Economic Benefits of Utilizing MDO Films in Flexible Packaging

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MDO, Film, Flexible Packaging, Cost Reduction, Source Reduction, Sustainability, Downgauge, Material Replacement

ABSTRACT
Machine direction orientation (MDO) greatly enhances film properties, namely the modulus, barrier, tensile strength and optics. By utilizing MDO films, a packaging producer can significantly reduce packaging costs by downgauging, replacement of less desirable materials and/or the elimination of secondary conversion processes. Doing so effectively reduces the amounts and types of material sourced and processing steps needed to manufacture a given package.

INTRODUCTION

In this paper, a brief overview of the enhancements in physical properties from MDO processing will be presented, with the objective of demonstrating economic drivers for utilizing MDO films in flexible packaging. General examples will be given that show the potential economic benefits associated with utilizing MDO films in flexible packaging.

IMPROVEMENTS IN PHYSICAL PROPERTIES THROUGH MDO PROCESSING

Machine direction orientation (MDO) is known to significantly change the physical properties of polymer films. Of particular interest are the increases in mechanical (modulus, strength) [1-5] and barrier (moisture, oxygen) [5-7] properties. Previous work has shown an increase of over ten times in machine direction modulus and break strength of HMW-HDPE films after MDO [1]. Such a film has a modulus of over 1,000,000 psi, twice that of commonly used PET. Additional work has shown a significant reduction in oxygen and moisture transmission rates for MDO seven layer films containing LLDPE, HDPE and EVOH [4], greater than 200% improvement in oxygen barrier for coextruded films containing LLDPE and EVOH [6], an improvement in oxygen barrier at high humidity relative to non-MDO films [6], and oxygen and moisture transmission rates reduced by greater than half for MDO HDPE films [5,6]. These improvements in properties allow a converter to significantly reduce a package's cost through downgauging, material replacement and process consolidation.

COST REDUCTION THROUGH MDO PROCESSING

Three ways to reduce the cost of a flexible package by utilizing MDO films are:

- Source Reduction = Downgauging the thickness of the film
- Material Burden Reduction = Replacement of less desirable materials

- Processing Reduction = Process consolidation

Source Reduction
The significant increase in the mechanical properties of a film as a result of MDO processing enables the downgauging of a polymer film without compromising the overall properties of the package. For example, MDO can be utilized to downgauge films for heavy duty shipping sacks, food and medical packaging.

One opportunity to reduce packaging costs through source reduction is in heavy duty shipping sacks. Fiscus has outlined both the minimum and actual properties of a 5 mil hexene LLDPE heavy duty shipping sack [8]. These are listed in Table 1, with comparable data for a specially developed MDO film that has a 10% reduction in gauge, relative to the incumbent.

Property	**Units**	**5 mil Hexene LLDPE Film (minimum) [8]**	**5 mil Hexene LLDPE film (actual) [8]**	**4.5 mil MDO film (measured)**
MD Modulus	psi	30,000	51,300	111,800
TD Modulus	psi	N/A *	N/A *	82,400
MD Yield Strength	psi	1,400	1,700	8,600
TD Yield Strength	psi	1,300	1,900	2,200
MD Break Strength	psi	4,500	6,700	13,500
TD Break Strength	psi	4,500	6,400	9,000
MD Break Strain	%	600	780	410
TD Break Strain	%	600	820	1300
MD Elmendorf Tear	g/mil	100	330	200
TD Elmendorf Tear	g/mil	100	570	>1400**
Dart Drop	g/mil	120	130	60
45˚ Gloss	Units	N/A*	N/A*	50

* TD Modulus and Gloss data were not included in Reference [8].
** Pendulum weights greater than 6,400 g were not available for Elmendorf tear testing, resulting in a maximum measurable tear strength for a 4.5 mil film at 1,400 g/mil.

Table 1. Data for 5 mil hexene LLDPE heavy duty shipping sack film and a downgauged 4.5 mil MDO film. Included are minimum requirements and actual data for the incumbent film and measured data for the MDO film.

The MDO film provides significant improvements in the modulus and tensile strength, allowing for further downgauging beyond the current 4.5 mil thickness. In this case, a MDO film of 3.0 mils would meet the minimum tensile requirements. Shortcomings of the MDO film include lower normalized machine direction tear (less than the actual, but still greater than the minimum required value) and dart drop (less than both minimum and actual) strengths. Tuning of these properties can be addressed through MDO operating conditions and film formulation, thus balancing the excess in the tensile properties with the shortcomings of the tear and dart drop values. In addition, an improvement in gloss is attained through MDO processing, significantly improving the overall aesthetics of the package. This example demonstrates the flexibility of the MDO process for providing films to meet specific application needs.

Material Burden Reduction

The improvements in modulus, clarity and tensile strength provide an opportunity to replace less desirable materials in packaging with those that are more cost effective and have properties that better suit the given application. An example would be replacing polyester films in specific applications with a MDO polyolefin film. In some cases, polyester is less desirable than polyolefins due to its higher density, which results in a significantly lower MSI yield. A specific example would be comparing a polyolefin-based MDO film with oriented polyester. The following table compares the two films:

Property	Units	0.48 mil Polyester	0.6 mil Polyolefin
Yield	MSI/lb	42.2 [10]	48.6
MD Modulus	psi	400,000 - 600,000 [9]	500,500
MD Break Strength	psi	32,000 [10]	60,000
TD Break Strength	psi	39,000 [10]	5,600
MD Break Strain	%	110 [10]	48
TD Break Strain	%	70 [10]	6.7
MD Elmendorf Tear	g/mil	30 [9]	11.1
TD Elmendorf Tear	g/mil	30 [9]	54.0
Haze	%	3.6 [10]	12

Table 2. Typical data for oriented polyester film and a MDO polyolefin film.

By utilizing the polyolefin-based MDO film, even at the heavier gauge of 0.6 mil, a package producer would capture a 15% yield improvement relative to 48 gauge PET film. Benefits other than the source reduction include twice the machine direction break strength, heat sealability, the inherent hydrophobic nature of the polyolefin and the anisotropic tear resulting in better straight line tear characteristics. Some significant shortcomings of the MDO polyolefin film should be addressed, and include the thermal stability at elevated temperatures, higher haze, lower oxygen barrier and lower transverse direction tensile properties. For these reasons, MDO polyolefin films may not be an acceptable substitution for all polyester applications, but can be an alternative in those cases where stiffness, tensile strength and directional tear are of primary interest.

In another case, MDO films can be utilized to replace incumbent films that are not ideally designed for a given application. For example, few varieties of uncoated BOPP products are available, primarily due to the limited flexibility of the extrusion and orientation lines used to manufacture these films. By utilizing a robust MDO process offline from extrusion, a film tailored specifically to the requirements of a given package can be produced. This film could have numerous benefits, such as improved performance and processability, thus increasing the efficiency of downstream processes, such as printing presses, laminators and bag/pouch making machines.

Processing Reduction

The potential exists to utilize MDO technology to eliminate the need for some secondary film conversion processes. An example would be replacing a laminated structure with a specifically designed MDO film. The improvements inherent to MDO films, increased modulus, barrier, strength and gloss, lend the technology to replacing laminations of printed films with sealant webs. Recent improvements in surface printing technologies also lessen the need to reverse print packaging films [11]. The large number of requirements for a given package makes this a challenging feat, but such developments can provide great economic benefits and improvements in process efficiencies.

The following is an example of a MDO film that combines improved barrier, good heat sealability, increased stiffness, high gloss and low haze.

Property	**Units**	**2.6 mil Lamination Replacement MDO Film**
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
45˚ Gloss (print side)		90.1
Clarity		92.2
Transparency		93.9
Haze		10.5

Table 3. Properties of a high barrier MDO film for replacement of laminated barrier structures in flexible packaging.

This developmental film also had excellent seal strength at moderate sealing temperatures, as indicated in Figure 1.

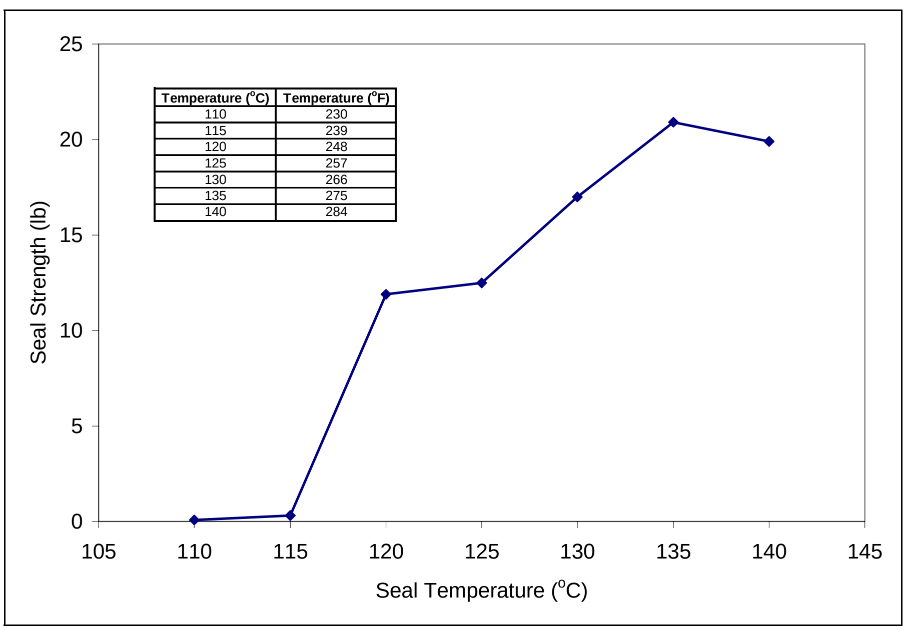

Figure 1. Heat seal strength vs. heat seal temperature for 2.6 mil MDO lamination replacement film. Seal testing was conducted at 0.5 seconds dwell time and at 50 psi seal pressure.

This film has similar oxygen barrier properties as many coated and metallized films [9,10,12]. Its tensile properties are significantly higher than laminated polyester structures. In addition, the high gloss surface is similar, if not better, than other lamination grade printed films and provides excellent aesthetics to the package.

CONCLUSION

The enhancements seen through machine direction orientation (MDO) lend its use for both product enhancement and significant cost reduction. Three ways that MDO films can be used to reduce packaging costs are through film downgauging, replacement of less desirable materials and process consolidation. By utilizing the MDO process and designing specific films to meet the requirements of a given application, significant economic savings can be achieved.

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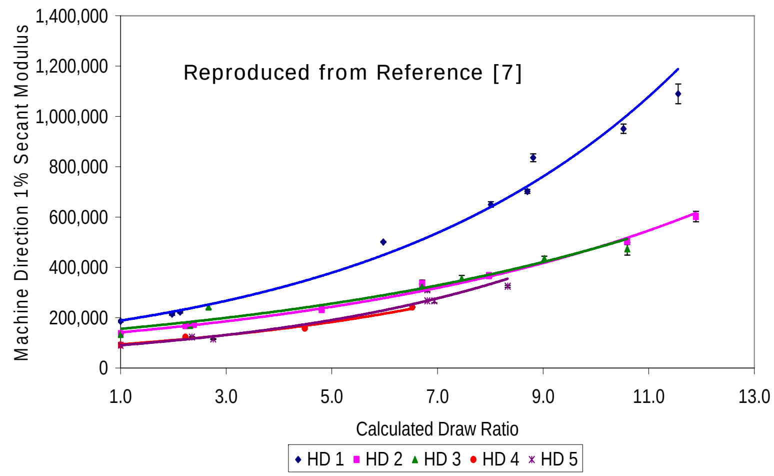
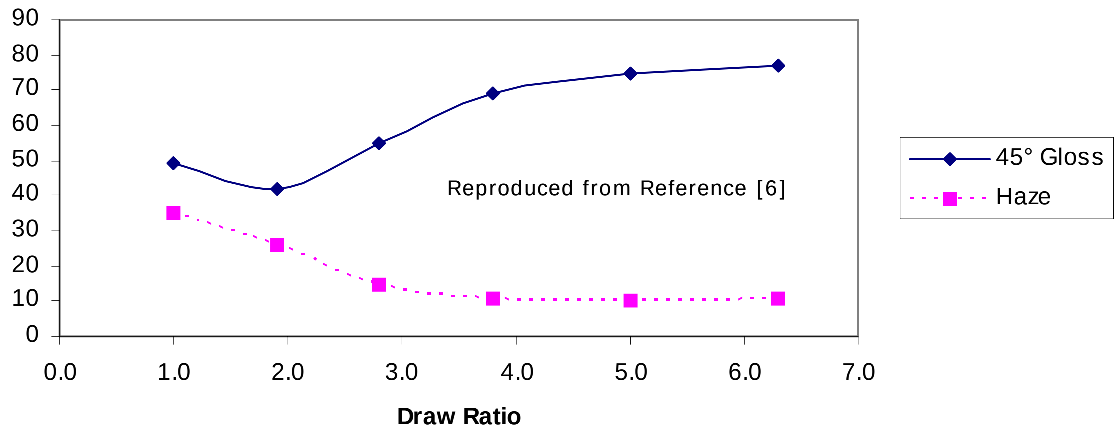
Agenda

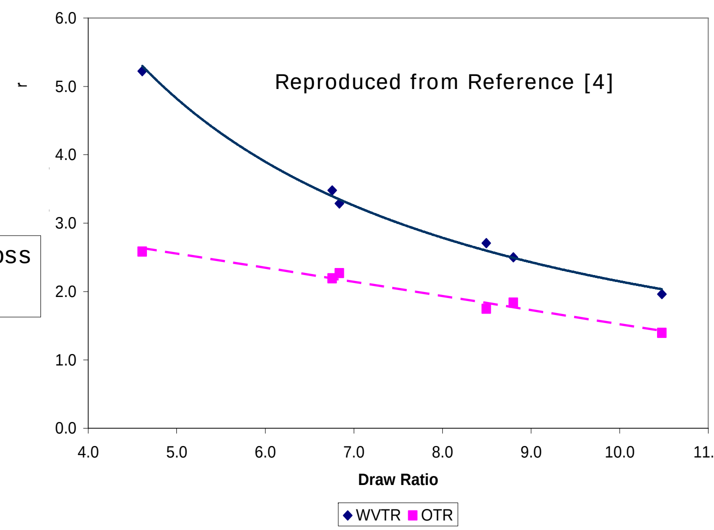
- Enhancements of MDO Film Properties
- Methodology for Economic Benefit through MDO
  - Source Reduction
  - Material Burden Reduction
  - Processing Reduction
- Conclusions

Enhancements of MDO Film Properties

- Increases:
  - Modulus
  - Tensile Strength
  - Barrier
    - WVTR, OTR
  - Optics: Haze & Gloss







Methodology for Economic Benefit

- Source Reduction
  - Downgauging
- Material Burden Reduction
  - Material replacement
    - Substitute for less desirable materials
- Process Replacement
  - Alternate for costly secondary processing
    - Laminations, coatings, etc.

Source Reduction

- Enhance film properties → Downgauge

- Improvements in physical/mechanical properties allow for thinner packaging

- Design optimization to meet film application needs
  - Orienting of the existing film used in an application is usually deficient in meeting all packaging requirements

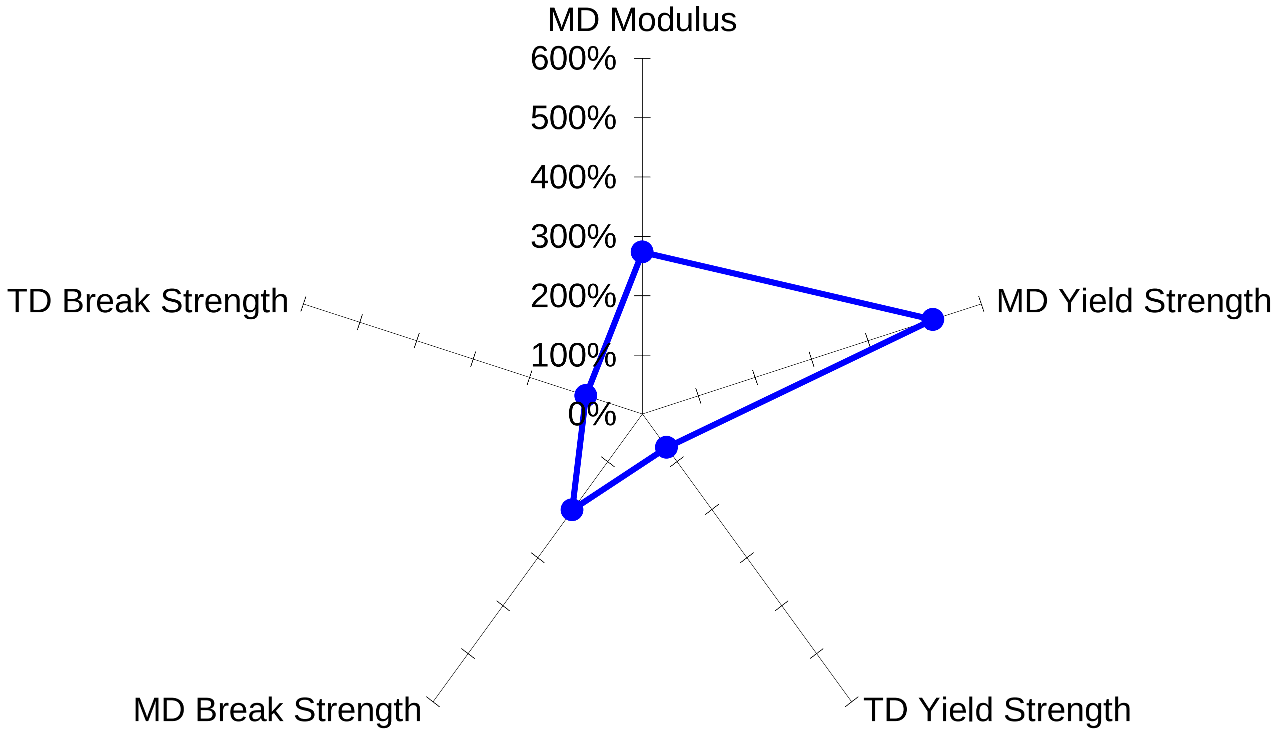
Source Reduction

- Example
  - Heavy Duty Shipping Sack
    - Markets
      - Lawn & Garden
      - Food
      - Chemical
    - Reduce structure gauge by 10%
      - 5.0 mil reduced to 4.5 mil

Source Reduction

<u>MDO HDSS Film Properties</u>

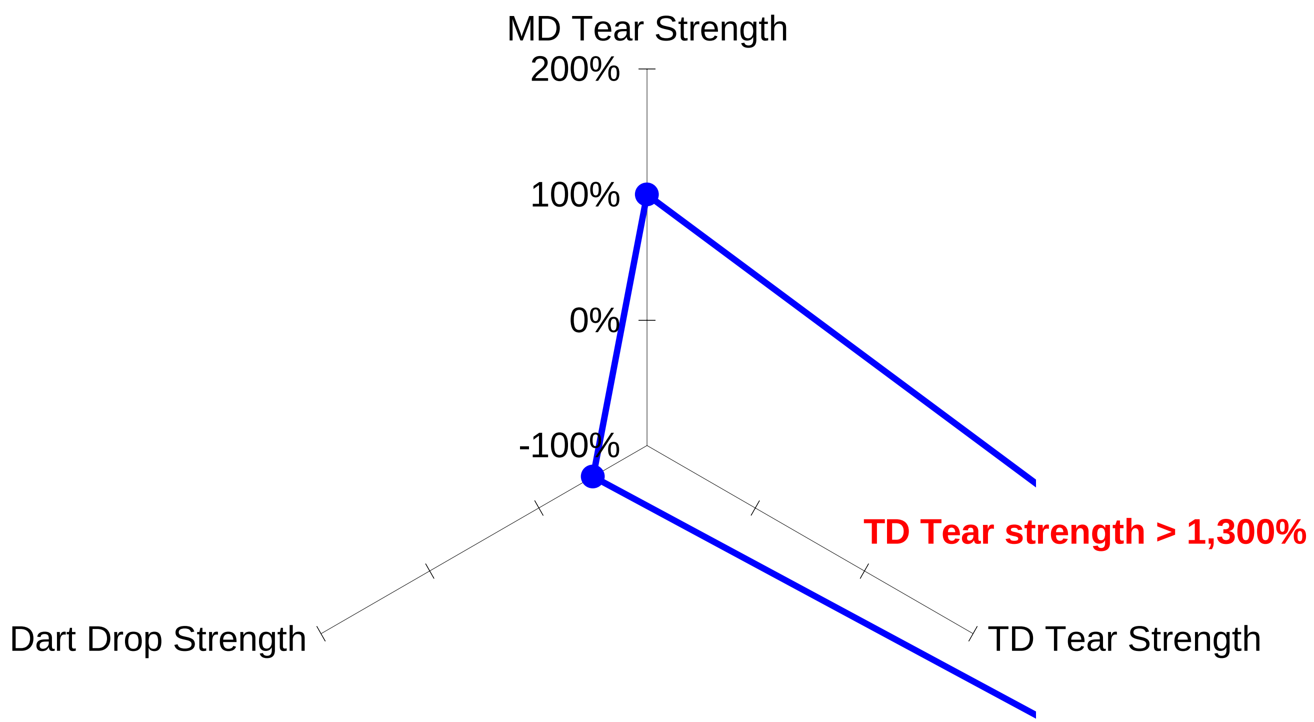
- Tensile Properties
  - All in excess of package requirements
  - 3.0 mil film of current structure would meet minimum requirements (References [8])



Source Reduction

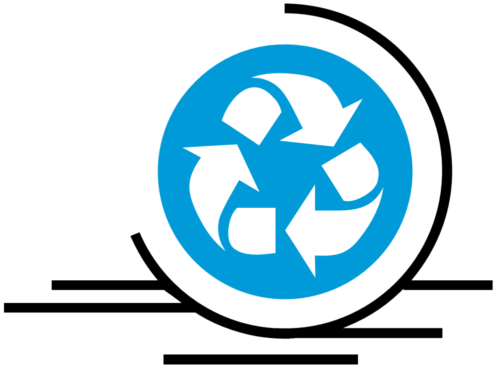
MDO HDSS Film Properties

- Tear strength greater than requirements
- Dart drop strength too low
  - Increase dart drop strength through film formulation and process conditions



Material Burden Reduction

- Replace less desirable materials
  - Higher cost
  - Higher density
  - Processing/handling issues
  - Printability
  - Environmental concerns – Pre-Cycling



Material Burden Reduction

- Example
  - PET Substitution
    - Markets
      - Food packaging: stand up pouch
      - Labels: release liner
    - Applications are likely niche
      - Off-line MDO process is more flexible than commercial scale in-line extrusion/orientatior
    - Initial evaluation: Increase yield by 15%
      - But…with a heavier gauge film???

Material Burden Reduction

MDO PET Substitution

- Properties
  - Modulus is equivalent
  - MD tensile is greater / TD tensile is less
  - MD tear is less / TD tear is greater
  - Tear anisotropy (directional tear) is greater
  - Haze is higher
  - Lower heat stability

Property	**Units**	**0.48 mil Polyester**	**0.6 mil Polyolefin**	**% Changes**
Yield	MSI/lb	42.2 [10]	48.6	**+ 15 %**
MD Modulus	psi	400,000 - 600,000 [9]	500,500	**Equal**
MD Break Strength	psi	32,000 [10]	60,000	**+ 88 %**
TD Break Strength	psi	39,000 [10]	5,600	**- 44 %**
MD Elmendorf Tear	g/mil	30 [9]	11	**- 63 %**
TD Elmendorf Tear	g/mil	30 [9]	54	**+ 80 %**
Tear Anisotropy (MD/TD)		1.0	0.21	**+ 80 %**
Haze	%	3.6 [10]	12	**+ 2.3 %**

Processing Reduction

- Eliminate costly secondary processes
  - Laminations
  - Coatings
- Reduces total packaging cost by:
  - Eliminating steps
  - Reducing production time
  - Reducing the number of SKUs
  - Reducing waste/scrap
  - Reducing logistical and material handling expenses

Processing Reduction

- Example
  - Barrier Lamination Replacement
    - Markets
      - Food packaging: stand up pouch
    - Current package
      - PET **/** LD or adhesive lamination **/** metallized sealant film
    - MDO lamination replacement
      - No lamination
      - Excellent properties
        - Stiffness and strength
        - Barrier
        - Optics
        - Heat sealability

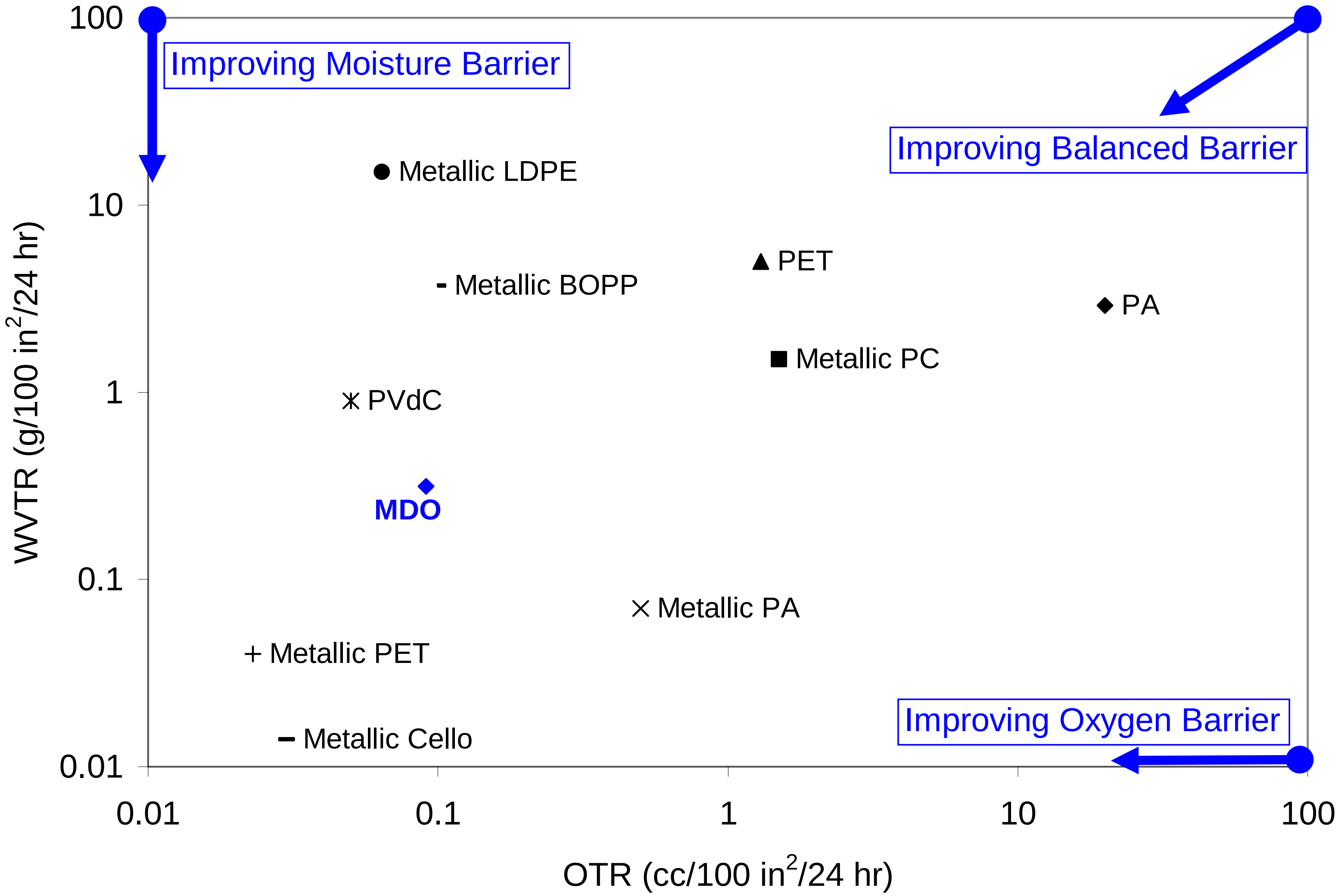
Processing Reduction

MDO Barrier film for lamination replacement

- Non-laminated/coated MDO film

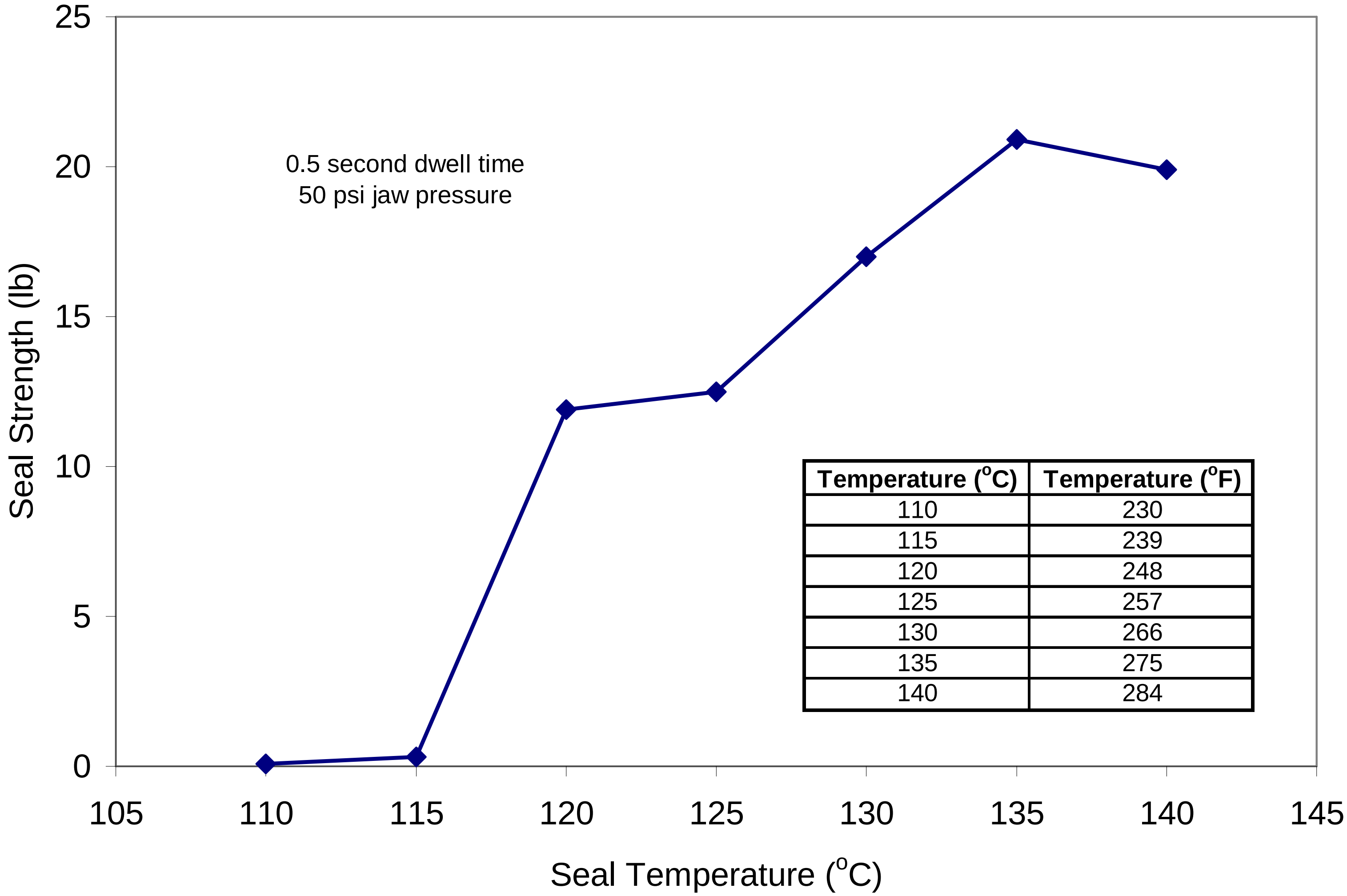
Property	Units	2.6 mil Lamination Replacement MDO Film
MD Modulus	psi	230,000
TD Modulus	psi	170,000
MD Break Strength	psi	13,400
TD Break Strength	psi	3,100
MD Elmendorf Tear	g	190
TD Elmendorf Tear	g	250
OTR	cc / 100 in^2 / day	0.091
WVTR	g / 100 in^2 / day	0.314
45° Gloss (print side)		90.1
Clarity		92.2
Transparency		93.9
Haze		10.5

Barrier Properties of Packaging Films



Data from Reference [10]: Brody, A. L., Marsh, K. L., *The Wiley Encyclopedia of Packaging Technology*, 2nd Edition, Wiley, New York (1997).

Heat Seal Curve for MDO Lamination Replacement Film



Temperature (°C)	Temperature (°F)
110	230
115	239
120	248
125	257
130	266
135	275
140	284

Conclusion

- Economic drives for MDO films:
  - Source Reduction
    - Downgauge
  - Material Burden Reduction
    - Replace less desirable materials
  - Processing Reduction
    - Alternate for costly secondary processing

Thank You

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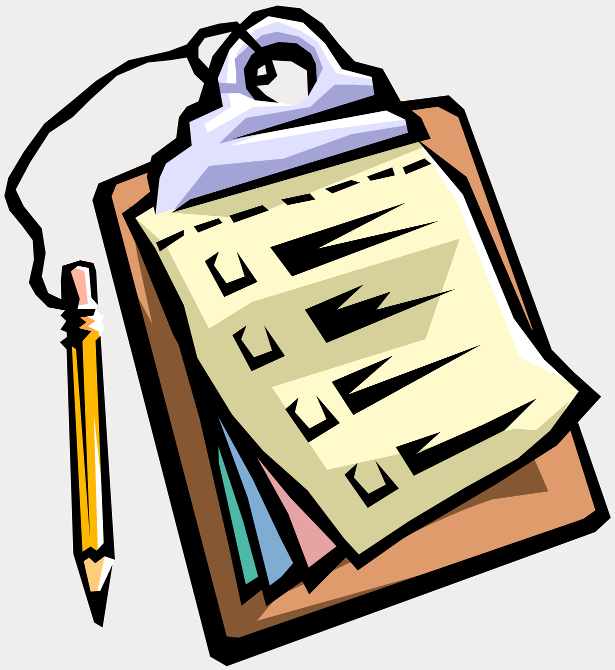

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