

Metallurgical quality based predictive simulation for the ductile iron foundry: IMPROVING PROCESS CONTROL AND CASTING YIELD

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AZTERLAN Metallurgy Research Centre (www.azterlan.es) has presented, in this series of three articles, the fundamental principles of thermal analysis as a process control tool for iron foundries.

The first two articles explained the operating principles of the technique and illustrated how thermal analysis can be used to improve process stability in demanding production environments.

This third and final article goes one step further, demonstrating how metallurgical information obtained in real time can be integrated into predictive filling and feeding simulation to improve process control, optimise feeding system design and increase casting yield.

INTRODUCTION

Like many manufacturing sectors, the foundry industry is under increasing pressure to reduce production costs without compromising product quality. In practice, this means looking beyond the optimisation of raw material costs and focusing on efficient process design, particularly the optimisation of gating and feeding systems, which directly determine both the internal soundness of castings and overall casting yield.

Simulation has become an indispensable tool for supporting these design decisions. Nevertheless, most commercially available simulation software is based primarily on modelling molten metal flow and heat transfer during solidification. These models successfully predict filling behaviour, thermal gradients and hot spots, but they do not always explain why a casting proves either sound or defective when the metallurgy of the iron changes.

This limitation is particularly significant in ductile iron casting. During the solidification of Fe-C-Si alloys, the formation of austenite is accompanied by volumetric contraction, whereas graphite precipitation simultaneously produces volumetric expansion. The balance between these two competing phenomena largely determines whether shrinkage porosity develops.

From an industrial perspective, this has an important implication: not every region of a casting requires the same amount of feeding, and not every melt possesses the same intrinsic self feeding capability, even when the thermal design remains unchanged.

Consequently, achieving a more efficient and robust process design requires simulation tools that incorporate thermal information and quantitative indicators describing the actual metallurgical quality of the molten metal.

VOLUMETRIC COMPENSATION AS THE KEY TO PROCESS CONTROL

The volumetric behaviour of ductile iron during solidification is governed by two concurrent phenomena:

- Volumetric contraction associated with austenite formation.
- Volumetric expansion resulting from graphite precipitation.

The extent and kinetics of graphitisation depend on several factors, including chemical composition (particularly carbon and silicon content), inoculation practice, undercooling, and the

nucleation and growth kinetics of graphite. When these conditions are favourable, graphite expansion can partially or even completely compensate for austenite contraction, thereby significantly reducing the need for external feeding.

From a process design perspective, this means that the internal soundness of a casting depends not only on its geometry or thermal history, but also on the metallurgical ability of the alloy to self feed during the eutectic reaction.

Being able to quantify this self feeding capability opens the way to:

- Reducing or eliminating oversized risers.
- Designing higher yield casting layouts.
- Making design decisions with a substantially lower degree of uncertainty.

FROM METALLURGY TO PREDICTIVE SIMULATION

For this approach to be applicable in an industrial environment, metallurgical information must be translated into variables that can be incorporated into predictive simulation models. This is achieved through the detailed analysis of solidification cooling curves recorded under actual production conditions.

Advanced processing of these cooling curves using digital thermal analysis systems such as Thermolan® enables the identification of key metallurgical parameters, including eutectic nucleation intensity, graphite precipitation kinetics, phase fractions, and the net volumetric change occurring during solidification.

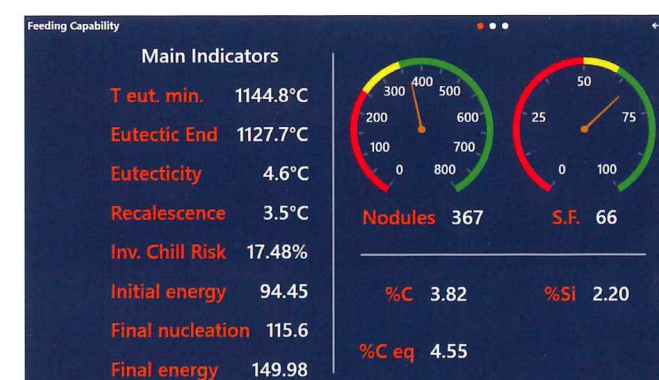


Fig.1 Advanced metallurgical parameters provided by the Thermolan® thermal analysis system

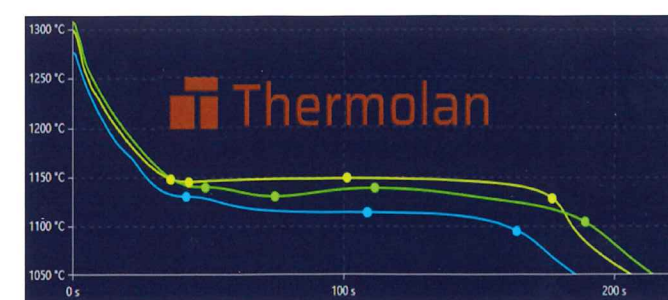


Fig.2 Cooling curve obtained using the Thermolan® thermal analysis system

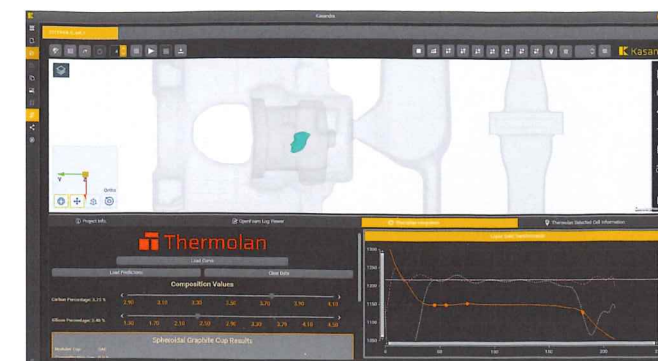


Fig.3 Integration of metallurgical parameters into casting soundness prediction using the Kasandra® predictive simulation system

This data is then used to calculate an overall metallurgical self feeding index, which quantitatively expresses the ability of the alloy to compensate for solidification shrinkage without the need for external feeding.

Originally developed within the Thermolan® metallurgical modelling framework and subsequently incorporated into predictive simulation tools such as Kasandra®, both developed by AZTERLAN, this methodology shifts the focus from a conservative, safety factor based design philosophy towards process design based on the actual behaviour of the molten metal.

OPTIMISING THE FEEDING SYSTEM

In industrial practice, combining thermal and metallurgical criteria enables a more accurate assessment of the actual risk of shrinkage in every region of a casting.

The procedure typically begins with a conventional thermal simulation to identify hot spots and regions of delayed solidification. These critical areas are then re-evaluated by incorporating the self feeding capability of the alloy, calculated from representative metallurgical conditions corresponding to the actual production process.

Assessing different process scenarios (including normal, optimum and unfavourable operating conditions) allows prediction of the average casting behaviour and provides valuable insight into the robustness of the process against the inevitable variations encountered in production.

From a business perspective, this methodology offers two major advantages:

1. Higher casting yield, achieved by rationally reducing riser volumes and eliminating unnecessary overfeeding.
2. Lower risk during the quotation stage, by providing a quantitative basis for deciding whether a riser is genuinely required.

Industrial applications have demonstrated casting yields of sixty to seventy per cent, together with substantial reductions in metal consumption and overall manufacturing costs.

ADVANCED METALLURGICAL CONTROL IN PRODUCTION

Beyond the design stage, continuous assessment of metallurgical quality on the production line completes the process control loop.

Real-time analysis of the solidification cooling curve for every melt provides a direct measurement of the effective metallurgical condition of the iron, complementing conventional chemical analysis. This makes it possible to detect, at an early stage, deviations caused by:

- Variations in carbon or silicon content.
- Insufficient inoculation.
- Transient process fluctuations.
- Magnesium fade.

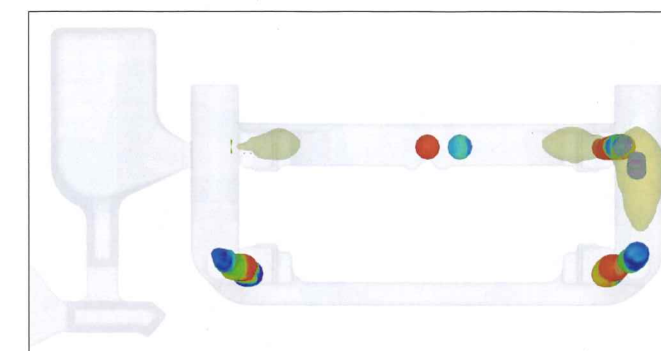


Fig.4 Thermal analysis of solidification showing isolated volumes and hot spots. Simulation performed using the Kasandra® system

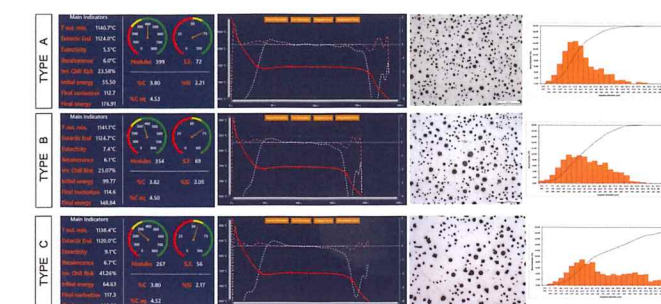


Fig.5 Characterisation of three representative process conditions

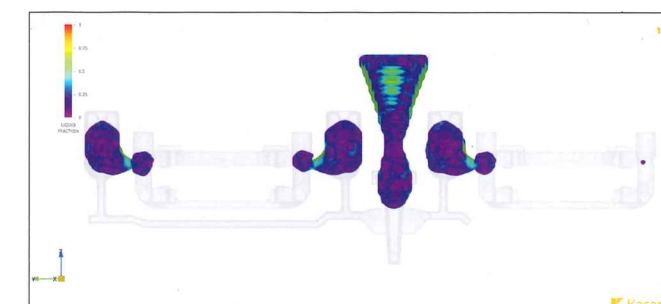


Fig.6 Solidification of a ductile iron brake yoke with one and two risers. Simulation performed using the Kasandra® predictive simulation system



Fig.7 Real-time prediction of internal casting soundness. Simulation performed using the Kasandra® predictive simulation system

This predictive capability enables foundries to take corrective action before internal defects develop, thereby reducing scrap, rework and the costs associated with process instability.

The Kasandra Lite® platform complements the metallurgical characterisation provided by the Thermolan® system and is responsible for predicting the behaviour of the metal within the casting. It establishes a direct correlation between the metallurgical quality achieved at the pouring stage and the expected final properties of the cast component.

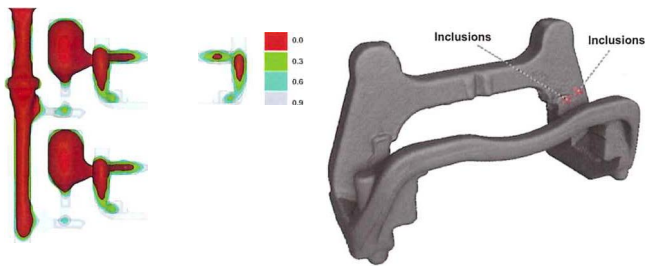


Fig.8 Manufacturing layout and resulting internal soundness of the casting

CASE STUDY: HIGH YIELD CASTING LAYOUTS AND CHALLENGING FEEDING CONDITIONS

A representative example of this approach was developed at AZTERLAN's Advanced Manufacturing Technologies Unit, which includes a pilot foundry, where a ductile iron brake yoke was produced using a feeding system consisting of a single small riser.

The combined thermal metallurgical analysis demonstrated that several critical regions of the casting possessed sufficient self feeding capability to compensate for austenite contraction during solidification. As a result, the two-riser feeding system originally specified in the design could be replaced by a single riser without compromising casting soundness.

The castings were subsequently validated by x-ray computed tomography (CT) and metallographic examination, confirming excellent agreement between the simulation predictions and the actual behaviour of the material.

These results demonstrate that, when the metallurgical quality of the molten iron is properly characterised and controlled, components traditionally regarded as requiring extensive feeding can be manufactured robustly using considerably simpler feeding systems.

Further results will be presented at the upcoming World Foundry Congress in the paper 'Use of thermal analysis for porosity prediction in spheroidal graphite iron', by R Suarez, D M Stefanescu, E Martínez, G Alonso and G Zarrabeitia (AZTERLAN, Spain; The Ohio State University and The University of Alabama, USA).

CONCLUSIONS

The integration of metallurgical quality into predictive simulation represents a significant step towards improved process control in ductile iron foundries. By quantifying the alloy's self feeding capacity through thermal characterisation of the melt, reliance on oversized feeding system designs is reduced, enabling more efficient, robust and cost effective feeding layouts.

- This approach enables foundries to:
- Manufacture castings with greater confidence and process reliability.
 - Increase casting yield.
 - Reduce the overall manufacturing cost per component.
 - Make engineering decisions based on quantitative scientific criteria rather than empirical assumptions.

Ultimately, the significance of this methodology extends beyond the specific software tools employed. The real innovation lies in a new design philosophy in which metallurgy is no longer treated as an implicit background variable but instead becomes a central element of predictive simulation and industrial process control.