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Microcellular Processing

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4 Microcellular Molding: The Basics

4.1 Background

Injection molding of microcellular parts is the most widely practiced commercial MuCell® process around the world, despite the fact that extrusion processing had at least a five year head start in development. Development in microcellular molding began by 1996 at Trexel, Inc. with the first injection molding machine modified for microcellular processing operating by mid-1997 in Trexel's development laboratory. This first machine was an Engel 150-ton screw and plunger model but reciprocating screw machines followed soon thereafter.

Commercial introduction of microcellular molding by Trexel occurred at the National Plastics Exposition (NPE) 2000 in Chicago, Illinois, USA; Trexel called the process MuCell® microcellular molding. At the commercial introduction, Trexel also announced that several injection molding machine original equipment manufacturers (OEMs) were licensed to sell new machines with a microcellular processing option.

Evidently, a few other injection molding companies in Japan, Europe, and Korea were also working on developing a microcellular molding process prior to Trexel's announcement. However, these efforts were not as successful in developing a commercially viable process. Thus, most of these companies have either abandoned their efforts or are now Trexel licensees. Table 4.1 lists the Trexel injection molding OEM licensees.

Table 4.1 *Trexel Injection Molding OEM Licensees (as of 1/1/03)*

Arburg, Germany	Italtech, Italy
Battenfeld Kunststoffmaschinen GmbH, Germany	JSW, Japan
Demag Ergotech, Germany	KraussMaffei, Germany
Dongshin Hydraulics Co., Ltd., Republic of Korea	Mitsubishi Heavy Industries, Ltd., Japan
Engel, Germany	Toshiba Machine, Japan
Ferromatik Milacron, United States	Toyo Machinery & Metal, Japan
Husky, Canada	Van Dorn Demag, United States

At least two other organizations have since announced that they are working on alternative microcellular molding technology to Trexel's design. These designs will be discussed further in Chapter 11 of this book.

4.2 Advantages of Microcellular Molding

Microcellular foam injection molding is a process and equipment technology for plastic injection molded components that results in an average cost reduction of 16 to 20% compared to conventional molding net of all equipment and licensing related costs.

The microcellular molding process changes the fundamental cost structure of injection molded parts through four main sources of economic benefit:

1. Reduced operating costs through cycle time reductions of up to 50%, reduced scrap rates, and lower energy consumption;
2. Lower capital costs through the purchase of smaller and fewer machines, and fewer and less expensive molds;
3. Reduced material costs through component density reduction, thinner design, and material substitution, and
4. The ability to mold thermoplastic parts that are flatter, straighter, and dimensionally improved due to the elimination of the molded-in stress associated with the pack and hold phases of conventional injection molding.

Greater detail of the microcellular processing advantages will be given in later chapters along with several case studies.

4.3 Comparison to Other Molding Processes

A number of older molding processes also use gas or a blowing agent. These processes include:

- Structural foam molding
- Gas assist molding and
- Foaming with chemical blowing agents (CBAs).

How is microcellular molding different from these processes?

The two main differences between microcellular molding and the three alternative processes are:

1. Microcellular molding works for parts of any thickness and is able to mold thin parts (less than 3-4 mm thick) where none of the other processes have been particularly effective.
2. Microcellular molding facilitates a more controlled weight reduction and generally homogeneous cell distribution throughout the part.

However, microcellular molding is not intended to compete with these other approaches though its usefulness may overlap with that for structural molding, gas assist molding, and CBA blown injection molded parts.

4.3.1 Microcellular Versus Structural Foam Molding

Structural foam molding is generally used for big parts and, most commonly, with HDPE on specialized low-pressure molding machines. Weight reduction over solid molding can be 10% or greater. Microcellular molding can be far superior to structural foam processes in terms of material reduction and cycle time reduction for most materials, including all of the commonly used engineering materials. Microcellular molding can also fill very thin sections at the same time as the thick sections providing greater design flexibility. However, microcellular molding does not provide any major advantages over existing techniques with high length-to-thickness parts and with thick (greater than 6 mm thick) parts, especially in HDPE.

4.3.2 Microcellular Versus Gas Assist Molding

Gas assist molding provides Class A surfaces by running a void through the middle of a relatively thick part using special mold and part designs. As stated above, the microcellular molding process does not work well in thick parts. Additionally, microcellular molding should not be expected to provide a Class A surface.

However, gas assist molding is often used merely to eliminate sink marks. In this case, microcellular molding may be a better alternative as microcellular molding generally produces higher weight reduction, faster cycle times, and less warpage than gas assist molding while still eliminating sink marks.

4.3.3 Microcellular Versus Chemical Blowing Agents

Chemical blowing agents (CBAs) are designed to decompose at a specific temperature, yielding the gaseous blowing agent. Various grades are designed for a range of decomposition temperatures to yield the blowing agent as close to the mold cavities as possible. CBAs are often used in thick parts to eliminate sink marks while at the same time producing density reductions as well. The use of CBAs in thin parts usually produces very poor surfaces and considerable porosity in the parts thus dramatically reducing the physical properties of the molded part. Also, higher density reductions are usually not economically feasible with CBAs.

Other issues problematic when using CBAs that microcellular molding overcomes include:

- Many endothermic CBAs generate water (as well as carbon dioxide blowing agent), which necessitates additional water scavenger additives to prevent degradation of the molten polymer due to water.
- CBA batch-to-batch inconsistency of chemical blowing agents that lead to having to continuously adjust process conditions.

- CBA's inherent thermal instability that makes CBAs more difficult to use in high-temperature resins.
- CBAs generate residual byproducts that remain in the plastic or the CBAs may not completely decompose to generate the gaseous blowing agent. The byproduct and non-decomposed CBA may lead to poor organoleptic properties, mold vent plugging, and to difficulty for use in in-house scrap recycling programs.

4.4 Microcellular Molding Equipment Basics

Microcellular molding equipment has two primary components: the injection molding equipment itself and a supercritical fluid (SCF) delivery system. The SCF delivery system is described in detail in Chapter 3.

The injection molding equipment is basically standard equipment; however, several modifications are made to facilitate the microcellular process. The changes are summarized below and illustrated in Fig. 4.1.

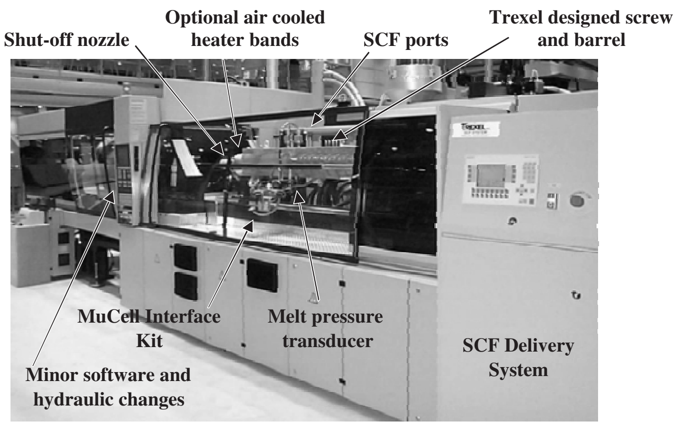

Figure 4.1 *Injection molding machine modifications to run microcellular process*

- The barrel must include drillings for SCF injection ports, pressure transducers, and rupture discs.
- A shut-off nozzle is added.
- A specially designed microcellular processing screw is installed.
- On new machines, programming changes are made to the machine controller.
- Optionally, the barrel length to diameter (L:D) ratio is increased.
- Optionally, air-cooled heating bands may be added to the end of the barrel.

Even with the machine modifications, the microcellular process capable injection molding machine can still run both solid molding and microcellular molding.

4.4.1 Shut-off Nozzle

The shut-off nozzle is a critical component for making the microcellular process work. The shut-off nozzle must be closed during all phases of the injection molding cycle except for injection and hold. To ensure this, the nozzle should be positively actuated to close. The shut-off nozzle is kept closed as 1) an open nozzle would allow the SCF laden molten polymer in front of the screw tip to foam and drool out of the opening and 2) the closed nozzle allows a constant and consistent back pressure to be maintained on the molten polymer. When the shut-off nozzle is closed, the back pressure can be programmed to maintain a pressure high enough to prevent the SCF from coming out of the SCF/molten polymer solution in the barrel. It is important that the shut-off nozzle is designed and manufactured according to the necessary pressure maintenance requirement.

Shut-off nozzles are readily available from most injection molding OEM manufacturers or some parts suppliers, including Herzog AG (Degersheim, Switzerland).

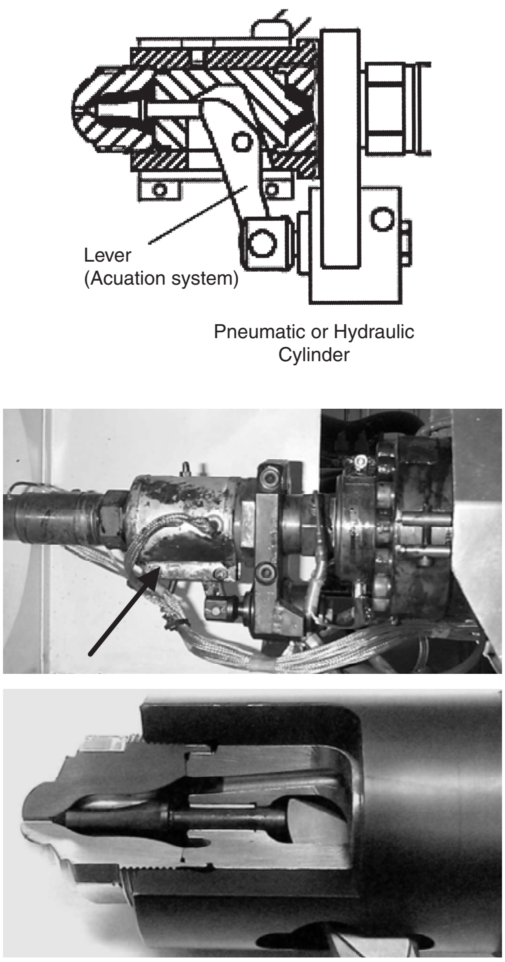

Figure 4.2 *Shut-off nozzle: Herzog needle-type design*
Top: schematic (from Herzog AG web site)
Middle: shut-off nozzle installed
Bottom: cutaway showing internal detail

4.4.2 Screw Design

A standard screw for injection molding must be able to melt, meter, and inject plastic into a mold. A screw designed for the microcellular process must also meet the following additional requirements.

- The screw must hold constant and consistent pressure during all phases of the injection molding cycle, except during injection.
- The screw must prevent escape of the injected SCF out of the feed throat.
- The screw must be able to mix the injected SCF into the molten polymer to form a consistent single-phase solution

To meet the standard requirements, a microcellular screw has conventional feed and compression zones with a short metering zone for the first 16D to 20D (D is the inner diameter of the screw barrel and the length is measured starting from the center of the feed port).

In a microcellular processing screw, the short metering zone is followed by a pressure restriction element. The purpose of this element is to reduce or eliminate reverse flow of the SCF blowing agent in the screw and barrel; the results of reverse flow of SCF would be blowing agent coming out of the feed throat as a small steady stream of gas or as small pops. The pressure restriction element also helps to maintain a constant and consistent pressure downstream.

The pressure restriction element can be of numerous design types including reverse flight elements, sliding check ring, or ball check valves. Figure 4.3 shows an example of a sliding check ring design. The design could also incorporate a spring for faster actuation.

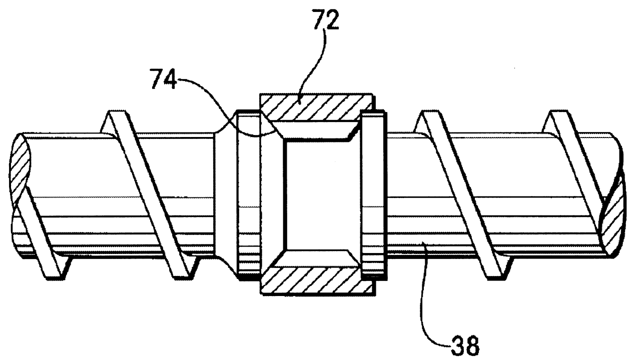

Figure 4.3 *Pressure restriction element – check ring design [from U.S. Patent 6 322 347]*

Figure 4.4 shows how a sliding check ring would operate when open and closed. In both diagrams, the feed throat would be to the left and the nozzle to the right. Molten polymer normally flows from left to right or in a downstream direction. When the ring valve is open, the molten polymer can flow through and past the restriction element; this would be the normal valve position when the screw is reciprocating and building up material in front of the screw for a shot. However, when the screw moves forward to inject the SCF/molten polymer mixture, the sliding check valve closes to block the backward flow of the SCF/ molten polymer solution as indicated by the arrow in the lower diagram.

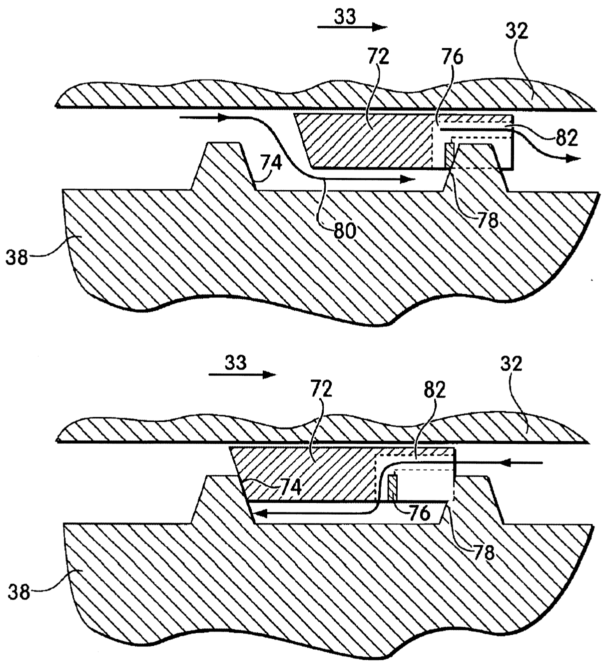

Figure 4.4 *Check ring action when open (top) and closed (bottom) [from U.S. Patent 6322347]*

An example of a ball check valve is shown in Fig. 4.5. The left photo shows the entrance and exit holes to the ball check that allow molten polymer to pass by the melt dam on the screw. The right photo shows some of the flow channel through the screw, including the ball valve itself.

Following the pressure-restriction element on a microcellular processing screw is a short wiping section. This section usually is only 1 to 4D long. The purpose of this section is to break the injected SCF blowing agent into smaller discrete masses for easier dissolution in the molten polymer as schematically shown in Fig. 4.6. This section may consist of broken screw flights but usually has continuous flights. To help maintain pressure on the molten polymer, the wiping section usually has little to no decompression compared to the upstream metering section.

Following the wiping section is a mixing section (see Fig. 4.7). The purpose of this screw section is to evenly disperse the SCF blowing agent throughout the molten polymer. The mixing forms the SCF/molten polymer single-phase solution that is critical for making consistent microcellular molded articles. The mixing section design can be any of a wide number of designs in the plastic industry including broken, cut or slotted screw flights, or Maddock-type mixers.

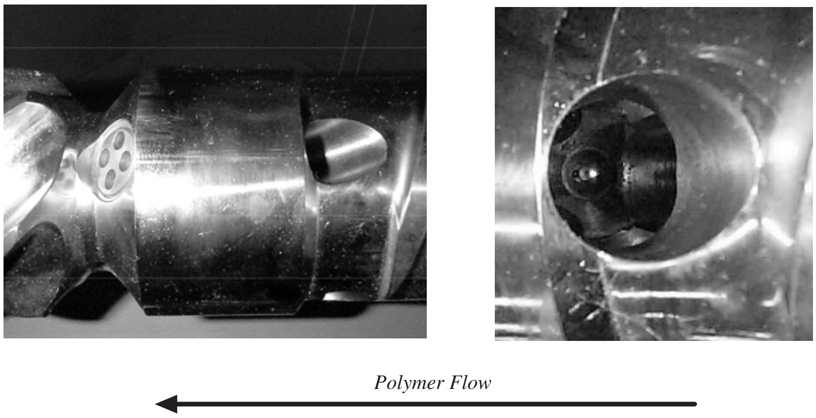

Figure 4.5 *Pressure restriction element – ball check valve*

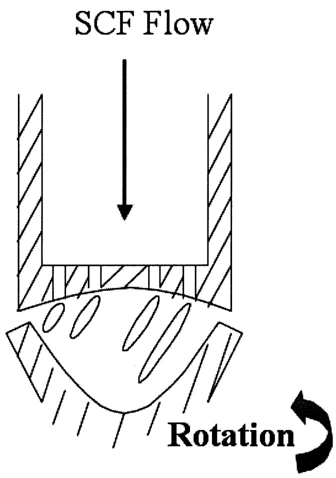

Figure 4.6 *Schematic of wiping action against injector*

The end of the microcellular processing screw has a screw tip valve. This valve is standard in the injection molding process to prevent upstream flow of molten polymer when the screw travels forward during injection. The tip valve plays the same role in microcellular processing; however, the tip valves are designed to provide improved closing consistency and speed.

To fit all the described zones onto the screw, the screws and barrels on the new OEM injection molding machines had a 26:1 or 28:1 L:D length. However in November 2002, Trexel announced that new and modified injection molding machines for the MuCell microcellular process will have screws and barrels of standard lengths, i.e., 22:1 to 24:1 L:D.

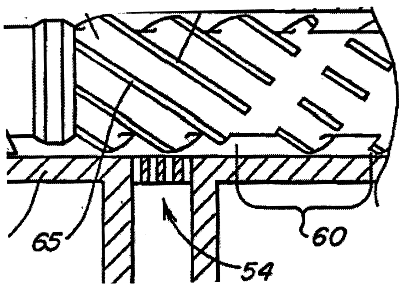

Figure 4.7 Schematic of wiping and mixing sections [from U.S. Patent 6 284 810]

4.4.3 Barrel Modifications

Numerous modifications associated with the extruder barrel may be made for microcellular processing. Some of the modifications are necessary while others are optional. The necessary changes include tapping the barrel for SCF injectors, a rupture disc, and a pressure transducer. Also, the barrel may need an extension or may need to be replaced if the screw is of a different length than the original design. The optional changes include tapping the barrel for an additional pressure transducer and adding air-cooled heater bands.

The microcellular molding machine may have one or more SCF injectors threaded into the barrel; usually the MuCell process uses two injectors. The multiple injectors are used to allow the addition of SCF blowing agent into the molten polymer at the wiping section of the screw throughout reciprocation. The downstream port is located near the furthest forward screw position and the upstream port is located at an adequate distance from the downstream one. With two injectors, the downstream injector operates first during screw reciprocation. However, as the screw continues to move backwards, the downstream injector may no longer be over the wiping section of the screw; when this occurs, the downstream injector would no longer operate and the upstream injector operates. The injectors are operated by a properly modified molding machine controller or a controller specific to the microcellular process.

A rupture disc is installed in the barrel for safety. The rupture disc is usually located on the non-operator side of the molding machine near the position of the downstream injection port.

The required pressure transducer is also located near the position of the downstream injection port. This pressure transducer would measure the melt pressure in the barrel of the molten polymer near where the SCF blowing agent is being injected. This pressure is called the SCF inlet melt pressure (SCF IMP) and is critical for maintaining consistent SCF addition.

The optional pressure transducer can be located near the downstream end of the barrel. This pressure transducer measures the molten polymer pressure downstream of the screw and gives a direct measurement of back pressure in a solid molding process or microcellular process pressure (MPP) in a microcellular process.

The optional air-cooled heater bands may be used downstream of the injection ports. The microcellular process uses lower barrel and melt temperatures than in the solid process at positions after the introduction of the SCF blowing agent; air-cooled heater bands help to cool the barrel faster and to obtain a consistent process on start-up of the microcellular process for manufacturing.

4.4.4 Control Modifications

New injection molding machines for microcellular processing often have a specific page in the injection molding machine controller for inputting and following parameters specific to the microcellular molding process. Upgraded or retrofitted equipment requires an additional controller either associated with the SCF delivery system or as a separate item.

An example of a MuCell process specific page offered by an injection molding machine original equipment manufacturer can be seen in Fig. 4.8. The screen shot shows the many added control functions. These functions include:

- Enabling/disabling the microcellular process
- Enabling/disabling the SCF injectors
- SCF injector opening and closing parameters
- Microcellular Process Pressure (MPP) setting
- SCF inlet pressure cutoff setting
- Barrel pressure readings and
- A SCF dosage calculator.

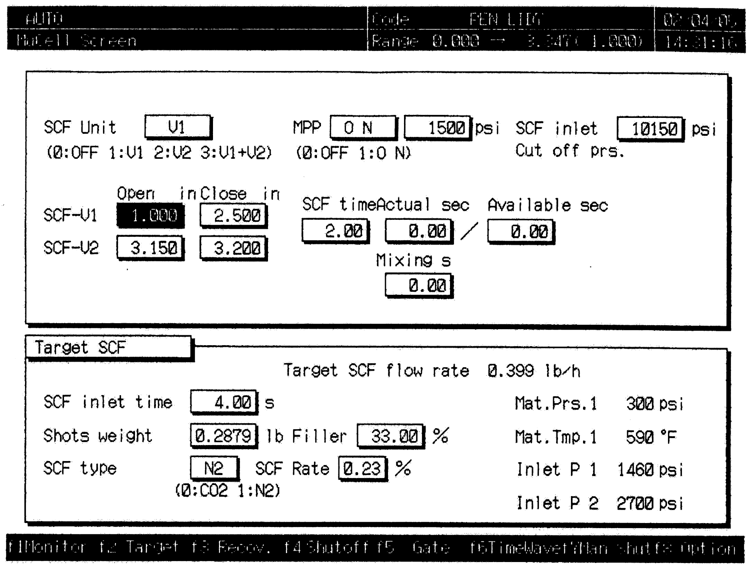

Figure 4.8 *Screen shot of JSW molding machine MuCell process page*

Further explanation of the use of these parameters will be given in the next chapter on microcellular processing.

4.5 SCF Delivery Equipment

Microcellular molding requires consistent dosing of supercritical fluid into the molten polymer stream within the plastication barrel. The standard SCF delivery equipment used in MuCell microcellular molding includes a gas source, gas pump system, bypass manifold, injection valves, and SCF injectors. The design of SCF delivery equipment for microcellular molding is discussed in Chapter 3.