A substantial increase in strength can be obtained by accelerating the saturation not to the total depth but to the effective depth. This is achieved by supplying ammonia to the carburizing atmosphere for 2 h and lowering the processing temperature from 930 to 850°C. In this time period the nitrogen is in solid solution, which greatly increases the hardenability of the steel. For example, the effective depth of saturation is double that achieved by the standard method in the case of steel 25KhGT.

For steels containing nitride-forming elements ammonia is supplied to the carburizing atmosphere in the initial stage of the process at a temperature of $Ac_1 \pm 50$°C. Hard-to-dissolve nitrides inhibit grain growth during subsequent heating, which substantially improves the mechanical properties of the carburized case.

The replacement of traditional methods of carburizing and carbonitriding with new complex processes has made it possible to increase labor productivity in chemicothermal treatments, reduce raw material and energy consumption, and substantially improve the quality of machine parts.

EFFECT OF CHEMICOTHERMAL TREATMENT ON THE STRUCTURE AND ENERGY OF THE SURFACE OF METALS AND THE BULK PROPERTIES

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UDC 621.785.5:539.219.3

The changes in the structure and energy that occur in the surface zones of metals in the process of chemicothermal treatment lead not only to new physicochemical properties on the surface but also affect the bulk properties. The effect of the diffusion layer is clearly apparent under the influence of mechanical stresses in a broad range of temperatures (cryogenic, high), heat flows, and magnetic and electric fields.

For example, a thin oxide film (1000 Å) on cadmium increases the shear strength by 50% (Cottrell), while a film of aluminum oxide 500 Å thick more than doubles the critical shear stress of aluminum (Roscoe).

Our studies indicate that the effect of a diffusion layer may be still greater. This depends on the nature of the diffusion layer, its physicochemical characteristics, and its thickness.

The free surface of a metal is characterized by various defects of the fine structure, disruption of the periodic arrangement of atoms in the crystal lattice, the existence of uncompensated bonds between atoms, a low coordination number, distortion of the crystal lattice, and microcracks. The density of these defects is high and the surface is in a metastable condition from the viewpoint of structure and energy.

The high level of free energy of surface zones of the metal predetermines the high probability of surface damage (chemical, mechanical, etc.) and as a consequence the entire section of the metal.

In the process of diffusion saturation of the surface of a metal (alloy) there are changes in the structure and energy of the diffusion zone, accompanied by a reduction of the thermodynamic potential of the surface, and changes in the strength of bonds between atoms and in the fine structure of the metal. The surface energy changes due to the increase in the coordination number and the more complete bonds between atoms.

A simple method of calculating the strength of bonds or the strength was proposed by Orowan.

The change in the bonds between neighboring atomic planes in an ideal solid solution per unit surface in tension with changes in the interatomic distance x at absolute zero takes the form:

$$\sigma = k \sin \frac{\pi}{a}(x - a_0),$$

where $k = (E/\pi)(a/a_0) = \text{const}$; a_0 is the lattice constant; a is the long-range interaction of atomic forces; E is the modulus of elasticity in tension.

MII GA. Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 7, pp. 69-71, July, 1978.

0026-0673/78/0708-0597$07.50

According to Orowan, lattice constant a can be determined as

$$\int_{a_0}^{a_0+a} \sigma\, dx = 2\gamma,$$

where γ is the surface energy, hence $a = (\pi\gamma)/k$.

$$\sigma_{max} = k = \frac{E}{\pi}\left(\frac{a}{a_0}\right)$$

$$\text{or } \sigma_{max} = \sqrt{\frac{E\gamma}{a_0}}.$$

Thus, the maximum strength of the diffusion layer must be optimized by the parameters of the constant of the radicand.

Another indirect characteristic of the surface energy is the work function of electrons.

The strongest bond between atoms occurs when electrons occupy orbits with the lowest energies, and thus the work function will be large in this case.

The ultimate tensile strength of metals is related to the work function by the following equation:

$$\sigma_b = 8.064 \cdot 10^{-3} \frac{\sigma_0^{3/2}}{\varphi^{1/2}},$$

where σ_0 is the coefficient of surface tension of the metal; φ is the work function of electrons;

$$\sigma_0 = 1.15 \cdot 10^3 \left(\frac{zD}{A}\right)^{5/6},$$

where z is the number of electrons per atom; D is the density of the metal; A is the atomic mass.

Combining both equations, we obtain

$$\sigma_b = B\left(\frac{2D}{A}\right)^{15/12} \varphi,$$

where $B = 9.6 \cdot 10^{3/2}$.

In the formation of a diffusion layer with the structure of the solid solution the work function obeys the general law [1]:

$$\varphi(C) = \varphi_0 + aC,$$

where φ_0 is the work function of the pure component; a is the proportionality coefficient; C is the atomic concentration of the element in the diffusion layer.

The values of constants φ_0 and a for solid solutions occurring in saturation of the surface of iron with chromium, nickel, boron, vanadium, and aluminum are given below (according to V. A. Kuznetsov).

System	Work function, eV/at.%
Cr → Fe	+0.028
Ni → Fe	+0.084
V → Fe	+0.001
Al → Fe	+0.008
B → Fe	+0.033

The work function for iron $\varphi_0^{Fe} = 4.17$ eV.

It can be seen from the data presented that diffusion saturation of iron with these elements makes it possible to increase the strength of the diffusion layer in conformity with the series (increasing from left to right) V, Al, Cr, B, Ni.

After diffusion chromizing of steel É12 the work function of electrons increases from 4.5 to 5.1 eV.

Other indirect characteristics for calculating the surface energy are the characteristic temperature, activation energy of self-diffusion, and energy of the crystal lattice.

The metal on the surface of which a diffusion layer is formed can be regarded as a composite material, since the composition and structure of the surface layers and the core differ considerably.

Investigations have shown that on the free surface and in surface zones of a metal after diffusion saturation the fine structure has dislocations, the density of which differs within the limits of the zone, traces of plastic deformation, and fragments. The change in the fine structure is due to microplastic deformation induced by diffusional flow of atoms. Such substantial changes in the fine structure of the surface have a large effect on the properties of the surface zones and also on the working capacity of the metal through the section.

The diffusion layer prevents dislocation movements to the surface (during operation of the metal under stress), thus slowing down the nucleation and growth of microcracks on the surface.

Thus, from the energy viewpoint the surface of a metal with a diffusion layer approaches the ideal, which permits use of the lefthand branch of the Oding–Bochvar diagram, while the "barrier effect" of the diffusion layer and the associated high dislocation density below the diffusion layer make it possible to use the righthand branch of this diagram.

Studies have shown that the average level of the bulk strength hardly changes in this case, but the kinetics of the nucleation and growth of microcracks on the surface under the influence of the structural and energy changes indicated above decrease considerably, as the result of which the service life of machine parts increases.

LITERATURE CITED

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CALCULATION OF THE PARAMETERS OF THE PROCESS AND THE GAS CONDITIONS DURING CARBURIZING

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UDC 621.785.51.062.5

Results are presented from a study conducted to formulate a method of calculating the basic parameters of the carburizing process and the gas conditions that would also made it possible to analyze the effect of individual factors on them.

The first step was to create a mathematical model of gas carburizing taking into account the basic characteristics under actual conditions and relating the quality of the treatment with the technological parameters of the process and the gas conditions in the furnace. The model has the following form:

$$\frac{\partial a(x, y, t)}{\partial t} = D_{\text{true}} \frac{\partial^2 a(x, y, t)}{\partial x^2}, \tag{1}$$

where $x > 0$, $t > 0$;

$$D_{\text{true}} = \frac{100 j \lambda_a}{\rho};$$

$$j = \frac{\left[0.01 f \exp\left(\frac{4847}{T}\right) + 0.197 a_{\text{atm}}\right] \left[0.01 f \exp\left(\frac{4847}{T}\right) + 0.197 a_0\right]}{0.01 f \exp\left(\frac{4847}{T}\right)};$$

Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 7, pp. 71–75, July, 1978.

0026-0673/78/0708-0599$07.50