Mould Fill Simulation to Improve the Quality of a Component

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High pressure die casting of large magnesium components is a very cost competitive technology for light weight designs.

As many functions can be integrated into a single part, significant assembly cost can be saved.

Besides the weight savings, dealing with a single integral part can be of particular interest for a given application.

For an instrument panel, the high specific stiffness, the resulting damping characteristics, the excellent mass tolerances are such advantages as well as the absence of rattling noises which can be a nuisance with assemblies.

The production of large high quality magnesium components requires high competence with regard to mould construction, metallurgy and die casting technology. Numerical simulation of mould filling and solidification is an invaluable method to the construction engineer, as the complexity of the interactions during mould filling goes beyond human imagination.

These simulation tools have become a powerful mean in identifying defects and for the optimisation of moulds.

Casting experiments and mechanical tests

A prototype instrument panel (figure 1) has been cast at Alusuisse BDW (Bayrische Druckgusswerke) on an Idra cold chamber die casting machine with 2500 tons clamping force.

The magnesium alloy AM50 has been used for the experiments.

Several series of test castings were carried out while monitoring the most important process parameters such as metal temperature, vacuum level and piston shot profile.

The mould filling times were around 50 ms and the average mould temperature was approximately 200 °C.

After each series, specimens for tensile tests were taken at 11 different locations of the component.

The dimensions of these specimens were 110 x 15 mm.

The original wall thickness was kept (2-3 mm depending on the location), thus conserving the casting skin whenever possible.

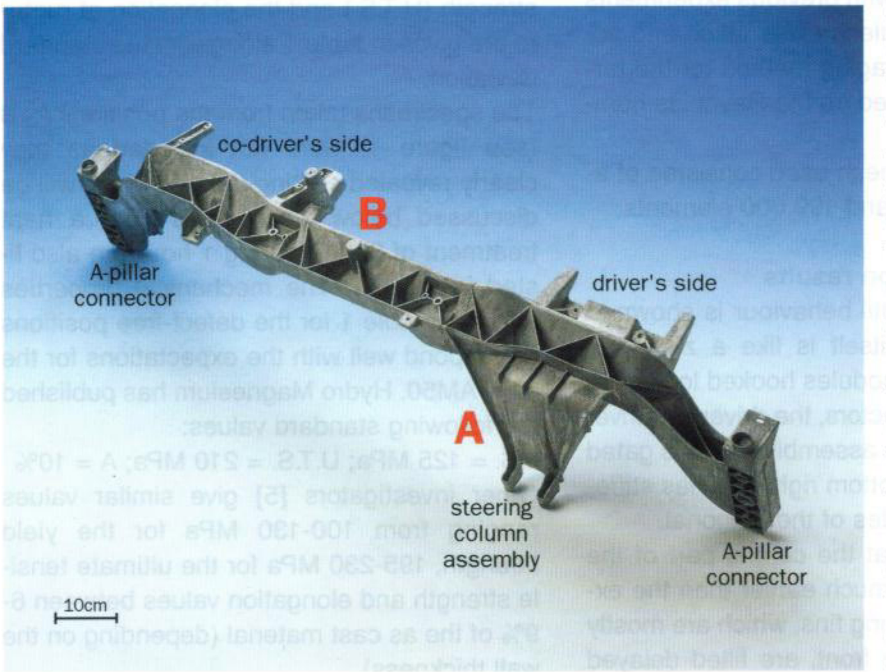

Fig. 1 • Prototype of a magnesium instrument panel produced by vacuum high pressure die casting on a cold chamber machine (magnesium alloy AM50).

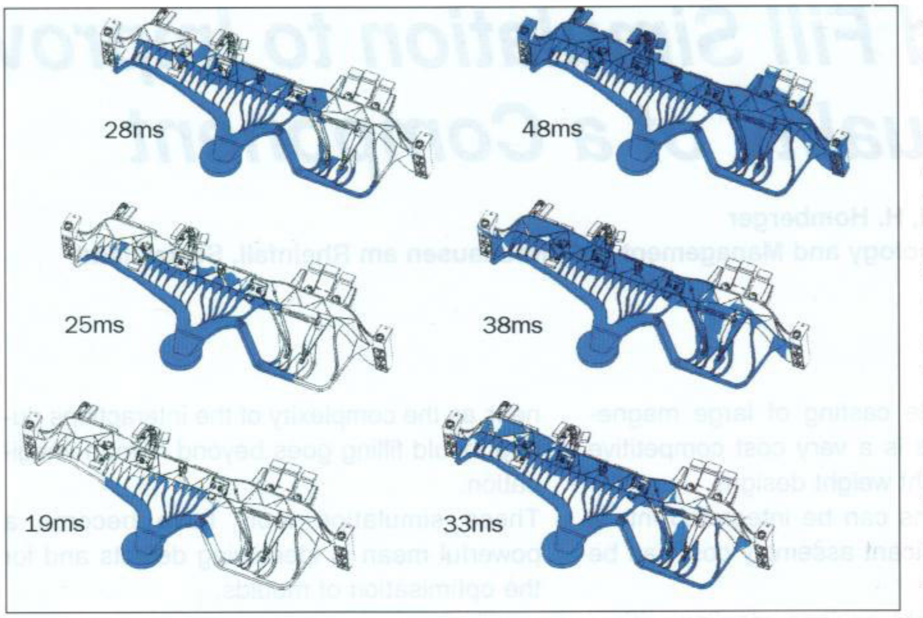

Fig. 2 • Simulated mould fill behaviour of the prototype instrument panel.

Simulation technique

The numerical mould fill and solidification simulations have been carried out using the casting simulation package ProCASTTM (V3.1.0) which is a finite element based program [1]. For the mould filling, the full Navier-Stokes equations are being solved whereas a SOLA-VOF algorithm [2] for the treatment of the free surface is being used. The solidification phase change is taken into account by an enthalpy method for the solution of the heat diffusion equation [3].

The assumptions made for the thermal and the hydrodynamic boundary conditions were derived by analogy with previous experiments on aluminium. Turbulence was taken into account using an averaging method for the turbulent viscosity based on the Reynolds number [4].

The finite element mesh used consisted of about 80.000 nodes and 190.000 elements.

Mould fill simulation results

The general mould fill behaviour is shown in figure 2. The part itself is like a z-shaped sheet with several modules hooked to it, such as the A-pillar connectors, the driver, co-driver and steering column assembly. The z is gated vertically from the bottom right and has stiffening fins on both sides of the diagonal.

It is clearly seen that the central part of the component is filled much earlier than the extremities. The stiffening fins, which are mostly diagonal to the flow front, are filled delayed with respect to the main sheet (figure 2, 25 ms +28 ms).

At the steering column assembly, two separate flow fronts meet (figure 2, 33 ms), one originating from the central gates, the other one from the lower gates.

The two A-pillar connectors are filled towards the end right before the driver's side filling is completed (figure 2, 48 ms).

Both A-pillar connectors have fins with a wall thickness of only 0.5mm. Despite this fact, they can still be filled, as the liquid metal arriving from the outmost gates is still hot enough to penetrate and fill these fins. Comment: for the sake of clarity, the local temperatures are not shown in this figure.

Results of the tensile tests

On each of the 4 tested components, 11 specimens were taken. The average values for the yield strength (Y.S.), the ultimate tensile strength (U.T.S.) and the elongation at rupture are given in table 1 along with the standard deviation.

The specimens taken from the positions A+B (see figure 1) were not included as they clearly revealed casting defects which will be discussed below. The values after a heat treatment of 320°C during 1 hour are also listed in table 1. The mechanical properties shown in table 1 for the defect-free positions correspond well with the expectations for the alloy AM50. Hydro Magnesium has published the following standard values:

Y.S. = 125 MPa; U.T.S. = 210 MPa; A = 10%

Other investigators [5] give similar values ranging from 100-130 MPa for the yield strength, 195-230 MPa for the ultimate tensile strength and elongation values between 6-9% of the as cast material (depending on the wall thickness).

Table 1• Average mechanical properties measured by tensile tests on specimens from 9 different locations (34 values in total).

	Y.S. [MPa]	U.T.S. [MPa]	Elongation [%]
As cast	130±8	228±16	10±3
After heat treatment (320°C/1hr)	134±14	236±24	12±5

Quality assessment by interpretation of the simulation results

Judging from the geometry of the component (i.e. thin walls, large flow paths), mould filling phenomena are most relevant for the quality of the resulting part.

The simulated temperature distribution and solid fractions are of minor importance and will not be discussed in detail. The interpretation of the simulation results leads to the following assessment of the part quality:

The part can be filled

The simulated piston pressure during the mould filling stage does not exceed 100bar. As the die casting machine used for the experiments has a much larger capacity, there should be no problem in filling the component.

No cold shuts

As the simulated temperatures of the flow fronts remain above a critical temperature (i.e. a critical liquid fraction) throughout the filling, cold shuts are not likely to occur.

If two flow fronts meet, they should be able to weld (provided that their cleanliness is sufficient).

No Sticking

In the case of aluminium alloys, sticking is observed when the separating agent is washed out locally; i.e. the local velocity remains high enough during a sufficient contact time [6].

As this criteria is not fulfilled in the simulated case and as the affinity of liquid magnesium towards steel is much lower than for aluminium, no sticking effects are to be expected.

Mind the venting

As the two connections with the A-pillars have no overflows attached due to the mould construction constraints, the venting of these areas has to be paid special attention.

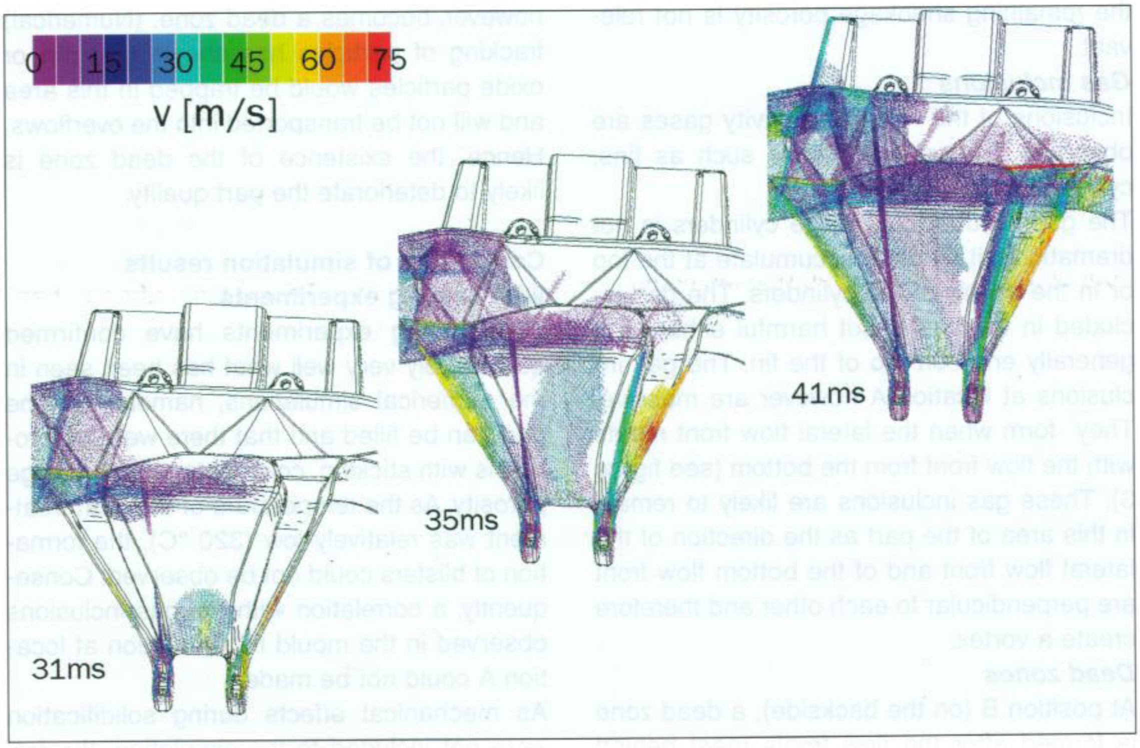

Fig. 3 • Formation of gas inclusions during mould filling at position A (module which accommodates the steering column assembly). The part is shown as being transparent. The colour of the vectors corresponds to the magnitude of the local velocity.

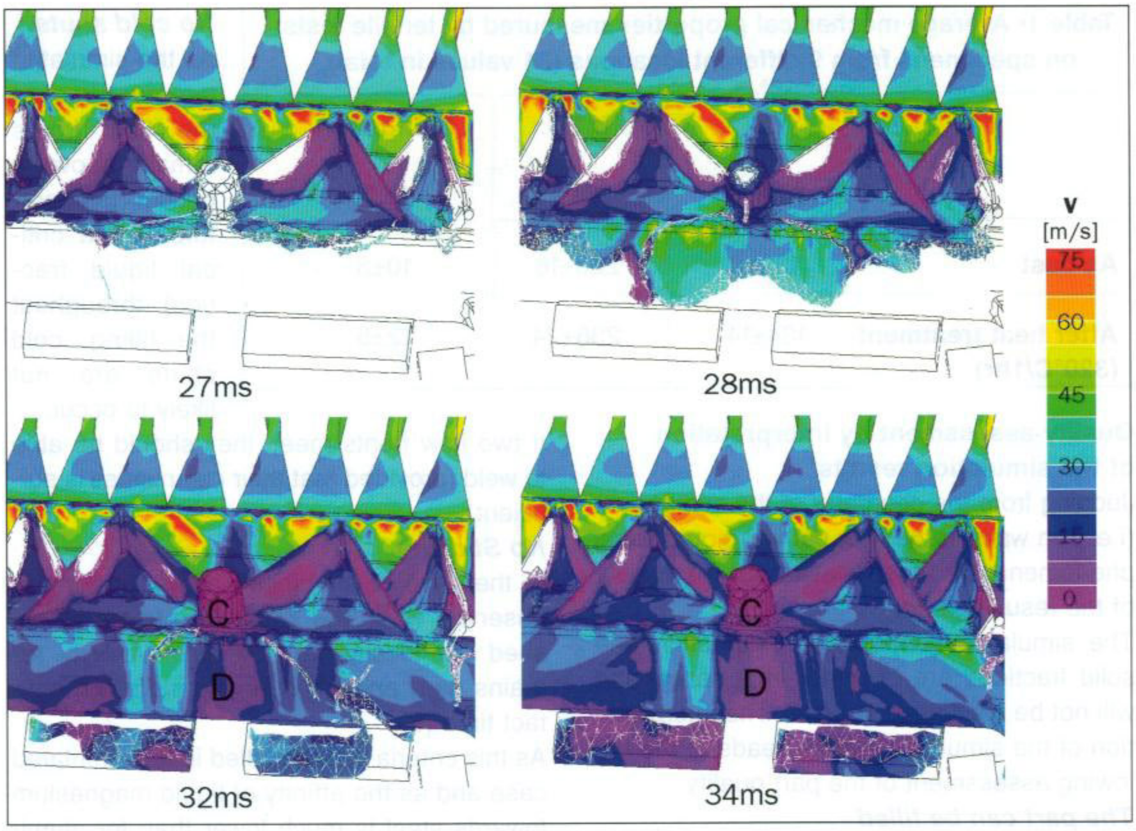

Fig. 4 • Formation of the dead zone (D) behind the cylinder (C) at position B. The colours show the local velocity, the white net corresponds to the position of the flow front.

Shrinkage porosity

All the connection cylinders are quite massive. The subsequent solidification simulation has shown that there would be shrinkage porosity in the centre of these cylinders.

As these areas are machined away (threats), the remaining shrinkage porosity is not relevant.

Gas inclusions

Inclusions of the remaining cavity gases are observed in several locations such as fins, cylinders and in location A.

The gas included inside the cylinders is not dramatic as it tends to accumulate at the top or in the centre of the cylinders. The gas included in the fins is not harmful either as it generally ends on top of the fin. The gas inclusions at location A however are massive. They form when the lateral flow front meets with the flow front from the bottom (see figure 3). These gas inclusions are likely to remain in this area of the part as the direction of the lateral flow front and of the bottom flow front are perpendicular to each other and therefore create a vortex.

Dead zones

At position B (on the backside), a dead zone is formed after the flow fronts meet behind the large cylinder (see figure 4). The reason for the formation of the dead zone is the arrangement of the two overflows. Once the part itself is filled in this zone, the liquid metal continues to flow into the overflows.

The liquid in the flow shade of the cylinder, however, becomes a dead zone. (Numerical) tracking of particles has shown that dirt or oxide particles would be trapped in this area and will not be transported into the overflows. Hence, the existence of the dead zone is likely to deteriorate the part quality.

Correlation of simulation results with casting experiments

The casting experiments have confirmed qualitatively very well what has been seen in the numerical simulations, namely that the part can be filled and that there were no problems with sticking, cold shuts and shrinkage porosity. As the temperature of the heat treatment was relatively low (320 °C), the formation of blisters could not be observed. Consequently, a correlation with the gas inclusions observed in the mould fill simulation at location A could not be made.

As mechanical effects during solidification were not included to the simulation, the formation of hot cracks could not be predicted. Some minor solidification related surface cracks, which are rather common for this type of alloy, have been observed during the first test castings. These hot cracks could be easily avoided in the subsequent casting experiments.

Correlation of simulation results with the mechanical tests

The simulation results correspond qualitatively with the results of the tensile test.
Quantitative prediction of mechanical properties by simulation is not yet possible. But the zones with "normal" filling behaviour reveal consistently high mechanical values with relatively little scatter.
The tensile test specimens taken at the positions A and B, however, have shown very poor results. In particular, the elongation values were extremely low, typically below 1%. These measurements correlate well with the defects which could be seen in the mould fill simulation.
The specimen at position A corresponds to the gas inclusions formed when to flow fronts from two different directions meet. Even with the vacuum applied, this gas inclusion could not be avoided.
The specimen B on the backside corresponds to the dead zone formed behind the cylinder. When the flow fronts meet behind the cylinder, pollution such as separating agents, dirt, oxides etc. will remain within the dead zone and lead to very poor elongation values.

How can the quality of the component be improved?

For the two defects which could be identified by both simulation and mechanical tests, the corrective actions are different:
The defect at position B (dead zone) can be avoided easily by modifying the arrangement of the overflows on the backside of the cylinder. It is sufficient to place an overflow directly behind the cylinder.
This will force the metal to flow through the former dead zone and will improve the part quality.
The other defect at position A is more difficult to avoid as an optimisation of the gating system in this zone would be necessary while keeping the effects of such changes for the backside areas in mind.
Such optimisations have been carried out successfully for similar components made of aluminium.
In this case, however, no optimisation was carried out as it would have been to much effort for a prototype.

Conclusions

The production of large magnesium components with high quality requires an excellent mould design. A high level of competence for numerical simulation is needed to assist the construction engineer while designing the casting and overflow system. It could be shown in the present study that many casting defects can be identified before a mould is built. The qualitative correlations between simulation, casting trials and destructive tests have been very good.
High mechanical properties can be achieved inside the cast component if defects are avoided.

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