

WHAT POSITION ON THE VISCOSITY CURVE IS THE MOST REPEATABLE WITH RESPECT TO END OF FILL CAVITY PSI.

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Abstract

For many years, educators in the injection molding industry have suggested that higher injection speeds result in more stable processes when using 2-Stage processes. However, little data exists to verify this assertion.

In this paper, injection speeds were varied on a 2-Stage process. Cavity pressure was measured at the end of the cavity to evaluate process stability in the face of several process perturbations. Results supported the claim that higher injection rates reduced overall process variation.

Introduction

It is well known that non-newtonian behavior of polymeric materials greatly influences their processing characteristics: as the injection speed increases, the viscosity of the melt decreases. While the impact of this behavior on the process seems relatively simple, more subtle implications exist.

A typical rheology profile for a polymeric material is shown in Figure 1. Not only does the viscosity drop with fill speed, but the change in viscosity with process variation is also reduced. Figure 1 shows that at high fill speeds, a small variation in fill speed results in a small viscosity change, while the same variation in fill speed at low velocities causes a much greater viscosity change.

Since material viscosity has such a significant effect on the injection molding process, this simple relationship suggests that faster fill rates should produce more consistent processes. While this phenomenon has been observed anecdotally, little has been done to verify this experimentally.

The objective of this paper is to evaluate the effect of injection speed on process consistency. To simulate the effect of typical process variation, several process perturbations were introduced, including small changes to raw material viscosity, fill speed, and shot size. The effect of these changes on the process was evaluated by monitoring a pressure sensor located at the end of the cavity of a simple test plaque.

Experimental

The mold used for this study was a flat test plaque measuring 150 mm by 37 mm (6" x 1.5"). The thickness of the plaque was adjustable on this mold, and a nominal wall thickness of 1.5 mm was maintained throughout the study. The mold was run on a Toshiba EC 45 electric press.

Two different polypropylenes were used for this experiment. The first material had a relatively low viscosity (Montell 6323 - 12 melt) and the second viscosity had approximately 25% higher viscosity (mixture of 6523 PP and SG 802 PP).

An in-mold rheology curve was performed using both materials to determine the fill speed – viscosity relationship. The results are shown in Figure 2. Based on these results, three different fill speeds were chosen for the study. The fastest speed chosen was in the “flat” portion of the curve, while the slowest was chosen in the “steep” portion. The medium speed was chosen at the “knee” where the curve transitions from relatively flat to steep. These 3 speeds were 190 mm/sec, 50 mm/sec, and 10 mm/sec.

The process was a DECOUPLED IISM 2-Stage process, where the part was filled approximately 95% full using a single fill speed on first stage then transferred to 2nd stage (hold) pressure. For each fill speed condition, the transfer position was adjusted so that the fill-only part was 95% full using the low viscosity

material, and the 2nd stage pressure was adjusted to the point where the end of fill cavity pressure reached 24 MPa (3500 psi).

At each of the three fill speeds, small process perturbations were introduced. The intention was to make these perturbations simulate typical sources of long term variation present in the molding environment. To perturb the viscosity, the material was switched from the low viscosity (6323) resin to the higher viscosity (6523 - SG 802 mixture). The fill speed perturbation was designed to simulate changes in operator setup, machine to machine variation, and was set at +/- 5% of the nominal injection speed. The transfer position perturbation was chosen to simulate variation in operator setup as well as variation in check ring seating. Here, the transfer position was set 1 mm earlier, a reduction in the fill-only shot weight of approximately 2%.

All possible combinations of these three perturbations were run, for a total of 8 conditions per nominal fill speed setting. Ten shots were taken at each condition after allowing the process to stabilize.

Cavity pressure data was recorded for all experimental runs using sensors and data acquisition equipment from RJG, Inc. Sensors were located just inside the gate (Post Gate) and near the end of the cavity (End of Fill), although the End of Fill data was used for the majority of the analysis since it is generally the most sensitive to process variation. The Peak data and the Cycle Integral (area under the entire curve during the cycle) were recorded for each sensor.

For each condition, the average and standard deviation were calculated for the End of Fill Peak pressure and the End of Fill Cycle Integral. While the peak pressure corresponds most directly to viscosity-induced pressure drops across the cavity, the Cycle Integral reflects all variation in the pressure profile throughout the cycle.

Results

The End of Fill Cycle Integral is plotted for all shots in Figure 3. Here, all perturbations are shown, although the most obvious is the effect of the material viscosity change. Also, it is possible to see the overall variation in the process. The low speed data has the greatest process shift and the greatest overall variation in the data, while

the high speed data shows the least shift and overall variation.

This shift can be calculated using the standard deviation of all data for each fill speed. This represents the variation in the process due to all process perturbations, in addition to baseline process variation. It is also interesting to evaluate the effect of each perturbation individually, as well as the effect of the baseline variation only. To determine the average baseline process variation, the standard deviation of each 10 shot run was averaged together.

The effect of each perturbation is slightly more difficult to calculate. For example, for each viscosity, four identical fill speed – transfer position perturbations were run at each of the three fill speeds. Thus, to calculate the variation due to viscosity, the standard deviation was calculated for each of these four sets individually. Since each set included only the viscosity change, they each reflect the effect of viscosity only. Averaging the four standard deviations provided the average effect of viscosity on process variation.

The results of this analysis are shown in Figure 4, where the End of Fill Cycle Integral standard deviation is plotted against fill speed. The cycle integral for the end of fill with **all** perturbations included shows that increasing fill speeds reduce overall process variation. This data shows that the faster speed is more repeatable than the medium speed by 37% and better than the slow speed by 164%. This demonstrates that faster injection speed yields more repeatability.

Figure 4 shows similar results for each individual perturbation, as well as for the baseline variation. Only the transfer position perturbation shows slightly lower variation at the medium speed than the fast fill speed. Figure 4 also shows that the viscosity perturbation has the most significant effect on process variation, while fill speed and transfer position have a much lower impact. This probably cannot be generalized to all molds; for example, thin-walled molds would likely be more sensitive to fill speed perturbation.

Figure 5 shows results for End of Peak standard deviation. While the general results are the same as the cycle integral analysis, there is

no significant difference noted between the medium and fast fill speeds.

Discussion

Molders often fill at a speed that they feel comfortable, but no faster. The results of the study suggest that higher fill speeds might produce more consistent processes, especially when the effects of multiple sources of variation are considered. This is not to suggest that a higher injection speed should be used if it compromises the quality of the part. For example, an excessive fill speed may cause gate blush, high skin layer orientation, or other defects. However, using the highest possible fill speed *without compromising quality* can reduce pressure variation inside the cavity. This in turn minimizes shorts, flash, sink, variation in part dimensions, and other pressure related quality concerns.

The results also assume that the machine is capable of transferring quickly enough from 1st to 2nd stage. In newer servo and proportional valve controlled machines, this response time increases with increased fill speed. At high fill

speeds, some machines do not transfer consistently due to the higher rate of deceleration. In these cases, it is predictable that intermediate fill speeds, where the machine transfers more consistently, will provide more consistent processes.

Conclusion

The results of this study confirm the theoretical hypothesis that faster fill speeds attenuate process perturbations better than lower fill speeds for 2-stage processes. Thus higher fill speeds tend to provide more consistent processes from the perspective of pressure inside the cavity. However, this may not hold true for presses that are incapable of transferring quickly at high fill speeds. It also does not suggest that fill speeds should be increased beyond the point where shear-induced defects begin to occur.

In this particular study, the effect of viscosity change on process consistency was the most significant, although other perturbations may be more significant for different molds.

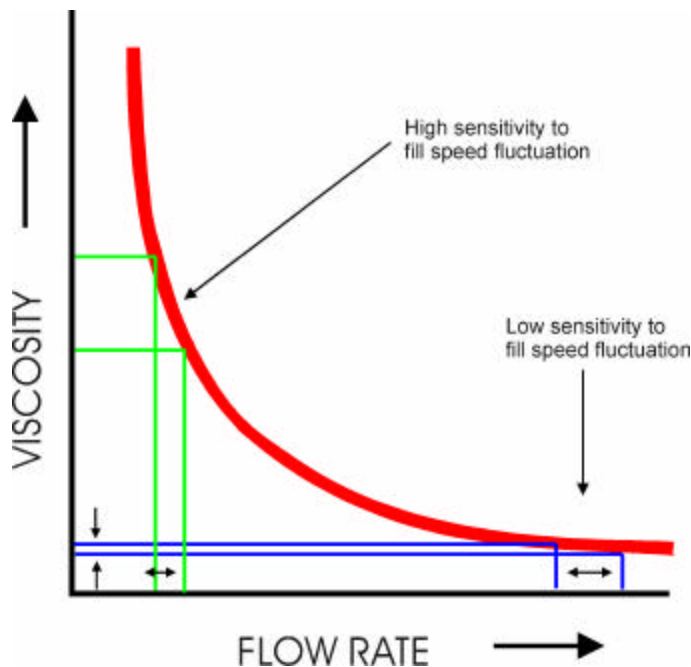


Figure 1 – Illustration of the Effect of Fill Speed Variation on Viscosity Consistency

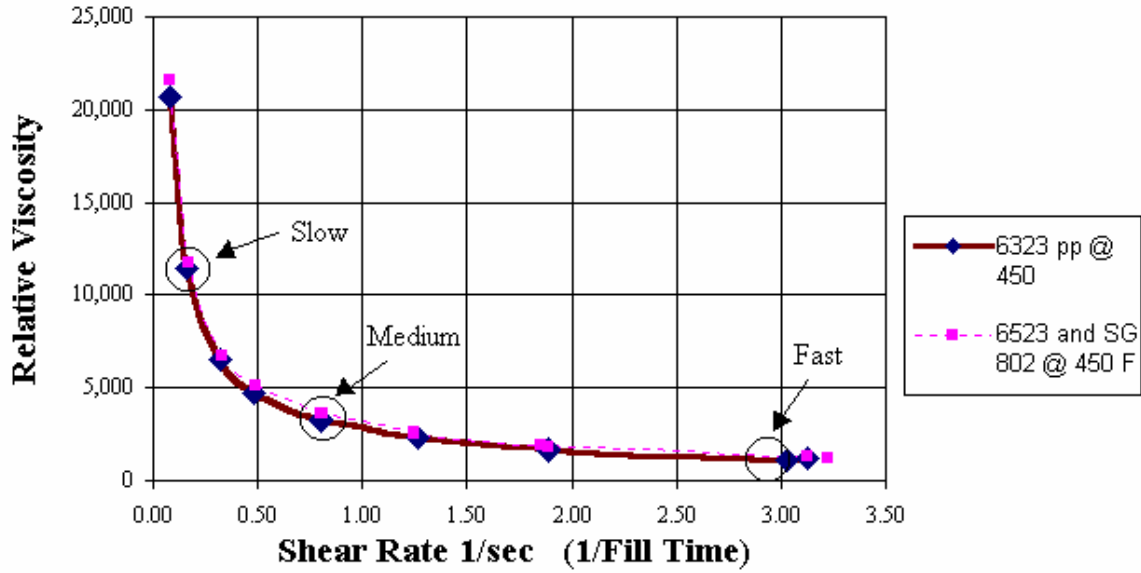


Figure 2: Relative Viscosity Profiles for Materials Used. Note Choice of Fill Speeds for this Study

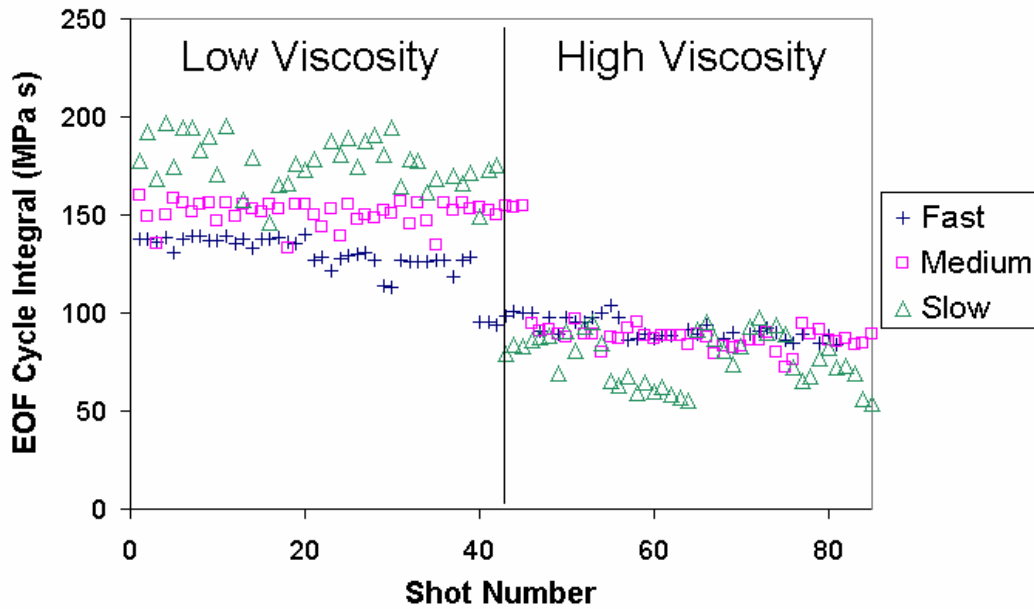


Figure 3 – End of Fill Cycle Integral Data for All Shots

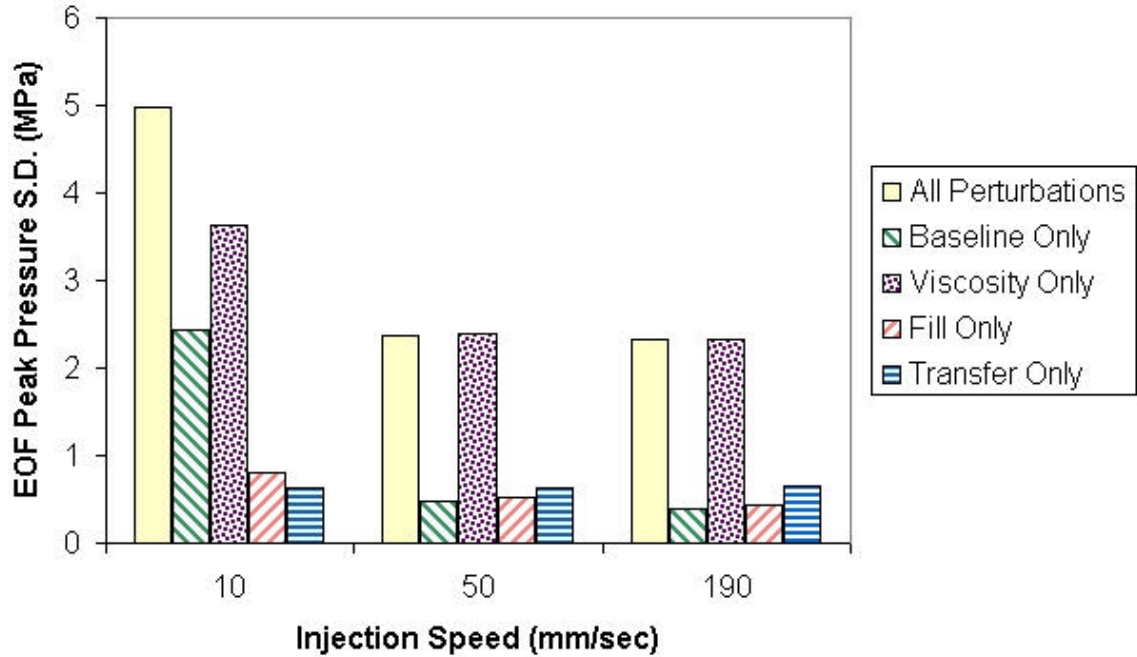


Figure 4 – Process Variation at Each Speed as Measured Using Peak End of Fill Cavity Pressure

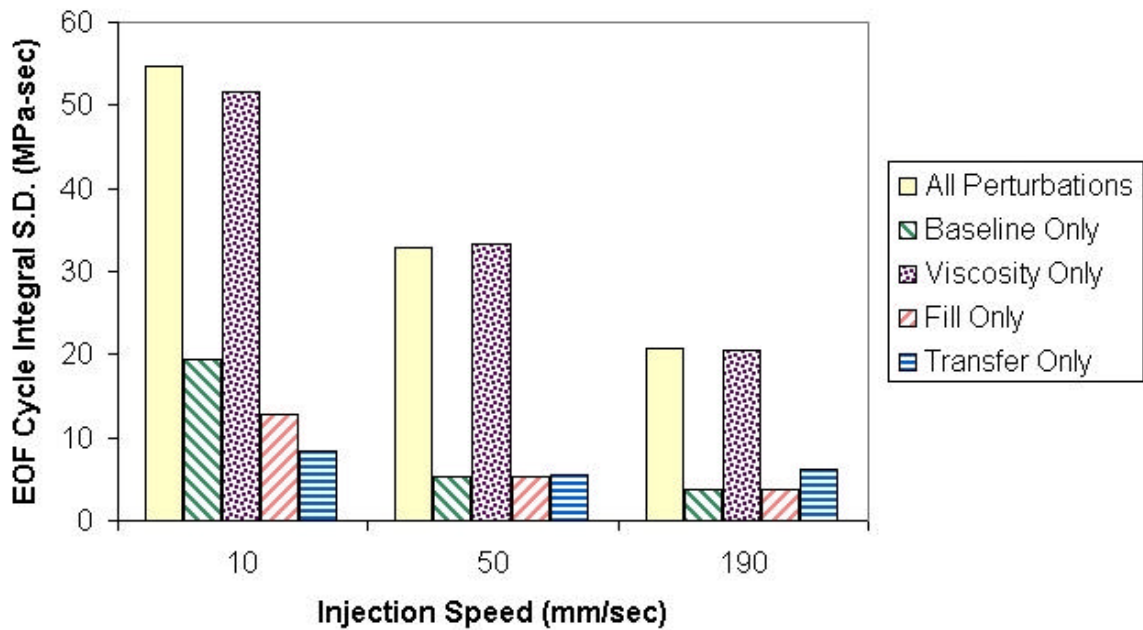


Figure 5 - Process Variation at Each Speed as Measured Using End of Fill Cycle Integral