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발포 성형 공정에 따른 사출 성형품 무게에 관한 실험적 연구

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Experimental study on injection molding parts weight according to foam molding process

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Abstract: Speaking in general terms the form injection process can be described as a new process-variant of already known structural foam molding technology which roots go back to the early sixties. The most limiting factors of already know foaming processes are large cell size and the lack of uniformity of these cells as well and the inability to foam all kinds of plastic materials. In this paper, Process Study on weight change in injection rate during foaming. Experimental conditions were set as the injection speed 50,150,300 and 450 mm/s. The experiments PA, PA+GF, PP, was confirmed that the weight increase to PP+TA.

Key words: form injection molding machine, injection speed, process, wight.

1. Introduction

Speaking in general terms the MuCell process can be described as a new process-variant of already known structural foam molding technology[1-3] (using chemical or physical blowing agents) which roots go back to the early sixties. The most limiting factors of already know foaming processes are large cell size and the lack of uniformity of these cells as well and the inability to foam all kinds of plastic materials.

The main advantages of structural foam molding is the ability to produce lightweight parts (for material saving reasons) and/or parts with increased stiffness compared on a weight basis (better weight-to-stiffness ratio) as a solid molded part. E.G. if increasing the wall thickness by 25% the rigidity/flexural strength can be more than doubled at the same weight of the part. For better understanding the following equation should show the relationship between wall thickness & higher stiffness. The MuCell process uses high cell nucleation rates within the foaming material to create foams with small, evenly distributed and uniformly sized cells (generally 10~150 micron diameter average cell size) To achieve these high nucleation rates, homogenous nucleation is required, which is driven by large thermodynamic instability. This instability is achieved first by dissolving high concentrations of blowing agent into the polymer at high pressure and temperature to create a single phase solution followed by lowering the pressure below the saturation pressure (pressure drop during injection). Atmospheric gases, such as carbon dioxide (CO_2) or nitrogen (N_2), which are less expensive than other blowing agents, can be

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used as blowing agents to create this fine cell structure.

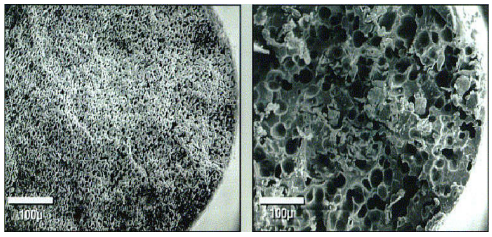

Fig. 1 The scanning electron microscope illustrates the uniform cell structure with the MuCell process (left) compared with conventional foaming technology using chemical blowing agents (right).

2. Experimental Procedure

Special designed 28:1 L/D ratio screw and barrel based on a barrier plasticizing section and a subsequent mixing section. Barrel with gas injectors(2-3 depending on screw stroke) monitored by pressure transducer with air-cooled band heaters in the front section and rupture disk as a safety feature. Including hydraulic shut-off nozzle with monitored end switches. Stand alone gas delivery system for the supercritical fluid (SCF) with closed loop weight control system to ensure precise metering of the SCF according to the percentage needed and the machine mounted interface kit. Hydraulic and software modifications to enable to maintain the necessary MPP pressure to the melt throughout the complete cycle. Additionally, enhanced safety features controlled by the MuCell software Accumulator for fast injection is highly recommended to ensure that there are no process limitations through the impossibility of having not enough injection speed

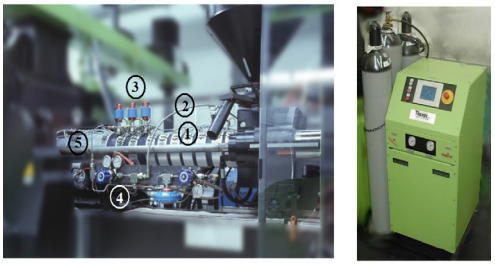

Fig. 2 Experimental set-up for form molding

available. The accumulator is standard feature in the MuCell package but under certain circumstances it is possible to produce suitable parts without it. This decision should not be made without a prior run trial to determine whether an accumulator is needed or not.

3. Consideration

Most outstanding advantage of the MuCell process is not to be limited to any plastic materials. It is possible to foam all plastic materials available for injection molding today. See enclosed material table to checkout the feasibility of selected material with the MuCell process. Material Savings is Due to the density reduction of the material, weight savings between 10~30% can be expected, depending on material and part design (wall thickness) There is no linear decrease in the mechanical properties to the weight savings achieved. 25% weight reduced parts were produced with only 7% loss of E-modulus compared to solid molded parts. Viscosity Reduction is The expanding gas during the filling reduces the viscosity of the material. This reduction leads to lower filling pressure, which is resulting in lower clamp force requirement to produce a part. Viscosity reduction is dependent on blowing agent used and processing conditions and can be 30% or more Lower Temperatures is The melt viscosity reduction gives the potential to process the material at a lower temperature without influencing the flow ability compared to a solid molded part. Less Warpage is Due to “internal hold pressure” accomplished by the expanding gas after injection and during cooling time. There is no hold pressure necessary for compensating the density change during the cooling. Cycle Time Reduction is all the above mentioned advantages can result in a cycle time reduction for the part being produced with MuCell. Less material will result in less heat needed to be chilled. Additionally, MuCell parts will be run with a holding pressure of 0.1sec. Which also reduces overall cycle time. Please note is Cells throughout the part work like an isolation which, in some cases can lead to longer cooling time, depending on cell size. Thin Walled Parts is The MuCell process even allows to foam thin wall parts with wall thicknesses down to 0.5

mm. This feature widely expands the field of possible applications for structural foamed parts. In conventional foaming this wall thicknesses would be the eliminating factor for the production of parts with such design. Gas Counter Pressure Molding: The gas counter pressure process uses a nitrogen pre-loaded mold. This gas counter pressure restricts the foaming process during the filling. Usually this pressure is set in a range about 30 bar (480 psi) The advantage of this process is the ability to produce MuCell foamed parts, with quite good surface qualities.

Depending which process advantage should be achieved there are several very influencing process parameters involved before getting the goal.

There are several influencing process parameters when running MuCell. Injection Speed, Gas Flow Rate, Melt Pressurization Pressure, Melt Temperature, Mold Temperature The two most influencing process parameters to keep in mind when running MuCell are injection speed and gas flow rate. The most-likely major influencing process parameter is injection speed. Injection speed has a huge influence on the number of cells resulting in smaller cell size and more weight savings.

It is the driving force for nucleation. There is also influence to cell number/cell size from gas percentage and melt pressurization pressure but not that influencing than injection speed. See pictures on the next page how cell structure improves by injecting plastic at higher speeds. That is the reason why an accumulator is highly recommended as a standard feature on MuCell machines. The left graph shows the basic relationship between injection speed, gas flow rates and weight saving. This graph is for basic understanding only. Due to the fact that during this trial also different mold temperatures were used the 0.75 GFR trial shows best the influence of the injection speed for weight saving. It can be seen that the rate of increase in weight saving drops down a little bit when injection speed is increased from 225 mm/s to 400 mm/s. One more time should be mentioned that an accumulator gives all possibilities to run the process optimized with respect to weight saving. Injection speed is also related to surface appearance of the part (the higher injection speed the more swirl effects can be detected) and the skin thickness formed. The following table shows the influence of injection speed to the maximum weight savings achieved during this experiment.

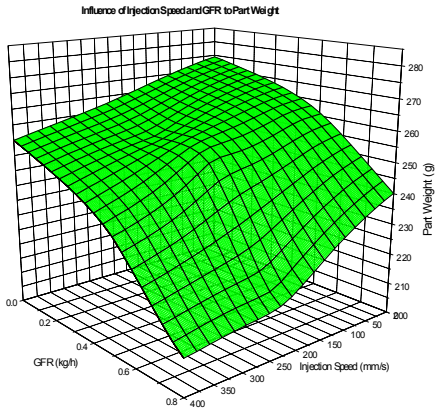

Fig. 3 Influence of Injection Speed and GFR to Part Weight

Gas flow rate is important because it gives the as % in the plastic part. Gas flow rate varies from material to material and gas used. As a simple guideline given can be stated that the more gas added to the material the more weight saving and the lower the viscosity can be gained.

If the gas flow rate setting is too high major problems may occur like screw stalling (if MPP is set too low or injector open time is too long), and uneven recovery time, which can lead to a machine error and production shut down. As shown in the graph below even small amounts of gas will result in a dramatically reduced melt viscosity (resulting in less pressure needed and lower clamping force requirement)

The reason for is that the gas occupies the interstitial sites between the molecules, which increases the distance between the polymeric molecules chains and they can easier move relative to each other. There is different viscosity reduction ability between carbon dioxide and nitrogen. Out of many trials done so far it has been worked out that roughly 3 times more carbon dioxide (on a weight basis) can be dissolved in a polymer that nitrogen.

It is well known that CO_2 has different solubility parameters and diffusion rates when compared to

Nitrogen. In most materials CO_2 diffuses through the polymer at rates of almost 20% faster than N_2 and the solubility level of CO_2 is (as mentioned above) much higher.

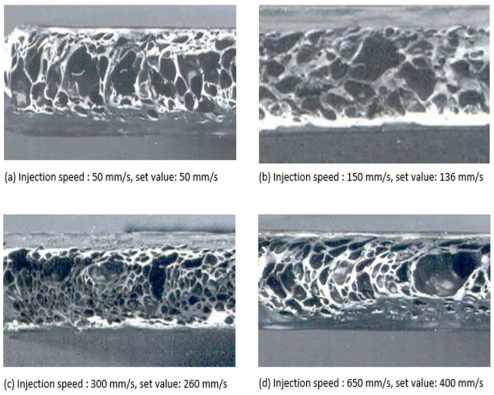

Fig. 4 Injection molded according to injection speed

The overall concentration is dependent on system temperature, pressure and solubility parameters of the used materials (see graphic as an example of the solubility of CO_2 in PP)

It is shows that at colder melt temperature more gas can be dissolved in the polymer, but also higher MPP leads to higher gas percentage.

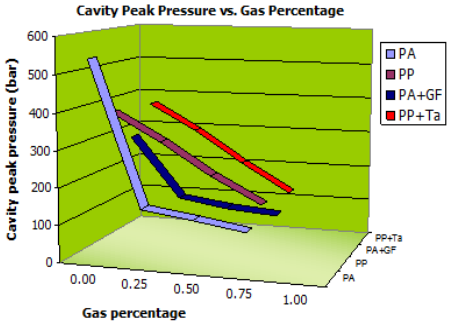

Fig. 5 Gas flow rate(cavity peak and gas percentage)

To answer the question what's the performance difference in micro-cellular foaming between CO_2 and N_2 an experimental procedure has been repeated on polypropylene using various levels of N_2 and CO_2 investigating the performance based on cellular structure, weight reduction and viscosity of the polymer/SCF system. See table below with the resulting numbers. N_2 tends to provide for smaller cell sizes throughout the part as CO_2 tends to provide for larger reduction in viscosity as measured by peak hydraulic injection pressure. No major differences in weight reduction were seen during this procedure. This experiment proved the trends that also have been seen during the real part applications tested so far.

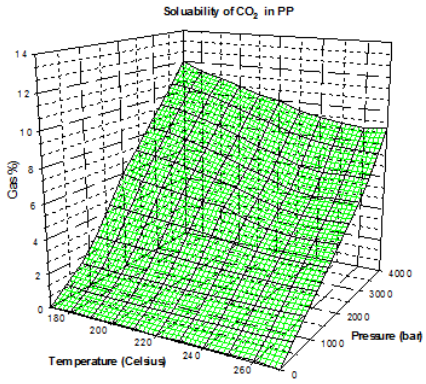

Fig. 6 Carbon dioxide and nitrogen

MPP Pressure (Melt Pressurization pressure) & Melt Temperature is MPP pressure setting is needed to keep the gas in solution within the melt to avoid to plastic to foam inside the barrel. The higher the pressure the more gas can be dissolved into the polymer (compare with 3D-graphics above chapter) which will more-likely result in higher weight savings, better cell structure and high viscosity reduction (less clamping force needed) Melt temperature as well is influencing the maximum possible amount of gas that can be dissolved in the material. The lower the melt temperature the more gas can be added. The most important fact to consider about when intending to increase the MPP pressure is that the higher back pressure is influencing the plasticizing capacity of the screw, due to the fact that barrier-typed screws react very sensitive to back pressure. If the MPP is increased by higher numbers the recovery time exceeds dramatically.

Melt Temperature is Melt temperature as well influences the process in certain ways. It is a kind of tricky adjustment to find a setting that fits between the lowest temperature possible (for cycle time) and best flow properties (for most clamp force reduction).

Mold Temperature is Mold temperature influences

the outer layer thickness of the molded part. The colder the mold the thicker the first layer, consequently the weight saving is reduced due to the fact that less volume is available for foaming. But in general the influence of the mold temperature is a minor one, it is of higher interest in special MuCell applications like reverse compression molding where the influence is higher because here it is a directly influencing process parameter when compression delay is used.

4. Conclusion

1) That is the reason why an accumulator is highly recommended as a standard feature on MuCell machines. The left graph shows the basic relationship between injection speed, gas flow rates and weight saving. This graph is for basic understanding only. Due to the fact that during this trial also different mold temperatures were used the 0.75 GFR trial shows best the influence of the injection speed for weight saving. It can be seen that the rate of increase in weight saving drops down a little bit when injection speed is increased from 225 mm/s to 400 mm/s. One more time should be mentioned that an accumulator gives all possibilities to run the process optimized with respect to weight saving.

2) Injection speed is also related to surface appearance of the part (the higher injection speed the more swirl effects can be detected) and the skin thickness formed. The following table shows the influence of injection speed to the maximum weight savings achieved during this experiment.

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