Gate design for a high-quality surface finish

1. Introduction

Substitution, integration and the thin-wall technique are the standard challenges encountered in the development and design of plastics components today – challenges which companies need to tackle in order to survive in the face of fierce competition.

In the past, a clear division prevailed in construction systems: there were visible parts subject to stringent surface-finish requirements on the one hand, and engineering parts of a functional nature on the other. Today, however, even engineering parts are increasingly required to combine functionality with a “cosmetic appearance”. Hence, terms such as “engine compartment design” are emerging in the automotive industry, while the concept of a “quality look” is to be found in the household goods industry.

This has meant that the range of functions offered by a component have basically come to be taken for granted, while the external appearance of the component has been upgraded into a sales argument.

As a result, there has been an increase in the requirements placed on all the individual elements of the process chain,

- material,
- molded part,
- mold and
- injection molding machine,

making it necessary for these elements to be specifically adapted to the new requirements.

2. Parameters influencing surface quality

Within the process chain, the material employed is key to successful design in terms of color, color depth, haptics and a degree of gloss, etc. These features must be taken into consideration during molded part design by ensuring that the design is suitably tailored to the plastic. Selection of an appropriate production process and a suitable mold design will then lead to the desired surface finish.

Figure 2 shows the main parameters affecting surface quality and, at the same time, highlights just how many different aspects there are to this subject in practice.

With consideration to what has been said above, this brochure focuses on the mold and, more specifically, on the gate design required to achieve high-quality surface finishes.

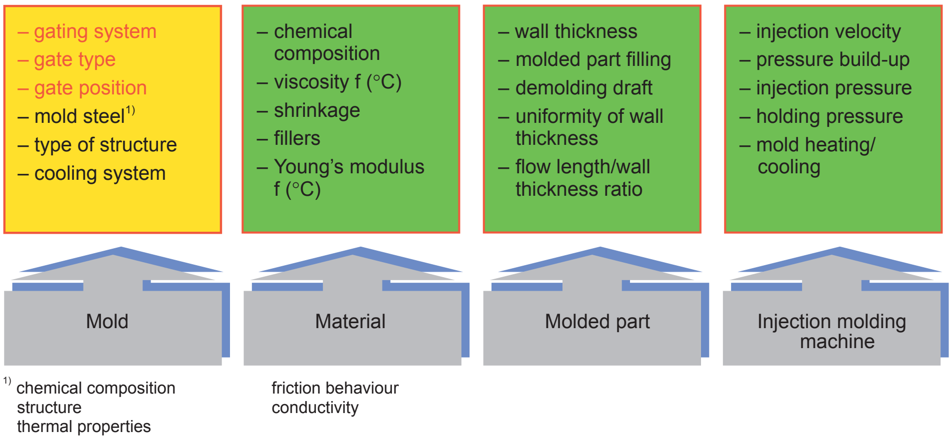


Fig. 2: Factors influencing surface quality

3. The gating system

The gating system is a process engineering "means to an end", which conveys the melt that has been compounded in the injection molding cylinder into the mold cavity. The article designer must bear this necessary function in mind right at the initial stage of design if he is to satisfy the basic conditions for a high-quality surface.

Three different points of view emerge:
1. from the design point of view, parts must be produced without any gate markings, or, alternatively, the injection point must be shifted to a non-visible point

2. as far as the raw materials supplier is concerned, the main consideration is gentle compounding and transport of the melt into the cavity

3. the processor requires short cycle times, minimal sprue waste, a high processing latitude and trouble-free production in order to ensure cost-efficient production

Figure 3 sets out the requirements placed on the gating system from the viewpoint of the raw materials supplier and the processor.

One further point: apart from what has already been said, the gating system must be dimensioned in such a way that the holding pressure necessary to offset the volume contraction (shrinkage) can act during the cooling phase.

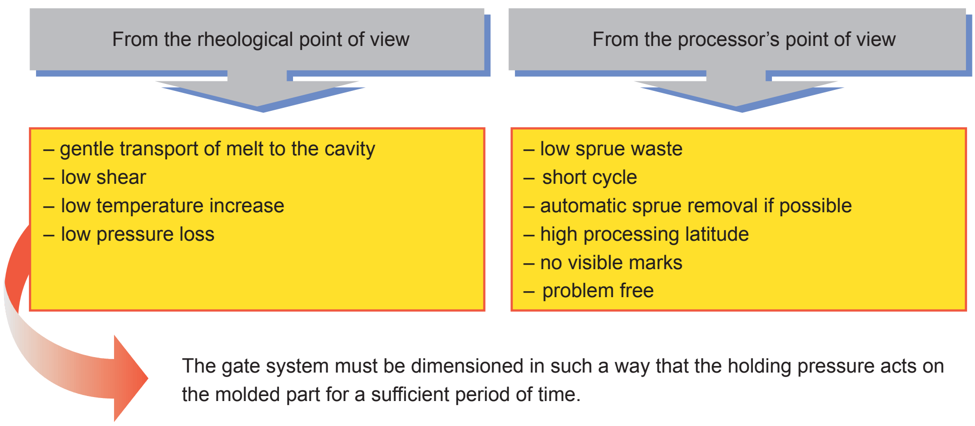


Fig. 3: Requirements on the gating system

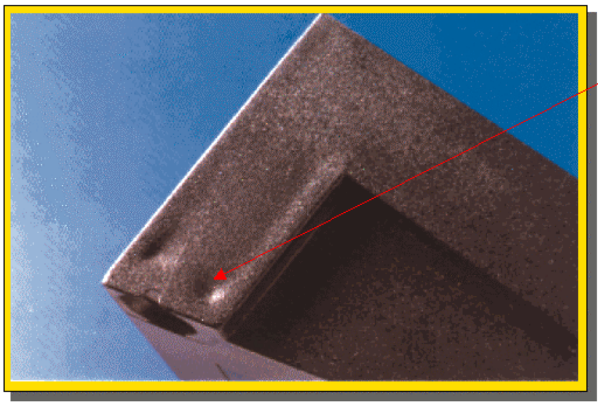


Fig. 4: A component with sink marks caused by unfavorable gate dimensioning

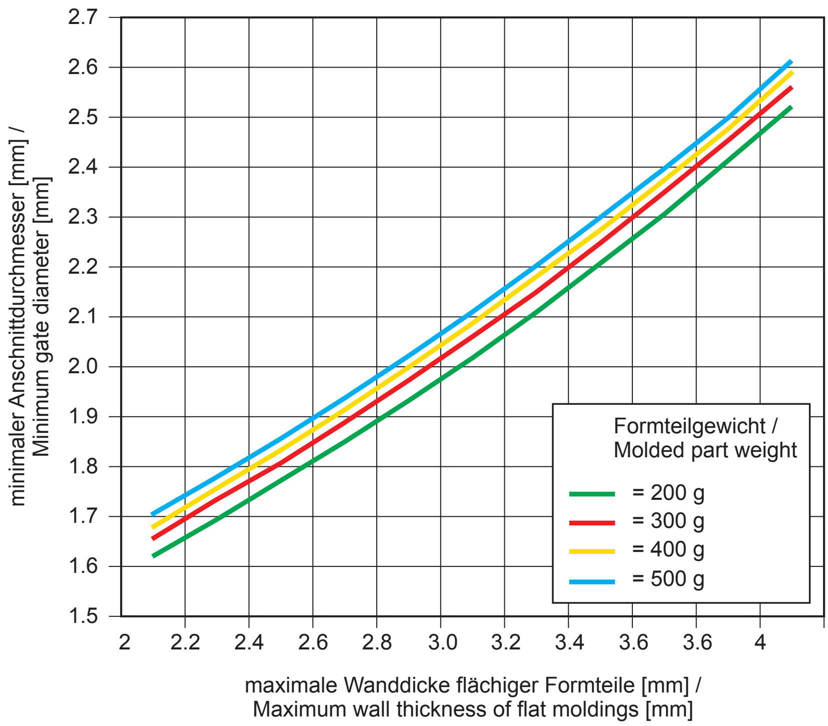


Fig. 5: Gate diameter (point) as a function of wall thickness and molded part weight

3.1 Dimensioning the gate

The chief criteria for dimensioning a gate are the weight of the molded part (volume), the length of the gate and the wall thickness of the molding (flow length). These affect the pressure requirements, the thermal stressing that prevails during filling and the shear stress. They are restricted by the material's limited flowability and by the sensitivity of individual grades to shearing. In addition to this, filling behavior, such as that seen downstream of sudden changes in wall thickness, and jetting are decisive for surface quality.

Against this background, the following targets should be set for the pressure requirement when designing molded parts and gating systems for engineering thermoplastics that are being used in general-purpose applications:

Pressure requirement
- gating system $\Delta p < 300$ bar
- gate $\Delta p < 50$ bar
- molding $\Delta p < 650$ bar

The diagram shown below for establishing the gate diameter has been drawn up as a function of the weight of the molded part. In accordance with the virtually linear profile of the graphs, this gate dimensioning rule, which has proved successful in practice, still remains valid today:

Gate diameter = 2/3 wall thickness (s)

3.2 Gating systems

Gating systems are made up of a cold or hot runner system, or a combination of the two.

A hot runner system can basically be viewed as an extension of the machine nozzles. The requirements placed on the hot runner system increase if a molded part has to be filled via a number of nozzles rather than through a direct gate. The majority of hot runner systems operate indirectly, i.e. there is still a transition between the nozzle and the molded part, in the form of a residual lug or a cold distribution system, for example.

In view of the restricted space available here for the topic being covered, the following aspects of gate design should be regarded as applying to both cold-runner and hot-runner systems.

3.3 Gate types

3.3.1 Sprue

In the simplest case, the gate takes the form of a sprue which, if correctly dimensioned and positioned, still constitutes a cost-efficient solution today, in that it will generally operate reliably during the process. A key feature alongside the diameter of the sprue is the conicity necessary for demolding. In the case of "hard" thermoplastics, a conicity of 1.5° on each side has proved successful.

3.3.2 Gate design for flat components

Flat component geometries which are required to be free from gate marks impose particularly stringent requirements on the gate technology. Special consideration will be given to these below.

When the gate is designed as a pinpoint gate in the side wall, this leads to the familiar phenomenon of jetting (Figs. 6a + 7).

The reason for this is:
- the plastic melt does not form a frontal flow
- a melt strand with a low level of wall contact forms (cooling)
- no homogeneous connection is made with the melt subsequently entering the mold

The target for gate optimization must therefore be to ensure that the melt immediately takes on the form of a frontal flow.

Jetting, remedies:
1. Increase the gate cross-section
2. Possibly select a gate position with a deflector surface
3. Reduce the injection velocity
4. Generate an injection profile: slow → fast

On flat parts where it is not possible to have the melt injected via a deflector surface on the lateral wall to ensure that it forms a frontal flow, the cavity must be filled with the aid of a film gate. Although a greater outlay will be involved in removing the sprue here, this technique is currently employed for transparent parts, such as headlamp diffusers (Fig. 7b).

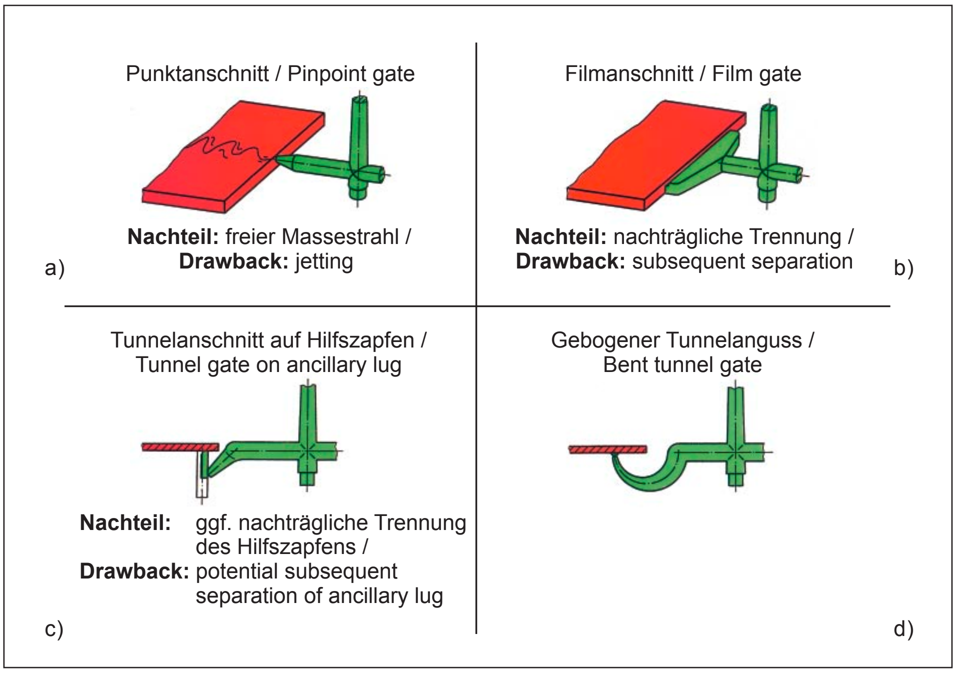


Fig. 6: Gate design for flat components

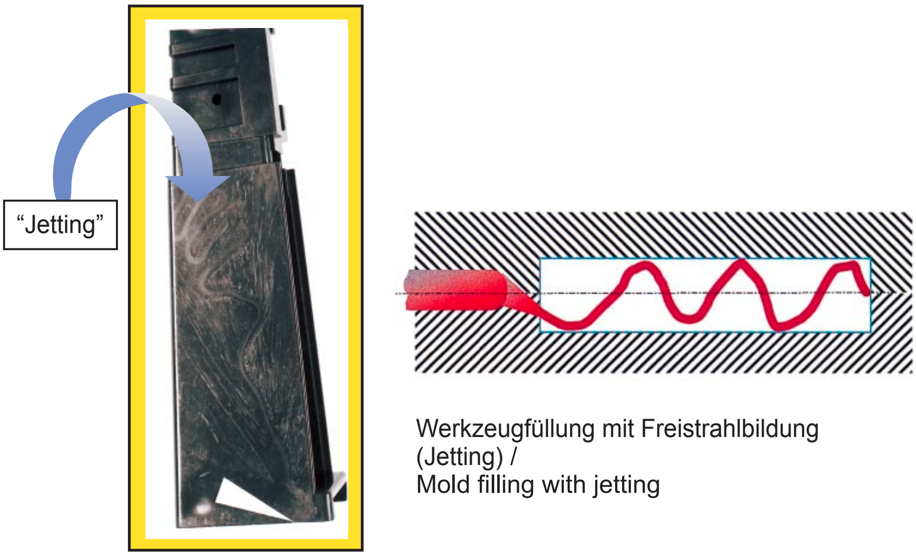


Fig. 7: Jetting through an unfavorable gate geometry and position

Fig. 7 b: Headlamp diffuser with a film gate

3.3.3 Film gate

In a film gate (Fig. 6 b), the centrally-fed melt is divided up in a pre-distributor in such a way that it attains the width of the gate. The pre-distributor must be designed so as to ensure that the melt requires an identical pressure over this path. The film gate with a delta distributor shown in Fig. 8 is an example of this. The pre-distributor ensures correct balancing and hence a constant pressure requirement over the flow paths.

Components with sensitive surfaces and those which are sensitive to stress, such as the polycarbonate diffuser shown here, are always injected via a film gate in order to reduce the level of shear.

Both gate variants display the 2–3 s ratio already referred to above for the film thickness.

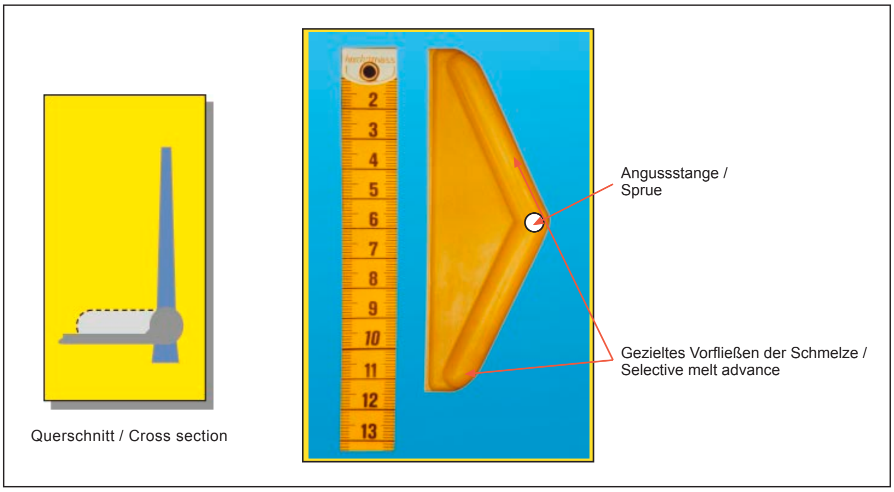


Fig. 8: Balanced film gate

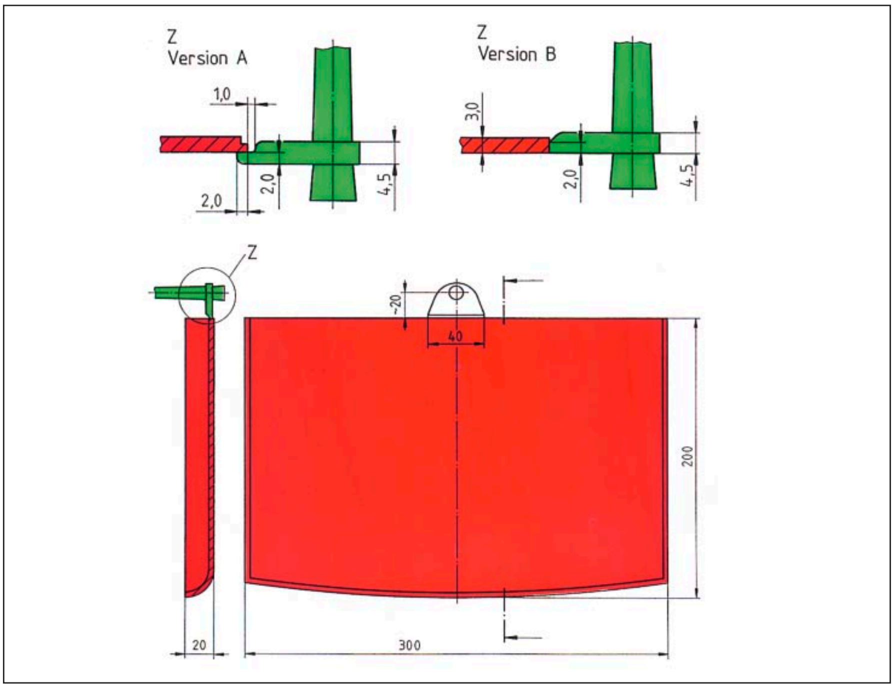


Fig. 9: Transparent polycarbonate diffuser (reducing shear)

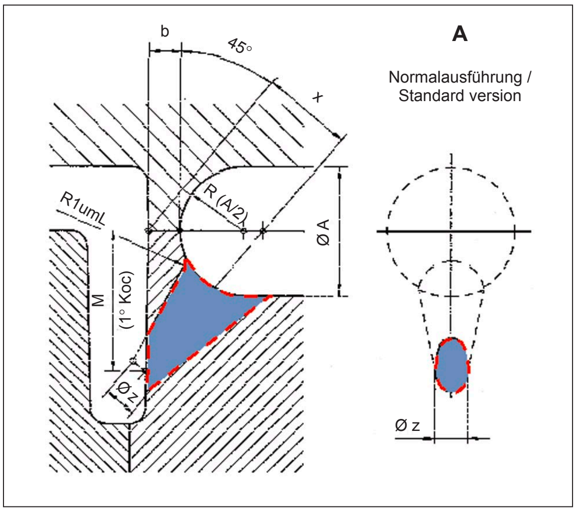


Fig. 10: Unfavorable tunnel layout
(Lenticular gate on edge, without a dead end)
Copy of a customer's works standard

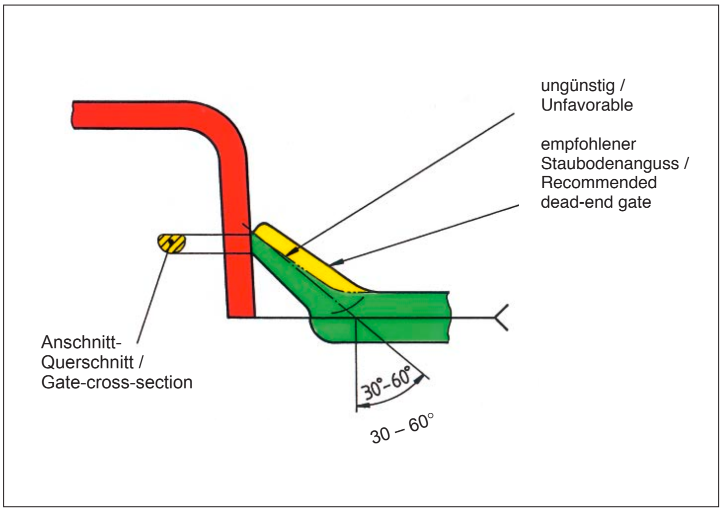


Fig. 11: Recommended design of a tunnel gate
(dead-end philosophy)

Comparison of shear
(tunnel gate versus dead-end tunnel gate)

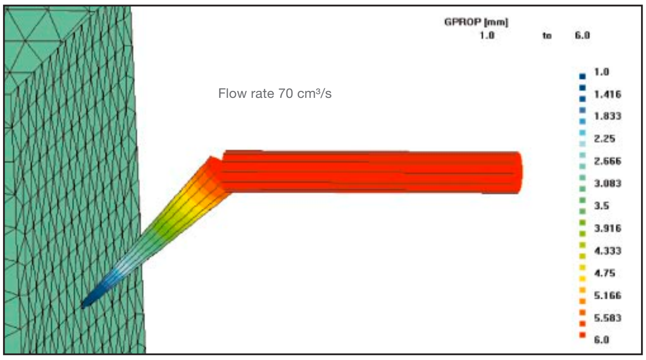


Fig. 12a: Tunnel gate

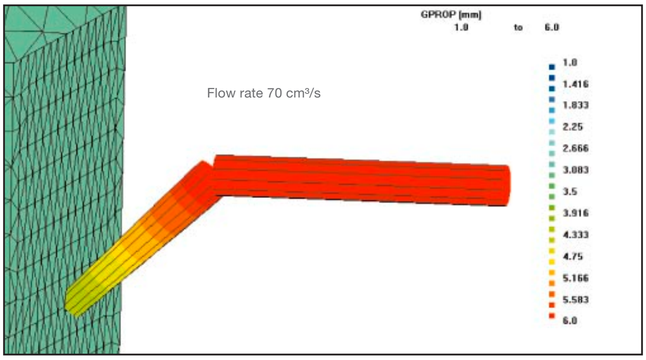


Fig. 12b: Tunnel gate with dead end

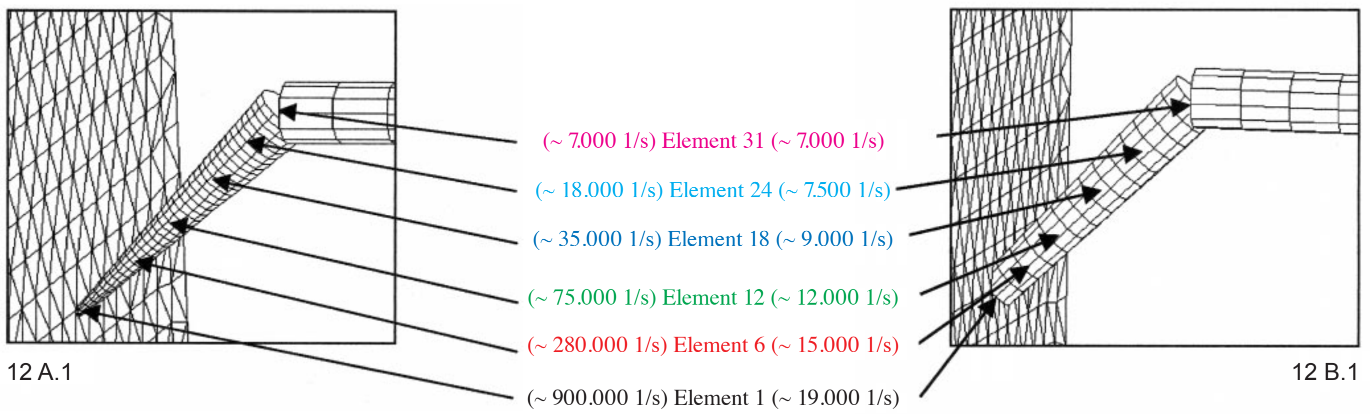
3.3.4 Tunnel gate

The tunnel gate meets the requirements imposed by automatic production and is thus widely used today. Unfortunately, the tunnel is frequently still designed as a simple cone – even in works standards.

It is regarded as sufficiently proven that a dead-end tunnel gate offers a large number of advantages, particularly when it comes to achieving high-quality surfaces.

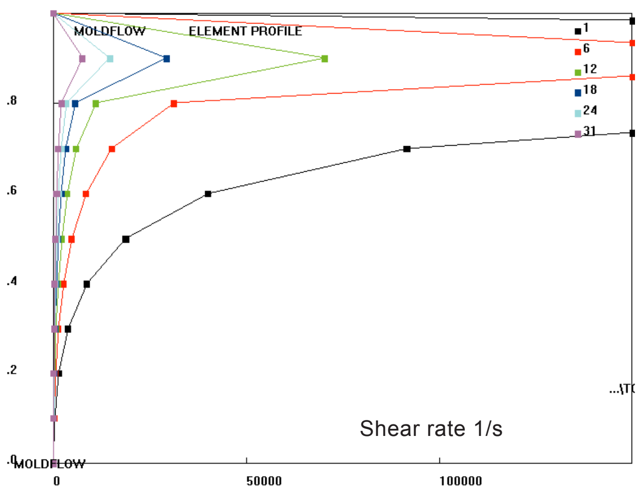
The advantage of this design is that the pressure loss and the shear within the tunnel are kept at a low level.

A comparative calculation of the shear (Fig. 12) supports this statement, since the tunnel with a dead end displays only half the level of shear stressing. In practice, this often produces a decisive increase in processing latitude, thereby fulfilling the chief condition for reliable production with defect-free surfaces.

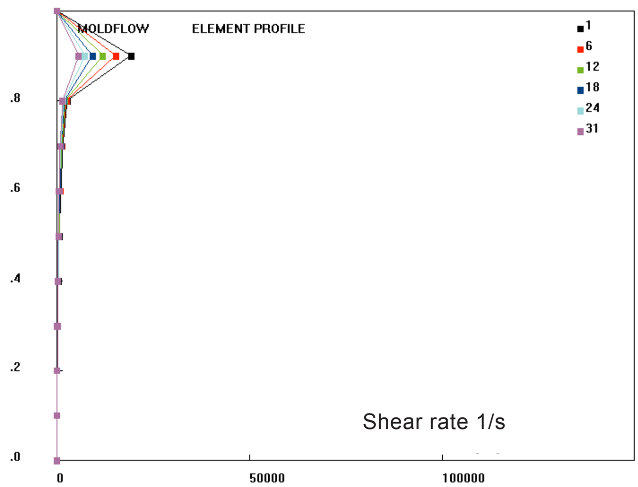


12 A.1

12 B.1



12 A.2



12 B.2

Fig. 12a 1+2: Tunnel gate: Cellular structure Calculated shear rate at elements 1 to 31

Fig. 12b 1+2: Tunnel gate with a dead end: Cellular structure; Calculated shear rate at elements 1 to 31

3.3.5 Tunnel on an ancillary lug

One way of avoiding jetting is to use a system where the tunnel is located on an ancillary lug. As the melt flows into the cavity, it hits the wall on the opposite side and ensures that filling continues with the type of frontal flow desired. Care should be taken here to ensure that the cross-sections are correctly coordinated, as described in Fig. 13. The ancillary lug is incorporated into an ejector, so that it is demolded during the ejection process. The ancillary lug still remains on the part, however, and will generally have to be removed in an additional operation.

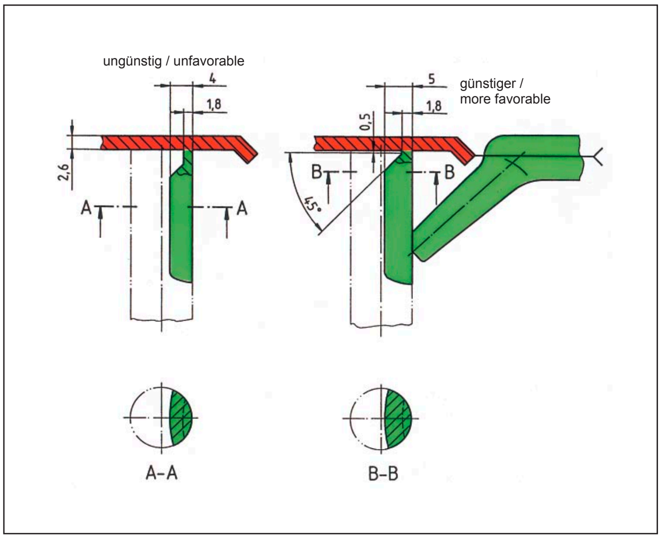


Fig. 13: Design of a break-off ancillary lug

3.3.6 Bent tunnel gate

Like the tunnel on an ancillary lug, the bent tunnel gate is also used for flat components for the same reason. It additionally has the advantage of not requiring any finishing work. Incorporating the bent tunnel in the mold, however, necessitates a greater outlay and a separate insert. The following dimensions should be observed in order to ensure reliable operation during the process:

- Bending lever > 20 mm
- distributor diameter 5 – 8 mm
- radius of bent tunnel at least R 5 – 25 mm

The bending lever and bent tunnel must be sufficiently flexible to permit expansion during the demolding phase without the permitted tensile strain at break being exceeded. The demolding operation should be supported by a centring tip with a long guide.

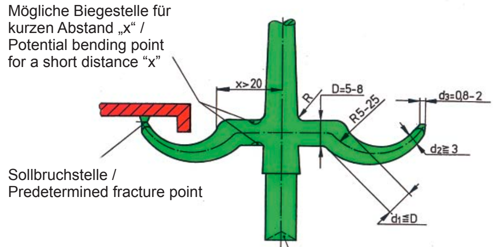


Fig. 14: Design of a break-off ancillary lug

3.4 “Matt halo”

A “matt halo” is a surface phenomenon which occurs in conjunction with the gating system. It is found either immediately around the gate (Fig. 15) or on the side opposite the gate (Fig. 16).

The first case results from a disturbance in the flow of melt, which causes the melt to be injected in with a high level of orientation and to solidify without coming into direct contact with the wall. Following this, the outer fiber is broken apart again as a result of high shear stress, and this solidifies together with the melt that flows in afterwards, forming very small notches.

By way of an initial approximation, the cause should be sought in the diameter of the gate in relation to the wall thickness. The phenomenon described is found primarily in thick-walled parts and, in some cases, is also referred to as “micro-jetting” in practice.

The second case results when the melt is injected on the side opposite the visible side. The visibility of the “matt halo” will be a function of the surface (with visibility increasing from polished to textured), the mold temperature and the processing conditions. In this case, the low-viscosity melt penetrates the structure of the opposite side, with an inherently high pressure and solidifies under pressure in the immediate vicinity, causing the compound somewhat further away to shrink away from the wall.

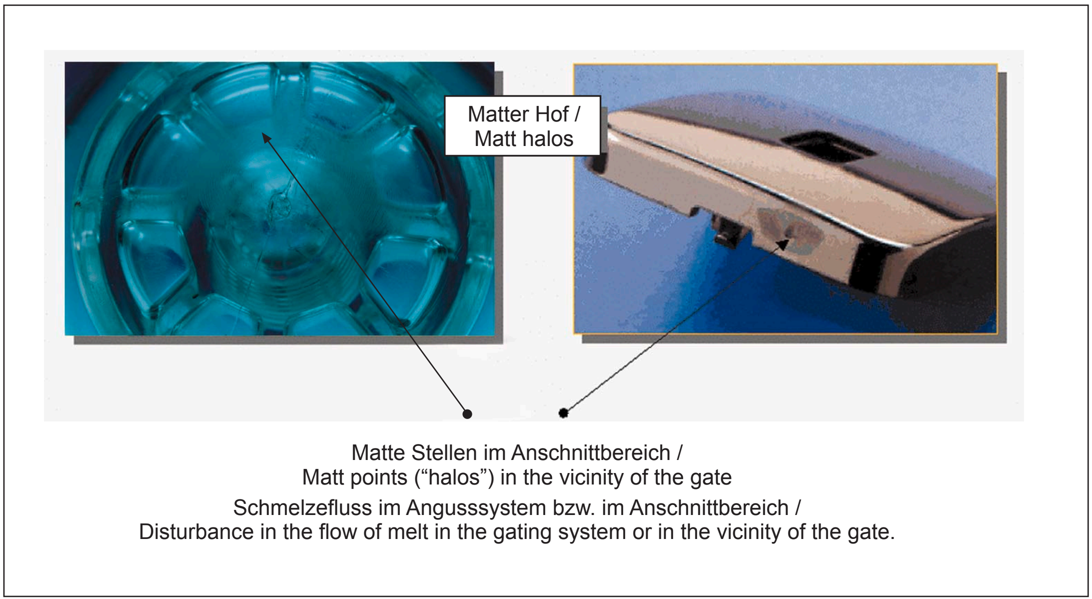


Fig. 15: Gate design: “matt halo”

3.4.1 Bent tunnel gate as a “mini-film” gate

Figure 16 shows a glove compartment lid where the melt is injected into the rear via a bent tunnel gate, giving rise to a pronounced “matt halo” of the type described above on the textured visible surface.

The “matt halo” phenomenon described above can be alleviated and, in some cases, eliminated altogether by reducing the specific pressure and the graduated injection profile.

In many cases, expanding the gate into a “minifilm” gate will prove successful, giving rise to an effect such as that described under “film gate” above.

Separation during demolding, however, will be conditional upon the strength of the material and on a sharp-edged transition between the tunnel and the molded part.

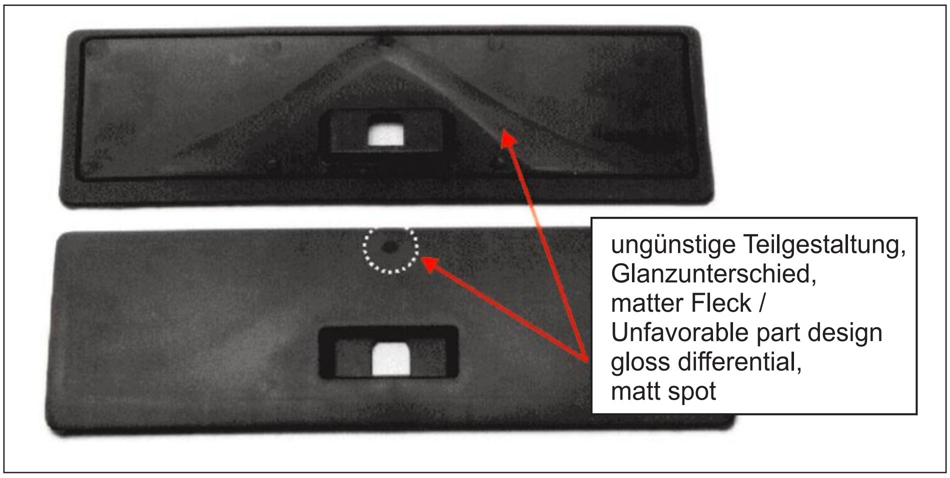


Fig. 16: Glove compartment lid

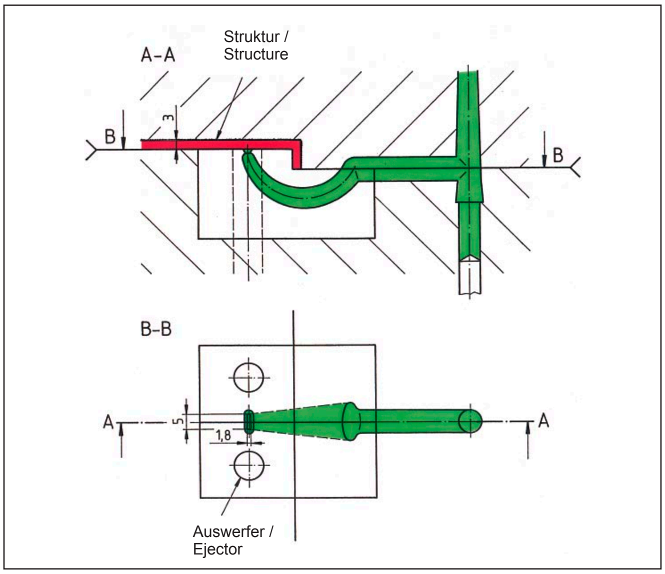


Fig. 17: Minimization of the “matt spot” on a bent tunnel gate

3.4.2 Tunnel gate with an ancillary lug

The same objective is pursued with the tunnel on an ancillary lug which is incorporated in a flat ejector. Here, the melt passes through the tunnel into the delta-shaped ancillary lug and is fed into the cavity at reduced speed and with a lower specific pressure, so that the pressure distribution over the gate is spread over a larger area and is more uniform. As a result, the texture above the gate is reproduced more uniformly on account of the lower pressure.

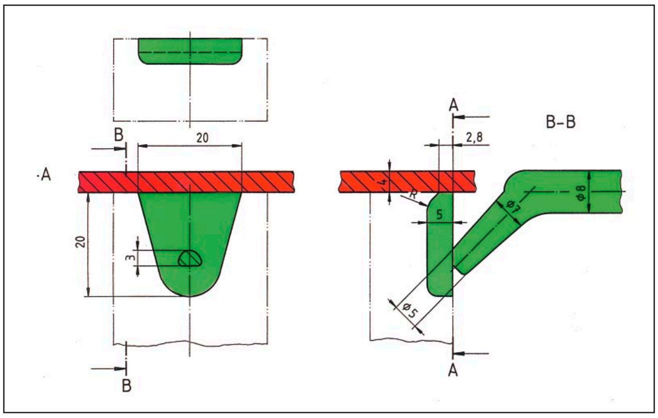


Fig. 18: Reducing the “matt halo” (Tunnel gate on an ancillary lug)

3.4.3 Gating system with graduated injection

A graduated injection profile is an approach frequently adopted in practice for influencing the intensity of the "matt halo". This effect can also be achieved through the design of the gate.

One special feature of gating technology designed to minimise the "matt halo" is a gate with a pre-distributor. This pre-distributor, whose diameter and length are carefully coordinated, divides the melt flow just prior to its entry into the cavity, thereby ensuring that the central flow of melt enters the cavity at reduced speed.

As described at the outset, this slowing down of the central melt flow with a view to reducing the "matt halo" can also be achieved, by reducing the injection speed. Since molds frequently "move around" from one machine to another within a company, making it necessary to set new parameters each time, it is useful to have a facility for reducing the injection speed that is actually incorporated in the mold (Fig. 19). The plots of Fig. 20 show the filling volume after an identical filling time. It is clear that the lateral pre-distributors are not yet full in this phase. Once the lateral arms have been completely filled, the entire volume flow is available for the central feed channel, causing the injection velocity to rise and ensuring that filling is completed with a high injection velocity.

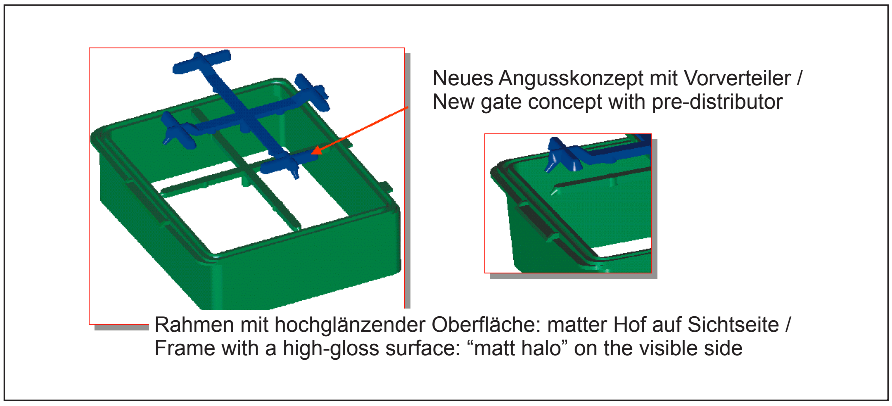


Fig. 19: Gate design for "graduated injection"

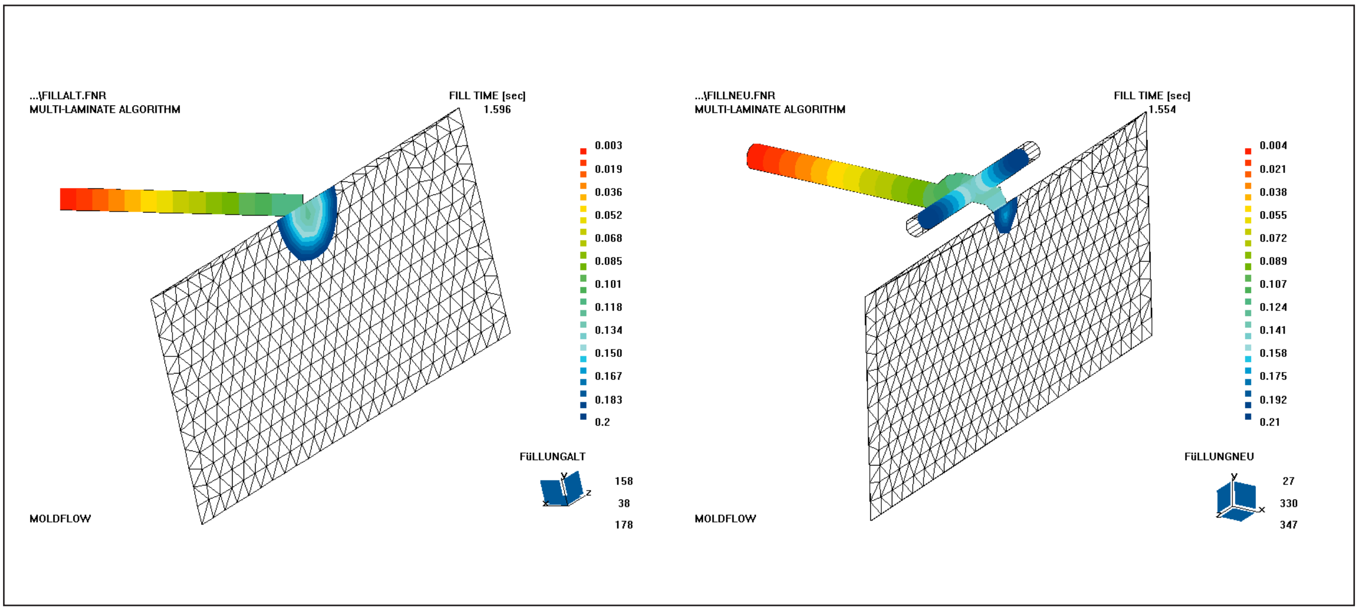


Fig. 20: Gate design: on the left: convential;
on the right: "graduated injection"

3.5 Influencing visible weld lines through the gating system

Any unplanned mark on the surface constitutes an unacceptable defect, particularly in the case of high-quality surfaces. Weld lines are one such defect and can be a key issue when it comes to production with quality assurance. Every attempt is therefore made at the mold design stage to influence unavoidable weld lines in terms of their position, length and quality. Gating technology offers a range of options here, and these are set out below.

Figure 21 shows the weld line forming between two injection points. In theoretical terms, the weld line should end when the tangents to the flow fronts form an angle of 120°. Other influences also act on the visibility of the weld line:

Factors influencing the visibility of the weld line:

- material
- processing parameters
- mold surface
- color

Following the above approach, it is now possible to minimize the length of the weld line as a function of the molding thickness and the size of the gate by reducing distance “a”.

In Fig. 22 the number of injection points has been increased to four, thereby reducing the length of the weld lines on the one hand, and ensuring that a uniform front is achieved more rapidly on the other.

If this is designed as a 4-point tunnel gate as shown in Fig. 23, then the shear can be kept to a minimum through the volume flow being divided up, with automatic tunnel separation at the same time.

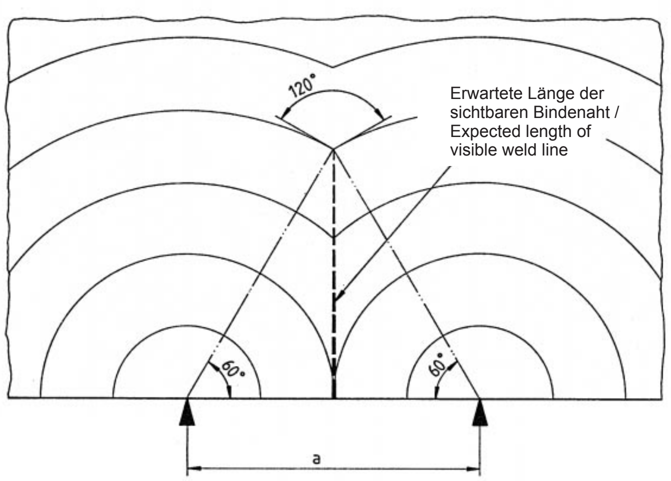


Fig. 21: Visibility of weld lines

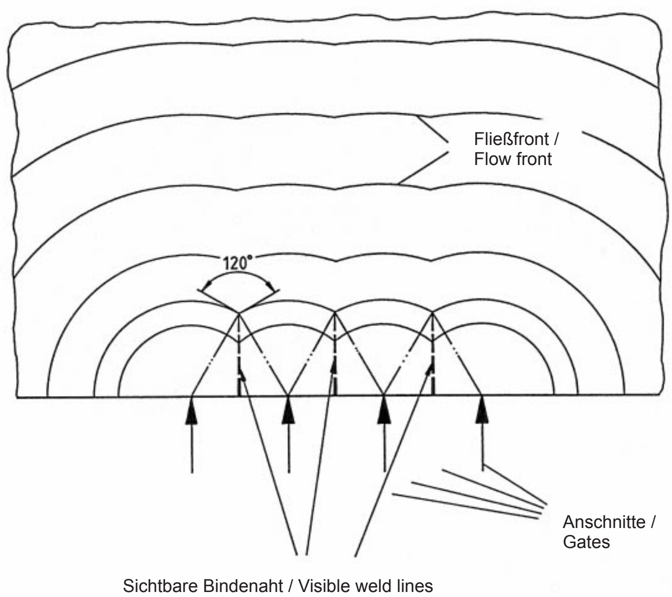


Fig. 22: Influencing the visible weld line length by means of the gate spacing

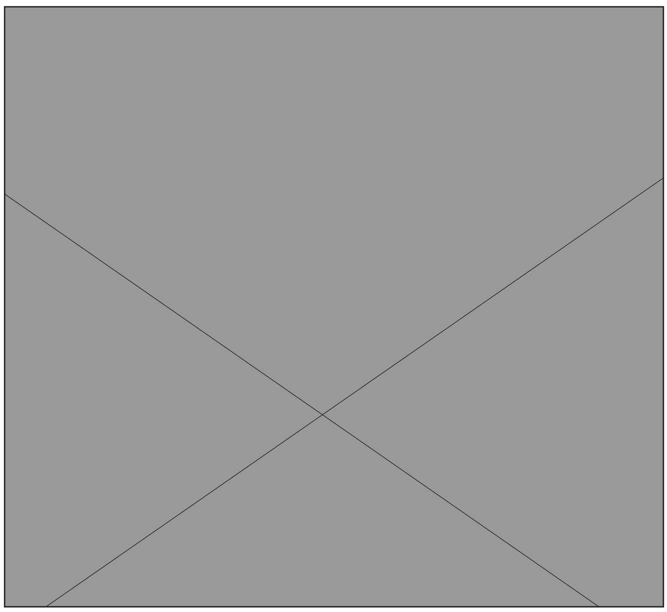


Fig. 23: Four-point tunnel gate to minimize shear

3.6 Influencing the position and length of the weld line on an actual engineering component

The following lateral component of an instrument panel involves the designer reducing the length of the weld line and shifting it into a non-critical area.

Figure 24 shows the approach adopted to the problem of the gate position, with the division of the flow paths/flow volumes and the position of the expected weld lines. The initial check conducted on the filling situation with the aid of a filling pressure curve is particularly helpful. This provides information, for the specific material in question, on flowability versus pressure requirements as a function of wall thickness. The component under observation here is filled via three injection points after the relevant constraints have been assessed. Points 1 + 2 are close together as per the concept described under 3.5 (short weld line) and, together with point 3, give main weld lines which are in a non-critical position from the optical and mechanical point of view. The subsequent rheological calculation in Fig. 25 confirms the expectations, providing the designer not only with further information on mold construction but also with the necessary degree of security.

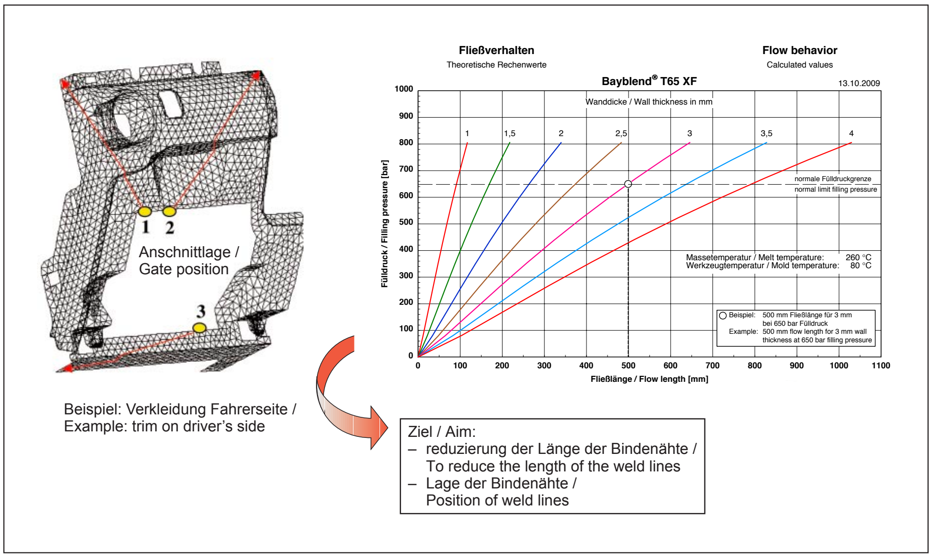


Fig. 24: Determining the number of gates and the gate position

B. Check expected position of weld lines

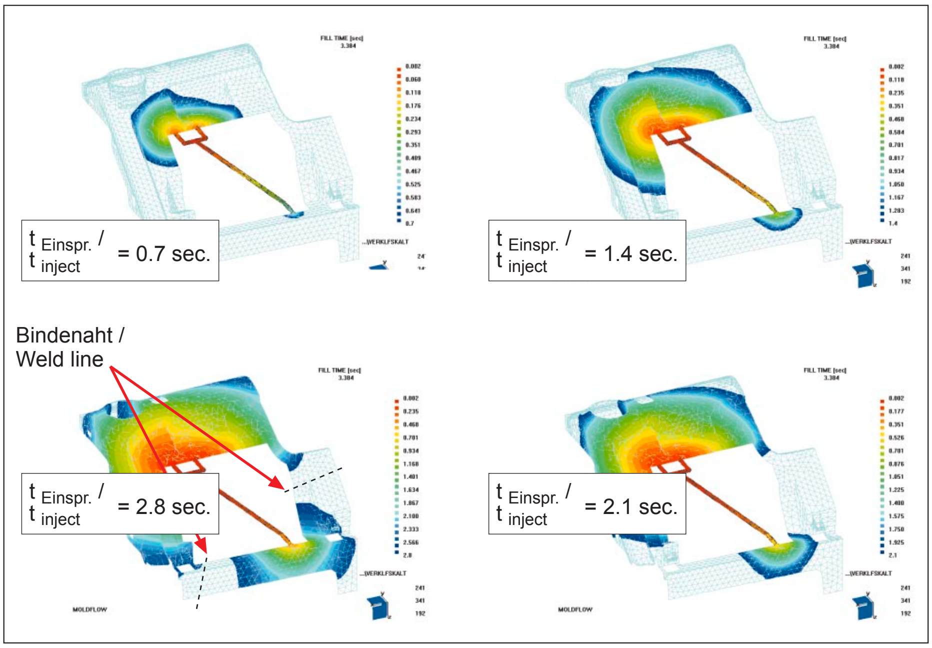


Fig. 25: Molded part filling in time stages (position of weld lines)

4. Gating technology for special processes

Ever since it has been possible to use hot-runner needle valve nozzles in controlled (open/close) operating mode, the cascade technique has been employed as a special process to solve specific problems. This technique is aimed at avoiding weld lines. The chief fields of application are flat components with long flow paths in

- in-mold decoration (IMD)
- in-mold carpeting

4.1 Process sequence for conventional/cascade processes

The top of Fig. 26 shows a long component with conventional gating technology and six hot-runner nozzles in diagram form. This results in five weld lines during filling. The diagram beneath this shows a hot runner for the cascade technique, with seven nozzles. Filling is initiated by opening the central needle. When the flow front reaches needles 2/3 (left/right), these will open, allowing the melt to flow into the flow front and advancing the flow front without a weld line.

Figures 27 and 28 show this process as a function of pressure. This makes it clear that the melt in needle 2 is released under pressure, so that the pressurized melt meets the flow front from nozzle 1 with a pressure potential close to zero. This leads to defects on the surface in the form of “matt halos” with a gloss differential on both textured components and polished components.

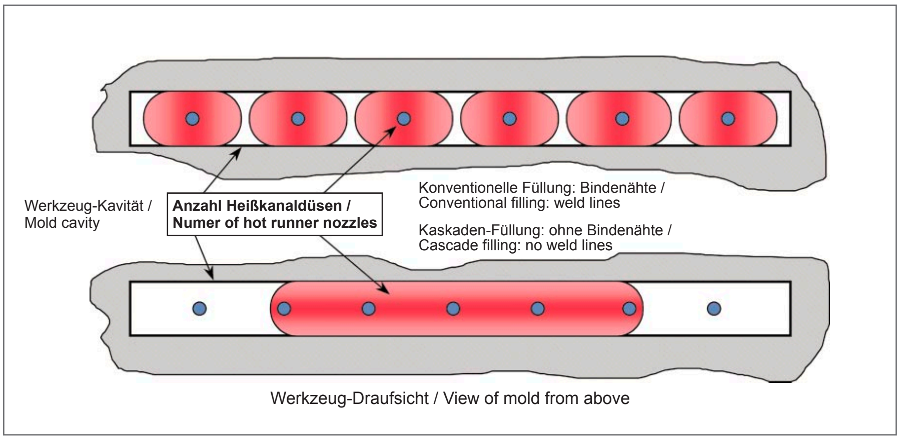


Fig. 26: Gating technology for special processes (cascade technique, sequence)

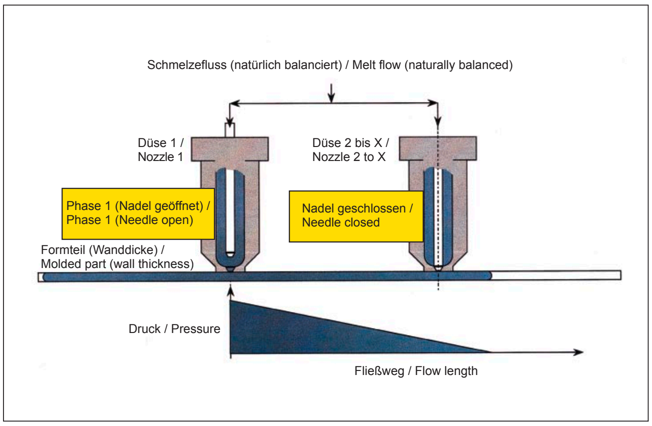


Fig. 27: Gating technology for special processes (cascade technique, sequence 1)

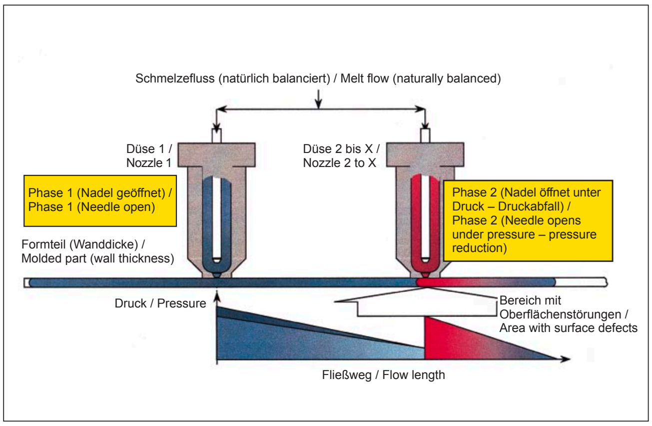


Fig. 28: Gating technology for special processes (cascade technique, sequence 2)

The engineering component was then developed employing the basic principle of the cascade technique. Panels like the one in Fig. 29 are injected with cosmetic considerations in mind, exploiting the flowability of the selected plastic. The component shown here is filled by means of two hot-runner nozzles. Eighty percent of moldings are produced in white, in response to market requirements; the weld line that forms between the injection points is not critical.

The weld line could not be tolerated on the brown and black parts that were also to be produced with this mold. This led to moldings requiring a higher level of finishing work. An increase in demand made it possible to build a new mold with a new gate concept.

Fig. 29: Gating technology (for the front panel of a dishwasher)

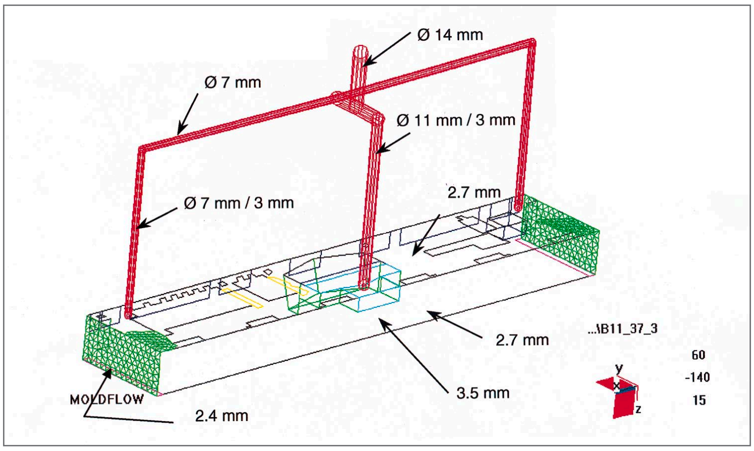


Fig. 30: Gating technology – for the front panel of a dishwasher (wall thicknesses and hot-runner diameters)

As shown in Fig. 30, a hot-runner concept was selected in order to displace the weld lines. This operates with three needle valve nozzles.

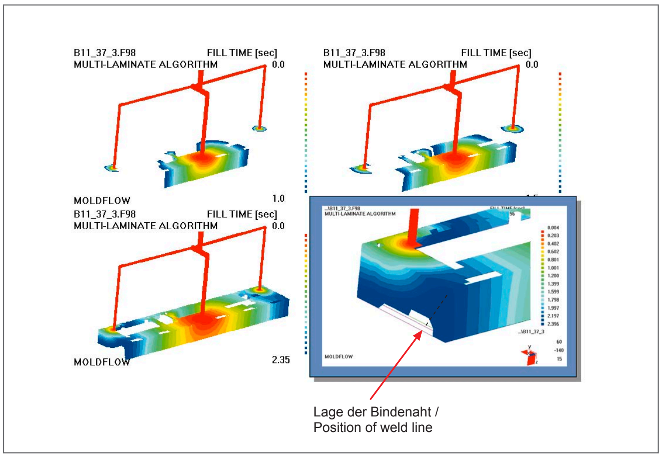


Fig. 31: Gating technology – for the front panel of a dishwasher (filling series)

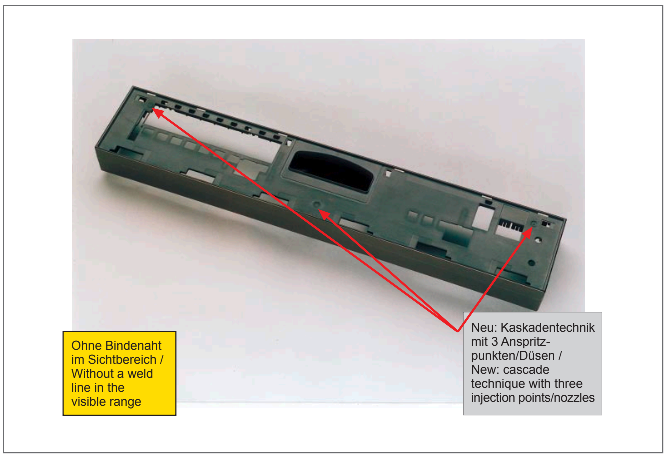


Fig. 32: Front panel of a dishwasher

The diameters selected and the delayed opening of the nozzles ensure that the flow fronts meet in the non-critical side section during filling (Fig. 31). An angle of >120° develops between the flow fronts after just a short distance so that the weld lines are also very short.

Figure 32 shows the result of the optimization: by using three controlled needle valve nozzles, it has proved possible to produce the part without a weld line in the visible section.

5. Conclusion

While the requirements imposed on producing plastic parts with a quality look, and hence the outlay involved in achieving such a look, increase naturally as a result of competition, they are also being increased to a significant extent by the growing complexity of the components themselves. The gating system is just one of many factors influencing surface quality. The reproducible production of high-quality surfaces requires not only knowledge of the design of gating systems but, in many cases, the adoption of an unconventional approach. This Technical Information Sheet deals with the requirements imposed on gating systems designed to achieve high-quality surfaces, together with the measures necessary to eliminate surface defects and the use of special processes.

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