Advanced Applications

Technical Bulletin

Melt Strength

Sterigenics employs their extensive knowledge and capability of radiation processing to modifying the rheological properties of linear polyolefins like high density polyethylene (HDPE) and linear low density polyethylene (LLDPE). While the physical properties of HDPE and LLDPE are highly desirable for many applications, they exhibit poor melt processability due to shear thinning. Shear thinning is the typical rheological behavior exhibited when stress is applied to linear polyolefins while in the melt phase. It can be compared roughly to the behavior of a salt water taffy. When pulled apart, it will thin and elongate from a single point and offers decreasing resistance to elongation. In terms of polymer melt processability, the shear thinning polymer will yield poor gauge uniformity in films and thermoforming, high neck-in and low maximum draw ratios in extrusion coating and cell collapse in low density foams.

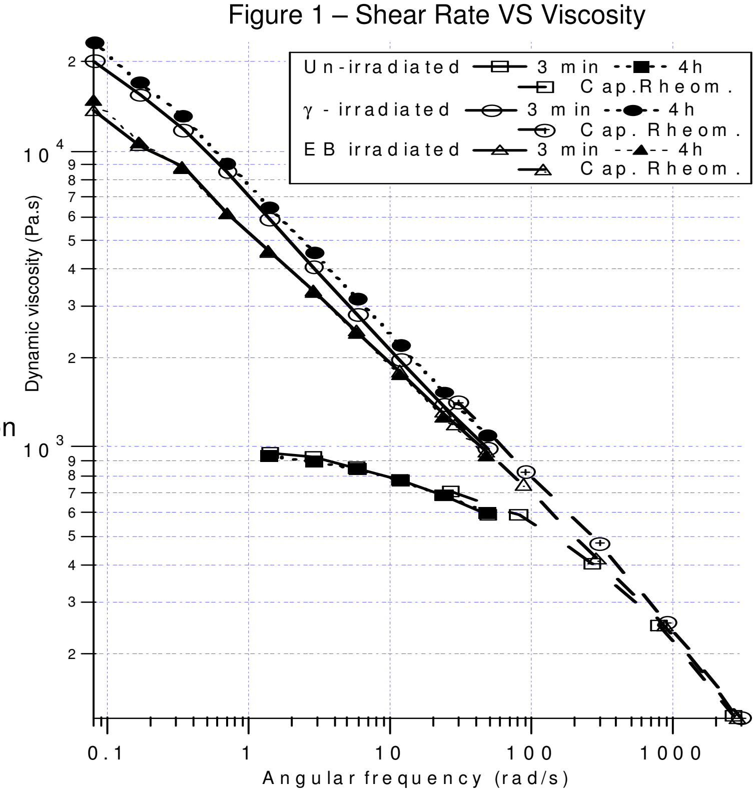
It is important to view melt strength over a broad shear rate and extensional rate range as various melt processes require different melt performance levels at low shear rates (profile extrusion) or high extensional rates (extrusion coating). In some processes like melt phase thermoforming, the polymer sheet is required to exhibit high melt strength at low shear rates as the sheet is being heated: ***sag resistance***. After the sheet is heated, the material is plugged, the molds close and the part is formed using vacuum at higher extensional rates and the material is required to resist thinning: ***strain hardening***.

At Sterigenics, utilizing our highly controlled radiation processes, we are able to induce long chain branching in linear polyolefins to create a network of entanglements. The result is Raprex® HDPE and LLDPE grades that exhibit extraordinary melt strength. They are not cross-linked. Gel content, if measurable, is less than 0.4% so the materials are 100% reprocessable.

Sag Resistance (high melt strength at low shear rates).

The shear VS viscosity curves in Figure 1, clearly show the dramatic increase in viscosity of the radiation processed HDPE VS their unprocessed, linear precursors. They exhibit the behavior of resins with a much broader molecular weight distribution. When a large, heavy extruded sheet is being heated to above its melting point in preparation for thermoforming, this is the type of behavior that allows the material to support its own weight and not sag into the heating bank. When blow molding large parts, the hanging parison will resist sagging.

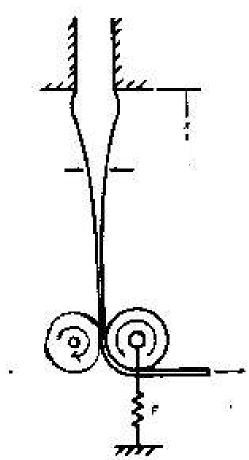
Figure 1 – Shear Rate VS Viscosity



Strain Hardening (High Melt Strength at High Extensional Rates)

Many melt processes require the melt to resist thinning at high extensional rates. In extrusion coating, the melt curtain is pulled from the die onto the substrate at draw ratios greater than 100:1 and at line speeds greater than 1000 feet / minute. Linear polymers exhibit necking and melt resonance at draw ratios and extensional rates far below the process requirements for economic production rates. Melt resonance is an oscillating, thick / thinning effect caused by the unstable melt curtain. In thermoforming and blow molding, after the mold closes and forming pressure is applied, extensional rates are accelerated and the polymer must resist thinning as material is distributed into the far corners of the part. Polymers exhibiting strain hardening or high extensional viscosity *deform uniformly* as stress is applied to the melt.

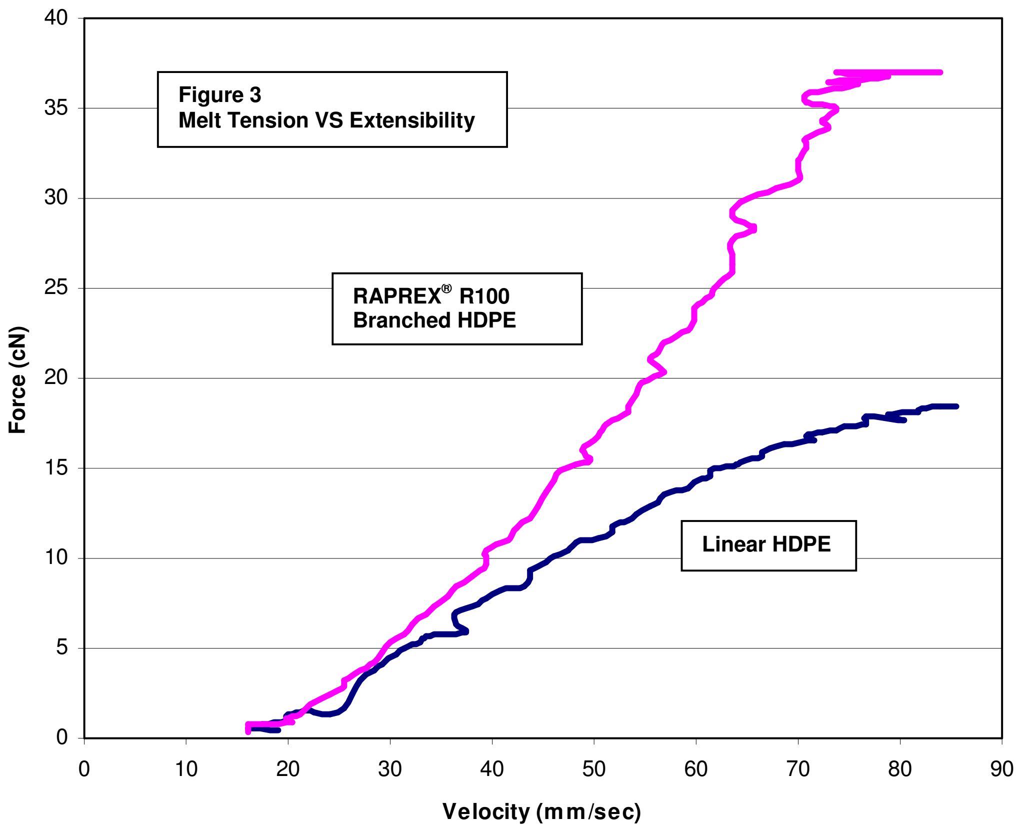
Figure 2
Gottfert Rheotens
Melt Tension (cN)
Velocity at Break (mm/sec)



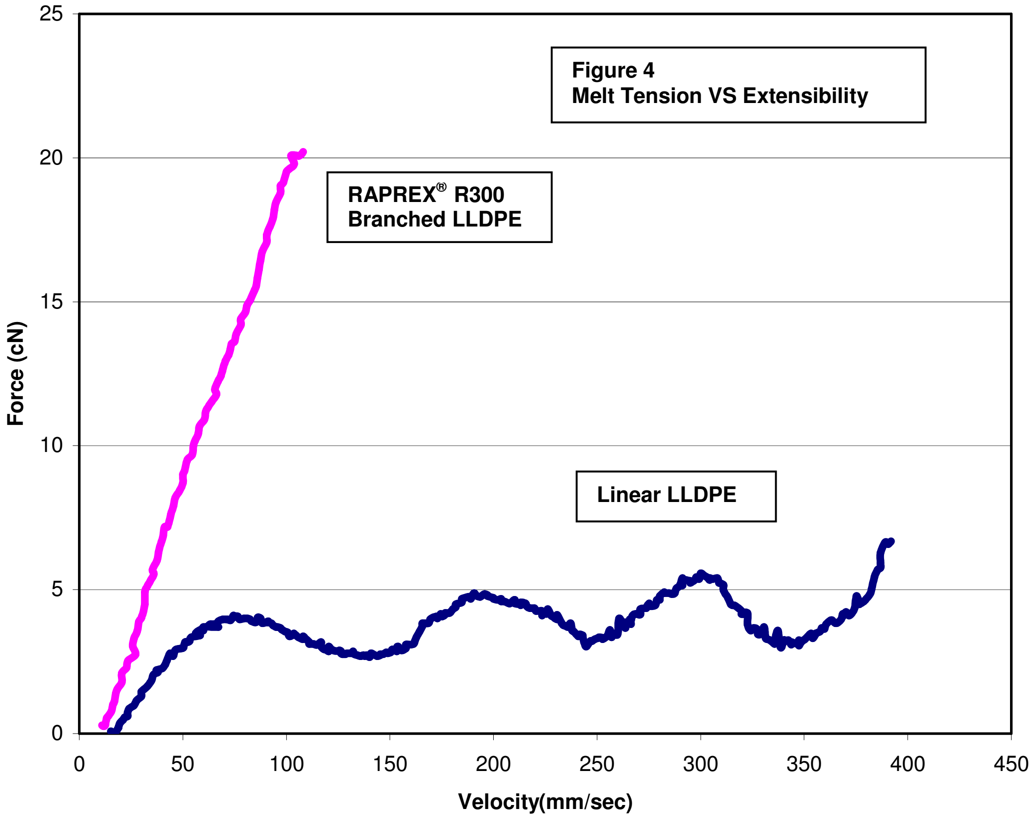
Extensibility

In melt processing, equally important as melt strength, is the ability for the polymer to exhibit high melt strength while being extended, at high rates, to form the finished product: coating, film, fiber, formed part. This extensibility requirement for each process must be considered when designing the higher performing polymers. The Gottfort Extensional Rheometer (Rheotens) is a device that measures both melt strength and extensibility simultaneously by combining the capillary rheometer with a device that pulls the melt away from the die at increasing rates and draw ratios. The throughput from the die remains constant. It is a relatively simple, fast but elegant way to relate rheological properties to melt processability.

In Figure 3, Raprex® R100, a radiation processed HDPE, is compared to its linear precursor. As the linear HDPE is extended, it exhibits an apparent increase in extensional viscosity as the polymer chains are strained. However, the polymer chains begin to slide over one another and the polymer begins to shear-thin at about 65mm/sec. The branched R100 exhibits a dramatic increase in melt tension that continues to increase as the melt is extended. The melt strength of Raprex® R100 at break (at the same extensibility) is two times that of the melt strength of its linear precursor.



In Figure 4, the comparison is even more dramatic between Raprex® R300 branched LLDPE and its LLDPE precursor which begins to exhibit melt instability or draw resonance at 70 mm/sec. The melt strength of Raprex® R300 at 70 mm/sec (the breaking point) is 3 times that of its linear counterpart.



To learn more about how the improved processability of RAPREX® branched HDPE and LLDPE will help you achieve faster line speeds, improved gauge uniformity and down-gauging, contact us at Sterigenics Advanced Applications.

Edward M. Phillips
Sterigenics Advanced Applications
Product Manager
303 Heron Drive
Swedesboro, NJ 08085
Phone: (856) 241-8880 ext.108
Toll Free: 888-RAPREX-1
Fax: (856) 241-8777
E-mail: ephillips@sterigenics.com
Web: www.raprex.com

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