POLYETHYLENE: PROCESS SENSITIVITY IN ROTATIONAL MOLDING

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Abstract

Rotational molding is a unique process that puts unusual demands on the average polyethylene. This paper looks at the optimum process conditions for different polyethylenes and the sensitivity of impact properties to the oven time and temperature. Process conditions become critical for maintaining impact properties while running multiple types of molds on one spider or varying from standard process conditions with like molds.

Introduction

The objective of the work is to study the impact behavior of rotational molded polyethylene. Not all grades of polyethylene with the same melt index and density perform the same. Without the proper antioxidant packages, impact strength can vary considerably with process conditions because of small process windows. This can become very evident when running multiple molds simultaneously where mold conductivity, part weight (thickness), and arm positions vary, or where oven time and temperature vary between cycles.

Background

In the 1950's, the first rotational molding grades of polyethylene appeared. Polyethylenes exhibited suitable chemical and rheological properties yet needed to be ground into powder. With the development of a grinding process for producing powder (with proper particle size and particle size distribution), polyethylenes became the largest consumed material in the rotational molding process [1].

Today, polyethylene is the most commonly used polymer in rotational molding and makes up over 90% of a 660 millions pounds a year market[2]. Many designers make polyethylene the resin of choice based on its availability, ease to process, and excellent properties. However, not all designers see the actual production of the parts and are not aware of multiple variables that are involved with processing the polyethylene.

Polyethylene data sheets normally list nominal impact strength of optimally molding parts, however the sensitivity of impact strength to the rotational molding process is not listed. In addition, many rotational molders process polyethylene without formal quality control on impact resistance and as a consequence, they risk sending out parts that may have dramatically lower impact strength and may be susceptible to brittle failures.

This paper presents the results of a study of the impact sensitivity of polyethylene to processing conditions and discusses methods to maintain high impact standards.

Experimental

Apparatus and materials

The materials used were a common rotational molding grade polyethylene modified with various rotational molding anti-oxidant additive packages and commercial polyethylenes from the market. The nomenclatures of the resins are not disclosed in this paper as not to reveal the manufactures. The resins are simply designated alphabetically with nominal density and melt index in Table 1.

For an additive comparison, Resin A with different rotational molding additive packages was molded at temperatures of 600 °F for set times at 8,10,12,14,and 16 minutes. For the commercial resin study, the process was the same except on Resin F(see Table 1). Here the process window was expanded. Resin F was molded at 500 °F, 550 °F, 600 °F, 650 °F and 700 °F oven temperatures with 8,10,12,14,and 16 minutes oven times. The oven times and temperatures were varied to simulate different maximum air temperatures inside the mold. The total oven time was limited to 16 minutes (and the oven temperature at 700°F) because most resins turned excessively yellow, a commonly accepted indication of over-curing.

Some process conditions were kept constant. A Ferry RS-220 rotational molding machine was used with a digital monitor upgrade with 4 cast aluminum, 12 by 12 by 12 inch box-molds. The cooling cycle was kept as a constant 12 minutes, with 8 minutes air, 2 minutes water and 2 minutes air. The rotation ratio was set at 8 RPM with an 8:1 ratio of major to minor axes.

At each condition for all resins, the low temperature impact strength was measured. All of the impact tests were performed on a semi-automated impact tester, following the guidelines set forth in the Association of Rotational Molders International for low temperature impact test (version 4.0 – procedure A).

Results and discussion

Not all polyethylenes perform the same in the rotational molding process. Specifically, resins that are not properly stabilized can provide acceptable impact strength but then exhibit a sharp decrease and sometimes the impact strength can recover with time (see Chart 1). However, the later oven times usually resulted in yellowing and are unfavorable for most manufactures for color and costs (cycle time). Yet, part color does not always correlate with impact strength and manufactures cannot use color for quality control of the impact strength.

In Chart 2 the commercial rotational molded resins show various behaviors in impact strength. Some offer a wide process window while others have dramatic changes with time. Chart 3 (response surface) represents a matrix of oven time and temperature for Resin F. The impact strength appears acceptable but with just small increases in oven time and temperature the impact drops considerably. (This dip in the impact properties is commonly called the impact knee.). More interesting results are the sudden increases in impact properties at higher oven times and temperatures. The mechanisms behind this behavior are not addressed here.

This impact behavior is a very critical in rotational molding where several differing molds are placed on an arm/spider and all processed at the same oven time. With the variations in mold conductivity, part weight, and mold position, each mold can experience a different internal maximum air temperature within the same cycle. This can lead to some products having very poor impact and others with acceptable impact, even though the parts were processed with the same material and oven conditions.

This polyethylene impact strength behavior could also be found when running like molds on one machine. Not all cycles on a rotational molding machine are consistent because of stuck parts, operator error, variances in external conditions (such as cooling water and ambient temperature), extended pauses in the cycle, and variances in machine conditions. All these conditions can affect the maximum air temperature in the molds. Thus molders that produce like parts on each cycle may still experience dramatic variances in impact properties if they are on the edge of the process window.

Conclusions

Although the mechanics of impact behavior are not explained in this paper, it is critical that rotational molders fully understand the impact behavior of the polyethylene. Some rotational molded polyethylenes can exhibit acceptable impact strength at certain process parameters, yet some polyethylenes can dramatically lose impact strength with the slightest changes in process conditions and nullify the designer's efforts.

Designers and processor alike should fully understand the process window of the polyethylene chosen for a part. By evaluating resins and the size of the process window, molders can insure designers that the nominal impact properties are maintained as designed. The molder can determine the size and sensitivity of the process window by running different oven times at different oven temperatures and recording the impact strength. By monitoring the inside air temperature during the cycle, molders can pinpoint the optimum process conditions for different molds and combine only the molds that have common process windows [3]. This practice will help predict impact properties for parts that experience oven times and temperature outside their normal set points and allow the molder to take extra steps to insure that proper impact properties still exist.

Most important of all, if the designers/molders choose a rotational molding resin with a wide process window, they dramatically increase the probability of good impact strength on their well designed part. This allows molders to reduce costs by allowing flexibility in molds that they can run together.

Acknowledgments

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References

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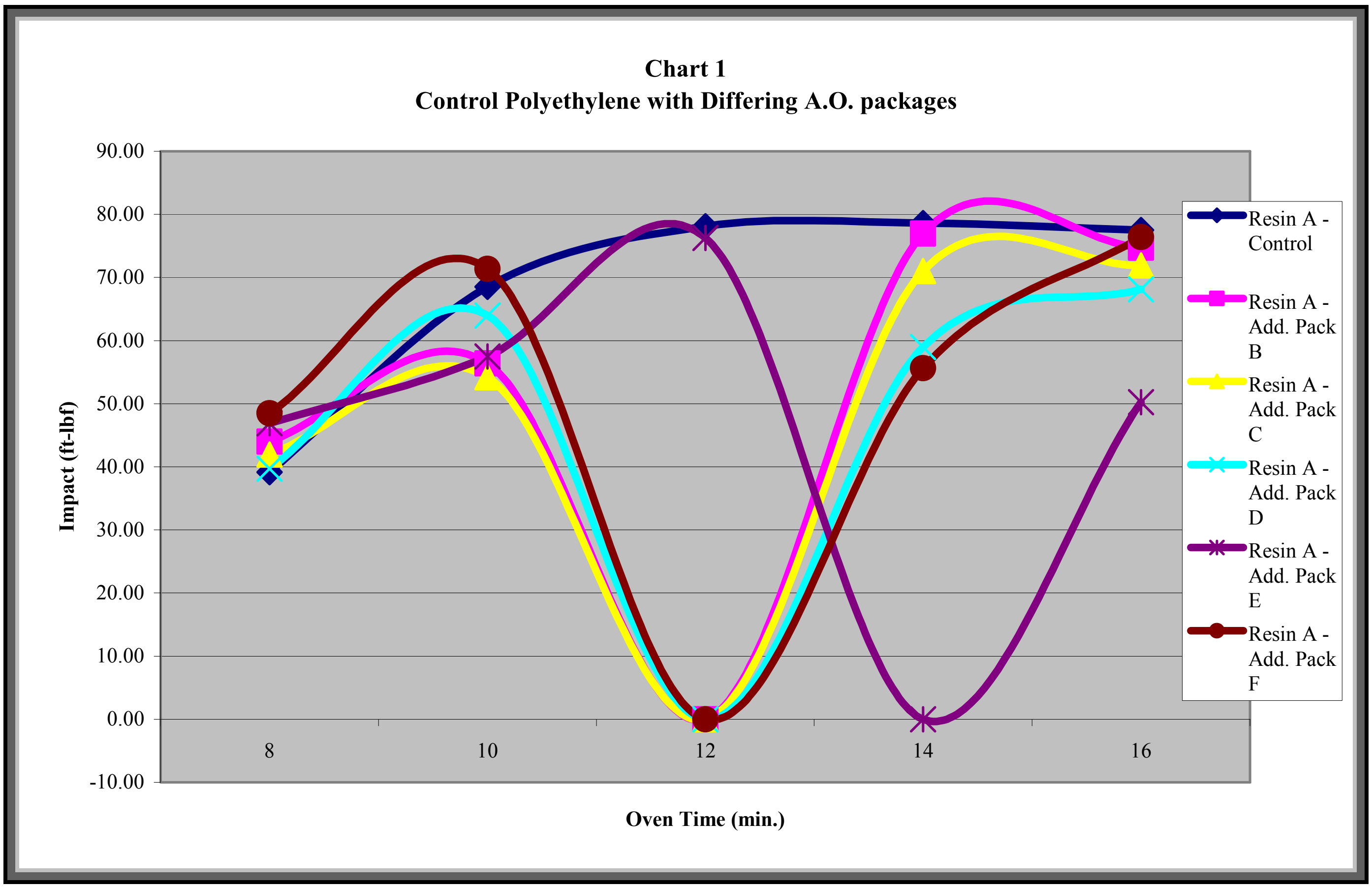
2. 2003 Townsend's Polymer Services & Information, Inc

3. Crawford, R.J, "Process Effects on Porosity, Impact Strength" in *Rotational Molding Technology*, Chapter 7, Plastic Design Library Norwich, New York (1992).

Key Words

Rotational molding, polyethylene, impact strength, process sensitivity

TABLE 1		
Resin	Density (g/cc)	Melt Index (g/10 minutes)
Nominal	ASTM D1505	ASTM D1238
A	0.938	3
B	0.935	6
C	0.935	6
D	0.942	2
E	0.942	2
F	0.945	6



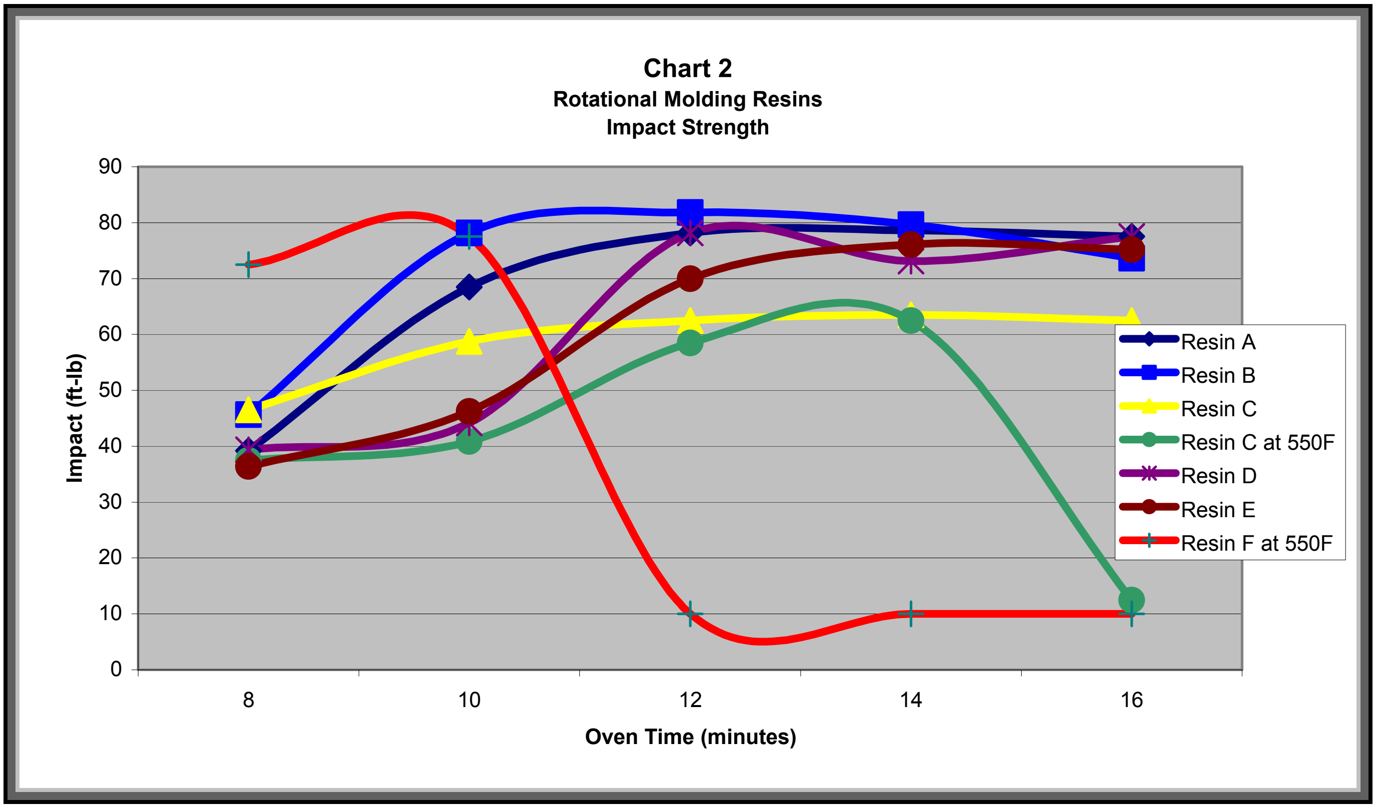


Chart 2
Rotational Molding Resins
Impact Strength
Impact (ft-lb)
0
10
20
30
40
50
60
70
80
90
8
10
12
14
16
Oven Time (minutes)
Resin A
Resin B
Resin C
Resin C at 550F
Resin D
Resin E
Resin F at 550F

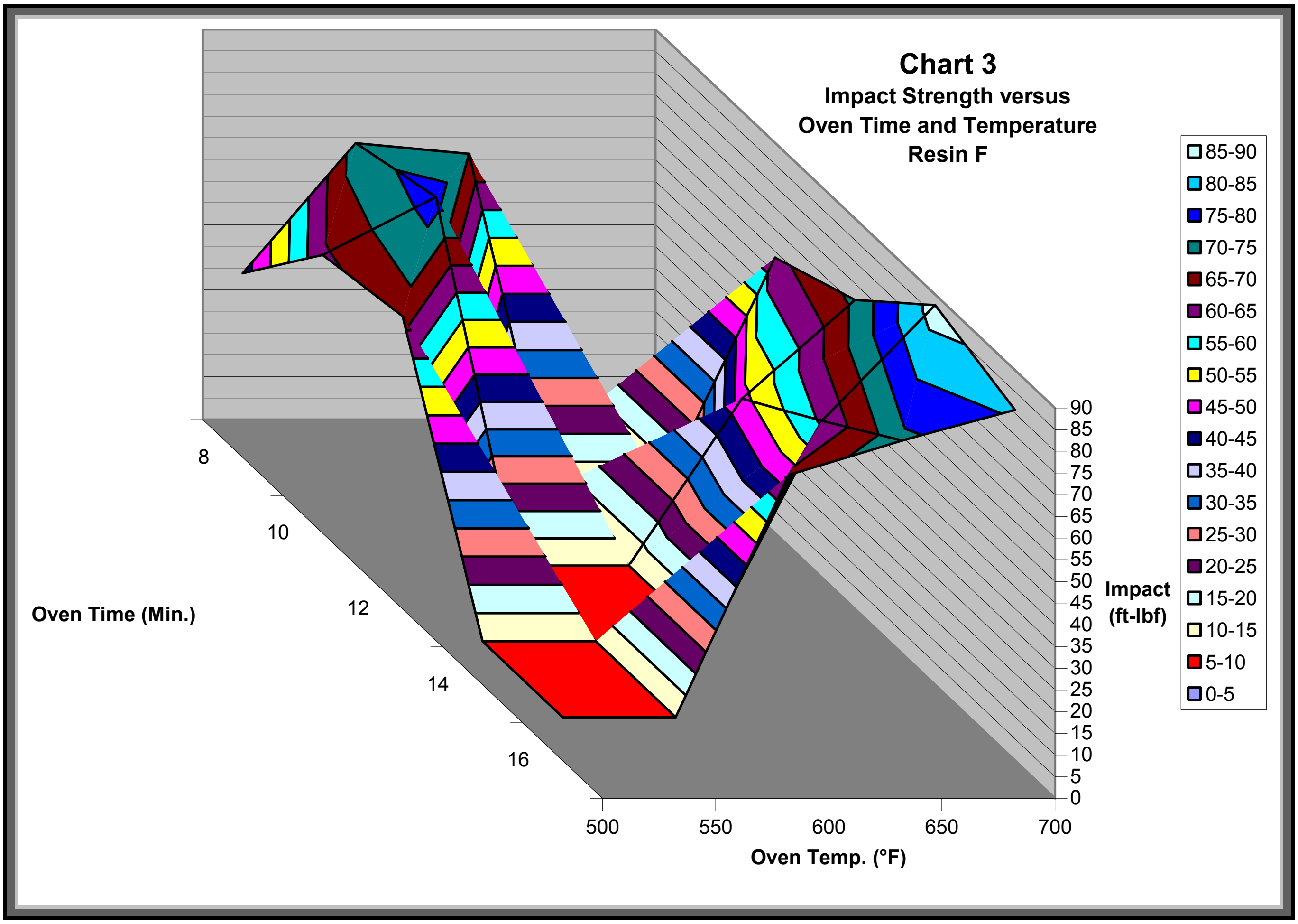


Chart 3
Impact Strength versus
Oven Time and Temperature
Resin F
Oven Time (Min.)
8
10
12
14
16
500
550
600
650
700
Oven Temp. (°F)
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Impact
(ft-lbf)
85-90
80-85
75-80
70-75
65-70
60-65
55-60
50-55
45-50
40-45
35-40
30-35
25-30
20-25
15-20
10-15
5-10
0-5