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

• Design and Process simulation Software with

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
- 2\textsuperscript{nd} derivative (blue), always passed through zero going up at the strongest point of an exothermic arrest.

Green curve: cooling rate

Blue curve: 2\textsuperscript{nd} derivative
Metrics by derivative

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

- 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.

Shrink Energy
Incorrect modification levels and nucleation levels can influence the degree of shrinkage.
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.
• Mel tbl 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

Green Curve: Cooling Rate

Blue curve: 2\textsuperscript{nd} 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

LOW NODULE COUNT

Start of nucleation
Slope
Shrink
Eutectic undercooling
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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You’ll find plenty information about Thermal Analysis and Meltlab system by David Sparkman on www.meltlab.com
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