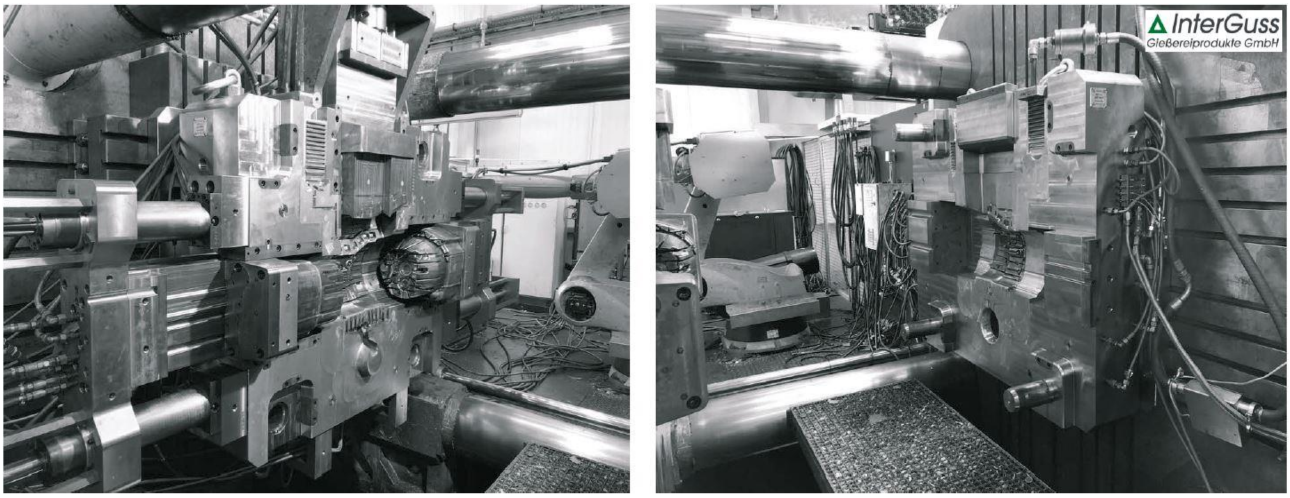
Case study on advantages and hurdles by casting chamber simulation

By Johannes Jerg, JERG Engineering GmbH

In the production of castings using horizontal cold chamber die casting machines, the casting process itself can be divided into several phases, all of which have an influence on the casting success.

A German article within the associated topic is published in GIESSEREI 109, 03/2022

NOVACAST



Die casting mold with three slides, venting insert and connection to vacuum system.

Phases and parameters

The parameters selected for the individual phases in the case study selected for the individual phases are given below in brackets:

> Dosing phase: Consisting of the melt dosing into the casting chamber for several seconds (5 s), plus a dripping or settling time (1 - 2.5 s).

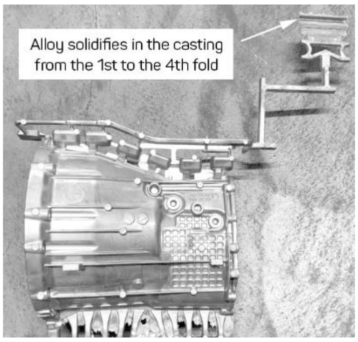
> 1st phase or prefilling phase: Filling of the casting chamber and the casting system. The start of the casting piston movement takes place with an acceleration within a certain piston stroke / stroke (approx. 0.15 - 2.5 x piston diameter (150 mm) = 23 - 375 mm) to a moderate casting piston speed (approx. 0.24 - 0.73 m/s), which is maintained up to the changeover point (500 mm). From the switchover point, the casting piston is accelerated to the speed required for the 2nd phase, usually during the filling of the casting system.

> 2nd phase or mold filling phase: Filling of the mold cavity of the casting, plus the overflows and the venting, in a correspondingly short mold filling time (approx. 60 - 70 ms) with comparatively higher casting piston speed (approx. 2.8- 3.3 m/s). The pressure in the mold cavity of the casting is initially low at the start of mold filling. At the end of mold filling, there is a considerable increase in pressure (≥ 320 bar) and a parallel decrease in speed.

> 3rd phase or holding pressure phase: Compression of trapped air/casting gases, to improve heat transfer and replenish shrinkage volume during solidification. For this purpose, an additional pressure increase in the mold cavity is possible via a multiplier (approx. 800 bar).

Did you know...
Horizontal cold-chamber die casting machines are used primarily for the production of aluminum, but also for magnesium and sometimes even zinc die castings, horizontal cold-chamber die casting machines are used. In this manufacturing process or rather machine type, the processes in the casting chamber exert an important influence on the success of the casting process. However, this is often still given too little consideration. With a case study on a BMW clutch bell, this paper describes the problems as well as possible solutions are presented in this article. By taking into account the processes in the casting chamber (casting chamber simulation), it is possible to improve the quality of the casting process compared to the traditional approach, in which only the mold filling and solidification are taken into account, which only takes into account mold filling and solidification from the point at which the melt enters the actual die casting mold, the reality can be represented more correctly and thus a significantly better casting result can be achieved.

A German article within the associated topic is published in GIESSEREI 109, 03/2022



Casting and die casting mold

The previously noted casting process parameters belong to the example casting (Fig. 1 to the left), the clutch bell of a BMW M model. Bandwidths have been given for the individual parameters, since several setting variants are shown below. The die casting mold used for the case study (see introductory photo) with 3 large slides, Interguss venting insert and possible connection to an Interguss vacuum system was made by Heck+Becker GmbH & Co. KG in Dautphetal and used there in the company's own die casting technology center on a Müller Weingarten 3200 t die casting machine.

Boundary conditions and challenges

In most cases, the 3D data of the casting, consisting of the casting system (approx. 4.0 kg), the casting (approx. 8.4 kg) and the overflows / venting system (approx. 1.2 kg) are used as the basis for a casting process simulation (Fig. 2).

In combination with further predefined boundary conditions for the materials (casting alloy EN AC-46000, AlSi9Cu3(Fe), hot work tool steel 1.2343 for molded parts with melt contact) and temperatures (melt at start of filling approx. 620 - 640 °C, mold inserts approx. 200 °C), only the mold filling process of the actual casting from the press residue, or from the switchover point, and the solidification taking place in parallel, or subsequently, are simulated. It makes sense to include the entire venting system with the venting insert, provided that the simulation software used is capable of doing so. By taking into account the actual, longer flow time of the gate, the deceleration of the melt at the end of the filling process in the venting system and finally in the venting insert, for example, the value for the heat input in the gate area and thus the best possible approximation to reality as closely as possible.

If the decision is made to use the entire processes in the casting chamber of the horizontal cold-chamber die casting machine to be taken into account in the simulation, to achieve a better representation of reality, more extensive 3-D data (Fig. 3) must be available, including the casting chamber casting chamber (inner diameter 150 mm, length 800 mm) with the filling area.

In parallel, further parameters for the entire casting process sequence must be defined in detail in advance, including additional materials (hot work tool steel 1.2343 for the casting chamber) and temperatures (melt at the start of metering approx. 670 - 700 °C, casting chamber approx. 180 °C). In this context, the selection and coordination of suitable crosslinking, the physical parameters of the materials and the parameters for metering and the 1st phase (Table 1) also play a decisive role, the implementation of which is a challenge.

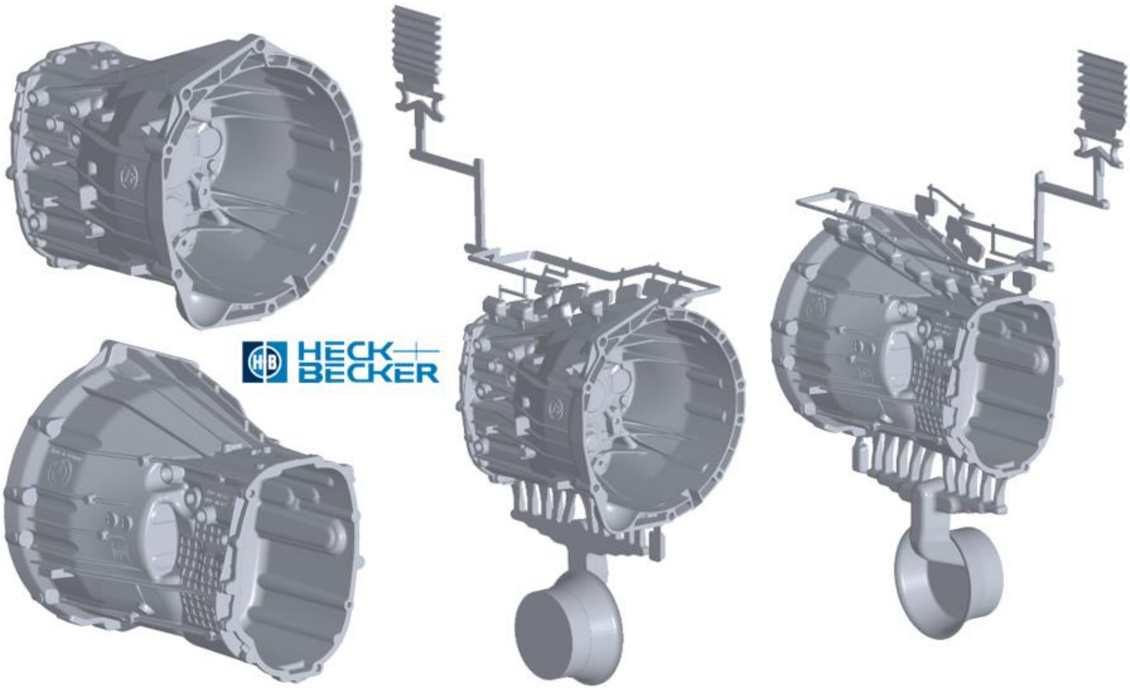


Fig 2. 3-D data of the part and the complete casting.

Table 1: Parameters of the dosing phase and the 1st phase in the case study.

	Sequence 1 (Fig. 6a and 7)	Sequence 2 (Fig. 6b and 8)	Sequence 3 (Fig. 6c and 9)
Dosing phase, filling level			
Dosing, duration in s	5,0	5,0	5,0
Settling time in s	2,0	1,0	1,25
Filling level after dosing, before piston start in %.	40	40	40
1st phase, pre-filling phase			
Start with acceleration, Stroke (Stroke = Factor x D_{Gk})[1]	263mm = 1,75 x D_{Gk} (225mm = 1,5 x D_{Gk})[2]	375mm = 2,5 x D_{Gk}	23mm = 0,15 x D_{Gk}
Piston speed (v_{piston} = factor x v_{krit})[3]	0,24m/s = 0,25 x v_{krit}	0,73m/s = 0,75 x v_{krit}	0,29m/s = 0,3 x v_{krit}
Switchover point, stroke in mm	500	500	500
Duration in s (End of filling opening to the full casting chamber, green area in Fig. 6)	1,8	0,8	1,3
Variant	**V 1 = 5,0+2,0+40%+ 1,75xD+0,25xv_{krit}**	**V 2 = 5,0+1,0+40%+ 2,5xD+0,75xv_{krit}**	**V 3 = 5,0+1,25+40%+ 0,15xD+0,3xv_{krit}**

[1] = Casting piston diameter D_{Gk} = 150mm

[2] = Optional variant

[3] = Critical casting piston speed v_{krit} = 0,97m/s

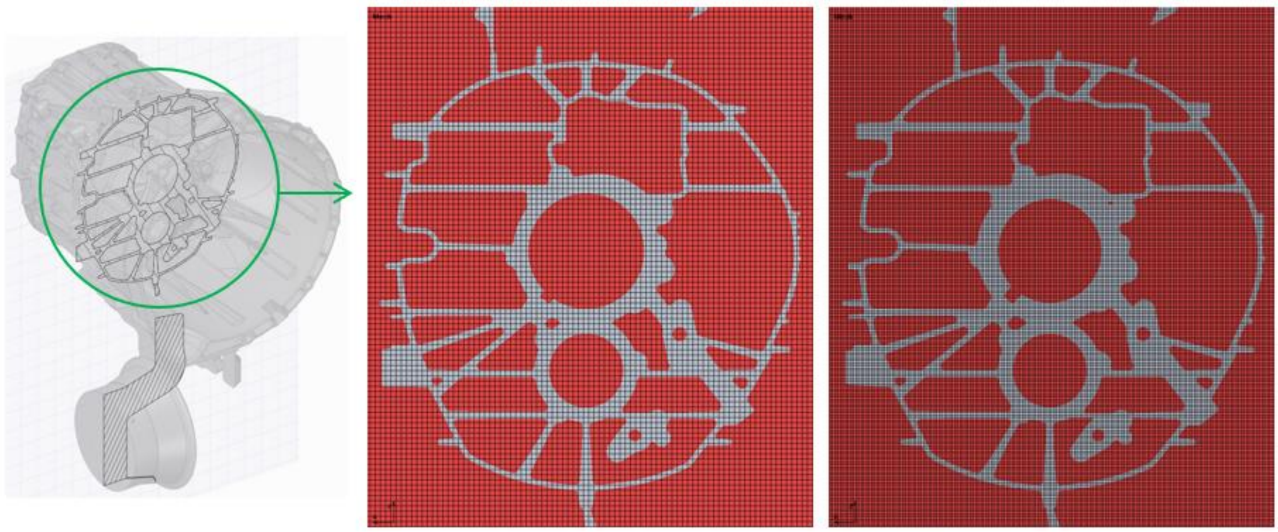


Fig 3. Virtual central section through:

a) the CAD model

b) the coarser meshing with 1 - 2 cells in the characteristic wall thickness

c) the finer meshing with 2 - 3 cells in the characteristic wall thickness

Table 2. Comparison of the standard composition with the simulation.

EN 1706	Chemical composition of the casting alloys in % by mass													
Alloy	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Pb	Sn	Ti	Other additions		Al
EN AC-46000	8,0-11,0	≤ 1,3	2,0-4,0	≤ 0,55	0,05-0,55	≤ 0,15	≤ 0,55	≤ 1,2	≤ 0,35	≤ 0,25	≤ 0,25	Individual ≤ 0,05	In total ≤ 0,25	Rest
AlSi9Cu3(Fe)		0,6-1,1			0,15-0,55						≤ 0,2			
Simulation	9,5	0,6	3,0	0,35	0,3	-	0,25	0,6	0,1	0,1	0,15	-	-	85,05

Meshing

In the first step of the simulation, the calculation area is meshing, i.e. divided into small cells or elements, for which the necessary calculation equations are later solved by the software. The accuracy and the representation of the simulation results depend, among other things, on the size and number of these cells or elements. Only with sufficiently fine resolution can precise and meaningful results be expected. Details (drops, air bubbles, ...), peak values (min. or max.) or a solidified edge shell in the casting chamber, for example, can only be calculated and displayed with correspondingly fine meshing. Within the case study, two different fine meshing were applied (Fig. 3), a coarser one with 1 to 2 cells and a finer one with 2 to 3 cells in the characteristic wall thickness. However, if the casting chamber is included, the volume to be simulated or the size of the calculation area is increased considerably. For the same meshing fineness, the required number of cells or elements increases by a factor of 2 to 3. As a result, the demands on the computer hardware used increase, the computer memory requirement increases and the calculation time is considerably extended by the higher number of cells or elements on the one hand and the additional dosing phase on the other.

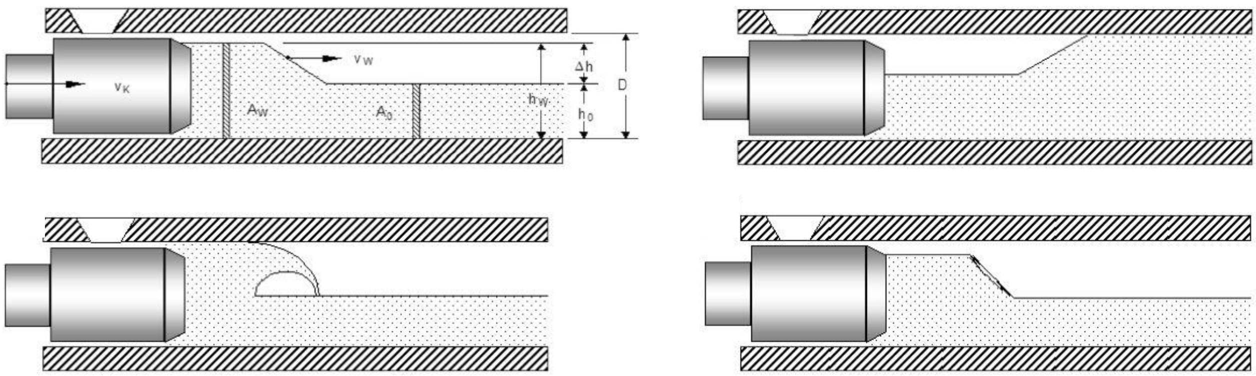


Fig. 4: Wave formation in the casting chamber and possible problems;

[top left] Principal drawing

[top right] Wave reflection with confinement due to unfavorable settings for the run-off of the 1st phase

[bottom] Wave flashover, rupture, breakage of the wave, and rise of the melt wave into the feed opening due to excessive velocity and/or acceleration

Casting alloy

During actual casting, the alloy used solidifies in the 1st-4th fold of the vent insert (see Fig. 1). Here, among other things, the selection and use of suitable material data for a simulation result that is as close to reality as possible plays an important role. Temperature-dependent values were used for both the casting alloy (EN AC-46000, AlSi9Cu3(Fe)) and the molding materials. For the casting alloy, an average composition (red data in Table 2) was used.

The solidification interval is between 599 and 532 °C (for comparison: solidification interval EN AC-46000, AlSi9Cu3(Fe), according to literature at 600 to 490 °C).

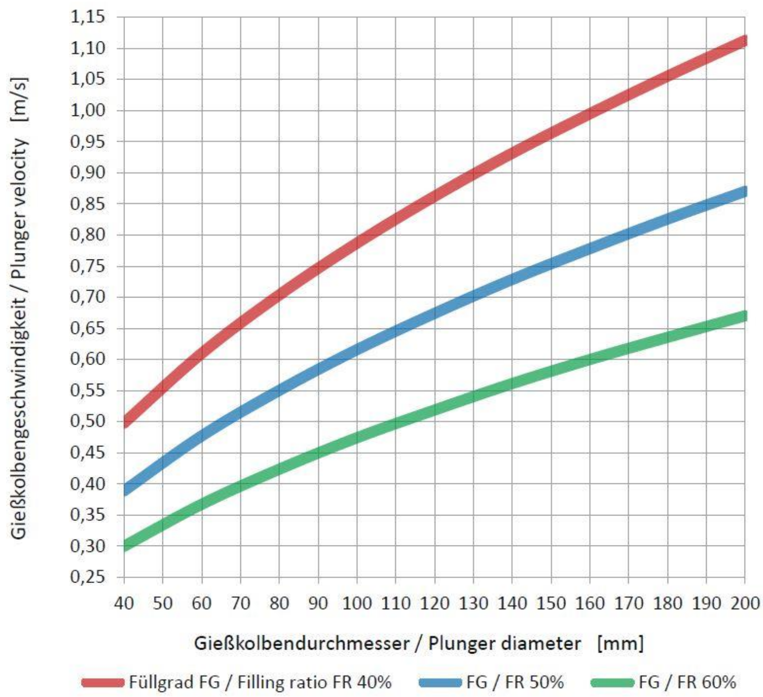


Fig. 5: v_{krit} diagram for estimating suitable casting piston speeds v_K.

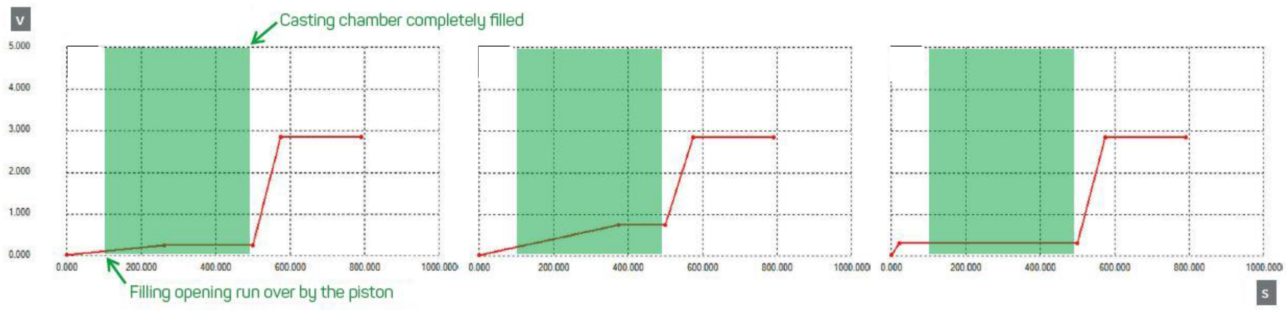


Fig. 6: Speed-displacement (v - s) diagram for three possible machine settings considered in the case study (see Table 1); V1, V2, V3.

Processes in the casting chamber - dosing and 1st phase

In reality, during the 1st phase, a wave is formed in front of the moving casting piston. Its formation depends on the sequence of melt dosing and the settings for the sequence of the 1st phase. If the casting plunger speed corresponds to the so-called critical speed ($v_K \cong v_{krit}$), the accumulating wave forming in front of the casting plunger exactly fills the entire casting chamber cross-section. If the parameters, or the settings of the die casting machine, are incorrectly selected, this results in problems such as wave flashover, rise of the melt wave up to the filling opening or wave reflection with gas entrapment (Fig. 4). The diagram in Fig. 5 can be used to estimate suitable values for the "critical pouring piston speed" (pouring piston diameter D_{Gk} 150 mm, filling level 40 %, v_{krit} = 0.97 m/s).

In practice, however, the indicated v_{krit} values often cannot be implemented, because they may not even be feasible for the die casting machine or they are too fast, because the melt wave already rises into the filling opening at the beginning, or the time required for good vacuum venting, or for the required pressure level to be reached, is not sufficient.

Therefore, it is often advantageous to work with lower values: with an acceleration phase at the beginning and then with low velocity values, e.g., in the case study in the range of 0.25 - 0.75 x v_{krit}. This sometimes results in no wave reflection, sometimes up to multiple wave reflection and subsequent air or casting gas displacement, if a good combination of dosing time, settling time and expiration of the 1st phase was selected.

The casting piston then moves at a constant speed until it reaches the changeover point. In modern, real-time controlled machines, the 1st and 2nd phases can still be divided into sub-areas with acceleration and constant speed, possibly also braking, if necessary.

Thus, among other things, adapted sequences of the 1st phase can be realized for corresponding requirements.

Fig. 6 shows three possible speed-displacement diagrams for casting piston movement. In all three processes, flashover and entrapment of air or casting gas in the chamber are avoided and complete displacement of air and casting gas into the mold cavity is achieved:

> With the first sequence (Fig. 6a), a longer duration of the 1st phase is possible for good venting or the use of a vacuum system.

> The second sequence (Fig. 6b) offers a very short duration of the 1st phase for only slight cooling of the melt up to the start of mold filling.

> The third sequence (Fig. 6c) with abrupt start (very short acceleration) and subsequent constant piston speed up to the changeover point for simple or older die casting machines.

For these three processes, simulations of mold filling and solidification, taking into account the processes in the casting chamber were carried out. The good agreement of the results obtained with the NovaFlow&Solid software with reality, if appropriate boundary conditions and meshing are applied, has already been shown in earlier work [1-3].

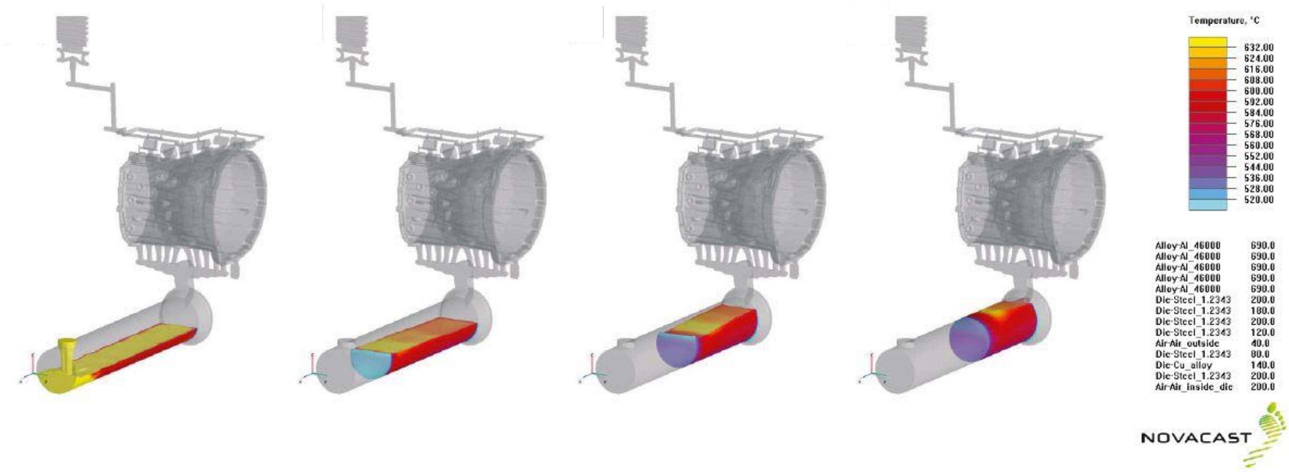


Fig. 7: Temperature simulation results of variant 1 (see Table 1);

a) Dosing generates a wave, to which the settling time must be adjusted

b) With moderate acceleration to a comparatively low piston speed, a very flat wave is generated

c) 1. wave reflection in the press rest area, thereby no entrapment of air / casting gases

d) 2. Wave reflection near the piston and complete air and casting gas displacement

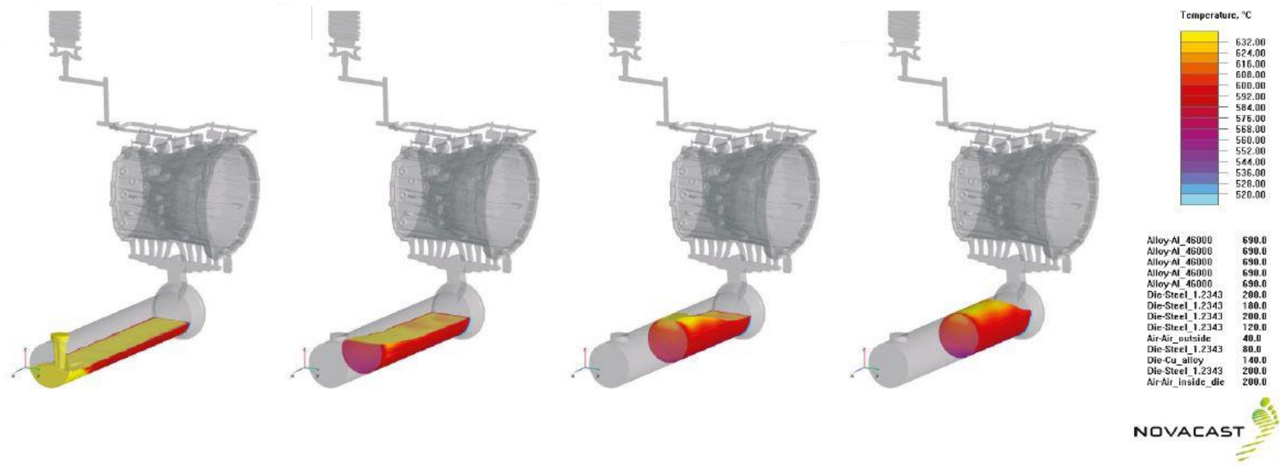


Fig. 8: Temperature simulation results of variant 2 (see Table 1);

a) A wave is generated by dosing, to which the settling time has to be adjusted to

b) A long flat wave is generated with a long piston acceleration stroke to a comparatively high piston speed

c) The wave fills the casting chamber cross-section in one stroke without wave reflection

d) Complete air and casting gas displacement without wave reflection

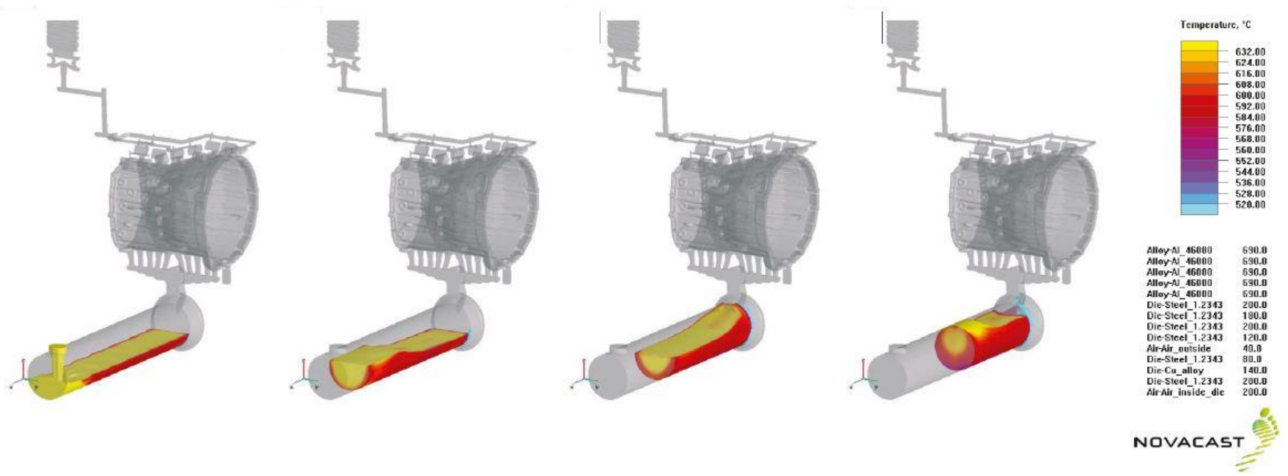


Fig. 9: Temperature simulation results of variant 3 (see Table 1);

a) A wave action is generated by dosing, to which the settling time has to be adjusted

b) Due to the abrupt start, the only short acceleration at the beginning, much stronger wave formation

c) 1. wave reflection in the press rest area, just no entrapment of air / casting gases

d) 2. wave reflection near the piston and complete air or casting gas displacement

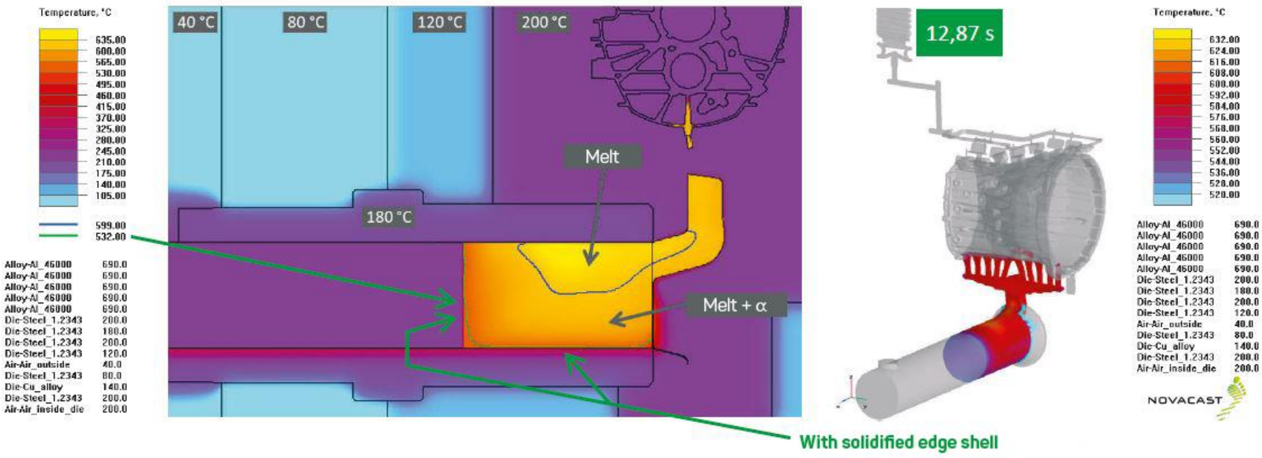


Fig. 10: Sectional view with temperature curve for variant 1 (see Table 1) at the beginning of mold cavity filling with solidified shell in the casting chamber. The duration from the start of dosing to the time shown is indicated in green. The extent of the solidified shell at the piston face depends on the piston system used and its temperature control.

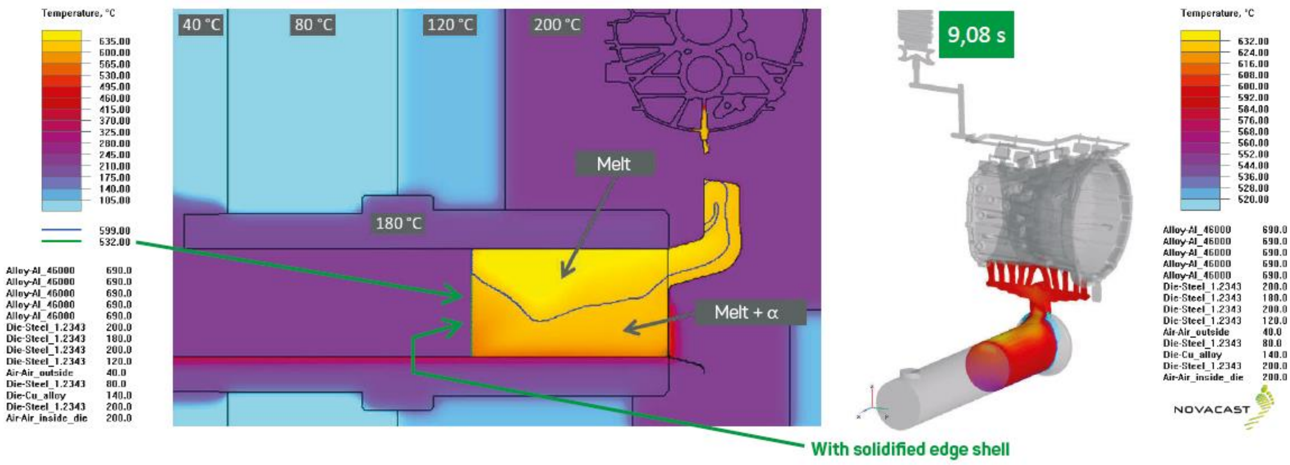


Fig. 11: Sectional view with temperature curve for variant 2 (see Table 1) at the beginning of mold cavity filling. The green line shows the duration from the start of dosing to the time shown.

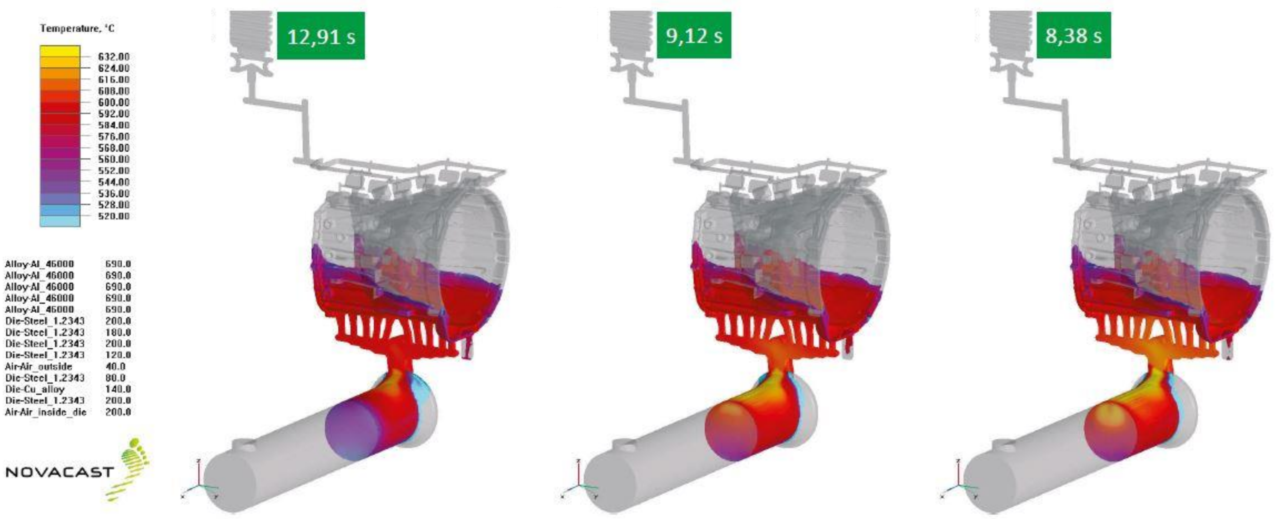


Fig. 12: Comparison of temperature simulation results, casting mold cavity filled to approx. 30 %. The duration from the start of dosing to the time shown is indicated in green; V1, V2, V3.

A German article within the associated topic is published in GIESSEREI 109, 03/2022

NOVACAST

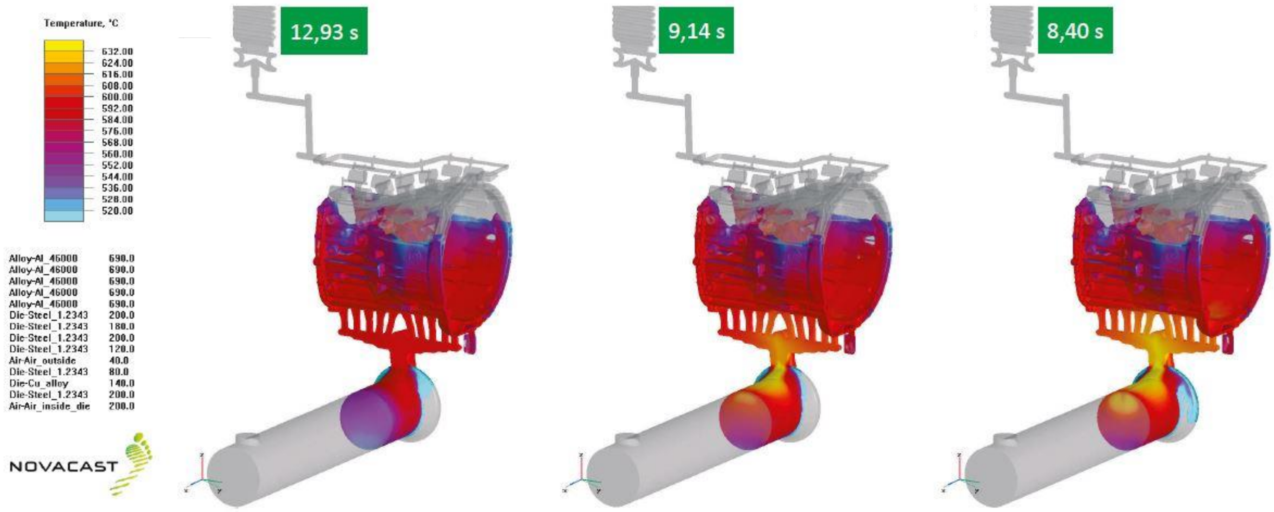


Fig. 13: Comparison of temperature simulation results, casting mold cavity approx. 60 % filled. The duration from the start of dosing to the time shown is indicated in green; V1, V2, V3.

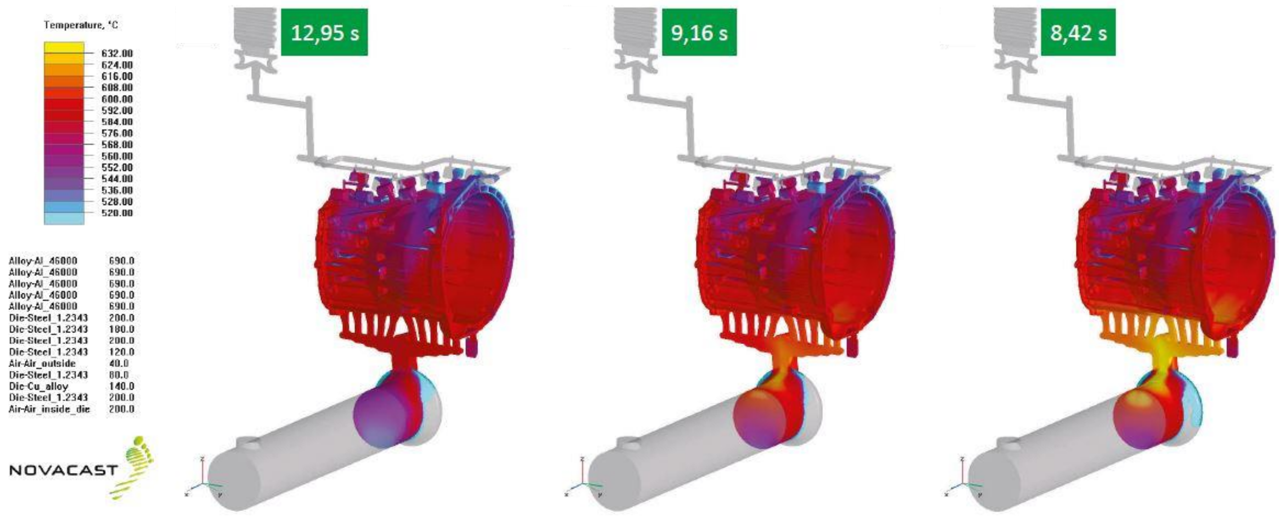


Fig. 14: Comparison of temperature simulation results, casting mold cavity approx. 100 % filled. The duration from the start of dosing start to the time shown; V1, V2, V3.

Simulation results

In all three variants presented (cf. Table 1), a faultless process could only be achieved with a selected combination of dosing time, settling time, casting piston acceleration phase and then piston speed level applied up to the switchover point. Slight changes to individual parameters, or other combinations, led to the problems described in the casting chamber of wave reflection with gas entrapment, wave flashover, ….

Figs. 7 to 9 show the essential times of all three processes, consisting of the dosing phase and the subsequent 1st phase, as well as the temperature curves within the casting chamber, with temperatures above and within the solidification interval. The size and position of these zones, together with the casting system geometry, influence the subsequent mold filling process.

Particularly in the case of multiple molds with more than one run, starting directly from the press residue, this can exert an influence and lead to differences in the mold cavities.

Usually, in a conventional simulation, without taking the casting chamber into account, the melt flows from the press rest area into the mold cavity at a uniform melt temperature, i.e. the temperature profile shown here is not taken into account.

If a good result is nevertheless to be achieved in such a simulation, the starting temperature of the melt must be matched as closely as possible to the real temperature profile in the casting chamber, i.e. it must represent an average value.

However, it will always remain only an approximation. Depending on the duration of dosing and the selected sequence of the casting process, a solidified edge shell may even be formed in the casting chamber before the actual filling of the casting begins.

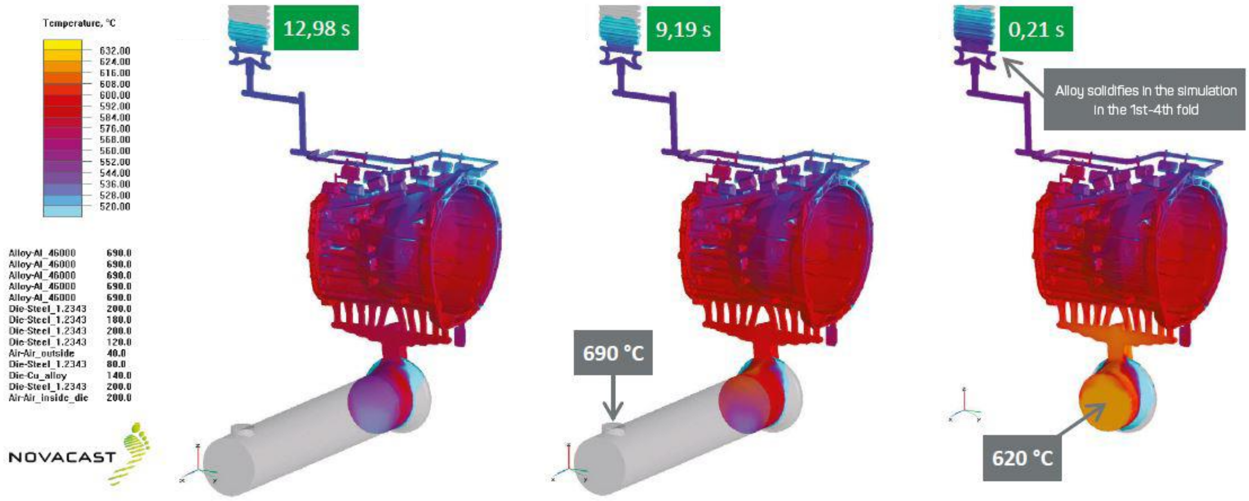


Fig. 15: Comparison of temperature simulation results, entire casting mold cavity approx. 99.X % filled. The green line indicates the duration from the start of simulation to the time shown; V1, V2 and simulation without consideration of the casting chamber.

In the longest sequence considered here (V 1, see Figs. 6a and 7), a total of 12.87 s is required to reach the casting mold cavity (Fig. 10). Due to the considerably shorter duration from the start of dosing to the time of 9.08 s shown for the 2nd flow (V 2, see Figs. Figs. 6b and 8), there is still a larger proportion of the melt at temperatures above the solidification interval and a solidified shell has not yet formed in the casting chamber bore (Fig. 11).

In a direct comparison of the three variants, clear differences in the temperature results can be seen for the mold cavity filling due to the different time elapsed until the time shown (Figs. 12 - 15). In practice, these cause different properties in the casting, but also different defect characteristics, e.g. cold flow marks, shrinkage cavities, ... At the top of the venting system, the alloy also solidifies in the simulation in the 1st-4th fold. This testifies to the very good reproduction of the real casting process by the simulation and speaks as a quality feature, both for the settings/parameters used as well as for the software package itself.

Summary and conclusion

In the interaction of dosing, settling time, sequence of the 1st phase (acceleration, piston velocity level, no wave reflection, multiple reflection, ...), several working variants are possible for each casting. Tuning the appropriate parameters is not trivial. Even small changes can cause errors in the casting, which only a simulation taking into account the casting chamber can correctly predict.

Although good simulation results are also possible without taking the casting chamber into account, the temperature representation is very similar but not the same. The prerequisite is a suitable choice of boundary conditions, if necessary, based on "empirical values", in particular the "mean" melt start temperature of here approx. 620 °C as well as, in practice, a run-off of the 1st phase without air and casting gas inclusion later on, so that a good agreement is possible.

A German article within the associated topic is published in GIESSEREI 109, 03/2022

It should also be considered that, depending on the time and sequence of the casting process, the pressure of the melt both in the casting chamber and in the casting system can be considerably higher than after the melt has entered the mold cavity. The pressures are not equalized until the end of mold filling. Gas trapped in the casting chamber gas trapped in the casting chamber, or gas bubbles then transported in the melt stream, are initially compressed and expand ("explode") as they flow through the gate and thus change the filling behavior.

In a comparison of mold filling and solidification simulations with and without a casting chamber, the casting chamber simulation enables a better simulation result, since the flow and cooling behavior in the casting chamber has a considerable influence on the casting process and is included in the result.

Parallelly, the selected combination of dosing time, settling time and further course of the 1st phase is checked and potential sources of error are eliminated in advance, which are otherwise difficult to identify and check.

However, this is also associated with a significant additional and higher complexity (parameters, meshing, time, hardware, costs).

Sources:

[1] Jerg, J.: Dosierung der Schmelze und Ablauf der 1. Phase - Simulation verschiedener Varianten. Vortrag mit Fallstudie zu einer Axialventilator-Nabenhälfte. 11. Aalener Praxistage Gießen. Aalen, 21.06.2012.

[2] Jerg, J.: Gießprozesssimulation – Wichtiges Werkzeug auf dem Weg zum guten Gussteil. Vortrag mit Fallstudie zu Triumph Kurbelgehäusehälfte. 1. InterGuss & Heck + Becker Symposium. Marburg, 16.-17.05.2017.

[3] Jerg, J.: Vorteile und Hürden beim Einsatz der Gießkammersimulation - Fallstudie anhand einer BMW-Kupplungsglocke. Vortrag. 20. Druckgusstag. Nürnberg, 14.-16.01.2020.