

High-temperature oxidation of NiCrAlY/(ZrO₂–Y₂O₃ and ZrO₂–CeO₂–Y₂O₃) composite coatings

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Abstract

Metal/ceramic coatings of Ni–22Cr–10Al–1Y/ZrO₂–8Y₂O₃ and Ni–22Cr–10Al–1Y/ZrO₂–25CeO₂–2.5Y₂O₃, which were prepared by the air plasma spray method, were oxidized at 900, 1000, and 1100 °C in air. The major oxidation product was α-Al₂O₃, which was formed by the reaction of inwardly penetrating oxygen ions with Al at the metal/ceramic phase boundaries. The oxidation of Ni and, moreover, Cr also occurred to a certain extent.

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1. Introduction

Typical thermal barrier coatings (TBCs) for gas turbine and diesel engines consist of stabilized ZrO₂ top coats and NiCrAlY bond coats. During service, a thermally grown oxide layer (TGO) consisting primarily of Al₂O₃ develops at the bond coat/top coat interface, which causes the integrity of TBC to degrade, resulting in the spallation of the top coat [1]. This failure can be evaded by introducing a functionally gradient coating (FGC), which has advantageously no sharp interface between coats [2]. To understand the oxidation characteristics of the FGC, composite coatings of NiCrAlY/(ZrO₂–Y₂O₃ and ZrO₂–CeO₂–Y₂O₃) were oxidation tested. To date, studies on the oxidation of FGC are scarce.

2. Experimental procedures

Table 1 lists nominal compositions of the prepared coatings that were applied by air plasma spray (APS).

The starting powders were ZrO₂–8Y₂O₃ (11–125 μm), ZrO₂–25CeO₂–2.5Y₂O₃ (16–90 μm), and Ni–22Cr–10Al–1Y (56–106 μm). The compositions are in weight percentages. The ceramic and metallic powders were sprayed simultaneously to approximately 500-μm thickness onto the SS41 substrate, which was later removed by grinding to study the coating layer only. Both sides of the plasma sprayed coatings were polished to a 2000 grit finish, degreased in acetone, and oxidized isothermally at 900, 1000, and 1100 °C for up to 500 h in air. The specimens were investigated by thermogravimetric analyzer (TGA), scanning electron microscope (SEM) with energy dispersive spectrometer (EDS), X-ray dif-

Table 1
Chemical composition of the prepared coatings

Designation	Composition (wt.%)
Coating 1	25% X+75% Z
Coating 2	50% X+50% Z
Coating 3	75% X+25% Z
Coating 4	25% Y+75% Z
Coating 5	50% Y+50% Z
Coating 6	75% Y+25% Z

X=(ZrO₂–8Y₂O₃); Y=(ZrO₂–25CeO₂–2.5Y₂O₃); Z=(Ni–22Cr–10Al–1Y).

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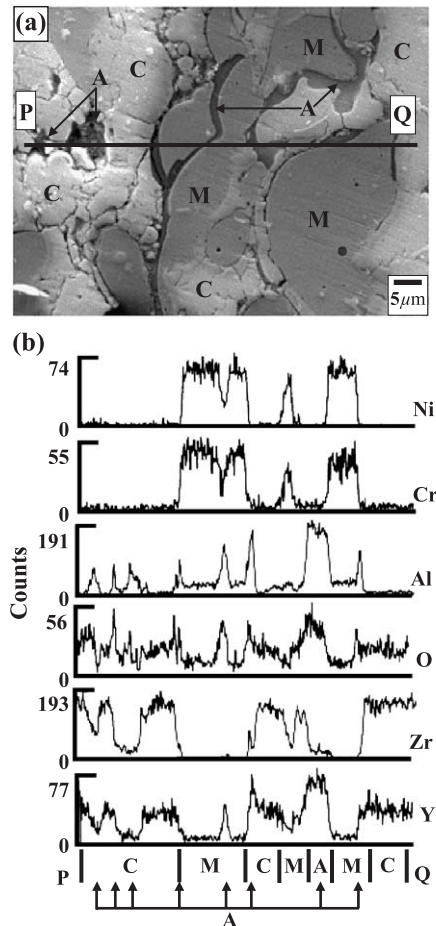


Fig. 1. As-APS'ed 'coating 3': (a) SEM cross-sectional image; (b) EDS line profiles across P–Q. M=metal-rich region; C=ceramic-rich region; A=Al₂O₃-rich region.

fractometer (XRD), and transmission electron microscope (TEM).

3. Results and discussion

Fig. 1 shows the typical cross-sectional image and corresponding elemental line profiles of the prepared

coating. Quite similar elemental profiles are displayed for Ni/Cr, Al/O, and Zr/Y, respectively (Fig. 1b). The white areas are ceramic-rich regions, the gray areas are metal-rich regions, and the dark areas are Al₂O₃-rich stringers in Fig. 1a. Generally, the active metal of Al in NiCrAlY was oxidized to α-Al₂O₃ [1,3], as confirmed by XRD, during APS for all the prepared coatings. Only a small amount of Al remained in the (Ni, Cr)-rich region, due to the selective oxidation of Al at the exterior of the metal-rich region.

The oxidation kinetics of the prepared coatings between 900 and 1100 °C in air are depicted in Fig. 2. A decrease in the oxidation resistance with an increase in oxidation temperature is seen. All the tested coatings approximately follow the familiar parabolic rate law. The oxidation resistance increases with increasing the ceramic content, but the difference between (50% ceramic+50% metal) and (75% ceramic+25% metal) is rather small, indicating that the oxidation of NiCrAlY tends to be deterred once a sufficient amount of ceramics exists. At the same ratio of ceramic/metal, (ZrO₂–CeO₂–Y₂O₃)-containing coatings display better oxidation resistance than (ZrO₂–Y₂O₃)-containing ones, due mainly to the presence of less amount of oxygen-permeable ZrO₂ [4].

Fig. 3 shows the cross-sectional image and corresponding elemental maps of 'coating 2' after oxidation at 900 °C for 500 h. The Al₂O₃-rich oxide stringers, (A), exist between the metal, (M), and the ceramic, (C). The ensuing oxidation of Al along phase boundaries, which are fast diffusion channels for the inwardly transporting oxygen ions, resulted in the deficiency of Al inside the (Ni, Cr)-rich region, when compared to as-sprayed coatings.

Fig. 4 shows the cross-sectional image and corresponding elemental maps of 'coating 3' after oxidation at 1100 °C for 300 h. Since the oxidation progressed further, Cr, the oxide of which is intermediate in stability between Al₂O₃ and NiO, was also diffused out toward the phase boundaries, and thereby oxidized to Cr₂O₃. Hence, in the metal-rich regions, Cr as well as Al was strongly depleted.

Fig. 5 shows a typical XRD pattern of the oxidized coating. For entire coatings, the major phase of ceramics was tetragonal-ZrO₂, with a less amount of cubic-ZrO₂,

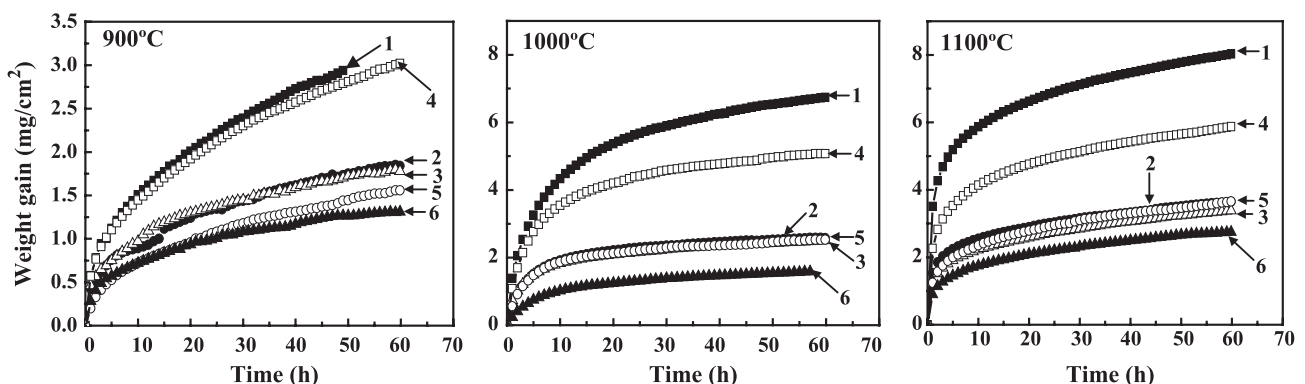


Fig. 2. Weight change vs. time curves of 'coating 1–6' at 900, 1000, and 1100 °C in air.

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