Polyethylene for low-temperature extrusion-coating applications

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The new polyethylene can be extruded at low temperature to 3-mil thickness at speeds of 1000 ft/min.

Environmental considerations have created a demand for disposable products that are biodegradable. The synthetic components in a biodegradable extrusion-coated structure contain nutrients—usually edible starches—within the interstices of the polymers. These starches attract microorganisms, which feed on the nutrients and degrade the synthetic material. Unfortunately, the edible starches are thermally sensitive and will cook (caramelize) when exposed to temperatures above ≅ 480°F. Thus biodegradable polyethylenes containing such starches must extrude satisfactorily at a melt temperature below 480°F.

Biodegradable resins are not the only thermally sensitive extrusion-coating material. If ethylene-vinyl alcohol copolymer (EVOH) is exposed to heat much above 500°F, the polymer degrades and loses its barrier properties. Structures containing EVOH usually contain at least one other polymer, either applied directly to EVOH film or coextruded with EVOH. Ideally, these other polymers should process at melt temperatures low enough to maintain the effectiveness of the EVOH barrier layer.

A new polyethylene has been developed for use in these and other low-extrusion-temperature structures.

Development of polyethylene for low-temperature applications

A low-temperature extrusion-coating polyethylene must:

- Process satisfactorily at melt temperatures below 500°F
- Coat at commercial speeds
- Draw to extremely thin coating thicknesses
- Achieve satisfactory adhesion.

A polyethylene with these characteristics was developed using the following approach.

Drawdown

Drawdown (thin coatings on high-speed production lines) was the first problem to be addressed in developing the new polyethylene. It was apparent that a low viscosity would be required to facilitate processing at the required low temperatures. Studies showed that a melt index (MI) of about 30 dg/min and above would permit extrusion of coatings as thin as 0.3 mil at speeds exceeding 1000 ft/min.

I. Properties of low-temperature polyethylene

			ASTM Method
Melt index	35	dg/min	D1238
Density	0.925	g/cm³	D1505
Vicat softening	75	°C	D1525
Brittleness temperature	<-18	°C	D746
	0	°F	
Tensile at yield	1200	psi	D638
	8.3	MPa	
Tensile at break	1100	psi	D638
	7.6	MPa	
Elongation at break	350	%	D638
Secant (2%) modulus of elasticity in bending	23,000	psi	D790
	159	MPa	

Adhesion

After establishing the required melt index, we had to deal with the problem of adhesion for a >30-MI polyethylene. We knew that a "pure" polyethylene would not adhere, even to natural kraft paper, when applied at or below 500°F. The surface of the polyethylene extrudate does not oxidize sufficiently at this temperature to form the polar groups that promote chemical bonding to paper. Also, most extrusion-coating-grade polyethylenes are too viscous to wet the surface of the paper at this temperature. The adhesion problem was solved by modifying the polyethylene to provide chemical functionality. The end result was a unique new polyethylene with the following properties.

Properties

The new polyethylene's basic physical properties are listed in **Table I.**

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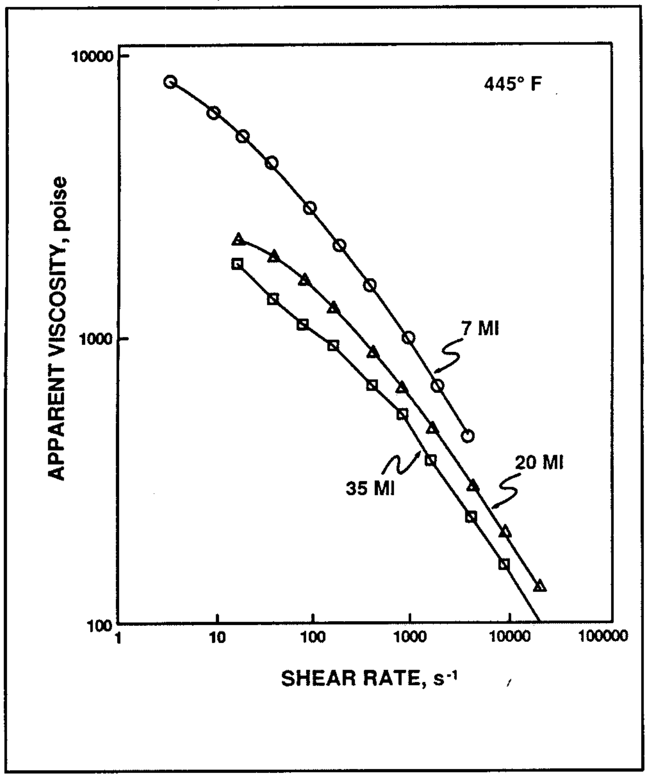
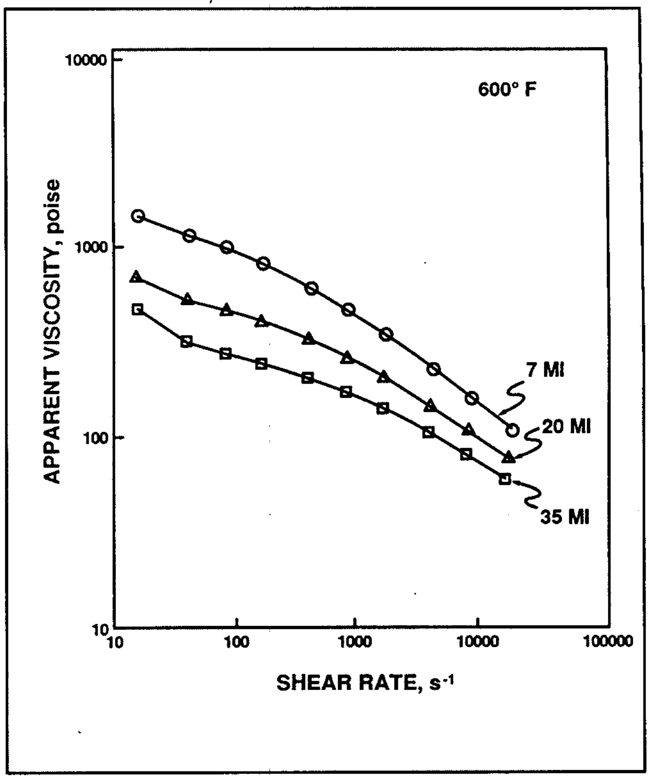
1. Apparent viscosity as a function of shear rate for three polyethylenes at 445°F (230°C). The 35-MI curve represents the low-extrusion-temperature polyethylene. (Instron capillary extrusion rheometer; length/diameter ratio. = 39.67.)



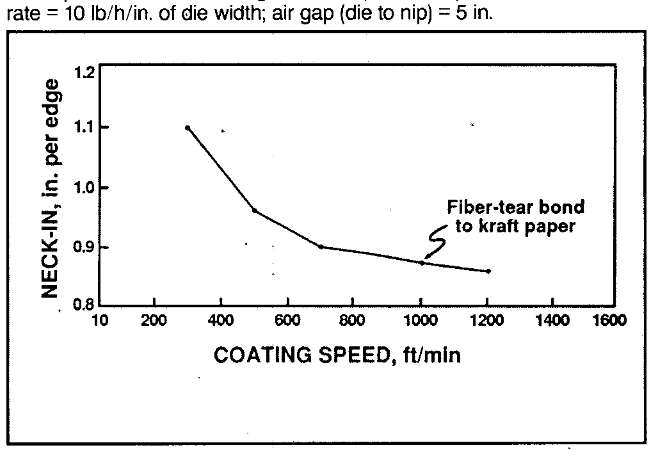
2. Apparent viscosity as a function of shear rate for three polyethylenes at 600°F (315°C). The 35-MI curve represents the low-extrusion-temperature polyethylene. (Instron capillary extrusion rheometer; length/diameter ratio = 66.50.)



Rheology and low-temperature processing

Figures 1 and 2 show viscosity vs. shear rate for three polyethylenes (the new polyethylene and two standard extrusion-coating-grade polyethylenes) at two extreme temperatures (445°F and 600°F, respectively). The two standard polyethylenes are of the same density but with melt indexes of 7 dg/min and 20 dg/min. The new material, with a melt index of 35 dg/min, is much more fluid. The unique rheological properties of this polyethylene explain its excellent extrusion-coating abilities at temperatures below 500°F. **Figure 3**, which plots neck-in as a function of coating speed, shows that the material is easily capable of applying a coating thickness of less than 0.3 mil at speeds in excess of 1000 ft/min. In addition, its neck-in is typical of most extrusion-coating polyethylene, i.e., about 1 in. per edge.

3. Neck-in on each edge as a function of coating speed. (1000 ft/min corresponds to 3-mil coating thickness.) Melt temp. = 450°F; extrusion rate = 10 lb/h/in. of die width; air gap (die to nip) = 5 in.



Adhesion

At extrusion temperatures below 500°F, the new polyethylene provides a fiber-tear bond to natural kraft paper and to machine-glazed paper. However, the new material will not bond to unprimed aluminum foil nor metallized aluminum foil at these low temperatures. The low-extrusion-temperature polyethylene has demonstrated an affinity for: polyethylenes, polypropylenes, ethylene-vinyl alcohol copolymers, ethylene-acrylic acid copolymers, ionomers, and other ethylene-based copolymers.

Heat sealing

Coatings of the new polyethylene were applied to unprimed natural kraft paper at a melt temperature of 445°F. The extrusion rate was 10 lb/h/in. of die width. Coating thickness was 0.8 mil, with fiber-tear adhesion.

Heat-seal studies were conducted, sealing polyethylene to polyethylene, in a Sentinel heat sealer. Both bars were heated, and heating time was 0.5 s. Clamping pressure was 30 lb/in.^{2} The minimum sealing temperature to effect a 100% fiber-tear seal was 200°F. This low-temperature sealing ability shows that the new polyethylene has the potential to be used in hot-melt-adhesive applications.

This is the same result obtained on a standard extrusion-coating-grade polyethylene of the same density but with a melt index of 20-dg/min. The new polyethylene, therefore, apparently offers no heat-seal advantages over other low-density polyethylenes.

Conclusion

A newly developed polyethylene can be extrusion coated at commercial speeds at temperatures less than 500°F. Even under these conditions, it is possible to obtain a thin coat with good adhesion to paper and some polymers. The low-extrusion-temperature polyethylene was developed for use as a matrix for the heat-sensitive edible starches in biodegradable extrusion coatings. It also should prove to be useful in applications involving direct extrusion coating or coextrusion of thermally-sensitive components. □

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