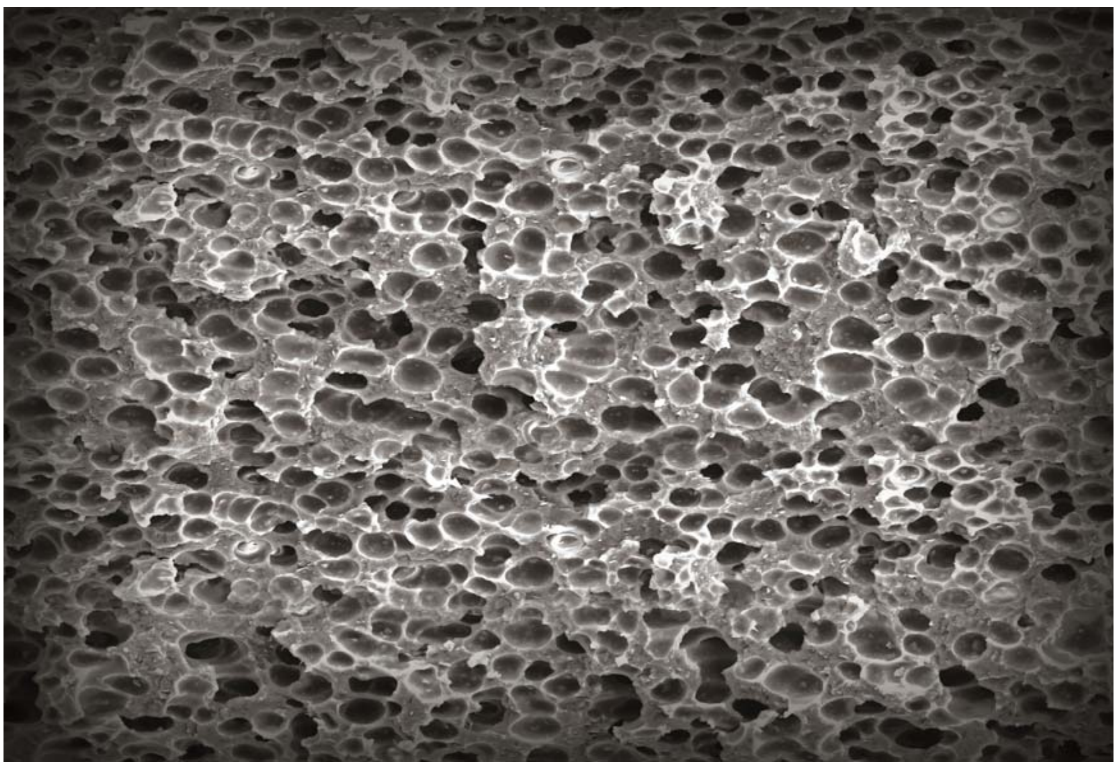
A GUIDE TO THE MUCELL® MICROCELLULAR FOAM INJECTION MOLDING PROCESS – T SERIES



Fundamentals, Set-up, Optimization & Troubleshooting

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Introduction

The foundations of this useful process technology can be traced back to Dr. Nam Suh's work at the Massachusetts Institute of Technology (MIT). In the 1980's, Dr. Suh and his students established the fundamental principles regarding the formation of microcellular structures in plastic parts. In 1995, Trexel Inc. obtained an exclusive license to the MIT technology and continued the development and commercialization of microcellular foamed plastics parts produced by extrusion, blow molding and injection molding. Trexel has since exited the extrusion and extrusion blow molding markets and is not focused only on injection molding and automotive blow molding.

This processing guide will cover the technical fundamentals, optimization and troubleshooting of MuCell microcellular foam technology as it relates to injection molding and the Trexel T-Series SCF System.

Microcellular Molding Fundamentals

To create a microcellular structure in injection molded parts, the MuCell process relies on the homogeneous cell nucleation that occurs when a single-phase solution of polymer and supercritical fluid (SCF) passes through the injection gate into the mold cavity. The pressure drop as the solution enters the mold causes the SCF to come out of solution creating cell nuclei. The cells then grow until the material fills the mold, the expansion capabilities of the SCF are expended, or the flow front freezes. The process runs on molding machines that have been modified to allow the metering, delivery and mixing of the SCF into the polymer to create the single phase solution.

The creation of the single-phase solution, in which the SCF is fully dissolved and uniformly dispersed in the molten polymer, takes place inside the injection barrel under carefully controlled process conditions: The SCF must be accurately mass flow metered into the polymer for a fixed amount of time. And during that dosing period, the right conditions of temperature, pressure and shear must be established within the barrel. Back-pressure, screw-speed and barrel-temperature control, as well as Trexel's patented restriction element mixing screw and SCF Delivery System, all play a role in establishing the process conditions that create the single-phase solution.

The importance of creating and maintaining a single-phase solution can't be overstated. *In fact, all process optimization and troubleshooting activities start with confirmation that the SCF and polymer have indeed come together in a single-phase solution.*

Once the single phase solution has been created, a MuCell-capable molding machine maintains it in a pressurized state until the start of injection. The machine does so through the combined efforts of a shutoff nozzle and screw position control. The shutoff nozzle prevents depressurization and premature foaming into the mold. Either active or passive screw position control prevents depressurization through the backward movement of the screw. During active screw position control, the position of the screw is continuously monitored, and the pressure applied to the back of the screw is adjusted to maintain a position setpoint or a constant pressure is held on the back of the screw. This technique is most common on OEM molding machines built to support the MuCell process. In passive position control, the oil used to regulate back pressure is prevented from draining to its tank at the end of screw recovery. This residual oil keeps the screw from moving backward due to the pressure of the single phase solution. Passive position control is used for MuCell Machine Upgrades (MMUs) and on some OEM machines.

Proper mold design also helps maintain the single-phase solution. Molds with a hot runner system need valve gates to prevent material drooling from the nozzles on mold open. Molds in which the machine nozzle breaks contact with the sprue bushing during normal operation–such as stack and tandem molds–require a shutoff on the sprue bushing. Otherwise, the pressure from the hot runner will be relieved through the sprue bushing.

Microcellular Foam Essentials

MIT researchers established three conditions that must occur for microcellular foams to form:

- **Single-phase solution**. A supercritical fluid must be uniformly and completely dissolved into the plastic.
- **Pressure drop**. Cell density, or the number of cell created per unit volume, depends on the SCF level and the rate of pressure drop.
- **Controlled cell growth.**

Types of Supercritical Fluids

The MuCell molding process relies on either nitrogen or carbon dioxide as the foaming agent. Each foaming agent has its place, depending on the application objectives.

Nitrogen is by far the most commonly used of the two. As the more aggressive foaming agent, it provides a greater weight reduction and a finer cell structure at a much lower weight percentage than carbon dioxide. In fact, nitrogen levels will typically be at least 75 percent lower than the carbon dioxide level required to achieve comparable parts. Carbon dioxide, however, is the preferred foaming agent in two situations: when viscosity reduction is the primary processing goal or when the application can't tolerate nitrogen's more aggressive foaming action.

Differences in the effectiveness of two foaming agents stem from their behavior in the polymer melt. Carbon dioxide, which becomes an SCF fluid at 31.1 C and 72.2 bar, is 4 to 5 times more soluble in polymers than nitrogen, which becomes a supercritical fluid at -147 C and 34 bar. For example, the saturation point in an unfilled polymer is about 1.5 to 2 percent by weight of nitrogen, depending on temperature and pressure conditions, while the saturation level of carbon dioxide is closer to 8 percent by weight. Carbon dioxide also exhibits a greater mobility in the polymer, allowing it to migrate further into existing bubbles than nitrogen. From the perspective of cell nucleation, greater solubility and mobility means fewer cells will be nucleated, and those that do nucleate will tend to be larger.

Solubility, however, becomes an advantage when the goal is viscosity reduction. An SCF dissolved in a polymer acts as a plasticizing agent, reducing the viscosity of the polymer. Because viscosity reduction is partly a function of the amount of SCF added to the polymer and because carbon dioxide has a higher solubility limit than nitrogen, the ability to reduce viscosity with carbon dioxide is greater.

Carbon dioxide is also preferred when the amount of nitrogen needed to produce a part is so low that it is not possible to consistently process parts. Given that carbon dioxide is a much less aggressive foaming agent, there are times where it is easier to run low levels of carbon dioxide, 0.15 or 0.2 percent, as compared to very low levels of nitrogen, less than 0.05 percent. This occurs primarily with soft materials and parts with thick cross sections. It some instances, low levels of carbon dioxide can be added to existing solid molded parts without any or with only minor changes in that part's surface appearance.

Material Effects

In general, injection molding materials can be categorized as amorphous and semi-crystalline and, within these two broad polymer families, there are filled and unfilled materials. The MuCell processing characteristics of the materials within each family tend to be similar, though there may be slight variations between individual grades. For example, unfilled amorphous materials tend to have similar processing characteristics. Glass-filled semi-crystalline materials likewise share their own set of processing characteristics. Here's an overview of what to expect within the most common polymer families:

- **Olefin semi-crystalline materials.** Unfilled polyolefins, such as HDPE or polypropylene, typically require higher nitrogen levels than most other materials need to achieve a good cell structure (see Table on page 20). As a rule of thumb, expect that the typical nitrogen levels for unfilled HDPE or unfilled polypropylene will be at least 0.6 percent. Levels as high as 1 percent are not uncommon. Unfilled polyolefins are also more likely to have cell structure variation from the gate to the end-of-fill. This variation will be aggravated when the wall thickness exceeds 2.0 mm (0.08 inches). As with all materials, the addition of fillers improves the "cell creation efficiency" of the SCF. Polypropylene commonly takes talc and calcium carbonate fillers. As talc levels approach 20 percent or more, the typical nitrogen level will be 0.4 to 0.6 percent. With a more efficient nucleating agent like glass filler, the typical nitrogen level can be decreased to 0.25 to 0.4% percent.

- **Semi-crystalline engineering materials.** Like polyolefins, unfilled engineering engineering polymers also tend to show cell structure variation from gate to end of flow. They also require relatively high nitrogen levels of 0.5 to 0.7 percent in order to achieve good cell structure. Adding 20 percent or more of glass fiber will allow the nitrogen level to be dropped to a range of 0.15 to 0.3 percent. Other filler types, such as mineral, will also act as a nucleating agent and allow for good cell structures at lower SCF levels, though mineral filler will also limit weight reduction potential. The presence of impact modifiers in materials such as toughened PA will necessitate higher SCF levels. One unique concern with unfilled POM is shear induced crystallization. This can cause the formation of voids in the molded part even when the SCF is in solution. This condition is the result of high shear through the gate and can typically be eliminated by changes to injection speed or gate size. It has also been seen that the typical nitrogen level for an unfilled POM is 0.15% to 0.2%.
- **Amorphous materials.** These resins included polystyrene, polycarbonate, acrylic and SAN, which do not contain an impact modifier, as well as ABS, HIPS and impact modified PC, which do contain an impact modifier. Unfilled amorphous resins will almost always require lower nitrogen levels than unfilled semi-crystalline resins although the presence of impact modifiers increases the SCF requirement to some degree. For those materials which do not contain an impact modifier, nitrogen levels will be about 0.2 to 0.4 percent. These materials typically achieve excellent cell structure at relatively low levels of supercritical fluid. Cell structure will be essentially uniform from gate to end of fill. However, these materials will have a MuCell Process Pressure (MPP) setting of as much as 207 bar (3000 psi). Adding an impact modifier has the effect of tending to increase cell size at a given SCF level. In order to achieve a cell structure that is microcellular or close to microcellular, nitrogen levels typically need to be closer to 0.3 to 0.6 percent with an increase in MPP up to 241 bar ((3500 psi). In amorphous materials, the addition of as little as 10 percent glass fibers will allow nitrogen level to be cut in half while still maintaining a microcellular structure.
- **Thermoplastic Elastomers (TPEs).** The TPE family includes a variety of soft, flexible thermoplastics. These materials have a wide variety of chemistries, including polyolefin based (TPO and TPV), polyester based, polyurethane based (TPU), styrene block copolymers (SBS and SEBS) and more. In general, amorphous TPEs tend to offer superior cell structure and higher weight reductions than semi-crystalline based TPEs. Regardless of their chemistry, all of these soft elastomers are susceptible to "post blow," which occurs when excessive internal cell pressure cause the part to expand after the mold opens. Because of the post blow issue, it is typical that when using TPE's, the primary goals cannot include cycle time.

Wall Thickness Effects
The MuCell process has been applied to parts with a wall thickness as low as 0.25 mm and as great at 12 mm. Most applications, however, are 3 mm and less.
There are two key attributes linked to wall thickness. The first is density reduction.
The second is cycle time which is a function of wall thickness and material stiffness. As the part is filled and gas expansion occurs, there is a residual gas pressure that on mold open is higher than atmospheric pressure.
As such, the skin layer of the part must have sufficient rigidity to withstand this internal gas pressure. If this condition does not occur, cell growth continues when the mold opens and the part swells.

There are some noteworthy trends regarding fillers that apply across all materials. Fillers act as nucleating agents, improving cell structure and increasing the efficiency of a given SCF dose. Of all the fillers, glass fiber is the most beneficial in terms of controlling cell structure and achieving weight and cycle time reductions. Talc, calcium carbonate and mineral fillers are less effective at reducing weight and cycle times. As with conventionally molded parts, the choice between fillers usually comes down to the desired mechanical properties. For example, talc and calcium carbonate both have a similar effect on cell nucleation and cell growth. Yet their influence on mechanical properties differs, with talc-filled materials tending to have higher stiffness and calcium carbonate-filled materials tending to have better impact and elongation. The application requirements, rather than the molding requirements, may drive the choice between the two.

Setting up The Process

MuCell set up procedures all revolve around establishing a controlled, gentle SCF dosing into the injection barrel under screw speed, temperature and pressure conditions that result in a single-phase solution. Logic built into the MuCell controller prevents many SCF dosing errors–by allowing the SCF injector to actuate only when the screw is rotating under position control and is in a position that corresponds to no more than 80 percent of the shot size.

Initial Setpoints

With the controller ensuring that the basic conditions of SCF dosing are met, the molder has only five process set-points to adjust. They are the following:

- **MuCell Process Pressure (MPP)** sets the plastic pressure against which the SCF is dosing during screw rotation. As such, it refers to both the specific plastic back pressure during screw recovery and also to screw position control during screw idle. The MPP setpoint is a function of the material type and can range from roughly 70 bar (1000 psi) to 220 bar (3200 psi). Typically setpoints for material families are:

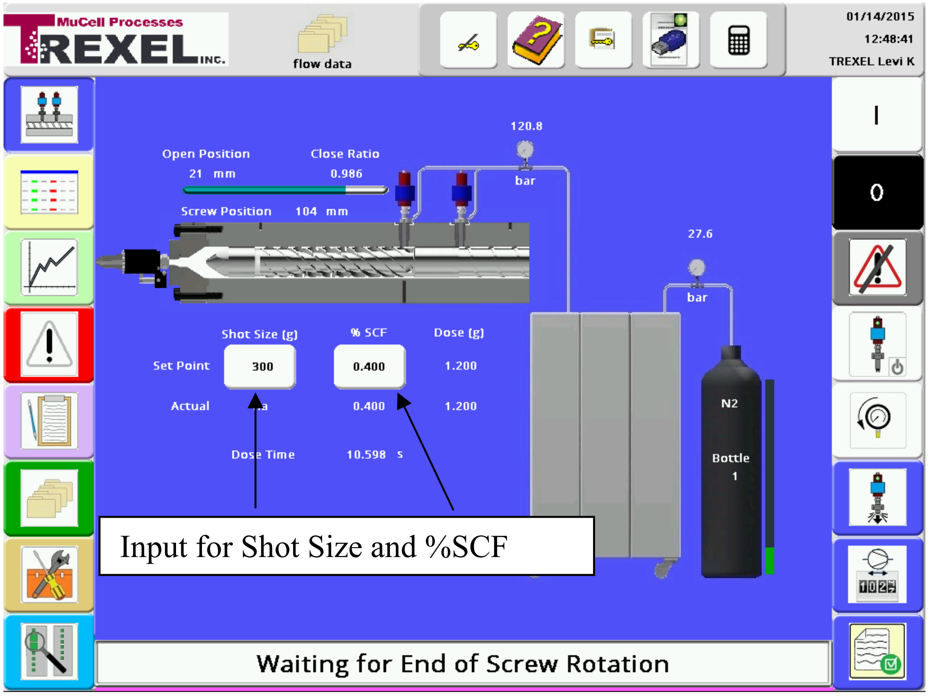
• Filled PA6, PA6.6, PBT, PET	90 - 110 bar (1300 - 1600 psi)
• Filled PP (20-40% talc/CaCO3/GF)	120 – 140 bar (1750 - 2000 psi)
• Unfilled Semi-crystalline	170 bar (2500 psi)
• Unfilled Amorphous	200 – 220 bar (2900 – 3200 psi)
• Filled Amorphous	140 bar (2000 psi)
• LGF PP	70 – 80 bar (1000 – 1150 psi)

- **SCF Delivery Pressure** sets the feed line pressure to SCF injector. The default setpoint for the T series SCF system is 103 bar (1500 psi). The T series is always in automatic mode and will adjust the delivery pressure to provide a 6 bar (90 psi) pressure drop at the start of SCF dosing. Depending on the dose size and the actual plastic pressure, the correct delivery pressure will be reached in less than 10 shots. Alternatively, the starting setpoint can be changed on the configuration page. The system will then convert to automatic control after the first dose. When setting an initial delivery pressure, choose a value that is approximately 15 bar (215 psi) higher than the MPP.

- **SCF Injector Open Position** sets the screw position at which the SCF dosing starts. This position should be set so that the pressure in the barrel during screw recovery has become stable prior to the start of dosing. Note that the polymer pressure inside the barrel does not stabilize in the first few rotations of the screw, so SCF dosing should not start as soon as the screw starts rotating. In order to allow the barrel pressure to stabilize, set the open position in the range of 10 to 15 mm. This is an offset from the forward most screw position and as such, this position will be maintained regardless of cushion.

  This is a general guideline based on normal shot size recommendations, minimum 1D of screw stroke. When the screw stroke is less than 25 mm, this open position will need to be adjusted down.

- **Shot size and % SCF** control the actual mass of SCF dosed during each cycle. The shot weight is for the expected MuCell process and not the solid shot weight. It should be the combined weight of all parts and cold runners. The %SCF is the target %SCF desired. These values are input on the process page. The T series will then optimize dosing time and flow rate to provide the maximum dosing time allowed.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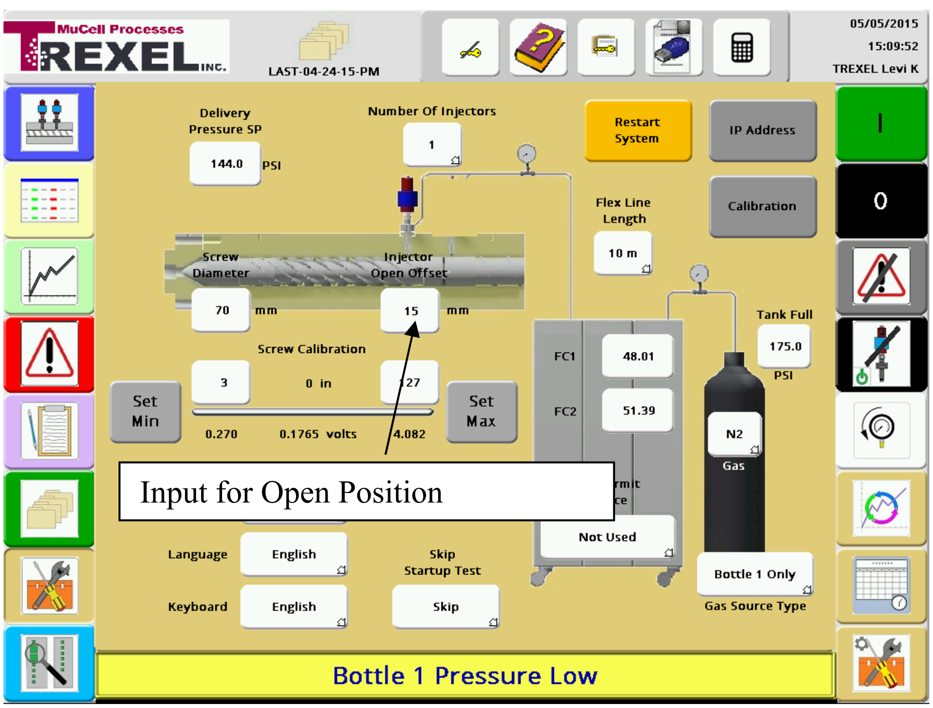
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T Series SCF Dosing Optimization

The T series SCF Delivery System is designed to optimize the dosing. This is accomplished by maximizing the dosing time and minimizing the flow rate (pressure difference between the pre-metering pressure and the delivery pressure). This is accomplished by targeting a closed position of 75% of the screw stroke, this is a close ratio of 1. The flow rate, P1-P2, is optimized to allow for the correct dose of nitrogen using the open position and a close position of 75% of stroke.

If the P1-P2 drops to 20 bar, the pressure is no longer decreased but instead the injector will close early, at a close ratio less than 1. If the P1-P2 decreases to 20 bar and the dosing time drops to less than 2 seconds, a warning, MFE too Large, is generated.

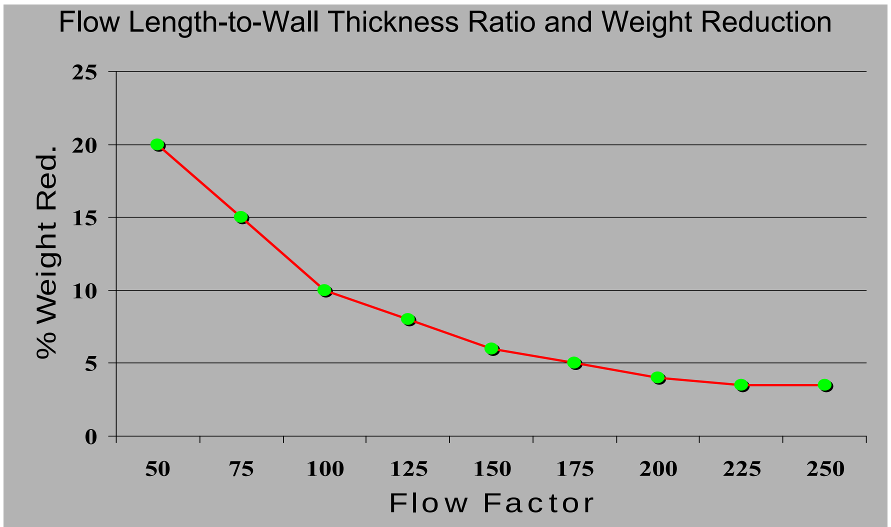
On the other side, if the pre-metering pressure reaches 340 bar (5000 psi) and the required dose cannot be reached with in the allotted dosing time, a warning, "MFE too Small", is generated.

Optimization

When properly optimized, the MuCell process offers a variety of molding benefits, including reductions in part weight, cycle time and warpage. Another important benefit is the ability to lower the clamp tonnage needed to produce a given molded part. In some cases, it may be necessary to prioritize as some of the process approaches to improve one benefit may have a negative effect on others.

Weight Reduction

Optimizing the process for weight reduction needs to start with a realistic understanding of the limitations imposed by part and mold design attributes such as flow paths, venting and gas traps. Consider the effect flow paths have on weight reduction. As flow length-to-thickness ratios increase, opportunities for weight reduction decrease (see graph at right). Poor venting, which traps gas in the mold cavity, is another barrier to weight reduction. In the MuCell process, foam expansion is the driving force that completes the filling of the mold cavity and packs out the part. Because foaming fills and packs at low pressures, it can easily be defeated by the pressure from unvented gas in the mold cavity. Poor venting can, in fact, cut the density reductions by as much as 50 percent. To fix venting problems, try to decrease the clamp tonnage by up to 50 percent. Another method is to put a piece of masking tape on the parting line, giving trapped gas an escape route. Both techniques, on a temporary basis, improve venting and should improve the ability to reduce part weight. For a more permanent fix, modify the mold to increasing perimeter vent depth by 25 percent and vent width by 50 percent.



The dominant influence on weight reduction is the part's flow length-to-wall thickness ratio. This value places an inherent limit on the maximum weight reduction possible with the MuCell process.

Gas traps, or gas entrapped by "race tracking" flow fronts, likewise reduces the potential for weight reduction. Unresolved gas traps can cause a MuCell part to weigh almost as much as a comparable solid molded part. Fixing gas traps usually involves both mold and part design changes. One minor mold modification involves venting trapped gas through ejector pins or blades. If there is an ejector mechanism at the trap location, it may be possible to create a vent by machining a small flat on the ejector. If an ejector pin or blade is not available, it might be possible to insert a dummy pin. This strategy, however, is less effective than an ejector pin as dummy pins are not self-cleaning and will eventually clog with off gases. Two other options are adding flow leaders to promote flow into and through thin sections and, where possible, limiting wall thickness transitions to less than a 25 percent difference between thick and thin sections.

Other than mold changes to resolve venting and gas traps, there are also a handful of processing changes that reduce part weight by maximizing the proportion of the part that completely foams:

- Increasing Process Temperatures. Increased melt and mold temperatures increase the time before the material freezes off, giving the polymer and SCF solution more time to fully expand in the mold cavity. Experience has shown that melt temperature is typically more effective in increasing weight reduction whereas mold temperature has a more significant effect on cycle time.
- Increasing SCF Level. The overall driving force to foam expansion is the internal gas pressure in the individual cells. As the SCF level increases, the internal gas pressure increases, resulting in more fully foamed, lighter parts. Increasing SCF level will increase surface splay.
- Increasing Injection Speed. As injection speed increases, the material cools less during the filling process which allows for more expansion to occur before the material reaches the critical cooling point. Increasing injection speed can increase surface splay.

Always Maintain Quality Cell Structure

While it is always best to use the minimum amount of nitrogen necessary to achieve the desired results, it is important to consider cell structure along with weight reduction when optimizing the process.

A quality microcellular cell structure is critical to the retention of mechanical properties of the material. It is possible to attain significant weight reductions and cycle time improvements, but have an unacceptable cell structure. After achieving the desired weight reduction it, may take a higher SCF level to develop the optimum cell structure.

The best method of evaluating cell structure is to break parts open. Cutting parts whether with a knife, saw or gate cutters will collapse the cell structure making proper evaluation difficult. Instead, the surface should be scored with a knife or razor blade. The part can then be broken at the location of the score mark. The best areas to check are the end of fill, weld lines, the base of ribs and bosses and near gates.

Cycle Time

The MuCell process has two characteristics that reduce cycle time. The first is that the pack-hold phase of the solid molding process is replaced by an SCF expansion that occurs simultaneously with filling. Therefore, most of the solid pack-hold time can be eliminated.

The second is that mold temperature recommendations in standard injection molding, particularly for amorphous materials, tend to be high based on the need to minimize residual stresses caused by the decreasing gradient of pack pressures from gate to end of fill. With MuCell's pack and hold coming from a uniform gas expansion, the usual residual stress patterns are reduced without the use of high mold temperatures. The ability to reduce these mold temperatures allows for a reduction in cooling time.

Limitations on cycle time reductions are typically associated with "post blow," which occurs in areas of the part where the internal gas pressure is greater than the strength of the part wall. When the ejected part is no longer constrained by the mold cavity, the cells resume their expansion and cause a localized deformation of the part surface. Post blow will always occur in the same part location, that which corresponds to the hottest location of the mold or the thickest cross-section of the part.

These hot spots occur for one of two reasons, poor cooling or a thick cross section of material. Areas with poor cooling are often the result of uncooled slides and cores as well as sections of tooling that form deep pockets. While mold temperature can be reduced, this typically has very little effect on the local temperature of these types of tooling conditions.

Thick sections in the part also result in hot spots. In conventional injection molding, thick sections can suffer from sink marks or vacuum voids due to excessive material shrinkage. When using the MuCell process, thick areas result in post blow as the core of the material stays hot and continues to expand after the part is ejected from the mold. Since the thermal conductivity of plastics and more specifically of foamed plastics is low, changes to mold temperature have very little effect on this condition. The best solution is to core out these sections to eliminate the thick sections.

When tooling changes are not possible, the most effective process approaches are reductions to process temperatures and SCF levels. With process temperatures, start with a reduction to the mold temperatures, since it tends to have a greater effect than reducing melt temperature. To gauge the effectiveness of the temperature reductions, make significant reductions in the range 10 to 15 C.

Reducing the SCF level minimizes the driving force behind post blow, which is the residual gas pressure in the cells. Another way to reduce residual pressure is to increase the weight reduction, which has the effect of expending more of the gas pressure in cell growth.

Warpage

When residual stress from uneven pack pressures, molecular orientation, glass fiber orientation, or some combination of these factors causes a differential shrinkage of the part, warpage results. Because the MuCell process provides a uniform packing phase–the expanding foam exerts the same packing pressure throughout the part – the process can reduce or even eliminate residual stress as a source of warpage. A weight reduction of 5 percent or more is usually needed to completely eliminate residual stresses in unfilled or talc-filled materials.

Warpage reduction is more difficult to achieve with glass-filled materials because glass fiber orientation will cause warpage. Still, the MuCell process can have some effect on the orientation of glass fibers. The primary variable effecting glass fiber orientation is a part's wall thickness. At 2.5 mm (0.10 inches) and thicker, it is possible to eliminate most of the glass fiber orientation. From 2.5 mm down to 1.75 mm (0.6 inches), orientation can be reduced but not entirely eliminated. Below 1.75 mm, no change occurs. A secondary factor is the level of glass fiber. At 10% to 15%, a greater degree of dimensional improvement will be seen in the thickness of 1.75 to 2.0 mm. As glass fiber levels approach 30%, the wall thickness will need to be closer to 2.25 to 2.5 mm to see changes in warpage.

The key process variables effecting glass fiber orientation are weight reduction and SCF levels. In order to maximize the benefits of the microcellular process on fiber orientation a weight reduction of at least 8 percent must be achieved. Increasing SCF level will also reduce fiber orientation. While typical nitrogen levels for glass filled materials are in the range of 0.25 to 0.3 percent, it is possible to run as much 0.5 percent. Assuming a desired weight reduction of at least 8 percent, it should not be necessary to run nitrogen levels above 0.3 percent for parts with a wall thickness of 2.5 mm or greater. As wall thickness decreases, the nitrogen level will most likely need to be increased to achieve the same 8 percent weight reduction.

Increased injection speed and decreasing mold temperature have also been shown to help with fiber orientation problems.

Surface Appearance

In general, the surface appearance of parts produced with the MuCell process will appear to be lighter in color and lower in gloss than a solid part. The reason relates to the structure of microcellular foams, which typically consist of two solid skins over a foam core. While these skin layers are solid, they are not smooth. Instead, the walls of cells at the flow front will elongate and then tear during mold filling, leaving micro-depressions in the flow front. When the material contacts the mold, these depressions freeze against the mold surface. Given that the gas expansion used to pack the MuCell parts is low pressure, the material is not pushed against the mold surface with sufficient force to press out the micro-depressions. These residual depressions cause microcellular foam parts to reflect light differently than solid molded parts, causing the color and gloss differences.

When using the MuCell microcellular foaming process, the goal should be to produce a part with a uniform surface finish. Adding texture to mold surfaces tends to improve the uniformity of the part surface while highly polished mold surfaces only highlight the surface imperfections.

There are a couple of processing variables that can help in achieving a more uniform surface appearance. SCF level and shear through the gate are the processing characteristics that have the largest effect on surface appearance. For glass-filled, semi-crystalline engineering resins–especially glass-filled PBT, PA6 and PA6.6–lower SCF levels improve surface appearance. At times, the SCF level for these materials can be as low as 0.1 percent. For unfilled materials and filled PP, by contrast, surface finish will become more uniform as SCF level is increased up to visually obvious point of diminishing returns.

In glass-filled PBT, PA6 and PA6.6, surface splay is minimized by decreasing SCF levels. The part starts to look somewhat lighter in color but relatively splay free. With the other materials, small amounts of SCF create the appearance of moisture or heat splay. The small amounts of SCF form isolated steaks on the part resulting in high gloss and low gloss areas of the part. As SCF level increases, a point will be reached where there are no longer visible high gloss areas on the part but only a uniform but low gloss surface.

Points of high shear create large disturbances in the flow of the material resulting in heavy swirls on the part surface. Profiling of injection speed so that there is an initial low-shear slow flow through the gate followed by an increased speed to complete the part filling is a common practice with the MuCell process. The profiling approach usually involves setting all injection steps to a common value and then gradually reducing each step as needed to decrease the heavy splay and move it closer to the gate. Once a speed is reached at which the splay no longer shows on the part surface, increase the last step of the injection profile to a normal value for the material and part. Then gradually increase the screw position at which the transfer from the slow to the fast speed occurs until the splay forms again near the gate. Once the splay shows near the gate, reduce the transfer position slightly. Note that decreasing injection speed will require a shot size increase to avoid a short part.

There are special processing techniques and material grades that have successfully offset some or all of the appearance issues. Variotherm processing, in which an elevated mold surface temperature keeps the skin of the part more pliable through injection and packing, has been effective at eliminating surface splay. Though effective, variotherm techniques are most likely not economically viable unless they used to replace a secondary operation such as plating or painting.

As for materials, there are grades of filled PA6 and PA 6.6 that produce a MuCell parts with a surface finish equal to solid. Many commercial grades of PA6 produce excellent surface finish as currently produced.

Clamp Tonnage & Injection Pressure

Cavity pressure, and therefore required clamp tonnage, are typically reduced with the MuCell process. Due to the lower packing pressures, the cavity pressure reductions are typically in the range of 25 percent for parts with a 4 percent weight reduction and 50 percent or more for a 6 percent density reduction.

And since SCF to a molten polymer has the effect of reducing the material viscosity, injection pressure requirement can drop too. Assuming identical process temperatures and speeds, it's possible to achieve injection pressure reduction of up to 25 percent with amorphous materials; 15 percent with filled, semi-crystalline engineering resins; and 10% with unfilled crystalline material. Remember, if maximum viscosity reduction is critical, carbon dioxide should be used as the foaming agent.

Taken together, the reductions in clamp tonnage and injection pressure allow parts to run on smaller molding machines than they might otherwise require, offering molders the opportunity to save money on operating expenses or even capital expenditures.