The application of synchronous heat treatment makes it possible to attain a higher level of mechanization in hardening and tempering cutting tools, to shorten the cycle of heat treatment and to ensure large savings by reducing laboriousness, saving materials and electric power, and by improving the quality of the tools.

Application of the new technology is efficient both in series and in individual production of tools.

The temperature of shortened tempering t_{tem} (°C) in synchronous heat treatment of all other high-speed steels can be approximately determined by our empirical formula

$$t_{tem}=600+(8...12)\,V+(1...2)\,Co,$$

where V and Co are the contents of vanadium and cobalt, respectively, in %.

LITERATURE CITED

1. A. P. Gulyaev, K. A. Malinina, and S. M. Saverina, Tool Steels (Handbook) [in Russian], Mashgiz, Moscow (1961).
2. E. A. Smol'nikov and V. V. Umanets, "Shortened tempering of high-speed steels R6M5, R6M5K5, and R9M4K8," Metalloved. Term. Obrab. Met., No. 2, 11-15 (1980).
3. Technological Instructions "Heat Treatment of Metal Cutting Tools for Conditions of Automated Production" [in Russian], VNIIinstrument (1982).

EFFECT OF THERMAL CYCLING ON THE MECHANICAL PROPERTIES OF STEEL 20Kh

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Steel 20 is used as material of many important tractor components subjected to nitriding with subsequent hardening and low tempering. In recent years the process of nitriding was greatly improved: a technology of preliminary heat treatment was worked out as well as controlled atmosphere on the basis of endogas, making it possible to improve the quality and extend the life of components. However, the time required for the process remained as before. In addition, a substantial shortcoming of this process was the increased grain size of the core of the components; this impaired their mechanical properties and often caused breakage of gear wheels in operation.

To obtain finer grain size of the core, regimes of preliminary heat treatment [1] were devised but they are effective only with high alloy steels. For the same purpose thermal cycling is used either before or after thermochemical treatment (TCT) [2].

By thermal cycling, austenite grain is refined to No. 11-12 within five to seven cycles. A characteristic feature of the known methods of thermal cycling is the application of accelerated heating (at the rate of approximately 100 deg/min); this makes it difficult to use thermal cycling in the process of TCT, e.g., in nitriding. We devised a method of thermal cycling that causes refinement of the austenite grains both in the surface layer and in the core of components in the process of TCT itself, and when the required rate of diffusion saturation is attained, the method makes it possible to shorten the duration of the process by eliminating the necessity of repeated heating prior to quenching and to improve the required complex of properties. It was shown [3] that nitriding using thermal cycling (heating rate 3-4 deg/min to 880°C, cooling at the same rate to the temperature ensuring full phase recrystallization) makes it possible within four or five cycles to reduce the grain size of the austenite considerably (to No. 11), to increase fatigue strength, and more than double the impact toughness of components made of steel 20Kh compared with the conventional method of TCT.

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TABLE 1

Heat treatment	Grain number	σ_u	$\sigma_{0,2}$	δ_5	ψ	a_1, MJ/m^2
		MPa		%		
Normalization at 880 deg C	6	500	320	26	65	1,1
Thermal cycling with heating at the rate of 100 deg /min to Ac_1 + (30-50) deg C and subsequent cooling in air to Ar_1 – (50-100)°C	11	500	320	25	68	1,8
Thermal cycling with heating at the rate of 100 deg/min to Ac_3 + (5–30) deg C and subsequent cooling in air to Ar_1 – (50–100)°C	11	560	400	25	72	1,8
Thermal cycling with heating at the rate of 5 deg/min to Ac_3 + (5–30) deg C and subsequent cooling at the rate of 17 deg/min to Ar_1 – (5–10) deg C	11	560	400	35	80	2,7

Note. The properties apply to the state after five thermal cycles.

TABLE 2

Heat treatment	Grain No.	σ_u	$\sigma_{0,2}$	δ_5	ψ	a_1, MJ/m^2
		MPa		%		
Hardening at 880 deg C	6	1250/900	900/750	4,5/10	23/45	0,44/0,48
Thermal cycling with heating at rate of 100 deg/min to Ac_1 + (30–50) deg C and subsequent cooling in air to Ar_1 – (50–100) deg C	11	—/1080	—/920	—/12	—/41	—/0,28
Thermal cycling with heating at the rate of 100 deg/min to Ac_3 + (50–30) deg C and subsequent cooling in air to Ar_1 – (50–100) deg C	11	1300/1200	1100/1050	10/10	41/46	0,49/0,48
Thermal cycling with heating at the rate of 5 deg/min to Ac_3 + (5–30) deg C and subsequent cooling at the rate of 17 deg/min to Ar_1 – (5–10) deg C	11	1500/1400	1370/1250	12/14	56,5/58	1,08/1,2

Note. The properties presented are those after five thermal cycles: in the numerator after cooling in water, in the denominator after cooling in oil.

Moreover, thermal cycling enabling austenite grain to be refined to No. 11 with slow heating (at the rate of approximately 3-5 deg/min) may be applied instead of annealing, normalization, and hardening of components which, for no matter what technical reasons, do not lend themselves easily to accelerated heating.

The present article contains the results of investigations of the mechanical properties of steel 20Kh after thermal cycling, both with accelerated and with slow heating. Cooling of the specimens from the temperature of the upper limit of the cycle $T_{u.lm}$ was carried out in water, oil, and in air. For the sake of comparison the specimens were hardened in water and in oil, and they were also normalized. The number of thermal cycles for each method was chosen such that austenite grain No. 11 was attained. Thermal cycling with slow heating was carried out in a laboratory furnace. The temperature of the upper limit of the cycle $T_{u.lm}$ was 5-30°C higher than the point Ac_3, amounting to 880°C; the temperature of the lower limit of the cycle $T_{l.lm}$ was chosen with a view to the necessity of full phase recrystallization in cooling, viz., 5-10°C lower than Ar_1. The rate of heating to $T_{u.lm}$ was 5 deg/min, the rate of cooling to $T_{l.lm}$ was 17 deg/min. For comparison we carried out thermal cycling with accelerated heating: at the rate of approximately 100 deg/min in the interphase range to Ac_1 + (30-50)°C and subsequent cooling in air to 50-100°C below Ar_1; with accelerated heating to 5-30°C above the critical point Ac_3 and subsequent cooling in air to 50-100°C below Ar_1. Accelerated heating was attained by preliminary overheating of the furnace to 1050-1100°C. To check the regime of thermal cycling, Chromel–Alumel thermocouples were welded to the specimens, and with a potentiometer KSP-4 the regime of heating and cooling of the specimens was recorded. Thermal cycling by all regimes was applied to specimens of steel 20Kh from the same melt: 0.22% C; 0.69% Mn; 0.21% Si; 0.85% Cr; 0.15% Ni.

Table 1 presents the mechanical properties of specimens of steel 20Kh after thermal cycling and final cooling from $T_{u.lm}$ in air, and for the sake of comparison after normalization. After all regimes of treatment the microstructure consisted of ferrite and pearlite. It can be seen from Table 1 that thermal cycling helps increase the impact toughness of steel 20Kh considerably in comparison with normalization. However, with the same size of the austenite grain (No. 11) the highest impact toughness (2.7 MJ/m^2), with sufficient strength maintained, was attained after thermal cycling with slow heating (compared with impact toughness after thermal cycling with accelerated heating). Table 2 presents the properties of steel 20Kh after thermal cycling with cooling from $T_{u.lm}$ in water and in oil and after conventional hardening. The microstructure of the steel after thermal cycling with cooling in water and in oil is martensite. It can be seen from Table 2 that when the austenite grain is refined from No. 6 to No. 11 as a result of thermal cycling with accelerated heating, the strength and ductility of steel 20Kh improve, impact toughness either remains practically unchanged or it even diminishes. After thermal cycling with slow heating, which causes refinement of the austenite grain to No. 11, the best characteristics of strength and ductility of steel 20Kh are attained, and in addition impact toughness becomes 2.5-3 times higher than after thermal cycling with accelerated heating.

It may be assumed that when steel is heated slowly to the austenitic state, the austenite is not subjected to phase strain-hardening as in the case of accelerated heating, and in consequence the best complex of mechanical properties is attained.

Conclusions. 1. The newly devised method of thermal cycling including heating at the rate of 5 deg/min to $T_{u.lm}$ (5-10°C higher than Ac_3) with subsequent slow cooling to 5-10°C below Ar_1 makes it possible within three to five cycles to refine the austenite grain of steel 20Kh to No. 11; this increases impact toughness after final cooling in air to a value 1.5-2.5 times as high as after normalization and thermal cycling with accelerated heating.

2. In the fine austenitic grain, obtained in thermal cycling with slow heating and cooling, phase strain-hardening does not occur, and in consequence, after final cooling in water or oil from the upper limit of the cycle, the impact toughness of steel 20Kh increases more than 3 times while strength and ductility are high compared with thermal cycling with accelerated heating in which the phase strain-hardening of the austenite is retained.

LITERATURE CITED

1. Heat Treatment in Engineering (Handbook) [in Russian], Mashinostroenie, Moscow (1980).
2. V. K. Fedyukin, Method of Thermal Cycling of Metals [in Russian], Leningrad State Univ. (1984).
3. L. P. Frantsuzova, A. V. Vladimirov, T. N. Chetchasova, et al., "Increasing the impact toughness of structural steels by thermal cycling," Metalloved. Term. Obrab. Met., No. 4, 15-17 (1984).