Development Needs for TBCs for Land-Based GTs

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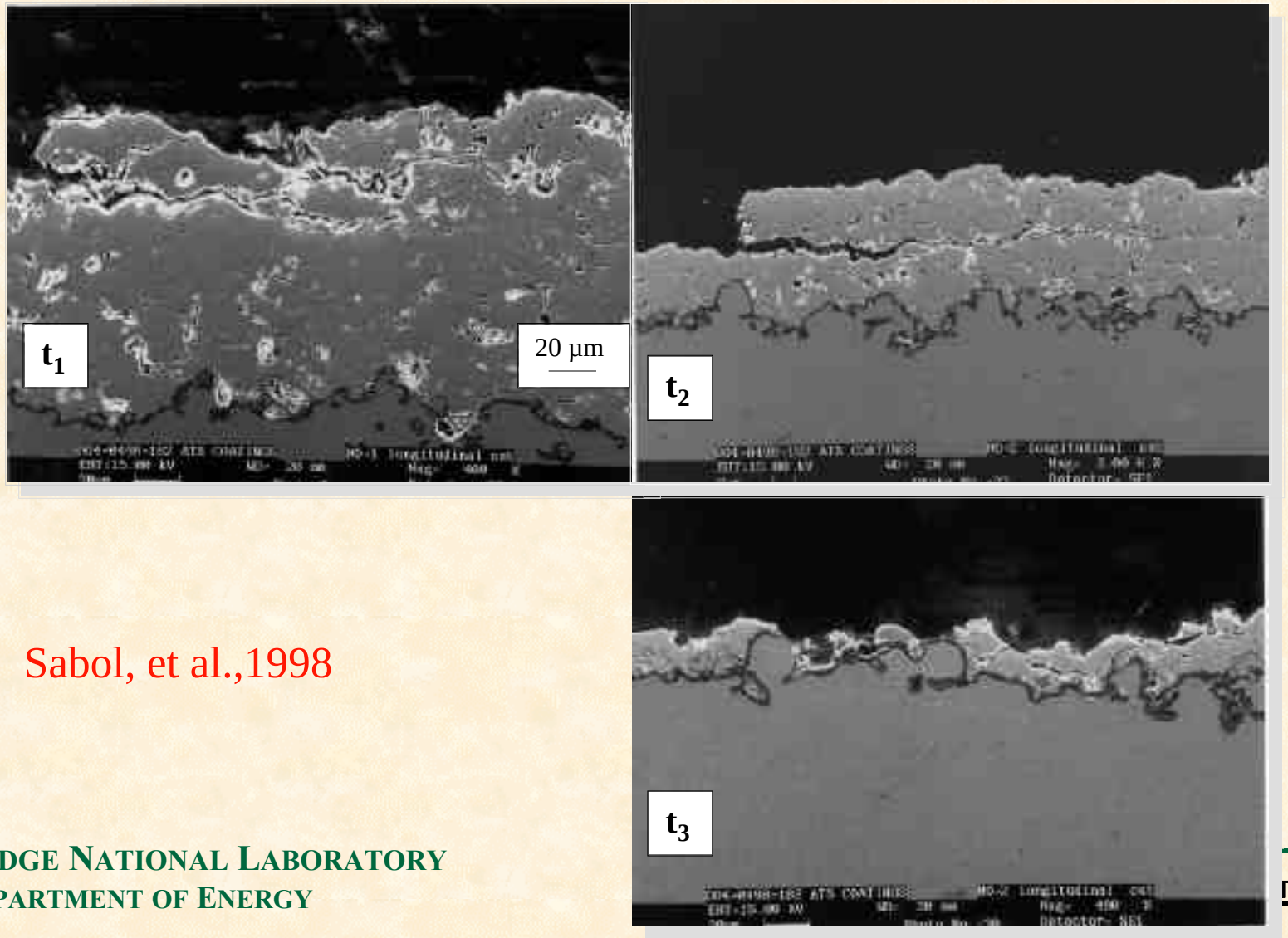
Operation: Assured Performance

- Deliver the expected ΔT
- Sufficient lifetime
- Refurbishable
- No unexpected failures
  - realistic life prediction models
  - condition monitoring?
- Cope with off-specification conditions
  - erosion
  - over-temperature
  - dirty fuels

Issues where understanding is needed before progress can be made

- What are the common failure modes?
  - interplay between oxide growth- and thermally-induced stresses
  - role of bond coat chemistry
  - PS versus PVD coatings
- How do service-induced changes influence properties (elastic modulus, thermal conductivity, residual stress, thermal expansion)?
- How are service-induced changes influenced by duty cycle?
  - 'isothermal' aging versus thermal cycling
  - mechanical loading
  - thermal-mechanical loading
    - thermal gradient testing?

Progressive failure of an APS TBC in a high thermal gradient cycling test



Sabol, et al.,1998

Implications of Increased RIT

- Increased rate of phase change in YSZ
- Increased rate of sintering of ceramic layer
- Increased rate of BC oxidation
  - increased rate of oxide thickening
  - Al depletion
    - oxide with the desired properties does not form on γ' NiAl
  - increased interdiffusion between BC and superalloy
    - change in oxidation behavior/rate
- Change in mechanical properties of the BC
  - transformation from β to γ' which has implications for volume change and CTE
  - stresses resulting from the associated changes in volume and CTE likely to cause physical disruption of the coating

Implications of Increased Cyclic Operation

- Increased stress generation
  - ceramic-oxide scale (CTE)
  - oxide scale-bond coating (growth stresses & CTE)
  - bond coating-superalloy (phase changes & CTE changes)
- More attention to superalloy-BC matching

Ceramic Thermal Barrier Layer Needs

- Lower *k*
- Increased microstructural stability
- Higher sintering temperature
- Higher CTE
- Resistance to erosion

Approaches:

- 'New' ceramics? (YSZ, GSZ, what next?)
- New microstructures
  - voids, cracks, multilayers, grading
  - possible by clever design/processing?

Bond Coating Needs

- Slower rate of oxide thickening
  - promote early formation of α-alumina
  - RE oxide doping effects (Y, Hf appear most powerful)
- Improved oxide adherence
  - low-S superalloy and BC
  - Pt effects (S tolerance; β-phase stability)
  - RE effects (S tolerance; control of oxide microstructure)
- Better CTE match with superalloy substrate
- Lower interdiffusion rate (diffusion barrier?)

Recommendations

- Need to develop a (public) database on modes of degradation
  - multiple processing options
- Ceramic top coating formulations (esp. PS) with improved resistance to sintering probably needed for increased T capability; lower *k* and higher CTE would be nice…
- Major TBC needs depend on research implicit in activities to characterize & understand the modes of degradation:
  - ceramic layer issues
  - bond coating issues
    - optimize ability to form the desired oxide scale
  - life prediction models for TBCs
  - condition monitoring approaches
  - inspection and repair techniques

Main Thesis: 'It's the TGO…'

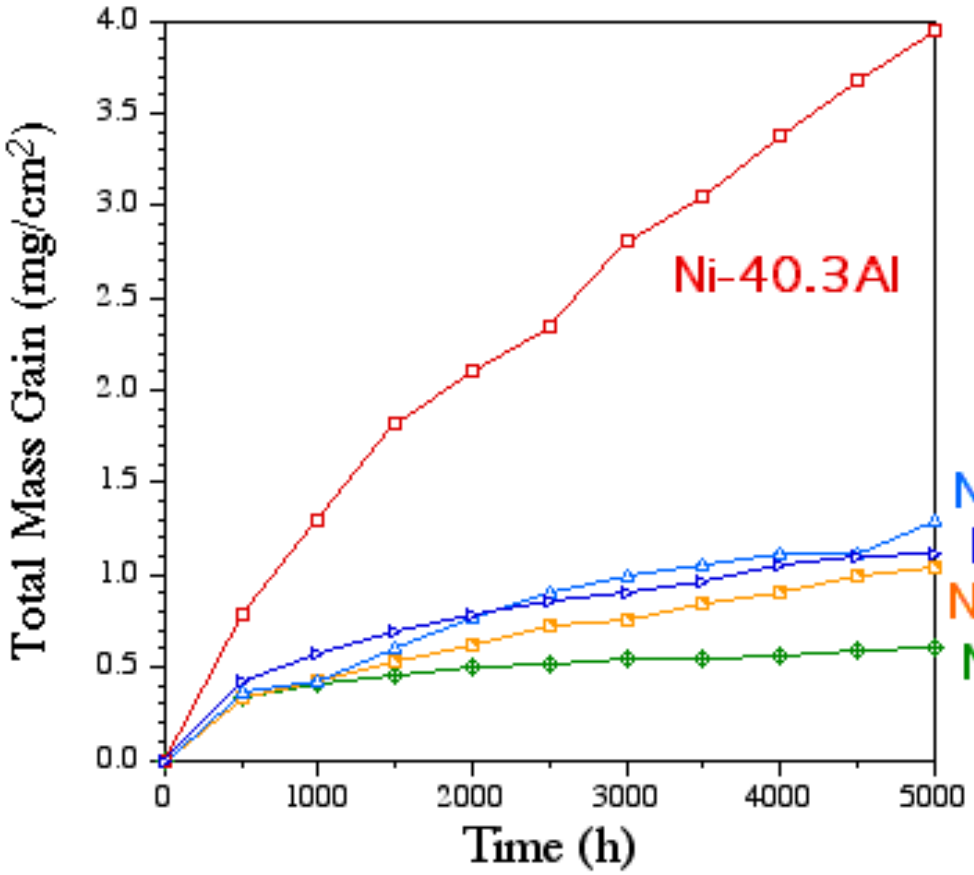
- Early demonstration of the influence of factors that control alloy oxidation behavior indicated that TBC life (PS or EB-PVD) was greatly improved if the substrate formed a 'perfect' alumina film
- Suggested that the ultimate weakest link would be the interface between the self-grown oxide layer and the metallic substrate
- A major goal is how to form a 'perfect' alumina film in practice
  - control of initially-formed film
    - Al_2O_3-YSZ interactions
    - α- Al_2O_3
  - minimize the oxide growth rate
  - maximize scale adhesion
    - manage stress generation

Unfortunately, there are many issues to be considered in the optimization of bond coatings, but some guidance is available..

- NiAl vs NiCrAl ✓
- Effects of S, RE, Pt ✓
- Effectiveness of different RE additions ✓
- Co-doping effects ✓
- Interaction of impurities (e.g., C and Hf) ± ✓
- Effect of thermal cycle time ✓
- Minimum Al level of NiAl for RE effectiveness ✓
- Effectiveness of precious metals (Ru, Pd, Ir) vs Pt ✓
- Influence of Pt on the CTE of NiAl ✓
- Susceptibility to hot corrosion ±✓
- Effect of BC surface finish ?

Improved selective oxidation with Pt

Total Mass Gain during 500h cycles at 1000°C



1000°C, 1832°F

Only Pt added, no Hf

Total = specimen+spall

NiAl+Hf - lower because of better adhesion and slower growth rate

Ni-42.6Al & Ni-50.1Al - undoped alumina growth + some spallation

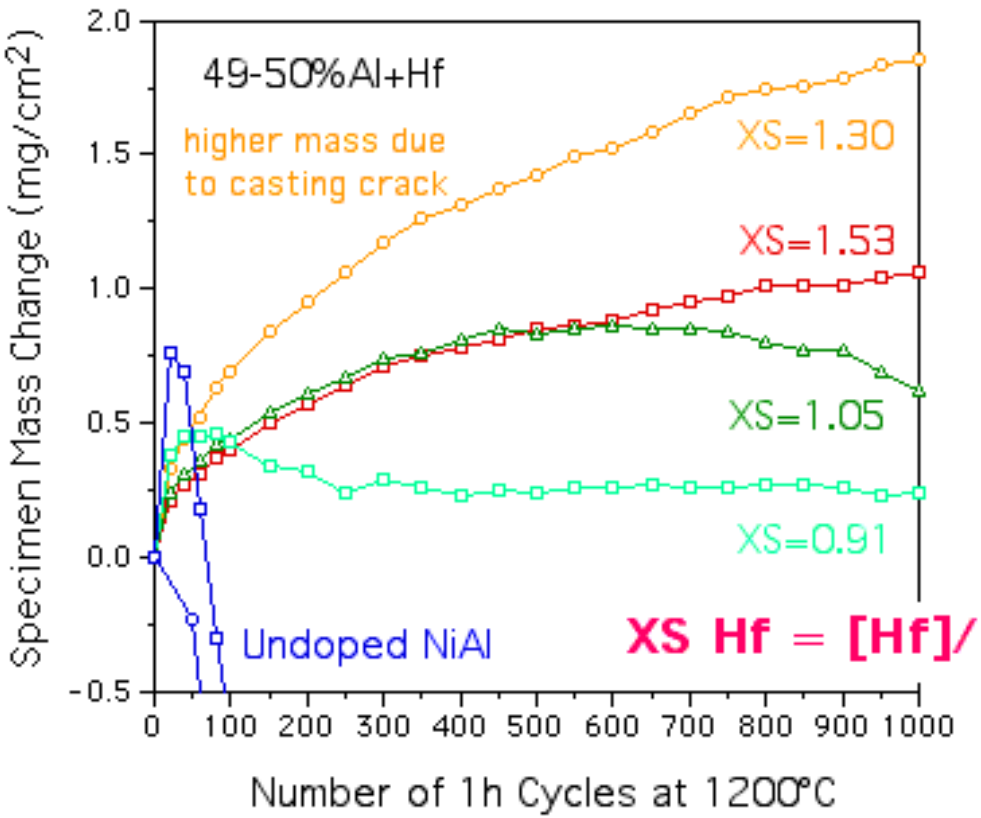
Ni-40.3Al - spinel formation increased total mass + some spallation

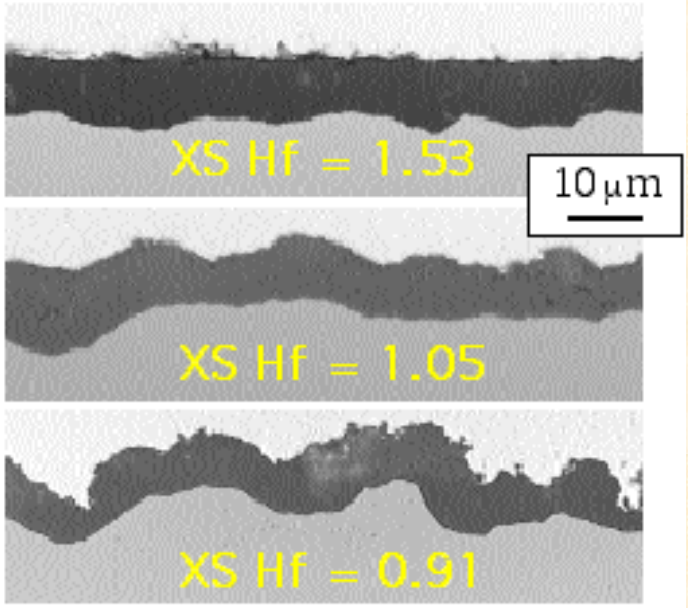
Ni-38.7Al-5.6Pt(20wt%) - better selective oxidation, i.e. no spallation

Pint, et al., 2001

Effects of C-Hf interactions on NiAl+Hf

testing in 1h cycles at 1200°C





XS Hf = [Hf]/([C]+0.5[O]+[N])

after 100h at 1200°C

Typically, [Hf] = 450-550ppma (plasma analysis)
[N] = <4ppma (LECO) [S] = <2 ppma (by GDMS)
[O] = 20-30ppma (LECO)

XS varied by changing [C] -> making graphite additions to the casting

Is XS Hf > 1 a critical parameter?

Pint, et al., 2001

Increased Performance

- Increased firing temperature/RIT
  - $Q = U \bullet A \bullet \Delta T$ where $1/U = [1/h_0 + x_{YSZ}/k_{YSZ} + x_{OX}/k_{OX} + x_{BC}/k_{BC} + x_{SA}/k_{SA} + 1/h_i]$
  - if ↑ T_0, increased cooling will be needed (= ↑ Q)
  - if ↑ x_{YSZ} or ↓ k_{YSZ}, can decrease cooling (= ↓ U)
- Decreased film cooling
  - affects h_0 (↑ U = ↑ Q), hence need increased cooling
- Increased time between overhauls
- Cyclic operation (peaking)?