Intermetallics 16 (2008) 1206–1211

Contents lists available at ScienceDirect

Intermetallics

journal homepage: www.elsevier.com/locate/intermet

On the influence of coating and oxidation on the mechanical properties of a γ-TiAl based alloy

M. Moser*, P.H. Mayrhofer, H. Clemens

Department of Physical Metallurgy and Materials Testing, Montanuniversität Leoben, Franz-Josef Straße 18, A-8700 Leoben, Austria

ARTICLE INFO

Article history:
Received 25 April 2008
Received in revised form 3 July 2008
Accepted 4 July 2008
Available online 28 August 2008

Keywords:
A. Titanium aluminides, based on TiAl
B. Oxidation
C. Coatings, intermetallic and otherwise
B. Brittleness and ductility

ABSTRACT

The use of γ-TiAl based alloys in high-temperature applications requires an effective protection against oxidation and concomitant loss of ductility. Two coatings, Al_2Au and $Cr_{0.45}Al_{0.53}Y_{0.02}N$ (CrAlYN), are tested for their oxidation protection in air and their influence on the mechanical properties of a Ti–47Al–2Cr–0.2Si alloy. Both coatings significantly improve the oxidation resistance of the investigated γ-TiAl. The plastic strain in the γ-TiAl outer fiber during four-point-bending tests at room temperature is reduced by the deposition with Al_2Au and CrAlYN. After 168 h oxidation at 800 °C uncoated and Al_2Au coated γ-TiAl samples crack without plastic deformation due to the oxide layers and interdiffusion zones formed. Contrary, a CrAlYN protected γ-TiAl four-point-bending specimen still exhibits a plastic strain of 0.12% after oxidation at 800 °C for 672 h, as a thin and dense oxide layer forms. We conclude that CrAlYN effectively retards oxidation and interdiffusion of γ-TiAl and hence the commonly observed deterioration of mechanical properties by oxidation and interdiffusion is significantly reduced.

1. Introduction

Within the Ti–Al system, the 40–50 at.% Al containing alloys – so-called γ-TiAl based alloys – exhibit the most attractive properties such as low density, high specific stiffness, high yield strength, and good creep resistance up to high temperatures. Consequently, γ-TiAl alloys have the potential to partly replace heavy steels and Ni-based alloys presently used in high-temperature automotive, aerospace and power-generation applications [1–5]. However, the long-term use of γ-TiAl based alloys in oxidative environments is limited to temperatures below 800 °C because of their poor oxidation resistance [2–11]. Consequently, the latter has to be improved to utilize the full potential of γ-TiAl. Alloying the material with e.g., Nb was shown to be an effective method in terms of oxidation resistance, but also influences the mechanical properties [3,7,12].

Improving the oxidation resistance by surface techniques allows the development of γ-TiAl based alloys with application-optimized mechanical properties. Hence, in recent years the effect of halogen ion implantation [13,14] or magnetron sputter deposited intermetallic coatings on the oxidation of various γ-TiAl based alloys has been studied [5,6,15–19]. Also, coating systems known for their good performance on Ni-based superalloys [5,9,11,20,21] or for protection of tool steels [22,23] have been tested.

However, due to the relatively low fracture toughness of γ-TiAl based alloys as compared to Ni-based superalloys the influence of the used surface modification on mechanical properties and ductility of γ-TiAl based alloys has to be considered. Contrary to Ni-based superalloys the mechanical properties of γ-TiAl are often reduced by a deposition process [5,9,20,24,25].

In the present paper we discuss, in addition to oxidation resistance, also the influence of coatings and the deposition process on the ductility of Ti–47Al–2Cr–0.2Si (in at.%) sheet material. The selected coatings, Al_2Au and $Cr_{0.45}Al_{0.53}Y_{0.02}N$ (CrAlYN), exhibit both good oxidation and thermal stability [18,26,27]. We show by means of four-point-bending tests that Al_2Au and CrAlYN only slightly reduce the room temperature (RT) bending strength of Ti–47Al–2Cr–0.2Si from 893 to 865 and 855 MPa, respectively. Small specific mass gain after 672 h oxidation at 800 °C is obtained for CrAlYN and Al_2Au coated Ti–47Al–2Cr–0.2Si, whereas uncoated Ti–47Al–2Cr–0.2Si shows a strong mass gain during oxidation in air. Already after 168 h of oxidation time at 800 °C uncoated and Al_2Au coated Ti–47Al–2Cr–0.2Si exhibit no plastic deformation as a thick oxide layer and large interdiffusion zone are formed. Contrary to that, four-point-bending specimen coated with CrAlYN can preserve plastic strain of 0.12% in the outer fiber of γ-TiAl after oxidation at 800 °C for 672 h.

Compared to commercial coatings like pack-cementated Cr–Al, electroplated Ni–Al, and plasma-sprayed CoNiCrAlY, our CrAlYN coating shows better oxidation resistance and lower influence on the mechanical properties of Ti–47Al–2Cr–0.2Si.

* Corresponding author. Tel.: +43 3842 402 4229; fax: +43 3842 402 4202.
E-mail address: martin.moser@mu-leoben.at (M. Moser).

0966-9795/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.intermet.2008.07.003

2. Experimental

Intermetallic Al_2Au and $Cr_{0.45}Al_{0.53}Y_{0.02}N$ coatings were deposited by DC magnetron sputtering, a physical vapour deposition (PVD) technique, on specimen with a dimension of $45 \times 8 \times 1$ mm^3 which were produced from Ti–47Al–2Cr–0.2Si sheet material. This particular γ-TiAl based alloy was selected as substrate material as it exhibits relatively high ductility at room temperature but low oxidation resistance [20]. The 2.5 μm thin CrAlYN film was deposited in a mixed Ar–N_2 glow discharge (0.4 Pa total pressure, ~35% N_2 partial pressure) using a $Cr_{0.36}Al_{0.66}Y_{0.02}$ target (PLANSEE SE, Austria), a sputter-power density of 6.8 W/cm^2, and a substrate temperature of 475 °C [22,28]. The 8 μm thick Al_2Au coating was deposited in Ar glow discharge from an Al target (Ø 150 mm) with Ø 10 mm Au inlets covering 8.8% of the total target surface. The substrate temperature was 300 °C and the sputter-power density was 2.7 W/cm^2. Further details on the deposition parameters are given in Refs. [28,29].

The films are compared to commercially available coatings, which are routinely used for the oxidation protection of Ni-based superalloys, such as chrome-aluminizing by pack-cementation (Cr–Al coating), nickel-electroplating with subsequent Al-pack-cementation (Ni–Al coating), and atmospheric plasma spraying of a layer of CoNiCrAlY. Details on deposition parameters, oxidation resistance and mechanical testing are reported in Refs. [20,30].

The coated and bare Ti–47Al–2Cr–0.2Si sheets were weighed in a Scaltec SBC21 microbalance before and after isothermal oxidation at 800 °C using a Nabertherm N11/HR box-furnace for one week (168 h) and one month (672 h).

Four-point-bending tests were conducted with a Zwick Z050 machine equipped with a 10 kN load cell. The experimental arrangement is shown in Fig. 1. The tests were carried out with a cross-head speed of 0.1 mm/min. The bending angle α is calculated from the cross-head displacement according to [31]:

$$\alpha = 2 \cdot \arctan \frac{f}{0.5 \cdot (l - l_p)} \quad (1)$$

and the bending strength R_{bb} is given by:

$$R_{bb} = \frac{3}{2} \cdot \frac{F \cdot (l - l_p)}{b \cdot h^2} \quad (2)$$

where F is the applied force, l is the distance between the lower rolls and l_p is the distance between the upper rolls (Fig. 1). The terms b and h denote the width and thickness of the specimen, respectively.

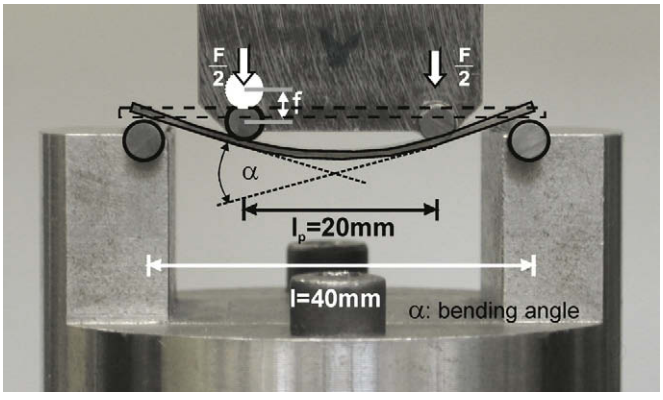

Fig. 1. Four-point-bending test setup [26].

The strain in the outer fiber of the specimens was calculated using [31]:

$$\varepsilon = \frac{4 \cdot h \cdot f \cdot c}{l_p^2} \quad (3)$$

where f is the cross-head displacement and c is a geometry factor of the bending cell (0.27). Further test conditions were selected as given in Refs. [20,30] to allow a full comparison of our results with already published data.

Fracture surfaces, coating morphologies and interdiffusion were investigated using a Zeiss EVO 50 scanning electron microscope (SEM) equipped with an energy dispersive X-ray analysis (EDX) unit. The EDX line-scans presented are derived from elemental maps and represent an averaged pixel count. They, therefore, do not describe an exact chemical composition, but give a good overview of the elemental distribution along the coating thickness. Quantitative elemental analyses were done on specific points of interest using metallic Ti, Al, Au, and Al_2O_3 and TiN as standards. Quantification of the latter was obtained by Rutherford backscattering spectroscopy, see Ref. [32]. For the elemental mapping and line-scans of the as-deposited and oxidized sample an electrolytic Ni support film was applied to avoid the removal of the brittle oxide layer during subsequent grinding and polishing steps.

3. Results and discussion

The oxidation behavior, characterized by the specific mass change versus time (t) of Ti–47Al–2Cr–0.2Si as well as Al_2Au and CrAlYN-coated Ti–47Al–2Cr–0.2Si (in the following referred to as γ-TiAl) after annealing in air at 800 °C is shown in Fig. 2. The unprotected γ-TiAl exhibits a mass gain of fast kinetics to 1.45 ± 0.15 and 8.97 ± 0.78 mg/cm^2 for $t = 168$ and 672 h, respectively. The coated materials have a much lower mass gain which is 0.79 ± 0.002 and 0.12 ± 0.003 mg/cm^2 after 672 h at 800 °C for Al_2Au and CrAlYN, respectively.

For comparison, the values of γ-TiAl coated with commercial Ni–Al are added to Fig. 2. In a previous study these coatings exhibited best oxidation resistance for γ-TiAl, see Refs. [20,21]. The results

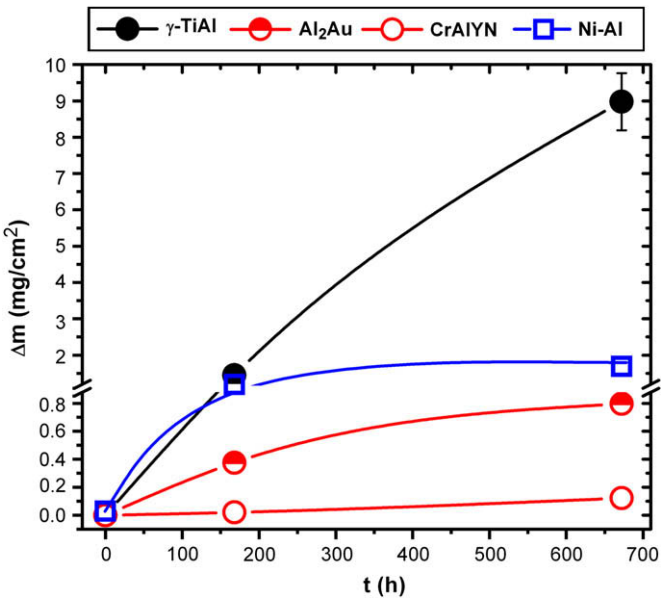

Fig. 2. Specific mass change as a function of time during isothermal oxidation in air at 800 °C. The data for Ni–Al coated γ-TiAl, which showed best results in Refs. [20,21] is added for comparison. The term γ-TiAl stands for the uncoated base material (Ti–47Al–2Cr–0.2Si).