Testing and Predicting Impact Puncture Resistance of Multilayer Flexible Packaging Films

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TAPPI people resources solutions

Outline

Background

Test Development

- Preliminary tests on food drop tests
- Test set-up
- Sample Results

Model development

- Introduction
- Obtaining material properties
- Multilayer level predictions

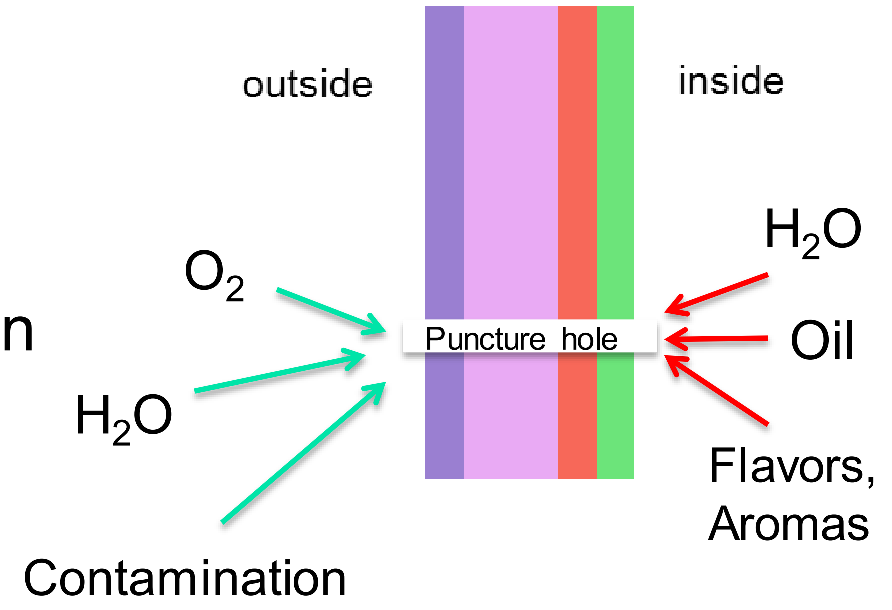
Conclusions

Role of Packaging

The main role of packaging is product protection

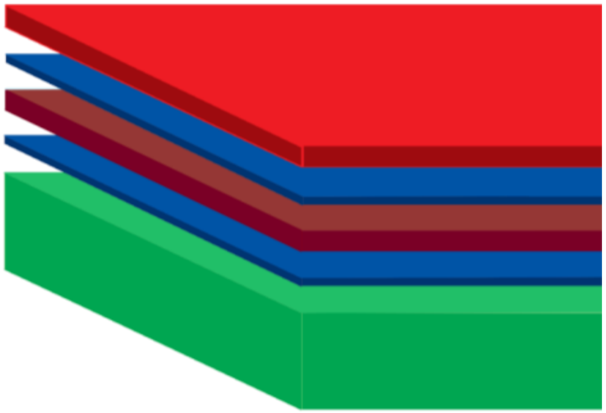
A hole in the packaging film can lead to:

- Loss of freshness
- Oil leakage
- Entrance of contamination



How to Make Puncture-Resistant Packaging?

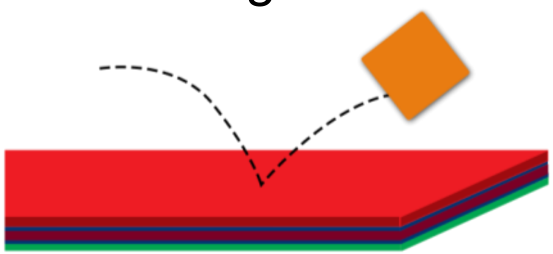
- Easy answer: Make everything thick
- Puncture-resistance with cost and material use reduction is much more difficult
- Options:
  - Thickness overall
  - Individual layer thickness
  - Location of layers
  - Resin types of each layer
  - Adhesion
  - Processing variables



There are many permutations!

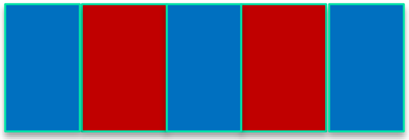
What is Key in Puncture Resistance?

Should sealant be stiff so sharp object doesn’t dig in?



Should sealant be soft so it deforms around sharp object?

Should the barrier layer be in split into thinner layers with soft material in between?



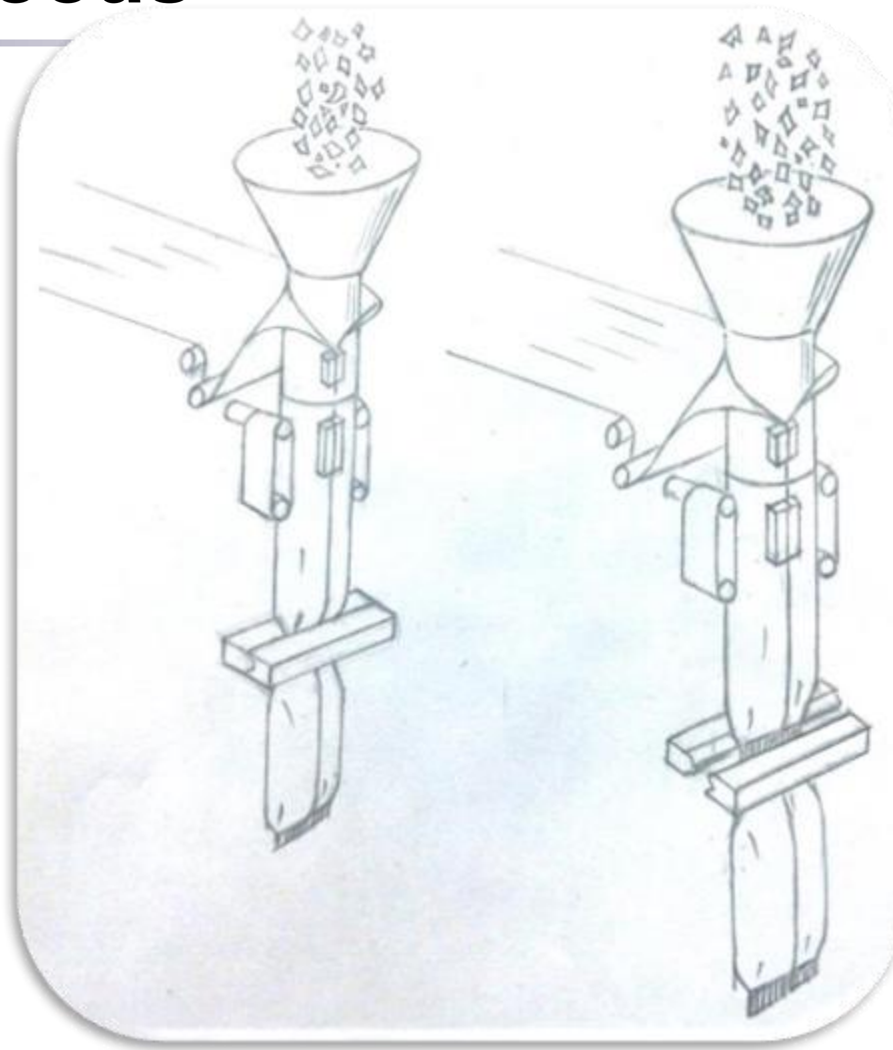
Should adhesion be weak or strong? Where?

How do we answer these questions?

Focus: Vertical Form-Fill-Seal for Packaging Dry Foods

Puncture Factors:

- Downgauging of package
  - Cost savings
  - Source reduction
- HDPE for moisture barrier (~25% stiffer)
- Higher speed



Focus: Dry foods - Crackers

Puncture Factor

"Razor-sharp" dry foods

"Crackers …, with relatively less cholesterol and calorie amounts, are expected to remain the highest selling salty snack segment …. Sales for the cracker segment are expected to rise by 33% … by 2018."

"Frito-Lay Dominates U.S. Salty Snacks, But Rising Cracker Sales Could Stall Growth." *Forbes*. Forbes Magazine, n.d. Web. 21 Oct. 2014.

Test Improvement Concepts

Trial and Error

- Resource intensive
- Lost production time
- High amount of material waste, transitions
- Lab data may not be meaningful or convincing
- Little access to filling lines

DuPont 9-layer blown film line
Wilmington, DE

Current Puncture Tests Predict Poorly

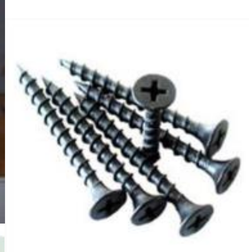
Tensile test

Current tests:

- Don't relate to actual filling lines well (too slow)
- Are cumbersome
- Are subjective
- Have poor gage repeatability, reproducibility, and resolution

<u>Practical Tests</u>

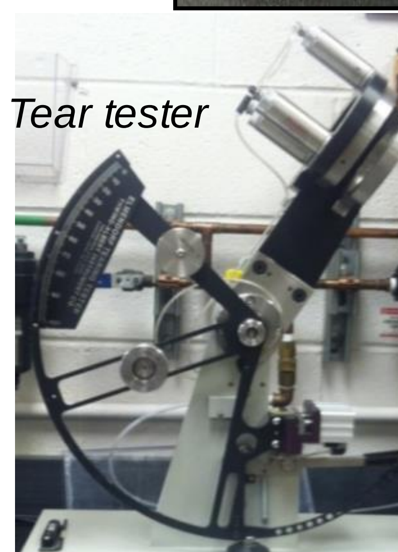
- Gelbo flex
- Dart drop
- Screw drop



<u>Film Physical Properties</u>

- Needle Puncture
- Elmendorf tear
- Graves tear
- Tensile tests
- Spencer Impact
- Scratch test

Tear tester



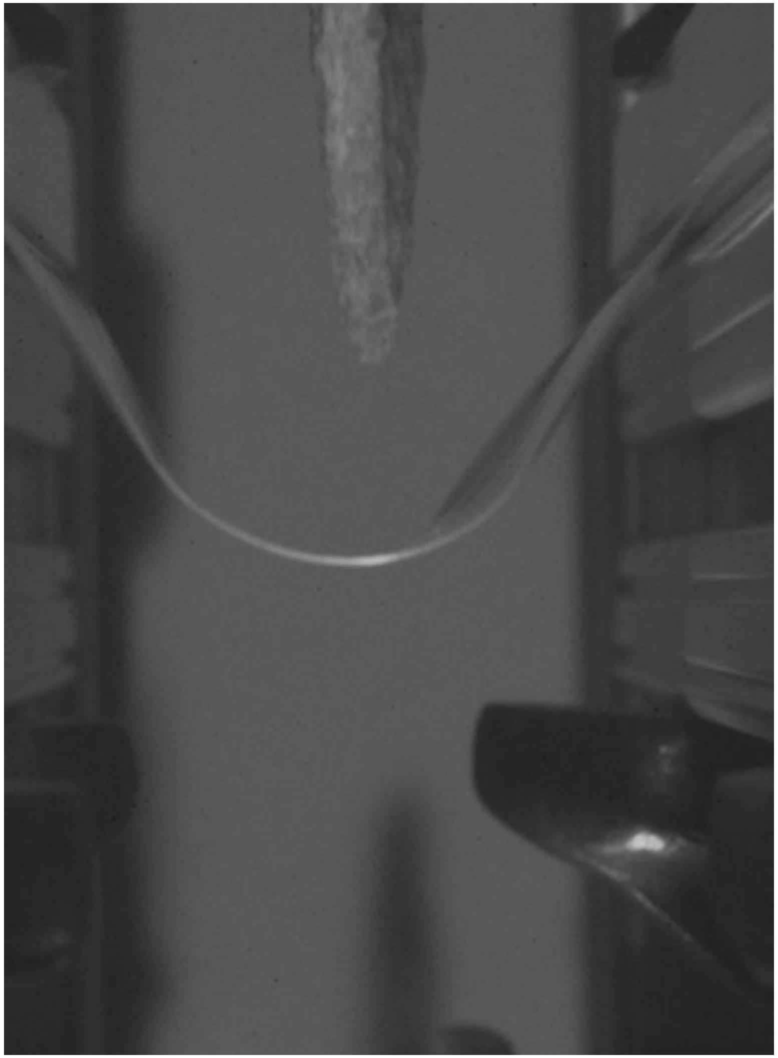
Screw drop

Test Development

- Unique characteristics
  - Speed
  - Diameter of punctured holes
  - Low stiffness and strength of food (deformation during event)
- Preliminary study
  - Non-woven cracker
  - Drop tests

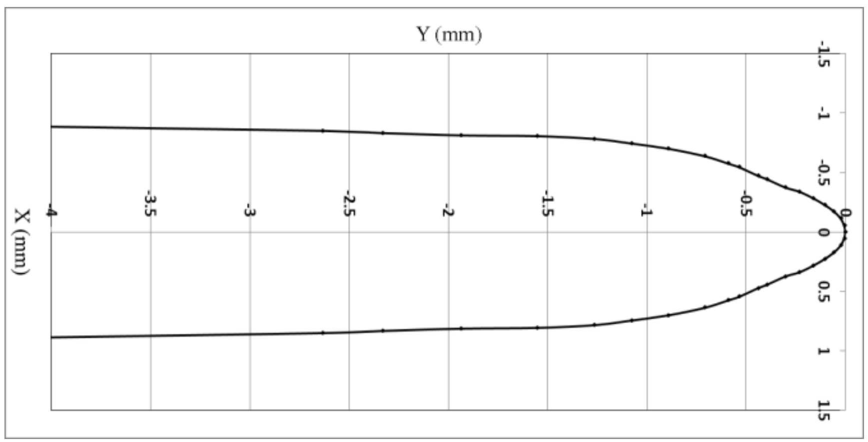
Cracker Drop Video

Impact zone of
1.83 m (6 ft) drop
height

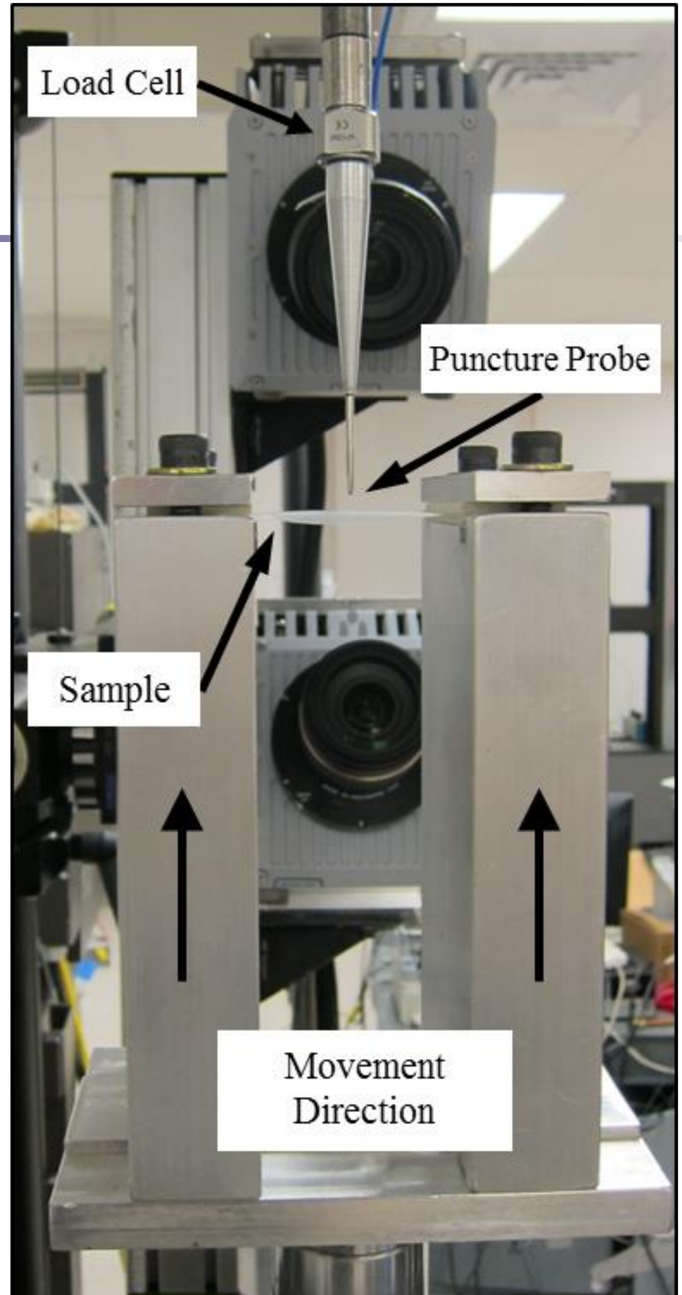


Reverse Impact Puncture Test

- Hydraulic frame with constant speed up to 12.7 m/s
- 5 cm x 5 cm square test specimen
- Cardboard tabs used in clamping device to distribute stress
- Hardened steel needle used as the probe

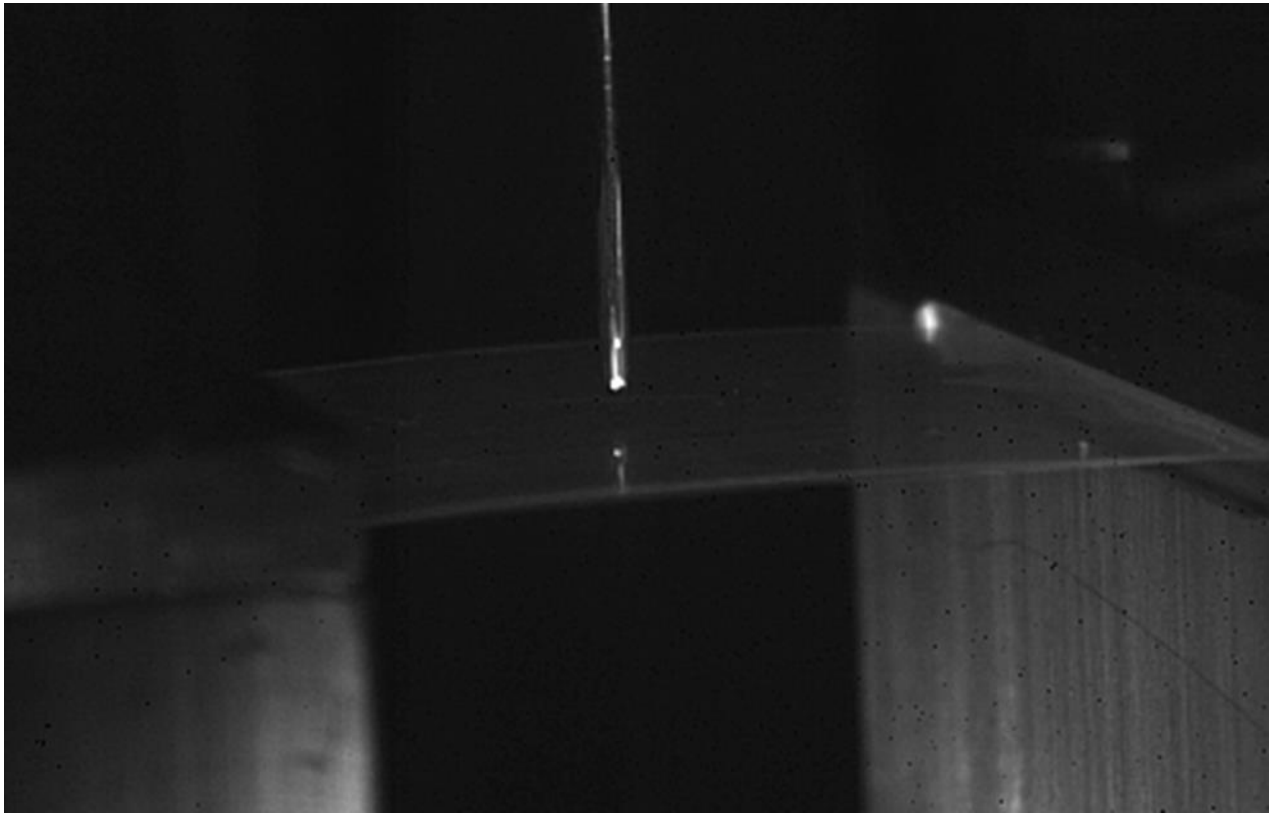


- 22 N load cell
- High speed camera (50,000 frames/s)
- Data acquisition system


Load Cell
Puncture Probe
Sample
Movement
Direction

Normal Angle Probe Test

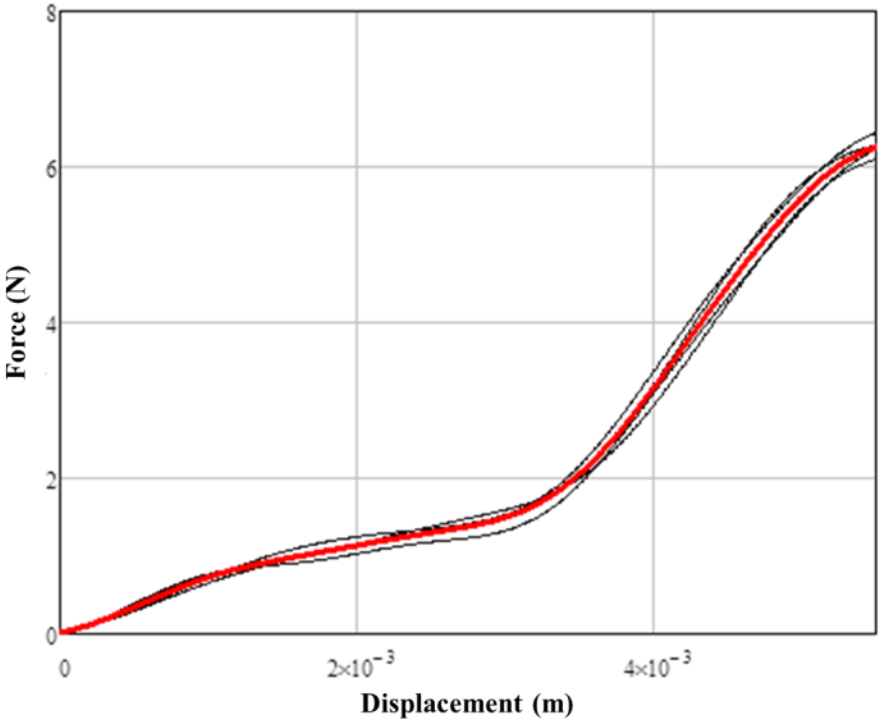
Statistically correlated to cracker drop



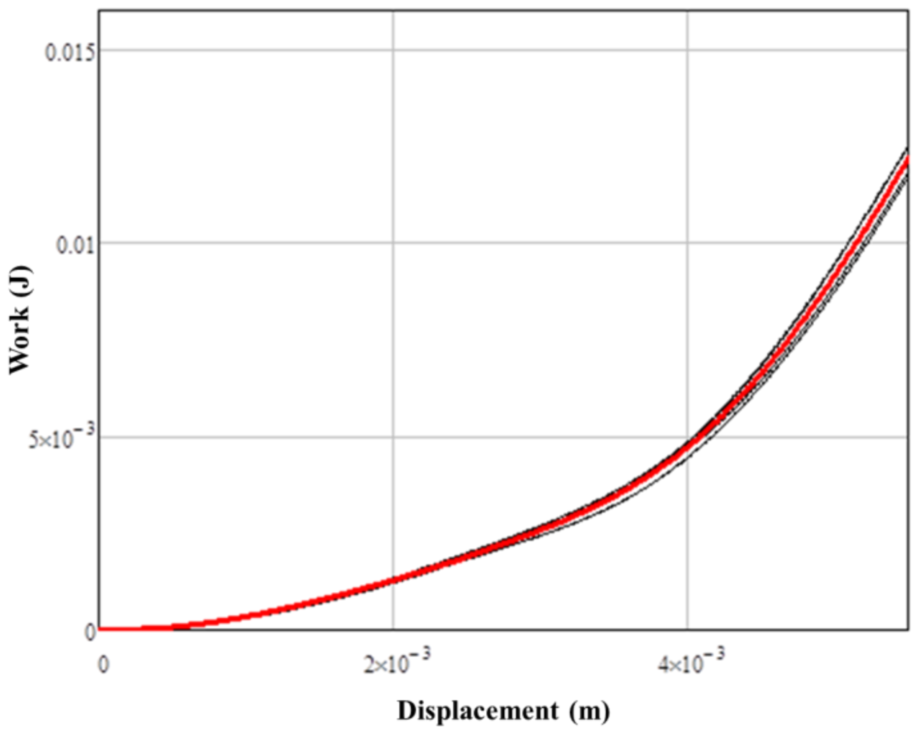
Experimental Film Structures

Sample	Thickness, µm	% PA	Sealant	
1	55	5.6	EVA + Ionomer	
1A	75	7.0	EVA + Ionomer	
1B	83	18.4	EVA + Ionomer	
1C	72	10.3	EVA + Ionomer	No Tie 1
2	65	7.5	Ionomer	
2A	74	11.3	Ionomer	
2B	80	17.7	Ionomer	

Sample Results

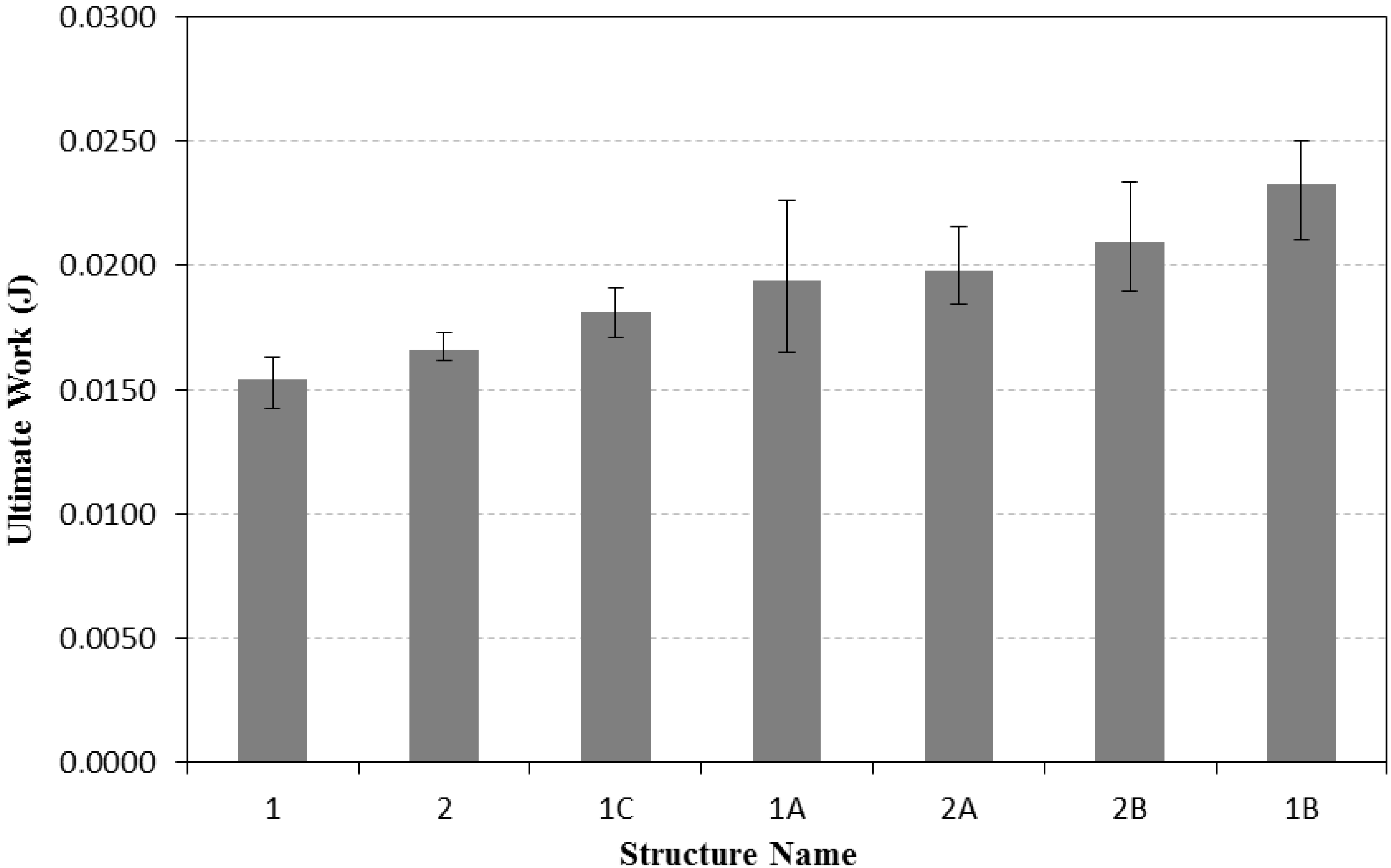


Force vs. Displacement



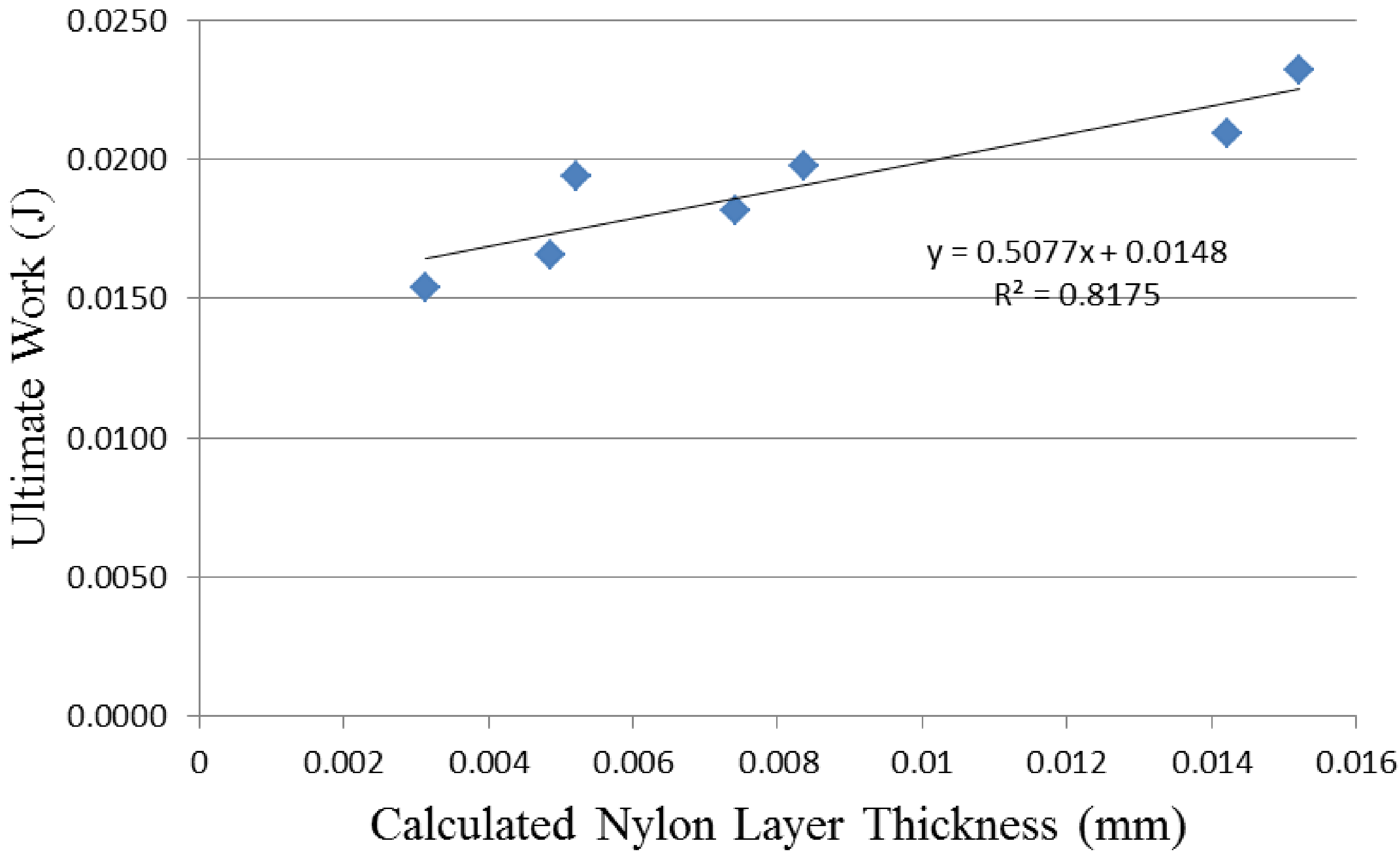
Work vs. Displacement

Results



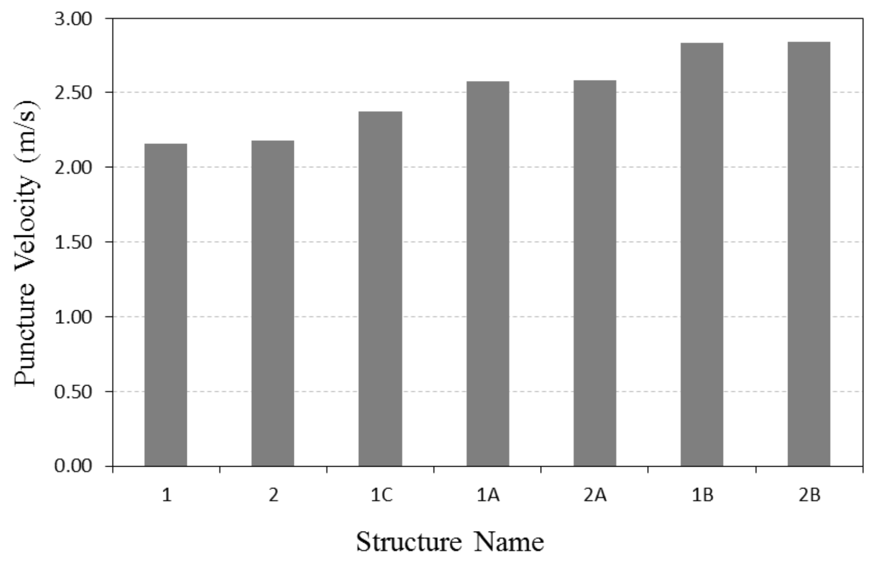
0.0300
0.0250
0.0200
0.0150
0.0100
0.0050
0.0000
Ultimate Work (J)
1
2
1C
1A
2A
2B
1B
Structure Name

Increasing Nylon Thickness Increases Puncture Resistance



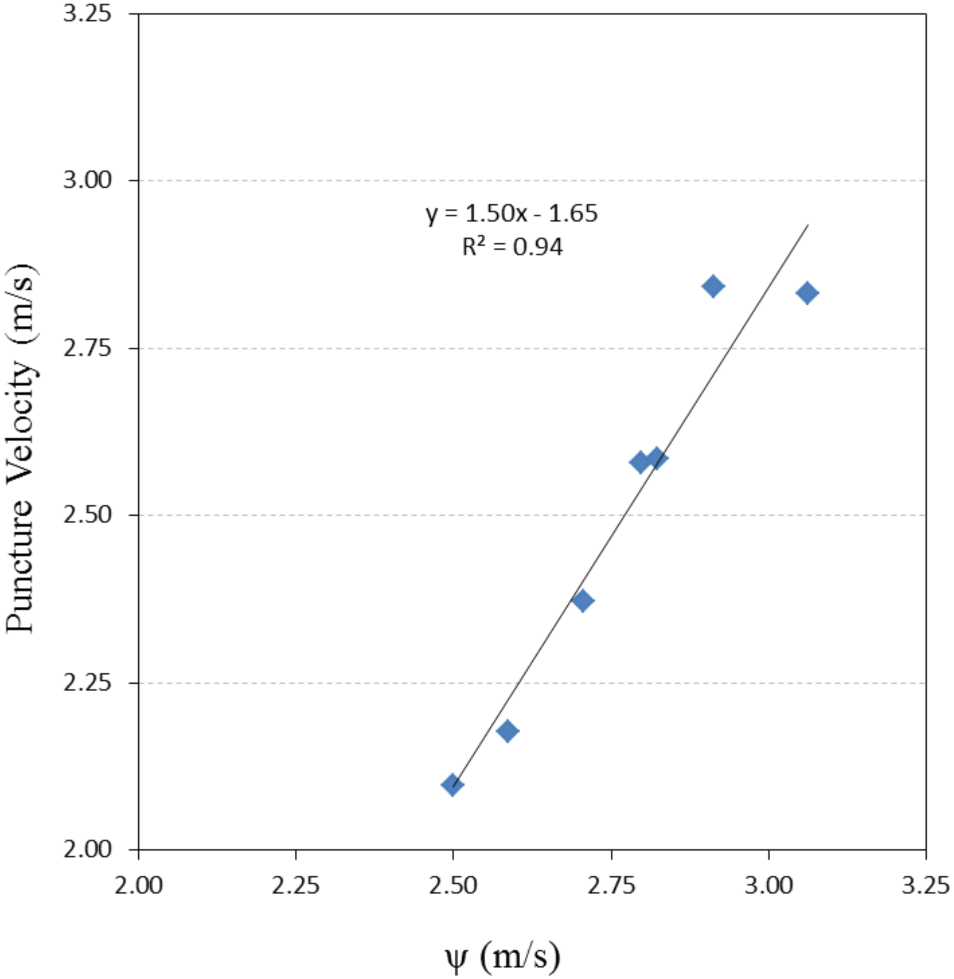
Comparison with Drop Test

- Used bullets rather than screws
  - Better flying stability
  - Weight similar to cracker
  - Similar tip dimensions as holes from cracker drop test
- Puncture velocity computed from high speed camera images



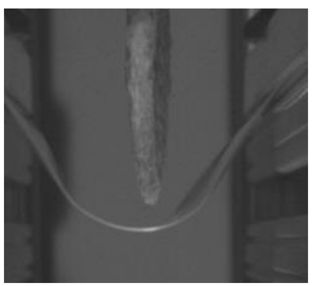
Comparison of Drop and Impact Tests

- Converted ultimate work into units of velocity
- $\psi = \sqrt{\frac{2 * Work_{ultimate}}{Mass_{projectile}}}$

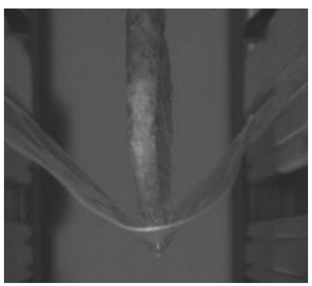


Model Development

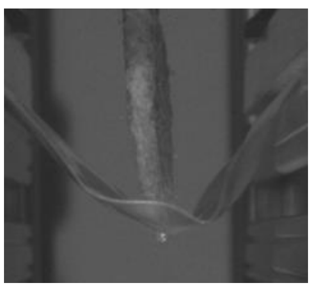
- Time scales short: < 0.01 s for deformation and puncture
- Failure zone is small: < 0.5 mm
- Probe or cracker is stiffer than film and not deformed during event



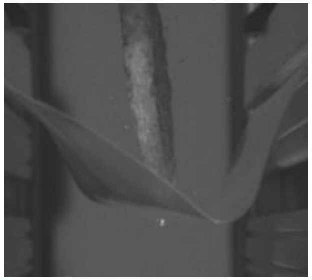
t = 0.0000s



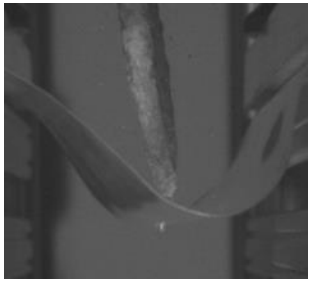
t = 0.0024s



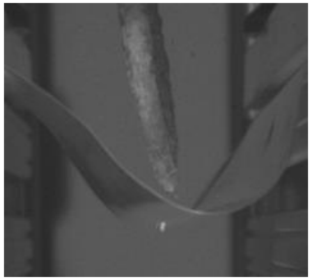
t = 0.0048s



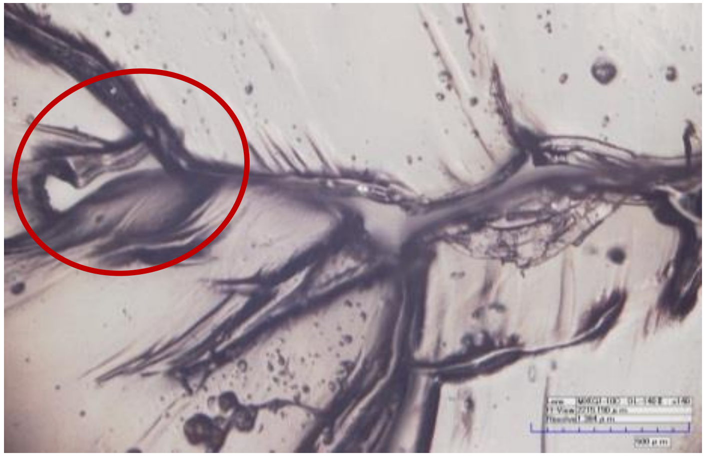
t = 0.0072s



t = 0.0096s

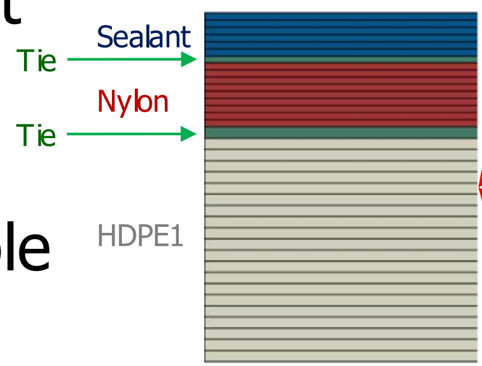


t = 0.0101s

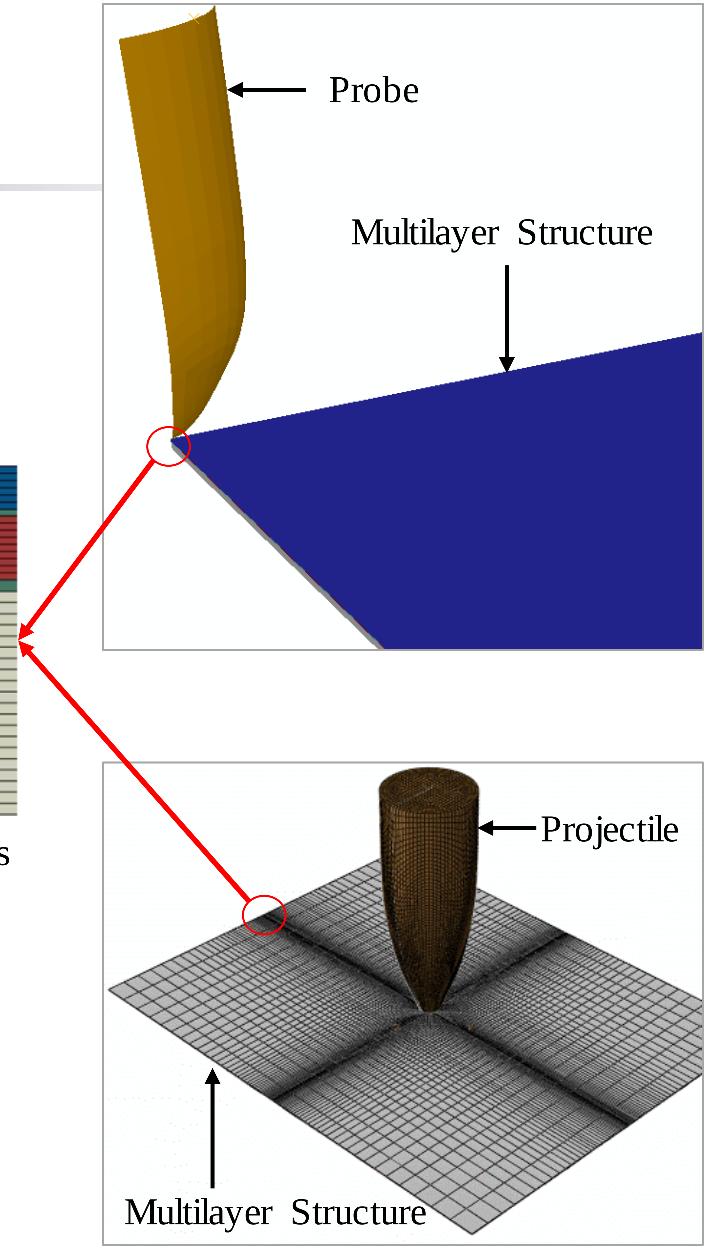


Model Characteristics

- Abaqus/Explicit software with explicit central-difference time integration
- Rigid, non-deformable probe
- Each material in the film structure is considered explicitly

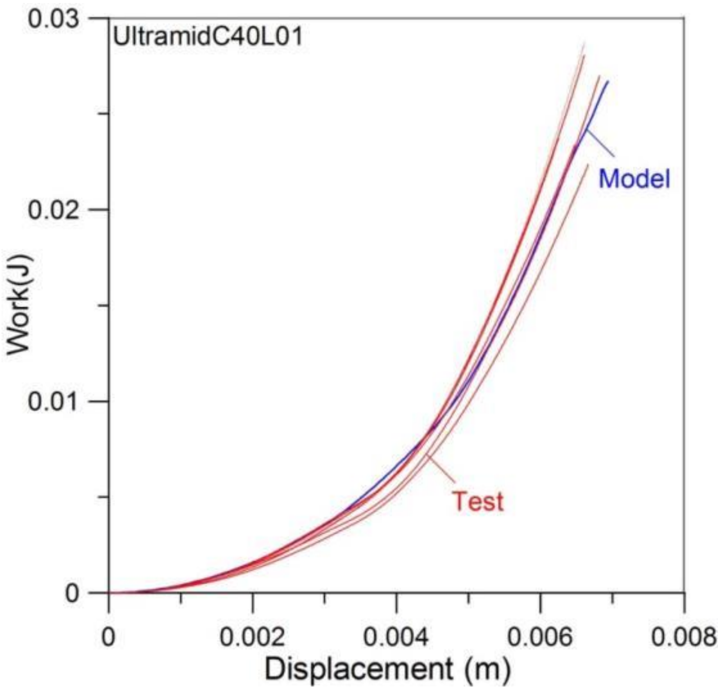


Thickness Details

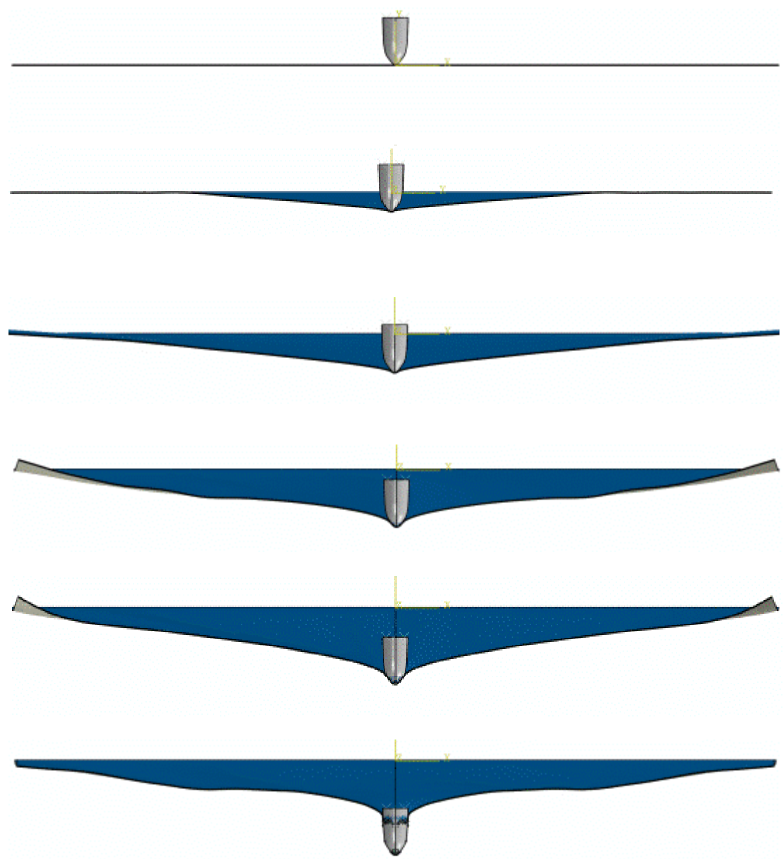


Obtaining Material Parameters

- Tensile tests on individual layers at 0.001 and 1 s^{-1}
- Reverse needle puncture test on individual layers
- Compare with numerical model
  - Begin with tensile test results
  - Make minor modifications to parameters to ensure good fit



Predicted Deformation Shapes



T=0.0ms

T=0.3ms

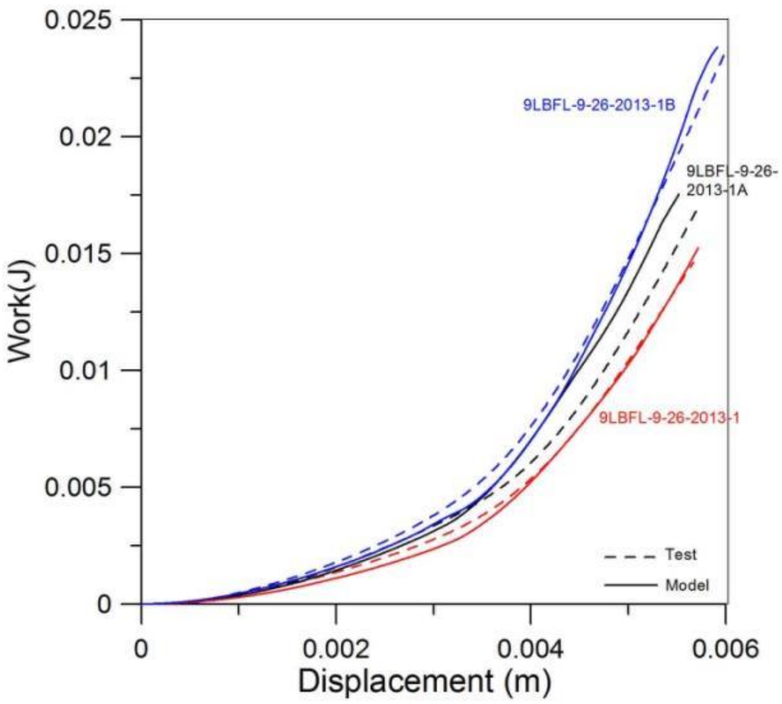
T=0.6ms

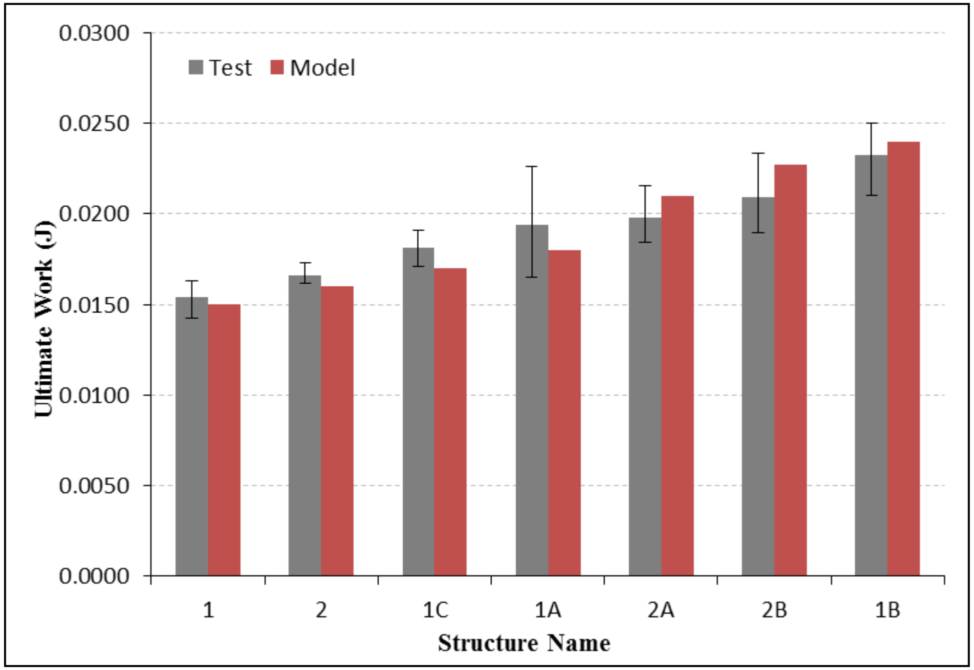
T=0.9ms

T=1.2ms

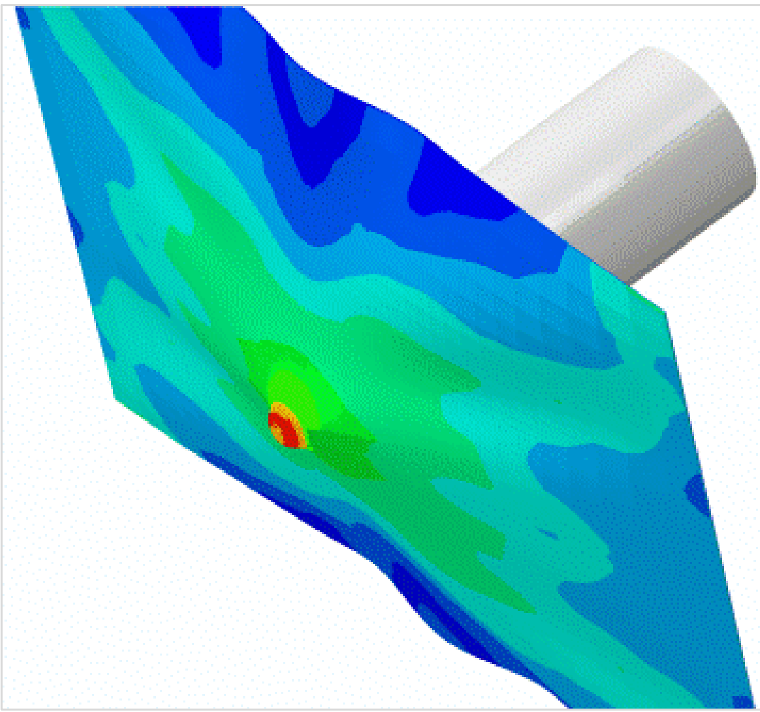
T=1.5ms

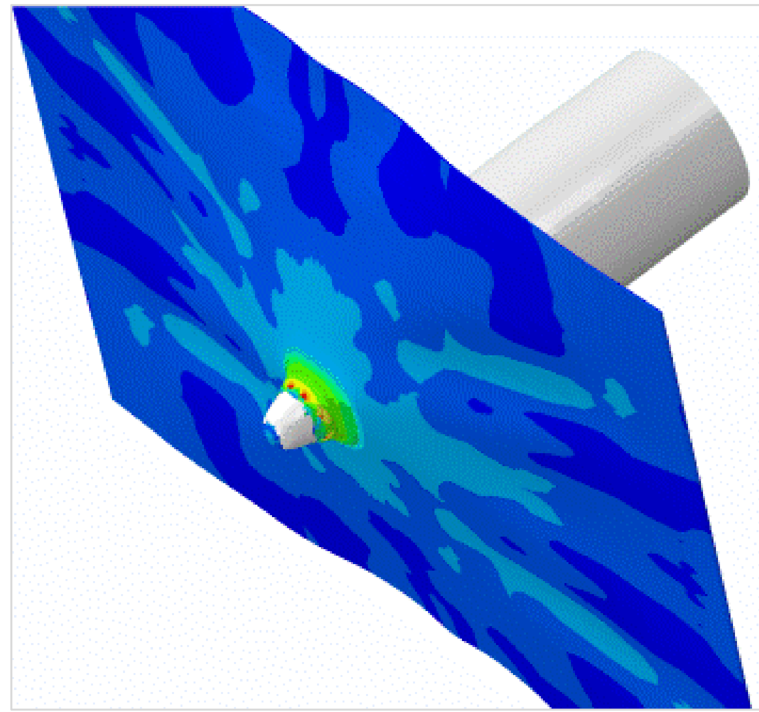
Comparison of Model and Reverse Puncture Test Results



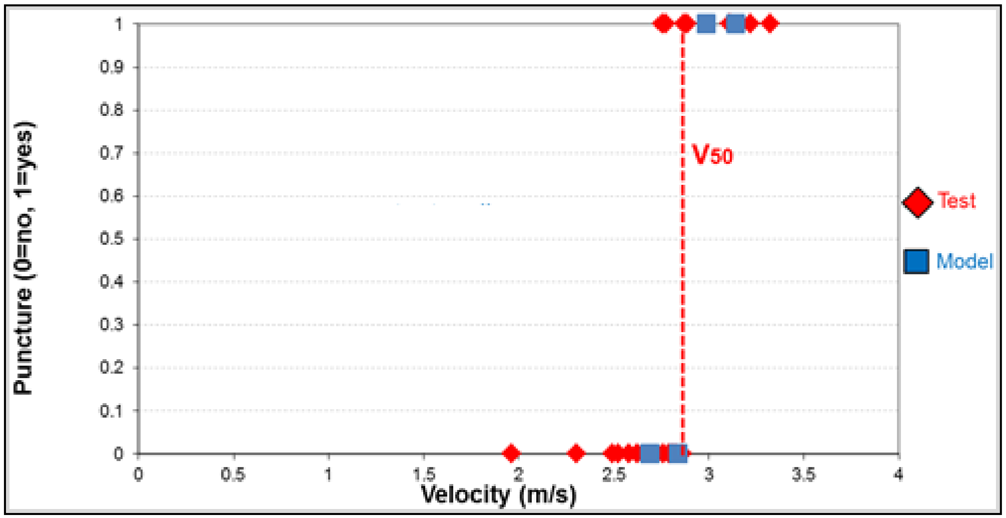


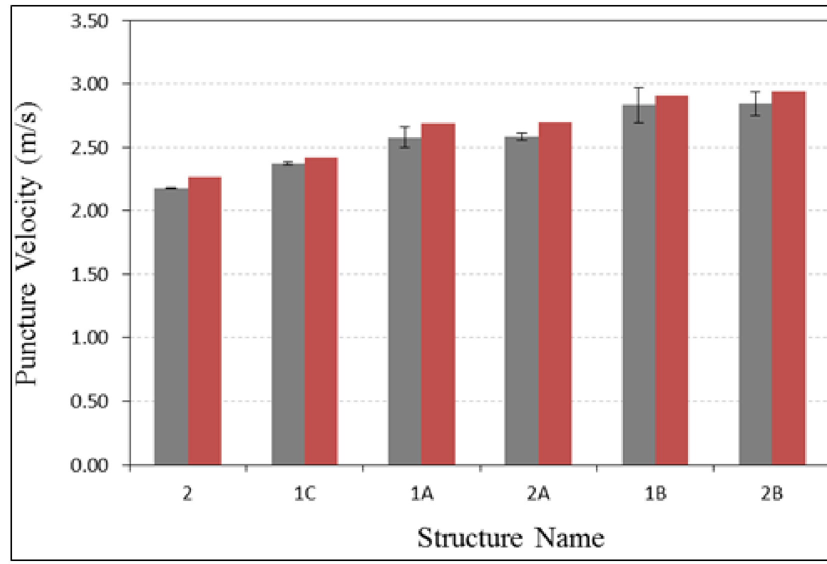
Simulation of Bullet Drop Test





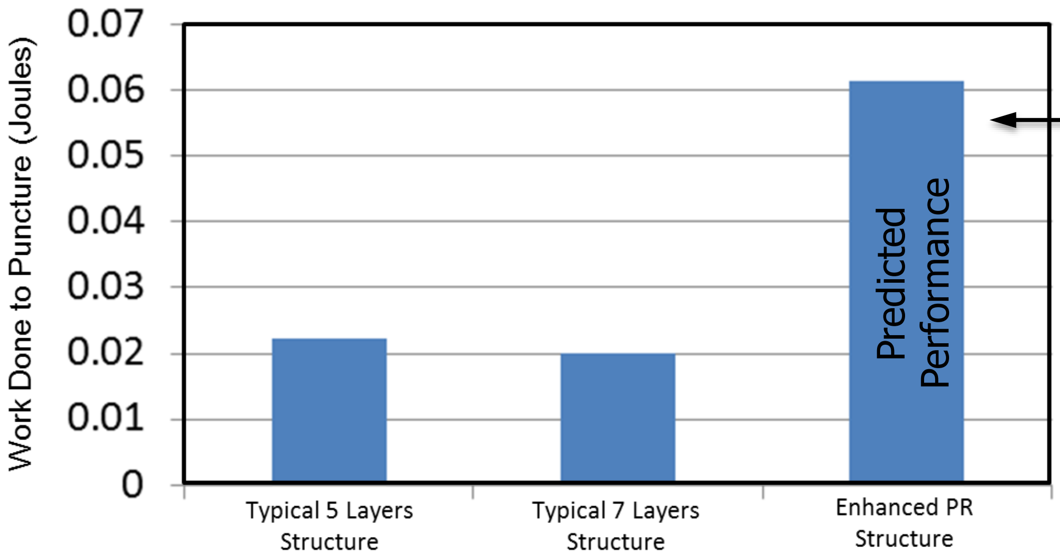
Comparison of Model and Bullet Drop Test

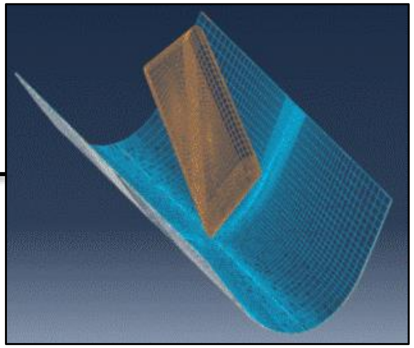


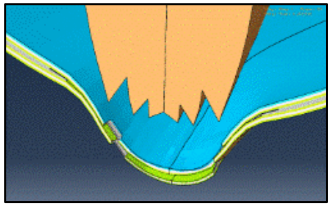


Current and Future Work

- Developing the ability to use the numerical models design packages
  - Building library of “layers”
  - Considering Interlayer Adhesion
  - Considering Material Properties and Geometry of the Impacting Food







Use numerical models to discover ways to improve the puncture resistance of packages

Conclusions

- High-sped reverse needle impact test developed
  - Differentiates amongst flexible packaging samples
  - Correlates with known structure effects
  - Agrees with drop test results
- Numerical model developed to predict impact puncture resistance
  - Method developed to obtain material parameters for each layer
  - Model agrees with experimental data from reverse needle puncture test
  - Model agrees with experimental data from bullet drop test
- New Test and model will be useful for developing improved packaging films

Testing and Predicting Impact Puncture Resistance

Thank you

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