NON-DESTRUCTIVE EVALUATION TECHNIQUES
HIGH TEMPERATURE CERAMIC COMPONENT
PARTS FOR GAS TURBINES

H. Reiter, S. Hirsekorn, J. Lottermoser, K. Goebbels

Translation of "ZfP von Hochtemperatur-Keramik-Bauteilen für KfZ-Turbinen", Fraunhofer-Institut für Zerstörungsfreie Prüfverfahren, Saarbruecken, West Germany, Report IzfP-800305-TW, March 6, 1980

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

September 1984
This report concerns studies conducted on various tests undertaken on material without destroying the material, including microradiographic techniques, vibration analysis, high-frequency ultrasonic tests with the addition of evaluation of defects and structure through analysis of ultrasonic scattering data, microwave tests and analysis of sound emission.
The present report deals with the studies conducted in 1979 within the second phase on the techniques appearing to be most promising in the first phase:
- Microradiographies
- Vibration analysis
- High frequency ultrasound

as well as several studies not conducted up to that time:
- Defect and structure assessment through analysis of ultrasonic scattering data
- Microwave tests
- Analysis of sound emission.

The resolution capacity was optimized through microradiographic techniques. This includes, on the one hand, mechanical means for adjusting the sample (sample table with horizontal and vertical movement capabilities, rotation of the sample) and film cassette mounts or image amplification adjustment (setting of the geometric distance relationships, direct enlargement). On the other hand, the correct adjustment of energy and exposure parameters (mA x time) in relation to film and foil combinations as well as type, geometry and wall thickness of the irradiated object also belong to optimization.

An improvement in the test arrangement for the vibration analysis - design and construction of an appropriate support and an impact transmitter - led to results which could be reproduced even for complex geometries (turbine blades).

*Numbers in the margin indicate pagination in the foreign text.
In addition to the RH heads with piezoelectrically vaporized layers [2] a further possibility was tested of generating ultrasonic waves of high frequency through the electrical excitation of LiTaO$_3$ single crystals. Tests with the ultrasonic microscope SLAM demonstrated the suitability for describing structural inhomogeneities and defect detection in Si$_3$N$_4$ and SiC with ultrasonic waves of 100 MHz.

The studies on ultrasonic propagation in multiple-phase systems is a possibility for recognizing defects and assessing structure. Reflection, scattering, bending and absorption supply statements on the scattering object and the structure of the observed medium.

The studies with microwaves and the sound emission test did not supply any satisfactory results on defect detection and characterisation of the material with the presently employed experimental set-up and evaluation techniques.

Both measurement set-ups (RF and SLAM) are necessary for the evaluation of structure and the detection of defects and the set-ups supplement one another. The RF measurement set-up is suitable for detecting very minute individual defects and offers the possibility of signal processing on the receiver side. Digitalisation and subsequent inverse filtration first via software and later via hardware in a black box will improve the resolution capacity. The commercially available SLAM, however, provides more rapid scanning of components with large surface areas and therefore permits a fast description of the structure and a corresponding quicker location of defects. It analyzes macroscopic volumes with microscopic resolution, somewhat comparable to microradiographic techniques.

In addition to this activity in the area of ultrasonics, there is a plan to supplement the series of studies conducted with one further method before concluding the project. Application of the heat conduction procedure for non-destructive techniques of high temperature ceramics SiC and Si$_3$N$_4$ will be tested.
Concept for a classification of defects in high temperature ceramics in relation to components and load:

(See following page for key)

<table>
<thead>
<tr>
<th>Belastung</th>
<th>Temperature</th>
<th>Zug, Druck, Scher</th>
<th>Korrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bauteil</td>
<td>(z.B. Thermoschock)</td>
<td>(z.B. Flieh-, Einsp.-Kräfte)</td>
<td>(z.B. Heißgasangriff)</td>
</tr>
<tr>
<td>Brennkammer, Flammrohr</td>
<td>31 Risse</td>
<td>30 amorphe SiO₂-Schichten</td>
<td>innere Oxidation</td>
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<tr>
<td>Wandstärke-änderungen</td>
<td>16</td>
<td>26 Erschütterung</td>
<td>29 Erschütterung</td>
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<tr>
<td>Bohrungen</td>
<td>16</td>
<td>26 Erschütterung</td>
<td>29 Erschütterung</td>
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<td>Einlaufkonus, Einlaufspirale</td>
<td>17 Geometrieunterschiede</td>
<td>26 Erschütterung</td>
<td>30 amorphe SiO₂-Schichten</td>
</tr>
<tr>
<td>Wandstärke-änderungen</td>
<td>16 Risse</td>
<td>26 Erschütterung</td>
<td>30 amorphe SiO₂-Schichten</td>
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<tr>
<td>Kanten</td>
<td>16 Klebestelle</td>
<td>26 Erschütterung</td>
<td>30 amorphe SiO₂-Schichten</td>
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<tr>
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<td>17 Geometrieunterschiede</td>
<td>26 Erschütterung</td>
<td>30 amorphe SiO₂-Schichten</td>
</tr>
<tr>
<td>innerer, äußerer Ring</td>
<td>12 Angleichmäßige thermische Ausdehnung</td>
<td>26 Erschütterung</td>
<td>30 amorphe SiO₂-Schichten</td>
</tr>
<tr>
<td>Schaufeln</td>
<td>11 Schaufenkante, -fuß</td>
<td>27 Exzentrizität, Reibung</td>
<td></td>
</tr>
<tr>
<td>Rotor</td>
<td>12 Thermoschockrisse</td>
<td>27 Exzentrizität, Reibung</td>
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<tr>
<td>HP-Nabe+Schaufeln</td>
<td>21 Kriechen, langsames Rißwachstum</td>
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<tr>
<td>HP-RB-Verbund</td>
<td>22 Geometrieänderungen</td>
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<tr>
<td>PB-Schaufeln</td>
<td>23 Bindefehler</td>
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<td></td>
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<tr>
<td>24 unterschiedliche Wärmeausdehnung</td>
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<tr>
<td>25 Zug, Druck, Scher</td>
<td>26 Einspannung</td>
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<td>27 Exzentrizität, Reibung</td>
<td>28 Schaufenkante, -fuß</td>
<td>30 amorphe SiO₂-Schichten</td>
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<tr>
<td>29 Korrosion</td>
<td>30 Oberflächenfehler</td>
<td>innere Oxidation</td>
<td></td>
</tr>
</tbody>
</table>
Key:  1. load  
2. component  
3. combustion chamber  
4. flue  
5. alteration in wall thickness  
6. holes  
7. inlet cone, spiral  
8. edges  
9. guide rim  
10. inner and outer ring  
11. blades  
12. HP hub + blades  
13. HP-RB combination  
14. RB blades  
15. e.g. thermal shock  
16. cracks  
17. geometrical differences  
18. adhesion point  
19. uneven thermal expansion  
20. thermal shock cracks  
21. crawling, slow formation of cracks  
22. alterations in geometry  
23. defects in binding  
24. differing heat expansion  
25. push, pull, cutting (e.g. centrifugal, clamping forces)  
26. clamping  
27. eccentricity, friction  
28. blade edge, base  
29. corrosion (e.g. attack by hot gas)  
30. amorphous SiO₂ layers, internal oxidation  
31. surface defects
Fig. 1: Sketch of the Microradiographic Set-Up

Key:
- a. basic frame
- b. image amplifier
- c. cassette mounting
- d. Sample and table with adjustment in height and in lateral direction
- e. X-ray instrument
Fig. 2: Microradiogram of HPSC and HPSN Samples with artificially applied Defect Points

Key:  
a. HPSC disc, 5.7 mm thickness, WC Inclusion  
b. 2 HPSN Samples, Fe and C Inclusion  
c. 1 HPSC Sample, Fe Inclusion (from the left to the right)
Fig. 3: SiC Pipes with different Content of Silicon, increasing from a to c.
Fig. 4: RBSN Centrifugal Disc with Saw Cuttings

Key:  
a. without optimizing  
b. after optimizing
Fig. 5: Support and Impact Transmitter in the Vibration Analysis
Fig. 6: Vibration Analysis with RBSN Blades
Key: a. series
Rückwandechos, LiTaO$_3$
90 MHz

Key: a. rear wall echo
b. and
c. sample
d. thickness

Fig. 7: High Frequency Ultrasound with a LiTaO$_3$ Converter
Fig. 8: Block Diagram of High Frequency Ultrasonic Measurement Set-Up (≤ 150 MHz)

See following page for key.
Key for Fig. 8:  

a. generation of impulse  
b. receiver amplification  
c. unit  
d. store  
e. computer  
f. generation of burst  
g. limiter  
h. output amplification  
i. sample  
j. manipulator control  
k. already present  
l. under construction
Fig. 9: Ultrasonic Test of a 3.5 mm thick HPSC rod with Fe Inclusion, 16 MHz

Key: 
- a. HPSC sample, free of defects
- b. HPSC sample, Fe inclusion
Fig. 10: Ultrasonic Test of a 3.5 thick HPSN rod with C inclusion, 16 MHz

Key: a. HPSN sample free of defects
    b. HPSN sample, C inclusion
Fig. 11: Mode of Function of SAM
Fig. 12: Schematic Diagram of the SLAM
Fig. 13: Detection of acoustic energy at the boundary surface by means of the laser.
Fig. 14: SLAM Photos of defect points in a HPSC disc.

Key:

a. Inclusion
b. Surface damage
Fig. 15: SLAM Photo of a saw cutting in a HPSN sample.

Key:  
  a. saw cutting  
  b. interferometrical representation
Fig. 16: SLAM Photos of defects in HPSN samples.

Key:  
a. Knoop impression  
b. C inclusion
Fig. 17: SLAM Photo of an Fe inclusion in an HPSC sample.

Key:  
- a. HPSC sample with Fe inclusion
- b. HPSC sample with Fe inclusion, interferometric representation
Fig. 18: Standardized scattering cross-section $\gamma_N$ for pores in the case of incident longitudinal wave
Fig. 20: Standardized longitudinal group and phase velocity $v_g$ and $v_{Ph}$ for various volume parts of scattering.
Fig. 21: Standardized dispersion coefficient $\alpha_N$ in the case of incident longitudinal wave.
Fig. 22: Standardized longitudinal group velocity, theoretical and experimental values; Si$_3$N$_4$

Key: a. measurements
b. theoretical results
c. experimental values of various RBSN qualities
Fig. 23: Microwave tests with an RBSN rod.
Fig. 24: Microwave test with an RBSN centrifugal disc

Key: a. scanning track
    b. defect area
Fig. 25: Energy ($E_{ges}$) and Event Rate ($n_{ges}$) as a function of Fracture Load

Key: a. load
Fig. 26: Energy rate as a function of fracture load with different Knoop loads

Key: a. Knoop load    b. total energy    c. load
Fig. 27: Rate of Events as a Function of Fracture Load with varying Knoop Loads.

Key: a. Knoop load  b. total events  c. load
Fig. 23: Energy rate with the first SE signal as well as maximum energy rate as a function of fracture load.

Key:  
a. energy with the first SE signal  
b. load
Fig. 29: Energy rate with the first SE signal with varying Knoop load as a function of fracture load.

Key: a. Knoop load  b. energy with first SE signal  c. load
Fig. 30: Maximum energy rate with varying Knoop load as a function of fracture load.

Key: a. Knoop load    b. load
Fig. 31: Sound emission signals, differences in signal form.
Key: a. at the probe   b. time
REFERENCES


