Application of the cooling curve analyses in aluminum casting plant

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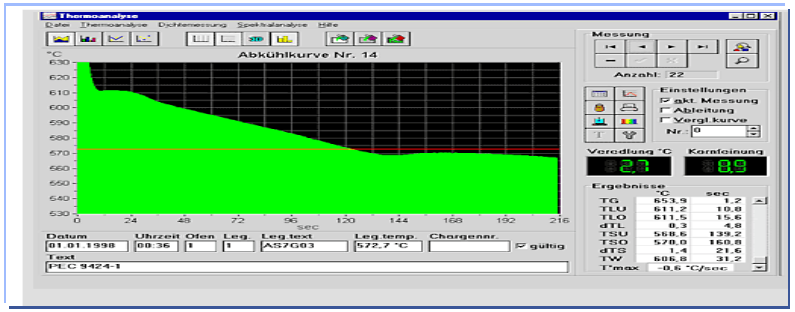
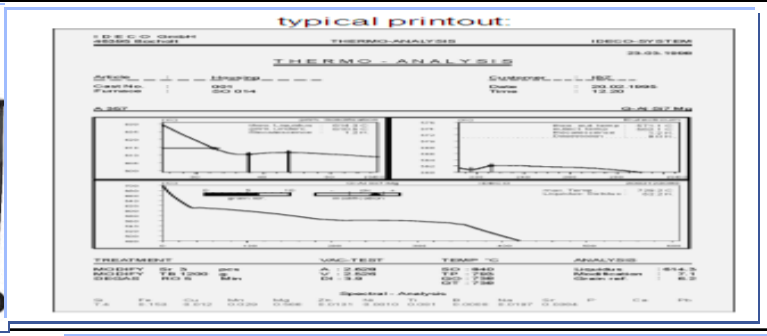
Introduction

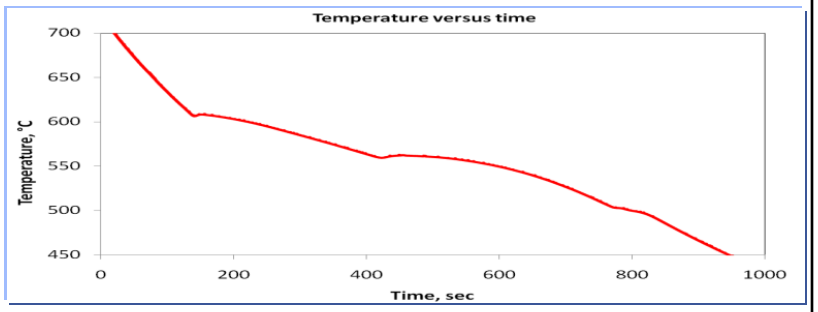
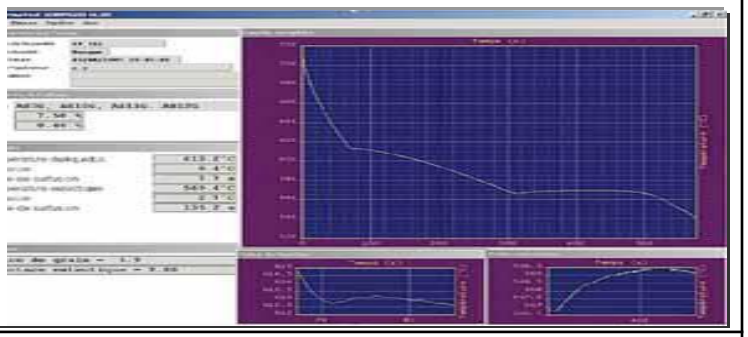
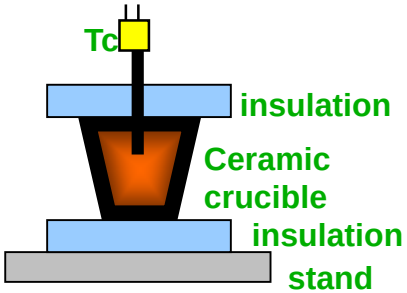
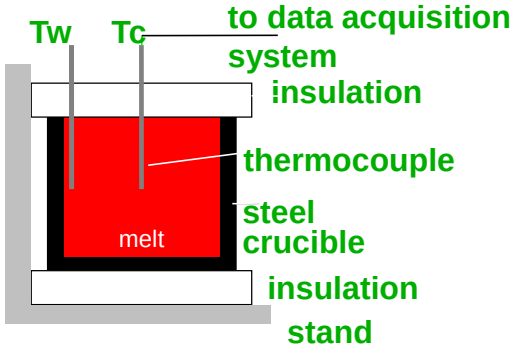
- Understanding of the melt quality is necessity for the control and prediction of casting characteristics.
- Assessment of these characteristics on-line during manufacturing process allowed foundry man to make decision relevant to melt and casting quality control, reducing cost downtime and scrap levels.
- Thermal Analysis (TA) has the potential of providing such capabilities.

What is Thermal Analysis ?

- Thermal analysis can be described as a “finger print” of the solidification process.
- Measuring and recording the temperature during solidification of an alloy, the temperature – time plot is obtained that yield useful information about how the alloy freezes.
- Such plot is called a **cooling curve** and general name to the technique is **thermal analysis**.
- Major and minor metallurgical reactions (that are thermodynamically strong enough in terms of latent heat evolution) are manifested on the cooling curve by inflection points and slope changes.
- In the aluminum casting industry, the attempts of thermal analysis to the study of the test sample structure was reported in the early 1980.

Review of major commercial TA apparatus presently used at Aluminum Casting Plants

Thermal Analysis System	Type of TA cup/weight of TA probe	Thermal Analysis Apparatus
MK	Steel/100g	 
Ideco	Steel/250g	 
OCC	Sand/ 80g	 

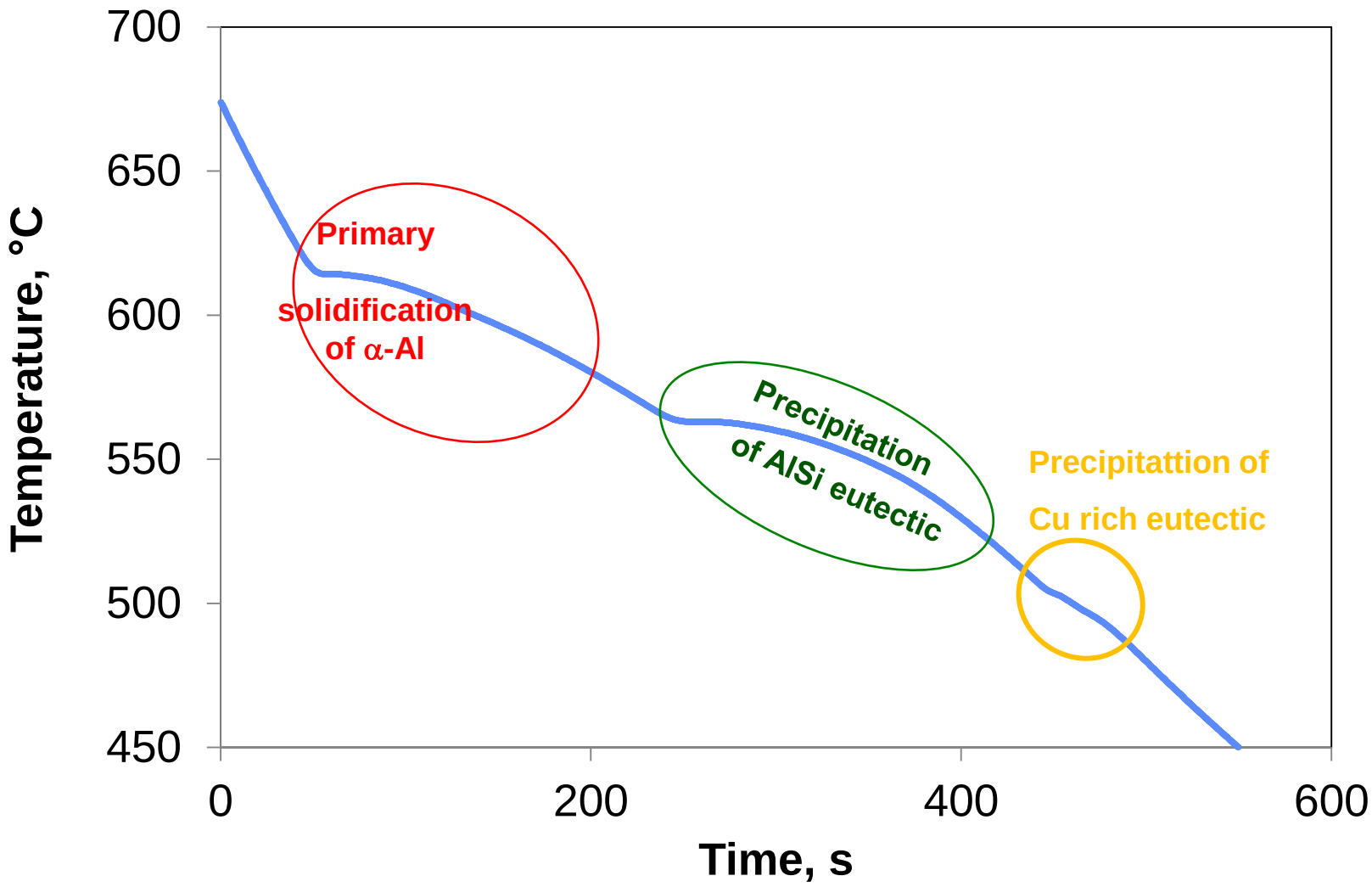
Thermal Analysis System	Type of TA cup/weight of TA probe	Thermal Analysis Apparatus
AluDelta	Sand/100g	 
Thermatest 5000 NG III (Foseco)	Ceramic/200g	 
Thermal Analysis Cup	Sand/ 200g Steel/200g	 

Present Application of Thermal Analysis in Aluminum Casting Plant

Thermal Analysis as a Quality Control Tool in Aluminum Casting Plant

- Presently cooling curve analysis has been mostly used in aluminum casting plant to quantify following two parameters:
  - **grain size,**
  - **level of silicon modification**

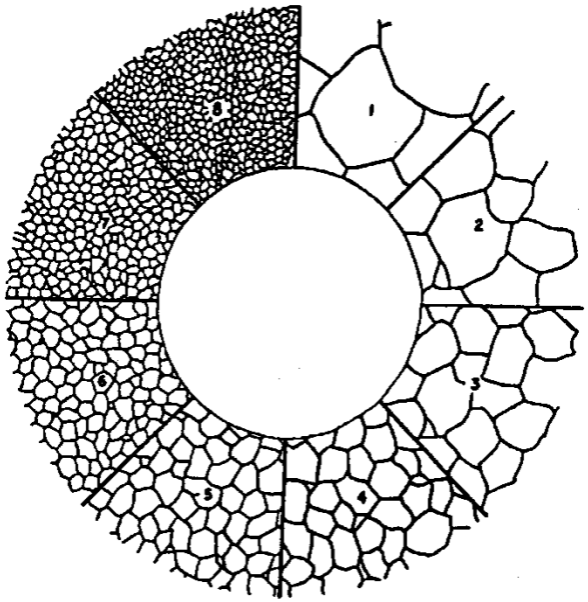
Cooling curve of AlSi6Cu4 alloy



Quantification of the Grain Size

Metallographically

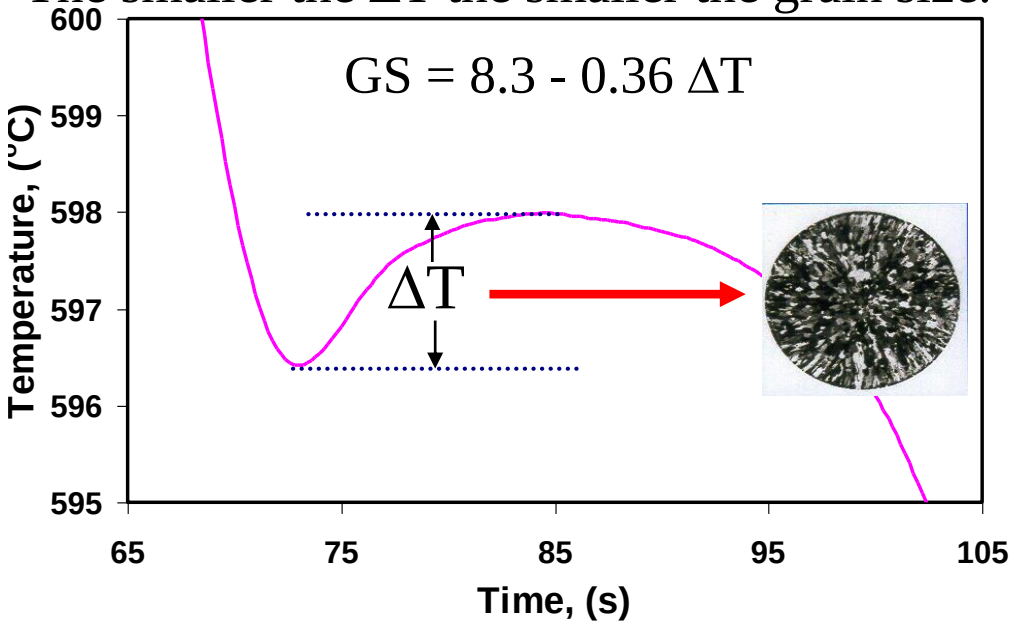
ASTM comparison chart for determination of the grain size from metallographically prepared samples.



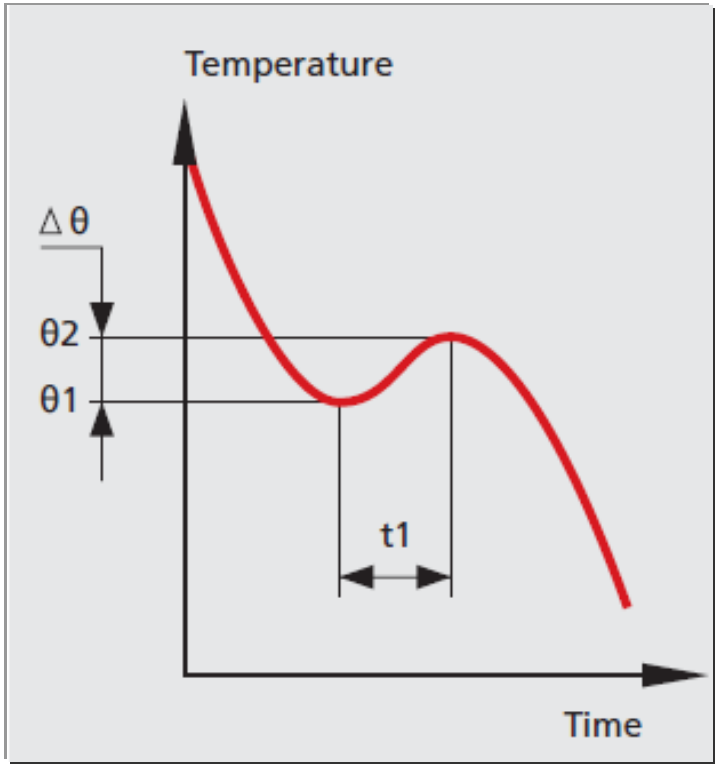
Thermal Analysis

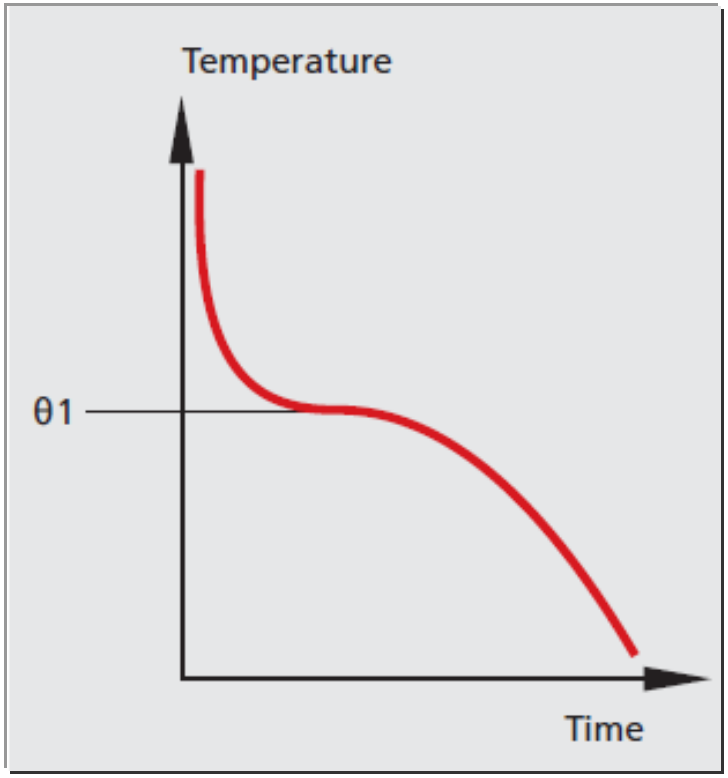
The determination of grain size by thermal analysis utilizes that portion of the cooling curve associated with the beginning of primary solidification.

The smaller the ΔT the smaller the grain size.



Assessment of the Grain Refinement by the Cooling Curve Analysis





θ1 is the temperature at which the solidification begins

θ2 is the maximum temperature reached at the end of the undercooling

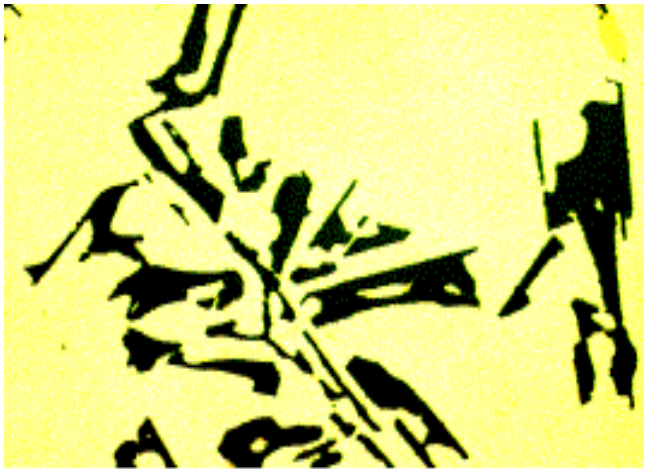
Δθ is the apparent undercooling equal to θ2-θ1

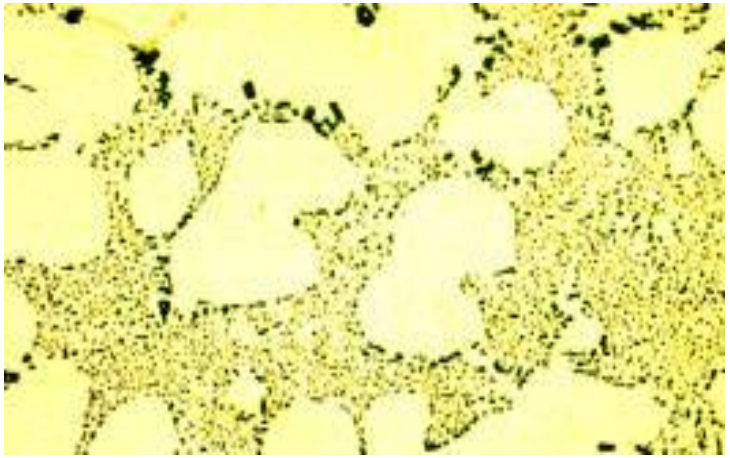
t1 is the duration of undercooling.

The smaller the ΔΘ, the higher the potency of master alloys for grain refinement and the smaller resulting casting grain size.

Modification of the eutectic microstructure

- The term “modification” describes the condition of refinement of the silicon particles.

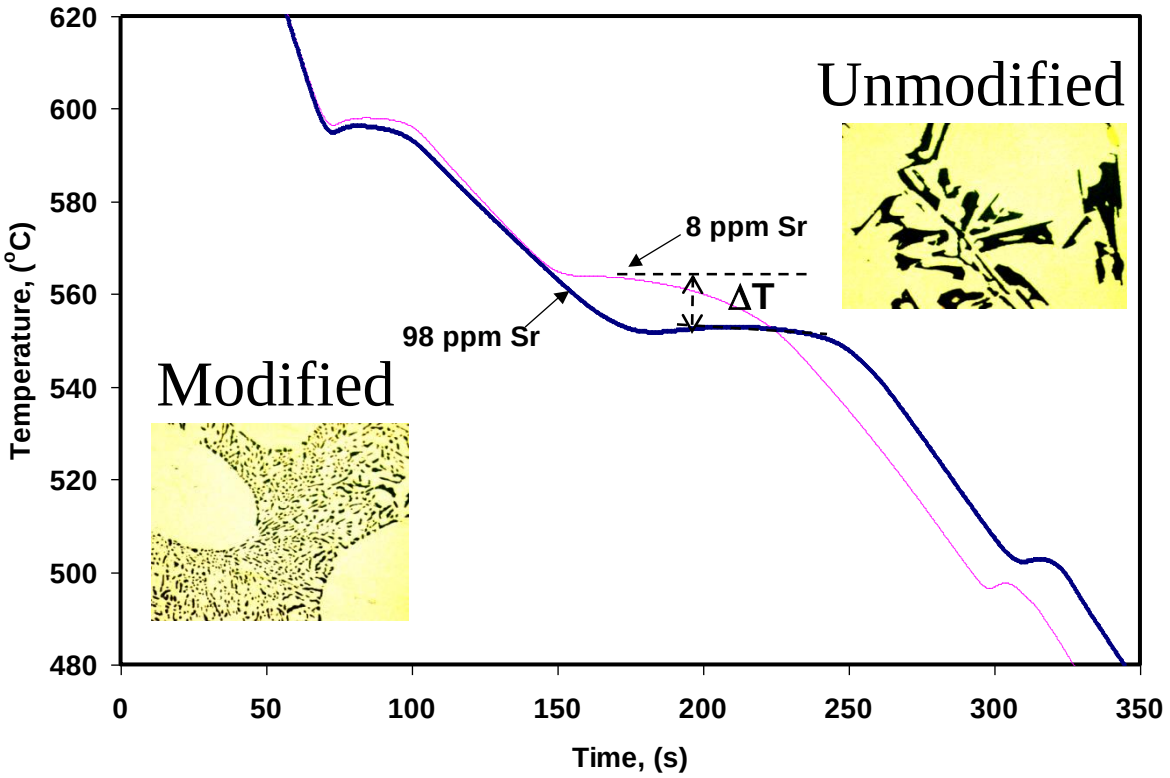




- The modifying effect is the transition from blocky, acicular and needle-like silicon phases to a fine fibrous silicon structure.
- Modification of Al-Si alloys can be achieved either addition of chemical modifiers such as: **Strontium,** Sodium or Antimony or through rapid solidification.

Thermal Analysis Cooling Curves for Low (8 ppm) and High (98 ppm) Levels of Strontium

- The depression of the Al-Si eutectic growth temperature, (ΔT) represents the temperature difference between the unmodified and modified Al-Si eutectic growth temperatures.



- The larger the ΔT, the higher the level of Si modification.
- The level of active and inactive Sr in the melt can be estimate **only** by ΔT parameter.

Advance Application of Thermal Analysis in Aluminum Casting Plant

Thermal Analysis as a Quality Control Tool in Aluminum Casting Plant

- A state–of-the-art thermal analysis system should be able to quantify parameters such as:
  - dendrite coherency point,
  - low melting point of secondary eutectic,
  - precipitation of iron intermetallics,
  - fraction solid and
  - other characteristic temperatures such as: T_{LIQ}, $T^{AlSi}_{E,G}$, $T^{AlCu}_{E,G}$ and T_{SOL}, liquidus, Al-Si eutectic, Al-Cu eutectic and solidus temperature, respectively.

Dendrite Coherency Point

Dendrite Coherency Point

The DCP is important feature for understanding and for consequent control of the alloy solidification process.

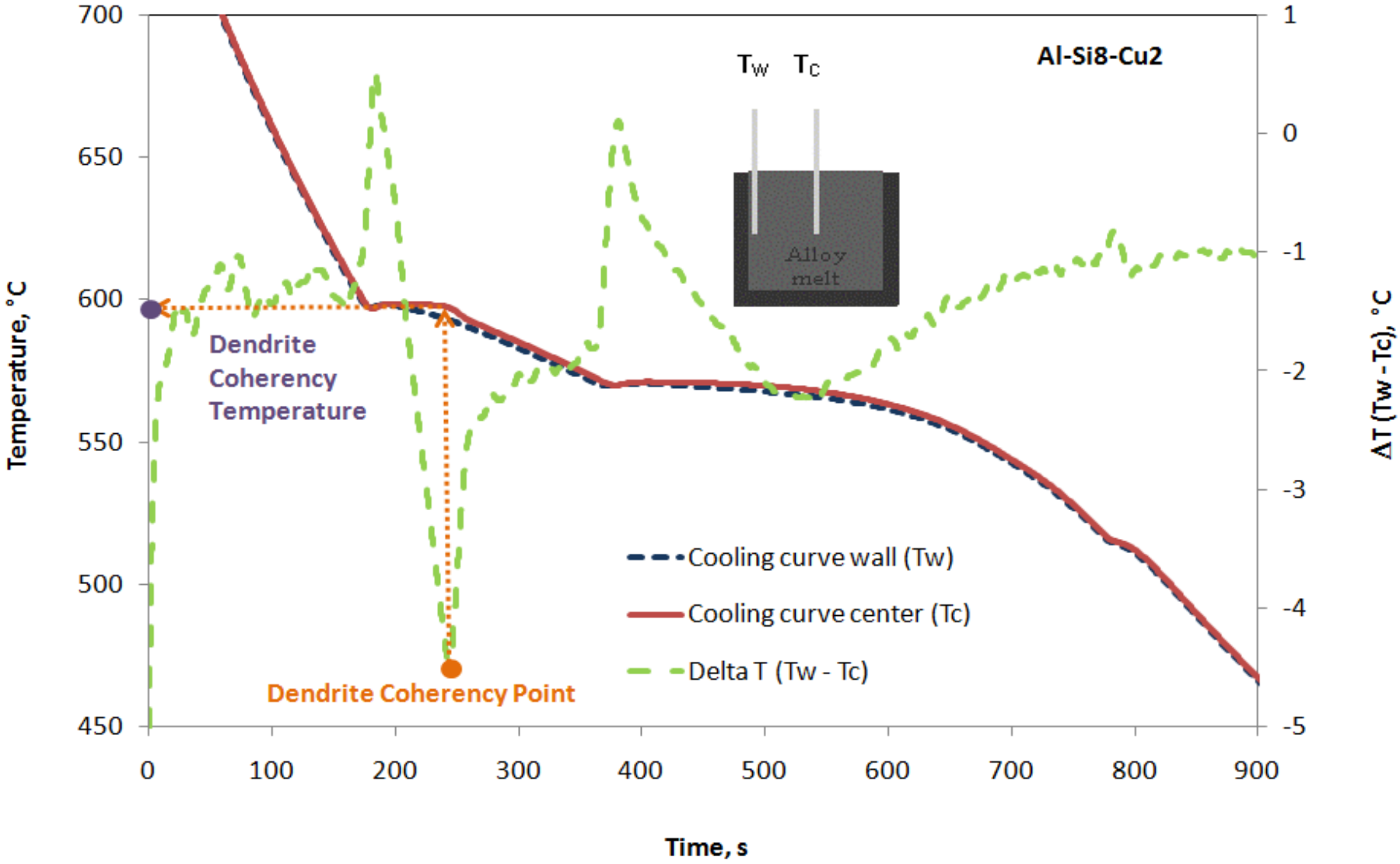
- The DCP marks the transition from mass feeding to interdendritic feeding in the solidification process.
- Casting defects such as macro segregation, shrinkage porosity and hot tearing begin to develop after the DCP event.

Major factors that have significant impact on DCP are:

- Solidification conditions – cooling rate
- Chemical Compositions
- Addition of grain refiners

The DCP is a physical phenomenon however, its direct detection is virtually impossible.

Detection of Dendrite Coherency Point using Cooling Curve Analysis

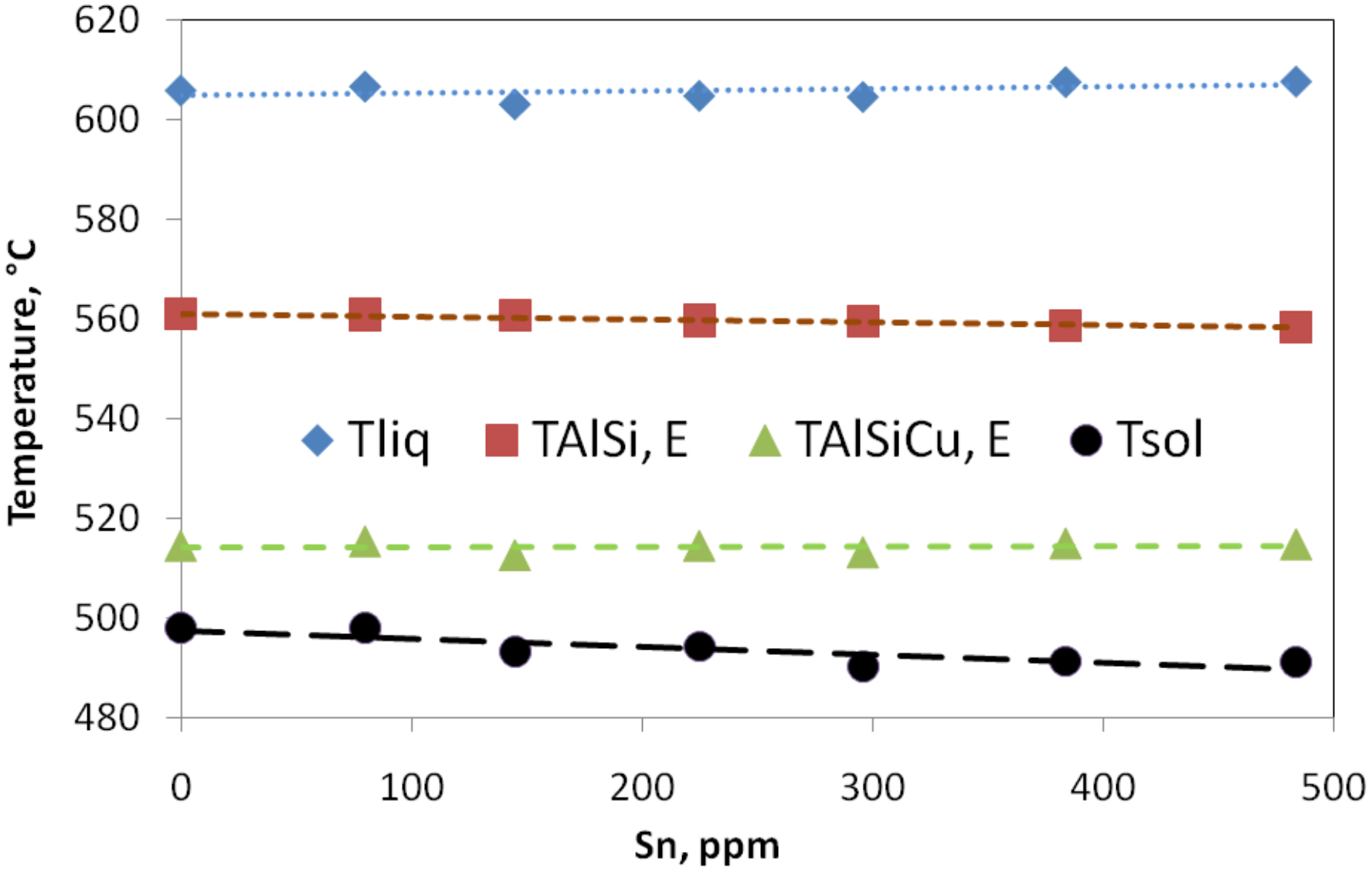


Temperature of Low Melting Point Elements

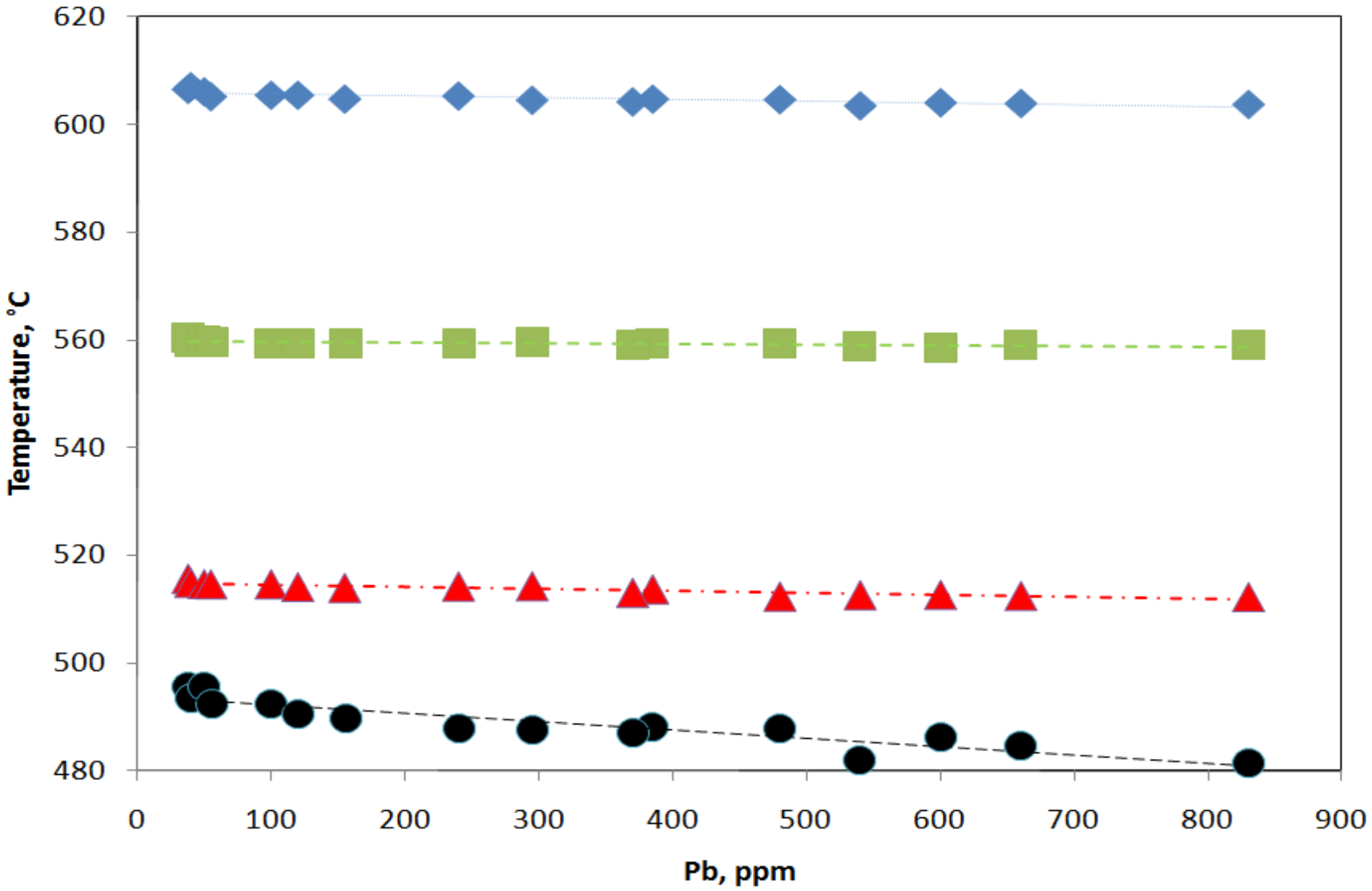
Introduction

- Aluminum casting plants are using significant amount of secondary aluminum alloys.
- Low melting point elements are unavoidable major impurities in these alloys, usually present in ppm level.
- Tin and lead belong to this group of alloying elements.
- There is no consensus in the literature and practice regarding the tolerable levels of Sn/Pb presents in aluminum alloys.
- The presence of Sn/Pb in excess amounts could cause very serious defects in as cast products.
- There is a need to analyze the impact of non uniform distribution of Sn/Pb in incoming ingots on the solidification path of secondary aluminum alloys and their mechanical properties.

Impact of Sn on the characteristic solidification temperatures of AlSi6Cu4 alloys



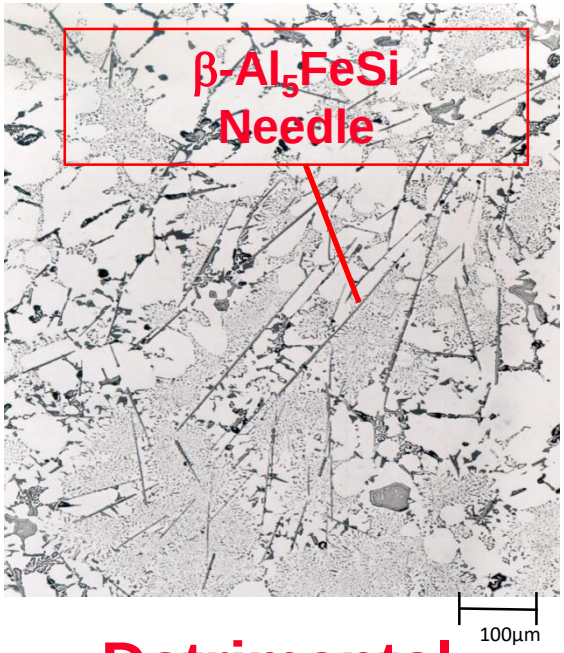
Impact of Pb on the characteristic solidification temperatures of AlSi6Cu4 alloys



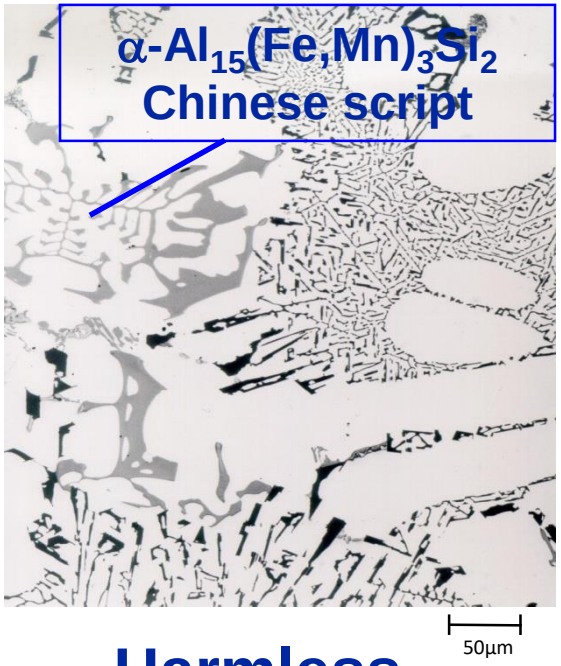
Precipitation Temperature of Fe Intermetallics

Iron in cast aluminum alloys

- Fe is the major impurity element in aluminium alloys
- Fe decrease mechanical properties of aluminium alloys
- Fe decrease castability of aluminium alloys
- Fe decrease ductility of aluminium alloys
- Fe together with Cr and Mn forms sludge phases

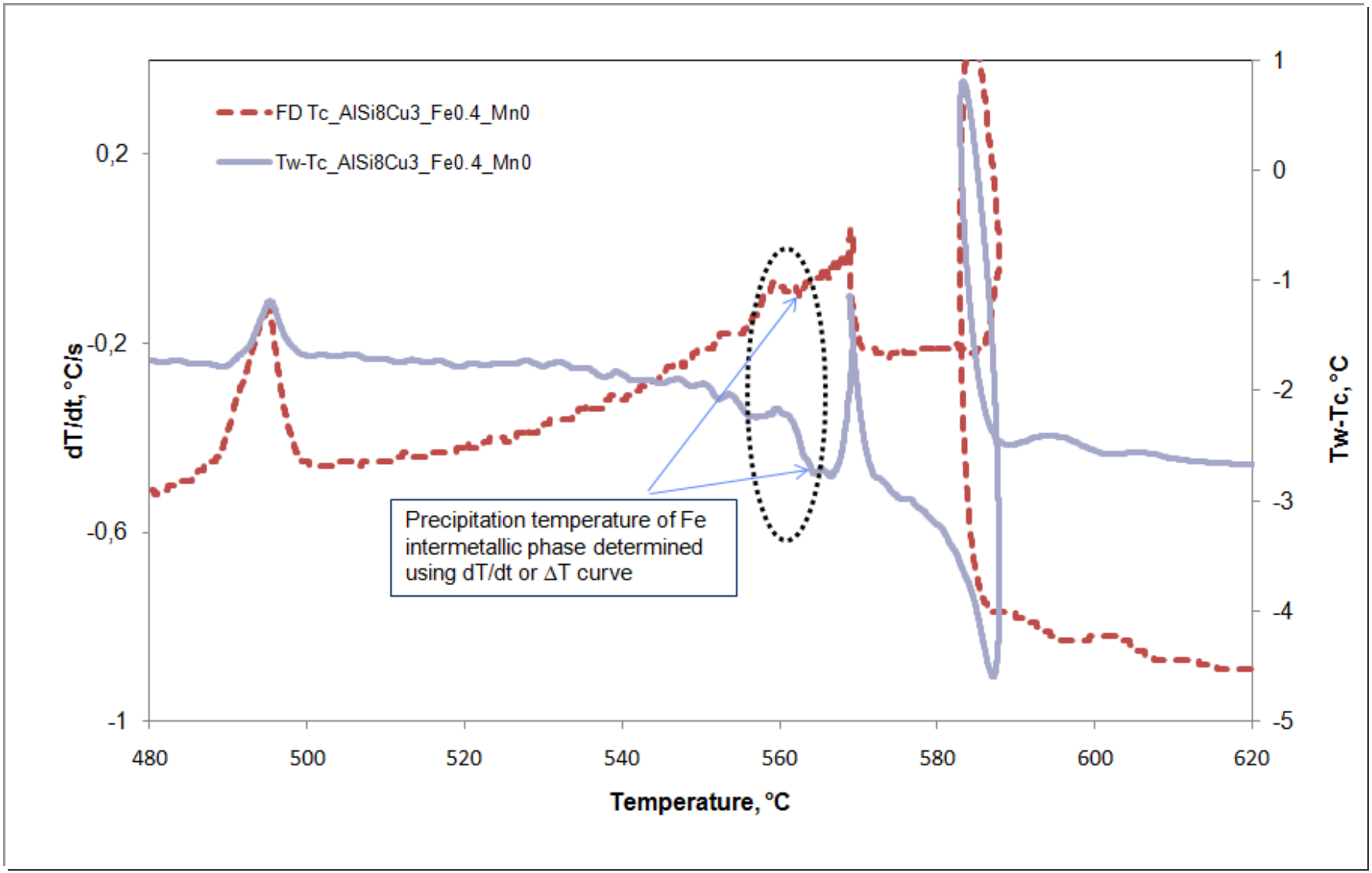


Detrimental



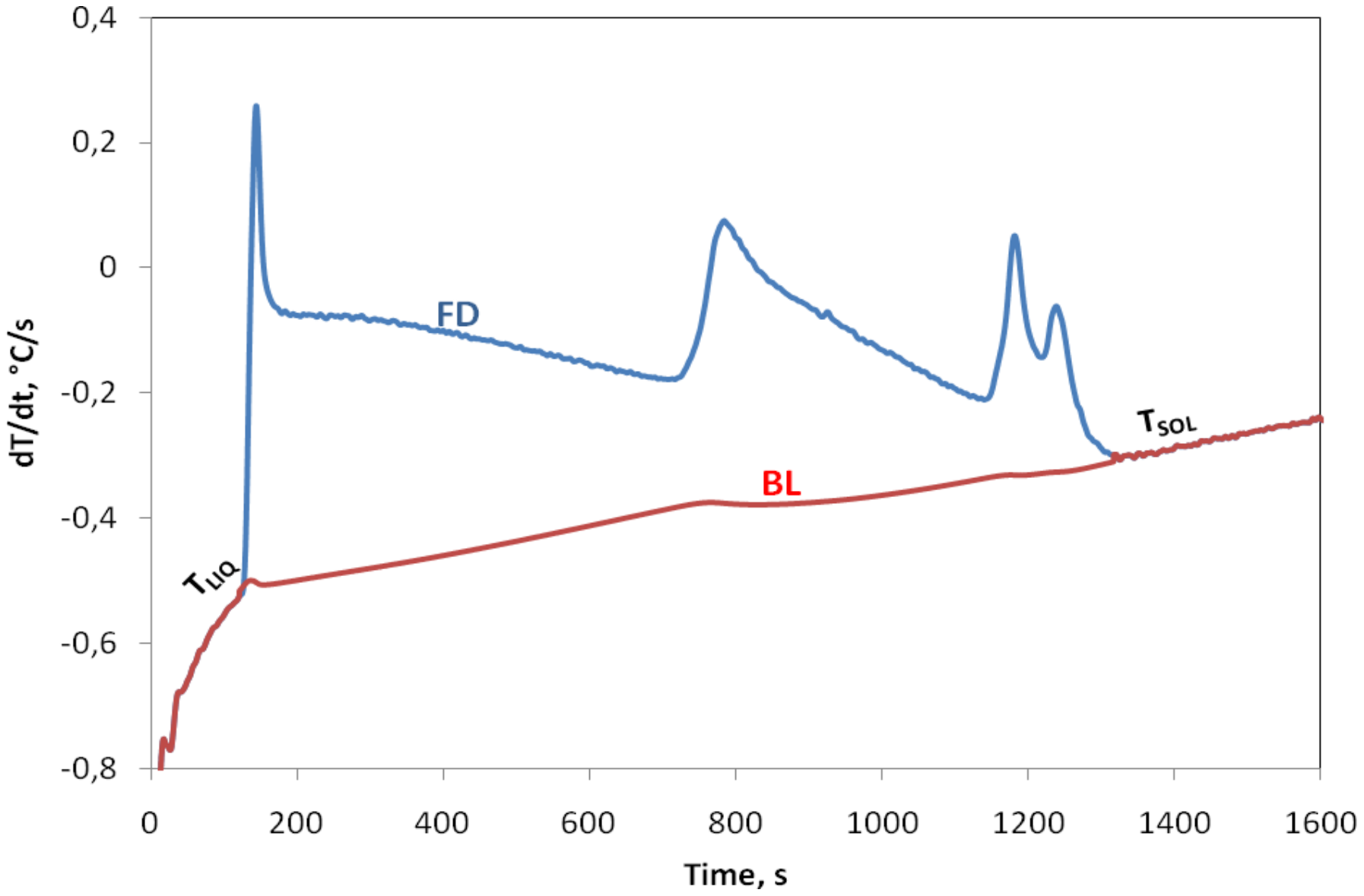
Harmless

Detection of the precipitation temperature of Fe intermetallics using cooling curve analysis

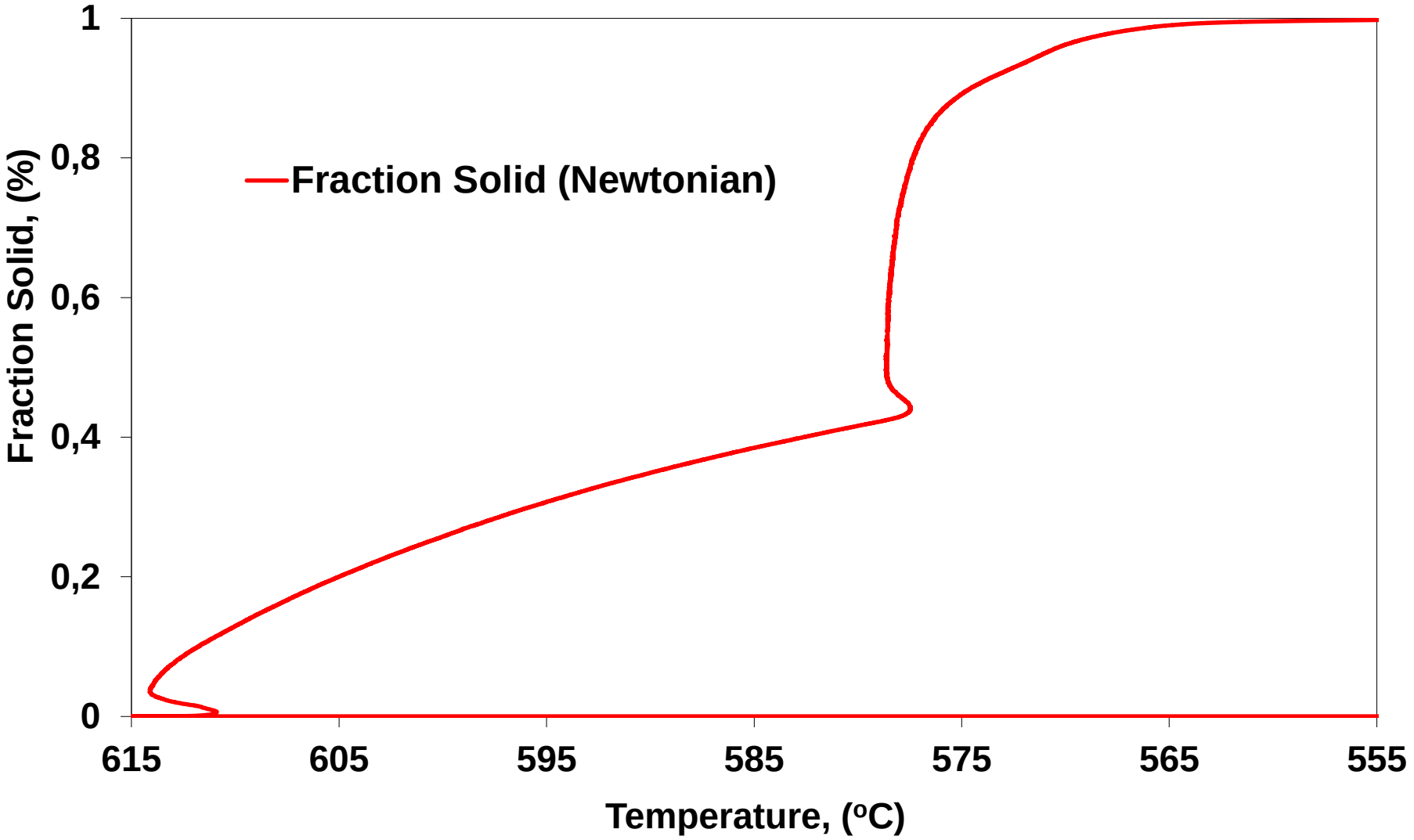


Fraction Solid Calculation using Thermal Analysis

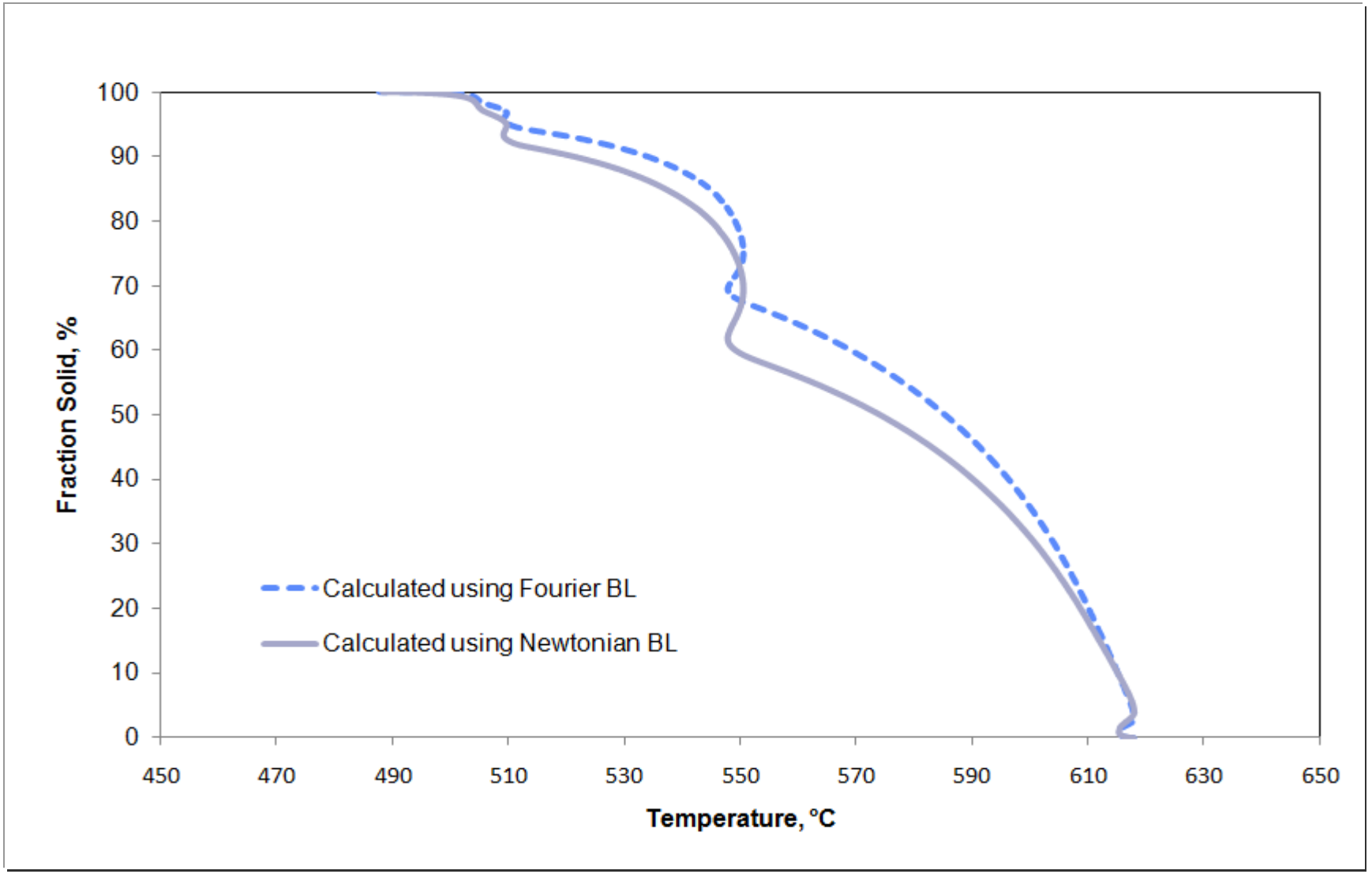
First derivative of AlSi5Cu4 alloy and its Newtonian base line



Calculation of the fraction solid applying Newtonian method



Fraction solid curves for AlSi5Cu4 alloy calculated using Newtonian and Fourier base lines



Conclusions

- Aluminum casting plant are using significant amounts (in number and quantity) of aluminum primary, secondary and master alloys.
- A comprehensive understanding of melt quality is of vital importance for the control and prediction of actual casting characteristics.
- In order to control the quality of incoming ingots, melts, cast products, optimize the amount of master alloys added into aluminum melt and do expert analyses of scrap products there is a need to use **Thermal Analysis** as a quality control tool.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