2 Polypropylene Films

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Polypropylene film is one of the most versatile packaging materials. It is economical due to its low density and is replacing other materials, such as polyethylene, polyvinyl chloride, polyester, and cellophane, in packaging applications. Almost 90% of plastic packaging is used in food applications; other applications include film packaging for stationery products, cigarettes, and textiles (Goddard, 1993; Graves, 1995; Shell Polypropylene Film Grade Resins Guide, 1992).

Both random copolymers and homopolymers are used in film production. Films can be unoriented, uniaxially oriented, or biaxially oriented and are defined as sheet materials that are less than 0.254 mm (10 mil) in thickness; thicker films are referred to as sheets. Resins with melt-flow indexes of ~2−8 g/10 min are generally used in films, although higher melt-flow rate resins are also used. Higher melt-flow resins are used in cast film processes (Fortilene Polypropylene Properties, Processing, and Design Manual (1981); Capshew (1997).

2.1 Unoriented Film

Unoriented polypropylene films can be produced by casting or blown film processes. Chill roll casting and tubular water quenching are commonly used. Conventional air quenching, widely used for polyethylene, produces brittle films with poor clarity in polypropylene; however, newer polypropylene resins and copolymers developed for air-quenched processes can provide economical alternatives to polyethylene. The tubular water-quench process is commonly used to produce monolayer film (Barnetson, 1996; Fortilene Polypropylene Properties, Processing, and Design Manual, 1981; Himont, 1992; Miller et al., 1991; Moore, 1996; Polymers in Contact with Food, 1991; Thompson et al., 1987).

Unoriented films have a very soft hand and are easily heat sealed. They exhibit good heat stability, low flexural moduli, excellent puncture resistance, excellent impact strength, and low moisture permeability but provide only poor barriers to gases, such as oxygen and carbon dioxide, some perfumes, and oil such as peppermint oil. Clarity of unoriented random copolymer film is moderate and is affected by processing conditions. Because its physical properties are balanced, unoriented film is easier to process on bag-making equipment than cast-oriented film, and slitting and sealing is easier in the transverse direction. Applications include packaging for shirts, hosiery, bread, and produce, used as a strength and barrier layer in disposable diapers, and used in electrical capacitors (Barnetson, 1996; Fortilene Polypropylene Properties, Processing, and Design Manual, 1981; Himont, 1992; Miller et al., 1991; Moore, 1996; Polymers in Contact with Food, 1991; Thompson et al., 1987).

2.2 Cast Film

Cast processes are usually used to produce uniaxially oriented film, oriented in the machine direction. Physical properties of the film depend on the degree of orientation, and a film is produced with different surface properties on each side. Oriented cast polypropylene film is clear and glossy, with high tensile strength. It is about three times stiffer and stronger than low-density polyethylene film. Cast film provides good moisture barrier properties and scuff resistance at low cost. Low-temperature brittleness is a problem with homopolymer polypropylene film; this can be overcome by the use of a copolymer resin (Fortilene Polypropylene Properties, Processing, and Design Manual, 1981; Graves, 1995).

A water bath is sometimes used instead of a chill or casting roll; the water bath process quenches the melt on both sides at the same time, producing a film with the same surface properties on each side. The machine direction orientation in the water bath process is somewhat different than that obtained using the casting roll, and the very rapid quenching

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lowers the crystallinity, producing a tougher film (Fortilene Polypropylene Properties, Processing, and Design Manual, 1981).

Tear initiation, by impact, puncture, or ripping, is difficult in oriented polypropylene (OPP) films; once initiated, however, the resistance to tear propagation is low. Tear strength depends on grade and process conditions and on whether the tear propagates in the machine or transverse direction. A tear strip is usually incorporated in OPP film packs to facilitate opening (Barnetson, 1996; Fortilene Polypropylene Properties, Processing, and Design Manual, 1981).

2.3 Biaxially Oriented Film

Biaxially oriented polypropylene (BOPP) film is film stretched in both machine and transverse directions, producing molecular chain orientation in two directions. BOPP film is produced by a tubular process, in which a tubular bubble is inflated, or a tenter frame process, in which a thick extruded sheet is heated to its softening point (not to the melting point) and is mechanically stretched by 300–400%. Stretching in the tenter frame process is usually 4.5:1 in the machine direction and 8.0:1 in the transverse direction, although these ratios are fully adjustable. It is a widely used process, more common than the tubular process, and a glossy, transparent film is produced. Biaxial orientation results in increased toughness, increased stiffness, enhanced clarity, improved oil and grease resistance, and enhanced barrier properties to water vapor and oxygen. Impact resistance, low-temperature impact resistance, and flexcrack resistance are substantially modified. BOPP films are used in food packaging and are replacing cellophane in applications such as snack and tobacco packaging due to favorable properties and low cost (Fortilene Polypropylene Properties, Processing, and Design Manual, 1981; Goddard, 1993).

Oriented films can be used as heat-shrinkable films in shrink-wrap applications or can be heat set to provide dimensional stability. Heat sealing is difficult in BOPP films, but can be made easier by either coating the film after processing with a heat-sealable material (such as polyvinylidene chloride) or by coextrusion with one or more copolymers before processing to produce layers of film. Copolymers used in sealing layers must have high gloss and clarity and should have low sealing temperatures to prevent distortion of the oriented polymer during sealing. Random copolymers containing 3–7% ethylene are often used as sealing layers; the

Table 2.1 Properties of OPP Films

Property	ASTM Test Method	Cast, Uniaxial Orientation	Biaxial Orientation
Area factor in 2/lb./1 mil film	–	30,400–31,300	30,600
Specific gravity (g/cm^3)	D1505	0.885–0.905	0.902–0.907
Tensile strength (psi)	D882	4500–7000	7500–40,000
Elongation (%)	D882	550–1000	352475
Tear strength (g/mil propagation)	D1922	25 MD 600 TD	3–10
Fold endurance	D2176	Very high	Excellent
24 h % water absorption	D570	0.005	0.005
Water vapor transmission rate (g/mil/ 100 in.^{2}/24 h at 100°F)	E96	0.7	0.25
Oxygen permeability (cm^3/100 in.^{2}/mil/24 h/ atm. at 77°F)	D1434	150–240	160
Heat-sealing temperature range (°F)	–	285–400	–
Gloss (%)	–	90	95
Haze (%)	–	1–2	1–2

MD, machine direction; TD, transverse direction.

Table 2.2 Properties of Novolen Cast Film[a]

Property		Unit	Test Method	Block Copolymer	Random Copolymer		Homopolymer		
Grade				2309KX	3200 MCX	3520 LX	1125N	1127MX	1325L
Additives				None	None	Antiblock agents	Slip, antiblock agents	Slip, antiblock agents	Slip, antiblock agents
Melt flow rate		g/10 min	ISO 1133	4	8	5	11	8	5
Gloss	20°	%	DIN 67530	5	130	130	110	95	115
Haze		%	ASTM 1003	28	0.5	0.3	2.3	3.0	1.7
Tensile strength at break	Machine direction	MPa	DIN 53455	55	37	32	42	44	35
	Transverse direction	MPa	DIN 53455	36	35	30	38	40	33
Elongation at break	Machine direction	%	DIN 53455	750	730	750	680	700	750
	Transverse direction	%	DIN 53455	720	750	760	720	730	780
Dart drop impact resistance F50		g	ASTM 1709	500	450	>800	280	300	800
Modulus of elasticity in flexure	Machine direction	MPa	DIN 53121	650	480	300	700	680	370
	Transverse direction	MPa	DIN 53121	640	470	310	670	650	350
Coefficient of friction			DIN 53375	0.90	Not measurable	Not measurable	0.25	0.17	0.13

[a] *50 μm gauge; Data was obtained using film specimens prepared by internal standards. Film properties depend considerably on processing conditions. This must be taken into account when comparing these data with data obtained under different processing conditions.*

lower melting point (< 132°C; <270°F) results in a 30% increase in line speeds, and they can be recycled with no significant loss of strength or clarity. Coating or coextrusion increases the barrier properties of BOPP film, decreasing its permeability to gases. Common barrier polymers are ethylene vinyl alcohol, polyvinylidene chloride, and polyamide; five or more layers may be coextruded or laminated, or the barrier polymer can be dispersed in the matrix polymer (Fortilene Polypropylene Properties, Processing, and Design Manual, 1981; Goddard, 1993; Polymers in Contact with Food, 1991).

Some typical properties of cast, uniaxially oriented film, and BOPP films are listed in Table 2.1. Properties of films made using Novolen (BASF) homopolymers, random copolymers, and block copolymers are listed in Table 2.2 (Fortilene Polypropylene Properties, Processing, and Design Manual, 1981; Novolen Polypropylene (PP), 1992; Thompson et al., 1987).

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