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IMPROVING THE PERFORMANCE PROPERTIES OF GEARS FOR MINING EQUIPMENT

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Abstract. Deformation hardening - important technological factor of management of carburized layer substructure. The formation of a favorable substructure - substructure with high resistance to local microplastic deformation - occurs in conditions of development of competitive processes. On a degree of their development is renders the influence of initial structural condition of a carburized layer, which, except chemical composition, is defined by technology of thermochemical treatment. To number of the factors, dependent from technology of thermochemical treatment, concern: carbon saturation in the carburized layer, the martensite morphology and carbon concentration in it, volumetric share of a redundant carbide phase and its distribution in a carburized layer.

Keywords: deformation hardening, thermochemical treatment, carburized layer, substructure, martensite morphology, carbide phase.

Introduction. To improve the performance of carburized gears, shot-impact hardening is widely used, which strengthens weak parts of the structure and thereby hinders the development of microplastic deformation in them under contact loading [1-3]. The effectiveness of shot blasting treatment (*SBT*) depends on the initial structural state of the carburized layer, which is determined by the carburizing technology in addition to the chemical composition of the steel. The factors that depend on the latter include: the saturation of the carburized layer with carbon; the morphology of martensite and the concentration of carbon in it; volume fraction of the excess carbide phase and its distribution over the thickness of the near-surface zone of the carburized layer.

All the above-mentioned structural characteristics, through which technological heredity manifests itself, should influence the degree of manifestation of heterogeneity of plastic deformation, the nature of changes in the substructure of the phases of the carburized layer during *SBT*, and, as a result, on the performance characteristics. The determining factor should be considered the saturation of the carburized layer with carbon, since the latter indirectly affects the mechanism of plastic deformation through the morphology of martensite and the volume fraction of the carbide phase.

A cardinal solution to the main issues in the field of thermochemical treatment is the use of new processes - ion carburizing (*IC*) or ion carbonitriding (*ICN*), recognized in Japan, Germany and the United States as the most priority processes for the formation of carrier diffusion coatings. The high efficiency of these processes has been confirmed in studies [4-5]. Plasma treatment of a glow discharge allows not only to reduce the duration of exposure several times and increase the level of mechanical properties, but also to achieve fundamentally new effects associated with the ability to control the phase composition and structure of the diffusion layer. It provides uniform carburization due to the exact repetition of the glow discharge plasma of all the contours of the part and spontaneous convection of the gas medium ionized by the discharge. The actuators of the plants allow rapid changes in the process temperature, pressure, and composition of the technological atmosphere and create conditions for various combined modes of diffusion saturation to create a layer of a given saturation.

There are other methods of producing high-load parts, such as composite materials [6, 7] or ceramics [8]. Recently, methods of surface hardening by electro-mechanical processing have been widely used [9-11].

The purpose of this work is to improve the technology of surface hardening of high-loaded gears made of heat - resistant steels.

Materials and equipment of the experiment

Objects of research made of steel C0.16Cr3NiWVMoNb (Tab. 1) both gas carburized (*GC*) and new processes carried out by heating a low-temperature glow discharge plasma - ion carburized (*IC*) and ion carbonitriding (*ICN*) were subjected to this method. Samples underwent typical gears thermochemical treatment: carburizing at 930-950°C, tempering at 650°C, hardening in oil from 910°C, cold treatment at –70°C, low tempering at 250°C. After a thermochemical treatment was performed *SBT* (micro balls of bearings with d = 0.2 *mm*) and low tempering at 200°C.

Table 1. – Chemical composition of steel C0.16Cr3NiWVMoNb

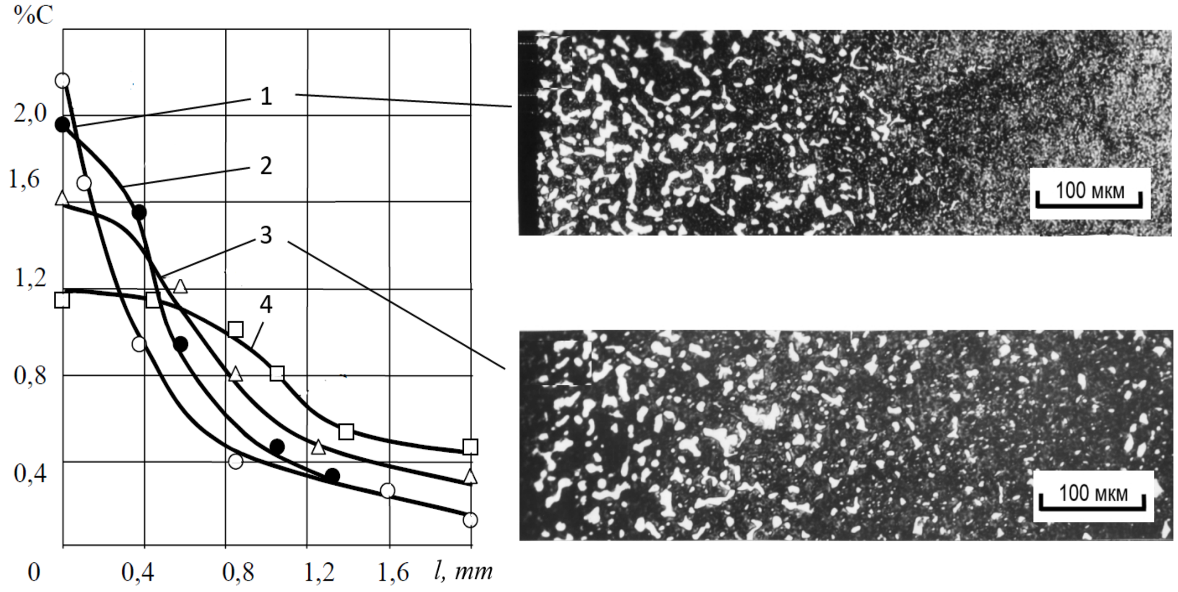
Content of elements, %								
C	Si	Mn	Cr	Ni	W	Mo	V	Nb
0.14-0,19	0.6- 0,8	0.4- 0,6	2.6- 3,0	1.0- 1,5	1.0- 1.4	0.4- 0.6	0.3-0.5	0.1- 0.2

Different saturation of the diffusive layer with carbon was obtained by performing one-stage (with constant technological parameters) and two-stage modes (with changing parameter). The latter was carried out at a constant temperature, but with a step-by-step mode of feeding the carbon.

IC was performed on equipment and according to the method [4] in an atmosphere of acetylene diluted with a gas mixture of argon and hydrogen, and *ICN* - in a gas medium of acetylene and dissociated ammonia. The time of the process was chosen in such a way as to ensure the saturation of the carburizing layer to the same degree as after gas carburizing.

Experimental results and discussion

Carrying out the process in two stages eliminates the supersaturation of the surface with carbon, reduces the density of carbides, and increases the effective thickness of the layer (Fig. 1). At the second stage, in the absence of carbon input from the gas environment, the carbon source for the formation of the layer is small carbide particles. Their distribution and diffusion redistribution of carbon increase the doping of the solid solution and the uniformity of the structure of the carbide zone: the difference in the size of the carbide particles decreases, and the density of their distribution is equalized.



a) *b)*

Fig. 1. – Carbon distribution *C* by thickness (*a*) and microstructure of carburized layer (*b*) of steel C0.16Cr3NiWVMoNb after *GC* (*t* = 940°C, total time = 10 *h*) with different duration of the second stage: 1 - 0 *h*; 2 - 3 *h*; 3 - 4 *h*; 4 - 5 *h*

Studies have shown that different carbon concentrations in the carburized layer of steel 16X3NVFMB-sh caused different effects of *SBT* on the martensite substructure, surface quality characteristics and durability (Tab. 2). The differences are due to the different proportion of the formed carbide phase. The volume fraction of the latter affects the degree of localization of microplastic deformation and the level of development of local stress relaxation processes in the martensitic matrix. Positive processes associated with the partial decomposition of martensite and the redistribution of carbon atoms in its crystal lattice in steel with a low proportion of the carbide phase in the diffusion layer, prevail over the increase in the density of defects for a longer time *SBT*. The increased ability of the martensitic matrix to relax stresses reduces the risk of areas with a critical concentration of microdeformation, and therefore contributes to a somewhat greater absorption of energy. It is determined that the optimal ratio of the duration of the first and second stages of the gas carburizing process is 60% and 40 %. The proportion of excess carbide phase in the diffusion layer is ~ 15 %, and the surface hardness is ~ 62 HRC (see Tab. 2).

The analysis of the obtained data allows us to explain the different efficiency of strain hardening after HZ for the specified modes as follows. When the near-surface layer contains large and closely spaced carbide inclusions, and there is no residual austenite, local stresses in their vicinity are large and commensurate with the yield strength of the material, which, when applying a cyclic load, facilitates the manifestation of the micro-fluidity effect and contributes to the early origin of a fatigue crack.

Table 2. – The durability of steel C0.16Cr3NiWVMoNb after thermochemical treatment (*GC*, *IC* or *ICN*), *SBT* and low tempering (190-200°C, 2 *h*)

No п/п	Thermochemical treatment		Volumetric share carbides in the layer 0-20 μm	Surface hardness, *HRC*	Durability, $N_{50}\cdot10^{-6}$cycles			N_3/N_1
					without *SBT*	after *SBT*	after *SBT* and tempering	
					N_1	N_2	N_3	
1	*GC* - 1 stage		25	63	11	4	32	3
2	*GC* 2 stage t=940°C τ_{tot}=10h	τ_2=3 h	20	63	17	18	40	2.4
		τ_2=4 h	15	62	16	24	44	2.7
		τ_2=5 h	10	60	8	12	24	2.9
3	*IC* - 1 stage t=950°C; τ=2,5 h		25	63	12	4	32	2.7
4	*IC* 2 stage t=950°C τ_1=τ_2=1,25 h		15	62	16	24	48	3.0
5	*ICN* - 1 stage t=950°C; τ=2,5 h		20	63-64	18	12	50	2.8
6	*ICN* 2 stage t=950°C τ_1=τ_2=1,25 h		12	62-63	25	36	58	2.4

In addition, the reduced carbon concentration in the surface area facilitates grinding and reduces the risk of cauterization. Both significantly improve the quality of products.

Under the same type of *IC* and *GC* modes, the distribution of carbon in the diffusion layer, its microstructure and phase composition do not differ from those that are characteristic of the *GC* and are shown above (Fig. 2).

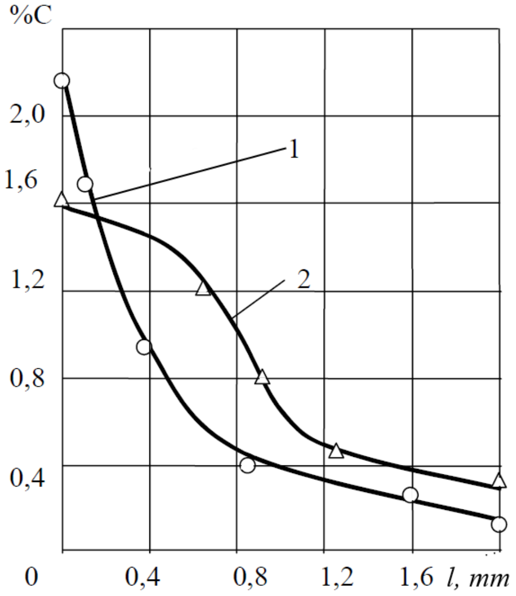


Fig. 2. – Carbon distribution *C* by thickness of carburized layer *l* of steel C0.16Cr3NiWVMoNb after *IC* (*t* = 950°C, total time = 2.5 *h*) with one stage (1) and two-stage (⍰$_1$ = ⍰$_2$=1,25 *h*) (2)

The presence of nitrogen in *ICN* affects the phase composition and structure of excess phases. Along with the main carbonitride $M_3(CN)$, which is mixed with a small amount of Cr_7C_3, a fine complex-doped nitride phase MN and M_2N is formed in the near-surface layer based on chromium nitrides CrN and Cr_2N. The amount of the nitride phase is ~ 3 %.

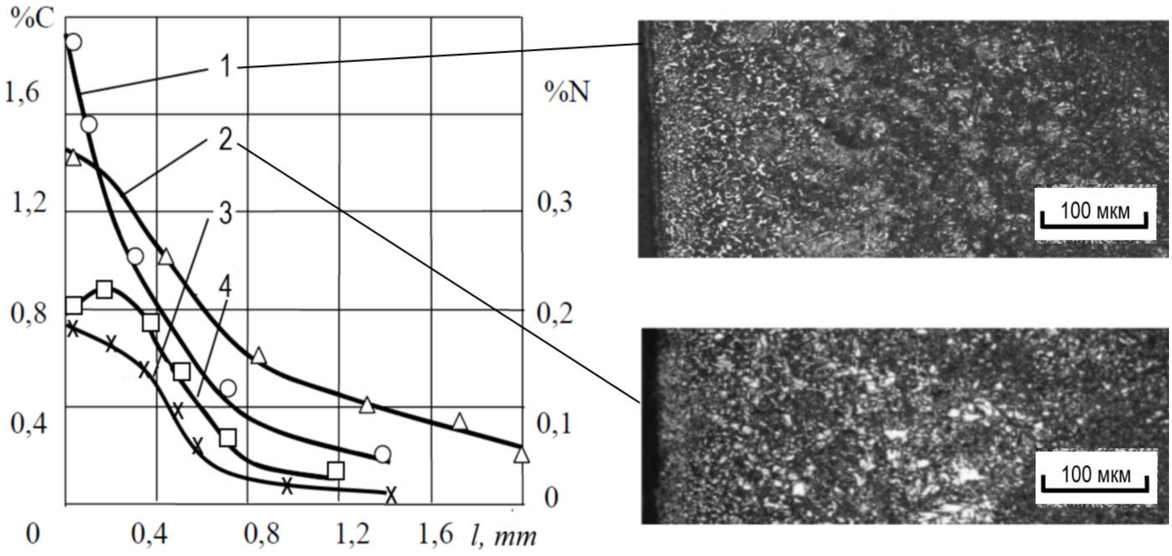
In the single-stage *ICN* mode, a diffusion layer is formed with less supersaturation of the surface with carbon at a flatter distribution than in the same *IC* mode (Fig. 3). This leads to the formation of a longer active carbonitride zone with a slightly smaller volume fraction of particles (see table 2). The two-stage *ICN* mode significantly increases the effective layer thickness, although the average particle sizes for these processes are almost the same.

It is necessary to emphasize the uniformity of the thickness of the diffusion layer along the profile of parts after termochemical treatment in the glow discharge plasma.

The same structural state of steel after the equivalent modes of *GC* and *IC* provides the same change in structure and properties at *SBT* to. However, all other things being equal, the slightly higher efficiency of *IC* and *ICN* is due to the greater uniformity of the distribution of the carbide phase in the layer, since this reduces the risk of stress localization in the boundary volumes.

The active carbonitride zone formed under the single-stage *ICN* regime with a slightly smaller volume fraction of particles and a martensitic matrix doped with nitrogen is more resistant to contact loads than the carburized surface.

Technological heredity is manifested in carbonitriding layers as well as after GS. After *SBT*, the durability of samples with a large proportion of carbonitride excess phase (after a single-stage *ICN*) does not increase, whereas in samples with a less developed excess phase (after a two-stage *ICN* mode), the durability increases by 40-50% after the rational mode (see table 2).



a) ***b)***

Fig. 3. – Carbon distribution *C* (1, 2) and nitrogen *N (3, 4)* by thickness (*a*) and microstructure of carbonitrided layer (*b*) of steel C0.16Cr3NiWVMoNb after *ICN* (*t* = 950°C, total time = 2.5 *h*) with one stage (1, 3) and two-stage ($\square_1 = \square_2$) (2, 4)

The additional low tempering after *SBT* increases the contact wear of steels subjected to *IC* and *ICN* as well as after *GC* (see table 2). Its positive effect, as noted in [4, 12], is associated with a decrease in local micro-stresses near structural stress concentrators (for example, the nitrides or the carbonitrides), as well as an increase in the degree of fixation of dislocations by embedding atoms. In this case, dislocations are blocked primarily by carbon atoms, not nitrogen.

Conclusions

1. The effectiveness of *SBT* depends on the technological inheritance created by the thermochemical treatment. For heat-resistant steels, *SBT* becomes effective if the *GS* is carried out in a two-stage mode. The optimal ratio of stage durations (60% and 40%) was determined, in which the durability of samples is 1.5 times higher than in a single-stage saturation process.

2. The preferred methods of saturation in the glow discharge (*IC* and *ICN*) are characterized by a more uniform distribution of carbides in the layer, the ability to control the saturation process and the stability of the results.

3. The use of rational technology that takes into account the technological inheritance of *SBT* increases the performance properties of the working surfaces of the gears for mining equipment by at least 2.5 times.

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