Experimental Investigation of the Polymer Melt Flow During Injection Post-Filling Process

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Injection molding, one of the important polymer processing techniques, consists of three stages: filling, packing and cooling. The latter two stages are also designated as the post-filling process. Although theoretical simulations and experimental studies of post-filling have been reported (Chung, 1985; Greener, 1986; Chiang et al., 1991; Chen et al., 1990), these research activities are not so extensive as those concerning the filling process. Experimental verifications of the post-filling process usually focus on the variation of cavity pressure as well as the part density. Almost no investigations regarding the polymer melt flow in this stage have been reported. Visualization techniques of the polymer melt flow inside an injection mold have been developed to study molding dynamics (Schmidt, 1974; Yokoi et al., 1991; Yokoi and Inagaki, 1992). Among these methods visualization with a laser light or highspeed video camera in a glass-inserted mold has been used by Yokoi's group (1991, 1992), recently. Although the dynamic visualization technique using a transparent mold can investigate time-sequential molding phenomena in detail, it is also subjected to the limitations of the maximum allowable injection pressure, the observation area, as well as the complexity and the expense in mold construction. Therefore, it is difficult to apply such a technique to thin cavities which require high injection pressure. Moreover, all these studies focused only on the filling process. In view of this, we proposed an easier way of studying the polymer melt flow in the injection molding process, particularly in the post-filling process, using a coinjection molding technique.

The coinjection molding process, one of the innovative multicomponent injection molding techniques recently developed, involves simultaneous or sequential injection of a skin polymer melt and a dissimilar but compatible core polymer melt into a mold cavity so that the core material is embedded within the solidified layers of the skin material (Escale, 1970; Sandifored and Oxley, 1971; Donovan et al., 1975; Young et al., 1980). The coinjection molding process is illustrated in Figure 1. This process was originally designed to provide flexibility in part design and manufacture by utilizing the optimal properties of each material. On the other hand, when a transparent skin material and a colored core material of the same brand are used, flow information regarding the conventional injection molding process may be obtained directly by viewing the coinjection molded parts. In this study, polymer melt flow during the post-filling process was investigated using a skin-core-skin sequential injection. Fringe pattern measurement of the sequential injection molded parts using the half-fringe photoelasticity (HFP) method was also performed as a separate verification.

Experiments

One line-gate plate cavity 90 mm long, 60 mm wide and 2 mm thick was built to conduct the process studies. A 75-ton Battenfeld 750/750 coinjection molding machine was used for the present experiments. CHI-MEI/PG33 transparent polystyrene resin (PS) was utilized as the skin material whereas green-colored PS of the same brand was used for the core layer so that the final distribution of both materials can be seen easily by viewing the molded parts. The melt temperatures for both skin and core resin were 210°C; the mold temperature was 25°C; the total filling time was 1.41 s. The switchover in injection sequence from the skin melt to

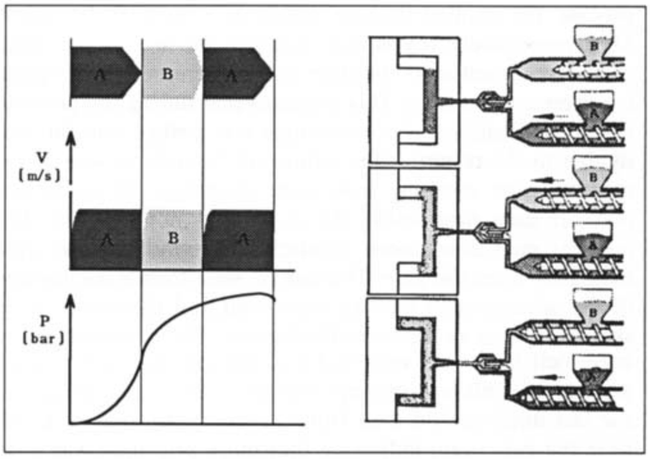

Figure 1. Coinjection molding process.

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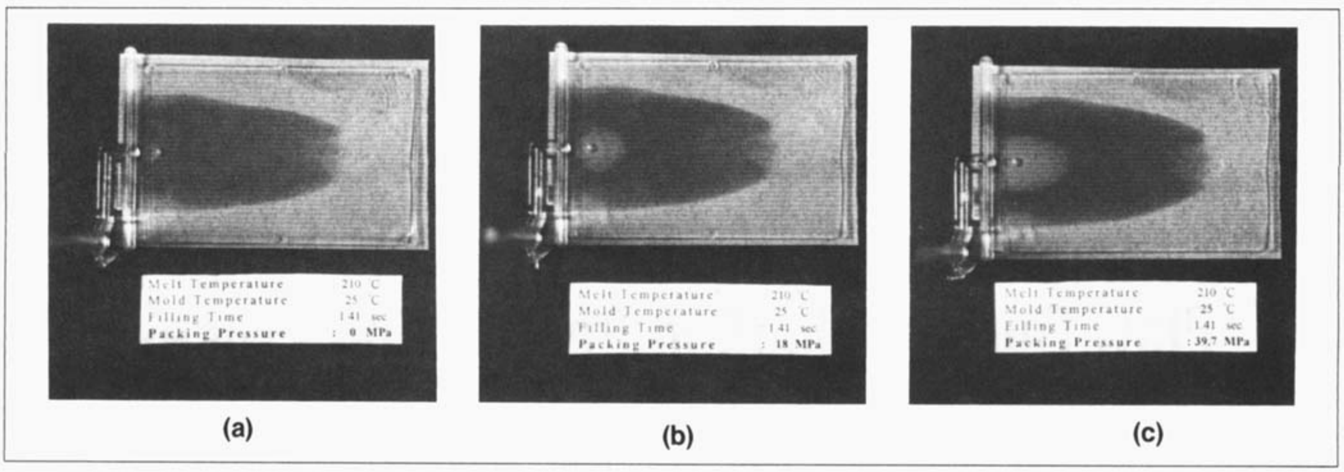

Figure 2. Coinjection molded plate using skin-core-skin sequential injection with (a) no applied packing pressure; (b) 18 MPa applied packing pressure; (c) 39.7 MPa applied packing pressure.

the core melt as well as the switchover from core melt back to skin melt injection were set at 0.68 s and 1.18 s, respectively, so that the last injected transparent PS barely enters the cavity position located near the gate. The packing and holding pressures were also varied within 0 to 40 MPa.

A half-fringe-photoelasticity system including a radiation source of light of 5,893 Å wavelength, two polarizers and a CCD camera was used to measure the fringe pattern as well as the birefringence value of the injection molded part. Detailed experimental work has been described elsewhere (Chen et al., 1994).

Results and Discussions

The coinjection molded parts are shown in Figures 2a, 2b and 2c, respectively. These parts were coinjected using a skin-core-skin sequence. The sequence corresponds to a 0.68-s, a 0.5-s and a 0.23-s injection for the skin, the core and the skin melts, respectively. Under such injection sequence, the last injected transparent PS barely enters the cavity. During all experiments it was evident that the core melt front was catching up with the skin melt front. This indicates that the fountain flow effect does exit and dominate the melt front movement. To study the polymer melt flow in the post-filling process, the applied packing pressures were at 0, 18 and 40 MPa, respectively. It was also clear that the area of the transparent skin melt near the gate region increases as the packing pressure increases. This indicates that during the post-filling process additional polymer melt was pushed into the cavity due to the compressible nature of the melt as well as the compensation resulting from melt shrinkage. However, the polymer melt flow inside the cavity was not uniform. The polymer melt flows more significantly around the gate area than away from the gate. This can be seen from a comparison of the advancement of core melt front and the last injected skin melt front as shown in the figures. The advancement of core melt front was very slight, indicating that only a small amount of melt was pushed around this location. However, the last injected skin melt front advanced more significantly near the gate area, indicating that more skin melt was compressed into this location. The plate cavity was also sequentially injected with transparent PS for both skin and core melts using the same injection sequence and molding conditions as in the previous examples. The fringe patterns were measured by the half-fringe photoelasticity method. Our earlier studies (Chen and Chen, 1994a,b) showed that the fringe pattern caused by the part residual stress is basically flow-induced origin. Therefore, the investigation of the melt flow can also be verified separately from the fringe patterns. The results shown by Figures 3a, 3b and 3c indicate that stripes of the fringe pattern which increase with increased packing pressure are also more extensive around the gate area and show less significant increase away from the gate. The corresponding birefringence values were averaged gapwisely, and their distributions in the flow direction within the samples are illustrated in Figure 4. The significant flow of the polymer melt around the gate area is believed to have occurred in the latter stage of the post-filling process of compensate for solidification-induced shrinkage.

Conclusions

Studies of the polymer melt flow during the post-filling process have been investigated via the coinjection molding technique using an alternate injection sequence of transparent skin PS and colored core PS. The following observations have been found:

(1) During the post-filling process, polymer melt flows significantly and the amount of melt flow increases with increased packing pressure. Also, the polymer melt flow is more concentrated around the cavity location near the area and is less distinguished far away from the gate.

(2) Fringe measurements and the associated birefringence values also indicate the increased amount of melt flow with an increased packing pressure. It is also evident that the polymer melt flows more significantly around the gate area. The result is consistent with that found in the flow visualization from coinjection molding experiments.

(3) The nonuniform polymer melt flow within the mold cavity during the post-filling process was believed to be due to the compensation of the solidification-induced shrinkage occurring in the latter post-filling stage.

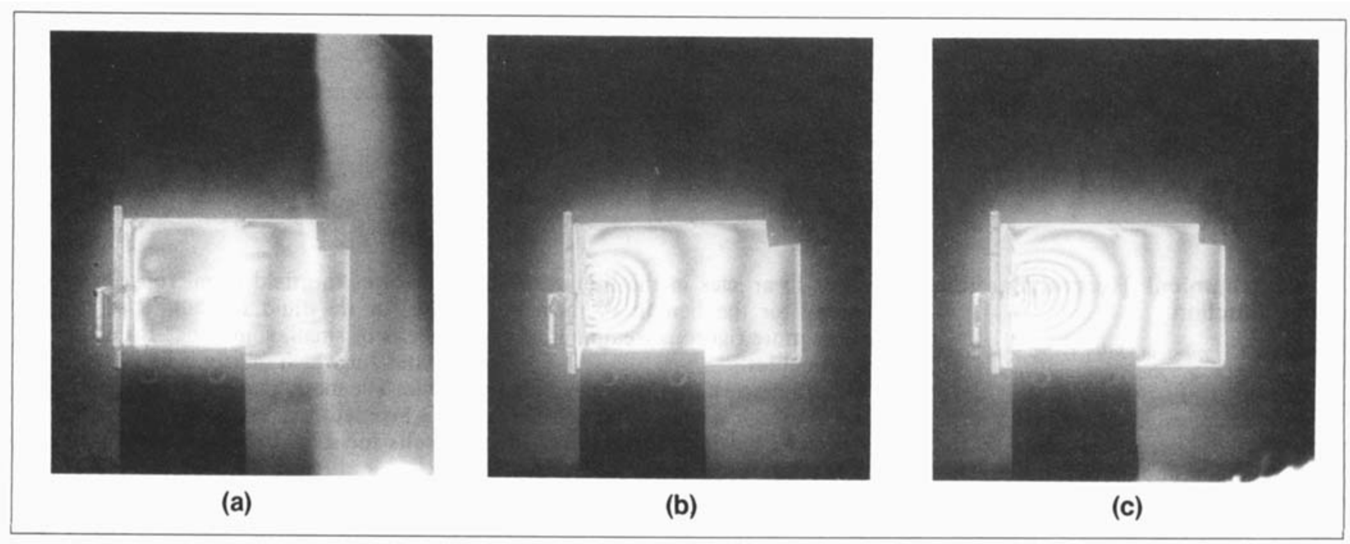

Figure 3. Fringe pattern of the skin-core-skin sequential injection molded plate (a) without applied packing pressure; (b) with 18 MPa packing pressure; (c) with 39.7 MPa packing pressure.

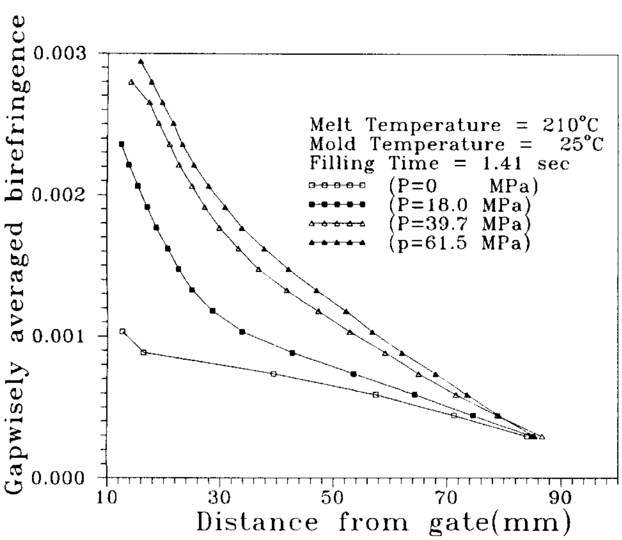

Figure 4. Gapwisely averaged birefringence values and their distribution in the flow direction within the samples corresponding Figures 3a to 3c.

Literature Cited

Chen, S. C., N. T. Cheng, and J. T. Teng, "A Study of Polymer Melt Compressible Flow and Pressure Development During the Post-Filling Stage of Injection Molding Process," *Chung Yuan J.*, **19**, 97 (1990).

Chen, S. C., and Y. C Chen, "Calculations of the Flow-induced Residual Stress Development in the Injection Molded Plate," *Comput. & Struct.*, **52**, 1043 (1994a).

Chen, S. C., and Y. C. Chen, "Effect of Process Conditions on Birefringence Development in Injection Molded Part I: Numerical Analysis," accepted by *J. Appl. Poly. Sci.* (1994b).

Chen, Y. C., S. C. Chen, and J. C. Chen, "Effect of Process Conditions on Birefringence Development in Injection Molded: II. Experimental Measurement," to be published.

Chiang, H. H., C. A. Hieber, and K. K. Wang, "A Unified Simulation of the Filling and Post-filling Stages in Injection Molding," *Poly. Sci. Eng.*, **31**, 116 (1991).

Chung, T. S., "Pressure Build-Up During the Packing Stage in Injection Molding," *Poly. Eng. Sci.*, **21**, 271 (1985).

Donovan, R. C., K. S. Rabe, W. K. Mammel, and H. A. Lord, "Recycling Plastics by Two-Shot Molding," *Poly. Eng. Sci.*, **15**, 774 (1975).

Escales, E., "The ICI Sandwich Molding Process," *Kunststoffe*, **60**, 847 (1970).

Greener, J., "General Sequences of the Packing Phase in Injection Molding," *Poly. Eng. Sci.*, **26**, 534 (1986).

Sandiford, D. J. H., and D. F. Oxley, "Serving Up a New Plastics Sandwich," *SPE J.*, **27**, 39 (1971).

Schmidt, L. R., "A Special Mold and Tracer Technique for Studying Shear and Extensional Flows in a Mold Cavity During Injection Molding," *Poly. Eng. Sci.*, **14**, 797 (1974).

White, J. L., and H. B. Dee, "Flow Visualization for Injection Molding of Polyethylene and Polystyrene Melt," *Poly. Eng. Sci.*, **14**, 212 (1974).

Yokoi, Y., Y. Murata, and K. Oka, "Visual Observation of Three-Dimensional Melt Flow Inside a Mold Cavity by Gate-Magnetization Method," *SPE Technical Papers*, **37**, 367 (1991).

Yokoi, Y., and Y. Inagaski, "Dynamic Visualization of Cavity Filling Process Along Thickness Direction Using a Laser-Light-Sheet Technique," *SPE Technical Papers*, **38**, 457 (1992).

Young, S. S., J. L. White, E. S. Clark, and Y. Oyangagi, "A Basic Experimental Study of Sandwich Injection Molding with Sequential Injection," *Poly. Eng. Sci.*, **20**, 798 (1980).

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