Low Earth orbit space environment conditions, including ultraviolet radiation, thermal cycling, and atomic oxygen exposure, can cause degradation of exterior spacecraft materials over time. Radiation and thermal exposure often results in the embrittlement and embrittlement of polymers, resulting in mechanical strength and structural integrity. An experiment called the Flexural Stress Effects Experiment (FSEE) was flown with the objective of determining the role of space environmental exposure on the mechanical properties of materials under flexural stress. The FSEE samples were flown in the wake orientation on the exterior of the International Space Station (ISS) for 1.5 years. Twenty-four samples were flown, 12 bent to 0.375 in. and 12 were 0.425 in. mandrel. This was designed to simulate flight configurations of insulation blankets on spacecraft. The samples consisted of assorted polymers and fluorinated polymers with various coatings. Half the samples were designated for bend testing and the other half will be tensile tested. A non-standard bend-test procedure was designed to determine the surface strain at which embrittled polymers crack. All ten samples designated for bend testing have been tested. None of the control samples’ polymers cracked, even under surface strains up to 19.7%, while one coating cracked. Of the ten flight samples tested, seven show increased embrittlement through bend test induced cracking at surface strains from 0.70% to 17.73%. These results show that most of the tested polymers are embrittled due to space exposure, when compared to their control samples. Determination of the extent of space induced embrittlement of polymers is important for designing durable spacecraft.

Space Environment

Materials on the exterior of spacecraft are exposed to many environmental threats that can be harmful to the spacecraft and its operation. These threats include:
- Solar radiation (ultraviolet (UV), x-rays)
- Charged particle radiation (electrons, protons)
- Cosmic rays (energetic nuclei)
- Thermal cycling (hot & cold cycles)
- Micrometeoroids & debris impacts (space particles)
- Atomic oxygen (AO, single oxygen atom)

FLEXURAL STRESS EFFECTS EXPERIMENT BACKGROUND

Objective: To examine the role of surface flexural stress (two different levels) on space environment induced polymer embrittlement.

- Samples were flown bent over a mandrel in the wake orientation, which imposed surface flexural stress, to the test of surface flexural stress on polymer degradation could be examined.
- Two different diameter mandrels (0.25" and 0.375") dia were used so the effects of different stress levels on the polymers could be compared

An example of the effect of surface exposure on polymer embrittlement can be seen on the Hubble Space Telescope, where the normally stretchy Teflon outer-layer of the insulation became brittle and cracked after only 5.8 years of space exposure.

FSEE Materials

<table>
<thead>
<tr>
<th>ID</th>
<th>Material</th>
<th>Tensile Thickness (mil)</th>
<th>ID</th>
<th>Material</th>
<th>Tensile Thickness (mil)</th>
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<tbody>
<tr>
<td>A1</td>
<td>Kapton XC/Al</td>
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<td>A1</td>
<td>Kapton XC/Al</td>
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<tr>
<td>B1</td>
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<td>B1</td>
<td>VDA/Inconel/VDA</td>
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</tr>
<tr>
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<td>B3</td>
<td>VDA/Inconel/VDA</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Results

Sample ID | Material | Thickness (mil) | Diameter at Which Sample Cracked (in) | % Strain Cracked (%)
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
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<td>D1</td>
<td>(DNIC)</td>
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<td>A-7</td>
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<tr>
<td>A-9</td>
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<td>11.73</td>
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<tr>
<td>A-10</td>
<td>Kapton HN/VDA</td>
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<td>D1C</td>
<td></td>
</tr>
<tr>
<td>B-1</td>
<td>Kapton XC/Al</td>
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<td>D1C</td>
<td></td>
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</tbody>
</table>

Spacecraft Blanket Examples

- Pictured below are examples of how insulation blankets are bent while in flight.
- Depicted in the image on the left is an example of a polymer insulation being bent around a corner on the Hubble Space Telescope (HST).
- Direction facing away from earth (i.e. straight down) is Kapton XC/Al.
- Direction facing towards earth (i.e. straight down) is FEP/Inconel/VDA.

Space Samples on ISS

MISSE BACKGROUND

- MISSE stands for the Materials International Space Station Experiment
- MISSE is a series of materials flight experiments consisting of trays called Passive Exposure Experiment Containers (PECs) that were exposed to the space environment on the exterior of the International Space Station (ISS).
- The Flexural Stress Effects Experiment (FSEE) samples were flown in the wake orientation on the ISS from November 23, 2009 to May 20, 2011 for 1.49 years, and received 2,000 equivalent sun hours (ESH) of solar radiation (Ref 3).

Flight Orientations & Environmental Exposures

- Ram: Facing the direction of travel (i.e. leading edge)
- Wake: Facing away from the direction of travel (i.e. trailing edge)
- Ambient: Moderately solar exposure
- Zenith: Direction facing away from Earth (i.e. directly above)
- grazing AO and highest solar exposure
- Nadir: Direction facing towards Earth (i.e. straight down)
- Grazing AO and lowest solar exposure

Bend Test Procedures

- Half the samples are to be analyzed for space-induced embrittlement using a non-standard bend-test procedure in which the strain to induce surface cracking was determined.
- Testing is conducted on a semi-unsupported sample surface held up with two supports to bend the samples without imposing a bulk tensile stress.
- Successively smaller mandrels (cylindrical steel pieces) were used to apply surface strain to samples. There were 23 mandrels (dia. range: 1.253 cm to 0.052 cm), providing varying strains. As diameter of mandrel decreased, strain on sample surface increased.

Post-Flight Procedures

- Post-flight photo documentation
- Photos of samples on holder
- Photos of individual samples (off holder)
- The samples were divided into two groups: Group A and Group B
- Group A: Bend Test Samples
  - Prior to testing the actual samples, practice tests were performed on x-ray exposed samples.
  - Bend testing determines the amount of strain required to produce surface cracks.
- Group B: Tensile Test Samples
  - Tensile testing test blank embrittlement
  - Sample thickness will be measured prior to tensile testing.

Flexural Stress Effects Experiment Background

To determine the amount of strain required to produce surface cracks, practice tests were performed on x-ray exposed samples. The results show that most of the tested polymers are embrittled due to space exposure, when compared to their control samples. Determination of the extent of space induced embrittlement of polymers is important for designing durable spacecraft.

Summary and Conclusion

Of the 10 FSEE flight samples tested, seven show increased embrittlement through bend-test induced cracking at surface strains from 0.70% to 11.73%, as compared to the control samples which did not crack. The more embrittled a sample is, the less post-flight strain is necessary to induce post-flight cracking. The samples under less stress-on-orbit (B samples, 0.375 in. dia.) cracked under less strain with post-flight bend-testing than the same samples under greater stress-on-orbit (A samples, 0.25 in. dia.). These results show that the more stress undergone during flight, the more strain needed for the material to crack post-flight. The CPL/VDA samples B-1 and B-2 were most embrittled and the Kapton XC/Al samples under the smallest strain. The Kapton XC/Al samples were the least embrittled, and neither the B-1 nor B-2 sample cracked post-flight.

Future Work

In the future, the flight and control samples designated for tensile testing will be tested to determine mechanical property degradation. The tensile results will be compared to the surface embrittlement bend test data to help determine which materials are most sensitive to space induced embrittlement and to see if surface embrittlement correlates with bulk embrittlement.

References: 2017-11-18T18:22:06+00:00Z.