Modeling Casting on the Move

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- **Most modeling work incorporates fixed geometries, but many casting practices, such as pouring, high pressure diecasting and squeeze casting, involve moving parts.**
- **To account for the moving parts that come into contact with the molten metal, a modeling tool was developed for casting processes with varying geometries.**
- **This general moving object method provides an accurate way to simulate 3-D motion of arbitrary shapes in a fixed computational grid.**

Casting process modeling tools are capable of modeling flow and thermal and structural aspects of the many casting processes. However, most of the modeling work involves fixed mold geometry. Nevertheless, many casting practices involve moving parts directly in contact with liquid metal.

For instance, metal handling before and during pouring involves moving furnaces and ladles. In high pressure diecasting, a plunger propels metal into the die cavity. In centrifugal and tilt pour castings, the molds spin. In squeeze casting, pieces of the die move together to form the liquid metal into a shape. Combined with heat transfer and air and oxide film entrainment methods, modeling these processes can yield detailed

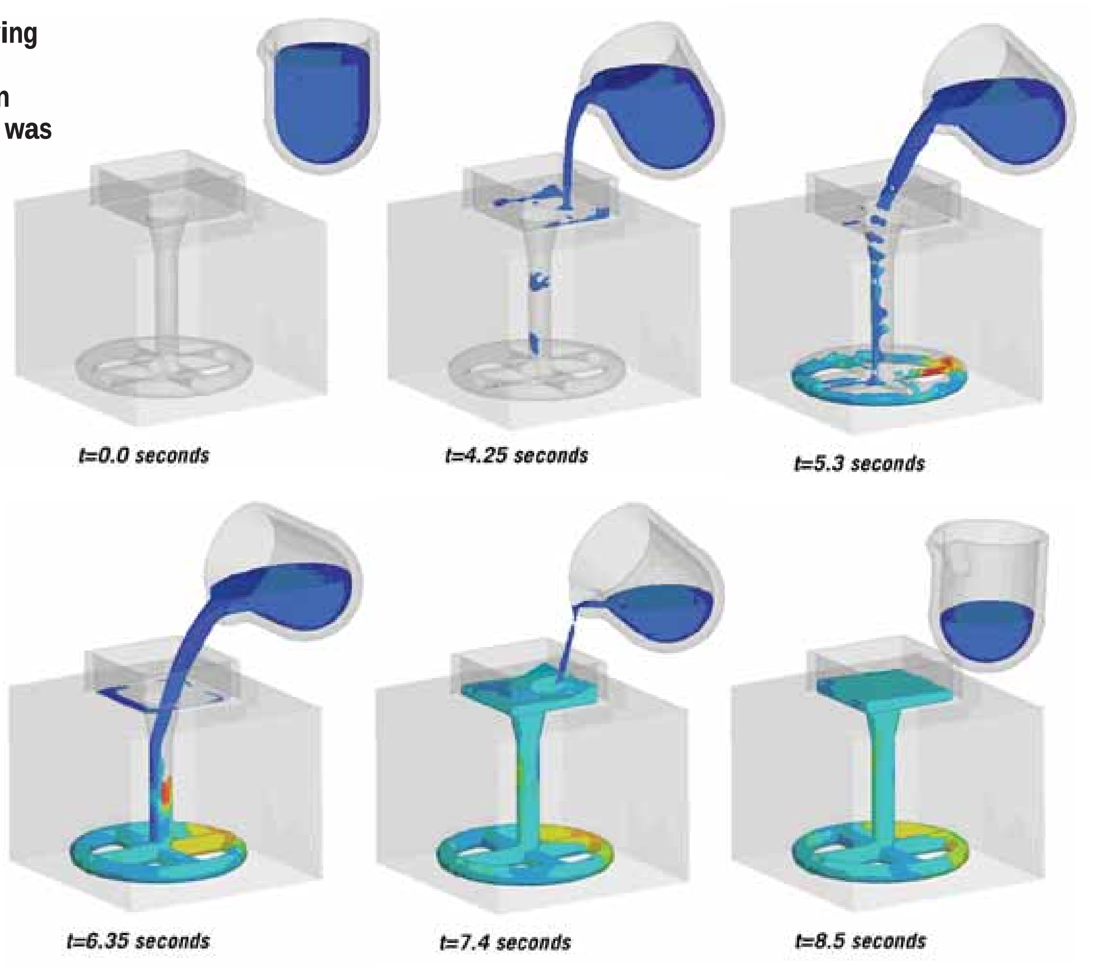


Fig. 1. In the simulated pouring sequence of a liquid aluminum alloy from a ladle into a sand mold using the GMO model, color represents volume fraction of the entrained air with the scale going from 0.0 (blue) to 8% air by volume (red).

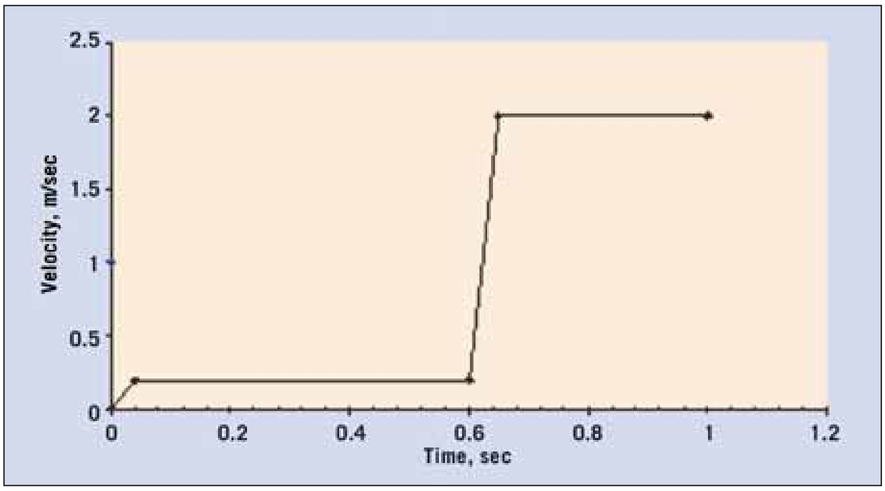


Fig. 2. This plunger velocity profile shows that the transition between the slow and fast stage is linear and occurs over 0.05 seconds.

insights and allow engineers to extend their knowledge and understanding of the complex interactions between various process parameters.

General moving object (GMO) modeling provides a robust and accurate way to simulate 3-D motion of arbitrary shapes in a fixed computational grid. Multiple moving objects can exist in the same domain, and each of them may have a different type of translational and rotational motion, either prescribed or dynamically coupled with metal flow. This fixed-mesh, GMO method has advantages over the moving and deforming mesh methods because the shape and motion of each moving object are not restricted in their complexity.

The GMO model is based on a technique that describes the mold geometry in fixed rectangular meshes by means of area and volume fractions. Volume fraction in a computational cell is defined as the ratio of the volume open to metal flow relative to the total cell volume. Area fraction at a cell face is defined as the ratio of the open area of the cell face relative to the total area of the face. At each point in time, area and volume fractions are updated in accordance with the object's motion to reflect its changing position.

In each example of a potential application described in this article, the motion of the moving part of the geometry is prescribed as if controlled by a programmable machine.

Modeling Turbulence During Pouring

Pouring out of a ladle employs both the translational and rotational time-dependent prescribed motion to model the process of liquid metal flowing from a ladle into a sand mold. The ability to model the handling of metal before it gets into the mold is an important extension of the general filling modeling capability. Even though significant metal damage through oxidation and air entrainment can occur during this early stage of the casting process, it is usually left out of the conventional filling

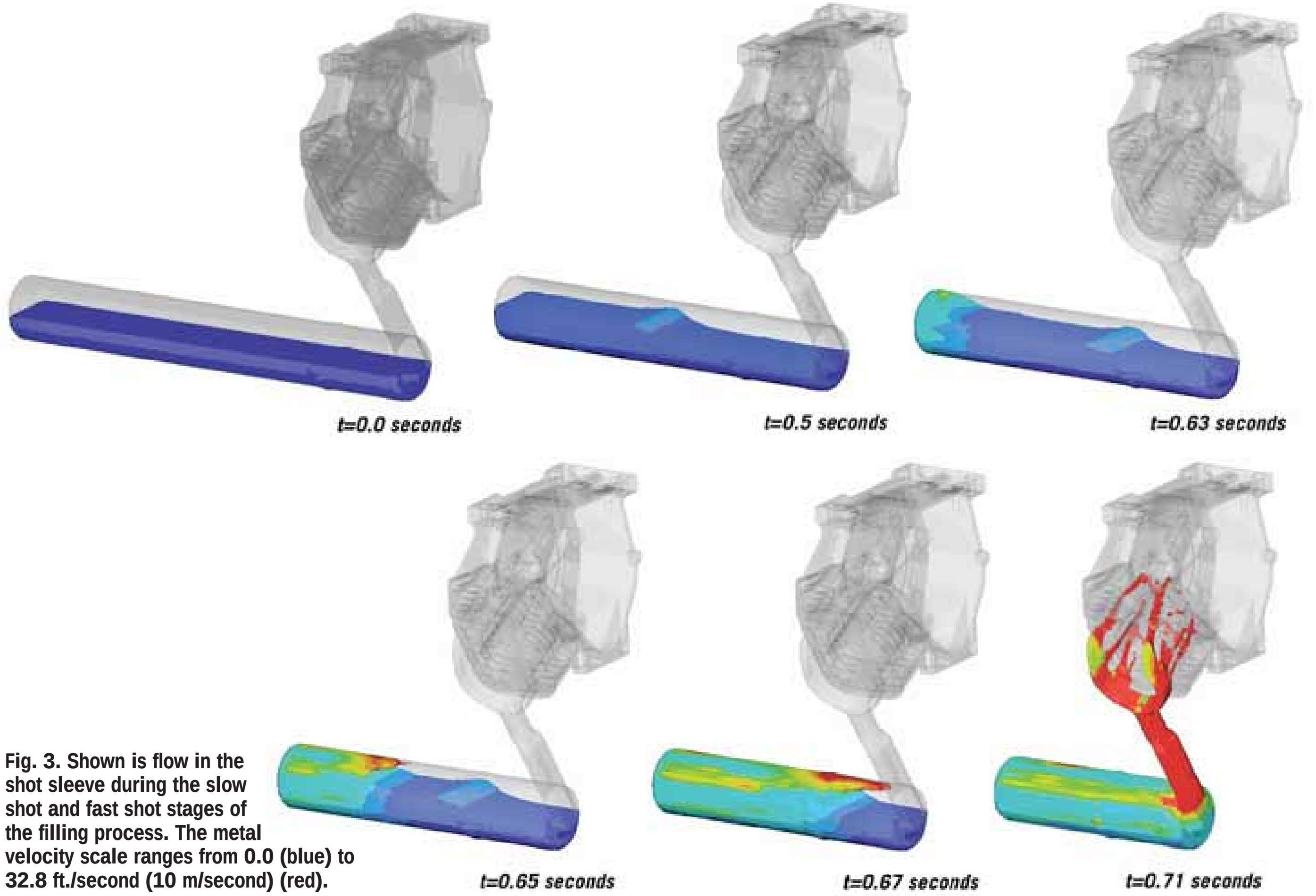
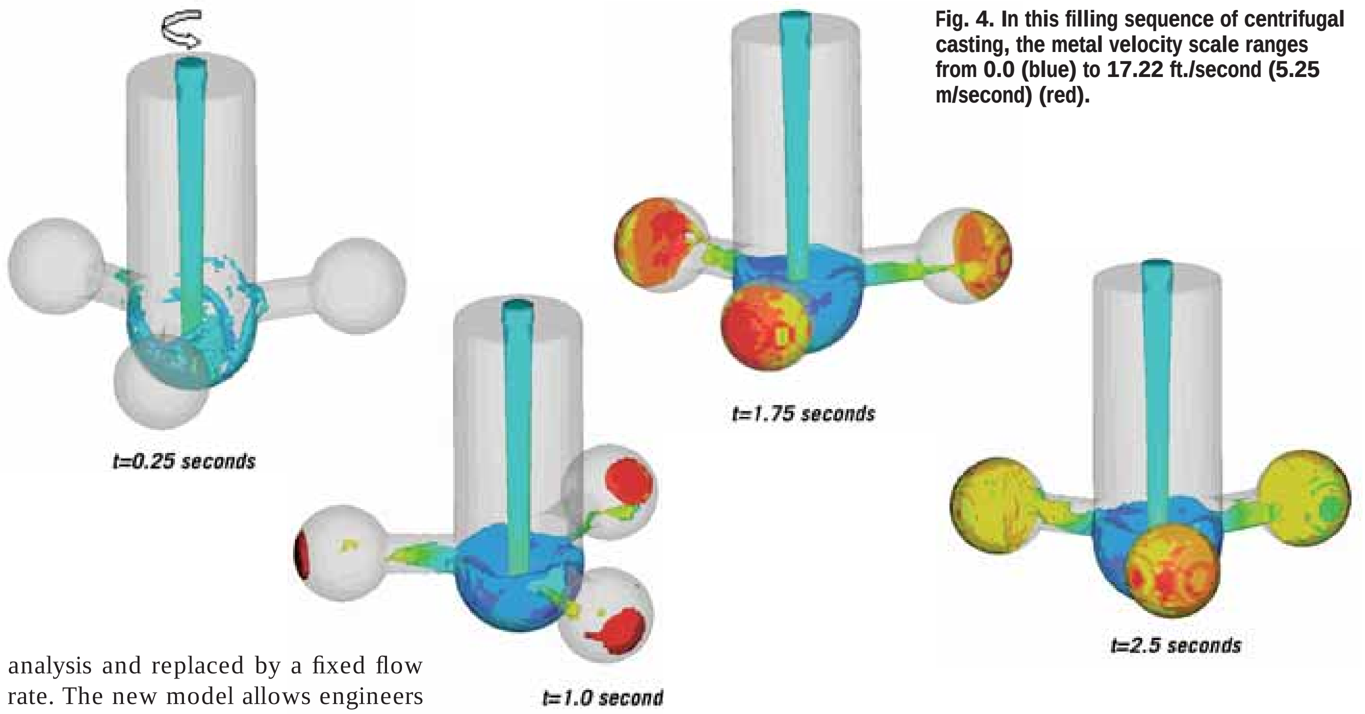


Fig. 3. Shown is flow in the shot sleeve during the slow shot and fast shot stages of the filling process. The metal velocity scale ranges from 0.0 (blue) to 32.8 ft./second (10 m/second) (red).


t=0.25 seconds

t=1.0 second

t=1.75 seconds

t=2.5 seconds

Fig. 4. In this filling sequence of centrifugal casting, the metal velocity scale ranges from 0.0 (blue) to 17.22 ft./second (5.25 m/second) (red).

analysis and replaced by a fixed flow rate. The new model allows engineers to investigate this highly transient and turbulent stage, and, combined with the heat transfer and defect tracking models, the quality of the filling process can be evaluated in more detail.

The metal initially was placed into a vertically oriented ladle, which then moved horizontally to above the pouring basin and stopped. After stopping, the ladle tilted forward 60 degrees, recovered and moved back to the initial position—all in the time span of 10 seconds. Selected frames from the process modeling are shown in Fig. 1.

The color represents the amount of entrained air in the metal, expressed by the fraction of the air volume in the air/metal mixture. The entrainment of air is the combined effect of the balance of the turbulent, surface tension and gravity forces.

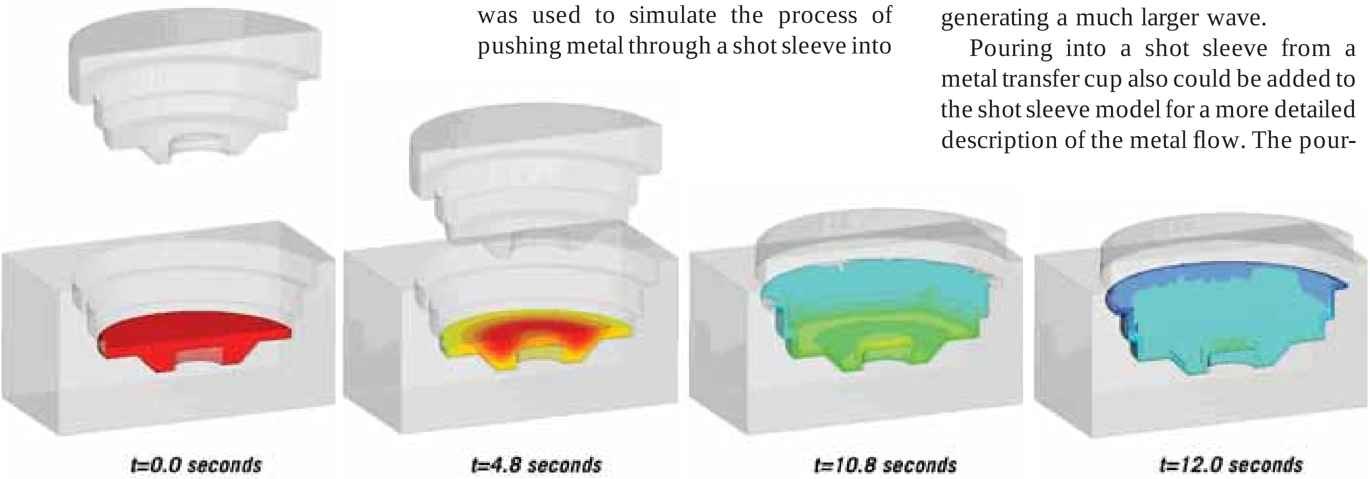
Most of the entrainment of air occurred in the sprue where the free falling liquid metal jet mixed with the metal already in the sprue. This was where the metal's speed and turbulence level were the greatest. In addition, the footprint of the jet moved in and around the top of the sprue, adding even more turbulence and variability to the flow in the basin and sprue. If one needs to minimize the metal damage at this point during filling, these aspects of the flow must be investigated closely.

Take a Shot

A linear, one-dimensional, time-dependent prescribed motion of a cylindrical plunger, 2.36 in. (0.06 m) in diameter, was used to simulate the process of pushing metal through a shot sleeve into a high pressure diecasting cavity. As with pouring from a ladle, proper handling of metal in the shot sleeve in the cold chamber process is critical to ensure a good quality casting. The speed of the plunger, which can be defined as an arbitrary function of time, must be carefully programmed to avoid the entrainment of air by overturning waves.

The shot sleeve initially was filled by liquid metal at 50%. The motion of the plunger was divided into the slow stage, 0.6 seconds long, with a velocity of 7.87 in./second (0.2 m/second), and a fast stage, with a velocity of 6.56 ft./second (2 m/second) (Fig. 2). The flow results are shown in Fig. 3, with metal colored by the velocity magnitude. A shallow wave was sent ahead of the plunger during the slow shot stage. Before the wave reached the end of the sleeve, the plunger accelerated, generating a much larger wave.

Pouring into a shot sleeve from a metal transfer cup also could be added to the shot sleeve model for a more detailed description of the metal flow. The pour-


t=0.0 seconds

t=4.8 seconds

t=10.8 seconds

t=12.0 seconds

Fig. 5. In this squeeze casting forming sequence, color represents metal temperature, with the scale ranging from 1,580F (blue) to 1,652F (red) (860-900C).

ing process may result in a significant residual metal flow in the shot sleeve before the plunger starts moving.

Go for a Spin

Centrifugal casting helps to achieve superior grain structure and minimize porosity compared to the conventional gravity casting. However, splashing and turbulence during the initial stages of filling can be excessive due to the high speed of the rotation of the mold. Careful design of the catching basin and the runners is important to minimize the damage to the metal due to oxidation and early solidification.

In this example, the whole mold was rotating at a constant speed of 400 rpm around its vertical axis of symmetry. Three identical spherical cavities were spaced in the horizontal plane by 120 degrees from each other and connected to the catching basin by rectangular runners. Metal was poured from the top at a constant rate to achieve the filling time of 2.5 seconds.

The results are shown in Fig. 4. The frames are 0.5 seconds apart, which is equivalent to 3.33 revolutions of the mold. The centrifugal force, due to rotation, pushed metal into the runners and mold cavities, and a vertical vortex formed along the axis of rotation. In the actual process, the rotation would continue until the metal was fully solidified, but it was not considered here.

This modeling was the most challenging of the examples because the geometry and its motion were quite complex. The moving solid surfaces swept the flow area many times during filling. Nevertheless, the overall volume error at the end of filling was less than 1.5% of the total poured volume.

Putting on the Squeeze

Squeeze casting uses two pieces of a die. The bottom piece is stationary, while the top piece slides up and down to form a cavity in the gap between them. Initially, the top piece is elevated, with the cavity open. Liquid metal is placed in the open cavity of the preheated bottom piece, and then the top piece moves down, squeezing the metal into its final shape, which in this case was a round, stepped plate with a uniform wall thickness of 0.196 in. (5 mm). Castings made this way usually have excellent mechanical properties, which are just short of those for a forged casting, but with greater savings in the production costs.

In the modeling, the downward velocity of the upper piece started with a constant speed of 3.28 ft./second (1 m/second), then linearly decreased to zero at the end of the process. It was calculated to leave just the right gap between the two die pieces when the top piece stopped. Fig. 5 displays four fames showing the initial placement of the die pieces and metal, an intermediate stage and the final position of the pieces and the shape of the casting. **MC**

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For More Information

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