Film Coextrusion

A Troubleshooting Guide

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Film Coextrusion: A Troubleshooting Guide

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Successful production of coextruded products depends on several key factors, including polymer selections, hardware design (screw, feedblock/die, handling equipment, layer construction and optimal processing conditions). Proper selection and adjustment of each factor will minimize difficulties and ensure high quality coextrusion results.

Troubleshooting methods for coextrusion become increasingly complex as the number of layers in the structure increases, as the asymmetry of multi-layer construction grows, or as processing and rheological characteristics of coextruded materials differ greatly from one another. Understanding the problems associated with non-uniform layer distribution and interfacial instability between layers or on film surfaces is very important when troubleshooting the coextrusion process.

The Uniformity Problem

Non-uniform layer distribution is one of the more common problems encountered in film coextrusion. This non-uniformity may appear in either the direction of extrusion or tangential to the direction of film production.

Layer uniformity in the machine direction can be influenced by die imperfections, poor die design or adjustment, excessive extruder pressure variation, variable film tension, or film bubble or web instability.

Layer uniformity tangential to machine direction can be influenced by poor melt temperature uniformity, viscosity mismatch between layers, poor hardware design, or viscoelastic flow characteristics induced by excessive shear stress.

Poor layer uniformity tangential to machine direction is caused by non-uniform melt temperature across a melt pipe, feedblock and/or die, as well as poor melting in an extruder. Melt temperature variance alters viscosity uniformity, which exhibits a change in flow characteristics and layer distribution. Melt temperature of a single polymer stream can often vary by as much as 30°F. A general rule of thumb is to achieve ±2°F or less variation in melt temperature for each extruder.

Homogeneous melt temperatures can be achieved through installation of a static mixer in the melt pipe, a dynamic mixer on the extrusion screw or a more efficient screw design, or through adjustment of pipe, feedblock and/or die temperatures.

Variation in the thickness of a film, which eventually reaches a steady-state condition of non-uniformity (assuming homogeneous melt temperature conditions for each polymer), can be caused by a viscosity mismatch between layers. In a coextrusion system, lower-viscosity polymers migrate to the region of highest shear stress (nearest the die wall) and tend to encapsulate higher-viscosity polymers. The amount of migration is dependent on the degree of viscosity mismatch, the length of the flow path, and the shear stress in the system.

Improving Layer Variation

Improvements in layer variations that are caused by viscosity-induced flow behavior can be achieved through adjustment of melt temperature, modification of distribution channels in the feedblock or die, or selection of a polymer with different viscosity characteristics which most commonly are measured by melt index. Also, annular dies typically are more tolerant of viscosity mismatch than flat-die systems.

Non-uniform layer distribution in the direction tangential to extrusion can also be caused by poor hardware design. Improperly designed flow channels of the feedblock or die can cause poor steady-state layer distribution of materials, even with the most closely matched viscosities.

Non-uniform distribution of layers, in the form of parabolic flow lines, intermixing of layers, roughness between polymer boundaries, melt fracture, or uncharacteristically high haze, can be caused by interfacial instability between layers or on film surfaces. The instabilities are believed to be a result of the viscoelastic behavior of polymers at the die land or region of highest shear stress.

Improvements in layer instabilities can be achieved by reducing the shear stress between coextrusion layers and/or the die-land surfaces. Shear stress can be reduced by decreasing total output rate, increasing skin-layer melt temperature (decrease in viscosity), increasing the die gap, adding a process lubricant to the skin material, or selecting a lower viscosity material.

An increase in the thickness of the skin layer can also reduce instability between polymer layers by moving the interface further from the high-shear-stress die wall. This is especially significant for asymmetric coextrusion constructions.

Finally, if coextrusion layers exhibit dramatic differences in melt elasticity, then choose materials that match more closely in extrudate elasticity as measured by extrudate swell.

Troubleshooting At A Glance

Problem	Possible Cause	Solution
Lines in the film surface	Die imperfections	• Clean die buildup • Remove contaminants from polymer melt channel • Repair die nicks and burrs
Gauge bands on film roll	Poor die design	• Install spiral-channel die design to eliminate weld lines • Install rotating nip assembly in tower
	Poor die adjustment	• Adjust concentricity of die gap • Center air ring in relation to die gap
Repeating pattern of variation in thickness of layer(s)	Excessive extruder pressure variation (surging)	• Achieve ±1 percent or less variation in total head pressure for each extruder • Adjust extruder temperature profile (feed and transition zones) • Increase back pressure with restrictor flow plug • Increase back pressure by installing fine-mesh screen pack • Change screw design of surging extruder(s) • Check for worn screw(s) and replace if needed • Check extruder feedthroat(s) for bridging and correct if needed
	Variable film tension	• Eliminate variability in drive speed
	Film bubble instability	• Protect bubble from atmospheric air turbulence • Correct pressure instability of air ring and/or internal air flow

Problem	Possible Cause	Solution
Intermittent and somewhat random variation in thickness of layer(s)	Poor melt temperature uniformity	• Achieve ±2°F or less variation in melt temperature for each extruder • Adjust extruder temperature profile to ensure complete melting of extrudate • Install new screw design with dynamic mixer for more efficient melting capacity • Reduce screw speed for increased residence time to complete melting of the polymer(s) • Adjust temperature of feed channels, die and/or feedblock
Variation in thickness of layer(s) that reaches steady-state distribution	Viscosity mismatch of polymer layers	• Select polymers with matching viscosities • Adjust temperature of polymers to aid in matching viscosities
	Poor hardware design	• Change die and/or feedblock design
Uncharacteristically high film haze	Viscoelastic flow characteristics induced by excessive shear stress between layers and/or feedblock/die surfaces	• Select lower-viscosity skin layer(s) • Increase melt temperature of skin-layer polymers • Increase die temperatures • Reduce total extrusion output • Increase die-gap opening • Add process lubricant to skin-layer polymer • Increase thickness of skin layers • Select polymer(s) that exhibit similar melt elasticity behavior (extrudate swell)
Parabolic-shaped flow lines in direction of extrusion	Same as for uncharacteristically high, film-haze problem	• Same as for uncharacteristically high, film-haze problem
Intermixing of polymer layers	Same as for uncharacteristically high, film-haze problem	• Same as for uncharacteristically high, film-haze problem
Roughness between polymer-layer boundaries	Same as for uncharacteristically high, film-haze problem	• Same as for uncharacteristically high, film-haze problem
Melt fracture of film surface	Same as for uncharacteristically high, film-haze problem	• Same as for uncharacteristically high, film-haze problem

Coextrusion Processing Defined

The conversion of multiple thermoplastics, flowing through separate streams, that are combined into a common primary passage and then shaped by a die. Multiple layers provide properties that cannot be provided by a single material for high barrier coextrusion processing. The main classes are: film; sheet; tubing; coating; and blowmolded shapes.

Successful Production of Coextruded Products Depends on Three Key Factors

1. Polymer Selections
2. Design of Hardware
   Screws, Feedblock/Die, Handling
3. Coextrusion Layer Construction
4. Optimal Processing Conditions

Layer Uniformity is Influenced by:

- Variations in extrusion pressure
- Nominal extrusion melt temperature
- Viscosity-induced web flow
- Bubble or melt instability
- Variable film tension
- Poor die design or improper adjustment
- Die imperfections or contaminants

Interfacial Flow Instability is Caused by:

- Interfacial critical shear stress

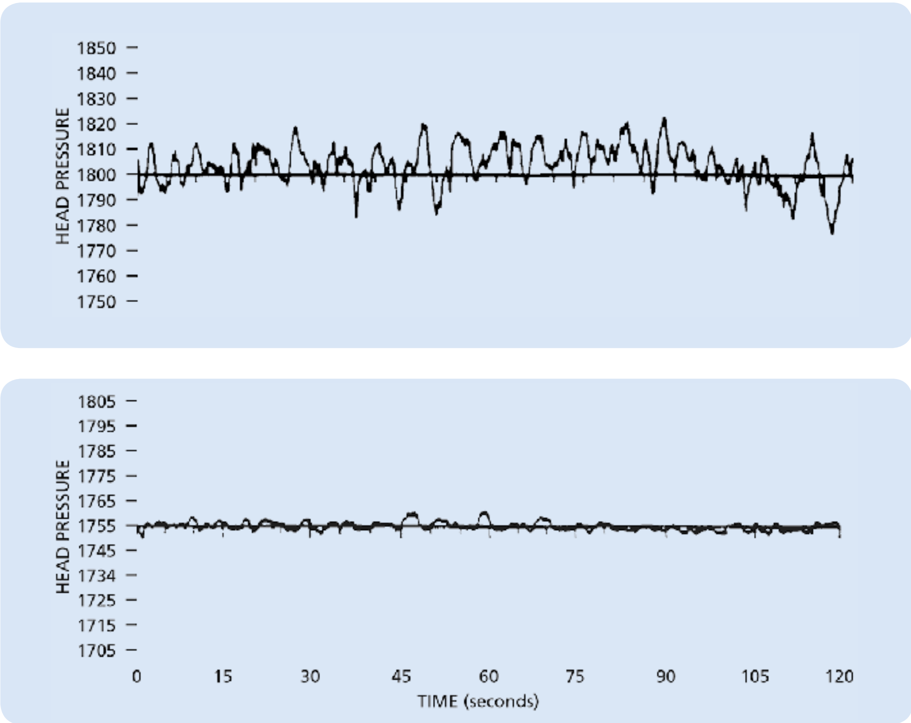
Extrusion Pressure Variations

Variation in extrusion pressure, often referred to as surging, is directly related to feeding stability of an extruder.

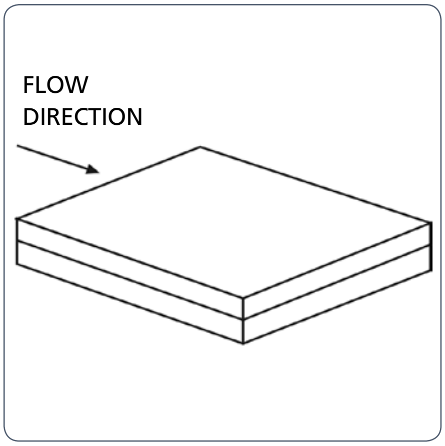
Improving layer uniformity caused by pressure variation can be achieved through:

- Adjustment of back pressure
  - Screen pack
  - Restrictor flow plug
- Extrusion screw design of feed and transition sections
- Adjustment of extrusion screw-temperature profile
- Prevent polymer bridging in feed throat
- Replace/repair worn extrusion screw

Head Pressure Trace

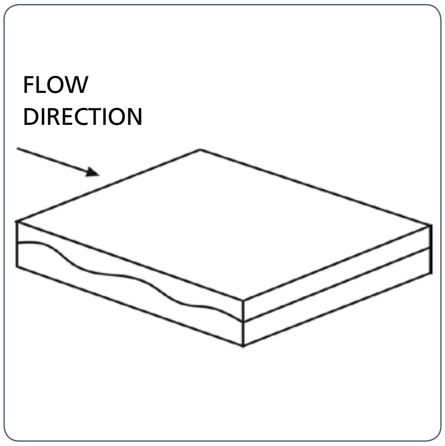


Layer Thickness Instability Caused by Pressure Variation



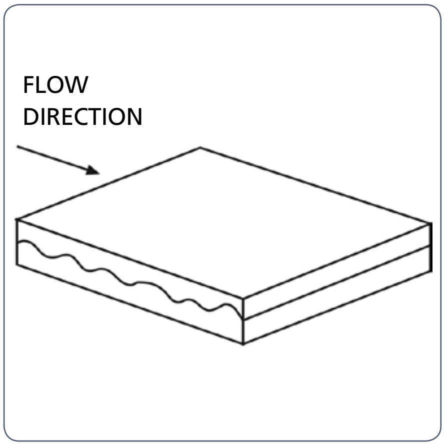
Stable Flow

Uniform thickness



Onset of Instability

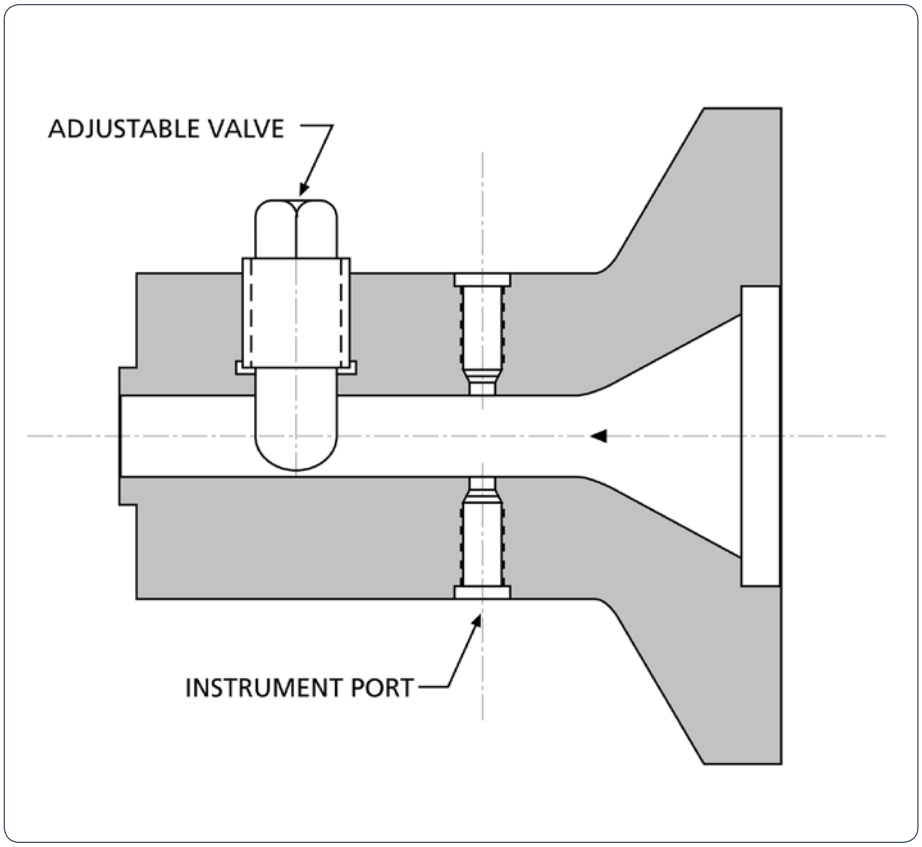
Small gauge variation



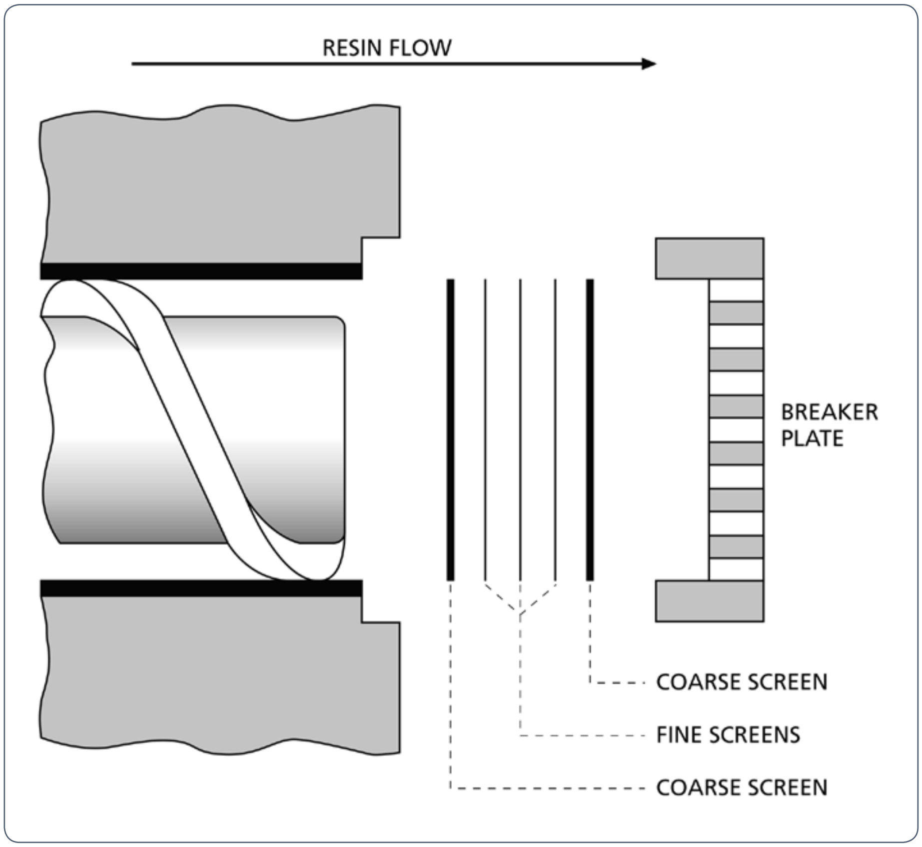
Severe Instability

Large gauge variation

Extrusion Flange Back Pressure Adjustment



Typical Arrangement of Coarse and Fine Screens Between the Screw and Breaker Plate



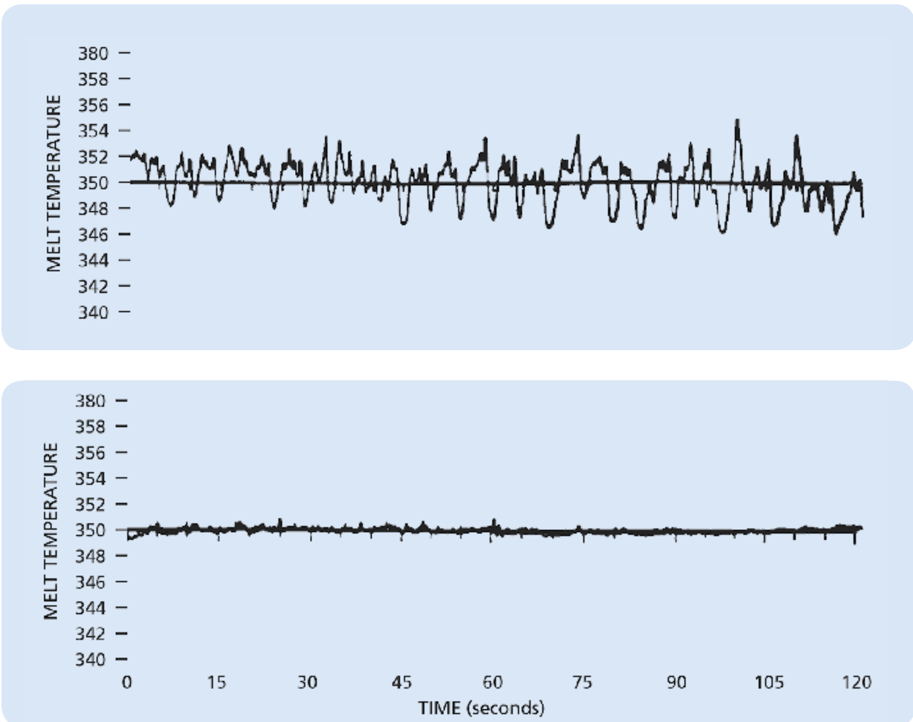
Melt Temperature Variations

Non-uniform melt temperature across a melt pipe, as well as poor polymer melting in an extruder, cause poor layer uniformity.

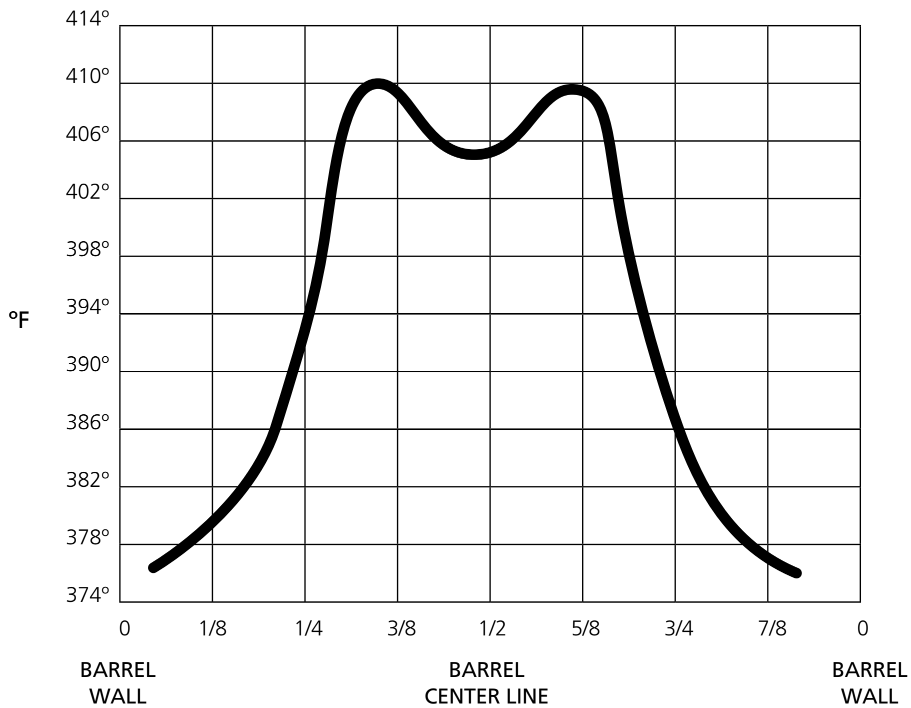
Homogeneous polymer melt temperatures can be achieved through:

- Static and/or dynamic mixers
- Adjustment of pipe and die temperatures
- Adjustment of extrusion screw temperature profile
- Replace/repair worn extrusion screw

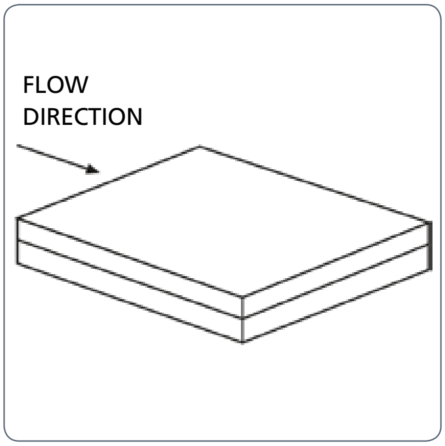
Melt Thermocouple Trace



Typical Temperature Profile of Polymer Melt Stream in Pipe

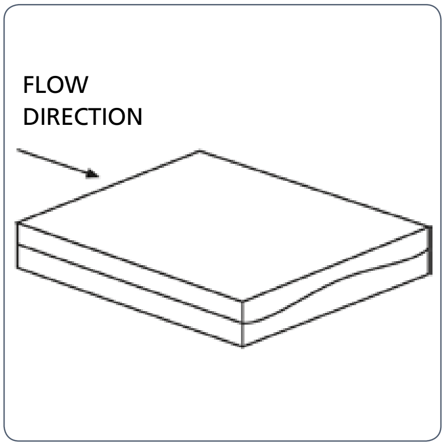


Layer Thickness Instability Caused by Non-uniform Melt Temperature



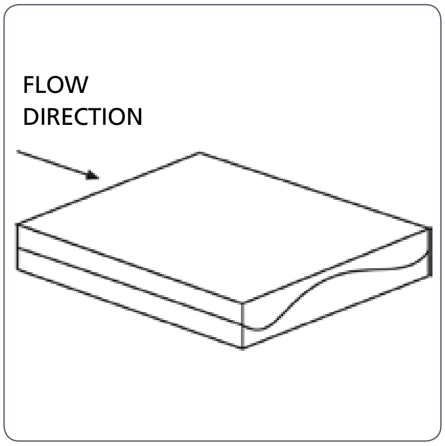
Stable Flow

Uniform thickness



Onset of Instability

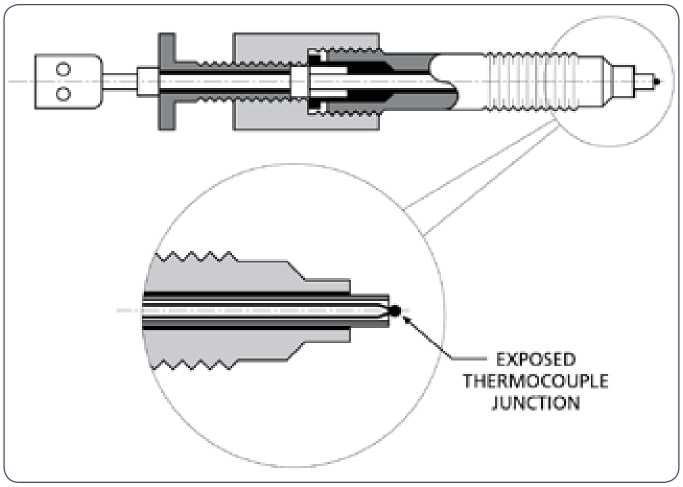
Small gauge variation



Severe Instability

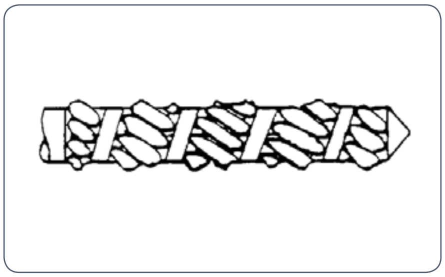
Large gauge variation

Adjustable Depth Probe Melt Thermocouple

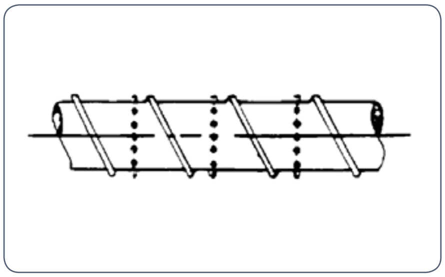


Distributive Mixing Sections

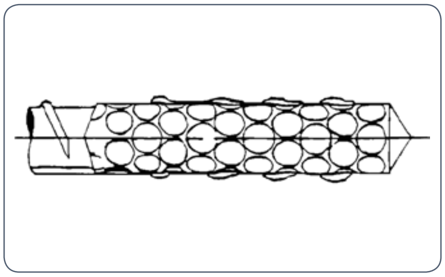
Dulmadge mixing section (Dow)



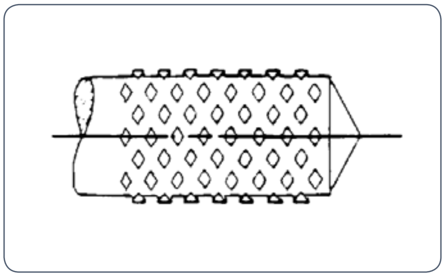
Saxton mixing section (DuPont)



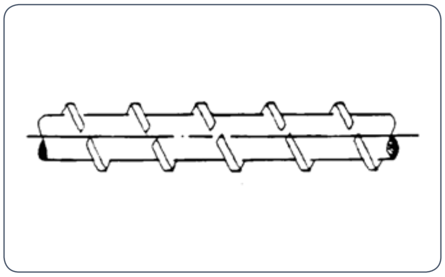
Pin mixing section (Barmag)



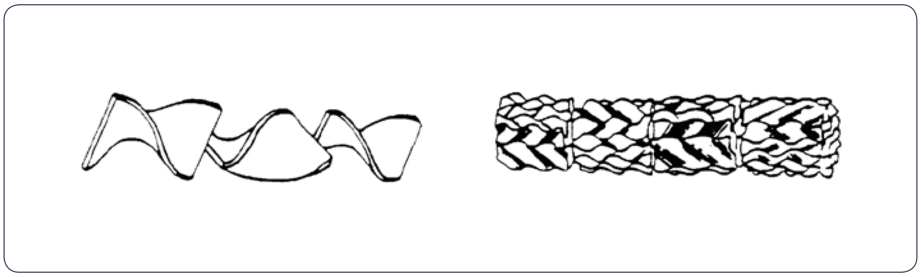
Cavity-transfer mixing section (Davis-Standard)



Pineapple mixing section



Slotted-screw flight (Axon)



Two types of static mixers (Kenics and Ross ISG)

Viscosity Related Behavior

Melt index selection and the related viscosity-induced flow behavior affect layer uniformity.

Improvement of layer variations caused by viscosity-induced flow behavior can be achieved through:

- Adjustment of melt temperature
- Modification of distribution channels
- Select polymer of different viscosity or viscoelastic characteristic

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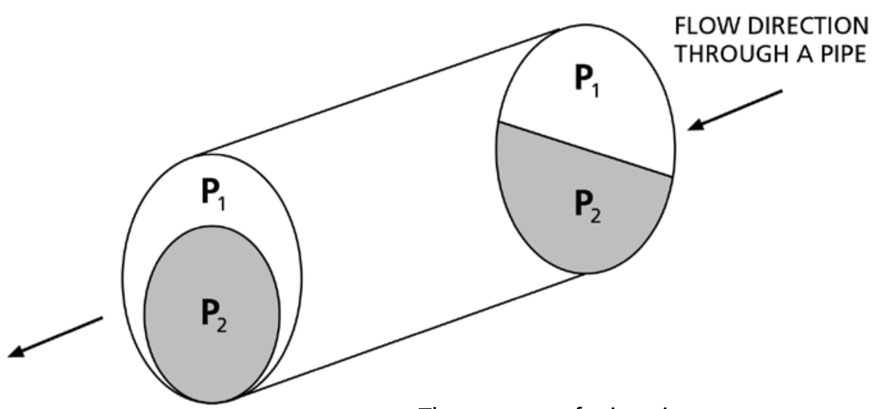
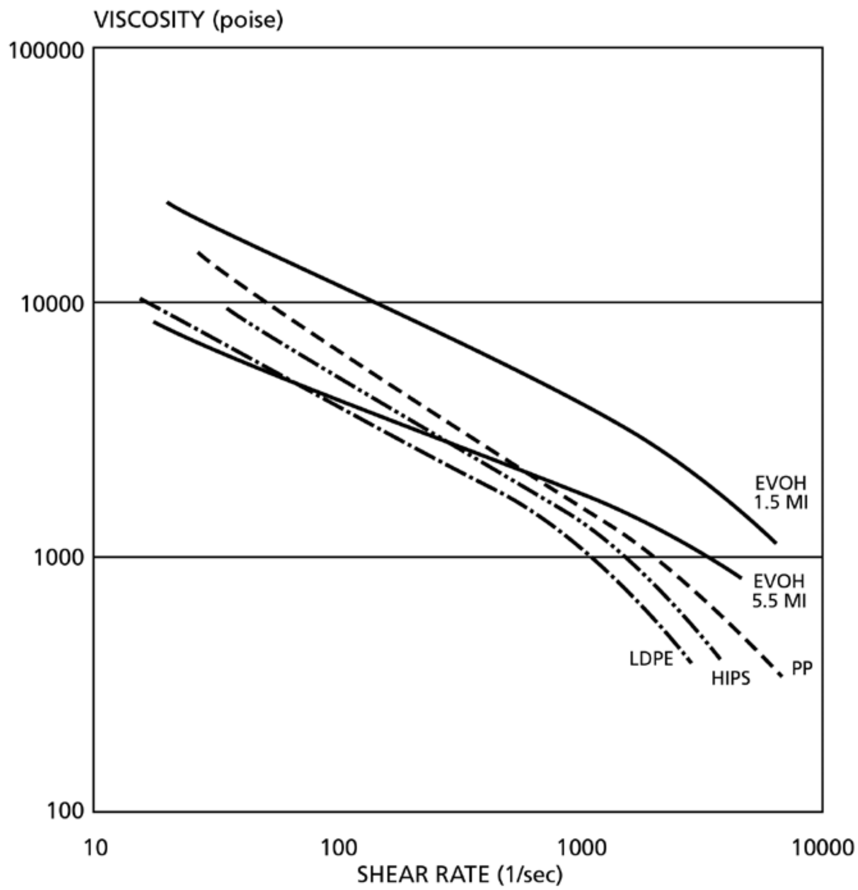
Viscosity-Induced Flow Behavior

Migration of lower viscosity polymer to the region of highest shear stress. The effect is encapsulation of P_2 by P_1.



The amount of migration or encapsulation is dependent on the degree of viscosity mismatch, the length of the flow path and the critical shear stress for the given system.

Viscosity vs. Shear Rate for Various Polymers @ 230°C



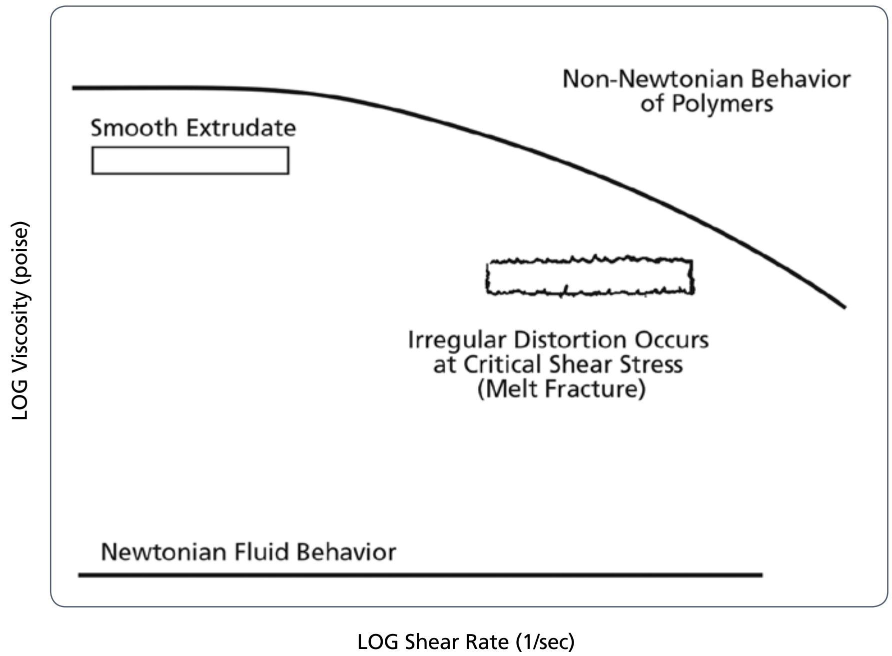
Interfacial Flow Instability

Excessive shear stress between layers, feedblock and/or die surfaces causes interfacial flow instability. Drag flow and differences in polymer velocities of multiple layers create shear stresses.

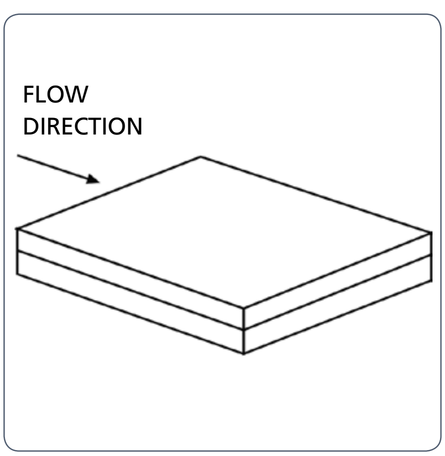
Reduction of interfacial shear stress near a die wall can be achieved through:

- Decreasing skin-layer viscosity or increasing melt temperature
- Increasing die temperature
- Increasing skin-layer thickness
- Reducing total extrusion output
- Increasing die-gap opening
- Adding process lubricant to skin layer
- Selecting polymers that exhibit similar melt elasticity

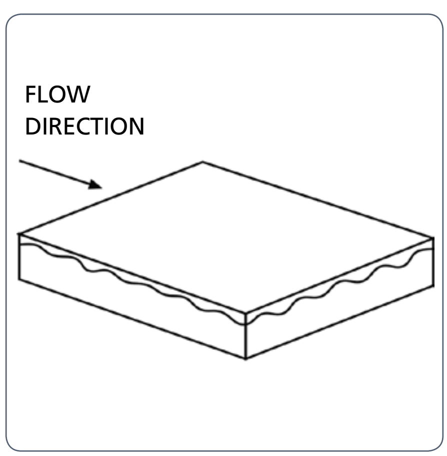
Critical Shear Stress of Polymers
Viscosity vs. Shear Rate



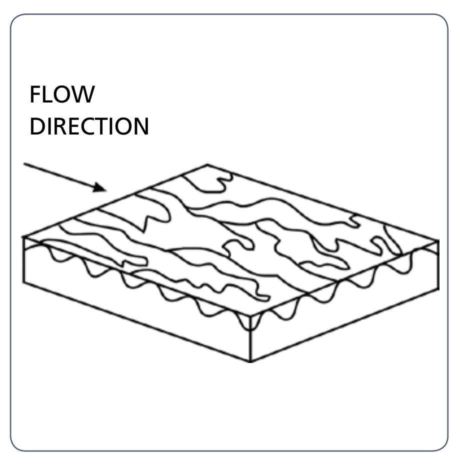
Interfacial Instability in Coextrusion Caused by Critical Shear Stress



Stable Flow
Smooth interface

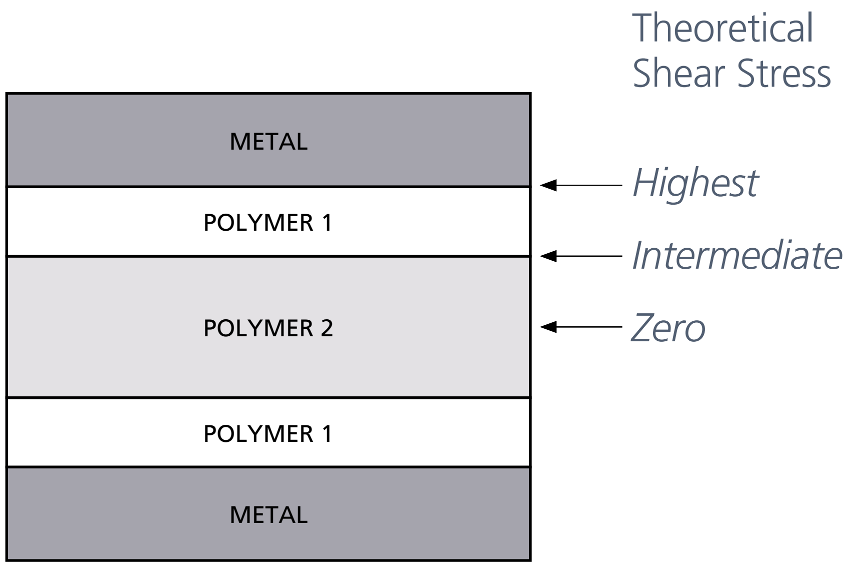


Onset of Instability
Wavy interface develops



Severe Instability
Propagation of waviness to surface

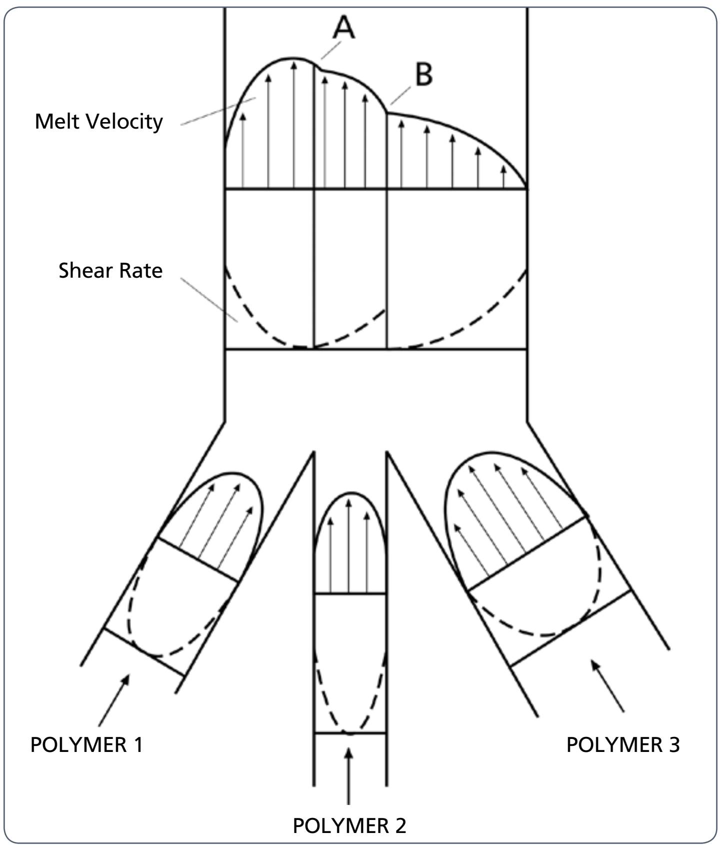
Polymer Interfaces and Critical Shear Stresses Encountered in Coextrusion



Coextrusion Melt-Flow Model

A = Stable Behavior

B = Critical Behavior
(Occurrence of Instability)



An Important Note

Pressure variation, non-uniform melt temperatures, viscosity mismatch and the effects of critical shear rate instabilities seldom occur independently of one another. They most often occur simultaneously, with variance in the degree of severity.

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