# Modelling the Investment Casting Process

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## Abstract

The capability to produce investment casting components of high quality while at the same time reducing product costs and development times is the challenge the foundry industry faces today. Casting process simulation helps achieve this goal, providing foundries a better process knowledge and control as well as an early confirmation of the component quality and metallurgy. To further reduce development costs, simulation should be applied very early in the process development phase and used as a Concurrent Engineering tool rather than a process verification tool. For this, an appropriate and efficient methodology needs to be developed.

**Keywords :** investment casting, modelling methodology, cost reduction, concurrent engineering, ProCAST.

## Introduction

Nowadays, investment casters need to stay on the cutting edge of new technologies to remain competitive in the marketplace. Computer Aided Modelling has been used by founders for several years, not only for designing new components, but also in the redesign of existing components. In order to make a powerful use of the modelling approach, foundries have to implement a numerical methodology which allows not only engineers, but all people involved in the development or redesign of the part, to use and analyse virtual results at the early stages. That way, the time between the concept stage and the production stage is drastically reduced and cost reductions are possible.

## The Investment Casting Modelling Methodology

Increasingly complex components are being made with the investment casting process with difficult to cast alloys. At the early stage of the development process, the final shape design of the component is not totally defined. It is therefore necessary to put in place a numerical modelling approach that takes into account these parameters. A modelling approach for the investment casting process is proposed on Figure 1. Starting from the component geometry, the casting process is gradually developed and optimised allowing critical process design decisions to be made.

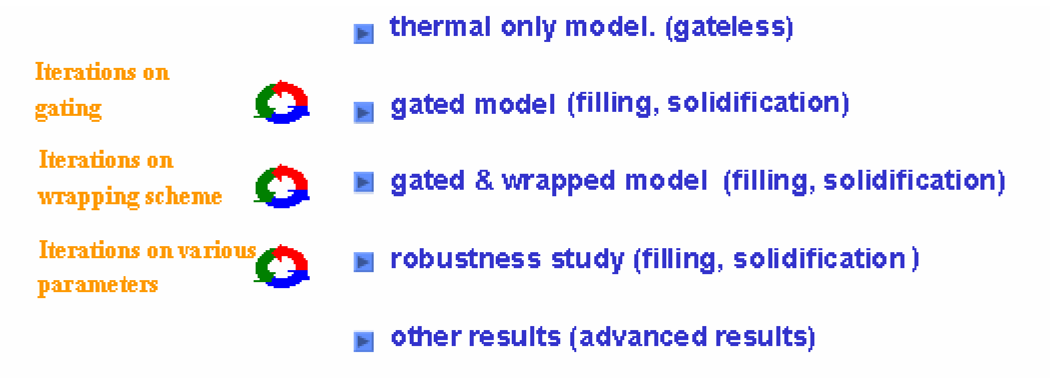


**Fig.1 Investment casting modelling methodology**

Each step of this methodology will be described now and industrial benefits for foundries highlighted.

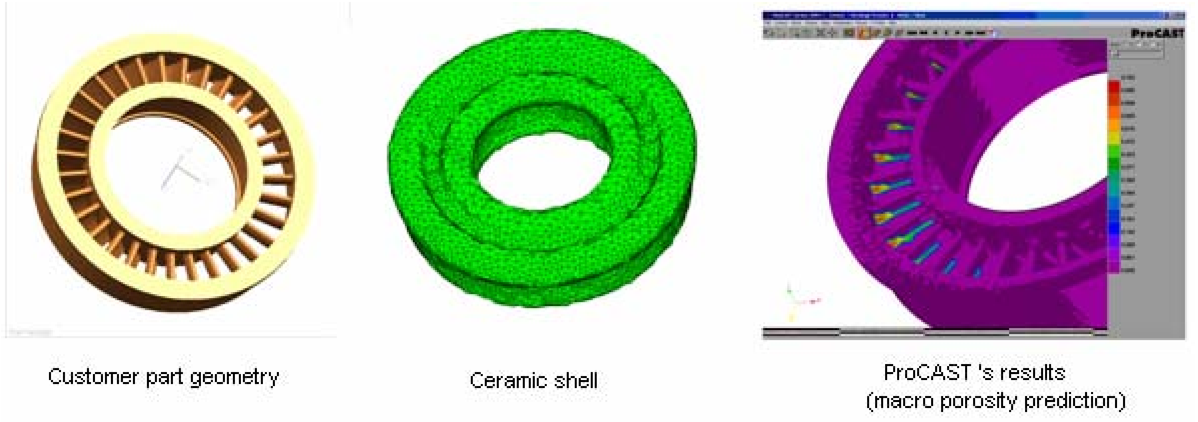
## Step 1: Thermal Only Model

Here, the final casting design is not totally defined as customers require foundries to help verify and optimise their part design. Several issues need to be addressed:

- Is the design castable?
- If not, what geometry changes are necessary?
- What can be optimised to match customer needs and foundry process requirements?

Appropriate answers can be provided by a thermal only model. For this type of model, we only consider the casting design and the ceramic shell around it (Figure 2). Initial casting temperature is defined for the part and a preheat temperature for the ceramic shell. These types of models are very easy to set up and very fast to run. It is therefore possible to run several models with different part designs and then analyze which design is the best to meet the customer objectives in terms of quality and the requirements of the investment casting process itself.

Hot spots in the 'naked' part and macro-porosity levels are computed with the ProCAST software [1]. The locations of macro-porosities provide useful information to help position and dimension the gating system. Important design decisions can therefore be taken at an early stage with a simple thermal only model.



Customer part geometry

Ceramic shell

ProCAST 's results
(macro porosity prediction)

Fig. 2 Thermal only model set up

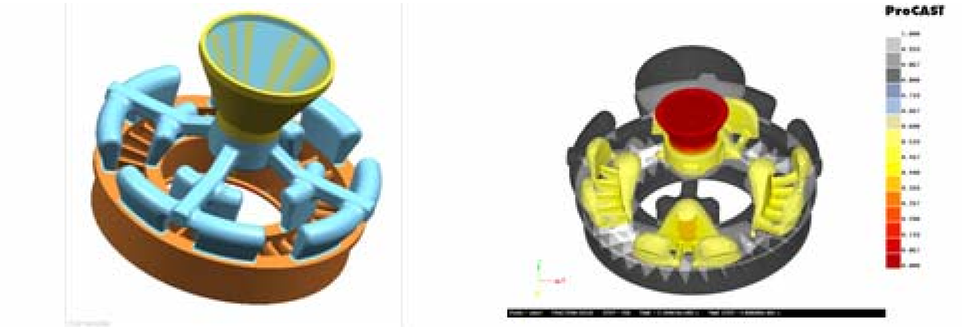
## Step 2: Gated Model

The second step consists in analysing the filling and the solidification of the model with the final part design and several potential gating designs. Several possibilities exist for the gating design and foundry engineers have to select between bottom or top filling solutions and to position the gates. An efficient gating design should provide:

- a smooth and regular metal flow in the cavity to avoid turbulence and air entrapments;
- no hot spots in the component's critical areas;
- a process design that is economically viable.

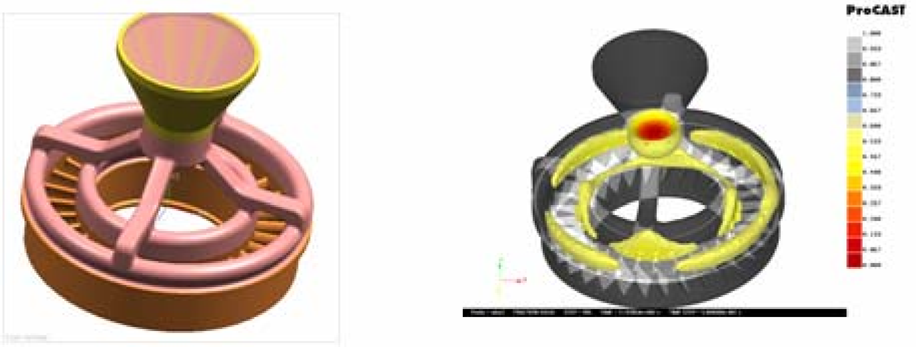
Figure 3 shows 2 possible gating designs for the part geometry set up during step 1. The first design (in blue) has 4 'arms' with a discontinuous feeder on each flange, whereas the second geometry (in orange) has a smaller 360° feeder on each flange. These models can be built, set up and run simultaneously. ProCAST is used here to perform both filling and solidification simulations.

The evolution of liquid metal pockets is used here to select the most favourable gating system. The gating design #1 shows 4 high very hot spots near each arm/feeder junctions. The liquid metal pockets even extend to the critical airfoil areas. The gating design #2 shows 2 hot spots at the interface between the part and the gate. The amount of liquid metal is lower in this case and does not affect the airfoil areas. It can be anticipated that an adequate wrapping scheme should remove these hot spots from the component into the gating and provide a sound casting.



Gating design #1

Solid Fraction analysis



Gating design #2

Solid Fraction analysis

**Fig. 3 Hot spot localisation for different gating designs**

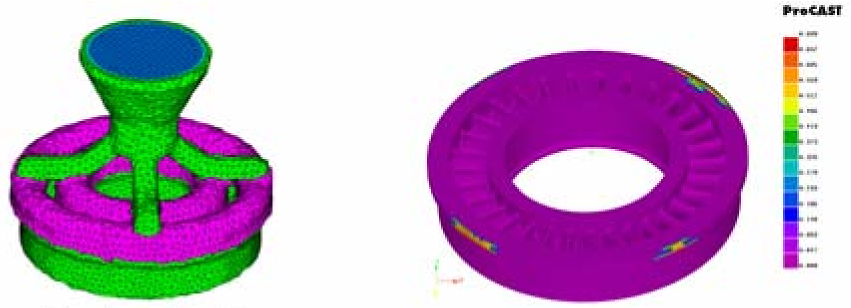
Based on simulation results, the gating design #2 is retained at the end of step 2. Moreover, this design offers the additional advantage of requiring 10% less alloy. Removing the few remaining isolated liquid metal pocket will be the objective of step3.

## Step 3: Gated and Wrapped Model

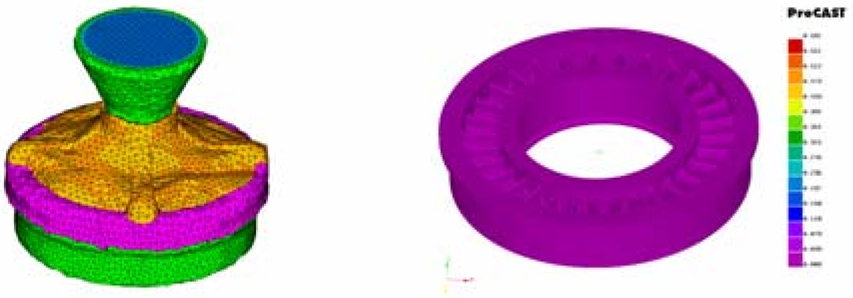
The investment casting process makes use of a disposable mould pattern made of a ceramic shell. The ceramic shell can have one or several layers. Defining the most appropriate wrapping scheme to remove remaining macro-porosities is the objective of step3. In order to achieve this goal, different models with different wrapping schemes are built based on the gating design #2 and set up to run both filling and solidification simulations.

Figure 4 shows the 2 different wrapping schemes selected. The wrapping scheme #1 consists of one layer of shell on each gate for both inner and outer flanges. An additional shell layer is applied around the gating area in the wrapping scheme #2. Computer modelling shows some isolated hot areas near each ‘arm’ for scheme #1. A result confirmed by a macro porosity prediction [2]. The wrapping scheme #2 by increasing the heat capacity of the shell is able to provide porosity free and sound casting.

At this stage of the investigation, a casting process enabling a sound casting to be obtained has been defined and validated. It is therefore possible to proceed to the die tooling manufacturing which can take for several weeks to a few months. This time can be used for more modelling investigation to address process robustness issues and casting metallurgical quality.



Wrapping scheme #1        Macro porosity prediction

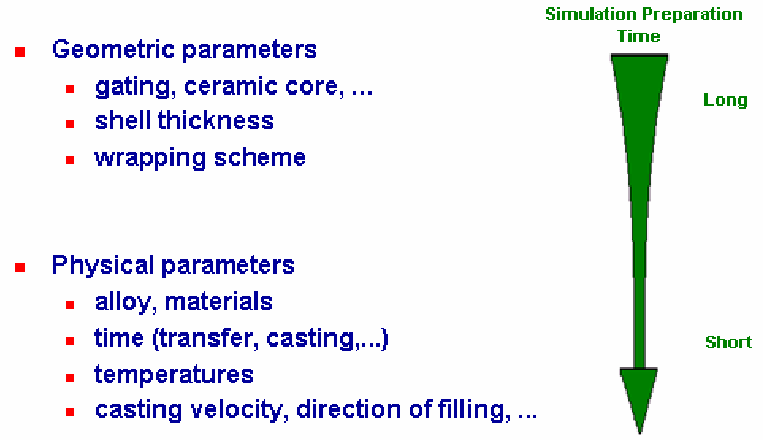


Wrapping scheme #2        Macro porosity prediction

**Fig. 4 Macro-porosity results for different wrapping schemes**

### Step 4: Process Robustness Study

The goal here is to investigate in more details the influence of chosen process parameters and thus, to obtain a more robust process. Clearly, the simulation preparation time for additional modelling work is longer whenever geometrical modifications are necessary (Figure 5). Physical parameters are however easier to change and allow testing a wide variety of process parameters.



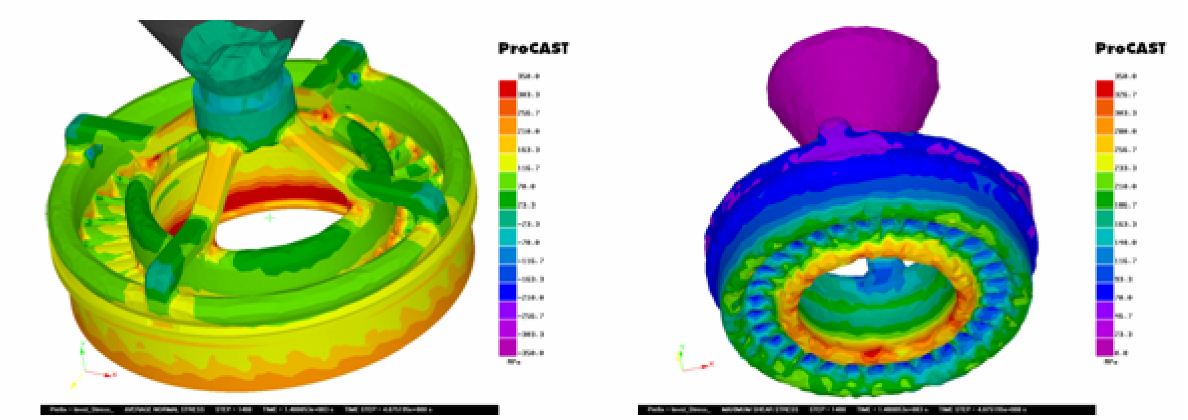
- Geometric parameters
  - gating, ceramic core, ...
  - shell thickness
  - wrapping scheme
- Physical parameters
  - alloy, materials
  - time (transfer, casting,...)
  - temperatures
  - casting velocity, direction of filling, ...

**Fig. 5 Simulation preparation time vs. parameters modification**

Material parameter variations, representative of industrial production conditions, can easily be analysed to verify the stability of the process. Pouring temperatures and shell preheat conditions are also investigated to achieve a fine tuning of the different process parameters.

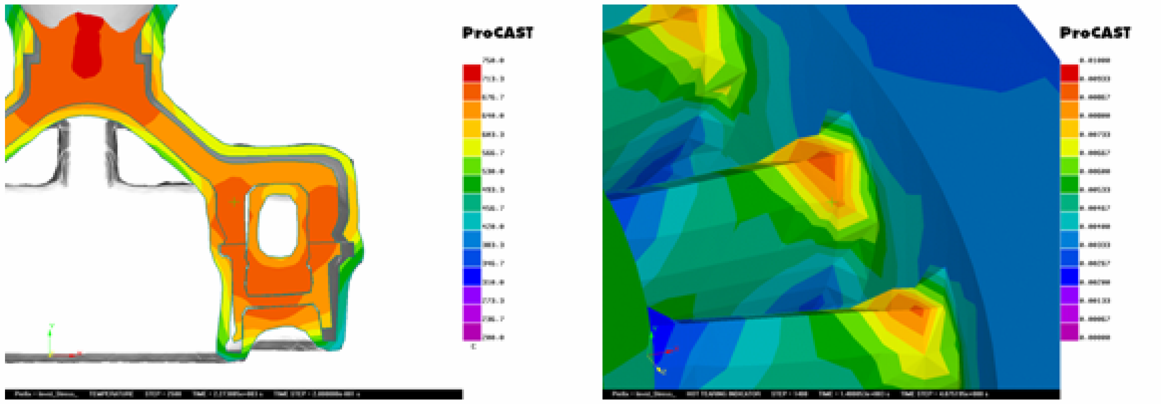
## Step 5: Advanced Investigations

Additional investigations can finally be made also on some specific topics, depending on the process used and/or on the customer requirements. The thermo-mechanical ProCAST solver provides a unique solution based on a fully coupled thermal, flow and stress model. Thermo-mechanical analysis can be used to investigate deformations, hot tearing and residual stresses (Figure 6).



Residual stresses in the casting

Residual stresses in the ceramic shell



Deformations (displacement magnitude : *10)

Hot tearing indicator

Fig. 6 Stress modelling

ProCAST also offers advanced metallurgical options which can be used to model:

- inter-dendritic shrinkage and gas porosities;
- microstructure;
- grain structure evolutions.

For example, the outcomes of a micro and gas porosity calculation are shown in figure 7. The model takes into account the pressure drop in the mushy zone, segregation of gases during solidification and solubility limit of gases as a function of segregation of the alloying elements along with the nucleation and growth of pores.

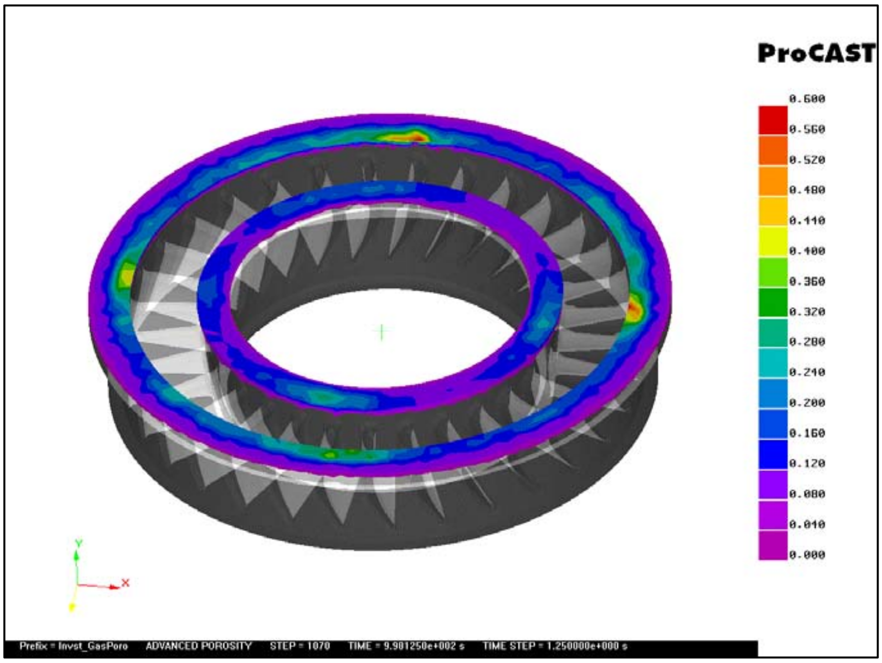


**Fig. 7 Micro and gas porosity modelling**

The results of a grain structure calculation, shown in Figure 8, illustrate with different colours the different grain crystallographic orientations [3]. Depending on the required component's in-service performance, the grain size and orientation may become a key criteria that needs to be investigated.

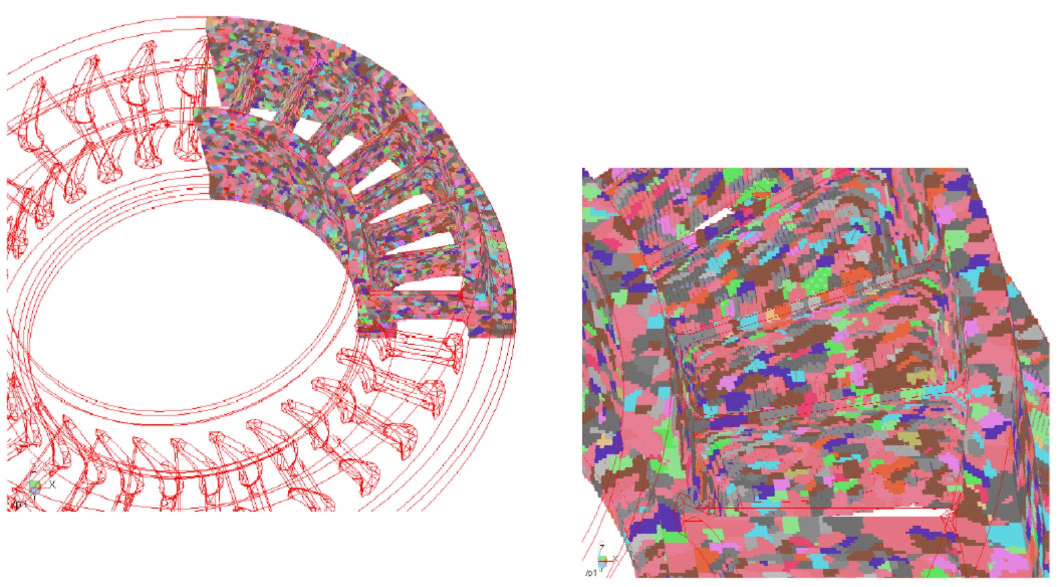


**Fig. 8 Grain structure modelling**

## Conclusions

Shorter development times and cost reductions (scrap costs, re-engineering costs) are required to the investment casting industry. Computer modelling with industrial and advanced solutions like ProCAST is an efficient way to achieve these goals. Simulation can be used at the very early stage of the design conception (concurrent engineering with customers). Modelling the investment casting process step by step with first thermal only models, filling and solidification analysis before taking into account the full process complexity allows foundry engineers to develop a robust process. The process development lead time using virtual manufacturing proves always shorter than a traditional trial and error approach. Making use of state-of-the-art modelling technologies, additional investigations can be conducted to assess the metallurgical quality and performance of the product.

## References

[1] ProCAST User Manual & Technical Reference 1998-2005

[2] Ch. Pequet, M. Gremaud, M. Rappaz, Modeling of Microporosity, Macroporosity and Pipe Shrinkage Formation during the Solidification of Alloys using a Mushy-Zone Refinement Method, Met. Mater. Trans. 33A (2992) 2095-2106.

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