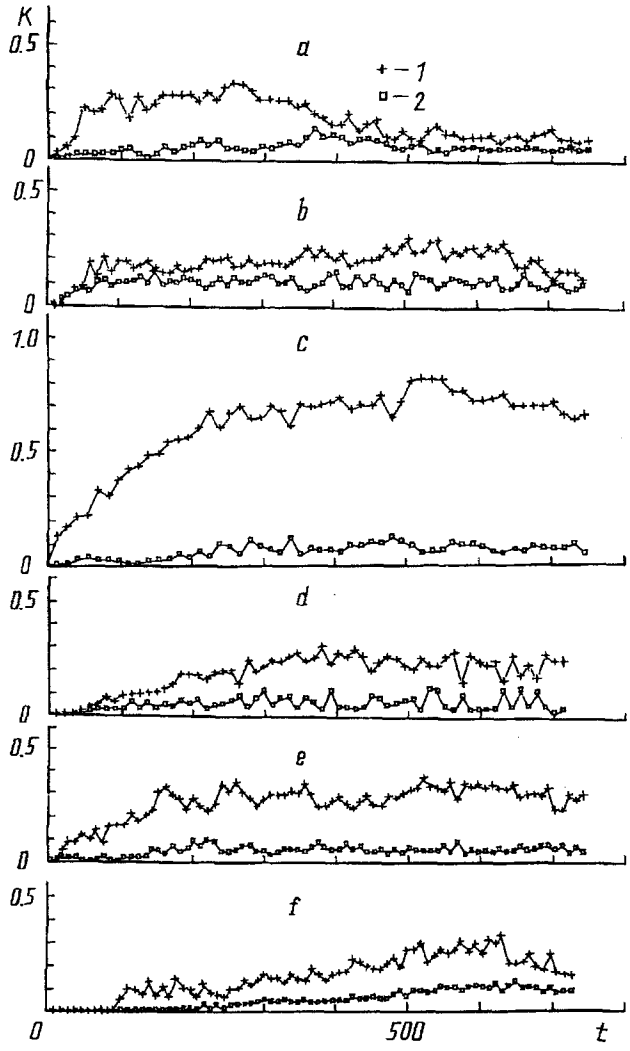

Fig. 2. Time variation of the scattering (1) and absorption (2) coefficients for targets of vanadium (a), chromium (b), manganese (c), iron (d), cobalt (e), and nickel (f).

$$\frac{Q_{sc}}{Q_{ab}} = \frac{\pi^3}{9}\left(\frac{d}{\lambda}\right)^3 \frac{(n^2-\chi^2-1)^2+4n^2\chi^2}{n\chi},$$

is valid, where Q_{sc} and Q_{ab} are the dimensionless scattering and absorption coefficients referred to the cross-sectional area of a particle; d is the particle diameter; λ is the probing radiation wavelength; n and χ are the refractive index the absorption coefficient of the complex refractive index $m = n - i\chi$.

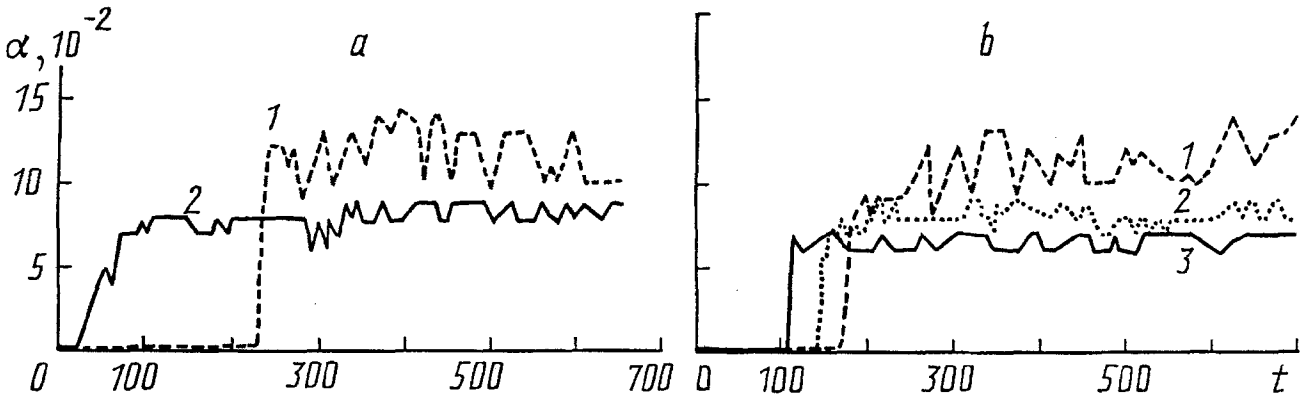

Fig. 3. Time variation of the dimensions of particles of the liquid drop phase for the nickel target (a) with the power density of the acting radiation of the neodymium laser: 1) 1.5; 2) 10 MW/cm^2 and for the cobalt target (b) with the power density: 1) 2.3; 2) 3.3; 3) 7.6 MW/cm^2. α, μm.

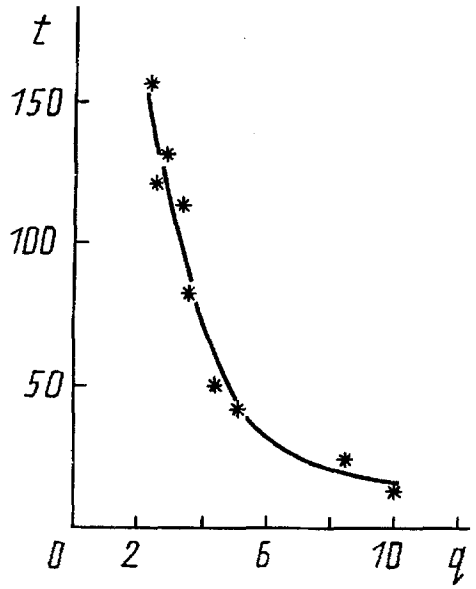

Fig. 4. Delay time of appearance of the liquid drop phase vs power density of the acting radiation of the neodymium laser for the nickel target. q, MW/cm^2.

From this relation it is evident that as the particle dimensions decrease scattering losses of radiation decrease compared to absorption losses. For very small particles absorption, if it takes place at all, becomes the main effect.

From this relation we can also judge quantitatively the dimensions of particles of the liquid drop phase that forms by volume vapor formation in erosion laser flames of the metals in question. As Fig. 2 shows, in all the cases the scattering coefficient is smaller than the absorption coefficient. This suggests that the particle dimensions are much smaller than the wavelength of the probing radiation of the ruby laser (0.7 μm). The smallest particles of the material of the metals in question form in manganese, somewhat larger ones form in cobalt and iron, and the largest particles form in nickel and chromium. Formation of particles of the liquid drop phase in vanadium has a special feature. Rather small particles form in the first phase of exposure and larger ones form in the second phase.

With a power density of 2.5 MW/cm^2 we observe some delay in the formation of the liquid drop phase relative to the onset of the action of the neodymium laser pulse. This delay is insignificant for the vanadium and cobalt targets, is somewhat larger for the chromium and iron targets, and is the largest for the nickel target, which

is associated with the optical and thermophysical characteristics of these metals. The liquid drop phase in the manganese target forms with practically no delay, which is associated with the structure of manganese.

For a more detailed study of quantitative characteristics of the liquid drop phase on some metals we measured the particle dimensions as a function of the action time and power density of the acting radiation. For this purpose the ratios of the absorption and scattering coefficients as a function of the particle dimensions were calculated by the Mie equations. These very ratios were then measured experimentally using the procedure described. The diameters d of the particles in question were determined from a comparison of these results. The present procedure is described in [4] in greater detail. Figure 3 gives the results of these experiments for the nickel (a) and cobalt (b) targets. As the figure shows, as the power density of the acting radiation of the neodymium laser increases the particle dimensions decrease. This is associated with two factors. First, with large power densities the thickness of the liquid metal layer in the action zone is smaller on account of a larger velocity for the evaporation front [5] and the melted layer thickness determines the upper limiting particle dimension. Second, with large power densities, more intense reevaporation of particles by the incident radiation from the neodymium laser occurs and particles with smaller dimensions arrive at the probing zone at a distance of 1.5 mm from the target surface.

The power density of the acting radiation also has a strong effect on the delay of the appearance of the liquid drop phase. As the power density increases the delay decreases, which is well illustrated by the behavior of the curves in Fig. 3. This was studied in greater detail in the action of neodymium laser radiation on a nickel target. Figure 4 gives results of the experiments.

It is pertinent to note that prior to the appearance of particles of the liquid drop phase destruction products in the form of vapors and a weakly ionized plasma form an erosion flame, and a liquid phase forms in the action zone. However, in this case, as the experiments show, the destruction products are transparent to the probing radiation. This case is described theoretically in [5].

Experiments on the action of pulses of neodymium laser radiation with different power density on the targets of the aforementioned metals enabled us to establish threshold power densities for each metal, with which the process of volume vapor formation begins to occur and a finely divided liquid drop phase of the target material begins to enter the erosion flame. Manganese develops the lowest threshold of volume formation, it is 0.22 MW/cm^2. The threshold in vanadium is equal to 0.82 MW/cm^2, in chronium to 1 MW/cm^2, in iron to 1.4 MW/cm^2, in nickel to 2.2 MW/cm^2, and in cobalt to 2.3 MW/cm^2.

The performed investigations can facilitate study of formation of a liquid drop phase in iron-based alloys of complex composition, which is necessary when optimizing the regimes of laser treatment of constructional and high-alloy materials.

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