CERAMIC BRUSH SEALS DEVELOPMENT

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CERAMIC BRUSH SEALS

METALLIC BRUSH SEALS

A. BENEFITS OVER CURRENT SEALS

1. HIGHER EFFICIENCY
2. ABLE TO WITHSTAND SHAFT EXCURSIONS
3. ABLE TO TAKE UP BUILD TOLERANCES
4. REDUCE SECONDARY FLOW LOSSES

B. LIMITATIONS

1. TEMPERATURE
2. LIFE/WEAR
3. OXIDATION
CERAMIC

A. HIGHER TEMPERATURE

B. LOWER WEAR

C. INTERFERENCE FIT BENEFIT

TECHNETICS TEST RIG
2450/36/0.003

PRESSURE DROP (bar)

CLEARANCE (in)

□ 0.3 SCFM △ 0.6 SCFM ○ 0.8 SCFM ▲ 1.0 SCFM × 1.2 SCFM ▼ 1.4 SCFM
R & D

PURPOSE:

A. INVESTIGATE AND SHOW FEASIBILITY

B. BUILD AND INITIAL TEST OF CERAMIC BRUSH SEAL

TECHNICAL OBJECTIVES:

A. IDENTIFY MATERIALS

B. DEMONSTRATE MANUFACTURABILITY

C. TEST SEAL INTEGRITY

MATERIALS:

INDUSTRY STANDARD MATERIALS

CERAMIC FIBER

A. NEEDS

1. SIZE (.002"-.006")

2. FLEXIBLE

3. QUALITY

4. PRICE

B. AVAILABLE

1. ALUMINUM OXIDE

2. SILICON CARBIDE

3. TITANIUM DIBORIDE

4. QUARTZ
AVAILABLE CERAMIC BRISTLE MATERIALS

<table>
<thead>
<tr>
<th>Material</th>
<th>AL₂O₃</th>
<th>SiC</th>
<th>SiO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Crystal</td>
<td>.005</td>
<td>.0056/.0031</td>
<td>.004</td>
</tr>
<tr>
<td>CVD Filament</td>
<td>60</td>
<td>58</td>
<td>10</td>
</tr>
<tr>
<td>Fiber Optics</td>
<td>--</td>
<td>500</td>
<td>--</td>
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</table>

<table>
<thead>
<tr>
<th>Property</th>
<th>AL₂O₃</th>
<th>SiC</th>
<th>SiO₂</th>
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</thead>
<tbody>
<tr>
<td>Size</td>
<td>.005</td>
<td>.0056/.0031</td>
<td>.004</td>
</tr>
<tr>
<td>Modulus (MsI)</td>
<td>60</td>
<td>58</td>
<td>10</td>
</tr>
<tr>
<td>Tensile (ksi)</td>
<td>--</td>
<td>500</td>
<td>--</td>
</tr>
<tr>
<td>Hardness (Mohs)</td>
<td>9</td>
<td>2040-4487 KG/mm²</td>
<td>7-8</td>
</tr>
<tr>
<td>Bend Radius (in)</td>
<td>5/16</td>
<td>13/64 / 7/64</td>
<td>1</td>
</tr>
<tr>
<td>Operating Temp (°F)</td>
<td>3632</td>
<td>BELOW 1800</td>
<td>2000</td>
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</table>

HAYNES 25
COBALT ALLOY

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Modulus (MsI)</td>
<td>25.9  @ 1300°F</td>
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<tr>
<td>Tensile (ksi)</td>
<td>145-165</td>
</tr>
<tr>
<td>Operating Temp (°F)</td>
<td>1200-1400°F</td>
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</table>

MANUFACTURING

A. ALL CERAMIC

1. BRISTLES CAST IN PLACE
2. BRISTLES PRESSED IN PLACE
3. POST FIRING BRISTLE PLACEMENT

B. BRAZED ASSEMBLY

1. METAL BACKING/CERAMIC FIBER
2. PLATING PROCESS
3. DIRECT BRAZE PROCESS
BRAZED ASSEMBLY DEVELOPMENT

A. BRAZE ALLOYS
   1. DUCTILE
   2. HIGH TEMPERATURE
   3. OXIDATION RESISTANT

B. BRAZE METHOD (WETTING OF CERAMIC)
   1. MOLY-MANGANESE
   2. ACTIVE METALS
      i.e., Ti, Zr, V, etc. (ABA)
   3. ACTIVE METAL HYDRIDES
      i.e., TiH₂, ZrH₂, etc.

CONTROLLING BRAZE FLOW

A. EXCESSIVE WICKING
   1. ABA ALLOYS (i.e., TiCuSil)
   2. ACTIVE METAL BRAZING

B. LIMIT FLOW USING BRAZE BARRIERS (STOP-OFF)

C. ACTIVE METAL HYDRIDE PROCESS
   1. ONE STEP
   2. EASY APPLICATION
   3. ALLOWS FOR BATCH PROCESSING
   4. BRAZE ONLY WHERE ACTIVE METAL IS DEPOSITED
## BRAZE ALLOYS

<table>
<thead>
<tr>
<th>NAME</th>
<th>COMPOSITION</th>
<th>LIQUIDUS (°F)</th>
<th>SOLIDUS (°F)</th>
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<tbody>
<tr>
<td>CUSIL</td>
<td>AG - 72, CU - 28</td>
<td>1436</td>
<td>1436</td>
</tr>
<tr>
<td>TICUSIL</td>
<td>TI - 4.5, CU - 26.7, AG - 68.8</td>
<td>1562</td>
<td>1526</td>
</tr>
<tr>
<td>50% GOLD, 50% COPPER</td>
<td>AU - 50, CU - 50</td>
<td>1778</td>
<td>1751</td>
</tr>
<tr>
<td>PALMANSIL 5</td>
<td>AG - 75, PD - 20, MN - 5</td>
<td>1962</td>
<td>1846</td>
</tr>
<tr>
<td>NIORO (AMS-4787: BAU-4)</td>
<td>AU - 82, NI - 18</td>
<td>1742</td>
<td>1742</td>
</tr>
<tr>
<td>PALNIRO 1 (AMS-4784)</td>
<td>AU - 50, PD - 25, NI - 25</td>
<td>2050</td>
<td>2016</td>
</tr>
<tr>
<td>PALNIRO 7 (AMS-4786)</td>
<td>AU - 70, PD - 8, NI - 22</td>
<td>1899</td>
<td>1841</td>
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</tbody>
</table>

### FIBER SELECTION

1. QUARTZ (SiO₂)
2. ALUMINUM OXIDE (Al₂O₃)
3. SILICON CARBIDE (SiC)

### CONSIDERATIONS

1. AVAILABILITY (Size/Price)
2. BRAZE WETTING
3. USE TEMPERATURE
4. INTEGRITY OF ASSEMBLY
BRAZE RESULTS

1. ALUMINUM OXIDE
2. QUARTZ
3. SILICON CARBIDE/Ni
4. SILICON CARBIDE/CuSil
5. SILICON CARBIDE/Au-Cu
6. SILICON CARBIDE/PALMANSIL

CURRENT CONFIGURATION

1. SiC/CuSil to 1200°F
2. SiC/Au-Cu to 1600°F

PRELIMINARY TEST RESULTS

1. LOW WEAR
2. SAME PERFORMANCE AS METALLICS
3. HIGH FRICTIONAL HEATING
CURRENT WORK

1. HIGHER TEMPERATURE FIBERS
2. HIGHER TEMPERATURE BRAZE ALLOYS
3. OTHER ACTIVE METAL HYDRIDES
4. IMPROVING PROCESS
5. TESTING

FUTURE WORK

1. ROTOR COATING
2. FURTHER TESTING
3. ALL-CERAMIC BRUSH SEAL
Figure 1
Sic/Palniro 7 Braze Sample

Figure 2
Nickel Attack on SiC Fiber
Figure 3
Cusil/Active Metal Wickng

Figure 4
Active Metal Hydride on SiC Fiber
Figure 5
Active Metal Hydride Deposited on SiC Fiber
Figure 6
SiC Fiber Braze Sample
Cusil/Active Metal Hydride

Figure 7
Improper Active Metal Hydride Application Result
Figure 8
Aluminum Oxide/50% Gold 50% Copper Braze Sample
Figure 9
SiC Fiber/Active Metal Hydride
Active Metal Flow
Figure 10
Aluminum Oxide/50% Gold 50% Copper
Dark Field

Figure 11
Aluminum Oxide/50% Gold 50% Copper
Light Field
Figure 12
SiC/Cusil/Titanium Hydride - Brush Seal

Figure 13
Brazed SiC Fiber/Metal Backing - Brush Seal
Figure 14
Cracking in Ceramic
Ceramic Powder Pressed Around Fiber
Figure 15
All-Ceramic Brush Seal Concept
Fiber Placed After Firing

Figure 16
Ceramic Ring with Aluminum Oxide Fiber