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The scaling behavior of sputtered Ni_3Al coatings with and without Pt modification

Jianmin Niu, Wen Wang *, Shenglong Zhu, Fuhui Wang

State Key Lab for Corrosion and Protection, Institute of Metal Research, Chinese Academy of Sciences, 62 Wencui Road, Shenyang 110016, People's Republic of China

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ABSTRACT

A Ni_3Al nanocrystalline film was deposited on the Ni_3Al-based superalloy IC6 by magnetron sputtering. Pt-modified coatings were obtained by electroplating 1.5 μm platinum onto the sputtered Ni_3Al film with and without annealing. Duplex scale developed on the sputtered Ni_3Al film after 20 h isothermal exposure at 1050 °C. Uphill diffusion of Al occurred in the Pt-modified coating system, which implied that inward diffusion of Al from coating to substrate was prevented. Platinum promoted selective oxidation of Al, although 5 at.% Pt was insufficient for the development of exclusive alumina scale on the Pt-modified sputtered γ'-Ni_3Al coating.

1. Introduction

Improving efficiency of aeroengine turbines involves raising the temperature of blade surface, but it is difficult for superalloys to simultaneously meet the performance of mechanics and oxidation resistance at high temperature, so protective coatings are often applied to the superalloys [1–4]. For traditional coatings, the protection from high temperature oxidation is achieved by raising the concentration of Al in coatings, such as β-aluminide and MCrAlY coatings. However, serious inward diffusion of Al from coatings to substrates occurs, which results in depletion of Al in the protective coatings [5]. Meanwhile, the formation of brittle phases in the interdiffusion zone resulted from the interdiffusion between coating and substrate reduces mechanical property of coating systems [5]. As a result, the traditional coatings with high Al concentration are barely capable of meeting the needs of further improving efficiency of aeroengine turbines.

The magnetron-sputtered nanocrystalline coating, with the same or similar chemical composition of superalloy substrates, prohibits or reduces the interdiffusion between coating and substrate during service at high temperature [6–8]. Additionally, the sputtered nanostructure supplies numerous grain boundaries as rapid diffusion paths, accelerating the diffusion of Al or Cr from coating to oxidation front and enhancing the formation of protective oxide scale.

Recent studies [4,5,9–13] have indicated that the Pt-modified γ-Ni + γ'-Ni_3Al coating exhibits excellent oxidation resistance, less interdiffusion and better compatibility between coating and superalloy substrate comparing to β-(Ni,Pt)Al coating. Platinum accelerates uphill diffusion of Al [11,14] and enhances adherence of oxide scale, improving oxidation resistance of superalloys [11–20]. However, the formation of exclusive alumina scale needs high Pt contents (no less than 10 at.%) for Ni–Pt–Al alloys [12,16,21].

Apparently, both sputtered nanocrystalline coating and Pt-modified γ-Ni + γ'-Ni_3Al coating show excellent compatibility to superalloy substrate. The effects of nanocrystallization and Pt-modification on the oxidation behavior of γ-Ni + γ'-Ni_3Al coating are similar, i.e. promoting selective oxidation, enhancing scale adhesion and impeding the interdiffusion between coating and substrate. In the present work, Pt-modified sputtered nanocrystalline Ni_3Al coatings were coated on Ni_3Al-based superalloy IC6 by two treatments. The surface scales and the coatings with/without Pt-modification were characterized after high temperature oxidation in order to investigate the influence of Pt on the scaling behavior of the sputtered nanocrystalline coating.

2. Experimental procedures

The substrate material was Ni_3Al-based superalloy IC6, with the nominal chemical composition shown in Table 1. Microstructure of IC6 alloy consists of γ'-Ni_3Al (~80 vol.%, the matrix phase), γ-Ni(Mo) solid solution (15–20 vol.%) and a small amount of boride phases (<2 vol.%).

Rectangular specimens of dimensions 12 × 10 × 2 mm with rounded corners and edges were obtained and polished. All specimens were blasted with glass balls and then cleaned in acetone prior to coating deposition. The Ni_3Al film was deposited on the substrate by magnetron sputtering. The nominal chemical composition

* Corresponding author. Tel.: +86 24 23904856; fax: +86 24 23893624.
E-mail addresses: jmniu@imr.ac.cn (J. Niu), wen@imr.ac.cn (W. Wang), slzhu@imr.ac.cn (S. Zhu), fhwang@imr.ac.cn (F. Wang).

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Table 1
The nominal chemical composition of Ni_3Al-base superalloy IC6 (at.%).

Al	Mo	B	Ni
15–19	5.5–8.6	0.098	72.3–79.4

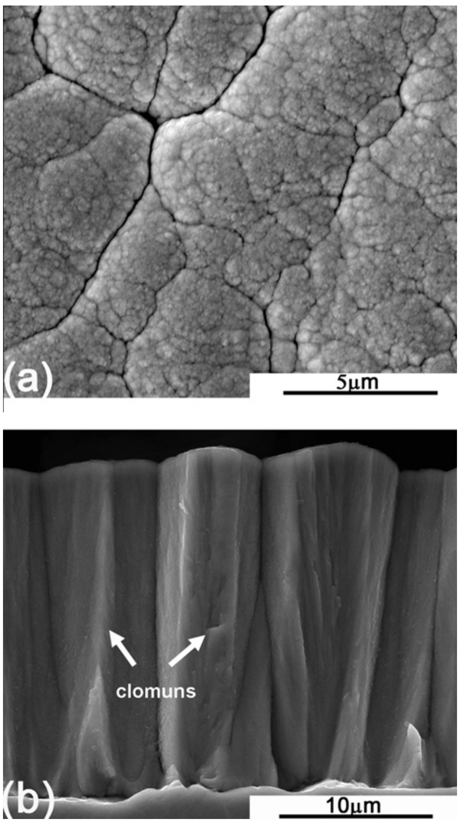

Fig. 1. Surface morphology (a) and fractured cross section (b) of the sputtered Ni_3Al film.

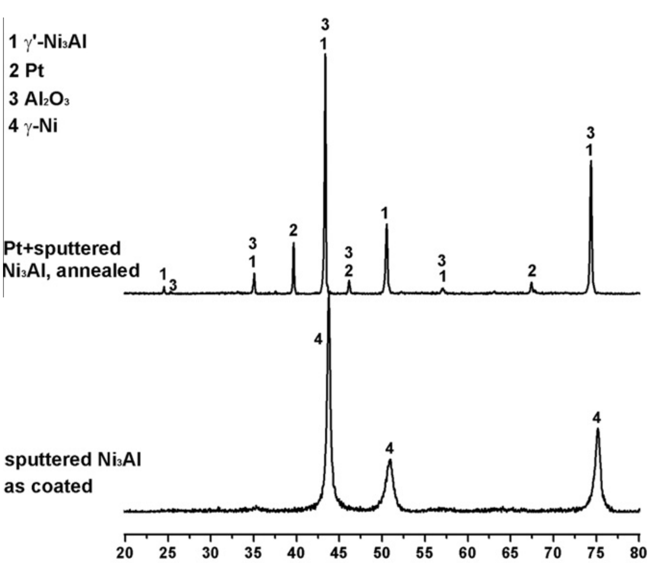

Fig. 2. X-ray patterns of the as-sputtered Ni_3Al film and the Pt-modified coating with annealing treatment.

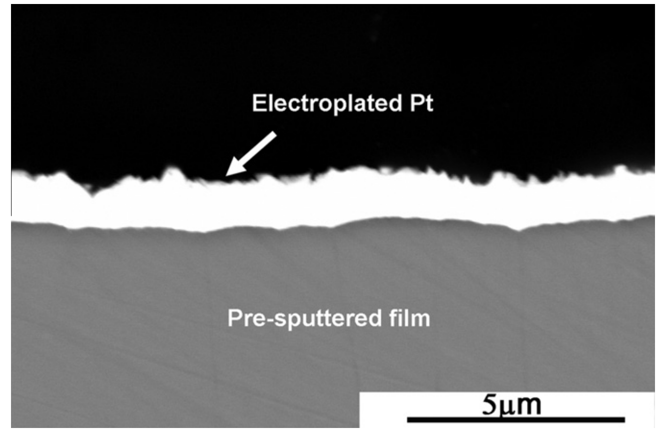

Fig. 3. Cross-sectional morphology of the sputtered Ni_3Al film with electroplated Pt layer.

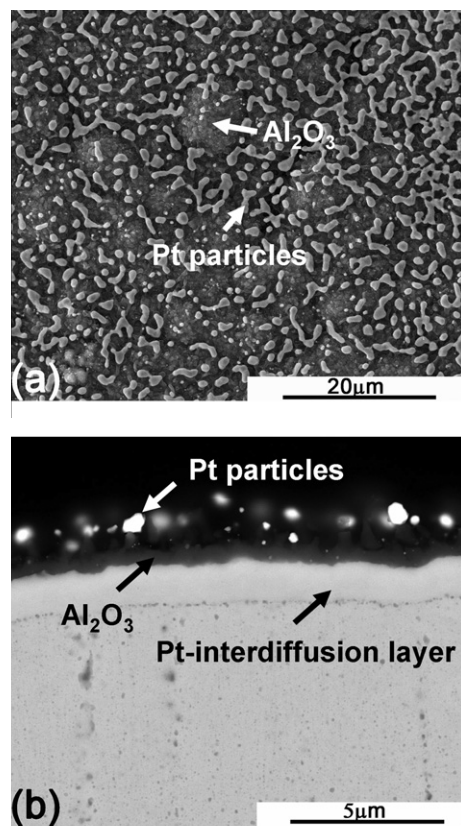

Fig. 4. Surface (a) and cross-sectional (b) morphologies of the Pt-modified coating with annealing treatment.

of the target is Al 25 at.%, and Ni 75 at.%. The sputtering parameters were as follows: background vacuum 5 mPa; argon pressure 0.2–0.3 Pa; substrate temperature 250 °C; power 2.0 kW; sputtering time 6 h. The grain size and thickness of the sputtered coating are about 90 nm and 20 μm [22].

Subsequently, two types of Pt-modified coatings (with different treatments) were prepared by electroplating 1.5 μm thick layer of platinum on the sputtered Ni_3Al coating system with and without a following vacuum-anneal. The annealing treatment was carried out at 1150 °C for 1 h at a pressure of 10 mPa. A thin alumina scale formed on the coating surface during high-temperature annealing, which was removed by polishing prior to oxidation test. In this