Evolution of Quenching Technology for Heat Treatment of Steel Band with Production Line

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Abstract: - The general principles of quenching technology optimization are discussed on the basis of modern approaches to the rational selection and use of quenchants. Using an example of modernizing quenching technology for cooling a band made out of high-carbon steel, the modern potentialities have been shown that allow to apply non-toxic quenchants with the high cooling capacity. For this purpose new equipment has been designed and manufactured. In such a way it was possible to transfer from toxic to environment friendly quenchants.

Key-Words:- New technology, Automated system, Steel band, Environment, Non - toxic quenchants.

1 Optimization of Quenchants as Important Element of Perfecting the Quenching Technology

Quenchants providing specified industrial cooling conditions must meet the requirements as follows:

- stability of repetition of these conditions in time (of operation of this quenchant);
- ecological cleanness;
- getting as much as possible clean surface of the part quenched;
- economical as for the cost of quenchant;
- economical as for the consumption of quenchant per mass or volume unit of the part.

Intensive steel quenching technology called IQ-2 has been developed, which lies in three-stage cooling of steel parts based on regularities of self-regulated thermal process, and which meets the mentioned requirements [1,2]. These stages are as follows: at the first stage a part is cooled intensively until no more than 50% martensite is formed at the surface layers of the part (within the range from 0 to 50%), and then, while the self-regulated thermal process takes place, the part's temperature is supported at the same temperature for some time. Upon finishing of nucleate boiling, the intensive cooling is interrupted and the part is cooled in air, where the temperature is equalized. After it, the intensive cooling is continued until the part is completely cooled.

Due to self-tempering of surface layer, the mechanical properties of material are improved. Hence, after keeping a part in air for some time and self-tempering of the surface layer, the intensive cooling can be continued until the parts are completely cooled with no fear of quench crack formation. This is the essence of intensive technology IQ–2. The technology can be easily implemented, if high-carbon steels are used, including alloy steels which martensite start temperature is below 200°C, that is $M_s \leq 200$ °C (see Table 1).

Table 1. Amount of martensite (in %) with regard to temperature at which the part is kept for some time

Steel	Austeniti	Carbon		25%
grade	zing	content	M_S	mart
AISI/	temperat	in steel,	°C	ensit
GOST	ure, °C	%		е,
				°C
W1/U8	800	0.81	235	150
W1/U10	780	1.1	200	130
A485(2)	850	0.99	200	120
/ShKh1				
5SG				
L2/	980	0.97	150	90
9Kh2				
T1/R18	1300	0.72	190	150

The self-regulated thermal process is a process during nucleate boiling at which the surface at the temperature is supported at approximately the same level for some time, which is the temperature of boiling on the surface of the part. Changing the pressure over the quenchant's mirror or the concentration of salt in water, one can regulate the temperature at the surface of the part to be quenched so that at the surface layer the amount of martensite is from 0% to 50%. The duration of the self-

regulated thermal process is determined by equation [2]:

$$\tau = \left[\Omega + b \ln \frac{\vartheta_I}{\vartheta_{II}}\right] \frac{K}{a}, \qquad (1)$$

where b=3.21;

$$\mathcal{G}_{I} = \frac{1}{\beta} \left[\frac{2\lambda(\mathcal{G}_{0} - \mathcal{G}_{I})}{R} \right]^{0.3}; \quad (2)$$
$$\mathcal{G}_{II} = \frac{1}{\beta} \left[\alpha_{conv} (\mathcal{G}_{II} + \mathcal{G}_{uh}) \right]^{0.3} \quad (3)$$

The self – regulated thermal process allows implementing isothermal holding in intensively cooling quenchants and optimizing the new technology.

2 Present Steel Quenching Technology for Steel Saw Band

At the base plant, quenching and tempering of steel band made out of U8GA steel is performed at a production line (aggregate), its scheme is presented in Fig. 1, and the chart of heat treatment processes, in Fig. 2.



Fig. 1. Scheme of the production line for the thermal hardening of steel band:

1 – uncoiling mechanism; 2 - press; 3 – contactpointed welding machine; 4 – finishing lathe; 5 – heating furnace; 6 – quenching bath; 7 – leading rollers; 8 – tempering press; 9 – drawing mechanism; 10 - press; 11- coiling mechanism



Fig.2. Chart of conditions of steel band heat treatment in production line (base version).

This follows that here martensite quenching is multi-step quenching. From heating temperature to temperature at which the part is kept for some time in the solution of lead (87 \pm 1% by weight) and antimony $(13 \pm 1\%)$ the average cooling rate is 200 grad/s, and during cooling in air within the martensite range it is about 1 grad/s. Such quenching conditions are classical with regard to customary methods of reducing thermal and structural stresses. Hence, despite the cooling rate considerably exceeds the critical cooling rate for such steel in the temperature range of metastable austenite, the abovementioned conditions do not result in quench cracking or significant distortions. At the same time, slow cooling within martensite range results in the increase in the amount of residual austenite. Although the tempering temperature is quite high for the decomposition of the residual austenite, the short time of tempering and the presence of manganese do not provide the complete running of this process. Also the products of decomposition of the residual austenite during tempering have properties far from those of the products of the martensite composition. In whole it has negative impact upon the operational stability of saws.

To obtain quite clean surface after heat treatment, before quenching a low-oxidizing atmosphere is created in the furnace for the account of burning oil that is put on the band surface before heating, using special equipment. After the band is taken out of the solution, its edges are cleaned from the lead spots.

This steel band heat treatment technology provides, in whole, the required properties, the hardness is to be within the range of 42...52 HRC. However, the considerable shortcomings of this technology are as follows:

- toxicity and high cost of the quenchant used;
- necessity to clean the band from products of its interaction with the solution of lead and antimony;
- high amount of residual austenite in the steel structure (it is a typical consequence of multi-step quenching), which is not removed during the abovementioned tempering conditions.

3 Improvement of Steel Band Quenching Technology by Various Methods of Modification of Present Production Line

The improvement of the technology of steel saw band quenching in production line has been performed with the purpose to eliminate shortcomings of the base version indicated in Section 2 through the investigation and selection of new quenchants. The potentialities of using new quenchants in both stationary (quench tank) and nonstationary (sprayers) state have been investigated. In the first case, the existing quench tank was used, in the second, the equipment related to cooling has been essentially changed. The total number of studied quenchants was 12, but the best results were obtained with two of them:

- 1. UZSP-1 universal quenchant on the base of polymers soluble in water (the concentration within 2...4%);
- 2. aqueous solution of bischofite at concentration of 34%.

Table 2 presents information on the cooling rate of the band in various temperature ranges and comparison with the corresponding data by the base method..

Table 2. Cooling capacity of suggested quenchants and their use in heat treatment of steel band in comparison with the base method

Quenchant	Cooling rate, grades/s, within temperature range		Hardness, HRC, After quenching and tempering	Band distortion	Quench cracks
	650550	30050			
Base method,	200	1	5052	No	No
Lead and					
antimony					
solution					
UZSP-1	80	35	4951	No	No
Aqueous solution	1000	200	4952	No	No
of bischofite					

It follows that the mentioned non-toxic quenchants, when the quenching is not interrupted and the self-regulated thermal process occurs, provide necessary hardness of the band while there is neither distortion nor quench cracking. The fact there is no distortion neither quench cracking is especially notable in case of quenching in aqueous solution of bischofite, when the cooling rate in the austenite state is by 5 times greater and within the martensite range by 2 hundreds times (!) greater than those by the base method. The essentially greater cooling rate within the martensite range in the mentioned quenchants significantly reduces the amount of residual austenite, and so increases the operational stability of saws. It should be noted that to obtain necessary (required) values of hardness, the tempering temperature is to be increased in comparison with the base method to 450...470°C in case of quenching in UZSP-1.

The transfer to uninterrupted quenching with the use of suggested quenchants simplifies the quenching technology in comparison with multi-step quenching and, in principle, allows to significantly reduce the length of the production line almost by 10 m. The state of the band's surface quenched in mentioned quenchants completely meet the requirements and it is implemented by simple mechanisms which are set up before the tempering section. The area released due to the transfer to uninterrupted quenching is more than enough for this purpose. In case of using UZSP-1, cleaning mechanisms are set up, and in case of using aqueous

solution of bischofite (which, in addition, provides light surface of the part even in case of quenching from the furnace with oxidizing atmosphere), a bath with running neutralizing solution is set up. With regard to the stability of cooling capacity, of two suggested quenchants the advantage belongs to the aqueous solutions of bischofite. Their cooling capacity weakly depends upon the agitation, bath temperature, and the solution concentration is quite stable during operation. In particular, during quenching in bischofite the main process is nonstationary nucleate boiling.

Also one of the advantages of the suggested quenchants is their low cost in comparison with those used by the base method. For example, 1 ton of UZSP-1 of necessary concentration is lower in cost by almost 50 times (!) than 1 ton of lead and antimony solution used at the steel works.

At the same time, the shortcoming of practically all quenchants used in stationary state is not wide range of their cooling capacity. Therefore, changes in steel grade often requires the changes in the concentration of aqueous solutions.

The use of non-stationary state of quenchant allows the successful fulfillment of any kind of band quenchant in production line, including multi-step or isothermal quenching, with the use of the most simple and most available non-toxic quenchant: water or water-and-air mixture. Fig. 3 shows the principal scheme of such equipment allowing to fulfill multi-step quenching of band without traditional tanks with solutions of metals or salts. This equipment gives opportunities to widely control the intensity of quench cooling depending on the steel grade *without changing the type of quenchant,* and also regulate the cooling rate after "isothermal step", within the martensite range.

The equipment consists of a system of sprayers performing the regulated cooling after the band is taken from the heating furnace and after the "isothermal" stage (the last are not shown in Fig.3). The isothermal stage, that is, keeping a part in the austenite state in pre-martensite range, is performed by a drum device made out of copper, the outer part of which is in outer contact with the band. The regulation of the temperature at the surface of the drum is performed by the heater placed in the upper part of the drum and cooling device of periodic action in its lower part. Both of them, heater and cooling device of periodic action, are connected to the automatic control block. All sprayers are provided with water in loop cycle from an appropriate tank placed under the band. The same tank can function also as pump-out system for the water already used.



Fig.3. Steel band quenching device in production line: 1 – furnace; 2 – bath; 3 – drum; 4 – heater; 5 – cooling device of periodic action; 6 – pump; 7 – sprayer; 8 – control block; 9 – pyrometer; 10 – tension rollers

Thus, a band, when it is taken from the furnace, is cooled by water or water-and-air sprayers at the rate exceeding the critical cooling rate for a value specific for each steel grade, until the temperature of isothermal stage is reached. Then, through the guiding devices, the band is put into thermostat of drum form, where it is kept at the same temperature for some time (isothermal step) for removing thermal stresses. After the band is taken out of the thermostat, it is cooled within the martensite range or in air, or at the set cooling rate with sprayers.

The band movement speed W depends on the duration of isothermal step and is corrected by the intensity of spraying, calculated through the Kondratjev number Kn. The process can be fully automated on the basis of known equation [9]:

$$W = \frac{L}{\tau} = \frac{aLKn}{(\Omega + b\ln\theta)K}$$
(4)

In the equation (4) the band movement speed is given in m/s. To set the speed at m/hr it is necessary to add 3600 to the numerator and the equation will have the convenient form as follows:

$$W = \frac{0.36 \cdot 10^4 \, aLKn}{(\Omega + f \ln \theta)K}, \quad (5)$$

where the band movement speed W is set in m/hr, a is thermal diffusivity, L is length of a band, Kn is Konddratjev number, θ is dimensionless temperature, K is Kondratjev form factor.

4 Conclusions

- 1. The technology of steel saw band quenching has been improved and new equipment has been developed for its implementation.
- 2. The production process can be fully automated and has advantage of lower costs and higher productivity.
- 3. The technology is energy-saving and ecologically clean.

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