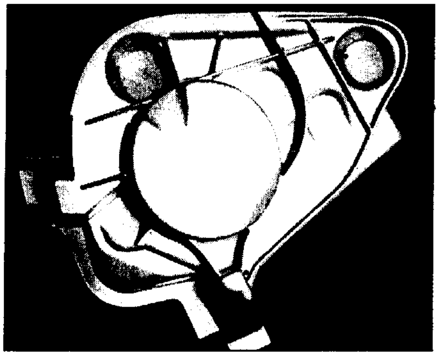
This company is using computer simulation to improve high-pressure die casting quality to eliminate porosity in high-pressure aluminum die casting. The result is a dramatic savings in prototyping and testing expense as well as the assurance that parts of the highest quality possible are being produced.

Computer Simulation Helps Eliminate Porosity

By Jamal Righi

Alcoa Technical Center is using computer simulation to improve high-pressure die casting quality by optimizing the filling pattern to eliminate porosity. Surface blemishes and pores can occur due to poorly fed regions, flow separations, metal recirculation zones, gas entrapment and the formulation of isolated fluid pockets. Simulating the filling process with computational fluid dynamics (CFD) software allows engineers to take a virtual look inside the die and see exactly how defects are being generated. Once the problem is fully understood, it can nearly always be solved by minor changes in the die design. The breakthrough that led to this success was the development of CFD software capable of predicting flows with free surfaces during die filling.

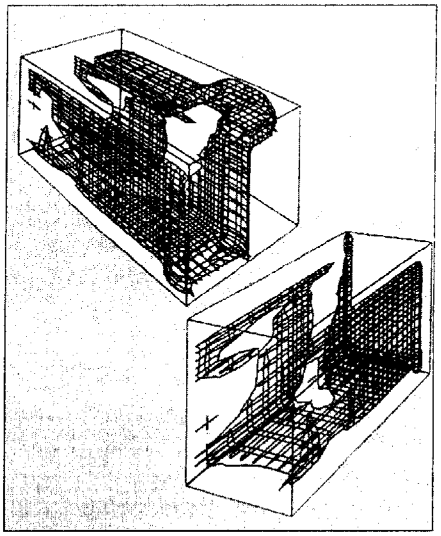


A typical automotive frame casting.

High-pressure die casting has emerged as one of the most economic methods for high-volume production of near net shape components. This technology is particularly well suited to meet product design requirements for complex multifunctional part shapes, thin walls and close tolerances. The proliferation of this technology has driven research into methods of assuring structural integrity of components produced by this method. Gas content and pore fraction are good indicators of the quality of a casting and the key drivers for quality improvement. In the filling stage, complicated three-dimensional, transient flow configurations involving free surfaces result when molten metal is injected under high pressure into the die cavity. The entrapment of gas by these flows during metal filling is one of the primary causes of porosity.

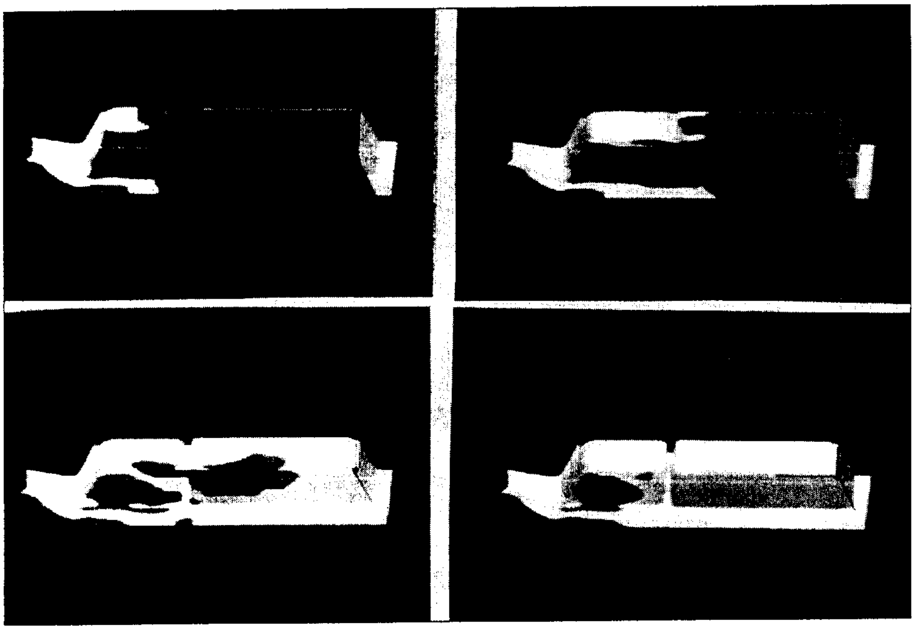
Pores are formed when two flow fronts rejoin and entrap the volume of gas existing between them. Sometimes a single flow front or ligament curls over itself forming a recirculation zone or eddy. Pores formed as a result of poor filling can be large enough to result in blisters within 2–4 mm thick wall regions during heat treating. An ideal runner and gate design generates a uniform filling pattern. The metal flow does not form ligaments or branches, but sweeps through the part pushing all existing and evolving gases in front of it. This sweeping motion also pushes gas and the formed oxidized layer on the surface of the metal flow front into the overflows.

Traditionally, the dies are designed by skilled craftspersons based on their experience and validated through a set of proofing trials before initiating commercial production. Adjustments to the die gating, vents and overflows are almost always required in order to achieve the desired cast quality. These adjustments are based almost entirely on trial and error so a considerable number of modifications are sometimes required before porosity problems are eliminated. Each iteration requires die modifications, usually to the runners or gates, that cost an average of $5,000–$10,000, and take between two and six weeks. Once the modifications are finished, additional production floor trials are necessary which tie up expensive equipment and generate further delays. In the most difficult cases, the problems cannot be fully eliminated prior to the product launch, making it necessary to start production with excessive scrap rates.



Predicted fill pattern at 24.2 msec.

That's why Alcoa has made a major effort to simulate the die casting process using CFD software. CFD involves the solution of the governing equations for fluid flow and heat transfer at thousands



Filling simulation view into channel.

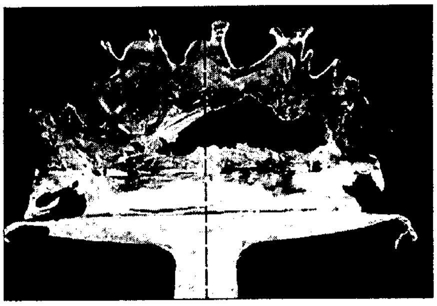
of discrete points on a computational grid in the flow domain. When properly validated, a CFD analysis allows engineers to look inside the die and determine the exact position of the flow front at any point in time as well as the temperature and pressure of the metal at any point in the die. This is far more information than can be obtained from a proofing trial and usually allows engineers to understand what is causing the problem. The geometry of the model representing the die can be changed quickly on the computer and reanalyzed to determine the effect of the change. As a result, engineers can usually eliminate porosity problems in days as opposed to the weeks or months required with the trial approach.

Alcoa has used this method to solve porosity problems for many of its customers. This, along with other techniques, has allowed Alcoa to produce high-performance components for critical applications such as the structural members in the Audi A8 automobile. These real world examples involve proprietary technology belonging to its customers. The following example involves a research casting containing a composite of some of the same geometrical features that have been shown to result in porosity in production parts. The simulations were conducted using FLOW-3D CFD software from Flow Science, Inc., Los Alamos, New Mexico. FLOW-3D is a general purpose, three-dimensional, CFD program that has the ability to predict flows with free surfaces during die filling. It uses the volume of fluid (VOF) method to predict free-surface fluid motions, surface tension and other flow complexities. In particular, this package provides algorithms that track sharp liquid interfaces through arbitrary deformations and applies the correct normal and tangential stress boundary conditions—an accuracy feature that distinguishes it from other CFD programs.

The first simulation evaluated a Y-branch runner with a uniform 1.27 mm gate thickness. For this design, the simulation showed that the metal entered the runner uniformly and filled the first flange completely. After 8 milliseconds, there was a considerable accumulation of metal against the side of the die cavity and the flow of metal into the first side wall. A stream of metal emerged sideways and formed a void region where die cavity gases are likely to be entrapped. These simulation results corresponded to physical tests on this die which showed high porosity formation and blistering after heat treating. It's interesting to note that the simulation at the 8 millisecond point in the filling shows a striking similarity to a short shot made as an investigative tool at the same time interval.

After reviewing these results, Alcoa engineers decided to investigate the effect of changing to a three-step gate design. It was also decided to evaluate a blockage of the gate at both sides, producing an ungated region that is 20 mm long on each side. Its purpose was to delay the accumulation of metal along the sides of the die cavity as happened with the first design. The three-step gate was comprised of a 2 mm thick step at the central third of the gate, a 1.65 mm thick step totaling another third of the gate length, and the remaining gated region was 1.27 mm thick.

The simulation predicted that the metal flow would form one ligament in the center of the gate and a large flow accumulation region against the side. This flow pattern occurs due to the preference of the flow to follow the path of least resistance. The metal continues to build up at the 900 turn between the first flange and the first side wall. A small void region develops in the flange immediately in front of the ungated region. The metal buildup against the side of the die cavity starts to exceed the flow in the center of the part. The void region in the center of the part starts to fill gradually. This fill pattern is better than the first design, but still not optimal. These results were confirmed by testing that showed parts produced with this die design had porosity and blister ratings that were better than the first design but still well below acceptable levels.



Partial shot corresponding to 8 msec fill (uniform gate).

Next, Alcoa engineers enlarged the 2.0 mm gate thickness to occupy half the length of the fully gated region. The rest of the gated region was maintained with a 1.27 mm thick gate. The 20 mm long ungated regions at the sides of the flange were unchanged. By extending the 2.0 mm

Simulation...

thick portion of the gate, they expected that more fluid would flow in the center of the part followed by fluid buildup against the sides of the die cavity. The flow front was then expected to equilibrate between the center and sides of the die cavity, producing a more uniform flow front in the part.

The simulation showed that the metal flow front is nearly uniform from the start of filling, so there is no significant accumulation of fluid in the side or the center of the die cavity. A small recirculation zone develops in front of the 20 mm ungated end of the first flange. This recirculation of fluid could entrap gases or cause cold shut defects in the part. Flow nonuniformity and the formation of fluid ligaments start to occur after 10 milliseconds of fill.

The ligaments merge and form a few voids that may entrap a small amount of gas in the metal. However, these voids are not nearly as severe or as numerous as in the case of the total flow front breakup. It was decided later to open the end gates, which eliminated the small recirculation zones.

After 14 milliseconds of fill, the runner, including the shock absorbers, fills completely; and the metal flowing to the Y-branch starts to accumulate against the side of the die cavity, favoring the flow of metal more to the side of the part than towards its center.

The filling of the side panel starts from the corner of the part where the first side wall, top wall and side panel meet. The side panel fills gradually from the corner and then directly from the top and first side wall. When the second side wall becomes nearly filled, a small fluid stream emerges from the second side wall into the base of the side panel. The last regions to fill in the second flange are located at the part centerline and sides of the flange.

The changes to the die design that were implemented during the simulation process resulted in a dramatic improvement in casting quality. Vacuum fusion measures total volume in a casting by melting a sample under vacuum and measuring the volume of gas released. The total gas and its components are reported in ml/100 g. The switch from design 1 to design 2 resulted in a reduction in gas content from 3.80 to 2.93 ml/100 g, a 23 percent reduction. The switch from design 2 to design 3 resulted in a further reduction to 1.96 ml/g, an additional drop of 26 percent. Additional optimization of operation practices lowered the total gas content to 1.62 ml/100 g for a total reduction of 57 percent.

This example illustrates the many dramatic improvements that Alcoa engineers have made in die casting quality in dozens of real world applications such as the Audi A8. The FLOW-3D simulation results were achieved in a much shorter period of time than would have been required building hardware and conducting proofing trials.

When simulated designs are initially machined into a die, proofing is often accomplished in a single day. The result is a dramatic savings in prototyping and testing expense as well as the assurance that parts of the highest quality possible are being produced. **dcm**