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SURFACE SATURATION OF STEELS WITH CARBON DURING MECHANICAL-PULSE TREATMENT

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We show that surface saturation with carbon from a special technological environment increases the microhardness of the hardened layer on low-carbon steels up to 8–12 GPa. We established an increase in the wear resistance of the white layer by a factor of 1.3–1.5.

Mechanical-pulse treatment [1] consists of high-rate (10^5-10^6 K/sec) heating of the surface sections of metal up to the temperature of the highest point of phase transformations (1100–1300 K) simultaneously with their intensive deformation with rates of 10^3-10^4 sec^{-1}, and subsequent rapid cooling (10^3-10^4 K/sec) at the expense of heat removal into the article, tool, and technological environment. A highly concentrated energy flux is generated in the zone of frictional contact of the treated article with the hardening tool, which rotates with a frequency of 80–90 sec^{-1}.

The physicomechanical properties of the surface sections of a hardened metal depend on the carbon content in them [2]. To decrease the amount of metal per structure, a number of articles (of the type of rods and plungers of hydrocylinders) are welded by using pipes of low-carbon steels as blanks, whose hardening is of low efficiency. It is possible to alloy the surface layers of a metal in the course of mechanical-pulse treatment in a technological environment [3]. The aim of the present work is to develop a special technological environment for improvement of the mechanical-pulse treatment efficiency for articles of this class.

It is known [4, 5] that the amount of dislocations generated in the course of mechanical-pulse treatment exerts a decisive influence on the mass transfer of alloying elements. Therefore, in selecting a technological environment, it is very important to evaluate its effect on the generation of dislocations. With the help of X-ray investigations of 45 steel (ferrite-perlite) after mechanical-pulse treatment in various technological environments (5% emulsol aqueous solution and I-5A industrial oil), we established that the highest dislocation density can be attained during treatment in oil (Table 1). Thus, by changing the technological environment, we can purposefully change the average density and distribution of dislocations over the volume of the metal in the sliding zone and, in such a way, affect the mass transfer of alloying elements in the surface layers. Proceeding from these considerations, we took low-viscosity I-5A mineral oil (GOST-20799-75) as the basis of the technological environment. It was shown [6] that the polymeric component of the technological environment decomposes in the temperature range 1100–1200 K according to the mechanism of chain radical depolymerization. In this case, immediately on the heated metal surface, carbon-containing low-molecular substances at high concentrations (various free radicals, pyropolymeric residues, and atoms of carbon, hydrogen, etc. which can actively interact with the metal surface) are formed. The pyrolyzate can manifest catalytic activity by accelerating the decomposition of polymeric molecules into elementary chains or groups of chains and affecting the saturation of the metal. Hence, we used the waste of the production of polyethylene as a source of carbon diffusant, namely, low-molecular polyethylene of the G type (TU 6-05-36-9-79) with the structural formula $(-CH_2-CH_2-)$, which is obtained in the process of production of high-molecular polyethylene. To improve the lubricating properties of the technological environment, we introduced antiwear and antiscuff additives into it. They prevent seizure and jam under high loads in the frictional contact zone, decrease the roughness of the surface being hardened [7], and increase the endurance of the hardening tool.

According to Epifanov's theory of the catalytic decomposition of a technological environment [8], under the action of the force field of juvenile surfaces appearing in the course of treatment of the metal, molecules of the technological environment dissociate with formation of atoms diffusing into the deformed metal. According to this the-

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ory, during the fracture of the metal surface in the course of treatment, any surface atom in the zone of deformation completely loses its bonds with the neighboring atoms and becomes unsaturated and, therefore, extremely active. Under the action of the force field of the metal juvenile surface, the molecule of the chemical compound is deformed, which can result in a complete break of bonds and its transition to the monatomic state. In the treatment zone, this process is stimulated by high pressures (the forces in the frictional contact zone are as high as 500–800 N) and temperatures, which attain 1200–1800 K during mechanical-pulse treatment depending on the treatment conditions.

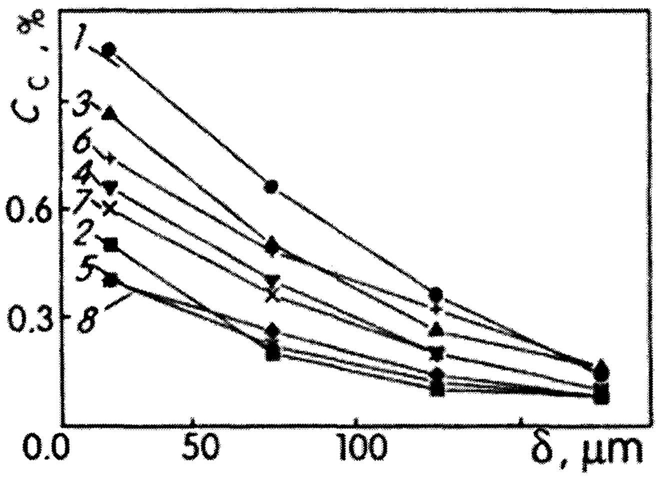

Fig. 1. Carbon distribution in the surface layers of armco iron depending on the kind of surface treatment (1, 2), rotational speed of the specimen (3–5), and longitudinal feed (6–8): (1) annealing and polishing, (2) annealing and grinding, (3) $n = 0.20\ \text{sec}^{-1}$, (4) $n = 0.52\ \text{sec}^{-1}$, (5) $n = 0.83\ \text{sec}^{-1}$, (6) $S = 2.08$ mm/rev, (7) $S = 1.5$ mm/rev, (8) $S = 1.0$ mm/rev.

We studied alloying of armco iron and 20, 35, and 45 steels after annealing with carbon using a special device [9]. The environment [10] makes it possible to obtain high carbon concentrations in the surface layers of armco iron (Fig. 1). We determined the carbon concentration with the help of layer-by-layer chemical analysis. This concentration is higher in an annealed specimen with a low dislocation density ($\rho = 10^6 - 10^8\ \text{cm}^{-2}$) as compared with that after electrogrinding with corundum ($\rho = 8 \cdot 10^9\ \text{cm}^{-2}$). Thus, the annealed structure with a minimum amount of defects has a maximum carbon concentration. This fact corroborates the conclusions in [11] that the amount of the alloying element carried into the metal surface layers is determined by the density of generated dislocations. Saturation of the surface layers of the metal being hardened with carbon from the technological environment depends on hardening conditions. As the rotational speed of a specimen increases, the carbon concentration decreases, which is obviously connected with a reduction of temperature because the residence time of a treated surface in the frictional contact zone decreases (see Fig. 1). On the contrary, as the longitudinal feed of a tool increases, the carbon concentration grows (see Fig. 1) because the area of the deformed metal widens and the density of generated dislocations increases (see Table 1). Thus, changing the treatment modes, we change the carbon concentration in the metal surface layers.

By using the developed technological environment during mechanical-pulse treatment of 20 and 35 steels, we obtain a microhardness as high as 8–12 GPa (Fig. 2), which can vary depending on treatment modes. Hardening is most efficient in the case of low rotational speed of the specimen and high feed rates of the tool: precisely under these conditions, the microhardness and depth of the hardened layer grow. These data (see Fig. 2) well agree with the carbon distribution (see Fig. 1). Using high feed rates ($S = 1.5–2$ mm/rev) during hardening increases the productivity of treatment and the depth and microhardness of the hardened layer, but, at the same time, worsens the roughness of the treated surface (Fig. 3). This fact should be considered in selecting treatment modes.

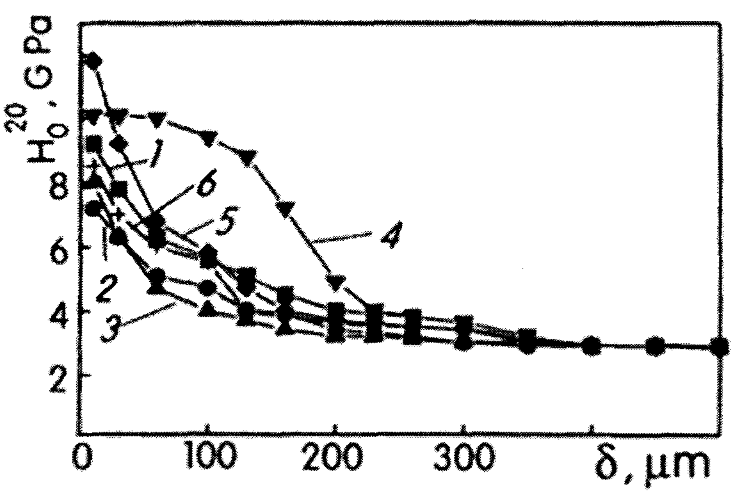

Fig. 2. Microhardness distribution in 20 (1–3) and 35 (4–6) steels hardened by a tool of VT6 alloy depending on the longitudinal feed (1–3) and rotational speed of the specimen (4–6): (1) S = 2.08 mm/rev, (2) S = 1.2 mm/rev, (3) S = 0.6 mm/rev, (4) $n = 0.33\ \text{sec}^{-1}$, (5) $n = 0.83\ \text{sec}^{-1}$, (6) $n = 1.05\ \text{sec}^{-1}$.

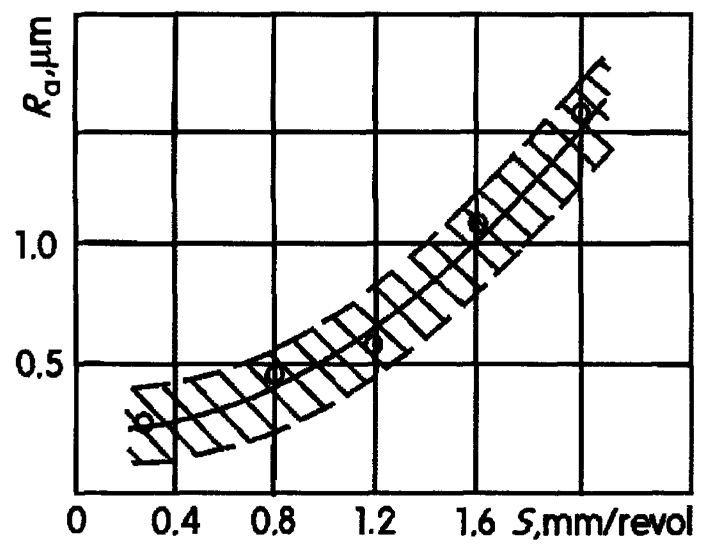

Fig. 3. Roughness of the hardened surface vs the longitudinal feed of a tool.

Table 1. Dislocation Density under Different Kinds of Treatment

Dislocation density	Kind of treatment			
	Grinding	Mechanical-pulse treatment, oil, S = 0.9 mm/rev	Mechanical-pulse treatment, oil, S = 2 mm/rev	Mechanical-pulse treatment, emulsol, S = 2 mm/rev
$\rho_d \cdot 10^{12}$, cm^{-2}	0.008	0.98	1.51	0.58

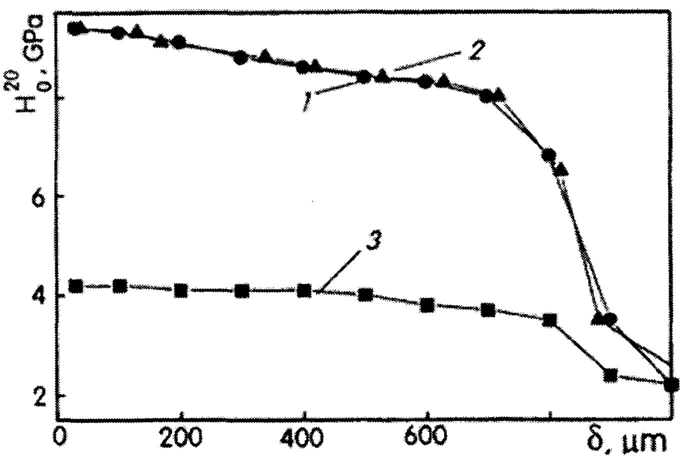

Fig. 4. Change in the microhardness of 45 steel hardened in the technological environment for carburizing: (1) without tempering, (2) tempering at 500 K, (3) tempering at 800 K.

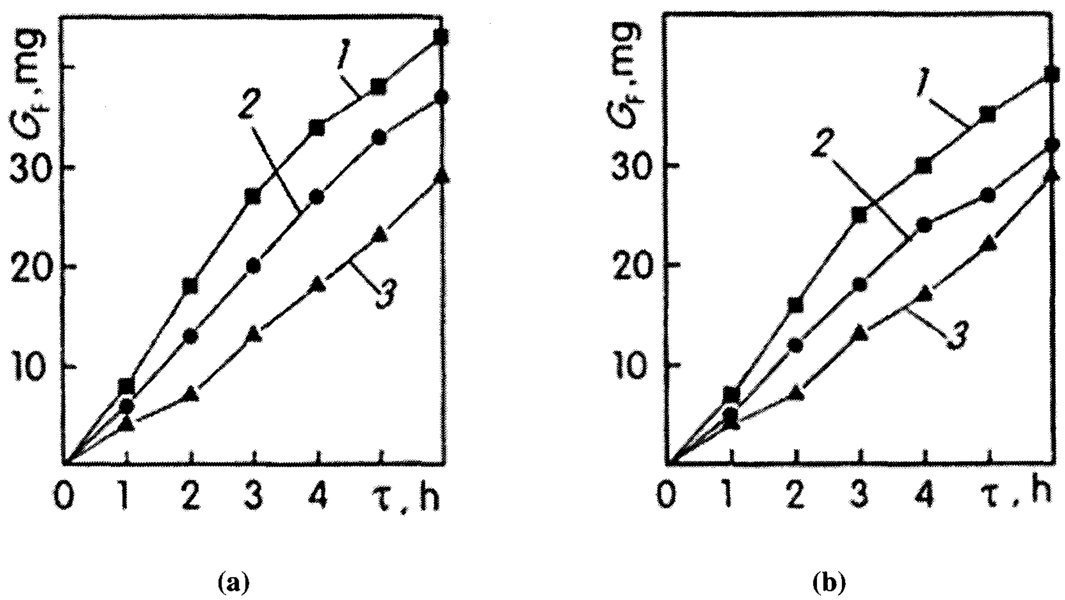

Fig. 5. Kinetics of wear of the 35 steel–ShKh15 steel couple under friction in an oil-abrasive environment for a ring (a) and a bushing (b): (1) Khtv. 24 coating, (2) hardening in mineral oil, (3) hardening with the use of the technological environment for carburizing (v = 0.9 m/sec, P = 1 MPa, TAP-30 oil + 0.1 mass % of abrasive).

We studied the phase composition of alloyed and hardened steels on a DRON-3 diffractometer in Fe_α radiation with $\lambda = 1.936$ Å. After saturation of 20 steel in the initial ferritic-perlitic state, the hardened layer has the ferritic-austenitic structure (α-Fe – 35%, γ-Fe – 65%). The parameter of the γ-Fe lattice $\alpha = 3.6$ Å, which corresponds to 1.2% of carbon. Thus, the data of X-ray investigations agree with the results of layer-by-layer chemical analysis. If the same environment is used for alloying of 45 steel, the ferritic-austenitic-cementitic structure and the oxides FeO and Fe_3O_4 are formed on the metal surface [4].

High carbon concentrations are explained by high-rate plastic deformation in the frictional contact zone, which attains 10^3 sec^{-1} during mechanical-pulse treatment. If the time of the action of maximum temperatures is 6–10 msec, the diffusivity is about 10^{-5} cm^2/sec [3]. Such an increase in the diffusion rate under the conditions of high pressures and intensive shear deformations (10^{-1} cm^{-1} and more) is known as mass transfer [12]. High diffusivities are caused also by high-rate heating ($10^5 - 10^6$ K/sec), which intensifies chemical reactions, adsorption, and chemisorption of the products of decomposition of the environment on the metal surface. Owing to high-rate heating, the activity and structural state of the metal surface layer change. As the heating rate increases, austenite becomes more fine-grained, grains and particles become smaller, and, therefore, the extent of the boundaries of grains is greater, which accelerates the advance of the saturating element.

Thus, as a result of alloying and hardening, structures of high microhardness, which depends strongly on the concentration of vacancies and dislocations [13], are formed. Heating to 500 K is sufficient for a sharp decrease in the concentration of vacancies, and heating from 500 to 800 K significantly reduces the density of dislocations. This information is important for the evaluation of the serviceability of a hardened metal under friction conditions. In practice, temperatures near 500 K can be reached in friction units in a liquid lubricating environment, but a temperature up to 800 K is reachable only in the case of dry friction. The microhardness of the hardened layer (Fig. 4) was obtained at the expense of a high density of dislocations. A decrease in the concentration of vacancies does not affect microhardness, and the hardened layer can operate under conditions of oil-abrasive wear when the temperature in the friction zone attains 500 K [13].

We carried out tests for wear resistance in an oil-abrasive environment with 35 steel treated in the presence of the given technological environment. We compared the efficiency of mechanical-pulse treatment of metal surfaces in the developed technological environment with that for Khtv. 24 chromium coating, which is applied for the improvement of wear resistance of hydrocylinder rods, and with the efficiency of mechanical-pulse treatment in I-12A mineral oil. Using the technological environment for carburizing increases the wear resistance of hardened rings by 1.3–1.5 times and that of nonhardened bushings (Fig. 5). This is connected with the high microhardness of the white layers and the positive influence of the surface film enriched by iron oxides, which promotes the formation of high-quality tribolayers [14].

CONCLUSIONS

We have shown the possibility of surface alloying of steels with carbon from the developed special technological environment, which results in a change in the chemical composition, structure, and physicomechanical properties of hardened layers of low-carbon steels.

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