Micro-Energy Analysis

The new “Microstructure”

MeltLab Systems

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***Introduction**: Foundrymen have tried for ages to produce consistency in castings. Strides were made in the 1960’s as electronic spectroscopy replaced wet chemistry. Still nucleation played a role unmeasurable by spectroscopy and many different inoculants have been produced to counter casting problems. In the mid-1900s, Thermal Analysis was introduced to replace flowability tests and later in the 1960’s improved to successfully predict carbon content. Several thermal analysis companies attempted to use pattern recognition to judge the quality of the iron by matching the shape of a temperature curve with past experience. But this fails if there is more than one way to accomplish the physical properties desired. Now, by applying physical metallurgy to the energy given off by solidification on a microscopic scale, it has become possible to detect and measure the properties of a molten metal in a quick test before casting. This gives a consistency to metal preparation that has formerly been unattainable.*

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Micro-energy analysis

Micro-energy analysis is made possible by magnifying the typical thermal analysis curve up to 1,000 times and examining not only the historical arrest points, but also micro inflections seen at these higher magnifications. For example, spheroidal graphite, vermicular graphite, and carbides all have different rates of heat production that can be seen at proper magnification.

Basic Concepts

A concept of signal processing to eliminate noise and use of calculus derivatives and integration are used to parse segments of the curve into phases and the energy they produce provides the analysis. And it is automated to work on the foundry floor in the short time it takes a standard cup sample to freeze. Ranges can be set on desired characteristics to allow better chemistry, inoculation and other treatments to aid in making a quality product.

Differing from the Past – A major step forward

In the past, systems have tried pattern recognition instead of using physics. Systems tried to correlate “bumps” with properties of the product without knowing the meaning behind what they saw.

Today we know that the heat absorbing reactions are shrink and stress buildup in the casting. That different forms of graphite produce heat at different rates. And that stress build-up in castings trigger graphite growth as well as gas bubbles, shrinkage and micro-porosity defects.

And with magnification that can approach 5,000X we can monitor various forms of graphite, gas and porosity formation.

Can we see when the graphite production transition from spheroidal to vermicular to flake? Can we see gas forming bubbles? Can we see shrinkage occurring? Can we measure carbide formation? The answer is yes, we can.

All answers are ratioed against the total heat of solidification (Heat of Fusion) to correct for minor variations in sample size. Detection is possible down to about 0.01% of total energy at better than 95% confidence.

CGI Inflections

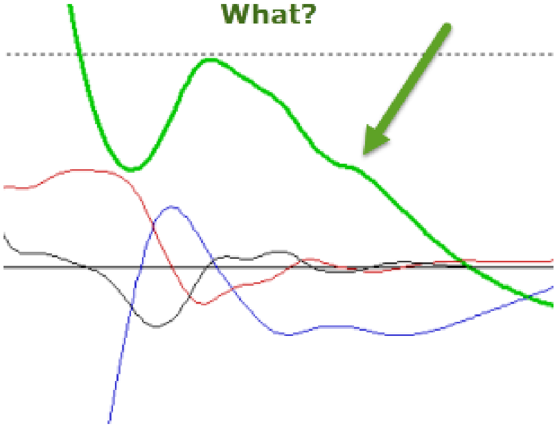
Below in a Compacted Graphite sample with a lab measured 20% nodularity, there is a micro-arrest point showing a slowing of heat production as the graphite formation changes from spheroidal to vermicular. This occurred as the sample approached the Eutectic undercooling. Detecting this micro-inflection makes it possible to estimate nodularity in CG Iron.

An example of a micro-energy event

Here the green curve is the rate of cooling. The first dip is the liquidus and toward the left it moves down into the eutectic. The accuracy of the additional curves can be seen as they correctly find the minimum and maximum of the previous derivatives. Blue tracks changes in the green curve, brown tracks changes in the blue curve, and black tracks the changes in the brown curve.

To the left of the arrow, we are producing spheroidal graphite. There is a pause, and then we move into producing vermicular in this CGI curve.

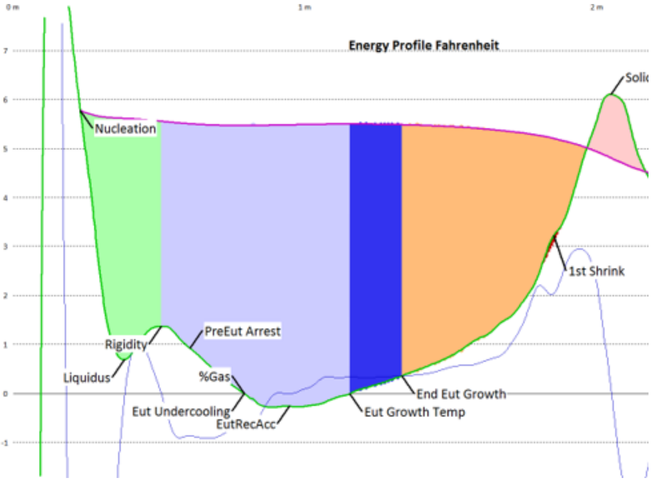
Figure 1 CG Iron Inflection



An example of integration

Here a micro-energy curve is broken down into various phases of dendrite growth, eutectic growth, stress development, and shrinkage. The shrinkage is minor at 0.08% of energy. Fraction solid information is also included. Note the dip in the blue derivative curve at the shrinkage arrest.

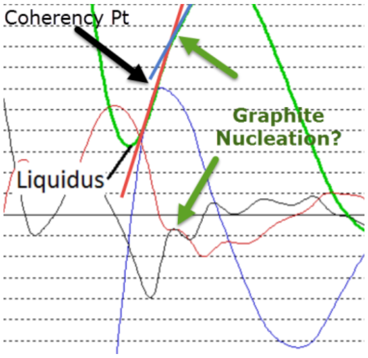
Figure 2 CG Iron with shrink



Nodular Iron inflections

Here is a micro-inflection common in spheroidal graphite formation. The formation of graphite increases the rate of austenite growth. Here, shortly after the coherency point, we see an increase in the rate of heat production.

Figure 3 Beginning of graphite growth in Ductile iron



The oscillation of the 4th derivative during nodule formation as seen in the black curve above is key to understanding how negative internal pressure affects graphite growth in ductile iron and in measuring nodularity.

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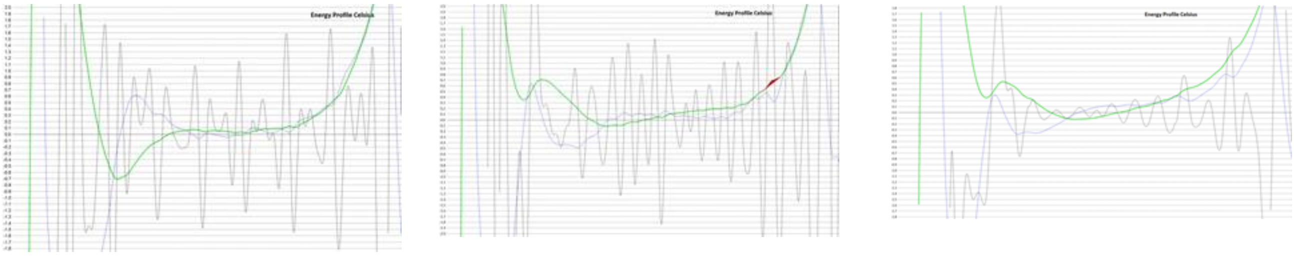
Internal Pressure fluctuation caused by solidification

As the iron contracts during solidification, it creates a reduced internal pressure. This triggers graphite growth which then increases the volume and internal pressure. This sets up an osculation that can be seen in the energy production of all types of iron, though it differs by iron type. Gray iron has a dual osculation that is perhaps tied to the A and B flake. Ductile iron has a steady osculation with a short period. CG iron has a slow osculation with lesser energy.

Figure 4 Gray Graphite, Ductile Graphite, CGI Graphite



Pre-eutectic Carbides for Pump housings

Wear resistant castings often use this form of carbide to impart wear resistant to thin sections of castings to increase the life of a pump or other component in a slurry system. These arrests occur around the rigidity point and in thin sections of a pump housing. This locates them away from most machined surfaces yet gives the pump increased wear resistance.

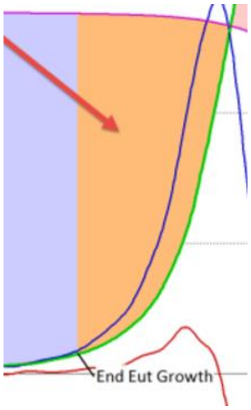
This area can be measured to assure consistant carbide content for good quality pump housings.

Figure 5 Pre-Eutectic arrests

White Iron Carbides

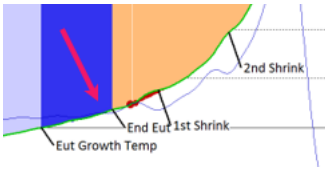
White iron depends of achieving strength and hardness by the amount of carbides. The amount of carbide correlates with several indicators in the micro-energy analysis. But the simplest one is the percent area after the End of Eutectic Growth.

Figure 6 White Iron Carbide content



Point of Maximum Stress – the EEEG Point

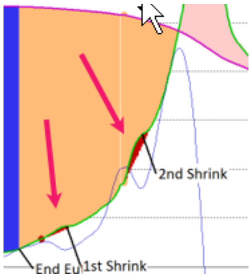
Figure 7 End of Eutectic Energy Point



As pointed out by several stress experiments, the maximum internal stress is reached shortly after the eutectic point and before the solidus point. We have identified this as the End of Eutectic Energy Growth or EEEF point. Shrinkage arrests occur after this point in order to relieve stress. Post-eutectic carbides also form after this point.

Shrinkage Arrests relieve stress and adsorb heat energy

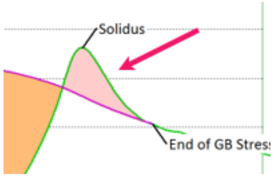
Figure 8 0.25% Shrink (two arrests)



Shrinkage and suck-in are responses to internal stresses within the casting. If stresses grow too large, then voids form to relieve the stress. Likewise, non-wetting impurities can lower the threshold of stress required to nucleate voids. Increased earl graphite nucleation during solidification can reduce stress and prevent shrinkage. Note: graphite formation while the gating system is still open increases the chance of shrinkage.

Residual Stress vs. Shrinkage

Figure 9 Grain Boundary Stress Energy



Gray iron, CG iron and Nodular castings can store their stress energy in their grain boundaries avoiding or at least minimizing micro and macro-shrinkage. The larger this energy is, the less shrinkage and micro-shrinkage occurred. The ideal energy of this residual stress depends on the chemistry/grade of material. If the casting can put it's stress into the grain boundary, the graphite growth between eutectic and eutectoid will tighten up the grain boundaries and produce a solid casting.

Conclusion:

Micro-Energy analysis opens a new method of quality control for irons including inoculation consistency, shrink, magnesium treatment, and carbide control in Gray, Ductile, CGI and White Irons. We welcome foundries with challenges to resolve, and researchers who want to explore.

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P.S. You ought to see what we do with aluminum alloys…