STRUCTURAL FEATURES OF VACUUM-DEPOSITED HIGH-HARDNESS CHROMIUM COATINGS


The structure and hardness of ion-plasma coatings, obtained by evaporating chromium with a low-pressure compressed arc, from a melting crucible with and without clusterization of the vapor flow, was studied. It is shown that the Hall—Patch equation can be used to calculate the yield point of the coatings where the effective grain size corresponds to the size of a dislocation cell. On the basis of the three temperature zones of coating applications, the structure of ion-plasma chromium coatings corresponds to the zone of heat application. High hardness of the coating is achieved primarily as a result of extremely small grain size (down to 0.1 μm).

In a number of investigations performed in the last few years [1-4] it has been shown that the hardness of chromium coatings obtained by ion-plasma deposition in vacuum is extremely high, usually approaching 10 GPa and in some cases reaching 20-30 GPa. At the same time, the hardness of cast chromium, even after warm deformation, performed when obtaining a semifinished product (sheet, wire), usually does not exceed 2-3 GPa. Such a sharp increase in the hardness of chromium in the form of coatings could be due to two factors: change in the structural state and increase of the content of interstitial elements. The present paper is devoted primarily to the study of the structural state of a coating and its relationship to hardness.

We investigated two types of vacuum-deposited chromium coatings, differing by the fact that in one case (batch 1) the coating was deposited from a crucible without clusterization of the vapor flux and in the other case (batch 2) the coating was deposited with clusterization. In both cases evaporation was conducted by heating the chromium with a compressed low-pressure arc [3, 5].

The microhardness of the coatings was investigated on a UPM-11 apparatus, which made it possible to record the diagram of the load on the indentor P versus the indentation depth h [6]. The indentation diagram was used to calculated the microhardness with the help of the expression [7]

\[
HV = \frac{0.069 N^3 P}{h^2},
\]

where

\[
N = \frac{h}{h_e} \left[ 1 + 1.35 \left( \frac{h}{h_e} - \frac{h_h}{h_e} - 1 \right) \right]^{-1};
\]

\(h_e\) is the elastic strain of the material, determined from the diagram, beneath the indentor tip and \(h_h\) is the height of the heaping around the hardness indentations.

For chromium it can be assumed, with accuracy sufficient for practical investigations, that \(h_h << h\) and the value of \(h_h\) can be neglected in the calculations. The dependence of the microhardness on the indentation depth for different coatings...
Fig. 1. Microhardness of chromium coatings of batches 1 (1) and 2 (2) and chromium single crystal (3) as a function of the indentation depth.

Fig. 2. Typical structure of chromium coatings of batches 1 (a) and 2 (b). ×10,000.

is presented in Fig. 1. Here, however, for comparison we present data for a chromium single crystal. The procedure employed makes it possible to determine, to a higher degree of accuracy than on the PMT-3 apparatus, the microhardness under small loads. This is significant in the case of coatings for which it is not always possible to prepare metallographic sections.

In order to study the grain structure morphology we prepared sections with a plane perpendicular to the coating plane. Etching was conducted in a boiling solution of Murakami etchant for 40 sec. The structure was investigated in a M-T20 scanning electron microscope. Typical photomicrographs of the coatings of the two batches are presented in Fig. 2. The average grain size in the coatings of batches 1 and 2 were 0.1 and 0.8 μm, respectively. The grain size was determined as the width of the forming fibers, since it is this parameter that determines the length of the glide plane.

Investigations performed with an EMR-100 electron diffraction camera in reflection with an accelerating voltage of 75 kV show that the polycrystalline structure contains axial texture with a {011} plane in the coating plane. No lines other than those of chromium were observed. An x-ray investigation in order to determine the physical broadening of the diffraction reflection lines was performed on a DRON-2 diffractometer in CuKα radiation. It was established that there is no reliable correlation between the hardness and the physical broadening.

Stresses of the first kind were determined by the method of repeated measurements [8] in CrKα radiation; the diffraction angles were calculated from the (211) diffraction line. An estimate showed that the internal stresses reach 410 MPa, i.e., the internal stress is quite high, but significantly lower than the yield stress (Fig. 3).

It is well known that hardness depends on the elastoplastic resistance of the material to indentation and on the indentor indentation depth, especially for small loads. The hardness of coatings is usually determined using small loads because the coating thickness is insignificant. Thus in [2] the microhardness was calculated for a load of 5 g on the indentor. When measuring microhardness with small loads (and small values of h) the uncertainty of the result obtained will be all the greater the higher the hardness of the coating. The experimental data of [8, 9] indicate that the following relation holds in a wide range of values of P and h:

\[ P = p \ (h/h_0)^n, \]  

(2)

where \( h_0 \) is the unit indentation depth (usually assumed to be 1 μm), and \( p \) and \( n \) are parameters of the material, which remain constant. Due to the deviation from the similarity law, \( n < 2 \). The greater the deviation of \( n \) from 2, the higher the hardness under small loads is. The parameter \( p \) equals the load required in order for the indentor to penetrate to unit depth \( h_0 \).