New approach to process control in cast iron foundries through thermal analysis

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Abstract

The continuous increase in the quality demand from final customers and the continuous need of reduction for the costs of production have further increased the importance of an effective control system of the production process in cast iron foundries. The modern thermal analysis systems, like for example ITACA MeltDeck and ITACA8, can generate an enormous contribution, allowing to reduce and manage the variance in the melting shop. In the first part of this work it will be described the role of thermal analysis in the foundries, briefly explaining how it integrates in the actual control processes and showing the main reasons making it an essential part of a modern productive system. In the second part four testimonies will be presented, written by foundries that have implemented these tools in their control system, reporting an evaluation on the results obtained.

Thus, it is understandable the high interest that always has been shown by the foundries for any tool or technique contributing to reduce this variability, or directly, or making some information available and usable to correct in real time the productive process.

The transformation of the foundries in complex industrial systems with high productivity started in the ’50s and continued until the ’70s. Since the beginning, it raised problems related with the quality control of big quantities of castings that theoretically should not have differed very much among them, if they were produced in the same production batch and even if they were part of different productions.

In reality any productive plant, especially if very complex or articulate, has a certain degree of variability that cannot be eliminated. This variability is often constituted by the sum of more single effects deriving from causes that are almost always difficult to be controlled or impossible to be cancelled, even if they can often appear as obvious.

The introduction of spectrometers in foundry

The shop of foundry that maybe more than the others has suffered big problems of process stability is the melting one. This is due to the big variety of used materials that are coming from the external and to the complex nature of the phenomena involved in the operations of melting of the charge, treatment out of
furnace and pouring in the moulds.
The metallurgists rapidly discovered how the simple
definition of a fixed charge recipe was not enough
to contain the variability in an adequate level, even
if were used only materials coming from the same
supplier.
In the castings were often detected relevant variations
in the chemical composition, whose impacts in terms
of variability in quality of the production will not
be here treated, since there is wide literature already
available on this subject. This problem appeared for
a long time as not solvable, because the only avail-
able analysis technique was the so-called “wet anal-
ysis” determination, an analysis method requiring
some highly skilled personnel, as well as being quite
complex, long and expensive. These characteristics
impeached any possibility of its use as control tool,
directly usable during the production.
Starting from the ’80s, the first optical emission spec-
trometers (OES, optical emission spectroscopy) dif-
fused in foundry, often simply called “quantometers”.
The introduction of this tool represented a real revo-
lution concerning the process control: in fact, it was
possible to determine in real time the chemical com-
position of the liquid metal, with accessible operating
costs and without using highly skilled personnel.
Even with some limits and defects, especially in the
first implementations, this tool allowed an enormous
reduction of the process variability, insomuch as it
became its linchpin. To this day, a lot of foundries
entirely base their process control on this tool.

Second revolution in process con-
trol: thermal analysis

Thermal analysis is a technique of analysis in real
time made through the direct measurement of the
temperature trend of a small sample of liquid metal
during its solidification (Fig. 1).
The first studies concerning this technique of research
go back to the end of the ’60s and the first measure-
ment systems started to appear in the foundries start-
ing from the second half of the ’70s. Regardless of
the high number of information that can be found out
from a single acquisition, the first measurement tools
aimed only at the determination of the contents of
Carbon, Silicon and at a direct estimation of Carbon
Equivalent. Thus, this technique was seen as a tool
alternative to the spectrometer, with the only target of
monitoring the chemical composition of the metal.
Before describing the further data that it is possible to
obtain from a thermal analysis, as well as the content
of some elements, it is important to observe how these
two tools measure only apparently the same physical
quantities. In fact, the optical emission spectrometers
base their functioning on the analysis of the light radi-
ation emitted exciting a small portion of the material
to be analyzed. The mainly used technique of exci-
tation employs an electric discharge vaporizing the
metal in the interested zone. Consequently, for each
chemical element that is present the total quantity will
be measured, independently from the state in which it
is.

Figure 1: Example of solidification curve of a cast iron
Nevertheless, there are wide studies proving how a generic element can be present into the metal in different shapes (when it is in the liquid state or after its solidification). In fact, it can be:

- dissolved in the liquid or in the matrix (as Silicon, or part of Carbon, for example);
- combined with other elements like Oxygen, Sulphur, Silicon, etc, in the form of chemical compound (oxide, disulfide, silicate, etc.);
- present as undissolved aggregate (particles of graphite, recarburizers, ferroalloys or inoculants that have not been solubilized and dissolved).

On the opposite, thermal analysis does not search the specific presence of the different elements, but it directly analyzes the solidification process from the thermo-physical point of view. During the solidification of a cast iron, there are various reactions that start, develop and end, and each one of them generates the production or subtraction of heat, significantly influencing the dynamics of the process. Analyzing the trend of the temperature over the time, it is possible to identify these single reactions and the corresponding parameters (as time and temperature of starting and end, for example).

Observing the influence of the different elements from the solidification point of view, the state under which they are present is fundamental. Considering for example the influence of Carbon, from the Fe-C diagram it is known that if its concentration is lower, higher will be:

- the temperature where the metal starts solidifying;
- the quantity of primary austenite that forms during the solidification;
- the mechanical properties of the casting, for example the ultimate strengthen (in particular for lamellar irons);
- the shrinkage that the liquid iron will develop during the solidification.

Nevertheless, considering all the Carbon present in the alloy, the quantity that effectively influences the process of solidification in the way described above, is the fraction that has been really solubilized in the iron, that is commonly called “free”, “not combined” or “active”. The thermal analysis systems estimate the Carbon content basing on the variations that it generates in the critical phases of solidification. As consequence of what here described, they detect only the active fraction on the total that is present. Anyway, the eventual combined or not dissolved fraction can influence the solidification from a physical point of view, even if not from a chemical one.

At this point, it is understandable the reason why these two tools often supply discordant results, that in some cases the metallurgists ascribe to failures of one tool or the other one: both supply a measurement of the quantity of a certain element, but in one case is the total quantity that present considering all the shapes, in the other one is only the active fraction.

This difference is very important for the process control. For example, supposing to produce a nodular eutectic cast iron, but at the end of the treatment the iron is hypo-eutectic (too low Equivalent Carbon) because of a lack of Carbon. The metallurgist will calculate and add to the ladle the quantity of graphite that is necessary to restore the correct value of Ceq. Nevertheless, it is not possible to determine a priori the part of this addition that will be correctly solubilized, contributing to the increase of Ceq. Thus, it could happen that the cast iron will not really reach the eutectic condition, despite the Carbon content detected by the spectrometer (that will probably result as coherent with the executed addition). On the other hand, the thermal analysis will correctly detect the real state of the cast iron, less hypo-eutectic as the previous one, but not yet eutectic.

Nevertheless, it is important to remark that thermal analysis has not to be seen as a replacing tool of the spectrometer, but as a complementary tool: in fact, there are some cases where a chemical element could be present in too low content to significantly influence the curve of solidification, but enough to change some
specific properties of the casting (for example, consider the impact of very low contents of Phosphorus on the resilience in the so-called “low temperature cast irons”, that is not easily detectable from the thermal analysis curves).

Further evolution: beyond the simple chemical approach

Up to this point, the process control has been analyzed in function of the chemical composition. Even if it is an important requirement, anyway it is not enough to guarantee the constancy in quality of production. Their formation can follow two ways: as spontaneous aggregation of groups of molecules (homogeneous nucleation) or as aggregation of molecules around an existing nucleus (heterogeneous nucleation). The second way is that one definitely prevalent and the starting centers of aggregation can be of many different types: impurities not dissolved coming from the materials of charge, minuscule lining particles eroded by the sided of the furnace, compounds expressly introduced for this target (as preconditioners or inoculants), or the “not active” fractions of the chemical elements that are present in the cast iron as mentioned above (the combined fractions and the not dissolved ones). The ability of the cast iron to nucleate grains, lamellas or nodules is called “nucleative potential” and by its nature, it is not directly quantifiable. The number of these germs and the speed of growing around them for the different phases are two fundamental parameters heavily influencing the continuing of solidification (with consequent influence on the formation of metallurgical defects) and the final characteristics of the castings (in terms of microstructure and of mechanical properties).

On a chemical point of view, the inoculants and pre-conditioners are usually composed for 75% by Silicon and, in function of the product, they can contain other elements in contents that rarely arrive at 10% and are typically between 1% and 5%. An in-stream inoculation at 0.1% will generate a restrained variation of chemical composition: an increase of 0.07% in Silicon and an almost negligible increase of the other elements (between 0.0001% and 0.0005%), often lower than the spectrometers resolution. Nevertheless, against these almost negligible variations in chemical composition, this operation generates some macroscopic changes in the cast iron. It is a very common experience to detect hardnesses excessively high or problems of carbides formation in castings that have been poured without a correct in-stream or in-mould inoculation, because of problems in the productive process. Moreover, this operation can enormously modify the way of solidification of the metal, when it is executed on cast irons with low nucleative potential: a strongly hypo-eutectic cast iron can arrive to have a fully eutectic solidification after a low inoculation, with consequences that can impact even on the feeding system of castings that was fitted in the moulds. Similar effects can be verified in every part of the productive process, even if not directly observable, if the nucleative potential of liquid metal is not correct.

It is certainly realizable the difficulty in the estimation of this parameter in absolute value, that is an operation almost impossible, because it is based only on the variation in chemical composition. Nevertheless, it is anyway possible to monitor it, analyzing the results of the curve of solidification and, if needed, to intervene on the productive process to restore it at an adequate value.

The development of computerized calculus systems has allowed an enormous evolution of thermal analysis systems: a modern software, as for example is ITACA MeltDeck (to control the base metal) and ITACA8 (to control the final cast iron), can autonomously execute the analysis of the solidification curve, the calculus of the main results and their interpreting, in order to supply simple indications for the operators.

The last versions of ITACA have, in addition to the main thermal results, some indications about the risk
of formation of the main defects (from carbides to shrinkage defects), as well as information concerning the grade of generated graphite expansion, the shape of graphite or the estimation of the main mechanical properties, even keeping simple their use.

Through the use of a last generation thermal analysis system, now the foundries can implement an effective control system of variability: through the combination of thermal and spectrometer analysis, it is possible to stabilize the quality of the metal in all the phases of the process, from the preparation of the base iron to the final pouring in the moulds, passing through the eventual monitoring of the holding furnaces and the control before and after the treatment in ladle.

The metallurgists can identify any deviation as regards the various quality targets in real time, and make the necessary corrections in the needed process phase, allowing as well the optimization of the used additives and ferroalloys.

Figure 2: ITACA MeltDeck thermal analysis unit

Figure 3: ITACA8 thermal analysis software
The experience of foundries

As you can easily guess, the main concerns of the foundries when they are going to plan an investment focus primarily in a few simple aspects. What are the benefits that can be achieved by this investment? Benefits are that my organization (as a set of people and skills) can get to achieve? In how much time? We decided to collect the testimonies of four foundries, our customers, which differ in their type of production and turnover, by sending them a brief questionnaire right about these aspects. Here are the results of the questionnaire, introduced by a brief description of the customers who kindly gave their testimony.

VonRoll casting (emmenbrücke) sa

VonRoll casting is a swiss foundry group producing gray and ductile iron: the materials range from the standard grades to special alloys such as SiMo, Ni-Resist and austempered ductile iron (ADI). VonRoll casting is producing castings for a wide range of market segments: the biggest segment represents the engines with exhaust manifolds, cylinder heads, turbochargers, etc., followed by vehicles (railway and trucks) with all kinds of safety parts, then the machine, textile and energy industry. The foundry of Emmenbrücke, produces castings from 2 to 200 kg with a moulding line from HWS. The melting shop has four induction melting furnaces (medium frequency) and one holding furnace.

«Are you using ITACA system as a process control tool?»

«Yes we are using the system as a tool for process control in addition to the verification of samples for new alloys and tests for the improvement of the inoculation process.»

«Have you obtained any benefit from the use of ITACA? What are these benefits? How much time has it taken?»

«Yes we did. We achieved a more stable process since the introduction of ITACA. There is still some work to do but we are on the right path. We could also reduce the amount of inoculant in the ladle by optimizing the inoculation process to save cost. We have realized that we are sometimes hypereutectic for certain alloys. With the help of the thermal analysis we could reduce the carbon and silicon content to get eutectic. Furthermore we could reduce problems caused by porosity.»

«What is the level of complexity of the system according to the workers?»

«Most of our workers in the melting shop understand how to influence the different temperatures and points in the iron-carbon phase diagram. We are still training the workers at the moulding line to give them the know-how to understand and use the system.»

Fonderie Glisenti

Foundry specializes in the production of castings of high and medium series, small and medium size (up to 70 kg) in ductile iron. The melting shop consists of 5 induction melting furnaces. The production is done in a horizontal moulding line for the industry of tractors, earthmoving machines and industrial vehicles. A vertical molding line allows to produce medium and high series for the automotive industry.

«Are you using ITACA system as a process control tool?»

«Yes, we will put it in the Control Plan soon.»
Have you obtained any benefit from the use of ITACA? What are these benefits?

Yes we did. Yes we did. Constance of liquid type at the pouring and customization of thermal analysis in function of the casting, in relation to the defects. We use ITACA MeltDeck as a system to stabilize, quickly and easily, the final iron and keep it in acceptable ranges defined for each casting or castings families. On some castings, this heavy control of the base and final iron has allowed us to reduce the porosity, returning within the parameters defined by the client.

How much time has it taken?

In general terms, we can say that starting from the installation of ITACA MeltDeck, which took place two years ago, we got benefits. In the last year we have inserted the operation into the procedure and we have seen benefits also in terms of documents.

What is the level of complexity of the system according to the workers?

After quickly gained acquaintance, the system now appears easy to use both in the execution of trials that in reading the results.

Are you using ITACA system as a process control tool?

Yes, the systematic control of all meltings in the furnaces and of all the ladles on pouring has been included in the process control for ductile iron, while we are studying how to apply it for the gray cast iron.

Have you obtained any benefit from the use of ITACA? What are these benefits? How much time has it taken?

Yes. In few months the systematic control with thermal analysis has allowed us to control and/or eliminate some variables, allowing us to restrict the range of HipoEuteticHiper, with important benefits on defects. At this time we are focusing on improving the yield metal/stirrup, made possible with the stabilization of the final iron.

What is the level of complexity of the system according to the workers?

The curves and some parameters controlled by the operators in the pouring line are very well defined and clear, allowing the interpretation of the analysis already at a quick glance. Other parameters, if necessary, always well-defined, are studied more carefully by other operators better prepared.

INFUN FOR

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 typical production mainly consists of engine parts, braking systems, transmission and suspension systems and includes both gray irons and nodular irons castings.

Atlantis Foundries

Atlantis Foundries (Pty) Ltd produces automotive castings for both the passenger and commercial vehicle industries. In addition, the company machines cylinder blocks and crankshafts for automotive applications. The company is a wholly owned subsidiary of Mercedes-Benz South Africa, belonging to the
Daimler AG group, and was established on 12 March 1979. The Atlantis Foundries plant is situated in Atlantis, South Africa, approximately 50 km north of Cape Town.

«Are you using ITACA system as a process control tool?»

«Yes.»

«Have you obtained any benefit from the use of ITACA? What are these benefits? How much time has it taken?»

«Yes, we have obtained reduced metallurgical defects at our customer (about 90% reduction), during the time of three months.»

«What is the level of complexity of the system according to the workers?»

«They found it easy to use as compared to the classical wedge test.»