LARGE PART INJECTION MOLDING PRODUCT OPTIMIZATION

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ABSTRACT

High-density polyethylene (HDPE) is widely used in large-part injection molding applications, such as five-gallon pails, agricultural bins, and refuse carts. Certain physical properties are critical in helping to ensure a long useful life for parts in these demanding applications.

This paper presents a predictive model that was developed from molded part testing and HDPE resin physical properties. By implementing this information effectively, the resin producer and the injection molder can work together to improve molded part performance.

INTRODUCTION

Injection molders of large parts, such as five-gallon pails, agricultural bins and refuse carts, are typically interested in optimizing the stiffness, impact strength and environmental stress crack resistance (ESCR) of their molded parts. In addition, maintaining processability, and hence cycle time, is a primary consideration. Unfortunately, increasing one property will ordinarily cause a corresponding decrease in another property as a result of the chemistry of HDPE, limitations of polymer technology and plant control. This natural balance of properties makes it difficult to maximize multiple properties concurrently. This article describes the unique use of existing plant quality-control resin measurements to predict topload (stiffness), drop impact and topload ESCR for parts molded from HDPE resins frequently used in these applications.

DISCUSSION

Molders of applications such as pails, agricultural bins, and refuse carts generally have well-defined processing needs and related methods to measure process consistency and molded part performance. Likewise, the polymer manufacturer has well-defined manufacturing and analytical methods for characterizing molecular properties and physical properties of the resin itself. A resin supplier's ability to translate polymer-manufacturing measurements back to the molder's process and the end-use applications often determines the degree of success for both the resin supplier and the molder. Table 1 generically defines the inter-relationships between a molder's processing and physical requirements for injection molded containers and the polymer producer's controllable resin characteristics.

The information in Table 1 shows that a resin manufacturer can define most resin and part physical properties through TS (Technical Service) laboratory measurements. However, the specific relationships between TS measurements and plant QC measurements are not explicitly defined. Historically, many product optimizations and subsequent recommendations have depended more on the "art" of material design than scientifically designed models relating part property with plant QC measurements of resin properties.

Table 1. Large Part Injection Molding Requirements vs. Resin Physical Properties

Molder Requirements	Polymer Producer	
	Technical Service	Plant QC Lab
Stackability	Flexural Modulus, Topload	Melt Index MFR Density
Impact Strength	Izod Impact, Dynatup, Drop Impact	
ESCR	ESCR, Modified ESCR, Topload ESCR	
Cycle Time	Shrinkage, Processing (Spiral Flow Number)	
Mold Fill	Aspect Ratio (L/T)	
Printability	Visual, Tape Test	
Resin Cost	Lightweight, Part Design	

Previous related work[1] has shown direct correlations between the TS laboratory spiral flow number (SFN) and molded part cycle times. SFN is the number of centimeters of flow produced when molten resin at 227°C is injected into a long, spiral-channel insert (half-round 0.635 x 0.157 x 127 cm) at a constant pressure of 6.9 MPa. A relationship between SFN and resin physical properties was also developed.

Traditionally, resin manufacturers have changed, singularly or in combination, polymerization catalyst systems, reactor configuration, and reactor-operating parameters, such as reactor temperature, ethylene, comonomer, and hydrogen concentrations, to vary molecular weight (MW), and crystallinity. More advanced process technology has given some manufacturers the ability to adjust the molecular weight distribution (MWD) of a product, which is necessary for the application of this model.

Melt index (MI_2) is measured in the QC lab and is used as an indication of resin molecular weight. It is defined as the number of grams of polymer extruded in ten minutes as measured by ASTM Method D 1238. The melt index is inversely proportional to molecular weight and melt viscosity under a specific shear force. It is associated with properties such as drop impact, processability, and ESCR.

The melt flow ratio (MFR or MI_{20}/MI_2) is a calculated QC lab number that is used as an indication of molecular weight distribution (MWD). It is calculated by dividing a melt index measured at a high shear stress (MI_{20}) by a melt index measured at a low shear stress (MI_2). A low MFR indicates a narrow MWD polymer; conversely, a larger MFR indicates a broad MWD polymer. It is associated with properties such as drop impact, ESCR, and processability. In general, a material with a broader MWD will flow easier than a material with a narrow MWD, at a given melt index.

Density, a measure of the crystallinity of a material, is the other important resin physical property that manufacturing controls. In HDPE, the density is a function of the amount of comonomer incorporated into a polymer. Increased comonomer incorporation reduces resin density. Density is measured by ASTM D 1505 and is reported in g per cc. Properties such as top-load strength, flexural modulus, drop impact, and ESCR are affected by density.

EXPERIMENTAL DATA

The resins used for this study are listed in Table 2. Polymer physical properties and part testing results are tabulated as well. Dishpans, measuring 30 cm x 25 cm x 16 cm (0.2 cm wall thickness) and used for part testing, were molded on a 330-ton Husky molding machine. **Topload** was conducted on an Instron at a crosshead speed of 2.5 cm/min. The maximum load on the dishpan before failure was measured. **Drop impact** was conducted by mounting the dishpans at an angle of 30°, filling them with five liters of water, sealed and freezing them to –40°C. The F_{50} value for this test was determined by dropping the dishpans on their edge at various heights. **Topload ESCR** was

[1] Todd, W. G., Wise, D. L. & Williams, H.: Plastics-Bridging the Millennia, ANTEC 1999 Proceedings

conducted by filling dishpans with 10% Igepal (a known ESCR agent), sealed and placing a 72.6-kg load onto the dishpan. The F_{50} failure value was determined by testing multiple specimens of each sample.

Table 2. Experimental Data

Resin	Melt Index (g/10 min.)	MFR	Density (g/cc)	SFN (cm)	Topload (N)	Drop Impact at -40°C (cm)	Topload ESCR (hours)
A	4.0	34.7	0.947	21.3	5,556	366	93
B	4.4	30.8	0.946	20.3	5,244	396	100
C	3.2	38.9	0.960	20.3	7,733	396	65
D	3.6	34.3	0.961	20.8	7,867	328	55
E	4.3	27.0	0.951	19.6	6,356	495	66
F	4.0	41.6	0.947	22.6	5,822	373	118
G	3.8	30.0	0.957	19.1	7,689	411	62
H	3.8	30.0	0.961	19.3	8,000	419	60
I	4.0	35.5	0.960	22.6	7,600	282	62
J	4.6	34.3	0.958	22.6	7,733	236	70
K	4.2	33.1	0.954	21.6	6,933	328	81
L	2.6	38.5	0.959	20.6	8,044	472	95
M	4.8	28.1	0.954	20.3	6,889	297	59
N	2.5	27.8	0.954	17.0	6,978	762	124
O	2.4	39.1	0.955	18.8	7,467	434	109
P	2.4	45.8	0.955	20.3	6,711	297	145
Q	2.7	39.6	0.959	20.6	7,956	480	86

DATA ANALYSIS

A multiple variable linear regression was performed to understand how each of the molded part test variables related to the plant QC lab tests of MI_2, MFR, and density. The general form of the equation was:

$$Var_i = a_i + b_i MI_2 + c_i MFR + d_i Density \qquad (1)$$

Table 3 lists the regressed constants for the equation.

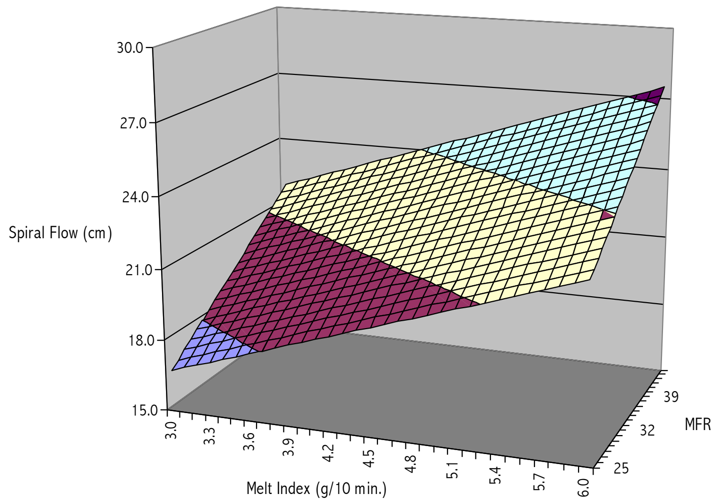
Table 3. Regression Constants for Equation 1

	a_i	b_i	c_i	d_i
Spiral Flow	-42.3	1.883	0.2564	49.29
Topload	-154,598	-102.8	-9.133	169,998
Drop Impact	9,240	-156.8	-18.74	-7,984
Topload ESCR	3,724	-21.91	1.155	-3,768

SFN

SFN is an important variable to the molder because it determines the ease of mold fill and molding cycle times. As SFN increases, the mold is easier to fill, which allows for a shorter cycle time by decreasing the injection time. Previous work has shown that MI_2 and MFR as the critical resin properties for SFN as shown in Figure 1. Figure 4 compares the SFN for the resins in this study. As expected, higher melt index and broader MWD resins process better than lower melt index and narrower MWD resins.

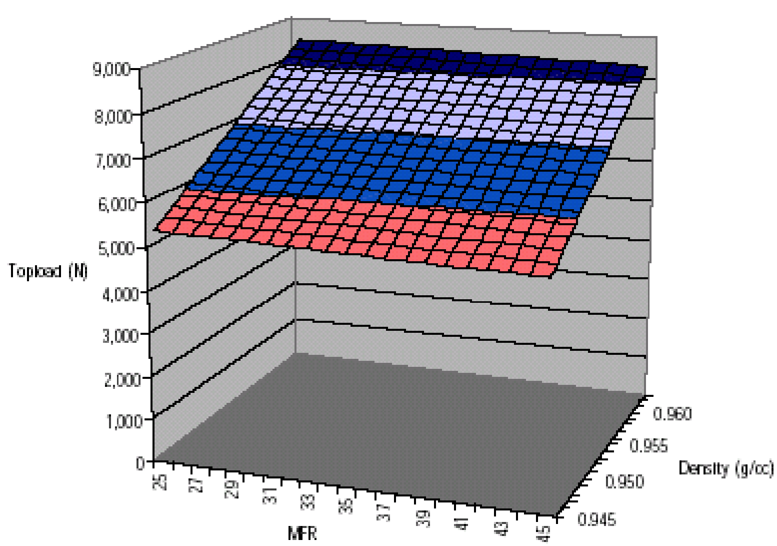
Figure 1. Spiral Flow as a Function of Melt Index and MFR
(Holding Density Constant at 0.953 g/cc)



Topload

Topload determines the maximum height that molded parts can be stacked, which is important for shipping and warehouse considerations. Topload as a function of MFR and density is shown in Figure 2.

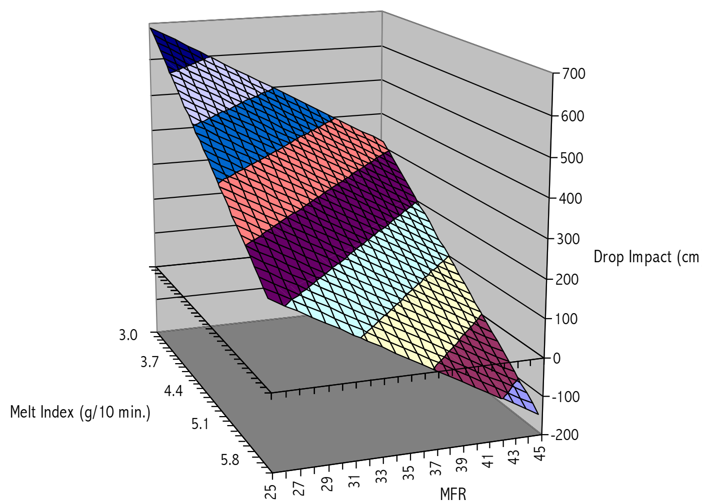
Figure 2. Topload as a Function of MFR and Density
(Holding Melt Index Constant at 4.0 g/10 min.)



Drop Impact

Drop impact is a critical property for applications such as pails, agricultural bins, and refuse carts because it determines the integrity of the container when it falls or is impacted. The relationship of drop impact to melt index and MFR is shown in Figure 3.

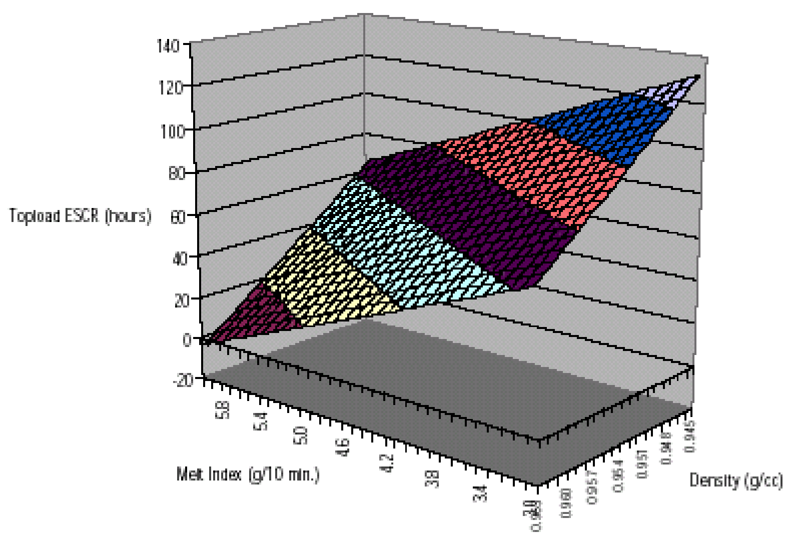
Figure 3. Drop Impact as a Function of Melt Index and MFR
(Holding Density Constant at 0.953 g/cc)



Topload ESCR

ESCR is also a crucial property for these types of applications because, as with most polymers, the nature of HDPE makes it susceptible to attack by certain types of chemicals. Melt index, MFR, and density affect topload ESCR and are demonstrated in Figure 4.

Figure 4. Topload ESCR as a Function of Melt Index and Density
(Holding MFR Constant at 30)



USAGE OF THE MODEL

By using the constants obtained from the linear regression for each of the studied properties, a model can be constructed to determine the molded part property effects by changing the melt index, MFR, or density of a particular product. An example of this type of model is shown in Table 4. In practice, a change to one or more of the molecular property values results in corresponding changes to the resulting physical property values.

Table 4. Predictive Molded Part Property

	Melt Index (g/10 min.)	MFR	Density (g/cc)
Base Case	4.0	42.0	0.953
Trial Case	4.9	35.0	0.955

	Base	Trial
Spiral Flow (cm)	23.0	23.0
Topload (N)	6,615	6,927
Drop Impact (cm)	216	190
Topload ESCR (hours)	93	58

In addition to this model, an optimization model was also developed that recomputes resin properties to meet minimum goal requirements for the molded parts. Minimum and maximum constraints are placed on the resin physical properties. Microsoft Excel Solver is then used to find a set of resin property values that will satisfy the minimum molded part requirements. In the example shown in Table 5, the model predicts the resin melt index, MFR, and density that are necessary to increase the drop impact of the base resin by 35% with minimal loss of the other physical properties.

Table 5. Product Optimization Model

	MI (g/10 min.)	MFR	Density (g/cc)
Minimum	3.0	25.0	0.945
Maximum	6.0	45.0	0.963

Base Case	4.2	42.0	0.953
Trial Case	4.3	38.6	0.951

	Base Case	Target	Trial Case
Spiral Flow (cm)	23.3	22.5	22.5
Topload (N)	6,595	6,300	6,300
Drop Impact (cm)	185	250	250
Topload ESCR (hours)	89	90	90

SUMMARY

This paper shows how molded part properties can be related back to the QC laboratory measurement at the HDPE manufacturing site. A model was developed to predict how changes in melt index, density and, of primary importance, MFR, will affect SFN, topload, drop impact and topload ESCR of the molded part. The model shows how the standard balance of properties imposed by processes only capable of modifications to melt index and density can be exceeded. Using this model, the resin manufacturer and the molder can work together to improve the performance of the molded part.

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