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A duplex nanocrystalline coating for high-temperature applications on single-crystal superalloy

Lanlan Yang, Minghui Chen*, Jinlong Wang, Shenglong Zhu, Fuhui Wang

Laboratory for Corrosion and Protection, Institute of Metal Research, Chinese Academy of Sciences, Shenyang 110016, China

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ABSTRACT

A new duplex nanocrystalline coating is designed for high temperature oxidation and hot corrosion protection. This coating combines the advantages of traditional NiCrAlY and nanocrystalline coatings, i.e., providing high resistance to oxidation and hot corrosion simultaneously, while avoids any disadvantages that the traditional coatings have suffered from, such as scale spallation, element interdiffusion (along with the formation of harmful TCP phases). It gives a good choice as the bond coating of a TBC system.

1. Introduction

The quest for improving engine efficiency and reducing pollutants has led to increasingly higher operating temperatures and extending the operating lives of gas-turbine superalloys. Considering operation surroundings of gas turbine, only composite materials are able to meet the harsh requirements: the necessary mechanical properties is offered by the base material such as single-crystal superalloy for it can provide higher temperature capacity as compared to its polycrystalline counterpart; and the protection against oxidation or corrosion is furnished by coating in the case of thermal barrier coatings (TBCs) [1–3]. The TBCs coupled with modern cooling systems can provide up to an almost 150 °C temperature reduction at the superalloy blade surface. A TBC usually consists of a thermal-insulating ceramic top coating and an oxidation-resistant metallic bond coating [4–7].

As we all know, all the metallic coatings including the traditional NiCrAlY coating and nanocrystalline coating rely on the formation of slow-growing, stable, and adherent surface oxides such as Al_2O_3 or Cr_2O_3 to protect them from oxidation and hot corrosion. However, as the service environment has become increasingly harsh, the current coatings feel more and more difficult to meet all the applying requirements. NiCrAlY coating [8,9] that has been applied universally as stand along protective coating or as bond coat of TBC even suffers from many threatens, such as cracking or scale spallation under thermal cyclic environments and continuing fast consumption of Al or Cr. Cracking or spallation of the oxide scale TGO (thermal grown oxide) plays the most important role in the final invalidation of TBC [10,11]. While the Al diffusion from coating into the underlying alloy substrate leads to the formation of SRZ (second reaction zone) with abundant harmful TCP (topologically close-packed) phases that destroy the mechanical properties of the superalloy component [12,13]. Accordingly, many novel metallic coatings [14–17] or interdiffusion barriers [18–23] were invented. However, none of these invents can completely solve all the problems simultaneously. Nanocrystalline coating invented by Lou and Wang twenty years ago [24], with the same composition to the alloy substrate, is one of such designs to avoid the problems of element interdiffusion and scale spallation. It still has a shortcoming of low corrosion resistance in sulfate environment. Corrosive media such as S and Cl- will diffuse easily along boundaries of the nano-grains as well to the superalloy substrate front, leading to hot corrosion [25,26].

In this work, we designed and prepared a duplex nanocrystalline coating which was expected to integrate the advantages of both the conventional NiCrAlY coating and the late-model sputtering nanocrystalline coating while avoids their shortcomings.

2. Experimental Procedure

Cylindrical specimens of Φ 15 × 2.0 mm were machined from a second generation single-crystal superalloy N5 bar. They were ground consecutively with 240#, 400#, 1000# and 2000# SiC papers, and then degreased by an ultrasonic cleaner in acetone

* Corresponding author. Fax: +86 24 23893624.
E-mail address: mhchen@imr.ac.cn (M. Chen).

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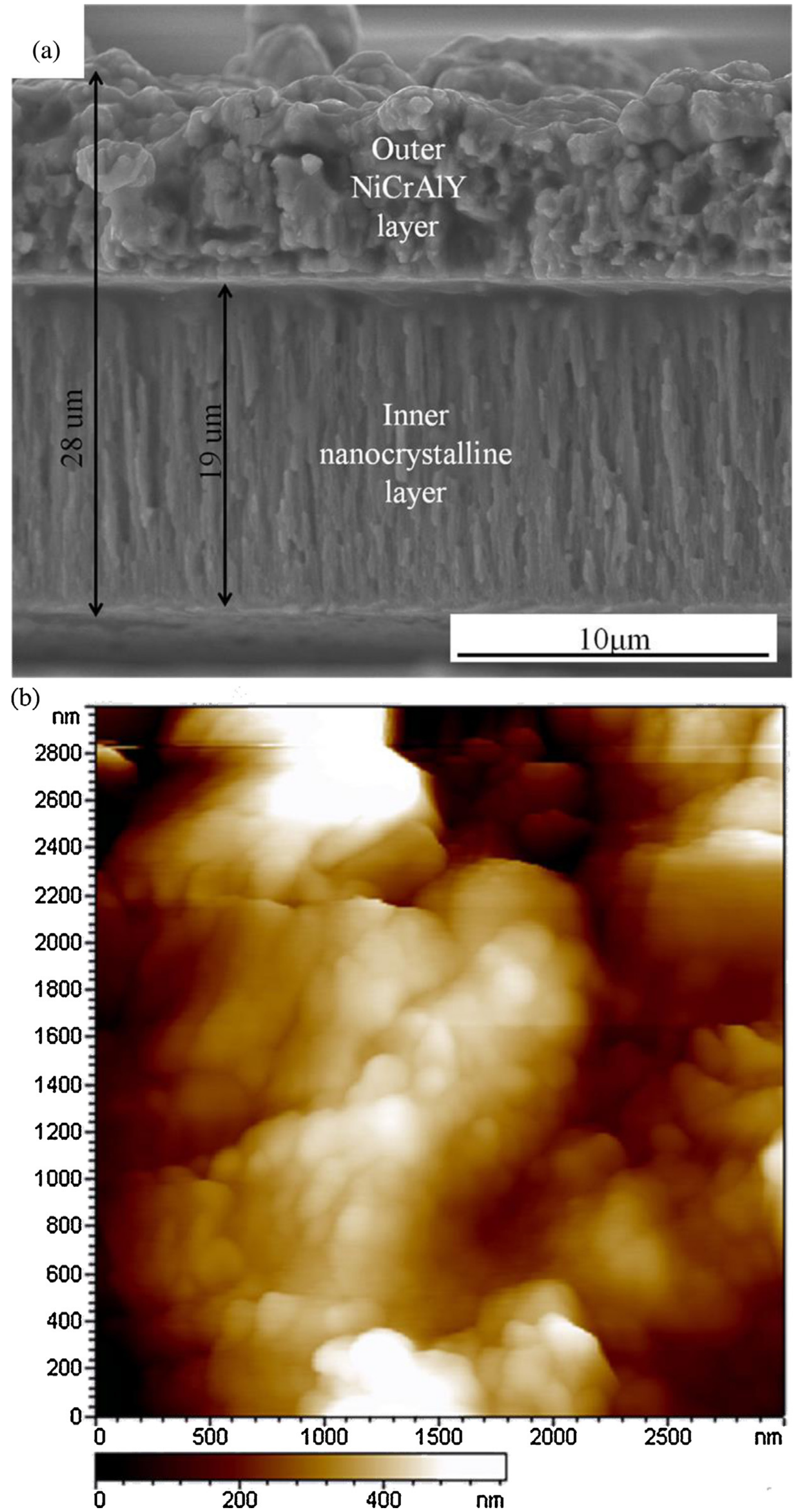

Fig. 1. (a) Fracture section and (b) AFM surface morphologies of the as-sputtered duplex nanocrystalline coating.

before magnetron sputtering. The target used for sputtering the inner nanocrystalline layer was a 382 × 128×8 mm sheet with the same composition of the superalloy substrate. Sputtering parameters were deposited as follows: argon pressure was 0.2 Pa; sputtering current was 3.5 A; and substrate temperature was 200 °C. The samples were rotated in the target during sputtering to ensure better uniformity. Thereafter, NiCrAlY outer layer was deposited upon the inner nanocrystalline layer using arc ion plating (AIP) in argon pressure of 0.2 Pa to obtain a two-layer structured duplex nanocrystalline coating. Compositions of the two layers are listed in Table 1.

Isothermal and cyclic oxidation tests were adopted to assess the interdiffusion, oxidation and scale spallation behaviors of the duplex nanocrystalline coating. Isothermal oxidation test was con-