HEAT TREATMENT WITH HIGH-ENERGY SOURCES

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DISTINCTIVE FEATURES OF THE SURFACE MICRORELIEF OF TECHNICAL IRON IN THE ZONE OF PULSE LASER RADIATION

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The effect of regimes of pulse laser radiation on the formation of the microgeometry of the treated surface of technical iron is considered. The energy density range characterized by the formation of a specific wavy microrelief on the surface of the melt is determined. The variation of its parameters with increase in the radiation energy is studied.

INTRODUCTION

The structural state of the surface layer treated by a laser beam determines the set of physical, mechanical and service characteristics of the surface of a part. The main laws of structure formation in iron and steel after laser treatment by both continuous and pulse radiation are described in [1, 2]. It is shown in some works [3 – 5] that laser treatment by milli- and nanosecond pulses causes fine phase and structural changes in the surface layer and produces a more developed substructure. This is connected with the high rates of heating and cooling and the considerable temperature gradients in the zone of laser effect (ZLE).

In the present work, we studied the microstructure of the laser spot in the plane of the treatment formed as a result of irradiation by a single laser pulse. The necessity of studying the microrelief of a separate spot is connected with the practical use of the technology of spotted laser hardening that involves the deposition of a mesh of laser spots on the functional surface of the part [2].

METHODS OF STUDY

The microstructure and the mechanical properties of the steels were mainly analyzed in the end plane of the specimens over the thickness of the ZLE. Such an approach was determined by practical interest in problems of wear of the surface of parts subjected to laser treatment [2]. It is also interesting to study the laws of formation of the microstructure on the functional surface of a part, i.e., in the plane of the action of a laser beam. It is practically important to study the effect of the parameters of laser heating, in particular, the energy, the pulse length, and the multiplicity of the action, on the microstructure and the microgeometry of the surface.

We studied technical iron after laser treatment in an air atmosphere in a KVANT-18M installation by single pulses lasting 8 msec and by a series of 3, 5, and 10 pulses of the same duration with a frequency of 0.5 – 1 Hz in a regime involving fusion of the surface. The energy density of the radiation q was varied within the range 3 – 24 J/mm^2. The diameter of the laser spot remained virtually constant ($d \cong 0.9 - 1.0$ mm). The polished sections for microstructural analysis were etched for 3 – 5 sec in a freshly prepared solution of nitric acid in hydrogen peroxide in equal proportions. The structure was studied under an MIM-7 light microscope. The microhardness was measured by a PMT-3 device under a load of 1 N on the indenter.

RESULTS AND THEIR DISCUSSION

The structure of the laser beam after irradiation in a wide range of energy density can be conventionally divided into two zones, namely, a transition zone and a remelting zone (Fig. 1*a* and *b*). The boundaries of the zones are well discernible and etchable. This indicates that a considerable number of defects have accumulated over the boundaries of the zones.

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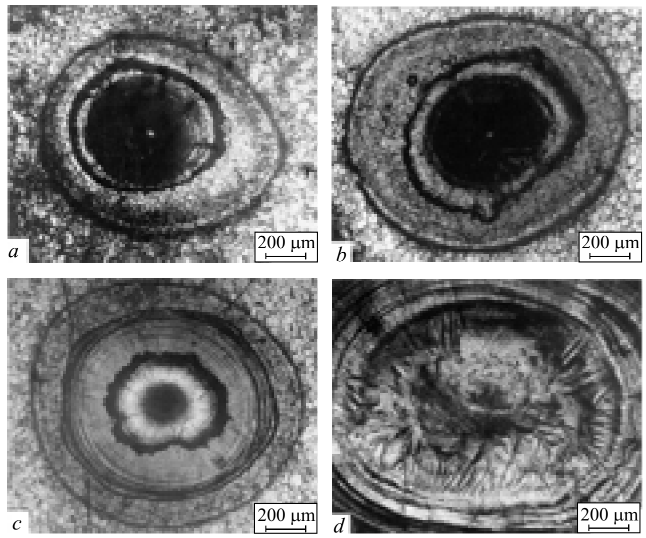

Fig. 1. Microstructure of technical iron in ZLE after laser treatment with different energy densities: *a*) $q = 3$ J/mm^2; *b*) 6 J/mm^2; *c*) 14 J/mm^2; *d*) 17 J/mm^2; *a – c*) × 65; *d*) × 100.

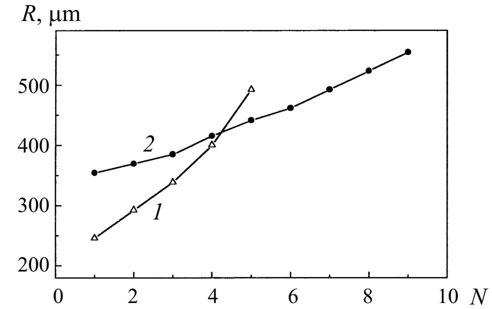

Fig. 2. Characteristics of a wavy relief (*N* is the number of the crystallization ring and *R* is its radius) after laser irradiation with different energy densities: *1*) $q = 9$ J/mm^2; *2*) 14 J/mm^2.

At an energy density of less than 5 J/mm^2, the surface of the zone of remelting in the central part of the ZLE has a convex cone-like shape and is etched poorly. The microhardness of this zone is 3100 – 3200 *HV* (at an initial value of 1500 – 1600 *HV*). The microhardness changes over the diameter of the spot by a curve with maximum in the center. The microhardness of the transition zone increases inconsiderably (as compared with the initial one) and is equal to 2000 – 2200 *HV*.

With the increase in the energy density of laser radiation the diameter of the ZLE and the width of the transition zone increase somewhat. There are no great changes in the diameter of the zone of remelting (Fig. 1*a* and *b*).

In an energy-density range of 6.3 – 19 J/mm^2, the laser spot has a wavy relief (Fig. 1*c*). The central part of the zone of remelting is represented by a crater formed as a result of the outbursts and evaporation of the metal in this region, which is typical for a laser thermal shock. The burst-out metal forms a mound 50 – 100 μm high etched to a structure resembling that of "white layers." The surface waves are represented by concentric closed rings that often have an irregular shape; the height of their ridges is 5 – 10 μm. The wave period increases monotonically with the distance from the center of the laser spot (Fig. 2). In various tests, the number of waves changed from 3 to 20 – 30.

The variation of the microhardness on the surface of the wave ridges is connected with the considerable methodological difficulties due to the small size of the areas of their tips, which does not allow us to form a normal indentation. Such an indentation occurs only when the tip of the wave is ground-off to a depth commensurable with its height. The values of the microhardness of the surface of the ground-off ridge and the neighboring regions of the laser spot are virtually the same. Consequently, the appearance of the mentioned waves is not connected with liquations of the chemical composition or other inhomogeneities on the surface of the melt but is rather determined by the features of the propagation of impact waves in the molten pool. Etching-off or grinding-off the of a part of laser spot to a depth of up to 100 μm does not leave traces of surface waves in the volume of the laser crater. This means that the wave microgeometry has a surface nature.

It has been shown earlier that the formation of a wavy relief on the surface of the metal is determined by the hydrodynamics of the molten pool produced by the laser and can be a result of resonance of gravity-capillary and heat-capillary waves [6 – 8].

A similar relief was observed in through piercing of thin aluminum foils in [9] and in laser treatment of niobium in [10] and of KhVG steel in [11]. It should be noted that in all the works where a wavy structure was observed on the surface of the metal, the laser beams used were incident in pulses with a length of the same order of magnitude (about 10^{-3} sec).

Based on the results of the given study, we can speak of the existence of two threshold values of energy density within which the conditions are favorable for the formation of a wavy relief. In our tests, the lower boundary of energy density before which we did not observe a wavy structure corresponded to $q = 6.3$ J/mm^2; the upper boundary above which a crater formed on the surface was $q = 19$ J/mm^2. We determined a nonmonotonic dependence of the number of surface waves on the energy density of the radiation and their surface instability ($n = 7 – 10$) in the range $q = 11 –$ 18.9 J/mm^2 (Fig. 3). For energies of 4 and 12 J (at $\tau = 8 \times 10^{-3}$ sec and $d = 0.09$ cm), the approximate values of the lower and upper thresholds of the power density were $w = 78.6$ and 235.7 kW/cm^2, respectively.

The wavy relief is also associated [9] with the motion of the molten surface that arises in the vapor stream under a thermal shock as a result of the development of gas-dynamic vortexes. In this case, a certain role can be played by the effect of self-excited oscillations [12] caused by the temperature fluctuations on the surface of the melt due to the heating of the melt by a laser beam with an energy density exceeding

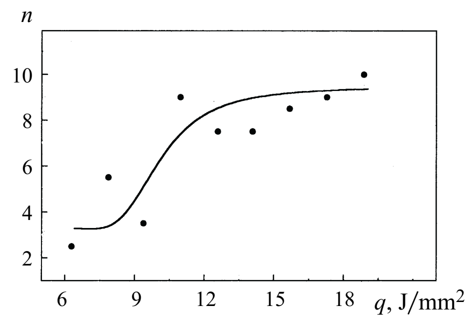

Fig. 3. Dependence of the number of surface waves *n* on the energy density of the radiation.

some critical value. The presence of temperature fluctuations slowly damping with time indicates the existence of resonance modes of metal heating.

When the treatment consisted of a series of pulses, the typical wavy microrelief was absent or poorly manifested.

The formation of a developed wavy structure seems to be expedient in places of contact between rubbing surfaces for holding the lubrication or improving the friction properties of the parts.

When the energy density of the laser radiation is increased within the range 14.9 – 19 J/mm^2, the crater formed in the central part of the laser begins to grow, which means that the volume of the evaporated metal has increased. At the same time, we observed the formation of additional surface waves mainly on the periphery of the zone of remelting. The structure of the surface obtained in laser treatment within this range of energy density is interesting in the fact that a great number of columnar dendrite crystals form on the surface of the crater (see Fig. 1*d*). The axes of these crystals can be regularly oriented along the direction of heat removal or can be random. This indicates that the temperature gradient in the plane of the laser spot is quite inhomogeneous. The most "regular" radial orientation of the axes of columnar crystals from the center of the laser spot to the original matrix was observed in the transition zone.

When the energy density was increased to $q > 20$ J/mm^2, we again observed the formation of two zones, the central of which (the zone of remelting) was a crater of considerable size.

CONCLUSIONS

1. Pulse laser treatment in a wide range of energy density in the plane of the action of the beam produces two zones, i.e., a transition zone and a zone of remelting, divided by distinct dark-etching boundaries.

2. Laser treatment under resonance conditions by pulses lasting several milliseconds causes the appearance of waves on the surface of the melt and the formation of a wavy relief in subsequent crystallization. We have determined the range of intercritical values of energy density in which we observed the formation of waves with a nonmonotonic dependence of the number of surface waves on the radiation energy.

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