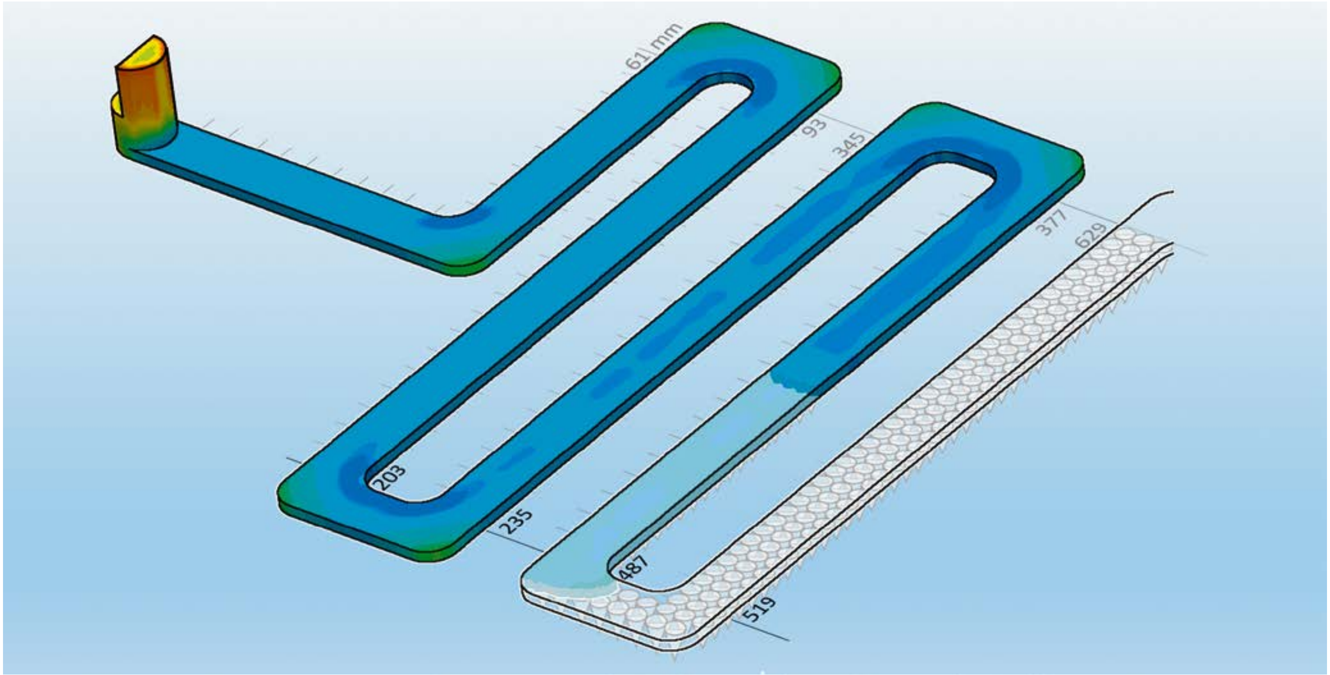
Everything Keeps Flowing

Structured Surfaces in Injection Molds Allow for Longer Flow Paths

The filling of injection molds with plastic melt depends, among other things, on the surface quality of the mold cavity. An application-oriented structuring of the cavity surface increases the length of the flow path of the melt by up to 18 %, depending on the plastic material. This opens up the possibility of achieving longer flow paths with existing injection molding technology.



Plastic melt continues to flow with microstructures in the mold (© IKV)

Whether display frames or housing covers, front ends or decorative trim – the list of plastic components with long flow paths is considerable. For the high-quality manufacture of all such products, a number of factors have to be taken into account. When designing the injection mold, the flow properties of the desired plastic must be considered when selecting the gate positions. In order to avoid long flow paths, multiple injection gates are often selected. In addition, the injection molding machine should generally be able to provide a high injection pressure.

If, however, problems with unattainable flow path lengths occur during filling of the part, it is usual to increase the injection speed, the melt temperature or the starting temperature of the mold temperature control. The melt temperature can often only be varied within a small process window, otherwise other processing problems will occur. Increasing the starting temperature at the temperature control units extends the necessary cooling time by 20 % per 10 °C and thus leads to uneconomical cycle times [1, 2].

The subject of numerous experiments by various injection molders worldwide is the question regarding the influence of mold roughness on the filling of the cavity. In one study, injection molding tests were carried out with average roughness values of the cavity surface of between 1.6 and 5.1 µm at different mold and melt temperatures [3, 4]. It was found that the cavities were filled further with lower surface roughness.

Microstructured Mold Surfaces

The researchers explain their results with the proportional behavior between surface roughness and thermal conductivity. The rougher a surface, the larger the contact area with the plastic and the more heat can dissipate. The flowability and thus the achievable flow path length become smaller [3, 4]. Researchers at a Czech

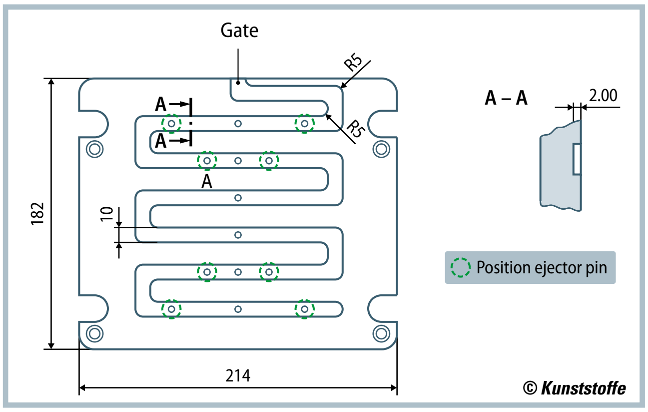


Fig. 1. Cavity with flow meander geometry. The total flow path length is 921 mm (source: IKV).

university come to a completely different conclusion. A test with similar surface roughness levels shows that the flow path length decreases with smooth surfaces [5].

Researchers at the Institute for Plastics Processing (IKV) in Aachen, Germany, are investigating how microstructured mold surfaces affect the flow path length of plastic melt. For this purpose, it is beneficial to use cavities with the longest possible flow paths in the smallest possible space like flow spirals or flow meanders. Taking into account the test molds available at IKV and good mold venting, a cavity is selected as the test geometry which forms a 921 mm long, 2 mm deep and 10 mm wide flow meander (**Fig. 1**).

The surface at the bottom of the cavity is microstructured by laser ablation (Sirris, Diepenbeek, Belgium) (**Fig. 2**). 50 µm deep conical structures with a basic cone diameter a of 46 µm are machined into the flow meander at a distance b of 125 µm from the centers of the cone bottom. A further, identical meander cavity remains unstructured and serves as a reference. The cavity is placed in the moving mold half. The fixed half has a brushed polished surface and is not changed.

Longer Melt Flow with Structuring and Heat

In addition to structuring, the melt temperature T_S, the mold surface temperature T_W, the maximum injection pressure p_E and the melt flow rate are varied (**Table 1**). The melt flow rate is changed by using two polycarbonates (type: Makrolon 2405 and Makrolon 2805; manufacturer: Covestro Deutschland AG, Leverkusen, Germany), which differ only in their molecular weight. The injection molding process is adjusted so that the filling of the cavity is pressure-controlled. This is contrary to conventional speed-controlled process control. However, the constant injection pressure allows a comparison of the molded parts and the attainable flow path lengths.

The analyzed factors and the interactions (**Fig. 3**) are all statistically relevant with a significance level of 95 %. The standard deviations are too small to be documented. As expected, the interactions of surface structuring, melt flow rate and mold temperature or melt temperature show a flow path lengthening effect with high temperatures and low viscosity. The higher the contact temperature between the plastic melt and the cavity wall, the longer the melt remains flowable. This leads to longer flow paths under the same pressure conditions.

The results so far confirm that the achievable flow path length depends to a large extent on the mold surface temperature. The lower it is, the less the cavities and microstructures are filled. This is mainly due to the fact that the flowability of the plastic melt depends heavily on the temperature [6]. The positive influence of mold structuring is also noticeable, which is particularly evident in the case of the more readily flowing PC (**Fig. 4**).

The schematic illustration of the filling process (**Fig. 5**) shows that the contact surface between melt and mold wall during the filling process depends heavily on the filling depth into the microstructures. The deeper the melt flows into the microstructure, the larger the contact area. On the left is the model showing how the flow front behaves on a structured mold

Parameter	–	0	+
Melt temperature [°C]	280	300	320
Mold temperature [°C]	60	90	120
Injection pressure [bar]	500	1000	1500
Melt flow rate MFR [g/10 min]	10		20

Table 1. Parameters examined and their levels. The temperatures indicated are measured with contact thermometers on the cavity surface and in the melt and are not the values set on the temperature control unit or on the machine control (source: IKV).

surface. According to the generally accepted model of frontal flow, the plastic melt does not slide on the cavity surface, but rolls off it and forms a solidified »

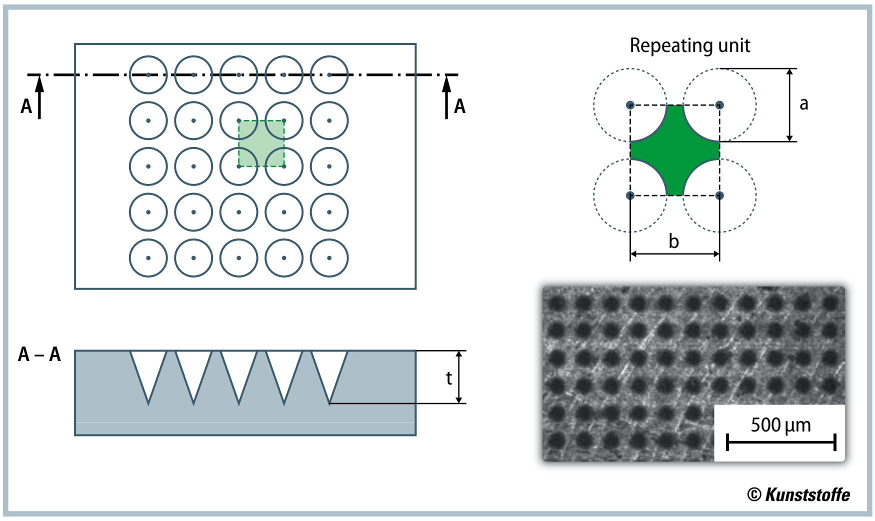


Fig. 2. Arrangement of the conical microstructures (bottom right: microscope image). These are machined by laser ablation (source: IKV).

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Practical Benefits

A reduction of injection pressures with the same flow path lengths or an increase in the attainable flow path length with existing injection molding technology is fundamentally relevant for injection molders. Structuring should only be used in the invisible area of molded parts, because surface marks are to be expected on the molded part.

To-Dos up to Series Maturity

The dependence on viscosity must be analyzed with further test series, as the optimal structure density depends on it. An influence of the surface structure on part warpage may be possible with one-sided structuring. This has to be checked before series production.

Service

References & Digital Version

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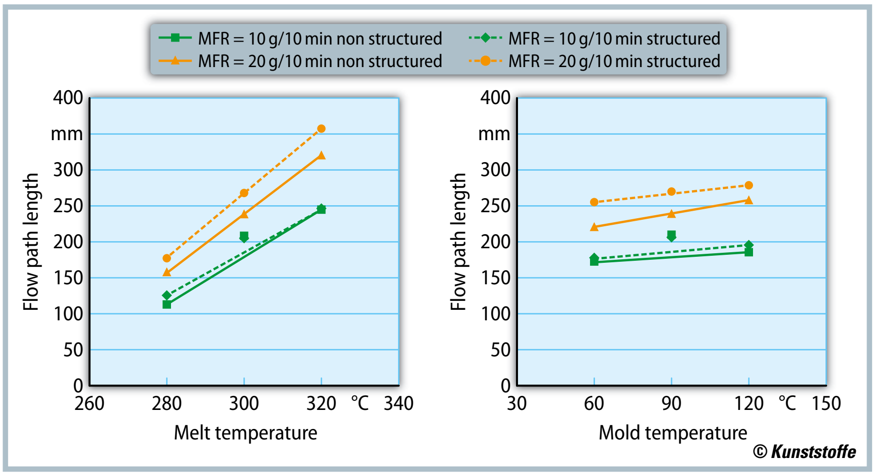

Fig. 3. The effects and interactions of the investigated parameters show a relevant influence on the flow path length (source: IKV).

surface layer. Wall detachment and sliding effects are excluded according to this theory.

Insulation Effect of Entrapped Air

At the flow front, the pressure of the melt corresponds to the ambient pressure. At this point it does not replicate the structure shape or only to a very small extent. According to this model, the melt directly behind the melt front comes partly into contact with mold steel and partly with air in the microstructure. Due to the thermal insulation effect of air, the heat flow transported from the melt into the air is significantly lower than the heat flow from the melt into the mold steel.

In comparison, in the case of a frontal flow of the plastic melt, the same amount of heat is dissipated from the melt into the steel mold wall via a non-structured surface (**Fig. 5, right**). According to this model, less heat is dissipated in case a) over the same flow distance and time than in case b), which leads to a higher temperature and longer flowability of the melt in case a).

This model is only valid if the structures in the mold are not filled until they are under pressure and not immediately after the overfeeding of the structure. In order to check whether this requirement is met, microscopic images of the surface of the flow meanders are taken at different points. The structure height decreases with increasing flow path towards the flow front, and reaches the height of 0 µm directly behind the flow front (**Fig. 6**).

A partial filling of the meander with different injection volumes confirms this result. With increasing pressure towards the gate, the structure height increases. The studies show that the prerequisite of structure filling under pressure for the model hypothesis is fulfilled, and that a microstructured surface reduces the contact of the melt with the mold during the period of the injection process relevant for flowability.

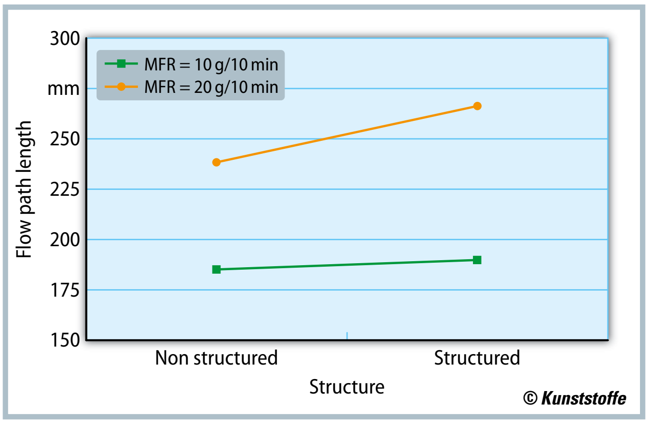

Fig. 4. The influence of the mold structuring on the achievable flow path length is clearly visible, especially with easy-flowing material (source: IKV).

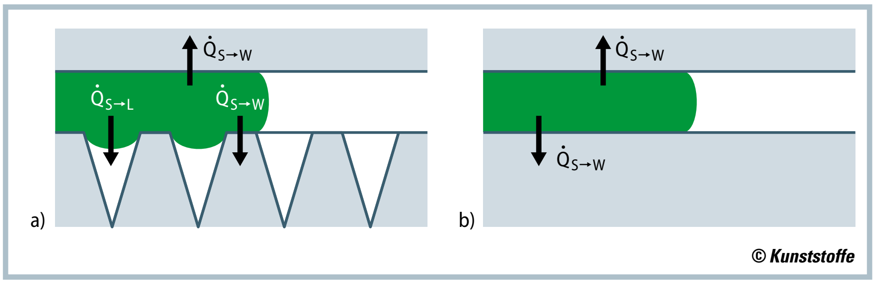

Fig. 5. Model presentation: the microstructure reduces heat dissipation (source: IKV).

High Structural Density Permits Longer Flow

A higher density of the microstructures arranged on the cavity surface should, according to the model, further extend the attainable flow path. To check this, two further mold inserts with the same flow meander cavities are produced and provided with a surface structure. The diameter (a) of the individual structures and the conical shape remain identical. Only the distance (b) from centre to centre of the structures is varied. A smaller distance increases the structure density ρ_S (**Table 2**) and thus reduces the contact surface between the molten plastic and the mold steel.

The measurements are plotted as the average flow path length of the meanders over the structural density (**Fig. 7**). In addition to the already presented results of 0% and 10.6% density, the flow path lengths for the structural densities of 28% and 44.7% are shown. For the more readily flowing polycarbonate, the flow path is extended to 282 mm at a structure density of 28%, which corresponds to an increase of approximately 18% compared to the unstructured cavity. At the highest structural density, however, the effect is reversed. The flow path length drops back to the initial level.

In the case of the less readily flowing polycarbonate, the flow path length increases by 12% up to the structural density of 28%. Compared to the low-viscosity material, however, no decrease in the achievable flow path length can be detected at higher structural densities.

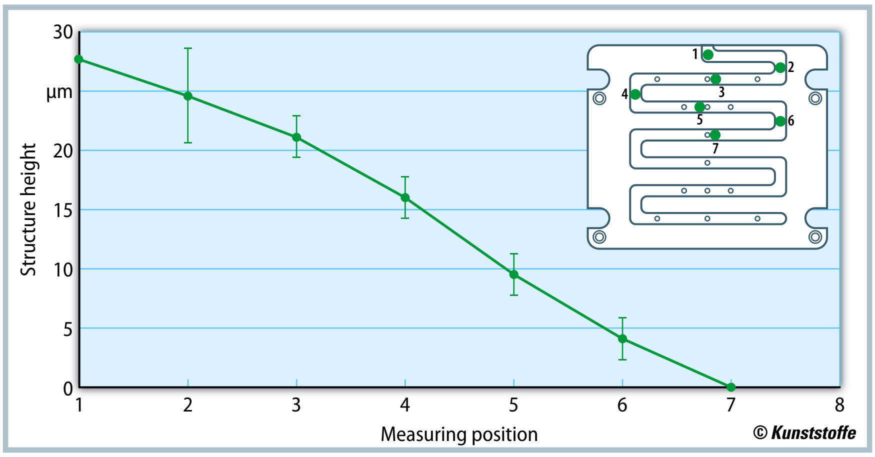

Fig. 6. At the flow front the structures are not filled (source: IKV).

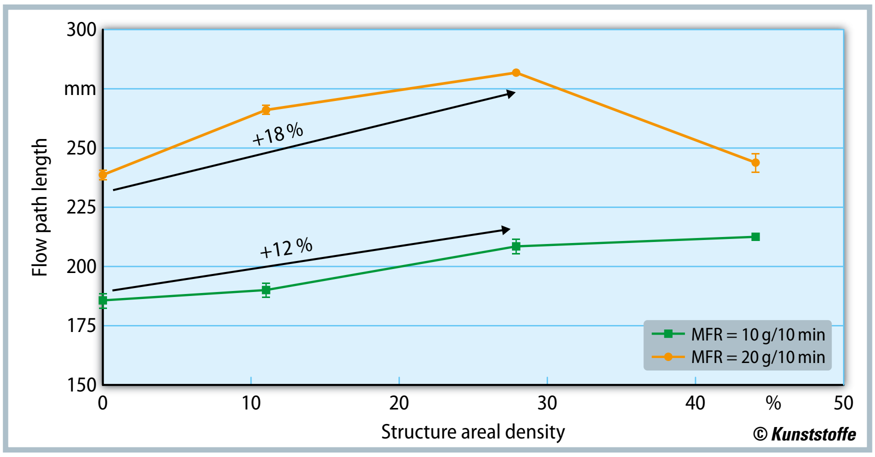

Fig. 7. The structure density has a decisive influence on the flow path length of the melt (source: IKV).

Cavity	*a* [µm]	*b* [µm]	ρ_S [%]
1	0		0
2	46	125	10,6
3	46	77	28,0
4	46	61	44,7

Table 2. Structural specifications of the four cavity inserts used (source: IKV).

Since the cavity surface for the densest structuring consists nearly 50% of air and less unstructured steel surface is available to serve as a contact surface, it is reasonable to assume that the low-viscosity melt tends to already flow into the structures behind the flow front. The contact surface and thus the heat dissipation to the mold steel increases, which shortens the attainable flow path. The higher-viscosity melt does not show this effect due to its lower flowability. Microscopic images of the flow fronts prove this theory. Similar results have been obtained with different types of polypropylene.

Conclusion

The results show that a structuring applied to one side of the injection mold significantly extends the flow path of the melt with the same process parameters. In addition, depending on the processing viscosity, there is an optimum structural density for the longest possible flow paths. Injection molders can use this knowledge to achieve longer flow paths with the same machine technology. If the structure is applied to the moving side of the mold, no impairment of visible surfaces is to be expected. It remains to be checked how a structuring applied on both sides affects the flow path and what temperature differences in the melt can be expected from the structuring. ■