Using Simulation to Control Microporosity Reduces Die Iterations

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Die casters have made dramatic strides in improving quality in recent years by using computer simulation to diagnose and eliminate conventional macroporosity caused by gas being trapped into the molten metal as it solidifies. But nearly as soon as this problem became manageable, another one filled its place to become probably today's most difficult quality challenge in the die casting business. Microporosity is the presence of numerous small pores — less than a millimeter in diameter — in the solidified casting. The pores negatively affect mechanical properties of the part and can also result in leakage. The formation of microporosity is not completely understood. It is believed to be caused by the reduction in pressure that occurs as metal cools and draws the surrounding liquid metal to replace the volume lost to shrinkage. If there is not enough liquid to compensate the shrinkage, then internal voids can form where the pressure decreases below the pressure of the dissolved gasses in the metal.

Computational fluid dynamics (CFD), the same tool that is responsible for largely taming the problem of conventional porosity, has up to now been ineffective in addressing microporosity because available CFD models have not calculated the change in pressure due to metal shrinkage. Recently, CFD software that takes microporosity into account has begun to appear. The engineering team at Albany-Chicago in Pleasant Prairie, Wisconsin, discovered that this software can accurately predict microporosity, making it possible to identify problems and evaluate design changes that can either eliminate microporosity or, more commonly, move it to areas where it's not a problem. As a result, they have been able to significantly reduce die iterations as they prove out the new dies.

Traditional Approach to Die Design

Albany-Chicago die casts complex aluminum parts and performs production machining to precise tolerances. The company's current equipment ranges in size from 2500 tons to 400 tons and can produce castings from more than 100 pounds to less than 1 ounce. Its customers are original equipment manufacturers in such industries as diesel engines, hydraulics, electromechanical devices, computers, health, and agricultural equipment. Over 400 people are employed at the 200,000 square foot facility. Engineering activity at the die casting company is crucial to the development of its products. The relationship between the part design and the cast, machined and assembled solution is the team's central focus. The simulation link targets closer relationships between process design and operations.

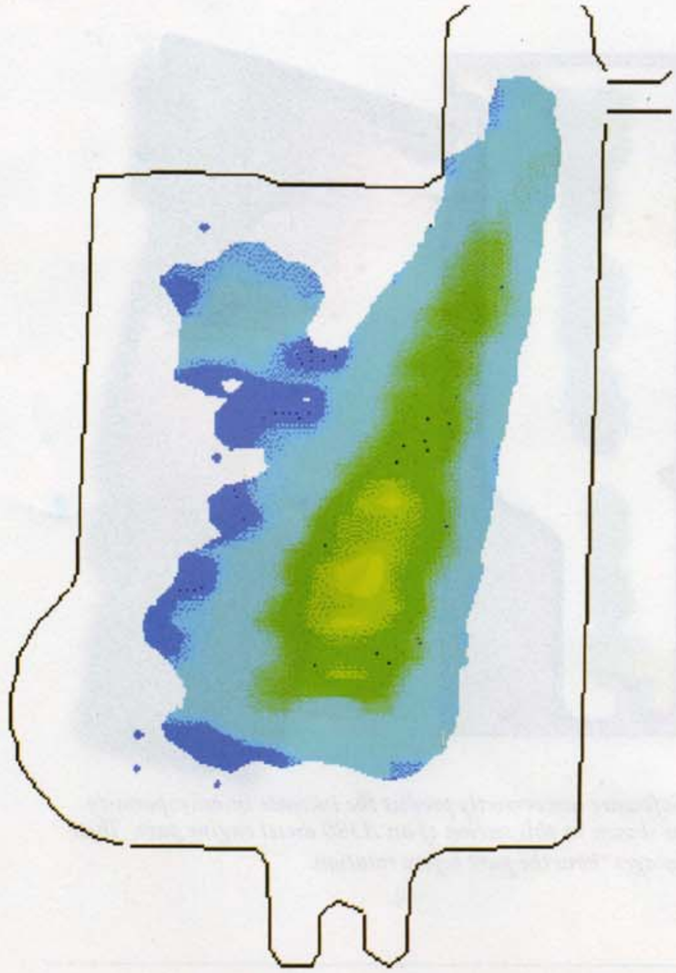
The traditional approach to die design was to rely on engineers' experience and guesswork to design the die. The problem is that the only way to determine whether the design works or not is to build the die and test it. Typically, the die needed to be modified many times before they were satisfied with the results at a cost of between $10,000-20,000 in order to achieve high levels of quality. The time and cost involved in these modifications and the fact that the tests themselves provide little information on why the design isn't working means that engineers are often forced to conclude the design process at a point where a significant amount of scrap is still being produced.

Evaluating Simulation Alternatives

In the 1990s, the engineering team began using a simple one-dimensional die design tool that provides general flow information. The software provided useful general guidelines but was not capable of fully simulating the die casting process. Based on the uneven results, it was decided to evaluate the leading technology on the market to see if software was available that would allow for troubleshooting dies in software rather than hardware. They compared their existing simulation software with two more elaborate CFD software packages in order to evaluate their ability to realistically simulate the die casting process.

FLOW-3D® from Flow Science, Incorporated matched the results from the die that the engineers chose for their trial significantly more closely than other software packages. The software's developer put considerable effort into ensuring that it accurately simulates the die casting process. The Albany-Chicago engineering team developed a new design process that begins by exporting the initial die design geometry to FLOW-3D and then using the software to simulate the molding process. The software proved its ability to accurately simulate common problems such as air entrapment and inclusion. Once they identified such problems, they then changed the model in order to evaluate potential fixes. They waited on building the actual die until they had a simulation model that worked perfectly. In this way, they were able to substantially reduce the number of hardware iterations, which saved time and money.

Microporosity in an A380 diesel engine part.



The Challenge of Microporosity

While the simulations helped the die caster eliminate many problems before building the die, it was discovered that in a number of cases, problems occurred that were unable to be predicted in the simulation process. The developer was already aware of this problem and working on a solution. The basic issue is that all available commercial CFD software packages at this time were unable to predict a problem called microporosity. As metal cools, it tends to become more dense because the thermal agitation of the molecules is less able to overcome the strong intermolecular forces pulling the molecules together. This shrinkage reduces the metal pressure, which in turn draws liquid metal in, providing there is any liquid nearby available to flow. After metal is cooled enough to exceed the point of rigidity, there can be no or very little additional flow to compensate for shrinkage.

Microporosity is characterized by the formation of small bubbles with a total average volume fraction on the order of one percent. The result is that some dies that were predicted to produce perfect parts sometimes showed problems. For example, fluid might leak through holes drilled into a part in an area where simulation showed that conventional porosity should not be any concern. Die casting engineers are typically able to solve the problem by trial and error using the traditional solution for microporosity of adding water lines in the affected area. But this was a difficult and expensive process because they have to make changes to an existing die or even build a new die and could never be certain whether the changes were effective until actually running the die.

New Model Helps Eliminate Microporosity

A new version of FLOW-3D has recently been introduced specifically designed to simulate microporosity. This model tests each element during the solidification process to determine if the adjacent elements that share a common face with the element have a solid fraction above the rigidity point. If all neighboring elements exceed the solid fraction for rigidity, then liquid feeding is not possible and the microporosity of the element is increased by the amount of shrinkage in that element during the time step. The model requires only basic material property data and adds virtually no noticeable CPU time to a casting simulation. It is complimentary to macroporosity models and may be used in conjunction with either a complete hydrodynamic shrinkage simulation that includes fluid flow or with a faster shrinkage simulation based on bulk fluid flow.

The die casting engineering team had its first chance to use the model on a three-gate part in which microporosity was detected through a tensile stress reduction in a critical area. Simulating the part with the new microporosity model revealed that microporosity was indeed forming in the critical area. Changing the model to add water lines as close as possible to the problem area showed that it was not possible to solve it in this manner. Instead, engineers modified the model to change the way in which the die was cooled between shots by spraying less water on the areas surrounding the sensitive area to keep them a bit warmer.

Software can correctly predict the increase in microporosity as shown in this section of an A380 diesel engine part. These images show the part before rotation.

The software correctly predicted the increase in microporosity in this section of an A380 diesel engine part. These images show the part after rotation.

Simulation showed that this would solve the problem by keeping the surrounding areas in a liquid state longer. This change actually did solve the problem on the physical die.

The new model was also used to solve a problem on a spacer that goes between the cover and the block of a diesel engine. Mounting holes are drilled through the part and these holes leaked during run-off testing. Again, the microporosity model accurately predicted the point at which microporosity would occur. Engineers changed the model to determine the effect of adding waterlines in different locations. In this case, the goal was cooling the most sensitive areas quickly so they would solidify at the same time as or before the surrounding areas. The solution developed with this approach fixed the problem on the very next die iteration.

The die caster has started using this model on every new die and has been so successful at predicting microporosity that most dies now work near perfectly on the first iteration and no more than three iterations have ever been required. The new model saves substantial amounts of money that was spent previously for changing the die and has also reduced the average time required to bring a new die into production.

About the Author

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