FOUNDRY SOLUTIONS
& Metallurgical Services Inc.

The Future and Present of Thermal Analysis of Aluminum

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Outline

- Introduction
- Thermal analysis principles
- Data analysis with derivatives and integration
- Aluminum approach and examples
- Ductile iron approach and examples
- Conclusion
- Questions

Who are you?

- Little poll to adjust my presentation
- What type of foundry are you ?
  - Ductile and grey iron ?
  - Aluminum (low pressure) ?
  - Aluminum (high pressure) ?
  - Steel, allied steels, wear resistant iron ?
  - Magnesium ?

The company

- Foundry Solutions & Metallurgical Services Inc.
  - We’re metallurgists working with foundries and casting users
  - Foundry Services and consultants
    - Process Improvement
    - Project leader
    - Training
  - Distributor and Services provider of
    - **Thermal Analysis with** MeltLab® Systems
    - **Design and Process simulation Software with** Finite Solutions Incorporated

Do you know our Casting Defect app ? www.castingdefect.com

AFS Conference theme

- Foundry challenges and futures in western countries
  - More competition coming from China and India
  - Decrease its cost and increase casting quality
  - Decrease delay and offers good customer services
  - Workers qualified less available
  - Investment in new equipment and process improvement

- What makes a Foundry in the communication age ?
  - Open-minded for new ways to do and adapt yourself
  - The world is your market, and the world is already here.
  - Real-time follow up your casting, quality, delivery and give excellent service to your client
  - Be Flexible and have fast delivery when needed
  - Use fast prototype and 3D technology

New basics for a modern foundry

- What should do a modern foundry?
  - Should use technology to measure and control every process variables
    - Wireless technology, connected Device, On-Line probes
    - Modern analysis equipment (As Thermal analysis system)
    - Updated parameters for operator
    - Process control (SPC)
  - Should collect and analyze data
    - Database and quality indicators
    - Big data analysis
  - Should have an efficient quality system
    - Casting defect and root cause analysis
    - Training team with new method and parameters

Thermal Analysis- a quality tool

- It's a powerful tool to measure and predict melt quality and casting defects.
- It's the fingerprint of the solidification process, and best allied of metallurgists.
- It can be used as quality control to adjust melt before pouring
  - Chill measurement, nucleate potential, shrinkage tendency (iron)
  - Modification and grain refinement levels (aluminum)
- It can be used as a process tool to adjust addition or find the best product. There is **potential saving** in your melt.
  - Additives as refiners, nodularizers, modifiers, inoculants
  - Adjustment of foundry return or second grade alloy

Do you let suppliers find the best product for you?

Thermal Analysis- Principles

- As the metal turns solid, all the heat energy that went into melting is released.
- Every transformation has different energy release (or absorb) that affect cooling curves.
  - Number of seeds, grain sizes, dendrites formation
  - Phase transformation
    - Liquidus, eutectic, solidus
    - Perlites, carbides, graphite forms
    - Beta crystal, Al-Si, MgSi, AlCu, etc.
  - Exothermic and endothermic events (shrinkage, oxides)
  - Even small event like void, gas or bubbles
- It works for any metal!

Base Iron chemistry Analysis

- Oldest use of TA (since 1931)
- It needs a tellurium cup (Ask for new Meltcup®)
  - Tellurium will prone white iron solidification
- Carbon equivalent, carbon and silicon are measured
- Carbon by TA is more accurate than by spectrometry. About equivalent to combustion analysis.
- Silicon needs to be adjusted by Spectro but it’s fastest. Can be used when Spectro is down.

Meltlab Aluminum TA Stand

- Stand design for foundry better than old Pechiney Stand
- Same reusable steel cup to hold molten aluminum
- Reusable thermocouple probe and easier to change
- Quartz glass tube for sleeves instead of steel (cheaper)
- More intuitive handle
- Very simple thermocouple holder

To ensure reliable results,

we need a stand

robust for the foundry.

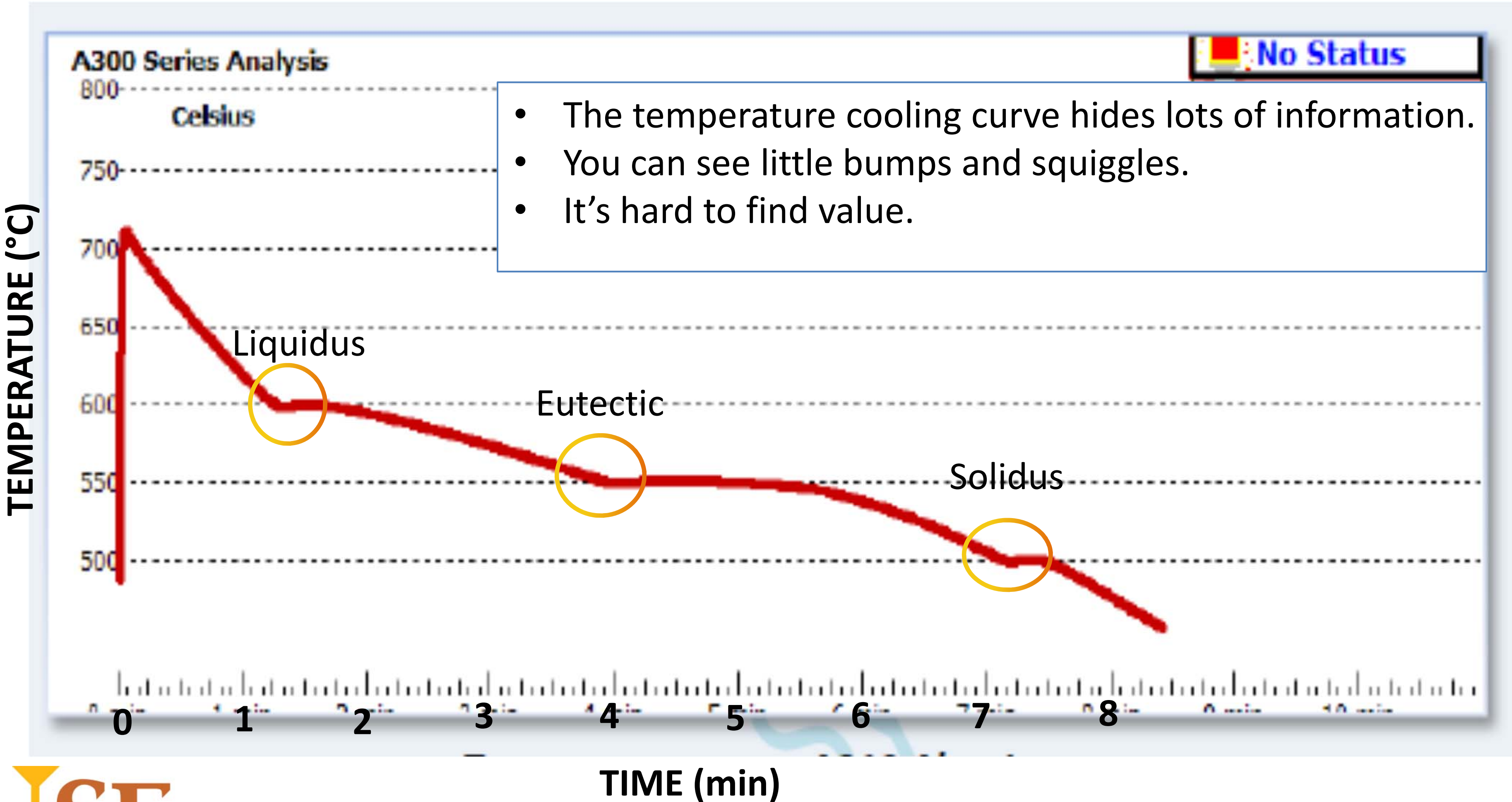
Derivatives are the microscope of TA

- Calculus, derivatives and integration, was invented by Newton.
- We use them to extract information from data in a reliable way automatically (by programming).
- Each derivative increase the magnification of variations in temperature showing smaller and smaller precipitants.
- The rate of cooling (1st derivative inverted) is used to find the strongest point in an arrest.
- Second derivative shows minor arrest and shrinkage activity
- Third, fourth and fifth derivatives are used to find the start and stop of a phase for integration purposes.
  - Heat proportion, phase proportion
- The zero energy curve is used with integration to calculation energy proportion of phases.

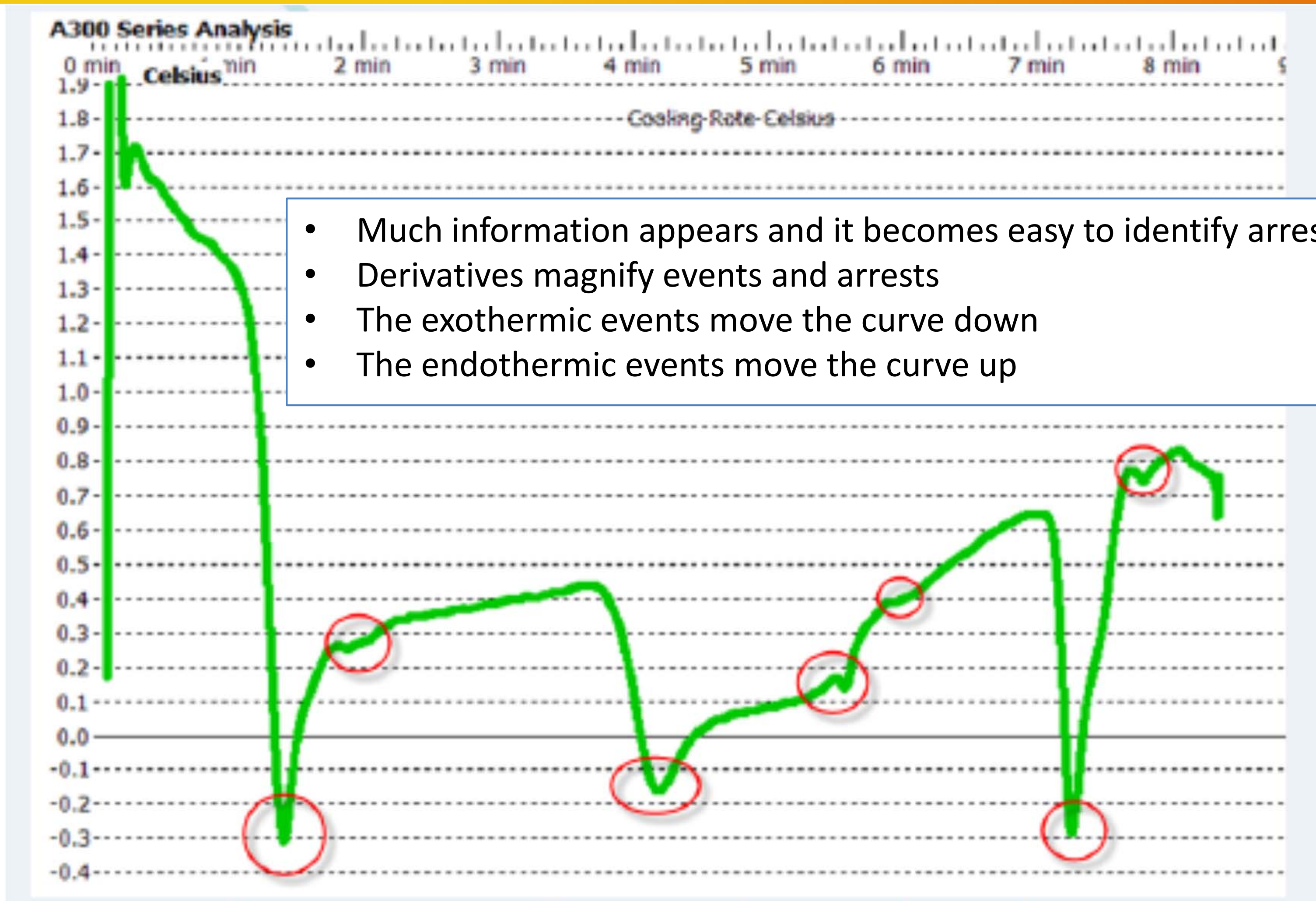
The zero energy curve is based on technical works by Jerry Sokolowski

Temperature cooling Curve

- The temperature cooling curve hides lots of information.
- You can see little bumps and squiggles.
- It’s hard to find value.

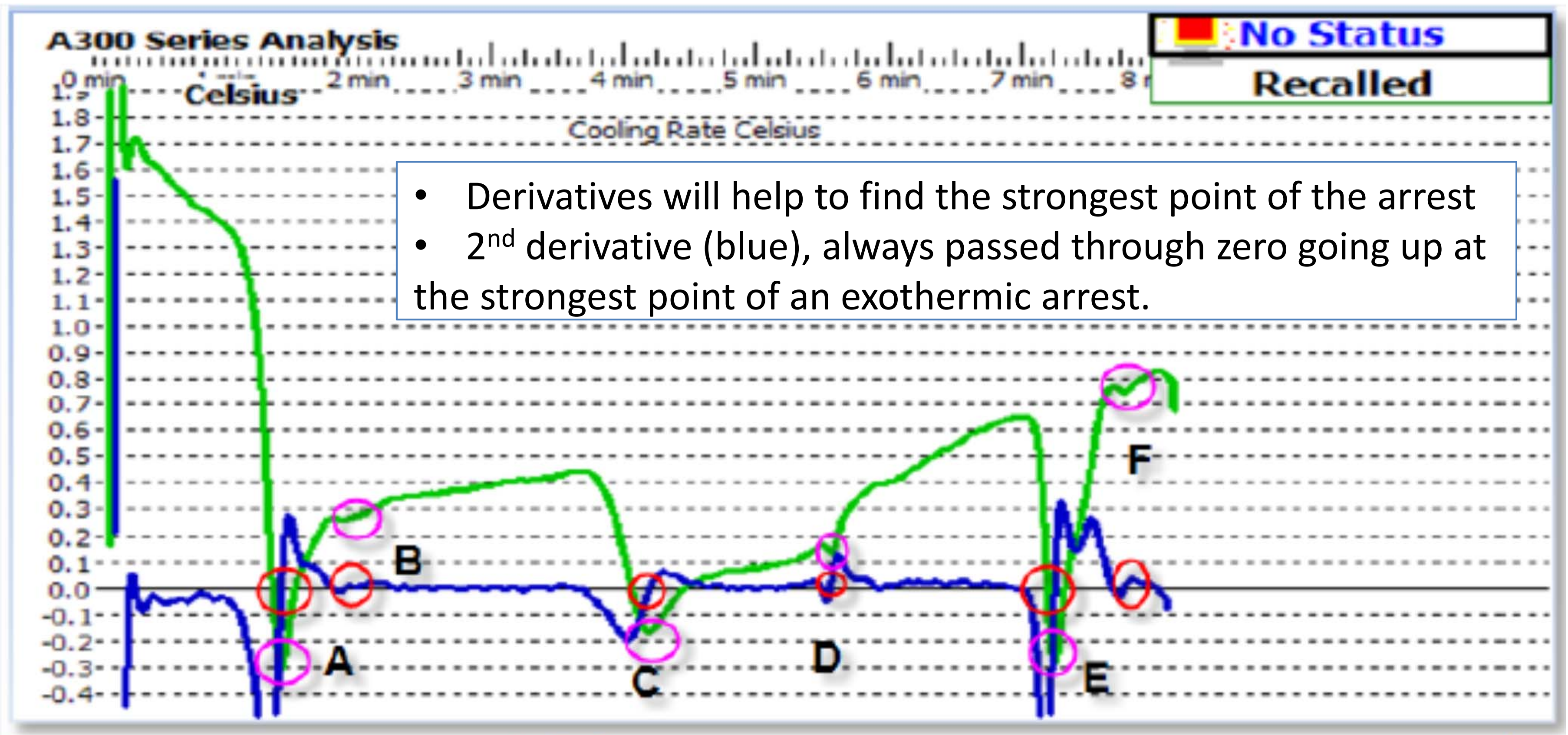


Cooling Rate Curve (1st derivative inverted)



- Much information appears and it becomes easy to identify arrest.
- Derivatives magnify events and arrests
- The exothermic events move the curve down
- The endothermic events move the curve up

Metrics by derivative

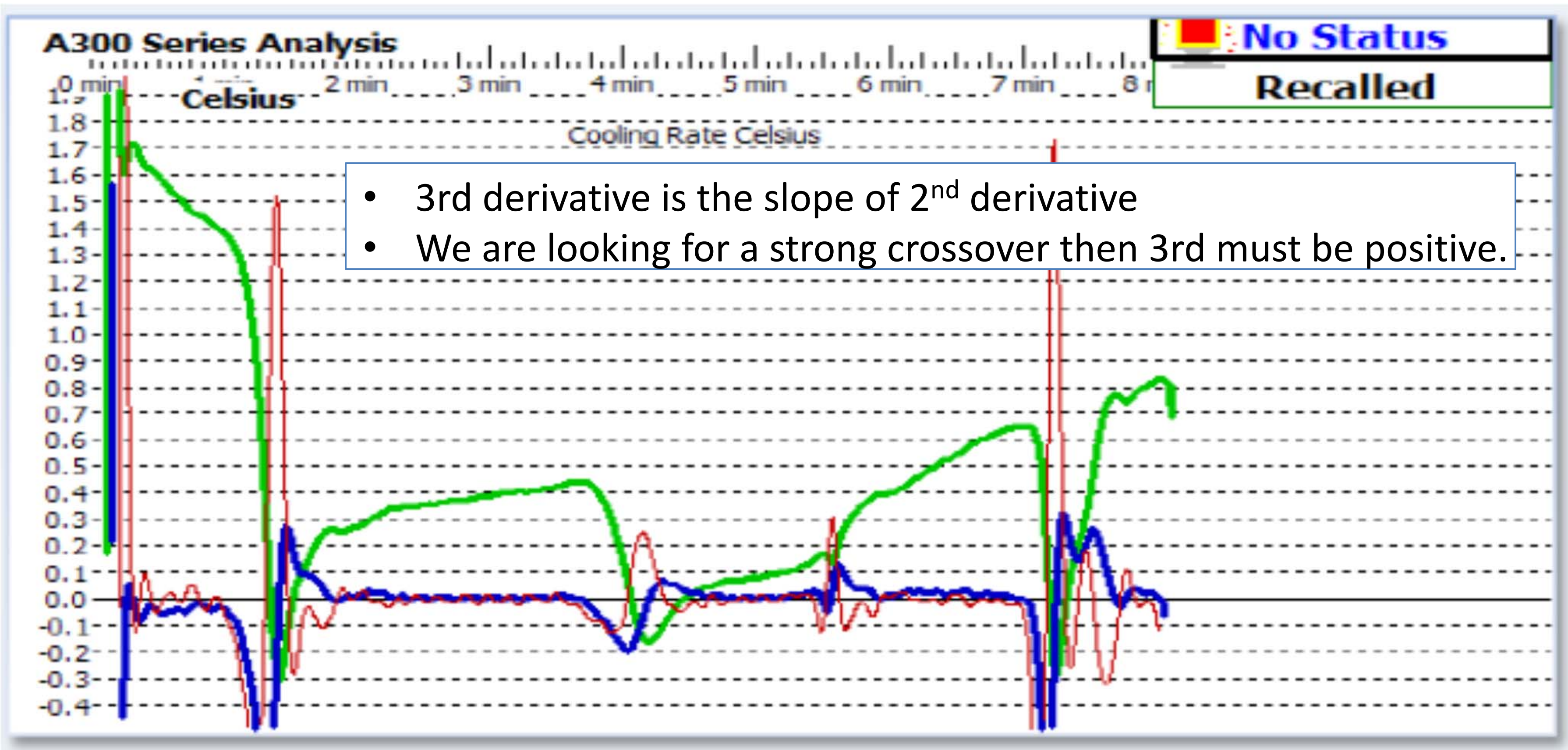


- Derivatives will help to find the strongest point of the arrest
- 2nd derivative (blue), always passed through zero going up at the strongest point of an exothermic arrest.

Green curve: cooling rate

Blue curve: 2nd derivative

Metrics by derivative

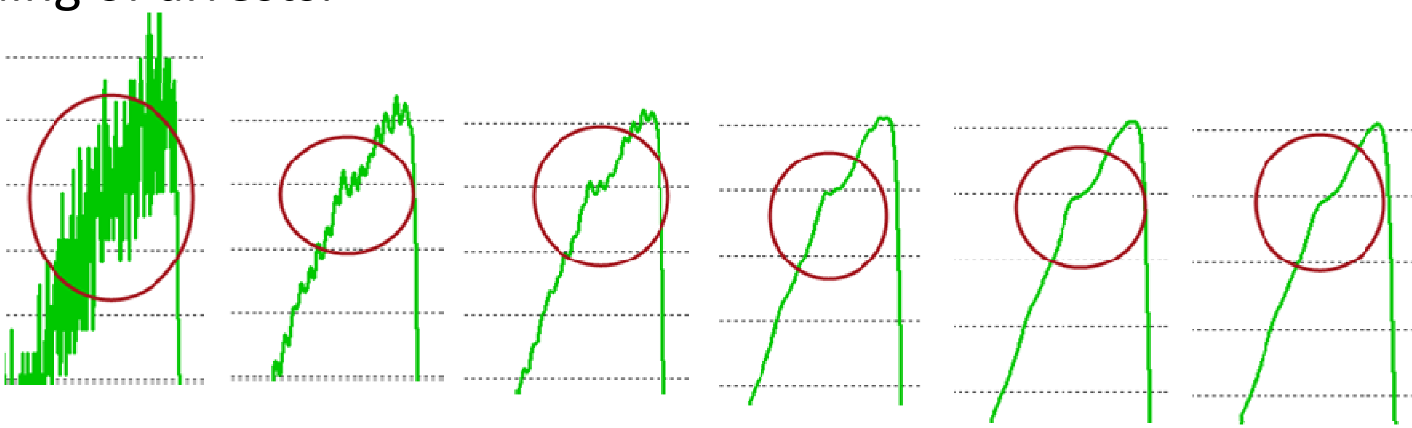


- 3rd derivative is the slope of 2nd derivative
- We are looking for a strong crossover then 3rd must be positive.

Green curve: cooling rate Blue curve: 2nd derivative Red curve: 3rd derivative

Filtering and smoothing data

- How are we able to use derivatives?
  - Precision measurement with 16 resolutions of the T/C voltage.
  - Millivolts to temperature equations with 0.01% error.
  - Noise suppression in the electronics.
  - Unique data smoothing techniques (Biggest Meltlab secret)
  - Fourth and fifth derivatives for pinpointing the starting and ending of arrests.

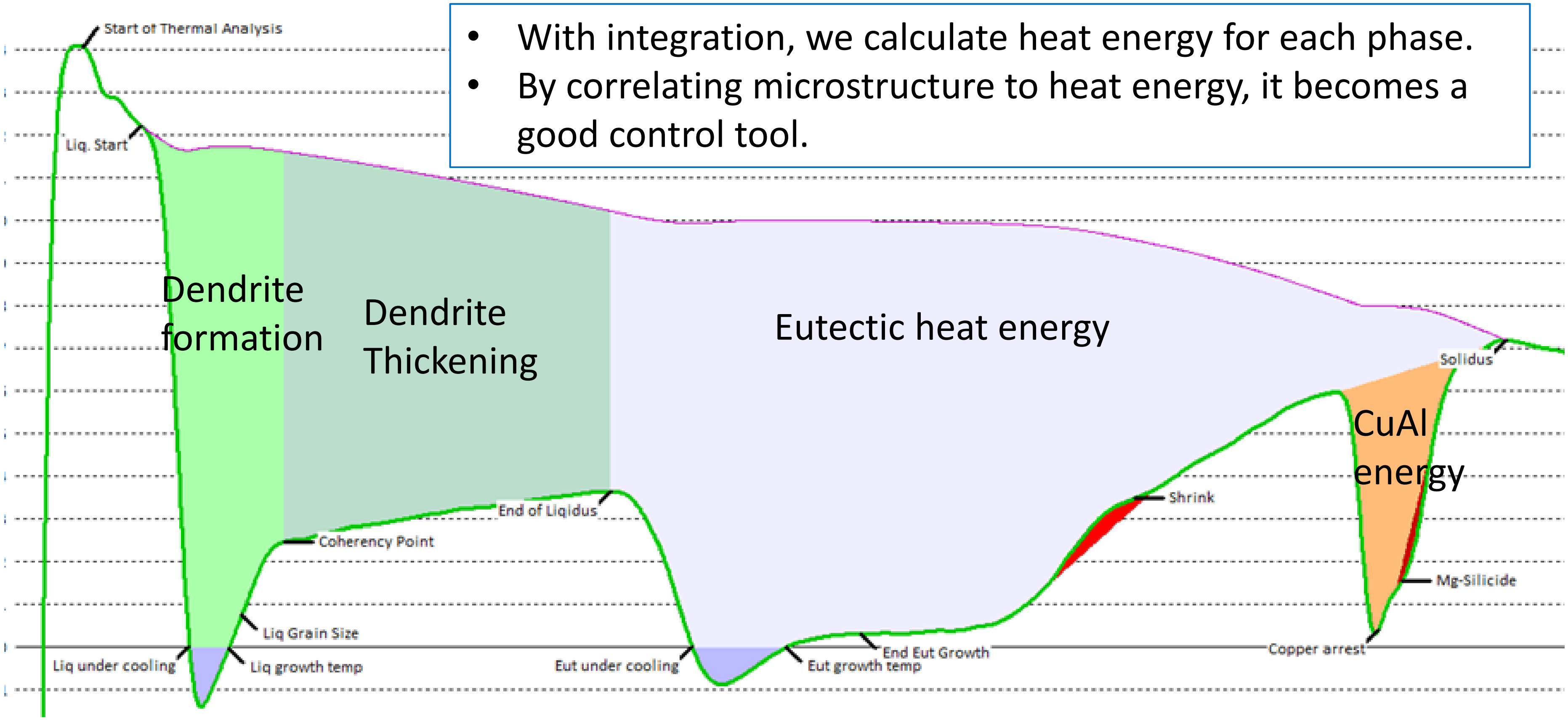


Aluminum approach

- Control additions by measuring the degree of inoculation and degree of modification.
- Compensate for different charges mixes – virgin and mixed returns with proper additions.
- Detect and measure shrinkage occurring with different procedures and different mixes.
- Detect gas bubbles forming in the metal sample and adjust process
  - Increase degassing or new alloy addition
- Control microstructures by using heat energy proportion for each phase.
- Keep all control parameters in range.

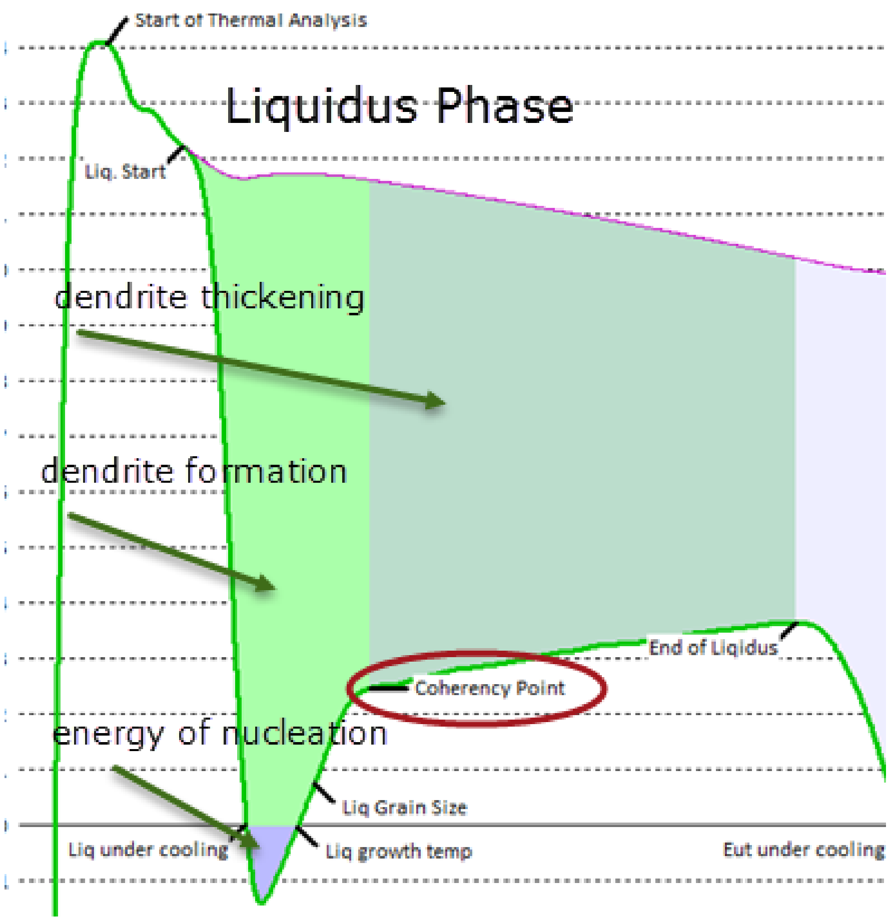
Aluminum (A300 series)

- With integration, we calculate heat energy for each phase.
- By correlating microstructure to heat energy, it becomes a good control tool.



Green Curve: Cooling Rate **Magenta: zero energy curve**

Aluminum (A300 series)



The **coherency point** is where the dendrite crystals start interlocking with each other and begin to block feeding.

- Higher dendrite formation energy provides better feeding

This example is *under inoculated* and quickly reaches this interlocking form.

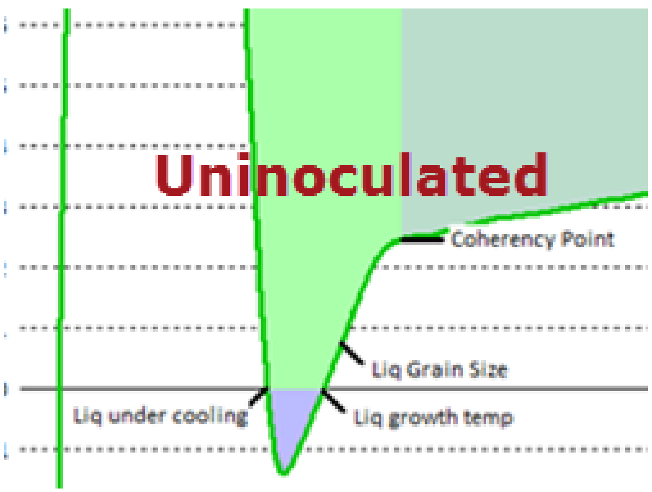
- The energy of nucleation is an inverse indication of inoculation.
- More inoculation would give better feeding characteristics for this metal.
- Use TA to control and stabilize your TiB additions.

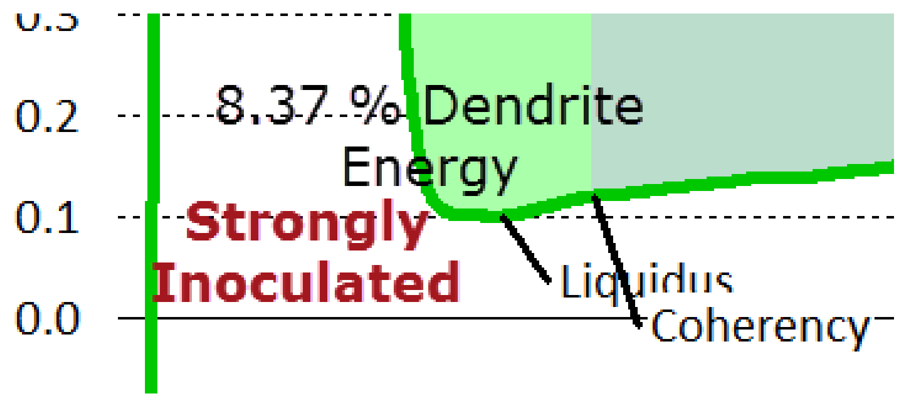
Green Curve: Cooling Rate

Magenta: zero energy curve

Aluminum- Inoculation (Grain refiners)

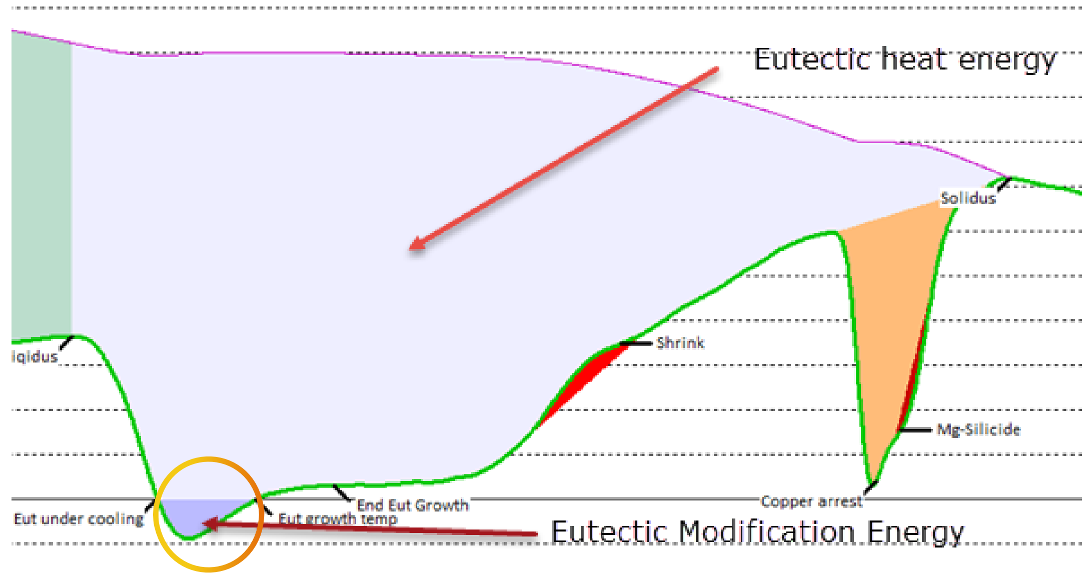
- Under inoculated aluminum produces large dendrites that decrease fluidity and blocks feeding.
- Liquidus has undercooling with less nucleation
- Fine dendrites become with inoculation
- Fluidity is better and coherency point is later.





Eutectic Phase Hypoeutectic A300

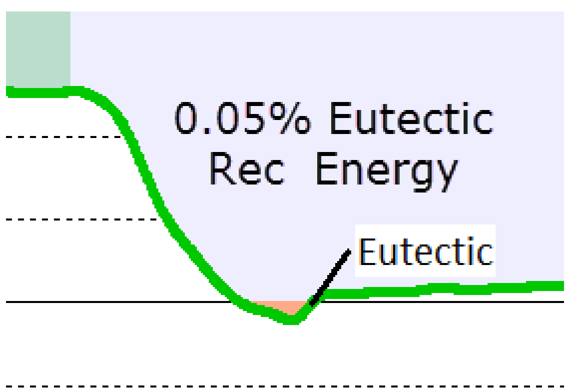
- The **eutectic heat energy** is a measure of the aluminum-silicon phase.
- As silicon levels increase, the percent of eutectic heat energy also increases. This is a control point.

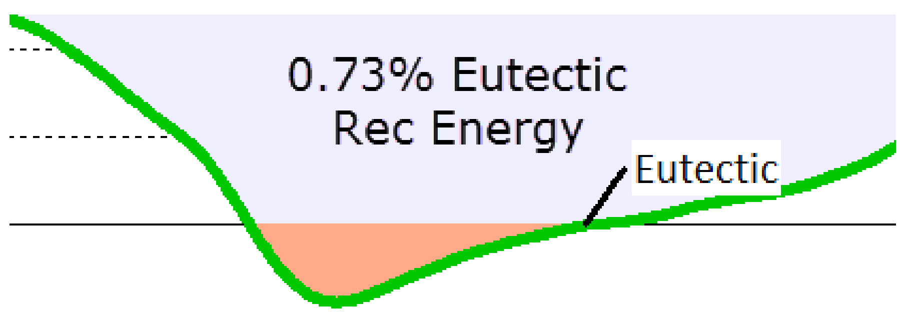


- The **eutectic modification energy** (blue area) is due to the degree of modification you have.
- Modification changes over time and with the different modifiers.
- Stabilize and control this with strontium or sodium additions to effect late feeding, decrease shrink and decrease heat treatment cost.

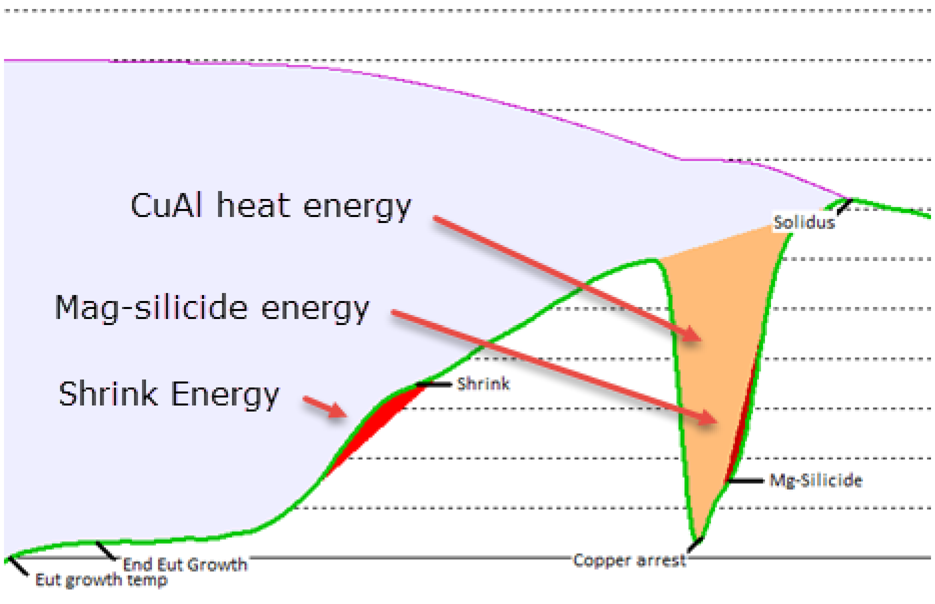
Aluminum- modification (A300)

- Modification lowers the freezing point of the eutectic allowing longer feeding times.
- The degree of modification is measured by both the freezing temperature and the degree of undercooling of the eutectic.
- Recalesence is one way to look at it. The amount of energy is another.
- Strontium is expensive. You must add the right amount.





Grain boundary phase (A300)



Shrink Energy

Incorrect modification levels and nucleation levels can influence the degree of shrinkage.

- The **copper phase (CuAl) heat energy** represents the copper that must be redissolved by heat treatment.
- This affects the strength you can achieve in the casting.

- The **mag-silicide heat energy** represents the amount of wear-resistant material you have in your casting.
- Magnesium burns out easily and may need replenishing to maintain this arrest.

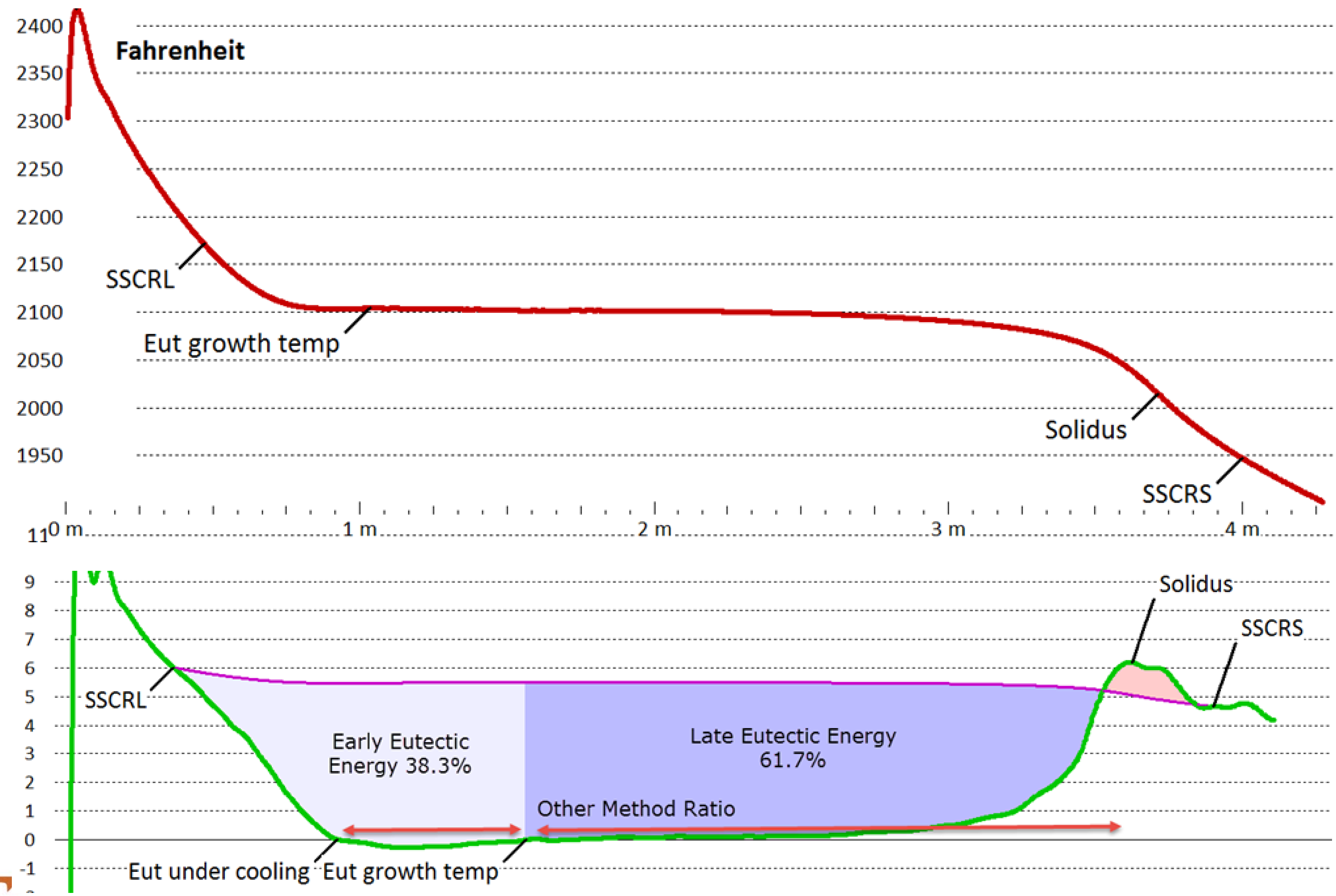
Aluminum- future development

- SF would develop a new tool based on TA to predict porosities with criterias of hydrogen and oxides level in Aluminum.
  - As you've seen, our system is very sensitive.
- A professor of Metallurgical engineering from Laval University sponsor us for this project
- Trials we'll be done in university and technology center.
- Meltlab will introduce the new tool into Aluminum system
- We're waiting about project and subvention approval (or not) soon.

Ductile iron approach

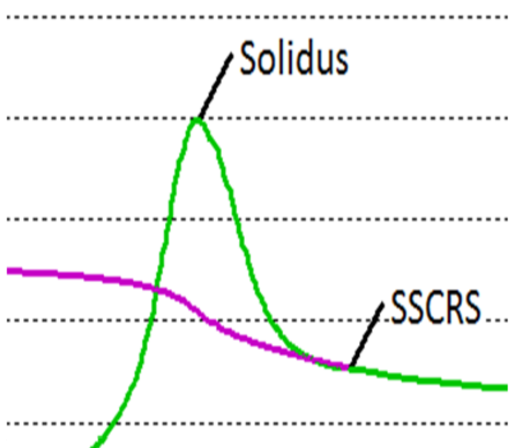
- Base iron chemistry: right amount of carbon and carbon equivalent.
- Base iron nucleation- nucleation potential change with time.
- Inoculation effectiveness – the right amount improves nodular count and reduces shrinkage
- Magnesium Treatment – the right amount improves nodular shape, reduces shrinkage, and prevents carbides. This needs balancing with inoculation.
- Nodularity – when magnesium is ideal, and sulfur controlled.
- Nodule Count – when inoculation is effective.
- Shrinkage – minimized when everything is well balanced, iron is clean, and tramps controlled.

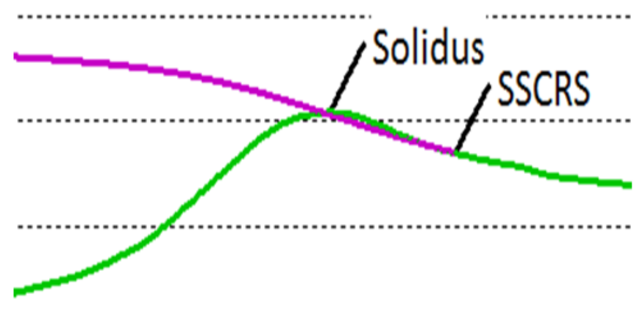
Ductile iron basic curve



Shrinkage in ductile iron

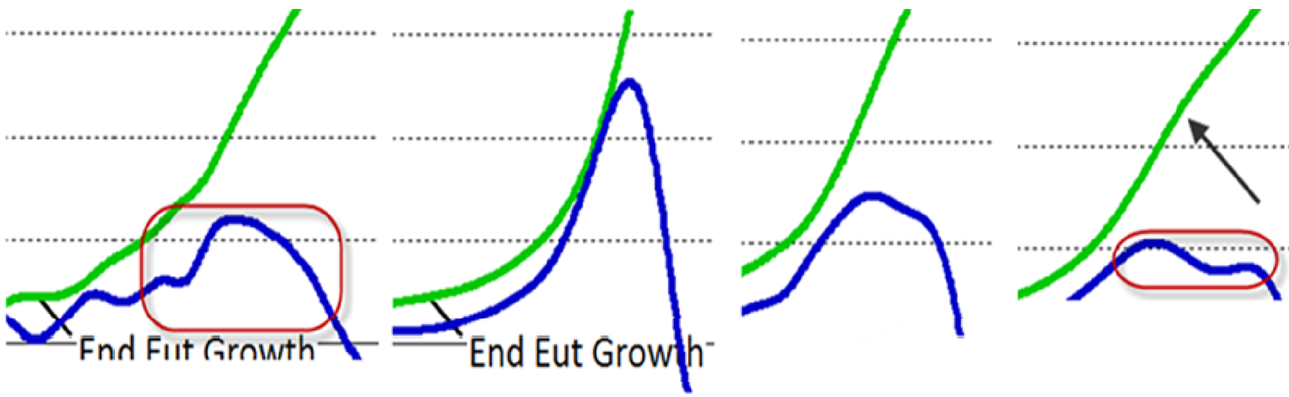
- Thermal analysis can detect the tendency of a sample of iron for micro and macro shrinkage, gas bubbles, and suck-in.
- We look for the presence of sufficient stress. If the stress has been reduced or totally removed by the time the casting has initially solidified, we know we have had a problem.
- The missing volume has been replaced with a shrink, gas holes or external shrink (suck-in).





Green Curve: Cooling Rate | Pink curve: zero energy curve

Shrinkage in ductile iron



Multiple shrinkage *Good Metal* *External Shrink* *Massive shrink*

Green Curve: Cooling Rate **Blue curve: 2nd derivative**

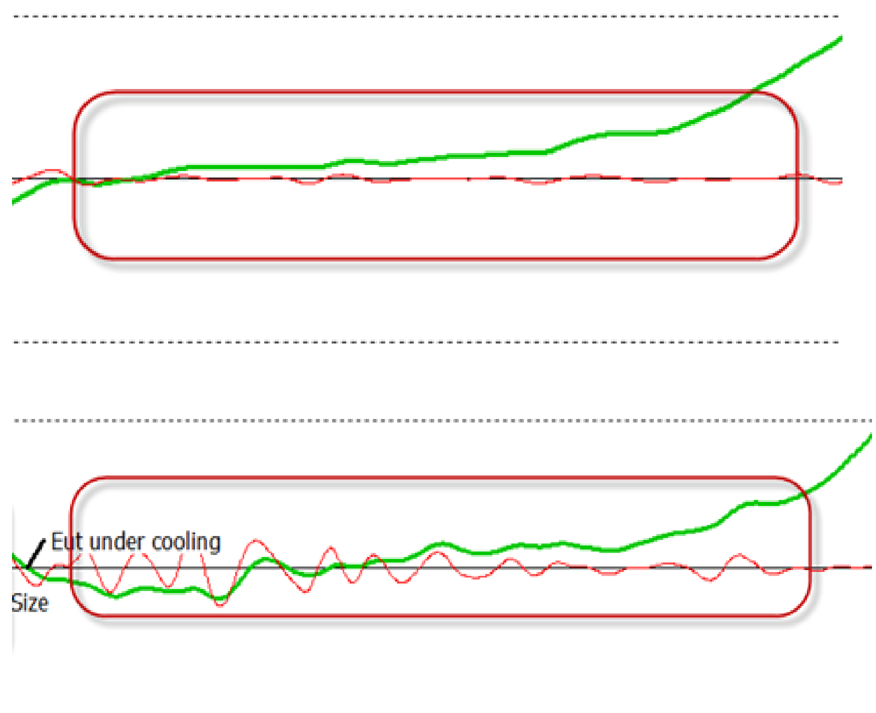
Nodularity in ductile iron

Can you see any difference?

Top curve is 95% nodularity

Bottom curve is 85% nodularity.

Smoothness tests on the 3rd derivative can calculate the difference.

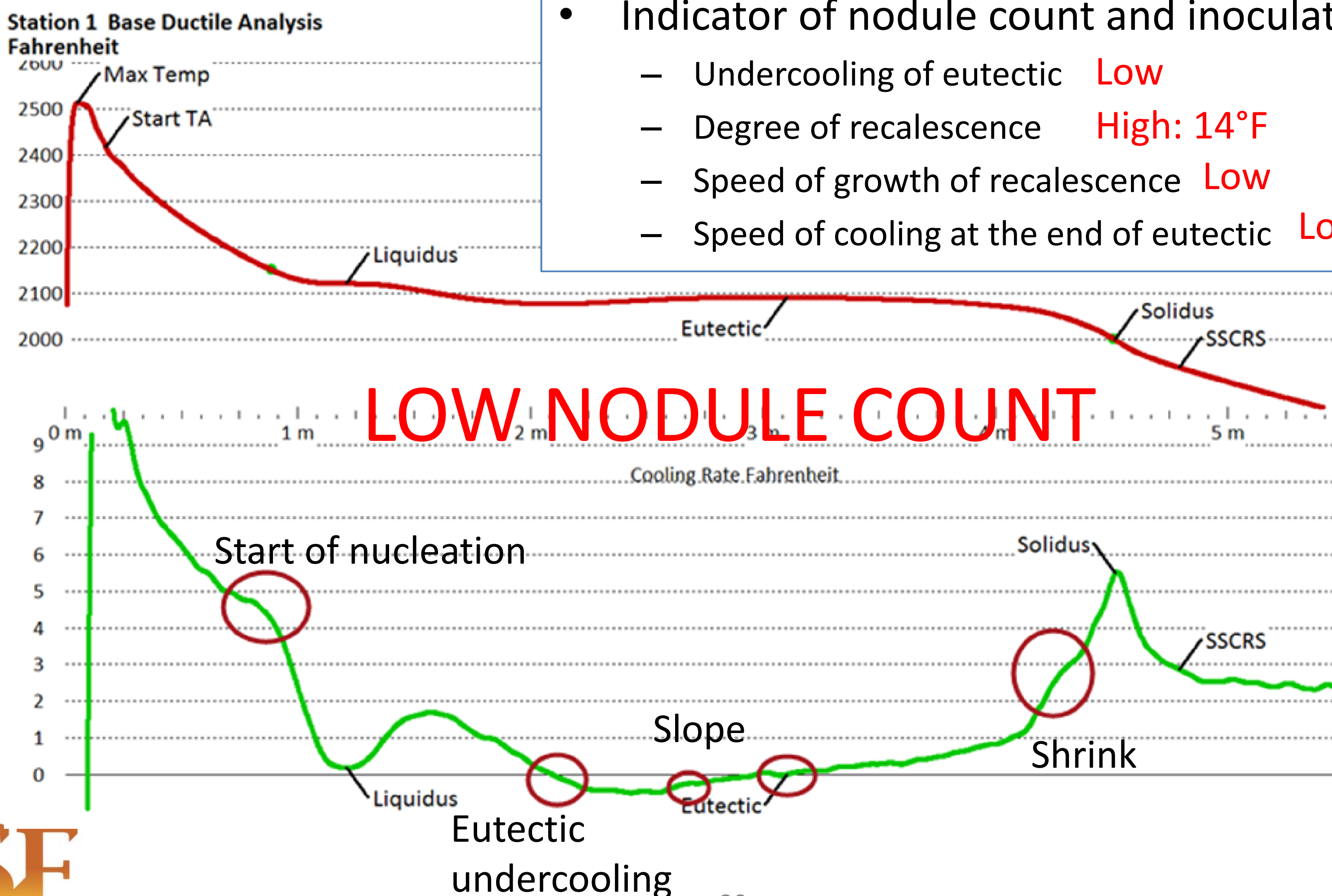


Green Curve: Cooling Rate

Red Curve: 3rd derivative

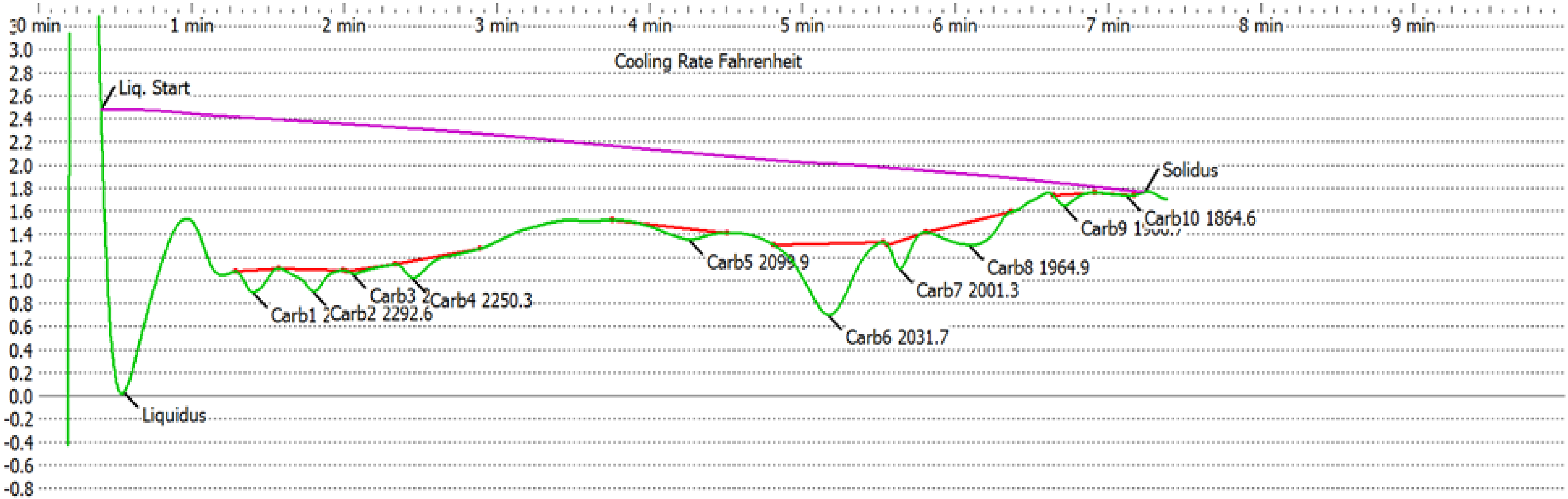
Nodule count in ductile iron

- Indicator of nodule count and inoculation
  - Undercooling of eutectic Low
  - Degree of recalescence High: 14°F
  - Speed of growth of recalescence Low
  - Speed of cooling at the end of eutectic Low



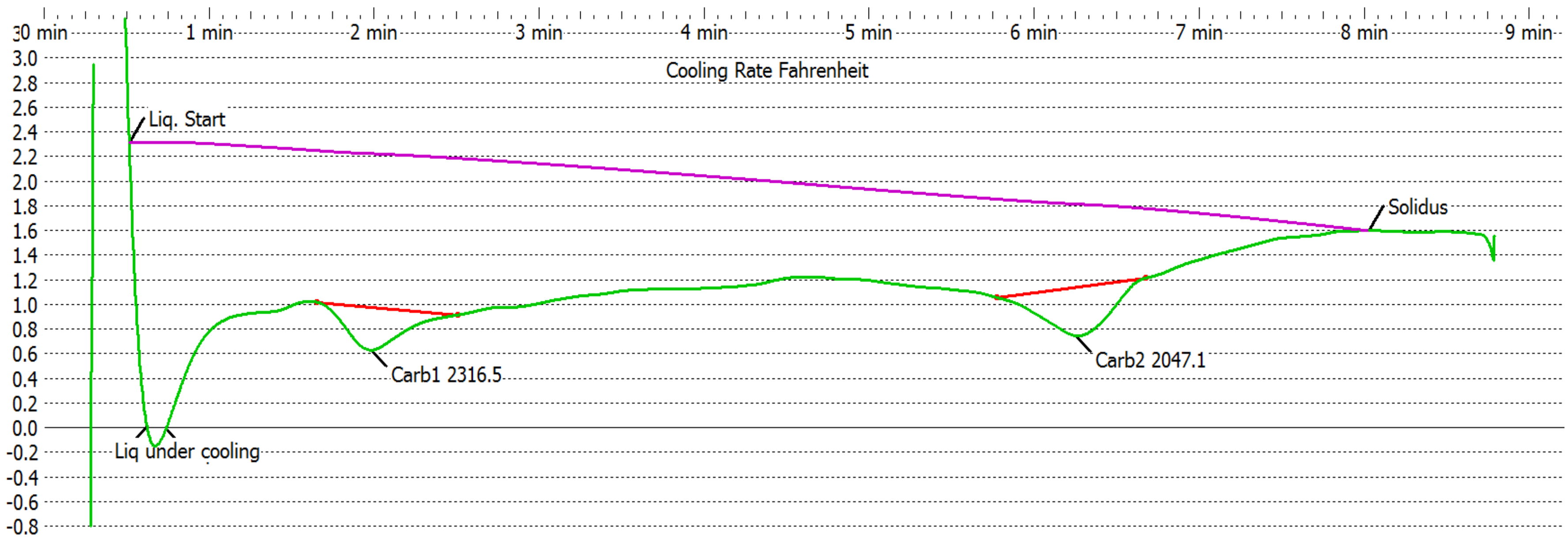
Tool Steel- Before refinement

- Meltlab can detect many carbides in this allied steel
- Before refinement there are up to 10 different forms of carbides
- To know each composition, you would need deeper analysis with microstructure, electron microscope, XRF analysis or technical paper research.



Tool Steel- After refinement

- After refinement with both FeTi and FeV, there are only two forms of carbides
- You can have energy proportion of each carbides
  - A correlation with mass proportion or by microstructure is easy to program.



Conclusion

- There are differences in the metal that change with time and treatment.
- TA measures many critical variables for your melt quality.
- The most important is to find the "sweet spot" where metal has proper inoculation, effective solidification and good feeding to make good casting.
  - With best product and better cost for you
- Don't forget, without measures, you can't improve your process!
- To make consistent castings, start with a consistent metal.
- TA and Meltlab is the tool you must have for a modern foundry.

References

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- A novel Algorithm for the calculation of Latent Heat of Solidification for Multi-component Aluminum Alloys, AFS03-094, Jerry H. Sokolowski
- Thermal Analysis of Al casting alloy, AFS Cast Expo presentation, AFS16-105, Geoffrey K Sigworth
- The modification of Al-Si Casting Alloys- Important Practical and Theoretical Aspects- AFS08-019, Geoffrey K Sigworth
- Improving Inoculation of Ductile Iron- AFS03-103, S.Lekahk

You'll find plenty information about Thermal Analysis and Meltlab system by David Sparkman on www.meltlab.com

Questions ?

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