Overview of Sulzer Metco Compressor and Turbine Abradable Technology

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The Secret of Staying Ahead
Overview

• Function of Abradable coatings
• Abradables for the compressor section
• Turbine abradables (high and low pressure section)
• Evaluation of abradables by incursion testing
• Summary
Function of Abradable Coatings

Outer Air Seal shown

casing segment
blade
blade root
disc

abrasive tip

abradable

abradable seal
Function of Abradable Coatings

Evolution of rotor clearance during rub interactions. (a) situation prior to rubbing, (b) rub interaction caused by main shaft bending and (c) situation and clearance after rub interaction. Top: ideal abradable interaction; bottom: non-abradable interaction with associated large increase in rotor clearance (yellow).
Modern Turbine (Aero, industrial gas & power, steam)

Compressor civil = subsonic (300-366 m/s), max 650°C  
Compressor military = supersonic (450 m/s), max 800°C

Turbines = 400-500 m/s,  
Inlet temp 1200-1450°C,  
Exhaust 520°C

Important abradable performance parameters:  
Good cutting performance over range of incursion conditions  
Temperature compatible  
Thermal shock & cycling  
Erosion resistant  
Oxidation resistant  
Robust & repeatable manufacturing & deposition processes
Abradables: Material Systems

- **Al-Si + polymer**
- **Al-Si + hBN**
- **Al-Si + graphite**
- **Nickel + graphite**
- **CoNiCrAlY + hBN + polymer** HR15Y 65-75
- **NiCrFeAl + hBN** HR15Y 52-64
- **NiCrAl + bentonite**: HR15Y 50-70
- **NiCrFeAl + hBN**: HR15Y 40-50
- **CoNiCrAlY + hBN + polymer**: HR15Y 30-50
- **Al-bronze + polymer**
- **YSZ - hBN + polymer**
- **DySZ - hBN + polymer**

Service Temperature/Cycle °C

- RT
- 200
- 325
- 450
- 650
- 750
- 900
- 1100

Components:
- **Fan**
- **Booster**
- **LPC**
- **HPC**
- **HPT**
Compressor Abradables

Aluminium matrix abradables

Metco 313NS  
Al-Si alloy / Graphite

Metco 320NS  
Al-Si alloy / (hexagonal) Boron Nitride

Metco 601NS  
Al-Si alloy / polyester

The dark phases are the graphite, BN and polyester.

Aluminium alloys: low shear strength (soft), cuts easily.

Fillers: promote coating removal (shear localisation)
Compressor Abradables

Nickel/graphite abradables

e.g. Metco 307NS-2, Durabrade 2223

Need for porosity to promote particle removal during cutting.
Compressor Abradables

Nickel-Cr-Al abradables
e.g. Durabrade 2313, Metco 314, Durabrade 2311, Metco 312

Ni-Cr-Al alloy with ceramic & porosity

Typically used vs. un-tipped Ni alloy blades commercial/military to 700°C.

Ni-Cr-Al: higher temperature capacity & harder particles.

Need for greater porosity to promote particle removal during cutting.
Compressor Abradables

Co-Ni-Cr-Al-Y alloy with hBN and polymer as porosity generator.

e.g. Metco 2042 – (Ti friendly) Metco 2043

Creep & oxidation resistant MCrAlY
To “weaken” structure:
  - High porosity (polyester) (35-40%)
  - Solid lubricant phase (hBN)
Recommend use of hard tipped blades @ hi temps
### Yttria stabilised Zirconia (YSZ)

To “weaken” structure & accommodate strains:
- Porosity & porosity defects
- Use of hard tipped blades (cBN)

Structure of a thermally sprayed YSZ thermal barrier coating with porosity and splat interfaces as desirable coating defects.
Abradables: cutting mechanisms

- **Softer matrices:***
  - "Shear" cutting mechanism
  - Al-Si + hBN
  - Al-Si + graphite
  - Al-bronze + polymer

- **Harder matrices:***
  - "Friable" cutting mechanism
  - NiCrAl + bentonite: HR15Y 50-70
  - NiCrFeAl + hBN: HR15Y 40-50
  - CoNiCrAlY + hBN + polymer: HR15Y 30-50
  - Al-bronze + polymer
  - YSZ + hBN + polymer
  - DySZ + hBN + polymer
Abradables: cutting mechanisms

- Softer matrices: "shear" cutting mechanism. Associated with abradables that have soft shearable matrix alloys, e.g., Al alloys.

- Harder matrices: "friable" cutting mechanism. Associated with abradables that have harder and require porosity to enable particle removal.

Schematic showing shear deformation & cutting abradability mechanism. Associated with abradables that have soft shearable matrix alloys, e.g., Al alloys.
Blade damage mechanisms

Blade wear e.g. abrasion  
Transfer to blade  
Tip heating, oxidation  
mixed: e.g. oxidation/ wear/ deformation/ cracking  
Titanium fire
Laby Seals: Steam Turbine Application

Nickel-Cr-Al abradables

Steam Turbine Labyrinth Seal
Ni-Cr-Al alloy with ceramic & porosity

Steam turbine sealing applications
Coating oxidation resistance important at high end temperatures e.g. 580°C

Worn abradable coating (section)

Worn seal strip
Abradables: Titanium blade compatibility

- Ti alloy blade compatible abradables
- Ti alloys ≤ 550°C
- Polymers
- Al-Si + polymer
- Al-Si + hBN
- Al-Si + graphite
- Nickel + graphite
- CoNiCrAlY + hBN + polymer HR15Y 65-75
- NiCrFeAl + hBN HR15Y 52-64
- NiCrAl + bentonite: HR15Y 50-70
- NiCrFeAl + hBN: HR15Y 40-50
- CoNiCrAlY+ hBN+ polymer: HR15Y 30-50
- Al-bronze + polymer
- YSZ - hBN + polymer
- DySZ - hBN + polymer
Abradables: Steel blade compatibility

- Stainless Steel Blade Compatible abradables

- Steels ≤ 550°C
  - Al-Si + hBN
  - Al-Si + graphite
  - Nickel + graphite

- NiCrAl+bentonite: HR15Y 50-70
- NiCrFeAl + hBN : HR15Y 40-50 : 52-64
- CoNiCrAlY+hBN+polymer : HR15Y 30-50 : 65-75
- Al-bronze + polymer
- Al-Si + polymer
- Polymers

- VYSZ - hBN + polymer
- DySZ - hBN + polymer

Service Temperature/Cycle °C

450
325
200
RT

Fan
Booster
LPC
HPC
HPT
Abradables: Ni superalloy blade compatibility

- Al-Si + polymer
- Al-Si + hBN
- Al-Si + graphite
- Nickel + graphite
- NiCrFeAl + hBN
- HR15Y 52-64
- NiCrAl + bentonite: HR15Y 50-70
- NiCrFeAl + hBN: HR15Y 40-50
- CoNiCrAlY + hBN + polymer: HR15Y 30-50
- Al-bronze + polymer
- YSZ - hBN + polymer
- DySZ - hBN + polymer
- cBN hard tipping
- & bare Ni superalloy: porosity ≥ ~30%
- Ni superalloy blade compatible abradables

Service Temperature/Cycle °C

RT 200 325 450 650 750 850 1100
Evaluation of Abradables

Test rig used to determine abradability of metallic and ceramic high temperature abradable coatings.
Sulzer Innotec, Winterthur, Switzerland.

**BLADE TIP VELOCITY:** 30-410 m/s

**RATE OF INCURSION:** 2 to 2000 µm/s

**SHROUD TEMPERATURE:** 20 to 1100°C
Evaluation of Abradables

- Burner
- Rotor
- Abradable coated specimen
- Incursion stage
- Casing
Blade tip seal tests using “dummy” or OEM blades

Knife or fin seal tests using knife specimens.
Tip width machined to suit.
Evaluation of Abradables

Incursion test conditions

<table>
<thead>
<tr>
<th>Incursion Rate (μm/s)</th>
<th>Tip Velocity (m/s)</th>
<th>X</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>500</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>500</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>5</td>
<td>250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>350</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>410</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Temperature: 1100°C
Blades: bare IN718

“Dummy” blade
GE Erosion test

General Electric specification E50TF121CL-A

Erodent feed hopper
Gas blast gun
Erosion tube
Specimen (20°)
Compressor Abradable Lay Out: Standard Aero Engine

- Fan
- Low Pressure Compressor
  - Metco 601
- High Pressure Compressor
  - Metco 320 or SM 2042
  - Metco 314 or SM 2043
- Abradable Coating
- Blading
  - Ti
  - Ni
  - Ti
  - Ni
  - Ti
  - Ni
  - Ti
Compressor Abradable Lay Out: Standard Gas Turbine

- SM2043
- M314 NS
- M301 NS
- M307 NS
- M320 NS
- Steel
- Ni alloy
- Titanium

Temperatures:
- SM2043: 650 °C
- M301 NS: 550 °C
- M307 NS: 450-500 °C
Titanium blade compatible abradables

Typical test outcome: SM2042 (as-sprayed with poly burnout) vs. TiAl6V4 blades at 550°C

Blade wear as % of total incursion into shroud. Measured using height change of blade and depth of wear track in shroud. Negative blade wear indicates transfer of shroud material to blade tip.
Titanium blade compatible abradables

Typical Ti alloy blade wear data vs. corresponding coating “GE” erosion resistance and vs. coating hardness for wide range of incursion conditions.

Note: all data is from coatings in the “as-sprayed” condition. In the case of SM2042, after polymer burnout treatment (550°C/5h).

SM2042 is the preferred choice for Ti blade compatibility in the LPC & HPC.

Blade wear as % of total incursion into shroud. Measured using height change of blade and depth of wear track in shroud. Negative blade wear indicates transfer of shroud material to blade tip.
## Titanium blade compatible abradables

<table>
<thead>
<tr>
<th>Product group</th>
<th>Corrosion</th>
<th>Blade wear (overall)</th>
<th>Material transfer to blade tip.</th>
<th>GE erosion resistance</th>
<th>Specific Track record</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlSi Polyester e.g M601</td>
<td>O</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>AlSi graphites</td>
<td>0</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>AlSi-hBN (M320)</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>NiCrAlFe-hBN (M301) (HR15Y 40-50)</td>
<td>+++</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>NiCoCrAlY-hBN-PE HR15Y 30-50 (SM2042)</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>++</td>
<td>+++</td>
</tr>
</tbody>
</table>

- **good**
- **better**
- **best**

8th International Charles Parsons Turbine Conference, Sept 2011/ Slide 28
Ni alloy blade compatible abradables

Typical Ni alloy (IN718) blade wear data vs. coating hardness and vs "GE erosion resistance" for wide range of incursion conditions.

Note: all data is from coatings in the “as-sprayed” condition. In the case of SM2043, after polymer burnout treatment (550 °C/5h).

SM2043 & M314/D2311 are the preferred choices.

Blade wear as % of total incursion into shroud. Measured using height change of blade and depth of wear track in shroud. Negative blade wear indicates transfer of shroud material to blade tip.
Ni alloy blade compatible abradables

Typical test outcome: M314 (as-sprayed) vs. IN718 blades at 500°C

<table>
<thead>
<tr>
<th>Incursion Rate (μm)</th>
<th>Blade Tip Velocity (m/s)</th>
<th>Wear map M314</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>250</td>
<td>9.8%</td>
</tr>
<tr>
<td></td>
<td>350</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>410</td>
<td>1.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.1%</td>
</tr>
</tbody>
</table>

% Blade wear
Temperature: 500°C
Ni alloy blade compatible abradables

Typical test outcome: SM2043 (after polymer burnout) vs. IN718 blades at 750°C

% Blade wear

<table>
<thead>
<tr>
<th>Temperature 750°C</th>
<th>SM2043 SIT standard vs. IN718 0.7 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.5%</td>
<td>9.0%</td>
</tr>
<tr>
<td>-1.4%</td>
<td>-2.5%</td>
</tr>
<tr>
<td>-7.8%</td>
<td>-7.8%</td>
</tr>
</tbody>
</table>

SM2043 SIT standard vs. IN718, 0.7 mm
Turbine Abradables

TURBINE SIDE ABRADABLES:

LPT: large radial displacements/ incursions
Honeycomb seals vs. shrouded blades. Low spatial density, thick, easily cut. MCrAlYs (porous) up to 850°C – application dependent

HPT: small displacements, higher temperatures.
Porous ceramic abradables with good oxidation resistance.
Turbine Abradables

Ideal would be to have bare metal blades which are not damaged by incursion.

Effect of coarse porosity & alternative Zirconia stabilisers investigated.

High pressure turbine sealing arrangement using ceramic abradable, blade abrasive tipping and active clearance control.
Turbine Abradables

Effect of coarse porosity & Yttria vs. Dysprosia Zirconia stabilisers on thermal shock & abradability investigated.

Yttria stabilised (YSZ)  
24% porosity

Yttria stabilised (YSZ)  
43% porosity

Dysprosia stabilised (DySZ)  
30% porosity

Microstructures of ceramic abradable coatings having various levels of coarse porosity introduced by a fugitive filler phase. 
(a) and (b) yttria stabilized zirconia ceramic matrix, (c) dysprosia stabilized zirconia.
Turbine Abradables

Improved thermal shock resistance of DySZ (50 -1150 °C cycle)

Thermal shock life of 1000 µm thick ceramic abradable coatings as a function of coating porosity and chemical composition.
Evaluation of Abradables

Dense CoNiCrAlY: poor high temperature performance (sintering & oxidation)

Abradability results for a dense CoNiCrAlY coating tested at 1100 °C under rig set conditions as indicated. Blade wear as a percentage of total incursion.
Evaluation of Abradables

Yttria stabilised (YSZ): 24% porosity

Abradability results for a porous (24%) YSZ ceramic abradable at 1100 °C under rig set conditions as indicated. Blade wear as a percentage of total incursion.
Abradability results for a porous (43%) YSZ ceramic abradable at 1100 °C under rig set conditions as indicated. Blade wear as a percentage of total incursion.
Evaluation of Abradables

Dysprosia stabilised (YSZ): 30% porosity

Abradability results for a porous (30%) DySZ ceramic abaradable at 1100 °C under rig set conditions as indicated. Blade wear as a percentage of total incursion.
## Summary

### Compressor

Ti blade compatibility using dense Al based abradables with low shear strength and dislocator/solid lubricant phases.

Higher temperatures: porous Ni-Cr-Al coatings vs. Ni blades. Also steam turbine use.

### Turbine

Porous MCrAlY's good up to approx. 850°C vs. bare or cBN tipped Ni alloy blades. Poor behaviour at higher temperatures (sintering & oxidation).

Ceramic YSZ/DySZ abradables: cut well vs. cBN tipped blades.
Higher porosities required for bare blade compatibility.
Improved thermal shock resistance with use of Dysprosia stabiliser.