Downgauge Paper Overwrap Films Using mLLDPE Blends

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ABSTRACT

Downgauging is a continuing trend in the evolution of the films used to package paper products, such as toilet paper, napkins, and paper towels. As is usual in almost all downgauging efforts, a basic goal of the film redesign process is that any decrease in film thickness be accomplished with little or no loss in film properties, such as stiffness, clarity, and puncture resistance.

A study of blends of mLLDPE with a medium molecular weight HDPE has shown that downgauged films can be designed with properties comparable to today's overwrap films. These mLLDPE-HDPE blends open new avenues to film formulation where film toughness and stiffness must be maintained while film thickness is reduced.

KEYWORDS

Polyethylene, Flexible Packaging, Polyolefin Blends, LLDPE, mPE, Metallocene Polymers

INTRODUCTION

Overwrap films are used to bundle paper products, such as toilet paper, napkins, paper towels, and the like. These overwrap films perform two main functions. One function is to contain the product and to protect it from contamination or damage starting from the time it leaves the packaging line until the ultimate consumer opens the package. The second function or role of overwrap film is to provide an attractive means for advertising the product. Obviously in this day and age, any viable overwrap film must fulfill both of these roles at the minimum cost. These basic packaging film functions can be translated into sets of performance requirements, one set for each link in the packaging chain. The packaging engineer then uses these performance requirements to design a film structure. For overwrap films the packaging chain can be divided into three parts, 1) the film producer/converter, 2) the packager, and 3) the shipper/grocer/consumer.

Generally speaking paper overwrap films have relatively low strength requirements when compared to other film packaging applications. Nevertheless one must realize that few consumers will purchase a package which has a hole in it or shows any evidence of damage, so overwrap film must be a least able to survive the packaging and transportation process intact. For the film producer, any polyethylene used to make an overwrap film must have good processability in terms of throughput combined with the ability to drawdown to thin gauges. The film must be relatively stiff with low extensibility to permit good registration during printing and good roll conformity. For the paper product packager, overwrap film must be stiff enough to run on his particular packaging equipment. This film stiffness requirement is both package size and packaging machine dependent. Single roll paper towel and four count toilet tissue packages are typically made using thinner gauge, more flexible films than larger packages. Likewise, the older single sheet, reciprocating packaging machines require much stiffer films than the newer form-fill-seal (FFS) machines which are better able to handle lower modulus films due to their continuous operation. Other requirements for packaging operation are a reliable film COF and good slitting/cutting/sealing performance. The shipper, grocer, and consumer have a common set of film requirements. Since the film is a primary means of advertising, film appearance as measured by its clarity and gloss and a high print quality are important. The film must also have good puncture resistance but at the same time be relatively easy to open. Each of these film requirements must be factored into the design of new overwrap films.

Two main trends are apparent today in the overwrap film market. The primary trend similar to almost all other packaging films is the constant drive for cost reduction via film downgauging. There are four factors behind this trend. The obvious is cost savings through more packages per pound of film. Secondly thinner film means improved packaging line efficiency due to fewer roll changes. Thinner film also provides for better utilization of storage facilities. Lastly there is some consumer demand, more prevalent in Europe, for reduced packaging as a method of source reduction/recycling. The second market trend, also part of the waste reduction effort, is the effort to incorporate post-consumer-recycle (PCR) into packaging films. This is currently a minor factor in the design of overwrap films in the US. The use of metallocene polyethylenes to produce "environmentally friendly" paper overwrap film incorporating PCR was the subject of an earlier paper (1).

CURRENT OVERWRAP FILM TYPES

There are many different types of overwrap films in use today. About equal amounts of blown and cast films are employed with the cast films having a slight clarity advantage and a stiffness disadvantage. In the past overwrap films were mostly monolayer films, but the use of coex film is rapidly increasing. Coex films allow the converter more flexibility in tailoring the film properties to the actual use requirements; in this case to use the surface layers to achieve high gloss and good heat sealing performance while the core layer imparts the overall film stiffness. Coex films also permit the inclusion of recycled material into a core layer where it would not come in direct contact with the packaged goods. Overwrap films are typically 1.2 mil (30μ) or less, the film thickness being a function largely of the package size. With the current down gauging trend the majority of the overwrap film is now < 1 mil (25μ).

Historically, high pressure low density polyethylene (LDPE or MD-LDPE) with a medium density (0.930 +) has been the main component in overwrap film. This LDPE gave the best combination of clarity and stiffness. In many cases a small amount (typically <30%) of LLDPE has also been added to the LDPE to achieve better drawdown and improved physical properties for down gauging. Numerous other polyethylene blends are also currently used, given the relatively lenient film strength requirements of overwrap films. Since film stiffness is a key attribute, HDPE is sometimes added to boost the overall film stiffness even though the presence of HDPE tends to degrade clarity and toughness significantly. A quick trip down the paper product aisle at any grocery will confirm that a wide variety of films are used for paper overwrap, each film with its own combination of advantages and disadvantages. The table below presents a very subjective performance comparison for four typical overwrap film formulations.

Table 1: Typical Overwrap Film Performance Comparison

	MD-LDPE	MD-LD/LL	LD/MD-LL	LD/HDPE
Extrudability	o	=	--	-
Downgauge	o	+	+	++
Stiffness	o	=	+	++
Clarity/Gloss	o	=	-	--
Slitting	o	-	-	-
COF Control	o	=	+	+
Puncture/Tear	o	+	+	=
Openability	o	-	-	-

As can be seen in the table above, the modifications to the base MD-LDPE film have been made mainly to increase film stiffness to allow for down gauging, even though there are significant negative trade-offs in the other important film properties.

Obviously the most efficient way of increasing film stiffness is to blend in the highest density polyethylene possible. Unfortunately many HDPE's do not blend effectively with LDPE or LLDPE and also significantly decrease film properties, especially the puncture performance. With the advent of metallocene catalyzed polyethylenes an alternative blend formulation route is now available in which high film stiffness can be achieved in a film that possesses good toughness and clarity. This is achieved by blending together an m-LLDPE and a new medium molecular weight (MMW) HDPE. Some of these blends and potential applications were described in an earlier TAPPI paper by S. Best & D. Houska (2).

OVERWRAP BLEND STUDY - OVERVIEW

The objective of this study was to determine whether blends of mLLDPE and an MMW-HDPE could be viable candidates for downgauged paper overwrap film. The ultimate film thickness target was set at 0.5 mil (12.7µ), with an immediate goal of a 0.7 mil (17.8µ) film which would have film properties similar to the current 0.9 - 1.0 mil (22.9 - 25.4µ) LDPE and LDPE/LLDPE films. Although the film properties would be better optimized though the use of coex films, monolayer films were used for this screening study, partly to simplify the analysis and partly because many overwrap film producers have only monolayer film capability. To get a better picture of the relative downgauging potential of each blend, the film properties were compared on an absolute basis versus the actual film thickness. The complete study included more films than are described in this paper.

EXPERIMENTAL DETAILS

Materials
All the resins used in this study were made by Exxon Chemical Company. Two films made from conventional polyethylenes were selected as baselines for the property and processing comparisons. A third base film was made from a blend of the conventional LLDPE and the MMW-HDPE. Those films are described in Table 2 below:

Table 2: Base Overwrap Film Descriptions

Film Designation	Component # 1	% of # 1	Component # 2	% of # 2
LDPE	LD-117.03	100	---	---
LD/LL	LD-117.03	80	LL-3201.63	20
LL/HD	LL-3201.63	65	HD-7845.30	35

The first base film was a 100% LDPE film made from Escorene® LD-117.03 (1.6 MI, 0.929 D), an HP-LDPE commonly used for overwrap films. The second film was a blend of LDPE with a minority amount of Escorene® LL-3201.63 (C6-LLDPE, 0.8 MI, 0.926 D). The third base film was a blend of the conventional LLDPE with the MMW-HDPE, Escorene® HD-7845.30 (0.45 MI, 0.958 D). This HDPE has been designed to extrude efficiently on conventional LLDPE blown film lines and blends well with most polyethylenes. This third base film was included to show the effect of the presence of mLLDPE in the test films.

Three mLLDPE/HDPE films have been included in this discussion. Their compositions are shown in table 3.

Table 3: mLLDPE/HDPE Film Descriptions

Film Designation	Component # 1	% of # 1	Component # 2	% of # 2
mLL/HD #1	Exceed 350D60	60	HD-7845.30	40
mLL/HD #2	Exceed 350D60	65	HD-7845.30	35
mLL/HD #3	Exceed 357C32	55	HD-7845.30	45

The two grades of Exxon Chemical's mLLDPE used were Exceed™ 350D60 (1.0 MI, 0.917 D) and Exceed 357C32 (3.5 MI, 0.917 D). The higher melt index mLLDPE blend was included in the study to provide a film that could be processed at extruder motorloads comparable to current overwrap films.

Film Fabrication and Testing
Monolayer films were produced on a 2.5" Gloucester (GEC) blown film line at constant throughput. Each resin pair was blended using the blown film line's inline blending system. No additional additives, such as antioxidant, slip, or

antiblock, were added. Processing aid was used to "treat" the die on start-up to eliminate melt fracture. The processing equipment/conditions were:

- 2.5" Gloucester extruder with 24:1 GEC barrier screw
- Dual-lip GEC air ring, no IBC
- 20/40/80/20 screen pack
- 6-inch GEC die, 60-mil die gap (LDPE films also produced using 30 mil die gap)
- 2.25 BUR, 21" lay flat, tube stock
- Target film thickness range: 0.5 - 1.0 mil (12.7μ - 25.4μ)
- Extruder/adapter/die temperature profiles for mLLDPE & LLDPE films: 320/410/380/380/380/390...390^{o}F (160/210/194/194/194/200...200^{o}C)
  Melt temperatures: 400 - 420 ^{o}F (205 - 216^{o}C)
- Extruder/adapter/die temperature profiles for LDPE films: 300/360/350/330/330/390...390^{o}F (150/183/177/166/166/200...200^{o}C); Melt temperatures: 385 - 400 ^{o}F (196 - 205^{o}C)
- Cooling air temperature: 45 - 55^{o}F (8 - 13^{o}C)
- Throughput = 150 lbs/hr (68 kg/hr).

Film properties were evaluated using standard EXXON test methods. In addition to the fundamental film properties (secant modulus, tensile/elongation, Elmendorf tear, puncture, dart drop impact, and clarity), heat seal profiles were generated.

The heat seals were made on a Theller Model EB heat sealer under the following conditions:

- Sample width: 127 mm (5 inches), no backing tape used
- Seal width: 9.5 mm (3/8 inch)
- Seals made across TD direction, pulled in MD direction
- Flat seal bars covered with Teflon tape
- Sealing pressure: 0.14 N/mm^2 (20 psi)
- Seal Time: 0.5 s.

The heat seals were aged for a minimum of 24 hours and then cut into 25.4-mm (1-inch) strips and tested on a United Six Station Tensile Tester at a rate of 508 mm/min (20 inch/min). The reported seal strength is the average peak load for the test specimens sealed at a given temperature.

RESULTS & DISCUSSION

Blown Film Properties

As was mentioned earlier, many film properties, such as modulus and tensile strength, are typically reported on a unit cross-sectional area basis (psi) which makes comparison of different thickness films somewhat difficult. To get a better idea of the property trends versus film thickness the properties have been plotted using the base force measurements. For example in the case of the films' secant modulus the comparison is based on the force measured at a 1% strain. This technique allows one to quickly compare films of different thickness. A second point to keep in mind when looking at the graphs which follow is that only two thicknesses were made for each formulation. The actual property trends are nonlinear, so extrapolations outside the data sets should be done with caution.

Film stiffness is a key overwrap film property and Figures 1 and 2 show the trends in film modulus obtained for the six formulations.

Figure 1: Machine Direction Film Stiffness

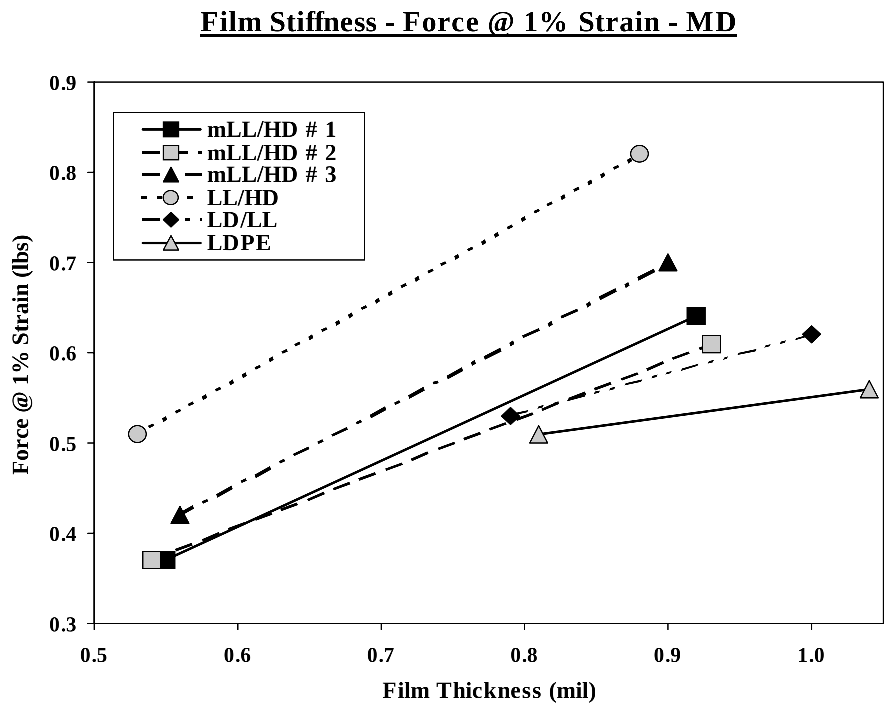
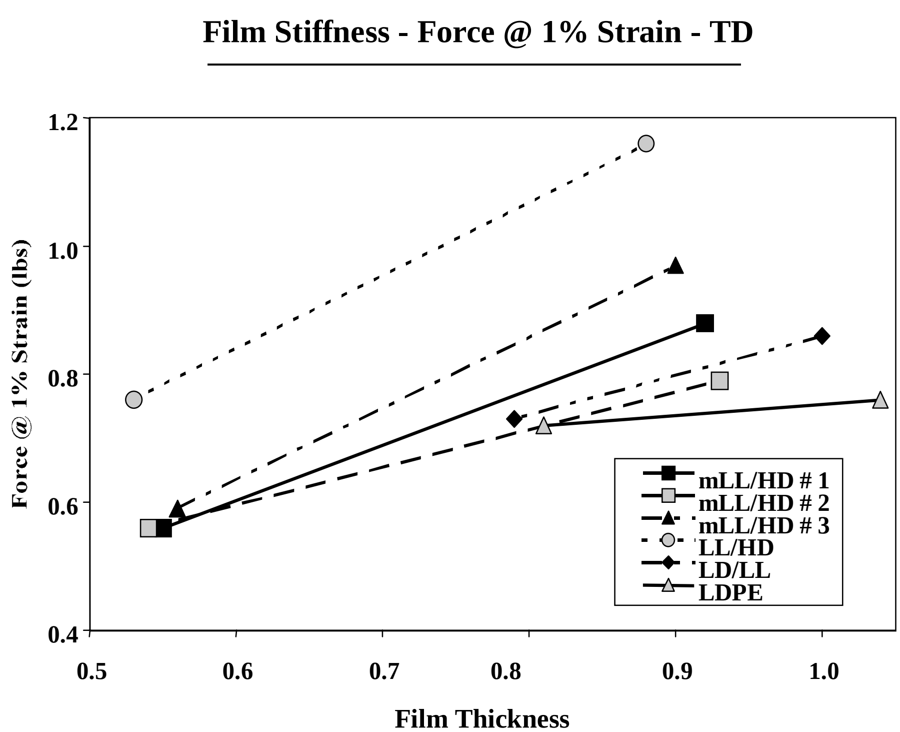


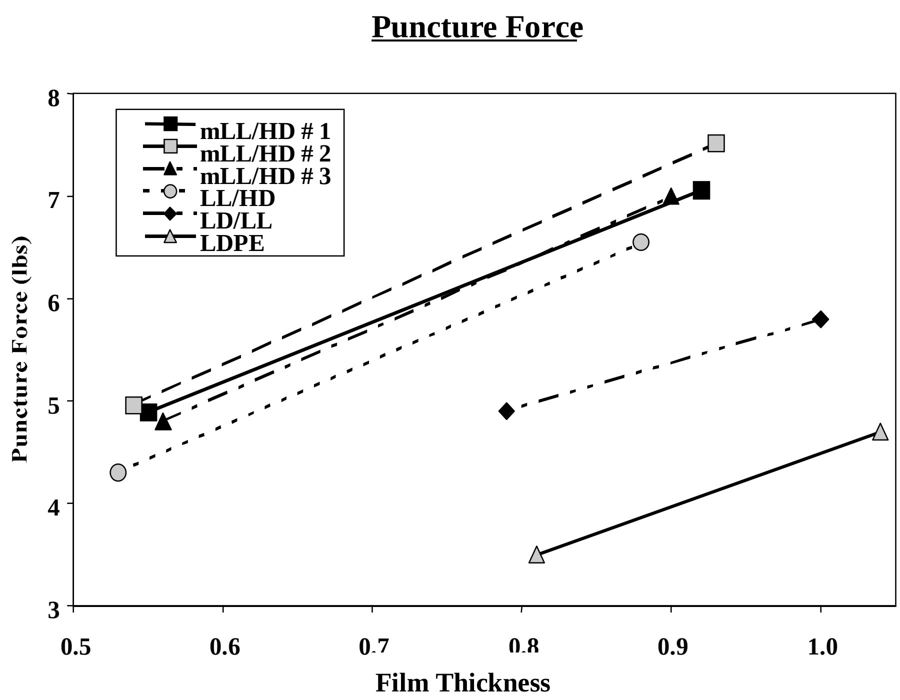
Figure 2: Transverse Direction Film Stiffness



Looking at the stiffness results it can be seen that the films with the higher blended density gave the highest stiffness. One could also conclude from the data that to obtain a 0.6-0.7 mil mLLDPE film with a modulus similar to a 0.9 mil LDPE film that between 40-45% HDPE should be used. Alternately a slightly higher density mLLDPE could be blended with a lower amount of HDPE.

Puncture is a key property for overwrap films. Figure 3 presents the puncture force comparison and shows that the mLLDPE films would provide superior puncture performance at even one half the thickness of the conventional overwrap films. The puncture energy comparison, Figure 4, emphasizes the point that the use of mLLDPE yields very tough films.

Figure 3: Puncture Force



Dart impact strength is another method of measuring a film's ability to resist a puncture force. The puncture test simulates a relatively slow puncture, similar to someone poking their finger into a package whereas the dart impact test is a higher speed test and would roughly model the forces involved when a package is dropped. The dart impact comparison, Figure 5, gives limited insight into the relative film performance since all but two of the film formulations possess impact strengths that are immeasurably low. Two of the mLLDPE blends give comparably high impact strengths even at thin gauges.

Film clarity as measured by haze and gloss are important properties of overwrap films. The clarity of the various films can be grouped into pairs as shown Figures 6 and 7. As can be seen in both the haze and gloss comparisons the use of an mLLDPE yields film clarity reasonably close to that of the current overwrap film formulations. Adding a small amount (5%) of an LDPE to the mLLDPE/HDPE blend would further improve the film clarity as well as adding to its bubble stability during film extrusion. The higher haze of the mLL/HD # 3 films is most likely due to the higher HDPE content of that blend.

Figure 4: Puncture Energy

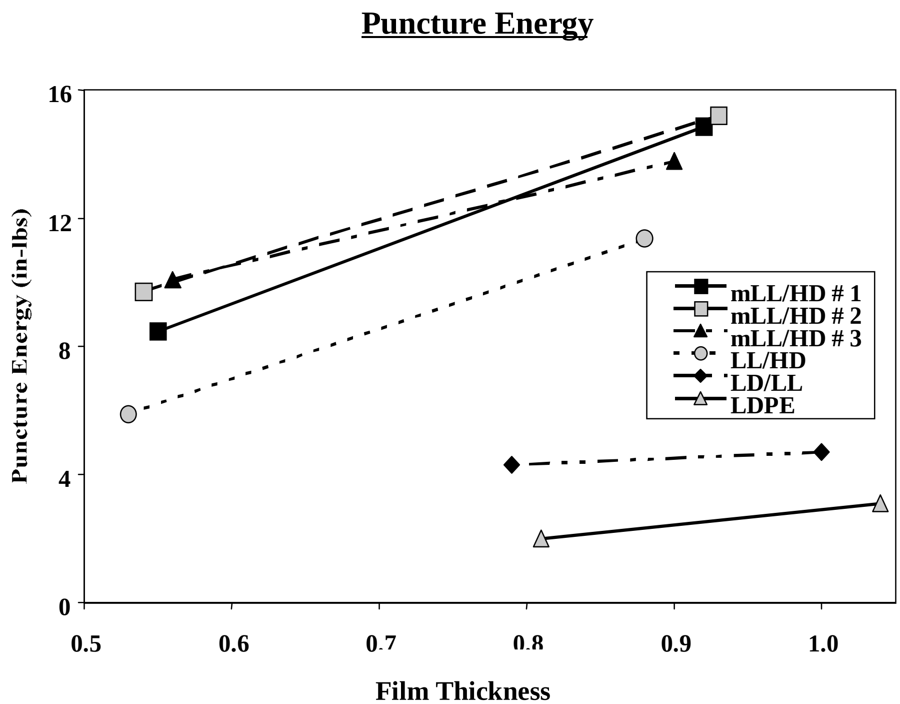


Figure 5: 26" Dart Drop Impact Strength

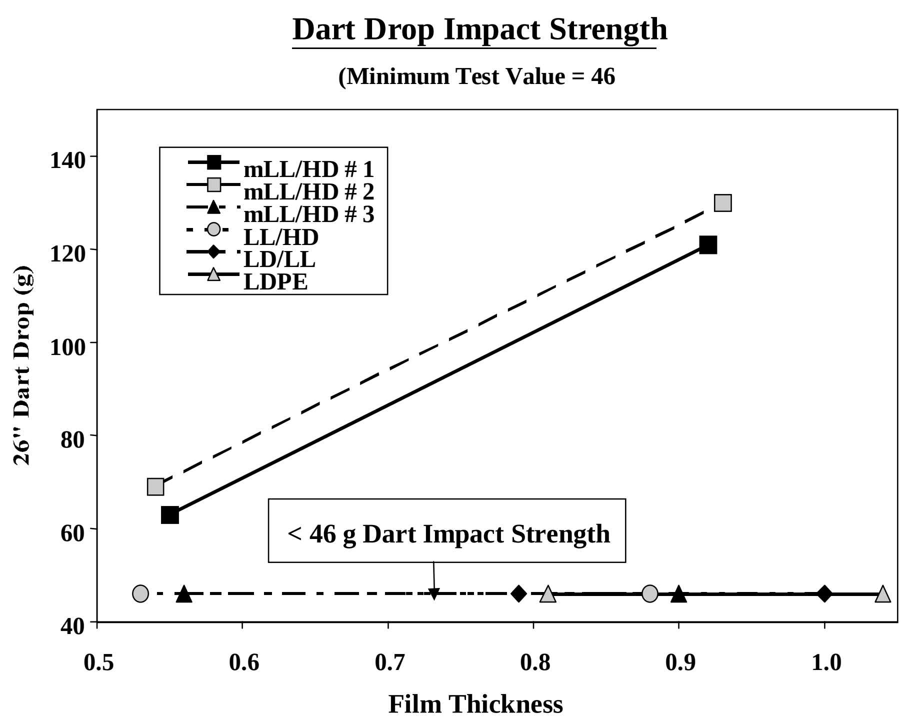


Figure 6: Haze Comparison

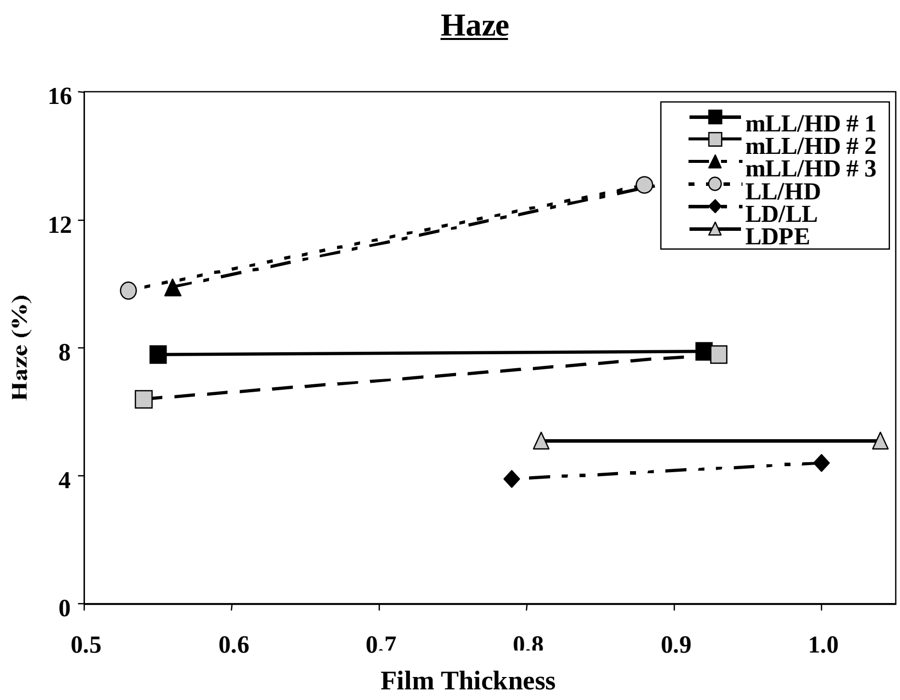
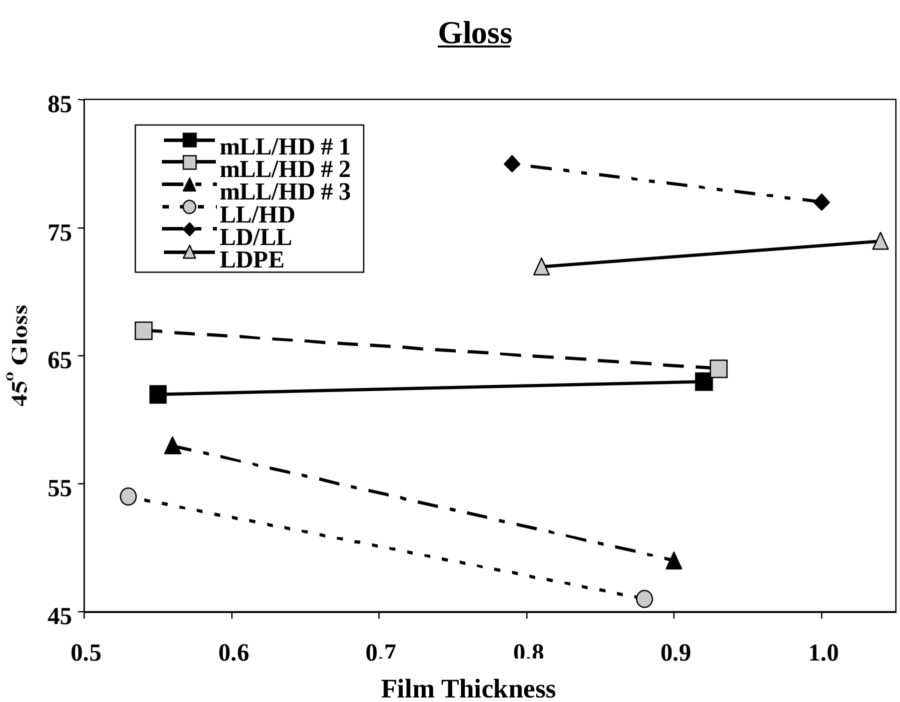
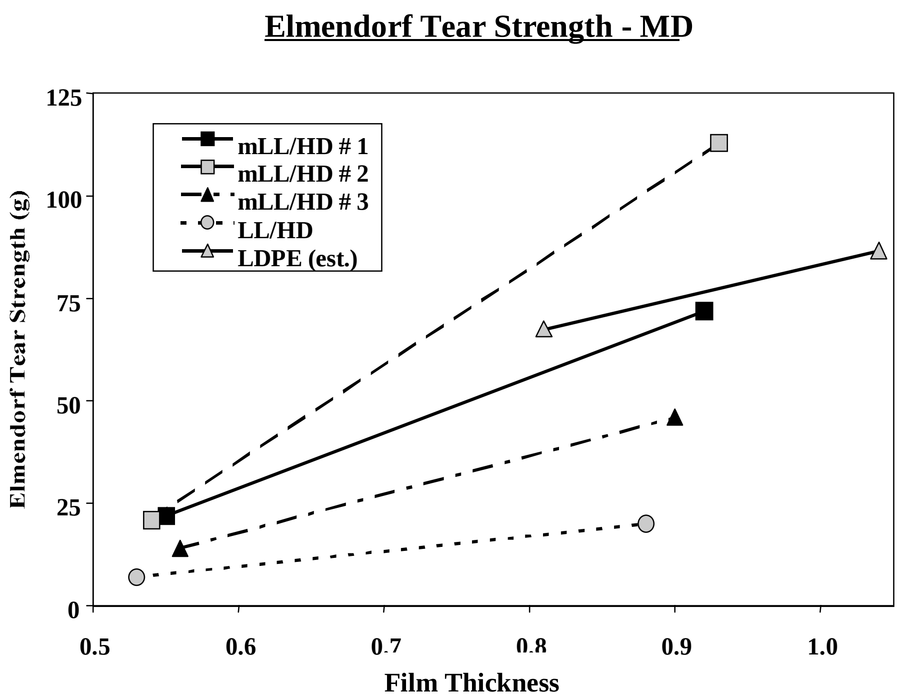


Figure 7: Gloss Comparison



The tensile strengths were significantly higher for the mLLDPE/HDPE films again indicating a good potential for downgauging. The machine direction Elmendorf tear results, Figure 8, show that at the thinner gauges the tear strength of the mLLDPE/HDPE films is relatively low. This difference from the baseline films may or may not be an issue since the higher puncture resistance and film strength of the mLLDPE films would tend to reduce the chance of initiating a tear. The MD tear data for the LDPE films was quite variable so average values are shown in Figure 8.

Figure 8: MD Elmendorf Tear Strength



Heat Sealing Performance
One would anticipate that the heat sealing performance of the mLLDPE films would not be as good in terms of seal initiation temperature (SIT) as a film made predominantly from LDPE due to the difference in melting points (10^oC). That is indeed the case looking at the heat seal profiles for three of the films in Figure 9. Downgauging does reduce the SIT due to the improved heat transfer through the thinner films but at the cost of a lower plateau seal strength.

Blown Film Processing
The mLLDPE/HDPE processed about the same as a conventional LLDPE as measured by the extruder head pressures and motor loads generated, Figure 10. Utilizing the higher melt index mLLDPE in blend mLL/HD #3 did reduce the motor load requirement to the same range as the LD/LL blend. The data in Figure 10 was measured using die gaps typical of the various polymers being extruded. LDPE-rich films are usually produced using narrow die gaps in the 30 mil range, while LLDPE-rich films are made using wider die gaps, typically 60 mils +.

Figure 9: Heat Seal Performance

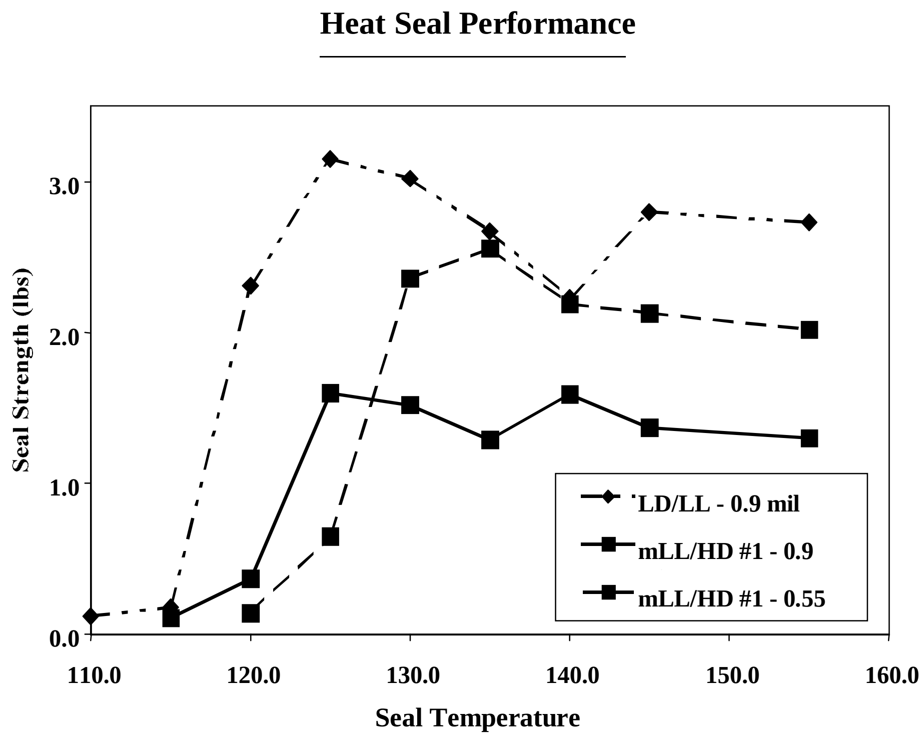
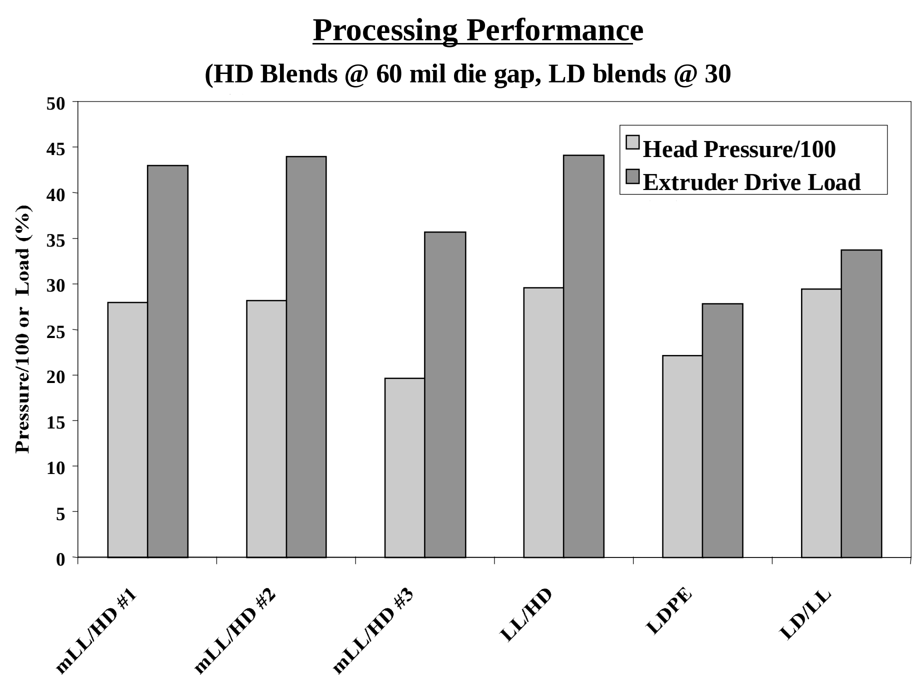


Figure 10: Blown Film Processing



CONCLUSIONS

The film property results generated in this screening study have confirmed that blends of mLLDPE and MMW-HDPE provide a viable route for downgauging paper overwrap film. These mLLDPE/HDPE films combine reasonable stiffness and film clarity with superior toughness and puncture resistance. Heat sealing performance of the blends could be further improved by adding a third component, either an LDPE/EVA or even a metallocene plastomer. Processing was found to be similar to conventional LLDPEs. The use of coextrusion is an option to further optimize the film properties.

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