Development of Cr-Si-Ge Alloys for High Temperature Structural Applications

A. Soleimani-Dorcheh, M. C. Galetz
Email: soleimani@dechema.de
Funded by: DFG

Highlights

• Novel oxidation and nitridation resistant chromium alloys are developed
• Synergic addition of Si and Ge to chromium shows significant oxidation protection
• Chromium silicide (Cr₃Si) A15 structure shows high temperature stability in N₂-containing atmospheres
• Addition of Ge enhances the stability of an A15 silicide layer at metal-oxide interface which provokes internal nitridation at high temperatures

Motivation

Higher efficiencies require higher temperatures

Core power versus turbine inlet temperature for selected gas turbine engines, state of the art [1].

- At temperatures above 1150°C Ni-base superalloys start to soften
- Refractory alloys (Nb, Mo, W, Cr) are candidates beyond Ni-base superalloys
- Challenges are the intrinsic brittleness and lack of environmental resistance of refractory alloys at high temperatures

Chromium and its alloys

- At high temperatures common Cr-alloys develop an internally grown brittle nitride which hinders the applicability of such alloys
- In this work, the nitridation behavior of the Cr-silicide system is studied using high temperature exposures in synthetic air (at T> 1200°C). The effect of Ge alloying on nitridation resistance is discussed

Materials and Methods

• CHARACTERIZATION
  - Thermogravimetry
  - X-ray diffraction
  - Microscopy
  - Elemental analysis

• STRUCTURE
  - Microstructure design

• PROCESSING
  - Alloy design
  - Cr-Si alloy
  - Ge alloying

• PROPERTIES
  - Oxidation
  - Nitridation

• PERFORMANCE
  - Oxidation at 1200°C

Results

Oxidation Kinetics

\[ \frac{dW}{dA} = (k_p T)^{0.5} \]

- Parabolic growth
- Linear evaporation

- Pure chromium severely oxidizes at temperatures higher than 1000°C
- Addition of Si reduces both vaporization and growth kinetics
- Synergic addition of Si and Ge further reduces the growth kinetics
- Cr-Si-Ge alloys as the most protective amongst other Cr-base alloys [3]

Thermodynamics

Cr₃N is only stable at low P(O₂) pressure and high P(N₂) with Si addition:

- SiO₂ is stable at lower P(O₂)
- The Cr₃Si silicide phase is stable in the whole P(N₂) range, while solid solution chromium is selectively nitrided

Subscale Nitridation

after 50h in air at 1200°C

Ge-alloying enhances the stability of the A15 layer at oxide-substrate interface which slows inward nitrogen transport

Ge-alloying enhances the stability of the A15 layer at oxide-substrate interface which slows inward nitrogen transport

Acknowledgements: German Research Foundation (DFG) is gratefully acknowledged for supporting this work.

References

2. A. Soleimani-Dorcheh, M. C. Galetz, Metall. and Materials and Corrosion, 2014, 46, P2383