# STRAIN EFFECTS DUE TO INTERACTION OF LASER RADIATION WITH A METAL

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Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, Vol. 8, No. 4, pp. 145–146, 1967

It is known [1] that the region of the crater produced by a laser beam in some alloys has "superhigh" hardness, which cannot be produced by any other methods (in the case of low-carbon steel it can reach 1500 $kgf/mm^2$). It has been suggested [2] that this effect may be due to thermal action on the crystals when the energy of the light beam is dissipated.

Below we describe experiments on the interaction of a laser pulse with metals. These experiments confirm the idea of the explosive nature of the destruction of metals. We suggest that the formation of a region of "superhigh" hardness at the site of destruction is due to strain processes similar to those associated with high-temperature hardening.

1. The emission of a solid-state laser operating in free-generation conditions has a complex nature and consists of a large number (of the order of $10^2$) of erratically occurring short ($5 \cdot 10^{-7}$ to $10^{-6}$ sec) pulses, the so-called spikes. The mean interval between them is one or a few microseconds [3].

2. In the experiment we used a laser in which the active element was a synthetic ruby rod 120 mm long and 12 mm in diameter. The wavelength of the emission was 6943 Å. The laser was pumped by an IFPP-7000 xenon flash lamp. The total output energy of the laser emission was about 10 J with a pulse length of $1 \cdot 10^{-3}$ sec.

3. The beam was focused by a lens with a focal length of 56 mm on the surface of zirconium iodide. The action of the laser beam produced a conical crater in the metal. The diameter of the crater at the surface was approximately 1 mm and its depth was 5 mm.

4. We found that the microhardness in the crater was greatly increased and was 650 $kgf/mm^2$, as compared with 150 $kgf/mm^2$ in the initial material.

The specimen was exposed to the laser radiation at atmospheric pressure and in a vacuum chamber at $5 \cdot 10^{-5}$ mm Hg. There was no appreciable difference in the results.

5. The processes occurring in the interaction of the laser emission with the specimens were investigated with an SFR-1 high-speed camera [4] using M3 film with a sensitivity of 65 GOST units. The slit of the camera was parallel to the flame axis, which enabled us to obtain a continuous scan of the interaction products in a direction perpendicular to their motion. A typical picture of the onset of the process is shown in Fig. 1. The scan rate was 15 000 rpm.

The figure shows that the investigated process has a discrete and irregular nature. The target substance is at first driven off in gaseous form (plasma); after some time the liquid phase is also observed. The plasma is not ejected continuously, but in the form of separate bright tongues of flame up to 15 mm high, occurring at intervals of about $10^{-6}$ sec, corresponding to the spike repetition rate. A comparison of the photographs with an oscillogram of the laser emission enabled us to identify these processes.

We inferred that each separate spike acts on the material as an independent micropulse, producing its own microcrater, ejection of plasma, and other effects. This hypothesis was confirmed by the following experiment. On the spindle of a high-speed electric motor we fitted a metal disk of diameter 10 mm. With the motor rotating at 25 000 rpm, measured by means of a MEI strobotachometer, we were able to extend the zone of action of the laser beam to an arc 100 mm long. The trace of the pulse in this case consisted of separate craters of area $10^{-3}$–$10^{-4}$ $cm^2$. The distance between them corresponded to the spike repetition rate (Fig. 2).

An analysis of the photographs gave a value for the time of ejection of the substance and, hence, of the time of formation of the microcrater; it was $10^{-7}$–$10^{-8}$ sec.

6. Since the mean energy of one spike in our case was 0.1 J, the energy flux density at the focal point was $10^{16}$ $erg/cm^2$ sec. Estimates show that such energy densities correspond to pressures of about $10^6$ at. Similar results have been reported by other authors [5].

7. In the light of the above account we can picture the interaction as follows. In a time of the order of $10^{-7}$ to $10^{-8}$ sec there is no appreciable heat transfer into the metal due to conduction. Evaporation cannot ensure complete removal of heat from the target either. The excess energy is concentrated at the focal spot. The absorption region is subject to the action of a very short high-pressure pulse and, hence, most of the absorbed energy is dissipated in the form of an explosion accompanied by the formation of a crater and the ejection of substance in plasma and liquid form. A change in microhardness in the crater region is characteristic of specimens subjected to an explosion [6], where the hardness is greatest at the surface and then decreases rapidly.

8. The similar type of destruction of the metal accounts for the anomalous increase in hardness of the metal in the region directly adjoining the crater formed by the light beam.

We can suggest that the mechanism of this effect is to some extent similar to high-temperature hardening [7], apart from the fact that in ordinary conditions of formation of the hard skin it is difficult to produce such high pressures and rates of heating and cooling as in the described experiments.

In conclusion the authors thank N. V. Barkov for discussion of the work and V. A. Zhuravlev for help in the experiment.

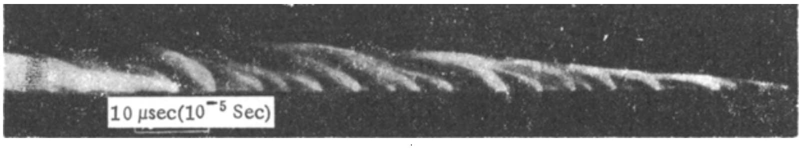


Fig. 1

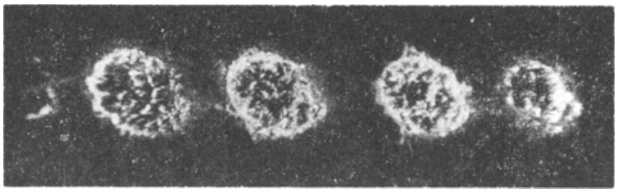

Fig. 2

REFERENCES

1. T. M. Aver'yanova, L. I. Mirkin, N. F. Pilipetskii, and A. R. Rustamov, "Effect of intense light beams on a metal surface," PMTF [Journal of Applied Mechanics and Technical Physics], no. 6, 1965.

2. T. M. Aver'yanova, L. I. Mirkin, and N. F. Pilipetskii, "Effect of a light beam on the dislocation structure of crystals," PMTF [Journal of Applied Mechanics and Technical Physics], no. 1, 1966.

3. B. Lengyel, Lasers [Russian translation], Izd. Mir, 1964.

4. A. S. Dubovik, Photograph of Fast Processes [in Russian], Izd-vo Nauka, 1964.

5. S. I. Anisimov, A. M. Bonch-Bruevich, M. A. El'yashevich, Ya. A. Imas, N. A. Pavlenko, and G. S. Romanov, "Effect of powerful light fluxes on metals," Zh. tekhn. fiz., no. 7, 1966.

6. J. Rinehart and J. Pearson, Behavior of Metals under Impulsive Loads [Russian translation], Izd. inostr. lit., 1960.

7. A. P. Gulyaev, Metal Science [in Russian], Izd. Metallurgiya, 1966.

13 March 1967 Moscow