MICROSTRUCTURE BY THERMAL ANALYSIS

Quick answers for Chemistry, Inoculation and Microstructure

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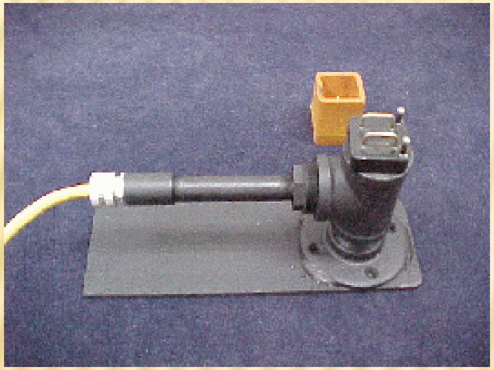
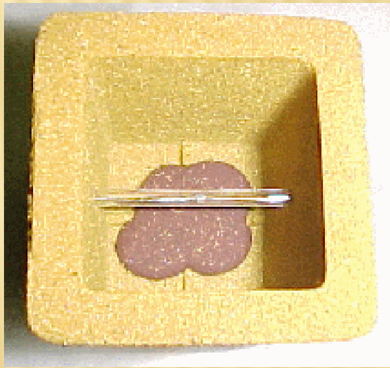
2013

THE PROCESS

Molten metal is poured into a sampling cup containing a thermal couple. May contain tellurium or not.





Takes about 30 seconds of operator time, results ready in 2 to 6 minutes. Example cup contains tellurium for chemistry. Microstructure cups are plain and contain no tellurium.

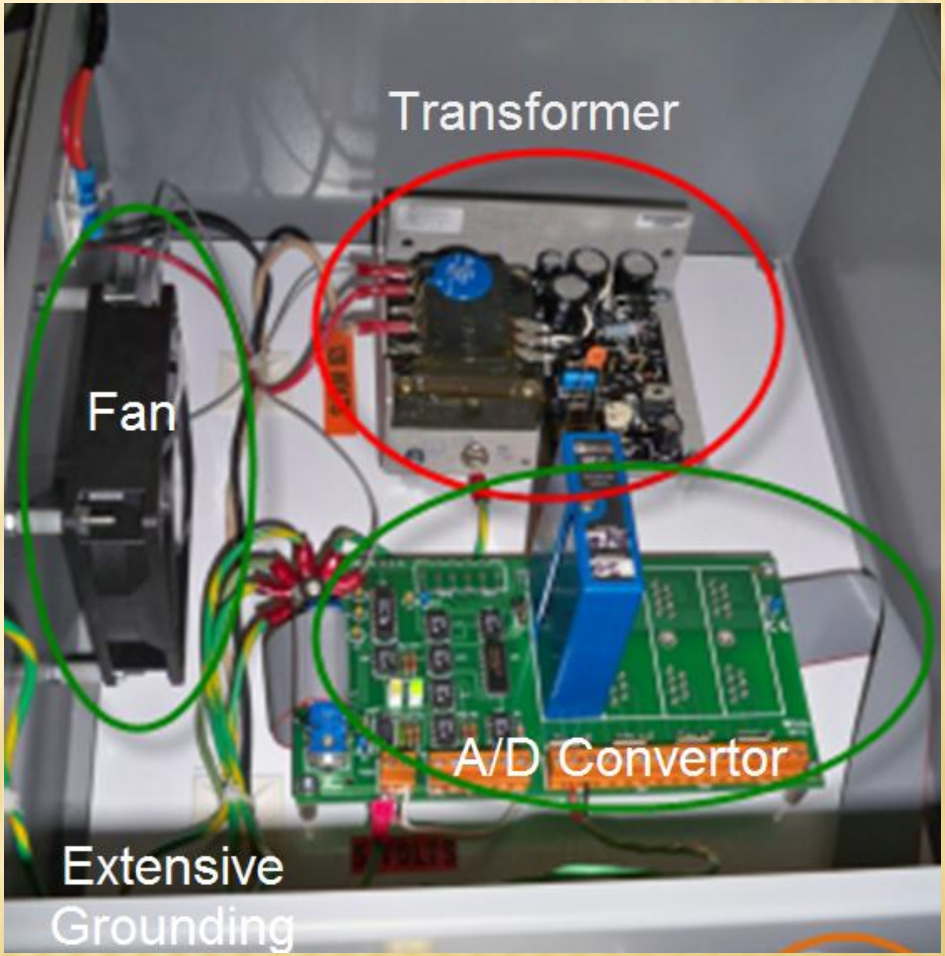
ELECTRONICS SIMPLISTIC IS BETTER

Transformer

Fan

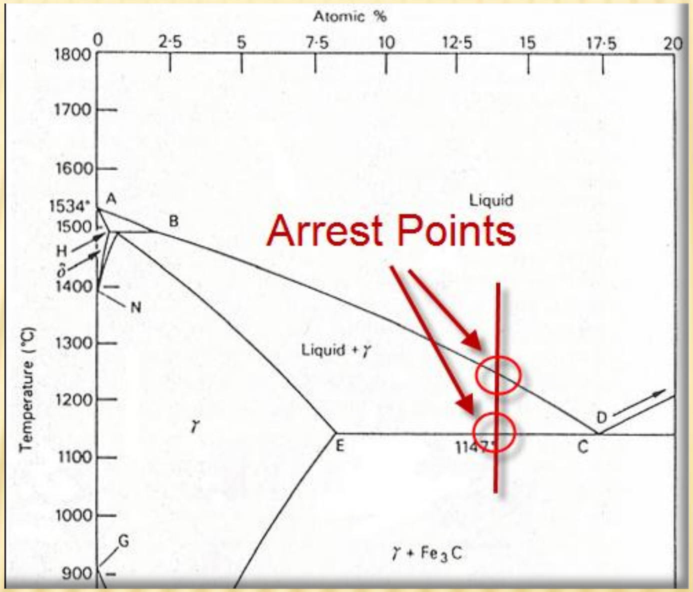
A/D Convertors (1..4)

Extensive Grounding



THE THEORY

Phase diagrams measure the transition points from liquid to solid, from one structure to another.



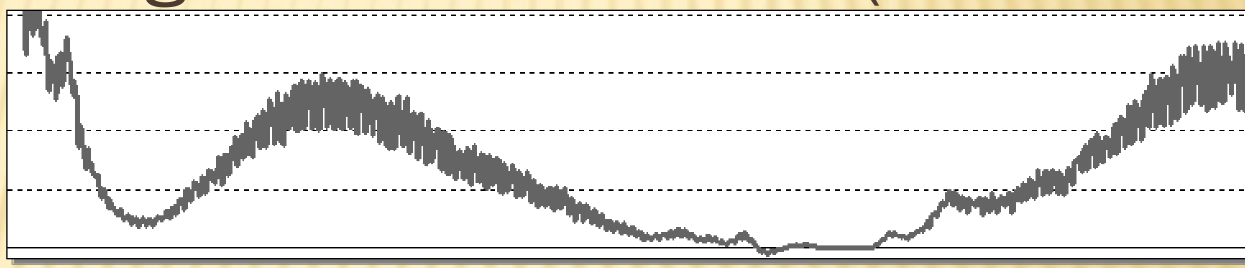
Iron-Carbon phase diagram

IMPROVED DATA SMOOTHING

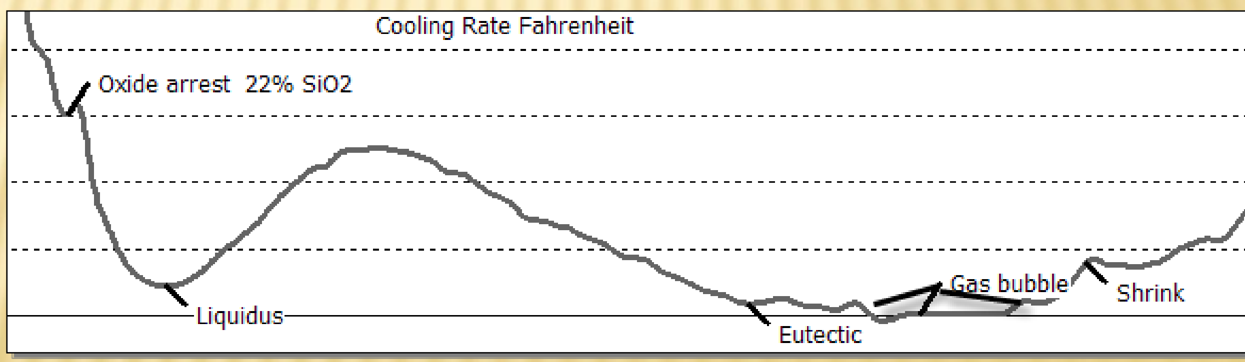
The key to this break though was a new mathematical method of data smoothing.

Cooling Rate of white Iron (tellurium cup)

Before

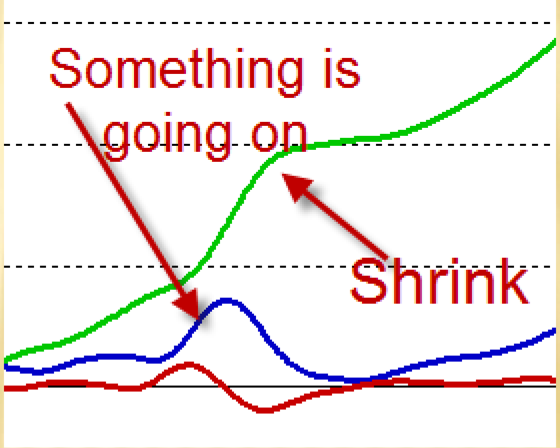


After



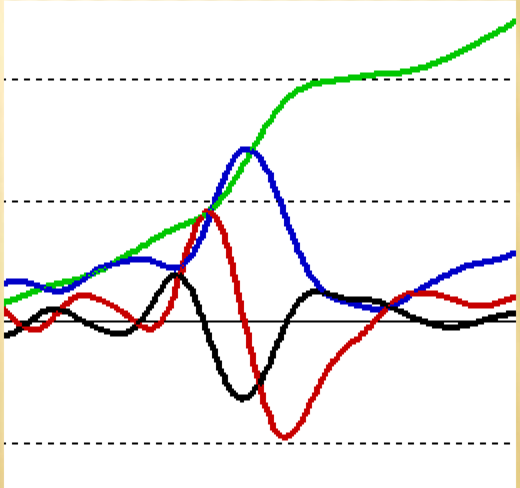
DERIVATIVES DEFINE THE MICROSTRUCTURE

Here a shrink arrest in the green Rate of cooling curve triggers a fluctuation in the 2nd (blue) and 3rd (brown) derivatives due to the steep slope of the green curve.



PUZZELING IT ALL OUT

Here the brown 3rd passes downward through zero indicating a upward bend in the RoC. The blue 2nd is strong enough to warrant investigation. Back tracking we find a downward pass of the 4th to mark the beginning and then move forward to the second downward pass to find the end of the arrest.



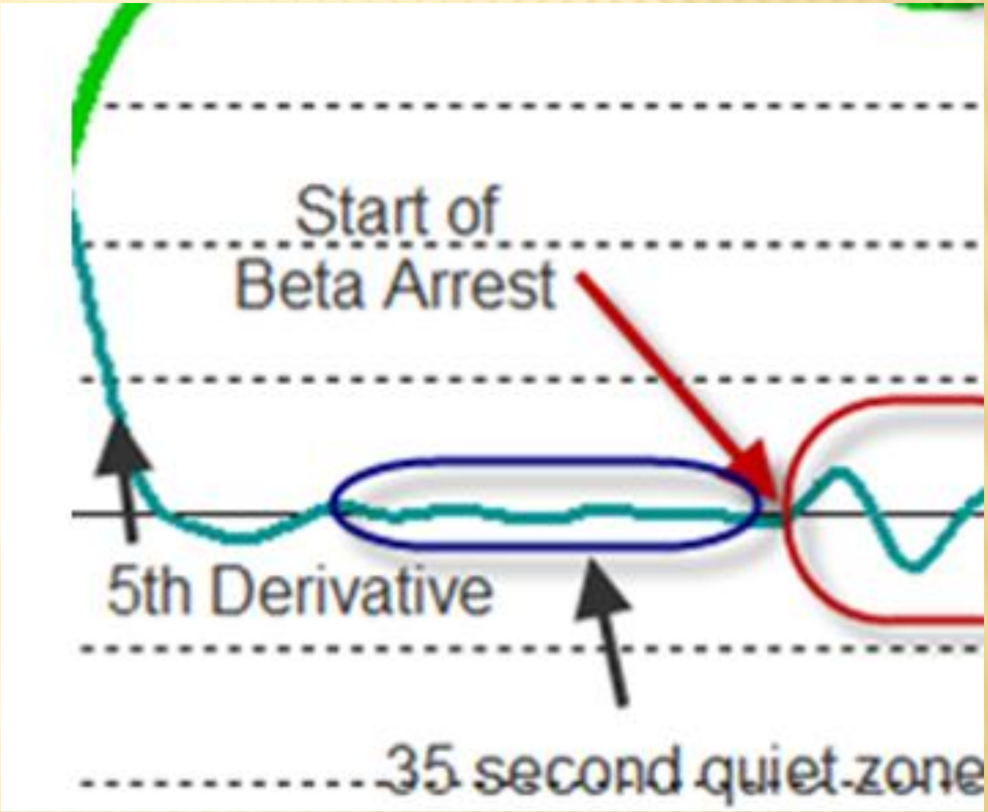
THE MAGIC OF THE 4TH DERIVATIVE

While the 2nd and 3rd derivatives indicate something is happening, the 4th derivative (black) gives the beginning and ending points of the shrink inflection as it passes downward through zero at both the beginning and the ending allowing us to draw a boundary line and integrate the area of the shrinkage.

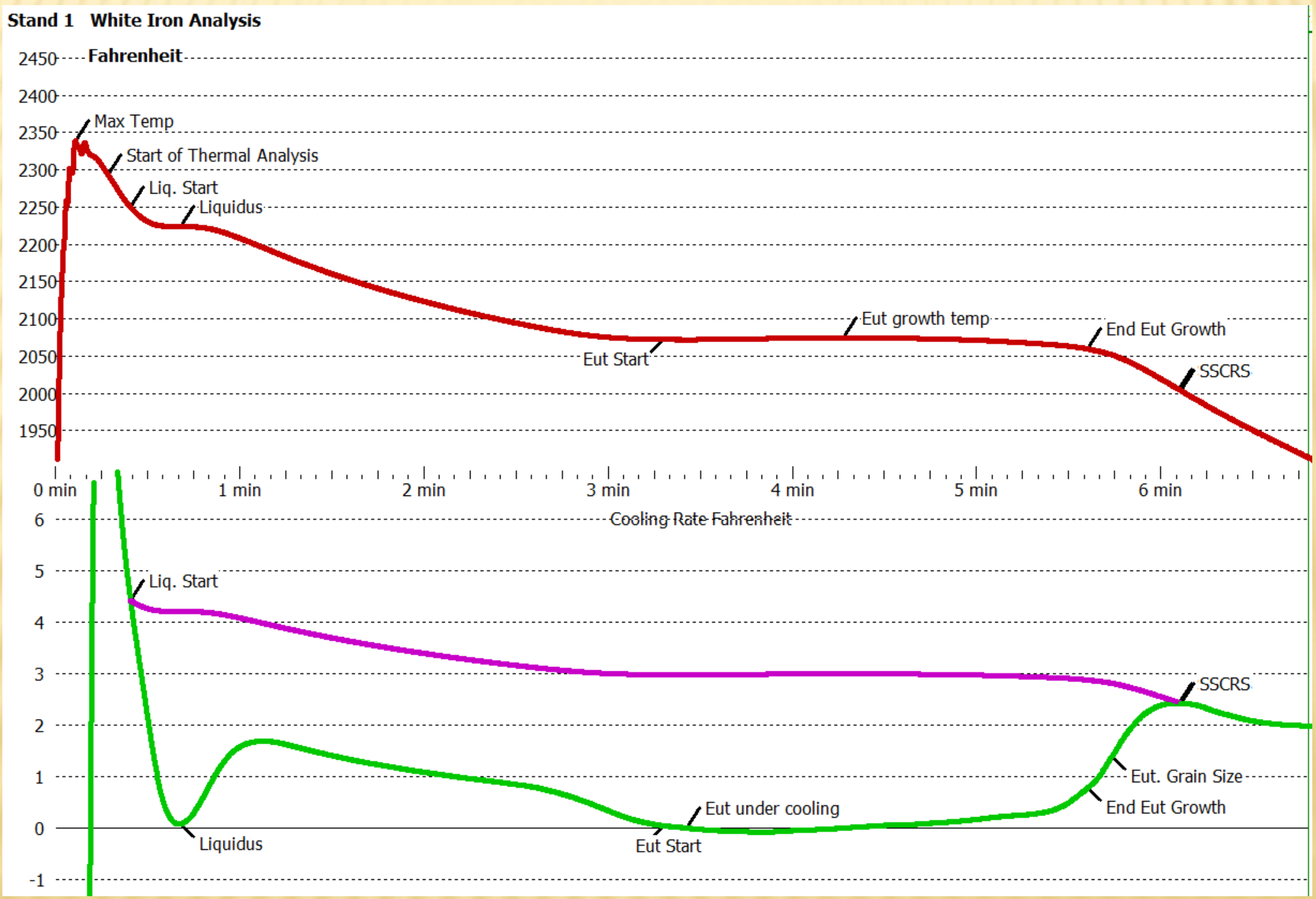
The yellow line is the strong point of the shrinkage.

STANDARD DEVIATION PROVES THE EVENT

Maximum inflection of 5th derivative is 5x the Standard Deviation of the derivative for the 10 seconds before the arrest. This is not noise!



WHITE IRON GRAPHITE CONTROL



2224.0	Liquidus
2074.4	Eutectic
2005.2	Solidus
28.6	G1 secs
55.4	G2 secs
3.74	C.E.
1.9	G2/G1
66.0	% 2nd G
HypoEut	Mode
115	Super Hea
2293	Start TA
2071.9	Eut UC
2074.4	Eut GT
2.4	Eut Rec
0.78	Activity
96	Nodulary
4	Nod Count
34	Sample Qu
97	Ferrite
0.051	Eut Cell Cn
28	Tramps

WHITE IRON TESTING

Larger cup

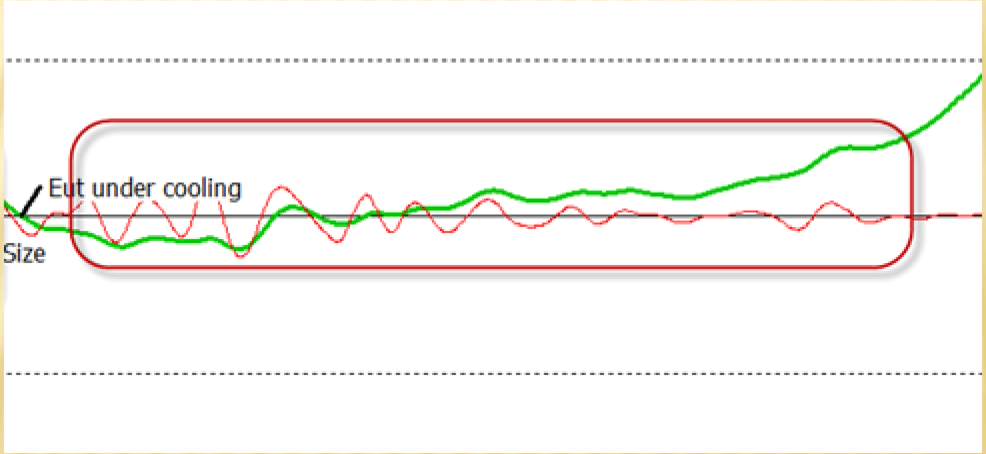
Covered cup with ceramic fiber for longer cooling time

Compared base with inoculated iron by small additions in the cup.

Too much inoculation to be avoided.

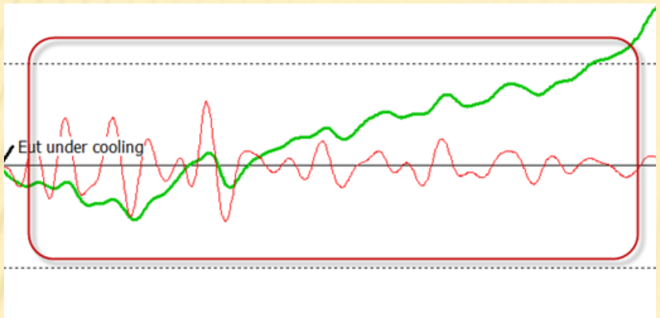
SEEING THE GROWTH OF GRAPHITE IN DUCTILE IRON

During the eutectic of Ductile iron the curve exhibits either a very smooth arrest or a bumpy arrest depending on the nodularity. We believe this is due to the different mode of growth of vermicular graphite from that of spheroidal graphite.

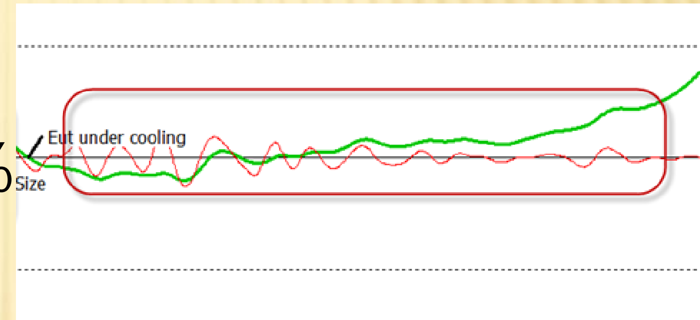


NODULARITY INDICATORS

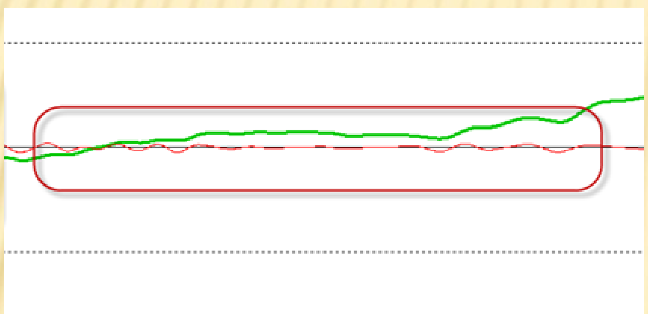
80%



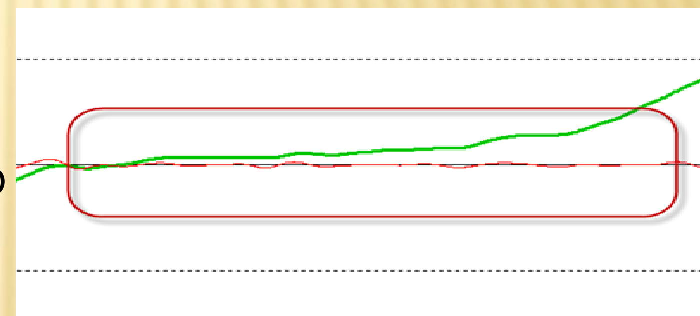
85%



90%



95%



The noise factor (5th derivative) of the eutectic arrest in DI over about 2 minutes for 80, 85, 90 and 95% nodularity. Nosier lines indicate lower nodularity.

NODULARITY CALCULATION

Nodularity = m * Ln(StdDev) + b

Where Standard Deviation =

Sqrt(Sum(Sqr(5^{th} Derivative))/(n-1))

And n = number of data points

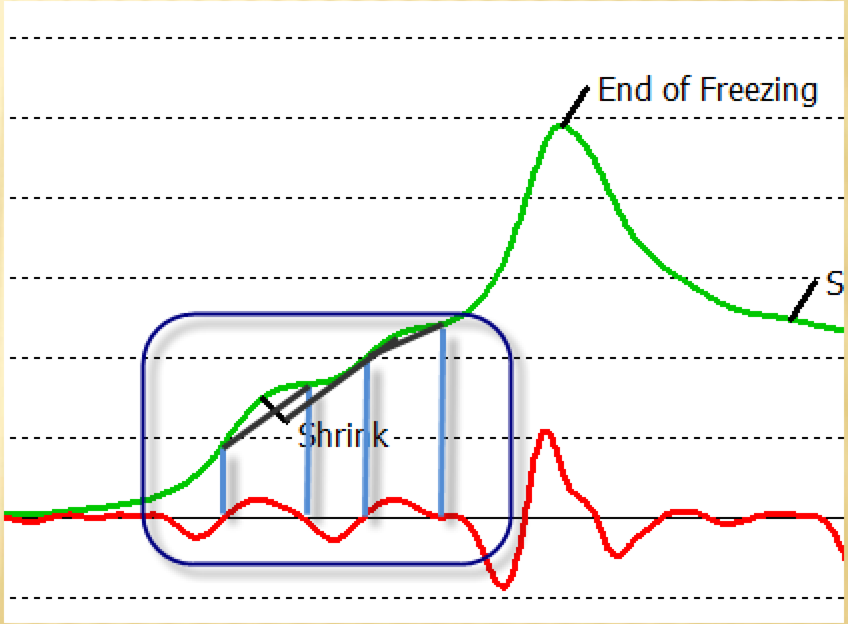
From our experience it seems to work well down to about 75% nodularity. But, it only works with good derivatives…

ENDOTHERMIC (NEGATIVE) EVENTS

While phases form exothermic (heat producing) events, there are also endothermic (heat absorbing) events caused by gas or shrinkage.

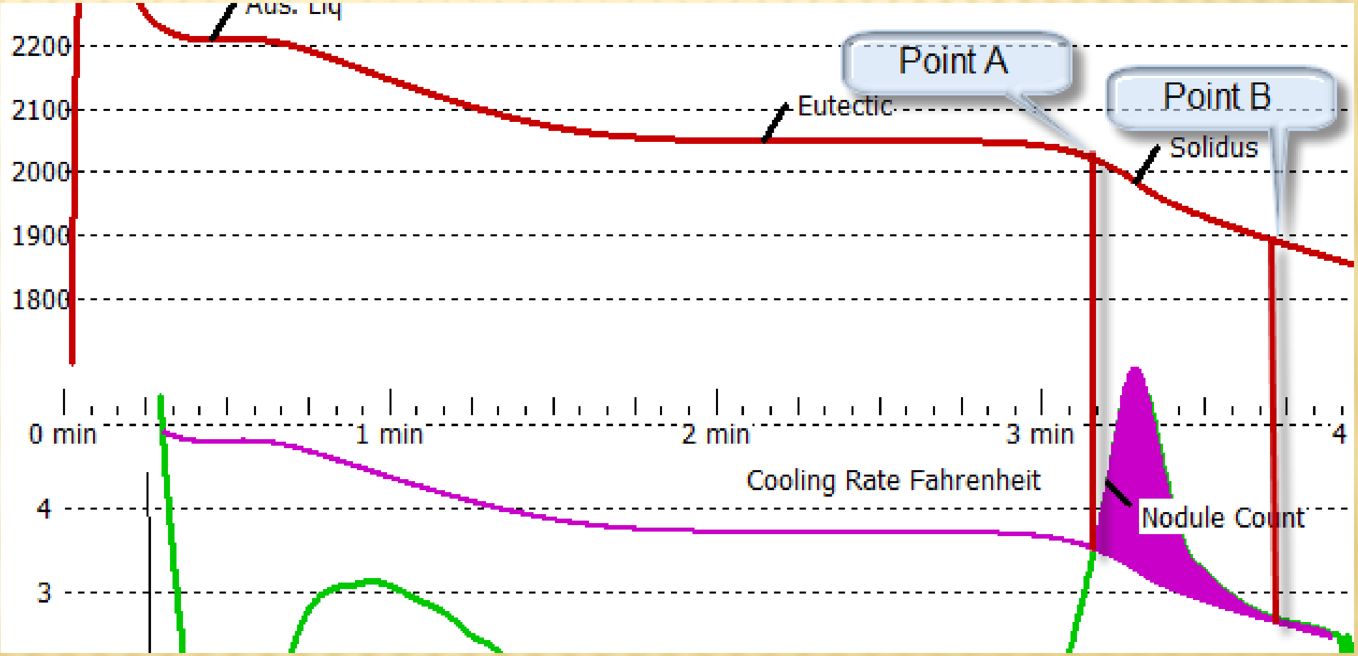
These too can be measured and quantified by higher order derivatives.

More on shrink later.



MEASURING THE STRESS IN DUCTILE IRON

The endothermic (heat absorbing) arrest at the solidus arrest is an important indicator of shrinkage. The stress energy is the area above the zero curve and is inversely proportional to shrinkage.



A NEW THEORY ON SHRINKAGE

The graphite formation in ductile iron is delayed with only about 40-50% graphite growth happening before Solidus.

This leaves a volume deficit in the casting that results in stress manifested in the grain boundaries. This stress is later relieved by further graphite growth.

A NEW THEORY ON SHRINKAGE - 2

Shrinkage or suck-in occurs when this stress is thermally concentrated in one area of the casting, or when a nucleate to shrinkage occurs such as gas or when there has been premature graphite growth in the liquid (graphite liquidus).

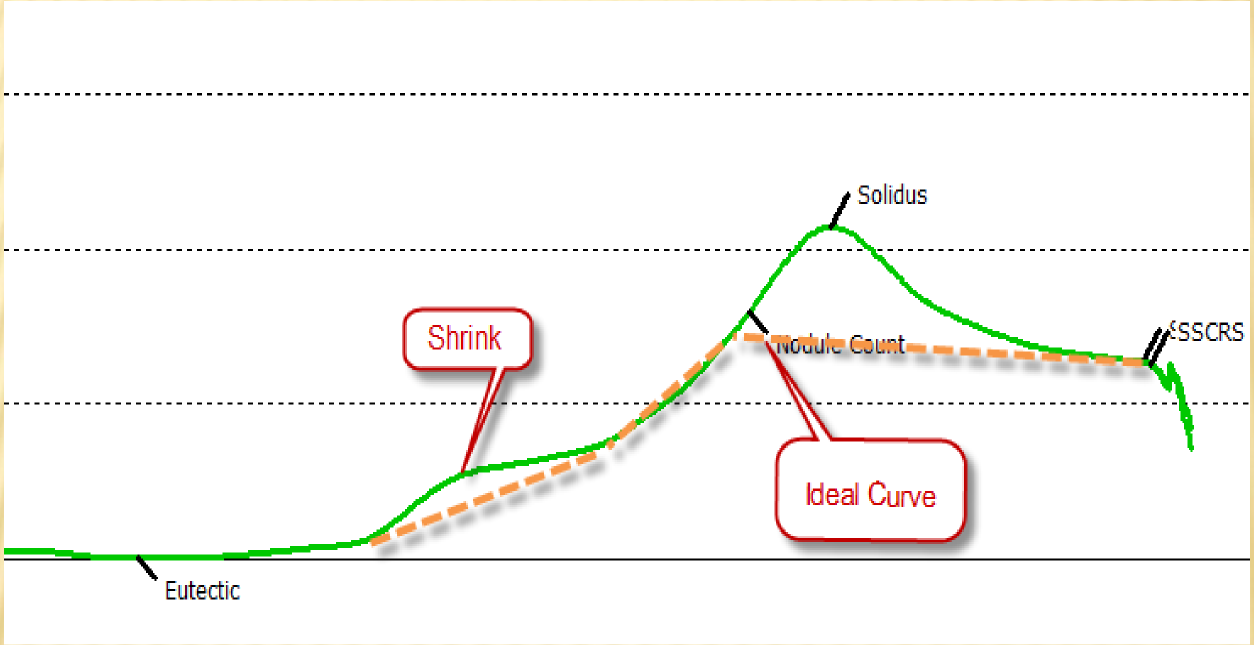
A Graphite liquidus is caused by a C.E. over 4.6 and results in bimodal graphite distributions and solid risers.

THERMAL ANALYSIS AND SHRINKAGE

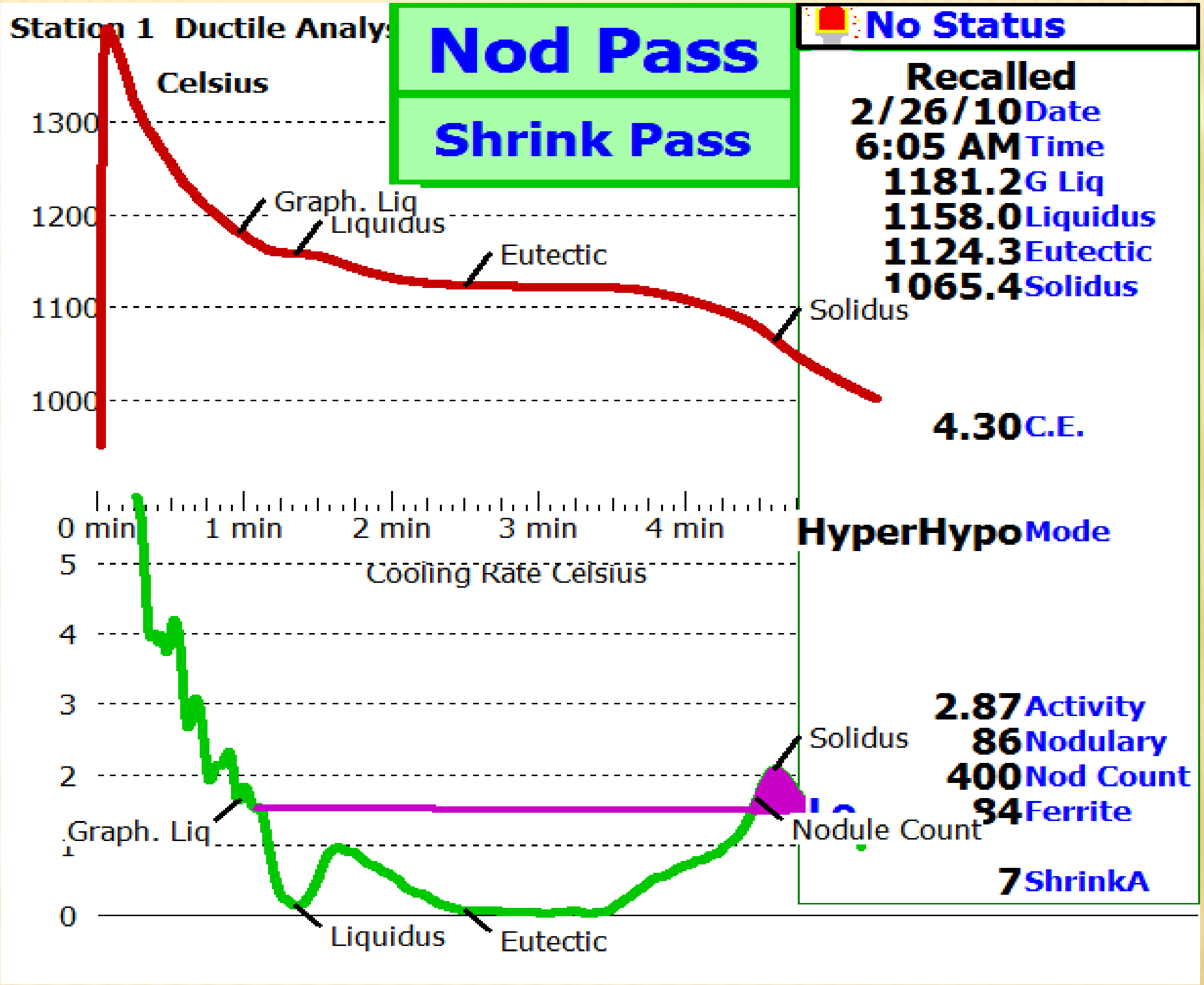
Thermal Analysis can detect graphite liquidus arrests and measure the degree of stress in the solidus arrest giving a predictor of shrinkage problems.

SHRINKAGE REDUCES THE STRESS

Here an actual shrinkage arrest has reduced the stress at solidus.



IRON MICROSTRUCTURE FOR DUCTILE



DUCTILE IRON MICROSTRUCTURE CONTROL

Gating – Gates should feed until solidification starts, then should close off to capture graphite expansion within casting.

Chemistry – determines if graphite grows in liquid (hyper-eutectic), if dendrites block gates (hypo-eutectic) or if eutectic freezing mode (thin walls with possible suck-in).

DUCTILE IRON MICROSTRUCTURE CONTROL 2

Inoculation – early or late graphite, nodule size, excess magnesium, pearlite, carbides. Depending on section size, the degree of inoculation and kind of inoculation needs to be varied.

Interaction of all three – results in either stress or shrinkage.

TUESDAY AM WHITE IRON ANALYSIS