An Alternative Method for Surface Cleanliness Characterization

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Introduction
Background on Surface Particulate Cleanliness Characterization

• Standard Characterization Technique: Tapelifts
  – Industry standard (ASTM E1216)
  – Particle counting on tape is complicated by background artifacts (e.g. air bubbles in adhesive, peeling marks, etc.)

• An Alternative Approach: Gel-Pak®
  – Repurposed from other applications (e.g., device handling)
  – Comparable performance to heritage 3M 480 tape
    • Based on lab and flight hardware testing
  – Heritage on previous missions (New Horizons¹)

Overview
Evaluating Gel-Pak® as a Surface Sampling Alternative

• Sampling Performance
  – Compare Gel-Pak® against industry standard methodology

• Cross-Contamination Risks
  – Assess Gel-Pak® contamination potential with outgassing testing

• Sampling Processing and Analysis:
  – Assess imaging and particle counting on Gel-Pak® samples

Aerospace in-house testing performed to compare Gel-Pak® and 3M 480 tape
Sampling Performance
Testing Liftoff Efficiency
3M 480 vs Gel-Pak®

1) Disperse particles over test and witness surfaces
   - *Use spherical glass beads (40 and 110 μm)*
   - *Allows differentiation from other particles (dust, fibers, etc.)*

2) Apply tape and Gel-Pak® to test surface
   - *Sampling of adjacent areas*

3) Particle Counting
   - *Compare tape and Gel-Pak® to witness surfaces (WS)*
   - *Two WS used to assess particle distribution uniformity*
Comparing 3M 480 Tape and Gel-Pak®
In-house Lab Testing: Results

Good agreement between Gel-Pak® and 3M 480 sampling on a hard surface
Cross-Contamination Assessment
Cross-Contamination Risk Assessment
Evaluating Outgassing from Gel-Pak® Sampling

• **Step 1:** Simulate Gel-Pak® sampling on clean surface
  – *Use pristine, UHV aluminum foil*
    • One for Gel-Pak® sampling
    • One for control

**Simulating Gel-Pak® Sampling**

[Images of Gel stamping, Gel stamped 8 times, and foil rolled up for outgassing experiment]
Cross-Contamination Risk Assessment
Evaluating Outgassing from Gel-Pak® Sampling

• **Step 2:** Measure outgassing from sampled surfaces
  – ASTM E1559 outgassing test

Aerospace In-House
Testing Chamber

Sample allowed to outgas for 24 hours:
• 32°C for 2 hours
• 125°C for 22 hours

Outgassed products collected on CQCMs at:
• 25°C, 12°C, and -73°C

Collected species analyzed with mass spectrometer
• Can determine type of contaminant (e.g. silicones)

Outgassing test assessing Gel-Pak® contamination potential
Cross-Contamination Risk Assessment

Results

- Outgassing rates measured by QCM (Quartz Crystal Microbalance)
  - Negligible outgassing from control and Gel-Pak® sampled foil

<table>
<thead>
<tr>
<th>Temp.</th>
<th>Outgassed Mass (mg / ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25°C</td>
<td>0.0</td>
</tr>
<tr>
<td>12°C</td>
<td>0.0</td>
</tr>
<tr>
<td>-73°C</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Negligible outgassing after Gel-Pak® sampling
Particle Counting and Analysis
**Image Analysis**

*Comparing backgrounds*

<table>
<thead>
<tr>
<th>3M 480 Tape</th>
<th>Gel-Pak®</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image of 3M 480 Tape" /></td>
<td><img src="image2.png" alt="Image of Gel-Pak®" /></td>
</tr>
</tbody>
</table>

Smooth background of Gel-Pak® enables simple image analysis
Sample Analysis
Imaging and Processing

• Automated sample imaging
  – Using microscope with motorized stage
  – Covers full sample

• Stitches tiles together
  – Outputs single image

• Image Corrections:
  – Relative position
  – Background
  – Blending

• Fully Automated
Sample Analysis
Imaging and Processing

Place GelPak on microscope stage
Image Analysis

In-House Graphical User Interface Tool for Automated Analysis

File Viewer

Particle Counting
- Find all particles by pixel thresholding
- Filter by size, shape, etc.

Particle Statistics
- Compute PAC
- Plot particle counts

Full Image with particles circled

Particle Size (μm)

Counts

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125

131 36 40 15 5 1 1 2 0

1 cm
A Closer Look at the Gel-Pak® Surface

Automated Particle Counting

• Smooth background makes particles stand out
• Automated algorithm can identify particles
  – Filters based on size, shape, color, etc. can isolate particles of interest

Clean Gel-Pak®

Glass Beads on Gel-Pak®

*Identified glass beads circled in red
*Other particles circled in blue

Good contrast of particles from background for automated counting
Conclusions

• Reasonable agreement in surface cleanliness measurements using Gel-Pak® and 3M 480 tape

• Negligible cross contamination from Gel-Pak® sampling

• Gel-Pak® simplifies sample processing and analysis
  – Enables analysis automation, enhancing counting accuracy

• Future Work:
  – Aerospace is looking for partnership in further assessing Gel-Pak® and its application in flight programs
  – Investigation of cleanliness sampling on non-flat surfaces in work

Gel-Pak® is a promising for surface cleanliness characterization
Acknowledgements

• Aerospace Technical Investment Program

• Dr. Ming (Mike) Lee
  – Aerospace Program Office (Systems Dynamics and Environments)
Backup
Other Advantages

Improvements with Gel-Pak®

• No sample preparation required
  – Tape segments must be carefully peeled from roll
  – Can optionally perform pre-counting

• Simplified sample handling and transport
  – Rigid tray makes handling easy
  – Gel-Pak® was designed for device handling, and can be easily transported

• Easier and more consistent surface sampling
  – Tape must be slowly and steadily peeled from surface to avoid adhesive artifacts
  – Rigid Gel-Pak® design simplifies uniform application of pressure when sampling
  – Reduces user error and variability

• Particles may be easily transferred for chemical analysis (e.g. SEM/EDX)

Gel-Pak® simplifies sample preparation, collection, handling, and transport
**Liftoff Efficiency Image Analysis**

*Only circular particles are included*

- **Particle sampling efficiency:**
  - The ratio of glass bead density on the Test Surface to that on the Witness Surfaces

- **Particle counting implemented via in-house MATLAB code**
  - All circles are automatically detected
  - Particle density per unit area is calculated
  - Imaging analysis on 3M 480 tape is possible using idealized spherical shape of glass beads in dark field

*Particle sampling efficiency calculation is done by automatic imaging analysis*
Contamination Effects, Research & Testing Chamber
CERT Chamber

• ASTM E1559 testing capability
  – Base pressure in the low $10^{-9}$ Torr
  – Effusion cell with temperature range from 0ºC to 212ºC
  – 4 CQCMs
  – Two Extrel mass spectrometers

• Other custom features
  – Deuterium lamp for UV exposure testing
  – Microscope and light scatter measurements to test droplet formation on surfaces
  – Vis-NIR spectrometer for spectral transmission measurements

General purpose test facility for space material contamination effects
**Gel-Pak® Sampled Al Foil Outgassing Results**

TGA on -73°C CQCM

Negligible difference between Gel-Pak®-sampled and control surfaces