Experimental verification of the ablation pressure dependence upon the laser intensity at pulsed irradiation of metals

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Abstract. Experiments for verification of a functional dependence of the ablation pressure on the irradiated surface of a target upon the laser intensity in a range from 1.2 to 350 TW/cm^2 have been carried out. For that, at some intensities of the laser irradiation, time intervals between the laser pulse maximum and the moment of the shock-wave front arrival to the rear surface of the target were measured, which are dependent on the ablation pressure. Two schemes of the measurements were used. At the first scheme, at higher laser intensities, the front arrival moment is determined via an electron-optical camera when the rear surface begins glowing. At the second scheme, the front arrival moment is recorded when a probe laser pulse changes the character of the reflection by the rear surface of the irradiated target. Results of measurements are in agreement with the ablation pressure dependence upon the laser pulse intensity within 20%.

1. Introduction

At studying the spall phenomena in our previous works [1–4], for determining the deformation rate and dynamic tensile strength of materials, the method was used based on numerical simulations of shock wave processes at a target irradiated by a laser pulse. At that, in the simulations, the ablation pressure P_a (TPa) at the facial (irradiated) surface of the target was calculated upon the experimental value of the laser pulse intensity I_l (TW/cm^2) via formulas [5]

$$P_a = \begin{cases} 1.2(I_l/100)^{2/3}\lambda^{-2/3}[A/(2Z)]^{3/16} & \text{if } I_l \geqslant 4.3, \\ 1.6(I_l/100)^{7/9}\lambda^{-3/4} & \text{if } I_l < 4.3, \end{cases} \tag{1}$$

where λ is the laser wavelength (μm), A is the atomic weight (at the unified atomic mass units), Z is the atomic number of the target material.

In the present work, we verify experimentally the formulas (1).

2. Measurements

The experiments were carried out at the laser facility "Kamerton-T" of GPI RAS. The pulse duration was $\tau = 2.5$ ns and 70 ps, the laser wavelength was $\lambda = 0.53$ μm.

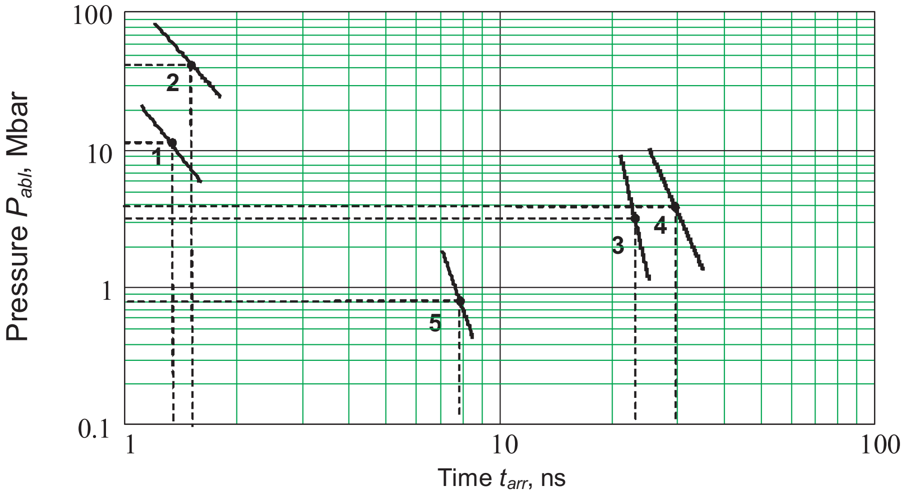

Figure 1. Nomograms for determining the ablation pressure P_a on the facial surface of a target from measured time interval t_{arr} between the laser pulse maximum and the shock front arrival to the rear surface of the target. Digits correspond to numbers of experiments listed in table 1.

Two schemes of the measurements were used. At the first scheme, at higher laser intensities, the front arrival moment is determined via an electron-optical camera when the rear surface begins glowing; the time resolution of the camera was 10 ps. At the second scheme, a probe quasi-continuous laser pulse is directed at the rear surface of the target opposite the zone of irradiation by the main pulse. The front arrival moment is recorded when a probe laser pulse changes the character of the reflection by the rear surface of the irradiated target (when the reflectance decreases abruptly). In the latter scheme, for diagnostics, we used a probe laser DPSS KLM-532-200 (the wavelength is 0.532 μm, the power is about 200 mW), a photodetector THOR LABS High-Speed Photodetector (the frame rate is 5 GHz) and an oscilloscope Le Croy Wave Runner 62 X (the scanning frequency is 600 MHz).

3. Determining of the ablation pressure on the facial surface of the target

The time interval between the laser pulse maximum and the moment of the shock-wave front arrival on the rear surface of target (t_{arr}) is related with the ablation pressure value on the irradiated surface (P_a) because of the shock velocity dependence upon the wave magnitude. For determining this relation $P_a(t_{\text{arr}})$, we carried out simulations using a numerical code based on the Courant–Isaacson–Rice scheme for the hydrodynamic equations [6]. In the code, wide-range equations of state were used for materials in question (aluminum, copper), which are based on the semiempirical model [7]. In the simulations, it was suggested that a temporal and spatial shape of the ablation pressure pulse on the facial surface coincides with the laser pulse shape. Results of the simulations are shown as curves $P_a(t_{\text{arr}})$ in figure 1. Using these curves, for each measured time t_{arr}, the pressure $P_{a,t}$ was determined.

4. Results

Obtained results of the measurements and calculations are presented in table 1. The values $P_{a,t}$ are compared with the values $P_{a,I}$ calculated using equation (1) upon the pulse intensity I_l in figure 2.

Table 1. The target material and thickness d, the laser pulse duration τ and maximum intensity I_l, measured time of the shock arrival on the rear surface of the target $t_{\rm arr}$, the pressure calculated upon the intensity using equation (1) $P_{a,I}$ and upon the measured time via the simulations $P_{a,t}$, and the pressure deviation $\delta_P = |P_{a,I}/P_{a,t} - 1|$.

#	Target	d, μm	τ, ns	I_l, TW/cm^2	$t_{\rm arr}$, ns	$P_{a,I}$, TPa	$P_{a,t}$, TPa	δ_P
1	Al	21	2.5	39	1.33 ± 0.02	0.96	1.11 ± 0.05	0.135
2	Al	45	2.5	350	1.50 ± 0.02	4.2	4.16 ± 0.17	0.010
3	Cu	110	0.07	6	22.9 ± 0.3	0.29	0.32 ± 0.05	0.094
4	Al	200	0.07	8.7	29.3 ± 0.3	0.36	0.380 ± 0.023	0.053
5	Al	50	0.07	1.2	7.8 ± 0.3	0.082	0.080 ± 0.025	0.025

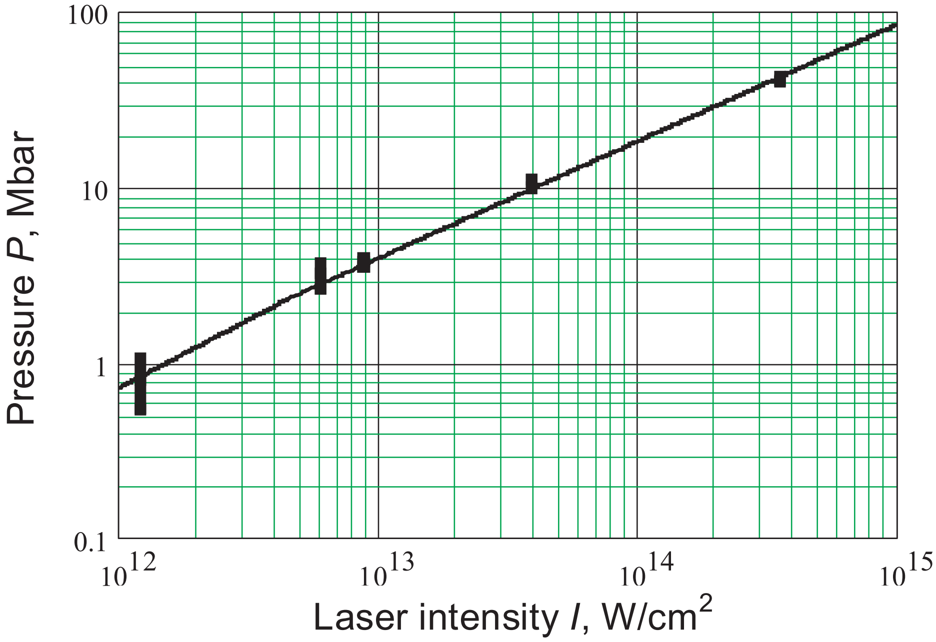

Figure 2. Comparison of results of determining the ablation pressure P_a on the facial surface of targets from the measured time interval $t_{\rm arr}$ (markers) and the laser pulse intensity I_l via equation (1) (solid line).

5. Conclusion

Thus, the results indicate that equation (1) enables to determine the ablation pressure upon the laser irradiation intensity with a deviation no more than 20%. At that, a maximal error of determining the spall strength and the strain rate of materials is 8% and 3.4%, respectively, by a method used in our previous works [1–4].

Acknowledgments

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