Complete Simulation of High Pressure Die Casting Process

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Abstract
The use of simulation programs saves time and reduces the costs of the casting system design. At the same time it is possible to meet stringent product quality. Simulation can make a casting system optimal: it enables the producing of sound, high-quality castings with fewer experiments. Furthermore environmental savings and economical use of materials can be achieved when the number of test castings is reduced.

Foundries use now widely simulation codes that are based on a thermal conduction model where thermal conduction in the melt and liberation of latent heat during solidification are considered.

Fluid flow simulations are less used. However, e.g. aluminium die casting is so complicated in which flow momentum plays a crucial role in the mould filling process due to the high velocity of the liquid metal. Inertia effects may cause splashing, jetting or undesirable filling of the metal flow into mould cavity. When considering complex parts, the accurate prediction of mould filling behaviour using empirical knowledge is nearly impossible.

In most of the industrial nations, about 70% of the diecast parts go to the automotive industry. Aluminium diecastings are gaining importance in the production of lightweight vehicle bodies, as for example used in new model Audi cars. Therefore, it is even more vital today that these castings can be produced with the high quality methods. In this context the simulation is becoming more essential in the designing process.

This paper describes the advantages of the Shot Sleeve simulations to attain better casting system design in HPDC castings. Filling analysis is used to determine the size and location of the gate as well as proper runner system design for ensuring a complete and balanced filling of the part. Shot sleeve simulations in High Pressure Die Casting process ensures the minimum air entrapment during the pre-filling phase.

Introduction
Computer simulations of various kinds are gradually becoming widely recognised tools in numerous design processes. Simulation codes are widely used in the foundry industry. Computer simulation of the casting process began with solidification modelling. For this reason, the codes are used, in most cases, for heat transfer calculations in order to predict hot spots and to avoid porosity in castings.

Fluid flow simulations are less widely used. One of the reasons is that only a few of the codes can adequately simulate highly dynamic flows. On the other hand, all of the known methods require a significant degree of human effort during the pre-processing phase of the simulation process. This excludes the everyday practical use of such methods, when complicated geometries are utilised: The enmeshing process takes simply too long and often calculation meshes must be fixed in order to achieve converged solutions. Furthermore, although the casting geometry has been received from the workshop, adding the channels may involve considerable effort. For these reasons, many foundries tend to trust to their empirical knowledge. However, fluid flow simulations should be used in many instances, e.g. in aluminium die casting, which is particularly because flow momentum plays a crucial role in the mould filling process due to the high velocity of the liquid metal. Inertia effects may cause splashing, jetting or undesirable filling of the metal flow into mould cavity. When considering complex parts, the accurate prediction of mould filling behaviour using only empirical knowledge is virtually impossible.

It is commonly accepted that shrinkage and gas are two major causes of porosity. The shrinkage porosity is associated with the hot spot in the casting. The gas porosity has four different reasons: 1) Trapped air that is entrained in the injection system and cavity; 2) Gas generated from burned lubricants; 3) Gas generated from water that may be in cavity and 4) Hydrogen gas. The gas
porosity due to the trapped air is an unwanted byproduct of relatively high velocity injection method used. Gas entrapment is caused by turbulent flow pattern generated during metal injection process. The location, size and total volume of contained gas porosity are influenced by the method chosen to fill cavity with molten alloy. In high pressure die casting, some efforts have been made to reduce air entrapment by the modification of conventional injection shot profile taking advantages of the development of advanced and reliable control systems.

The paper describes Shot Sleeve simulations for the High Pressure Die Casting Process. Different process parameters were tested and plunger speed was optimised by using simulation.

**Shot Sleeve simulation**

In the cold chamber die casting process, molten metal is injected into the die cavity by means of a plunger, which forces the metal flow through a horizontally-mounted cylindrical shot sleeve. Usually, the shot sleeve is only partially filled with molten metal, the amount of metal depending on the volume of the casting piece and its system. The remaining volume of the shot sleeve is filled with air. Theoretical and experimental research work has shown that the motion of the plunger, the shot sleeve dimensions and the initial amount of metal in the sleeve all affect the types of waves which are created during the shot and furthermore, the amount of air which may become entrapped.

Fluid flow simulations should start in the sleeve and comprise the moving boundary of the plunger. With this model, the simulation of wave formation in the shot sleeve and all of its effects, such as air entrapment, is possible. It is not only desirable to define the critical velocity of the plunger, but also to achieve optimal plunger acceleration because this will help to create a stable wave front and at the same time keep both turbulence and air entrapment to a minimum. Theoretical research has shown that both plunger velocity and acceleration affect wave formation and air entrapment. By expanding the simulation model to include the parameters and attributes of the die casting machine, it is possible to simulate the filling process more accurately.

In principle, the casting process can be divided into three phases:

- pre-filling phase
- mould filling phase
- final pressure phase

The pre-filling phase serves the purpose of moving liquid metal in the cold chamber towards the gate, preferably without entrapping the air in the cold chamber. The low velocity of the plunger enables the air to escape via parting line or vents. The plunger velocity during the pre-filling phase must be adjusted to a value that develops a banked up wave that fills up the complete cold chamber cross section. If the velocity is too low, the resulting wave will not be sufficiently high, whereas too high a velocity results in a surging wave that traps air. Mould filling phase the plunger is accelerated to a high velocity. In this short mould filling phase venting of the die cavity is practically impossible.

In industry and in theoretical papers have been suggested that some various degrees of cavity pre-fill is preferrable. This means that the casting cavity is partially filled with molten metal using slow shot velocity before fast shot starts. These practises have shown equal or superior quality of castings in terms of porosity and surface finish compared to castings made by conventional approach when fast shot begins immediately after the shot sleeve and runner system are full of molten metal by slow shot. However, injection parameters for machine set points, such as pre-fill percentage and plunger acceleration rate from slow to fast shot for the maximum quality castings in terms of air entrapment are not known. Most injection profiles used in industry are determined by trial and error method.

Several simulations were carried out using different combinations of plunger speed and movement to demonstrate importance of right plunger movement profiles. Figures 1 to 4 shows a situation in which the plunger is moving first of all at a constant speed and then accelerated to high speed. Constant speed causes the first wave which is quite shallow; however, when the plunger speed is accelerated, it causes a very strong splashing effect which reaches the shallow wave before the end of the cylinder. These two waves entrap a considerable quantity of air.
Fig. 2. First acceleration cause shallow wave. (Colour scale: Meters per second).

Fig. 3. Second acceleration causes splashing wave which is crushing shallow wave.

Fig. 4. When these two waves collide, a large air entrapment is formed inside the waves.

Figures 5 and 6 show the volume fractions of both metal and air during the simulation process. With these pictures, it is easier to estimate air entrapment. It can be seen that when the two waves collide there is a large air entrapment which will enter into to cavity with the metal. (Colour scale: White is 100% metal and blue is 100% air)

Fig. 5 and 6. Volume fraction picture illustrates air entrapment and how the air mixes with the metal. In these pictures, it can be seen how the two waves form an air bubble inside the sleeve. (Colour scale - volume fraction: White is 100% metal and blue is 100% air)

The second simulation was done using two constant plunger accelerations. The wave fronts which form stay together and hit the cylinder head at the same speed. There is minimal air entrapment. The plunger movement and the wave formation are shown in figures 7 and 8.

Unlike modelling the flow of sand casting and injection moulding, for fluid flow model in die casting, the solution of the complete Navier Stokes equations including the convection terms to calculate transient velocity and pressure changes is essential requirement. The other requirement is free surface modelling of the fluid flow, which is capable of tracking complicated flow fronts as well as the formation of jets and flow separation caused by high velocities.
Fig. 7. The plunger is moved using two constant accelerations. The two waves form a combined wave front which hits the cylinder head. Minimal air entrapment occurs. (Colour scale: Meters per second).

The volume fraction figure 8 shows that the forming wave fronts hit the cylinder head at the same time and air entrapment is avoided.

Fig. 8. The two waves form a combined wave front which hits the cylinder head. Minimal air entrapment occurs.
Shot Sleeve simulation results were used as boundary condition for cavity filling simulations (see Fig. 9). Simulation results were verified with short shot experiments. The results showed the importance of shot sleeve simulations in order to get reliable data in cavity filling simulations.

**Fig. 9.** Short shot experiments proved that it is vital to simulate shot sleeve process before cavity filling simulations.

**Conclusion**

Shot sleeve simulations give valuable information to the manufacturer what will be the final quality of the product. If the HPDC machines could be controlled according to these simulation results, it would mean substantial savings in lead times, production planning and high decrease in scrap production.

Along with cavity pre-fill percentage and transition time, cavity geometry including the design and locations of gates and vents was found to be very important parameter to be considered to achieve optimal cavity fill in terms of air entrapment.

The shot sleeve process is quite difficult process to simulate and the efficient usage of results require the possibility to control HPDC machines.

Following direct improvements could be gained:
- Improvement of the casting quality by minimising the entrapped air during the shot sleeve process
- Minimising set up time during the start of casting process
- Possibility to control HPDC machines more precisely
- Optimisation of the whole casting process by controlling filling with optimal plunger movement
- Shorter lead time during the tool designing process
- Less scrap and waste production when new design is taken on the use.

Simulations demonstrated the importance of calculating the filling of the casting in Aluminium Casting process. With certain castings, there are situations where the channel design can prevent the proper filling of the casting. These situations are very difficult to predict without simulations.

Shot Sleeve simulations proved that it is extremely important to simulate the process with actual plunger movements. The optimisation of plunger movement is impossible to achieve without simulation. It is important that the simulation program employed is able to model the free surfaces of the flow correctly in order to predict air entrapment.

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References


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