Impact Puncture Resistance of Multilayer Flexible Food Packages

Barry A. Morris, Diane M. Hahm – DuPont Performance Polymers

Leopoldo A. Carbajal, Rong Jiao and Randy R. Kendzierski – DuPont Engineering Technology

SPE FlexPackCon Conference
October 10-12, 2016
Memphis, TN
Outline

• Background

• Review of Lab Test Development

• Model Development

• 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

- Flavors, Aromas
- Contamination
- $H_2O$
- $O_2$
- Oil
- $H_2O$
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 there is no deformation and sharp object doesn’t dig in?

Should sealant be soft with high elongation so it deforms around sharp object?

Should the barrier layers be in one thick layer or be split into thinner, separated layers with soft material in between?

Should adhesion be weak or strong? Where in the structure should the adhesion be?

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

Where Most Sustainable Packaging Efforts are Directed

- 65% Design for Recyclability or use of Recycled Content
- 57% Weight Reduction
- 41% Renewable or Bio-based Materials
- 25% Compostable Materials
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.”

Test Improvement Concepts

Trial and Error

- Resource intensive (especially if replicates and controls are included)
- 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

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

**Practical Tests**
- Gelbo flex
- Dart drop
- Screw drop

**Film Physical Properties**
- Needle Puncture
- Elmendorf tear
- Graves tear
- Tensile tests
- Spencer Impact
- Scratch test
Experiment with Current Puncture Tests

Controlled test with 5 and 7 layer films, varying nylon thickness, resins, etc.

<table>
<thead>
<tr>
<th>Key</th>
<th>Poor Correlation</th>
<th>Med Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD/tie/ny/tie/Sealant</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Total Thickness (mil)</th>
<th>Total Nylon Thickness (mil)</th>
<th>Total HDPE Thickness (mil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elmendorf Tear (MD&amp;TD)</td>
<td>R² = 0.0025</td>
<td>R² = 0.0015</td>
<td>R² = 0.0019</td>
</tr>
<tr>
<td>GravesTear (MD &amp;TD)</td>
<td>R² = 0.0024</td>
<td>R² = 0.3038</td>
<td>R² = 0.0601</td>
</tr>
<tr>
<td>Tensile Break</td>
<td>R² = 0.2741</td>
<td>R² = 0.3451</td>
<td>R² = 0.106</td>
</tr>
<tr>
<td>Spencer Impact</td>
<td>R² = 0.2643</td>
<td>R² = 0.8076</td>
<td>R² = 0.0233</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Total Thickness (mil)</th>
<th>Total Nylon Thickness (mil)</th>
<th>Total HDPE Thickness (mil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elmendorf Tear (MD&amp;TD)</td>
<td>R² = 0.1565</td>
<td>R² = 0.0018</td>
<td>R² = 0.4115</td>
</tr>
<tr>
<td>GravesTear (MD &amp;TD)</td>
<td>R² = 0.1169</td>
<td>R² = 0.2355</td>
<td>R² = 0.2586</td>
</tr>
<tr>
<td>Tensile Break</td>
<td>R² = 0.0037</td>
<td>R² = 0.209</td>
<td>R² = 8E-05</td>
</tr>
<tr>
<td>Spencer Impact</td>
<td>R² = 0.0444</td>
<td>R² = 0.2198</td>
<td>R² = 0.1727</td>
</tr>
</tbody>
</table>

Lab tests showed poor correlation
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
Cracker Drop Tests

- No significant breakage/deformation of cracker => can use steel probe
- Pinhole at 6.1 m/s – gave bounds of speed for test
  - Ranged up to 12.7 m/s
  - Initial test at 4.2 m/s (3 ft drop)
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
Experimental Film Structures

<table>
<thead>
<tr>
<th>Sample</th>
<th>Thickness, µm</th>
<th>% PA</th>
<th>Sealant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55</td>
<td>5.6</td>
<td>EVA + Ionomer</td>
</tr>
<tr>
<td>1A</td>
<td>75</td>
<td>7.0</td>
<td>EVA + Ionomer</td>
</tr>
<tr>
<td>1B</td>
<td>83</td>
<td>18.4</td>
<td>EVA + Ionomer</td>
</tr>
<tr>
<td>1C</td>
<td>72</td>
<td>10.3</td>
<td>EVA + Ionomer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No Tie 1</td>
</tr>
<tr>
<td>2</td>
<td>65</td>
<td>7.5</td>
<td>Ionomer</td>
</tr>
<tr>
<td>2A</td>
<td>74</td>
<td>11.3</td>
<td>Ionomer</td>
</tr>
<tr>
<td>2B</td>
<td>80</td>
<td>17.7</td>
<td>Ionomer</td>
</tr>
</tbody>
</table>
Sample Results

**Force vs. Displacement**

**Work vs. Displacement**
Results

The bar chart illustrates the Ultimate Work (J) for different structures. The structure names range from 1 to 1B. Structure 1A has the highest Ultimate Work, followed by Structure 2B and 1B, which both have similar Ultimate Work. Structures 1, 2, and 1C have lower Ultimate Work compared to the others.
Results

![Bar chart showing ultimate work for different structure names. The x-axis represents the structure names (1, 2, 1C, 1A, 2A, 2B, 1B), and the y-axis represents the ultimate work in J. The bars indicate the range of values with error bars.]
Increasing Nylon Thickness Increases Puncture Resistance

Increasing nylon thickness increases puncture resistance. The graph shows a linear relationship between calculated nylon layer thickness (mm) and ultimate work (J). The equation of the line is:

\[ y = 0.5077x + 0.0148 \]

with a coefficient of determination \( R^2 = 0.8175 \).
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

\[ \psi = \sqrt{\frac{2 \times \text{Work}_{\text{ultimate}}}{\text{Mass}_{\text{projectile}}}} \]
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
Model Characteristics

Abaqus/Explicit software with explicit central-difference time integration

Rigid, non-deformable probe

Each material in the film structure is considered explicitly
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-speed 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
Thank You

Questions?

Barry Morris
DuPont Performance Materials
Wilmington, DE
Barry.a.morris@dupont.com