Simulating the Lost Foam Casting Process

Adrian Paine, Matthias Gäumann and Marco Gremaud
Calcom SA
www.calcom.ch

Abstract

Throughout the manufacturing industry, process simulation software has been accepted as important tools in product design, process development, improving yield and in solving processing problems.

The lost foam casting process, also known as the evaporative pattern process, involves casting liquid metal into a non-vacant sand mould filled with a combustible polymeric material. The foam disappears as the molten liquid enters the mould, causing the progressive burn-out of the foam pattern. The metal precisely replaces the foam pattern to form an identical geometric copy of the pattern.

Although there has been a rapid increase in the use of the lost foam casting process (LFC) world wide, not too much has been clearly understood about the factors which influence the thermal and flow behaviour of the metal and foam during casting. Along with the large benefits associated with lost foam casting there is also the increased risk of producing defected components due to the strong requirement for precise process control. Thus, in order to get a good understanding of the process, there has been a strong drive from industry to produce mathematical models which are used to accurately simulate the lost foam casting process.

Due to the complexities associated with modelling this process, which involve numerically coupling the heat transfer, the fluid flow, the foam evaporation and the gas transport, makes this certainly one of the most challenging processes to model. Various industrial cases are presented in the paper showing applications of the simulation software *Procast*™ in lost foam casting.

1. Introduction.

The lost foam process involves moulding expanded polystyrene into cast pre-forms using standard aluminium dies. These pre-forms are then glued together to form complex shapes which are then assembled around a gating and runner system. The foam pre-form is then coated with a permeable ceramic coating which helps to prevent inclusions forming as a result of sand erosion during filling. Dry sand is then compacted by vibration around the assembly in simple moulding boxes. The liquid metal is then poured into the mould, causing the foam to progressively burn up as the metal moves to completely replace the pre-form pattern. For each casting produced a new pattern must be made, thus known as the lost foam casting process.

The main benefits of the lost foam process include increased dimensional accuracy, increased production rates, increased geometric complexities, less machining and better process control. Some disadvantages include longer development times for new castings, expensive pre-form tooling and the need for tighter process control. Some of the problems associated with the lost foam process include:

- Merging of liquid metal streams or trapping of foam products can lead to internal casting defects and cold shut;
- The back-pressure created by gas entrapment or inability for the gas to escape from the pyrolytic zone fast enough can result in incomplete pattern fill;
- Excessive temperature drop in the metal due to the retardation of the filling velocity can result in the creation of surface folds and misruns, particularly in thin sections.

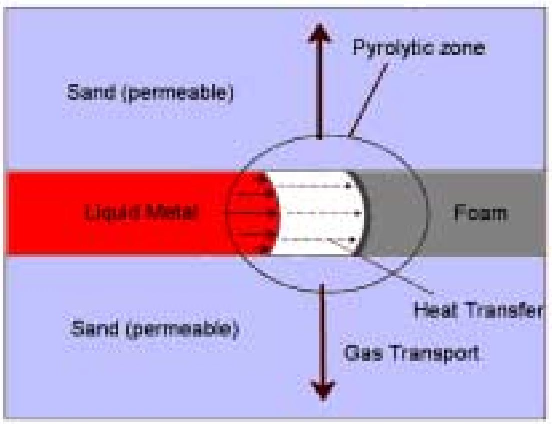


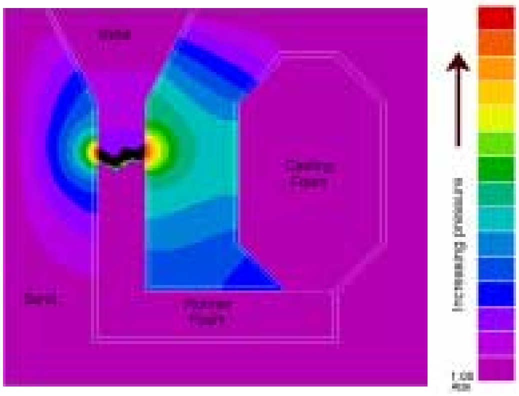
Figure 1: *The figure shows the pyrolytic zone were the metal is advancing and the foam is progressively disappearing through pyrolysis.*

A schematic representation of the pyrolytic zone is shown in **Figure 1**. Pyrolysis occurs in the foam as a result of the energy created during foam ignition, where the gas, given off by the heated foam, causes the break-up of the solid foam.

2. Description of the process model.

Since 1989, a consortium of foundries, suppliers, and academia joined the U.S. Department of Energy to research and improve the understanding of the lost foam process. The project is now entering its fifth phase and will continue for three additional years. It has resulted in significant improvements in lost foam process controls. These developments have been, and continue to be adapted for use in industry. *Procast*™ has been involved in this consortium since its beginning and therefore the software contains a sum of experiences unique in its field.

In order to simulate the process, besides the free surface fluid flow, solidification, and mechanical analysis that it has in common with other casting processes, one must now also consider the heat transfer between the liquid metal and the foam, the liquefaction and pyrolysis of the foam pattern, the transport of liquid foam and gas products, the influence of the ceramic coating, and the effect of the trapped gas on the movement of the liquid metal.



The simulation of a 2D bottom fed aluminium casting, comprising of a pre-form foam region (pouring cup, down sprue, and part) surrounded by a silica sand mould region, is shown in **Figure 2**. The sand material is considered to be porous with a given permeability. The model takes into account the gas transport through the mould and also considers the effect of the pre-form ceramic coating.

Figure 2: *(left) Pressure contours after 1.0 second. The pressure contours, caused by the formation of gas, follow the movement of the pyrolytic zone (Procast™).*

The flow of gas is driven by the pressure gradient in the sand. In **Figures 2 & 3**, contours of pressure show the evolution of gas during casting. The pressure contours follow the movement of the pyrolytic zone. It can be seen that the gas will flow from the pyrolytic zone towards the outside boundaries of the sand. In **Figure 3**, the pyrolytic zone is shown to be at the top of the casting where the gas flowing out from the right end of the mould is substantially higher due to the large pressure gradient across the relatively narrow width of the mould. The build up of pressure in the mould will result in the flow of gas from the mould to the outside surroundings. In **Figure 3**, the increase in pressure in the metal is caused by the increased pressure head as the metal moves up into the casting region.

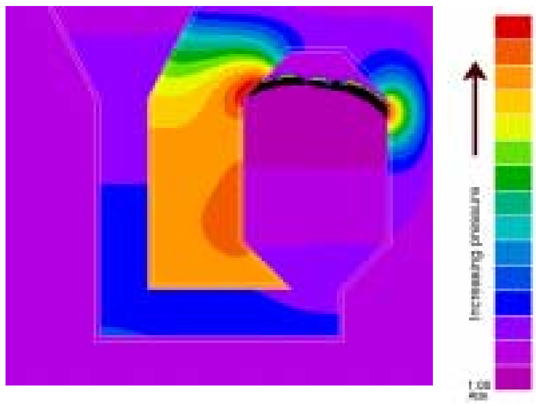


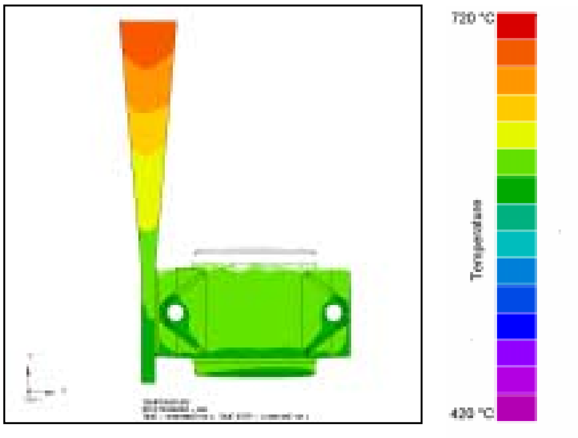
Figure 3: *(right) Pressure contours after 6.9 seconds (Procast™).*

3. Industrial examples of lost foam simulations.

In the casting of an aluminium component, during simulation a comparison was made between a casting without the lost foam pre-form (**Figure 4**), and a casting with the lost foam pre-form (**Figures 5** - **8**). In both cases the gas transport in the mould was taken into account.

The flow behaviour of the metal differs significantly in the two cases. In the first simulation, as shown in Figure 9, we can see that the metal flows directly to the bottom of the mould cavity and then progressively moves to the top. In the second simulation, as shown in **Figures 5 & 7**, we can see that the metal is significantly retarded by the foam burnout causing the metal to flow in a horizontal fashion before completely filling the foam pre-foam. The influence of gravity in the second simulation is less evident due to the influence of the foam burn out. The filling time for the first simulation was 10 seconds while the second simulation was 13.6 seconds.

Figure4: *Contours of temperature during the filling of a mould when simulating a sand casting without the use of a pre-form foam pattern (Procast™).*



In **Figures 6 & 8**, velocity vectors show the transport of gasses in the mould. The highest gas velocities are closest to the edges of the pyrolytic zone, where the zone comes into contact with the mould. The gasses are then transported through the mould until it escapes into the surroundings. This is clearly shown in **Figure 13**, where the vectors are evident on the outside surfaces of the mould.

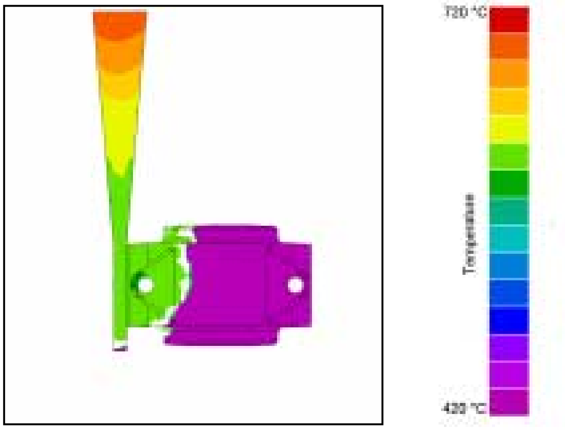


Figure 5: *Temperature contours showing the position of the pyrolytic zone after 10 seconds (Procast™).*

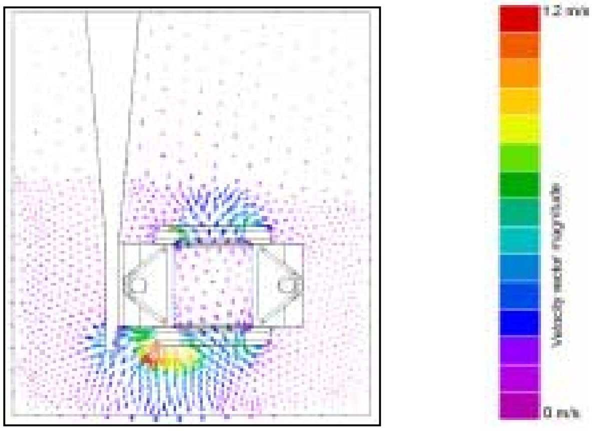


Figure 6: *Velocity vectors showing the gas transport in the mould after 10 seconds (Procast™).*

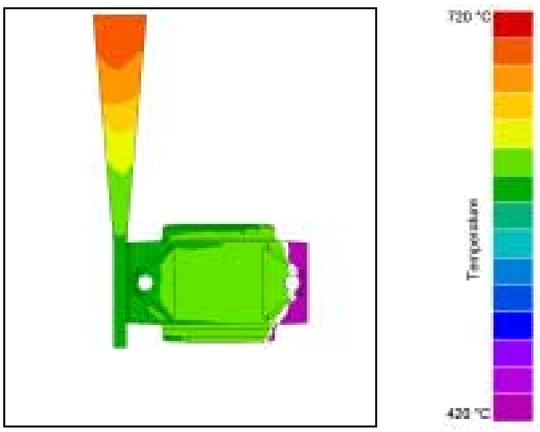


Figure 7: *Temperature contours showing the position of the pyrolytic zone after 12.8 seconds (Procast™).*

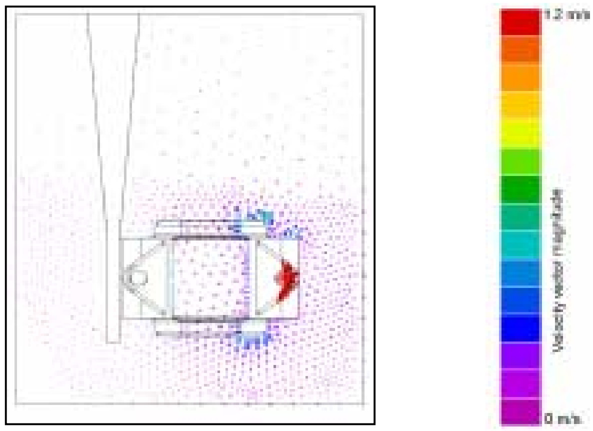


Figure 8: *Velocity vectors showing the gas transport in the mould after 12.8 seconds (Procast™).*

During the casting of a cylinder head component, the effects of an accelerator slot (vacant slot without foam) positioned in the down sprue of a lost foam casting, as shown in **Figure 9**, is demonstrated.

The first simulation without the accelerator slot showed that the metal will enter the casting through the top in-gates, as shown in **Figure 10.** It then moves progressively downwards until the last foam to be burnt is positioned at the bottom of the casting.

The second simulation shows that the accelerator slot helps to control the flow behaviour in the casting so that the metal enters the casting through all the in-gates at the same time, as shown in **Figure 11**. The last foam to be burnt is positioned at the rim of the cylinder head component. This flow condition helps to maintain an optimal gas removal and an ideal temperature gradient in the casting which decreases from the in-gates to the component rim.

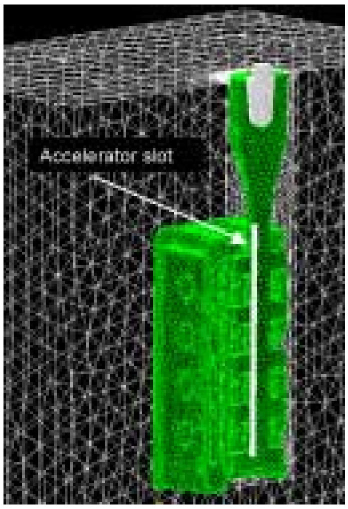


Figure 9: *(right) The Finite Element mesh of an industrial lost foam casting of a cylinder head component. (Procast™).*

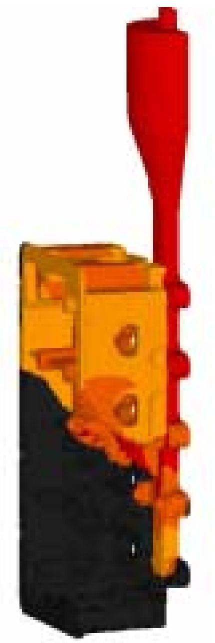


Figure 10: *(left) Casting without the accelerator slot. Filling starts entering the casting through the top in-gates.*

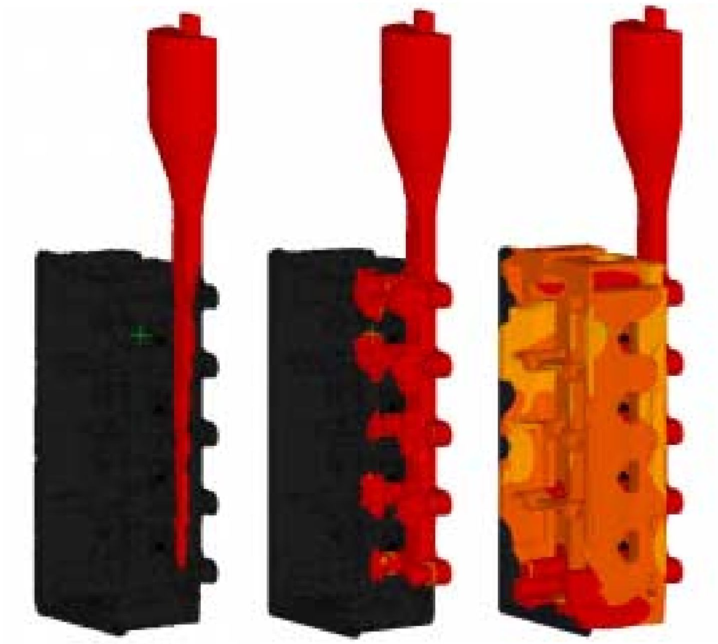


Figure 11: *(right) The three images show temperature contour plots during the progressive filling of the casting. An accelerator slot helps to speed up the flow in the downsprue so that all in-gates fill at the same time (Procast™).*

4. Conclusions.

More and more manufacturing companies are implementing simulation software into their processes and accepting that these technologies are pre-requisites for successful product and process development.

The lost foam casting process has been successfully simulated using process modelling software, taking into account the burn-out of the pre-form foam pattern, the thermal heat transfer across the pyrolytic zone, the influences of the ceramic coating as well as the transport of gasses from the pyrolytic zone through the mould.

By using process simulation software a good understanding of the process can be achieved in order that typical casting defects related these processes can be prevented.