Maximizing Graphitization

In cast iron

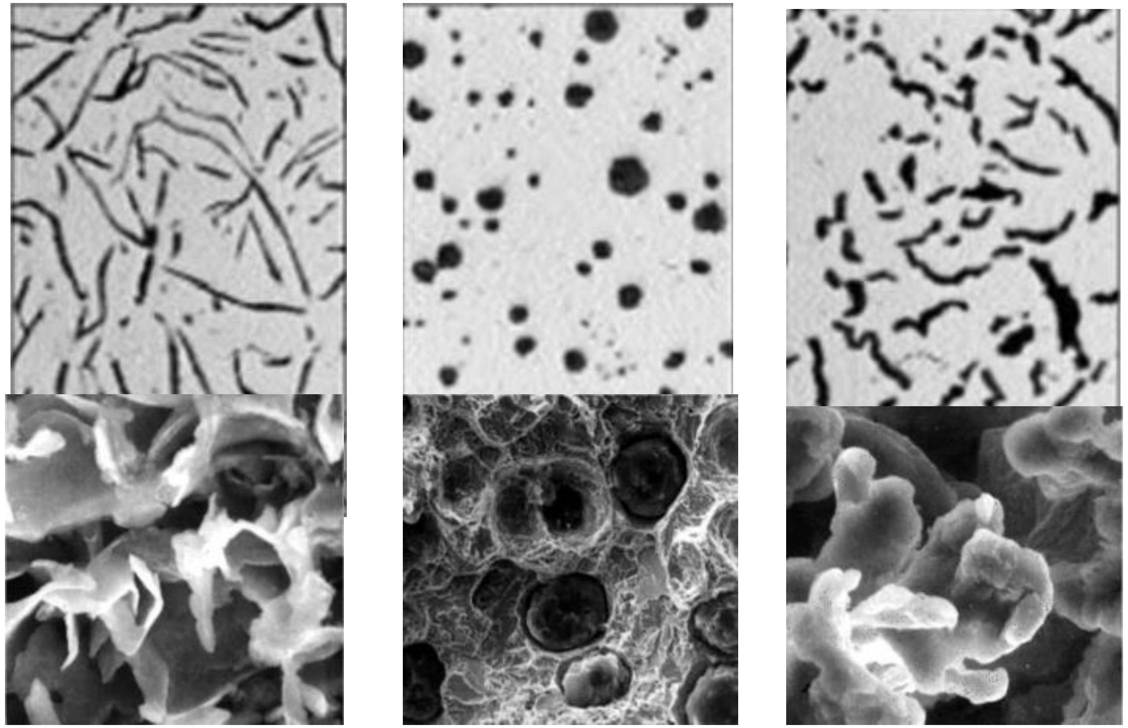
NOVACAST

For a more responsible foundry industry.

What is graphitization?

Graphitization is the formation of graphite in the cast iron as the molten iron solidifies.

When the iron solidifies, graphite is formed in various amounts and shapes based on many different factors.



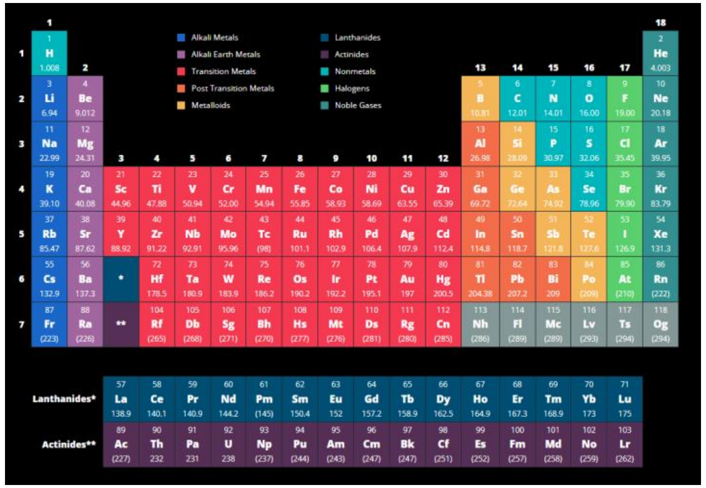
Flake Spheroidal Vermicular

What does graphitization affect?

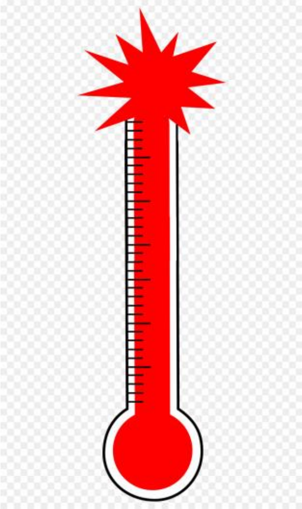
Defects, such as micro and macro shrinkage.

Mechanical properties, such as tensile strength.

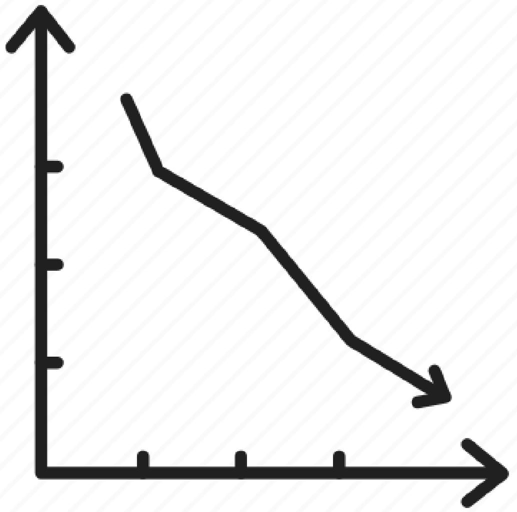
What affects graphitization?



Chemical composition



Holding temperatures



Cooling rate (in mold)

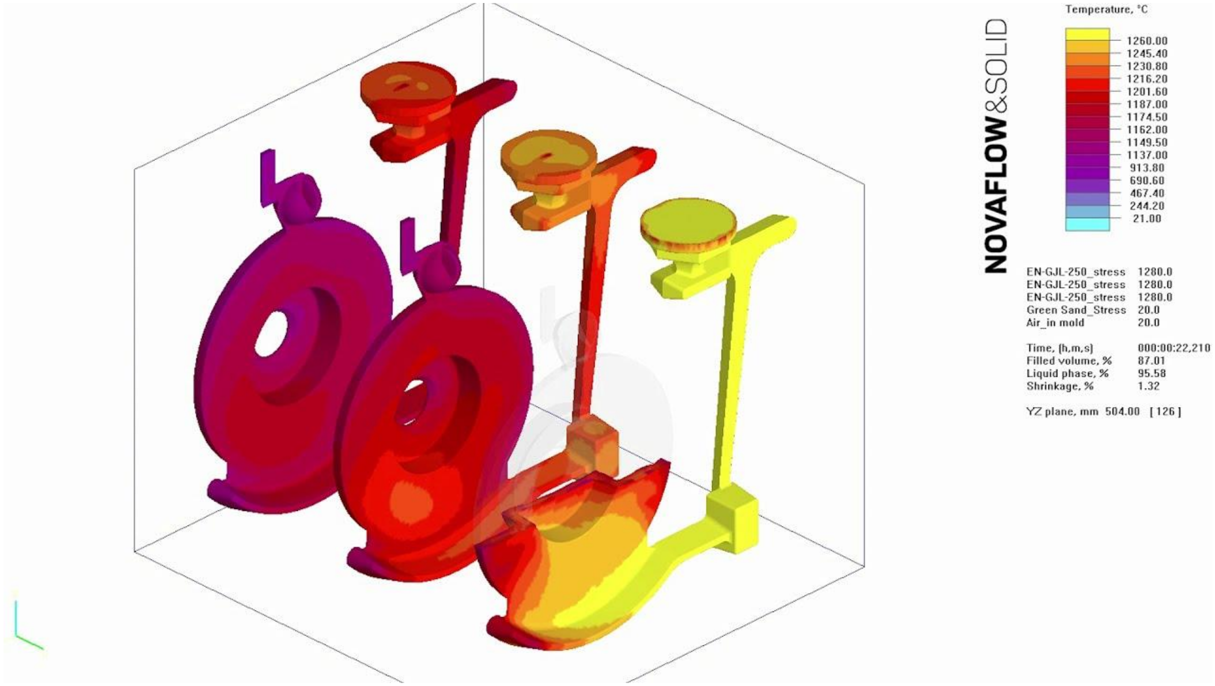
Holding temperature

Too low of a temperature will result in the graphite not being able to dissolve in the melt.

Too high of a temperature will result in the deterioration of the graphite morphology, and hinder proper nucleation.

The proper temperature is dependent on the chemical composition and can be determined with a tool, such as ATAS MetStar.

Cooling rate

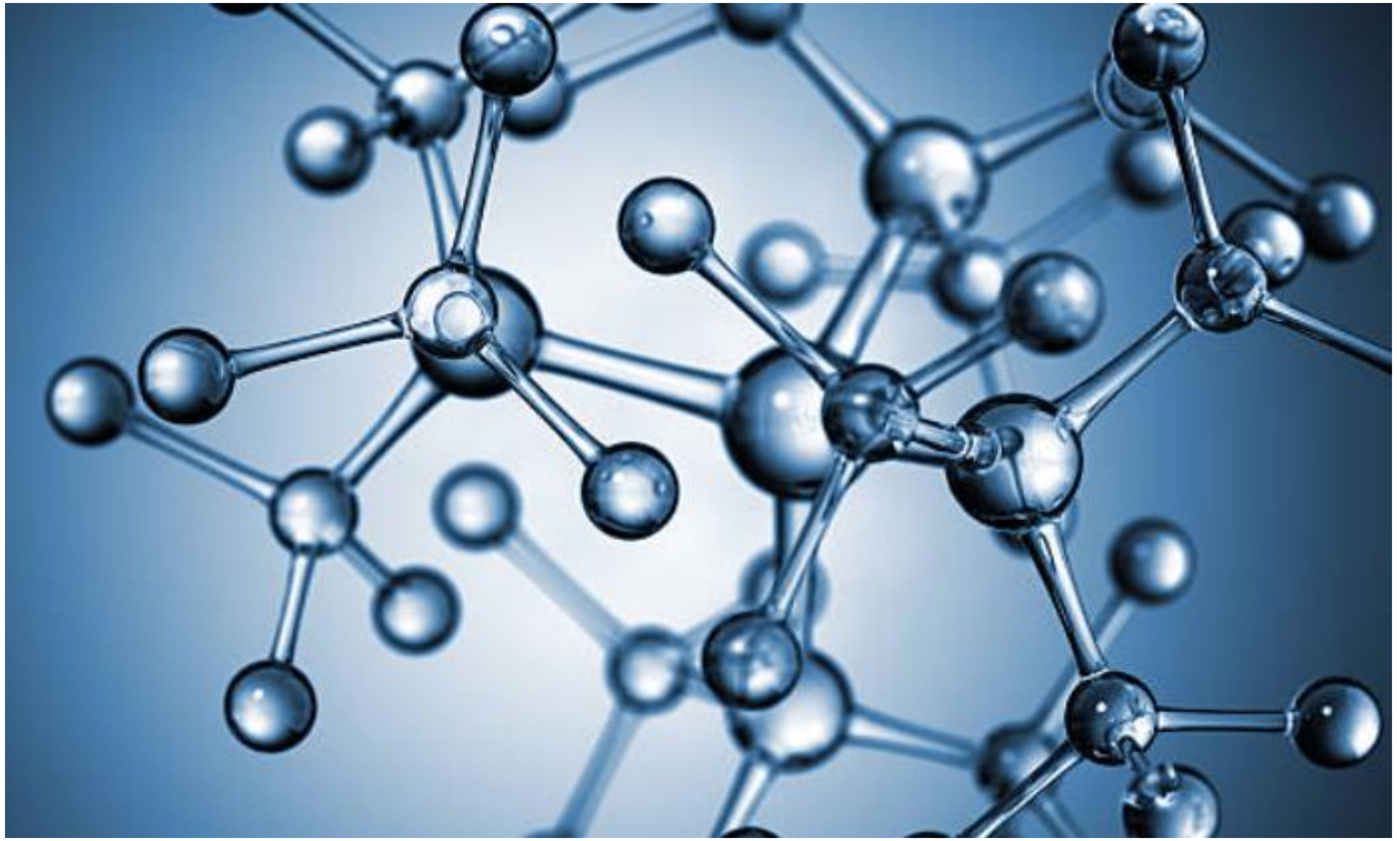


A lower cooling rate will generally promote the graphitization in the casting.

The cooling rate itself is dependent on a number of factors, such as the properties of the mold and the pouring temperature.

Perhaps the most important factor is the thickness of the casting, or in other words, its thermal modulus.

Chemical Composition



Carbon is, for obvious reasons, necessary for the graphitization.

Some elements, such as C and Si, promote graphitization, while others may hinder the graphitization.

Other elements' effect on the graphitization is not as straightforward. Ce and Ti, in very low quantities, can promote graphitization; in higher quantities, they can have the opposite effect.

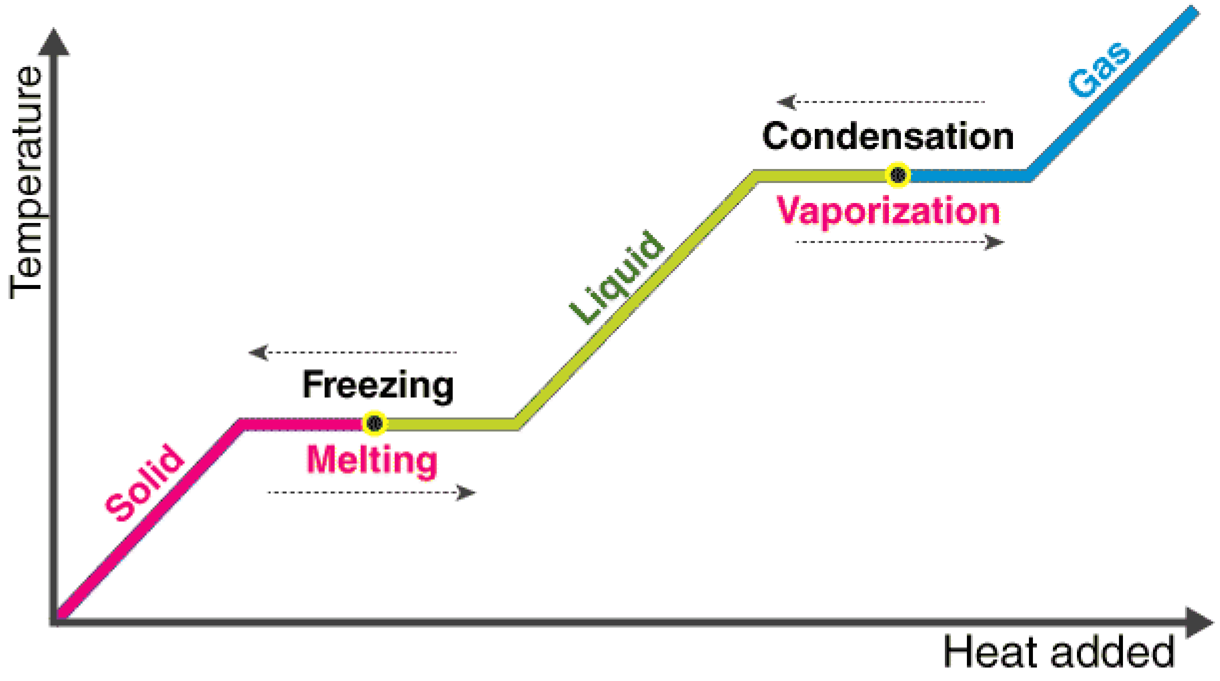
Melter's dilemma

The effect of the chemical elements on the graphitization is complex.

Even having the knowledge of the amounts of all the individual elements, it would not be possible to calculate the total effect on the graphitization.

If only there was a way to measure the effect of graphitization.

Thermal Analysis



When compounds change phase, energy is either absorbed or freed.

In the case of graphitization, the energy released is greater than it otherwise would have been.

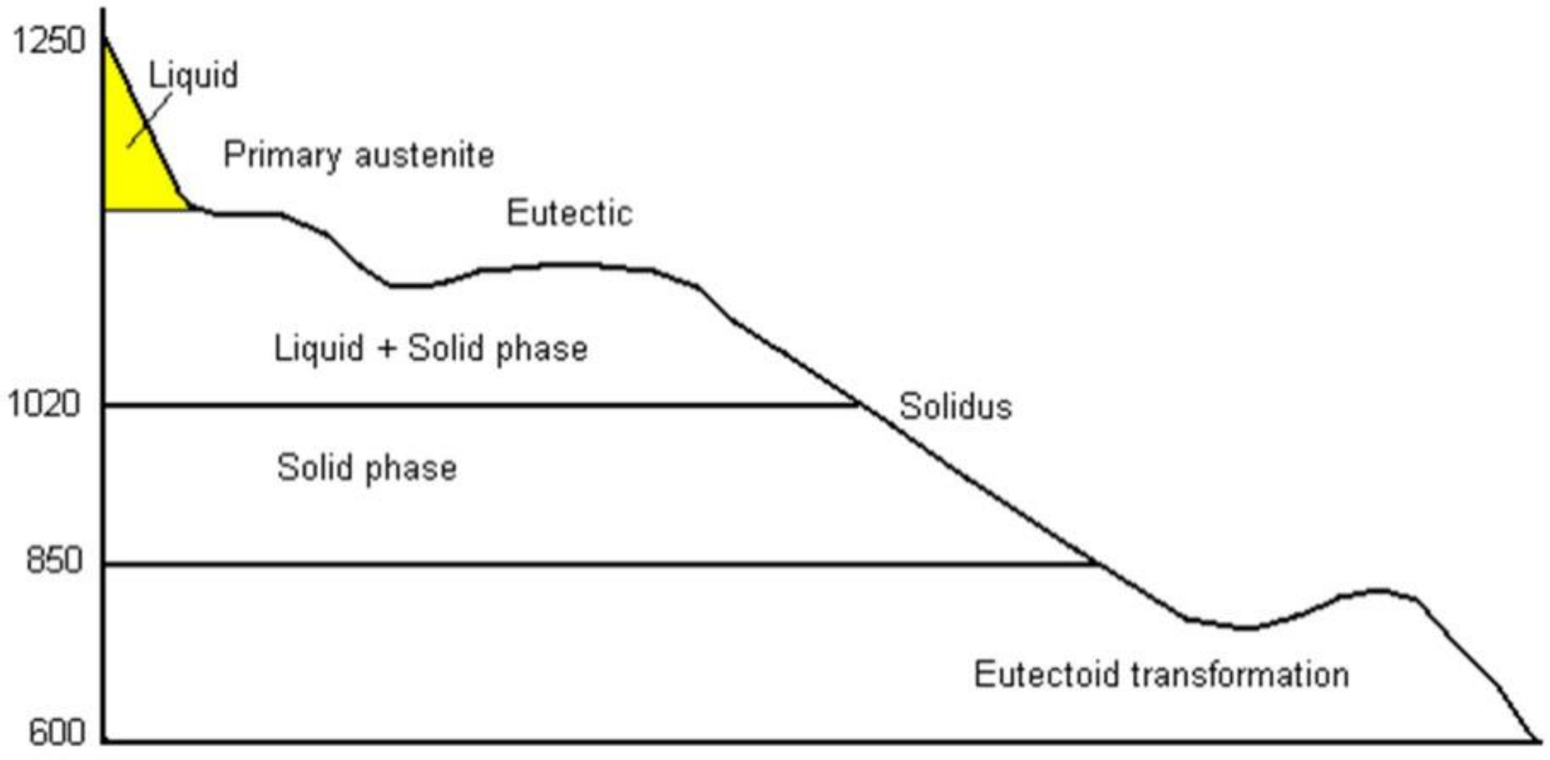
The degree of graphitization could be measured using thermal analysis. This would show the resulting effect of all the chemical elements contained.

Thermal Analysis

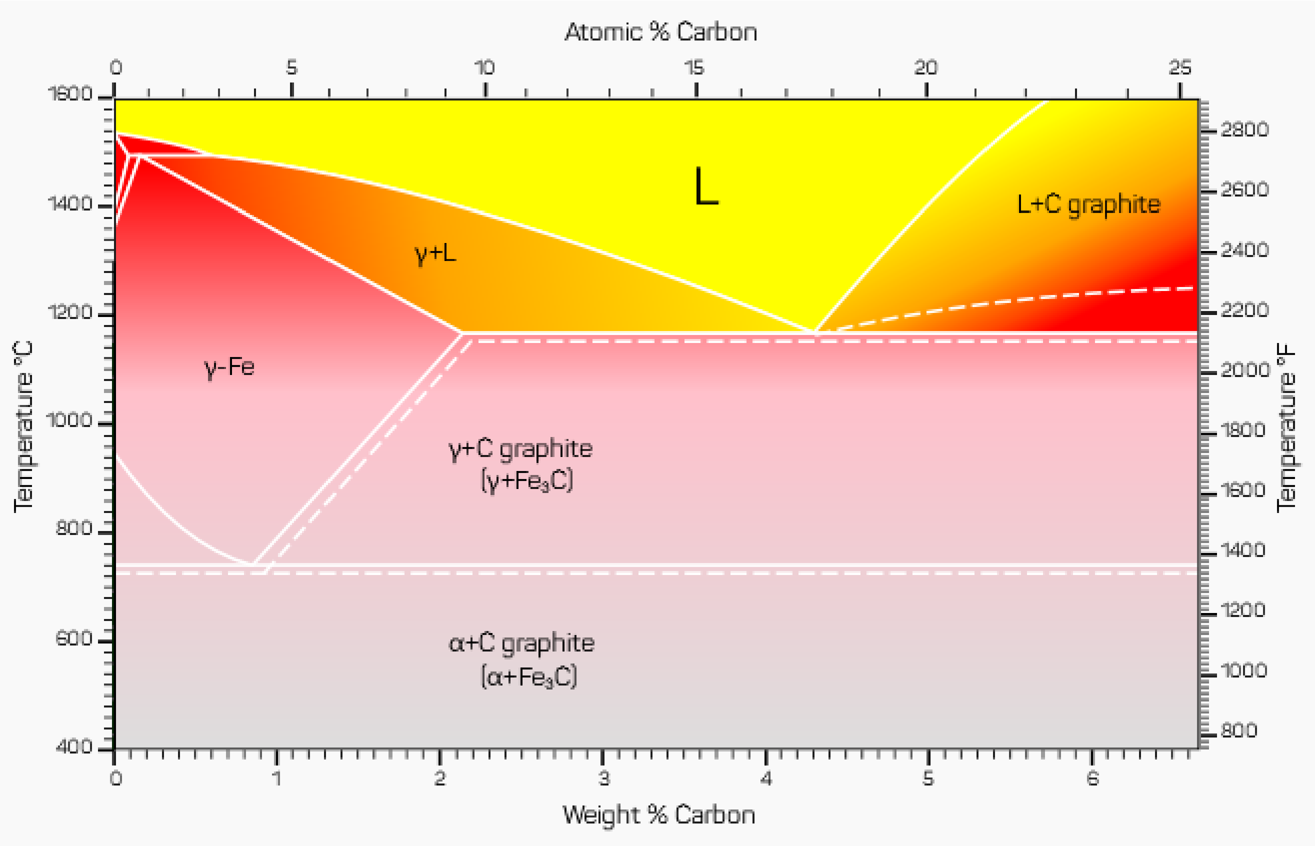
A cooling curve, or temperature vs time graph, has several interesting areas.

Each deviation from the naturally sloping curve is associated with a release of energy.

The points where these relases occur and their extents and durations are a function of the total effect of the chemical elements.



Iron-Carbon Phase Diagram



When compounds change phase, energy is either absorbed or freed.

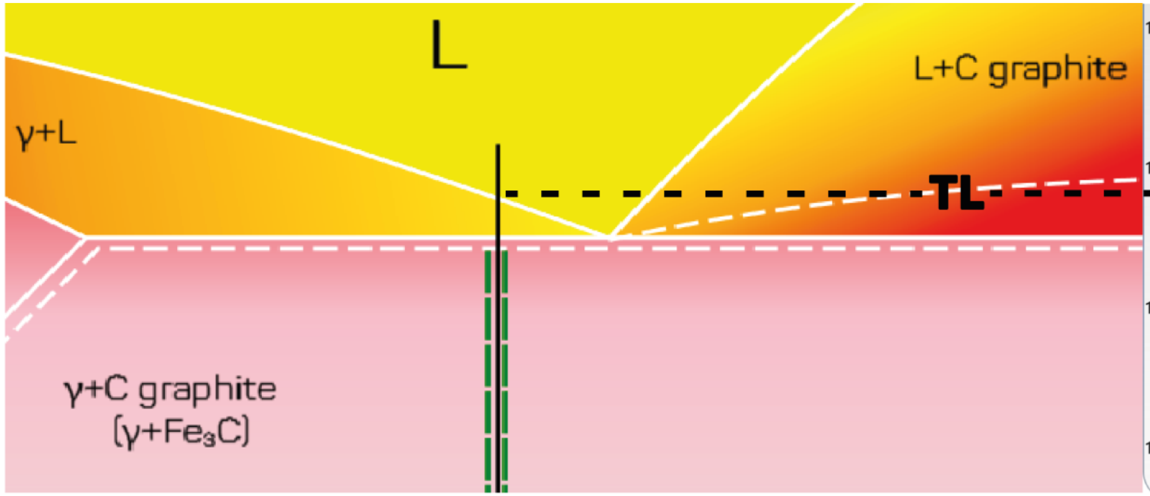
In the case of graphitization, the energy released is greater than it otherwise would have been.

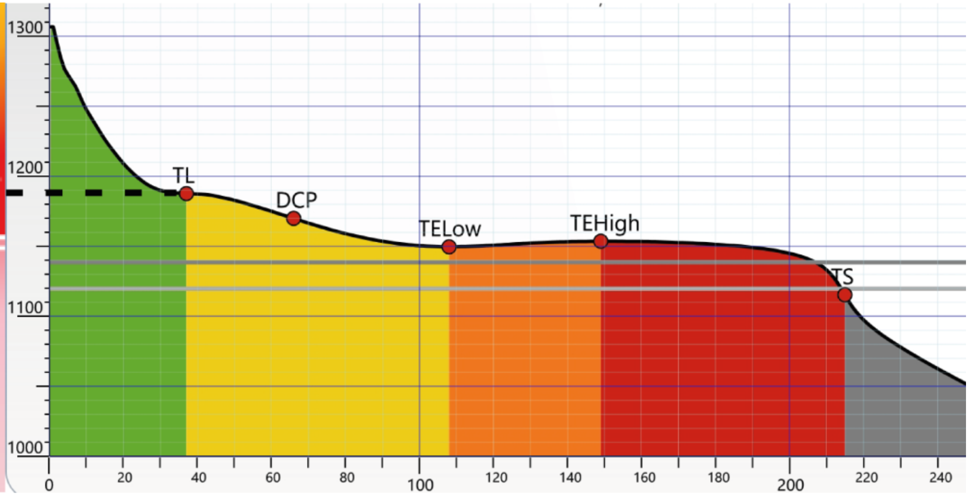
The Fe-C equilibrium is a good reference but is not actually accurate. Thermal analysis shows exactly what your melt chemistry and conditions will produce, based on values for CEL, Grey Eutectic, White Eutectic and amount of undercooling.

Carbon Equivalent

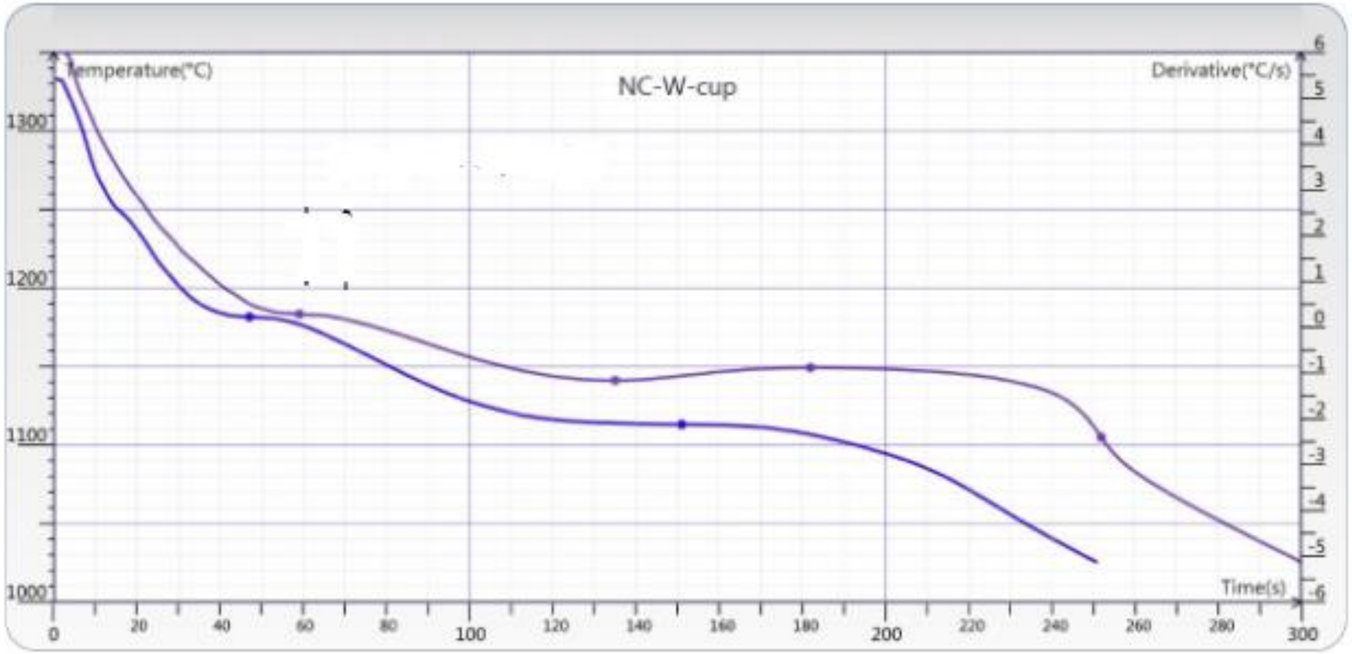
The carbon equivalent gives the total effect of all alloying elements.

Each cooling curve can be traced to the FeC phase diagram, based on TL.





Graphitization



Comparing the cooling curve of a cup with tellurium, which stops the graphitization, and one without, shows the heat release of the graphite formation.

The carbon equivalent gives the total effect of all alloying elements.

Tellurium in cup

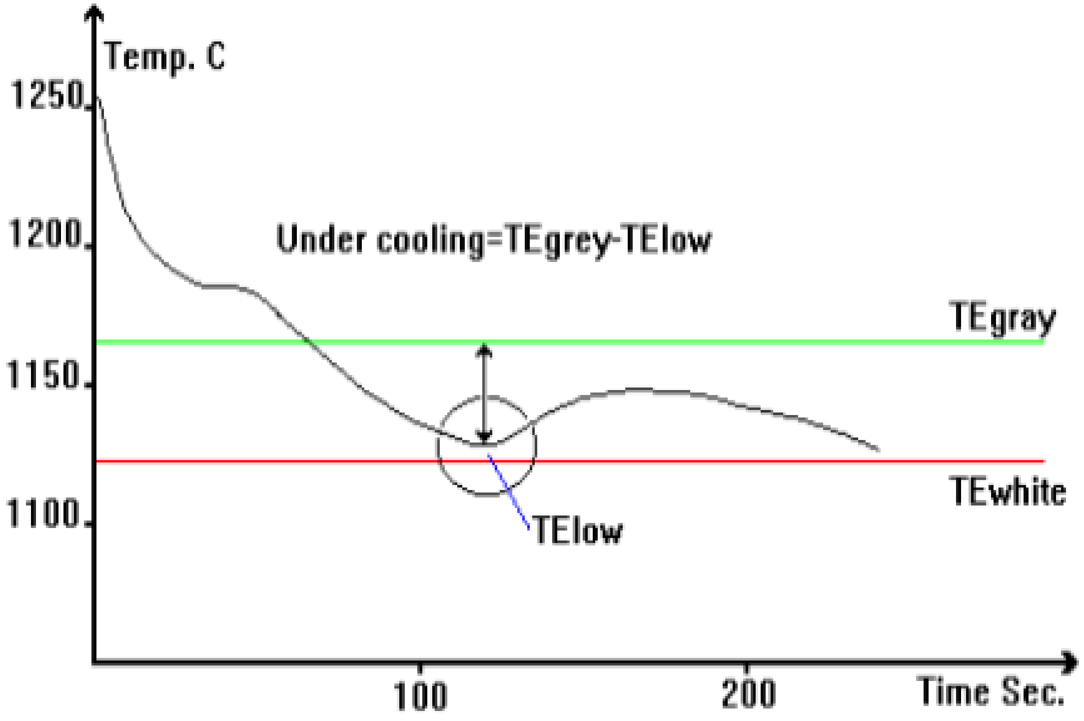
No tellurium

Inoculation

If there are not enough nucleation points to promote the graphitization, it will be delayed and we get undercooling.

TELow is very low.
TEHigh is low.
R is low.

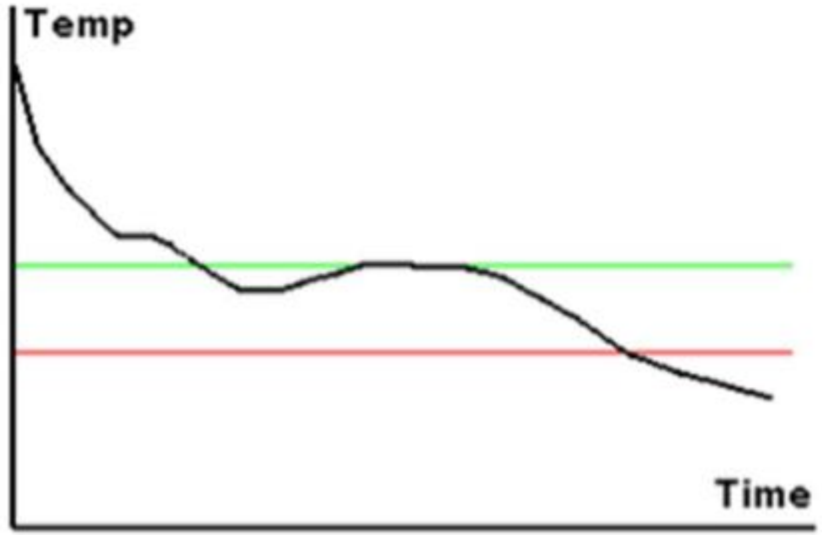
The amount of inoculation has not been optimized.

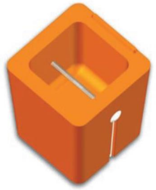


Inoculation

TELow starts at a higher temperature.
TEHigh has reached its full potential.

Graphitization has been maximized thanks to the proper amount of inoculation.





M=0.5cm

M=0.75cm

M=2.6cm

Modulus

Graphitization depends on the cooling rate, which in turn depends on the modulus. Modulus = Volume / Surface Area.

Thermal analysis is done with the same modulus cup, M=0,75cm.

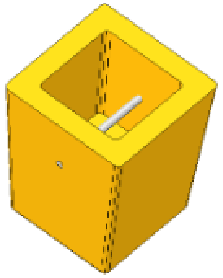
We are not able to have a cup with each specific modulus for each casting.

Practical tests

The modulus of the casting affects the cooling rate, which in turn affects the graphitization. The lower cooling rate promotes graphitization.

The effect is shown in the Carbon equivalent as determined by Thermal Analysis.

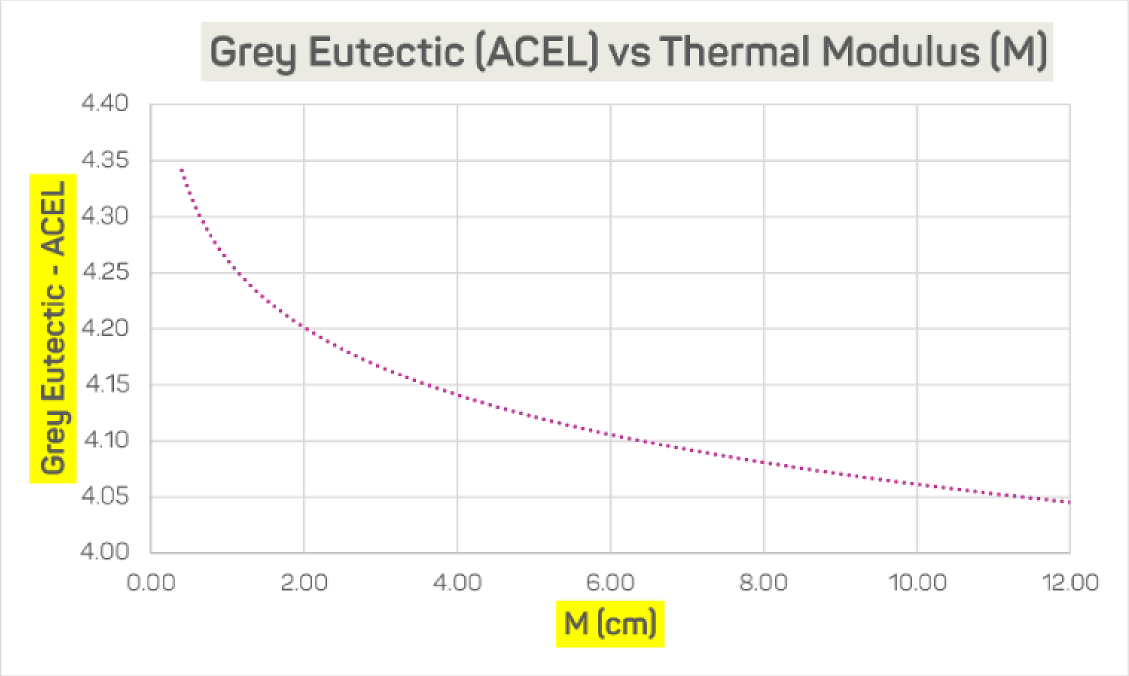
M=0.5cm
Cooling rate:
1.1°C/s



M=0.75cm
Cooling rate:
0.45°C/s

M=2.6cm
Cooling rate:
0.01°C/s

Thermal Analysis and Modulus

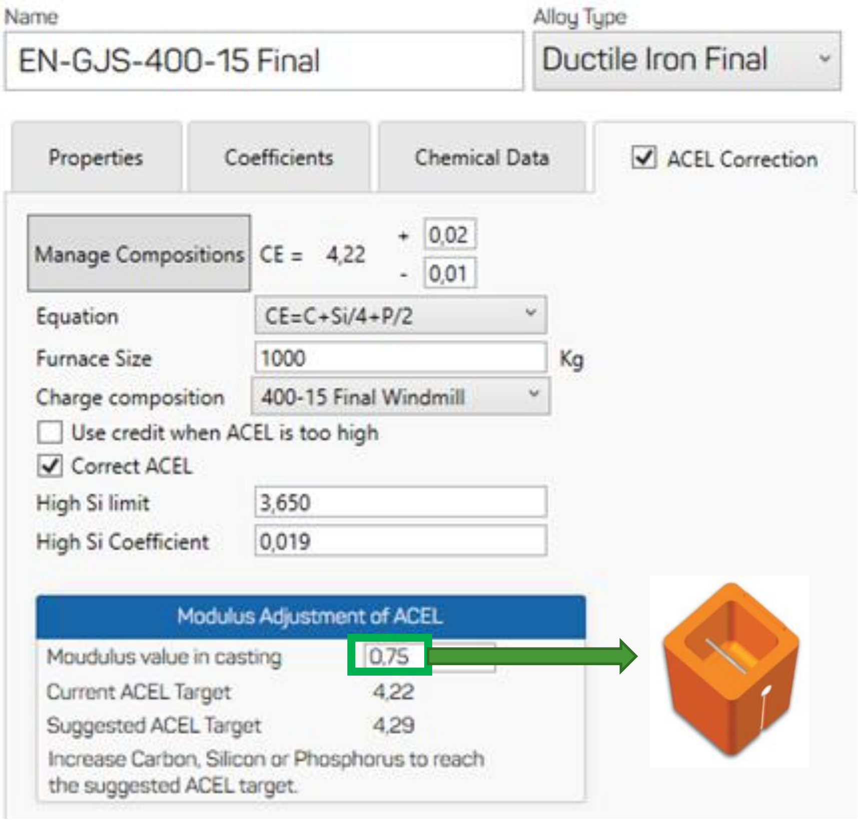


Experiments show that the modulus through the cooling rate has a predictable correlation with the carbon equivalent. The values here are for ductile iron.

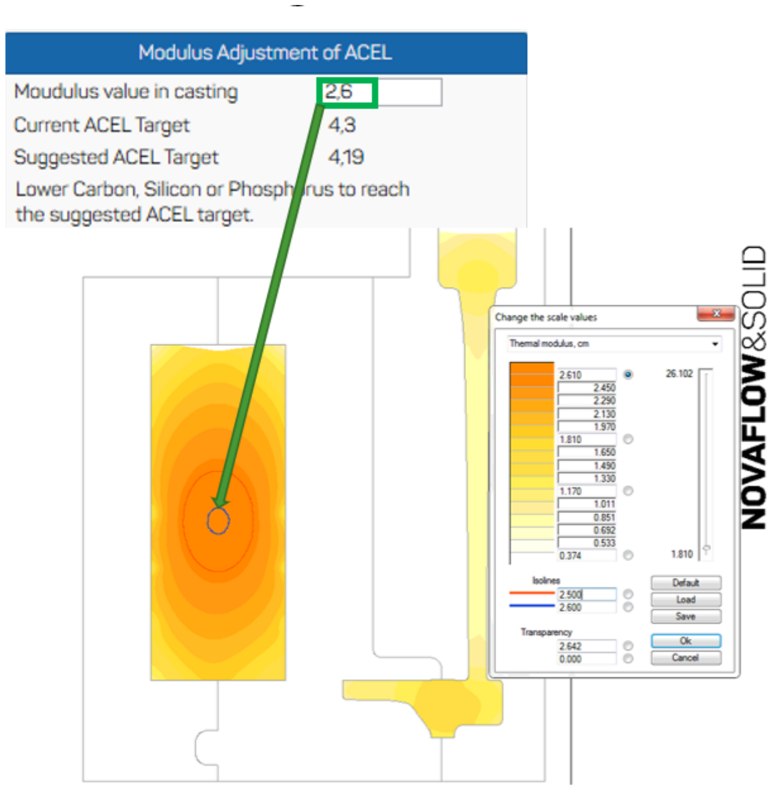
The target ACEL in thermal analysis needs to be adjusted based on the significant modulus of the casting.

Thermal Modulus adjustment

In ATAS MetStar, we can provide the thermal modulus in our casting to determine a new ACEL target for optimal graphitization.



Thermal Modulus adjustment



When we set up for each casting, we can enter the significant thermal modulus.

Together with information about the chemical composition, we can determine a new ACEL target and suggest changes.

Summary

- Graphitization depends on a number of factors;
  - Cooling rate
  - Chemical composition
  - Holding temperature
- Graphitization in turn affect a number of things in the final casting.
  - Mechanical properties
  - Defects
- Thermal analysis is effectively used to show the total effect of the chemical composition on graphitization which is key element (compare to spectrometer) to understand solidification process in cast irons and how to benefit in the best possible way.
- ATAS MetStar can also determine the optimal holding temperature for each casting.
- The cooling rate in the casting also needs to be accounted for, but is unfortunately often overlooked by operators and engineers. Therefore, we strongly suggest using a tool such as ATAS MetStar to actively adjust the ACEL target in the alloy inside ATAS MetStar in order to find ”sweet spot” (eutectic composition) for significant thermal modulus in the casting.

We are here for you:

support@novacast.se

Thank you.