NOVEL V/P TRANSFER ACTUATION METHOD AND INJECTION MOLDING STRATEGY AND THEIR COMPARISON TO TRADITIONAL METHODS

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Abstract

The use of one novel and three well-known injection strategies were investigated to determine the effect on variation in part weight for each when variation in material viscosity and check ring leakage were introduced to the process. In addition, a comparison was made of the use of traditional screw position, cavity pressure sensing, and a novel switch closed by the melt front to actuate v/p transfer with each of the processing strategies. Velocity to pressure transfer when the part was not quite full (2-stage, pack with second stage), after the part was packed with a fast velocity (2-stage, pack with first stage), and after the part was packed with a slow velocity (3-stage) were the well-known injection strategies evaluated. The novel strategy was a modified 3-stage where the v/p transfer was actuated after the first velocity (as in 2-stage, pack with second stage) and the pack velocity was set as the limit during the first profile of the second stage of injection. It was found that the modified 3-stage process reduced variation compared to traditional 3-stage and that the novel switch used to detect the flow front was the most consistent method to actuate v/p transfer.

Introduction

Two of the biggest sources of variation in injection-molded parts are plastic viscosity variation and injection screw check-ring leakage variation [1]. In addition to taking steps to minimize this variation, it is also important to set up processes so that they are as robust as possible to normal viscosity and check-ring or other type of non-return valve variation.

Ways that viscosity variation can be minimized include providing a consistent mix of colorants and other additives, consistent regrind, and consistent temperatures / thermal history as the plastic goes from pellet to molded part. Choosing an optimum injection velocity that will minimize variation in process viscosity when the incoming plastic has a slightly different starting viscosity is also important [2, 3]. Running the proper barrel temperatures and replacing check-rings and/or barrels when worn or damaged is important to minimize check-ring leakage variation. However, some leakage is inevitable when the screw starts to come forward during injection and, it has been found that, the amount of decompression after screw rotation has a large effect on check-ring leakage [1]. Different decompression settings will be used to cause different check ring leakage in this study.

One of the things that viscosity and/or check ring leakage variation can alter in the process is volume of plastic in the mold when transferring from fill to pack and from pack to hold. The set-up of the injection portion of the process is commonly done using scientific or Decoupled^{SM} molding techniques [2, 4, 5]. There are variations to these techniques that will be referred to as 2SP1 (2-stage, pack with first stage), 2SP2 (2-stage, pack with second stage), and 3S (3-stage) injection strategies in this paper. Each can be affected by a change in transfer from fill to pack or pack to hold. A modification to the 3-stage process, which is called MOD3S here, will be introduced in this paper.

For the 2SP1 or Decoupled^{SM} 1 process, the part is completely filled and the pack is started with the optimum velocity. The velocity to pressure transfer (V/P transfer) therefore occurs during pack. Variation in this transfer can lead to over-packed or flashed parts and/or under-packed parts or a change in velocity before the part is full.

The 2SP2 or Decoupled^{SM} 2 process is, from this author's observations, the method that is most utilized by those who are doing scientific or Decoupled^{SM} molding. With this method the part is filled with the optimum injection velocity until the flow front is just short of hitting the last place to fill (95 – 98% full) and that is where V/P transfer occurs. The remaining fill, as well as pack and hold are done with pressure control.

The 3S or Decoupled^{SM} 3 process is the same as the 2SP2 up to the point that the part is 95% full. At this point, the screw is slowed to typically about ten to twenty percent of the optimum velocity and the part is packed with velocity control. The V/P transfer occurs at the end of pack and hold is done with pressure control. Like 2SP1 the pack is done with a controlled velocity. 3S is used when the pack velocity needs to be lower than the fill velocity.

The novel MOD3S process is very similar to the 3S or Decoupled^{SM} 3 process. The difference is that V/P transfer on the machine occurs after the first velocity. Two profiles are then used for the "pressure" control, with the second profile set as it is for the 3S process. The first pressure profile is velocity-limited with the pressure set at maximum with the same slow velocity setting as the 3S process and, therefore, effectively becomes a second controlled velocity for a set amount of time. This method was developed to address the part variation issue when check ring shut-off varies that was discovered in a prior study [10]. A requirement of this strategy is that the molding machine controller has a maximum velocity setting for the second stage of injection.

The standard V/P transfer method is the use of the injection screw position. A common option on molding machines gives the user the ability to use an external signal for V/P transfer actuation. The conditioned signal provided by cavity pressure sensors are commonly used as the transfer method for the Decoupled[SM] molding techniques [4, 5] by transferrig when a set pressure is reached. Conditioned signals from surface temperature sensors can also be used and work by detecting the rapid rise in temperature when the melt reaches that position (edge detection). The V/P transfer can be delayed after the edge is detected. Pressure sensors can also be used for edge detection. Using sensors for edge detection is a Priamus patented technique [11].

The novel V/P transfer method used in this study is a patent pending switch (MeltSwitch™) that is placed either behind a moveable pin in the cavity or behind an ejector pin. This is similar to the edge detection method since, as the melt goes over the pin, the pin is pushed down approximately 0.15 mm and the switch is closed which provides a contact closure and actuates the V/P transfer (see Figure 2). In some cases, the switch is connected to a timer relay so that the V/P transfer can be delayed after the switch is closed. Unlike a sensor, the switch requires no signal conditioning to actuate V/P transfer.

Part weight is the only metric used in this study to detect variation. It has been shown to be an excellent tool for process analysis [6]. The ability to get very fast and reliable measurements is very advantageous when making many trials. It should be noted however that the weight does not always correlate well to part dimensions or other properties.

Most other studies [7, 8, 9] done on this topic have tended to focus only on very small viscosity variations or changes in process metrics (peak cavity pressure, pressure integrals, etc.) instead of an actual part characteristic. This study will investigate which transfer methods minimize variation in the V/P transfer part weight when viscosity and check ring leakage vary. Viscosity will be varied by using two different grades of material. Check ring leakage variation will be accomplished by using two different decompression strokes.

A similar study [10] showed that using edge detection for V/P transfer was superior or, at worse, equivalent to the other transfer methods for the 2SP1, 2SP2, & 3S process strategies. The goals of this paper are to confirm those results on another mold and to determine whether the hypothesis that the MOD3S process strategy using the switch for V/P transfer will be an improvement over 3S process strategy can be confirmed.

Materials & Equipment

Two polycarbonate resins were used for the experimental work. Both resins had a solid density of 1.20 g/cm^3 and a melt density of 1.03 g/cm^3. The melt indices (MI) for the resins were 24 and 5.5 dg/min (300 ºC, 1.2 kg). For all experiments, the 24 MI material was used as the low viscosity material and a 5 to 1 mix of the 24 MI to the 5.5 MI materials was used for the high viscosity material. This mix gave a material that was approximately ten percent higher in viscosity than the low viscosity material when molded at the injection velocity used in this study.

The molded part is shown in Figure 1 with gate location, cavity pressure sensor and switch locations as shown. The majority of the part is 2 mm thick with two thinner regions on each side of the runner that are 1.3 mm thick. The pressure sensor is a piezoelectric directly in the cavity. Switch 1 is directly in the cavity and switch 2 is behind an ejector pin.

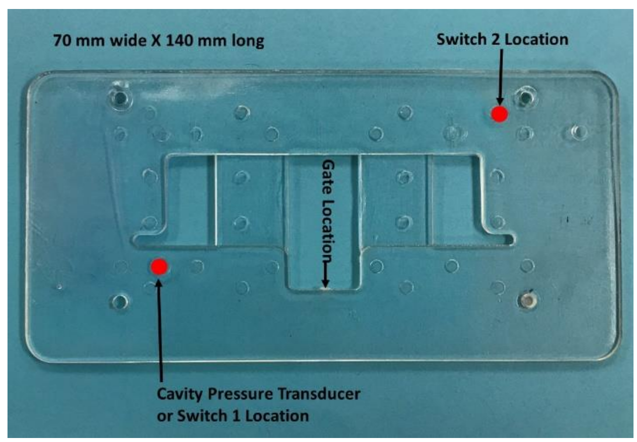
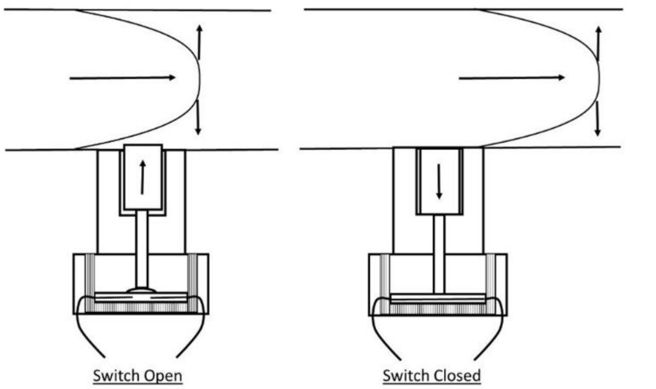


Figure 1. Molded part

The piezoelectric cavity pressure transducer was a standard 4 mm diameter direct type. Switch 1 was designed with geometry to be a drop-in replacement for pressure transducer and was changed out when needed. Figure 2 is a schematic showing how the switch works and the configuration used when put behind an ejector.

The parts were all molded in a 500 kN clamp injection molding machine with a 25 mm diameter screw and 44 cm^3 shot capacity. The machine had closed loop velocity and pressure control and the ability to accept an external signal for V/P transfer. The cavity pressure signal was read by an external data collection system which completed a circuit to the molding machine when used for V/P transfer. The data collection system also saved the cavity pressure curve for each cycle. The switch used for V/P transfer was hooked up to a timer relay which, after a delay, completed the circuit to the molding machine.

A digital scale with resolution to the nearest 0.001 gms was used to measure all the parts.



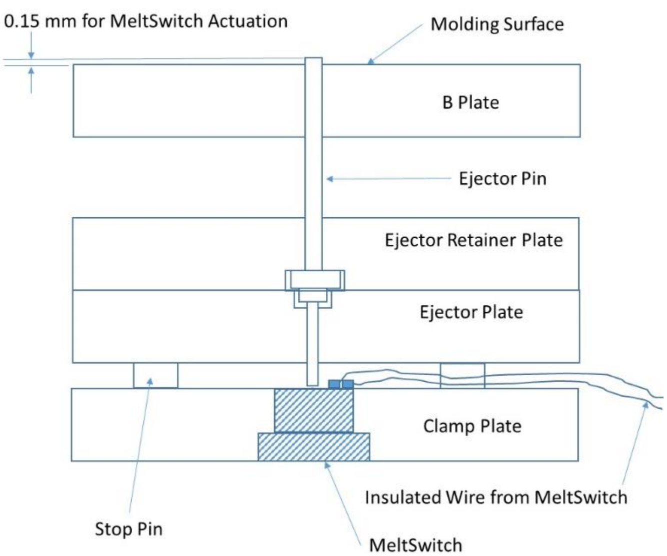


Figure 2. Schematic of switches. The top is a schematic of how Switch 1 works and the bottom shows the configuration for Switch 2 which is actuated when the melt goes over the ejector pin.

Experimental Procedure

The baseline process set points were first set up with the low viscosity material and 6.4 mm of decompression. Table 1 shows the constant process parameters that were used during the experiment. Before any parts or data were collected the process was given sufficient time to stabilize. The process ran in automatic for a minimum of 30 minutes when first started and until the mold temperature stabilized after occasional process interruptions. This was important to minimize any temperature or residence time effects on the part weight.

Table 1. Constant process settings.

Parameter	Setpoint
Barrel Temperatures (all zones)	316 °C (600 °F)
Mold Cooling Water Temperature	60 °C (140 °F)
Shot Size	61 mm (2.4 in)
Primary Injection Velocity	25 mm/s (1 in/sec)
Screw Speed	300 RPM
Back Pressure	5.5 MPa (800 psi)
Hold Pressure	0
Hold Time	5 sec
Cooling Timer	6 sec
Mold Open Time	About 5 seconds (actual)

The four run, full factorial DOE shown in Table 2 was run for every combination of injection strategy and V/P transfer option shown in Table 3. It should also be noted that the pack velocity (2nd controlled velocity) was set at 5.0 mm/sec (0.2 in/sec) for the 3S and MOD3S trials. For the MOD3S process, the 2nd velocity timer was 0.68 seconds.

Table 2. DOE set-up for all trials.

Run #	Material Viscosity	Decompression
1	Low	0
2	Low	6.4 mm (0.25 in)
3	High	0
4	High	6.4 mm (0.25 in)

Table 3. V/P set points for each injection strategy/transfer option run (Set-up with low viscosity material).

Method / Sensor	2SP1	2SP2	3S	MOD3S
Screw Position	7.6 mm (0.30 in)	11.4 mm (0.45 in)	7.6 mm (0.30 in)	11.4 mm (0.45 in)
Cavity Pressure	13.9 MPa (2020 psi)	8.8 MPa (1280 psi)	20.7 MPa (3000 psi)	8.8 MPa (1280 psi)
Switch 1 Timer Delay	NA	1.02 sec	1.70 sec	1.02 sec
Switch 2 Timer Delay	0 sec	NA	NA	NA

In Table 3, the boxes marked “NA” were not run because the other switch was used.

The time on the data acquisition system was noted as the parts were molded so that process curves and summary data could be obtained for results analysis. The 2SP2 trials were run first with ten parts being collected per run. For the subsequent 2SP1, 3S, and MOD3S trials, five parts were collected since less variation was observed due to the parts being packed (not short shots).

Results

The estimated effect of the viscosity change and the decompression change on the part weight was calculated for each transfer method / injection strategy combination. The effects as a percent of average at the high level of either the viscosity or decompression, along with 95% confidence intervals, are shown in Figures 3 – 10.

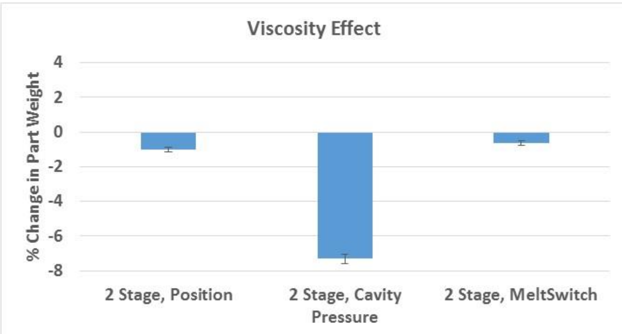


Figure 3. Viscosity effect with 2SP2

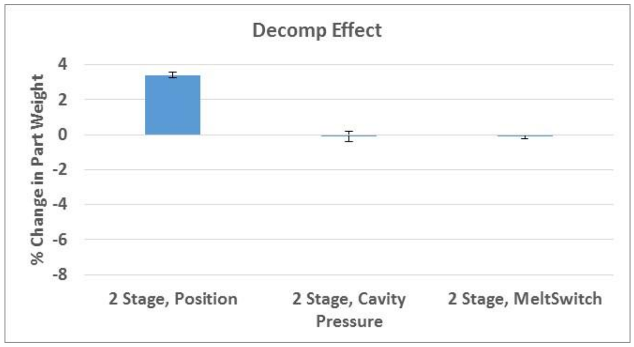


Figure 4. Decompression (check ring leakage) effect with 2SP2

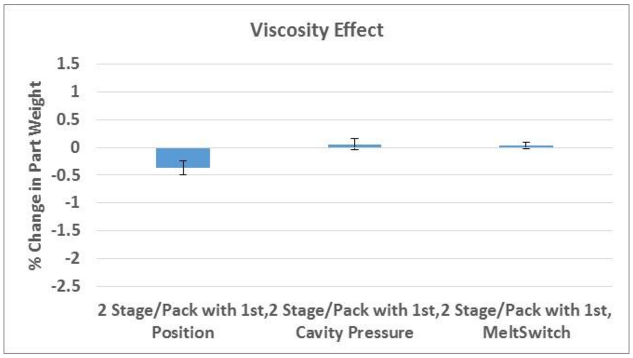


Figure 5. Viscosity effect with 2SP1

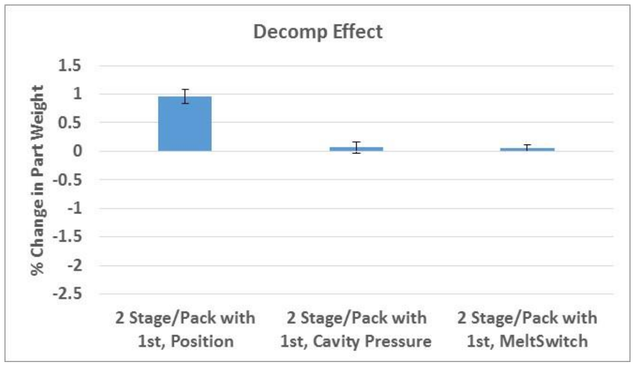


Figure 6. Decompression (check ring leakage) effect with 2SP1

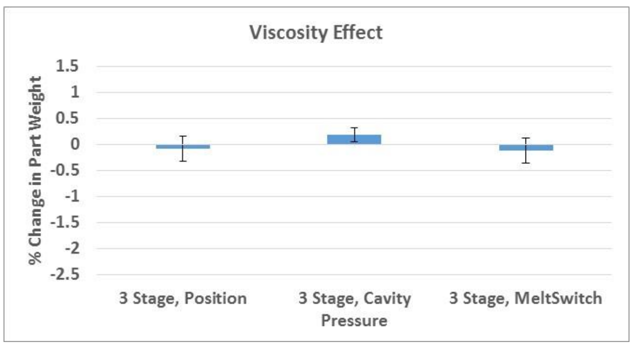


Figure 7. Viscosity effect with 3S

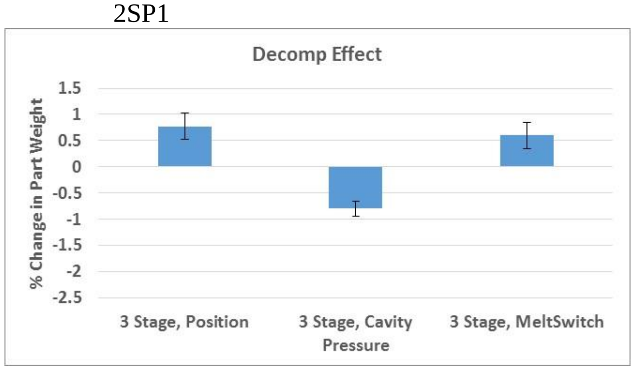


Figure 8. Decompression (check ring leakage) effect with 3S

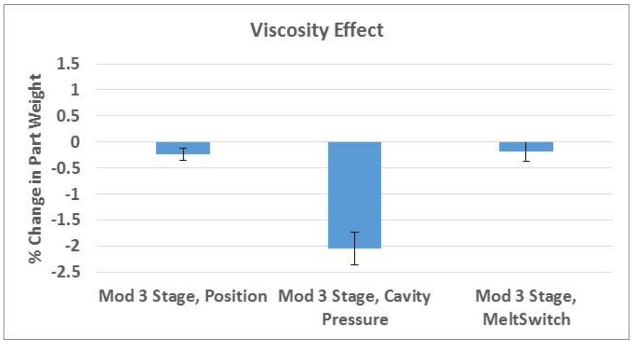


Figure 9. Viscosity effect with MOD3S

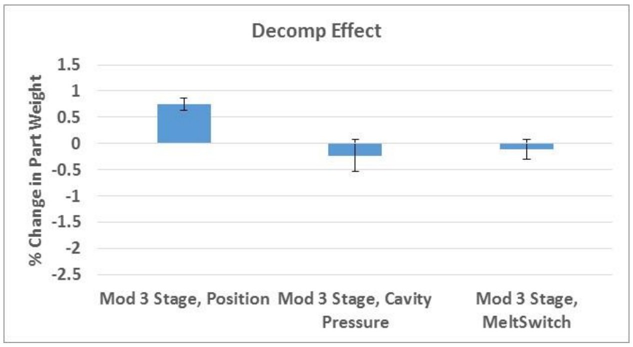


Figure 10. Decompression (check ring leakage) effect with MOD3S

Discussion of Results

When examining Figures 3 – 10, a bar that is above zero means that that V/P transfer method gave heavier parts at the high level of the factor, either the high viscosity or the 6.4 mm decompression. If the bar is below zero, the part weight was higher at the low level of the factor, either the low viscosity or when decompression was set at zero. The results for each processing strategy will be discussed as to which transfer methods would be better than the traditional position method. If the 95% confidence interval includes zero then the effect of that factor, either viscosity or decompression, is not statistically significant.

2SP1 – 2-Stage, Pack with First Stage

Figure 5 shows that Position V/P transfer was the only transfer method that was slightly affected by viscosity. The low viscosity parts weighed about 0.4% more than the high viscosity parts. Since the Cavity Pressure transfer setting of 13.9 MPa was above the red line shown in Figure 11, it was expected that viscosity would not affect the part weight for that method. The Switch transfer method also did not affect the part weight.

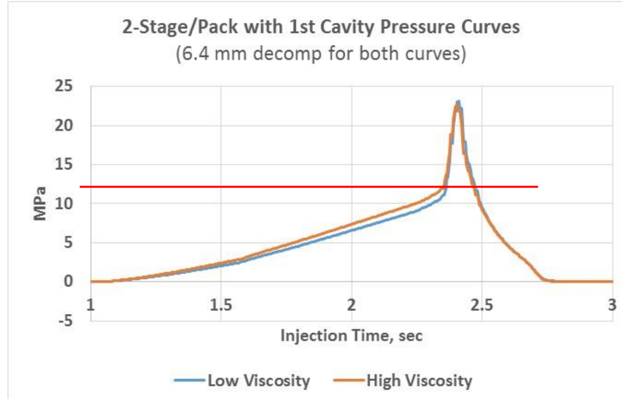


Figure 11. Cavity pressure curves for 2SP1

Figure 6 shows that the only transfer method that affected weight with a change in decompression was Position. The parts made with decompression weighed about 1 % more than those molded without decompression. This was expected since only one viscosity was used and the only difference was the check-ring leakage as the screw started to come forward. As long as there was still a cushion at the end of injection and the injection time was not limited, the other V/P methods could compensate and transfer at different times. This variation when using Position transfer is why cavity pressure or edge detection transfer is generally recommended for the 2SP1 injection strategy.

2SP2 – 2-Stage, Pack with Second Stage

For the 2SP2 injection strategy, as expected, using edge detection with the Switch V/P transfer was the method that performed best in reducing variation when considering both the effect of viscosity and decompression (check ring leakage). The Position V/P transfer method resulted in about a 3.5% difference in part weight with decompression variation (check ring leakage variation) and can be seen in the difference in the size of the parts at transfer in Figure 12. Figure 13 shows the difference in the size at transfer for the Cavity Pressure method with viscosity variation. The low viscosity part weighed over 7% more than the high viscosity part.

Using pressure to transfer when the parts are not full is a problem for the reasons discussed with 2SP1. If transfer occurs at a pressure before the curve reaches the red line in Figure 11, when the parts are not full, it can easily be seen that transfer will occur at different times for the two different viscosities and result in parts of different percents filled.

Figure12. Parts at transfer with a 2SP2 injection, with Position transfer, and low viscosity material, with and without decompression.

Figure13. Parts at transfer with a 2SP2 injection, with Cavity Pressure transfer, and 6.4 mm decompression, with low and high viscosity material.

3S, 3-Stage

It was found that for the 3S injection strategy that none of the transfer method weights were significantly affected by the viscosity variation (see Figure 7). Figure 8 shows that decompression (check ring leakage) variation had a small effect on part weight variation for each method.

The effect of decompression is due to the fact that the change from the 25 mm/sec to 5 mm/sec velocity is done by screw stroke in all cases. The parts were about as full as Figure 12 shows when the velocity changed occurred. As can be seen in Figure 14, with no decompression, this causes more of the part to be filled with the second, slower velocity and for the part to not be packed to as high of a pressure when transferring by Position or the Switch. The parts molded without decompression were about 0.8% and 0.6% lighter for the two methods, respectively. Figure 15 shows that, for Cavity Pressure V/P transfer, in addition to more fill with the slower velocity the parts are also packed longer until reaching the set pressure for the no decompression case. This causes the parts without decompression to weigh about 0.8% more than those with decompression when Cavity Pressure is used for transfer.

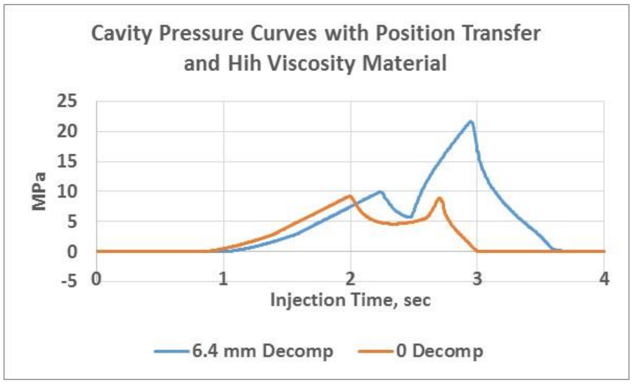


Figure 14. 3S process with Position transfer with and without decompression.

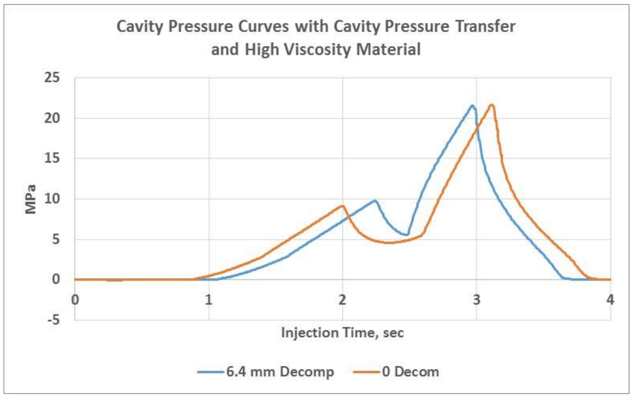


Figure 15. 3S process with Cavity Pressure transfer with and without decompression.

MOD3S, Modified 3-Stage

Figures 9 and 10 show that the hypothesis for this study was confirmed for this study. Using the MOD3S process strategy and the switch for V/P transfer is an improvement over the 3S process strategy when viscosity and decompression (check ring leakage) are varied. When using Switch V/P transfer, there was no significant variation in part weight when the viscosity or decompression (check ring leakage) varied.

Using Position V/P transfer gave the same results as for the 3S process strategy. This was expected since the change from the first to second velocity was still achieved using injection screw position.

Using Cavity Pressure V/P transfer resulted in about 2% lighter parts with the high viscosity material compared to the low viscosity material. The reasoning here is the same as for the 2SP2 process strategy as the cavity pressure transfer set point was reached sooner with the high viscosity material so the part was less full. As with the 2S process strategy, decompression (check ring leakage) variation had no effect when using Cavity Pressure transfer.

Conclusions

For the material, part geometry, and process set-up conditions used in this study, the following conclusions can be made.

1. For the 2SP2 and MOD3S process strategies, using Switch V/P transfer showed the least variation when the material viscosity and the decompression (check ring leakage) varied.
2. For the 2SP1 injection strategy, using Switch V/P transfer or Cavity Pressure V/P transfer showed the least variation when either the material viscosity or the decompression (check ring leakage) varied.
3. For the 2SP2 injection strategy, in-cavity pressure V/P transfer is not effective when viscosity varies.
4. For the 3S injection strategy, all of the transfer methods are sensitive to decompression (check ring leakage) variation.
5. Traditional Position V/P transfer had significant part weight variation for all four of the process strategies when at least one of the two, viscosity or decompression (check ring leakage), varied.
6. The MOD3S with Switch V/P transfer and the 2SP1 with either Switch or Cavity Pressure V/P transfer showed no significant part weight variation when either viscosity or decompression (check ring leakage) varied.

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References

1. M.R. Groleau and R.J. Groleau, *SPE-ANTEC Tech. Papers*, **46**, 729 (2000).
2. J.R. Wareham and J.D. Ratzlaff, *SPE-ANTEC Tech. Papers*, **45**, 335 (1999).
3. S. Mertes, C. Carlson, J. Bozzelli, M. Groleau, *SPE-ANTEC Tech. Papers*, **47**, 620 (2001).
4. Groleau, R.J., *Injection Molding & Process Control* (1995), RJG Associates, Traverse City, MI.
5. Sloan, J., *Injection Molding Magazine*, October (1997), 118.
6. J.J. Wenskus, *Journal of Injection Molding Technology*, **1**, 151 (1997).
7. B.G. Johnson, and G.A.Horsemanko, *SPE-ANTEC Tech. Papers*, **47**, 445 (2001).
8. A. Schubert, *SPE-ANTEC Tech. Papers*, **54**, 139 (2008).
9. D.O. Kazmer, S. Velusamy, S. Westerdale, and S. Johnston, *SPE-ANTEC Tech. Papers,* **54**, 337 (2008).
10. B. Johnson, "Determining Which In-Mold Sensors Should Be Used For V/P Transfer During Injection Molding For Three Different Injection Strategies", SPE-ANTEC® 2013- Chicago, IL, USA May, 2013. [On-Line], Available: www.4spe.org
11. Jurgen Frey, "Method of Filling the Cavity of a Tool." U.S. Patent 7,682,535, issued March 23, 2010.