

Lost Foam Variable Pattern Density

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Overview

Making foam patterns for use in the lost foam casting process is a difficult business. To make a pattern foam beads are blown into a mold containing discrete vent locations for the displaced air and steam. This makes the density of the packed beads difficult to control. Patterns typically show final density variations of $\pm 20\%$. Much larger variations are not uncommon.

One goal of the Lost Foam Consortium is to evaluate techniques for improving the uniformity of patterns. A related goal is to determine to what extent density variations in patterns are significant with respect to the quality of the parts produced.

Recent real-time X-Ray observations of the metal filling process reported by Dr. Wayne Sun (Advanced Lost Foam Casting Technology-Phase V Meeting, June 20-21, 2001) revealed several interesting facts about the behavior of foam patterns. In particular, when the foam has a low degree of fusion metal is observed to move very fast into the foam (e.g., 4 to 5 times faster than in normal fusion foam). The advancement of the metal is typically in the form of fingers, which subsequently spread sideways causing the meeting of metal fronts that result in many fold defects. Furthermore, the location of the fingering is significantly affected by density variations in the foam pattern.

In contrast, when the foam patterns consisted of normal fusion foam, the metal front moved smoothly (i.e., no fingering) and considerably fewer fold defects occur. Also, the presence of density variations in the foam has little effect on the propagation of the metal fronts.

Based on these findings it was concluded that no attempt should be made to model low fusion foam because this is not likely to be choice for production work. Instead, we report here the development and testing of a model for adding a variable foam density to the **FLOW-3D**[®] software package from Flow Science, Inc.

Model Development

Density variations in foam typically occur at walls of the pattern mold where foam beads are cooled most rapidly and near blow holes where the foam material is injected into the pattern mold. Any model for density variations in a pattern must be general enough to incorporate these and other possible sources of density variation.

As noted in the previous section, foam density variations are not particularly significant for most applications, so the model extension for this effect should not increase the computational work or otherwise restrict the present lost foam model for uniform foam applications.

The lost foam model contained in the **FLOW-3D**[®] program makes use of the foam density in two ways. First, it uses the product of the density times the specific heat of the foam as a heat capacity variable, which controls the amount of heat energy needed to raise the temperature of the foam and subsequently melt and possibly vaporize it. Second, the density of the foam is used in the foam-residue defect model to characterize the mass of defect material produced when the foam is degraded.

To satisfy the requirements for generality, without compromising the existing constant density model, we have chosen to include pattern density variations through the use of a scalar variable. Scalars are passive variables subject to advection and diffusion that do not affect the fluid dynamics (unless specifically programmed to have an effect). **FLOW-3D**[®] has scalar variable feature where any number of these quantities can be introduced. The computer memory needed for these variables is dynamically allocated, which means that they require no memory unless a user asks for them. The foam defect mass is one example of a scalar variable.

The scalar for variable pattern density is defined in such a way that a zero value for the scalar results in the nominal foam density:

$$\rho_{foam} = \rho_{foam}^0 (1 + S)$$

where S is the scalar and a superscript 0 indicates the constant nominal density. S cannot be less than -1, but could be arbitrarily large. S is a non-dimensional quantity.

Scalars in **FLOW-3D**[®] are automatically initialized with zero values. Non-zero values can be specified in the problem set up in terms of specified values in defined regions, or in terms of general quadratic functions (e.g., a linear variation in some direction). This type of input is acceptable for parts that are not too complex. For more complex shapes the user will have to customize the definition of the initial values of S. A source-code routine is available for this purpose. Of course, to do this the user will have to know what the density variations are in his pattern, something that might be difficult to determine.

At some time in the future it might be possible to predict pattern density variation, which could then be imported into **FLOW-3D**[®]. However, it's just as likely that the future will include improved pattern making techniques that eliminate density variations, so that determining what values to assign the S array will no longer be important.

Testing the Model

X-Ray tests that show the filling of vertical plates offer an ideal test bed for the variable density model. The simplicity of the geometry and the correlation of metal front shapes with density variations give the kind of straight forward test data that is most useful in the development of a new computational model.

The plate considered has dimensions 8" by 6" by 0.315" and is arranged with the 6" direction vertical. A gate is located at the midpoint of the right hand side. The foam pattern has a nominal density of 1.3 pcf. Two blow ports were used to make the pattern and were located in the central region of one of the 8" by 6" faces. For the test simulation it is assumed that the density in the blow holes is 30% greater than elsewhere. Figure 1 shows a photo of the plate and attached

sprue along with the model geometry that shows the increased density regions and the computational grid used in the simulations.

The metal front speed for the test was set at 4.6 cm/s, which is specified in the simulation in terms of the metal-foam heat transfer coefficient. This is the only empirical parameter required in the *FLOW-3D*[®] model and is used to account for the combined effects of gas generation, coating permeability, and all other factors that affect the propagation of metal into foam.

Snapshots of the filling (metal configuration and velocities) at two separate times are shown in Fig. 2. Both images show a dimple in the metal front where it has passed through the higher density regions. These dimples arise because the metal moves more slowly where the density is

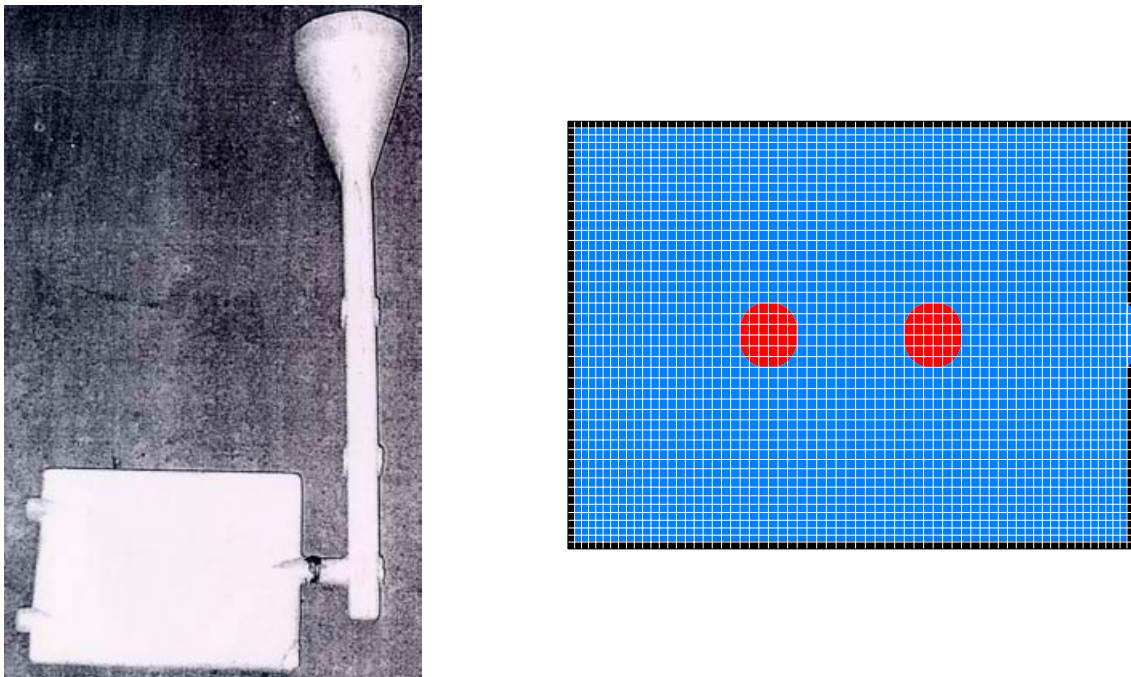


Figure 1. Photo of plate and sprue (left) and computational grid for plate (right). The central circular regions have a density that is 30% larger than the remainder of the plate.

higher; that is, more heat must be transferred to the higher density foam to degrade it, which requires more time.

The dimples are not large and become smaller with time. Their initial size is proportional to the size of the region having a higher density. For example, the blow holes have a diameter of 2 cm so that a 30% reduction in speed, times the time of travel over the hole (about 0.43 s), suggests a maximum dimple amplitude of about 0.6 cm. As the metal front progresses it always tries to advance perpendicular to itself (the direction of maximum heat transfer) and this causes the fronts on either side of a dimple to move together, diminishing its size.

A qualitative comparison with an X-Ray test case is also given in Fig.2 (see arrows). The comparison is only qualitative because the exact density variations in the model were not the same as those in the test, which had many small density variations throughout the entire plate. Nevertheless, the general agreement is sufficient to support the validity of the variable pattern density model. More detailed comparisons will be difficult to make since the effects of a variable density are generally quite small.

This model extension will be a standard feature in all versions of *FLOW-3D*[®] beginning with Version 8.2.

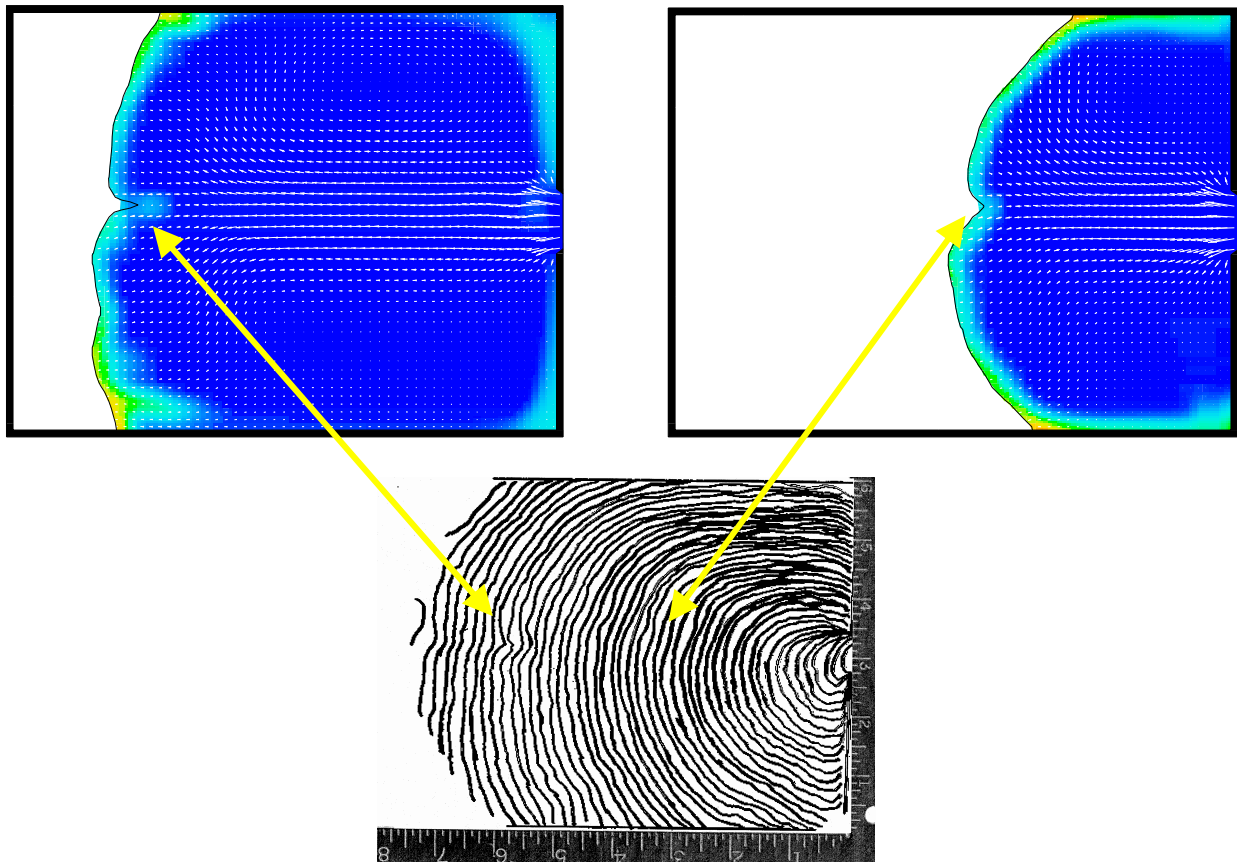


Figure 2. Snapshots of computed filling pattern compared to metal front shapes taken from an X-Ray video. Arrows indicate dimples in the front caused by increased density regions.