Evaluation of a Conductive Elastomer Seal for Spacecraft

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52nd AIAA/SAE/ASEE Joint Propulsion Conference
Salt Lake City, UT
July 27, 2016

Introduction

- Future spacecraft will require gas pressure seals with very low leak rates
- Some locations on vehicle outer mold line (e.g., doors, hatches, access panels) also require low impedance between metal interfaces
  - Provides fault current path to protect personnel from electrical shock
  - Protects equipment from lightning strikes
- Class L electrical bonding requirements necessitate direct current resistance between metal interfaces of 2.5 milliohms or less for protection from lightning strikes
- Gas pressure seal that provides continuous, low-resistance electrical pathway is desirable
- Electrically conductive elastomer was evaluated as potential material for future spacecraft seals

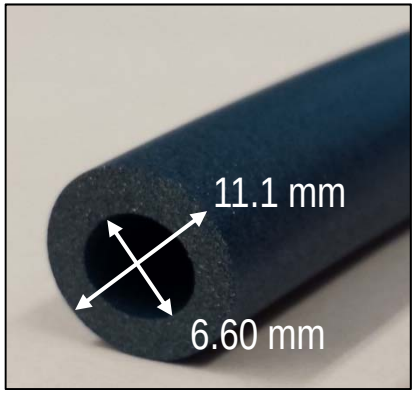
Orion spacecraft

Testing

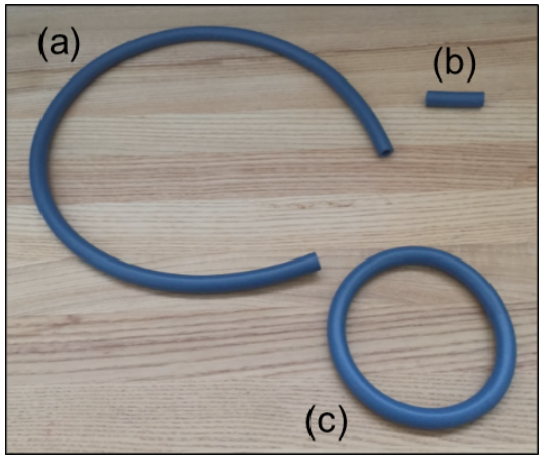
- Performed a series of tests to evaluate material properties and performance characteristics:
  - Outgassing
  - Electrical resistivity
  - Compression set
  - Compression and adhesion forces
  - Leak rate

Test Articles

- Seal material:
  - CHO-SEAL® 1285 compound manufactured by Parker Hannifin Corporation's Chomerics Division (Woburn, MA)
  - Contains silver-plated aluminum in a silicone matrix
- Specimen geometry:
  - Hollow O-ring
  - Nominal cross section dimensions:
    - 6.60 mm (0.260 in.) inner diameter
    - 11.1 mm (0.438 in.) outer diameter
  - Different specimen lengths used for different types of tests



Hollow O-ring design used for testing



Test articles used for different tests:
(a) electrical resistivity, compression force, & adhesion force, (b) compression set, (c) leak rate

Outgassing Tests

- Elastomers can release products (especially under vacuum) that condense on other nearby surfaces
- Seal outgassing contaminants must be minimized so they do not compromise functionality of surfaces with highly controlled optical properties (e.g., windows, lenses, solar arrays)
- Objective: Measure outgassing properties of CHO-SEAL® 1285 compound
- Test details:
  - Three samples cut from linear segment of hollow O-ring
  - Average sample mass of 225 mg
  - Tests conducted per ASTM E595-07
- Results:
  - Compound met outgassing requirements for spacecraft materials with total mass loss (TML) less than 1.0% and collected volatile condensable materials (CVCM) value less than 0.1%

	Measurement	Requirement
TML, %	0.041	Less than 1.0
CVCM, %	0.014	Less than 0.1

Electrical Resistivity Measurements

- Objective: Measure electrical resistance of structural joint formed by seal compressed between two platens
- Test details:
  - 62.2 cm linear segment of hollow O-ring was compressed between two platens made of aluminum coated with electroless nickel (0.008 to 0.01 mm thick; class 4, grade A per SAE-AMS-C-26074)
  - Only conductance path was through test article
  - Resistance measured by milliohm meter through electrical leads connected to upper and lower platens
  - Measurements were made at three compression levels by applying additional weight to upper platen:
    - Upper platen by itself (91 N)
    - Upper platen plus 45 N
    - Upper platen plus 89 N

Hardware setup for electrical resistivity measurements

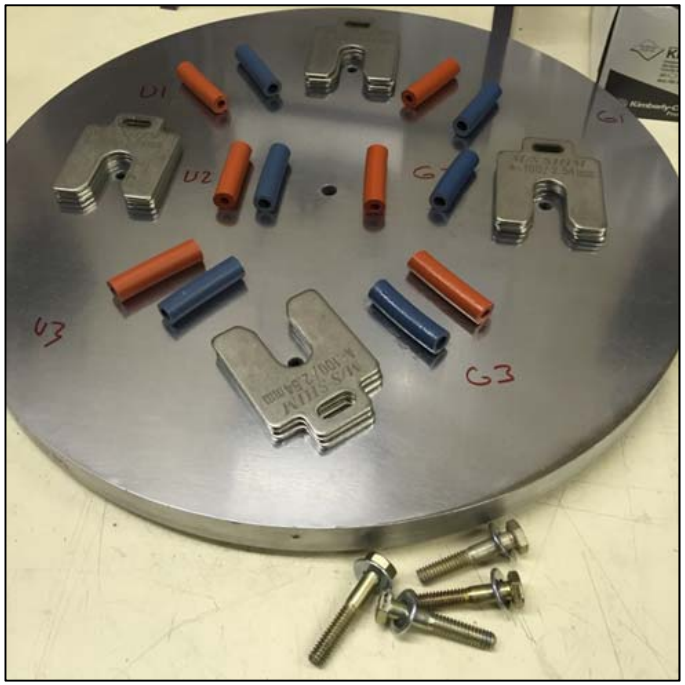
Electrical Resistivity Measurements (cont.)

Configuration (total force)	Resistance, milliohms
Upper platen only (91 N)	0.70
Upper platen plus 45 N (136 N)	0.66
Upper platen plus 89 N (180 N)	0.62

- Results:
  - Electrical resistance of assembly decreased slightly as more weight was applied to upper platen
  - All tested assemblies met Class L electrical bonding requirement of 2.5 milliohms or less
  - Results suggest that elastomer is capable of conducting electrical charge with minimal resistance
  - However, actual resistance for potential spacecraft seal application will be dependent on seal length and cross section dimensions

Compression Set Measurements

- Seals must remain in contact with adjacent sealing surfaces to form an effective seal
- However, elastomer seals can take on permanent deformation (i.e., “set”) after they are compressed, especially for long period of time
- Objective: Measure permanent deformation of seal after force is applied for a period of time and then removed
- Test details:
  - Two lots of three specimens each: with and without vacuum grease
  - Followed ASTM D395 Method B guidelines with minimal exceptions
  - Compressed specimens at room temperature for 70 hrs between two steel platens
  - Used spacers to compress test articles to 75% of average pre-test height



Test articles (4 cm long) arranged on steel platen with spacers before 70 hr compression hold

Compression Set Measurements (cont.)

- Measurements & calculations:
  - Measured test article heights before and after using non-contact laser profile measurement system
  - Recorded average of four measurements for each test article
  - Reported final compression set measurement as median value from three test articles in each lot

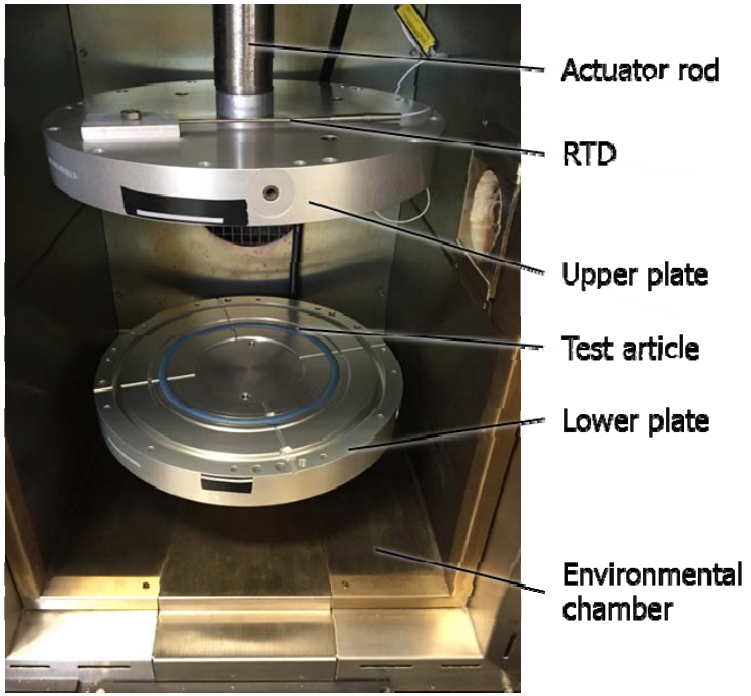
$$\frac{h_o - h_{70}}{h_o - h_{spacer}} * 100$$

- Results:
  - Lubricated test articles exhibited less compression set; allowed for greater deformation and reduced stress
  - Compression set values were higher than those for other silicone elastomers (typically 5-11%)
  - Compression set must be evaluated for longer durations and at representative temperatures before using this compound in space seal applications

	Unlubricated	Lubricated
Compression set measurement	15.3%	14.0%

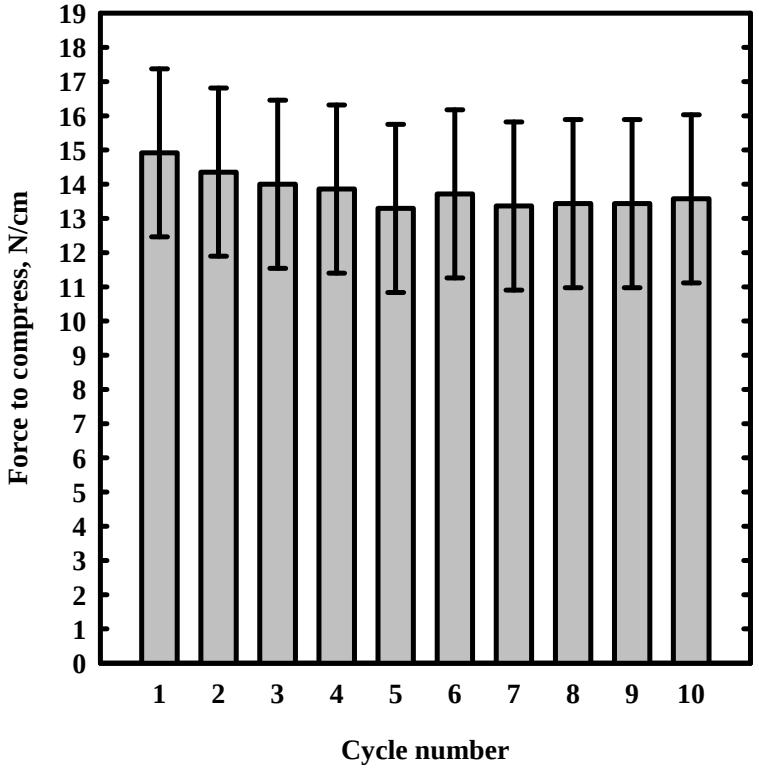
Compression & Adhesion Force Measurements

- Objectives:
  - Measure force required to compress the seal
  - Measure force required to separate seal from opposing sealing surface
- Test details:
  - Tested seal at 18.3°C in test fixture installed in Instron electromechanically actuated load frame
  - Seal was installed in dovetail groove and compressed against flat plate
  - Plates made of aluminum with clear anodized finish per MIL-A-8625, Type II, Class 1
  - Fully compressed seal for 10 load cycles
    - Compress at 0.2 mm/sec
    - 1 minute hold
    - Separate at 0.25 mm/sec
    - 1 minute recovery



Test setup for seal compression & adhesion force measurements

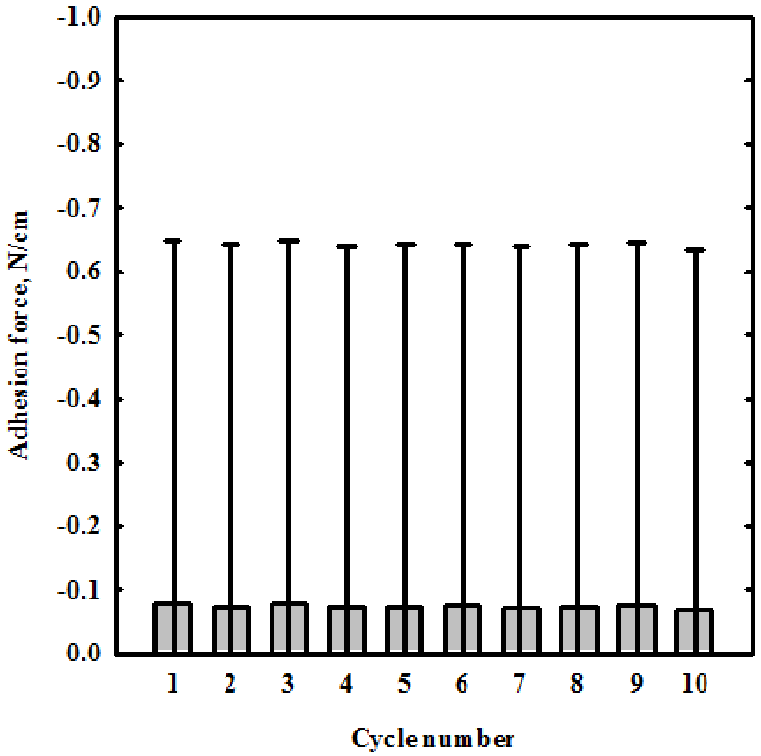
Compression Force Measurements



Cycle number	Compression force, N/cm	Uncertainty, N/cm
1	15.1	±2.5
2	14.5	±2.5
3	14.2	±2.5
4	14.0	±2.5
5	13.5	±2.5
6	13.8	±2.5
7	13.5	±2.5
8	13.7	±2.5
9	13.7	±2.5
10	13.7	±2.5

- Force required to compress seal decreased slightly with load cycling
- Relatively soft elastomer compound and hollow O-ring design resulted in low forces to compress seals when compared to solid seal designs made of higher durometer materials
- Additional testing would be required to evaluate compression force response over time and at representative operating temperatures

Adhesion Force Measurements



Cycle number	Adhesion force, N/cm	Uncertainty, N/cm
1	-0.08	+0.08 / -0.6
2	-0.07	+0.08 / -0.6
3	-0.08	+0.08 / -0.6
4	-0.07	+0.08 / -0.6
5	-0.07	+0.08 / -0.6
6	-0.08	+0.08 / -0.6
7	-0.07	+0.08 / -0.6
8	-0.07	+0.08 / -0.6
9	-0.08	+0.08 / -0.6
10	-0.07	+0.08 / -0.6

- Force required to separate seal from sealing surface (i.e., seal adhesion) was very low and not significantly different than zero
- Desirable characteristic → minimizes need for mechanism to separate the joint
- Additional testing would be required for longer hold durations and at representative operating temperatures

Leak Rate Measurements

- Objective: Measure seal leak rates
- Test details:
  - Tested seal at 23 and 61°C in test fixture installed in environmental control chamber to maintain constant test temperature
  - Seal was installed in dovetail groove and compressed against flat plate
  - Plates made of aluminum with clear anodized finish per MIL-A-8625, Type II, Class 1
  - Pressurized volume inboard of seal to 129 kPa
  - Controlled pressure in volume downstream of seal (low-pressure side) to maintain constant differential pressure across seal of 101 kPa throughout test
  - Used mass point leak rate method to analyze data and obtain leak rate results and uncertainty

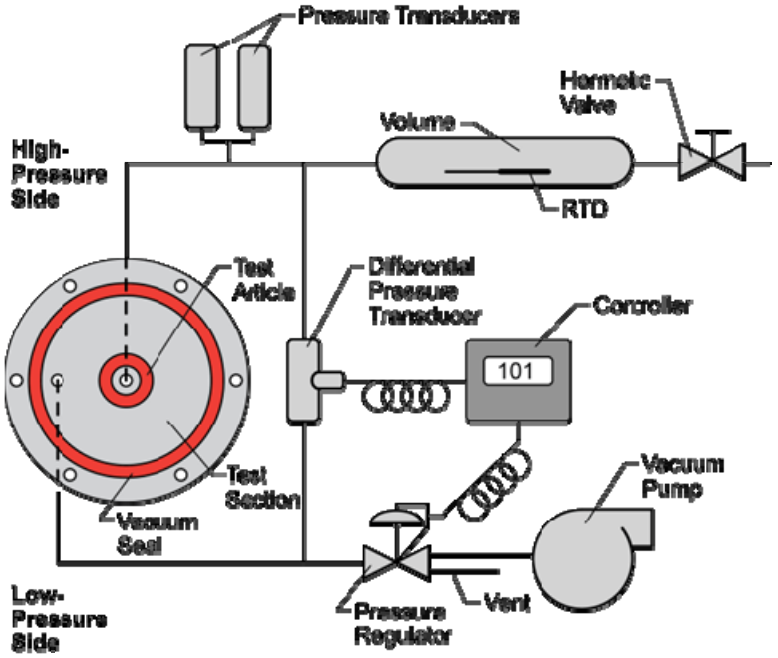
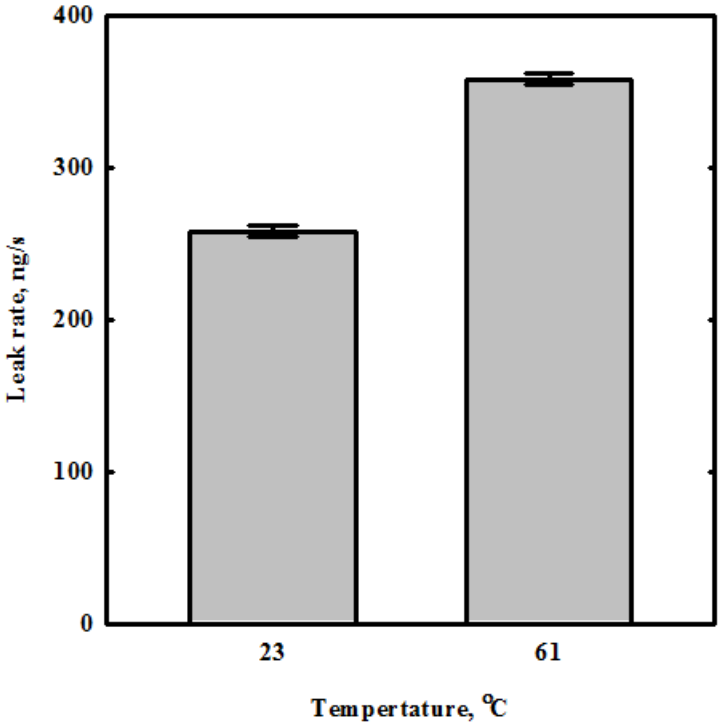


Diagram of leak rate measurement test apparatus

Leak Rate Measurements (cont.)



Temperature, °C	Leak rate, ng/s	Uncertainty, ng/s
23	258	4.08
61	358	3.28

- Results:
  - Leak rate increased at warmer test temperature
  - Leak rates were higher than those for other seals used for space applications but still reasonable
    - Void in hollow O-ring provided no resistance to flow
    - Force required to compress seal was low; allowed for increased leakage through interfaces between seal and sealing surfaces

Summary

- Electrically conductive elastomer was evaluated as potential material for future spacecraft seals
- Compound met outgassing requirements for spacecraft materials with TML less than 1.0% and CVCM less than 0.1%
- All tested assemblies met Class L electrical bonding requirement of 2.5 milliohms or less
- Hollow O-ring seal made of candidate compound required low forces to compress it but exhibited higher compression set values than those for other silicone elastomers
- Seal exhibited very low, near-zero adhesion forces
- Leak rates were higher than those for other seals used for space applications but still reasonable
- Overall, compound shows promise as potential material for spacecraft seals, but additional testing should be performed under representative operating conditions (e.g., temperatures) and for longer durations before implementation

Acknowledgments

- The authors would like to thank:
  - Nathan Williams for assistance with electrical resistance measurements
  - John Mayer and Joseph Assion from Vantage Partners, LLC for engineering design support
- Funding for this work was provided by NASA under contract NNC13BA10B