Measurement of Mechanical Properties of Polymers at Cryogenic Temperatures

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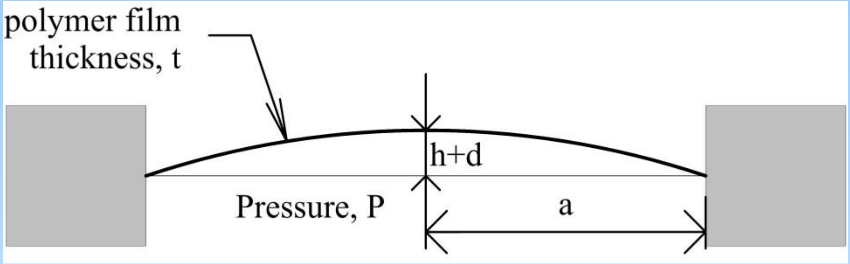
Introduction

In-space radiation is one of the largest uncertainties currently in human spaceflight

- Recent studies have suggested that secondary particle damage caused by uncharged particles (e.g. neutrons) released by a radiation shield can be worse than the original particle
  - Many studies have shown that liquid hydrogen is the best material for stopping Galactic Cosmic Radiation due to the low number of neutrons present
  - Liquid hydrogen must be contained
  - Containment materials must be such that they don't degrade the radiation shield performance
- Understand the applicability of advanced polymeric materials as a possible liquid hydrogen containment solution
  - Also provide feedback on desired and required material properties for mission architectures
- Need to understand mechanical properties that would be required to contain liquid hydrogen in a pressure vessel

Bulge Test Theory

- As pressure is increased behind the thin film, the film "bulges"
- Begins to form curved surface in a predictable geometry that can be related to the stress in the material



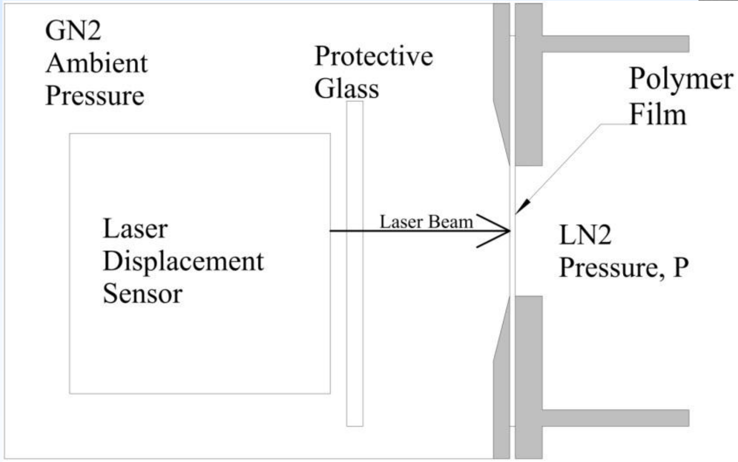
- Most classical solutions (such as in Roark) are limited to deflections less than the thickness of the film

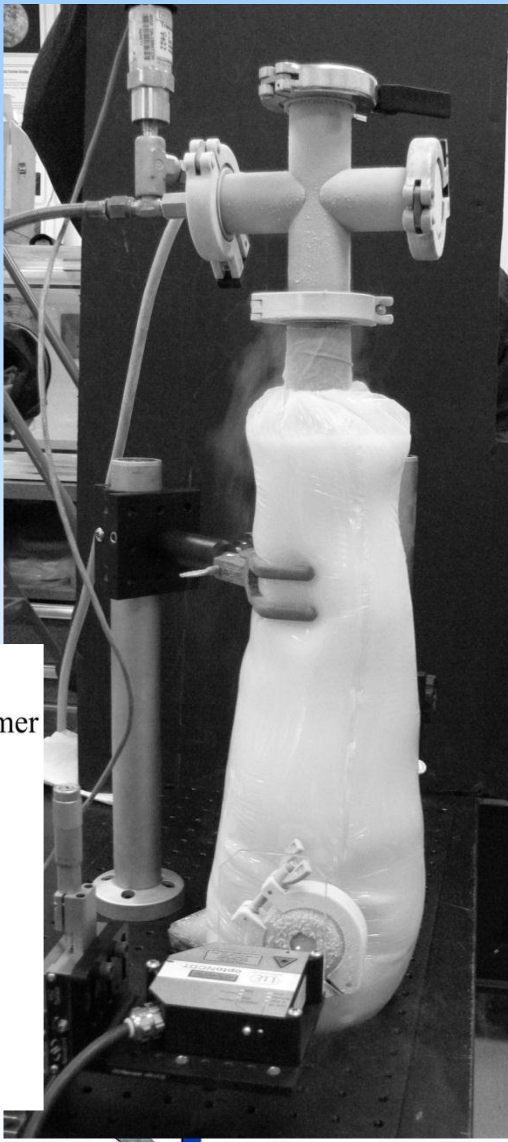
$$P = \frac{8Et}{3a^4(1-\nu)}(h+d)^3 + \frac{4\sigma t}{a^2}(h+d)$$

- Small and Nix derived the equations with the result on the right that are more generally applicable to the linear region of stress
- By incrementally increasing the pressure behind the bulge, multiple points are taken to allow determination of Young's Modulus (with assumed Poisson's ratio)
- Additional non-quantitative insights beyond the linear regime
  - Pressure failures
  - Material changes at high stresses

Experimental Setup

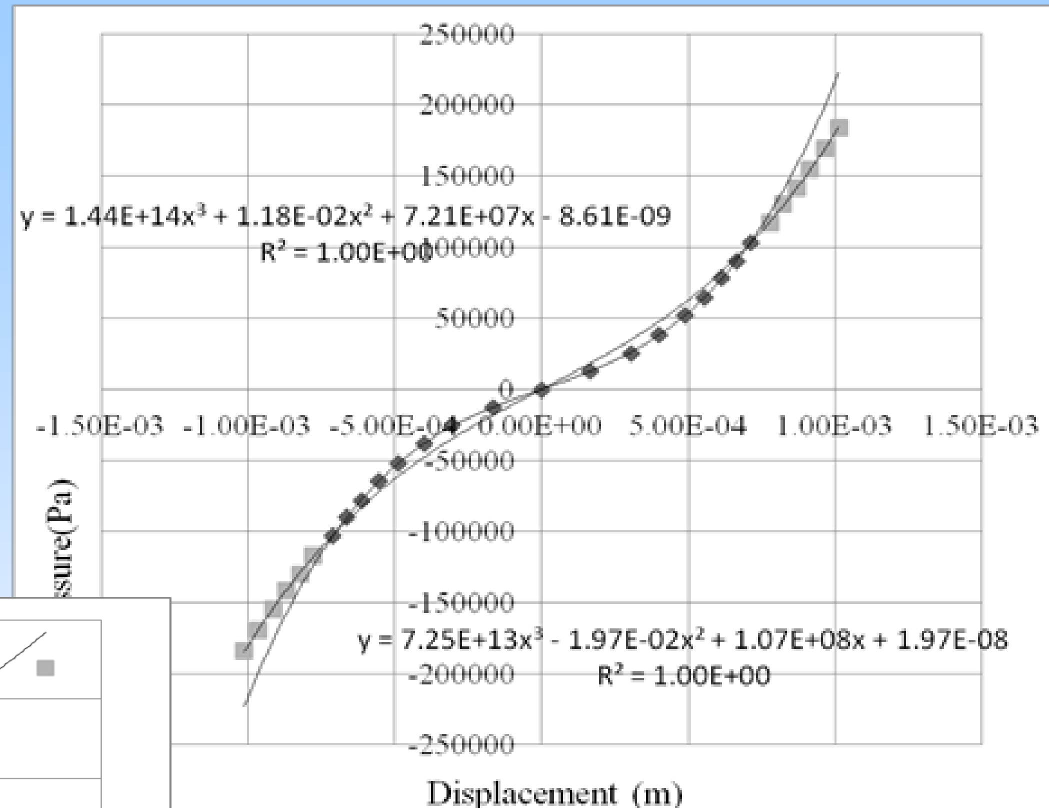
- Stainless Steel pressure system
- Laser Displacement Sensor:
  - Resolution of 0.15 micrometers
  - Uncertainty +/- 2 micrometers
  - 10 kHz data frequency
- Pressure Transducer 0 – 30 psig
- Nitrogen pressure supplied by PPRU 0 – 50 psig
- RV set for 30 psig
- 0.13 inch orifice for venting boil-off and controlling pressure
- Allow for frost growth to keep sample cold
- Have tested sample sizes of 12, 17, & 25 mm in diameter

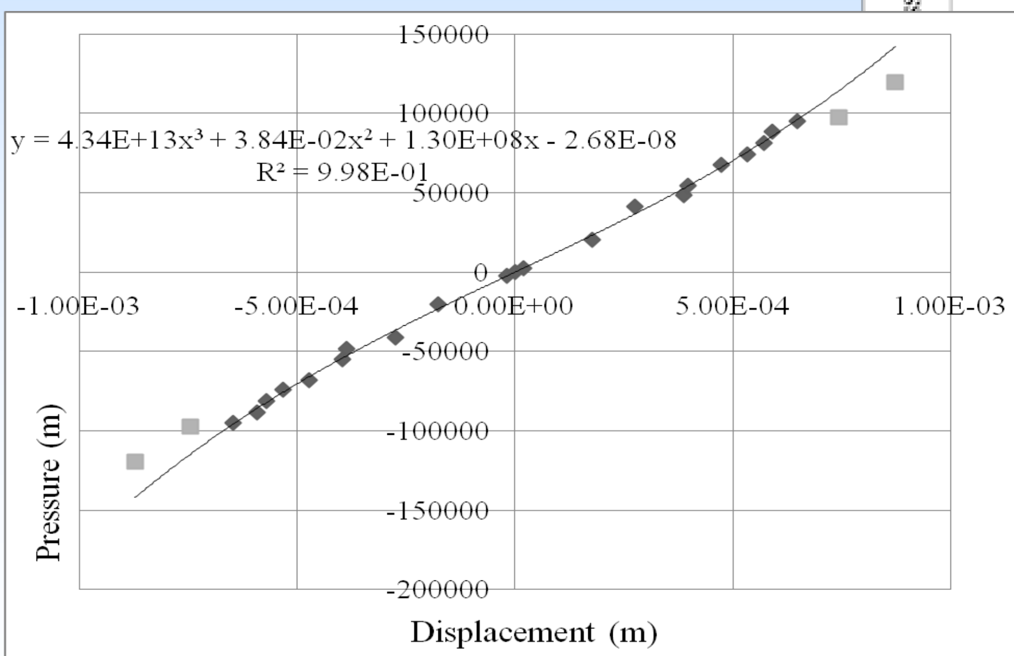




Results: Polyether Ether Ketone (PEEK)

- PEEK Ambient Temp
  - Thickness: 0.075 mm
  - Measured E:3.8 GPa
  - Vender E: 3.6 Gpa
  - Note: at roughly 15 psig E dropped to 1.9 GPa
- PEEK LN2 Temp
  - Measured E: 1.9 GPa
  - Still transition ~ 15 psig

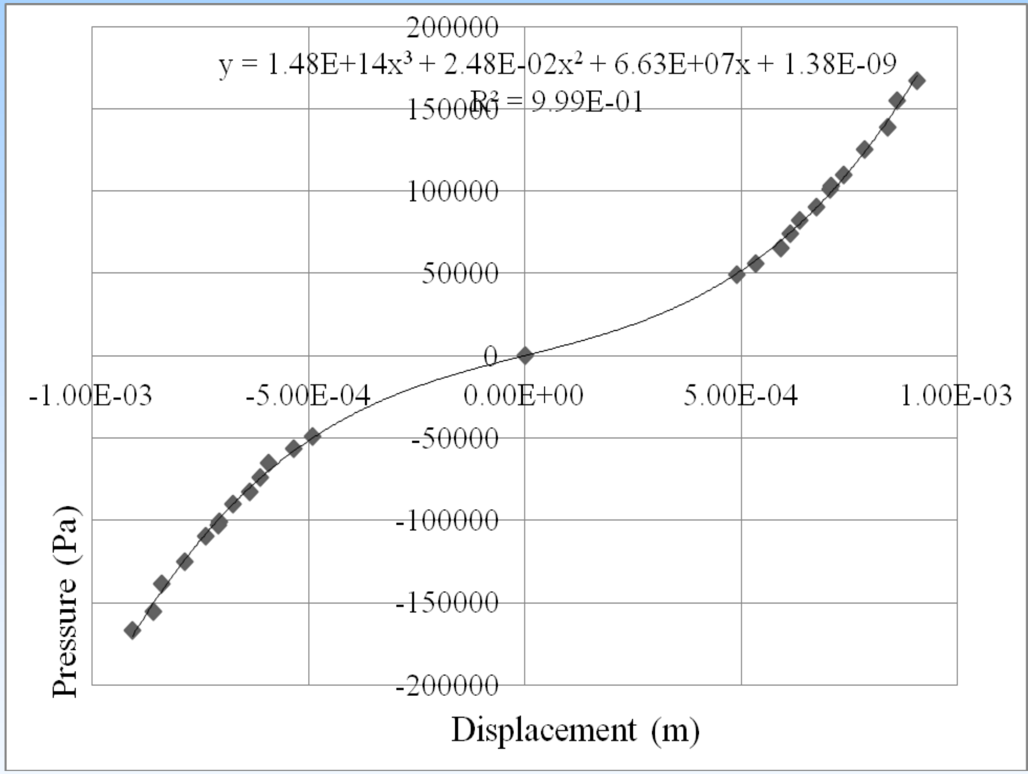




Results: Ultem

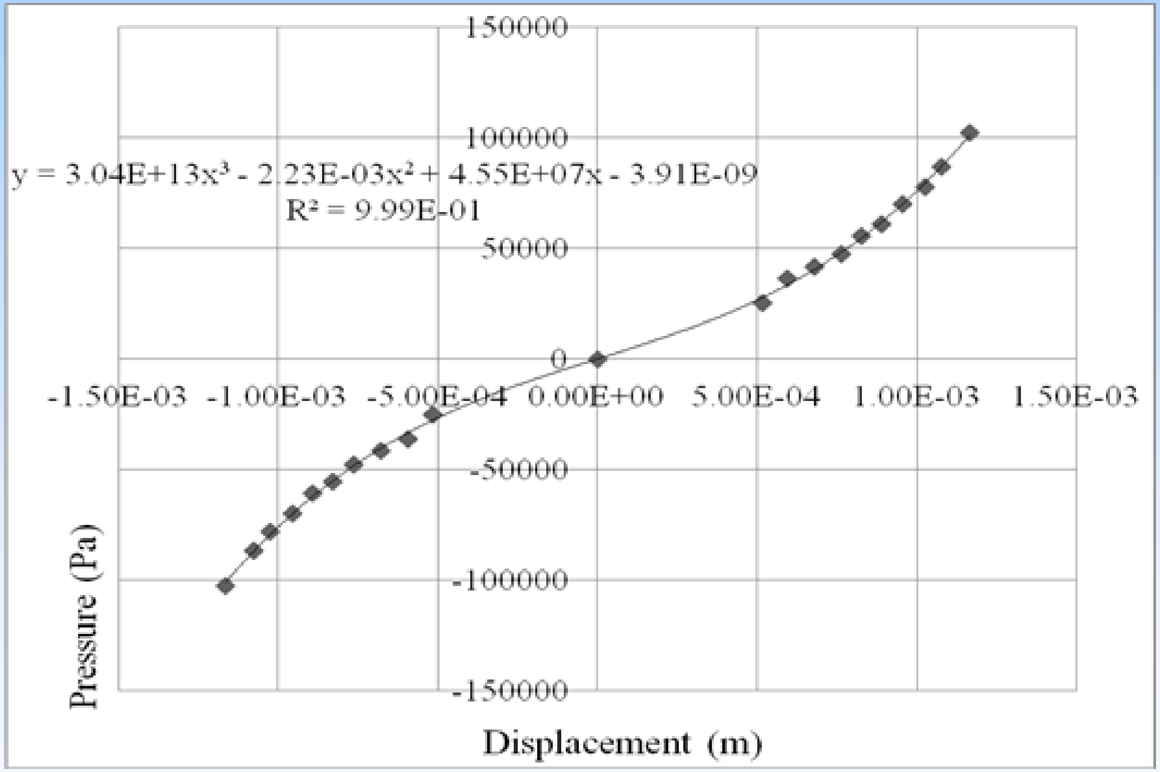
ULTEM (Polyetherimide)

- Thickness: 0.014 mm
- Measured E:
  - 2.6 GPa ambient
  - 5.8 GPa LN2 temperature
- Published E: 3 GPa (ambient)
- Higher residual stress due to chilling sample in holder



Results: Ethylene Vinyl Alcohol (EVOH)

- Aluminized Ethylene Vinyl Alcohol
  - Thickness: 0.014 mm
  - Measured E:
    - 4.5 GPa (LN2)
  - Vendor E:
    4 GPa (ambient)



Conclusions

- Work at the Cryogenics Test Laboratory at Kennedy Space Center has demonstrated that bulge testing can be accomplished at liquid nitrogen temperatures
- The measured room temperature data for Young's Modulus on various polymers compares well with published values
- As expected most polymers show an increase of strength between 293 K and 77 K (with the exception of PEEK)
- Other interesting phenomena such as burst and apparent material changes have been observed during testing as well
- The main issue with testing is differential CTE during chilldown
  - Too much residual stress can mask the third order term needed to determine Young's modulus

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