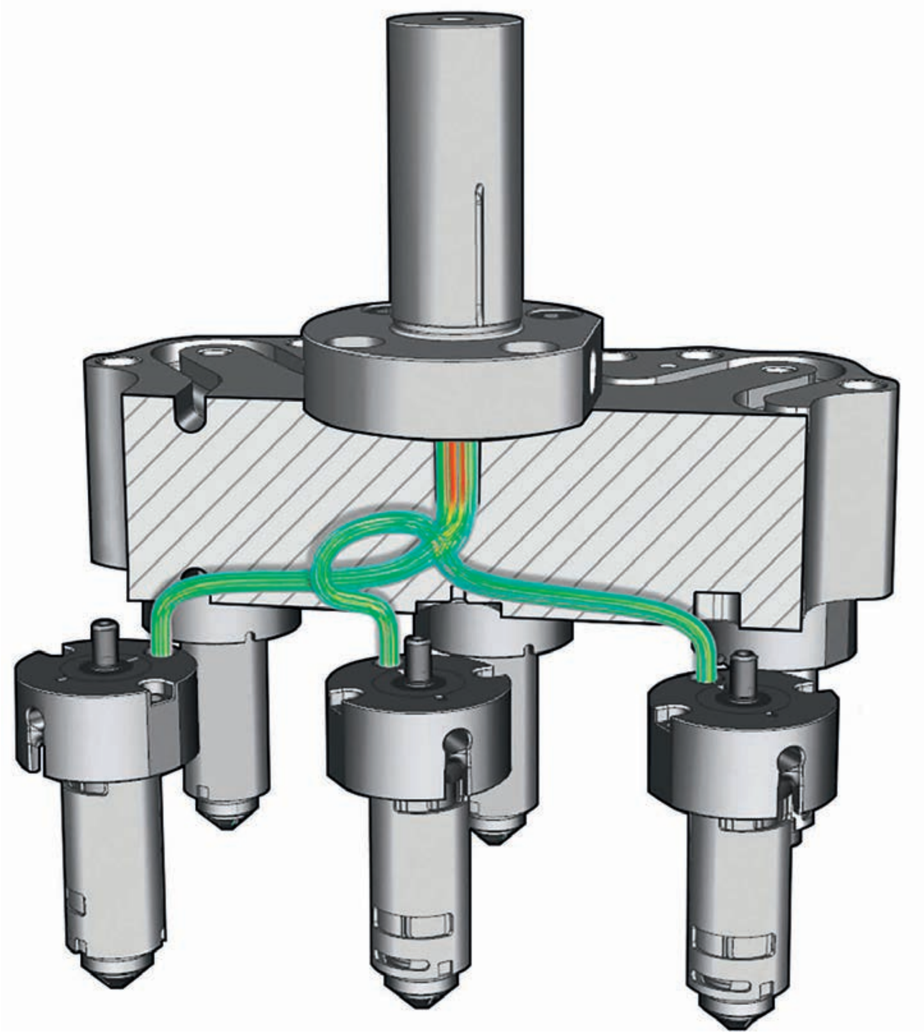
Mass Channel Design Using Additive Manufacturing Opens up Quality Advantages

Three-Dimensional Melt Flow System in the Hot Runner Manifold Block

The objective of the hot runner design is to ensure that all cavities are supplied with the same melt quality, filling and compression pressures and filling speeds without damaging the melt along the way. The distributor block plays a key role in this process, as it is responsible not only for melt transfer but also for distributing the melt to the individual cavities. Additive manufacturing enables significant improvements in this area – in several dimensions.



Six-cavity mold with naturally balanced three-in-a-row layout instead of the conventional double-Y layout. © Barnes Molding Solutions/ Institute for Product Engineering, University of Duisburg-Essen

The hot runner system is supplied with the plastic melt prepared by the injection molding machine from the machine nozzle over the sprue bushing and guides the melt via the manifold block and the hot runner nozzles to the gate into the cavity. In general, the goal is to achieve the shortest possible dwell time. In the area of multi-cavity molds, natural balancing using equal flow path lengths is usually selected, as this enables these requirements to be met independently of the injection molding process itself.

Manufacturing Hot Runner Manifold Blocks

Today's hot runner manifold blocks are usually manufactured conventionally by drilling and thus the melt channels are formed from straight sections. The melt is diverted and divided by means of transverse holes in conjunction with end plugs, which are inserted into the manifold block as additional elements. This restricts the design possibilities of the melt channel geometry and, due to narrow deflection angles and small radii at the deflections, different shear loads and flow velocities can occur across the melt channel cross-section, which can impair the purging properties of the manifold [1].

In contrast, split manifolds offer the possibility of producing the melt channels by milling and thus similar design options as cold runners for melt guidance in the parting line [1]. This allows larger radii to be produced within the parting line for deflecting the melt, thus improving purging properties and reducing shear stress on the plastic. However, the riser bores from the sprue bushing into the manifold and from the manifold to the nozzles can only be rounded to a small extent in these manifold designs, since possible deformation of the channel geometry during the joining process must be considered. »

A three-dimensional design of the melt channel geometry is made possible by additive manufacturing of the hot runner manifold block. The melt deflections can be designed independently of planes in the manifold and thus potentially the rheological optimal melt flow can be achieved. Furthermore, this manufacturing method offers the greatest possible flexibility in terms of melt distribution. (**Fig. 1**)

Challenges for Manifolds that Deviate from 2^x Cavities

Greater challenges in natural balancing arise with hot runner layouts for cavity numbers that do not correspond to a power of two. As a result, flow path splits must be selected that meet at different angles. For example, in a six-cavity mold, the double-Y layout is often chosen. With these layouts, the same length of all flow paths can usually only be achieved by lengthening the flow paths, which increases the dwell time. Furthermore, this layout very often requires a considerably larger installation space due to the resulting position of the crossing points. This also means a larger cutout in the hot runner plate, which can negatively influence the mold stiffness and results in a higher manufacturing effort for the mold maker.

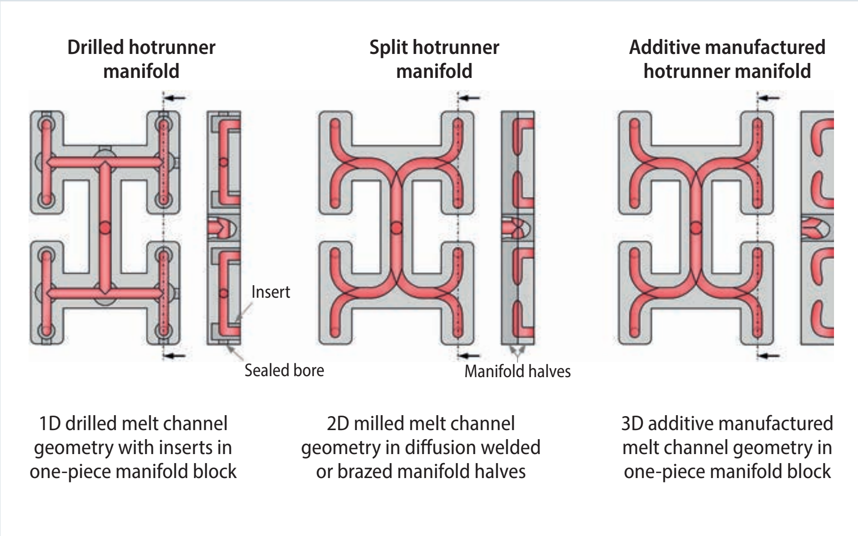


Fig. 1. Possibilities of melt channel design for naturally balanced manifold blocks in dependence on manifold block manufacturing method. © Simon Wurzbacher, Barnes Molding Solutions

Experimental Setup of a Six-Cavity Test Mold

With the possibilities of additive manufacturing, the flow paths can also be achieved without shifting the flow path division through intelligent design, whereby a naturally balanced three-in-row layout can be combined with the other advantages of this manufacturing method already described, instead of a double-Y layout (**Title figure**).

A six-cavity test mold (**Fig. 2**) equipped with a cylindrical valve gate hot runner system from Otto Männer GmbH with a cavity spacing of 70 mm and a row spacing of 100 mm is used for the tests. The test specimen is a simplified cap with a volume of 3.15 cm^3. The polypropylene molding compound Moplen RP340N from LyondellBasell Industries is used for design and validation.

The numerical design of the manifold block is carried out with the flow simulation software Ansys Fluent. Relevant software for filling pattern simulations, as used for injection mold design, can only be used to a limited extent in this case, since the hot runner manifold is not a cavity to be filled. For this reason, the injection phase of the injection molding cycle is assumed to be a steady-state flow, allowing the use of the more detailed evaluation capabilities of Ansys.

The same global settings for meshing and boundary conditions are chosen for all simulations performed to ensure

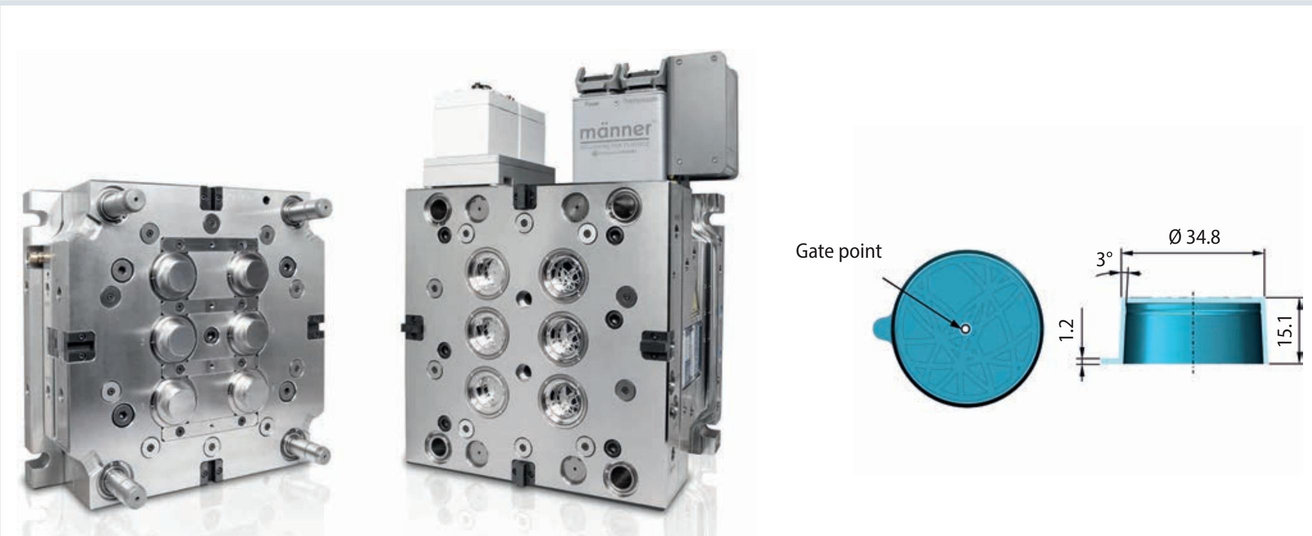


Fig. 2. The six-cavity test mold is used to produce simple closure caps as test specimens. © Barnes Molding Solutions

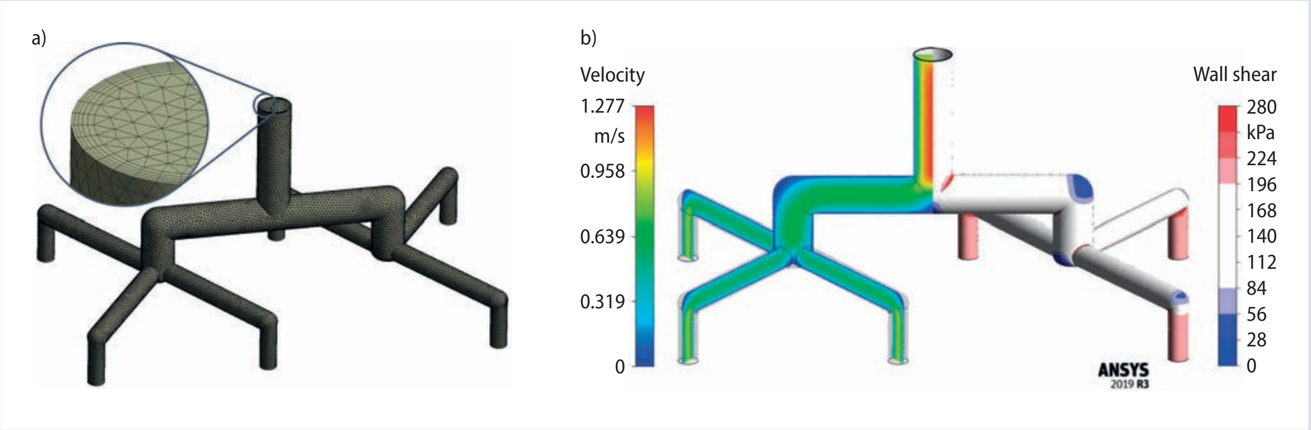


Fig. 3. Meshing and results of the numerical study of the conventional manifold (double-Y system). In regions of melt division and deflection, zones of low velocity and low wall shear stress are found. © Institute for Product Engineering, University of Duisburg-Essen

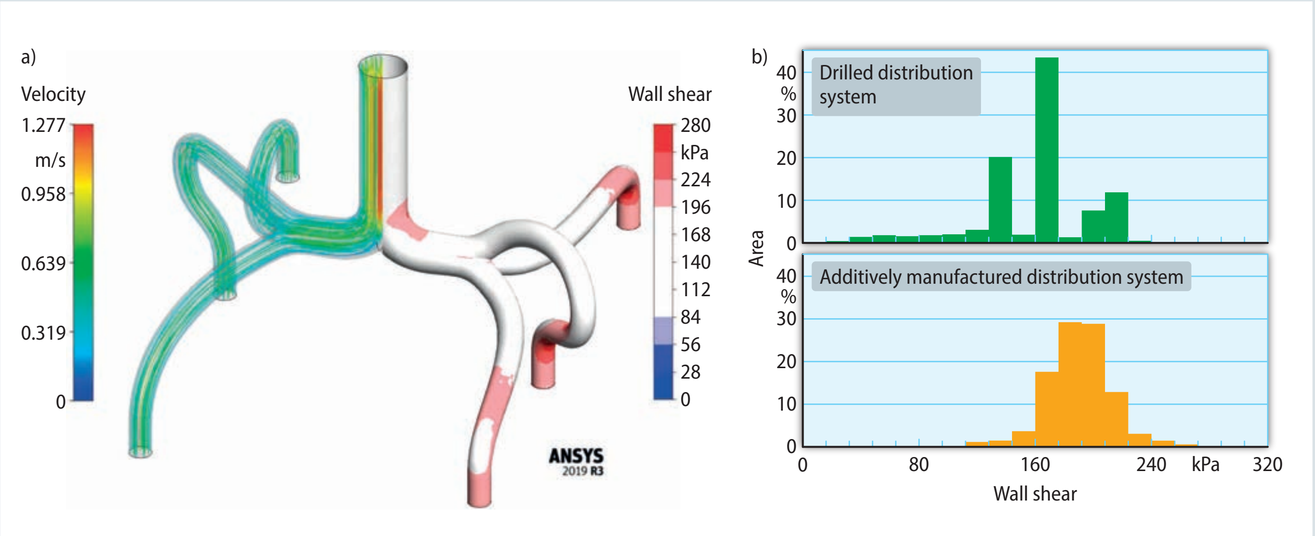


Fig. 4. Simulation results of three-in-row distribution and comparison of wall shear stresses of drilled and additively manufactured manifold block.
Source: Institute for Product Engineering, University of Duisburg-Essen; graphic: © Hanser

comparability of results. Meshing is performed with a hybrid mesh of tetrahedral elements in the channel center and hexahedral elements in the boundary layers for a more accurate representation of near-wall flow effects (**Fig. 3 left**). The design criteria are the standardization of flow velocities and wall shear stresses over all flow paths with the aim of significantly improving the purging properties and evaluating the potential of additively manufactured hot runner systems.

Numerical Analysis of the Conventional Design

The conventionally drilled manifold block is designed as a naturally balanced double-Y layout. The layout is designed on two levels to compensate flow paths deviations [2]. The design of the manifold deliberately avoids the use of flow-optimized plugs. Analysis of the manifold show zones of low velocity and low wall shear stress in melt splitting and deflection zones (**Fig. 3, right**). In color change processes, this can increase the number of cycles required for complete purging of the manifold [1].

An examination of the wall shear stresses shows that they vary with an average absolute deviation of 30 kPa around the mean value of 160 kPa. The result may be, among other things, an uneven strain of the melt and an inhomogeneous melt history at the outlet of the geometry.

Design of a Three-Dimensional Manifold System

By using the degrees of freedom of additive manufacturing, the conventional geometry can be designed to optimize flow based on the simulation results. To this end, an initial model is first constructed based on the example of bionic flow paths in nature, followed by automated optimization based on genetic algorithms. This allows the evaluation of many geometry variants with reduced time expenditure. To specifically investigate the influence of the melt flow, all boundary conditions, such as manifold block outer geometry, hot runner nozzles, melt transfer points and bolting positions, are designed in the »

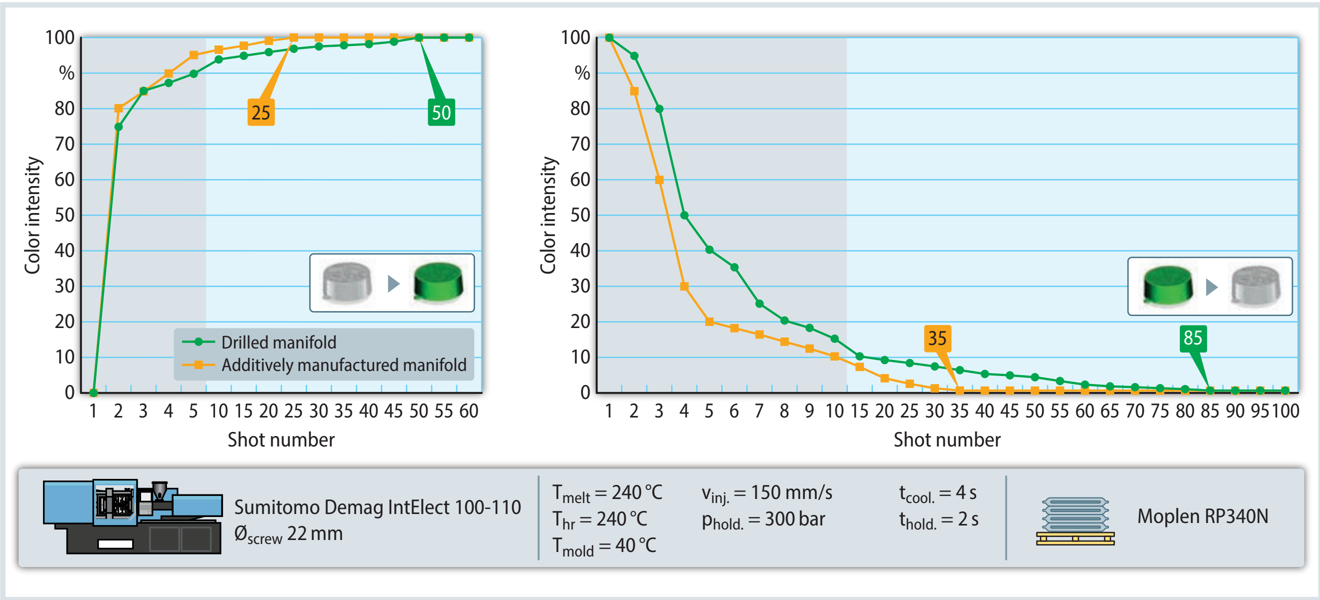


Fig. 5. Color exchange trials make clear that purging processes are much more effective on the additively manufactured manifold. The injection molding parameters are summarized below. Source: Barnes Molding Solutions; graphic: © Hanser

same way and effects such as energy and manufacturing time savings through the reduction of the manifold thickness are not considered.

The design-study resulted in several possible geometries, of which the three-in-row distribution proved to be particularly promising for a six-cavity layout. Large radii in the channels allow the melt to be distributed in a way that is as gentle on the material as possible and naturally balanced (**Fig. 4, left**). However, investigations of the new distribution system show that natural balancing over the length of the flow path, as is the case with conventional distributors, is not sufficient. For the same pressure drop across all channels and the same mass flow rate, the volume of each channel must be equivalent. For the balancing of drilled manifolds, this goes hand in hand with the balancing of the flow path length; for free-flowing channels, the geometry must be adjusted due to different curvatures and the resulting different volumes.

Besides the homogenization of the velocities in the manifold, the evaluation of the wall shear stress shows an improvement. Compared to the drilled manifold, the mean absolute deviation can be reduced by almost 50 % (**Fig. 4, right**). With a slight increase in the mean value, the wall shear stresses are thus clearly brought into line with each other. As a result of the optimizations, a significant reduction in the cycles required for the purging process can be expected.

Significantly Faster Purging Processes

Validation of the purging properties of both manifolds was carried out in the described test form, based on the color change performance from natural transparent color to green (**Fig. 5, left**) and green to natural (**Fig. 5, right**). The injection molding parameters are summarized in **Figure 5, below**. For the color change tests, the natural transparent molding compound is colored green with 2 % color masterbatch. For comparison of the two manifolds, no further changes are made to the hot runner. To exclude the influence of the plasticizing unit, the plasticizing unit is purged with the respective material before the color change trials. The residual color content is analyzed from the first shot. Due to the complex shape of the article, the residual color content of the components could only be determined by visual comparison.

The results confirm the improved purging properties of the three-dimensional melt channel layout, which could be demonstrated in the simulation. The color change time can be reduced by 50 % for natural to green from 50 cycles for the conventional manifold block to 25 cycles for the additive manifold block. The change from green to natural, in which color additives in potential stagnation zones can still lead to streaks over a longer period of time, can be reduced by 60 % from 85 to only 35 cycles.

Conclusion

Additive manufacturing offers new possibilities for melt flow in the hot runner manifold block. Naturally balanced manifold layouts become possible, which would have resulted in great

Info

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References

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restrictions like flow path prolongation with conventional manufacturing methods. However, the greater freedom also results in new challenges; for example, existing design criteria with identical flow path lengths can no longer be applied without further ado. In the investigated system, it was possible to homogenize the wall shear stress over the entire flow path by means of specific optimizations. The validation tests show that the cycles required for purging such a distributor block can be halved as a result.

Future investigations of three-dimensional melt channel layouts have the goal of automating the design of the channel geometry. In particular, the qualifying criteria required for evaluating the geometry variants has great potential, since in addition to the approximation of velocities and wall shear stresses, variables relating to the balancing or pressure loss of the system can also be considered. In parallel, the criteria will be validated with further tests in the real process. ■