FOLLOW-UP ON THERMAL ANALYSIS

The foundry industry has been performing thermal analyses for many years. However, recent developments in electronics and computers have enabled the foundries to achieve more accurate thermal analysis results. Foundries mainly rely on carbon equivalent value, carbon content (%) and silicon content (%) to control the liquid bath composition (although it is more accurate to speak about “silicon equivalent” (Si + any other elements that modify the eutectic temperature) than silicon content). However, the liquidus temperature that may be used to select the pouring temperature (pouring temperature = liquidus temperature + superheat, superheat being dependent on the casting thickness and composition, the melting and pouring processes, etc.) is also a very useful data. The theoretical values of the “graphite” eutectic temperature (Te Gray) and of the “carbide” eutectic temperature (Te White or Te Fe₃C), i.e. the temperatures at which carbon precipitates as graphite or reacts with iron to form cementite, also appear on the curve. Other parameters such as undercooling (ΔT=Te Gray - Te Low), recalescence (R=Te High - Te Low) and solidus temperature (Ts) are more and more taken into consideration by the foundries and the thermal analysis equipment suppliers. These parameters will be described in further details later.

Let’s go through some theoretical explanations. Any material, including an alloy, has or generates electrical parameters that are typical of its various physical states (liquid, « mushy », solid) and of its state changes (liquid ↔ solid, liquid ↔ « mushy » or « mushy » ↔ solid). A mushy material is referred to as a material that has solid and liquid zones during a certain period of time (usually called “freezing range”).

These electrical values are then recorded by the thermal analysis device and transferred into a graph (see the figures below) or into digital values that are then displayed on a screen.

Example of a Solidification Curve of a Cast Iron.

![Solidification Curve of a Cast Iron](image)
WHAT IS THERMAL ANALYSIS USED FOR?

- To control the chemical composition: C equivalent, %C, %Si (Si equivalent);
- To define the pouring temperature: T liquidus + superheat;
- To characterize the liquid iron:
  - Carbide formation tendency or need to optimize inoculation: \( \Delta T \), Te Low
  - Micro-shrinkage tendency: R,
  - Inverse chill tendency: Ts.

Changes in these three characteristics are easily detected when the composition of the charge is modified. In most cases, the use of Sorelmetal provides the following benefits:

- A decrease in undercooling (\( \Delta T \)) and, then, a reduction of the risk of chill;
- A reduction of the recalescence (R) and, then, a reduction of the risk of micro-shrinkage;
- The achievement of the Te « Low » value well beyond the Te « White » value which eliminates the risk of carbide formation;
- The achievement of a Ts value higher than the Te « White » value and the avoidance of inverse chill.

A lack of control in the melting process (excessive undercooling and holding time, absence of pre-conditioning, inappropriate additions) inevitably cancels the effect of high quality charge materials. Consequently, in such a case, the indicators provided by thermal analysis are practically all off spec.

INTERPRETATION OF THE THERMAL ANALYSIS RESULTS

- Each type of iron has its specific cooling curve. Curves « D-E » are typical of untreated Ductile Irons (base iron). Curve N represents adequately treated and inoculated Ductile Irons.

Flake Graphite Types A, B, C, D and E; Nodular Graphite Type N.

Typical Cooling Curves Corresponding to the Various graphite Morphologies Shown in the Figure Above.
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- Ductile Iron has different cooling curves according to its state: base iron, treated iron, inoculated iron. Thermal analysis enables the foundry to qualify the iron at each of these states and provides indications on the efficiency of the preconditioning, inoculation and/or melting processes. For example, once treated, a base iron with a low ‘Te Low’ is likely to contain carbides (‘Te Low’ lower than ‘Te White’) after solidification. In this case, the iron must be over-inoculated (which leads to additional costs). The inoculation process increases the eutectic and solidus temperatures (see graph below). One way to avoid low eutectic temperatures consists in optimizing the charge through the use of Sorelmetal, that will produce a proper amount of good quality nuclei.

![Graph showing cooling curves](image)


- The recalescence (R) of a base iron must always be of a few degrees (~3°C) (5°F) in order to achieve efficient nodularisation and inoculation. The recalescence value often changes with undercooling (ΔT). However, excessive undercooling with a ‘Te Low’ near the white eutectic (‘Te White’ or ‘Te Fe₃C’) leads to a strong carbide forming tendency of the treated iron. Excessive recalescence (R) creates strong disparities in the liquid (between liquid and solid zones) and generates a major risk of micro-shrinkage. If solidus temperature (which is often neglected) decreases below the white eutectic temperature, a strong inverse chill tendency appears.

- In these three cases, the problem can be solved through an optimization of the inoculation. However, the preventive solution consists in choosing the charge materials carefully (role of Sorelmetal) and to comply with the melting process parameters (undercooling, holding time, use of good quality raw materials and additives).

- The following example proves the efficiency of thermal analysis to control the molten iron quality and namely to determine the effect of holding the liquid iron in the furnace. Both curves below were plotted for liquid iron samples taken from the same heat but at different times, i.e. at 18 minutes interval.
The second sample (bottom figure) shows a recalescence and an undercooling of 1°C (2°F) larger for only 18 minutes of additional holding time. These two iron grades will have a different behaviour during solidification. Imagine what would happen after a holding time of one hour, which is routine in many foundries!

TO CONCLUDE

Thermal analysis and cooling curves analysis are excellent tools to control the quality of the base and of the treated irons. The defects revealed by thermal analysis can often be corrected by a more stringent inoculation, which is however more costly. One solution is to use Sorelmetal which is capable of providing to the iron an adequate quantity of nuclei that allows the production of an iron of optimum quality: low recalescence (R) and undercooling (ΔT), proper solidus and ‘Low’ (Te Low) eutectic temperature.

For further information on this issue, please contact one of the metallurgists (or representatives) of the Rio Tinto Technical Services.