Benefits of machine direction-oriented (MDO) films in flexible-packaging applications

By Ryan Breese, Ph.D., technical director, Eclipse Film Technologies

Machine direction orientation (MDO) of polymer films improves numerous properties, including stiffness, strength, barrier and optics. The types of films that can be enhanced by MDO are limitless. This combination of improved properties and substrate flexibility makes MDO films applicable to a wide range of end-use markets, including food, medical, industrial and specialty products. These enhancements help converted-packaging suppliers meet the needs of their customers. The enhancements in properties of MDO films, relative to blown and cast films, allows packaging to be more cost-competitive and sustainable by source reduction (downgauging), replacing less desirable materials and minimizing the number of processes needed to produce a package.

MDO Overview

The machine direction orientation process consists of a series of stages—preheating, orienting, annealing and cooling (see Figure 1). The film enters the MDO and is preheated to the required orientation temperature. In the orientation stage, the film is nipped between a slow and a fast, rotating roller. The ratio of these rollers' speeds is referred to as the draw ratio. Depending on the desired film properties, the film can be quenched or annealed after orientation. In the final stage, the film is cooled to near ambient temperature.

Enhancement in film properties

Table 1 shows the typical relationships between the changes in film properties with increasing draw ratio [1]. The modulus of the polymer film can increase considerably with increasing draw ratio, as shown for various MDO HMW-HDPE films in Figure 2 [2].

Barrier properties also improve significantly, with the water-vapor transmission rate reduced by nearly 70 percent for MDO HDPE [3]. The oxygen-transmission rate is reduced by over 40 percent in an LLDPE/tie/EVOH/tie/LLDPE coextruded films [4], as shown in Figure 3. In addition, the MDO film has 70-percent better oxygen barrier at a high relative humidity (90 percent RH) than the undrawn film [4], as seen in Figure 4.

Optical properties of MDO films improve drastically after orientation. For HDPE, the gloss increases by over 70 percent, while the haze decreases by nearly 60 percent at a draw ratio of 6:1 [3]. For EVOH coextruded films, the gloss increases by 60 percent, and the haze decreases by more than 70 percent at a draw ratio of 6.5:1 [4].

Typically, machine-direction tear and dart-drop strengths decrease with increasing draw ratio. Specially formulated film structures can have acceptable tear strengths for a given application, while obtaining several of the previously mentioned benefits from the MDO process [2]. Additional work also has shown that through film

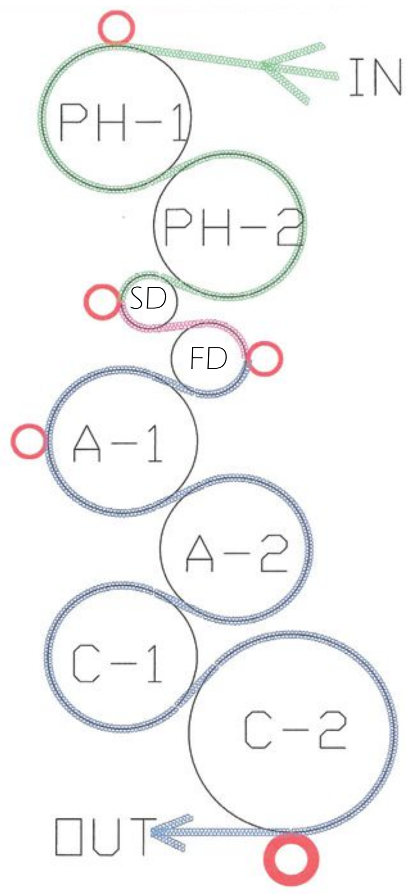

FIGURE 1: *Schematic of an MDO process: Equipment consists of preheat (PH), slow and fast draw (SD, FD), annealing (A) and cooling (C) rolls. Nip rolls are shown on PH1, SD, FD, A1 and C2.*

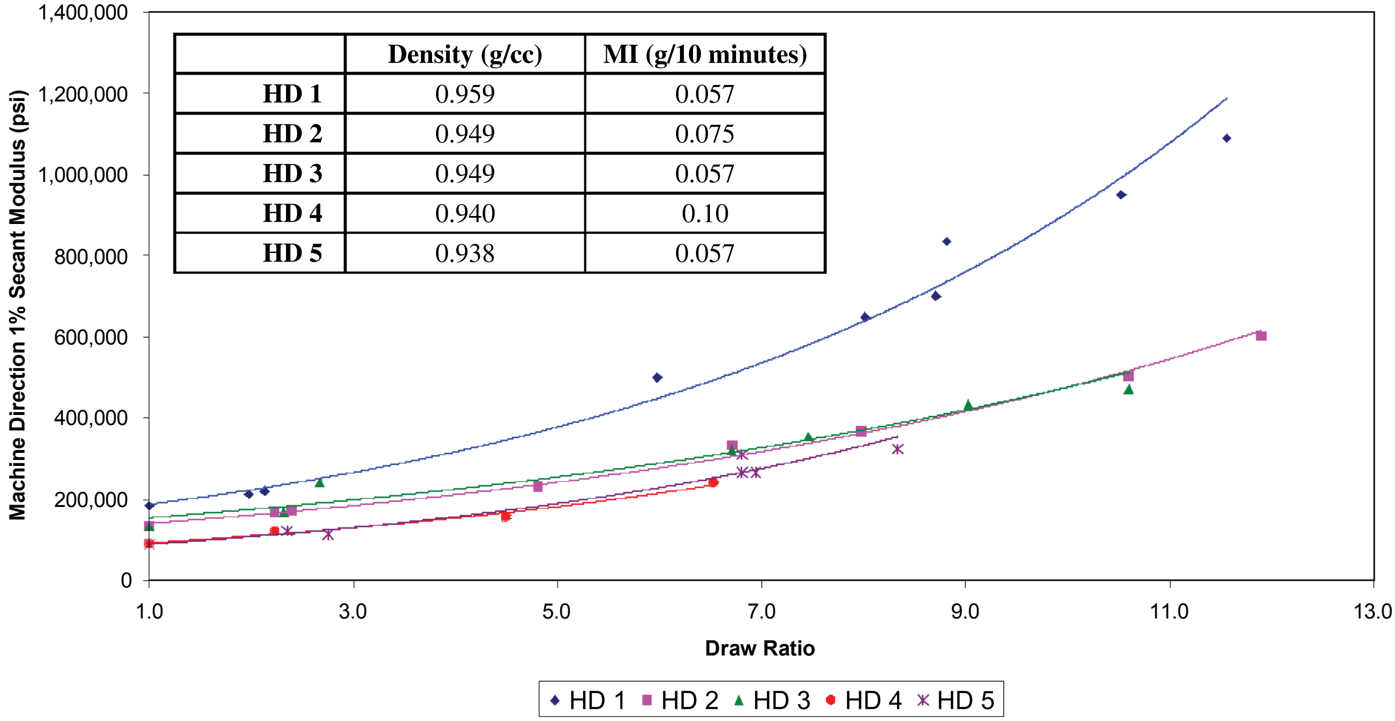

FIGURE 2: *Plot of the machine-direction modulus relative to increasing draw ratio*

design, the relationship between dart drop and draw ratio can be reversed, producing films that have increasing dart-drop impact strength with increasing draw ratio [5].

Economic drivers

Using MDO films as part of a flexible-packaging laminated structure can greatly reduce cost, improve downstream-conversion efficiencies and enhance consumer appeal. Three ways MDO films can reduce packaging costs are [6]: Source reduction (downgauging), replacing less desirable materials and minimizing the number of processes needed to produce a package.

Regarding the first scenario, the increase in modulus allows the downgauging of a film without compromising the structural rigidity of the package. The Table 2 example of an MDO-sealant film for a standup pouch, when compared to a standard sealant film, provides a 32-percent yield increase with improvements in mechanical and optical properties [1].

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TABLE 1: *Relationships between property changes in MDO films with respect to increasing draw ratio*

Property	Change
Modulus	Increases
Tensile Strength	Increases
Barrier (Water, Oxygen, Grease)	Increases
Gloss	Increases
Haze	Decreases
Machine-Direction Tear Strength	Decreases
Transverse-Direction Tear Strength	Increases
Dart Drop	Decreases

TABLE 2: *Typical data for a standard sealant film and a downgauged MDO-sealant film*

Property	Units	Standard Sealant Film	MDO Sealant Film
Gauge	mil	2.0	1.5
Yield	MSI/lb	15.0	19.7
MD Modulus	psi	35,000	310,000
MD Break Strength	psi	4,500	28,000
TD Break Strength	psi	4,000	2,400
Haze	%	10	9.0
45˚ Gloss		65	75
Heat-Seal Temperature for 5 lbs/in. seal strength	deg F	200-250	200-250

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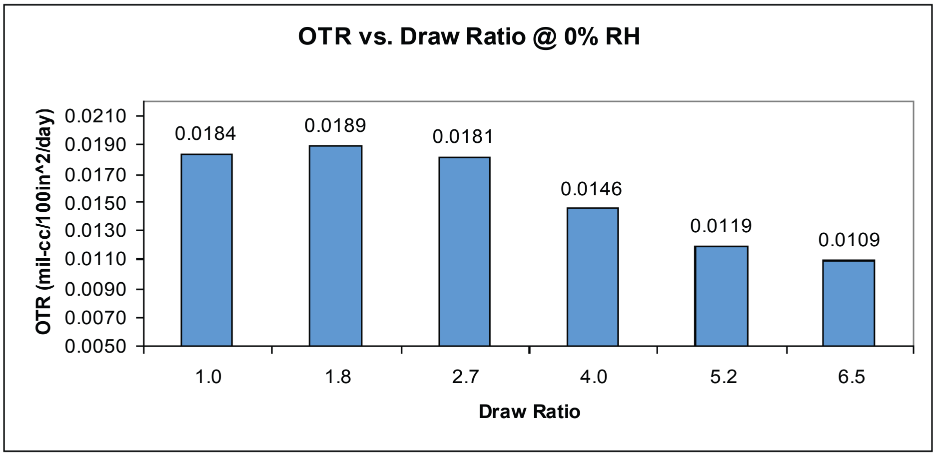

FIGURE 3: *Effect of increasing draw ratio on oxygen-transmission rate for an EVOH coextruded film at zero-percent relative humidity*

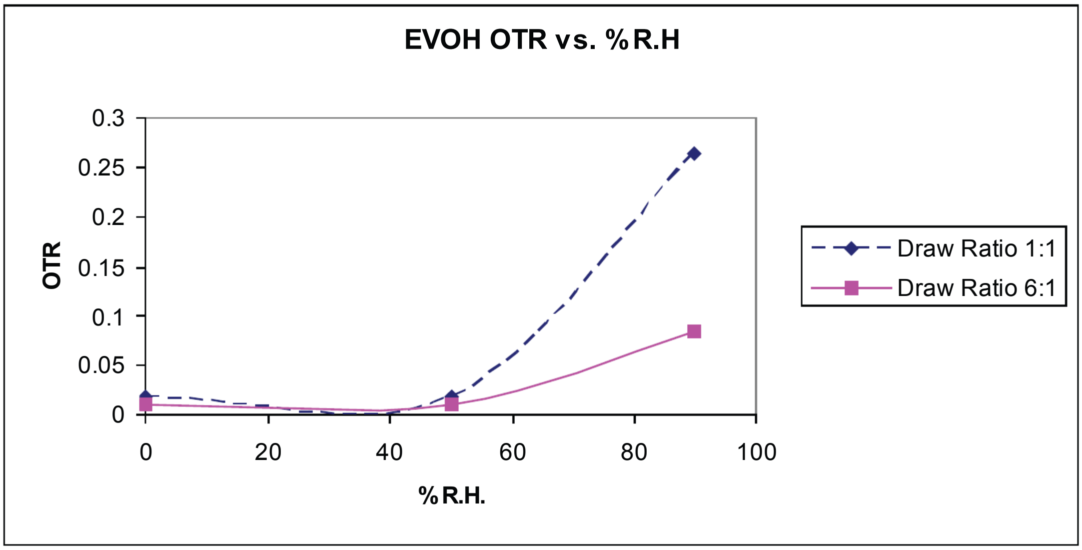

FIGURE 4: *Oxygen-permeation rates (cc-mil/100in²-day-atm) of a MDO and an unoriented-EVOH coextruded film at various relative humidities*

The Table 3 example for the second scenario involves replacing a polyester film with an MDO-polyolefin film. A specific case involves replacing a 48-gauge PET film with a 0.60-mil polyolefin film [6].

While the gauge of the polyolefin film is 25 percent heavier, the yield (MSI/lb) is improved by 15 percent. This is due to the difference in the densities of the two polymers. One benefit of MDO PE film is its clean, straight tear. This characteristic improves the ease of opening and reclosing pouches, a characteristic desired by consumers. Shortcomings of the MDO polyolefin film, relative to the PET film, should be acknowledged and include the lack of thermal stability at elevated temperatures, higher haze and lower transverse-direction tensile properties.

Specially designed MDO films can be used to reduce the number of processes necessary to produce flexible packaging. In this case, a high-barrier mono-web can replace a PVDC-coated PET/PE lamination, eliminating the need for a lamination process [6]. The Table 4 example of a lamination-replacement film combines a heat-stable, print-receptive outer skin, a low seal temperature inner skin, excellent moisture and oxygen barrier, high stiffness and excellent optics. This film has similar oxygen- and moisture-barrier properties as many coated and metalized films [1], as shown in Figure 5.

Conclusion

Machine direction orientation (MDO) of polymer films provides significant improvements in both the performance and the cost of

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flexible packaging for a wide range of end-use markets. These include food, medical, industrial and specialty applications. Considerable increases in stiffness, strength, barrier and optics are readily attained through MDO. Using MDO films can reduce packaging costs through source reduction (downgauging), replacing less desirable materials and optimizing overall process efficiencies. ■

D. Ryan Breese, technical director of Eclipse Film Technologies (Hamilton, OH) holds a Bachelor's in Chemical Engineering, and a Master's and Ph.D. in Materials Science and Engineering—all from the University of Cincinnati. Previously, he had various work roles at Lyondell Chemical Co. A member of the Society of Plastics Engineers, Ryan sits on the Flexible Packaging Div. board and serves on the New Technology committee. He can be reached at 513-942-2900, ext. 1, email: rbreese@eclipsefilmtech.com, www.eclipsefilmtech.com.

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TABLE 3: *Typical data for oriented polyester film and an MDO polyolefin film*

Property	Units	0.48-mil PET	MDO Polyolefin Film
Gauge	mil	0.48	0.60
Yield	MSI/lb	42.2	48.6
MD Modulus	psi	400,000-600,000	500,500
MD Break Strength	psi	32,000	60,000
TD Break Strength	psi	39,000	5,600
MD Break Strain	%	110	48
TD Break Strain	%	70	6.7
MD Elmendorf Tear	g/mil	30	11.1
TD Elmendorf Tear	g/mil	30	54.0
Haze	%	3.6	12

TABLE 4: *Properties of a sealable, high-barrier MDO film for the replacement of a laminated barrier structure in flexible packaging*

Property	Units	Sealable High-Barrier MDO Film
Gauge	mils	2.6
MD Modulus	psi	230,000
TD Modulus	psi	170,000
MD Break Strength	psi	13,400
TD Break Strength	psi	3,100
MD Break Strain	%	57
TD Break Strain	%	1,440
MD Elmendorf Tear	g	190
TD Elmendorf Tear	g	250
OTR	cc / 100 in^2 / day	0.091
WVTR	g / 100 in^2 / day	0.314
45° Gloss (print side)		90.1
Transparency	%	93.9
Haze	%	10.5
Heat-Seal Temperature for 10 lbs/in. seal strength	deg F	250

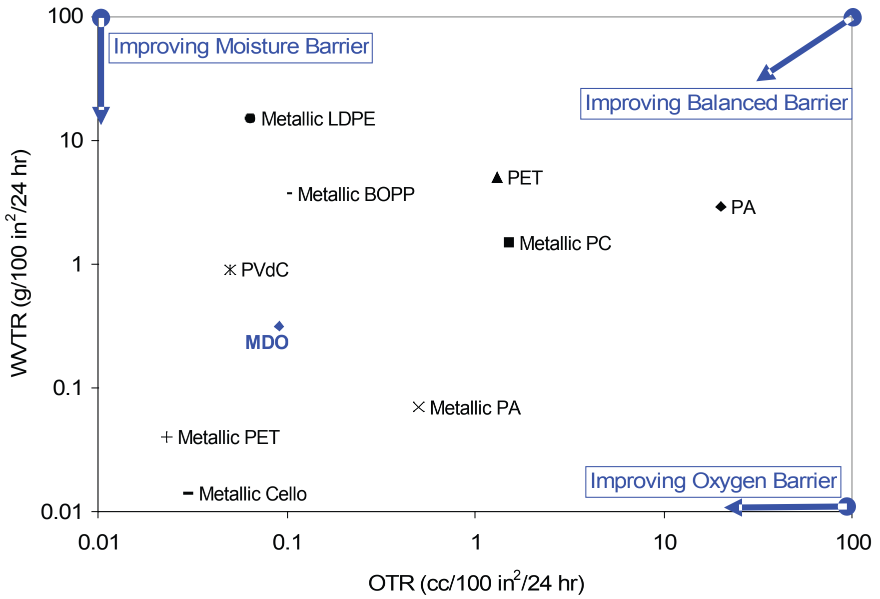

FIGURE 5: *Water- and oxygen-transmission rates for various polymer films*