13. A. N. Bortsov and N. M. Fonshtein, "The influence of cold working and low-temperature tempering on the mechanical properties of two-phase ferritic-martensitic steels," Fiz.-Khim. Mekh. Mater., No. 2, 56-61 (1984).

FEATURES OF THE STRUCTURE AND PROPERTIES OF HIGH-SPEED STEELS AFTER LASER TREATMENT

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For development of scientifically based laser heat-treatment cycles for high-speed steel tools it is necessary to establish the relationship between the irradiation conditions and the structures and properties of the steels formed in the zone of action of the light beam. Existing information on this question refers primarily to R6M5 and R18 steels. For steels with an intermediate tungsten content and additionally alloyed with vanadium, cobalt, and molybdenum such data is limited although such steels are widely used for machining of difficult to machine materials. In connection with this an increase in the life of cutting tools of these steels is especially important.

This article presents the results of an investigation of the influence of pulsed laser treatment on the structure of the irradiated layers and the structure and properties of previously hardened R9K5, R9M4K8F, R10K5F5, R12F5M, and R12F2K8M3 high-speed steels. The specimens were laser treated on a Kvant-16 machine in air. After irradiation transverse microspecimens were prepared, etched in a 10% ethyl alcohol solution of HNO_3 using the method described in [1], and then investigated by metallographic, electron microscopic (carbon replicas tinted with tungsten oxide), x-ray diffraction, and microhardness methods. The electron microscopic and x-ray methods of investigation were used after layer-by-layer grinding off of the surface layers of the irradiated areas, which made it possible to clearly compare the data obtained with the results of metallographic investigation.

The carbon content in the α-solid solution was determined by the method presented in [2]. The microhardness was measured on the transverse specimens in the center portion of the irradiated volume on a line coinciding with its axis of symmetry (Fig. 1a). The life tests of the laser treated tools were made using the method described in [3, 4]

The irradiated portions formed under the action of the pulses, the power density of which exceeds 320 MW/m^2, consist of three characteristic zones with different structures (Fig. 1b), which are responsible for the character of change in microhardness (Fig. 1c).

In the original condition (zone I) the microhardness of R9M4K8F steel is 880H. In laser treatment the hardness of the steel in zone II (tempering zone) drops as the result of decomposition of the martensite. The minimum microhardness (760H) is observed at the boundary with zone III (heating temperature corresponds to the Ac_1 point) [5]. The results of electron-microscopic investigations made is possible to establish that in the zone considered even after treatment at temperatures close to the Ac_1 point the size of the carbide particles does not exceed the size of the carbides formed in standard tempering in through heat treatment (Fig. 2a, b). Consequently, in laser treatment in the subcritical temperature range coagulation of the carbide particles does not occur since the heating time is short.

On the basis of the results presented it may be concluded that in contrast to normal tempering in the 560°C-Ac_1 temperature range, in which the reduction in hardness is caused both by decomposition of the martensite and by coagulation of the carbide phases [6], in laser treatment softening occurs only as the result of decomposition of the solid solution. This may be explained by the fact that after laser treatment in the temperature range considered the hardness of the steel is significantly higher than after normal tempering (for R9M4K8F steel after tempering at temperatures close to Ac_1 760H and 400H, respectively).

The maximum microhardness is reached at the boundary with zone IV (heating temperature corresonds to T_s, the solidus temperature) [5]. In external appearance the structure of

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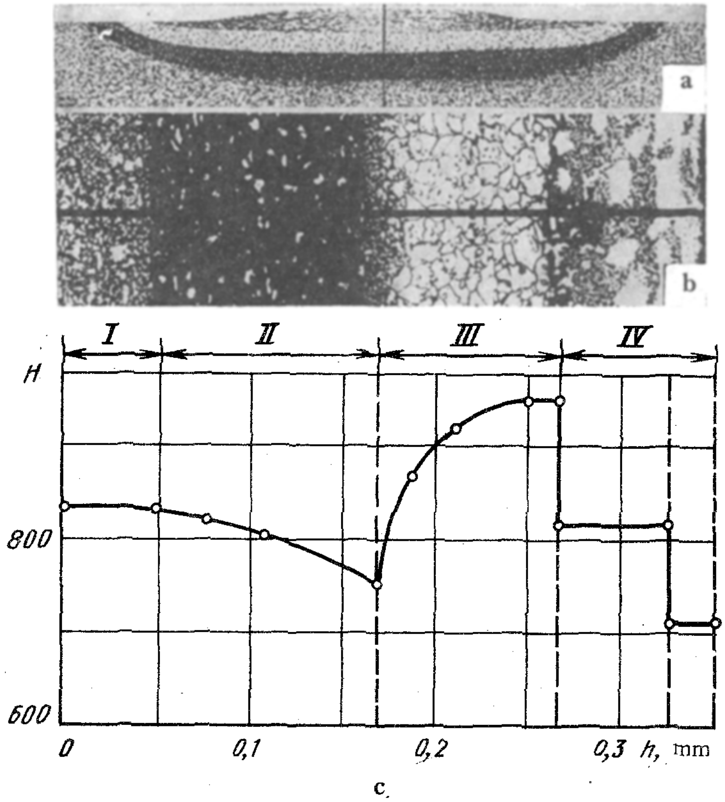

Fig. 1. Structure of the irradiated volume (a, b) and the change in hardness in the zone of action of the laser radiation (c) of R9M4K8F steel (power density 40 MW/m^2, h is the distance from the surface): a) 100×; b) 450×.

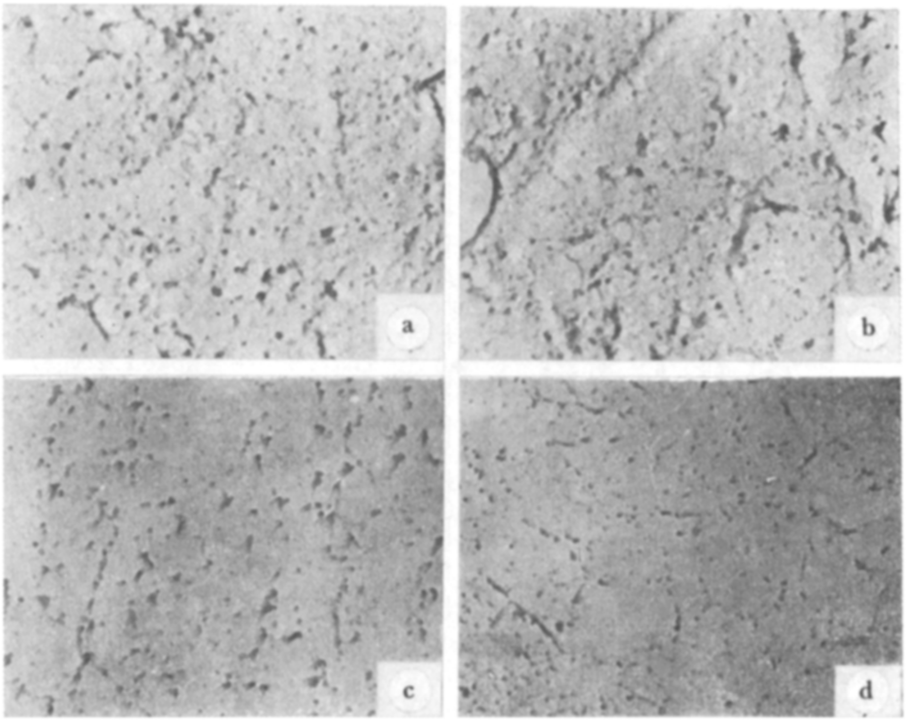

Fig. 2. Secondary carbides in R9M4K8F steel (extraction relicas) after standard (a) and laser (b–d) treatments (2500×): b) zone II (heated close to Ac_1) c) zone III (heated close to Ac_1); d) zone III (heated close to T_S).

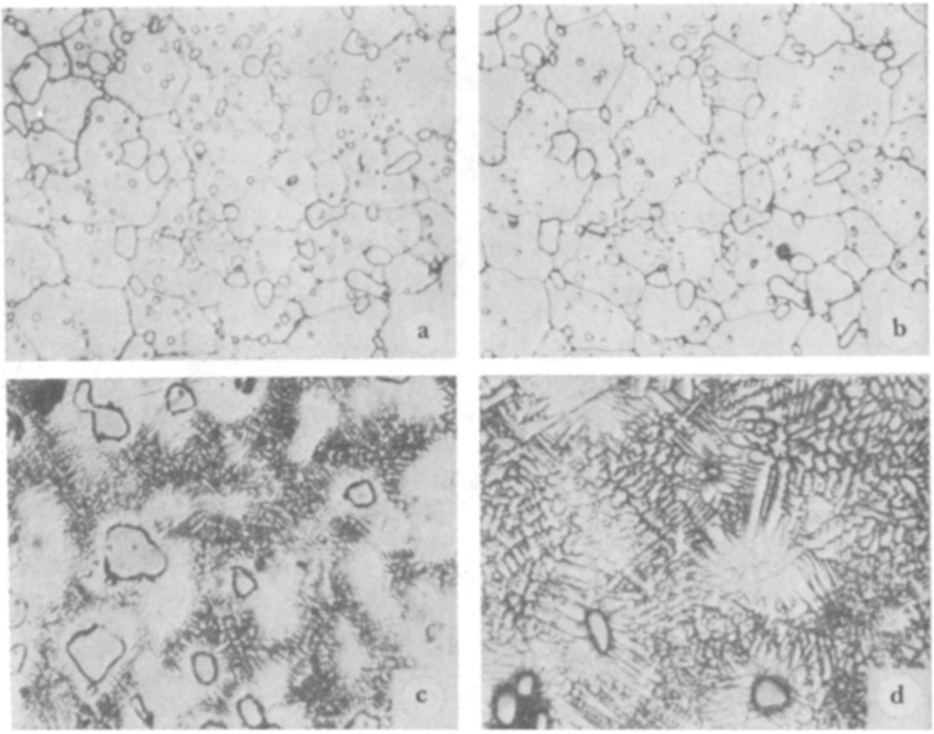

Fig. 3. Structure of R9M4K8F steel after through (a) and laser (b-d) hardening: b) zone III; c, d) zone IV; a, b) 700×; c) 600×; d) 1500×.

high-speed steels is practically the same after laser treatment and after through hardening (Fig. 3a, b). Consequently in laser treatment (the same as in through treatment with a high heating rate) in repeated heatings under the action of radiation in the Ac_1-T_S temperature range restoration of the original austenitic grain size occurs [7].

The investigation results showed that after laser treatment the martensite of R9M4K8F steel contains 0.4% C and after through hardening and the standard heat treatment (hardening with a triple temper at 560°C) 0.6 and 0.2% C, respectively [8]. Since during the time of action of a pulse even in heating to temperatures close to T_S the secondary carbides are able to dissolve only partially in the austenite (Fig. 2c, d),; the carbon content in the martensite formed during laser hardening is lower than after through hardening but higher than after the standard heat treatment.

With the help of the x-ray method of investigation it was established that in the structure of high-speed steels after laser treatment there is practically no residual austenite even in cooling from temperatures close to the solidus temperature (Fig. 4b) while after through hardening from the same temperatures its content reaches 40% [8, 9]. This may be explained by the fact that the austenite formed in the zone of secondary hardening is impregnated to a lesser degree with carbon and alloy elements than in normal hardening. In addition this is apparently also caused by the decrease in the quantity of residual austenite in cooling at high rates, which is observed for constructional steels [10]. The absence of residual austenite in the structure of the steels after laser hardening from temperatures close to the solidus temperature may also explain the fact that their hardness does not decrease as is observed in through hardening.

In zone III the structure of laser treated high-speed steels is microcrystalline martensite containing 0.4% C and eutectic secondary carbides not capable of dissolving during the time of action of the pulse. After through hardening microcrystalline martensite (about 0.6% C), residual austenite, and eutectic carbides are formed in the structure of the steels, and after the standard heat treatment tempered martensite (about 0.2% C) and eutectic and secondary carbides.

The results obtained provide a basis for assuming that the higher hardness than after standard heat treatment reached as the result of laser treatment is caused not only by the increase in density of crystalline structure defects [11], refinement of the areas of co-

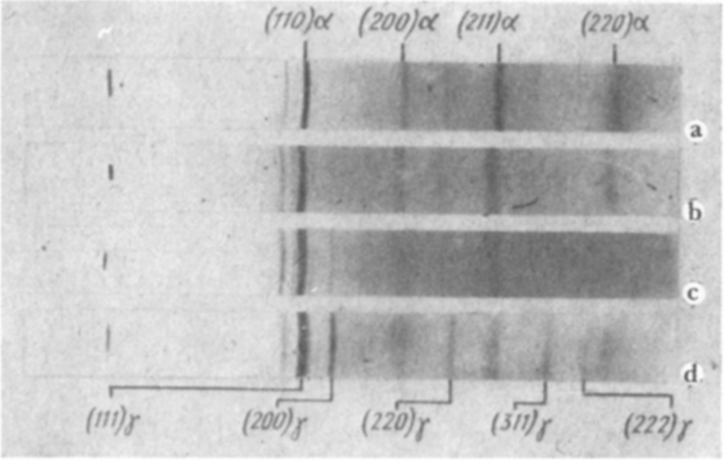

Fig. 4. X-ray diffraction patterns of R9M4K8F steel: a) standard heat treatment; b-d) laser treatment: b) zone III (at the boundary with zone IV); c) zone IV (at the boundary with zone III); d) zone IV (at the surface of the specimen).

herent scattering [12], and the occurrence of microchemical inhomogeneity [13], but also by the increased carbon content in the martensite, the presence of dispersed carbides, and the absence of residual austenite.

In zone IV in addition to eutectic carbides light and dark structural constituents having either a dendritic or a cellular structure are observed (Fig. 3c, d). This is an indication of the fact that zone IV was formed during solidification from a liquid. According to the data of x-ray microspectral analysis, the light areas (R9M4K8F steel) contain 12.3% W, 5.7% Mo, 3.4% V, 4.3% Cr, and 8.8% Co and the dark 6% W, 3.0% Mo, 1.8% V, 4.1% Cr, and 8.9% Co, which practically coincides with the chemical composition of the martensite after through hardening from the optimum temperatures: 5.2% W, 2.8% Mo, 1.7% V, 3.7% Cr, and 8.9% Co [8]. The higher content of the elements in the light areas may be explained by the fact that they are formed from the liquid surrounding the carbide particles (Fig. 3c, d). With an increase in temperature (with approach to the surface) the quantity of dark areas in the structure of the steels decreases and the quantity of light increases. With the help of metallographic and x-ray investigations, it was established that the formation of the light structural constituents coincides with the appearance on the x-ray diffraction patterns of lines of γ-phase, the intensity of which also increases with an increase in irradiation temperature (Fig. 4c, d). This makes it possible to identify the white areas as residual austenite (apparently a small quantity of martensite is present in them), which is confirmed by their relatively low microhardness (600 H). The dark areas are martensite of dendritic morphology and residual austenite, which is indicated by their high hardness (850 H) and clearly expressed two-phase structure.

Since the hardnesses of the dark and light areas are different and their sizes exceed the length of the microhardness tester pyramid impression diagonal, the microhardness in zone IV changes in jumps (Fig. 1c).

Therefore, depending upon the nature of the processes occurring in high-speed steels in laser treatment their hardness may be higher or lower than the hardness obtained both after through hardening and after the standard heat treatment (Table 1).

The results obtained indicate that in laser treatment the maximum hardness is reached as the result of the second hardening from temperatures close to the solidus temperature but not exceeding it. Consequently, for surface hardening of high-speed steel parts it is necessary to laser heat treat without fusion so that the zone of secondary hardening is of the maximum possible thickness, which is provided with the use of pulses with the proper power density since under otherwise equal conditions it determines the temperature of heating of the surface layers of the materials. In investigated high-speed steels irradiated areas with such a structure are formed with a pulse power density of the laser radiation of 310-330 MW/m^2. After laser treatment under these conditions not only the maximum surface hardness but also the maximum wear resistance is obtained. The results of experiments conducted under laboratory conditions and presented below showed that after laser treatment the

TABLE 1

Steel	Microhardness H after					
	through heat treatment		laser treatment			
					fusion zone	
	hardened from optimum temp.	standard	tempering zone	secondary hardening zone	martensite + residual austenite	residual asutenite
R9K5	850	890	700	1120	820	550
R9M4K8F	880	920	760	1150	850	600
R10K5F5	860	910	750	1140	830	580
R12F5M	860	900	730	1130	800	560
R12F2K8M2	880	930	770	1150	840	590

Note. The tests were made on experimental cutters of R9M4K8F steel.

life of a tool increases only if a martensitic—carbide structure is formed in its cutting portion under the action of irradiation as the result of secondary hardening.

Treatment	Life, min
Standard	17
Laser: rapid tempering	9
secondary tempering	52
fusion	6

The life of the tool is the time which is required for the wear land on the flank to reach 0.35 mm.

Production tests showed that the life of tools (cutters, milling cutters, drills) increases by two to three times after laser treatment in comparison with the life of tools not laser-treated.

Conclusions. 1. Depending upon the nature of the processes occurring in high-speed steels in laser treatment, their hardness may be higher or lower than the hardness obtained both directly after through hardening and after the standard heat treatment (harden and triple temper at 560°C).

2. In the zone formed as the result of rapid laser tempering the hardness of the high-speed steels decreases from 890-930 H to 700-770 H. In contrast to through tempering in the 560°C-Ac_1 temperature range, when the reduction in hardness is caused both by decomposition of the martensite and by coagulation of the carbide phases, in tempering under the action of laser irradiation the loss of hardness occurs only as the result of decomposition of the solid solution.

3. In those cases when laser treatment is done with fusion the microhardness of the structural constituents formed in crystallization from liquid is lower than after the standard heat treatment and does not exceed 800-850 H.

4. Specimens with a martensitic—carbide structure formed during secondary hardening from temperature close to the solidus temperature but not exceeding it have the highest hardness after laser treatment (1120-1150 H).

5. In high-speed steels after laser hardening, practically no residual austenite is observed and their structure is microcrystalline martensite containing 0.4% C and eutectic secondary carbides not capable of dissolving during the time of action of the pulse. The absence of residual austenite in the structure of steels after laser hardening may explain the fact that their hardness, in contrast to the hardness in through hardening, does not decrease in cooling from temperatures close to the solidus temperature.

6. In laser hardening structural heredity, including restoration of the original grain size in reheating under the action of irradiation in the Ac_1-T_s temperature range, is revealed.

7. To harden high-speed steels with the use of laser treatment it must be done without fusion and so that a zone of secondary hardening of the maximum possible thickness is obtained in the surface layer. This is obtained with a laser irradiation pulse power density of 310-330 MW/m^2.

LITERATURE CITED

1. V. S. D'yachenko, A. A. Korosteleva, T. A. Syritskaya, and G. N. Tverdokhlebov, "A method of revealing the structure of the white layers formed in high-speed steels during laser irradiation," Zavod. Lab., No. 3, 33 (1982).
2. L. A. Kremnev, A. M. Adaskin, and A. V. Bogolyubov, "Determination of the carbon content in martensite from the asymmetry of the lines of reflection," Zavod. Lab., No. 9, 1086 (1971).
3. V. N. Poduraev, Machining of High-Temperature Strength and Stainless Materials [in Russian], Vysshaya Shkola, Moscow (1965).
4. V. S. D'yachenko, G. N. Tverdokhlebov, and A. A. Korosteleva, "Features of laser heat treatment of high-speed steel tools," Metalloved. Term. Obrab. Met., No. 9, 25 (1984).
5. V. S. D'yachenko, A. A. Korosteleva, T. A. Syritskaya, and G. N. Tverdokhlebov, "The structure of high-speed steels in the zone of action of laser radiation," Izv. Akad. Nauk SSSR, Met., No. 4, 71 (1983).
6. Yu. A. Geller, Tool Steels [in Russian], Metallurgiya, Moscow (1975).
7. V. D. Sadovskii, Structural Heredity in Steel [in Russian], Metallurgiya, Moscow (1973).
8. I. K. Kupalova, "The phase analysis and phase composition of high-speed steels," Zavod. Lab., 49, No. 1, 27 (1983).
9. A. P. Gulyaev, K. A. Malinina, and S. M. Saverina, Tool Steels (Handbook) [in Russian], Mashinostroenie, Moscow (1975).
10. D. A. Mirzaev, S. E. Korzunov, V. M. Schastlivtsev, and I. L. Yakovleva, "The influence of cooling rate in hardening on the quantity of residual austenite and the hardness of carbon steels," Fiz. Met. Metalloved., 56, No. 5, 1033 (1983).
11. M. A. Krishtal, A. A. Zhukov, and A. N. Kokora, The Structure and Properties of Alloys Treated by Laser Radiation [in Russian], Metallurgiya, Moscow (1973).
12. L. I. Mirkin, Physical Fundamentals of the Treatment of Materials by Laser Beams [in Russian], Moscow State Univ. (1975).
13. V. A. Burakov, G. I. Brover, V. N. Varavka, and S. I. Gubenko, "The influence of microchemical inhomogeneity on hardening of die and high-speed steels in laser hardening," in: Progressive Methods of Heat Treatment in Tractor and Agricultural Machine Building [in Russian], Rostov.-na-Donu Inst. Sel'skokhoz. Mashinostr. (1982), p. 55.

DETERMINATION OF THE HEAT-TREATMENT CYCLE FOR 110G13L STEEL FOR INCREASING THE ABRASIVE WEAR RESISTANCE

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The majority of recommendations on increasing the wear resistance of high-manganese steel by heat-treatment methods propose a combination of aging and low-temperature hardening cycles with different temperature–time conditions of conducting them. At the same time the formation of an excess carbide phase without additional alloying of 110G13L steel and the obtaining of a relatively uniform distribution of the dispersed carbides in the volume of the grain providing an increase in wear resistance in abrasive wear are possible.

However, such dispersion hardening is accompanied by embrittlement of the steel. The impact strength may be increased by recrystallization under conditions of low-temperature hardening of the austenite cold hardened in the phase transformation. The recrystallization must be done at a temperature at which significant coagulation or solution of the carbides in the austenite cannot occur.

To determine the optimum aging and low-temperature hardening cycles providing the necessary level of wear resistance and impact strength requires the conduct of many experiments with variation of the austenitizing temperature (t_h) and time (τ_h) and the aging temperature (t_a) and time (τ_a). To reduce the number of tests in this work an orthogonal plan

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