Predicting Defects in Lost Foam Castings

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Inside This Story:

- A research project at General Motors to correlate casting process modeling of lost foam to actual casting trials is examined.
- Lost foam process modeling allows foundries to analyze foam-metal interface reactions to determine how metal flow affects defect development and casting quality.

While lost foam casting interest increases because of the process' ability to produce near-net-shape components of high complexity, it has had its production difficulties. These have been due in large part to the process' requirements for a higher degree of process control compared to traditional casting processes.

Foam patterns must have the proper characteristics and be coated with just the right slurry. The gating systems must be arranged perfectly because the metal and polystyrene mix isn't forgiving. Metal pour temperatures must be sufficiently high to prevent premature solidification. In addition, the filling pattern of a mold must be such that metal fronts do not merge in a way that traps liquefied foam material, causing internal defects in the cast part.

In an attempt to address these difficulties, experiments were performed by GM Powertrain, Pontiac, Michigan, through the AFS Lost Foam Consortium in conjunction with the U.S. Dept. of Energy and the Univ. of Alabama-Birmingham to simulate the lost foam casting process with casting process modeling software. The computational fluid dynamics (CFD) modeling software Flow-3D from Flow Science, Santa Fe, New Mexico, was outfitted with modeling capabilities to simulate the lost foam process. Using these models, it is possible to simulate the filling of a lost foam mold and the subsequent solidification of the metal, as well as the capability to predict where folds or other defects associated with trapped foam products are likely to be located.

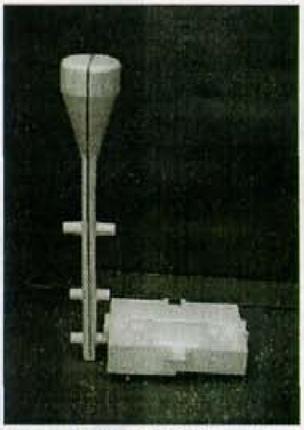


Fig. 1. Pictured is the experimental box casting foam pattern with gating system attached.

This article compares the experimental and computational results from the casting and modeling of a lost foam test component from General Motors. This comparison demonstrates the accuracy of lost foam predictions.

Experimental Component

The part to be cast and modeled, called the "box cast," was designed by GM as a test part for lost foam research. Although simple, the part has posts, partitions, and sections of differing thickness, all things known to be a challenge to casters.

In this experiment, the part was gated in a non-optimum way. This was done in order to increase the likelihood of defects that could serve as a guideline for comparing the relative advantages of a variety of process changes. Figure 1 shows the part with an attached sprue

495.3 mm (19.5 inches) high at one end. The box part is resting horizontally with its internal posts and partitions upward.

The single gate between the sprue and the box is a circular cylinder 20 mm in diameter. Two additional gates are visible along the sprue, which were used to fill the part when the box was oriented vertically rather than horizontally.

As will be seen in casting, an important feature of the test component is the variable thickness of its bottom. Half the bottom nearest the gate is twice as thick (19.8 mm) as the remainder of the bottom (10.3 mm).

Aluminum alloy A356 was poured at 1540F (838C). Experiments indicated that the average speed of the metal front was 53.34 mm/sec (2.1 in/sec).

For simplicity in the numerical model for casting process modeling, the sprue was removed and replaced at the entrance to the gate with a boundary condition consisting of liquid metal at 1540F (838C) and having a driving pressure corresponding to a metalostatic head of 495.3 cm (19.5 in).

The computational grid chosen to represent the box pattern in the simulation consisted of 124,200 rectangular elements in a regular array of 23 by 60 by 90 elements. A stereolithography file was used to specify the box geometry.

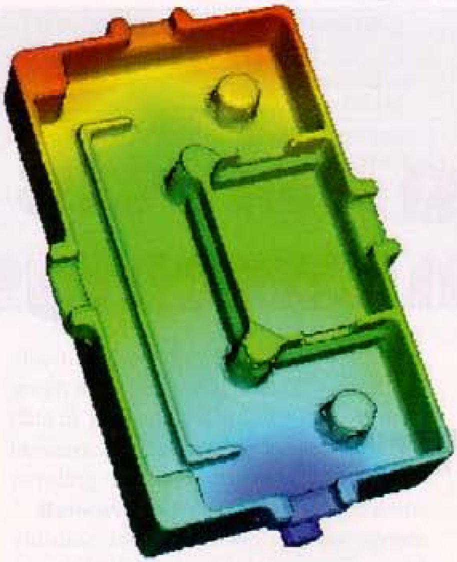


Fig. 2. Shown are the filling time contours from casting process modeling for the experimental casting.

Lost Foam Modeling Results

All computations indicated a smooth filling history for the experimental component with the metal flowing continuously from the gate toward the opposite end of the box. A characteristic feature of this flow is that metal enters the box as a narrow jet, while at the metal-foam interface it is moving tangential to the interface toward the sides of the box. This flow carries degraded foam material that could be trapped and cause internal defects.

An overall idea of the filling history is shown in Fig. 2, where color indicates the time of filling. The first place to fill is at the in-gate while the last place to fill is at the top-right corner, the furthest point from the in-gate.

Bottom Defects—Defects observed in the experiments were primarily confined to surface observations. For example, on the bottom of the box, fold defects were consistently observed on that portion having a thinner thickness. Furthermore, these defects were quite repeatable. These defects are marked on the casting shown in Fig. 3a.

For comparison, Fig. 3b shows the computed probability of defects in the bottom-most layer of computational elements, while Fig. 3c shows the same thing in the second layer of elements above the bottom of the box. Clearly, the casting process modeling has identified the thinner bottom section as having a much greater likelihood of defects. In addition, in agreement with the data, the modeling has predicted that defects are most likely to lie toward the left and right sides of the bottom surface.

Top Defects—On the top surface of the box a variety of defects were found to occur. For example, Fig. 4a indicates that a cold shut and "blister" were typically seen on the top of a short partition located closest to the last place to fill (top left corner in the figure). A high likelihood of occurrence of these defects was predicted by casting process modeling (Fig. 4b), which shows the high probability of defects on the post and along the top of the partition that are located nearest the last place to fill.

Origin of Defects—The agreement between experiment and modeling is good, but the true power of simulation is that it not only indicates problem areas, it also provides detailed information as to why the problems have occurred. For example, if metal temperature in the mold is examined, a short time after filling (t=6.0 sec) the coldest spot is precisely where cold shuts in the partition were seen on the casting. However, this spot is not the last place to fill, as may be expected. Residual momentum in the metal at the end of filling carries cold metal from the last place to fill back to the partition where the observed "cold shuts" occurred.

Returning to the defects on the bottom surface, a review of the modeling results shows that these tend to be located toward the side walls because of the flow pattern that develops during filling. As observed earlier, a tangential flow of metal along the metal-foam interface is di-

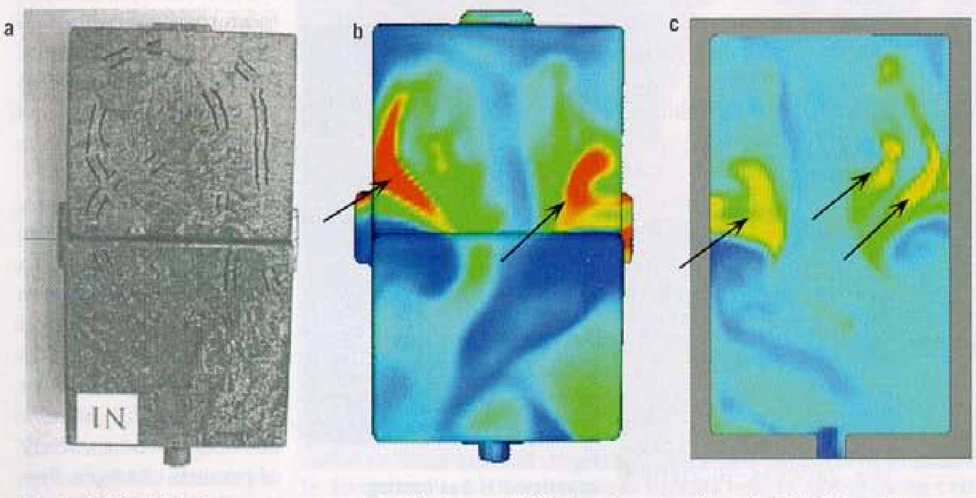
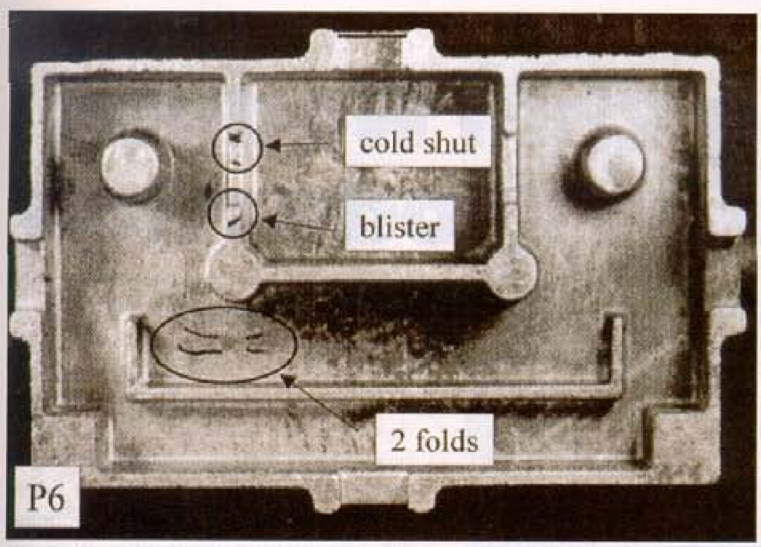


Fig. 3. At left (a) is the cast component with observed defects. At center (b) and right (c) are the casting process modeling predicted defects.



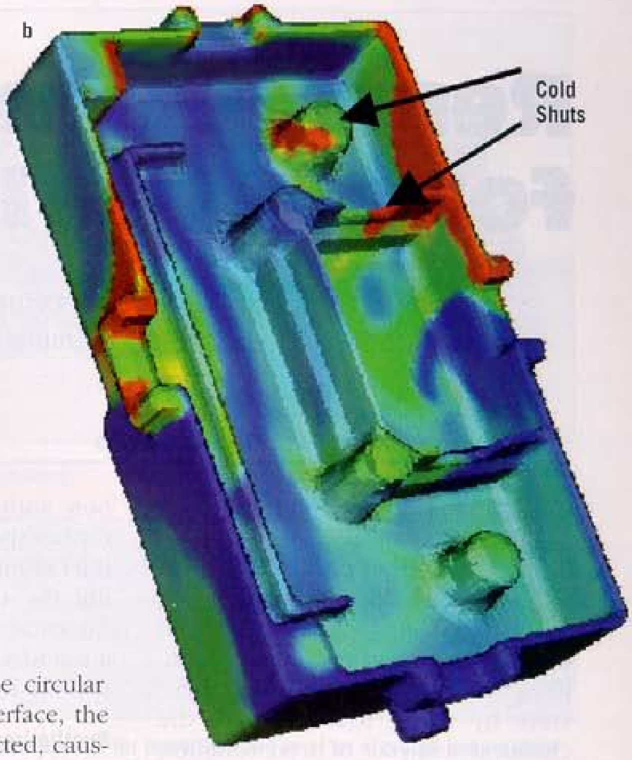


Fig. 4. Pictured at left (a) are the defects found on the top surface of the cast component. At right (b) are the predicted locations of defects on the top surface. Cold shuts are indicated by arrows.

rected toward the sides of flat sections of the part. At the sides of the bottom, two such sections meet at right angles, so one would expect an accumulation of foam residue along these corners. However, excess fluid momentum at the end of filling is strongest in the sidewalls. This eventually pushes the surface defect material away from the corners and a little way back into the bottom surface.

Excess and Residual Momentum Effects—It has already been pointed out that residual momentum is responsible for both moving the coldest metal away from the last place to fill and for altering the location of trapped foam residue. For this reason, consider the origin of residual momentum and what might be done about it.

Metal enters the mold through the 20 mm-diameter gate. Since the speed of advance of the metal-foam interface is nearly constant, the volume flow of metal through the gate must be proportional to the area of the interface (assuming the pressure head in the sprue is sufficient to maintain the flow). This area increases rapidly as the interface expands outward to fill the box pattern. Inspection of the computed metal velocity in the gate reveals that it reaches a maximum speed of about 2.070 m/sec even though the interface speed is only 0.0533 m/sec.

A significant consequence of such high-speed metal entering the mold is the potential for turbulent mixing of foam residue into the body of the metal. In this example, metal jets straight into the box cavity from the circular gate. At the metal-foam interface, the high-speed jet flow is deflected, causing metal to flow tangentially along the interface, trapping foam residue in the corners of the box.

From a general point of view, the presence of more (excess) momentum in the metal to simply fill the pattern is a cause for concern. Excess momentum appears in the form of secondary flows, often eddies or re-circulations, that may mix liquid and/or solid foam products into the bulk metal. These secondary flows also may cause folding of the interface.

A relatively simple way to reduce the amount of residual or excess momentum is to redesign the gate(s) so that a larger cross sectional area is feeding the pattern. Ideally, the gate(s) also should spread out the metal flow and prevent the formation of localized high-speed flows such as jets.

Testing Excess Momentum—A test of this idea was conducted by repeating the simulation using a modified gate. The original cylindrical gate was flared out to increase (approximately double) its surface area where it is attached to the surface of the box. It was hoped that the incoming metal flow would stay attached to the sides of the gate, but the flare angle was too much and the metal continued to jet into the box. However, the flare did cause a re-circulation at the base of the jet that helped it spread out, reducing its speed considerably.

With the new gating, the prediction of defect potential in the bottom and top surfaces, is much less than it was with the original gating. At least, computationally, this confirms the assertion that excess momentum arising from poorly sized gates can be a source of casting defects in the lost foam process.

Experiment Shows Results

It has been shown through the comparison of computation results with carefully performed experiments that casting process modeling can identify probable defects in lost foam castings. In addition, modeling can provide insight into the origin of defects, which can then be used as the basis for making improvements in the process. **MC**

About the Author

C.W. Hirt is the founder and chief technologist of Flow Science and was an early developer of the computational methods now in use in some casting process modeling software. Michael R. Barkhudarov is a senior scientist for Flow Science and has extensive experience assisting users with simulation problems.

For More Information

"Lost Foam Casting Simulation with Defect Prediction," C.W. Hirt and M.R. Barkhudarov, Modeling of Casting, Welding and Advanced Solidification Processes VIII, San Diego, California, 1998.

"Lost Foam Casting Simulation Helps Mercury Marine Reduce Defects," C.W. Hirt and M.R. Barkhudarov, Engineered Casting Solutions, p. 53, Spring 2001.