A Novel Approach for Non-Destructive Testing of the Adhesion of Thermal Barrier Coatings

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Structure

• **Motivation**
  - increase of the efficiency of gas turbines
  - non-destructive testing of thermal barrier coatings (TBCs)

• **Non-contact characterization**
  - infrared-optical properties
  - structural properties
  - adhesive properties

• **Conclusions and outlook**
  - characterization of coating and layers
  - structural analysis
Motivation

Improvement of the energy efficiency of gas turbines using TBCs.

Non-destructive determination of adhesion or delamination of layer systems.

Relevant quantities:
- temperature
- heat transfer by thermal radiation (infrared-optical properties)
- structure (morphological properties)
Delamination

TBC on substrate: structural changes due to delamination

partial delamination caused by thermally grown oxide (TGO)

J.A. Nychka, D.R. Clarke,
Surface and Coatings Technology,
146-147 (2001) 110-116
Radiative Transfer

Transfer of thermal radiation through TBCs

IR-radiation

surrounding

ceramic coating

scatter center

delamination

substrate

PS-PVD-coating

EB-PVD-coating
Radiative Transfer

Infrared-optical characterization and modelling of radiative transfer

- transmittance, reflectance, emittance
- refractive index, structure, etc.

three-flux-calculation ➔ scattering-theory

scattering and absorption coefficient

- transmittance, reflectance, emittance
- equation of radiative transfer
- refractive index, structure, etc.

- radiative thermal conductivity
Integrating Sphere

Setup for measurement of transmittance and reflectance at ambient temperature

[Diagram showing the setup of an integrating sphere for measuring transmittance and reflectance]
Blackbody Boundary Conditions (BBC)

Apparatus for measurement of transmittance and emittance at high temperatures
Blackbody Boundary Conditions (BBC)

Apparatus for measurement of transmittance and emittance at high temperatures
Structural Analysis

Characterization of alumina (Al$_2$O$_3$) with a porosity of 2 %

transmittance, reflectance, emittance
refractive index, structure, etc.
three-flux-calculation scattering-theory

scattering and absorption coefficient

transmittance $T_{dh}$
reflectance $R_{dh}$

$d = 1$ mm
$d = 2$ mm
$d = 3$ mm

wavelength $\lambda$ / $\mu$m

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Structural Analysis

Characterization of alumina (Al$_2$O$_3$) with a porosity of 2 %

- Transmittance, reflectance, emittance
- Refractive index, structure, etc.
- Three-flux-calculation
- Scattering-theory
- Scattering and absorption coefficient

Scattering coefficient $S^*$ / mm$^{-1}$

<table>
<thead>
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<th>Wavelength $\lambda$ / µm</th>
<th>Scattering Coefficient $S^*$ / mm$^{-1}$</th>
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</tbody>
</table>

- Measurement: sample set 2 with $\eta = 2 \%$
- Fit: sample set 2 mit $D = 2.2 \mu$m

- Measurement: sample set 1 with $\eta = 2 \%$
- Fit: sample set 1 mit $D = 0.4 \mu$m
Characterization of Radiative Transfer

Freestanding TBC: partially yttria stabilized zirconia (PYSZ)

d\uparrow\downarrow

PYSZ

substrate

heat-treatment

transmittance $T_{dh}$

wavelength $\lambda$ / µm

0.0 0.1 0.2 0.3 0.4 0.5

PYSZ with $d = 0.3$ mm

coating after 100 hours at 1400 K

dotted line: coating without heat treatment

radiative thermal conductivity $\lambda_{rad}$ / W/(m·K)

0.0 0.1 0.2 0.3 0.4

PYSZ with $d = 0.3$ mm

for comparison: solid thermal conductivity $\lambda_{solid}(T = 1400$ K $) \approx 1.2$ W/(m·K)

temperature $T$ / K

400 600 800 1000 1200 1400
Delamination of TBC

Partial delamination:
- change of the morphology
- change of the radiative transfer
- change of the temperature gradient

Determination of Temperature Gradient

Change of the temperature gradient due to delamination: sapphire on a substrate: without gap and with gap

without gap

with gap
Determination of Temperature Gradient

Change of the temperature gradient due to delamination:

sapphire on a substrate: without gap and with gap

Without gap

With gap
Determination of Temperature Gradient

Change of the temperature gradient due to delamination:
sapphire on a substrate: without gap and with gap

without gap

with gap

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Conclusions and Outlook

Characterization of free-standing layer
- infrared-optical characterization at high temperatures
- determination of structure and morphology
- modelling of the radiative transfer and radiative thermal conductivity

Analysis of coatings and layer systems
- non-destructive testing at high temperatures
- possibility of detecting delamination of TBCs

Outlook
- correlations need to be further investigated and thoroughly quantified
- further work will be done on testing adhesion of TBCs
Thank you!