3

24,427

BDX-613-1002

AN INVESTIGATION OF INTERNAL CAVITY
PRESSURE AND THICKNESS RESPONSE
FOR INJECTION-MOLDED POLYCARBONATES

PDO 6984324, Topical Report

P. C. Black, Project Leader

Project Team:
R. K. Rogers

Internal Distribution November 1973

Prepared for the
United States Atomic Energy Commission
Under Contract Number AT(29-1)-613 USAEC

**Kansas City
Division**

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

AN INVESTIGATION OF INTERNAL CAVITY
PRESSURE AND THICKNESS RESPONSE FOR
INJECTION-MOLDED POLYCARBONATES

BDX-613-1002

Internal Distribution November 1973

Project Leader:
P. C. Black
Department 835

Project Team:
R. K. Rogers

PDO 6984324
Topical Report

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Technical Communications

**Kansas City
Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

**AN INVESTIGATION OF INTERNAL CAVITY PRESSURE AND THICKNESS
RESPONSE FOR INJECTION-MOLDED POLYCARBONATES**

**BDX-613-1002, UNCLASSIFIED Topical Report, Internal Distribution
November 1973**

Prepared by P. C. Black, D/835, under PDO 6984324

The internal cavity pressure of an injection mold was evaluated as a controlling variable for the thickness of typical polycarbonate moldings. Mold temperature, melt temperature, and mold-fill mode were evaluated for their effects on molding thickness and thickness runout, designated as the total indicator reading (TIR).

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

A prime contractor for the
Atomic Energy Commission
Contract Number AT(28-1)-613 USAEC

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

CONTENTS

Section	Page
SUMMARY	9
DISCUSSION.	11
SCOPE AND PURPOSE	11
PRIOR WORK.	11
ACTIVITY	11
<u>Experimental Equipment and Setup</u>	11
<u>Experimental Design</u>	12
<u>Experimental Variables</u>	16
<u>Data Collection</u>	16
<u>Analysis of Data</u>	21
<u>Mold and Melt Temperature Effects</u>	35
ACCOMPLISHMENTS	37
FUTURE WORK,	37
REFERENCES.	39

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

ILLUSTRATIONS

Figure		Page
1	Typical Injection Moldings From the Three Experimental Mold Cavity Inserts (P-82553)	13
2	Mounted Mold C-Cavity Insert, 0.2605 Inch Thick (6.617 mm), Showing the Three Transducer Transmission Pins (P-82556)	14
3	Part Thickness Versus Cavity Pressure for the 0.2605-Inch (6.617 mm) C-Cavity	22
4	Part Thickness Versus Mold Temperature for the 0.2605-Inch (6.617 mm) C-Cavity	23
5	Part Thickness Versus Melt Temperature for the 0.2605-Inch (6.617 mm) C-Cavity	24
6	Part Thickness Versus Cavity Pressure for the 0.0960-Inch (2.438 mm) B-Cavity	25
7	Part Thickness Versus Mold Temperature for the 0.0960-Inch (2.438 mm) B-Cavity	26
8	Part Thickness Versus Melt Temperature for the 0.0960-Inch (2.438 mm) B-Cavity	27
9	Part Thickness Versus Cavity Pressure for the 0.0650-Inch (1.651 mm) A-Cavity	28
10	Part Thickness Versus Mold Temperature for the 0.0650-Inch (1.651 mm) A-Cavity	29
11	Part Thickness Versus Melt Temperature for the 0.0650-Inch (1.651 mm) A-Cavity	30
12	Runout Versus Primary Variables for the 0.2605-Inch (6.617 mm) C-Cavity	31

Figure		Page
13	Runout Versus Primary Variables for the 0.0960-Inch (2.438 mm) B-Cavity.	32
14	Runout Versus Primary Variables for the 0.0650-Inch (1.651 mm) A-Cavity.	33

TABLES

Number		Page
1	Experimental Matrix	15
2	Experimental Variables	17
3	Thickness Response for 0.0650-Inch (1.651 mm) A-Cavity	18
4	Thickness Response for 0.0960-Inch (2.438 mm) B-Cavity	19
5	Thickness Response for 0.2605-Inch (6.617 mm) C-Cavity	20

SUMMARY

An experiment was conducted, as an extension of earlier work, to determine the feasibility of using internal cavity pressure as the controlling variable for constant-temperature injection-molding. Independent variables in the experiment were internal cavity pressure, mold temperature, melt temperature, and three distinct mold-filling modes. Combinations of these variables were treated on three mold cavity inserts of different thicknesses: A-cavity, 0.0650 inch (1.651 mm); B-cavity, 0.0960 inch (2.438 mm); and the C-cavity, 0.2605 inch (6.617 mm). The measured response for the experiment was the thickness of the molding. The injection press, mold, monitoring equipment, and molding compound were identical to those used in an earlier phase of this endeavor.¹

The following conclusions have been formulated from the experiment.

- Internal cavity pressure cannot be used alone as a thickness-controlling variable for thick mold cavities (0.2605 inch) (6.617 mm) or thin mold cavities (0.0650 inch) (1.651 mm). The thickness of specific intermediate cavities (0.0960 inch) (2.438 mm) can be controlled by internal cavity pressure alone.
- Mold-filling mode is significant to the control of molding thickness. The thin (0.0650 inch) and thick (0.2605 inch) mold cavity inserts are the most sensitive to the fill mode.
- Mold and melt temperature is significant to the control of thickness only for thick (0.2605 inch) and thin (0.0650 inch) cavities. The intermediate thickness shows no dependence on mold and melt temperatures within normal operating limits.

Future activity should include the investigation of molding size variation (width and length) as a function of actual cavity pressure. The use of pressure transducers in cyclic injection molds should also be pursued.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

DISCUSSION

SCOPE AND PURPOSE

The experiment was performed to resolve the following questions:

- Can peak internal cavity pressure be employed as the single controlling variable to maintain the thickness of typical polycarbonate injection moldings?
- With internal peak pressure held constant, how does molding thickness vary when subjected to the three most commonly used mold-filling modes?
- While holding internal peak pressure constant, what effects on the cavity thickness result from variations of melt and mold temperatures?

Answers to these questions in the form of general relationships will be used to improve the understanding of the phenomenon of injection-molded plastics.

PRIOR WORK

Earlier investigations, using a mold fitted with pressure transducers, were performed as a part of this development endeavor. Two specific mold studies,^{1,2} one using liquid transmission transducers, and one using solid-pin transmission transducers, were completed and evaluated. The intent of both studies was to equate internal cavity pressure as a function of external variables, including injection pressure, fill time, mold temperature, melt temperature, and cavity thickness.

A secondary response of both experiments was cavity thickness. Insufficient data were available from these earlier studies to provide a relationship between thickness and internal cavity pressure. As a result of these earlier studies, a third experiment was planned to provide answers to the questions generated about the independent variable (internal cavity pressure) and the primary response (molding thickness).

ACTIVITY

Experimental Equipment and Setup

The equipment used in this experiment was identical to that described in a previous report.² The injection press was a 350-ton-clamp, (317,450 kg),

20-ounce (0.58 kg), 20000 psi (137.9 MPa) HPM Model 350-DX-20. The press was equipped with a dual-bank Whitlock desiccant hopper-drier to keep the polycarbonate molding compound at something less than 0.02-percent moisture-by-weight.

Mold temperature was controlled by a dual-zone Sterlco oil heater/circulator. Actual mold temperature was monitored by a hand-held pyrometer placed directly on the molding surface. Melt temperature was sensed in the injection barrel by a type-J bayonet thermocouple and was monitored on a Honeywell Elektronik chart recorder.

Injection pressure (primary and secondary) can be controlled independently from zero to 20,000 psi (137.9 MPa). A three-plate injection mold was used in the experiment. Both Punch and Cavity sections were cored for hot-oil flow, and a 0.170-inch-diameter (4.32 mm) gate was used. The three diamond-shaped cavity inserts (Figures 1 and 2) simulate typical production geometries.

The mold was fitted with three Control Process pressure transducers, Model 405, driven by 0.130-inch-diameter (3.30 mm) dummy core pins. The pins were spaced 0.75, 2.0, and 3.25 inches (19.05, 50.80, and 82.55 mm) from the gate entry of the mold. The input for the transducers was a Control Process two-channel amplifier/recorder, Model 220. The gate and tip positions were monitored for all experimental runs performed during the experiment. The maximum deflection of the gate position transducer was adjusted to provide the required internal cavity pressures for the experiment.

The molding compound used for this experiment was Merlon M40F (Mobay) low-molecular-weight polycarbonate. Hopper-drier temperature was maintained at 250 to 260°F (121 to 126°C).

Experimental Design

The intent of the design selected for this experiment was the provision of sufficient treatments to evaluate product thickness for three individual cavity inserts as functions of peak gate cavity pressure, mold temperature, melt temperature, and injection mode. A 23-line matrix was selected to provide 15 primary lines for peak cavity pressure and injection mode, and 8 secondary lines for combinations of mold and melt temperatures (Table 1). The 15 primary lines yielded five data points for each of the three injection modes. These five points reflected the full range of peak cavity pressure. The eight remaining treatments featured a constant cavity pressure of 7500 psi (51.7 MPa) and the B-fill mode. All possible combinations of mold and melt temperatures were provided in these eight lines and in line 1. The intended response of the experiment was the thickness of each molding and the thickness runout

Text continued on page 16.

Figure 1. Typical Injection Moldings From the Three Experimental Mold Cavity Inserts

Figure 2. Mounted Mold C-Cavity Insert, 0.2605 Inch Thick (6.617 mm), Showing the Three Transducer Transmission Pins

Table 1. Experimental Matrix

Line	Peak Cavity Pressure at Gate (psi) (MPa)	Mold Temperature (°F) (°C)	Melt Temperature (°F) (°C)	Injection* Mode
1	7500 (51.7)	260 (127)	560 (293)	B
2	6500 (44.8)	260	560	B
3	5500 (37.9)	260	560	B
4	8500 (58.6)	260	560	B
5	9500 (65.5)	260	560	B
6	9500 (65.5)	260	560	A
7	8500 (58.6)	260	560	A
8	7500 (51.7)	260	560	A
9	6500 (44.8)	260	560	A
10	5500 (37.9)	260	560	A
11	5500 (37.9)	260	560	C
12	6500 (44.8)	260	560	C
13	6500 (51.7)	260	560	C
14	8500 (58.6)	260	560	C
15	9500 (65.5)	260 (127)	560	C
16	7500 (51.7)	280 (138)	560	B
17	7500	240 (116)	560 (293)	B
18	7500	240	580 (304)	B
19	7500	240 (116)	540 (282)	B
20	7500	260 (127)	540	B
21	7500	280 (138)	540 (282)	B
22	7500	280 (138)	580 (304)	B
23	7500 (51.7)	260 (127)	580 (304)	B

*A-Mode. Primary = secondary injection pressure;

B-Mode. Primary = 0; secondary injection only; and

C-Mode. Primary = 750 psi (line) (5.17 MPa); secondary adjusted as necessary to yield the required peak gate pressure. Primary timer adjusted to expire as the transducer shows deflection.

(the variation from gate to tip of the part thickness). Sixty-nine lines of moldings, a total of three cavities times 23 lines, were required to complete the study. Five moldings were required for each line to be used for average thickness readings.

Experimental Variables

The four variables selected for this study were mold temperature, melt temperature, injection fill mode, and peak cavity pressure at the gate position transducer.

The mold temperatures evaluated were 240, 260, and 280°F (116, 127, 138°C), which are normal molding temperatures for polycarbonate. The three levels of melt temperature used, 540, 560, and 580°F (282, 293, 304°C), were within normal operational limits.

The three injection-fill modes evaluated were intended to simulate common forms of filling a constant-temperature mold. The A-fill mode simulated a rapid fill situation with the injection pressures set at equal values. The injection pressure for all A-mode treatments was set to achieve the desired peak gate pressure. The B-fill mode was intended to simulate a medium fill rate used for many cyclic molding applications. The primary (high-injection) pressure was set at zero, and the fill of the mold was achieved on secondary (low injection) pressure. The secondary pressure was set to yield the correct peak gate pressure. The C-fill mode was intended to simulate a slow fill required on many molded products to eliminate trapped air and flow lines. The primary inject pressure was set at 750 psi (5.17 MPa) (line) for a C-mode treatment. The inject speed setting was adjusted at 8.5, on a scale of zero to 10, for these treatments. The primary inject timer was set for the various combinations to expire just as the mold filled. Mold fill was defined as that point in time when the gate transducer readout began to show deflection. The secondary inject pressure was then adjusted to provide the desired peak gate pressure.

The peak gate cavity pressure, which was the major variable in this experiment, was varied from 5500 psi to 9500 psi (37.9 to 65.5 MPa) in 1000 psi (6.9 MPa) increments.

A summary listing of variables and levels is shown in Table 2.

Data Collection

One hundred fifteen moldings from each of the three cavity inserts were serialized and retained for evaluation. Typical moldings are shown in Figure 1.

and the 0.2605-inch (6.617 mm) cavity insert is shown in Figure 2. Thickness readings to the nearest 0.0001 inch (0.0025 mm) were taken at the gate, middle, and tip positions of each molding (Tables 3, 4, and 5). A deep-throated ball micrometer was used to measure thickness. Total data could not be obtained from the A-cavity moldings (0.0650 inch) (1.651 mm) because some of the treatment combinations produced moldings that were not completely filled. Line 3 of the medium fill rate B-mode filled only to within 0.5 inch (12.7 mm) of the tip transducer, and no data appear for these moldings at the tip position. Line 3 used the lowest value of peak cavity pressure (5500 psi) (37.9 MPa), which is not sufficient to completely fill the mold in the B-mode. Lines 11 through 15 used the C-mode of fill which was not sufficient to completely fill the thin 0.0650-inch (1.651 mm) cavity for all of the peak cavity pressures evaluated. The range of fill for these five treatments ranged from 0.5 to 1 inch (12.7 to 25.4 mm) from the tip transducer position.

Table 2. Experimental Variables

Level	Mold Temperature (°F) (°C)	Melt Temperature (°F) (°C)	Injection Fill Mode*	Peak Cavity Pressure at Gate (psi) (MPa)
-2	- -	- -	- -	5500 (37.9)
-1	240 (116)	540 (282)	A	6500 (44.8)
Zero	260 (127)	560 (293)	B	7500 (51.7)
+1	280 (138)	580 (304)	C	8500 (58.6)
+2	- -	- -	- -	9500 (65.5)
*Refer to text above.				

Most of the 0.0650-inch moldings were distorted because of gate pull as the mold opened. The distortion, however, was not severe enough to affect the measurement of thickness at the gate position. Line 19, mold 240°F (116°C) and melt 540°F (282°C), lacked approximately 0.125 inch (3.18 mm) of being completely filled. Measurement of this part was not hampered. Lines 16, 21, and 22, mold 280°F (138°C), reflected sinks up to 0.0003-inch (0.008 mm) at the tip position because of the excessive mold temperature. The sinks are attributed to either trapped air or uneven cooling at the 280°F (138°C) level.

Text continued on page 21.

Table 3. Thickness Response for 0.0650-Inch (1.651 mm)
A-Cavity

Line	Molding Thickness (Inch) (mm)		
	Gate	Middle	Tip
1	0.0657 (1.669)	0.0644 (1.636)	0.0639 (1.623)
2	0.0650 (1.651)	0.0641 (1.628)	0.0630 (1.600)
3	0.0648 (1.646)	0.0639 (1.623)	Non-Fill
4	0.0656 (1.666)	0.0649 (1.648)	0.0640 (1.626)
5	0.0660 (1.676)	0.0649 (1.648)	0.0640 (1.626)
6	0.0661 (1.679)	0.0650 (1.651)	0.0641 (1.628)
7	0.0655 (1.664)	0.0648 (1.646)	0.0639 (1.623)
8	0.0651 (1.654)	0.0642 (1.631)	0.0638 (1.621)
9	0.0651 (1.654)	0.0640 (1.626)	0.0632 (1.605)
10	0.0649 (1.648)	0.0638 (1.621)	0.0622 (1.580)
11	0.0649 (1.648)	0.0639 (1.623)	Non-Fill
12	0.0650 (1.651)	0.0640 (1.626)	Non-Fill
13	0.0654 (1.661)	0.0641 (1.628)	Non-Fill
14	0.0655 (1.664)	0.0641 (1.628)	Non-Fill
15	0.0659 (1.674)	0.0642 (1.631)	Non-Fill
16	0.0655 (1.664)	0.0645 (1.638)	0.0642 (1.631)
17	0.0652 (1.656)	0.0644 (1.636)	0.0632 (1.605)
18	0.0652 (1.656)	0.0644 (1.636)	0.0637 (1.618)
19	0.0652 (1.656)	0.0640 (1.626)	0.0625 (1.588)
20	0.0658 (1.671)	0.0642 (1.631)	0.0633 (1.608)
21	0.0656 (1.666)	0.0643 (1.633)	0.0638 (1.621)
22	0.0652 (1.656)	0.0644 (1.636)	0.0635 (1.613)
23	0.0656 (1.666)	0.0644 (1.636)	0.0638 (1.621)
Coecal* Mold Thickness Readings	0.0680 (1.727)	0.0671 (1.704)	0.0679 (1.725)
* Product of Coe Laboratories, Inc., Chicago, Illinois			

Table 4. Thickness Response for 0.0960-Inch (2.438 mm)
B-Cavity

Line	Mold Thickness (Inch) (mm)		
	Gate	Middle	Tip
1	0.0946 (2.403)	0.0931 (2.365)	0.0932 (2.367)
2	0.0942 (2.393)	0.0928 (2.357)	0.0930 (2.362)
3	0.0940 (2.388)	0.0925 (2.350)	0.0929 (2.360)
4	0.0950 (2.413)	0.0933 (2.370)	0.0932 (2.367)
5	0.0955 (2.426)	0.0938 (2.383)	0.0935 (2.375)
6	0.0953 (2.421)	0.0938 (2.383)	0.0935 (2.375)
7	0.0950 (2.413)	0.0934 (2.372)	0.0932 (2.367)
8	0.0948 (2.408)	0.0930 (2.362)	0.0931 (2.365)
9	0.0942 (2.393)	0.0929 (2.360)	0.0930 (2.362)
10	0.0940 (2.388)	0.0925 (2.350)	0.0929 (2.360)
11	0.0940 (2.388)	0.0925 (2.350)	0.0929 (2.360)
12	0.0944 (2.398)	0.0929 (2.360)	0.0930 (2.362)
13	0.0948 (2.408)	0.0931 (2.365)	0.0931 (2.365)
14	0.0951 (2.416)	0.0935 (2.375)	0.0932 (2.367)
15	0.0956 (2.428)	0.0938 (2.383)	0.0935 (2.375)
16	0.0948 (2.408)	0.0931 (2.365)	0.0931 (2.365)
17	0.0948 (2.408)	0.0931 (2.365)	0.0931 (2.365)
18	0.0949 (2.410)	0.0931 (2.365)	0.0931 (2.365)
19	0.0948 (2.408)	0.0931 (2.365)	0.0931 (2.365)
20	0.0948 (2.408)	0.0931 (2.365)	0.0931 (2.365)
21	0.0949 (2.410)	0.0932 (2.367)	0.0932 (2.367)
22	0.0950 (2.413)	0.0933 (2.370)	0.0933 (2.370)
23	0.0948 (2.408)	0.0931 (2.365)	0.0931 (2.365)
Coecal* Mold Thickness Readings	0.0962 (2.443)	0.0956 (2.428)	0.0963 (2.446)
*Product of Coe Laboratories, Inc., Chicago, Illinois.			

**Table 5. Thickness Response for 0.2605-Inch (6.617 mm)
C-Cavity**

Line	Molding Thickness (Inch) (mm)		
	Gate	Middle	Tip
1	0.2561 (6.505)	0.2552 (6.482)	0.2585 (6.566)
2	0.2553 (6.485)	0.2555 (6.490)	0.2584 (6.563)
3	0.2550 (6.477)	0.2547 (6.469)	0.2583 (6.561)
4	0.2561 (6.505)	0.2556 (6.492)	0.2588 (6.573)
5	0.2563 (6.523)	0.2559 (6.500)	0.2588 (6.573)
6	0.2564 (6.513)	0.2558 (6.497)	0.2589 (6.576)
7	0.2565 (6.515)	0.2558 (6.497)	0.2588 (6.573)
8	0.2562 (6.508)	0.2555 (6.490)	0.2585 (6.566)
9	0.2565 (6.515)	0.2556 (6.492)	0.2584 (6.563)
10	0.2568 (6.523)	0.2556 (6.492)	0.2582 (6.558)
11	0.2570 (6.528)	0.2559 (6.500)	0.2582 (6.558)
12	0.2568 (6.523)	0.2558 (6.497)	0.2582 (6.558)
13	0.2562 (6.508)	0.2554 (6.487)	0.2585 (6.566)
14	0.2568 (6.523)	0.2558 (6.497)	0.2588 (6.573)
15	0.2570 (6.528)	0.2560 (6.502)	0.2589 (6.576)
16	0.2590 (6.579)	0.2580 (6.553)	0.2582 (6.558)
17	0.2558 (6.497)	0.2549 (6.474)	0.2589 (6.576)
18	0.2559 (6.500)	0.2550 (6.477)	0.2590 (6.579)
19	0.2559 (6.500)	0.2550 (6.477)	0.2590 (6.579)
20	0.2561 (6.505)	0.2553 (6.485)	0.2586 (6.568)
21	0.2578 (6.548)	0.2569 (6.525)	0.2584 (6.563)
22	0.2592 (6.584)	0.2575 (6.541)	0.2583 (6.561)
23	0.2552 (6.482)	0.2553 (6.485)	0.2558 (6.573)
Coecal* Mold Thickness Readings	0.2618 (6.650)	0.2609 (6.627)	0.2612 (6.635)
*Product of Coe Laboratories, Inc., Chicago, Illinois			

All of the 0.0960-inch (2.438 mm) cavity moldings filled, and no indications of sink marks were noted. Some distortion was noted from gate pull but not to the extent seen in the thinner moldings. Measurement of the thickness of the three points on the 115 quantity of 0.0960-inch moldings was easily achieved.

The 0.2605-inch (6.617 mm) moldings all reflect sink marks on both Punch and Cavity surface. The most severe sinks are seen in the low pressure lines (3, 10, and 11) and the high mold-temperature lines (16, 21, and 22). Thickness measurement was difficult with the high incidence of sunken areas, and the repeatability of moldings for any one set of molding conditions was poor. For the sake of study continuity, the indicated maximum gate pressures for the 0.2605-inch cavity were maintained. To predict more accurately the effects of melt and mold temperatures, however, higher values of internal cavity pressure should have been used.

Molding width and length could have provided some interesting relationships, but measurement of these dimensions could not be achieved. Warpage, gate pull, and the exaggerated draft used on all three mold inserts made accurate and repeatable readings impossible.

Analysis of Data

Thickness responses of all the experimental treatments were plotted against the four major variables: peak cavity pressure, fill mode, mold temperature, and melt temperature. For the purposes of analysis, separate graphs were prepared for the three cavity inserts. The actual part thicknesses are reflected in Figures 3 through 11.

Runout, or the thickness variation of the molding between the tip and the gate positions, which is the most meaningful response plotted, is shown in Figures 12, 13, and 14.

In evaluating the A-fill mode (primary equals secondary injection pressure), it was observed that the runout for each of the three cavities was significantly affected by peak cavity pressure at the gate. The thick C-cavity (0.2605 inch) (Figure 12), the most sensitive of the cavities tested, reflected a runout increase of approximately 0.0003 inch per 1000 psi (0.0076 mm/6.985 MPa) of cavity pressure increase. The C-cavity alone exhibited a negative value of runout which meant the gate position was shrinking at a greater rate than the tip. The B-cavity (0.0960 inch) reflected a runout increase of approximately 0.0002 inch per 1000 psi (0.0051 mm/6.895 MPa) increase of cavity pressure (Figure 13). The thin 0.0650-inch A-cavity showed a decrease in runout at an approximate rate of 0.0007 inch per 1000 psi (0.0178 mm/6.895 MPa) of

Text continued on page 34.

Figure 3. Part Thickness Versus Cavity Pressure for the 0.2605-Inch (6.617 mm) C-Cavity

Figure 4. Part Thickness Versus Mold Temperature for the 0.2605-Inch (6.617 mm) C-Cavity

Figure 5. Part Thickness Versus Melt Temperature for the 0.2605-Inch (6.617 mm) C-Cavity

Figure 6. Part Thickness Versus Cavity Pressure for the 0.0960-Inch (2.438 mm) B-Cavity

Figure 7. Part Thickness Versus Mold Temperature for the 0.0960-Inch (2.438 mm) B-Cavity

Figure 8. Part Thickness Versus Melt Temperature for the 0.0960-Inch (2.438 mm) B-Cavity

Figure 9. Part Thickness Versus Cavity Pressure for the 0.0650-Inch (1.651 mm) A-Cavity

Figure 10. Part Thickness Versus Mold Temperature for the 0.0650-Inch (1.651 mm) A-Cavity

Figure 11. Part Thickness Versus Melt Temperature for the 0.0650-Inch (1.651 mm) A-Cavity

Figure 12. Runout Versus Primary Variables for the 0.2605-Inch (6.617 mm) C-Cavity

Figure 13. Runout Versus Primary Variables for the 0.0960-Inch (2.438 mm) B-Cavity

Figure 14. Runout Versus Primary Variables for the 0.0650-Inch (1.651 mm) A-Cavity

cavity pressure increase in the range of 5500 to 7500 psi (37.9 to 51.7 MPa) cavity pressure (Figure 14).

From 7500 to 9500 psi (51.7 to 65.5 MPa), in general terms, where the mold fill is not significantly restricted, which is the case for the B- and C-cavities, the runout over a molding will increase with increasing cavity pressure. The reason for the increase is that the gate position grows in thickness at a faster rate than does the tip position. For thin cavities, such as the 0.0650-inch A-cavity mold insert, sufficient flow restriction exists such that an increase of cavity pressure at the gate position enhances the previously limited flow, and actually improves the fill quality of the molding. At some point beyond 7500 psi in this experiment, the thin cavity showed a thickening at the gate and acted much like the thicker B- and C-cavities.

The three fill modes, when plotted against thickness runout, have provided some very interesting curves. The thick C-cavity reflects the most variation with respect to fill mode (Figure 12). It should be noted that all of the C-moldings show significant sink marks. To review, the three fill modes represent the following conditions:

A-Mode. Primary = secondary injection pressure;

B-Mode. Primary = 0, secondary injection only; and

C-Mode. Primary = 750 psi (line) (5.17 MPa); secondary adjusted as necessary to yield the required peak gate pressure. Primary timer adjusted to expire as the transducer shows deflection.

The high shrinkage of the gate area of the thick C-cavity was the cause for the very high runout values, up to 0.0037 inch (0.0940 mm), shown in the graph. The A- and C-fill modes produced similar curves of runout. In both cases the tip shrinkage was reduced with increasing pressure, while the gate shrinkage remained high and constant. The result was a greater difference between the tip and gate thickness reading. The B-fill mode (secondary pressure only) showed a high runout at low pressure with improvement as cavity pressure increased. The C-mode of fill produced the lowest values of runout for all the samples tested. The C-mode offered a significant advantage for thick cavities over the other modes tested as it allowed a slow fill followed by a rapid pressurization of the cavity. It is believed that trapped air is a major contributor to sinks in thick moldings. The C-fill mode allows much of the air in the cavity to be forced out as the mold slowly fills.

The middle cavity (B) runout showed no measurable significance for the three modes of tested mold fill (Figure 13). The A-mode (fast fill) yielded a slightly lower runout at high injection pressure.

Runout of the thin A-cavity moldings was sensitive to fill-mode in that the C-mode could not completely fill the molding (Figure 14). The tips of the molding were unfilled for all five treatments using the C-fill mode. The tips of the molding were also unfilled for the low-pressure (5500 psi) (37.9 MPa) treatments of fill modes A and B. For all other points where fill was achieved, no measurable significance between modes A and B could be seen.

Mold and Melt Temperature Effects

The middle (B) cavity reflected thickness changes of less than 0.0002 inch (0.0051 mm) for all combinations of melt and mold temperatures tested (Figures 7 and 8). Within the limits of this experiment, the thickness of the 0.0960-inch (2.438 mm) cavity must be considered insensitive to changes in melt and mold temperature.

The thick C-cavity reflected the most measurable mold and melt temperature sensitivity (Figures 4 and 5) of the three cavities tested. The gate position thickness increased approximately 0.0030 inch (0.0762 mm) for a 40°F (22°C) increase in mold temperature for melt temperatures of 560°F (293°C) and 580°F (304°C). The increase for the 540°F (282°C) melt treatments, over the same range, was approximately 0.0020 inch (0.0508 mm). The tip position thickness, in general, decreased approximately 0.0006 inch (0.0153 mm) for a 40°F (22°C) increase in mold temperature. This decrease was probably caused by trapped air or a heat sink at the tip, either of which could result from increased mold temperature. Because of the rapid thickening of the gate position, the runout across the molding at a melt temperature of 560°F (293°C) is reduced significantly with increased mold temperature.

The effects of melt and mold temperature on the thickness of parts molded in the thin A-cavity were measurable and significant (Figures 10 and 11). At the zero experimental level of mold temperature (260°F) (127°C), the gate thickness variation (0.0002 inch) (0.0051 mm) was not significant over the range of 540°F to 560°F (282°C to 293°C). The tip position, however, showed an increase of 0.0005 inch (0.0127 mm), which was significant over the same range of melt temperature. At the -1 experimental level of mold temperature (240°F) (116°C), the gate was unaffected by an increase in melt temperature, while the tip increased in thickness by 0.0012 inch (0.0305 mm) over a melt temperature increase of 40°F (22°C). At the high mold temperature (280°F) (138°C), it was observed that the gate thickness was reduced by 0.0004 inch (0.0102 mm) over the range of increasing melt temperature.

The tip position thickness peaked at 560°F (293°C), and was low at 540°F and 580°F (282 and 304°C). The total tip variation was 0.0007 inch (0.0178 mm). Sink marks could be seen on the tips of the parts molded at 580°F melt (304°C)

and 280°F (138°C) mold temperature, which was probably the reason for the reduced thickness of these treatments. In general terms, the thickness near the gate of a thin molding (A-cavity) is not significantly affected by melt temperature, regardless of the mold temperature being used. However, since the tip is 3 inches (76.2 mm) away from the gate entry, it is affected by changes in melt temperature. At nominal molding temperatures (240 to 260°F) (116 to 127°C), the tip thickness increases predictably as the melt temperature is increased. At a high molding temperature (280°F) (138°C), the tip thickness drops off as melt temperature is increased because of the appearance of sinks in the molding.

With the melt temperature held constant and the mold temperature varied from 240°F to 280°F (116 to 138°C), the same general tip and gate thickness variation was noticed. Tip and gate thickness variation was most significant at a melt temperature of 540°F (282°C). The total gate variation from a mold temperature modulation of 240 to 280°F was 0.0006 inch (0.0152 mm) with a maximum thickness at 260°F (127°C). The tip position increased smoothly a total of 0.0013 inch (0.0330 mm) over the same mold temperature range. The gate thickness was not significantly affected at the 560°F and 580°F (293 and 304°C) levels for any of the mold temperatures tested. Tip thickness increased 0.0010 inch (0.0254 mm) for the 560°F melt temperature, and 240°F to 280°F mold temperature treatment.

At a 580°F melt temperature, the tip thickness dropped off slightly (0.0002 inch) (0.0051 mm) with increasing mold temperature as sinks appeared on the tips of the specimens. In general, increasing the mold temperature improves flow to the part tip and causes a thickness increase. Only at a high melt temperature does the molding thickness drop off for increasing mold temperature.

A plot of thickness runout (gate thickness minus tip thickness) versus melt temperature for the three values of tested mold temperatures (Figure 14) showed a reduction in runout of 0.0010 to 0.0012 inch (0.0254 to 0.0305 mm), for all treatments between 540 and 560°F (282 and 293°C). Between 560 and 580°F (293 and 304°C) the runout was affected differently for each of the three mold temperatures. At 240°F (116°C), the runout was reduced in a linear fashion. At 260°F (127°C), the runout was unchanged from 560 to 580°F. At a mold temperature of 280°F (138°C), the runout increased as melt temperature was increased. Of all the treatments evaluated, the 560°F melt, 280°F mold combination produced the lowest value of runout (0.0012 inch) (0.0305 mm).

The middle B-cavity reflected thickness changes of less than 0.0002 inch (0.0051 mm) for all combinations of melt and mold temperatures evaluated (Figures 7 and 8). Within the limits of this experiment, the thickness control of moldings of an approximate thickness of 0.10 inch (0.254 mm) was independent of both mold and melt temperature.

Because of the relatively low cavity pressures used in this experiment, all of the 0.2605-inch (6.617 mm) C-cavity moldings showed sink marks on both flat surfaces. For this reason, changes in thickness were relatively sharp for some of the melt/mold temperature combinations. Changes in melt temperature while holding the mold temperature constant resulted in no significant changes in thickness at 240 or 260°F (116 or 127°C) (Figure 5). At 280°F, the thickness of the gate and middle positions increased with increasing melt temperature, while the tip position was relatively unaffected. With a constant melt temperature, a sharp increase in thickness of approximately 0.0030 inch (0.0762 mm) of the gate and middle positions was observed for an increase in mold temperature of 40°F (22°C). The tip thickness decreased slightly (0.0005 inch) (0.0127 mm) as mold temperature was increased, because of the higher incidence of sinks.

ACCOMPLISHMENTS

The following conclusions have been formulated as a result of this endeavor.

- Peak internal cavity pressure is highly significant in the control of product thickness. The dimensional response of the 0.0960-inch (2.438 mm) cavity is nearly identical for equivalent internal cavity pressures regardless of fill mode, melt temperature, or mold temperature within the limitations of this experiment. Internal cavity pressure cannot be used alone to control thickness for the thin (0.0605-inch) (1.651 mm) and thick (0.2605-inch) (6.617 mm) cavities as changes in fill mode, mold temperature, and melt temperature cause significant thickness variations.
- Melt temperature and mold temperature produce significant changes in thickness and runout for the thick (0.2605-inch) (6.617 mm) and thin (0.0650-inch) (1.651 mm) cavities for constant values of internal cavity pressure. The 0.0960-inch (2.438 mm) cavity is not temperature-sensitive.
- Mold-fill method or mode is very critical to the thickness response of the thin (0.0650-inch) cavity and is moderately effective in altering the thickness response of the thick (0.2605-inch) cavity. The three fill modes evaluated had no effect on the thickness of the 0.0960-inch cavity.

FUTURE WORK

This development endeavor represents the final experimental phase of Process Development Order 6984324. Future activity associated with transducer-fitted injection molds will be performed under Process Development Order 6984642. This work will include the following studies:

- Pressure transducer studies for temperature-cycled injection molds,
- Continued constant temperature studies to relate length and width responses to internal cavity pressure, and
- Resin flow analysis using a pressure transducer fitted "stair-step" injection mold.

REFERENCES

¹ P. C. Black, Pressure Distribution in Polycarbonate Injection Moldings (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-951, October, 1973.

² P. C. Black, An Investigation of Internal Cavity Pressure for Injection-Molded Polycarbonates (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-601, April, 1972.