ADHESION OF ION COATINGS OF FERROCHROMIUM TO STEEL

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By the ion plating method it is possible to obtain coatings with good adhesion and high protective and mechanical properties without preliminary heating of the part to be metallized. The high adhesion strength of the coating to the base is the result of intense ion bombardment of the surface being coated both in the stage of cleaning of it and in the stage of deposition of the coating. Cleaning in the plasma of a glow discharge maintained in the inert gas between the evaporator and the base leads to activation of the surface of the steel. At the same time existing contaminants, oxides, and other films are completely removed. The flow of ions of the metal and the gas acts only on the surface of the base, which makes it possible to reduce its temperature in comparison with normal vacuum spraying.

The influence of the ion cleaning and plating conditions on the temperature of heating of the base and the adhesion of ion coatings of ferrochromium to steel was investigated. In addition a comparative analysis of the results obtained and earlier published data on the adhesion of vacuum chromium coatings and coatings of stainless steel [1, 2] was made.

The ion coatings of FKh015 ferrochromium were applied in a vacuum chamber [3] in an argon atmosphere with an electron beam gun with a tubular cathode. The thin-sheet steel base was cleaned in the glow discharge plasma with a pressure of $p = 1.5$-4.3 Pa and an accelerating voltage on the base of $U = 4$-5 kV. The temperature of the steel was measured with the use of metal indicators, the thin plates of which were located on the back side of the base above the depressions. After ion cleaning the base was removed from the chamber and the temperature range of heating of it at the finish of the experiment determined. The boundaries of this interval were established from the melting point of the indicators filling the depressions in the base. The temperature of the base was determined not only from the melting points of tin, lead, and aluminum (230, 330, and 660°C, respectively) but also from the moment of the start of visible luminiscence of the steel according to the temperature color scale (this corresponds to a temperature of about 450°C).

It was experimentally established that the temperature of a 1-mm-thick steel base increases during ion cleaning with an increase in treatment time τ_0 and in the specific power of the glow discharge N (Table 1).

To determine the influence of ion cleaning conditions on the adhesion strength of the ion coatings with the steel a qualitative method of determining the adhesion including bending of flat samples in a vise with a radius of curvature the jaws of 2 mm was used. The criterion of good adhesion was assumed to be the absence of peeling off of the coating with a bend of 180°. If this condition was not fulfilled the adhesion was evaluated as unsatisfactory. After cleaning of the steel using one of the conditions given in Table 1 a 20-μm-thick coating was applied in 2 min with a pressure of $p = 0.67$ Pa, an accelerating voltage of $U = 4$ kV, and a current density of $i = 1.5$ A/m^2. The experimental results are

TABLE 1

Specific discharge power N, kW/m^2	Temp. of the base, °C, after treatment of it in the discharge for the time τ_0 in min						
	0,25	0,5	1,0	2,0	3,0	4,0	5,0
50	<230	<230	<230	<230	<230	<230	<230
100	<230	<230	230 .330	330 450	330 450	330 450	330 . 450
150	<230	230 330	330 450	330 450	450. 860	450.. 660	450 660

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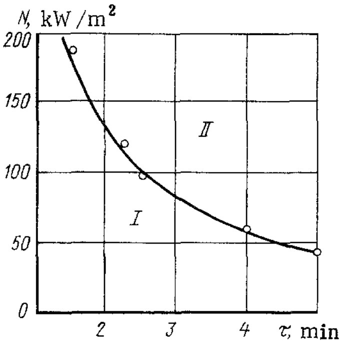

Fig. 1. Diagram of unsatisfactory (I) and good (II) adhesion of ion coatings of ferrochromium to steel.

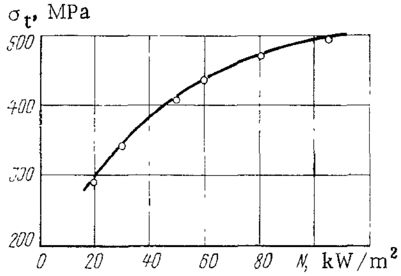

Fig. 2. Relationship of the strength of the ferrochromium condensate to the specific power of the glow discharge.

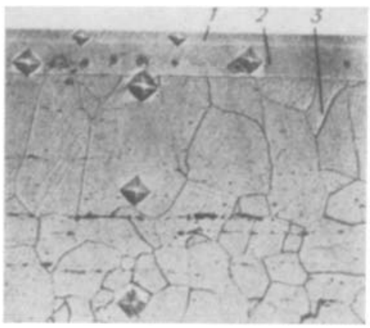

Fig. 3. Microstructure of a tranverse sample of low-carbon steel with an ion coating of ferrochromium (400 ×); 1) coating; 2) transition zone; 3) base.

presented in Fig. 1. From the data of Table 1 and Fig. 1 the minimum temperature of heating of the base which provides reliable adhesion of ion coatings of ferrochromium to steel, t_{min} = 330-450°C, was established. It is characteristic that reliable adhesion of vacuum coatings of stainless steel and ferrochromium to steel is provided with preliminary heating of the steel to 650-700°C [2]. The reduction in the optimum temperature of heating of the base in ion plating may be explained in the following manner. Probably cleaning of steel by ion bombardment is a more effective means than high temperature heating since in addition to desorption of contaminants cathodic spraying of the base material occurs. In addition the accelerated ions of inert gas create a large quantity of point defects in the crystalline lattice of the steel, which leads to an increase in the diffusion coefficient of the chromium into the steel in subsequent deposition of the coating.

For a quantitative determination of the adhesion of ion coatings of ferrochromium, the method of normal rupture of tapered pins was used. Before deposition of the coating, the steel pins were treated in the glow discharge according to one of the conditions of zone II (Fig. 1): $U = 5$ kV, $i = 20$ A/m^2, and $\tau_0 = 3$ min. The 200-250-μm-thick coatings were deposited with different glow discharge specific powers (accelerating voltage $U = 3$-6 kV) at a rate of 15 μm/min.

It was experimentally established that in the whole investigated range of specific power in tensile tests failure occurs within the coating material. Consequently the adhesion strength of ion coatings of ferrochromium deposited with $N = 30$-100 kW/m^2 exceeds the tensile strength of the coating material. The relationship of the ferrochromium condensate to specific discharge power is shown in Fig. 2. An analysis of metallographic investigation results showed that the increase in condensate strength with an increase in specific discharge power is caused by the change in the structure of the condensate from columnar to equiaxial as the result of the action of ion bombardment.

The maximum value of adhesion of the ion coatings to the steel (more than 500 MPa) exceeds by 2.5 times the adhesion of vacuum chromium coatings measured by the same method [1]. It should be noted that the maximum adhesion of chromium coatings (200 MPa) was obtained in heating of the base to 600°C. In addition, before deposition of the chromium coatings the steel pins were subjected to electrochemical degreasing, pickling in a sulfuric acid solution, and drying with hot air.

Therefore use of the method of ion plating makes it possible to substantially increase the adhesion of coatings, to eliminate chemical preparation of the surface, and to reduce the temperature of heating of it. It was established that in ion plating of a 20-μm-thick coating with $N = 50$-200 kW/m^2 the temperature of the base varies from 330 to 660°C.

To determine the mechanism of the high adhesion of ion coatings to steel the structure of samples of low-carbon steel with a coating of ferrochromium was investigated in the transverse direction. It was established that between the coating and the base metal there is located a zone of variable composition the width of which depends upon the specific discharge power in deposition of the coating. A typical structure of the transition zone is shown in Fig. 3. The formation of the transition zone between the coating and the base is caused by penetration of metal ions into the depth of the base and also by an increase in the diffusion rate of chromium into the steel as the result of local heating of the steel. The presence of the transition zone leads to a sharp reduction in internal stresses in the coating and at the coating–base interface, which probably may explain the higher adhesion strength of the ferrochromium coating to the steel.

Therefore, iron coatings of ferrochromium applied to constructional and tool steels possess high protective properties, which makes it possible to recommend their use in place of stainless steel in service of parts in humid and industrial atmospheres with sulfur dioxide and also in seawater [4].

For example, production tests made by us of steel fasteners (M6-M12) with protective coatings showed the desirability of their use in place of fasteners of expensive stainless steel.

LITERATURE CITED

1. I. L. Roikh, L. N. Koltunova, and S. N. Fedosov, Application of Protective Coatings in Vacuum [in Russian], Mashinostroenie, Moscow (1976).
2. I. L. Roikh, A. I. Kostrzhitskii, O. V. Lebedinskii, and L. M. Snitkovskaya, "The formation and protective properties of vacuum coatings of iron–nickel–chromium alloys on steel," Vestn. Mashinostr., No. 2, 68-69 (1977).
3. A. I. Kostrzhitskii and O. V. Lebedinskii, "Obtaining protective coatings of copper and ferrochromium by the ion deposition method in vacuum," in: Materials of a Scientific Seminar: Methods of Application of Coatings on Light Metals and Alloy Steels [in Russian], Mosk. Dom Nauch. Tekh. Prop. (1978), pp. 94-105.
4. I. L. Roikh, O. V. Lebedinskii, and A. I. Kostrzhitskii, "The protective properties of ion coatings on steel," Dokl. Akad. Nauk SSSR, 242, No. 6, 1386-1389 (1978).