Integrated Melt Shop Process Control

Introduction

The continuous increase in the quality demand from final customers and the continuous need for reduction of production costs have further increased the importance of an effective control system for the production process in cast iron foundries. The large variety of materials that are coming from outside and the complex nature of the phenomena involved in melting charge materials, in treatments out of furnace and pouring in the moulds always generate a certain degree of variability, which can change by melt and ladle to ladle. Each foundry is characterised by its kind of furnaces and its plant layout, its internal specifications and procedures. Virtually all the production processes of foundries can be divided in three main stages:

• Base iron preparation
• Treatments out of furnace
• Pouring in mould

The variability of final iron is a result of the sum of the variability of the iron in each stage, but the cost of managing this variability increases the later in the process it occurs. It is therefore clear that any optimisation on the control process strategy can immediately turn into a cost saving, which in many cases can allow an almost immediate payback of investment.

Standard Approach to the Control Process

The foundries standard approach to the control process is mainly based on the chemical analysis coming from the spectrometer and sometimes other simple control procedures, like a chill sample to control the tendency to form carbides.

Concerning the chemical composition, the foundries usually define an acceptable range for each chemical element that is considered important for the production, generating one or many tables with ranges. The control procedure is therefore composed of the following steps:

• Chemical analysis of base iron and comparison of results with the ranges table;
• If one or more elements are out of range, a corrective action is executed;
• In case of corrective action, new check with the spectrometer;
• Start tapping from furnace to the ladle and pouring into the moulds.

Although this procedure would seem to be effective, it often hides some problems and has several disadvantages. This approach relies on the wrong assumption that a certain chemical composition always corresponds to the same behaviour of melted iron. In the solidification process many physical and thermodynamic factors are involved and their influence is not irrelevant. As a result even with the same chemical composition it is possible to get different results in terms of solidification (eutectic, slightly hypoeutectic or slightly hypereutectic) and the probability to form metallurgical defects (cementite, porosity, shrinkage, etc.).

In addition, the precision of spectrometer for some elements is not good enough (for example, the determination of Carbon amount), but foundries usually decide to take corrective actions and calculate the amount of materials based only on these values. Some foundries define very close ranges of acceptability for Carbon and Silicon content on the base and final iron (range width less than 2% of target value), that are often comparable with the uncertainty of the instruments (the minimum unavoidable error of spectrometer on Carbon estimation is not lower than 3% and it can reach 7%)[1].

Moreover, the foundry procedures usually do not take into account the holding phase, since the iron in the melting or holding furnaces changes overtime, not only from a chemical point of view (decarburisation and oxidation phenomena) but also for a solidification point of view (loss of nucleation potential). These changes can be easily verified by pouring a series of chill samples at different intervals of time during the holding phase: one of the effects of the nucleation potential decrease is the increasing of carbide formation tendency, clearly observable by measuring the thickness of the transition zone between white and grey iron. The most important peculiarity of all these phenomena is probably the unpredictability of their intensity: melt by melt. The decarburization can be more or less enhanced; for the same holding time the decreasing of nucleation potential can be high or negligible. Although foundries seek to manage these variations, the procedures defined are usually static: they do not periodically repeat the measurements and they do not calibrate the action in function of the actual values.

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A New Dynamic Approach to Process Control

Based on the expertise accrued in foundries over numerous years and on the study of control procedures and production processes of its customers, ProService has developed a new concept of process control, aimed at solving the problems and limits of the controls currently used by the majority of the foundries.

The procedures define fixed times and quantities, like for example:

- 60 minutes after the tapping starts, always add 0.5 kg of graphite in each ladle (independently if the current iron status requires this addition or not);
- every 30 minutes, pour a chill sample with the iron of the holding furnace and, when the transition thickness exceeds 4 mm, add 0.2% of preconditioner in the furnace (independently if this amount is correct, greater or less than the required).

Finally, the executions of the measurements, of the analysis and of the process operations are managed manually. This can result in some errors or problems, especially when the production process requires high output rates.

The need to work quickly leads the operators to often make mistakes on the results report or to skip the execution of an analysis (the most typical case is the temperature measurement, the results of which are sometimes written in any case, inventing it, to avoid incurring violations of procedures). Concerning the additions in the furnaces and in the ladle, misunderstandings between the analyst and the operator and imprecise dosing can result in an increasing of variability instead of a decreasing. One of the most used systems to add graphite, ferrosilicon or other similar materials is to take them with a bailer and “launch” them into the ladle. It is very common in these foundries to see that sometimes all the material falls into the ladle, and sometimes a part of this material falls outside the ladle.

The results of this static control approach are therefore:

- sometimes the foundryman performs a correction that is not required, due to a wrong evaluation;
- sometimes a correction is executed by adding the wrong quantity of materials;
- sometimes an anomaly is not detected and consequently it is not corrected.

The result is an increase of production costs, related to the unnecessary use of ferroalloys and potentially to scrap castings. It can also increase costs in the quality department since the presence of variability requires an increase in the number of checks on the batches produced in order to identify and separate the non-conforming castings.

This new approach is based on four key points:

- the properties of liquid iron change over time;
- all measurement results have to be automatically input and stored, discouraging or preventing any manual input;
- each specific anomaly requires focused and reasoned action, defined on the basis of a global evaluation of all the parameters involved, usually coming from different instruments;
- all the additions of material in each phase of the process have to be executed automatically by machines.

For simplicity, the foundry process here is divided into two stages only: preparation of the base iron and treatments in ladle. Each stage will be treated separately on this paper.

Base Iron Preparation

In regard to the base iron preparation, ProService developed a specific thermal analysis software, ITACA MeltDeck™, which allows in-depth analysis of base iron, integrating the information coming from the spectrometer and from the temperature probes, in order to consider these variables. It is equipped with an interface, which allows the foundry to define a list of parameters to be controlled, the target value for each parameter and the validity time. The last point is very important, due to the various phenomena of degeneration of the iron that can change from foundry to foundry. A specific furnace can prevent decarburization, but the iron can suffer a high loss rate of nucleation potential. In this case, a periodic check of this property, also after the completion of furnace preparation, is mandatory in order to always obtain a stable base iron.

The procedure module shows in an easy and intuitive way the status of the furnaces, driving the operators to execute the required analysis at the right time, highlighting the anomalies and allowing an automatic storage of measurements.

ITACA MeltDeck™ is also equipped with a module aimed to help the operators to calculate the amount of materials to be added in furnace (or in the ladle, if a correction in the furnace is not possible) in order to fix the anomalies. The use of advanced software for these evaluations is profitable for many reasons: it is able to perform sophisticated mathematical operations (out of reach for a human operator) in few seconds, calculating the best solution in terms of both quality and cost goals. The analysis system can be connected to specifically designed dosing systems in order to send (automatically or with the supervision of an operator) the instruction about materials and quantities to be released, ensuring that all the materials required will be correctly added. The adjustment of the base iron is not only limited to the primary factors, like the carbon equivalent, the position in the Fe-C diagram or the state of nucleation of the iron, but it can take into account also other factors, like the pearlite stabilising elements, in order to minimise the costs related to them.
Concerning the second stage of the process, the operation out of furnace, ProService has developed thermal analysis software focused on the evaluation of the final iron. In this case, the system automatically collects the results of thermal analysis, integrated with the results of the spectrometer, of the temperature measurements and of other equipment, like the moulding machine (to automatically associate the current casting produced), the sand preparation plant, the in-stream inoculation check system etc. In addition, it communicates with the systems dedicated to the base iron, in order to join these two stages which in some foundries are treated as two independent processes, without any coordination.

This configuration not only overcomes the problems described above, but also allows other two important aims:

- It constructs a consistent database of production that allows, for each production batch, to reconstruct the whole production history, in order to identify the source of any anomaly which has occurred;
- It allows defining and managing custom targets for a specific casting, not only considering the last operation in the process, but managing the process since the base iron preparation.

This new way of working has been successfully implemented in a variety of foundries. In the next paragraph, the results obtained in Infun For will be reported. [2], Infun For is a leading company in Europe for the manufacture of high quality mechanical parts and safety components for the automotive Industry. Its typical production consists of engine parts, braking systems, transmission and suspension systems and includes both grey iron and ductile iron castings. This foundry started a study to evaluate the possibility to reduce scrap (and their associated costs) related to metallurgical defects by the use of thermal analysis and a dynamic process control procedure.

Conclusions

Analysis of the obtained benefits

The introduction of an accurate procedure for the preparation of the base metal in melting furnaces has allowed a significant reduction in the variability in the final iron (minimising the effect on the normal series of the workers operations) and resulted in a drastic reduction of the internal scrap rate, that was the main target of the project.

Nevertheless, the benefits were not limited to scrap reduction. Variability, in a productive process, always entails increasing costs connected to the actions required to address scrap issues. A working method enabling a reduction of the variability in the base iron allows a reduction of process costs through:

- minimising of the use of corrective materials, which are used only in the necessary amount and in the stage of the process in which they maximise the yield;
- energy savings, eliminating overheating in melting furnaces and allowing, in some cases, a reduction of the pouring temperature;
- the possibility of using less costly materials, both in the melting furnaces charge and in the treatment and correction operations.

The sum of these contributions can lead to obtain a significant annual savings that, in cases of high-volume foundries, can reach six figures. It is therefore an investment with a quick return, both on the economical and qualitative side.

References

2. Andrea Zonato, Massimo Agio, Claudio Mazzocco, Reduction in the variability of the iron castings production process by the use of the thermal analysis software “ITACA”, E-journal, Issue 01-2013.