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Cryogenic Quenching of High – Speed Steels after Vacuum Heating

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Abstract:- An advantageous quenching method for high-speed steels after vacuum heating is suggested. It lies in cooling tools by inert gases from austenitizing temperature to martensite start temperature *Ms*, keeping at this temperature for some time, and then the transfer of the tool to a cryogenic media with the regulated cooling rate within the martensite range at supercritical rate. Engineering calculation methods have been developed for the calculation of thermal and physical processes. The software has been developed for the control over the heat treatment process.

Key - Words:- Vacuum heating, Cryogenic quenching, Tool service life, Ecologically clean technologies, Software.

1 Introduction

Due to significant increase in the price of high - speed steels and necessity to eliminate salt and alkali melting, it became necessary to develop efficient and ecologically clean technologies of thermal strengthening of high-speed steels.

The paper presents a new technology of tool quenching, based on the discovered property of material superstrengthening when the cooling rate during quenching within the martensite range is very high [1, 2]. In these works it has been established that the high cooling rate within the martensite range results in the considerable increase in the service life of tools. Heating tools is performed in vacuum, and quenching in special cryogenic equipment. The cryogenic equipment allows to adjust the cooling rate within the martensite range. The regularities of cooling and heating tools have been studied and, as a result, special SOFTWARE for the control of heat treatment processes has been developed.

2 Vacuum and Cryogenic Equipment

Vacuum elevator electric resistor furnace SEVG-5.5/13-IZG is supposed for quenching various parts made out of alloy steels by streams of inert gas. The furnace consists of the main mechanisms as follows (see Fig. 1):

- case with heating module,
- loading mechanism,
- vacuum system,
- system of gas cooling for cages,
- system of water cooling,
- system of control.

The steel furnace case is closed from two sides by elliptic bottoms. Inside the case in its upper part a heating module is set on special brackets. The thermal insulation of the module and heaters are made out of carbon-composite materials.

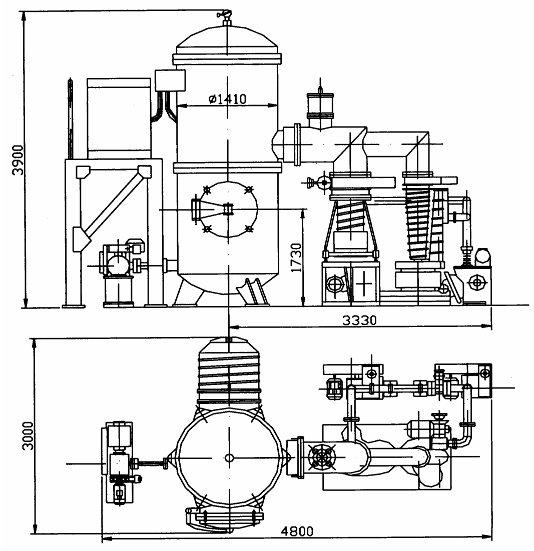
The movement of the cage from the cooling area to the heating module and back is performed by elevator mechanism with electric gear. The electric furnace control system operates in both manual and automatic modes.

The lower part of the chamber, if necessary, can be heated to the martensite start temperature, to prevent them when the steel is cooled by inert gas.

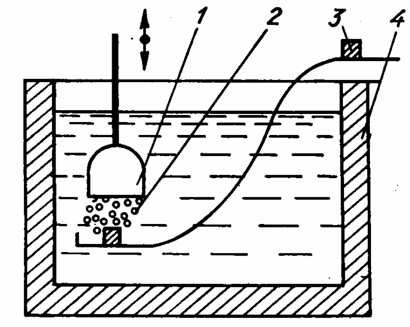
The furnace is equipped with necessary blocking devices preventing the damage of furnace mechanisms in case of incorrect actions of an operator.

The nominal temperature in the work space is 1300°C. The non-uniformity of temperature in the work space is 10°C. The accuracy of supporting the temperature is plus/minus 5°C [3].

Various methods of cryogen cooling of tools have been developed [4, 5]. A principal scheme of one of them is presented in Fig. 1 b. In Fig.1 bell 1 vibrates at resonance frequency and cooled gas 2 is supplied to it. The specified scheme was tested in laboratory conditions. For industrial conditions, special cryogen equipment has been developed, which are being patented in Ukraine and USA and are “Know How”. When quenching tool steels in cryogenic systems, cooling rate within the martensite range can be adjusted within the wide range.



a)



b)

Fig. 1 Vacuum furnace a) and cryogenic equipment b) for cryogenic quenching of High-Speed Tool steels: 1- vibrating bell for the supply of cooled gas, 2 – gas bubbles, 3 – a part to be quenched, 4 – a thermostat containing a cryogen liquid.

3 Mathematical Description of Heating and Cooling Processes

For approximate calculation of the heating and cooling time for parts of various configuration generalized dependence (1) can be used [4].

More precise calculations are made by computer simulation with the use of appropriate experimental databases. Databases are created through solving inverse and reverse heat transfer problems. For this purpose there are special software [6].

$$t = \left[\frac{kBi_v}{2.095 + 3.867Bi_v} + \ln \frac{T_0 - T_C}{T - T_C} \right] \frac{K}{aKn} \qquad (1)$$

Here t is time of cooling of steel parts;

Bi_v is generalized Biot number;

K is Kondratjev form coefficient;
Kn is Konddratjev number;
T_C is medium temperature; a is thermal diffusivity;
T_o is initial temperature.

Table 1 Kondratjev form coefficients K for bodies of a simple configuration

No.	Shape of the part	Coefficient K, m^2	$\frac{S}{V}$, m^{-1}	$K\frac{S}{V}$, m
1.	Plate of thickness L	$\frac{L^2}{\pi^2}$	$\frac{2}{L}$	$\frac{2L}{\pi^2}$
2.	Cylinder of radius R	$\frac{R^2}{5.784}$	$\frac{2}{R}$	$0{,}346\,R$
3.	Square infinite prism with equal sides of L	$\frac{L^2}{2\pi^2}$	$\frac{4}{L}$	$\frac{2L}{\pi^2}$
4.	Cylinder of radius R and height Z	$\frac{1}{\frac{5.784}{R^2} + \frac{\pi^2}{Z^2}}$	$\left(\frac{2}{R} + \frac{2}{Z}\right)$	$\frac{2RZ(R+Z)}{5.784Z^2 + \pi^2 + R^2}$
5.	Finite cylinder, R=Z	$\frac{R^2}{15 \cdot 65}$	$\frac{4}{R}$	$0.256R$
6.	Finite cylinder 2R=Z	$\frac{R^2}{8.252}$	$\frac{3}{R}$	$0.364R$
8.	Finite square plate with sides of L_1, L_2, L_3	$\frac{1}{\pi^2\left(\frac{1}{L_1^2} + \frac{1}{L_2^2} + \frac{1}{L_3^2}\right)}$	$\frac{2(L_1L_2 + L_1L_3 + L_2L_3)}{L_1L_2L_3}$	---

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$$\overline{Nu} = 0.021\,\mathrm{Re}^{0.8} \cdot \mathrm{Pr}^{0.43} (\mathrm{Pr}_m / \mathrm{Pr}_{sf})^{0.25} \cdot \varepsilon_e , \qquad (2)$$

where Nu is Nusselt number, $\mathrm{Re} = \frac{wD}{\nu}$ is Raynolds number, $\mathrm{Pr} = \frac{\nu}{a}$ is Prandtle number.

Correctional function $\varepsilon_\lambda = f(\lambda/d, \mathrm{Re})$ depends on the correlation of the length to diameter.
If $\lambda/d > 50$, then ε_e=1. When $\lambda/d < 50$, tabulated values are used.

Heat transfer coefficient for cooling tools in stream of neutral gases is determined by equation formula (2), then the generalized Biot number is determined, which is placed in equation (1). Having numerical values of K and Kn, it is easy to determine the time of tool cooling from austenitizing temperature to martensite start temperature. The average values of heat transfer coefficients for cooling in cryogen equipment with liquid nitrogen are presented in Table 2.

Table 2 Heat transfer coefficients with regard to the state of the quenchant [5]

Quenchant	Medium temperature, °C	Cooling conditions	Vibration frequency, Hz	Vibrator acceleration, g/g₀	$\overline{\alpha}$, W/m²K
Liquid nitrogen	-196	No vibration	-	-	160- 230
Liquid nitrogen and nitrogen vapor	- 196	Vibration agitation	72	17	331 -532
Liquid nitrogen and vapors of nitrogen and helium	-196	Airing, vibration agitation	72	17	334 - 544

The cooling rate for tools of various configuration within the martensite range can be determined by equation (3) as follows:

$$V = \frac{\overline{a} \cdot \overline{Kn}}{K}\left(T - T_m\right), \quad (3)$$

where V is cooling rate (°C/s);
a is average thermal diffusivity (m²/s);

T is current temperature (°C);
T_m is temperature of medium.

As is known, Kondratjev form coefficient for cylinder-shaped bodies is $K = \frac{R^2}{5.783}$ or $K = \frac{D^2}{23.13}$, therefore, equation (3) can be presented as follows:

$$V = \frac{23.13 \cdot \overline{\alpha} \cdot \overline{Kn} \cdot \left(T - T_m\right)}{D^2}.$$

Table 3 presents results of calculation of cooling rates within the martensite range (200°C) for cooling cylinder-shaped specimens of 6-mm and 12-mm diameter. It shows that cooling rate within the martensite range significantly increases if a cryogen medium is used instead of mineral oil. This is reached mainly for the account of big difference of temperatures between the part's temperature and liquid nitrogen boiling point (see equation (3)).

Table 3 Cooling rate of the core of cylinder-shaped specimens of 6-mm and 12-mm diameter during their cooling in oil Houghton K, having temperature 43°C, and vibrated liquid nitrogen

. Diameter of specimen, mm	Cooling rate in oil, °C/s	Cooling rate in nitrogen, °C/s
6	12	26
12	3	6.5

4 Results of Field Testing

By the present there are a lot of data accumulated that confirm the favorable impact of intensive cooling within martensite range upon the service life of tools made out of high-speed tool steels. Many authors have noted the increase in service life of tools by 2 or 3 times [7, 8].

Some data on tests with a punch (Fig.2) are presented in Table 4.

Fig. 2 A punch made out of High-Speed Tool Steel.

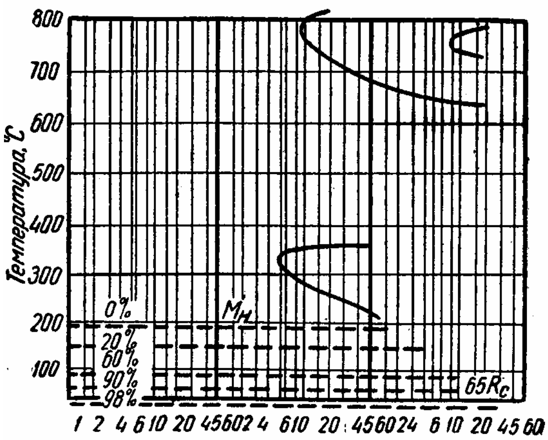
Table 4 Field trial of wear improvements in deep cold treated of tools made of high speed M2 steels

Tool Type	Tool Material	Improvement in wear rate (%)
Punch	M2	300
Drill	M2	200
Milling cutters	M7	250

5 Discussion

The distinctive feature of the cooling process is that the vacuum furnace provides keeping a high-speed tool at temperature M_S for some time after cooling by neutral gas. The transformation of austenite into martensite takes place outside the vacuum furnace in cryogen liquid at supercritical cooling rate within the martensite range. The fact that it is possible to have such a process is proved on the basis of CCT diagram, which presented in Fig. 3. The diagram shows that there is enough time to implement two-stage cooling process with the delay of martensite transformations at the first stage of cooling.

The process suggested by this technology is ecologically clean since it becomes unnecessary to use melted salt or alkali, or quench oils as quenchants. Since the service life of tools after cryogenic quenching increases by 2 or 3 times, the consumption of expensive metals is reduced by 2 or 3 times, which makes lesser contaminations in the environment. At the present serious attention is paid to ecologically clean technologies. So, WSEAS and other authority organizations delivered the initiative of solving ecological problems on the Earth (see **www.wseas.org/wipe**)



sec **min** **hrs**

Fig. 3 CCT diagram for steel R18. Heating is to 1290°C.

At the first time notion of critical cooling rate within the martensite range and super strengthening of a material was formulated by author [8]. It was noted further that quenching in liquid nitrogen increases service life of tools [9]. Explanation of this phenomenon is provided in [4]. Here cooling rate adjustment within the martensite range is widely discussed.

6 Conclusions

1. Vacuum equipment has been created for heating High-Speed Tool Steels in vacuum with their further cooling in neutral gases. Cooling in neutral gases occurs from austenitizing temperature to martensite start temperature M_S. The equipment allows to keep parts for some time at this temperature.
2. Special equipment has been developed for cryogenic quenching of High-Speed Tool Steels in conditions of regulated cooling within the martensite range.
3. The service life of High-Speed Tool Steels increases for the account of quite high (supercritical) cooling rate within the martensite range.

4. The critical cooling rate in the martensite range, which provides superstrengthening, depends on the content of carbon and alloy elements in steel.
5. Special Software has been developed for the control of heat treatment processes

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