INTEGRATING THIN-WALL MOLDER'S NEEDS INTO POLYMER MANUFACTURING PART II

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This article originally presented at ANTEC, May 8, 2000.

ABSTRACT

Polyethylene (PE) injection molded rigid containers are widely used for food packaging and promotional drink cups. Molders of these containers have well-defined processing needs and molded part requirements. Likewise, the polymer manufacturer has well-defined manufacturing and analytical methods for characterizing resin properties.

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

INTRODUCTION

A previous paper[1] discussed how frustrating it is for a resin manufacturer to not be able to relate molded part requirements back to manufacturing synthesis conditions and laboratory quality control (QC) measurements. This article describes a unique use of existing QC-measured resin properties to predict top load (stiffness), lip integrity, and drop impact for parts molded from high-flow polyethylene (PE) resins.

DISCUSSION

Molders of rigid food packaging containers and promotional drink cups 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 resin properties and physical properties. 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 attempts to define these inter-relationships between a molder's processing requirements for injection molded containers and the polymer producer's process measurements.

The information in Table 1 shows that a resin manufacturer can relate most molded part needs through TS (Technical Service) laboratory measurement. The problem is how does the TS measurement relate back to a plant QC measurement? For example, the previous paper (1) showed how TS laboratory spiral flow number (SFN), which is the number of centimeters of flow produced when molten resin at 227^{0} 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., could be related to molded part cycle times. A relationship between SFN and resin physical properties was also developed.

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

Table 1. Frozen Lid and Base Molding Requirements versus Resin Physical Properties

Molder Requirements	Polymer Producer	
	Technical Service	Plant QC Lab
Dimensional Lid Fit	Gage Measurement	
Cold Impact	Drop Impact, MD Tear	
Lip Integrity	Lip Pull Test	
Printability	Visual/Tape Test	Melt Index
Topload - Compression	Compression Test	MWD
Stiffness	Sidewall Indentation Test	Density
Mold Fill	Aspect Ratio (L/T)	
Cycle Time	Nucleation, Shrinkage, Processing (SFN)	
Resin Cost	Lightweight, Design	

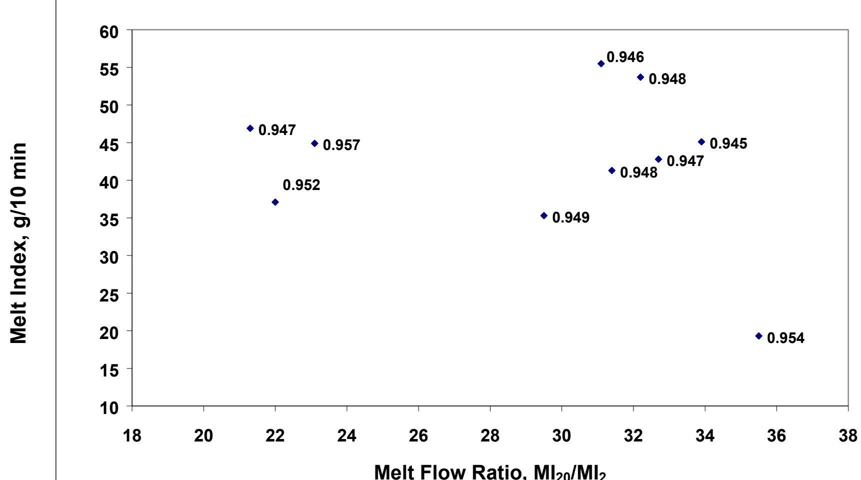
Typically a resin manufacturer changes polymerization catalyst systems, modifies reactor configuration or adjusts reactor-operating parameters, such as temperature, ethylene and hydrogen concentrations, to vary molecular weight (MW) and molecular weight distribution (MWD).

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 D1238. The higher the melt index, the lower the molecular weight and melt viscosity which means the resin processes more easily.

Melt flow ratio (MFR or MI_{20}/MI_2) is a calculated QC lab number that is used as an indication of MWD. It is calculated by dividing a melt index measured at a high shear rate (MI_{20}) by a melt index measured at a low shear rate (MI_2). A low MFR indicates a narrow MWD; conversely a larger number indicates a broader MWD polymer. In general, a broader MWD resin flows easier than a narrow MWD resin at a given melt index.

The other important resin physical property that manufacturing controls is density, which is a function of the amount of comonomer incorporated. Increased comonomer incorporation reduces resin density. Density is measured by ASTM D1505 and reported as grams per cubic centimeter. Figure 1 plots the high-flow resins used in this study as functions of melt index and MFR. Individual resins are identified by their density.

Figure 1. Experimental High Flow Resins



EXPERIMENTAL DATA

The resins used for this study are listed in Table 2. Resin physical properties and part testing results are tabulated. SFN specimens and the 20-ounce containers used for part testing were molded on a 170-Ton Van Dorn molding machine. Melt temperatures were adjusted to approximate the viscosity as determined by SFN to that of Resin J. This was described in the previous paper[1]. **Top load** was conducted on an Instron at a crosshead speed of 2.5 cm/min. The maximum load on the container before failure was measured. **Lip integrity** was conducted on an Instron® at a crosshead speed of 1.25 cm/min. The bottom of the container is attached to the base of the Instron while the lip of the container is connected to a gripping fixture and pulled until a failure is recorded. **Drop impact** was conducted at 4.4°C and 23°C by filling the containers with water. Experiments conducted at –18°C were filled with 50:50 mixture of glycol:water. The F_{50} value for this test was determined by dropping the containers at various heights.

Table 2. Experimental Results

Resin	MI_2 (g/10 min.)	MFR	Density (g/cc)	SFN (cm)	Topload (N)	Lip Integrity (N)	Drop Imp. -17.8°C (m)	Drop Imp. 4.4°C (m)	Drop Imp. 22.8°C (m)
A	19.3	36	0.9535	36.6	585	1,032	1.18	2.72	4.34
B	35.3	30	0.9491	43.4	510	1,044	1.27	2.44	4.42
C	41.3	31	0.9478	46.0	478	1,002	1.07	2.46	4.07
D	37.1	22.0	0.9520	41.1	536	1,013	1.57	4.14	4.34
E	44.9	23	0.9556	43.4	599	1,160	2.13	3.51	4.42
F	42.8	33	0.9470	49.3	474	1,023	1.20	3.66	4.34
G	45.1	34	0.9449	52.1	438	983	1.07	2.59	4.19
H	46.9	21	0.9470	45.2	458	998	1.68	4.11	4.42
I	55.5	31	0.9461	55.1	484	1,008	1.07	2.08	3.47
J	53.7	32	0.9483	53.3	496	1,084	1.07	1.61	3.38

DATA ANALYSIS

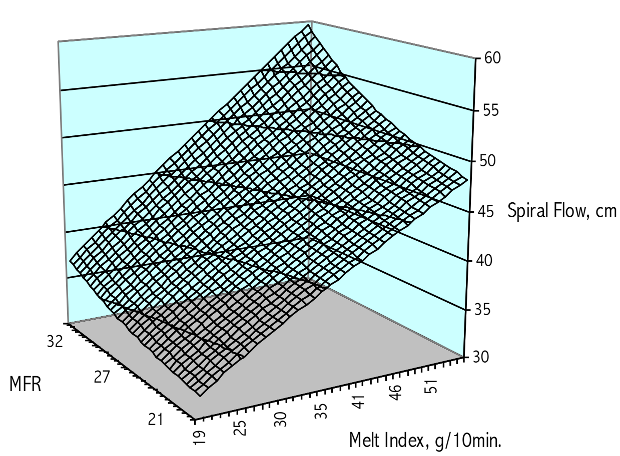
Dominant Variables

A cursory look at the data identified the two most dominant variables for each molded part properties.

SFN

SFN is an important variable to the molder because it determines ease of mold fill and molding cycle times. The higher the SFN, the shorter the cycle time. Work from the previous paper[1] identified MI_2 and MFR as the critical resin properties as illustrated in Figure 2.

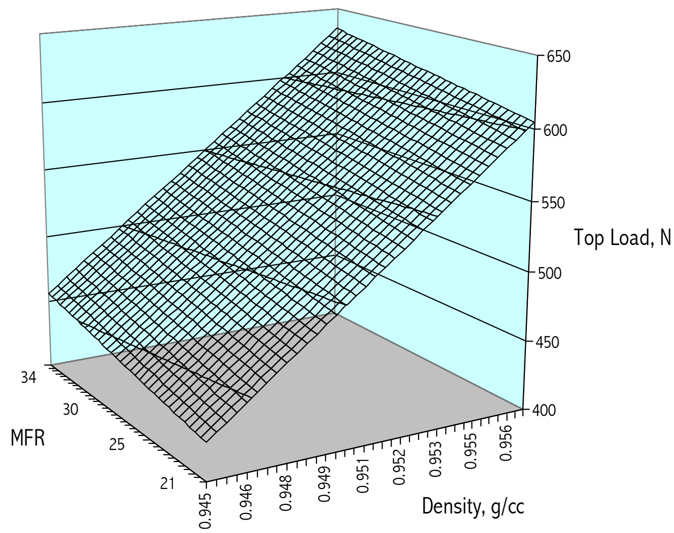
Figure 2. Spiral Flow as a Function of Melt Index and MFR



Top Load - Compression

Top load determines the maximum height that molded containers can be stacked, which is important for shipping and warehousing considerations. Density and MFR were found to correlate well with top load as shown in Figure 3.

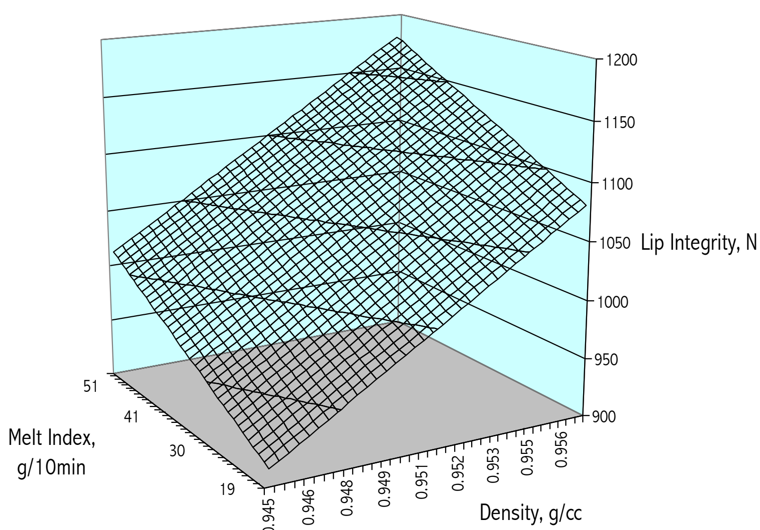
Figure 3. Top Load as a Function of Density and MFR



Lip Integrity

The integrity of the container lip is critical in ensuring maximum product protection. Density and MI_2 correlated best for lip integrity as shown in Figure 4.

Figure 4. Lip Integrity as a Function of Density and Melt Index



Drop Impact

Drop impact is a critical property for a molded part, particularly for refrigerated containers, because it determines the integrity of the container and the packaged product. Both MI_2 and MFR affect drop impact, but test temperature is the controlling variable as seen in Figures 5 and 6.

Figure 5. Drop Impact as a Function of Melt Index and Temperature

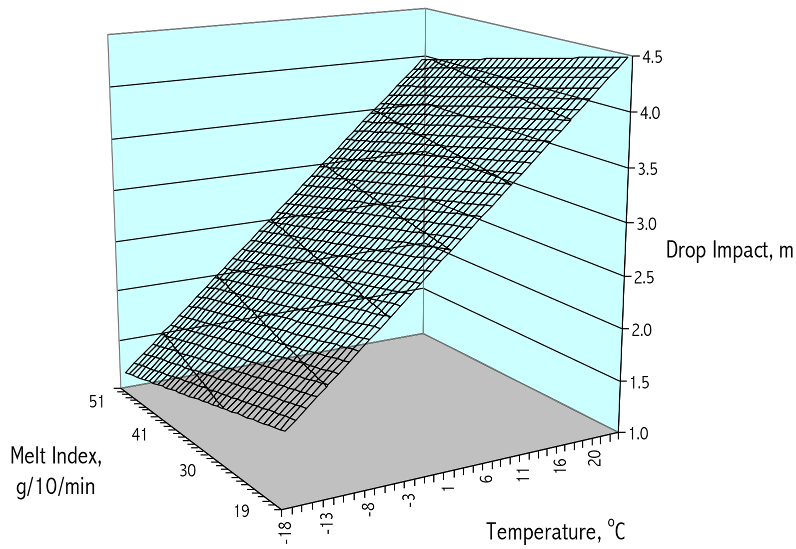
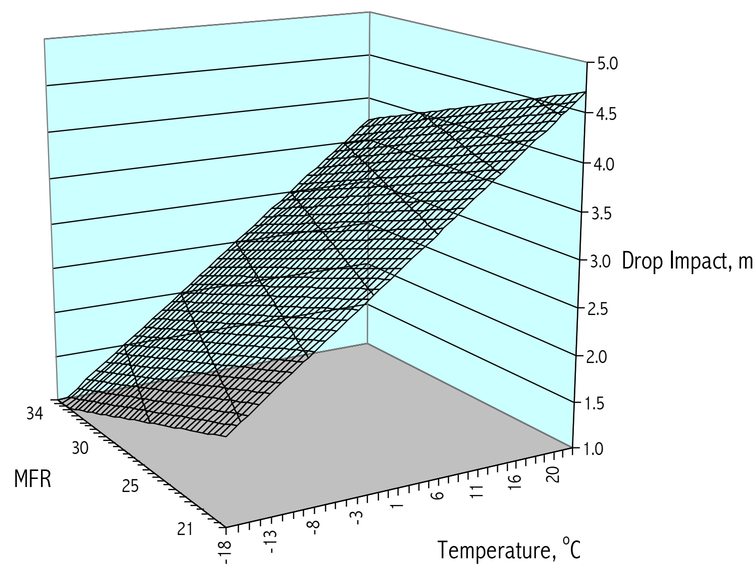


Figure 6. Drop Impact as a Function of MFR and Temperature



Multiple Variable Data Analysis

A multiple variable linear regression was performed for better definition of the molded part properties. The general form was:

$$\mathrm{Var}_i = a_i + b_i \mathrm{MI}_2 + c_i \mathrm{Density} + d_i \mathrm{MFR} + e_i \mathrm{Temperature} \qquad (1)$$

Table 3 lists the regressed constants for the equation. The Excel spreadsheet shown in Table 4 was constructed to predict changes to the molded part when resin physical properties are varied. One simply adjusts the trial value of resin property to see the effect on the molded part.

Table 3. Regression Constants for Equation 1

	a_i	b_i	c_i	d_i	$e_i \times 10^2$
SFN	7.3	0.4834	0	0.622	0
Topload	-13,501	-0.0882	14,698	2.017	0
Lip Integrity	15,155	3.4844	16,796	3.403	0
Drop Impact	16.27	-0.0238	-10.91	-0.079	6.94

The optimization spreadsheet shown in Table 5 was developed to determine resin physical properties required to meet minimum goal requirements for an existing resin. Minimum and maximum constraints are placed on the resin physical properties and then Excel Solver is used to find a set of resin property values that satisfy the minimum molded part specification. In this example the base resin had a SFN of 45.5 cm and the minimum specification was 50.5 cm. The optimizer raised MI_2 and lowered density and MFR to meet or surpass all the molded part specifications.

Table 4. Predictive Molded Part Property

	MI_2	Density	MFR
Base Case	50	0.950	23.5
Trial Case	45	0.948	32.0

	Base	Trial
Spiral Flow, cm	46.0	48.9
Topload, N	505	493
Lip Integrity, N	1,055	1,033
-18°C Drop Impact, m	1.61	1.08
4.4°C Drop Impact, m	3.15	2.62
23°C Drop Impact, m	4.43	3.89

Table 5. Optimize Resin Properties Model

	MI_2	Density	MFR
Base Case	38.0	0.9520	32
Trial Case	53.5	0.9491	28.0
Minimum	20.0	0.9400	22.5
Maximum	65.0	0.9650	50.0

	Base	Min.Spec	Trial
Spiral Flow, cm	45.5	50.5	50.5
Topload, N	553	500	500
Lip Integrity, N	1,076	1,000	1,067
-18°C Drop Impact, m	1.20	1.00	1.19
4.4°C Drop Impact, m	2.74	2.50	2.73
23°C Drop Impact, m	4.02	4.00	4.00

SUMMARY

This paper shows how molded part properties can be related back to laboratory QC measurement at the PE manufacturing site. A model was developed to predict how changes in MI_2, density and MFR would affect SFN, top load, lip integrity, and drop performance of the molded part. Using this model, the resin manufacturer and the molder can work together to improve molded part performance.

Future studies are planned to study the effect of resin properties, aspect ratio, and molding conditions on mold fill, molded part shrinkage, and sidewall stiffness.

ACKNOWLEDGMENTS

The authors would like to acknowledge the following Equistar Chemicals associates who developed the laboratory data used to generate the correlations presented in this article: David Banach, George Ghiurcan, Kent Evans, Betty Humble, and Chris Vaniglia.

Key Word/Phrase Index

1. Thin Wall Molded Parts 2. Polyethylene Physical Properties 3. Molded Part Performance

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