FOAMING WITH CELLFORM

FOR LIGHTWEIGHT AND COST-EFFECTIVE PARTS

KraussMaffei

Pioneering Plastics

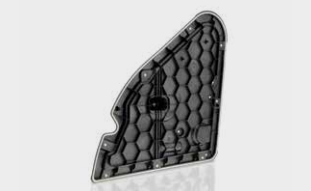
FACTS & FIGURES

APPLICATION AREAS OF **CELLFORM TECHNOLOGY**

Automotive industry

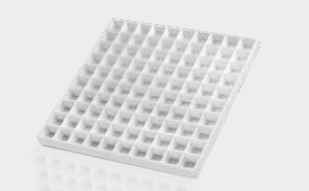
Automotive industry

Electricals/electronics



Automotive industry

Construction / recreation



Infrastructure/construction

Property/process matrix

Properties	Chemical foaming	MuCell®
Uses	– Parts, primarily with thick walls – Small to medium number of units	– Technical parts, even with thin walls – High production rates
Cell structure	+	++
Used for standard polymers	+	+
Used for technical polymers	0	++
Process window	+	+++
Reproducibility of the process	0	+
Potential reduction in weight	+	++
Dimensional stability	++	+++
Surface quality	–	– –
Thin walls (< 4 mm)	+	+++
Residues during foaming process	–	+++
Gas pressure during foaming process	+	++
Reduction in required clamping force	+	+
Investment costs	+++	–
Blowing agent costs	–	+++

– lower performance, 0 average performance, + higher performance

FOAMING WITH CELLFORM
COST-EFFICIENCY MADE EASY

At KraussMaffei, CellForm stands for the chemical and physical foaming of thermoplastics (thermoplastic foam casting). Foamed plastics possess the perfect combination of a lightweight structure, dimensional stability and cost-efficiency, which means they can be used to make many parts of outstanding quality. Foamed parts meet the increasingly urgent demand for conserving resources in every respect.

Machine concepts from KraussMaffei are able to cover the full range of physical and chemical foaming processes. Our extensive machine portfolio contains the right solution to meet any requirements. KraussMaffei is an established system partner for the MuCell® process and is one of the few companies to offer both process and machine engineering from a single supplier.

Your benefits at a glance:

- Complete solutions from a single supplier
- Processing expertise included
- System partner for MuCell®
- All common physical and chemical foaming processes available
- Extensive product portfolio of electric and hydraulic injection molding machines for CellForm
- Easy to operate and maintain

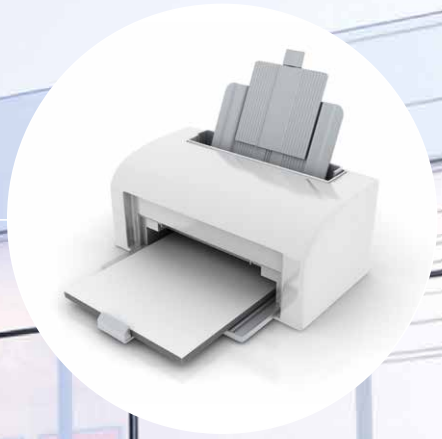
Packaging
Whether beverages, cosmetics or foodstuffs – almost everything is packaged with plastics today. With significant weight reductions and an infinite variety of designs for virtually unlimited individualization of the packaging

Electrical system
Warp-free and dimensionally stable foamed holders for ink cartridges

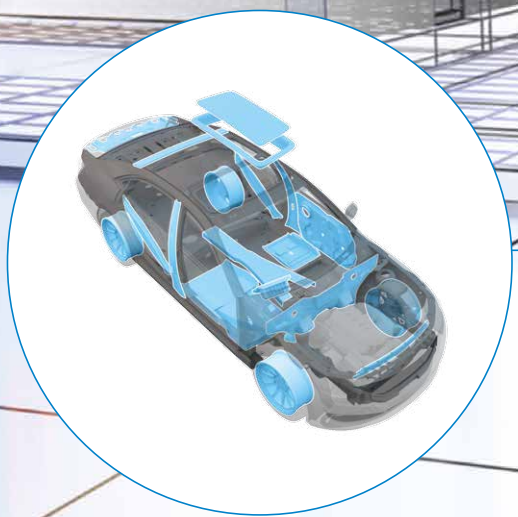
Transport
Sturdy foamed pallets and boxes for transportation that is both safe and lightweight

Leisure products
Large-format, contoured parts for sun loungers with a foamed core

CELLFORM TECHNOLOGY
VERSATILE APPLICATIONS



Household goods
Large-format, contoured electrical and housing parts for household appliances made from foamed thermoplastics



Automotive industry
Lightweight and low-warpage foamed car parts for low CO_2 output and easy mounting

CELLFORM REDUCES WEIGHT AND INCREASES EFFICIENCY **FOR COST-EFFECTIVE PRODUCTION**

In the CellForm process, blowing agents are fed into the raw material or melt in the form of granulate or gas to lower the density of the polymer. Essentially, there are two different types of foaming process: Chemical and physical foaming.

Gas preparation and foaming process

In the chemical foaming process, a granulated blowing agent is mixed into the polymer and disintegrates following a chemical reaction, releasing the propellant gas. In the physical foaming process, by contrast, a gas is added directly to the polymer melt. The foaming process always occurs in the cavity following the pressure drop. Maintaining a constant pressure level prevents premature foaming in the hot runner or plasticizing unit. Physical foaming is primarily known through the MuCell® process, which is patented by Trexel.

Both variants allow the density to be lowered and the holding pressure on the polymer to be eliminated. This has numerous advantages: faster cycles, less material consumption and better geometrical stability. CellForm is suitable for a wide range of parts in all industries and for nearly all thermoplastics. The specific advantages that CellForm confers vary from process to process.

Lower weight and less material consumption

The most obvious advantage of foamed parts is that they consume less material and have minimal weight. The material's lower density translates to savings of five to ten percent, depending on the part, without overly affecting its mechanical properties. For parts exposed to less mechanical stress, the weight can even be reduced by over ten percent. If the foaming processes are taken into account when the part is in the design phase, its wall thicknesses and weight can often be substantially reduced even more. In other words, the design of the part determines its weight.

Shorter cycles

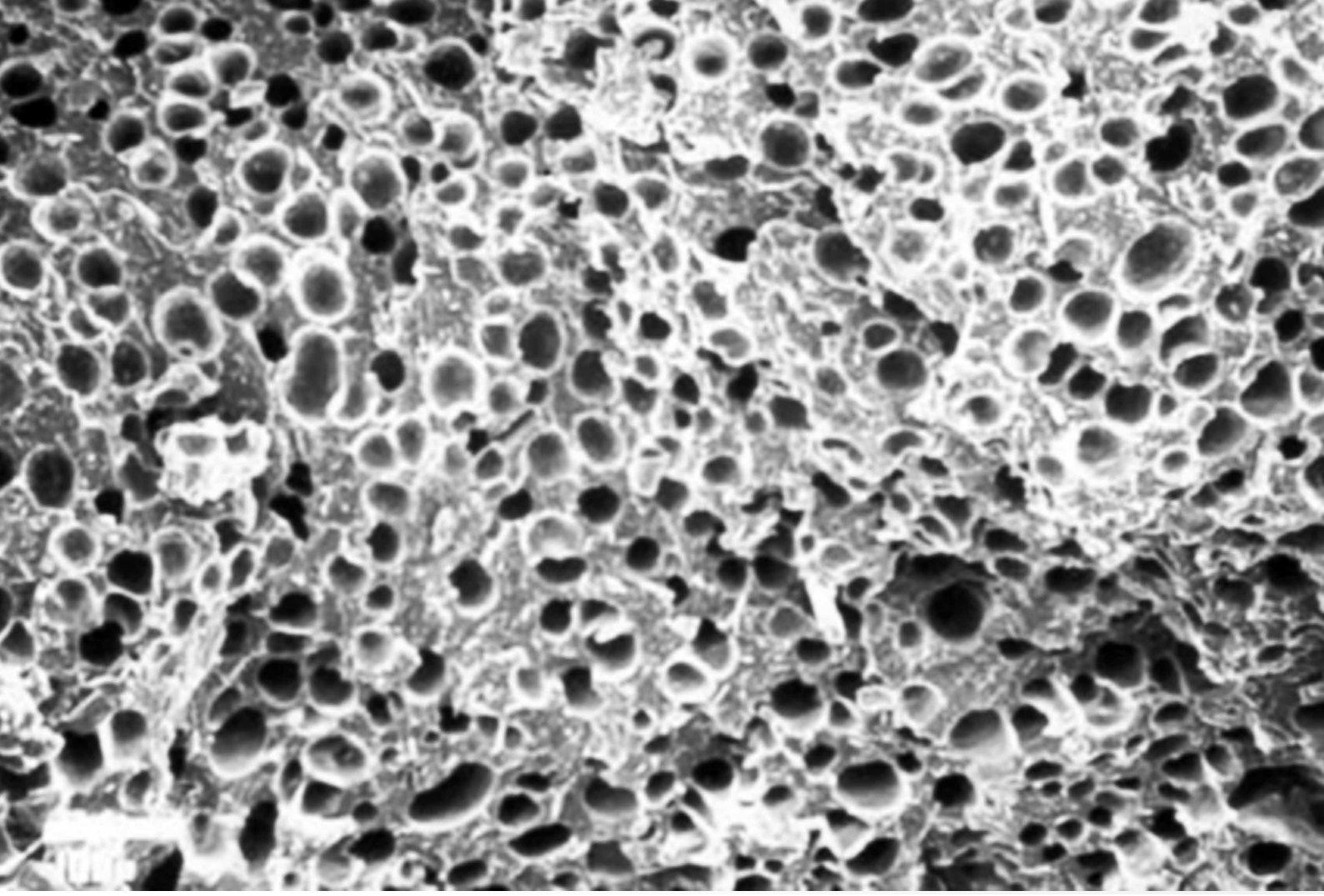
The viscosity of foamed materials is very low. This means that injections are generally quicker and temperatures of the melt and the mold are lower. The latter can result in a shorter cooling time. The greatest potential for saving lies elsewhere, however: Due to the foaming process, it is usually possible to do away with the holding pressure completely. Even if part of the holding pressure time goes into the cooling time, part of this time can be reduced. But this requires accumulation of material in the part and hotspots caused by that. These would cause a post-blow effect of the surface after the demolding.

More dimensionally stable, less warpage

Foaming, which eliminates the need for holding pressure, occurs uniformly throughout the cavity. Sunk spots are therefore reduced to a minimum and the melt solidifies under very little stress. The outcome is low-stress, low-warpage parts that are dimensionally accurate—and can be reproduced exactly cycle after cycle.

More cost-efficiency and flexibility due to reduced clamping force

Lower viscosity and no holding pressure means that the cavity pressure for foamed parts does not have to be so high. Reduction of the clamping force by up to 40 percent or more is entirely feasible. This increases flexibility, as the parts can be also be produced safely on machines with a lower clamping force.



Foamed part: a foamed core and compact outer layer as one

Optimal surfaces

The frontal flow generated during the injection process causes gas bubbles to rise to the surface, which then freeze when they come into contact with the mold wall, resulting in the formation of streaks. Increasing the mold wall temperatures during injection (DMH Dynamic Mold Heating) is one way of avoiding this. Another way is to minimize the pressure decrease during injection because the drop in pressure is the reason why the gas bubbles are generated in the first place. Specially designed or optimized materials (predominantly polyamides or polypropylene) may also help to minimize streaks. Finally, surfaces can also be laminated using textured surfaces, films or textiles (for example, with the in-mold labeling and DecoForm processes).

YOUR BENEFITS:

- Short cycle times
- Low part weight and lower material consumption
- Excellent dimensional stability for low-warpage parts that are dimensionally accurate
- Flexible and cost-efficient due to reduced clamping force

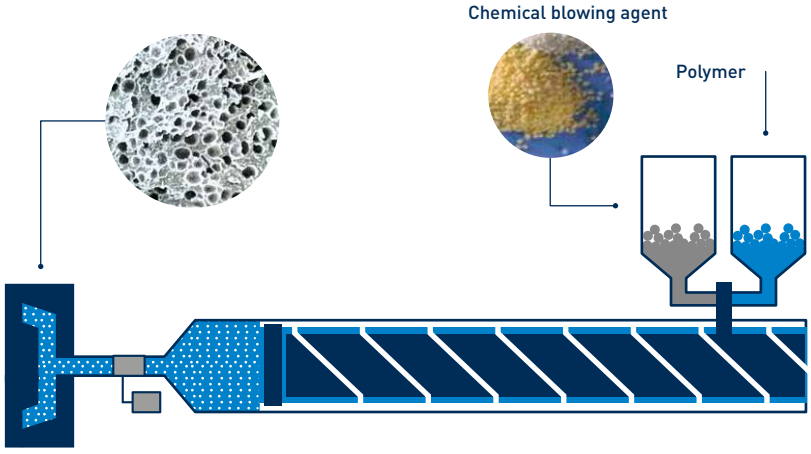
CHEMICAL FOAMING
HOMOGENEOUS DISTRIBUTION OF BLOWING AGENTS THANKS TO EXPERTISE IN SCREW DESIGN

In chemical foaming, a granulated blowing agent is added to the granular molding compounds in the hopper. The blowing agent must therefore be adapted based on the respective type of thermoplastic so that a chemical reaction can occur at the correct place within the plasticizing unit. Here, it is particularly important for the blowing agent to decompose neither too soon nor too late, since otherwise the gas either escapes from the hopper or is released too late.

The pressure drop during the injection process initiates nucleation and leads to the formation of gas bubbles. The foaming process takes place in the cavity, where there is room for the mixture of polymer and gas to expand. There is usually no need for holding pressure after injection, as that pressure is provided by the gas. The result is a closed cell structure. The process is optimal for manufacturing parts in low quantities, as the machinery investment costs are lower than for physical foaming. The blowing agents can be changed to meet specific requirements, for example in order to achieve better surfaces. Thermoplastics with lower processing temperatures, such as polyolefins and polystyrenes, are usually used to do this.

Blowing agent metering

When highly reactive additives – such as chemical blowing agents – are used, they need to be dispersed uniformly throughout the polymer melt. KraussMaffei offers special high-performance screws (HPS screws) that distribute the blowing agent extremely evenly, thus ensuring high process reliability and consistent product quality. KraussMaffei supplies HPSM screws for cost-efficient screw replacement. These screws also boast excellent mixing performance and, unlike the other HPS screws, can be used in standard cylinders as well.



YOUR BENEFITS:

- Very uniform distribution of the blowing agent
- Thus high process reliability and reduced blowing agent costs

Chemical foaming machinery specification

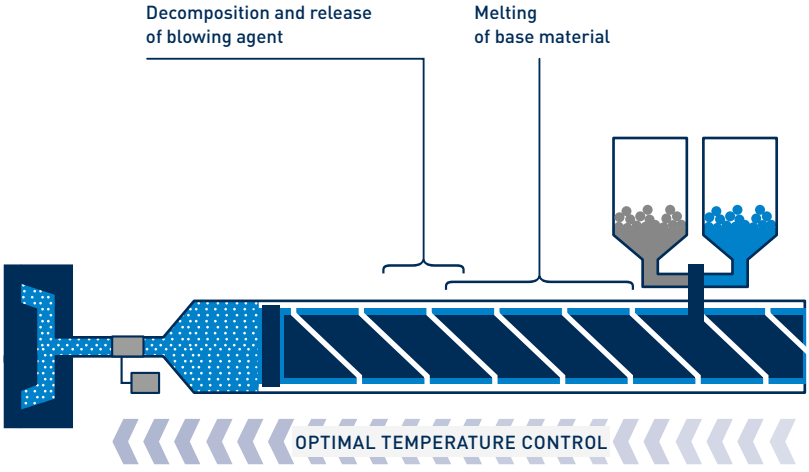
The chemical foaming process requires machinery with certain equipment. Under certain conditions, it is also possible to retrofit existing machines for chemical foaming.

Equipment required

– Pressure accumulator for enhanced injection performance
– HPS-UN or HPS-M screw

"CellForm" equipment package

– Active dynamic pressure control
– Safety-related preparations
– Reduced nozzle contact force while the mold is moving
– Machine shut-off nozzle or pintle with special monitoring function
– Active dynamic pressure monitoring when safety gate is open



Optimal temperature control for the best possible gas yield

Temperature too low: *Not enough or no decomposition of the blowing agent*
Temperature too high: *Decomposition reaction too soon*

HPS-UN screws with excellent mixing performance are particularly well-suited to chemical foaming

PHYSICAL FOAMING WITH MUCELL®
SUCCESS COMES QUICKER WITH A SINGLE SYSTEM PARTNER

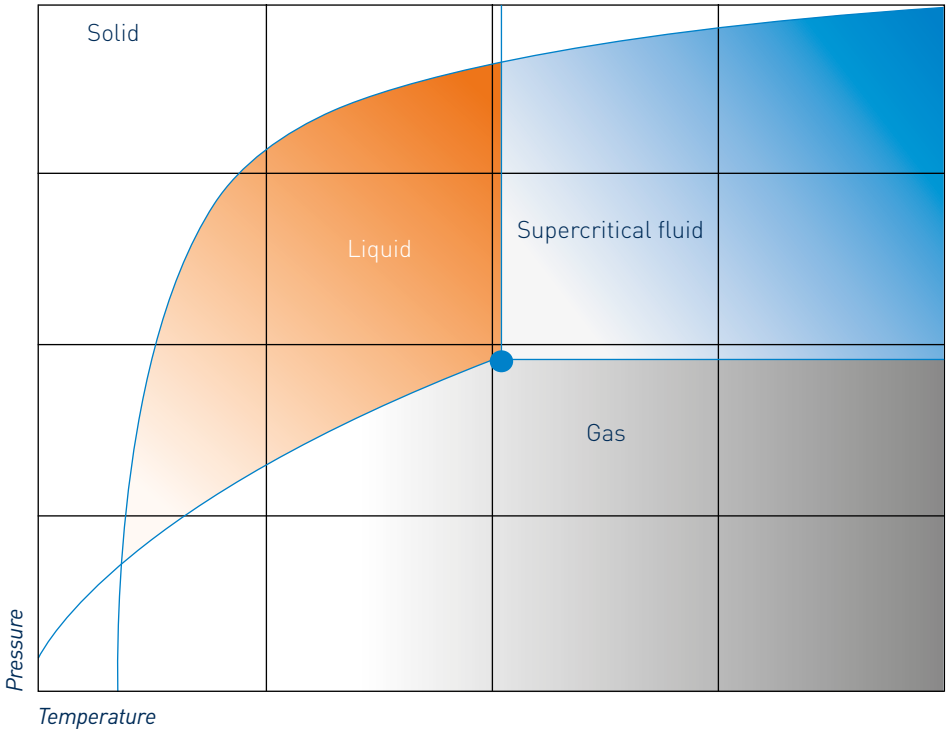
The MuCell® process is probably the best-known form of physical foaming. In the MuCell® process, gaseous blowing agent – N_2 or CO_2 – is injected under high pressure into the already completely melted polymer in the plasticizing unit. The quantity of gas metered in is determined by the type of thermoplastic.

Prior to injection, the blowing agent is a so-called supercritical fluid (SCF), a physical state which means that it has the incompressibility of a liquid and the solubility of a gas. This enables the SCF to dissolve completely in the thermopolymer melt and yield an extremely fine monophase system with the polymer melt. The back pressure, which in conjunction with MuCell® is also called the MuCell process pressure (MPP), plays an important role in the process. In the front mixing area of the screw it is responsible for forming and maintaining the monophase system, which ensures that the gas can dissolve in the melt.

Unlike the chemical foaming process and the usually alternative physical foaming process, the amount of gas can be set precisely and reproducibly by means of the injector opening time and mass flow of the gas.

Having been injected rapidly, the low-viscosity mixture experiences a rapid pressure drop inside the mold that generates nucleation seeds. The gas is then released from the melt and the resulting foaming pressure takes on the role of the holding pressure. The MuCell® foaming process is particularly suited for parts with wall thicknesses less than 4 mm and for high quantities.

Phase diagram – typical state changes for a gaseous mix



Like other gases, *nitrogen (N_2) is a supercritical fluid (SCF) under specific pressure and temperature conditions. The SCF dissolves completely in the polymer melt and is released again as a gas inside the mold cavity.*

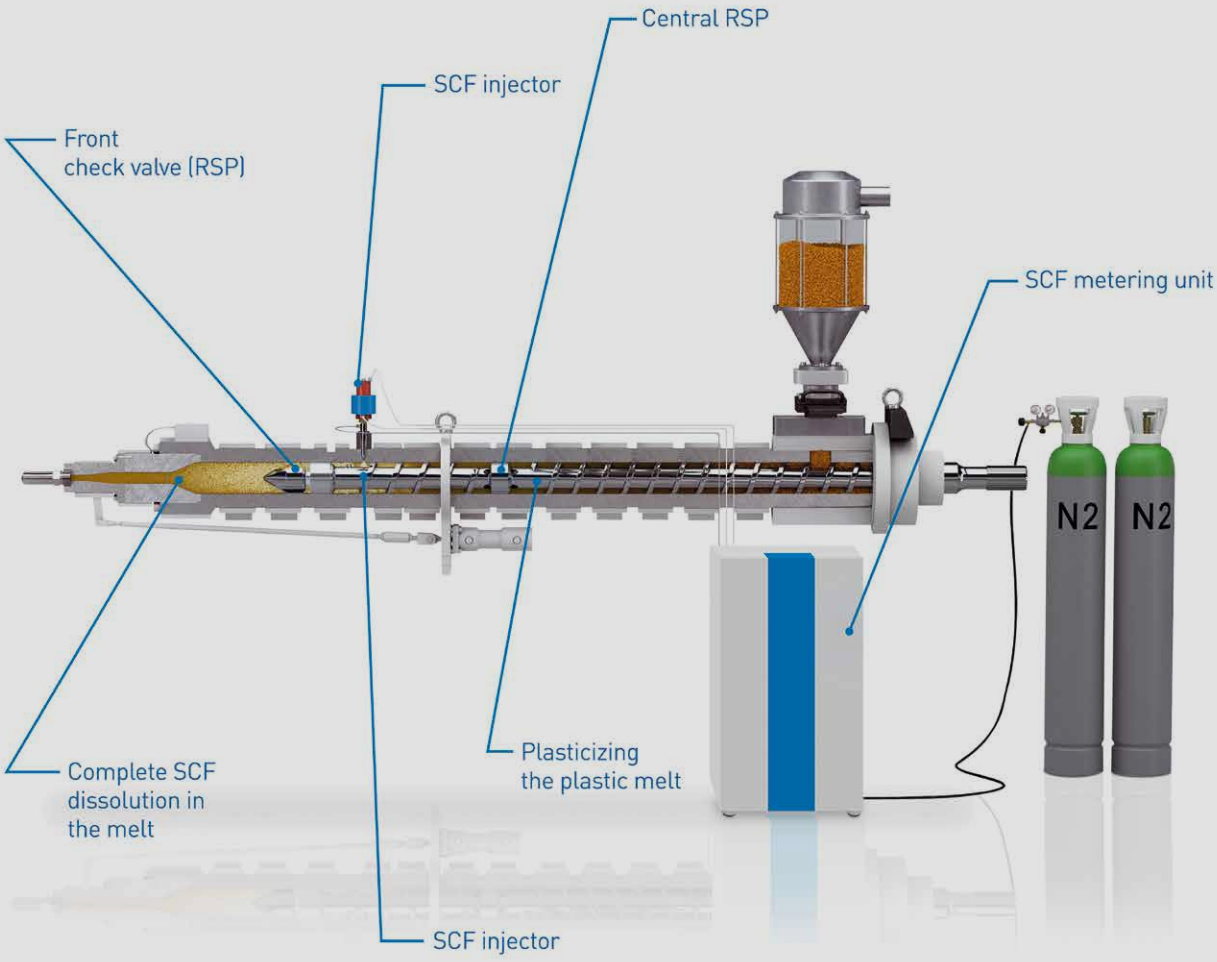


Diagram of plasticizing unit with MuCell® equipment

The graphic shows the most important components of the MuCell® system. The gas, usually N_2, can be supplied from cylinders, cylinder bundles or a nitrogen generator. The gas is transformed at high pressure into the supercritical fluid state in the SCF metering unit.

Control system

The Trexel self-optimizing system enables a fully automated process that generates a constant mass flow, thus ensuring identical gas content from shot to shot. One or two injectors inject the SCF into the melt via the plasticizing cylinder. Injection is triggered by a time- or position-controlled signal. An additional check valve in the middle of the screw prevents unwanted expansion of the gas-melt mixture back towards the feed.
The machine shut-off nozzle and the active dynamic pressure maintain the melt pressure to prevent foaming in the plasticizing unit.

YOUR BENEFITS:

- High foaming pressure for greater dimensional stability and smaller sunk spots
- Precisely adjustable, reproducible gas nucleation
- No decomposition products generated during gas release
- Low costs for gas

DETAILED PRODUCT INFORMATION
INJECTION MOLDING MACHINE AND MUCELL® – PERIPHERALS IN PERFECT HARMONY

KraussMaffei injection molding machines are perfectly matched to Trexel system components

Everything from a single source

The MuCell® process is licensed by Trexel. KraussMaffei has been successfully using MuCell® technology for many years and is one of Trexel's major clients. The fact that we have authorization to market MuCell® directly around the world further highlights our technological expertise. This means you can order your complete MuCell® system directly from KraussMaffei—without the need for additional agreements with third parties, without problems during the course of the project and including all usage rights.

Extremely easy to operate

The MuCell® control system features a special safety gate monitor that allows the back pressure to stay active even when the safety gate is open. The pressure on the gas-laden melt is not reduced. This has the benefit of keeping the start-up phase itself very short and simple. And it extends the uptime of the MuCell® machine while offering a consistently high level of safety for the operator.

Plasticizing unit optimized for MuCell®

MuCell® plasticizing units, like all KraussMaffei plasticizing units, are made in-house—and this is done fully in compliance with the Trexel guidelines. The screws have an L/D ratio of 23 for reliably generating the polymer/SCF monophase system.

They are wear-resistant to ensure the screws have a long service life and guarantee that processes are consistent. The screws themselves feature an intensive

plasticizing section and a downstream intensive mixing zone. In the cylinder, the plasticizing zone is installed, followed by the gas injector (up to two may be installed), which is connected to the SCF metering unit. A second check valve prevents the gas from expanding prematurely in the cylinder back towards the feed opening.

Locking system for controlled conditions

For cold-runner molds, the injection units of the injection molding machines are equipped with needle shut-off nozzles. The nozzles are extended to ensure perfect mating and will reliably prevent unwanted expansion into the cold runner. Alternatively, where molds have needle shut-off nozzles, a pivot pin needle valve can be provided on the machine side.

Total control thanks to full integration in the MC6 control system

All the functions of the Trexel controller are fully integrated into the KraussMaffei MC6 machine control system. All values, such as throughput rates, injector opening time, pressures, etc. are grouped together on their own MuCell® screens. The most important process parameters can be monitored via tolerance bands. This allows centralized adjustment and monitoring of the entire injection molding process and adds an additional level of process reliability thanks to full integration.

MuCell® option package – retrofittable in stages

Any new or existing machine can be prepared or retrofitted for use of MuCell® with little effort.

Equipment required:

– Pressure accumulator for enhanced injection performance
– Active dynamic pressure control system, including proportional valve control
– Reduced nozzle contact force
– Nozzle closure actuation while the mold is moving

All process parameters can be set centrally from the MC6 control system using the special MuCell® controller

YOUR BENEFITS:

- Complete solution from a single supplier
- No interface problems
- Active back pressure (screw position point control) even when safety gate is open
- All usage rights included
- Plasticizing unit specially optimized for MuCell®
- Complete integration in MC6 control system

Preparation for CellForm and MuCell®:

– Interface for MuCell® peripherals
– Safety modifications
– HSVN needle shut-off nozzle with additional monitoring
– Active dynamic pressure control when safety gate is open

MuCell® equipment package:

– MuCell® plasticizing unit
– MuCell® software package

MuCell® peripherals:

– MuCell® gas metering unit (SCF system, pressure control module, injector, supply lines)
– All usage rights included

Option of opening compression injection (SGI):

– Parallelism control (only available for GX and MX)
– Compression package for closing compression, expansion compression or opening compression, in parallel or in sequence with the injection process

OPEN COMPRESSION MOLDING (OCM)
FOAMING WITH A DEFINED FOAM STROKE

In the case of open compression molding, unlike the standard thermoplastic foam casting process, the cavity is completely filled so that expansion of the melt is initially prevented after the injection process. After a short phase of cooling time in which the surface congeals and forms an outer layer, the clamping force is quickly released and the cavity opens to a defined gap dimension.

This results in more space for expansion in the opening direction. The pressure in the still plastic core of the part falls and the gas can foam the plastic melt in the opening direction. After the residual cooling time, the clamping unit is opened completely and the part is removed. The mold cavity pressure in this process is higher than in the standard thermoplastic foam casting process (low-pressure process), which is why it is also called a high-pressure process. Over time, many names for this process have arisen on the market (such as SGI, breathing mold, CoreBack process, negative compression).

Details about the opening stroke

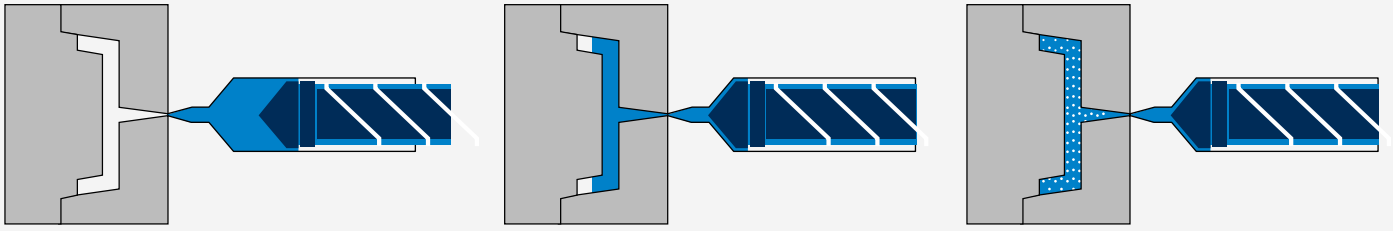
The filling can be done in a purely volumetric manner or in a brief holding pressure phase. Which opening stroke is possible depends on the following factors:

- Waiting time between end of injection and beginning of opening stroke
- Material
- Opening speed

KraussMaffei offers a special compression package in conjunction with a very precise parallelism controller for the opening stroke. If necessary, this can be used to insert a compression stroke in the clamping direction before the opening stroke. This is particularly suited for very large or very thin-walled parts so that the cavity can be completely filled as uniformly as possible with little need for pressure (see Figure 1a).

1a. Low-pressure process:

The degree of foaming corresponds to the ratio between a completely filled cavity with holding pressure (=compact injection molding) and a partially filled cavity.



1. Start injection

2. Partial filling

3. Foaming until volumetric filling

Goal and limits of the process

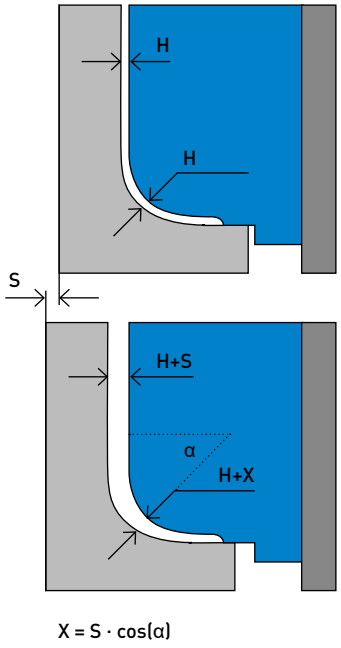
There are three basic rules:

1. The injection should produce the thinnest possible walls to achieve the lowest possible shot weight
2. Pull up only enough to achieve the necessary bending stiffness of the part
3. Unlike in the low-pressure process, where the shot weight is determined by the partial filling (approximately 85-95%; see Figure 1a), in the OCM high-pressure process the shot weight is defined by the complete filling of the cavity. After the injection, the part is nearly compact because there is no room available for expansion. (see Figure 1b)

To reduce the weight and amount of material used as much as possible, therefore, the injection has to produce the thinnest possible walls, but that results in the part having a low bending stiffness. So the purpose of the opening stroke is to make the part thicker, thereby increasing the bending stiffness. A distinction is made here between one stroke in which the entire mold is opened and one or more strokes carried out partially over cores. The first is ideally suited for flat parts, while the second is better for complex 3D parts. The process requires a change in thinking during the design phase since the geometry of the part has to enable an opening stroke.

As a general rule, the foaming occurs only in the stroke direction. No new space is provided perpendicular to the stroke direction or in areas without stroke movement so that the material does not expand here (see Figure 2) and predominantly remains compact. This can be used specifically in areas where special strengths are required.

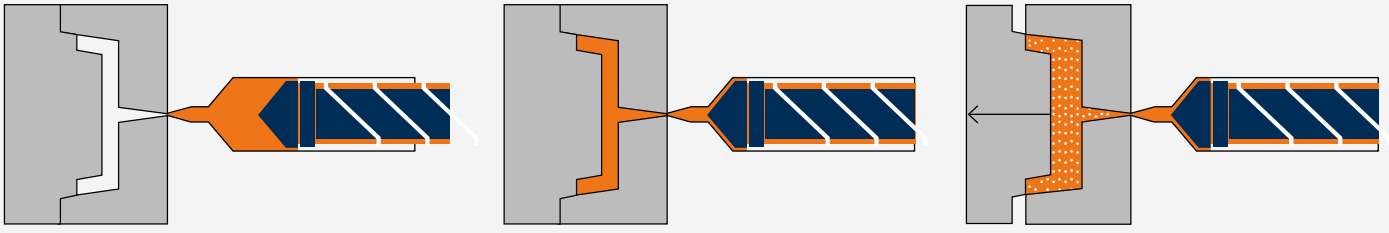
2.



$X = S \cdot \cos(\alpha)$

In the OCM process, the foaming occurs only in the opening direction.

1b. High-pressure process: After the injection, the part is nearly compact because there is no room available for expansion. The degree of foaming is determined by the stroke.



1. Start injection

2. Volumetric filling

3. Foaming due to opening stroke

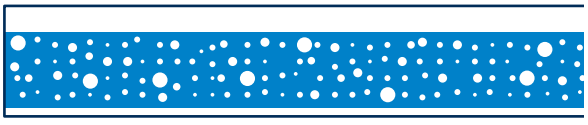
Low pressure and high pressure

Technically possible strokes can be more than double the original wall thickness. Practically necessary strokes depend on the desired bending stiffness. When the measures just described are taken into account, then weight advantages of 25% and much more are possible. Another advantage of the process is the uniform distribution of pressure for the melt in the closed mold. Here, unlike the low-pressure process (see Figure 4a), you have a uniform start condition for the foaming over the entire flow path. The outcome is a uniformly distributed foam structure perpendicular to the opening direction (see Figure 4b). The edge of the part, which is pulled up by the stroke movement, is held at the corners by the formation of a compact outer layer. As a result, it is possible for the edge to develop a bulging contour (see Figure 5).

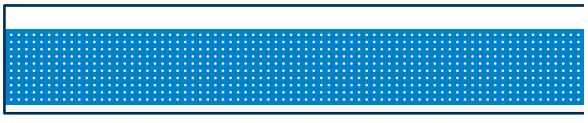
From the standpoint of process technology, the limits of the process have been reached when the foam structure tears off or delaminates in the core of the part. This can be easily and reproducibly prevented by means of limited opening strokes and process technology measures.

As the process was developed, KraussMaffei was significantly involved from the very beginning and thus gained a lot of experience. A corresponding number of KraussMaffei machines are on the market with this process. We will gladly share our knowledge with you!

4a. Standard foaming (low-pressure process):



4b. OCM / SGI (high-pressure process):



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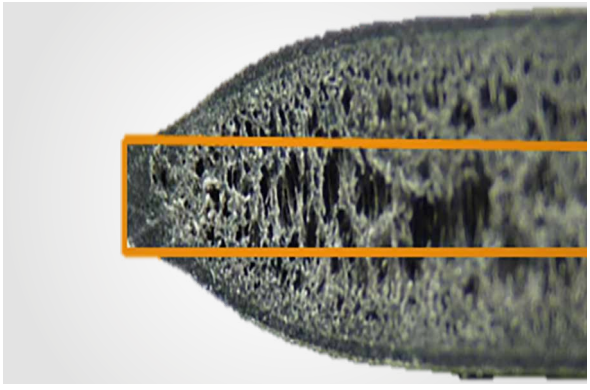

MOST IMPORTANT EQUIPMENT OPTION:
A HIGH-PRECISION COMPRESSION MOVEMENT

In the past, the mold was frequently opened by mold-side gas pressure springs or hydraulic cylinders. State-of-the-art machines from KraussMaffei can enable this process on the machine side by means of an optional compression package with parallelism control.

The core of this package is a hydraulics concept that enables a specifically defined opening movement of the mold by means of a controlled, finely metered hydraulic system. The opening movement is produced by the opening force of only the movement cylinders or by additional machine-side or mold-side opening cylinders. Since the cavity is opened during the cooling process, there is a danger that edges can move out uncontrollably or be overinjected. Depending on the design requirement, this is frequently unwanted and can be prevented by a positive mold or a mold with a movable, trailing contour frame. The stroke movement of the frame can be driven mechanically by springs or hydraulically by what is called a parting plane control. To prevent damage with this type of mold design, the two mold-halves must have a very parallel opening movement. This is made possible by the extremely precise platen parallelism control developed by KraussMaffei for the GX and MX machines series, in which the four pressure pads are each separately activated by a proportional valve.

The pressure pads counteract the opening force in a controlled manner and balance the set and actual values. The measuring system required for this is on the clamping unit in the standard version. Optionally, a separate measuring system can be installed at the mold gap. That results in a very finely controlled stroke movement.

The machine-side requirement for high process quality is to have extremely sturdy mold fixing platens that neither bend nor tilt during the movement. KraussMaffei machines have already satisfied these conditions in the standard version by means of excellent platen rigidity in combination with flux-optimized sliding shoes.

This means a greater expense is required on both the mold side and the machine side. On the other hand, the material savings are substantially higher compared to the low-pressure process, which can become cost-effective very quickly, particularly for high shot weights, and can lead to a significant increase in productivity.

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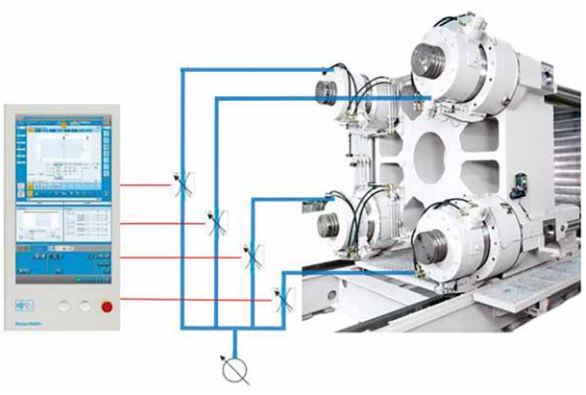

OUR WORLDWIDE EXPERTISE IS YOUR ADVANTAGE
DIGITAL & SERVICE SOLUTIONS

With your KraussMaffei machine, you have chosen a product that delivers the highest levels of productivity and reliability. In addition to our range of machinery, KraussMaffei focuses on comprehensive and future-oriented solutions, innovative business models and an innovative portfolio of digital products.

Customer service at the touch of a button

The process of digital transformation is becoming faster and easier than ever for the customer. Our Digital & Service Solutions unit makes your production chain even more flexible and efficient with future-oriented solutions. KraussMaffei thus globally provides an all-inclusive customer service package and networks machines and processes with each other. Our global support offers a sound basis for your local long-term success.

Individual challenges in mechanical engineering call for intelligent solutions

With our services portfolio, we support you throughout your machine's lifecycle with a strong focus on your specific needs. In order to satisfy your wishes, we offer you a wide range of solutions in order to ensure maximum availability and optimum productivity of your machines.

Technology³ as a unique selling proposition

KraussMaffei is the only supplier in the world with a product range comprising the most important machine technologies for plastic and rubber processing: injection molding machinery, automation, reaction process machinery and extrusion technology. KraussMaffei is represented worldwide with more than 30 subsidiaries and over 10 production plants as well as about 570 commercial and service partners. Working together with our customers and partners, we are thus in a position to offer vast and unique expertise in the industry.

You can find further information at:
www.kraussmaffei.com

KRAUSSMAFFEI – PIONEERING PLASTICS

Extensive expertise from a single supplier

KraussMaffei is one of the world's leading manufacturers of machinery and systems for producing and processing plastics and rubber. Our brand has been synonymous with cutting-edge technology for over 180 years. Our product range includes all technologies in injection molding, extrusion and reaction process machinery. KraussMaffei has a unique selling proposition in the industry as a result. By drawing on our proven innovative capacity, we can guarantee our customers sustained additional value over their entire value-adding chain through our standardized and individual product, process, digital and service solutions. The range of our products and services allows us to serve customers in many sectors including the automotive, packaging, medical and construction industries. We also supply manufacturers of electrical and electronic products and household appliances.

At your service all over the world

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