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USE OF CONTROLLED HEAT TRANSFER IN THERMAL HARDENING OF WEDGE-SHAPED WORKPIECES

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The possibility of using controlled water-air cooling in thermal hardening of "thin" workpieces, for which the time of cooling lies in the range of a few seconds, is considered. A variant of the setup for realization of the technological process and regimes of cooling of wedge-shaped workpieces are proposed. The experimental data obtained are shown to be in agreement with the corresponding calculated data.

The main limitation of traditional methods of hardening is that they do not provide a means for controlling the rate of cooling of workpieces in the process of their thermal treatment. Because of this, the properties of workpieces subjected to such treatment differ from the prescribed ones. In this connection, a search for new cooling media and development of systems for controlling the thermal state of workpieces is an urgent problem in science and technology [1-3].

With the aim of widening the limits of application of systems for controlled water-air cooling, we performed a series of experiments on cooling of platelike workpieces 4–5 mm in thickness having a wedge-shaped side surface with teeth (mower segments) additionally cut on it using different cooling regimes. At industrial plants, such workpieces are cooled in oil.

Figure 1 shows the experimental time dependence of the temperature of the segment surface in oil cooling by a traditional technology involving induction heating within 0.8–1 sec, cooling within 3 sec, and tempering within 2 h at a temperature of 400°C in a continuous furnace.

To verify the possibility of using controlled water-air cooling, we performed a series of experiments on a laboratory setup in which induction heating was replaced by furnace volume heating. We manufactured a device that allowed us to heat and harden two segments at a time. In this case, the segments were linked together by a wide plane, and the wedge-shaped part with the cuts (teeth) faced the incoming water-air flow.

Our experiments on controlled pulse cooling of the above-indicated workpieces gave positive results, which allowed the conclusion that controlled gas-liquid cooling is appropriate for use in the process of hardening of workpieces of this kind.

To determine the regularities of the process of cooling of the investigated segments, we manufactured a three-section laboratory setup for controlled water-air cooling. The segments were cooled from 1150 down to 400°C in the first section, from 400 to 250°C in the second section, and from 250 to 175°C in the third section. After the tempering, they were cooled in air. We performed these experiments with the aim of determining the time dependence of the temperature of the segment surface for different regimes of water-air cooling and comparing this dependence with the analogous dependence obtained in the case where cooling was performed in oil. The data obtained for different regimes of cooling are presented in Table 1.

For each section we set a constant ratio between the duration of the acting pulses and the intervals between them, since the control system could generate only one pulse sequence in each section. The highest rate of cooling was obtained in regimes 1, 2, and 9. The maximum approach to the temperature dependence observed in oil cooling corresponds to the rate of cooling obtained in regimes 4, 5, and 7. Variations in the surface temperature obtained for regimes 3, 6, and 8 and for regimes 10-12 lie, respectively, higher and lower

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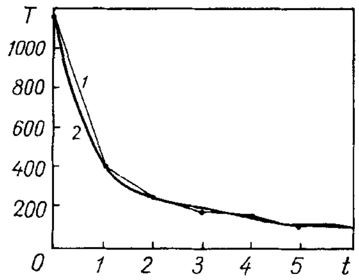

Fig. 1. Time dependence of the temperature of the surface of a segment cooled in oil: 1) experimental dependence; 2) smoothed curve; T, °C; t, sec.

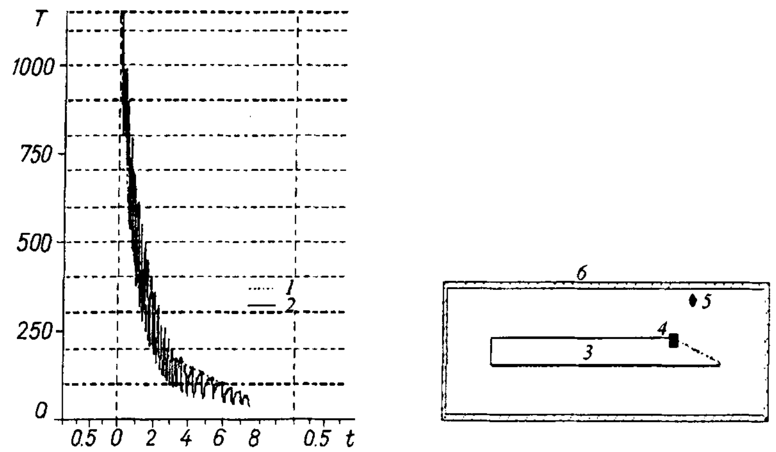

Fig. 2. Modeling of controlled heat transfer for cooling of wedge-shaped workpieces: 1) prescribed time dependence of the temperature of the cooled surface; 2) calculated time dependence of the temperature of the cooled surface; 3) wedge-shaped workpiece; 4) reference point for calculating the temperature; 5) injector; 6) hardening chamber.

TABLE 1. Duration of Pulses and Intervals between Them in Controlled Hardening

No. of regime	First section		Second section		Third section	
	τ_p	τ_i	τ_p	τ_i	τ_p	τ_i
1	0.9	0.1	0.9	0.1	0.9	0.1
2	0.9	0.1	0.9	0.1	0.2	0.5
3	0.9	0.1	0.1	0.1	0.2	0.3
4	0.1	0.1	0.1	0.1	0.3	0.1
5	0.1	0.1	0.1	0.5	0.1	0.1
6	0.1	0.2	0.1	0.3	0.1	0.4
7	0.1	0.15	0.2	0.2	0.1	0.9
8	0.1	0.1	0.15	0.2	0.1	0.9
9	0.9	0.1	0.9	0.1	0.1	0.1
10	0.1	0.9	–	–	–	–
11	0.1	0.1	–	–	–	–
12	0.1	0.1	0.1	0.9	–	–

than the analogous variations obtained in the case of oil cooling. The pressures of water and air were constant in the experiments: R_w = 0.18 MPa and R_a = 0.45 MPa. The temperature was controlled with a Chromel-Alumel thermocouple installed at a depth of 2 mm. The indications of the thermocouple were recorded with a mirror-galvanometer oscillograph. The segments hardened under the conditions corresponding to regimes 4, 5, and 7 had a required hardness of 59–62 HRC units.

The experiments performed provided support for the assumption that the procedure of controlled pulse water-air cooling can be used in the process of thermal hardening of wedge-shaped workpieces, the surface of the wedge of which has a cut of teeth and, consequently, is prone to crack-forming stresses. Cracks and microcracks were absent on the surface of the workpiece cooled by a water-air flow under the conditions corresponding to regimes 4, 5, and 7.

At this stage of investigations we did not have a mathematical model for describing the thermal processes occurring in hardened workpieces of similar shape. Figure 2 shows the results of modeling of the process of hardening cooling performed with the use of the time dependence of temperature presented in Fig. 1. A demonstration program for modeling the process of controlled hardening cooling can be found on the Internet at the following address: www.itmo.by/division/avt/project1/demo.exe. The best agreement between the experimental time dependences of the temperature of the surface of the investigated workpieces and the analogous calculated dependences is obtained in the case of cooling regime 7.

It should be noted that the cutting surface of the workpieces subjected to controlled thermal treatment had a prescribed hardness and their soft core was retained.

Thus, the system for controlled cooling makes it possible to thermally treat a large variety of workpieces, exert local control of the rate of their cooling, and replace different hardening media, which opens up a new direction in the field of thermal treatment.

NOTATION

T, temperature, ^oC; t, time, sec; τ_p, duration of the action pulse of the water-air mixture, sec; τ_i, interval between the action pulses of the water-air mixture, sec; HRC units, units of Rockwell surface hardness.

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