Effect Of Time, Temperature, And Draw Down On Interlayer Peel Strength During Coextrusion Coating, Film Casting and Film Blowing

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Outline

Background
Experimental
Results
Discussion
  Time
  Temperature
  Area Creation
Practical Implications
Conclusions
Coextrusion

- Combination of resins in the melt
- Cost effect technique to make functional articles

[Diagram of coextrusion process with labels for die, chill roll, nip roll, substrate, line speed, air gap, and note that the diagram is not drawn to scale.]
Many factors influence adhesion

- Compatibility of polymers and their ability to interdiffuse
- Presence of functional groups to promote chemical bonding at the interface
- Contact time and temperature
- Thickness and physical properties of the layers
- Stress imparted by drawing and other means
- The environment the article is subjected in its end use (RH, temperature, chemicals, etc.)
Time in Air Gap Known to Effect Adhesion to Solid Substrates

Antonov and Soutar (1991) little attention given to affect on interlayer adhesion in coextrusion.
Blown Film
Morris (1996)

Blown Film Results
(HDPE-Adh-EVOH)

Peel Strength (g/25mm)

EVOH Process time (sec)

- ADH1
- ADH2
- ADH3
Coextrusion tie resin technology

Tie resin is polyethylene or ethylene copolymer based to promote diffusion at PE/Tie interface.

Tie has anhydride groups for chemical interaction at Tie/EVOH interface.

Tie may contain modifiers such as rubber that enhance peel strength.
Blown Film

Blown Film Results (HDPE-Adh-EVOH)

- Tie resins
  - ADH1: LLDPE, low anhydride
  - ADH2: LLDPE, high anhydride
  - ADH3: rubber modified LLDPE, medium anhydride

- Stress believed to be involved

Morris, 1996 SPE ANTEC
Current Study

Purpose: Look at the effect of process time on interlayer adhesion in coextrusion coating/cast film

What is the appropriate process time?

**Constant velocity**

\[ t_f = TIAG = \frac{L}{v_f} \]

**Linear model**

\[ t_f = \frac{L}{v_f} \left( \frac{DDR}{DDR - 1} \right) \ln(DDR) \]

**Newtonian Model**

\[ t_f = \frac{L}{v_f} \left( \frac{DDR - 1}{\ln(DDR)} \right) \]
Experimental

Structure: Kraft Paper/LDPE//(tie-EVOH-tie-LDPE)

19 5 6.3 5 25 microns

Resins:

<table>
<thead>
<tr>
<th>Resin</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDPE</td>
<td>Standard coating grade</td>
</tr>
<tr>
<td>EVOH</td>
<td>44 mol % ethylene</td>
</tr>
<tr>
<td>Tie 1</td>
<td>LLDPE with low anhydride</td>
</tr>
<tr>
<td>Tie 2</td>
<td>LLDPE with high anhydride</td>
</tr>
<tr>
<td>Tie 3</td>
<td>Rubber modified LDPE with intermediate anhydride</td>
</tr>
</tbody>
</table>

Variables:

- Die gap: 0.5 mm, DDR 18
- Air gap: 13 - 25 cm (5 – 10 in)
- Line speed: 61 – 183 m/min (200 – 600 fpm)
- Process time: 0.22 – 1.3 s
Experimental

Structure: Al/(EAA-LDPE)

50  5  25 microns

Resins:

• EAA: 9% AA, 10 MI
• LDPE: 0.923 g/cc, 4.5 MI

Variables:

• Die gap: 0.5 mm, DDR: 20
• Air gap: 11.4 – 22.9 cm (4.5 – 9 in)
• Line speed: 61 – 183 m/min (200 – 600 fpm)
• Process time: 0.21 – 0.42 s
Results

Coextrusion Coating Results
Paper/LDPE//(tie/EVOH/tie/LDPE)

Peel Strength to EVOH, g/25mm

Tie3
Tie2
Tie1

Process Time, s

Results

Coextrusion Coating
50-μm Al/(5-μm EAA - 25μm LDPE)

Peel Strength to LDPE, g/25mm vs. Process Time, s
Comparison of EC and BF Results

Extrusion Coating results suggest kinetic effect
Slope Differences

\[ G_a = W_b(1 + \Phi(R, T)) \]

where

- \( G_a \) = fracture energy
- \( W_b \) = work of adhesion or bonding
- \( \Phi \) = local viscoelastic energy dissipation
- \( R \) = rate
- \( T \) = temperature.

Multiplying effect

- Rubber modification increases \( \Phi \)
- If \( W_b \) = constant, adding rubber shifts curve upward (blown film)
- If \( W_b \) increases with process time (kinetics), slope also increases
Differences between blown and cast film

Time scales

- Process time
  - Blown film: 5-10 s
  - Cast film/EC: 0.2-1.0 s

- Crystallization time
  - Blown film: 2-5 s
  - Cast film/EC: 2-10 ms

Temperature during drawing

Interfacial area creation
Temperature measurements of outside of film using IR thermometer
Crystallization time: Blown Film

Plateau of Bubble Temperature

Morris, 1998
Time Scales: Cast Film/EC

Model Prediction of Temperature at EVOH-Tie Interface

paper/LDPE//(tie-EVOH-tie-LDPE)
123 m/min, 13-cm air gap

Temperature, C

Contact with Chill Roll

Web
Chill Roll

Time Since Die Exit, s

0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4
Time Scales: Cast Film/EC

Results using heat conduction model
Interfacial Area Creation

A/A_0 = g_o/g

Blown film

- A/A_0 = (BUR)*(DDR)

Cast film and EC

- A/A_0 = DDR
Interaction of area creation and temperature in blown film

Data from Morris, 1998 SPE ANTEC

(45-mm HDPE - 23-mm EVOH) Blown Film
BUR = 2.2, DDR = 6, FLH (EVOH) = 20 cm

Data from Morris, 1998 SPE ANTEC
Interaction of area creation and temperature in cast film/EC
Summary

Blown film

• Rapid increase in interfacial area near frostline
• Time available for bonding and relaxation after area creation has ceased is several orders of magnitude greater than for cast film

Cast film

• High temperatures in air gap
• Exponential increase in interfacial area
• Very rapid freezing – little time for reaction and relaxation after interfacial area creation has ceased.
Practical Implications

Effect of Output on Peel Strength

Peel Strength, g/25mm

Output (at constant air gap)
Conclusions

Interlayer adhesion generally increases with increasing process time

Character of curves differ between cast film/EC and blown film

- Cast film/EC appears to be kinetic effect; BF stress effect
- Related to differences in
  - Time scales
  - Temperature
  - Area creation
Thank You

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