ROLE OF ZIRCONIUM ON THE OXIDATION RESISTANCE OF NICKEL ALUMINIDE COATINGS

S. Hamadi, M.-P. Bacos, M. Poulain, ONERA, France
A. Seyeux, V. Maurice, P. Marcus, Ecole Nationale Supérieure de Chimie de Paris, France
Background

Aeronautical turbine blades

Engine schematic diagram

Aeronautical turbine blades are located at the combustion chamber exit. They are then exposed to the hot combustion gases. The temperature can reach about 1600°C.
Role of zirconium on the oxidation resistance of nickel aluminide coatings
Sarah HAMADI (ONERA, ENSCP) – Euromat 2009

Background
Thermal barrier systems

Turbine blade cross section

Thermal Barrier system

1150 - 1200 °C

Thermal barrier
Internal cooling

Ni-based superalloy (mechanical properties)

β-NiAl(X) coating

YSZ (ZrO₂-Y₂O₃)

alumina

100 µm

1100°C

Key point:
Adhesion of thermally grown alumina on top of the NiAl coating

600 - 700°C
Internal cooling
Background
NiAl(X) coatings

Influence of adding elements on the oxide adhesion

3 types of NiAl coating
- unmodified NiAl
- Pt-modified NiAl: great improvement of alumina adhesion, system in production, high processing costs
- Zr-doped NiAl: Zr as a reactive element is said to improve alumina adhesion on NiAl and NiCrAl bulk materials *

NiAl(Zr) has to be investigated as a coating. One-step elaborating process.

Studied system
Ni-based superalloy: AM1 (Ni, Cr, Co, Mo, W, Al, Ti, Ta)
oxidation protective coating: Zr-doped NiAl
No thermal insulating topcoat

What is the role of Zr on the oxidation resistance of the NiAl coating?

* Smialek, 1987 ; Pint et al., 1996
AM1/NiAl(Zr): better oxidation resistance than AM1/NiAl. WHY?
as efficient as the industrial system
AM1/NiAl(Zr) characterization

Process

Deposition process*

H₂, 1100°C

Vapor Phase co-deposition of Al and Zr on AM1 Ni-based superalloy

NiAl(Zr) coating:
β-NiAl phase (XRD)
Al: 36 at. % (EPMA)
Zr: 300 at. ppm (GDMS)
~ 20 µm from the surface


EPMA: Electron Probe Micro Analysis
GDMS: Glow Discharge Mass Spectrometry

Role of zirconium on the oxidation resistance of nickel aluminide coatings
Sarah HAMADI (ONERA, ENSCP) – Euromat 2009
AM1/NiAl(Zr) characterization

Zr distribution in oxidising conditions

- As aluminized
- Oxidised 10 min 950°C
- Oxidised 50 1h-cycles 1100°C

GDMS depth profile

ToF-SIMS depth profile

Role of zirconium on the oxidation resistance of nickel aluminide coatings
Sarah HAMADI (ONERA, ENSCP) – Euromat 2009
Zr diffuses quickly through the coating towards the metal/oxide interface. After longer oxidation, Zr is present in all the layers of the sample.

How does Zr improve the oxidation resistance of NiAl?

Comparison between the AM1/NiAl and the AM1/NiAl(Zr) systems:

1. β-NiAl ageing
2. oxide growth
1. β-NiAl ageing

1h-cyclic oxidation tests

NiAl: The whole coating is γ phase as soon as 500 oxidation cycles

NiAl(Zr): β-phase is still present after 500 oxidation cycles the coating is γ/γ’ after 1000 and 1500 oxidation cycles

Zr delays the coating ageing
2. Oxide growth

Isothermal 1100°C oxidation tests

96 h 1100°C, synthetic air, followed by TGA

The parabola
\[ t = A + B \frac{\Delta m}{S} + \frac{1}{kp} \left(\frac{\Delta m}{S}\right)^2 \]

is used to fit the isothermal oxidation curves on selected intervals.

Transient regime:
fast oxide growth
first few hours

Stationary regime:
slow oxide growth

Zr lowers the global mass gain
→ Reduces the oxide thickness
2. Oxide growth

Growth kinetics \( t = A + B \Delta m/S + 1/kp \left( \Delta m/S \right)^2 \)

- \( Zr \) has no major effect on \( \theta \) and \( \alpha \) growth kinetics.
- \( Zr \) reduces the transient regime duration.
- When exposed to oxidation at 1100°C, as \( Zr \) reduces the period during which \( \theta \)-alumina grows, it reduces the formation of interfacial cavities.
Role of zirconium on the oxidation resistance of nickel aluminide coatings

Sarah HAMADI (ONERA, ENSCP) – Euromat 2009

Long-term cyclic oxidations

1h-cyclic oxidation tests

Oxidised surfaces

AM1/NiAl

AM1/NiAl(Zr)

• The alumina is more adhesive
• Oxide spallation is delayed, as well as spallations/reoxidations that lead to metal consumption
Role of zirconium on the oxidation resistance of nickel aluminide coatings

Sarah HAMADI (ONERA, ENSCP) – Euromat 2009

**AM1/NiAl**

- As-deposited
- Short-time oxidation
- Long-term oxidation

**AM1/NiAl(Zr)**

- Zr is located at the superalloy/coating interface
- Zr migrates through the coating and favours $\alpha$-$\text{Al}_2\text{O}_3$
- Zr delays the oxide spallation

- $\theta$-$\text{Al}_2\text{O}_3$
- $\alpha$-$\text{Al}_2\text{O}_3$
- Cavity
- Spallation

- Coating
- Superalloy
- Oxide
- Coating
- Superalloy
Conclusions

• Zr reduces the transient regime of oxidation, favouring alpha alumina nucleation

• Zr reduces cavities and delays the oxide spallation

→ Zr increases the system lifetime

NiAl(Zr) promising protective coating, is being investigated as a bond coat in TBC systems
Acknowledgments

Eric Dubois (Snece ma) for providing access to the Setaram thermobalance.

The financial contribution of DGA (Délégation Générale pour l’Armement)
ROLE OF ZIRCONIUM ON THE OXIDATION RESISTANCE OF NICKEL ALUMINIDE COATINGS

S. Hamadi, M.-P. Bacos, M. Poulain, ONERA, France
A. Seyeux, V. Maurice, P. Marcus, Ecole Nationale Supérieure de Chimie de Paris, France