Implementation of the MuCell® Process in Commercial Applications

Authors: Levi Kishbaugh (Trexel Inc.), Uwe Kolshorn (Trexel GmbH)

PRESENTOR BIOGRAPHY:

Dr. Hartmut Traut received his Master of Business Administration and a Doctorate in Philosophy from the University of Siegen (Germany).

Dr. Traut came to Trexel from Thermo Detection, where he was the Sales and Marketing Director for Europe, Middle East and Africa supplying chemical and optical detection equipment to the food and beverage industry. This equipment was used to detect foreign materials in refillable PET bottles.

Previously, he was founder and CEO of Centro Kontrollsysteme GmbH, which develops and manufactures advanced control and handling systems. Today Dr. Traut manages Trexel's business relationships and licensing activities in Europe since 2002.

Levi Kishbaugh is the VP of Engineering at Trexel. He has been at Trexel 8 years starting as the Director of Process Development for injection moulding technology. He now has responsibility for all technical activities. Prior to Trexel, Levi spent 4 ½ years in product and applications develop for injection moulding resins at Montell Polyolefins and 6 ½ years at The Dow Chemical in Plastics Technical Service and Development to the automotive industry. He received his Bachelor's Degree in Science from Stevens Institute of Technology.

Dipl.-Ing. Uwe Kolshorn wrote his diploma at the University of Applied Sciences in Iserlohn, Germany.

Mr. Kolshorn worked two years as a project engineer and an additional four years as a product manager in the automotive industry. At Trexel Mr. Kolshorn is responsible for applications development and technical support activities in Europe. This includes MuCell® training, processing and supporting customers in mould and part design.

ABSTRACT:

The MuCell process for producing microcellular injection molded parts is accepted as a technology for providing a more dimensionally stable part through a reduction in residual stress with increased productivity over compact molded parts. The first commercial applications of the process were simple conversions of compact parts with minimal or no changes to the part geometry or material. As the commercial use of the technology has expanded, three trends have developed in part commercialization:

1) Design optimization to allow for maximum material savings
2) Material optimization to achieve unique performance
3) Combination with older technologies to achieve unique performance characteristics

The intent of this paper is to provide examples of how the MuCell microcellular foam injection molding process is allowing users to advance their business.
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INTRODUCTION:

Microcellular foam injection moulding is a technology that has received significant attention over the last 6 to 7 years. The basis of this technology originated in the Mechanical Engineering Department at The Massachusetts Institute of Technology (M.I.T.) the early 1980's. That work, which was lead by Dr. Nam Suh, forms the basis for the technologies currently available in the market today. Trexel was the first company to bring the technology to market and continues to be the leader in hardware and know how.

The initial implementation of the microcellular foam molding process was in applications designed and optimized for the solid injection molding process. Implementation in these designs resulted in productivity improvements through increased dimensional stability and reductions in part weight and cycle time. While these types of applications were used as the proving ground for the technology, the design requirements for injection mold compact parts resulted in less than optimum productivity improvements.

As companies become more comfortable with the use of the MuCell technology, three trends have developed in part commercialization:

1) Design optimization to allow for maximum material savings
2) Material optimization to achieve unique performance
3) Combination with older technologies to achieve unique performance characteristics

The intent of this paper is to provide examples of how the MuCell microcellular foam injection molding process is allowing users to advance their business.

TECHNOLOGY FUNDAMENTALS:

The fundamentals of microcellular foam moulding have been covered in many papers and articles including work by M.I.T., Trexel, Sulzer Chemtech and IKV Aachen. As such, we will not go into details here but just provide a basic summary. The concept as it applies to the injection moulding process involves introducing a physical foaming agent, typically nitrogen or carbon dioxide, in the form of a supercritical fluid into a molten polymer. That molten polymer is under the appropriate temperature and pressure conditions to cause the foaming agent to dissolve into the polymer to create a single phase solution. Implied in the term single phase solution is not only that the foaming agent is completely dissolved in to the polymer but that it is also uniformly dispersed throughout the polymer. Once the single phase solution is created, it must be maintained until the material is injected into the mould cavity.

When the single phase solution of foaming agent and polymer is introduced into the mould, it undergoes a thermodynamic change, a pressure drop, which causes cell sites to form (cell nucleation) and then grow as the foaming agent comes out of solution. Cell density, the number of cells for a given volume of material is a function of the amount of foaming agent as a function of its saturation limit and also the rate of pressure drop (change in pressure/time increment). This basic mechanism is applicable to any system using a physical foaming agent to create a microcellular injection moulded part.

LIMITATIONS OF SOLID PART/MOLD DESIGN:

The injection molding of solid or compact parts is a very well understood and well documented process. It can certainly be argued that solid injection molding has been a commercial technology since the late 1940's and over its lifetime, a set of universally accepted design principles have been developed. These design principles are related to the standard injection molding process and in particular, the need to compensate for the shrinkage that occurs as the material cools with a pack/hold phase. There are a couple of design rules that are of particular interest when evaluating a solid part design for the microcellular foam injection molding process. These are:

- Gating such that material flow is from thick to thin sections
- Ratio of rib thickness to wall thickness

The issue of gating such that material flow is from thick sections to thin sections is dictated by the need to properly pack the injection molded part to minimize sink marks and vacuum voids and provide dimensional stability. Inherently, the material will freeze more quickly as the wall thickness decreases. In addition, the ability to effective pack a part stops when the material freezes as this prevents any additional material flow. As thin sections freeze more quickly and require less pack time, it is desired to put these sections at the end of flow. The maximum pack pressure, which occurs closer to the gate, can be more effectively applied to the area which requires it most, the thicker sections. However, if the part function requires a thicker area at the end of flow, the entire nominal wall must be increased to allow proper packing to the end of flow where the thickness is critical. In this instance the process (injection molding) dictates the part design.

At the junction of a rib and the nominal wall, there is an increase in the cross-sectional area of the material. This results in an increased tendency for a sink mark to form at this point or in some instances a vacuum void. In order to minimize the potential for a sink mark, a ratio has been developed for the thickness of the rib to the thickness of the nominal wall, about 0.7 for an amorphous material and about 0.6 for a crystalline material. This is based on the shrinkage of the material and the ability to properly pack the part to compensate for that shrinkage. The thickness of the support rib is dictated by the process limitations and not necessarily by the part performance requirement. Or when a minimum rib thickness is required, the nominal wall must be increased do to process limitations.

Applying the microcellular foam molding process to a part designed for compact molding reduces the benefits of microcellular foaming. In addition, the microcellular foaming process changes these fundamentals design rules such that part function becomes the driver more than the manufacturing process.

DESIGNING FOR MICROCELLULAR FOAMING PRACTICAL APPLICATIONS:

The Basics of Microcellular Foam Process:

The best place to start this discussion about the design rules for microcellular foaming is with a short review of the key differences between microcellular foam molding and compact molding. The first difference is the fact that in microcellular foam molding, a single phase solution of molten polymer and physical foaming agent is created. This has the effect of decreasing the viscosity of the material. The exact amount is dependent on the material type and the foaming agent type but the change is typically between 10% and 25%. This results in an increase in material flow and the potential for thinner parts.

The second and more important with respect to part design is the fact that the process of packing out the part is no longer achieved through pack and hold pressure. Instead, the packing process is now done through material expansion that occurs through the creation of a microcellular structure. This creates two conditions that benefit the molded part; the first being packing pressure is essentially uniform throughout the mold cavity because the gas is uniformly dispersed in the mold cavity. The second benefit is that because the packing pressure is coming from the gas expansion which is uniformly dispersed, the packing is pressure does not need a pathway from the gate to the area requiring packing. Both of these lead to the condition that thick areas can be designed were needed and not just as a conduit for pack pressure to get to the end of fill.

Designing for Function with the MuCell Process:

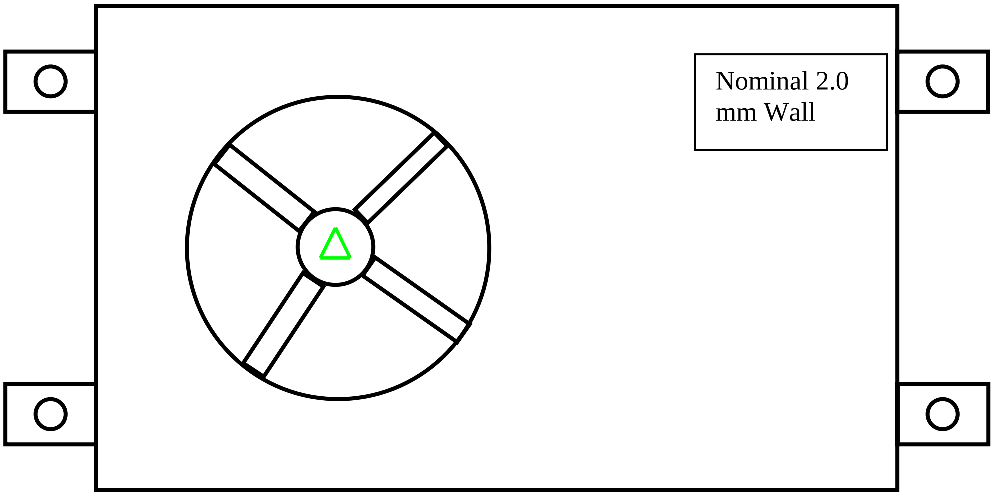
Designing for function means putting material where it needs to be and not simply to assist in filling and packing out the part. As noted above, when converting a part designed for compact molding to microcellular foaming, part weight reduction comes strictly through reducing the density of the part and density reduction is always limited by the flow factor of the part (L/t ratio). When designing for function with the assistance of microcellular foaming, weight reduction is achieved as much or more through changes to the nominal wall as it is from density reduction. In most cases, a part designed for function ends up with less density reduction than the same part design for compact mold and converted to foam but with a much higher overall weight reduction.

The Fan Shroud:

Fan shrouds are typically a glass fiber or glass fiber and mineral filled PA6. In some cases there has been a conversion to glass fiber filled PP however in this particular example, the material was a filled PA 6. As designed for compact molding, this shroud had a nominal wall thickness of 2.0 mm. There was a single gate in the center hub of the part with material flow through the four support legs into the main body of the shroud. In addition to the strength of the attachment legs, the four mounting points were the critical locations both for dimensions and strength.

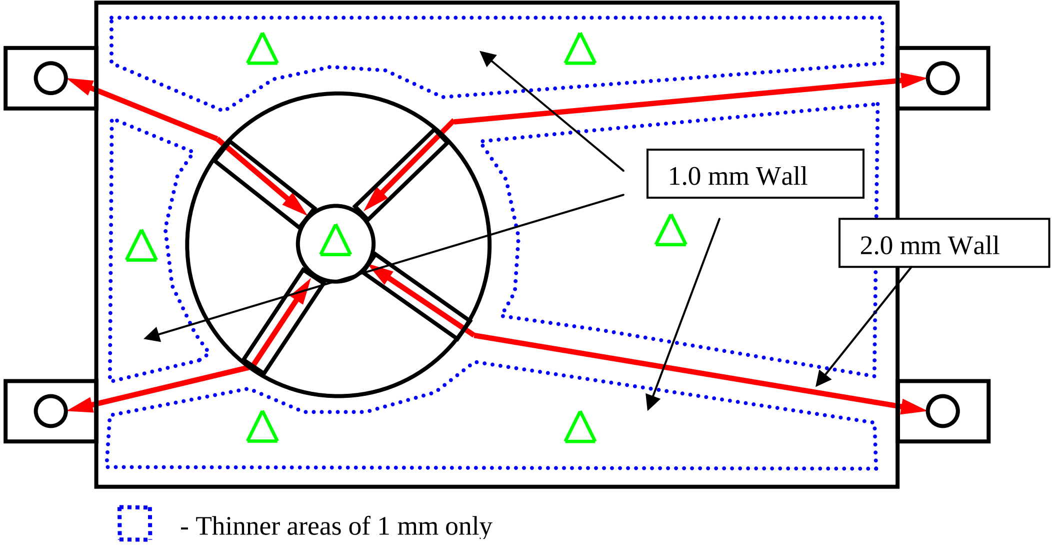
In addition, the hub of the shroud needed sufficient strength to support the fan motor and prevent noise during operation. As can be seen, a large amount of the part performed no real function other than to allow for proper fill and packing of the part.

Solid Design:



In redesigning this part for the MuCell process, the areas of the part that required mechanical strength, the attachment points, hub and support material were left at 2.0 mm but the remainder if the part was thinned to 1.0 mm. Gates were then added to the thin sections to promote fill in these areas while the thicker areas at the end of fill were packed through the expansion on the supercritical nitrogen.

MuCell Design:



This design reduced the part weight by 0.4 kg for an annual savings of 160 T of material. This translates into 320,000 Euros/year material savings which cover the additional cost of the more complex hot runner system in the first 4 months.

The Door Trim:

A second example of how the MuCell process allows for changes to the part design and significant reductions in part cost is a door bolster for the for the VW Touran. The part is a talc filled PP injection molded behind a PVC coverstock to provide a grained surface.

This part had two key requirements that drove the part design. The first was an impact requirement. This part had to absorb energy during an impact event and this was achieved by a series of 2.2 mm ribs on the back surface. The second driver was that no sink marks could be visible through the PVC coverstock. Given the shrinkage of talc filled PP and the need for 2.2 mm ribs to achieve the proper energy management, the nominal wall of this part in compact had to be designed at 4.4 mm. In addition to these design limitation, a secondary module was welded to the back of the assembly.

The driver in converting this part to the MuCell process was to use the ability of the supercritical nitrogen foaming agent to eliminate the sink marks at the intersection of the ribs and nominal wall and then reduce the nominal wall to a level that still allowed the part to meet the energy management of the solid part. The microcellular foam design had a nominal wall of 2.2 mm and a rib thickness of 2.4 mm. A slight increase in the rib thickness compensated for the effect of the thinner wall to maintain the impact requirements. In addition, it was possible to eliminate the secondary module. The total weight savings in converting the part to the MuCell process was 40%, 20% through design, 6% through density and 14% through the elimination of the secondary module. In addition, the operation of adding the secondary module was eliminated.

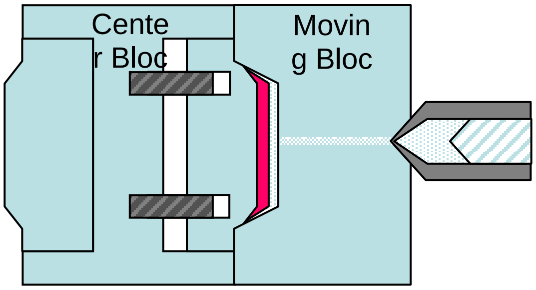
The Jounce Bumper:

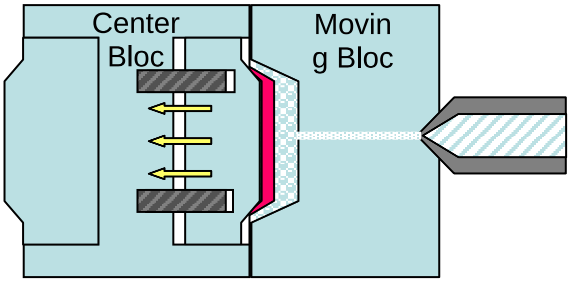
Jounce bumpers were historically produced with rubber. Over the last 20 years, there has been a conversion to thermoset polyurethane materials. While this material is easier to process, it is still a thermoset material that can not be reprocessed and due to the part thickness has cycle times that can be 10 to 15 minutes.

Society de Polymer Barre’ Thomas (SPBT) undertook a project to produce a jounce bumper using a thermoplastic polyurethane (TPU) foamed with the MuCell process. The goal was to produce a jounce bumper using a material that was recyclable and could be processed in a more environmentally friendly method. TPU was chosen as the base material due to the requirements of oil and grease resistance as well as a need to maintain flexibility over a temperature range from -30 C to +85 C. The MuCell process was chosen as the foaming process because density reductions of 50-60% were required while maintaining an integral skin (micro organism and moisture resistant) and a closed cell structure (water absorption). This combination of features could not be achieved with other foaming technologies.

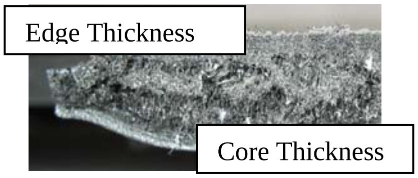
Through a series of testing and simulation techniques, SPBT were able to optimize the energy management curve of the jounce bumper to equal the performance of the thermoset materials. The parts are now in production for the Citroen C5 using a rotary table, MuCell enabled Engel injection molding machine with a vertical injection unit.

Injection/Expansion Molding:

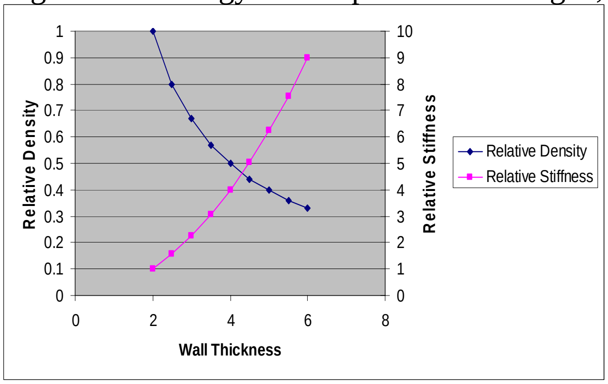




Injection/expansion molding is not a new technology. It has been used commercially with chemical foaming agents and provides a unique weight/stiffness ratio. The process involves injection a foaming agent laden polymer into a mold cavity. After allowing the skin layer to form, the mold cavity volume is increased resulting in the expansion of the still hot core. The ability to expand is limited by the expansion capability of the foaming agent as well as the initial thickness of the mold cavity. Historically chemical foaming agents have been limited in the ability to produce high expansion level and this is particularly true with thin initial cross sections. One example that demonstrates the increased process flexibility supercritical physical foaming agents is a door module where the starting thickness was 1.6 mm. Using injection/expansion molding with tradition foaming technologies, a maximum expansion of 2 to 2.5 times would be expect giving a final wall thickness of 3.2 to 4.0 mm. Using the MuCell process, it was possible to expand by as much as 3.5 times for a final wall thickness of 5.6 mm.



What can be seen from the graph is that using this technology with supercritical nitrogen, a 3 times expansion ratio is very easy to achieve which results in a material density reduction of 67%. At the same time, the part stiffness can increase by a factor of 9 times. This is due to the fact that stiffness is directly proportional to the flexural modulus of the material but proportional to the thickness cubed. This allows for part stiffness to increase rapidly despite the fact that material modulus decreases with density reduction. Using this relationship of stiffness to thickness allows for the design and molding of very rigid parts without adding weight.



A second interesting application of this technology is the use of a soft material in the expansion process. An example of this is the Dolphin process developed by a consortium of Engel, BASF, P-Group and Kaufmann with the MuCell process, where the expansion step is done using a TPE to provide a soft touch surface on a rigid substrate. In this particular case, expansion was critical to achieving the proper feel. This technology is a unique way to produce a rigid substrate with a soft flexible cover without the use of urethane foams or expanded PVC sheet stock.

CONCLUSION:

The MuCell process for producing microcellular injection molded parts provides the end user a new range of part design options. These design options are enabled by the fact that the use of supercritical physical foaming agents reduces the material viscosity and replaces the tradition pack and hold process with gas expansion. In addition, the use of these foaming agents results in the ability to use much higher levels of foaming agent resulting in a greater potential for density reduction and material expansion. Examples of how current Trexel customers are applying these unique advantages to:

1) Optimization part design for maximum material savings
2) Achieve unique part performance by combining with materials
3) Achieve unique performance characteristics through combinations with older technologies

can be seen in the fan shroud and door trim (optimized part design), the jounce bumper (part performance through materials) and the use of injection/expansion molding.