New materials for heavy-duty packaging applications*

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ABSTRACT: Two new classifications of materials have been developed for use in heavy-duty packaging. These materials are targeted at high-performance applications by virtue of their excellent combination of physical properties. The new polymers impart excellent dart impact and tear strength with high modulus and yield strength in a combination not previously available in polyolefin film resins. Different types of materials have been developed for fabrication using conventional blown film extrusion and grooved-barrel, high-stalk extrusion.

KEYWORDS: Density, extrusion, mechanical properties, molecular weight, packaging materials, performance, plastic films, polyethylene.

Polyethylene films are popular for a wide variety of packaging applications. Liners, bags, and sacks constitute the largest segment of the polyethylene film packaging market. One participant in this market segment is heavy-duty or heavy-gauge films. Heavy-gauge films are typically 3 mils (76 µm) thick or greater, with many having thicknesses of 6 mils (152 µm) or more.

Heavy-duty shipping sacks and other heavy-duty films are used to package a wide variety of materials. They are generally used to package either a large volume or large weight of material. The performance requirements for heavy-duty films vary with each application. Abuse resistance is generally very important. This requirement may be quantified as high dart impact strength, high tear strength, or high tensile strength. High yield strength and modulus are often important, and heat seal strength is important for most applications. Other properties necessary for certain applications include heat resistance and neutral organoleptic characteristics.

Some of the materials packaged in heavy-duty sacks include insulation, plastic granules, chemicals, fertilizers, and lawn and garden products. Heavy-duty bags are also used to package bulk food items for commercial and institutional use. There are many specialty uses for heavy-duty films as well.

A variety of polymers are currently used to make heavy-duty film. For applications requiring the highest level of performance, premium materials may be used. These premium materials include polybutylene, rubber-modified high-density polyethylene, and other high-performance polymers and copolymers. To achieve premium performance and reduce the manufacturing cost of these films, coextrusions and blends are often used.

For the more typical, slightly less demanding heavy-duty applications, films are often made from low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), or a blend of the two. While LLDPE generally provides better toughness, LDPE can be more easily fabricated into thick film because of its much higher melt strength. Although LLDPE/LDPE blends are widely used and well known in the industry, they generally require an undesirable tradeoff between bubble stability and film physical properties *(1–4)*. Films requiring greater stiffness are sometimes made from medium-density polyethylene (MDPE) or blends containing high-density polyethylene (HDPE), but this is generally

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done at the sacrifice of both tear strength and impact strength.

The purpose of this paper is to describe the performance of two types of new materials that have been developed for use in heavy-duty film applications. Both types provide a combination of stiffness, tear strength, dart impact strength, and processability previously unavailable without blending or coextrusion. The first material presented is designed for extrusion using conventional LDPE or LLDPE extrusion equipment. This material is classified as a medium-molecular-weight, medium-density polyethylene (MMW-MDPE). The second set of materials is designed for extrusion with grooved-barrel, high-stalk equipment typically used for high-molecular-weight, high-density polyethylene (HMW-HDPE). These materials are classified as high-molecular-weight, medium-density polyethylene (HMW-MDPE).

I. Resin properties for first evaluation

Sample	*Material*	I_2*	*Density, g/cm³*	*Additives*
A	MMW-MDPE	0.3	0.935	AO/PA
A2	MMW-MDPE	0.3	0.935	AO
B	MDPE	1.0	0.935	AO/PA
C	LLDPE	1.0	0.920	AO
D	MMW-HDPE	0.1	0.951	AO

*I_2 is reported in grams of flow in 10 min using a 2.16-kg weight.

II. Competitive material*

Sample	*Material*	I_2	*Density, g/cm³*	*Additives*
E	RM-HDPE	0.1	0.935	N/A

*Resin data taken from product data sheet. N/A = not available.

III. Resin properties for second evaluation

Sample	*Material*	I_5*	*Density, g/cm³*
F	HMW-MDPE 1	0.35	0.942
G	HMW-MDPE 2	0.35	0.935
H	HMW-MDPE 3	0.45	0.930

*I_5 is reported in grams of flow in 10 min using a 5-kg weight.

Experimental procedures and materials

The new polymers discussed in this paper were designed to yield superior product performance while providing fabrication alternatives for converters currently using different types of film extrusion equipment. The new resins provide alternative uses for equipment already in place. This allows the converter greater flexibility in manufacturing a variety of packaging types without the expense of installing new equipment. For the comparisons presented in this paper, blown films were prepared using two different types of fabrication equipment.

The first set of films was prepared by conventional blown film extrusion using a blown film line well suited to the fabrication of LLDPE and LDPE films. A 63-mm (2.5-in.)-diam. extruder with a 24:1 length/diameter (L/D) ratio was fitted with a barrier screw. A 152-mm (6-in.)-diam. die with a 1.8-mm (70-mil) die gap was used. All films except the MDPE were made using a reverse temperature profile that resulted in melt temperatures of 225–235°C (437–455°F). The MDPE resin was extruded using an incline profile to improve melt quality. All other fabrication variables were held as constant as possible for all films. Blowup ratio (BUR) was held constant at 2.5:1, and output was maintained at 64 kg/h (141 lb/h), equivalent to 8.6 kg/h/cm (7.5 lb/h/in.). Films were compared at a thickness of 3 mils (76 μm). Materials examined in the study are indicated in **Table I.**

Note that both the MMW-MDPE and MDPE samples were fabricated with process aid in order to make a film completely free of melt fracture. The MMW-MDPE was also extruded without process aid to compare the effect of the process aid on extrusion.

A high-performance competitive material, rubber-modified high-density polyethylene (RM-HDPE), was not part of this comparative study, but it is included in the comparison to demonstrate the outstanding balance of properties achieved with the

IV. Test procedures

Property	Procedure
Density	D-792
Melt index	D-1238
Tensiles	D-882
Secant modulus	D-882
Dart impact	D-1709
Elmendorf tear	D-1922

V. Extrusion response

Sample	Material	Melt temp., °F	Pressure, psi	Amps
A	MMW-MDPE	445	3170	58
A2	MMW-MDPE[a]	452	3260	59
B	MDPE[b]	438	3170	71
C	LLDPE	437	3130	65
D	MMW-HDPE	455	3420	58

[a]No process aid

[b]Note: An incline temperature profile was used for the MDPE to improve melt quality. A reverse temperature profile was used for all other samples.

VI. Film properties

Sample	Material	Dart A, g	MD tear, g	CD tear, g
A	MMW-MDPE	425	324	1419
B	MDPE	250	328	593
C	LLDPE	800	1558	>1600
D	MMW-HDPE	125	80	284
E	RM-HDPE	375	136	7162

VII. Film properties

Sample	Material	MD yield, psi*	CD yield, psi	MD 2% modulus, psi
A	MMW-MDPE	2,300	2,860	51,800
B	MDPE	2,420	2,600	47,100
C	LLDPE	1,620	1,730	26,800
D	MMW-HDPE	3,700	4,410	88,100
E	RM-HDPE	2,200	2,100	49,600

*To obtain kPa, multiply by 6.89476.

MMW-MDPE resin. The RM-HDPE film studied was the same thickness as the other films tested: 3 mils (76 µm). RM-HDPE is typically used for premium applications requiring a combination of impact strength, tear strength, stiffness, and heat resistance. The resin properties for the RM-HDPE evaluated are shown in **Table II.**

The second set of films was prepared using a Keifel high-stalk blown film line. This line was equipped with a 70-mm grooved-barrel extruder, decompression screw, and a 113-mm die with a 1.2-mm die gap and no. internal buble cooling or internal bubble stabilization. All films were made using a 193°C (380°F) flat temperature profile on the extruder. The BUR was held constant at 3.3:1, resulting in a 58-cm (23-in.) layflat. Films were compared at nominal thicknesses of 0.5, 3.0, 5.0, and 8.0 mils (13, 76, 127, and 203 µm). Extruder output was maintained at 100 kg/h (220 lb/h), or 18 kg/h/cm (15.7 lb/h/in.), for all samples except the 0.5 mil films; these films were fabricated at 77 kg/h (170 lb/h), 14.1 kg/h/cm (12.2 lb/h/in.), due to bubble instability at the higher rate. The frostline height was maintained at 104 cm (41 in.) for all samples. The materials compared in the second evaluation are shown in **Table III.**

The resins listed in Table III differ from those of the first evaluation primarily by their higher molecular weight. Note that their flow behavior is described by an I_5 melt index rather than the I_2 index used for the other materials. Higher-molecular-weight materials such as these must be fabricated on special equipment designed to accommodate their higher viscosities, i.e., equipment with grooved barrels and decompression screws. The three materials at different densities are designed to provide a slightly different combination of properties, depending on the performance requirements for a given application. The higher-density materials provide greater stiffness, while the lower-density materials offer higher impact and tear strength. Film testing was completed using standard ASTM test procedures.

The tests performed and the methods used are shown in **Table IV.** Dart impact testing was conducted using Method A and is reported to the nearest 25 grams, because 25-g weight increments were used in the testing. Elmendorf tear was measured using Method A (a rectangular geometry specimen).

Results and discussion

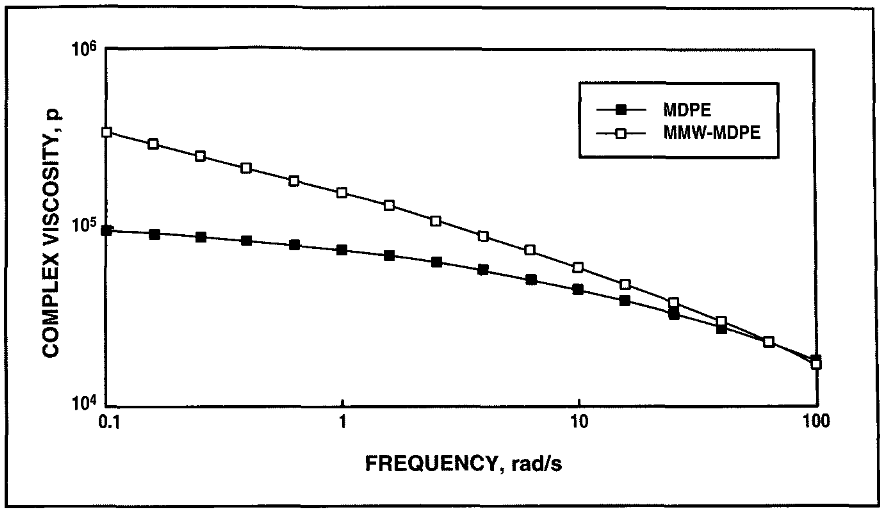
MMW-MDPE

Processability. The MMW-MDPE resin processed with lower amps but a slightly higher melt temperature than the 1.0 I_2 LLDPE resin. Three factors most likely contributed to the lower motor amp requirements for this resin: the higher observed melt temperature, the resin's rheological behavior, and the presence of process aid in this material. The effect of the process aid is noted by comparison to Sample A2, which is the same MMW-MDPE material without process aid. The presence of process aid does have a small but noticeable effect on melt temperature and pressure. Its biggest effect, and the one for which it is incorporated into the polymer, is in the elimination of melt fracture from the extrudate.

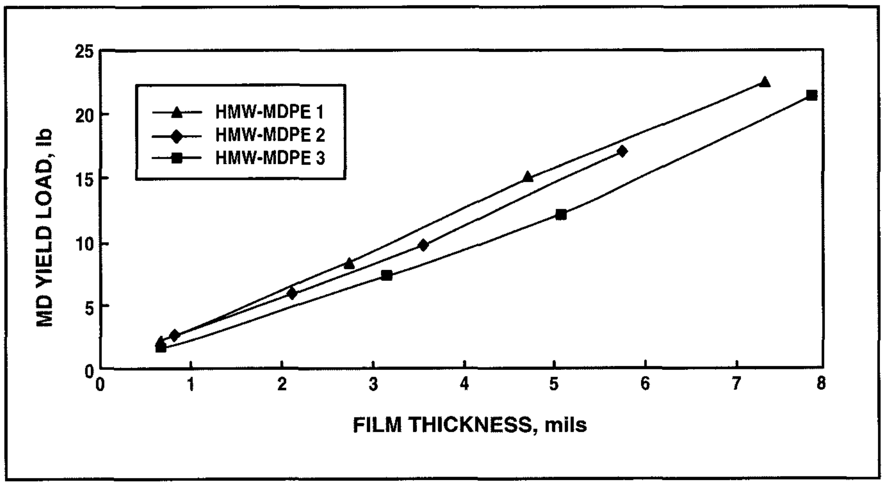
Direct comparison of melt temperature and pressure for the MDPE resin is not possible, since a minor adjustment to the extruder temperature profile was necessary to obtain a high-quality melt for this material. Except for the MDPE, the same temperature profile and output rate were used for extrusion of the materials listed. Extruder speed was adjusted as necessary to obtain a constant output rate. Complete data showing differences in melt temperature and pressure, as well as motor amps, are shown in **Table V.** Data for the MDPE resin are included for completeness.

The MMW-MDPE resin exhibited excellent bubble stability during the fabrication of blown film. This can be explained by the rheological behavior of the material. The MMW-MDPE exhibits greater shear thinning than the comparative MDPE or LLDPE resins. Its higher viscosity at lower shear rates provides its excellent bubble stability. Its lower viscosity at higher shear rates makes extrusion relatively easy, given its low melt index. The relationship between apparent vis-

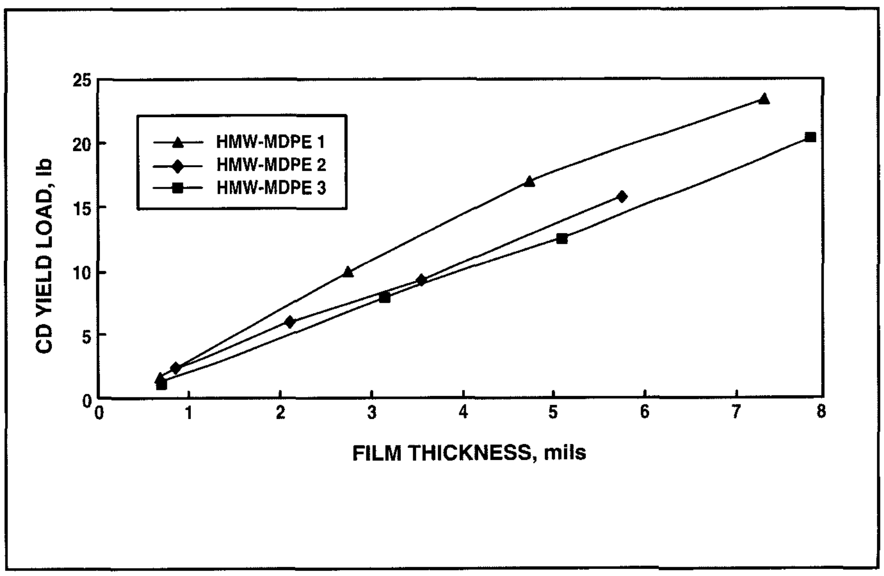
1. Complex viscosity for MDPE and MMW-MDPE



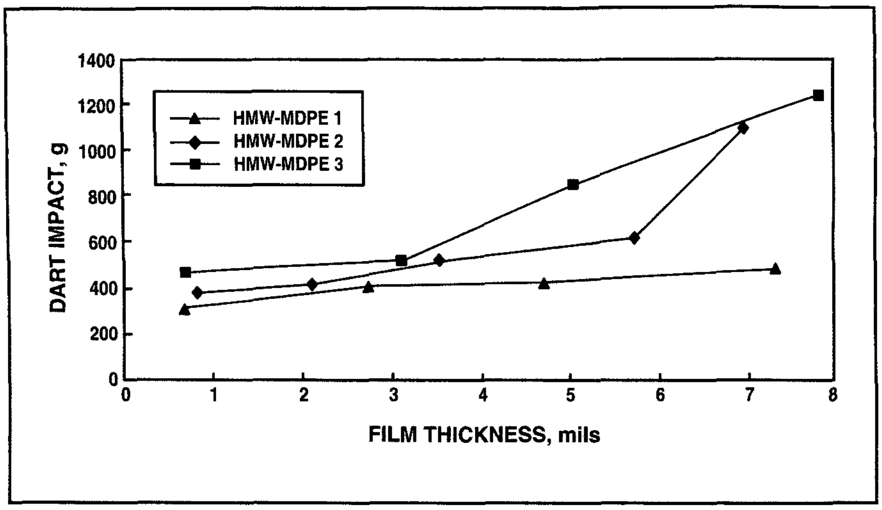
2. MD yield load



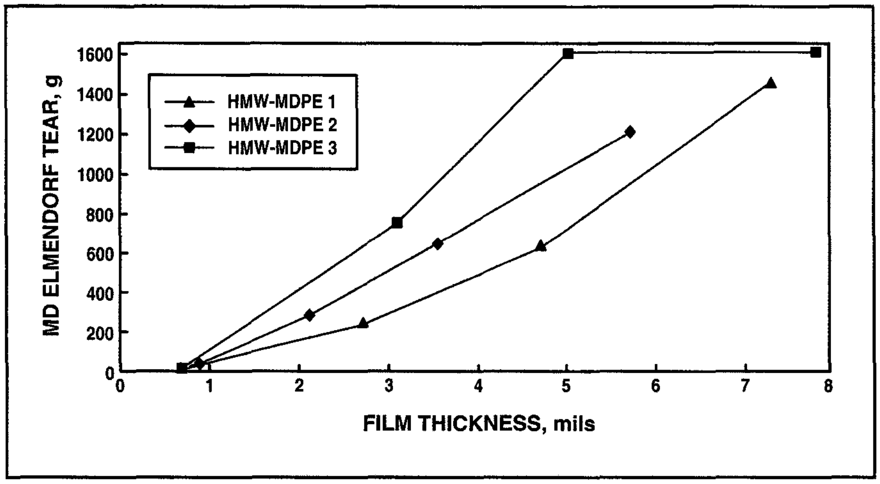
3. CD yield load



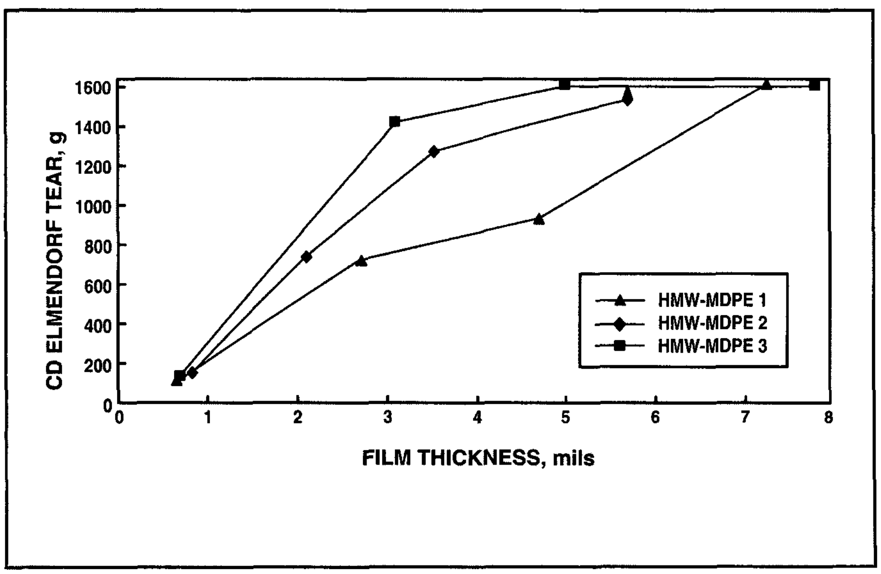
4. Dart impact



5. MD Elmendorf tear



6. CD Elmendorf tear



cosity and shear rate is shown in **Fig. 1** for the MMW-MDPE and comparative MDPE.

Film properties. The comparison of film properties for the new MMW-MDPE resin to currently available resin technologies is provided in **Tables VI and VII.** Compared to a similar-density 1.0 I_2 MDPE, the MMW-MDPE exhibits slightly higher yield stress and modulus, and significantly greater cross direction (CD) strength and dart impact strength. This offers the opportunity to increase film physical properties at constant thickness, or to maintain film physical properties while downgauging. As previously discussed, the MMW-MDPE resin has greater bubble stability due to its higher low-shear viscosity. The high low-shear viscosity of the MMW-MDPE makes it possible to fabricate thick films from the material. Conventional materials with lower viscosity cannot be easily made into thick films.

Compared to the LLDPE resin, the higher-density MMW-MDPE resin provides increased stiffness and heat resistance while maintaining fairly high tear strength and dart impact strength. It also offers significantly greater melt strength, as indicated by its much lower melt index, yet it can be processed on conventional LDPE/LLDPE blown film extrusion equipment. LLDPE resins frequently lack the melt strength necessary for fabrication into very thick films. LDPE is sometimes blended with LLDPE to increase melt strength, but the addition of LDPE generally results in a decrease in physical properties. The addition of LDPE is unnecessary with the higher-melt-strength MMW-MDPE. Because of its higher density, the MMW-MDPE resin is better suited for high-temperature applications than is the LLDPE resin.

In comparison to the MMW-HDPE resin examined, the new MMW-MDPE provides far superior tear and impact strength. Because of its lower density, stiffness is reduced. However, the material remains significantly stiffer than the LLDPE examined. Due to its slightly lower molecular weight, the MMW-MDPE resin processes on conventional equipment with a lower motor amp requirement and produces a lower melt temperature and lower back pressure.

Comparison of the MMW-MDPE film properties to those observed in the RM-HDPE film shows that the MMW-MDPE has significantly better tear strength and slight advantages in the other key physical properties measured. Since RM-HDPE is considered a premium performance material, the MMW-MDPE can also be considered to provide the premium performance necessary for demanding applications.

In summary, the MMW-MDPE resin characterized offers an excellent combination of dart impact and tear strength, modulus, and yield strength, with the ability to be fabricated at heavy gauges on conventional blown film extrusion equipment. No other single material provides all these benefits. It provides an alternative to the use of coextrusions, blends, or other premium materials such as rubber-modified high-density polyethylene.

VIII. Lawn and garden bag application comparison

Property	*Commercial film*	*HMW-MDPE 3*
Film thickness, mils	3.0	3.1
MD yield load, lb	6.7	7.3
CD yield load, lb	4.9	7.8
MD ult. tensile, lb	13.2	19.6
CD ult. tensile, lb	13.3	19.2
MD elongation, %	685	1100
CD elongation, %	930	1165
MD Elmendorf tear, g	405	760
CD Elmendorf tear, g	>1600	1415
Dart impact, g	335	525

IX. Salt bag application comparison

Property	*Commercial film*	*HMW-MDPE 2*
Film thickness, mils	7.0	7.0
MD yield load, lb	13.6	18.1
CD yield load, lb	13.9	19.4
MD ult. tensile, lb	30.7	42.6
CD ult. tensile, lb	27.9	43.7
MD elongation, %	690	1475
CD elongation, %	700	1470
MD 1% modulus, psi	47,880	70,100
CD 1% modulus, psi	55,050	70,740
MD Elmendorf tear, g	1550	1530
CD Elmendorf tear, g	>1600	>1600
Dart impact, g	1100	1100

HMW-MDPE

Processability. All the HMW-MDPE resins processed similarly on the Keifel extrusion line used for this evaluation. Since this type of extrusion equipment is not typically used to make thick films, there are no comparative polymers for this set of materials. The HMW-MDPE resins presented in this paper offer a new use for high-stalk extrusion equipment: the fabrication of heavy-gauge films.

The 193°C (380°F) flat extruder temperature profile yielded a melt temperature of 218°C (425°F) and a melt pressure of 44,800 kPa (6500 psi) at the 100 kg/h (220 lb/h) output rate used. The bubble stability of these materials is excellent. The stability of these materials actually increases with film thickness, which is opposite to the trend observed in LLDPE film extrusion. This allowed fabrication of the thicker-gauge samples at a high extrusion rate. The frostline was held constant at 104 cm (41 in.), although the bubble stability of these materials is sufficient to permit 203–229-cm (80–90-in.) frostline heights. It is important to be able to control the frostline height, so machine direction/cross direction (MD/CD) orientation can be controlled. As with HMW-HDPE thin-film extrusion, the frostline height, stalk height, and BUR greatly influence the MD/CD orientation. This in turn affects the final film strength.

Film properties. The film properties of the three new HMW-MDPE resins are shown as a function of thickness in **Figs. 2–6.** Figures 2 and 3 show that the yield strength is directly proportional to the density of the polymer. The 0.942-g/cm^3 density samples (HMW-MDPE 1) have the highest yield point, and the 0.930-g/cm^3 samples (HMW-MDPE 3) exhibit the lowest yield strength at any given film thickness.

Figure 4 shows the excellent dart impact strength of these resins. This strength increases with film thickness, and the increase is most noticeable for the lowest-density material. Figures 5 and 6 show the Elmendorf tear strength for these samples. As indicated in Fig. 5, the machine direction tear strength for the 0.5-mil HMW-MDPE 3 sample is 25 g/mil, while the 5.0-mil film has a tear strength of 315 g/mil. This is a tremendous increase in normalized tear strength. In fact, HMW-HDPE 3 reaches the upper limit of the test, 1600 g, at thicknesses above 5 mils.

Figure 6 shows a similar relationship for cross direction tear strength. This high tear strength is combined with high stiffness, as previously indicated. The combination of film thickness, tear strength, and modulus is what makes these new HMW-MDPE resins ideally suited for heavy-duty thick-film markets. This combination of properties may also permit downgauging in heavy-duty film markets.

Tables VIII and IX compare the performance of two of the new HMW-MDPE resins to commercial films currently used in heavy-duty applications. Table VIII provides a comparison of HMW-MDPE 3 to a commercial film used in a lawn and garden bag application (e.g., dirt or bark mulch). The films compared are approximately 3 mils thick. Compared to the incumbent commercial material, HMW-MDPE 3 provides increased stiffness, as indicated by higher yield strength, and at the same time provides improved dart impact strength and machine direction tear strength. Unlike the comparative commercial film, its high melt strength allows extrusion on equipment originally designed for HMW-HDPE extrusion.

Table IX compares the performance of HMW-MDPE 2 to a commercial salt bag at a thickness of 7 mils. HMW-MDPE 2 provides increased stiffness, as indicated by increased yield strength and modulus, while maintaining high tear strength and excellent dart impact strength.

These comparative examples illustrate how heavy-gauge films meeting the performance requirements for heavy-duty packaging applications can be fabricated from these HMW-MDPE materials. The new HMW-MDPE materials therefore offer an alternative use for high-stalk, grooved-barrel extrusion equipment. Because they offer excellent melt strength and can be processed at high output rates, they offer the potential for high utilization of existing manufacturing equipment.

Conclusions

The following conclusions summarize this study:

- The new MMW-MDPE resin provides a highly desirable combination of stiffness, impact strength, tear strength, and the ability to be fabricated at thick gauges on conventional extrusion equipment.
- The new HMW-MDPE resins offer the opportunity to make high-modulus, heavy-duty films with excellent tear strength and dart impact strength while running at high output rates on high-stalk equipment.
- The combination of stiffness, toughness, and processability available from these two types of polymers provides the opportunity to improve performance, downgauge, or use high-stalk equipment to make heavy-duty films. T

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