Mold filling simulation in 3D (SIGMAsoft) for PIM materials

Simulation for MIM / PIM

The effects of PIM feedstock on the mold filling behavior and the holding pressure phase are illustrated below using the example of a relatively simple part, the standardized MIM tensile test specimen:

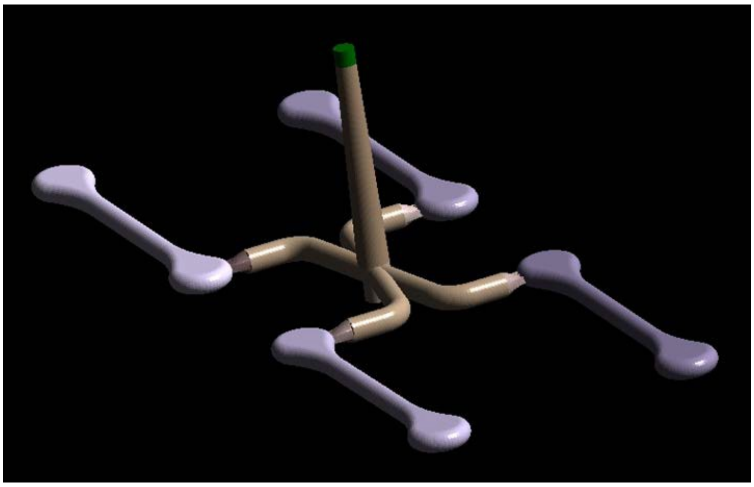

Fig. 1: 3D model of the "tensile test specimen" 4-cavity mold with gating system

Really a relatively simple geometry, however experience has shown that the production of tensile test specimens can result in problems, as internal defects arise, which can be attributed to injection the molding parameters, but cannot be explained without intensive investigation. Examples of such defects are shrink holes or internal flow lines at the head end of the tensile test specimens and a cylindrical core over the test length that is not joined to the outer area. Both types of defect cannot be seen from the outside of the tensile test specimens and can only be found by breaking green or sintered parts.

The reason for internal defects in the head areas is quickly found if we look at the liquid melt areas at a point during the injection molding process when gate and runner are more or less frozen:

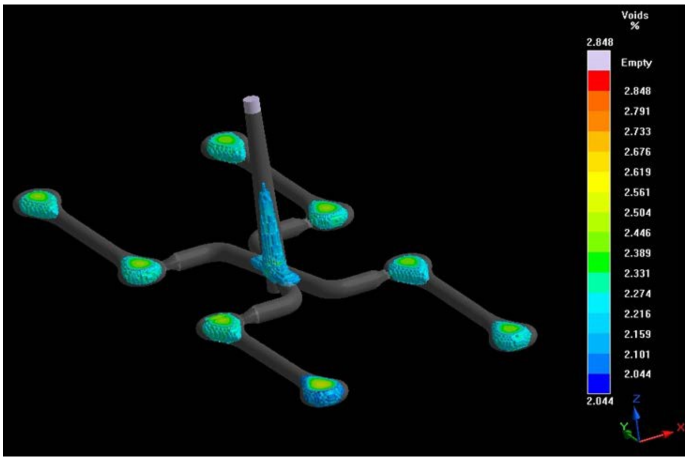

Fig. 2. Liquid melt areas after 4 s cooling time

No matter what holding pressure is programmed in the machine at this point – no shrinkage compensation can take place in the tensile test specimens!

So how does the ideal holding pressure phase look?

Which parameters ensure the smallest possible difference in shear rate between the wall and the melt core in the area of the test length?

What influence does the feedstock have?

What gate geometry has a generally positive effect?

In order to answer these questions, relevant parameters for the simulation of the injection molding process were systematically varied and their influence on two results regarded as characteristic for the process, the shear rate or the difference in the shear rate between the middle of the test sample and the edge of the test sample over the test length, and the shrinkage potential during the holding pressure phase were examined.

Influence of the parameters:

The following parameters were varied and used for the simulation of the injection molding process for three different types of binder, two PE and PP-based polymer wax binders and one POM-based feedstock, each with different powder filling:

No.	Parameter
1	Basic setting
2	Elliptical gate form
3	Round gate form
4	Gate increased to 2.0 x 4.5
5	Gate increased to 2.2 x 5.0
6	Injection speed reduced to 50 mm/s
7	Injection speed increased to 100 mm/s
8	Mold temperature reduced by 15°C
9	Mold temperature increased by 15°C
10	Feedstock temperature reduced by 20°C
11	Feedstock temperature increased by 20°C
12	Holding pressure profile increased by 500 bar and 5 s longer
13	Holding pressure profile reduced by 300 bar and 2 s

Mold filling:

The comparison of the calculated maximum shear rate occurring at the start of the holding pressure phase (point "Holding pressure start") in the middle of the test specimen shows the differing behavior of the three feedstock types and the influence of the process parameters.

The injection speed, for example, particularly highlights the differences between the feedstock types due to the cooling with slower mold filling, while the actual holding pressure causes very little material to move at the shear rate level remains relatively constant (cf. No. 6 and 7, and 11, 12 and 13 in Fig. 3).

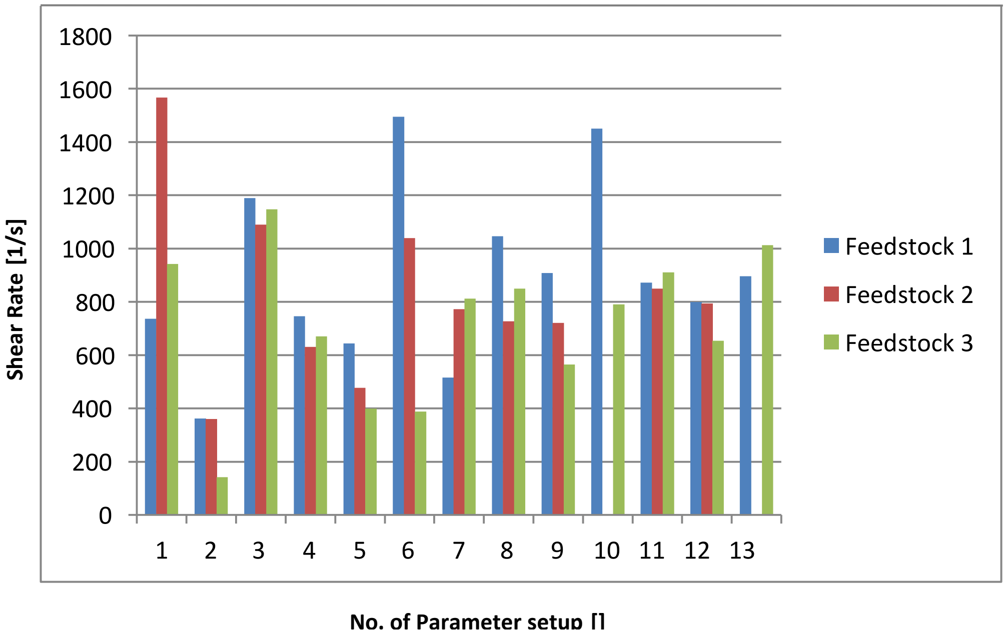

Fig. 3 Maximum shear rate [1/s] at the beginning of the holding pressure phase as a function of the parameter setting

The influence of the gate geometry takes full effect during this phase of forming. A larger gate (cf. No. 4 and 5 in Fig. 3) allows a holding pressure phase with less material stress due to shear for all three feedstock types.

In order to investigate the defect of internal material separation over the test length, the shear in the middle of the specimen and at the edge was calculated for one defined point in the middle of the test length for each parameter setting and the difference was plotted in the following
Figure 4:

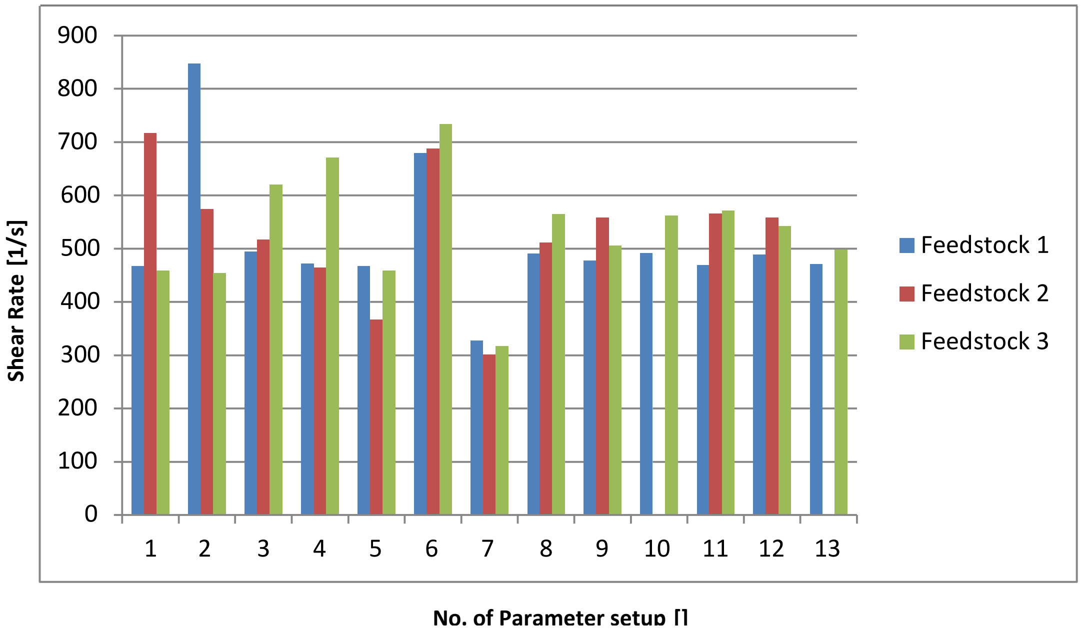

Fig. 4 Difference in the shear rate between specimen middle and specimen edge at the end of the filling phase

This shows clearly that if this type of defect is fostered by a large difference in shear rates, it can only be effectively prevented by an increase in the injection speed (cf. Fig. 4, No. 7) in order to delay the cooling of the outer layer. This obviously holds true generally for the three feedstock types used.

Holding pressure:

The following diagram shows a good example of the importance of the holding pressure phase for the optimum formation of the molding. The purpose of the holding pressure phase is to compensate the part shrinkage during cooling; the evaluation of the shrinkage potential during the cooling time calculated from the PVT data and the pressure and temperature values can be used for this.

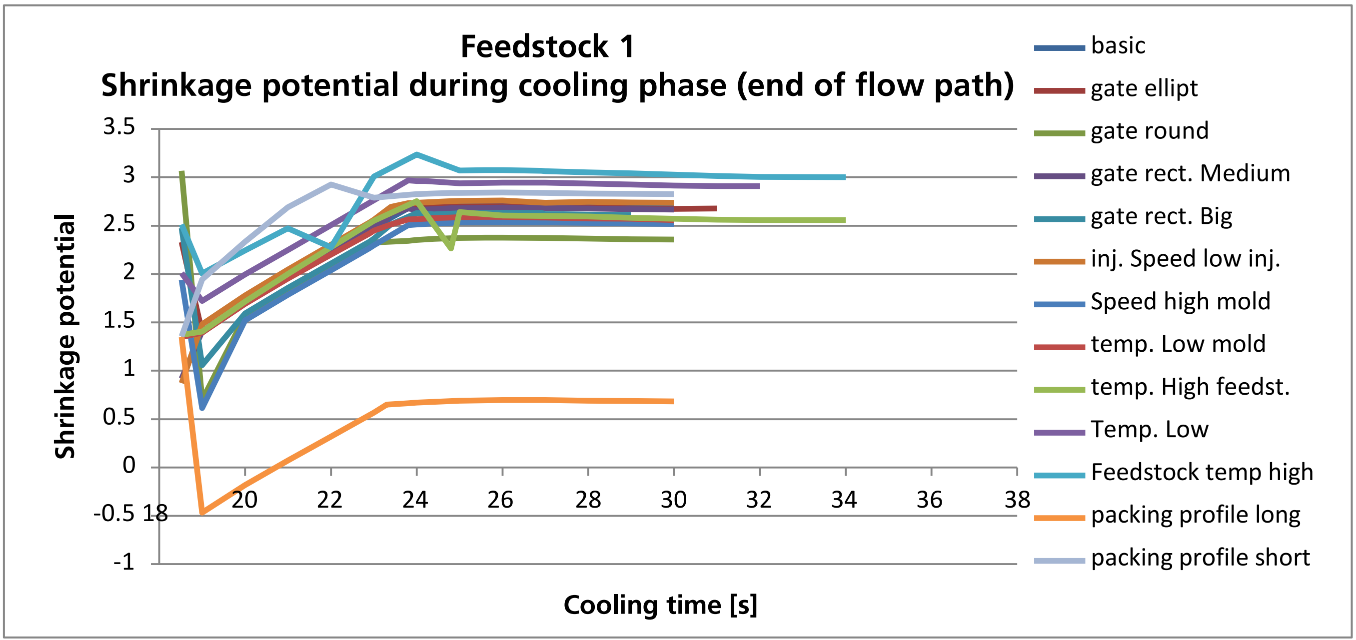

Fig. 5 Shrinkage potential of feedstock 1 during the cooling phase as a function of the varied process parameters

In all the simulations it was seen that the shrinkage potential can be effectively influenced only by the design of the holding pressure profile. Depending on the feedstock used, the level with the basic setting lies between 0% (feedstock 2) and 4.7% (feedstock 3).

The goal of the holding pressure optimization must be to set the pressure curve during the cooling time such that the level of the potential shrinkage at the start of mold opening is slightly above 0% before the gate or runner system freeze – and that as homogeneously as possible over the molding and the whole flow path length. A huge challenge!

Conclusion:

3D simulation if the injection molding process is no longer used just for visualization of the mold filling – it can do a whole lot more. It allows the whole process – not only for plastics, but also and particularly for the characteristics of PIM materials – to be optimized in order to minimize or even completely eliminate injection molding defects, as long as the transferability from the computer to production in practice can be assured! This can only be achieved with realistic material data acquisition, because the studies have shown clearly that the influence of the feedstock properties on shrinkage and solidification is greater than that of the process parameters.

Process optimization and troubleshooting by computer can only start when the specific material data are precisely known. A material database is gradually being built up at the IFAM in which these data are being implemented for input into the simulation software for both customized and commercial feedstock.