Gating Conference Explores the Use of Fluid Flow Modeling

By examining the simulation software use by aluminum foundries and applications that have benefited from it, casters can determine how this software could further aid production.

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We are in the midst of the computer age. For foundries, the most significant effect of the computer age goes beyond office accounting and production process control to the very heart of metalcasting—the flow of metal into the mold. Due to the proliferation of casting simulation software, the days of the "cast and see" method are quickly becoming the past.

But to what extent is your foundry utilizing this technology on its jobs? At the 1st International AFS Conference on Gating, Filling and Feeding of Aluminum Castings held October 10-13 in Nashville, Tennessee, the topic of casting simulation software and its infiltration into daily foundry production was explored.

This article revisits two of the presentations from the conference. The first discusses the extent that process modeling is used by U.S. aluminum metalcasters, while the second relays case studies in which fluid flow modeling was an essential tool used to eliminate casting defects.

Casting Simulation Software Use

In his presentation titled "Computer Simulation of Mold Filling and Solidification in Aluminum Foundries," Tony Midea, Foseco, relayed the findings of a survey sponsored by the AFS Process Modeling and Design Committee (1-F). The survey, which was returned by 100 aluminum casting operations, analyzed the extent to which casting simulation software is used. The responses were grouped by small foundries (less than 200 employees), mid-size foundries (200-500 workers) and large foundries (more than 500 workers). Following are some of the questions asked in the survey as well as a summation of the responses:

Does your foundry use computer simulation?
- Only 30% of small foundries use computer simulation. Of the users, 30% use in-house software while the rest utilize outside contractors to perform the modeling. About 80% of mid-size foundries perform simulations in-house. All of the large foundries surveyed utilize simulation software in house.

What is the main task of the simulation software?
- For the small foundries using PC-powered packages, the software is used only for solidification analyses, with porosity being the main concern. Outside consultants (using more powerful software) design gating/rising, evaluate filling characteristics, and review solidification profiles and porosity predictions. In both cases, the results are used for tooling design.

Mid-size and large foundries use the software for gating, mold and component design, problem solving, cooling line size and location, process parameter variations, what-if analyses, and yield improvement.

How do you decide which parts to model?
- Small and mid-size foundries have specific criteria to decide which parts to model. Common themes include: new products, difficult components, high-volume components, high-risk designs, and expensive and problematic components. Large foundries model all new jobs.

How many castings are evaluated each month at your facility using computer simulations?
- Small foundries model up to 5 castings/month. This low number is because few small foundries have simulation in house, which results in expensive outside contracts for modeling. Mid-size to large foundries typically simulate up to 5 jobs/month and up to 600/year.

My foundry uses simulation software to model: Fluid flow? Solidification? Other?
- All foundries using simulation software would like to model both filling and solidification, however, some foundries software is solidification only and the cost is too high to add fluid flow.

Which casting process do you model in aluminum?
- Small foundries model sand and low-pressure/gravity permanent mold processes. Mid-size and large foundries model all processes.

What needs to be improved/developed to increase the capability and/or accuracy of aluminum casting process modeling? Where are the holes in the technology?
- The responses to this question generally were in agreement. For filling, users would like to see the following developments: variable hydrogen level in melt, viscosity vs. temperature, more accurate cooling (turbulence), oxide formation, and properties (friction), tilt flow, turbulence detection, surface area, peak velocity, and mean free path length. Due to the fact that these requests were process specific, it is believed that current filling predictions are relatively accurate. The one area of concern for aluminum is turbulence, which has been an area of work by the aerospace industry.

For solidification, users want better porosity predictions, heat transfer predictions at coolant lines, models of 2 and 3 phase materials, hydrogen gas in the melt, lost foam process modeling, gas level and entrapment predictions, distortion predictions, silicon eutectic morphology, die coating heat transfer coefficients, and accurate material thermophysical and heat transfer coefficient data.

One specific request from large foundries was for computer simulation programs to have more powerful predictive features such as the ability to give guidelines for riser size and placement, to predict water line size and placement, and calculate and caution against high inlet velocities. Another
suggestion was that all the software programs should allow users to provide results in a readily exportable format for other types of programs such as spreadsheet and slide presentations.

In your opinion, what areas should process modeling software development activities focus on?

For filling, users want improved accuracy of filling characteristics (turbulence, viscous effects, sand erosion), injection and ejection of gases, and lower cost software. In addition, some users hope there are developments with counter-gravity casting, cavitation and bubble free prediction.

For solidification, users want better porosity, hot spot and hot spot analysis, casting heat transfer coefficients, and the ability to simulate the effect of grain refiners and modifiers. Also requested was second phase eutectic morphology, trap elements on solidification and non-equilibrium.

The committee expects to perform another survey of foundry survey of use of casting simulations software later this year.

Simulation Case Studies

In a presentation by Mark Jolly, Castings Centre, Univ. of Birmingham, England, the discussion focused on "Practical Solutions for Aluminum Castings Using Quiescent Running Systems and Computer Modeling."

One of the components examined was an aluminium housing for an NCR, Ltd., automated teller machine. Originally manufactured as a plastic component, NCR wanted a conversion to aluminium to make the component more robust. NCR contacted Johnstone Casting & Engineering to produce 7000 castings in AlSi7 (without the magnesium) aluminium alloy via gravity permanent mould.

This 750 x 350 x 300 mm aluminium casting, which was 5.6 mm thick, was supplied to the foundry with a design fit only for plastic injection moulding. The foundry needed to redesign it while keeping in mind the importance of surface finish. In addition, the parting plane on the casting had to be horizontal and the feeding system could not use side runners due to the space envelope of the already cast permanent mould die.

The critical component in the redesign of this 3.6 kg casting was going to be the gating system. The casting needed to be filled in less than 10 sec to eliminate the possibility of mismatch, as the estimated solidification time for the component was 12.5 sec. The main features of the gating system (Fig. 1) included: a pour basin with weir, a half round downslope with a top area of 750 sq mm and an exit area of 460 sq mm; a runner bar area of 100 sq mm; and four ingates with a total area of 2300 sq mm. A ceramic foam filter with a restricted filter print was positioned at the lowest part of the system just above the downslope. The first results with simulation showed that the design of the downslope combined with the filter enabled the downslope to backfill in 1 sec.

Analysis of the flow pattern of the metal during the first simulation (Fig. 2) indicated the potential for a flow defect (porosity) or venting problems in one of the flat areas of the casting. As a result, two further geometries were proposed to eliminate the problems with the addition of bridging sections across the cut-out areas (Fig. 3) and substantial venting. Although the bridges didn't eliminate the defect completely, the area of the problem was reduced with a narrow bridge. Although it wasn't possible to simulate venting, vents were used as a result of other analyses.

During simulation, it was determined that the casting did not need risers. However, small flow-offs were positioned at the top edge of the casting to provide the necessary feeding without affecting machining or adding potential porosity.

The second case study was a gravity permanent mold cast heat sink casting for use on marine gearboxes for the U.S. Navy. The customer, CEGELEC, had contacted Barton Aluminum to produce this casting in two widths using AlSi6 aluminium alloy. The production run would be 2000 pieces.

The geometry of the 6 kg castings is deceptively simple. Both are rectangular slabs (626 x 30 mm) with a width of either 150 or 168 mm. However, embedded within the castings are six stainless steel tubes with an outside diameter of 12.7 mm, a wall thickness of 1.5 mm and a pitch of 19 mm. These tubes needed to be cast with a gap of only 3.2 mm between them. In addition, the casting had to be X-ray inspected, the tubes could not touch or change length, and the casting could not exhibit porosity between the tubes.

Initially, it was determined that the steel tubes would be preheated to
302°F (150°C) before placement in the mold. A filling time of 10 sec was chosen to fill the mold before solidification. As a result, the sprue top area was calculated at 800 sq mm, the gate area was 2450 mm, and a 70-sq mm/22 mm-thick ceramic foam filter was placed in the runner at the lowest point. Since the casting was vertical in the mold, it was determined that a long vertical gate up one side of the casting with an upper runner and a feeder at the top would be successful.

The first simulation results showed problems in controlling the metal velocity. The 750-mm head meant that the velocity at the bottom of the downspine was more than 3.8 m/sec. In addition, the castings were only filling 40 and 80% (depending on width), with porosity throughout.

Further analysis of the simulation results illustrated why the casting was difficult to feed. The steel tube assembly was reaching 1112°F (600°C) during filling due to the molten aluminum heating the stagnant air within the tubes (turning it into an insulator). In addition, the first aluminum contacting the tubes was rapidly solidifying, imparting some input of latent heat. Subsequent heating of the tubes by fresh molten aluminum then caused recalcitrant. As a result, the center of the casting was becoming a hot spot, which fed the solidifying metal around the outside of the casting.

The first solutions revolved around removing heat from the center of the casting by cooling the tubes. Although water or air cooling of the tubes was raised as a possibility, it was discounted as impractical. Another suggestion was to convert the component to a sand casting to allow for more control and directional solidification. In addition, it was determined the component should be cast in A360 for a shorter freezing range.

The change to sand casting required a thinner runner system and an increase in filling time to 15 sec. Although the velocity down the spine does not change, the longer filling time provides a more favorable temperature gradient within the casting. With the addition of feeders, the simulation of the new design showed that the internal space was free of porosity (Fig. 1). The feeders were needed to lessen the porosity in the regions away from the tubes.

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