Computer power and the right software, when applied to metal flow simulation, can help manufacturers design thinner-walled, lighter parts and eliminate much of the trial and error involved in the tooling design process.

Computer simulation is playing a major role in reducing the weight of intake manifolds by making it possible to meet the challenges posed by thin-wall magnesium diecastings. A wide range of problems, including the danger of solidification, oxide generation, and air entrapment put major limitations on reducing wall thickness. In the past, these problems were addressed by trial and error. However, it could take six weeks to implement changes to the gate, runner and venting system of the production die, and no one knew how many more changes would be required to produce parts of consistently high quality.

A few farsighted diecasters, such as Werkzeugbau Schaufler, Laichingen, Germany, have tackled this problem by using computational fluid dynamics (CFD) software to predict the performance of various die configurations on the computer. This approach can accurately evaluate the design and provide detailed information on conditions inside the die cavity that speed up the process of iterating to a solution. Using these methods, Werkzeugbau Schaufler has successfully produced 50 dies for different thin-wall magnesium parts during the last several years.

Schaufler ranks among the top European diecasters and specializes in manufacturing dies for aluminum and magnesium castings. Its facility covers about 50,000 ft², providing the infrastructure for building dies up to a weight of 35 tons for transmission and clutch housings,
body and structural parts, cylinder blocks, variable inlet manifolds. The company recently opened a technical center to meet customers' demands for short development times and the elimination of sand casting patterns in favor of diecasting prototypes. The Diecasting Center Laitingen (DCL) features an automated cell based on a Buhler SC 270M diecasting machine with a locking force of 2,700 metric tons, aluminum and magnesium furnace, SSM slug heating station, ABB spray and extraction robot, cooling basin and machining center.

Fig. 1. Flow distribution in gating.

**Trend to Thinner-Wall Diecastings**

In the last several years, Schaufler and other top-ranked diecasters have been asked by automobile manufacturers to produce dies for thinner wall diecast components in order to pass on incremental weight savings to consumers. One of the most interesting examples of this trend is the move to thin-wall magnesium variable inlet manifolds that combine weight savings with performance improvements. Casting of these parts is, however, a very challenging task. Magnesium has a very low specific heat content, significantly lower than aluminum, which means that it cools very quickly, running the risk of solidification during the filling process. This problem is particularly challenging when wall thickness is reduced to the 1.8 to 2 mm range, as has occurred with the most recent designs.

In order to avoid solidification problems, filling has to be performed at a very high flow velocity, often 60 m/s in the ingate and 100 m/s plus in thin-walled regions. Unfortunately, high flow velocity has the tendency to cause flow separation and vortices that, in turn, produce air entrapments that lead to porous regions and oxide generation. In most cases, these problems can be overcome by changing wall thickness or adding flow channels in suitable areas of the part. However, it is far from obvious where such features need to be added. In the past, the only way that die designers had to evaluate the effectiveness of a proposed change was to build a new die and test it out by producing parts. The parts were then X-rayed to determine whether they had internal flaws that would cause them to fail the automotive OEM's quality standards.

**Previous Difficulties and Delays**

The results of the testing provided little or no information on critical flow patterns during the filling process; engineers had to rely upon intuition and guesswork. This situation began to change a few years ago as developers of CFD software began to provide features that made it possible, for the first time, to accurately simulate high flow-rate diecasting operations. CFD involves the solution of the governing equations for fluid flow and heat transfer at hundreds of thousands of discrete points on a computational grid in the flow domain. When properly validated, a CFD analysis allows engineers to "look inside the die" and determine the exact position of the flow front at any point in time, as well as the temperature and pressure of the metal at any point in the die. The geometry of the model representing the die can be changed quickly on the computer and re-analyzed to determine the effect of the change.

**Software Designed for Diecasting**

Rolf Krack, process engineer for Schaufler, has had excellent results using a CFD software package, called FLOW-3D, from Flow Science, Inc., Santa Fe, NM, that has implemented several important features designed to improve diecasting simulation. The first is the use of the volume of fluid (VOF) method to predict free-surface fluid motions, surface tension, and other flow complexities. This feature makes it possible to accurately track the fast moving flow front through the die cavity, a major prerequisite for accurate diecasting simulation. In particular, FLOW-3D provides algorithms that track sharp liquid interfaces through arbitrary deformations and applies the correct normal and tangential stress boundary conditions. This makes it possible to easily detect the formation of vortices that cause the recirculating metal surfaces to come...
into contact multiple times and begin to solidify while flowing, increasing the formation of air pockets and the trapping of inclusions. The software also provides a feature called surface defect tracking that identifies the location of oxides and impurities at each stage of the filling process so that overflows can be sized and dimensioned appropriately.

As a typical example, Rolf used FLOW-3D to simulate the magnesium variable inlet path manifold for the current Audi V8 engine. “I started the simulation as early as possible in the design cycle so that any changes that were required could be made at a time when they were least expensive to implement,” Krack said. “I began by performing a flow analysis of the runner and gating system. The simulation results showed me areas of undesirable flow separation due to abrupt changes in cross-sections and other flow features. I corrected these problems by making appropriate design modifications to the gating. Then I proceeded to simulate the filling of the part. This simulation took into account heat transfer to and heat conduction through the die, as well as solidification of the molten alloy, thus helping to detect areas of early solidification.”

“Looking Inside the Die”

The simulation process made it possible for Rolf to do something that was never possible with physical testing—to “look inside” and view the flow of the molten metal throughout the part. The key factors that he considered were:

• Is the part being filled continuously, or are there regions that are filled much later than others?
• Are there any air entrapments?
• Are there any regions of flow separation or vortices?
• Is the flow front moving continuously or is it bursting and splashing?

“There were plenty of problems the first time I simulated this,” Rolf Krack said. “With the simulation, I could see exactly what was happening, try different design changes, and very quickly determine what effect they had.

Fig. 5. Temperature distribution in the die 30 sec after start of filling.

Using the insight that I had gained,” Rolf continued, “I was able to devise a strategy to correct the problems. Primarily, it involved using flow channels and increasing or decreasing wall thickness in order to either eliminate the vortices or to move the voids and inclusions so that they flowed out of the overflow vents, where they were of no concern to anyone.

“Since this was one of the first times that I used the software, I was concerned about its accuracy. We ran a series of trials with the part filled only partially to a series of different levels and matched them against the simulation results. The software matched the tests nearly perfectly. This gave us confidence to build a prototype tool according to the design that we had developed using the simulation, and it produced excellent parts. Due to the success of this project, we made the decision to adopt these methods for all thin-wall aluminum and magnesium dies. The result has been a series of successful projects that has established us as one of the leaders in this exciting new manufacturing technology.”

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