VALIDATION OF FOUNDRY PROCESS FOR ALUMINUM PARTS WITH FLOW3D® SOFTWARE

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Abstract

The importance of smooth mould filling in the foundry casting process has been recognized for a long time. More uniform the filling process is, the better the quality of the casting of the products produced. Successful computer simulations can help to reduce the number of trials and cut down the lead time in the design of new casting products by better understanding the complex mechanisms and interplay of different process parameters in the mould filling process.

This work deals with the numerical simulation of the filling of gravity die casting, lost foam casting and its solidification. Computations were carried out using Flow3D® which is a general computational fluid dynamics (CFD) code [1]. The simulation involved viscous fluid flow with transient free surfaces, metal/mould heat transfer, conduction in both metal and mould, and latent heat release. Full Navier-Stokes equations, energy equations and Volume of Fluid (VOF) methods were used to simulate this topic.

Simulations results were compared with experimental data and good correlation for thermal effects and front tracking evolution throughout the parts have been found.

Introduction

PSA Peugeot Citroën owns three foundries. They are located in northern France. The foundry of Charleville Mézières produces cylinder heads by gravity die casting, and lost Foam cylinder heads as well as GJS cast-iron parts. The Foundry of Mulhouse produces crankcases cylinders in high pressure die casting. Lastly the foundry of Sept-Fons produces crankcases cylinders and revolution parts in GJL Cast.

For many years, PSA Peugeot Citroen has been using the numerical simulation in its projects development of new vehicles and new parts.

The foundry was one of the first processes modelized. For twenty years, design and new part's development of power units or crossmember parts were based on the numerical simulation of the foundry.

Presently, the tools for simulation are impossible to circumvent from the numerical channel of design as well as the CAD.

The application of the foundry simulation in the projects has considerably advanced in particular thanks to the contribution of the different software used these last two decades. Flow3D® used since 2008 in PSA Peugeot Citroen shows a new step of this evolution.

Flow3D® represents a new ambitious goal with respect to the objectives that we fixed in terms of predictability for all the foundry process. Among those, is the lost Foam, High Pressure Die Casting and gravity die casting process which inaugurates this new stage.

Lost Foam process offers today some Industrial advantages. Particularly, the costs are between 15% and 30% lower compared to more conventional methods of moulding. However, this technique requires expertise and significant experience during development phases. Defects in specific processes can occur on parts such as effects of ceiling or partial vitrification (deposit of sand). Other defects (defects misrun, blowholes, turbulent flow and solidification defects) are similar than in gravity die casting even if their origin is different.

Like other processes, the formation of defects during aluminum cylinder heads Lost Foam casting can be affected by the flow, solidification and cooling. We did this study in order to understand the evolution of the flow front and the thermal process during filling and solidification of our process. This complexity was proven by tests, used to detect the progress of the flow using binary metal detector. The same tests have been used for the gravity die casting process. This study is achieved to supplement the understanding of the flow for Lost Foam and gravity die casting using specific tools Flow3D®, numerical modeling, physical modeling (Flow3D® model) and industrial testing. Each one of the tests and calculations that was made by using these methods helped to validate the numerical model and gives an idea of the parameters which impact fluid flow and temperature. As it is the temperature which governs all the defects, we will see if the thermal evolution is well reproduced for our applications.

In this paper we describe the models that are used in industrial applications and have provided validation for the thermal and flow front evolution.

Model

FAVOR is an acronym for Fractional-Area-Volume-Obstacle-Representation. It was originally developed for defining obstacles of general shape within a grid composed of rectangular brick elements [2]. The concept is to define for each brick element the fractional areas of each of six faces that are open to flow, together with the open volume of the brick. These fractions are then incorporated into the finite-volume equations of motion. For instance, convective fluxes of mass, momentum and energy between two elements at their common face must contain the open area of this face as a multiplier. If there is no open area, there can be no convective flux. The strength of the FAVOR method is the modeling flexibility it offers [3]. For heat transfer between fluids and solids, the FAVOR method gives high solution accuracy by providing a good approximation of the areas of the fluid/obstacle interface within each brick element.

For an incompressible, viscous fluid, the FAVOR equations take the form:

$$\nabla \cdot (Au) = 0 \qquad (1)$$

$$\frac{\partial u}{\partial t} + \frac{1}{V} \cdot (Au \cdot \nabla)u = -\frac{1}{\rho} \nabla p + \frac{1}{\rho V} (\nabla A) \cdot (\mu \nabla) u + g \qquad (2)$$

$$\frac{\partial H}{\partial t} + \frac{1}{V} \cdot (Au \cdot \nabla) H = \frac{1}{\rho V} (\nabla A) \cdot (\kappa \nabla T) \qquad (3)$$

where

$$Au = (A_x u_x, A_y u_y, A_z u_z)\ ,\ (\nabla A) = (\frac{\partial}{\partial x} A_x, \frac{\partial}{\partial y} A_y, \frac{\partial}{\partial z} A_z) \qquad (4)$$

$$H = \int C(T)\, dT \quad + (1 - f_s) \cdot L \qquad (5)$$

In these equations A_i is the open area fraction associated with the flow in the i^{th} direction, V the open volume fraction, ρ density, p pressure, u_i the i^{th} velocity component, μ the fluid viscosity coefficient, g gravity, H fluid enthalpy, T fluid temperature, f_s solid fraction, L latent heat, and C and κ fluid specific heat ant thermal conductivity coefficient, respectively.
For the mould, the energy equation has the form:

$$\frac{\partial T_m}{\partial t} = \frac{1}{\rho_m C_m V_c} (\nabla A_c) \cdot (\kappa_m \nabla T_m) \qquad (6)$$

where the subscript m indicates a parameter related to the mould and the subscript c indicates quantities that are complements of the volume and area fractions. At the metal/mould interface the heat flux, q, is calculated according to

$$q = h \cdot (T - T_m) \qquad (7)$$

where h is the heat transfer coefficient.

Applications

Die casting for cylinder head is a case of industrial castings vehicle engines by PSA Peugeot Citroen fabricated by gravity casting source (permanent die-casting) or Lost foam casting. We have studied the case of a cylinder head. During the filling and the solidification, thermocouples and sensors were introduced into the mold to obtain the evolution of the temperature and detect the metal. Therefore, some test data were used to compare the results obtained in simulation. Thus we can see whether the software Flow3D® accurately models the actual behavior of the aluminum alloy during the casting of the part.

This section shows the various steps of the gravity casting process: filling and solidification of the part.

Gravity Die Casting

Gravity die casting is a process where the liquid metal is poured into metallic moulds without application of any external pressure, Figure 1 (a) and (b).

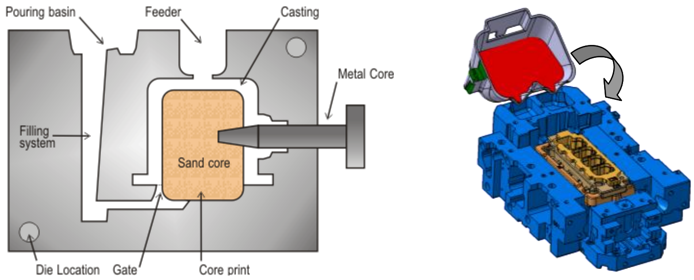

Figure 1. (a) illustrative case, (b) industrial case "cylinder head"

Figures 2 (a) and (b) shows the results of the flow front during filling, and Figure 3 shows the results of the thermal during the filling and solidification.

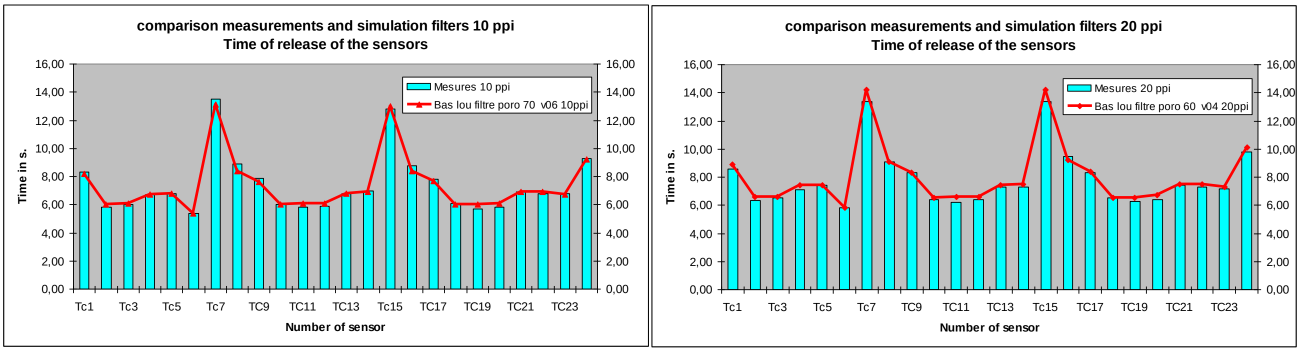

Figure 2 (a). Evolution of front filling, experimental test/simulation for gravity die casting process

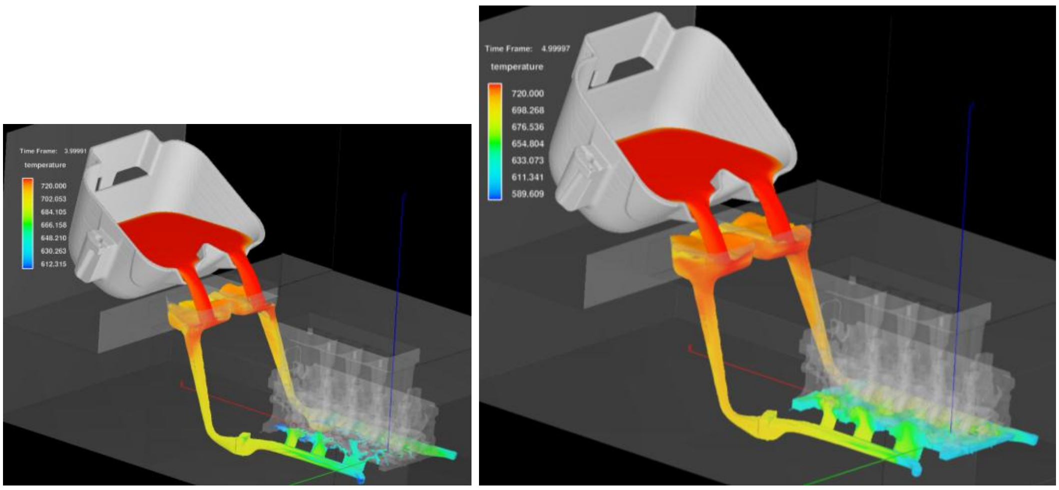

Figure 2 (b). Visualization of filling at time = 4 seconds, and time =5 seconds

In Figure 2 (a), we can say qualitatively that the behavior of the metal is well reproduced by the simulation in all the part. Figure 2 (b) shows the filling of the part at time = 4 seconds and 5 seconds.

In Figure 2 (b), we can see the progress of the flow front during mold filling. We can also see the tilt pouring to model the arrival of aluminum liquid at 720 ° C.

On Figure 3 we can notice the temperature evolution obtained in simulations until 200s. The graphs show the general behavior of the alloy, which is well reproduced by the software Flow3D®, according to the thermocouples 1, 4 and 6. Indeed we can see that the liquidus and eutectic levels are present at the same time in simulations and tests.

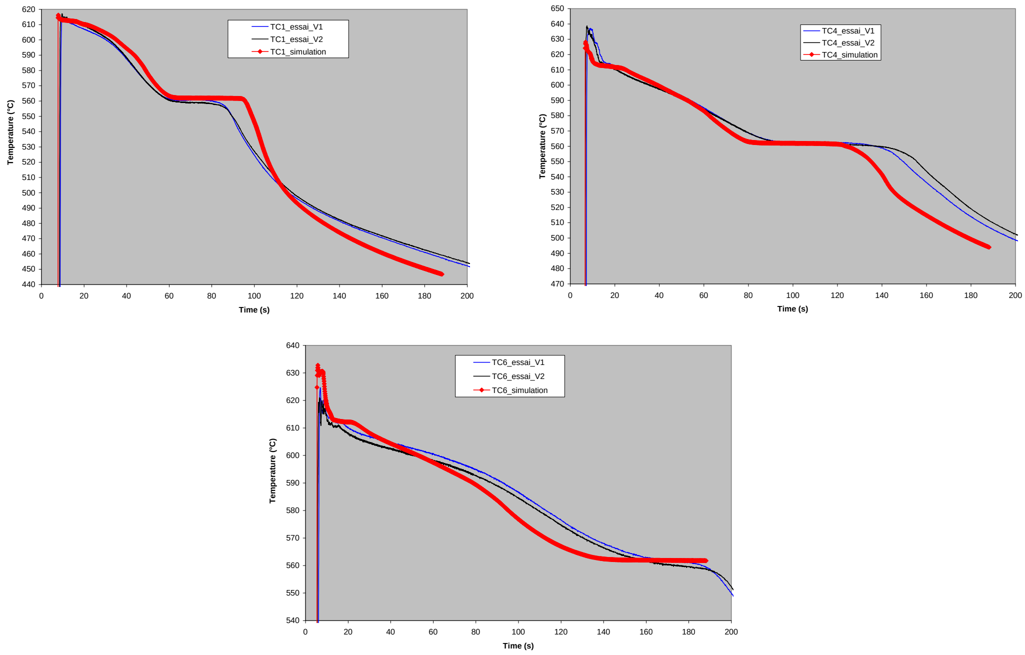

Figure 3. Thermal validation for gravity die casting process

Nevertheless we can see differences of over 20°C between the results obtained in simulations and those obtained during the tests. This can be explained by the fact that the transfer coefficient between the permanent "solid steel" and the aluminum alloy is not exactly known.

Lost Foam Casting

Lost Foam Casting is particularly used for automotive applications. It is a molding technique that produces patterns by blowing polystyrene beads into aluminum mold cavities. Injecting steam into the tooling cavity expands the beads. The beads will flatten against the tool surface and stick to one another. After cooling, the patter is ejected from the tool Figure 4. The multi component patterns with gating systems are assembled with contact adhesive. The assembly is coated, usually by dipping, in a permeable coating, and then air or oven dried. The coating prevents sand collapse during pouring. The coated pattern-gating assembly is set in a flask, and the unbonded sand is added to the flask. In order to compact the sand, the flask will first need to be vibrated during filling. When molten metal is poured into the mold, the pattern vaporizes, allowing the metal to fill the mold cavity.

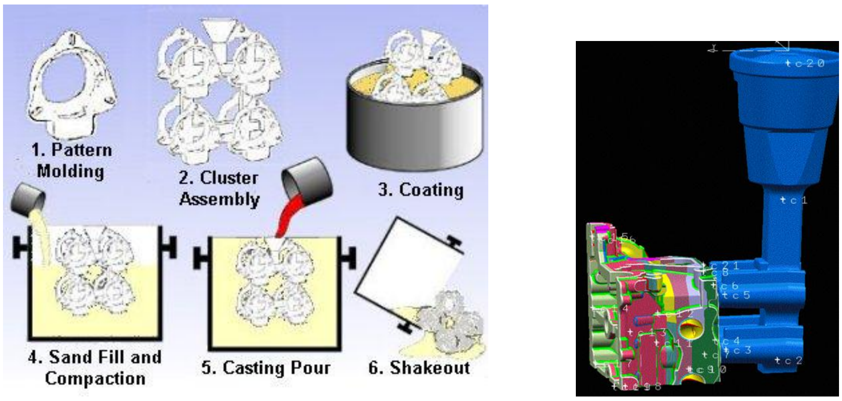

Figure 4. (a) illustrative case, (b) industrial case "cylinder head"

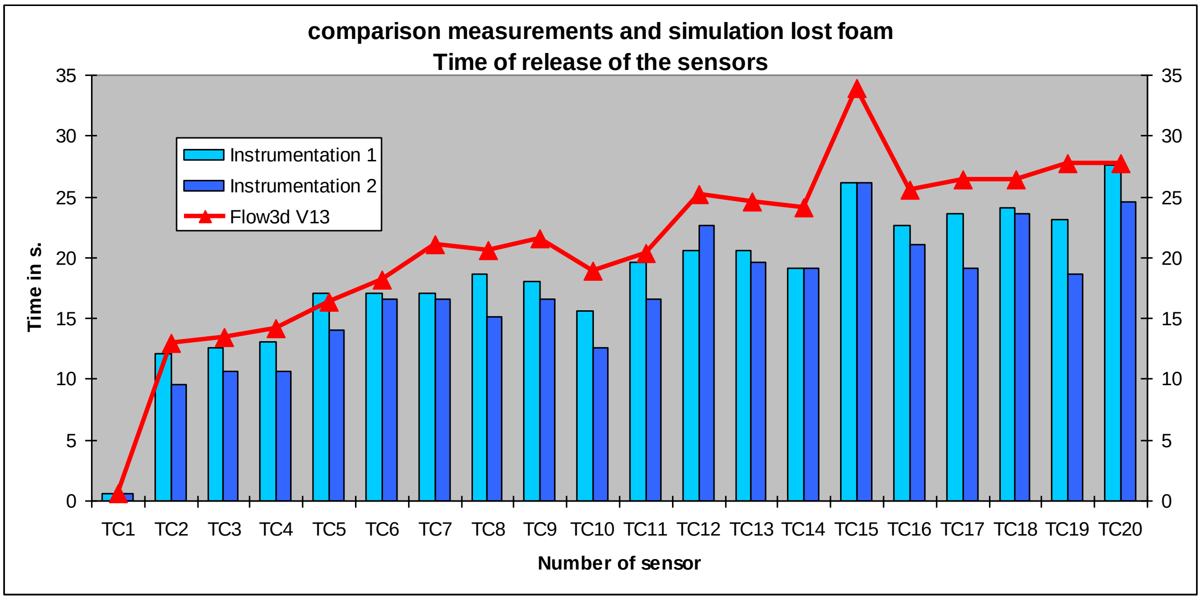

Figure 5 (a). Evolution of front filling, experimental test/simulation for Lost Foam process

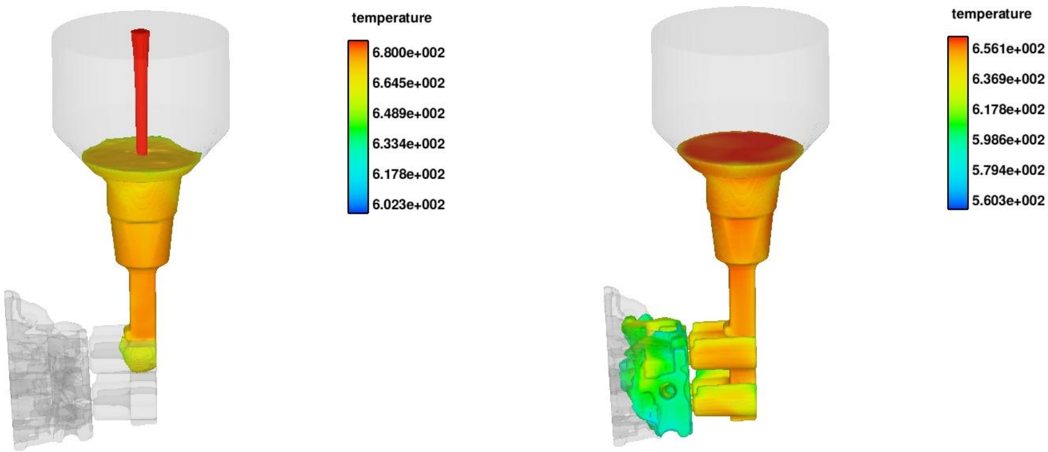

Figure 5 (b). Visualization of filling at time = 5 seconds, and time = 14 seconds

In the Figure 6, the mean differences in temperature testing / calculation at the end of filling is about 5 °C for the 4 thermocouples shown. Sensitivity to material parameters is very important for this process, for example, the conductivity of the sand mold which is of the order of 0.702 W / (mK): if we have a difference of ± 0.1 W / (mK) we have a gap at the end of filling of ± 21 ° C.

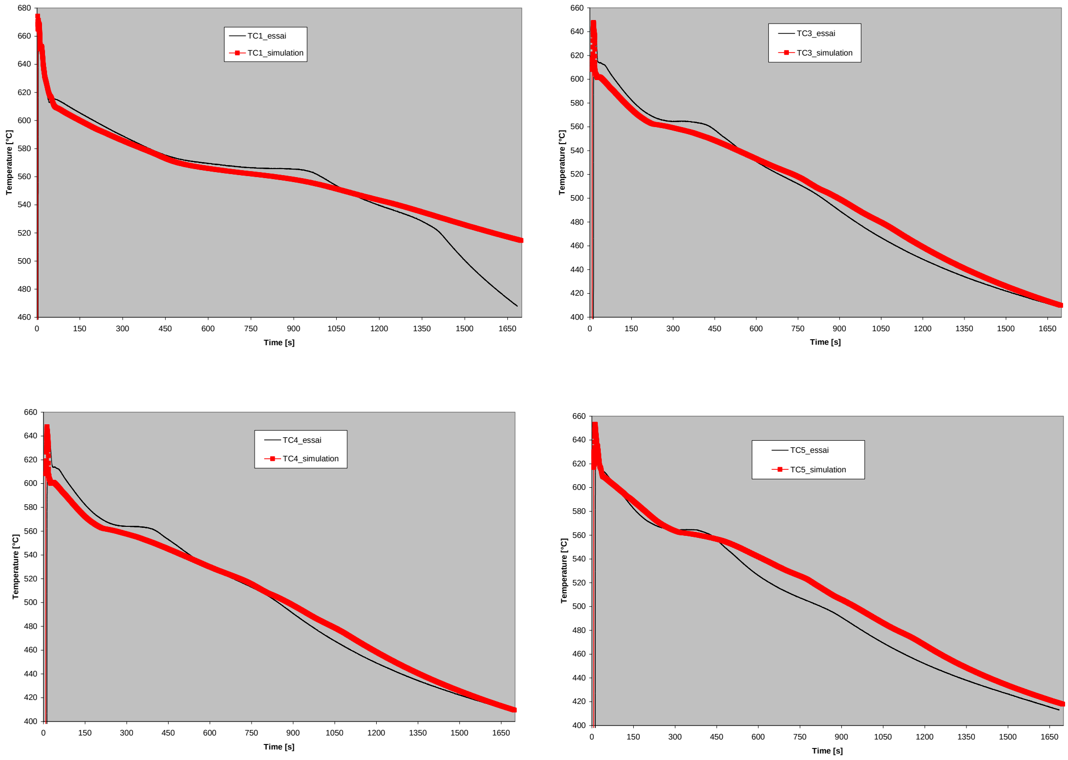

Figure 6. Thermal validation for Lost Foam process

In summary, a difference of ±0.1 on the thermal conductivity which is a characterization tolerance, we have ±21 °C which is a very important temperature difference (risk of misruns, impact on the viscosity, etc.)

For the transfer coefficient between the polystyrene and metal, a variation of the combustion of polystyrene of 10% produce a delay of 10% on total filling time.

The results are correct but very sensitive to material data.

Conclusion

The prediction is very good for filling; solidification is to improve, with consideration of thermal die cycling for gravity die casting.

The metal detectors show a good correlation of the flow front. Levels of gating are well respected. For lost Foam process, we have a delay of about 6% on the flow front evolution. The work must still be done for accurately represent the combustion process of polystyrene

In order to achieve the ambitious goal of ± 5°C gap between test and simulations, on all the thermocouples for the all casting process (from filling to solidification), it is necessary to have precise data for simulations. Indeed, it is required to control and consistently reduce the measurement dispersion on industrial case. (The thermal objective is difficult to reach with the actual resources and processes).

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