Review of Silicon Coatings Capabilities and Applications

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Overview

• Background:
  – About silicon coatings, CVD process and capabilities

• Comparative Testing, Benefits, Applications
  • Inertness and Sulfur
  • Corrosion resistance
  • Anti-coking
  • Purity/Ultra high vacuum

• Questions
Why use coatings?

- Reduce loss of active compounds
  - Avoid false negatives
  - Sulfur compounds quickly lost without coatings
  - Improved sample transfer
  - Sample stable from field to lab
  - Avoid loss of sample due to adsorption
    - Sulfur
    - Mercury
  - Immediate response during process changes
  - Creates savings when used in feedback monitors
  - Reduces moisture contamination effects
No Loss during storage!

- Reduces adsorption effects
- Improves analytical reliability
- Faster cycle times and
- increased accuracy
  - 17 ppbv H₂S Containment in 500ml Cylinders

![Graph showing RRF (H₂S to DMS) over time for coated and uncoated steel cylinders. The graph indicates a lower rate of decrease for coated/functionalized steel cylinders compared to uncoated steel cylinders.](image)
No transfer Loss!
Reduce sample adsorption by 98%
Improve Process Response
Improve Yield

Adsorption of CH$_3$SH on different tubings

- Sample 1: Standard RVS weldless
- Sample 2: TrueTube EP
- Sample 3: TrueTube EPS
Mercury stable during storage!

Average Mercury Response Comparison of Stainless Steel vs. Silicon Functionalized Surfaces

- Untreated cylinders (n=2)
- Functionalized cylinders (n=2)
SilcoNert 2000 Advantages

• Most inert coating available
• High Temperature
• Durable/flexible/high tolerance
• Enable testing in rugged environment
• Allows user to modify surface without redesign/remanufacture
## SilcoNert 2000 & Dursan Applications

<table>
<thead>
<tr>
<th>Process Description</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur contaminants, CO2</td>
<td>NOx and SOx from coal plants</td>
</tr>
<tr>
<td>Sulfur emissions, refinery flares</td>
<td>Mercury emissions, coal and gas</td>
</tr>
<tr>
<td>Ethylene/propylene feedstock testing</td>
<td>Water quality testing, headspace + purge and trap</td>
</tr>
<tr>
<td>Exhaust, stack emissions, ammonia</td>
<td>Toxic organics, whole air monitoring</td>
</tr>
<tr>
<td>Defense security, chemical warfare agents, explosives</td>
<td>Low moisture sampling and control</td>
</tr>
<tr>
<td>GC testing of active compounds</td>
<td>Oil and gas, downhole, transport and refinery sampling</td>
</tr>
</tbody>
</table>
Why use coatings?

- Corrosion resistance
  - Prolong component life
    - Salt water environments (platforms)
    - Chemical process industry
    - Refining
  - Save money by avoiding use of chrome/moly or high-nickel alloys for:
    - Chloride exposure
    - Produced water
    - Instrumentation
  - Some coatings offer both corrosion and inertness
2 Corrosion Resistant Coatings

- **Silcolloy 1000**
  - Silicon, up to \( \frac{1}{2} \) um thick
  - Semiconductor, purity

- **Dursan**
  - Silicon, carbon, oxygen, 1/2um + thick
  - High durability, greater corrosion resistance
# Wear Resistance Comparison

<table>
<thead>
<tr>
<th>Pin on Disc; 2.0N</th>
<th>316 SS</th>
<th>Silicon</th>
<th>Carboxysilane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wear rate ((x10^{-5} \text{mm}^3/\text{N m}))</td>
<td>13.810</td>
<td>15.344</td>
<td>6.129</td>
</tr>
<tr>
<td>Improvement Factor over Stainless Steel</td>
<td>---</td>
<td>0.9 X</td>
<td>2 X</td>
</tr>
</tbody>
</table>

- **CSM Instruments**
- **Tribometer 18-343** used to measure surface wear resistance
# Acid Corrosion Resistance

- **ASTM G31 Guidelines:** 6M HCl; 24hr; 23°C

<table>
<thead>
<tr>
<th></th>
<th>316L SS</th>
<th>Silcolloy</th>
<th>Dursan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MPY</strong></td>
<td>181.98</td>
<td>4.32</td>
<td>0.44</td>
</tr>
<tr>
<td><strong>Improvement Factor</strong> over 316L stainless</td>
<td>---</td>
<td>42</td>
<td>411</td>
</tr>
</tbody>
</table>

![Image of test tubes after exposure](image-url)
## Comparative Corrosion Resistance

- **10% $H_2SO_4$; 24hr; 22°C**

<table>
<thead>
<tr>
<th></th>
<th>ASTM G31</th>
<th>316L SS</th>
<th>Silcolloy</th>
<th>Dursan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MPY</strong></td>
<td>22.35</td>
<td>2.52</td>
<td>2.42</td>
<td></td>
</tr>
<tr>
<td><strong>Improvement Factor</strong></td>
<td>---</td>
<td>8.9</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td><strong>over 316L stainless</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Base Corrosion Resistance

- **ASTM G31 Guidelines:** 1M KOH; 24hr; 22°C

<table>
<thead>
<tr>
<th></th>
<th>316L SS</th>
<th>Silcolloy</th>
<th>Dursan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MPY</strong></td>
<td>0</td>
<td>3.40</td>
<td>0.01</td>
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<tr>
<td><strong>Improvement Factor Over a-Silicon</strong></td>
<td>--</td>
<td>--</td>
<td>261</td>
</tr>
</tbody>
</table>
Chemical Inertness

H₂S Stability: Dursan vs. Stainless Steel

50ppmv, 300cc cylinder

<table>
<thead>
<tr>
<th>Time</th>
<th>Stainless Steel</th>
<th>Dursan</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>25 hours</td>
<td>19</td>
<td>98</td>
</tr>
<tr>
<td>50 hours</td>
<td>10</td>
<td>96.6</td>
</tr>
<tr>
<td>75 hours</td>
<td>4</td>
<td>98.3</td>
</tr>
</tbody>
</table>

Uncoated Cylinder

Dursan coated
# Hydrophobic Properties

<table>
<thead>
<tr>
<th></th>
<th>304 SS</th>
<th>Silcolloy 1000</th>
<th>SilcoNert 2000</th>
<th>Dursan</th>
<th>PTFE Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advancing</strong></td>
<td>36.0</td>
<td>53.6</td>
<td>87.3</td>
<td>105.5</td>
<td>125.4</td>
</tr>
<tr>
<td><strong>Receding</strong></td>
<td>5.3</td>
<td>19.6</td>
<td>51.5</td>
<td>85.3</td>
<td>84</td>
</tr>
</tbody>
</table>

- **Krüss K100 Tensiometer**
- Testing on **304 SS**
- **¼” OD tubing**

![Images of droplets on different materials](image-url)
Materials Cost Comparison

80% estimated life cycle cost savings: a-Si vs. HP Alloy
Dursan Advantages

• Significantly improves material performance beyond exotic alloys
• Improve SS acidic and basic corrosion resistance
• 2X improvement in wear resistance
• Inert, non reactive, non-adsorptive
• Withstands temperature up to 450°C
• Hydrophobicity and oleophobicity similar to Teflon surface
Coating Advantages

• Longer Life:
  – Extend lifetimes of equipment exposed to corrosive environments
• Low Cost Material Option
• Protection:
  – Protection of high value equipment
• Inert:
  – Provide enhanced corrosion resistance to analytical equipment
  – Maintain inert sample pathway
  – More inert than Inconel, Hastelloy, or glass. Ideal for 10ppm levels or higher
• High Temperature:
  – High temperature stability up to 1000°C
Silcolloy & Dursan Applications

- Process streams
- Process sampling/Refinery
- Continuous Emissions Monitoring Equipment
- Automotive Exhaust
- Semiconductor corrosion (Silcolloy)
- Fasteners in Offshore/Marine, Drill bits
- Off-shore drilling platform equipment
- Produced water management
Why use coatings?

• Reduce coking and carbon fouling
• Extend maintenance cycle
• Improve equipment efficiency
• Reduce emissions
• Prevent system failures due to fouling
Why use coatings?

• High Purity
  – Reduce system contamination
  – Reduce moisture effects
  – Eliminate ion contamination
  – Reduce vacuum pump down time
Conclusion

• Coatings are available for a wide range of applications

• Optimize based on desired property
  • Inertness
  • Corrosion Resistance
  • Anti-Coking
  • Purity

• Ultimate benefit is superior performance
  – Analytical results
  – Extend life
  – Reduce labor and capital cost
  – Improve efficiency
  – Optimize material selection and cost performance