Strategies to Avoid Interfacial Instability in Multilayer Films
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Optical Properties

- Haze (> 2.5 °)
- Gloss (45 °, 60 °)
- Clarity (< 2.5 °)
- Transmittance
- Opacity
Root Causes of Hazy Film

Two types of haze

1. Internal Haze
   - Caused by scattering of light by large crystalline structures called lamellae or very small inorganic particles (antiblock additive)

2. External Haze
   - Very mild version of melt fracture or die lines that is often confused with reduced gloss
Strategies to Reduce Internal Haze

Raw Material
• Select formulation with better optical properties:
  – Less crystalline (lower density polyolefin)
  – More amorphous (more linear molecular structure)
  – Lower average molecular rate (lower MFI / MFR)
  – Select inorganic additives with smaller particle size or better dispersion

Processing Conditions
• Increase film cooling rate (colder casting drum, colder or higher chilled air circulation rates)
• Decrease temperature of melt:
  • Decrease die lip or die temperature
  • Decrease melt temperature by adjusting extruder temperature profile
  • Decrease extruder screw speed and line speed (less output)

Equipment
• Check and repair cooling systems that solidify melt
• Recalibrate blenders if required to correct formulation
## Strategies to Reduce External Haze (Dull, Low Gloss Surface)

| Raw Material                      | • Reduce shear viscosity by selecting formulation with higher MFI / MFR  
|                                  |   • Reduce COF of metal surfaces by adding polymer processing aid (PPA) |
| Processing Conditions             | • Decrease film cooling rate so that film surface will be smoother before it solidifies:  
|                                  |   • Increase casting drum temperature (cast film)  
|                                  |   • Increase air temperature (blown film)  
|                                  |   • Increase air gap (cast film)  
|                                  |   • Decrease cooling air velocity (blown film)  
|                                  |   • Increase melt temperature by adjusting extruder temperature profile  
|                                  |   • Increase extruder screw speed and line speed (more output)  
|                                  |   • Increase die temperature  
| Equipment                        | • Clean downstream surfaces that can scuff film surface |
Migration and Viscous Encapsulation Problem Along a Pipe

- Material seeks the path of minimum resistance and pressure drop
- Severity of interfacial distortion (migration and encapsulation) depends on:
  - magnitude of the viscosity difference
  - shear rate
  - length of the flow path

Start of flow through pipe
Green more viscous than Yellow

End of flow through pipe
Yellow encapsulate Green

Start of flow through pipe
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End of flow through pipe
Yellow encapsulate Green
Migration and Viscous Encapsulation Profile Along a Pipe

Entrance Orientation

Viscosity_{A} >> Viscosity_{B}

Exit Orientation
Encapsulation Flow in Single Manifold Cast Film Die

Feed Block Exit Profile
- 80% High viscosity layer
- 20% Low viscosity layer

Die Exit Profile
- 20% Low viscosity layer
- 80% High viscosity layer
Viscous Dissipation Visible as Edge Defect
Cast Film Multilayer Die Systems

Feed blocks are designed to:
• arrange the polymer streams in the desired order
• reshape the polymer streams for combining
• join the polymer streams together prior entering the die manifold

Three commercial feed block styles:
1. Dow block
2. Insert style block
3. Adjustable vane/distributor pin block
Advantages of Multilayer Feed blocks

- never more than 3.5% difference from an optimum flow condition.
- flow rate balancing is dependent only on proper sequencing pin selection eg: direct flow to 1 channel for a 7.5% skin layer, 2 adjacent channels for a 15% skin layer
- changing flow patterns with pin makes more consistent and repeatable product changes than changing temperatures or extruder output rates alone

3D Analysis of 14 Layer Dow Style Converging Feed block
Distribution Pins Correct Encapsulation

- Vanes
- Distribution Pins
- Core Layer
- Cap Layers

Courtesy of Cloeren Incorporated
Coextrusion Die with Good Layer Convergence

- Velocity profile of individual layers
- Position of minimum shear stress of individual layers
- Acceleration of minor layer velocity profile
- Velocity profile with combined layers
- Position of minimum shear stress with combined layers
- Smooth, stable interface
Long Wave Interfacial Instability Pattern

- Similar to draw resonance behavior at die lip exit
- Occurs when acceleration of flow velocity is too large (usually the minor layer)

- Affected by:
  - Layer thickness ratio
  - Formulation
  - Change in channel depth
  - Merge angle

Diagram:
- Rapid acceleration of minor layer velocity profile
- Elongational strain hardening of minor layer
- Long Wave instability pattern at interface
- Moderate change in major layer velocity profile
- Unstable velocity profile of combined layers
Strategies to Prevent Long Wave Interfacial Instability Pattern

**Raw Material**
- Modify formulation to delay onset of strain hardening, usually in the minor layer
- Change layer ratio so that minor layer is a larger percentage of the total film structure (minor layer is too thin)
- Reduce shear stress at the merge point by adding polymer processing aid (PPA) to the minor layer

**Processing Conditions**
- Reduce extensional viscosity and stress at layer interface by increasing melt temperature of minor layer. Change in 10°F (5°C) increments and wait 15 to 20 minutes for process to stabilize.
- Decrease output rate gradually to decrease acceleration rate of minor layer (slower screw rotation speed). Decrease line speed to maintain correct gauge.

**Equipment**
- Decrease the channel depth of the minor layer to pre-accelerate minor layer before it reaches the merge point
- Decrease the merge angle at which the layers combine to minimize stress and flow direction changes at the merge point
Zig-Zag Interfacial Instability Pattern

- Looks like melt fracture inside transparent film
- Caused by a high shear stress at the interface between adjacent layers
- Critical shear stress depends on formulation
<table>
<thead>
<tr>
<th>Strategies to Prevent Zig-Zag Interfacial Instability Pattern</th>
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<tbody>
<tr>
<td><strong>Raw Material</strong></td>
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<tr>
<td>• Modify formulation to minimize shear viscosity differences of adjacent layers</td>
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<tr>
<td>• Change layer ratio to shift layer interface towards the center of the merged flow channel where shear stress is minimized</td>
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<td>• Reduce coefficient of friction of die block surfaces (replace worn out plating)</td>
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<td>• Inspect and replace defective thermocouples or heaters in die block or die (if required)</td>
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Root Causes of Melt Fracture

1. Slip / Stick

- Velocity of surface and bulk are equal
  \[ V_{\text{surface}} = V_{\text{bulk}} \]

- Elongation > critical elongational shear rate, causing surface (skin) rupture

2. Skin Rupture

- Slip / stick pattern because velocity near metal surface of land is much less than center of flow channel.
  \[ V_{\text{surface}} \ll V_{\text{bulk}} \]
Strategies to Prevent Melt Fracture

Raw Material
• Reduce viscosity by selecting higher MFI blend
• Add polymer processing aid (PPA)

Processing Conditions
• Increase die lip temperature in 10°F (5°C) steps
• Increase die body temperature in 10°F (5°C) steps
• Increase melt temperature by modifying extruder temperature profile
• Decrease output rate gradually to decrease shear stress at die lip surface (slower screw rotation speed). Decrease line speed to maintain correct gauge.

Equipment
• Inspect and repair die lip heaters and thermocouples (if required)
• Increase die gap by turning die bolt ¼ turn at a time. Increase line speed to maintain correct gauge
• Reduce coefficient of friction of die lip surfaces (replace worn out plating)
Is it Melt Fracture or Interfacial Instability?

Melt Fracture becomes transparent

Interfacial Instability remains hazy
For more information

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