



# Modeling the Solidification of Cast Irons

## Introduction

Successfully modeling solidification of Cast Iron is of great help for the foundries to reduce their production costs and thus to increase their profits. If the basic physical solidification phenomena are correctly modeled by the simulation tools mold risering can really be optimized.

Recent developments done in ESI Casting Solutions allow to significantly improve the defects prediction in cast iron casting.

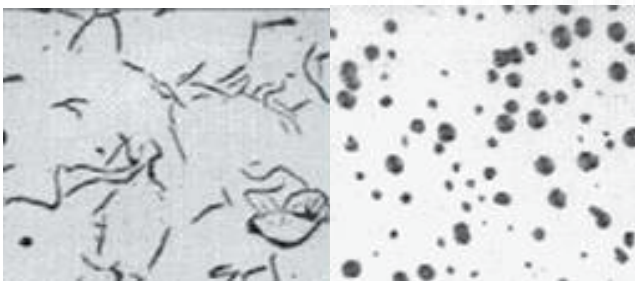
## Metallurgy of Cast Iron

Cast iron is a generic term for a high carbon (more than 2%), high silicon, Fe-based alloy.

Cast iron is unique in that carbon is added in excess of its solubility in iron at room temperature. During solidification, as the molten metal cools and the solubility limit of the carbon in the iron decreases, excess carbon precipitate usually under the form of graphite lamella.

Graphite lamella can be present in cast iron alloys under different shapes. All these different forms can be achieved from the same melt by small adjustments of the chemical composition or by changing the cooling rate.

Spheroidal Graphite cast Iron (or also called ductile or nodular cast iron) is a specific cast iron material in which the graphite is present as nodules (**Figure 1, right**). Because of additional elements, i.e. magnesium or cerium, introduced in the molten iron before casting, the graphite nucleates as spheres (nodules), rather than as lamella of any of the forms characteristic of grey iron. The formation of these graphite nodules leads to a volume expansion during the solidification that needs to be correctly modeled in casting simulation for a good matching with real production parts.



**Figure 1:** Magnified graphite structures in cast iron. In grey iron, the graphite appears as flakes (left), while in ductile iron (right) the graphite appears as nodules.

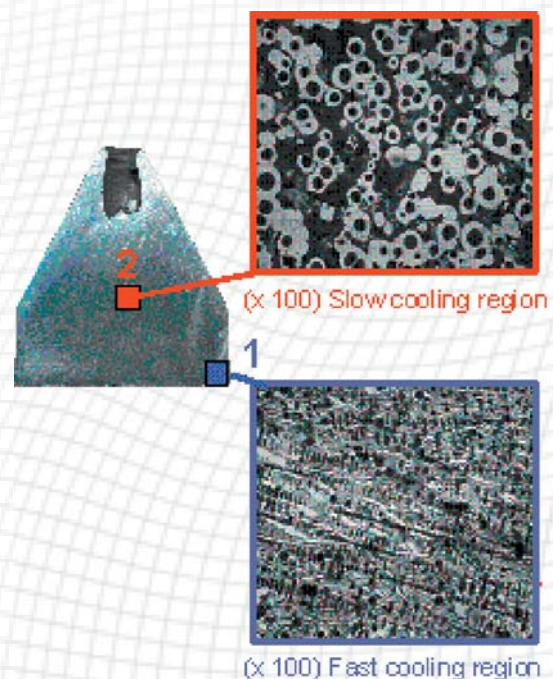
## Cast Iron Microstructure Modeling

Microstructure formation during the solidification of alloys is a very important factor for the control of the properties and the quality of casting products. There are different types of microstructures for different alloys. The types of phases present, the volume fraction of the phases, the grain size, and grain shape determine the properties, which in turn govern the appropriate application of the alloy.

To obtain microstructure predictions, ProCAST couples thermodynamic calculations (from CompuTherm® LLC databases) with microstructure models and the macro-scale thermal and fluid flow calculations. Depending upon the chemical composition, the microstructure module automatically detects the phases which will appear and the type of microstructure which should be computed (dendritic, eutectic, nodular ...).

For instance, if nodular cast iron is defined, automatically, the nodule counts, the austenite radius, the pearlite and ferrite fractions will be computed, together with the corresponding mechanical properties (such as elongation, hardness, yield and tensile strength). The software will also automatically detect that if there is no magnesium in the cast iron, the structure will be lamellar rather than nodular.

The eutectic transformation process in ductile iron is a divorced growth of austenite and graphite, which do not grow concomitantly. Because of the density variation resulting from this phenomenon, the expansion/contraction of the grain is taken into account by allowing the final grain size to vary. Therefore, during ductile solidification, the densities of the different phases are computed according to the composition of the phase at that particular temperature (**Figure 2**). In the calculation, the graphite expansion is also included.



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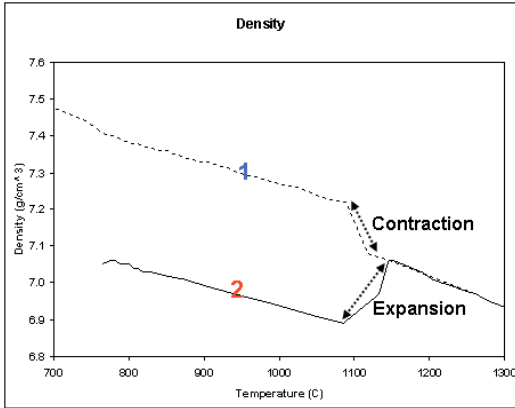


Figure 2: Example of microstructure and its corresponding local density in cast iron observed in a simple test.

In the region 1, because of the high cooling at the corner of the casting, the microstructure is mainly constituted of metastable phase (Ledeburite). In this region, a local density with no expansion is taken into account. In the region 2, where the cooling is slower, a local material expansion needs to be taken into account due to the nodules formation generated in that volume area.

### Coupling Microstructure Models with Porosity Model

Finally, the successful approach to model and simulate the cast iron industrial components consists in fully coupling the microstructure and the porosity model. Indeed, predicting the behaviour of the metal during solidification is not trivial as one needs to consider the different modes of shrinkage as well as trace the evolution of the liquid metal free surface. The amount of shrinkage for cast iron will depend on the following factors:

- Thermal cooling conditions
- Filling behaviour
- Pouring temperature
- Casting material properties
- Inoculation
- Amount of graphite expansion occurring during solidification
- Mold/Core material properties
- Mold/Core dilatation which will influence the pressure in the liquid

One can see that the process is complex and demonstrating that same parameters as in the actual production must be applied in simulation for accurate modeling of physical phenomenon. As explained above, during casting, nodular cast iron does not simply contracts when it cools and solidifies but it expands due to graphite expansion. If the outer surface of the casting is preventing from expanding, then an increasing pressure inside the casting can help to compensate the formation of micro and macro shrinkage porosity. This physical phenomena is not trivial to understand and subsequently not straightforward to model. Indeed, it is required to consider microstructure, process conditions, material properties and mechanical properties of the mould to accurately predict porosity in cast iron. Today, by coupling thermodynamic database with micro and macro model, it is possible to predict porosity by taking into account alloy expansion (see Figures 3 & 4).

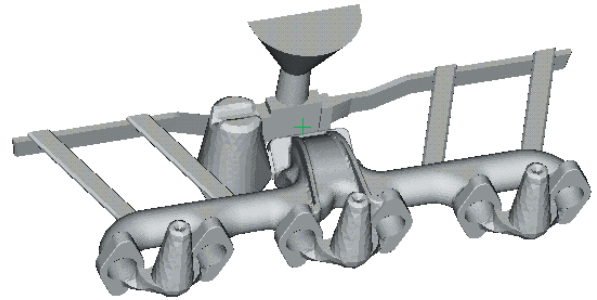
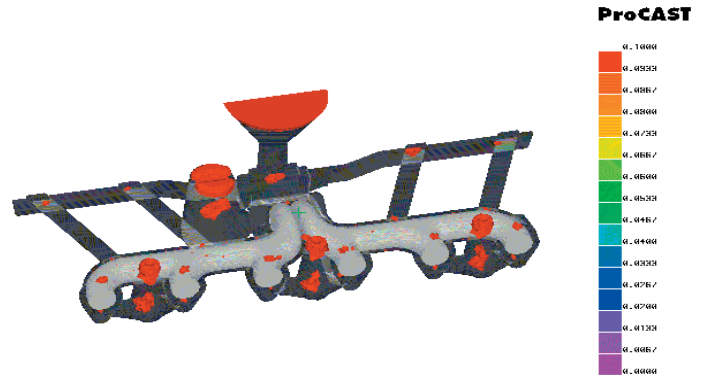
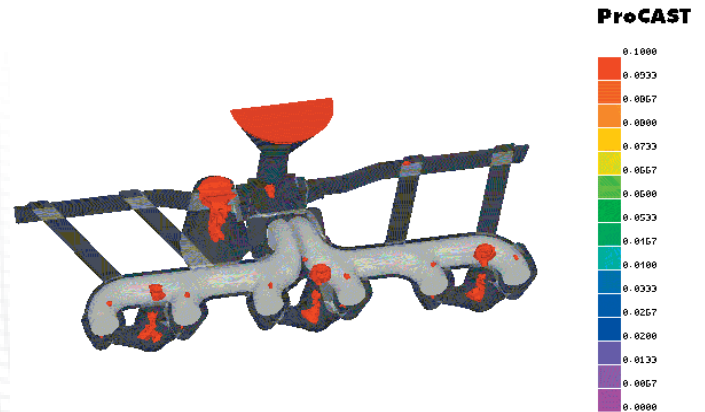


Figure 3: Geometry of nodular cast iron manifold indicating the risers and down sprue. (Courtesy of Fonderia Casati SpA, Italy).



(a) when not considering the graphite expansion.



(b) when considering the graphite expansion with a low level of inoculation.



(c) when considering the graphite expansion with a high level of inoculation.

Figure 4 : Numerical X-ray plot of macro-shrinkage porosity (cut-off level of 10%). These shrink locations are in the form of dispersed shrink pockets (i.e.sponge).