DECHEMA FORSCHUNGSINSTITUT

High Temperature Materials

Inhibition of high-temperature embrittlement in titanium aluminides by designed pack cementation coatings and the halogen effect

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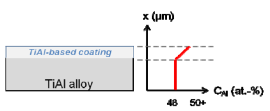
Introduction

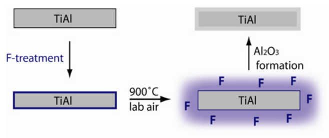
Intermetallic TiAl-based alloys represent an important class of high temperature structural materials providing a unique set of physical and mechanical properties that can lead to substantial payoffs in industrial applications, e. g. for turbine blades or turbocharger rotors. With less than half the weight of nickel-base alloys, they offer a huge potential for applications where high specific strength and stiffness are required and therefore, they have the potential to enhance performance and operating efficiency [1]. To exploit the maximal potential of the TiAl-based alloys the problem of insufficient oxidation resistance and embrittlement at higher temperatures (> 700°C) must be solved. Al-enriched coatings formed by pack cementation can promote the formation of a protective Al_2O_3 layer at high temperatures which protects the alloy from oxidation and to impede embrittlement at high temperatures as only very little oxygen can be dissolved in these coatings [2]. Because the Al-rich TiAl phases are very brittle the major intermetallic aluminide phase in the coating plays a critical role for the protection behavior. Therefore the aim of this study is to produce thin (< 10 µm) coatings consisting of Al-rich TiAl without the brittle Al-rich $TiAl_3$ and $TiAl_2$ phases.

2-step surface treatment of TiAl alloy



1st step: deposition of an Al-rich γ-TiAl coating

- Provides an Al-reservoir to form and maintain an alumina layer
- Acts as barrier between the substrate to avoid nitridation



2nd step: fluorine treatment (halogen effect)

- Selective formation of Al_2O_3 scale
- Good oxidation protection of Al_2O_3 because of its very low permeability for O, N, H, and metal ions

Pack Cementation Process

Advantages:

(1) Economical deposition of diffusion coatings
(2) Simple and relatively inexpensive process with a high deposition rate

Disadvantages:

(1) Large amount of powder is necessary
(2) Incorporation of contaminants

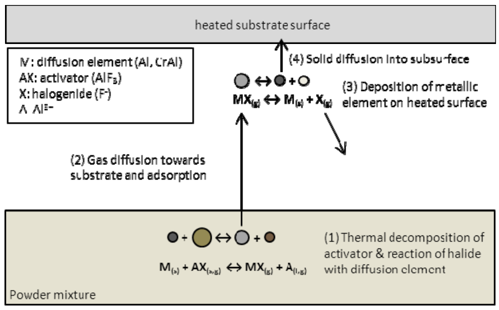


Figure 1: Schematic diagram of pack cementation process

Thermodynamic Calculations and Resulting Coatings

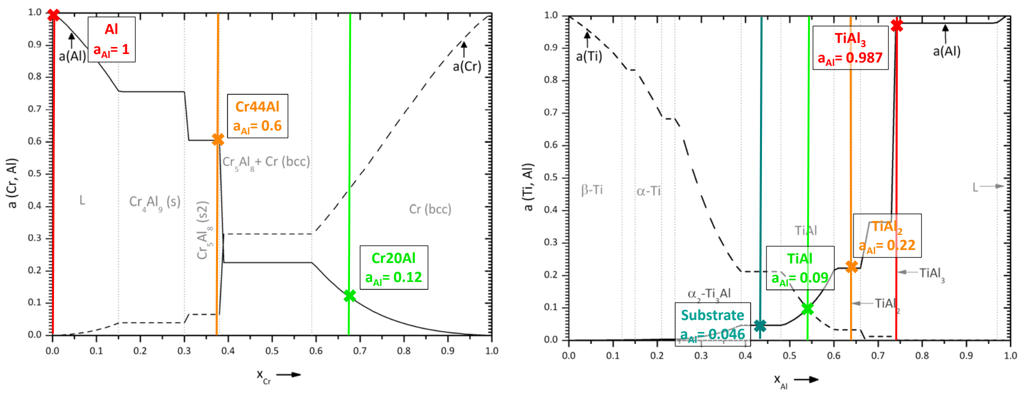
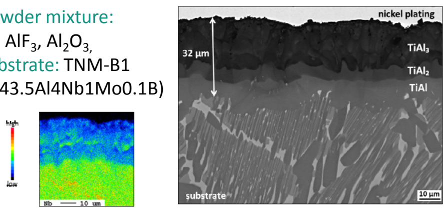


Figure 2: Calculated thermodynamic activities of Al and Cr in solid Cr-Al powders and Al and Ti on the alloy surface at 1050°C

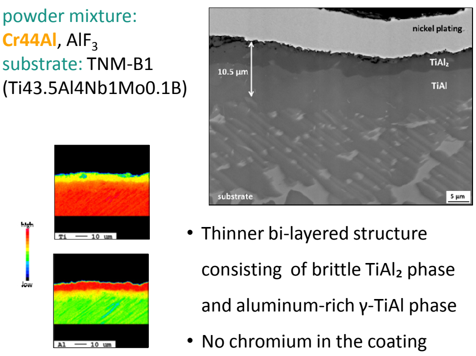
- Large activity gradient between master alloy and substrate surface
  → Al is supplied in excess
- preferential diffusion of the aluminum through the aluminide layer being formed
- high-activity pack powder mixtures produces Al-rich outer phases with a similar high-activity
- Different chromium aluminides to decrease the chemical Al-activity
- **Activity gradient is driving force of the pack cementation process**

powder mixture: **Al**, AlF_3, Al_2O_3,
substrate: TNM-B1
(Ti43.5Al4Nb1Mo0.1B)



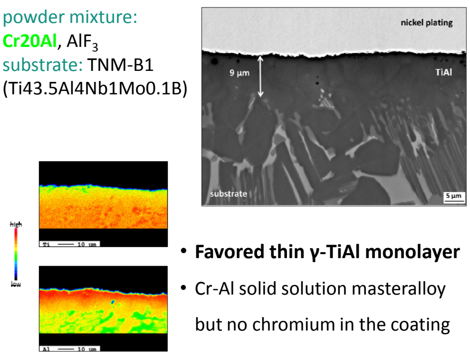
- Multi-layered coating with brittle phases ($TiAl_3$, $TiAl_2$)
- Nb is incorporated in the coating (cubic $AlNb_3$, tetragonal Al_3Nb)
  →diminishes inward diffusion of Al + enhances mechanical properties

powder mixture: **Cr44Al**, AlF_3
substrate: TNM-B1
(Ti43.5Al4Nb1Mo0.1B)



- Thinner bi-layered structure consisting of brittle $TiAl_2$ phase and aluminum-rich γ-TiAl phase
- No chromium in the coating

powder mixture: **Cr20Al**, AlF_3
substrate: TNM-B1
(Ti43.5Al4Nb1Mo0.1B)



- **Favored thin γ-TiAl monolayer**
- Cr-Al solid solution masteralloy but no chromium in the coating

Outlook

Al-rich coating → Fluorination → Oxidation tests → Mechanical tests

- Al-rich coating: * Advanced coatings on TNM
- Fluorination: * PI³ (HZDR Dresden[a]) * F-polymer spraying
- Oxidation tests: * Isothermal (900°C) * Thermocyclic (900°C)
- Mechanical tests: * 4-point bend tests with acoustic emission

References

[1] Xiang, Z.D. et al. *J. Mat. Sci.*, **2004**. *39*: p. 2099-2106
[2] Schütze et al. *Mat. Res. Soc. Symp. Proc.*, **2012.** Vol. 1516

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