Fine Structure and Phase Composition of NiCrAlY Sputtered Coatings

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Abstract—Structure of sputtered high-temperature coatings of composition (wt %) 20–22 Ni, 11–13 Cr, 0.3–0.5 Al, and the balance Y was studied by transmission electron microscopy. The information obtained may be useful in an analysis of the deposition process and operating damages of such protective coatings.

INTRODUCTION

NiCrAlY protective coatings produced by high-energy vacuum-plasma technology with MAP-1 plants begin to be widely used [1]. Such coatings are intended to protect parts of high-temperature nickel alloys against high-temperature gaseous corrosion at about 950–1150°C.

According to [1], NiCrAlY coatings have a heterophase structure and are quasi-amorphous after their deposition, as indicated by strong broadening of X-ray lines. Vacuum annealing at 1000°C for 4 h results in internal stress relaxation and homogeneous microstructure of a coating with the phase constitution γ, γ', β, and α-Cr.

As is shown in [2], in a NiCrAlY coating, during prolonged annealing at 1100°C, both the coagulation of the main phases and formation of areas enriched in chromium and aluminum take place, and the content of β and γ' phases decreases. These changes indicate that the structural and phase stabilities of a NiCrAlY coating are poor at high temperature.

EXPERIMENTAL

We studied the fine structure of a (wt %) 20–22 Ni, 11–13 Cr, 0.3–0.5 Al, and the balance Y coating deposited with a MAP-1 plant on a KC26 high-temperature nickel-based alloy. The structures of a coating after both its deposition and the following high-temperature annealing at 1100°C for 10 h were studied by thin foil transmission electron microscopy with an EMV-100L electron microscope. The foil’s plane parallel to the coating surface was at a depth of about 30 μm that is half the coating’s thickness.

RESULTS AND DISCUSSION

The Structure of the Coating after Its Deposition

The structure of an unannealed coating as a whole is irregular as regards the size and shape of structural and phase components. Fig. 1 illustrates the characteristic features of the main phases revealed in such a coating.

Figs. 1a and 1b show typical rounded disperse inclusions in an ordered bcc phase based on NiAl intermetallic compound (β-phase), which, in the unannealed coating, is present in the form of relatively large and irregularly shaped fragments. Electron diffraction patterns of the β phase occasionally show diffuse effects, i.e., bars and satellites, close to its fundamental (not superstructural) reflections. These effects point to the fact that the β solid solution is inhomogeneous. The own reflections of the disperse inclusions in the β-phase, which would not coincide with basic β-phase reflections, are unrevealed, which allows us to associate the formation of these inclusions with the precipitation from supersaturated β-solution of a bcc phase, which is isomorphic to the β-phase, although based on chromium (ε).

Nevertheless, phases based on an fcc solid solution prevail in the unannealed coating. Electron diffraction patterns of grains with the fcc lattice reveal, in virtually any case, more or less intense superstructural reflections which are indicative of Ni3Al-type ordering and characteristic of a γ' phase. Thus, the disordered γ phase, if it is present in a coating, measures no larger than several fractions of a micron (during electron diffraction analysis; the minimal selective diaphragm corresponded to the analyzed area of about 0.3 μm) in a diameter.

Two types of grains containing γ'-phase were revealed.

The first, visually prevailing, type is γ'-phase grains of different size and shape, which have no inclusion of any phase and no evidence of solid-solution decomposition, because TEM images of such grains presented in Fig. 1 show homogeneous contrast. The orientation of adjacent grains of this type is, as a rule, substantially and randomly different, which points to independent nucleation of such grains during the deposition of the coating. However, some of such grains contain rather
wide twins forming along \{111\}_γ planes (E sites in Figs. 1b and 1c).

The second, less but enough frequently observed, type of grains containing γ'-phase have two specific features (see Figs. 1c and 1d).

The first feature is bcc α-Cr inclusions with a disordered structure as evidenced by the absence of superstructural reflections in their electron diffraction patterns. These inclusions are frequently of a regular plate-like or rod-like shape. Electron diffraction patterns show that, for the crystalline lattices of α and γ' phases, the Kurdymov–Sachs orientation relation is true, and α-phase facets are matched by \{111\}_γ-plane parallel to \{110\}_α-plane involved in the Kurdymov–Sachs relation. Thus, during the deposition of the coating, crystallographically regular precipitation of the α phase based on chromium from the initial fcc solid solution occurs in some areas.

The second feature is that the image of the grain around α-phase segregates has inhomogeneous contrast pointing to precipitation from the initial solid solution, the degree of which substantially varies as seen in Figs. 1c and 1d. Some images, as in Fig. 1e, clearly show a typical but, in places, very dispersed γ'/γ binary