Predicting Microstructure and Mechanical Properties of GCI and SGI by Thermal Analysis

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ABSTRACT

In current scenario the foundry industry is experiencing tremendous changes because of global competition, increasing demands and requirements to be produced in time and at very competitive price. It is necessary to set new objectives and strategies in order to increase actual competitiveness.

Advance Thermal Analysis System can help to improve the foundry's actual competitiveness, by way of the more effective process control. Even small improvements such as reduction in rejection will have a substantial impact on profitability, since the improvements will affect the total poured tonnage. It can help to reduce rejection due to metallurgical causes, improve yield, less variations in mechanical properties, reduced amounts of inoculants and Mg-alloys. Thermal Analysis gives us information not only about Carbon Equivalent, % Carbon, %Silicon but also about contribution of melt quality in achieving Tensile strength, Hardness, Microstructure, % Nodularity, Nodule count, Effectiveness of inoculants, Eutectic Cell Count. It also gives information of shrinkage tendency, chilling tendency, Carbide index, Chill depth etc.

Key-words : *Predicting Microstructure, mechanical Properties, Advance Thermal Analysis System, Effective Process Control, Cast Iron, S. G. Iron.*

INTRODUCTION

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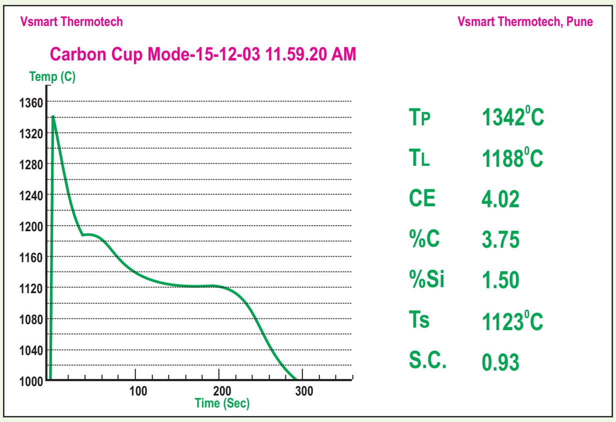
"Advance Thermal Analysis System" can help to improve the foundry's actual competitiveness, by way of the more effective process control. Even small improvements such as reduction in rejection will have a substantial impact on profitability, since the improvements will affect the total poured tonnage. It can help to reduce rejection due to metallurgical causes, improve yield, less variations in mechanical properties, reduced amounts of inoculants and Mg-alloys. Thermal Analysis gives us information not only about Carbon Equivalent, % Carbon, %Silicon but also about contribution of melt quality in achieving Tensile strength, Hardness, Microstructure, % Nodularity, Nodule count, Effectiveness of inoculants, Eutectic Cell Count. It also gives information of shrinkage tendency, chilling tendency, Carbide index, Chill depth etc.

THERMAL ANALYSIS AS C- Si ANLYSER :



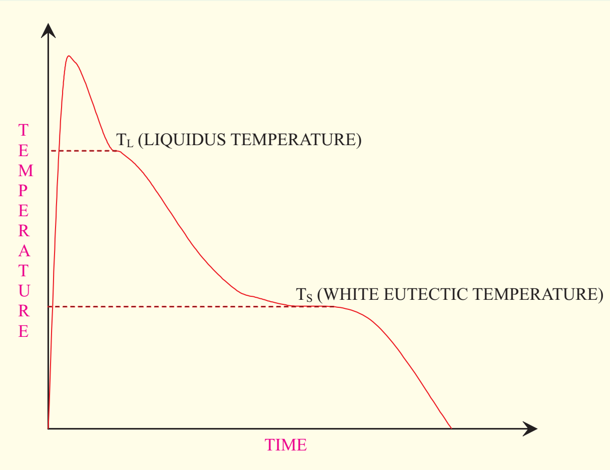


Fig (1) : A typical cooling curve showing liquidus and white eutectic temperatures suitable for carbon and silicon calculations

Traditionally Thermal Analysis is been used to show two distinct thermal arrests. First at Liquidus Temperature and second at White Eutectic Temperature. Tellurium coated cups are used to determine white eutectic temperature from these two temperature arrests %CE, %C and %Si can be determined.

THERMAL ANALYSIS FOR MONITORING NUCLEATION STATE OF MOLTEN METAL:

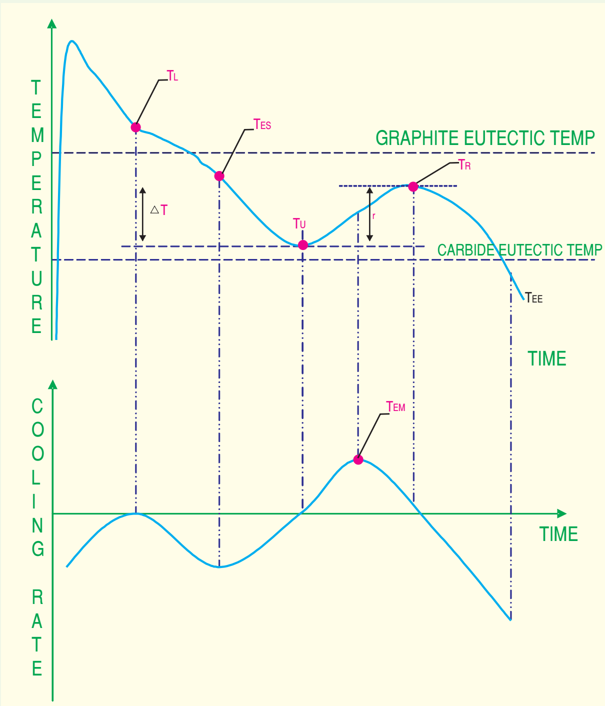


Fig (2) : A typical cooling curve and its first derivative for hypoeutectic Grey Iron solidification.

T_L = Liquidus Temperature

T_{ES} = Temperature of start of eutectic solidification

T_U = Temperature of eutectic Undercooling

T_R = Temperature of Recalescence

T_{EE} = Temperature of end of solidification

T_{EM} = Maximum Recalescence rate

r = Recalescence

T = Degree of Undercooling

The liquid cools at a rate determined by the component design and casting method selected. Once the liquid iron has been poured in to the mould, it cools continuously until the temperature T_L is reached when austenite nucleates and grows in to a dendritic array during further cooling, the latent heat released slows the rate of cooling as shown in fig :2

The liquid continues cooling until T_{ES} is reached when graphite nucleation commences the formation of the eutectic cells. Nucleation continues accompanied by increasing latent heat liberation, until the cooling is arrested at temperature T_U. Thereafter, eutectic cell growth becomes established and occurs initially during recalescence. It is accompanied by reducing driving force until a steady state growth temperature T_{ER} is established as a result of a balance between heat evolved & heat removed by cooling. As eutectic solidification nears completion the latent heat liberated reduces gradually and the temperature falls. Eutectic solidification is complete at temperature T_{EE}.

The location of these various temperatures & hence the structural features of the iron are determined by various particles present in the liquid which acts as nucleants for primary & eutectic solidification. In order to obtain the iron structure necessary to satisfy the specified component properties, a foundryman have to control variations in major element content like C, Si, Mn, S and P, minor element content like Al, Cu, Mg, Ce, Sr, Ti, Bi, etc and process variables like melting conditions, pouring temperatures, inoculation , graphitization potential, cooling rate etc. Thus methods of monitoring a solidification process are essential feature of cast iron.

PRIMARY CAST IRON SOLIDIFICATION STRUCTURES

A cooling curve has the ability of recording and identifying all the events that occur in the solidification process and offers the opportunity to evaluate the effect of changes made by the foundryman on the primary solidification structure.

The original melting charge of major element content (C, Si, Mn, S etc), melting method and liquid metal treatment produce a liquid iron of a certain graphitization potential and with a base nucleation level . The solidification of the iron without inoculation or spheroidizing treatment may be considered in relation to the cooling curve shown in fig2.

The first solidification event is the nucleation and growth of austenite dendrites commencing at temperature T_L. The second significant event is the nucleation of eutectic at T_{ES}. The location of T_{ES} and that of T_U depends on the nucleation level in the liquid .It has been shown that if the melt is uninoculated the most effective nucleant for graphite is MnS particles. Thus, the Mn:S ratio is of significance.

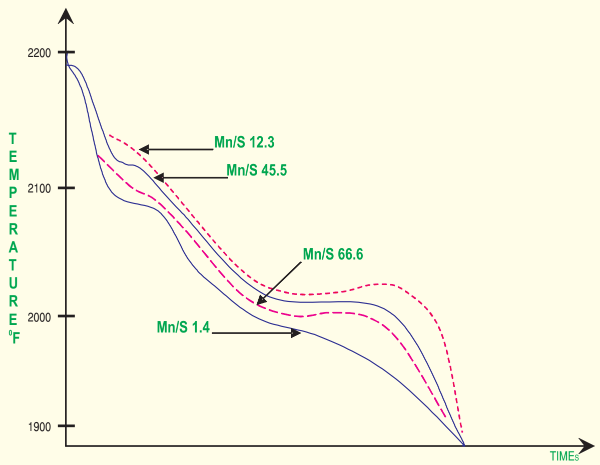


Figure 3 Effect of S and Mn on the cooling curve of an uninoculated grey iron of composition 3.4%C,1.9% Si,0.07%P

Table 1 The influence of inoculation on nucleation and undercooling in a flake iron

Table 2 The influence of cooling rate on the nucleation and undercooling in a flake iron

Inoculant % CaSi	0	0.05	0.1	0.2
Eutectic Undercooling°C	24	15	4	4
cell count/cm²	55	108	160	215

Cooling rate C/min	60	120	200	375
Eutectic Undercooling°C	12	14	18	22
cell count/cm²	57	75	94	113

The effect of the inoculation of liquid iron are evident from the cooling curves in fig 3.

There are few Mn S particles when the Mn:S ratio is high the Mn and S are unbalanced and the iron is poorly inoculated. Both T_U and T_R are low and the graphite flakes are type D. Decreasing the Mn:S ratio increases the number of nuclei (cell count) , T_U and T_R also increase and the flake morphology gradually changes to type A. However, the lowest Mn:S ratio leaves free S in the liquid, which promotes inoculation raises the nucleation level and increases all the eutectic temperatures to an extent depending on the amount and type of inoculant. It also promotes Type A graphite structures .This effect is illustrated in table 1.

On the other hand , as indicated in table 2 , increased cooling rate raises the nucleation level but lowers the cooling curve temperatures.

The graphite morphology in a flake iron will change to type D with a moderate increase in the cooling rate. Further increase leads to the iron being chilled below the Fe-Fe$_3$C eutectic temperature . This will occur at the surface of a casting where white iron forms. This liquid is undercooled significantly with respect to the graphite eutectic temperature and the graphite eutectic can nucleate and grow. The latent heat associated with these events raises the temperature of the remaining liquid above the Fe-Fe$_3$C eutectic temperature. The liquid solidifies grey, thus producing a mottled iron.

The total chill occurs with a rapid cooling rate. The liquid iron cools rapidly below the Fe-Fe$_3$C eutectic temperature at a rate sufficiently fast to prevent recalescence raising the temperature above the metastable eutectic temperature. The tendency for chill increases as the C.E.V. decreases because the volume fraction of eutectic liquid and, hence, the latent heat evolved decreases. Thus additions in the form of moderate amounts of O and S in irons with a Mn:S ratio reduce the undercooling for graphite nucleation and increase cell count by more efficient heterogeneous nucleation. Inoculants have a similar effect. On the other hand, additions of greater amounts of S, N and several minor elements combined with as increased in cooling rate increase cell count, but with an increased cooling. This is due to the generation of constitutional undercooling by the solute additions and to thermal undercooling at the increase the cooling rates. If this undercooling is extensive, metastable carbide forms.

The chilling tendency may be increased or decreased by adjusting the graphitization potential in the liquid. This is achieved by alloying, which influences the two eutectic temperatures. The behavior indicated in fig 4. is for the normal solute concentration used in the cast irons.

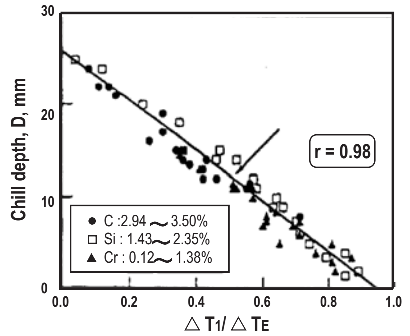


Figure 4 Effect or △ T1/ △ TE on chill depth for various elements, C, Si and Cr

Graphitization elements increase and decrease graphite eutectic temperature and carbide eutectic temperature respectively. Carbide stabilizers decrease the graphite eutectic temperature and increase the carbide eutectic temperature.

It is important to realize that carbide formation occurs for different reasons and remedies are different. Raising the level of graphitizers in the iron is effective in reducing chill. However it is not necessarily, the best method of avoiding intercellular carbides because graphitizers segregate away from the cell boundries. A more effective solution is to reduce the level of carbide stabilizers, particularly those that segregate strongly.

The relationship between cooling curve characteristics & sample microstructure has been studied sufficiently for the cooling curve characteristics to be used to predict the sample microstructure. This provides a range of quality control tests that can be applied rapidly at any stage of liquid iron preparation in the foundry.

Prediction of Tensile Strength and Brinell Hardness:

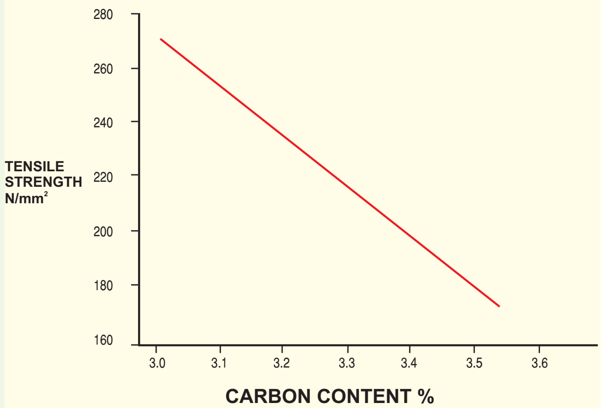
Most of materials standards specify grey cast iron by reference to its strength when cast in to test bars of fixed diameter. To obtain various grades of casting, a variation in chemical composition is necessary.

Unalloyed grey cast irons can be considered essentially as iron, carbon, silicon, phosphorus alloys, these elements have major effect in determining the strength and hardness of an iron cast in to a given section size.

Most engineering grey irons have CE values below 4.3%. An increase in the proportion of the primary dendrites present relative to the graphite bearing eutectic structure, as the CE value decreases below 4.3% the strength and hardness of a grey iron increases respectively.

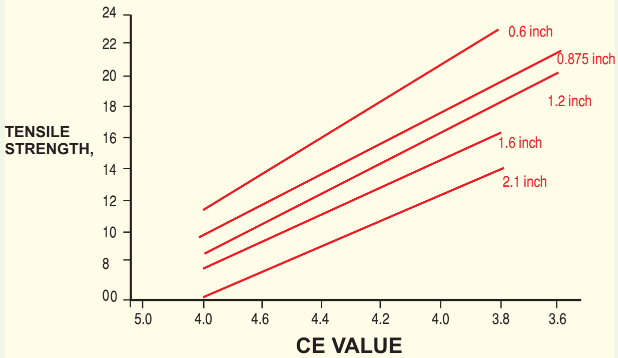
Thus CE value is a useful index of the strength of the iron in a given cast section size. To predict strength and hardness more precisely, it is essential to monitor and control Eutectic cell counts also along with CE value.

The effect of carbon content and carbon equivalent (CE) value on tensile strength can be illustrated in simple diagram. The figures below show the connection between these parameters in grey iron.



Effect of increasing carbon content on the tensile strength in grey irons

Figure : 5



Tensile strength as a function of carbon equivalent value (CE value) in grey irons

Figure : 6

Measurement of Eutectic Cell Counts:

To measure the Eutectic cell counts, we have to allow the sample to solidify Grey, for this we have to use cups without tellurium. A typical cooling curve is shown in fig.2. Here we can see a undercooling (TU), recalescence (r), and maximum recalescence rate (TEM) on first derivative. Using this data the ECC can be determined.

The Eutectic Cell Count value can be used to,

- Predict the Microstructure of Grey iron by graphite form and distribution.
- Predict the shrinkage tendency (Shrinkage tendency in grey irons increases for very high cell counts)
- Optimize the Inoculation
- Study/Check Inoculation Effectiveness and fading effect of innoculant.
- Compare two different inoculant's behavior.

Inoculation Deciding Factor:

Inoculation deciding factor gives us information about whether inoculant is used effectively or not for a given condition of base metal. The effect of inoculation depends on the nucleation level of the base metal & type of inoculant.

$$\text{Inoculation Deciding factor (IDF)} = \frac{\text{Graphite Eutectic Temp.} - \text{TU of uninoculated metal}}{\text{Graphite Eutectic Temp.} - \text{TU of inoculated metal}} = \frac{\text{U IF}}{\text{A IF}}$$

If IDF is 1 then the effect of the inoculation is nil. Normally value of IDF is with in 1.6 to 2.6. If the value is higher than 2.6, then the iron is "over inoculated".

1. IDF value < 1.3 : small content of effective crystallizers in the melt mistake during melting, wrong material and/or wrong inoculation.
2. IDF value from 1.3 to 1.6 : in case of perfect inoculation there may be a lack of inoculation readiness of the iron and of factors influencing the cast iron.
3. IDF values from 1.6 to 2.6 characterise the best operating range. Good relation between input & output of inoculation.
4. IDF values > 2.6 are obtained with a large number of effective crystallisers. Danger of excessive inoculation and thus of greater possibility of piping.

Thus by varying the amount of inoculant on nucleation level of base metal you can reduce the casting defects & variations in physical properties.

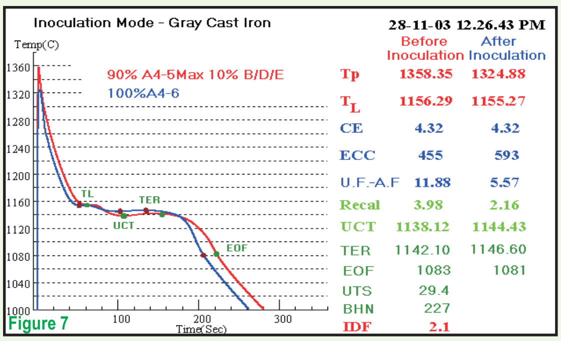


Figure 7

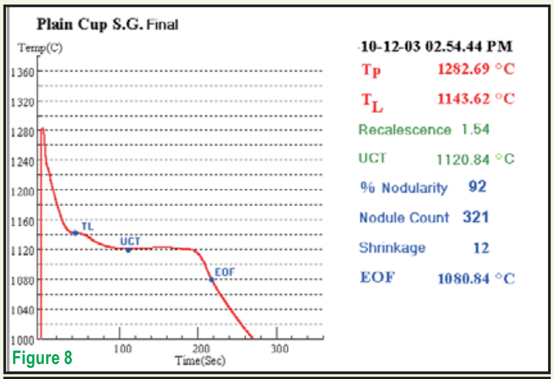


Figure 8

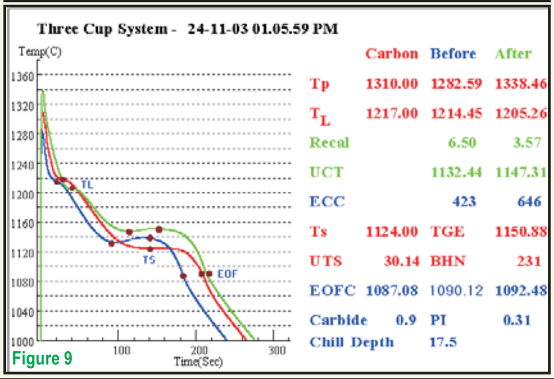


Figure 9

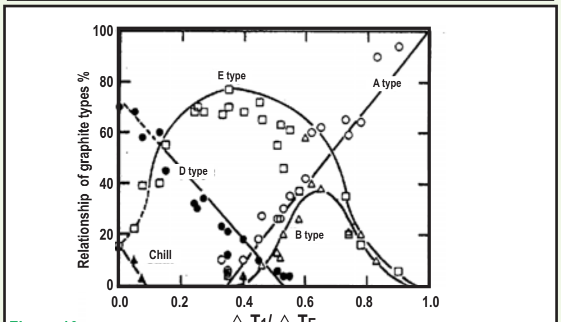


Figure 10

Relationship between △ T1/ △ TE and ratio of graphite

Conclusion: Advance Thermal Analysis system can be used for

- Determination of CE, % C, % Si.
- Display & Storage of Real Time cooling curve.
- Prediction of Tensile strength, BHN for grey iron.
- Prediction of microstructure by graphite distribution & size.
- Measurement of Eutectic cell counts.
- Measurement of graphite eutectic & carbide eutectic temperature.
- Inoculation effectiveness, Comparison of two inoculants.
- Prediction of % Nodularity, Nodule count, and Shrinkage tendency.