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PHASE CONVERSIONS IN STEEL UNDER THE INFLUENCE OF A BEAM FROM A CONTINUOUS-ACTION LASER

by

A. I. Barchukov, L. I. Mirkin

EDITED TRANSLATION

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В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
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Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

PHASE CONVERSIONS IN STEEL UNDER THE INFLUENCE OF A BEAM FROM A CONTINUOUS-ACTION LASER

A. I. Barchukov, L. I. Mirkin

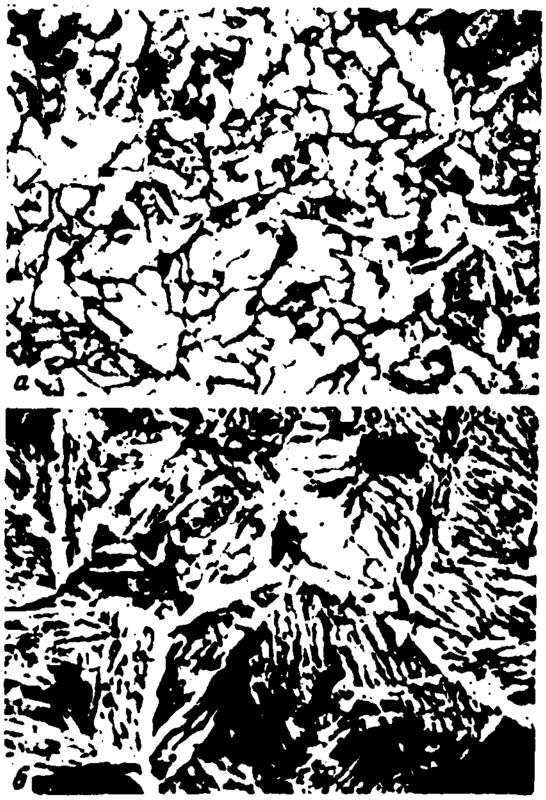
Studied is the influence on steel of an intense light beam of a continuous-action laser. Metallographic and rentgenostructural investigations and measurements of hardness showed that, depending on the composition of the steel after irradiation, we observe effects of coarsening of grains, decarbonization, hardening and annealing. The action of a continuous laser radiation is compared with other types of action on steel.

The action of a laser's light pulses on steel, as is known, can lead to hardening of annealed steel [1], secondary hardening of hardened steel [2] and a number of other effects of heat treatment. It was of interest to study the action on steel of an intense light beam of a continuous laser.

Carbon and alloyed steels of various composition with various purity of treatment of the surface were subjected to the action of a beam of a continuous CO_2 laser (IR radiation, wavelength 10.5 μ), focused with the aid of a concave mirror on the surface of metal samples. After the action of a beam for various amounts of time (from 1 to [illegible] seconds), we conducted metallographic and roentgenostructural investigations and measurements of hardness. With irradiation for a period of the first 0.[illegible] to 1 sec, we observe a darkening of the sample's surface, after which there occurs a cavern whose depth gradually increases with further irradiation. With some modes of irradiation, we can acquire fusion of the metal without formation of a cavern.

The results of structural investigations show that, depending on the composition of the steel, we can observe different effects with irradiation. We shallpresent several typical examples.

Figure 1. Structure of low-carbon steel (0.2[illegible] %) before irradiation (a) and after irradiation (b). x[illegible].



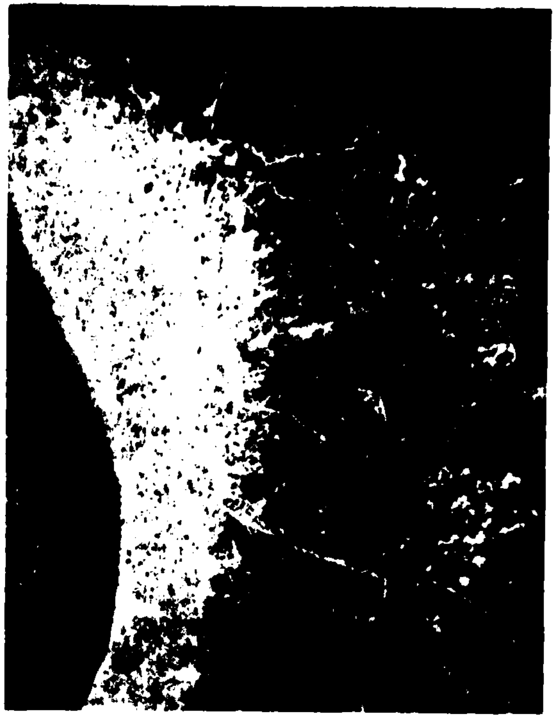


Figure 2. Structure of steel containing 0.7% C, after irradiation. x70.

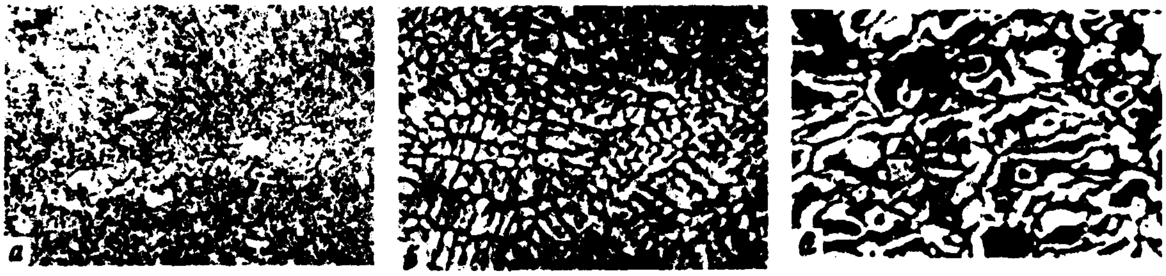
Effect of coarsening of the grains. With irradiation of low-carbon steel (0.2-0.3% C), there occurs large-grained Widmanstätten structure. On the edge of the crater, we observe clarified grains of ferrite. We do not observe a substantial change in hardness in comparison with the initial annealed state. For an illustration of the degree of coarsening of the grains with the formation of Widmanstatten structure, Figure 1 presents microphotographs of steel before and after irradiation taken with one and the same magnification.

Effect of decarbonization. With irradiation of steel containing a greater amount of carbon, for example steel 70 (0.7% C), we observe an additional effect of decarbonization to a depth of up to 0.6 mm from the surface of the cavern (Fig. 2). In the initial state, the steel consists of pearlite and ferrite lattice. In the decarbonized region, we observe weakening and a Vikkers hardness is 90 kG/mm² instead of 170 kG/mm² in the initial state.

Hardening effects. Strengthening effects due to hardening are observed in steels which are hardened well in air. As an example, let us examine the results acquired on the fast-cutting steel R9. The initial structure of the samples is granular pearlite with a hardness of 300 kG/mm^2 and carbides. After irradiation and cutting we see that the zone with a changed structure has a length of about 3.5 mm.

The surface zone (zone 1) of the crater has a dendritic structure with a microhardness of 765-925 kG/mm^2. Apparently, there occured in this zone hardening from fusion with the formation of a martensite-austenite structure. Further, there occurs the region of large equiaxial light grains with a microhardness of 645-765 kG/mm^2, which apparently correspond to the troostite-martensite structure (zone 2). The following zone with a large amount of troostite has dark grains with a microhardness of 550 kG/mm^2, then there occurs the thin layer of troosto-sorbite with a hardness of 320-470 kG/mm^2 and, finally, the initial structure. Some of these structures are given in Fig. 3.

Figure 3. Structure of fast-cutting steel R9 before irradiation (a) and after irradiation: first zone (b) and third zone (c). x450.



Hardening of steel R9 with the influence of a continuous laser's beam is also supported by the results of rentgenostructural investigations. Photographing of rentgenograms was done on the URS-50 IM device in the radiation of an iron anode with recording of intensity by a scintillation counter. Before irradiation, we observe on the rentgenograms lines of ferrite and carbides; after irradiation, we observe on the rentgenograms of the surface layer typical lines of martensite and austenite. Some results of measurement of the rentgenograms are given below.

Treatment	Width of lines				Location of maximum (110), ~ rad
	110	200	Radian·10^{-3} 211	220	
annealing	5.7	7.4	9.6	19.0	28°27'
irradiation	13.5	—	23.8	—	28°07'

Dashes correspond to very large expansion of the lines; here, the intensity of the maximums becomes so low that we cannot measure the width of the lines. Thus, the results of an X-ray analysis support the effect of hardening of fast-cutting steel with the influence of continuous-laser radiation.

We must point out that with selection of the mode of irradiation causing not the formation of a cavern but fusion, which was usually successfully done for thin cross sections, we obtained a hardened zone with a diameter of up to 10 and with a depth of up to 2 mm. On the surface of the sample here, we often observed a deposit.

Effects of secondary hardening. Let us examine the results of irradiation of fast-cutting steel subjected to preliminary hardening. In this case, the initial structure consisted of martensite and a large amount of fine carbides. The microhardness was 710 kG/mm^2. In zone 1, close to the surface of irradiation, we observe martensite with a coarse carbide lattice, and hardness increases to 850 kG/mm^2. Behind that, zone 2 consists of large grains containing fine carbide impurities; the hardness of this zone is 925 kG/mm^2.

Effects of annealing. Effects of annealing were observed in many cases of irradiation of heat-treated samples. They were particularly clearly apparent with burning-through of film made of high-carbon steel U10 (1.0% C), where the dimension of the annealed zone reached several centimeters. Indicators of the presence of annealing were acquired both by metallographic and X-ray means.

On the basis of the results of structural investigations, we can propose the following physical mechanism of processes which occur with the action of a continuous-action laser's beam on steel.

At the beginning of irradiation, part of the energy of the light beam is reflected, and part is absorbed at a depth of an order of a micron, heating the metal. A further sequence of phenomena is connected with the relationship between the speed of advance of energy and the speed of its distribution due to heat conductivity. With a speed of heat distribution exceeding the speed of advance of energy and equal to it, there occurs heating of the entire sample, and the structural effects in this case resemble those observed with contact heating of the same material.

With the rate of heat distribution substantially less than the speed of advance of energy, there occurs heating, fusion and evaporation (or combustion in an oxidation atmosphere), mainly of the surface layer of the sample. Fusion, as follows from direct measurements [3], leads to a sharp decrease in the coefficients of reflection of metals, i.e. to an increase in the fraction of absorbed energy and to an increase in the speed of heating. With heating, there can occur changes in the chemical composition of alloys, for example decarbonization of steel, changes in structure, for example annealing, alpha-gamma transition, solution of carbides, etc.

After completion of the action of the beam, there occur processes, to a significant degree determined by the resulting distribution of temperatures in the sample and cooled by the ability of the environment. So, with various combinations of these conditions, we can acquire annealed, hardened or recrystallized structures, i.e. practically all basic structures obtained with heat treatment of alloys.

There is interest in comparing the action of continuous-laser radiation with other variations of action on metal.

A comparison with the action of a pulsed light beam shows that some similarities are observed only for steels which harden well in air. For all other cases, the action of a continuous-laser beam resembles the slower variations of heating, for example heating with an open flame.

Meanwhile, the use of a continuous-action laser for heating of metal has a number of advantages. Specifically, a noncontinuous beam can interrupt with any assigned rate, changing thus the rate of heating and cooling of the metal, i.e. selecting the optimal mode of treatment. This advantage, as is known, is absent in pulsed lasers which operate in a mode of free generation, where the possibilities of change in pulse duration are not great. Treatment of the surface along stencils provides the possibility of acquiring heat-treated regions of random form.

There is still another interesting possibility - conducting experiments for saturation of the surface of metals with other elements of solid, liquid or gas phases. Tests in the use of pulsed lasers for this goal showed the promise of such a method of saturation [4].

Let us note that for heat calculations of the processes of treatment of metals with a continuous laser beam, we apparently do not need the development of a new apparatus, but we can use existing solutions to the problems which arise with an analysis of heating of metal with usual welding and heat-treatment, with consideration of the change in coefficient of reflection of metals with phase transitions.

In conclusion, the authors thank T. I. Aver'yanov and L. I. [illegible] for aid in conducting the experiments and I. [illegible] [illegible] for discussion of the results.

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