DECHEMA FORSCHUNGSINSTITUT

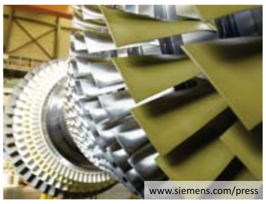
Development of a mechanism-based lifetime model for bi-layer thermal barrier coating systems II

M. Rudolphi, M.C. Galetz, M. Schütze | rudolphi@dechema.de | DFG, FVV | 1st July 2015 – 31st March 2018

Motivation

1

- Thermal barrier coatings (TBC) are state-of-the-art in gas turbines
- Higher efficiency and lower CO_2-emission push materials to their temperature limits
- Improvement for yttria-stabilized zirconia (YSZ) as thermal insulation layer required at T> 1250 °C



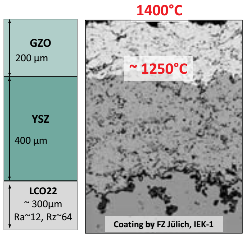
Turbine blades coated with conventional TBCs

Approach

2

Bi-layer concept to combine advantages

- Gadoliniumzirconate ($Gd_2Zr_2O_7$, GZO):
  - (+) excellent HT phase stability
  - (-) low mechanical strength
- YSZ: (+) good mechanical stability
- Coating thickness ratio:
  - 1400 °C surface temperature
  - 1250 °C at GZO/YSZ interface



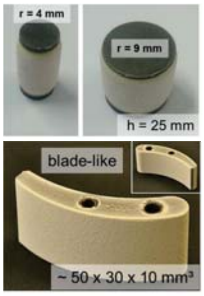
Bi-layer coating concept

Microstructural analysis

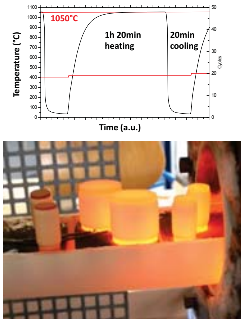
3

Effect of curvature on crack growth

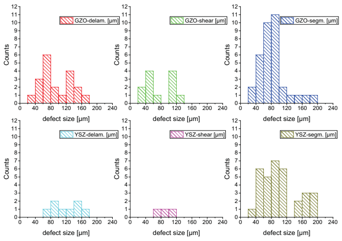
- Different radii and convex/concave surface
- Introduced damage by cyclic oxidation (1050 °C)
- Metallographic inspection (SEM):
  - Crack length measurement
  - Categorization (ceramic layer location & orientation)



Sample geometries



Cyclic oxidation (1050 °C)



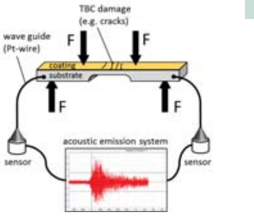
Categorical crack analysis

Mechanical 4-point bending

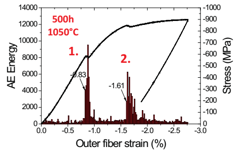
4

Brittle failure of ceramic layers

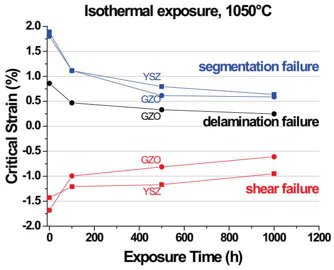
- Determine critical strain values
- Acoustic emission measurement to differentiate failure modes of individual layers
- GZO and YSZ failure distinguished
- Used for modelling together with crack length values



Bending setup with acoustic emission measurement



Typical measurement result



Critical strain values of bi-layer system

Appearance of macrocracks

Modelling

5

Fracture mechanics approach

- Griffith model of brittle failure
- Defect size, stiffness (modulus) and critical strain → input values
- Mechanical stability diagrams → output
- Finite element model (FEM) to perform transition to complex geometries
  → prediction of failure time and location

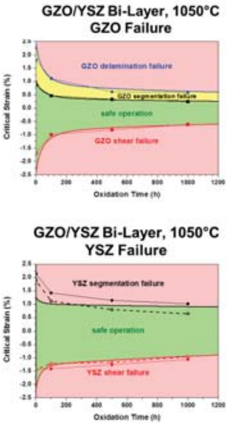
Critical strain

Fracture toughness

$$\varepsilon_c = \frac{K_c}{f \cdot E^*_{TBC}\sqrt{\pi c}}$$

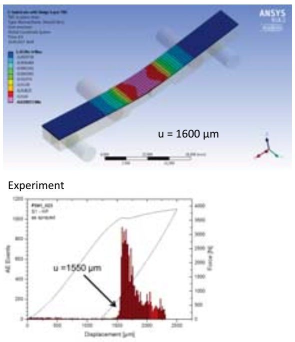
Shape factor *Stiffness* *Crack length*

Modelling equation



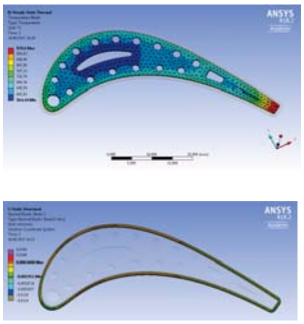
Mechanical stability diagrams for GZO and YSZ failure

Verification



Finite element model of 4-point bending test

Complex geometry



Calculated temperature distribution and resulting cooling strain in TBC

MPA IfW TECHNISCHE UNIVERSITÄT DARMSTADT
JÜLICH FORSCHUNGSZENTRUM
DFG
FVV
imagination at work Schweiz
MAN Diesel & Turbo
MTU Aero Engines
Rolls-Royce
SIEMENS