Finite Element Analysis of Bending Barrier Films

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Introduction

- Barrier film is a critical component of VIP
- Some VIP applications require 10 to 50 year life
- Barrier performance by
  - Oxygen Transmission Rates (OTR)
    - ASTM D3985 23ºC 50% RH
  - Water Vapor Transmission Rate
    - ASTM F1249-90
  - Testing performed on flat undamaged film samples

Introduction Cont.

- In use barrier films experience bending
  - Edges of the panel
  - Folding and taping of the seal flaps
- At each International Symposia there are presentations on barrier films
  - 2001 DuPont Teijin Films presented many mechanisms that damage barrier film
    - Tensile strain
    - Long term creep
    - Thermal stress
    - Dust inclusion
    - Abrasion

Introduction Cont.

- DuPont microscopic studies
  - White spots where the barrier is compromised

  - Foil barrier structure subjected to 4% strain

Introduction Cont.

- DuPont microscopic studies
  - White spots where the barrier is compromised

  - Metallized barrier structure subjected to 4% strain

Introduction Cont.

- Diffusion through the compromised "white spots"
  - Approx. 1 million times higher
    - At best they are polymer film with no additional barrier
    - At worst they are physical holes
  - A small number of "white spots" can substantially reduce the barrier performance
- Presentation "Application of Vacuum Insulation Panels in Extreme Environments"
  - 7th International Vacuum Insulation Symposium
  - By Roderick, Glover, and Smith
  - Shows manipulation of barrier can result in failure or locally increased diffusion

Introduction Cont.

- Thermal Visions, Inc. studies
  - Failures where no obvious cause could be found
    - No cuts, scratches, bad seal, etc.
  - Helium mass spectrometry used to identify the failure area
  - **NO** failures have been found on the large flat surfaces of the panels
  - All leaks occurred on the corners and 90 degree bent edges of the panels
    - Small pin-hole leaks similar to the "white spots"
  - Almost all leaks occur near end where core is pushed up against barrier pouch
  - Few leaks near the chamber seal flap

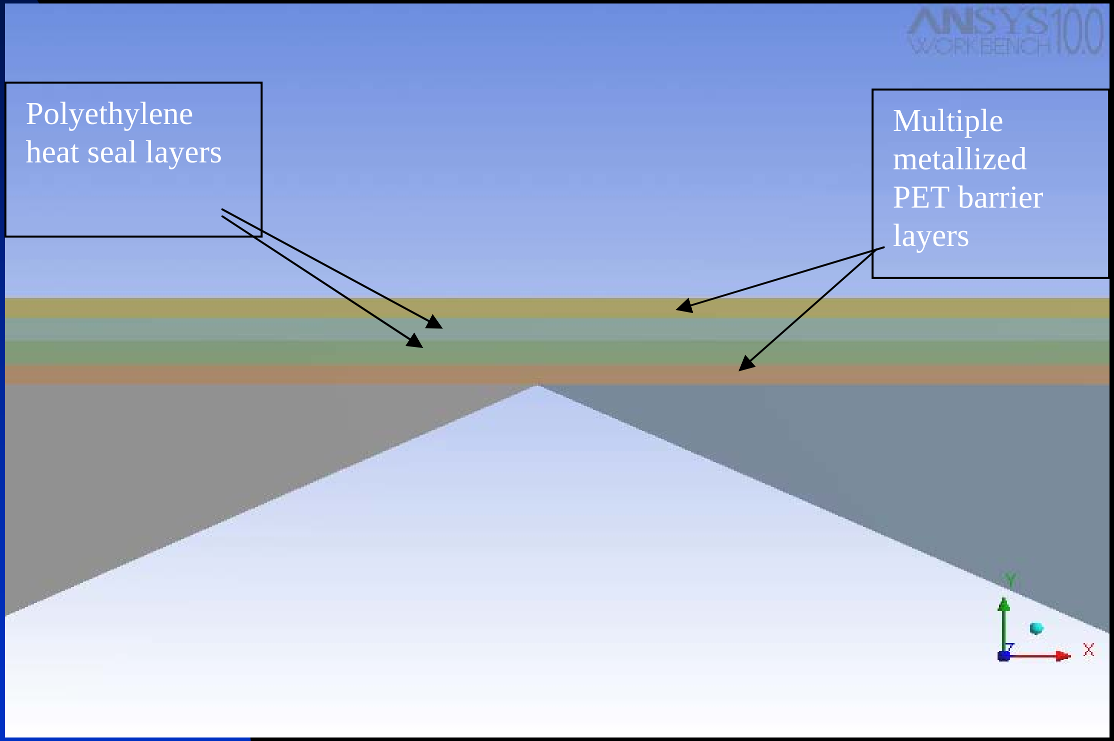
Typical Barrier Design

- Current barrier designs provide outstanding performance when not under stress or strain
  - Multitude of layers
    - Fault tolerant (defect in one layer not catastrophic)
    - Layers very thin to minimize lateral diffusion
  - Heat seal layers LDPE or HDPE
    - Low modulus “yielding” materials
  - Metallized PET layers take most of the stress
    - Damage is very local as seen in the previous micrographs

Barrier Film Structural Analysis

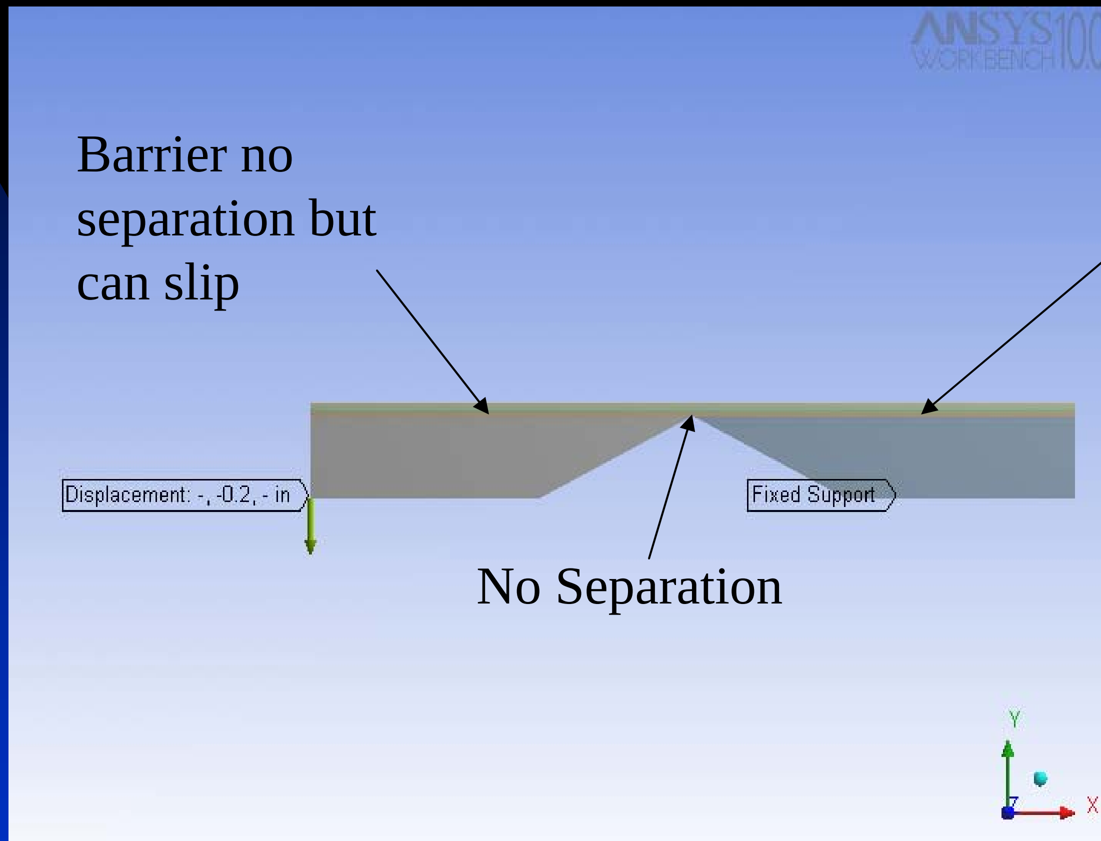
- Finite Element Analysis (FEA) technique devised to better understand stresses in barrier films when bent
  - Each layer of the barrier film modeled
    - Thickness
    - Material properties - modulus
  - Results include stresses and strains for each layer
  - SolidWorks CAD used to build the initial model
  - Model then transferred into ANSYS for analysis
    - ANSYS is a well known computer analysis software program

Analysis Model



- Typical VIP barrier

Model Boundary Conditions

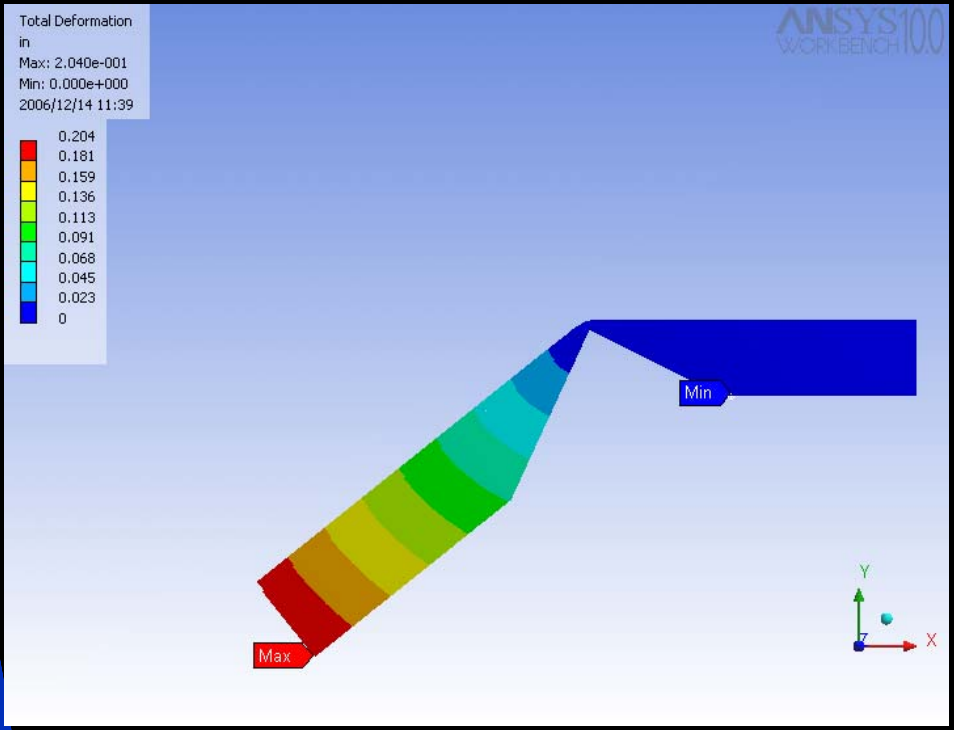


- Loads and constraints
  - Left trapezoid forced to bend about 45º

Analysis Results

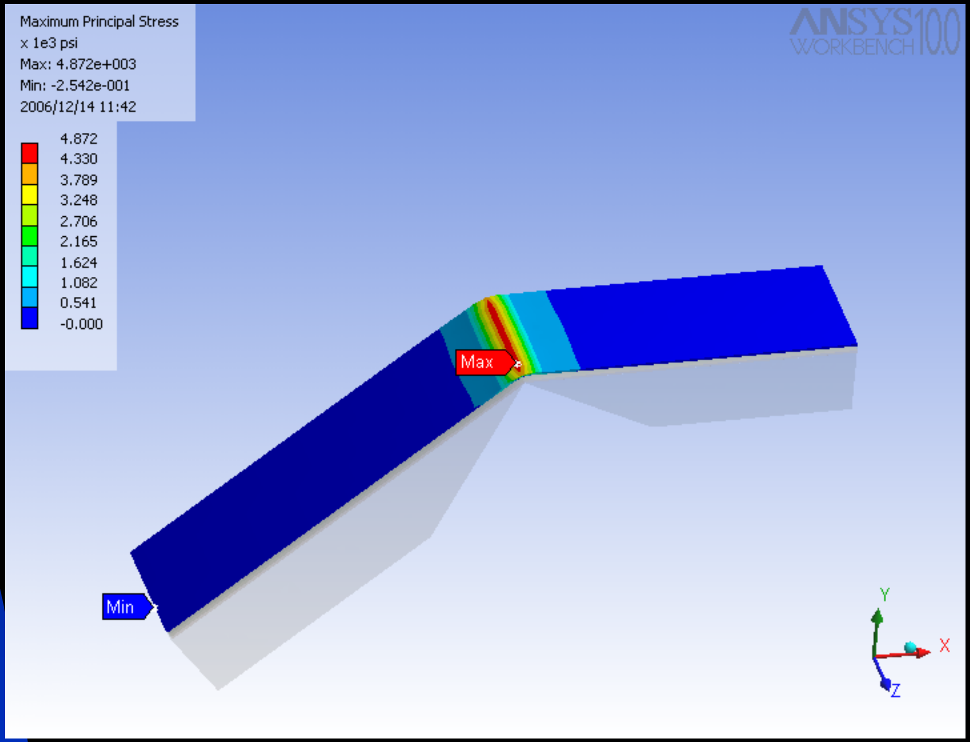
- Linear elastic analysis
  - Stress and strain at 90º bend is approx. twice the observed value at modeled 45º
- Each barrier film design results based on
  - Film layer thicknesses
  - Film layer structural material properties
- Use model for design comparisons
  - Relative results not absolute
  - Assumptions on bend radius, model mesh density, etc. can effect the predicted stress and strain

Analysis Results



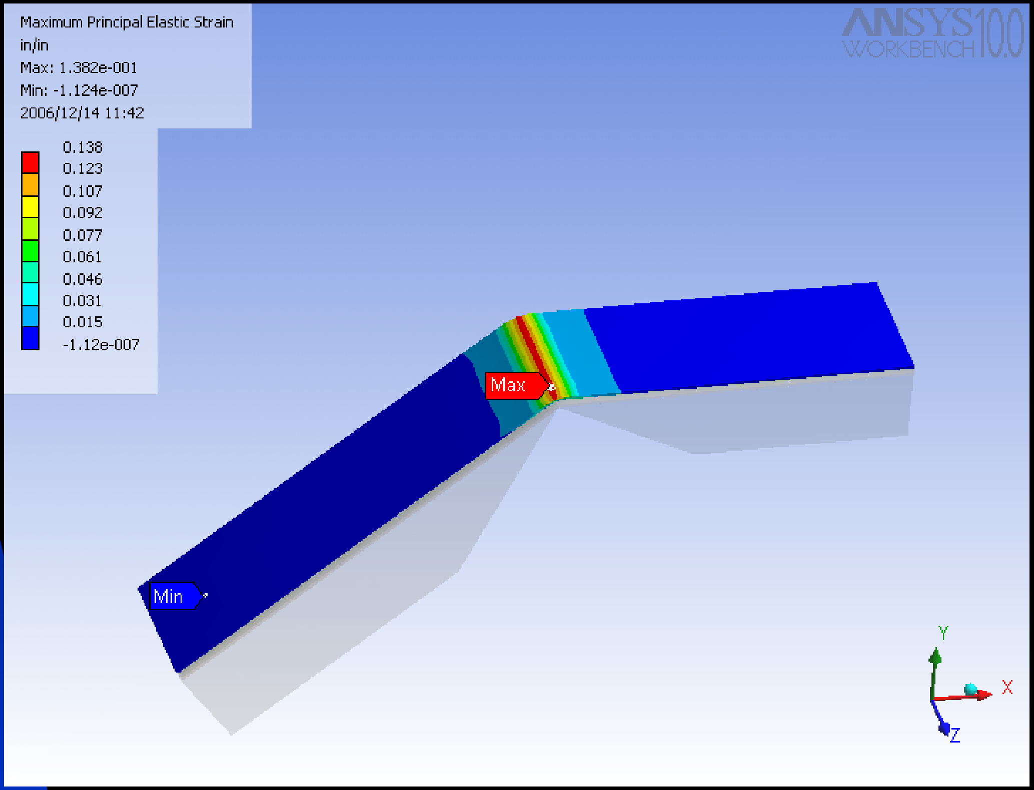
- Total deformation displayed in real scale
  - Approx. 45º rotation

Analysis Results



- Exterior PET barrier layer stress
  - Peak stress 4872 psi or 33591 kilopascal

Analysis Results



- Exterior PET barrier layer strain
  - Maximum strain 13.8%

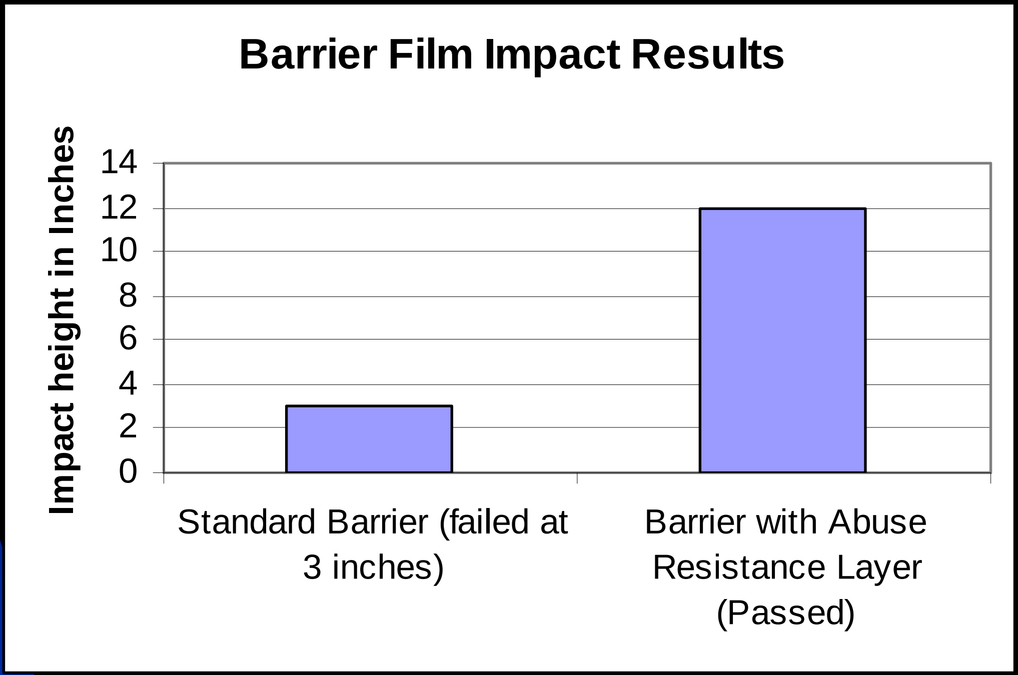
Analysis Conclusions

- Qualitatively the results are what would be expected
  - Highest stress and strain on outer surface of bend
- Model imposed bend radius is 2 times the barrier thickness since modeled two layers together
  - Simulates double layer near seal area
  - Inner surface radius is zero

Alternate Barrier Design

- Additional abuse resistant layer added to standard barrier film
  - Improved abrasion resistance
  - Improved puncture resistance
- Custom impact test developed
  - Wire brush dropped onto panel from various heights
    - Height at panel failure is the result

Impact Results

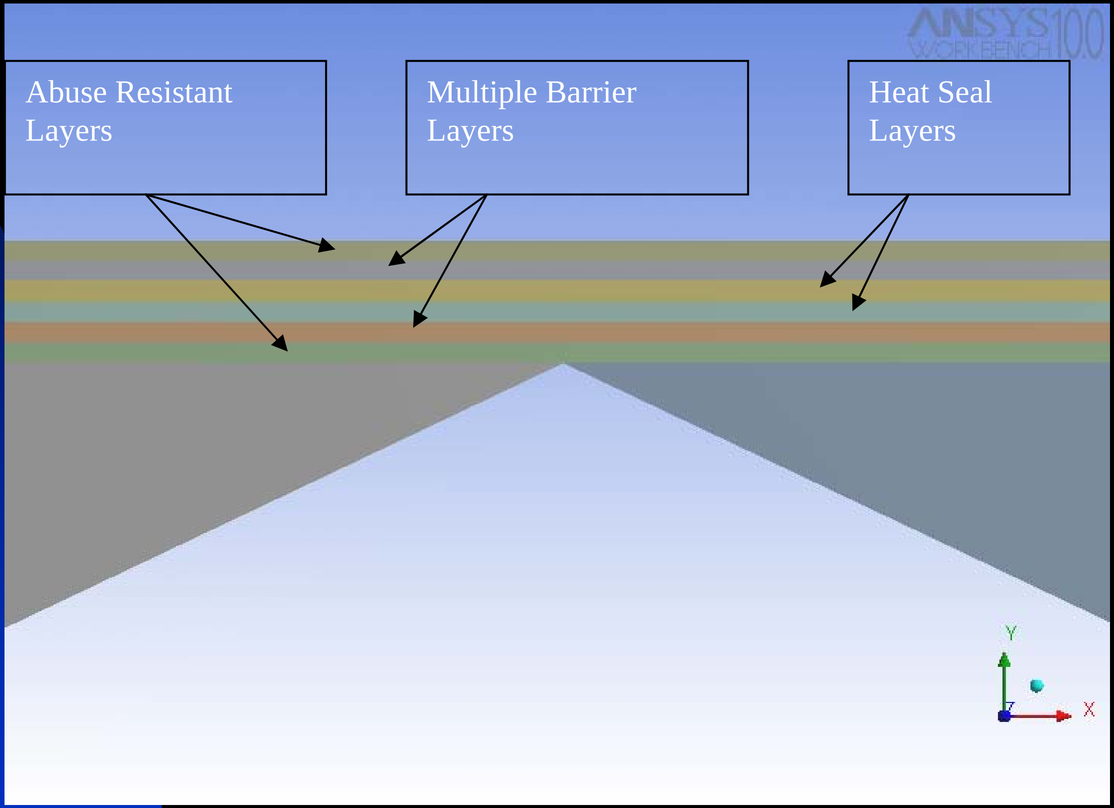


- Barrier with new abuse resistant layer
  - Passed at 12 inches (305 mm)
  - Failed at 18 inches (457 mm)
- Improvement over standard barrier 16 times higher impact energy
  - Energy increases with the square of the vertical distance

Abuse Resistant Layer Effect on Barrier Properties

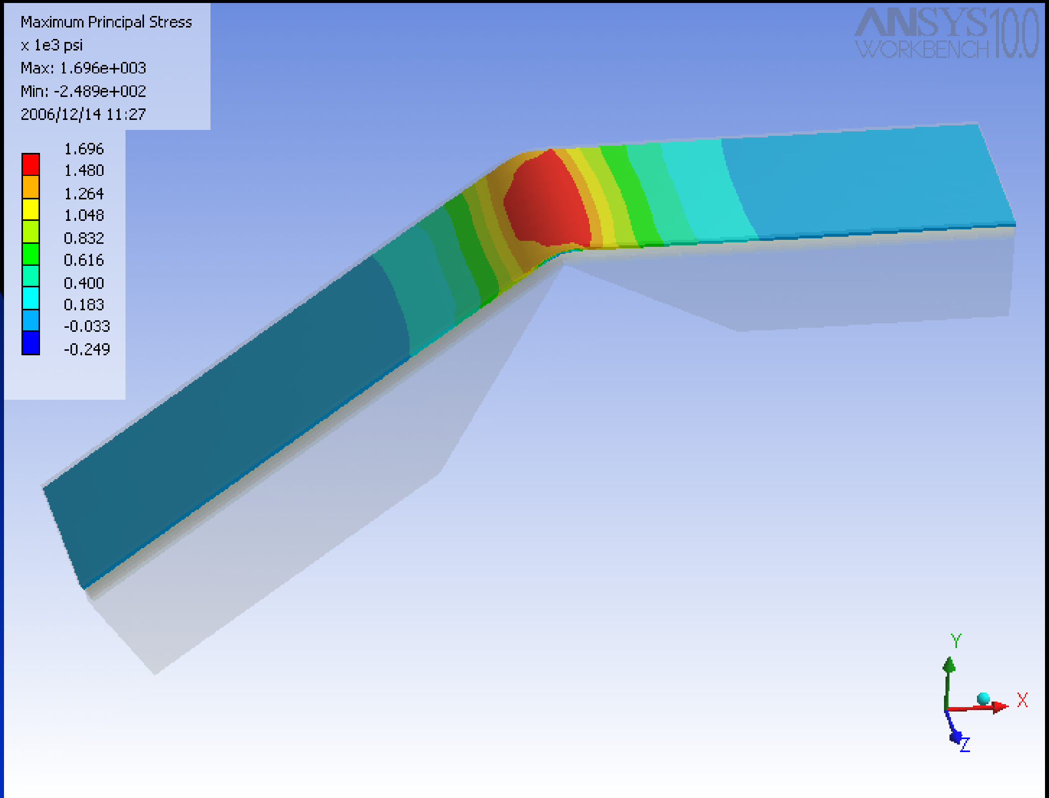
- Initial assumption – no effect
  - Diffusion rate of abuse resistant layer several hundred thousand times higher than the barrier
- If abuse resistant layer can reduce the barrier layer stresses and strain, possible benefit in addition to reduced impact damage

Analysis Model



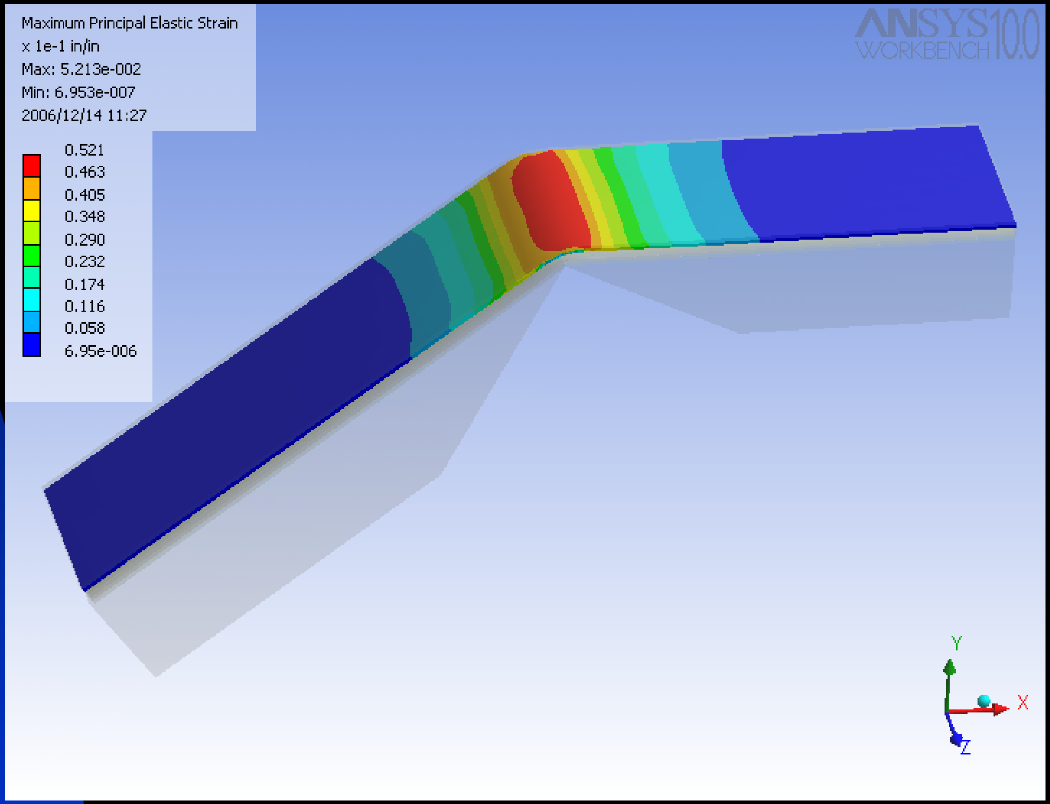
- Abuse resistant layer added to normal barrier film

Analysis Results



- PET barrier layer stress
  - Peak stress 1696 psi or 11693 kilopascal

Analysis Results



- PET barrier layer strain
  - Maximum strain 5.2%

Conclusions

- Abuse resistant layer reduces the barrier layer stress
  - Maximum stress and strain reduced by 65%
  - This should result in less damage during barrier bending and folding and taping seal flaps
- Abrasion and impact damage is also substantially reduced

Summary

- Importance of structural design in designing barrier films has been shown
- One method of relative structural evaluation of designs has been presented
- Benefit of adding an abuse resistant layer to barrier film designs has been shown