DESIGN AND ANALYSIS OF MOLDED ELASTOMER SEALS

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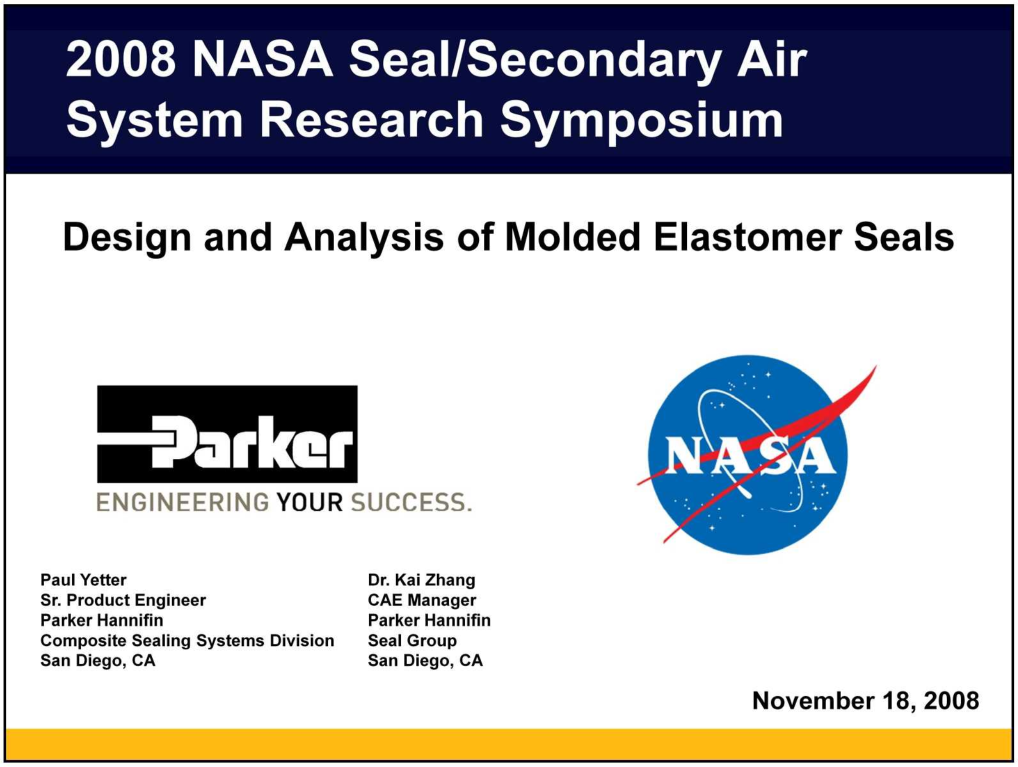

Gask-O-Seal™ Heritage in Space

Space Shuttle

Gold Plated Magnesium Fuel Cell Plates and Seals
Solid Rocket Motor (SRM) Stat-O- Seals
SRM Safe and Arm Igniter Seals
SRM Inner and Outer Seals

International Space Station

Common Berthing Mechanism Seals
Hatch Seals
Electrical Connector Seals
Fluid Connector Thermal Isolator and Seals
Cupola Window Frame and Seal
Window Frame and Seal

Delta II Launch Vehicle

ISA Cover Seal
Electrical Connector Plate Seal

International Space Station

Intravehicular Activity Seals
Hatch Stops
Window Pane Bumper
Columbus Module Seal
Mini Pressurized Logistics Module Seal

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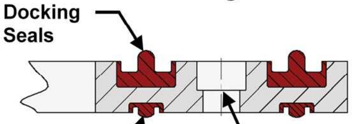
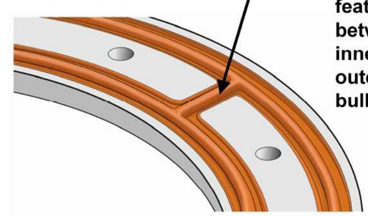
LIDS Seal Construction and Functional Requirements

- Elastomer: Parker compound S0383-70 vacuum molded and bonded to 6061-T651 aluminum retainer.
  - Materials meet low out gassing requirements for Total Mass Loss (TML) and Collected Volatile Condensable Materials (CVCM)
- Dual seal bulbs on top and bottom to meet redundancy requirement.
- Ladder features divide annulus between inner and outer seals into multiple zones for added reliability.





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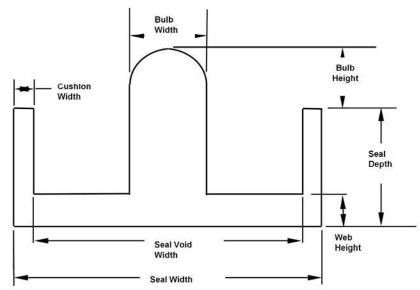
LIDS Seal Construction and Functional Requirements

- Seals must withstand exposure to space environments without excessive damage or loss of sealing ability:
  - Atomic oxygen (AO)
  - Ionizing and ultraviolet (UV) radiation
  - Possible impacts from micrometeoroids and orbital debris (MMOD)
  - Vacuum conditions
  - Thermal cycling
- Temperature:
  - Operating: -50°C to +50°C (-58°F to +122°F)
  - Non-operating: -100°C to +100°C (-148°F to 212°F)
- Exhibit extremely low leakage rates (≤0.0025 lbm/day) at pressure of 14.8 psia to minimize overall LIDS leakage.
- Long mating periods (216 days) and repeated docking.
- Max compressive load < 70 lbs/linear inch/seal bead.
- Max separation load < 300 lbs total.



FEA in Parker Seal Group

- Parker Seal Has Been Using FEA for Optimizing Seal Designs for 18 Years
- Nonlinear FEA Software, Marc, is Deployed in All N.A. and European Divisions
- Software Ansys is Used in Asian Division

Major Issues in Sealing FEA

1. Modeling of Materials
   - Rubber Compounds Are Complex Composite, and Exhibit Thermo-Visco-Elastic Behavior
   - Hyperelastic Model is Widely Used in Seal Industry, but Its Limitation is Often Ignored
   - Viscoelastic Model is Rarely Used, and Should Get More Research and Application.
2. Test and Characterization of Materials
   - Which Testing Modes Are Best for Hyperelastic Modeling is Debatable
   - Testing at High and Low Temperature is Challenging

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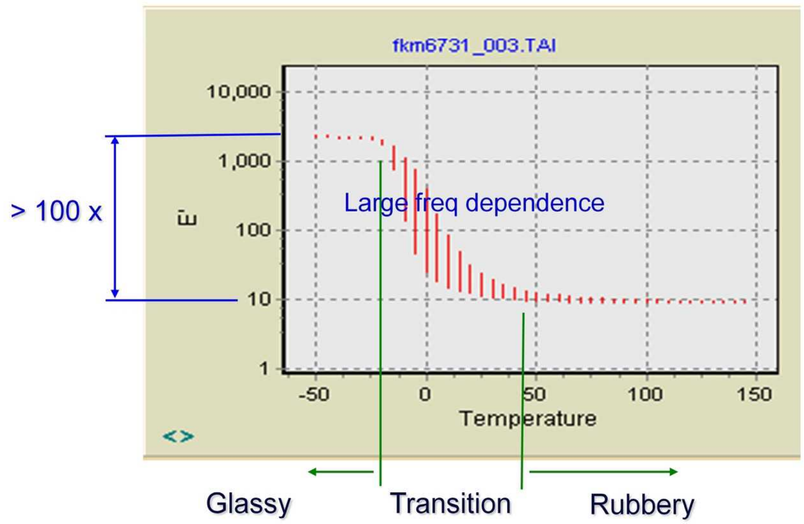
Hyperelastic Model

- Capable of Capturing Nonlinear Elastic Response of Rubber Compounds in Thermodynamic Equilibrium State
- Applicable to Static and Some Dynamic (Quasi-Static) Problems at Room and High Temperature
- Can't Predict Rate or Time Dependent Responses
- Be Cautious of Using it for Low Temperature Sealing Analysis

Thermodynamic Behavior

High Rate Dependent Response in Transition State



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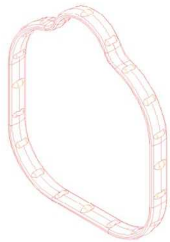
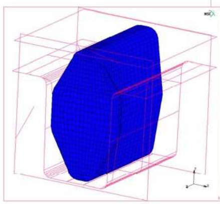
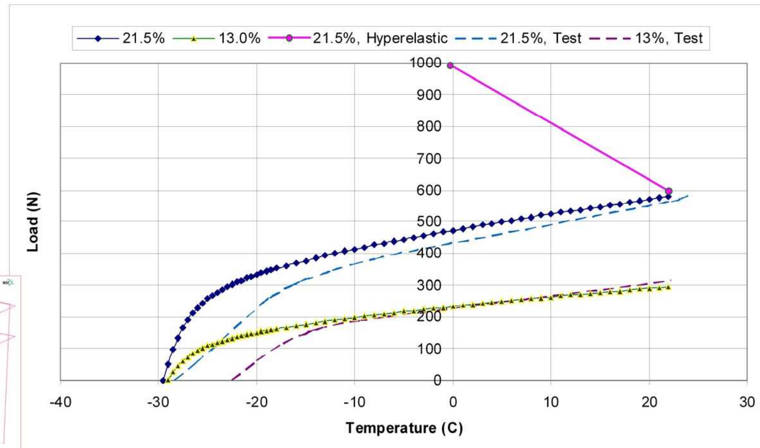
FEA Predictions of Sealing Force Deduction at Low Temperature







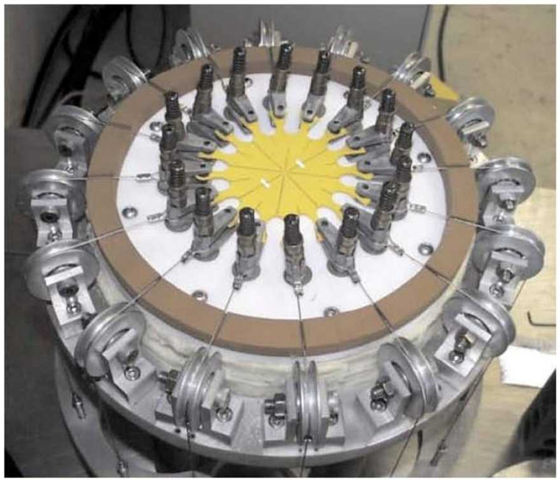
Test Data Provided by Dyneon

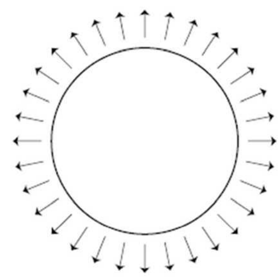
Testing Modes for Hyperelastic Modeling

Simple Compression or Biaxial Tension ?

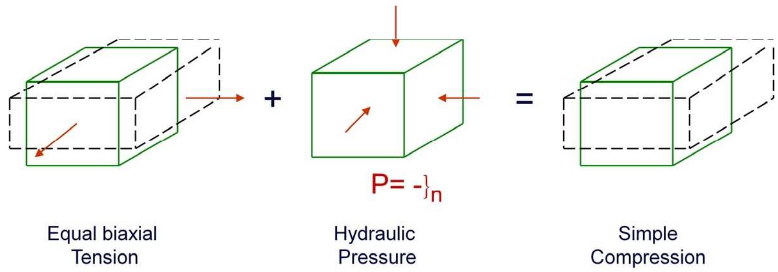
- Inaccuracy Due to Interfacial Friction in Simple Compression Test
- Theoretically, Equal Biaxial Tension is "Equivalent" to Simple Compression

One of Equal Biaxial Tension Devices
(Developed by Axel Test Lab)





What's the "Equivalence"?

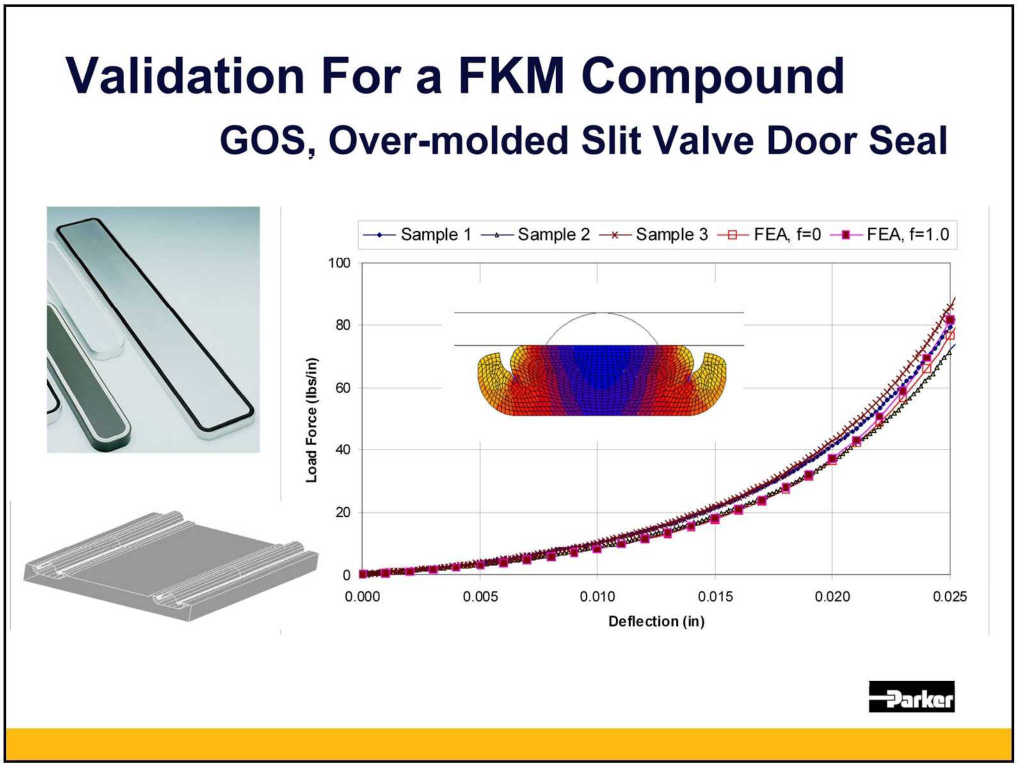


- Derived in the Framework of Continuum Mechanics
- Assumption: Difference in Stress State Does Not Affect Mechanical Behavior of Materials

Is This Valid for Rubber Compounds with Complex Composite Structure ??

Practice of Parker Seal

- Simple Tension and Compression Tests
- Stress vs. Strain Data of Two Tests is Combined for Curve Fitting and Generation of Hyperelastic Model Constants

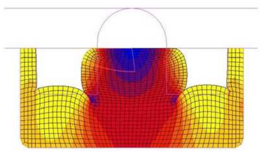


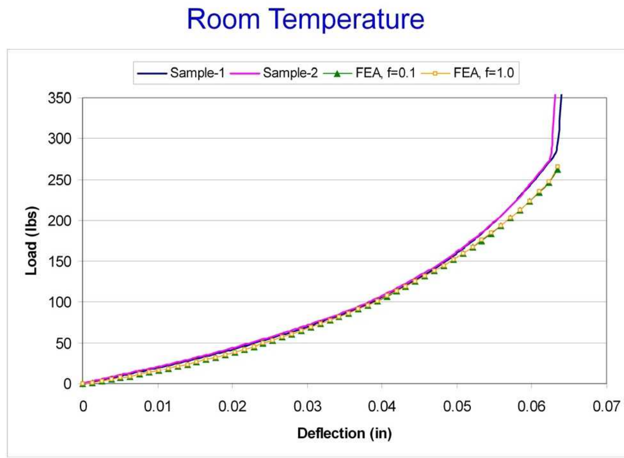
Plane strain analysis.

Sample are 2” long, so end effect is negligible.

Validation For S0383-70 Compound

LIDS Docking Seals





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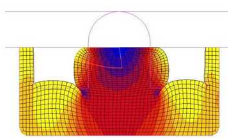
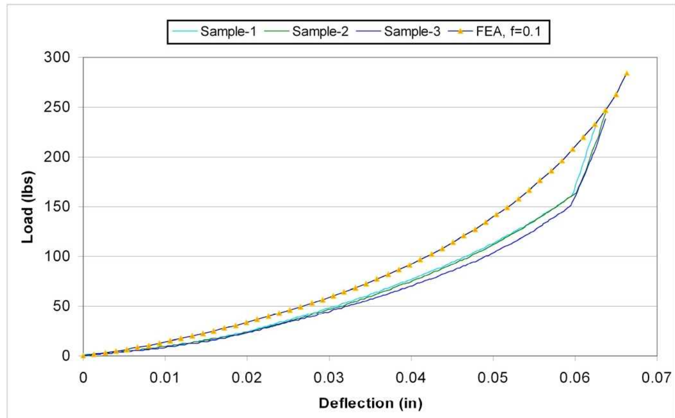
Axisymmetric analysis

Validation For S0383-70 Compound

LIDS Docking Seals

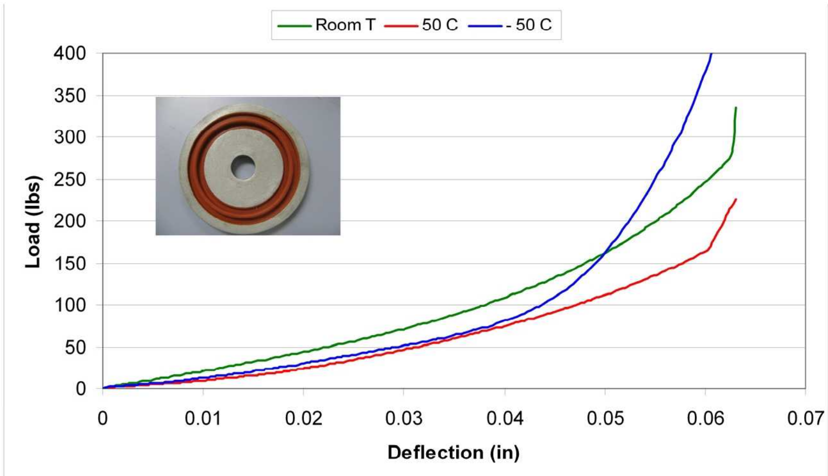


At 50° C



Axisymmetric analysis with thermal expansion. In FEA, the beat height at 50° C is about .066”. However, the height of tested samples is about .060”, possibly due to permanent set after previous loading.

LIDS Docking Seals
Load-Deflection Curves at Three Temperature



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FEA Simulation of Elastomers in Sealing

Modeling Materials

- Hyperelastic Model Used for Room Temperature and Higher, But Has Limitations at Predicting Response at Different Compressive Rates and at Low Temps.
- Viscoelastic Model is Rarely Used, and Needs More Research and Application.

Test And Characterization of Materials

- Better Material Characterization Using Biaxial Tension vs Simple Compression Testing Modes is Debatable.
- Testing at High and Low Temperature is Challenging.

Questions?

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