The fact that the heated parts are not moved reduces distortion, which is the advantage of this design. A mechanism for raising and turning the cover is mounted on the frame, along with a fan and an electric motor. Thermal insulation in the sidewalls is provided by a graphite cylinder wrapped with several layers of graphite felt and bound with two metal halfcylinders.

The ends are thermally insulated with graphite rings and graphite felt. The heating elements are graphite rods suspended from two molybdenum brackets. In the process of heating, the openings in the upper and lower parts of the thermal insulation are closed with blinds. A diffuser placed under the lower blind directs the main gas flow into the working space during quenching. The gas-cooling system is placed at the end of the frame. The furnace is powered by a reducing transformer and thyristor regulator. The temperature is controlled by a programmed device.

Laboratory and production tests have confirmed the main advantages of the vacuum-quenching process:

1) The reduction of distortion due to reduction of the thickness of the surface layer with changes in chemical composition;

2) a bright surface, due to which pickling or sandblasting is unnecessary, and reduction of mechanical operations (for example, grinding of bearings);

3) an increase in the service life of parts due to the improvement in the quality of the surface, higher ductility due to degassing, and so forth;

4) better working conditions and the absence of toxic substances in the atmosphere.

EFFECT OF THE CONDITION OF THE SURFACE LAYER ON COMPLEX (BULK) PROPERTIES OF METALLIC MATERIALS

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Most of the physicochemical processes that occur during operation of machine parts are concentrated primarily in surface zones of the metal. This is observed not only in those cases were the free surface of the metal is subject to the direct influence of chemical and electrochemical corrosion, erosion, friction against a counterbody, and sublimation due to high-energy particles, but also under the influence of mechanical stress fields. Stresses are usually distributed unevenly through the section of a part and induce deformation and fracture primarily in surface zones. Changes in the chemical composition, structure, and properties also occur in the surface zones of alloys under the influence of high temperatures and surrounding media.

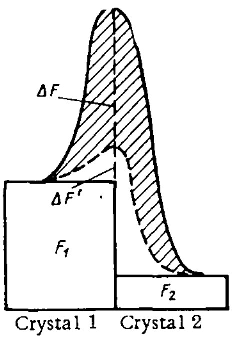

Fig. 1. Change in free energy at the boundary between two crystals in the process of diffusional interaction. ——) Before saturation; – – –) after saturation.

Moscow Institute of Civil Aviation Engineers. Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 8, pp. 47–49, August, 1977.

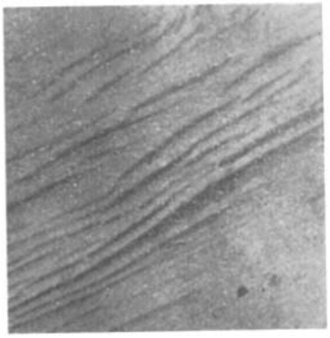

Fig. 2. Dislocation pile-ups in the surface zone of a diffusion layer after aluminizing of steel 12Kh18N10T (×3500).

In the latter case the process controlling the change in the chemical composition, structure, and properties of the surface is the diffusion of elements from the surrounding medium, sublimation of elements from the surface of the alloy, and, as a consequence of these processes, diffusional redistribution of the elements of the alloy to the surface. Consequently, under the influence of many operating factors the surface of an alloy has a direct effect on the reliability and service life of the part. Thus, to increase the operational reliability of machine parts it is expedient to change the structural–energetic condition of the free surface of the metal, which makes it possible to improve not only the physicochemical properties of the surface but also the bulk properties of the part (through the section) [1].

The energetic condition of the surface is calculated by the level of the free (surface) energy, which is determined by the binding force between atoms. The free surface of the metal constitutes a break in the periodic arrangement of atoms in the crystal lattice, as the result of which the bond between atoms is not comprehensive. Consequently, near the surface and in layers immediately bordering the outside medium there are energy changes leading to a substantial reduction in the thermodynamic stability of the surface A high level of free energy in the surface zones of the metal predetermines its highest liability to damage (chemical, mechanical, and so forth).

The energetic condition of the surface can be changed by diffusional saturation (alloying) of the surface with different elements or combinations of elements: Cr, Al, B, Si, Cr–Al, Cr–Al–Si, and others.

Figure 1 shows the change in the free energy of the surface of a crystal with an original energy F_1 due to diffusion into the metal of atoms of an element contacting the crystal with energy F_2. The reduction of the free surface energy is explained by the annihilation of vacancies in the surface layer, due to which the atomic bonds are more completely realized [2]. The latter increases the resistance of the metal to plastic deformation and especially to brittle fracture.

Along with the energy factor, the structural factor is of particular importance to improve the operational reliability of machine parts. The phase transformations and changes in the fine structure associated with changes in the chemical composition of the alloy due to interaction with the surrounding medium in the process of operation lead to substantial changes in the structure and properties of the surface in comparison with the original surface.

Diffusional saturation with elements makes it possible to change the structural condition of the surface of an alloy due to changes in chemical composition and thus ensure long-term stability of the structure of the surface in the process of operation.

Depending on the nature of the diffusing element, a single-phase or multiphase diffusion layer forms on the surface of the metal that consists of a solid solution of the interacting elements or their chemical compounds, or is heterophasic in nature. As a rule, in the first two cases the diffusion layer has a texture, the grains of which are almost monocrystalline, as the result of which the polycrystalline complex of the surface layer is statistically anisotropic.

In the process of diffusion there are also changes in the fine structure of the metal associated with formation on the surface and in surface zones of the diffusion layer of dislocations and a polygonal structure. Electron microscopic studies of aluminized steel 12Kh18N10T at a depth of 10 μ from the surface showed a diffusion zone (FeAl at the lower boundary of the layer) in which dislocations were observed (Fig. 2).

With a diffusion layer the structure of the surface approaches the ideal, which makes it possible to use the lefthand branch of the curve on the Oding–Bochvar diagram (Fig. 3) and also serves as a barrier to dislocations running to the surface. This leads to dislocation pile-ups below the diffusion layer, which makes it

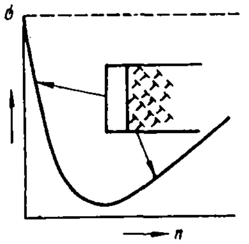

Fig. 3

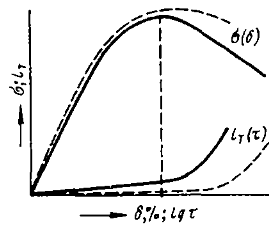

Fig. 4

Fig. 3. Oding–Bochvar diagram.

Fig. 4. Effect of diffusion layer on ultimate strength and kinetics of fracture. ——) Before saturation; – – –) after saturation.

possible to use the righthand branch of the Oding–Bochvar diagram (Fig. 3) [2].

The average level of the bulk strength hardly changes in this case, but the probability of the nucleation of microcracks on the surface of the metal and the kinetics of their propagation into the depth of the metal (log τ) decrease (Fig. 4), as the result of which the service life of the machine part increases.

Thus, under the influence of mechanical stresses the diffusion layer has a strong effect on the kinetics of fracture despite its relatively small thickness when compared with the total section of the part, and thus increases the service life of the part as a whole. An oxide film formed on the surface during oxidation of the metal can also have a large effect on the kinetics of fracture at high temperatures. The role of oxide film should evidently be considered not only in connection with their protective influence against oxidation but also in connection with their effect on the development of microcracks on the surface of an alloy. When dense and tightly adherent oxide films are formed on the surface, plastic deformation of the surface zones will be inhibited and the time to failure will increase. Such oxide films as Cr_2O_3, Al_2O_3, and spinel $NiO \cdot Cr_2O_3$ evidently have such properties.

The high alloying of the solid solution that occurs with diffusional saturation of the surface of heat-resistant alloys inhibits impoverishment of the grains and grain boundaries generally observed during oxidation of an unprotected alloy and thus increases its heat resistance. Alloying of the surface with elements evidently permits not only the healing of vacancy sinks, which are dislocations, but also reduces the size of regions free of subboundaries, increasing the misorientation of neighboring grains.

Consequently, within submicroscopic regions of the surface layer, conditions are created for stable disruptions of the chemical heterogeneity and the regular periodicity of the structure within coherent submicroscopic regions of the crystal. This leads to stabilization of dislocation pile-ups and substructures and also to inhibition of the processes of climb and recovery. One would expect recrystallization processes in surface zones of alloys to occur much more slowly after saturation than before, which would also lead to an increase of the heat resistance.

Consequently, structural–energetic changes in the surface may affect not only the physicochemical properties of the surface (hardness, wear resistance, resistance to erosion, corrosion, contact, and thermal and electromagnetic properties) but also the bulk properties of the alloy, which is especially notable in operation under conditions of creep, fatigue (including thermal fatigue), and under the influence of magnetic and electric fields.

The energetic condition of the surface and its relationship with the physicochemical properties can be determined indirectly from the characteristics of the activation energy of self-diffusion of elements in a layer (Q), the temperature characteristic (θ), the residual stress (σ_{res}), the modulus of elasticity (E), the electronic work function (φ), the energy of the crystal lattice (W), and others.

LITERATURE CITED

1. G. N. Dubinin, Diffusion Chromizing of Alloys [in Russian], Mashinostroenie, Moscow (1964).
2. G. N. Dubinin et al., "Structure and properties of alloy VKh4 after aluminizing," Zashch. Pokrytiya Met., No. 7, 97 (1973).