Stresses Induced by Interdiffusion
in Nickel Aluminide Coatings

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Coatings based on nickel aluminide, □-NiAl, are widely used in high temperature applications for oxidation protection of Ni-base superalloys. During service, the content of aluminum in the coating gradually reduces as a result of surface oxidation and interdiffusion with the superalloy. Both these processes cause a substantial evolution of the coating structure and properties, which includes pore formation, hardening, phase transformations, diffusion of impurities from the alloy into the coating, oxide spallation, surface roughening, etc. A number of intriguing phenomena arise from the fact that intrinsic diffusivities of nickel and aluminum in □-NiAl are drastically different ($D^{Ni} \approx 3D^{Al}$ in the Ni-rich aluminide [1]). For example, the nonreciprocal diffusion in the vicinity of the metal-oxide interface during selective oxidation of aluminum may result in tensile stresses and generate voids in the metal [2, 3]. In this work, another, qualitatively similar effect related to the coating-substrate interdiffusion is described. Unlike the oxidation reaction, this process can induce a biaxial *compressive* stress in the coating with the concurrent creep relaxation of the stress at elevated temperatures.

The diffusion-induced stresses have previously been reported in the literature. One typical example is the macroscopic bending of thin-sheet Au/Ag diffusion couples [4], in which the flux of one component (Ag) in solid solution is greater than the opposite flux of the other component (Au). Similar bending was observed during interdiffusion in Ti-Zr and Ni-Cu thin couples [5]. Obviously, no bending occurs in thick samples due to the mechanical constraint by the material outside the diffusion zone. Nevertheless, the diffusion-induced stress and plastic relaxation may also be expected in □-NiAl coatings on a Ni-base alloy.

In the case of a Ni-rich aluminide coating, the outward flux of nickel from the alloy is larger than the inward flux of aluminum (Fig. 1). This leads to the Kirkendall shift of the coating-alloy interface, which is equivalent to the thickness increase of the coating. Such an increase can readily be explained using a simple model, in which the accommodation of mass displacements occurs by inserting new lattice planes in the coating parallel to the interface, i.e. by the dislocation climb normal to the diffusion direction. This work provides a set of observations showing that, in addition to the thickness increase, the aluminide coatings also exhibit some lateral expansion during interdiffusion with the superalloy. The experiments were performed with diffusion couples consisting of a model NiAl alloy (~50 at % Al) bonded to 3 mm thick substrates of a Ni-base superalloy. In order to observe the expansion transverse to the diffusion direction, rectangular samples were cut and polished perpendicular to the coating-alloy interface and then annealed at 1150^{o}C. A typical example of the surface configuration, which develops during interdiffusion, is shown in Fig. 2. The initially flat surface produces a distinct bow-shape distortion with the size in the diffusion direction being equal to the thickness of the Ni-enriched □-NiAl. Apparently, the substrate constraint is much smaller near the sample edge, whereas a biaxial compressive stress in the coating is expected in the regions far from the edge.

Similar observations were made on commercial Pt-modified aluminide coatings. The presence of the compressive stress may affect mechanical behavior of the coating, while the creep relaxation at elevated temperatures can produce undesirable changes of its surface configuration. A possible link between the diffusion-induced stresses and the observed morphological instability of the aluminide coatings (rumpling) during cyclic oxidation is discussed.

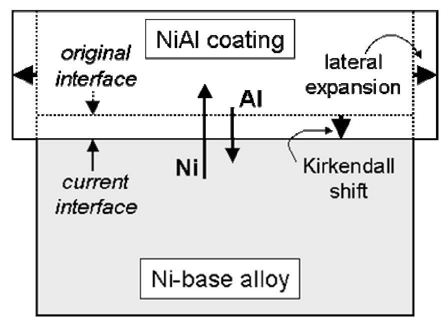

Fig. 1. Schematic illustration of the volumetric changes of NiAl coating during interdiffusion with Ni-base alloy. Stress in the coating is due to substrate constraint.

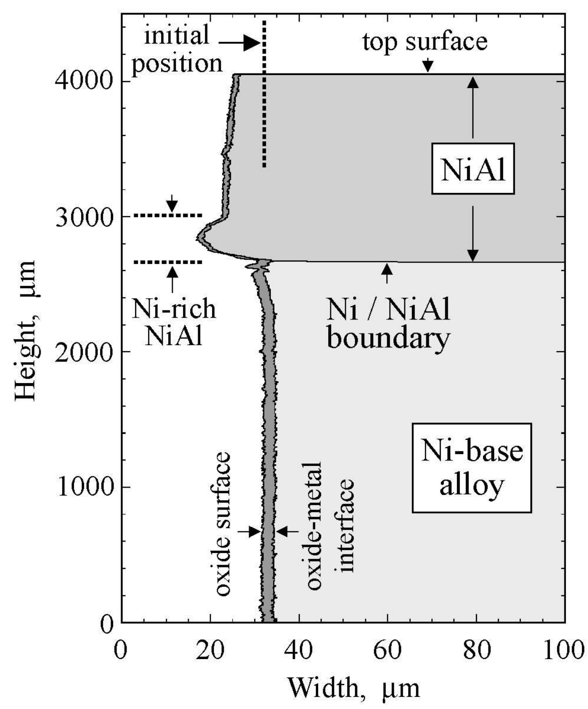

Fig. 2. Shape of a rectangular sample after diffusion annealing for 40 h at 1150^{o}C. The sample was cut and polished perpendicular to the Ni/NiAl boundary prior to annealing. The vertical axis is compressed about 30 times.

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