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High Temperature Damping Behavior of Plasma-Sprayed Thermal Barrier and Protective Coatings

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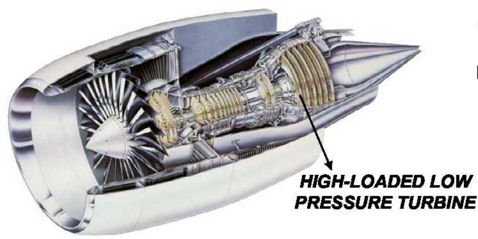
Abstract

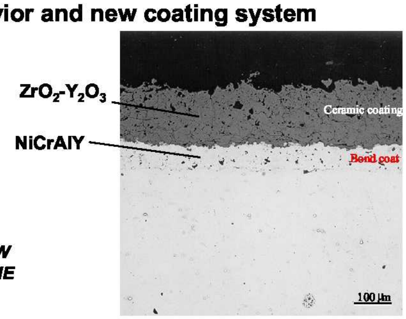
A high temperature damping test apparatus has been developed using a high heat flux CO_2 laser rig in conjunction with a TIRA S540 25 kHz Shaker and Polytec OFV 5000 Vibrometer system. The test rig has been successfully used to determine the damping performance of metallic and ceramic protective coating systems at high temperature for turbine engine applications. The initial work has been primarily focused on the microstructure and processing effects on the coating temperature-dependence damping behavior. Advanced ceramic coatings, including multicomponent tetragonal and cubic phase thermal barrier coatings, along with composite bond coats, have also been investigated. The coating high temperature damping mechanisms will also be discussed.

Introduction

- High cycle fatigue (HCF) becomes of increased concern for highly-load turbine systems
- Integrated turbine blade coatings may offer viable solutions to improved blade vibration damping, surface erosion and oxidation protections
- Current high temperature turbine damping efforts emphasizing low pressure turbine (LPT) systems
- High temperature damping testing and modeling methodologies aiming at understanding coating damping behavior and new coating system development



(a) Turbine Engine



(b) Plasma- Sprayed TBC coating

Outline

- **High temperature material damping testing approach**
  - Laser damping rig fixture design and modeling
  - Modal analysis
- **Experimental setup**
- **High temperature damping testing**
- **Damping behavior of ceramic coating**
- **Summary and Conclusions**

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Coating and Material Damping Testing Approach

— **Electromagnetic shaker (TIRA S540 25 kHz Shaker, peak force 90 N)**
  - **Initially tested at 1 and 2 g acceleration**

— **Polytec OFV 5000 Vibrometer system**

— **High power CO_2 laser for specimen heating**

— **Coating specimens designed using ASTM standard E756-05**

— **FEM and analytical solutions used for vibration modal analysis**

— **FEM used for test rig optimization**

CO_2 Laser

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Experimental

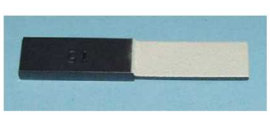
— **Coating and substrate material systems**
  - — CMSX4+Y single crystal superalloy substrate (25 X 10 X 1 mm)
  - — CMSX4+Y/HVOF NiCrAlY bond coat (0.127 mm)
  - — CMSX4+Y/HVOF NiCrAlY bond coat (0.127 mm)/t' low k TBC*
  - — CMSX4+Y/HVOF NiCrAlY bond coat (0.127 mm)/cubic low k TBC**

— **Initially 14 mm diameter uniform laser beam with minimum specimen cooling (very low thermal gradients across the specimen thickness)**

— **Maximum testing temperature 1230 °C with a heating cooling cycle**

— **Resonance peak data collected at steady-state heating conditions**

— **Resonance peak width used for determining loss factors $1/Q = \Delta f/f$ at -3dB**



*** Plasma-sprayed ZrO_2-4mol% $(Y,Gd,Yb)_2O_3$**
**** Plasma-sprayed ZrO_2-10mol%$(Y,Gd,Yb)_2O_3$**

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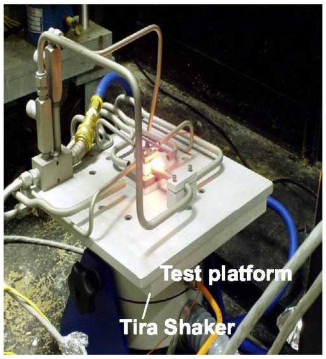
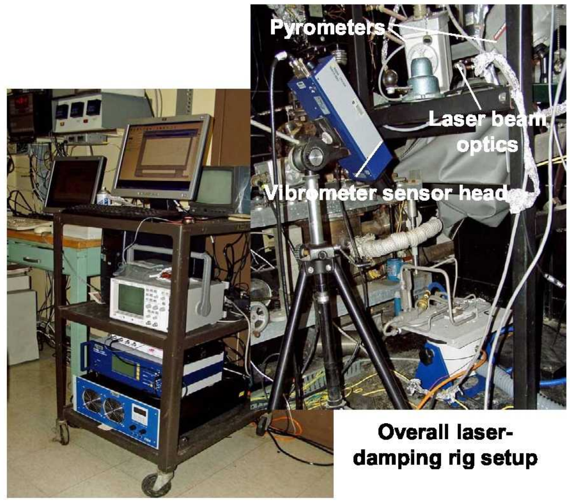
Experimental Setup



Shaker and test platform



Overall laser-damping rig setup

Control and data acquisition unit

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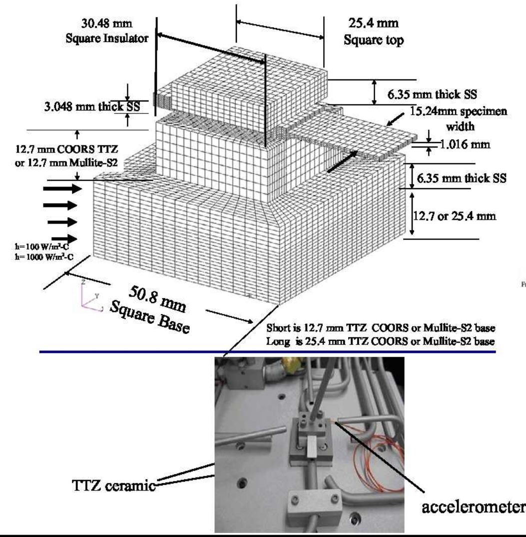
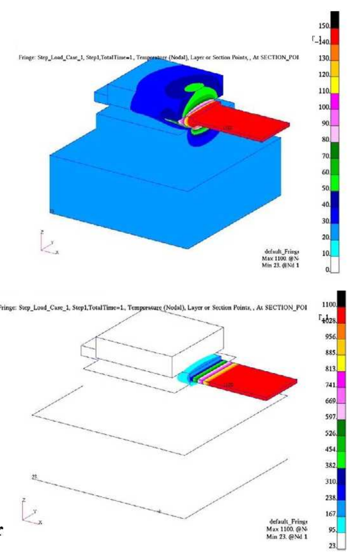
Damping Test Rig Fixture

- FEM modeling of cooling requirements





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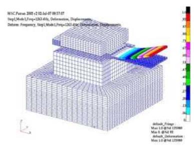
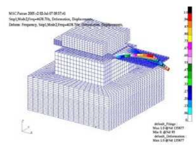
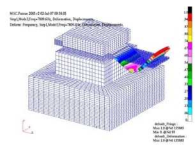
Damping Test Rig Fixture (Continued)

- FEM resonance frequency modeling

COORS TTZ   Short Fixture, 41.148 mm total height

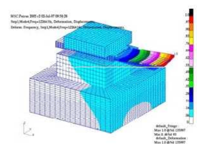
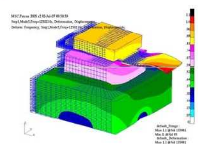
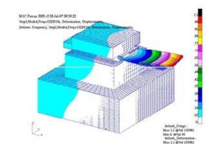




Mode I 1263.4 Hz
Specimen 1st Bend

Mode II 4638.7 Hz
Specimen 1st Twist

Mode III 7809.6 Hz
Specimen 2nd Bend

Specimen frequencies

Mode IV 12264 Hz

Mode V 12502 Hz

Mode VI 13229 Hz

Fixture frequencies

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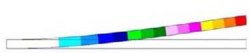
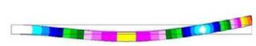
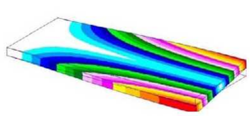
Test Specimen Mode Shapes and Resonance Frequencies
(uncoated; HVOF bond coated; Ceramic TBC/HVOF bond coated)



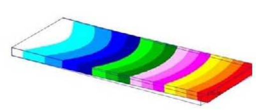
1st Bending mode: 994; 1,212; 1,226Hz



2nd Bending mode: 6,180; 7,565; 7,665Hz

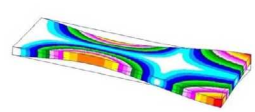


1st Twisting mode: 7,787; 8,599; 8,580Hz



1st Stiff-wise Bending mode: 9,230; 9,770; 9,554Hz

3rd Bending mode: 17,385; 21,233; 21,509Hz



2nd Twisting mode: 23,857; 26,536; 26,496Hz

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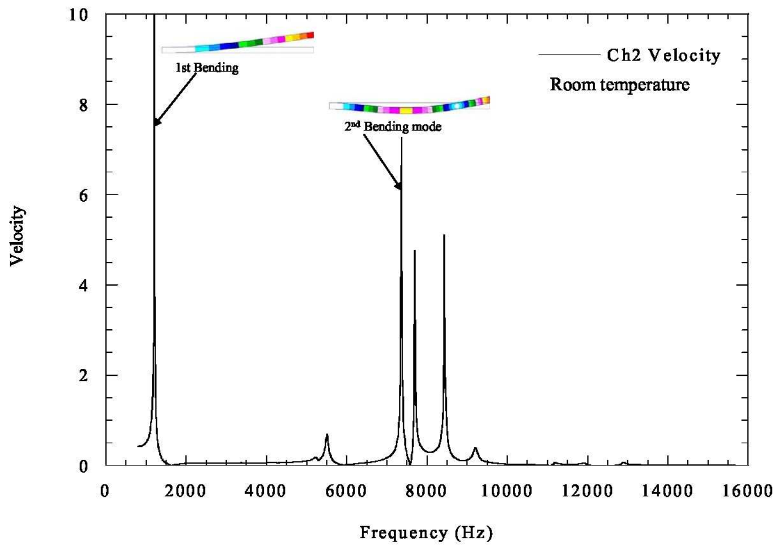
Damping Mode Characterizations of a Ceramic TBC Coated Specimen



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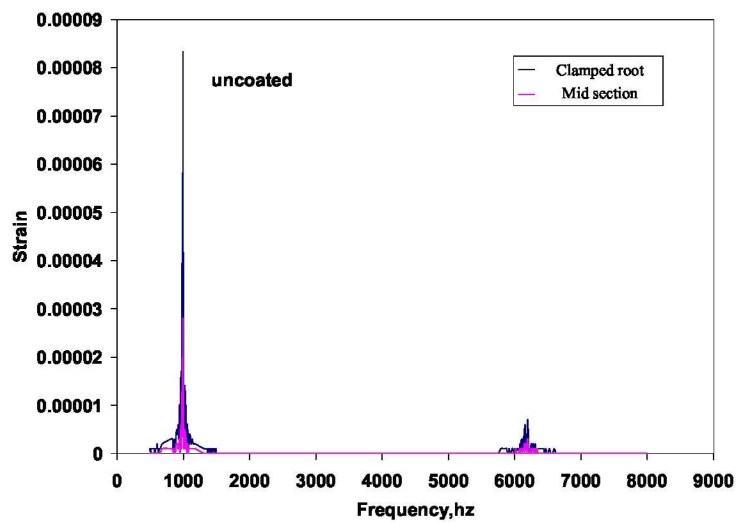
Strains Associated with The 1st and 2nd Bending

- Modeled for 1 g acceleration; higher strain testing planned for future studies



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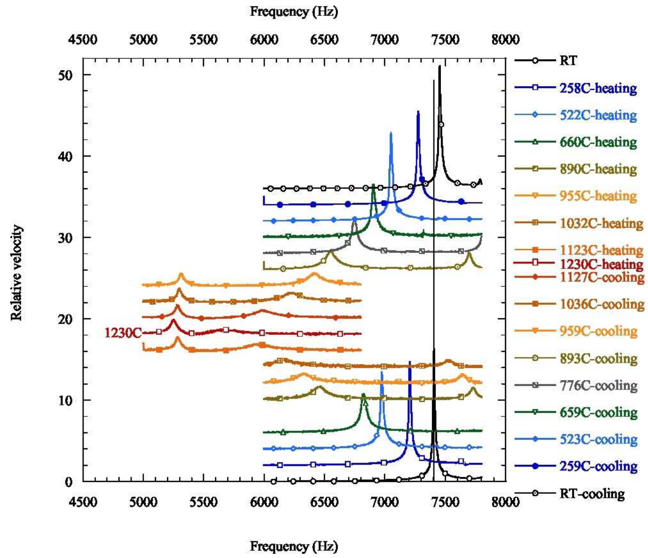
Damping Characterization of a Cubic Phase Low Conductivity Thermal Barrier Coatings



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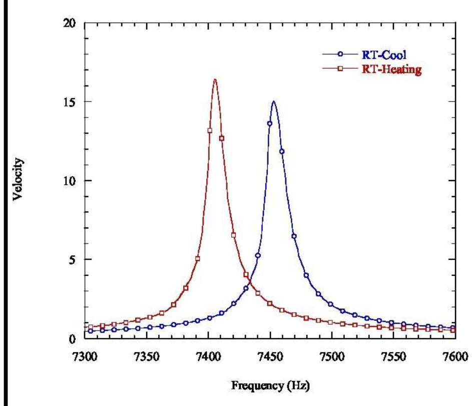
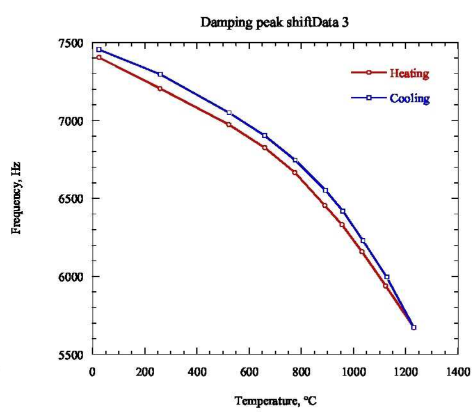
Resonance Peak Shift Observed During the Heating Cooling Cycle





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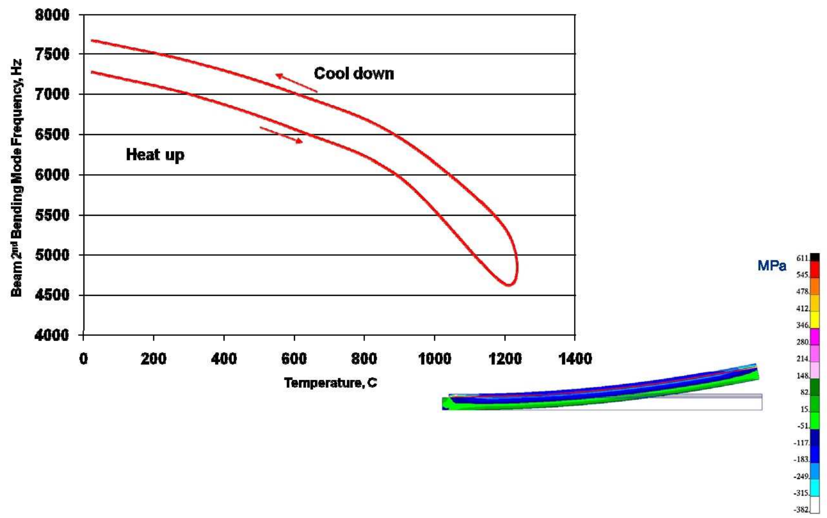
FEM Modeling of Peak Shift for a Stiffened Beam System



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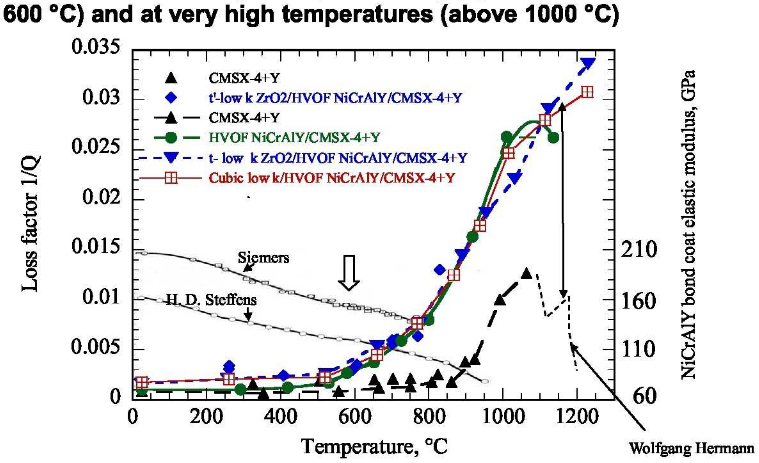
Damping Behavior of Thermal Barrier and Protective Coating Systems

— The coated systems showed significant damping improvements compared to the CMSX-4 substrate

— Ceramic thermal barrier helped improve damping at low temperatures (below 600 °C) and at very high temperatures (above 1000 °C)



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Conclusions

- Laser rig based high temperature damping rig demonstrated
- HVOF NiCrAlY bond coat significantly improved damping performance of turbine alloy systems
- Ceramic thermal barrier coatings showed slightly improved damping at lower temperature and very high temperatures compared to the metal bond coat-substrate system
- The coating damping temperature dependence corresponded to the materials Young's modulus changes
- Resonance peak shifts to higher frequency observed due to possible residual stresses that stiffened cantilever beam systems
- Coatings demonstrated a viable approach for vibration control and high cycle fatigue reduction for turbine blade systems

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14. ABSTRACT
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15. SUBJECT TERMS
Thermal barrier coating; NiCrAlY bond coat; Damping; Vibration; Resonance peak frequency; Loss factor; Young's modulus

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