



Oxidation behavior of aluminide coatings on carbon steel with and without electrodeposited Ni–CeO₂ film by low-temperature pack cementation

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ABSTRACT

A CeO₂-dispersed aluminide coating was fabricated through aluminizing the electrodeposited Ni–CeO₂ nanocomposite film on carbon steel using pack cementation method at 700 °C for 4 h. The isothermal and cyclic oxidation behavior of the CeO₂-dispersed aluminide coating at 900 °C, including the growth of oxide scale and the microstructure of the coatings, have been investigated comparing with the aluminide coating on carbon steel. The results show enhanced oxidation performance of the CeO₂-dispersed aluminide coating, which is concerned with not only CeO₂ effect on the microstructure and oxidation, but also decreased interdiffusion between the aluminide and the Ni film. The CeO₂ benefit effects and interdiffusion are discussed in detail.

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1. Introduction

Ferritic steels are widely used as structural materials for components such as reheating tubing and turbines in electrical power generation plants by burning fossil fuels such as coal, because of their higher thermal conductivity and strength, lower coefficient of thermal expansion and higher cost effectiveness [1,2]. However, the steels cannot guarantee the formation of a protective scale as Cr₂O₃ and Al₂O₃ because of low Cr and Al content [3]. Hence, the fast oxidation of the steels minimizes their service life of the steel-made components. Therefore, applications of the chromia or alumina scale-forming coatings are always a preferred choice to extend their application and lifetime of the steel-made component at high temperature. However, Cr₂O₃ is not chemically and thermodynamically stable due to the reaction of Cr₂O₃ with water vapor or oxygen to form volatile species such as CrO₂(OH)₂ or CrO₃ at high temperature [4–7]. At the same time, the oxidation of chromium carbides formed during the chromizing and oxidation led to the cracking and spallation of the oxide scales [8–10]. Al₂O₃ is chemically and thermodynamically stable in water vapor-containing environments and thusly Al₂O₃-forming coatings would be better in the power plants due to highest chemical stability [11]. Aluminide coatings produced using simple pack cementation

methods are the well-known Al₂O₃-forming coatings [12,13]. Unfortunately, the pack cementation was normally performed at temperatures above 1000 °C, limited by the diffusion and reaction kinetics involved. Such a high temperature treatment inevitably limits the applications of aluminide coatings due to grain growth of the substrate materials, which has a detrimental effect on the mechanical properties of workpieces [14]. Therefore, reducing pack cementation temperature is required for the widespread application of the aluminide coatings on carbon steels. Generally, aluminizing kinetics is governed by a combination of gaseous diffusion in the pack and solid state diffusion in the coating [15]. Therefore, increasing the solid state diffusivity can greatly improve the kinetics of formation of aluminide coatings during pack cementation process.

It is well-known that the effective diffusivity in nanocrystalline (NC) materials is several orders of magnitude greater than coarse-grained materials of identical chemistry [16,17]. For example, it is found that the value of self-diffusion coefficient of Cu in NC copper at 80 °C is about 16 orders of magnitude larger than microcrystalline copper [18]. Therefore, it seems that the application of NC materials is a helpful approach to reduce the time and temperature of the process. Rashidi et al. [19] indicated that the aluminizing time need for the onset of formation of aluminide phases on electrodeposited NC Ni was shorter than microcrystalline (MC) Ni at 475–600 °C. And the aluminide coating formed on NC Ni was δ-Ni₂Al₃ single layer or NiAl₃–Ni₂Al₃ double layers depending on aluminizing time and temperature. However, aluminized coatings

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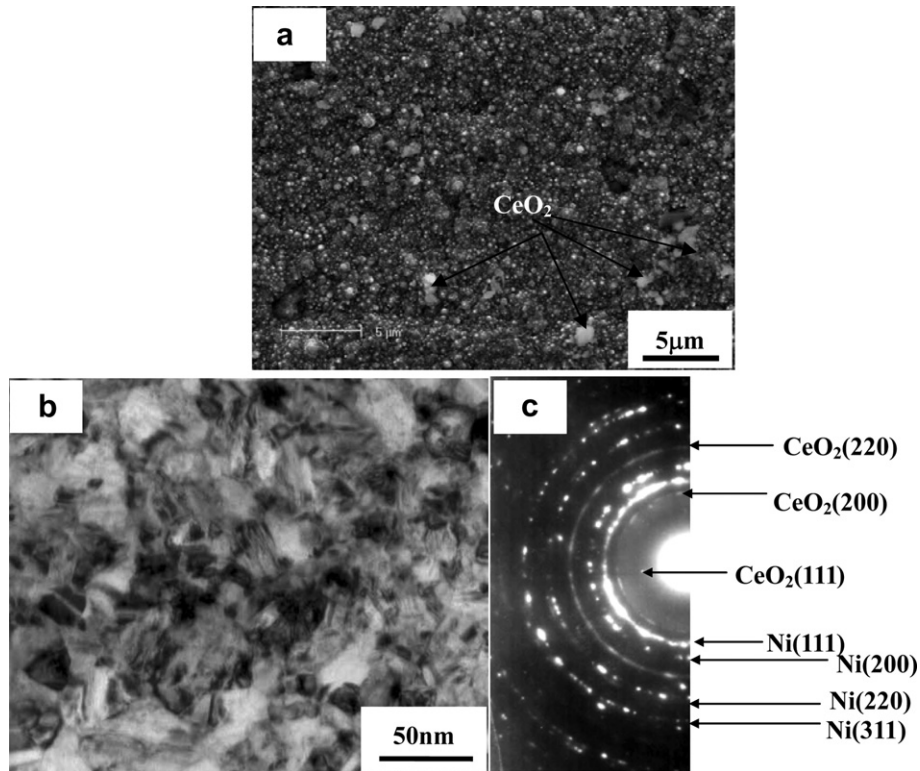


Fig. 1. Surface morphology (a), and TEM bright-field image (b), and the corresponding SEAD pattern (c) of as-co-deposited Ni–CeO₂ nanocomposite.

prepared on low alloying steels with nanostructured surface layer at temperature below 700 °C are normally η -Fe₂Al₅ phases with poor oxidation resistance due to the severe interdiffusion between coatings and substrate at high temperature [20,21]. Taking into account that the low diffusion rate of Al in Ni than that of Al in Fe resists the aluminide recession by interdiffusion, carbon steels with an appropriate thick layer of electrodeposited NC Ni were aluminized at 615 °C using pack cementation methods. The results showed that the produced δ -Ni₂Al₃ coatings formed on NC Ni coated carbon steel exhibited improved dry and wet isothermal oxidation resistance at 900 °C [22]. However, the cyclic oxidation resistance of the pure δ -Ni₂Al₃ coatings is inherently poor due to the formation of cavities at the coating/scale interfaces [23].

The addition of small amounts of reactive elements (RE), such as Y, Ce, La or their oxides have profound beneficial effects on the growth mechanisms and adhesion of the oxide scale at high temperature for alumina-forming alloys and coatings [22–27]. The

scale adhesion enhancement is associated with the presence of REs or their oxides either in metals or at the scale/metal interface profoundly retarding the formation of the interfacial cavities [28,29] or effectively decreasing the interfacial activity of sulfur [30,31]. REs or RE oxides are commonly added into alloys or coatings by different techniques [32–34]. Electrodeposition is another technique to co-deposit RE oxides particles with Ni to form Ni–RE_xO_y composite coatings by adding RE oxides particles to the plating bath [23–25]. Peng et al. [23,24] produced CeO₂-dispersed δ -Ni₂Al₃ coatings on Ni by aluminizing the electrodeposited Ni–CeO₂ nanocomposite coating on Ni. The oxidation results showed that the addition of CeO₂ nanoparticles enhanced the isothermal and cyclic oxidation resistance of δ -Ni₂Al₃ coatings. However, the effect of CeO₂ on its oxidation resistance is unclear. And there is so far no report about the comparison of the oxidation behaviors between the CeO₂-dispersed δ -Ni₂Al₃ coatings on carbon steel and aluminide coatings on carbon steel fabricated by

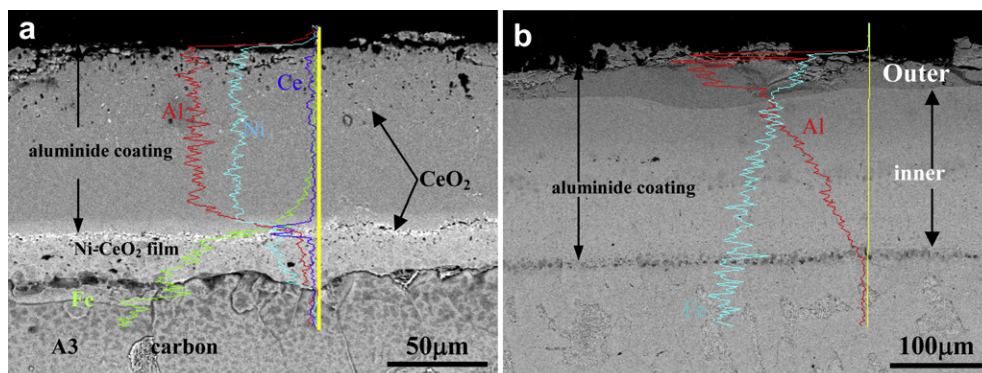


Fig. 2. Cross-sectional SEM images and elemental depth profiles of (a) aluminide coating on Ni–CeO₂ nanocomposite-coated A3 and (b) aluminide coating on A3 carbon steel.

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