Sample Sealing Approaches for Mars Sample Return Caching

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Overview

- **Objective:** Investigate sealing methods for encapsulating samples in 1 cm diameter thin-walled sample tubes applicable to future proposed Mars Sample Return
- **Techniques implemented include:** a spring energized Teflon sleeve plug, a crimped tube seal, a heat-activated shape memory alloy plug, a shape memory alloy activated cap, a solder-based plug, and a solder-based cap
Proposed Mars Sample Return Campaign

1. Caching Rover
2. Lander
3. Orbiter
4. Handling Facility

Sample Canister
Mars Ascent Vehicle
Fetch Rover
Earth Entry Vehicle
Orbiting Sample Container
Integrated Mars Sample Acquisition and Handling (IMSAH)

1. Caching Subsystem
   - (sample canister)
   - (19x sample tubes)

2. Tool Deployment Device
   - (5-DOF robotic arm)

3. Sample Acquisition Tool
   - (core sample) Ø1 cm
   - (hollow center) 5 cm

(coring drill)
(coring bit)
SHEC (Sample Handling, Encapsulation and Containerization) Concept

- Sample carousel
- Measurement/sealing station
- Bit carousel
- Bit chambers with coring bits
- Removed cache canister
- Sample tube
- Plug
- Core sample
- Gripping feature
- Spare tubes
- Cache canister with sample tubes
- Plugs
- Transfer arm
- Bit changeout port
Sample Integrity

**Containment**
- Containerization
- Leak rate

**Contamination and Chemical/Mineral Integrity**
- Container/Sample Interaction
  - Material Contamination
  - Forward Contamination
  - Cross Contamination

**Chemical/Mineral/Physical Integrity**
- Temperature
- Pressure
- Radiation
- Magnetic Fields
- Shock
- Absorption

*** Sample integrity issues being addressed in this task that deal directly with the sample tube, seal, and sealing operation boxed in red.
Commercial Sealing Techniques

Sample Sealing Approaches for Mars Sample Return Caching

Mechanical

Pharmaceutical

Fluid, Thermal, Adhesive

Injectable Media

Differential Thermal Expansion

Metallurgical

Soldering/Brazing

Welding

(Includes Vacuum Environments and Petroleum)
Sealing Techniques in Research

Sample Sealing Approaches for Mars Sample Return Caching

- Soft Metal Cup (Kong et al., 2000)
- Serial Radial Seal
- Cap with Brazed Seal Using Induction Heating
- Cap with Knife Edge Sealing and Top Heating for Soldering
- Plug with Radial Solder Seal (Backes et al., 2009)
- Explosive Welding (Dolgin et al., 2000)
- Teflon Cap (JPL Athena Study, ~2000)

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Sealing Techniques in Previous Missions

Apollo

Figure 1. Close-up view of Apollo Sample Return Containers in Various Configurations. Upper left, a closed ALSRC (NASA Photograph S72-37196). Upper right, an ALSRC loaded with clean sample containers and other hardware (NASA Photograph S70-52550). Lower left, ALSRC after being opened on return to the Lunar Receiving Laboratory after being loaded on the lunar surface by the Apollo 16 crew; (NASA Photograph S72-36984).

Stardust

Figure 3. Close-up view of Stardust’s flight hardware Sample Return Capsule with integrated sample tray assembly (STA) and aluminum canister housing.

Genesis

Figure 2a. Close-up view Genesis’ flight hardware Sample Return Capsule with integrated Science Canister.

Hayabusa

Figure 2b. Close-up view Genesis’ flight hardware Science Canister.

Double Viton O-rings - seals sample catcher in sample container

Figure 4. Close-up view of Hayabusa sample container.
Design Considerations

• **Power**
  – The sealing device must operate within the power budget of the rover.

• **Environment**
  – The Martian temperatures assumed for this research activity are -130°C during a Martian winter night up to 40°C during a Martian summer day. The pressure on Mars is assumed to be between 0.2666 to 1.599 kPa.

• **Dust Tolerance**
  – The seals must be dust resistant since the sample tube surfaces would be susceptible to dust upon sample acquisition.

• **Shock and Vibration**
  – The seals must be robust enough to remain intact during vibration seen from rover driving and rover operation.

• **Sample Integrity**
  – Sample integrity must be considered, which would include limiting the potential of damaging the sample due to significant application of heat, pressure, acceleration, impact, magnetic fields, radiation, chemical interactions, and contamination.

• **Hermeticity**
  – To maximize science return on sample return missions, in-situ technologies must be developed to maintain the physical integrity of the sample from acquisition, encapsulation and containment such that volatiles in solid samples, and evolved gases resulting from the sublimation would be retained.

• **Packaging**
  – Considerations must be made to limit the amount of mass and volume required for the seals and sealing device.

• **Risk**
  – Low failure rate for a seal and sealing device is desirable for maximum science return.

• **Autonomy**
  – The sealing process must be executable in-situ autonomously with limited ground-in-the-loop control.
Candidate Sealing Methods

- Spring Energized Teflon Plug
- Solder Cap
- Shape Memory Alloy Cap
- Cold Weld
- Solder Plug
- Shape Memory Alloy Plug

- 316 Stainless Steel tube
- 316 Stainless Steel with Nickel plate and Indium coating tube
- 316 Stainless Steel tube
Spring Energized Teflon Plug

Overview

Application

Prototype
Crimped Tube

Overview/Application

Crimped end cold welds to form hermetic seal

Tube wall compressed

Prototype
Solder Plug

Overview

Application

Prototype
Shape Memory Alloy Cap

Overview

Prototype

Application

1. Cap pressed onto tube
2. Cap left in tube
3. Cap pressed onto heating element
4. Heating element contracts shape memory alloy

Shrunk ring swages cap with teeth onto tube to form seal

Sample tube (Stainless steel 316)
Core sample

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Shape Memory Alloy Plug

Overview

Application

Prototype
Seal Testing

• For each sealing method, three of the test pieces will be sealed in a clean tube, and three will be sealed in a tube covered with a layer of Martian simulant dust.

  1. Helium leak test
  2. 1 cycle down to -130 C for 15 min, up to 40 C for 15 min
  3. Repeat He leak test
  4. 4 more cycles down to -130 C for 15 min, up to 40 C for 15 min
  5. Repeat He leak test
  6. Destructive testing with Instron to measure plug retention force
Thermal Analysis of Sealing Process

- Multiphysics modeling of SMA plug, sample, and sample tube to study heating during sealing process
Contact heating 200°C till 3rd fin over 100°C including Martian CO2 in the gaps

Gap between the fin and the tube 0.1 mm
Gap between the rock and the tube 0.25 mm
Sample Sealing Approaches for Mars Sample Return Caching

Contact heating 200°C till 3rd fin over 100°C including Martian CO2 in the gaps (Conductivity of 0.016 W/m K)

Rock_centr: Temperature at center of the rock up surface. The maximum is 32.9 °C. 
Rock_Edge: Temperature at edge of the rock up surface. The maximum is 31.5 °C. 

Total heating energy: 270 J
Initial Testing of SMA Plug with Mars Simulant Dust

Application of Simulant Dust

Sealing with Heat Gun
Initial Helium Leak Testing of SMA Plug

After initial sealing:

<table>
<thead>
<tr>
<th>CLEAN TUBE</th>
<th>Leak Rate:</th>
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<tbody>
<tr>
<td></td>
<td>$0.2 \times 10^{-9}$ cc/sec</td>
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</table>

<table>
<thead>
<tr>
<th>DIRTY TUBE</th>
<th>Leak Rate:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$2.2 \times 10^{-5}$ cc/sec</td>
</tr>
</tbody>
</table>

After cycling once down to $132.7^\circ$ C for 15 min and back up to room temperature:

<table>
<thead>
<tr>
<th>CLEAN TUBE</th>
<th>Leak Rate:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$0.6 \times 10^{-9}$ cc/sec</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DIRTY TUBE</th>
<th>Leak Rate:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\approx 2 \times 10^{-4}$ cc/sec</td>
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NOTE: Dirty tube expressed severe leakage after cooldown, and actual reading fluctuated between $0.2 \times 10^{-7}$ and $8 \times 10^{-8}$...reading was unstable.
• Sealing methods for encapsulating samples in 1 cm diameter thin-walled sample tubes applicable to future proposed Mars Sample Return missions were investigated.

• Techniques implemented include a spring energized Teflon sleeve plug, a crimped tube seal, a heat-activated shape memory alloy plug, a shape memory alloy activated cap, a solder-based plug, and a solder-based cap.

• Thermal models were developed to study heating of the sample inside the sample tube during the sealing process.

• Initial helium leak testing and thermal analysis for heating of shape memory alloy plugs showed potential for being a viable hermetic sealing option for Mars Sample Return.

• Further testing and analysis will be performed on the other sealing techniques for comparison.