Reduction in the variability of the iron castings production process by the use of the thermal analysis software ”ITACA”

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Abstract

The production of high quality cast irons is a very complex process, subject to the effect of many factors affecting the final result. A poor control over such phenomena produces a high variability in the cast iron, with unavoidable effects on the quality of the produced castings. A variance in the productive process always entails higher costs, even if not scraps have been produced, since it needs to be managed. This article illustrates the results gained through a project aimed at quantifying and decreasing, by the use of the ITACA thermal analysis software, the variability in the productive process of InfunFor S.p.a., a foundry with premises in Rovigo (Italy) and belonging to the Infun Group. All the project stages (study of the initial situation, analysis of the causes, identification of the action modes and analysis of the obtained results) will be described and analysed, both from the point of view of the foundry and of the ProService consultants, who have supported the Infun For staff during its execution.

The production of high quality iron castings is a very complex process, which includes several stages. Each stage sees the involvement of different factors, whose values have to be kept within definite ranges. For example, the chemical composition and the amount of the materials constituting the metallic charge, the additives and the corrections introduced in the molten metal or, in case of nodular irons, the features and the amounts of the materials introduced to produce the nodularization reaction. Some of such values can be easily managed and set (like for example the amount of the added materials), while other values cannot be identified with precision or adjusted (like for example the chemical composition of the pani di ghisa or the nodularization treatment yield).

This implies an unavoidable variability in the features (and so in the quality) of cast iron in the various process phases. In order to prevent part of the production from not meeting the specifications, such a variability needs to be managed, and this will entail an increasing in the costs.

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Introduction

Importance of the initial variability management

In a generic process constituted by various phases, the variability in the final product is the sum of the variabilities introduced in each phase. For simplicity, dividing the foundry process in only two stages (preparation of the base iron and treatments in ladle), the variability in the final iron will be given by the sum of the variability introduced by the treatment in ladle and the variability got from the base iron. As a consequence, a high variability in the base iron will lead to a higher variability in the final iron, being much more difficult and expensive neutralizing it in the second phase of the process (Figure 1).

\[\text{Figure 1: quality trend of the final iron with a high variability in the base iron}\]

Importance of the thermal analysis

Historically, the control of the cast iron quality during the productive process in foundry has always been based on the chemical analysis of the metal: some ranges of acceptability on the contents of the main chemical elements were defined for each type of cast iron. This approach is grounded on the assumption that to a certain chemical composition the same results in the castings quality always correspond. Nevertheless, in the solidification process many physical and thermodynamic factors are involved and their influence is not irrelevant: with the same chemical composition it is possible to get different results, in terms both of casting properties (matrix structure, quantity and shape of the graphite, mechanical properties, etc.) and of probability of metallurgical defects formation (cementite, porosity, shrinkages, etc.).

Thermal analysis allows to carry out a direct evaluation of these phenomena in a simple, quick and cheap way. Its use in the foundries open new ways to the process control, since it allows to:

- determine the real position of the cast iron in the Fe-C state diagram (this position does not depend only from the chemical composition);
- measure the real effect of of the chemical elements added in alloy aggiunti in lega (for exam-
ple, the added frazione di carbonio which has been effectively dissolved solubilizzata);

- evaluate the degeneration of the cast iron in case of overheatings or long periods of permanence in the furnace;

- measure the efficiency of the introduced additives, allowing to identify both the best material (for example in the test of two different inoculants), and the optimal amount (maximation of the result minimizing the cost);

- evaluate also the effects due to factors which cannot be easily measurable (for example, the cast iron oxidation level).

The successful aspect of this kind of analysis is linked to its nature of direct measure: without the need of having to suppose and forecast the effects deriving from the presence or amount of a chemical element, all the possible mistakes due to a wrong estimation or to the exclusion of phenomena considered as minor are removed. Thermal analysis gives a picture of the metallurgical status and allows both the carry out of focused corrections and the assessment of their effectiveness.

Use of thermal analysis to reduce variability

Based on the know-how and expertise accrued in foundry during the years, ProService has developed the new version of its thermal analysis software for the control of the cast iron quality in the furnaces: ITACA MD (MeltDeck).

ITACA MD is a powerful and flexible tool, realazed on the grounds of the specific needs of the foundries melting shop. It makes a complete evaluation of the cast iron quality, supplying the operators with few, simple and clear indications wsimply by pouring a sample of cast iron in the special cups (Figure 3). The software allows to define some ranges of acceptable values for each parameter and highlights possible anomalies in case some values do not fall within the acceptability ranges. Its use allows to manage:

- the chemical composition;

- the main thermal parameters involved in the solidification process;

- the nucleative properties of the cast iron;

- the real position of the cast iron in the Fe-C state diagram;

- the bath temperature.

ITACA MD does not only give evaluations on the cast iron status, but also simplify the correction operations on the found anomalies, suggesting the amounts of the materials to be added to the bath (Figure 4). It also enables the operators to see the quality trend of the final iron in the pouring lines, in so that the cast iron can be corrected directly in the furnace or in the ladle.

ITACA MD supports the procedures management, that are series of operations that have to be carried out during the preparation of the cast iron in the melting furnaces and whom results are stored for possible analysis.
The use of ITACA thermal analysis software to stabilize the quality of base iron has been successfully experimented in many foundries. In particular, here below there is the description of the results gained in InfunFor S.p.a., with premises in Rovigo (Italy), belonging to the Infun group.

**Case study: reduction of the variability in Infun For foundry**

*Claudio Mazzocco - Analysis Laboratory - Massimo Agio - Production Manager -*

**Introduction of the company**

Infun For is a leading company in Europe for the manufacturing of mechanical parts and high quality and safety components for the automotive industry. The factory of Rovigo, established in 1971 as Peraro For, has been acquired in 2000 by the Infun Group, a multinational corporation specialized in the iron castings sector for the automotive.

The factory has a total surface of 105.723 m², of which 24.744 m² indoors, with a productive capacity of 60.000 tons/year. The company has the following certifications: ISO/TS 16949 (Quality management systems for automotive production), ISO 14001 (Environmental management systems) e OHSAS 18001 (Occupational health and safety management).

The typical production mainly consists of engine parts (shafts, bielle gruppi cappello), braking systems (dischi e pinze grezze) and transmission and suspension systems (scatole cambio e differenziale, bracci sospensione, mozzetti ruota), and includes both gray iron (where the graphite is present with a lamellar structure) and nodular iron (where the graphite is present with a nodular structure) parts. This second morphology reduces the mechanical strains and highly increases the main mechanical properties.

The production floor of the foundry is constituted by 4 melting furnaces (Figure 5), where the materiali grezzi di carica are melted, 2 green sands moulding plants (Figure 6), where the cast iron is poured in the moulds, and a cores moulding floor. Furthermore, the factory has a R&D department, including a Planning office, a patterns shop and a chemical and physical laboratory (Figure 7).

For what the process quality control is concerned, the foundry uses not only the traditional and most common procedures (chemical and micrographic analysis), but also a modern system of thermal analysis, constituted by 2 units installed respectively in the melting and in the pouring station, each one equipped with two acquisition supports and an interface which allows to see the cooling curves, the main thermal parameters and a series of dashboards for the metal quality monitoring, both from the metallurgical and the defects formation point of view, in a very user-friendly way.

The configuration of this system allows the monitoring of the cast iron characteristics along all the productive process, from the base metal preparation to the pouring in flask.

**R&D activities**

At the end of 2010 it was started a study to evaluate the possibility of reducing scraps (and their costs) due to metallurgical defects by the use of thermal analysis.

In collaboration with the software supplier (ProService??), and with the support of the inoculants supplier, 1500 cooling curves have been analyzed, in
Figure 5: Melting furnaces dep.

Figure 6: Moulding dep.

Figure 7: Chemical-physical lab.
various way. The obtained results proved interesting and, in some cases, unexpected (like for example the great variability of the cast iron position in the state diagram). In particular, this analysis showed how a considerable part of the production was poured with a hypo-eutectic iron; this aspect had never been noticed before, since the pattern plates were suitable also for this kind of solidification and so no scraps were obtained.

During the year 2011 the activity was focused at reducing the variability of cast iron through a strict definition of the parameters to be monitored, concerning both the thermal analysis and the used raw materials (chemical composition) and the addictions carried out in the process (kind and quantity).

**Difficulties in fulfilling the project**

The main difficulty in fulfilling this project was the collection and the analysis of thousands of production data, necessary to define the parameters to be monitored. For example, for the definition of the optimal value of the eutectic factor it was necessary to correlate the data of this parameter with the carbon, silicon and residual magnesium content and the minimal temperature of the eutectic reaction obtained from the analysis carried out on about 1500 ladles. The results were then compared with the data relevant to the scraps found in the various productions.

In the chart 1 there is an example of the collection and analysis of the data for the identification of the work target.

**Table 1: Determinazione del contenuto ottimale di Carbonio in funzione del fattore eutettico**

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<th>% C</th>
<th>% Si</th>
<th>%Ceq</th>
<th>%Mg residuo</th>
<th>Temp. eutettica</th>
<th>Eutettico</th>
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average | 3.63 | 2.31 | 4.40 | 0.040 | 1144 | 30 |

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average | 3.65 | 2.33 | 4.42 | 0.040 | 1145 | 38 |

Continua nella pagina seguente...
Table 1: Determinazione del contenuto ottimale di Carbonio in funzione del fattore eutettico

innovation contents

The main innovation this project has brought is the new approach in evaluating the cast iron quality, from the static one (based on absolute references on the chemical composition) to a dynamic one, based on the analysis of the thermal parameters in every single casting. This new approach led to the definition of specific intervention procedures to be carried out promptly in the production process, both in the melting and in the pouring furnaces, by specific actions on the ferro-alloys addictions, temperature variations and inoculants amounts. The application of such procedures has allowed to reduce significantly the scraps (both internal and external) and to ensure a higher stability of cast iron.
Obtained results

The main objectives of the project were the reduction of defects (in particular, of the internal backwashes) in the castings, the stabilization of the process from the eutecticity point of view and in the ferro-alloys consumption.

All these objectives have been achieved, with also considerable savings on the additivation products used in the process. In particular, thanks to the introduced improvements, a decrease of scraps has been achieved (Figure 8).

![Andamento dello scarto](image)

*Figure 8: andamento dello scarto complessivo*

Description of the adopted methodology

Andrea Zonato -ProService Tecnology-

The starting point of the analysis has been the internal scraps trend: in fact, the foundry had a very variable scrap rate, especially for some kinds of castings: batches free of defects alternated with batches containing a certain portion of scraps.

The analysis carried out on the production data history has highlighted a considerable variability in the final iron quality, especially in relation to the position in the Fe-C state diagram. The produced cast irons have been classified in 7 classes:

- Strongly hypoeutectic irons, in which the amount of primary austenite that forms in the first part of the solidification is very high;

- Hypoeutectic irons, similar to the previous ones but with smaller formation of primary austenite in the first part of the solidification;

- Hypoeutectic irons with low formation of primary austenite or eutectic irons with low values of recalescence (optimal type of cast iron for such castings: target to be reached);

- Two classes of cast irons at the limit of acceptability (slight deviations from the target), that do not necessarily produce castings with defects, but their pouring in flask entail a certain degree of risk;

- Eutectic irons with high recalescenses, that are not advised to be used in the production of the examined types of castings, since they often causes working problems to the castings feeding system;

- Hypereutectic irons that, if used to product these kinds of castings, are almost warranty of obtaining scraps.
This fact suggests the presence of a problem of variability management along the whole productive process, that therefore has been broken into subprocesses to be singularly analysed:

1. Base iron preparation;
2. Spheroidization treatment in ladle;
3. Pouring in flask through pouring furnace.

The treatment in ladle is the classic Tundish cover process, that in this foundry is always carried out according to a standard procedure, without varying materials nor used quantities. A quick survey has allowed to exclude the hypothesis according to which the main part of the final iron variability were originated in this stage of the production process.

With regards to the stage of the pouring in flask, the only operation that has been carried out is an inoculation on the flow, keeping constant the supplied quantity. The effect of the inoculant can change according to the cast iron features, but, as some trials have demonstrated, the cast iron features being equal, the inoculant develops always the same effect. Therefore, it does not introduce a new variability, but can however amplify the effects of the already existing one, deriving from the previous stages of the productive process.

These results have allowed the hypothesis that the most part of the measured variability originated during the preparation of the base iron. By studying the changes brought by the spheroidization treatment to the cast iron features and combining them with the results got from the analysis of the history of data of final iron, 4 classes have been defined in order to group and analyse the base irons produced in the melting furnaces:

- Hypoeutectic cast irons with too high quantity of primary austenite, generally due to too low values of Carbon equivalent;
- Hypoeutectic cast irons with a correct quantity of primary austenite that, once treated, will allow to obtain a final iron in line with the fixed target;
- Eutectic cast irons, with a too high value of Carbon equivalent;
- Hypereutectic cast irons.
• Cast irons with a too low Carbon equivalent can be easily corrected, acting both in the melting furnace and in the ladle, allowing the problem solving;

• Cast irons with a slightly high value of Carbon equivalent can also be corrected in the melting furnace, but only with difficulty in the ladle since they require the execution of “extraordinary” actions that, in some cases, cannot be possible to execute;

• The hypereutectic cast irons cannot be corrected in the ladle and only with difficulty in the melting furnace (since after the reduction of Carbon equivalent it is necessary to re-establish the whole chemical composition of cast iron).

In the Figure 10 it is possible to observe the subdivision of the cast irons produced by InfunFor in May 2010. Comparing such data with the ones obtained from the final iron analysis of the same period, it is possible to see a substantial conservation of the proportions of base and final amount of iron meeting the target, with Carbon equivalent too high or too low.

In the light of this analysis, the foundry has decided to change the charge composition in the melting furnaces, in so to reduce the Carbon equivalent obtained on average, with the aim of voiding the production of irons with too high Carbon equivalent (situation difficult to correct) and, as a consequence, the scraps connected to this cause. This action has actually void the production of hypereutectic base irons and drastically reduced the amount of eutectic base irons, even if increasing the amount of the base iron too hypoeutectic, as it can be seen in the Figure 11, which represents the evolution of the base iron production, from May to October 2010. During this last month, the production of base iron within the target exceeded...
the 50%, but at the same time significantly increased also the amount of base iron with too low Carbon equivalent (Figure 12).

These variations have of course reduced the variability of the final iron, as it is showed in the Figure 13, but the consequent reduction in the quantity of produced scraps has not been considered as sufficient.

In order to furtherly decrease the base iron variability a new procedure for the preparation of the base iron has been formulated and tested; this procedure envisages the execution of certain thermal and chemical analysis after the execution of each operation for the preparation of the base iron and whose results are used to define the subsequent operation (like for example the types and amounts of the correctives to be introduced in the metal).

The quality trend was monitored for the subsequent 6 months and is represented in the Figure 14: you can easily observe a gradual reduction of the out-of-target amount of cast iron, as the operators became familiar with the new procedure. In April 2011 the percentage of in-target base iron reached close to 80% and uncorrectable out-of-target castings have practically disappeared (Figure 15).

The effects on the final iron variability are represented in the Figure 16: during the month of April 2011 the percentage of in-target irons exceeded 70% (compared to 30% of the same period in the previous year); if we include also the slightly out-of-range, the total amounts to 90% (compared to 50% of the previous year) and, the most important thing, the cases of hypereutectic or eutectic final iron with high recalescence, which provoked production batches with a very high scraps rate, are disappeared.

**Analysis of the obtained benefits**

The introduction of an accurate procedure for the preparation of the base metal in melting furnaces has allowed to drastically reduce the variability in the final iron, acting in a only stage of the productive process (and so minimizing the effect on the
normal series of the workers operations) and so obtaining a drastic reduction of the internal scraps rate, that was the main target of the project.

Nevertheless, the benefits are not limited to the (however important) scrap reduction. Variability, in a productive process, always entails a costs increasing, connected with the production of scraps or to the actions adopted to correct the anomalies.

A working method enabling a reduction of the variability in the base iron allows a reduction of process costs through:

- a minimization of the use of corrective materials, which are used only in the necessary amount and in the stage of the process in which they maximize the yield;
- an energy saving, 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, can reach six figures. It is therefore an investment with a quick return, both on the economical and qualitative side.