INVESTIGATION OF THE PORE-FORMATION PROCESS DURING THE CHROMIZING OF STEEL 40Kh BY THE CIRCULATION METHOD

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During the chromium plating of carbon steels, a carbide possessing elevated hardness and wear resistance is formed on the surface. It is known that the development of diffusion porosity, which is associated with the different diffusion mobilities of the atoms, is possible in the coatings. Use of carbides as an anti-corrosion protective layer requires its continuity; this is difficult to achieve by chromium plating in accordance with applicable regimes. In the literature, there are virtually no studies in which pore-formation processes are addressed as applies to carbide coatings. This paper examines diffusion processes that take place in the surface layers of steel 40Kh during long-term annealing after chromium plating by the circulation method. The composition and properties of the chromium-plated layer are studied. Possible mechanisms of pore formation and recommendations for the use of diffusion carbide coatings are proposed.

We investigated steel 40Kh specimens (0.36-0.44% C; 0.8-1.1% Cr; 0.17-0.37% Si; and, 0.5-0.8% Mn), which were fabricated in the form of disks 20 mm in diameter and 5 mm thick. The disks were ground with a minimum cutting depth of 2 μm. The thicknesses of the disks were measured in several sections on a IZV-1 length gage with a scale division of 1 μm. The spread of the thickness values amounted to ±1 μm. The specimens were chromium-plated in a DKh2 laboratory circulation unit at 1000°C for 2 and 5 h. The circulation method of diffusion saturation, which is applicable in the present investigation, is promising, since it is possible to develop production regimes to achieve a continuous protective layer [1].

After chromium plating, the specimens were subjected to prolonged tempering at 1000°C for 50 and 100 h. To prevent oxidation, they were soldered into a quartz ampule filled with commercially pure Grade "A" argon with no more than 0.003 and 0.1% of O₂ and N₂ impurities, respectively. To exclude possible rupture of the ampule during heating, the argon was evacuated with a residual pressure of 13.3 Pa using a vacuum pump prior to its being soldered. Annealing was carried out in a laboratory furnace with automatic temperature maintenance in accordance with the following scheme: heating to 1000°C for 4 h, holding for 8 h, and cooling to room temperature over 12 h. This regime was repeated several times so that the overall holding time ran tₐₙₙ = 50 or 100 h. The temperature was controlled using a TKhA thermolectric transducer. Some of the specimens were removed from the furnace after being held for 50 h at 1000°C. The remaining specimens were resoldered and subjected to further annealing for a period tₐₙₙ = 100 h.

The annealing temperature of 1000°C corresponded to the chromium-plating temperature and was selected as methodologically convenient for investigation of pore-formation processes during the production of a carbide coating.

Metallographic investigations and measurement of the thickness of the carbide layer was carried out under a "Neophot-21" optical microscope. The specimens were etched in Murak [10 kg of K₃(FeCN)₆, 10 g of NaOH, and 100 ml of H₂O] and nital (3-5% solution of HNO₃ in ethyl alcohol) reagents to expose the structure of the surface carbide layer [2]. Micro-X-ray-spectral analysis of the specimens was carried out at the I. P. Bardin Central Scientific-Research Institute of Ferrous Metallurgy under a BS-340" electron microscope with an X-ray analyzer manufactured by the "Link Analytical" Co. The visible porosity on three segments of microsections under a magnification of ×1000 was assessed on the analyzer via a special program. the overall field of view was 170 μm²; this made it possible to determine the porosity of a layer 170 μm thick into which the zone of the diffusion carbide coating and transition zone entered. The microhardness was measured on an "HMV 2000" hardness tester manufactured by the Shimadzu Co. under a load of 0.1 N for 5 sec. After the deposition of chromium atoms on the
Fig. 1. Schematic diagram showing measurement of displacement $\Delta_{in}$ of "carbide-layer/steel" boundary.

1, 2) surface of disk prior to and after chromium plating; 3) "carbide-layer/steel" boundary; $h_c$) thickness of carbide layer; $h_{ini}$ and $h_n$) thickness of disk prior to and after chromium plating, respectively.

Fig. 2. Change in position of disk surface (2) and boundary of carbide layer (3) relative to initial position of surface (1) during chromium plating at 1000°C (a) and annealing at 1000°C after chromium plating at 1000°C for 5 h (b) (see diagram in Fig. 1).

surface of the steel, its penetration inside is arrested by a counter diffusion of carbon as a result of the vigorous chemical affinity of these elements and the formation of a carbide layer. It is known that the diffusion coefficient of carbon at 1000°C is three or four orders greater than that of the substitutional atoms [3, p. 171]. In determining the direction of growth of the carbide layer, it was assumed accordingly that the surface of the disks is the initial "carbide-layer/steel" interface. It should be pointed out that during chromium plating, the thickness of the disks is increased, i.e., the diffusion layer grows not only into the depth of the metal, but also outward. The displacement of the "carbide-layer/steel" interface $\Delta_{in}$ (Fig. 1) relative to the initial position of the disk’s surface was calculated from the formula:

$$\Delta_{in} = \frac{h_{ini}}{2} - \frac{h_n}{2} + h_c,$$

where $h_{ini}$ and $h_n$ are the initial and new thicknesses of the disk, respectively, and $h_c$ is the thickness of the carbide layer. The results of the calculation are presented in Fig. 2.

It is indicated (Fig. 2a) that during chromium plating, ~70% of the thickness of the carbide layer is formed due to its outward growth, and only ~30% due to inward growth into the depth of the specimen being saturated. Consequently, not only the carbon, but also the iron participates actively in the formation of the carbide layer. The mutual diffusion leads to an increase in the thickness of the carbide layer, even in the process of subsequent annealing (Fig. 2b). The thickness of the layer reaches 23 $\mu$m after annealing at 1000°C for 100 h.

The structure of the surface diffusion layer on steel 40Kh after chromium plating at 1000°C for 5 h is shown in Fig. 3a. Pores with a size of approximately 1.9 $\mu$m are detected at individual points on the "carbide-layer/steel" boundary. It is