EVALUATION OF PRESSURE REDUCTION FOR VARIOUS MATERIALS AT VARIOUS LENGTH TO THICKNESS RATIOS USING AN IMFLUX® CONSTANT PRESSURE PROCESS

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Abstract

This paper will show that an iMFLUX® constant pressure process can significantly reduce molding pressure requirements compared to conventional velocity controlled injection molding while molding a part with an equal length to thickness ratio. A significant pressure reduction is observed for all materials; regardless of material type or family. All comparisons in this paper are based on the maximum achievable flow length of a conventional velocity controlled process for each material.

Introduction

Conventional injection molding can create material flow length limitations by the way a standard fill velocity control to hold pressure control process is developed. When building an injection molding process, a screw velocity set point is selected to inject the material at a constant fill rate relative to the screw's position. This constant velocity set point is selected from a relative viscosity curve developed by injecting at various injection velocities and recording the resulting melt pressures and fill times and calculating apparent viscosities.

There is often a non-linear relationship between the speed of the screw and the speed of the plastic flow front, with increasing variability as the distance from the gate increases. The variability can further by compounded by any number of changes in geometry or surface area of the part. As the material is injected at a constant screw velocity the melt pressure will increase as the resistance to flow through the cavity increases. This constant climb in melt pressure will limit the process window with respect to length to thickness ratio (L/T) by driving the machine to operate close to its pressure limit or maximum alarm pressure limit.

The process then goes from a velocity controlled portion of the process to a pack and/or hold pressure controlled portion of the process in which an abrupt change in plastic flow front velocity often occurs. This transfer takes place as the part is anywhere between 90%-98% of the part being full. This can additionally limit the achievable flow length of a conventional injection molding process because any hesitation in the plastic flow front velocity this far away from the gate is sometimes hard to overcome or compensate for with a lower pack or hold pressure applied.

The constant pressure process can counter this phenomenon by accurately controlling the injection of the plastic into the mold cavity in a manner in which the melt pressure does not reach the upper pressure limits of the machine. The key to improving the L/T of a material is through dynamic injection velocity profiling that does not allow the flow front to hesitate. The constant pressure process alters the velocity of the screw to maintain a constant pressure set point, allowing the screw velocity and position to be non-linear in shape which eliminates max pressure alarms and screw hesitation [1].

Design of Experiment

A study was designed to investigate how much a constant pressure process could reduce the melt pressure required to matched flow lengths of the conventional molding process for 4 different materials.

The conventional process was set up for fill only velocity control. The velocity chosen was dictated by the pressure limitation of the machine, setting the velocity just under the threshold velocity that would cause a machine alarm for high pressure. No transfer or hold was used, similar to the method for determining a viscosity curve in scientific molding procedures. The fill times achieved for the conventional process were then matched by the constant pressure processes so that the interaction between process method and pressure reduction could be evaluated without adding a time variable. This procedure was then repeated for multiple data points between 25%-100% of the maximum L/T that could be achieved for the conventional velocity controlled process. This was done to generate at least 6 data points to improve curve fitment for the graphs that were generated.

The constant pressure process melt pressures and the conventional melt pressures that were required for the targeted flow lengths and flow times were recorded then for each material for each L/T value. After evaluating pressure reductions between constant pressure control and conventional velocity control at equal fill times, increasing the fill time was evaluated for both constant pressure and conventional processes for all 4 of the materials.

Adding more time to the conventional process by reducing injection velocity did not significantly improve the conventional flow length that could be achieved, nor did it provide a significant pressure reduction. However, adding extended time with the constant pressure process did further improve the pressure reduction due to the fact that the constant pressure process can continuously inject at a lower pressure without exhibiting a flow front hesitation.

Samples were made with a constant pressure process at 2 times (2X) and 3 times (3X) the original fill time for each of the 4 materials tested and the resulting melt pressures were recorded.

Materials

The study was performed on both semi-crystalline and amorphous materials using an Axxicon 2mm Spiral mold in a 150 Ton Fanuc Roboshot. Figure 1 below shows parts from both a constant pressure process and a conventional process.

Figure 1. Axxicon 2mm Spiral mold parts. [2]

The materials that were tested were an 11 MFI polycarbonate (PC), a 10 MFI general purpose polystyrene (GPPS), a 6 MFI high density polyethylene (HDPE) and a 20 MFI polypropylene (PP).

Results

Comparison of Melt Pressure for maximum L/T based on fastest achievable Conventional Fill Time with matching Constant Pressure Fill Time

Processing with a constant pressure process showed very positive results for PC. The highest L/T that could be achieved conventionally while running PC was 80 (160 mm flow length/2 mm thickness) before reaching a pressure limitation of 26000 psi on the Roboshot machine. For the same flow length and using the same fill time, a constant pressure process was able to achieve the same 80 L/T at a 47% reduction in pressure. The reduction in pressure increased as the L/T decreased with a maximum pressure reduction of 62% for a 32 L/T

For the GPPS trials that were performed, a 283 L/T was the highest that could be achieved with a conventional process before reaching the machine pressure limitation. The constant pressure process was able to achieve the same flow length over the same amount of time at a 26% reduction in pressure. The reduction in pressure increased as the L/T decreased with a maximum pressure reduction of 53% for a 79 L/T.

HDPE trials yielded a 37% pressure reduction for the constant pressure process for the maximum 157 L/T that could be achieved using a conventional process. The reduction in pressure increased as the L/T decreased with a maximum pressure reduction of 64% for a 44 L/T.

Trials for PP showed the greatest range of L/T for a conventional process, which was expected due to the higher MFI compared to the other materials that were tested. The highest L/T that could be achieved conventionally while running PP was 375 before reaching the pressure limitation of the machine. For the same flow length and using the same fill time, a constant pressure process was able to achieve the same 375 L/T at a 22% reduction in pressure. The reduction in pressure increased as the L/T decreased with a maximum pressure reduction of 57% for a 94 L/T.

For the first trials that were performed at equivalent fill times, Table 1 below shows the resulting melt pressures for each of the materials at each of the L/T values evaluated.

Table 1. Pressure Reduction at different L/T for PC, GPPS, PP and HDPE.

PC		GPPS	
Pressure Reduction (%)	Length / Thickness	Pressure Reduction (%)	Length / Thickness
62.24	32	53.82	79
55.78	40	39.36	126
48.50	60	35.24	157.5
47.67	68	29.43	236.5
45.97	72	27.55	267.5
46.94	80	26.33	283.5
PP		**HDPE**	
Pressure Reduction (%)	Length / Thickness	Pressure Reduction (%)	Length / Thickness
57.24	93.75	63.57	44
38.47	150	43.17	70
31.55	187.5	42.98	87.5
26.48	281.25	36.56	131.5
27.34	337.5	35.69	149
22.14	375	36.7	157.5

Figure 2 below shows best fit curves with corresponding R squared values from the data shown in Table 1.

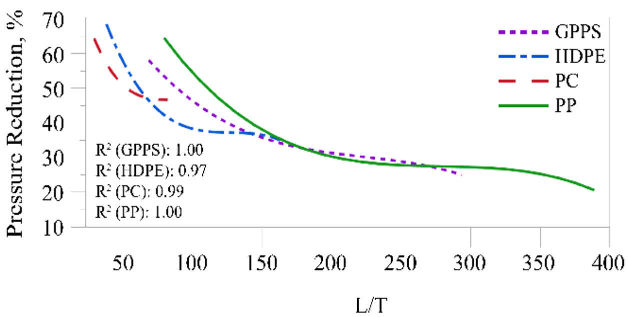

Figure 2. Constant Pressure Melt Pressure Percentage Reduction Compared to Conventional as a function of L/T (up to Maximum Achievable Flow Length of a Conventional Process).

Comparison of Melt Pressure for maximum L/T based on fastest achievable Conventional Fill Time with increased Constant Pressure Fill Time

The same 4 materials from Trial 1 were compared at the maximum flow length for each material. Constant pressure process fill times of double (2X) and triple (3X) the original fill time were run and compared to the fixed original fill time for the conventional process. This was done in order to simulate a typical constant pressure process with a longer "Step Time" or Fill Time.

Processing with a constant pressure process again showed very positive results for PC. Samples were made at an 80 L/T. As the constant pressure fill time increased from 1X to 2X, the resulting melt pressure reduction compared to a 1X conventional fill time went from 47% to 60%. Increasing the constant pressure fill time from 1X to 3X resulted in a melt pressure reduction range of 47% to 62%.

GPPS trials showed positive results as well. Samples were made at a 238 L/T. As the constant pressure fill time increased from 1X to 2X, the resulting melt pressure reduction compared to a 1X conventional fill time went from 26% to 40%. Increasing the fill time from 1X to 3X resulted in a melt pressure reduction range of 26% to 41%.

For the HDPE material, samples were made at a 157 L/T. As the constant pressure fill time increased from 1X to 2X, the resulting melt pressure reduction compared to a 1X conventional fill time went from 37% to 47%. Increasing the fill time of the constant pressure process from 1X to 3X resulted in a melt pressure reduction range of 37% to 51%.

For the PP material, samples were made at a 375 L/T. As the constant pressure fill time increased from 1X to 2X, the resulting melt pressure reduction compared to a 1X conventional fill time went from 22% to 34%. Increasing the fill time of the constant pressure process from 1X to 3X resulted in a melt pressure reduction range of 22% to 39%.

For the trials that were performed at extended constant pressure fill times, Table 2 below shows the resulting melt pressures for each of the materials at each of the maximum L/T value.

Table 2. Pressure Reduction at 1X, 2X and 3X Constant Pressure Fill Times for PC, GPPS, PP and HDPE.

PC		GPPS	
Pressure Reduction (%)	Fill Time (sec)	Pressure Reduction (%)	Fill Time (sec)
46.9	0.25	26.3	0.27
59.9	0.50	39.5	0.54
62.4	0.75	41.1	0.81
PP		**HDPE**	
Pressure Reduction (%)	Fill Time (sec)	Pressure Reduction (%)	Fill Time (sec)
22.1	0.33	36.7	0.28
34.4	0.66	46.6	0.56
38.9	0.99	51.1	0.84

Figure 3 below shows best fit curves with corresponding R squared values from the data shown in Table 2.

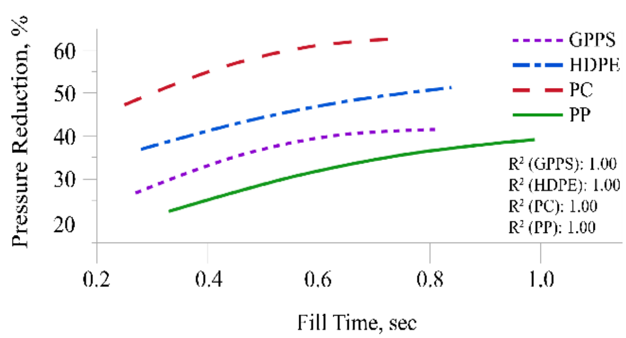

Figure 3. Constant Pressure Melt Pressure Percentage Reduction vs. Fill Time.

Discussion

The ability to run lower plastic melt pressures at various flow lengths can help to improve part design, material selection, mold design and machine flexibility. Compared to running a velocity controlled process that is on the threshold of the machine maximum pressure, process capability can also be improved by lowering the melt pressure required to fill the part.

Part Design Flexibility

The ability to run at significantly lower pressure enables part designers to take advantage of constant pressure capabilities by reducing wall thickness on parts [3] which can offer significant cost savings. A constant pressure process can also offer advantages for other flow filling challenges such as bosses or ribs, especially ones that are located further away from the gate of the part.

Mold Design Flexibility

Reducing injection pressure allows for lower machine tonnage which can increase possible cavitation for an existing machine platform. In addition to this, due to the increased L/T that can be achieved using a constant pressure process, fewer gates can be used in cases where multiple gates or drops are needed to fill a part.

Machine Flexibility

As mentioned before, processing with a constant pressure process allows for the ability to increase the cavitation for an existing machine platform. Alternatively, if machine selection is possible for a particular application with a specific cavitation in mind, the type of press that can be utilized can be minimized to improve energy efficiency or reduce overall capital cost. The tonnage of the machine for the same conventionally filled part can be reduced, for example. In other circumstances, an application that requires a higher pressure injection unit option for a particular machine can be eliminated.

Process Capability

Because a constant pressure process has the ability to run higher L/T parts without reaching the upper pressure limit of the machine, a much higher Process Capability (Cpk, Ppk) can be achieved on higher L/T parts due to the fact that there is not a control limitation. Conventional injection molding is not accurate or repeatable if a pressure limitation is present during the velocity controlled portion of the process since it reverts to open-loop control while trying to control velocity in a pressure limited environment.

Conclusions

For both amorphous and crystalline materials, the constant pressure process significantly reduced the melt pressure required to achieve equal L/T as a conventional process . For each of the different melt flow indexes tested, with a range of 6 MFI to 20 MFI, the constant pressure process again significantly reduced the melt pressure required to achieve equal L/T. For each of the fill times that were sampled, the constant pressure process further reduced the melt pressure required to achieve equal L/T.

References

1. iMFLUX (2020) 'Education - Plastic Show Demonstrations - 2020 Plastec West Show.' Available at https://www.youtube.com/watch?v=oYT_WkWcYEw&list=PLburU8BvtXKq2xLf6iAV5Cffs3-Vumxjc [Verified 19 December 2020]
2. Axxicon (2020) 'Shaping Your Ideas - Axxicon Design - Insert Spiral Flow (2mm).' Available at https://catalogus.axxicon.com/products-page/aim/ [Verified 19 December 2020]
3. SPE (2020) 'Webinar Video and Presentation - iMFLUX's Novel Low, Constant Pressure Molding Technology - June 17, 2020.' Available at https://www.4spe.org/i4a/pages/index.cfm?pageid=5707 [Verified 19 December 2020]