

# Tracking of collapsed bubbles during a filling simulation

R. Pirovano, S. Mascetti

*Casting process simulation software are more and more common in analyzing and projecting casting parts and molds. One of the biggest numerical challenges is to simulate the smallest air particles that can be entrained in the metal. In fact, in common fluid-dynamic simulations each time a region of air gets smaller than the cell size, it disappears, losing all the information about its presence and the possible defects that this implies. By tracking the bubbles smaller than the cell size, it would be possible to keep this information and to use it to improve the accuracy of the simulation itself. It is for example possible to rejoin them with the existing air regions, eventually modifying the filling itself, or to calculate the final size and position of the related defects. Through a customization of FLOW-3D Cast source code, implemented in the last official release of the software, XC Engineering has been able to track the defects due to the air entrained in the liquid metal. Whenever a bubble gets smaller than the cell size during a filling simulation, it is replaced by mass particles, which retain all the lost information and behave like little spheres of air. By following the displacement of the new objects and their interaction with other air regions, a new output is created and available for further analysis.*

**KEYWORDS:** DEFECTS - HPDC - AIR - BUBBLES - PARTICLES - SIMULATION

## INTRODUCTION

Casting process simulation software packages are, due to their high reliability, efficiency and accuracy, more and more used in the everyday analysis. Many defects are already successfully caught and prevented through numerical simulations and this technology is rapidly evolving to represent the details of foundry processes in a better way. Even if actual powerful workstations are able to simulate complex problems by subdividing the domain with millions of cells, resolving the "sub-grid" physics - the ones that involve behaviors with a characteristic length smaller than the cell size - is still the biggest approximation.

Among them, one of the biggest numerical challenges is to simulate the smallest air bubbles that can be entrained in the metal. In fact, in common fluid-dynamic simulation of an HPDC filling each time a region of air gets smaller than the cell size it disappears, losing all the information about its presence and the possible defects that this implies.

As a workaround, the user can track the regions of air entrapped during the filling and check manually where they, especially the last ones, close up and disappear. This approach is too approximated and does not keep in account the final displacement of the bubble.

## FLOW-3D CAST SOFTWARE AND THE ADIABATIC BUBBLE MODEL

FLOW-3D Cast is a powerful software, designed specifically for modeling a wide range of casting processes. It consists of a full flow and thermal solution for both the cast alloy and the die or mold.

Even if it can simulate the complete fluid-dynamic of metal and air together, in most of the cases this is not necessary. Because of the relatively small influence of the air on the fast and dense metal surface, the motion of the alloy can be accurately caught without spending time and resources in calculating the motion of the surrounding gas. On the other hand, neglecting completely the influence of the air by considering for example an ideal porous mold, can result in wrong outputs. To find the best compromise between fast and accurate simulations, two models have been introduced in FLOW-3D Cast: the air entrainment model and the adiabatic gas model.

The air entrainment model [1] has been developed to simulate the effect of the turbulence in free-surface flows, which may be sufficient to disturb the surface to the point of entraining air into the flow. The air is then represented as a diffused quantity into the flow because of the microscopic size of the entrained bubbles. The air entrainment model can be used to simulate the "bulking" of fluid volume and the buoyancy effects associated with entrained air, as well as the possible escape of air if it rises to the surface of the metal. Finally, the air can be compressed, changing its volume while conserving the mass.

The adiabatic bubble model [2], instead, is able to represent bigger bubbles that are closed into the fluid because of the move-

**Raul Pirovano, Stefano Mascetti**  
XC Engineering Srl

ment of the free surface. In particular, any continuous region of void cells defines a void region, or bubble. Each void region is characterized by uniform pressure, temperature, volume, and inertia; the friction at the interface with fluid can be neglected. These assumptions are generally valid if the gas density is much smaller than the one of the fluid and the gas speed is comparable with that of the fluid, typical of mold filling with liquid metal. This approach is a powerful method that provides efficient and accurate solutions: including the details of gas flow in such cases is usually computationally expensive and unnecessary. If a flow contains multiple bubbles, in each of them different pressure is

stored and applied as a boundary condition at the fluid free surface surrounding the void.

Due to the dynamic of the flow, each bubble is subject to an evolution of its volume, and its pressure consequently changes following the adiabatic law:

$$p = p_0 \left( \frac{v_0}{v} \right)^\gamma \quad (1)$$

By compressing a bubble its pressure increases, resulting in a higher force given back to the fluid itself (Fig.1). Finally, a bubble can be vented through a valve with a certain loss coefficient.

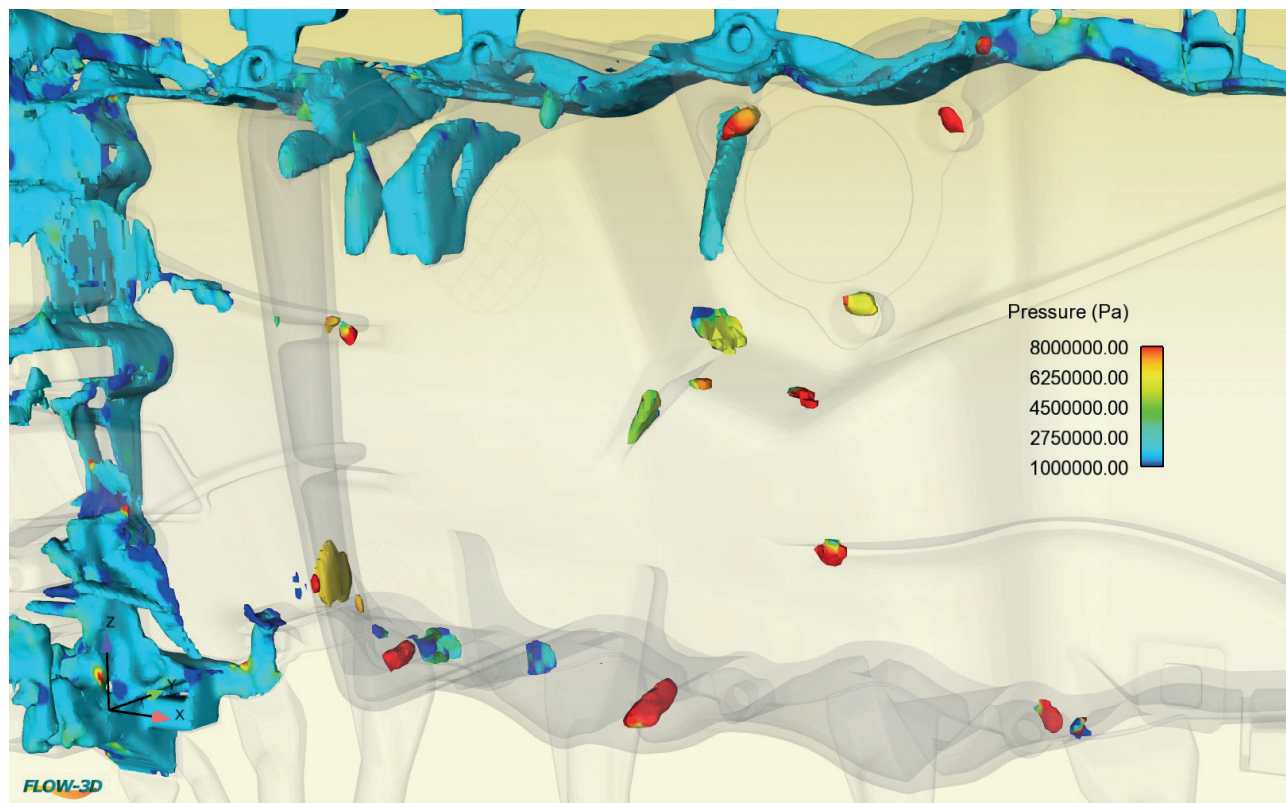


Fig. 1 - Bubbles during an HPDC filling, colored by pressure

### CATCHING THE SMALLEST BUBBLES: THE CUSTOMIZATION OF FLOW-3D

The adiabatic bubble model is a powerful model that gives the possibility to track the gas regions during a filling process, influ-

encing the flow dynamic itself and giving the possibility to the user to guess the location of some typical defects connected to the entrapment of bubbles of gas (Fig. 2).

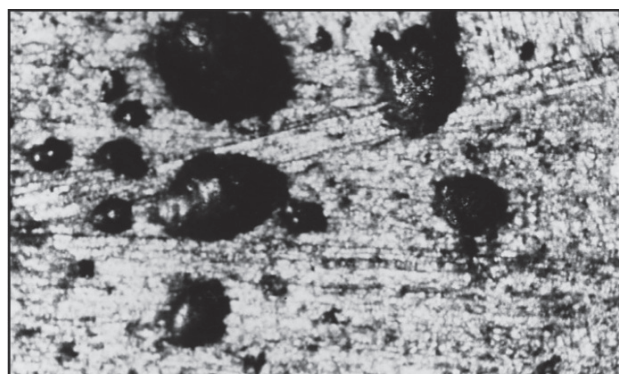
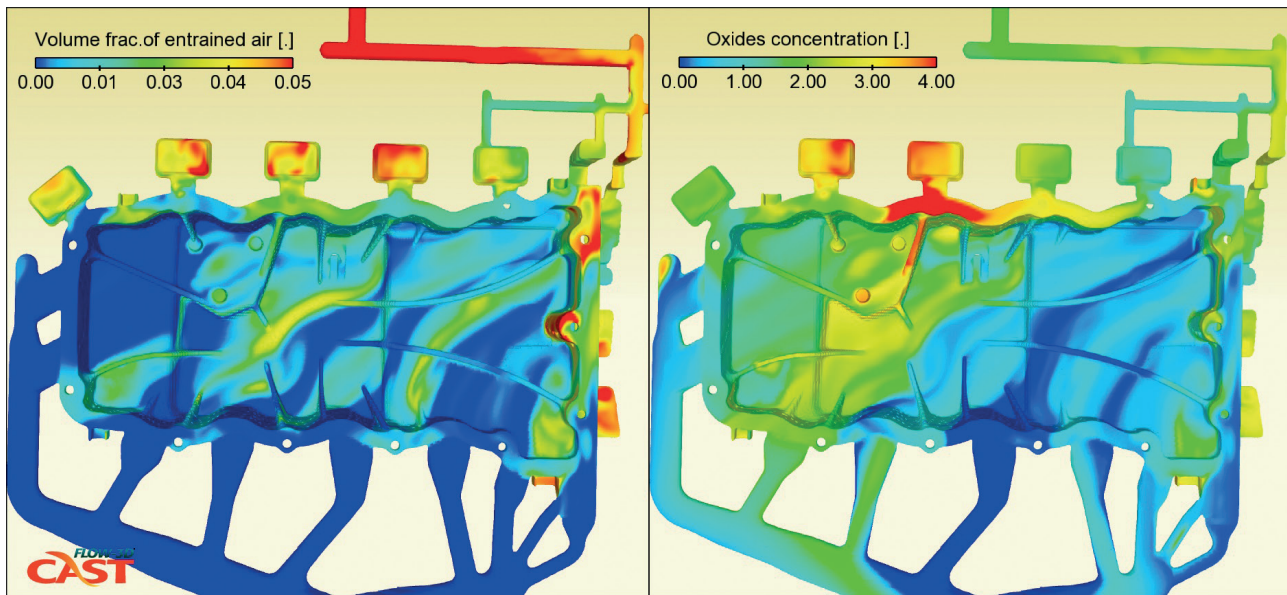


Fig. 2 - Some typical trapped gas porosity - Courtesy of NADCA [3]

This kind of defects can be modeled only with the adiabatic bubble model or a similar approach, because they are generated by a closed region of air that is core and more compressed during the filling. They have a well-defined shape and cannot be modeled with a dispersed quantity in the fluid. Moreover, inside each bubble some specific information (such as pressure and temperature) is stored and shared with the external metal only as a boundary condition. The amount of gas itself is also localized: it can be eventually split in more bubbles, but it is generally not diffused into the metal.

For this reason, these defects cannot be simulated using the air entrainment model or the surface defect tracking model of FLOW-3D Cast (Fig.3), because they represent two different kinds of defects. Both quantities are entrained from the free surface and are dispersed into the metal, where they represent respectively the entrapped gas due to the turbulent free surface, and the oxides and other impurities collected on the free surface.



**Fig. 3** - Diffusion of the entrained air (left) and surface defects (right) at the end of an HPDC filling

The adiabatic bubble model has one limitation: in order to work it needs that the bubble is bigger than the cell size. When a bubble gets smaller, it collapses losing its information and its effects on the flow.

The traditional way of trying to determine the position of the related defects is to check whenever a bubble collapses during the simulation, especially during the last part of the filling. Due to their higher internal pressure, those last bubbles generate more likely defects in the real casting part.

This approach is generally not reliable because it does not keep in account the movement of the bubble after it is deleted from the simulation. Moreover, it does not provide any information about the size of the defect itself, because it does not keep in account the evolution of the bubble volume and pressure.

To overcome this limit, a customization of the standard FLOW-3D Cast code has been done. Each bubble, and even the smallest one, should be tracked during the filling, varying their size and internal pressure. Moreover, they should influence the movement of the fluid itself and eventually rejoin with other bubbles. Finally, their movement must involve drag and floating, and they cannot diffuse.

To keep in account all these properties, it has been chosen to convert each collapsed bubble into a mass particle which, if

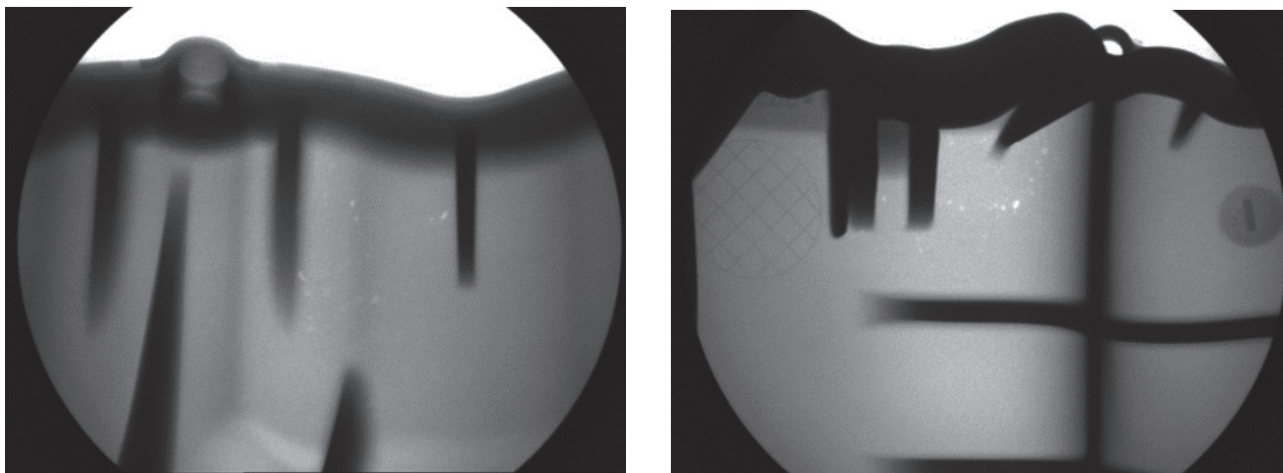
properly defined, is able to simulate accurately the characteristics of a gas bubble. More specifically, when a bubble gets smaller than the cell size and collapses one or more mass particles are generated through the customization, storing all the information of the disappeared region of gas. The particle moves carried by the metal velocity, but because of its drag and buoyancy it can deviate from the metal path. These effects are functions of the size of the particle, that changes accordingly to the local metal pressure, following the adiabatic law. Moreover, if a particle enters into a void region, it rejoins summing up the two volumes of air. At the end of the filling, the intensification pressure compresses each particle, giving to the user the final position and the exact size of the defect.

## NUMERICAL RESULT AND VALIDATION

Several tests have been done to validate the code, from the simplest test cases to simulations of real parts, comparing numerical results with experimental analysis.

In this section, a comparison with a real casting part provided by Form Srl is shown.

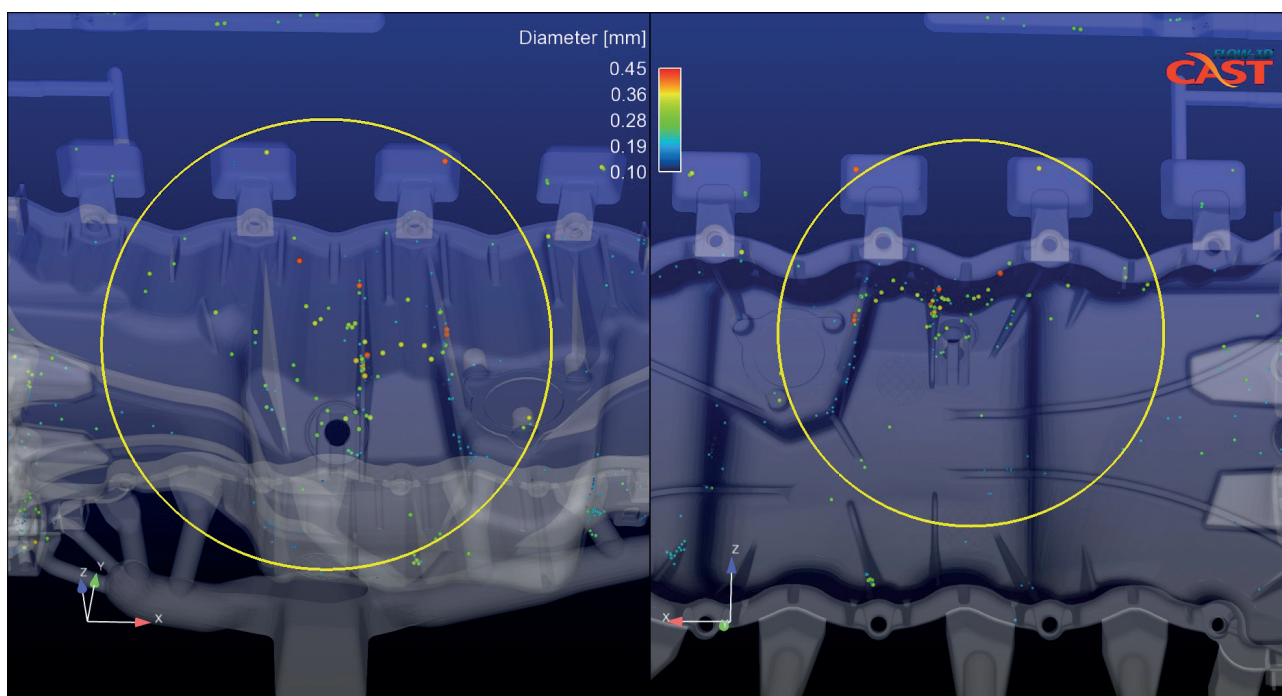
In the real cast, several and repeatable defects due to gas bubbles were detected in the upper central zone of the part, which were not detectable with the standard code (Fig. 3).



**Fig. 4** - X-ray of the part, showing (in white) the gas defects - Courtesy of Form Srl

Thanks to the customized code, each collapsed bubble generates some gas particles that are moved and compressed until the end of the filling. Looking at the result at the end of the simulation

(Fig. 4, gas particles colored by their size), it can be noticed that the highest concentration of gas particles is in the same region where the defects were observed in the real part.



**Fig. 5** - Numerical result of the filling, gas particles colored by their size

## CONCLUSION

A new model has been developed to track the smallest bubbles entrapped into the metal during an HPDC filling, and it has been successfully validated with experimental evidences. The model could be improved in order to combine different filling defects and its results could be used to extend FLOW-3D Cast capabilities.

## REFERENCES

- [1] C. W. HIRT, Modeling Turbulent Entrainment of Air at a Free Surface, Flow Science Report 01-12, (2012).
- [2] C. W. HIRT, Void Regions and Bubble Models in FLOW-3D, Flow Science Report 01-13, (2013).
- [3] W. G. WALKINGTON, Die Casting Defects Troubleshooting Guide, NADCA, Alington Heights, Illinois (2003).