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 Al2O3 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 and TiAl 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 Al2O3 scale
- Good oxidation protection of Al2O3 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

<table>
<thead>
<tr>
<th>Powder mixture</th>
<th>Substrate</th>
<th>Resulting Coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>AI, AlF3, Al2O3</td>
<td>TNM-B1 (Ti43.5Al4Nb1Mo0.1B)</td>
<td>Inhibited TiAl41γ, TiAl41δ</td>
</tr>
<tr>
<td>C44A1, AlF3</td>
<td>TNM-B1 (Ti43.5Al4Nb1Mo0.1B)</td>
<td>Aluminide alloy</td>
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<tr>
<th>Al-rich coating</th>
<th>Fluorination</th>
<th>Oxidation tests</th>
<th>Mechanical tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced coatings on TNM</td>
<td>PP (HZDR Dresden)</td>
<td>Isothermal (900°C)</td>
<td>4-point bend tests with acoustic emission</td>
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<tr>
<td>F-polymer spraying</td>
<td>Thermocyclic (900°C)</td>
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Outlook

- Multi-layered coating with brittle phases (TiAl, γ-TiAl)
- Nb is incorporated in the coating (cubic AlNb, tetragonal Al2Nb)
- Decreases inward diffusion of Al + enhances mechanical properties

- Thinner bi-layered structure consisting of brittle TiAl2 phase and aluminum-rich γ-TiAl phase
- No chromium in the coating

References


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