Casting Process Simulation

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Considering the long tradition of casting, the history of casting process simulation is a small cultural revolution within the foundry industry. The 5,000 year-old art of casting through trial and error is transformed into a transparent, reproducible process where process parameters can not only be predicted,but also manipulated.

Basis of Simulation – Filling and Solidification

The first steps of describing the process in virtual terms were taken by focusing on heat transfer calculations and focused on the solidification process. As a result, the entire field of casting process simulation is often called solidification simulation. However, the whole process is called "casting" not "solidification". The mold filling is an integral part of the process and therefore must be considered. This is not only important for the gating layout but for the detection of filling related defects as well. Indeed, the inhomogeneous temperature distribution in the melt caused by the filling process has an impact on the solidification process.

Even today, the dynamics of the mold filling process are often underestimated by foundrymen. Key words like "quiet filling" and "laminar flow" are frequently used, but from a physical point of view, all filling processes from sand castings to high pressure die castings are more or less turbulent in some kind. This fact is based on the rheological properties of metal melts.

The energy that is created by the flowing melt is so high that it cannot be eliminated through foundry technological

efforts. Therefore, strong turbulences and recirculation are found inside the melt even when the melt surface appears to be rising quietly. Many casting defects result from these under-surface movements, as well as reactions between melt and mold material. These defects include mold defects, air entrapments, oxidation defects, slag entrainments or metallurgical challenges.

The fundamentals of the flow simulation provide quantitative information of velocities, pressures and temperatures.

These are the tools the casting expert uses to develop robust gating systems. The question of pressurized or non-pressurized gating systems can be answered quantitatively.

The simulation of the filling shows the cooling behavior of the melt all the way to a potential premature solidification.

Thereby, the deciding criteria to develop an effective gating system are available early in the gating design process.

Current solidification simulation does not simply provide a description of the heat transfer process, however. Many of the criteria used to evaluate the solidification behavior are based on the information gained from the solidification simulation and thereby can provide the first clues to the casting quality. As soon as a 3-dimensional geometry of a casting is available, a basic solidification and cooling simulation can be performed in minutes. The prediction of hot spots and areas of final solidification do not only help the metal caster in the engineering department, but also support the designer in evaluating the designs. The heat loss prediction is an important factor for their layout, especially in permanent molds. The impact of boundary conditions such as preheating, coating, heating or cooling, can be determined quantitatively in a short period of time. The knowledge of temperatures and solidification behavior leads to a quantitative prediction of the local thermal Modulus in the casting, as well as solidification times, cooling rates, and temperature gradients.

The Process Chain

Making castings today requires more than just pouring liquid metal into a mold. Most castings receive their final properties through processes after the casting process, i. e. heat treatment or machining. Therefore it is crucial for casting process simulation to consider these processes to reliably predict casting properties when the part is delivered.

One Example

How this expanded process chain can be displayed is the presentation of residual stresses in a casting as it is delivered to the customer. Sometimes the residual stresses are completely eliminated by a stress relieving heat treatment process. However, even the removal of the gating system can lead to a stress re-distribution, which can lead to a measurable distortion of the casting. Rapid cooling or quenching, on the other hand, can again induce high stresses, which can be reduced or eliminated by a successive time or temperature dependent tempering or aging process.

The machining process relieves, as the practitioners say, stresses again. Indeed, the removal of material leads to a new stress equilibrium. Only the consideration of this aspect leads to useful results for the end user. Process steps after the actual casting process also impact the properties of the micro structure and of the casting. It is possible today to couple a heat treat simulation with the consideration of diffusion and phase transformation phenomena to predict the micro structure and mechanical properties of the final product. This especially helps the steel foundries to recognize potential hardness immediately, as it helps aluminum foundries to find the parameters for an optimal aging process to achieve the desired strength and elongation.

Simulation as Development Tool

The initial area of utilization for casting process simulation tools was the engineering and/or the quality department of foundries. However, it became clear over the last twenty years that simulation can contribute the more to cost reduction efforts the earlier it is used in the part development process. Only in the early stages of the part development process it is possible to consider potential design modifications to avoid problems at the end of the manufacturing process.

This fact, unfortunately, generates a conflict: On the one hand, casting process simulation requires a detailed description of the part. On the other hand, the design still needs to be flexible enough to incorporate potential changes to find a better solution. The solution to this dilemmais the utilization of fast and flexible software tools, which use the data which is available.

Casting designers and buyers have learned over the years that the prediction of local mechanical properties does not only support quality assurance (risk minimization), but it also provides them with the opportunity to reduce weight and optimize a part for a specific load scenario.

Simulation as a Management Tool

The areas of application for casting process simulation are multi-fold and even exceed the dreams of 30 years ago.

From the technical point of view, casting process simulation is capable of offering important benefits to any foundry.

The amount of added value is strongly dependent on the implementation and use, the established structures and the companies' internal communication.

That is why the introduction of casting process simulation has become a management responsibility.

Successful users regard the application of simulation in a foundry as being less a technical but rather as a high priority entrepreneurial function. Apart from solving daily issues, they use casting process simulation as a tool for standardization, to secure the companies' know-how, as an educational tool for young staff, for human resource acquisition (demonstrating an attractive job environment), and as an internal and external communication tool.

The successful use of simulation requires an open flow of information. Casting process simulation demands clear rules regarding decision-making. Who is providing which information at what time, who is taking decisions based on the simulation results, and finally who is implementing decisions and monitoring the required actions? Without implementing these clear rules, simulation will remain isolated in an "ivory tower". The big opportunities for increasing the companies' profitability which simulation tools offer can only be realized, if simulation is established in everyone's mind and is "lived" on all levels of the organization.

NOW – Optimization (MAGMA 5.3)

Casting process simulation always displays the status quo of its expert user. The user decides if the rigging system or process parameter set led to an acceptable result. Additionally, proposals for optimized solutions have to come from the operator.

One of the biggest benefits of the casting process is also its biggest downfall : Everything happens at the same time and is coupled. Changes in one process parameter impact many casting quality defining features during the process, i.e., a change of the pouring temperature does not only change the solidification behavior, it also changes the fluidity of the melt, which can lead to a misrun. The metallurgy of the melt might be impacted, which could lead to changes in the temperature balance of the mold or die, which again can lead to problems with overheating or erosion. Multi-objective autonomous optimization offers a way out.

Starting at the end of the 80's, Peter R. Sahm's group began its first research activities in the area of autonomous optimization of casting gating, risering and process parameters. At that time, the problem of a necessary re-enmeshment of the casting during each optimization step was identified as a huge handicap.

Autonomous optimization uses the simulation tool as a virtual experimentation field and changes pouring conditions, gating designs or process parameters and tries this way to find the optimal route to fulfill the desired objective.

Several parameters can be changed and evaluated independently from each other. Autonomous optimization tools take the classic approach of foundry engineers, to find the best results based on your objectives and parameters (Figure 1).

FIGURE 1

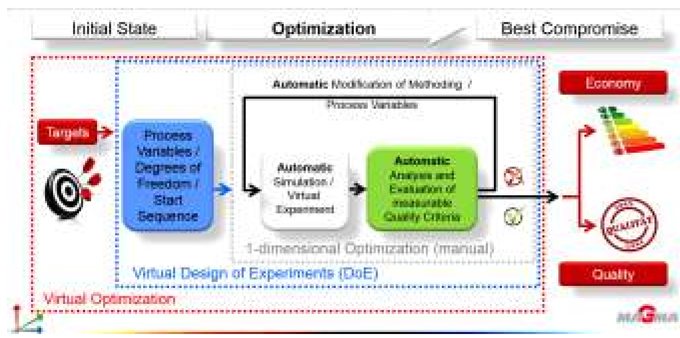


FIGURE 2 : DEGREES OF FREEDOM FOR OPTIMIZATION

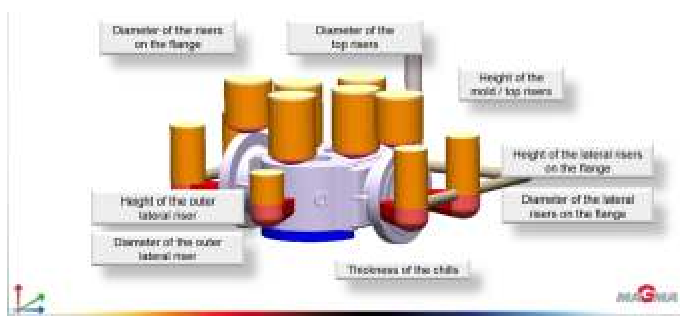
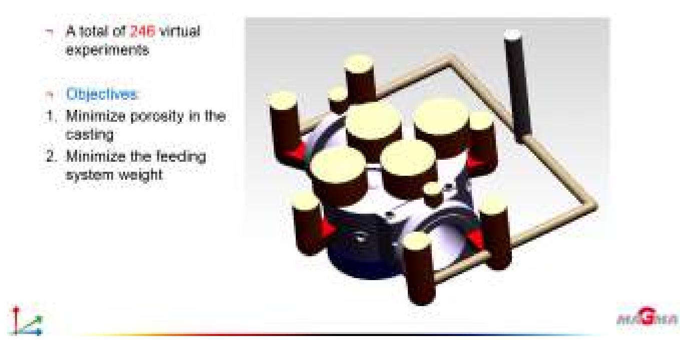
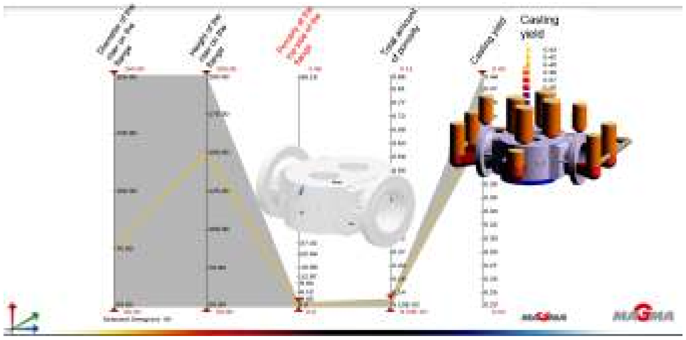


FIGURE 3



After running the optimization, it start calculating for 246 virtual experiments after defining the objectives of the simulation process (Figure 3).

FIGURE 4



Parameter analysis for the best design which will achieve the objectives (Figure 4).

The Strategic Partner for your Business

For the casting simulation software , you have to look for the global market leader in the casting process simulation,because this software will be a strategic partner for your foundry, casting designers and castings users, concentrating on the prediction and optimization of the physical processes in foundries using simulation. With the help of us optimize the complete process of casting production from design through casting up to finishing.

References

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