# A Comprehensive Study of Thermo-Physical Properties of Investment Shells

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# Outline

- Thermal properties measurements
- Process history effect on silica based shells

# Introduction

- Thermal Properties of shells
  - Casting microstructures
  - Casting defects
  - Solidification simulations
- Challenges
  - Various levels of porosities
  - Metastable components

# Before this work…

- Properties from handbook
- Rule of mixture estimation considering shell porosity

  $k_r = \exp(-1.5\varphi/(1-\varphi))$
- Hot wire method

# Standard Laser Flash

- ✓ Temperature dependent Diffusivity ($\alpha$):

$$\alpha = 0.1388 \mathbf{L}^2/t_{1/2}$$

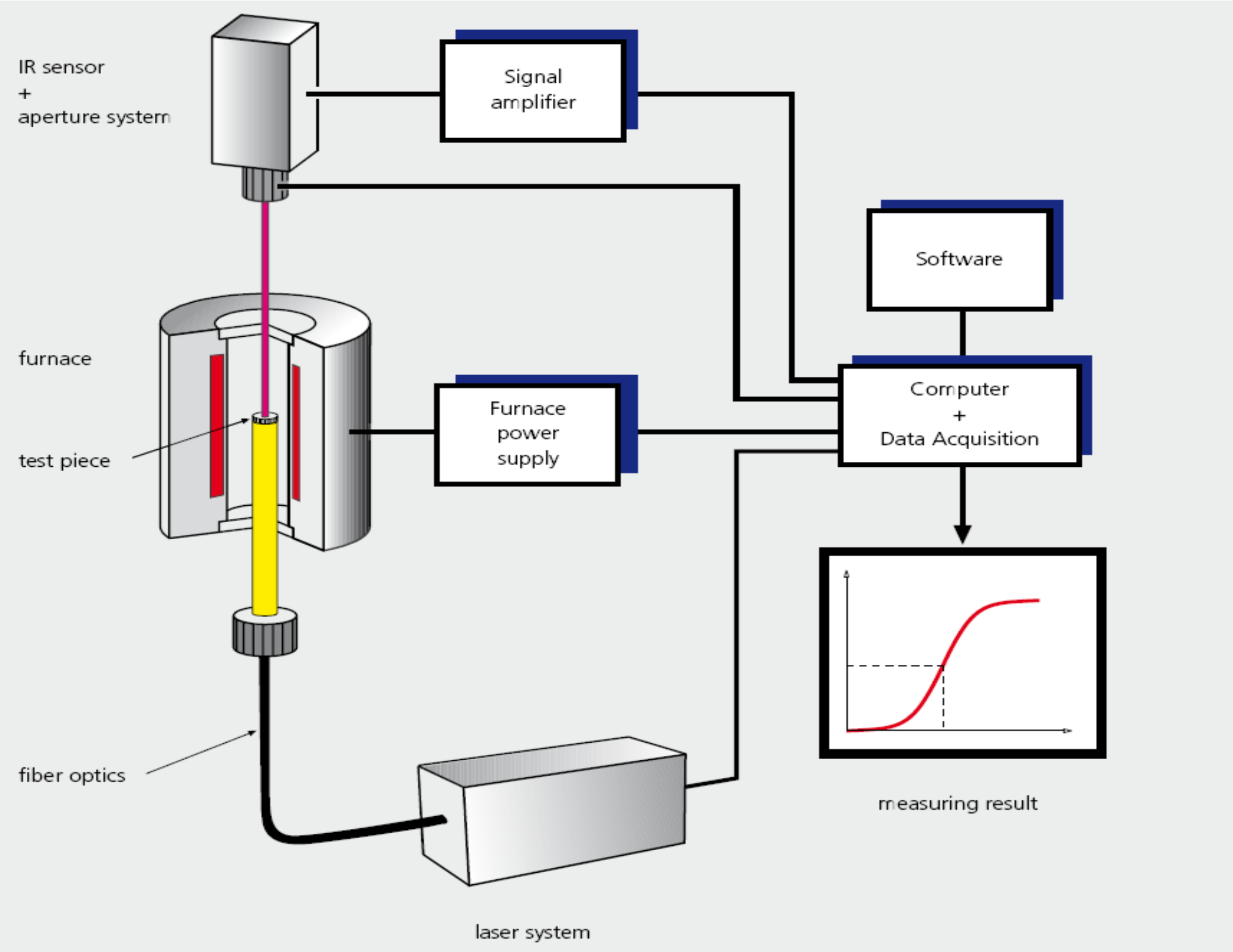
$L$: specimen thickness
$t_{1/2}$: time required for rear face temperature to reach 50% of its maximal value

- ✓ $C_p$:

$$(\rho c_p)_M = \frac{L_R \Delta T_R}{L_M \Delta T_M} (\rho c_p)_R$$

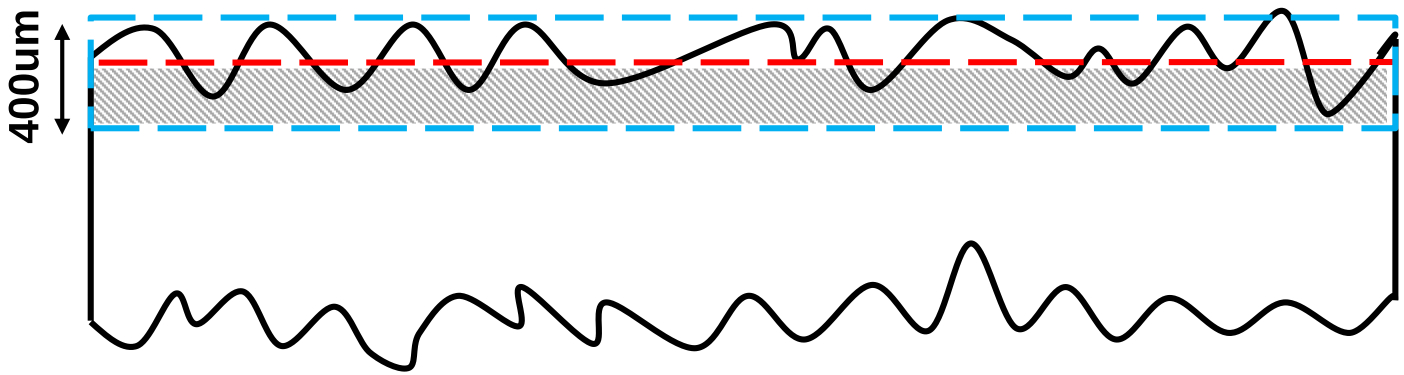
- ✓ Thermal conductivity ($K$):

$$K = \boldsymbol{\rho} C_p \alpha$$

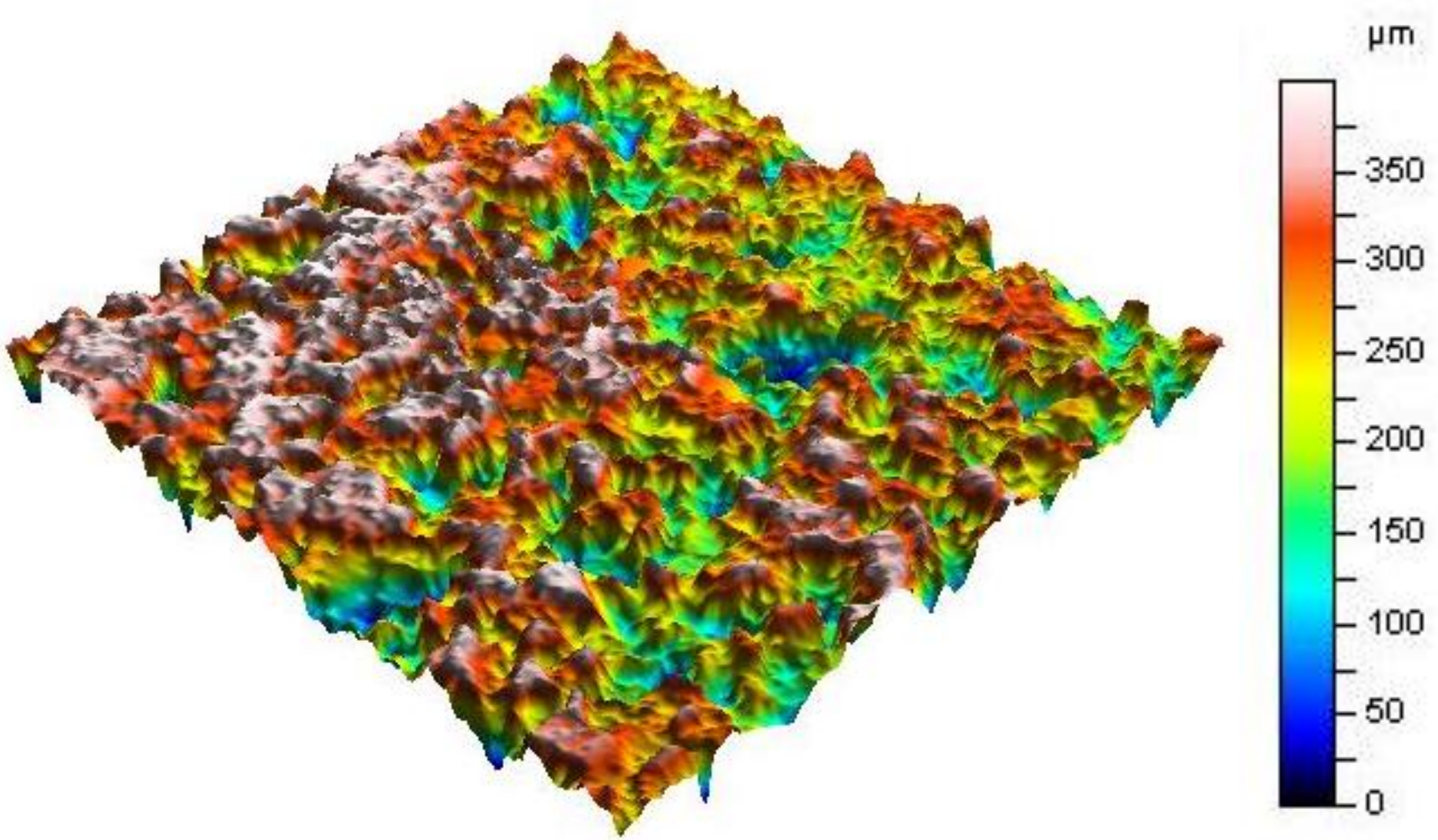


# Surface roughness

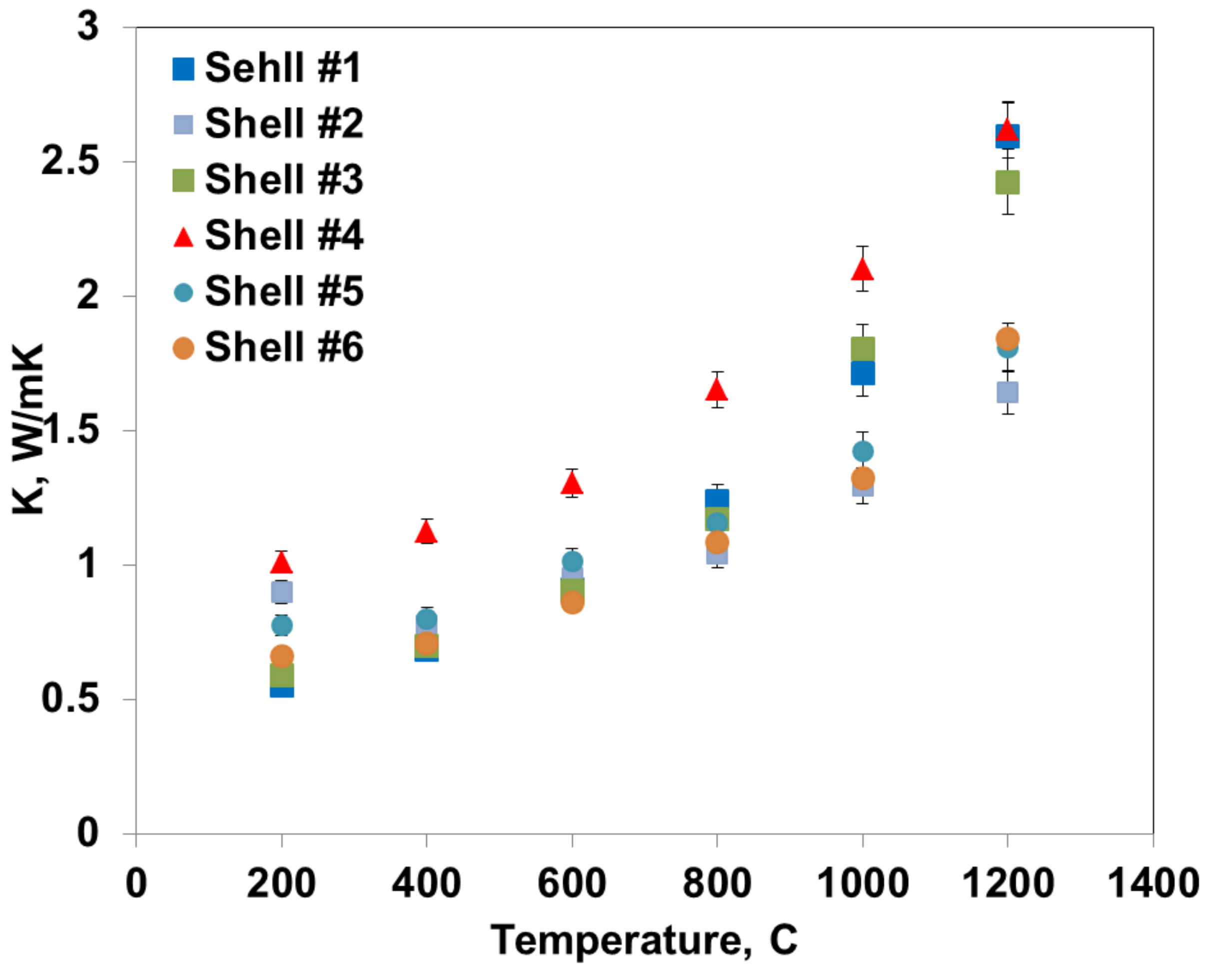
- Challenges to accurately determine the sample thickness
- "effective" plane is drawn
  - Volume of "mountain" = volume of "valley"



# Effective Thickness Using 3D Optical Profiler

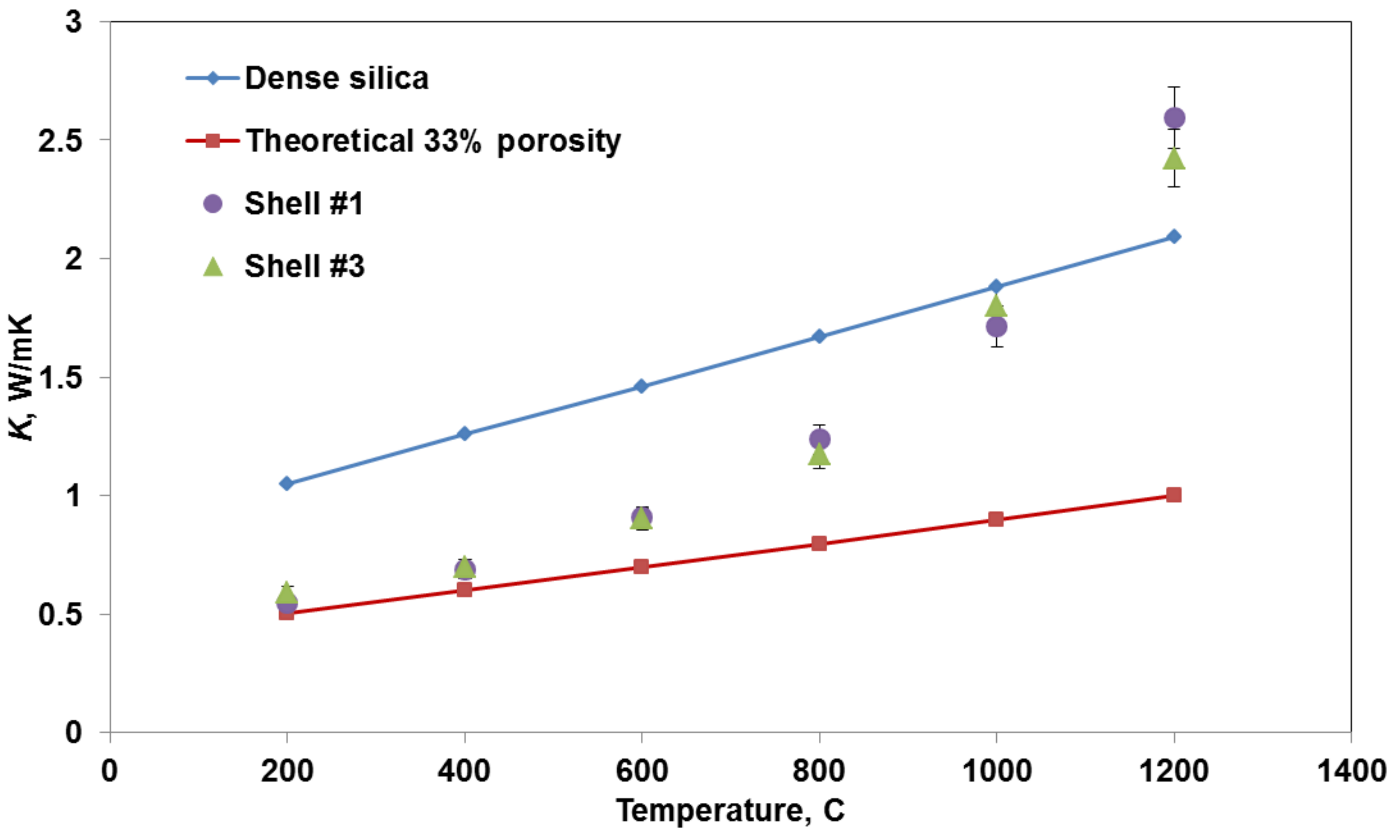


# Thermal Conductivity from Laser Flash




Xu et al., AFS transaction 2014

# Comparison to Theoretical values



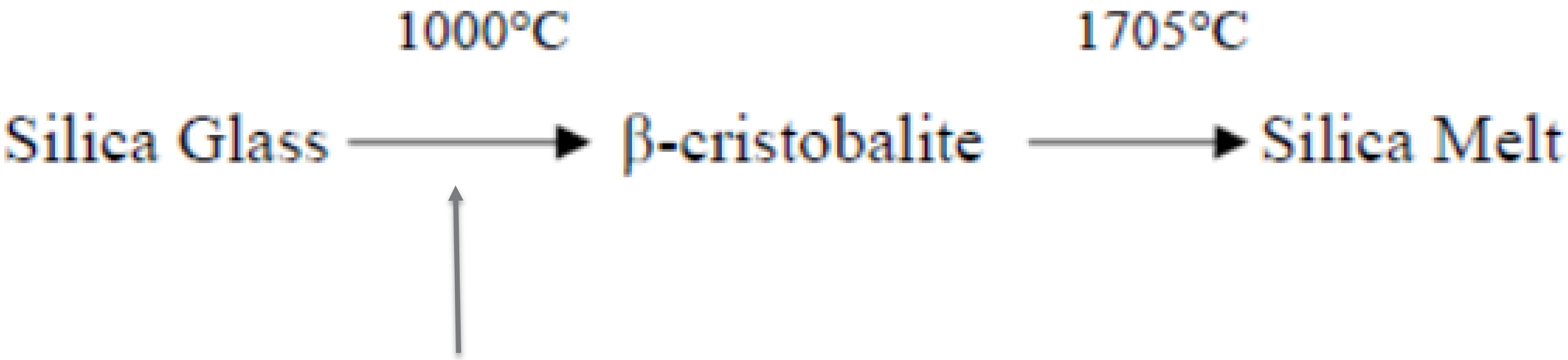

- Discrepancy from photon conductivity

# Time to think…

- Modified laser flash
  - Samples equilibrated at test temperatures
  - Good for steady state thermal properties

# In Reality…

- Phase transformation of fused silica



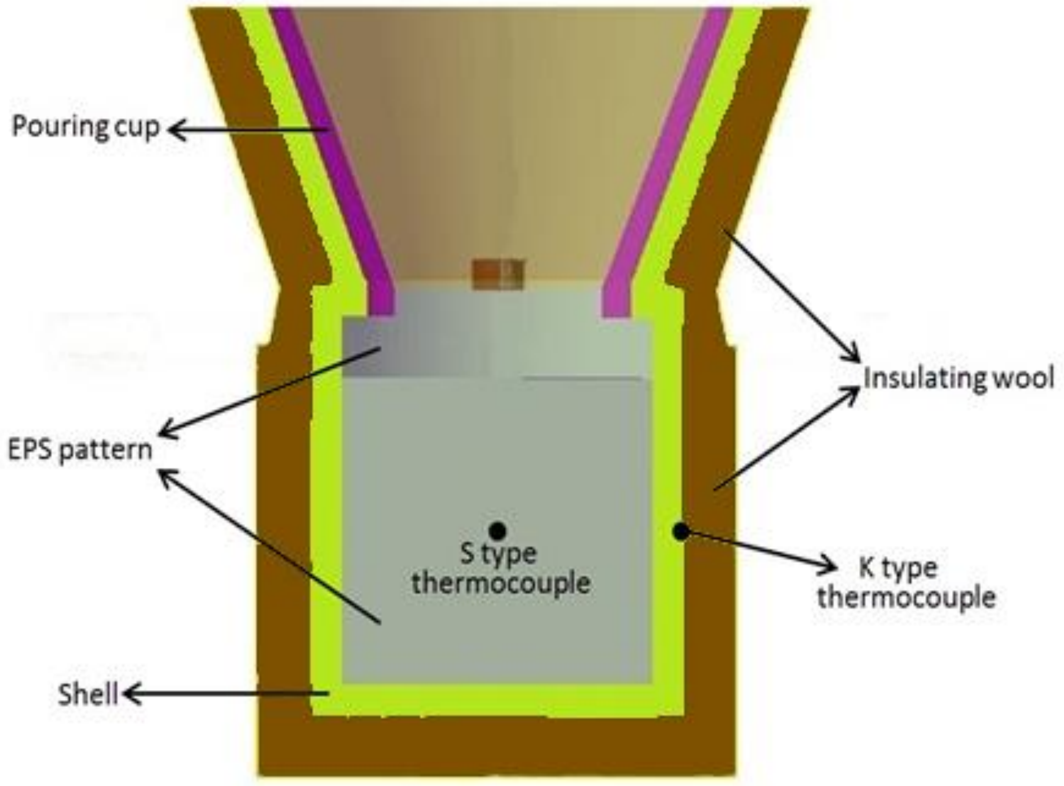

Releases 9500 J/mol or 158 J/g

- Ways to measure the transient properties?

# Inverse Method

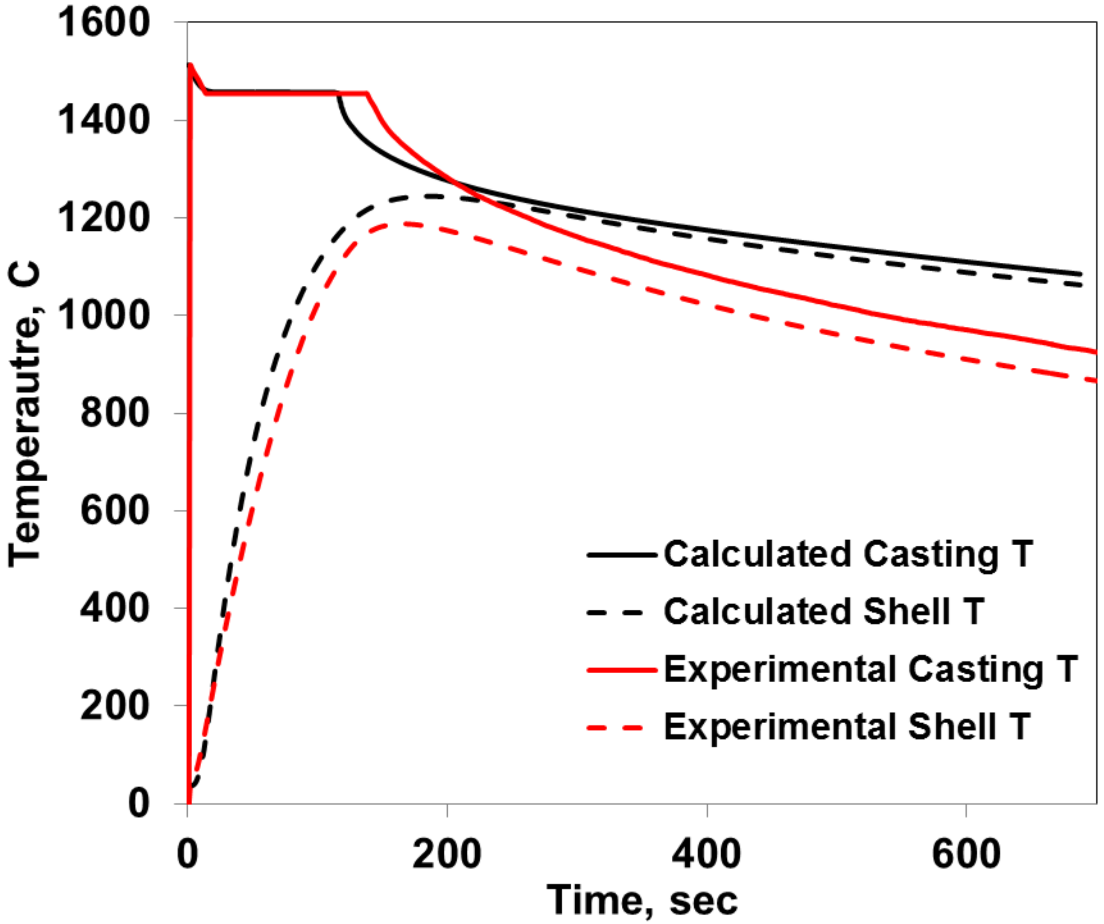
- Calculating thermal properties from a real-time heat

- The shell was pre-fired at 850 C for 1 hour and cooled to room temperature
- Reference material pure *Ni* was poured at 1520 C into the shell
- Two temperature curves were recorded

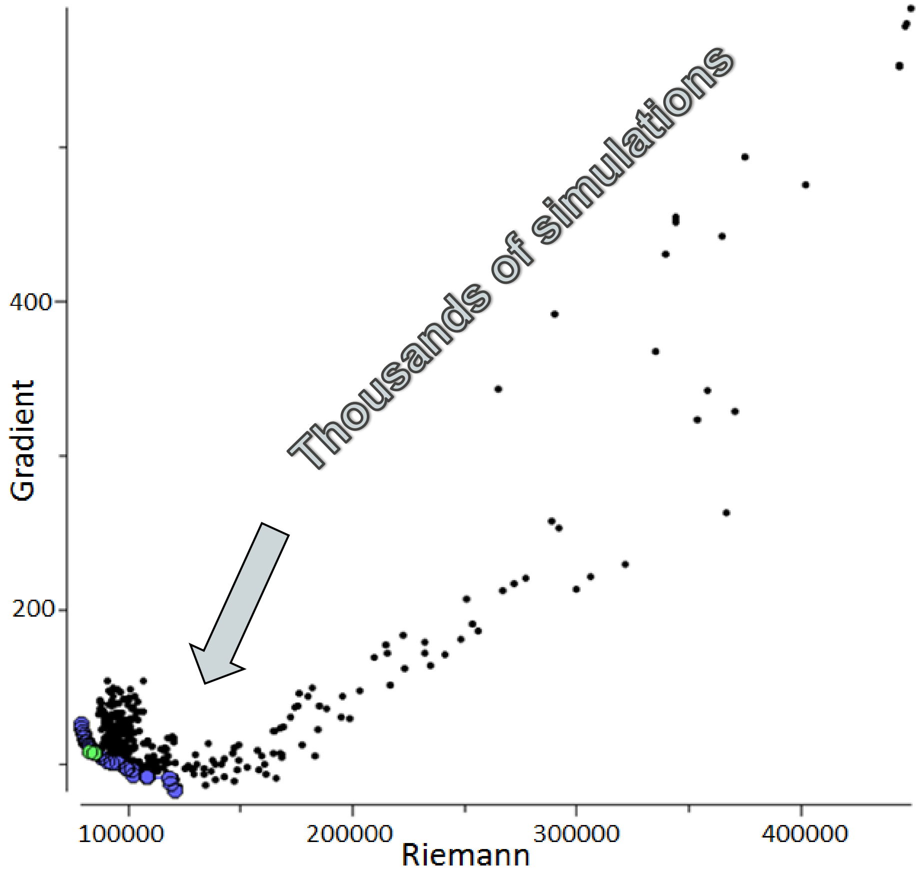


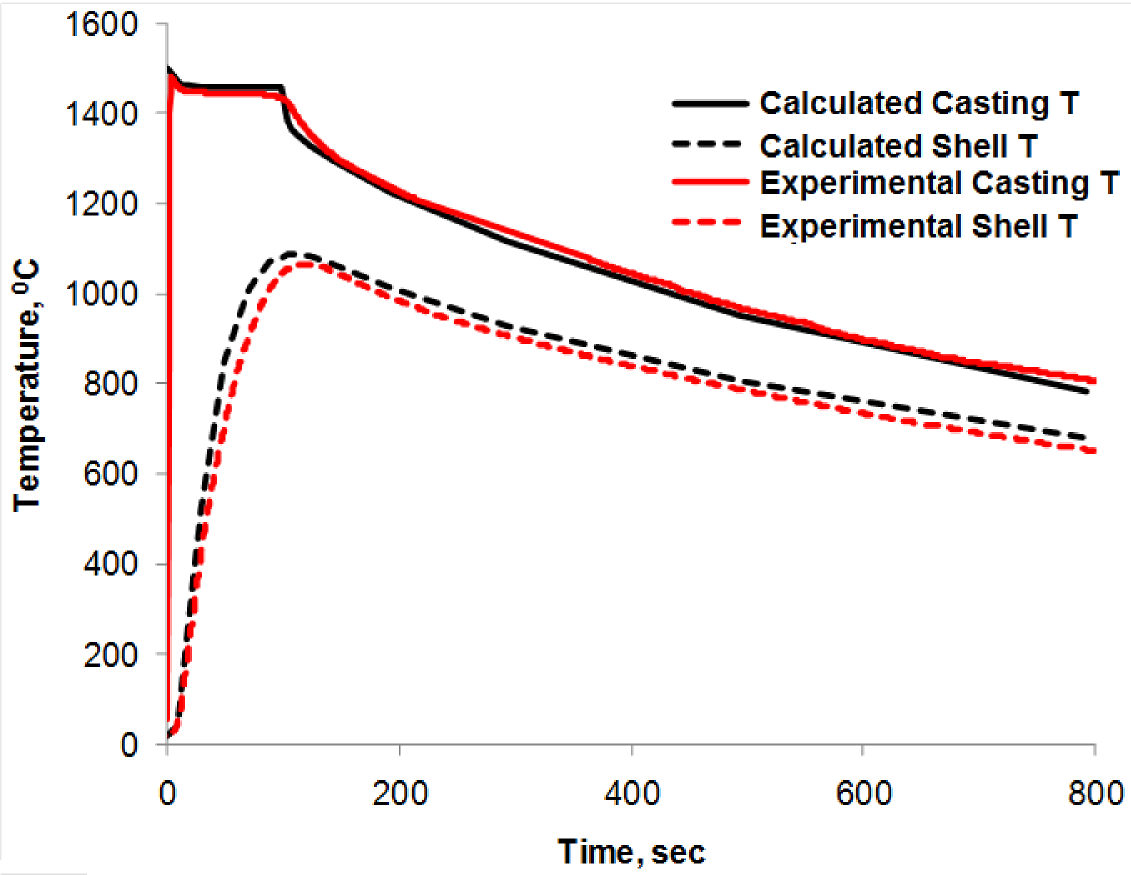
# Inverse Method

- LF results as the starting point

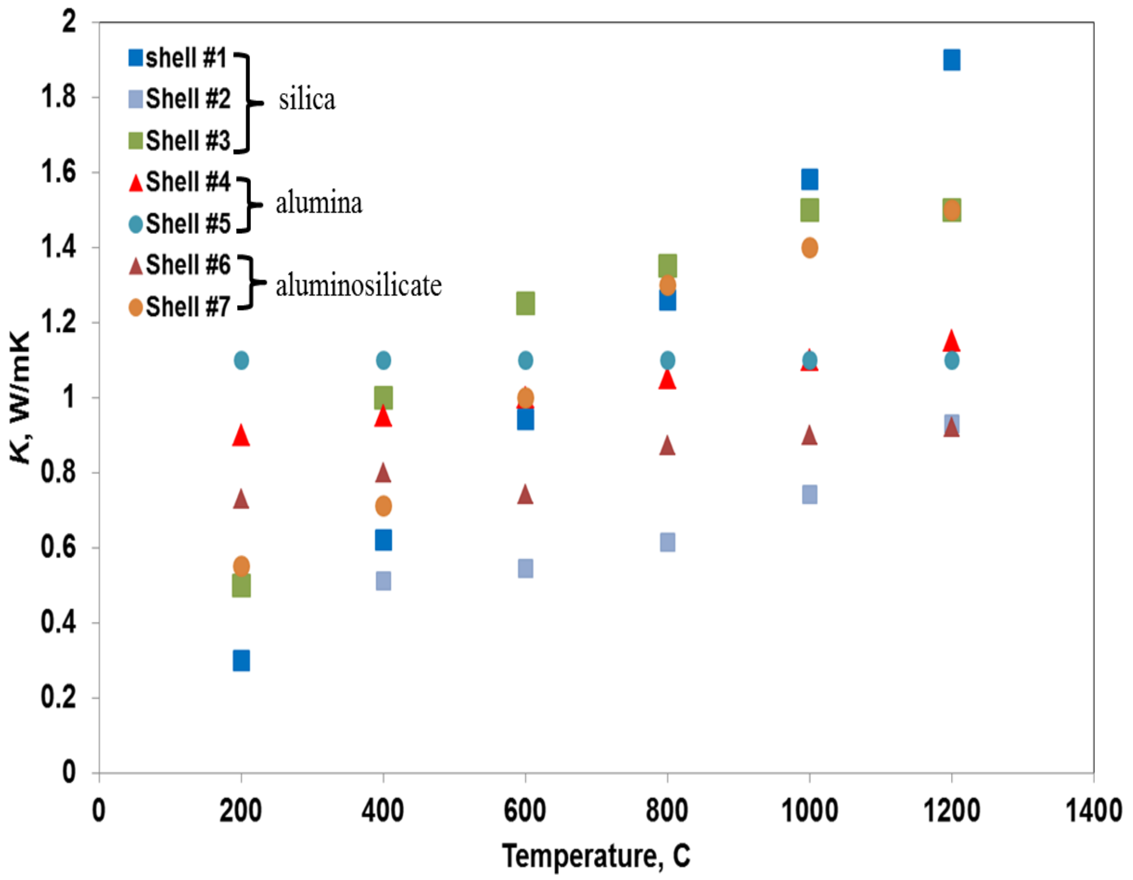


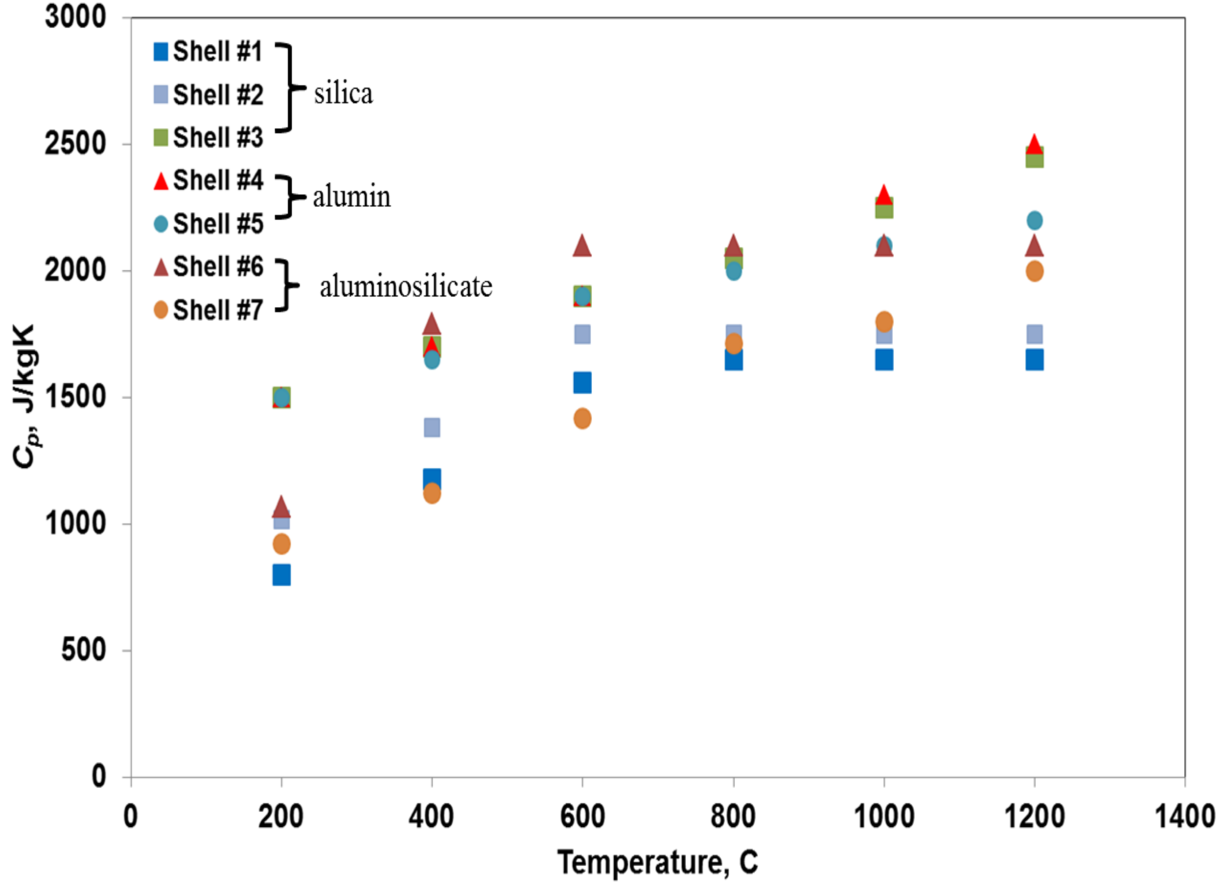
# Inverse Optimization



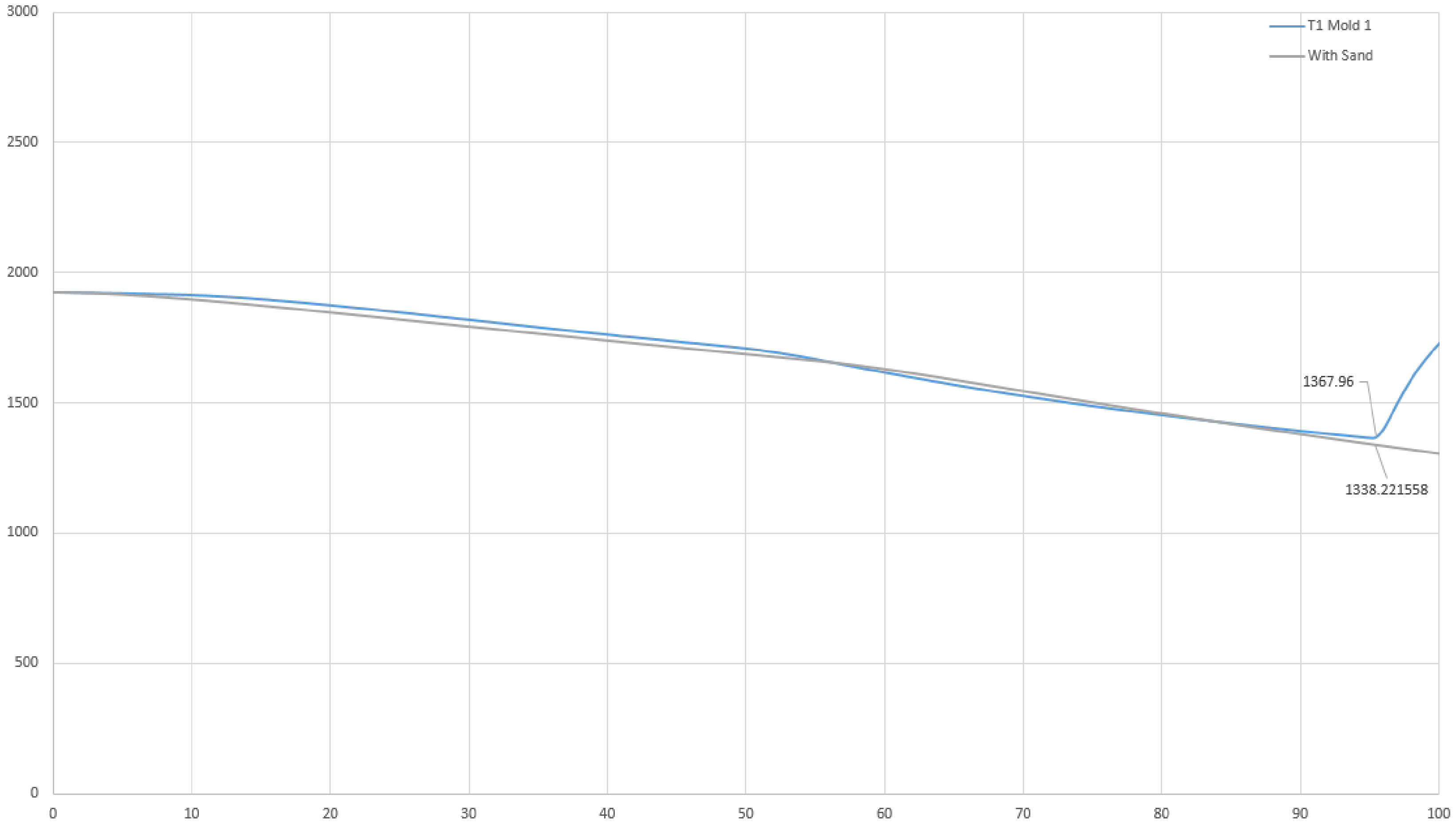
# Examples for database



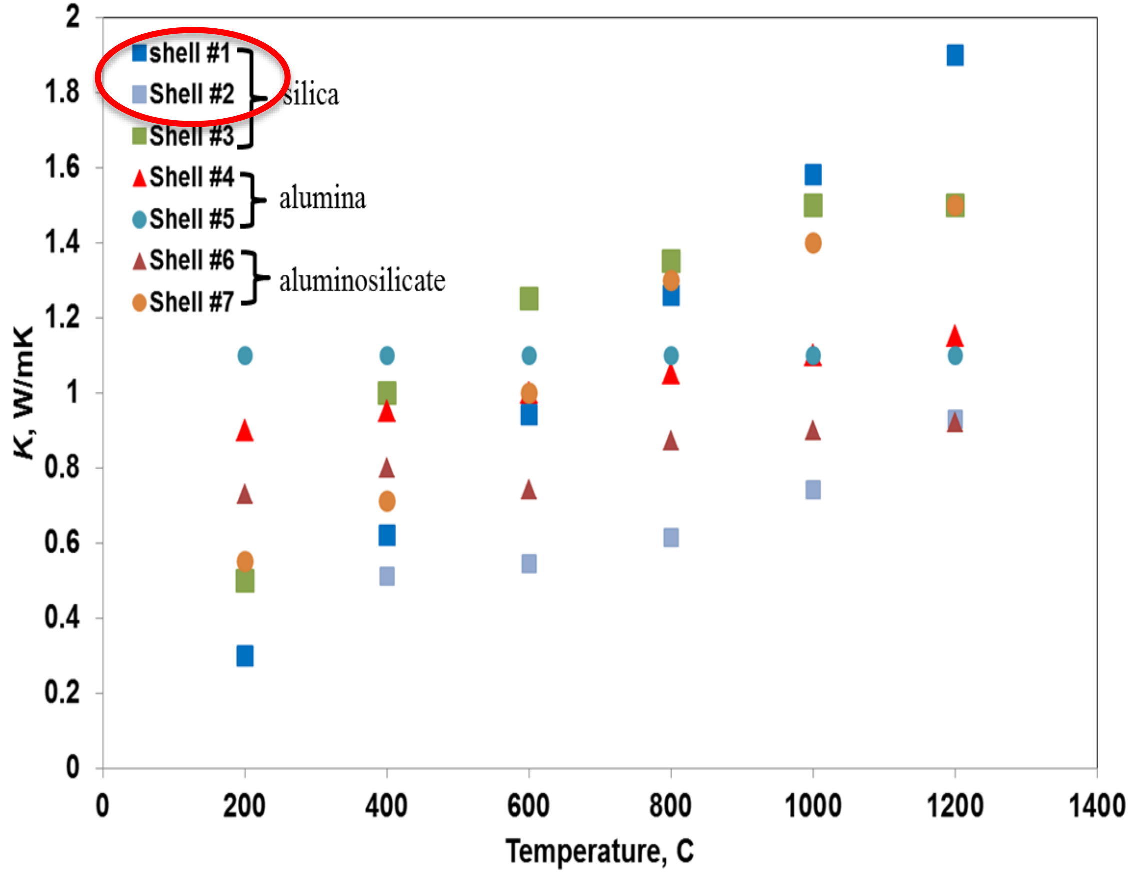

Xu et al., International Journal of Metalcasting, Volume 10, Issue 3, 2016

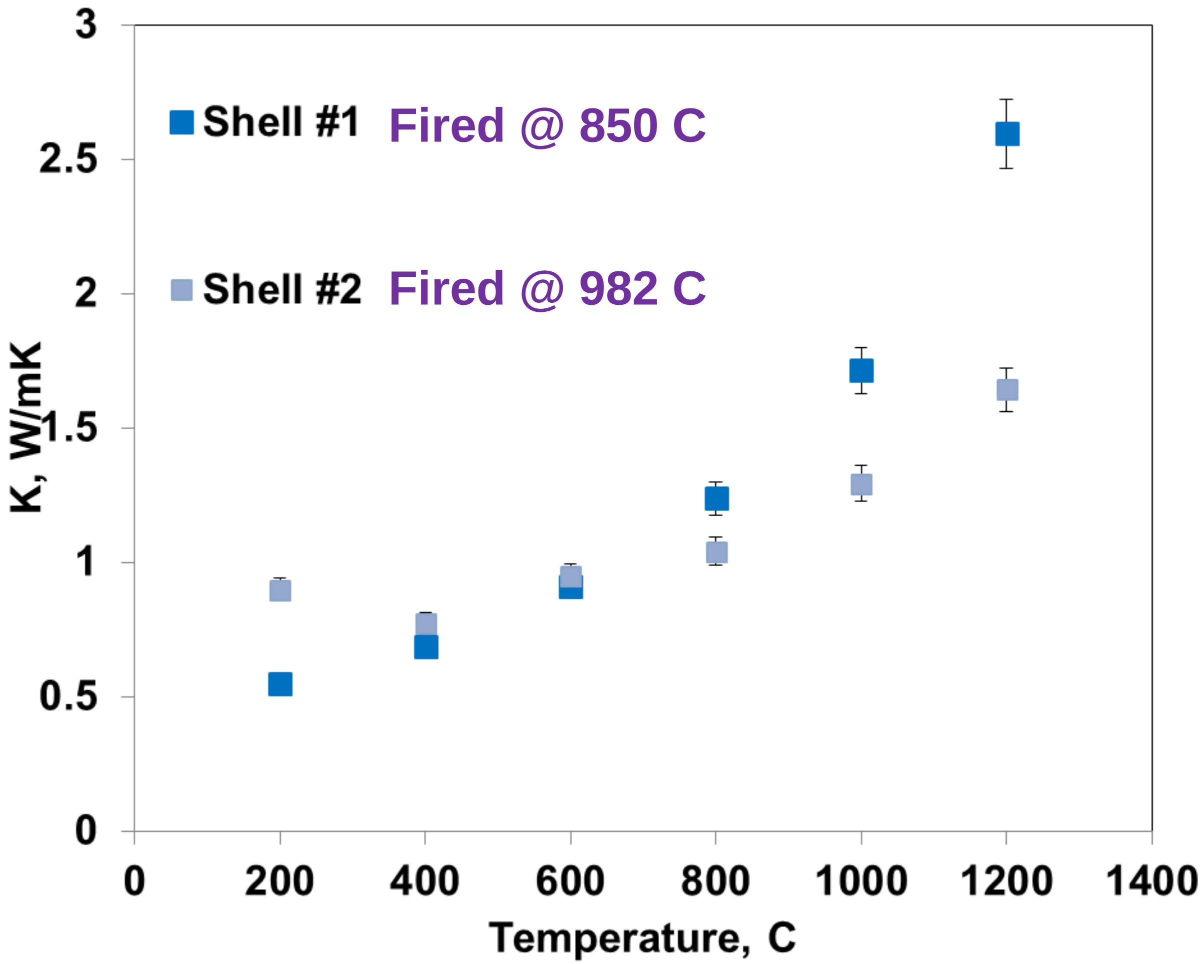
# Industrial Responses




"Overall I think we are very satisfied with the results of this test, I think the material properties you calculated were spot on."

# Time to think again…

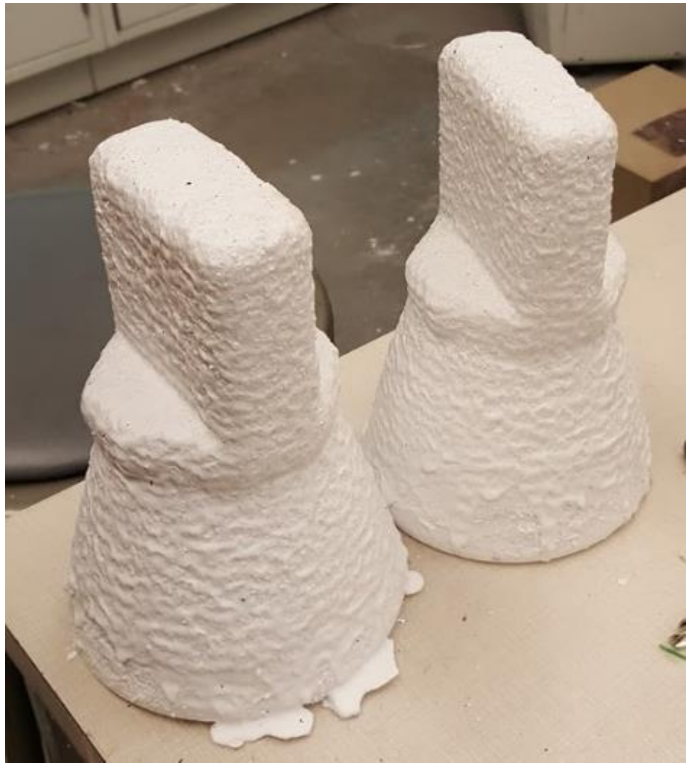



**Question: different firing parameters result in different amount of devitrification?**

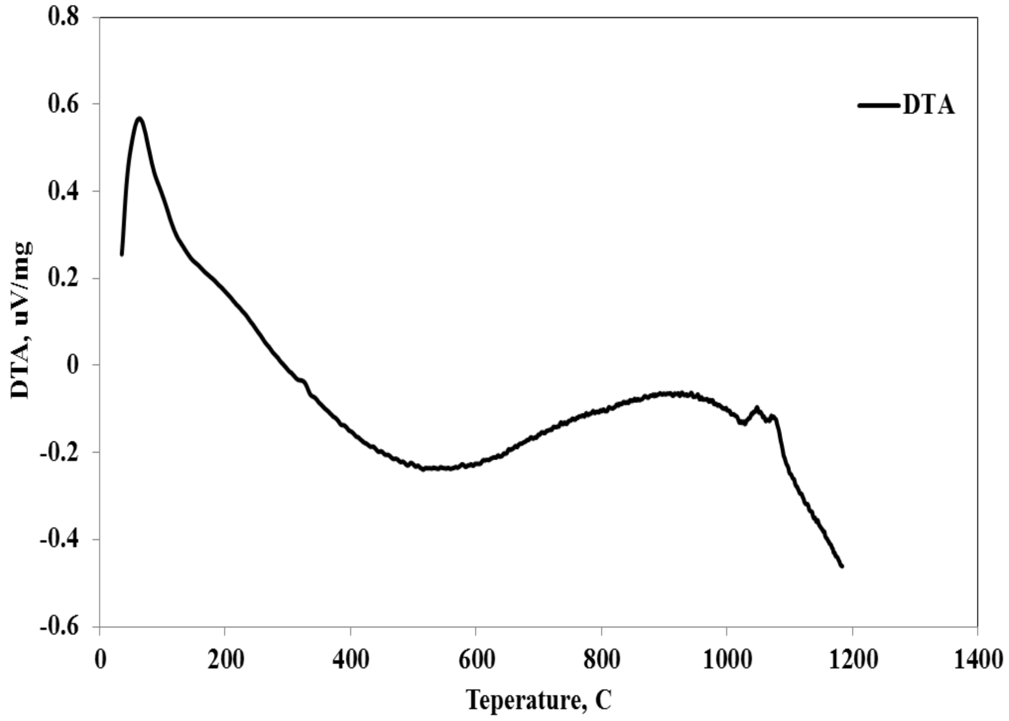
# Shell Preparation

- Fused silica based shell
- Fired at 600$^0$C, 850$^0$C, 1000$^0$C for one hour
- 3-point bend samples
- Shell ingredients dried and crushed

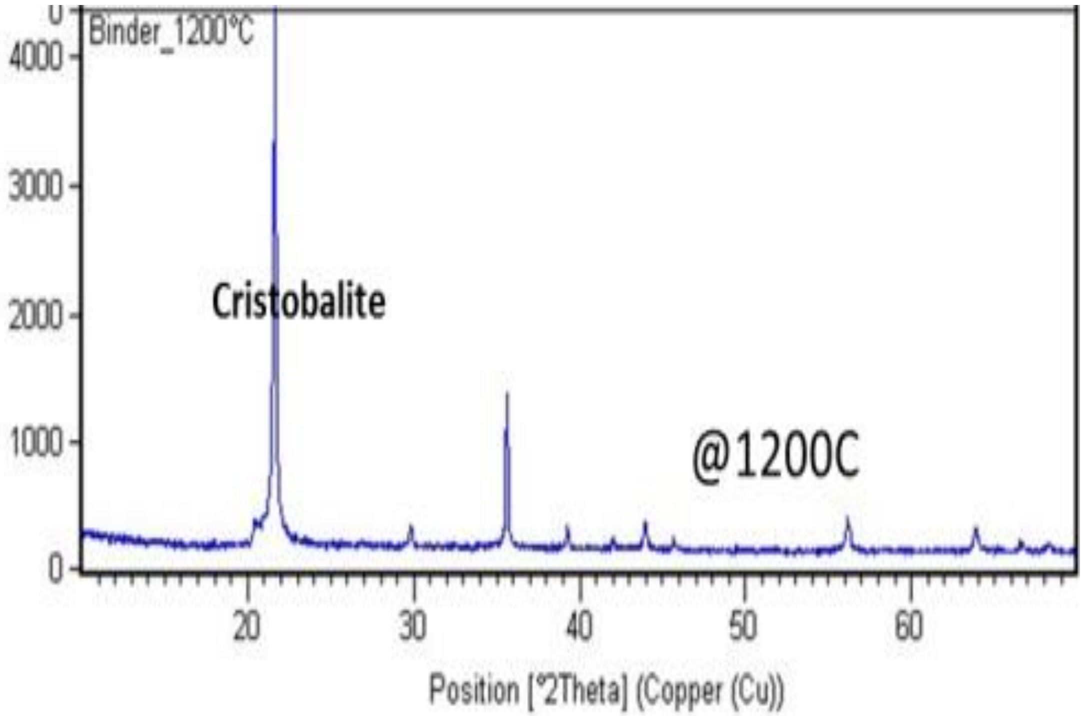


# Silica Devitrification

- Silica binder was found the only ingredient that devitrifies at up to $1200^0C$



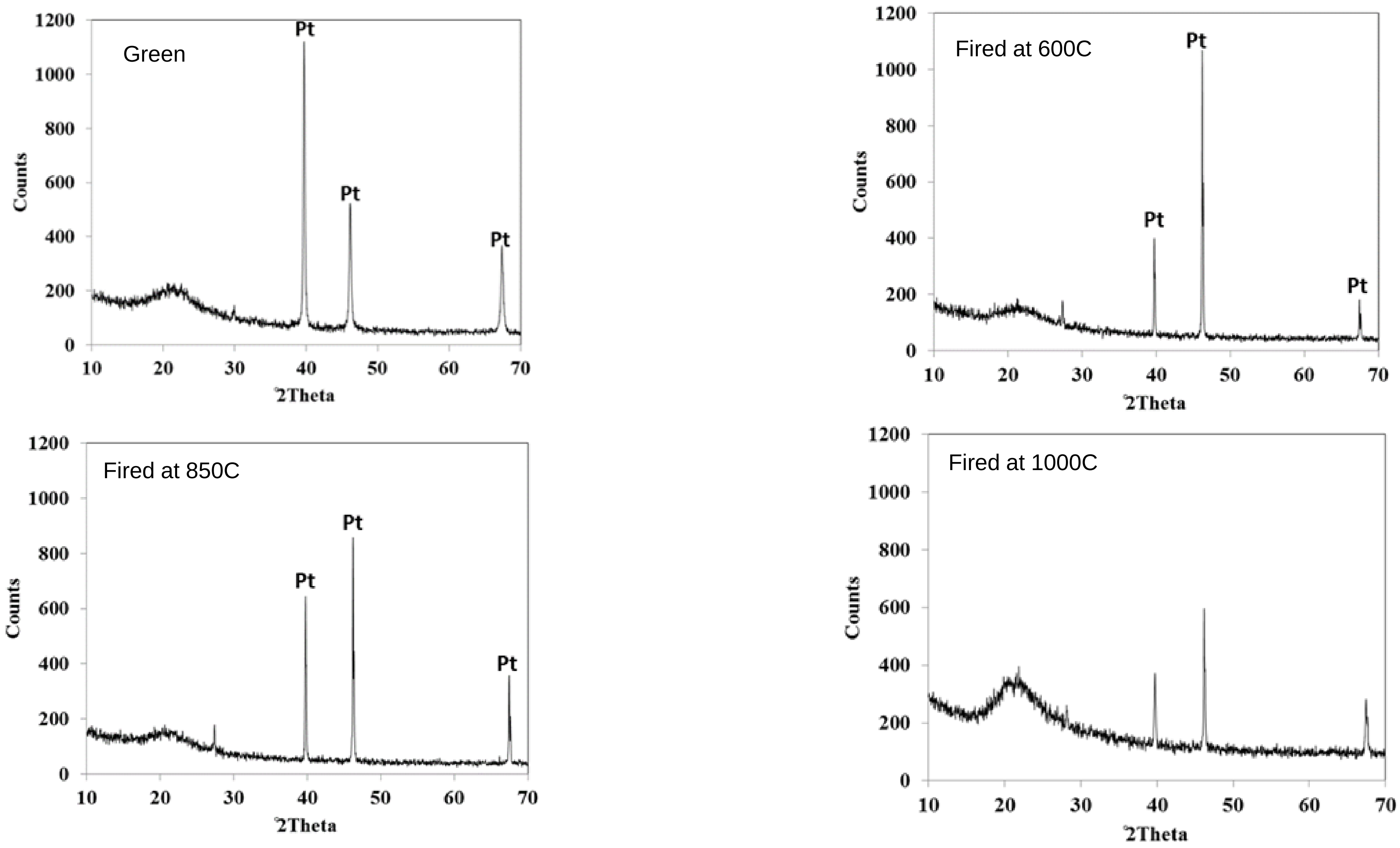

DTA at a $15^0C/min$ heating rate




XRD of silica binder at $1200^0C$

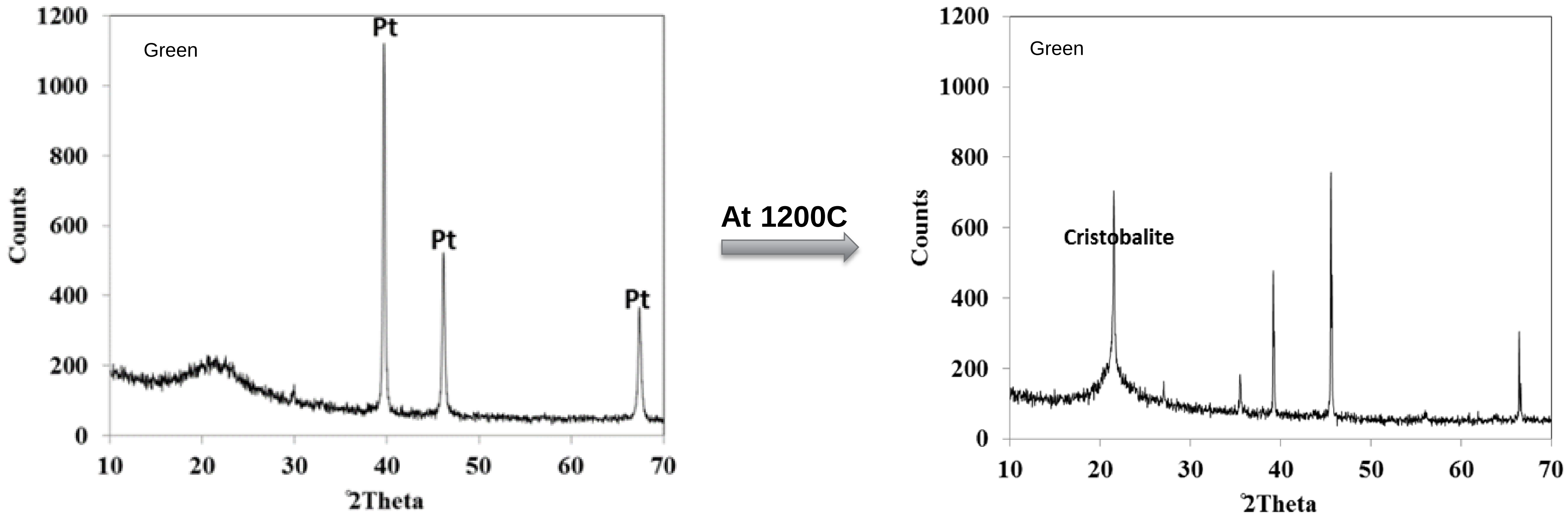
# Phases Present after Firing

- Fired at $600^0$C, $850^0$C, $1000^0$C for one hour – XRD at **RT**



# Phase Present during Pouring

- To simulate the subsequent pouring – XRD at **$1200^0$C**



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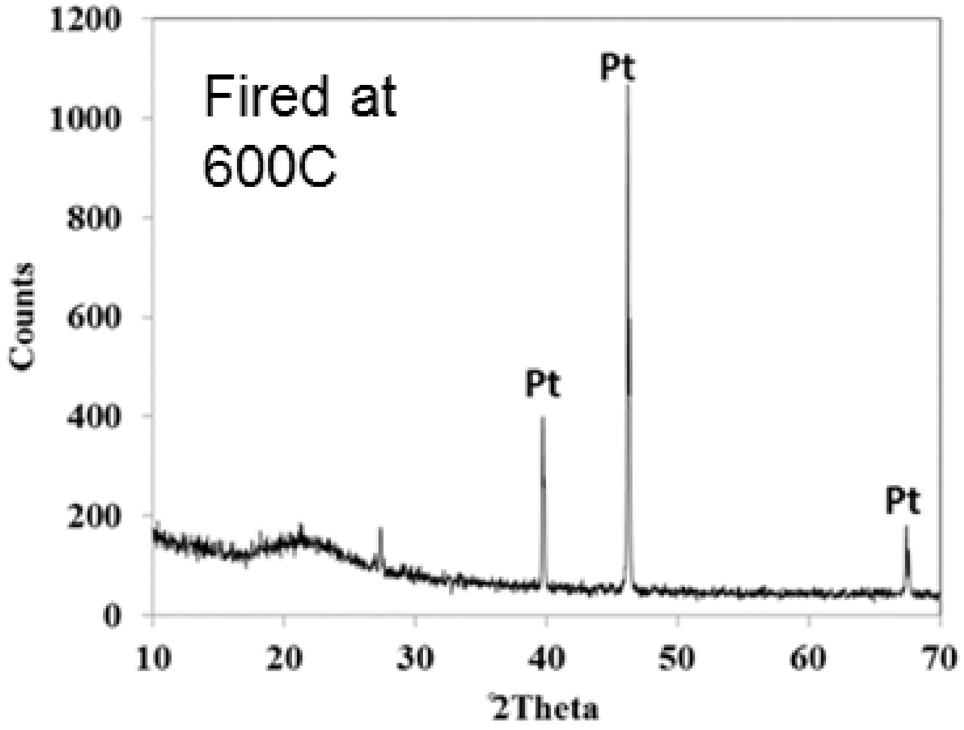
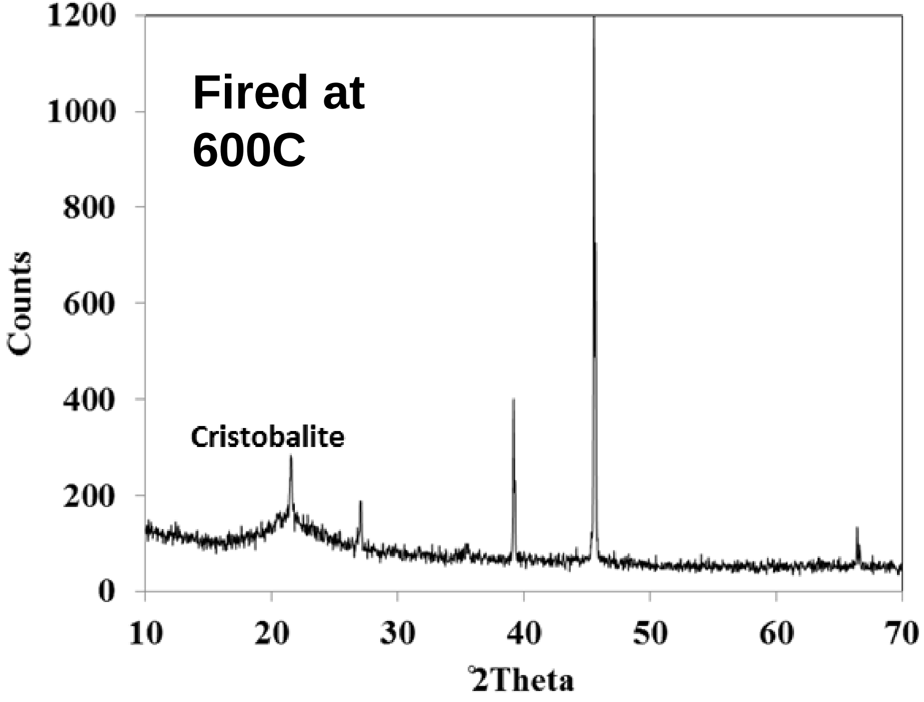



**At 1200C**



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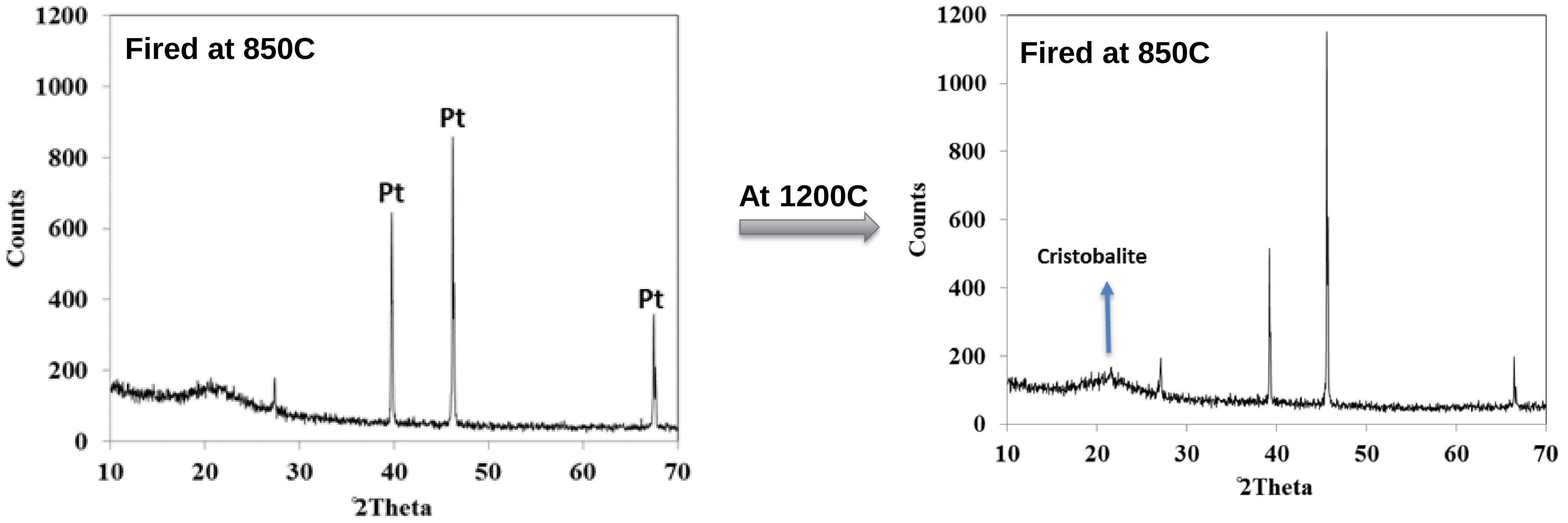

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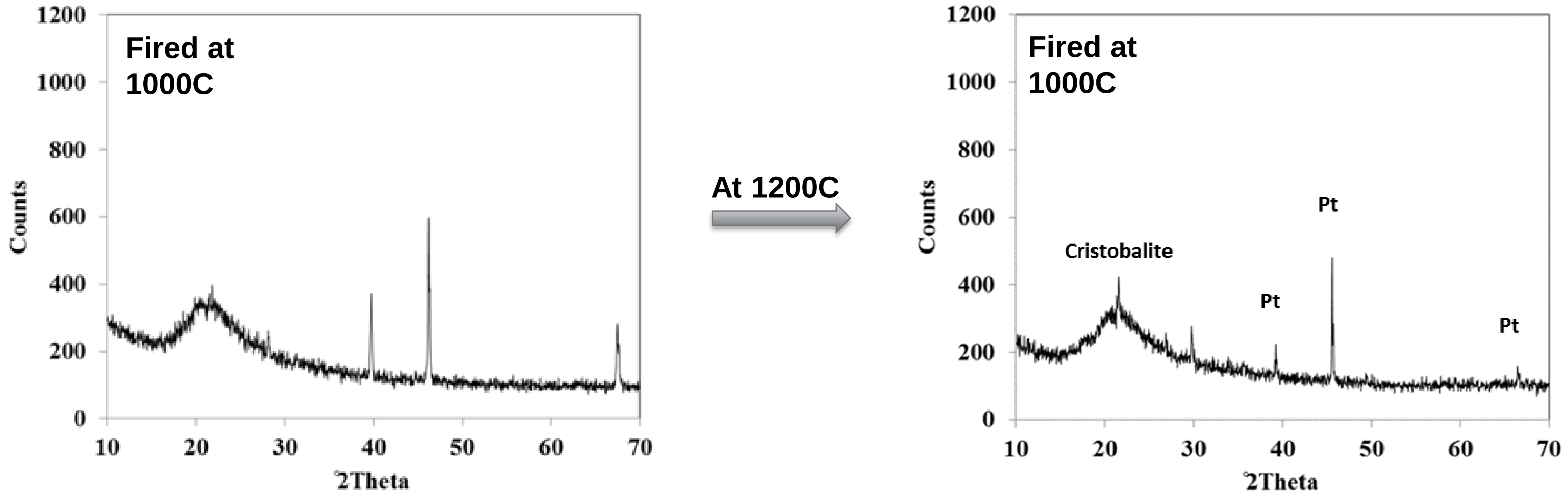


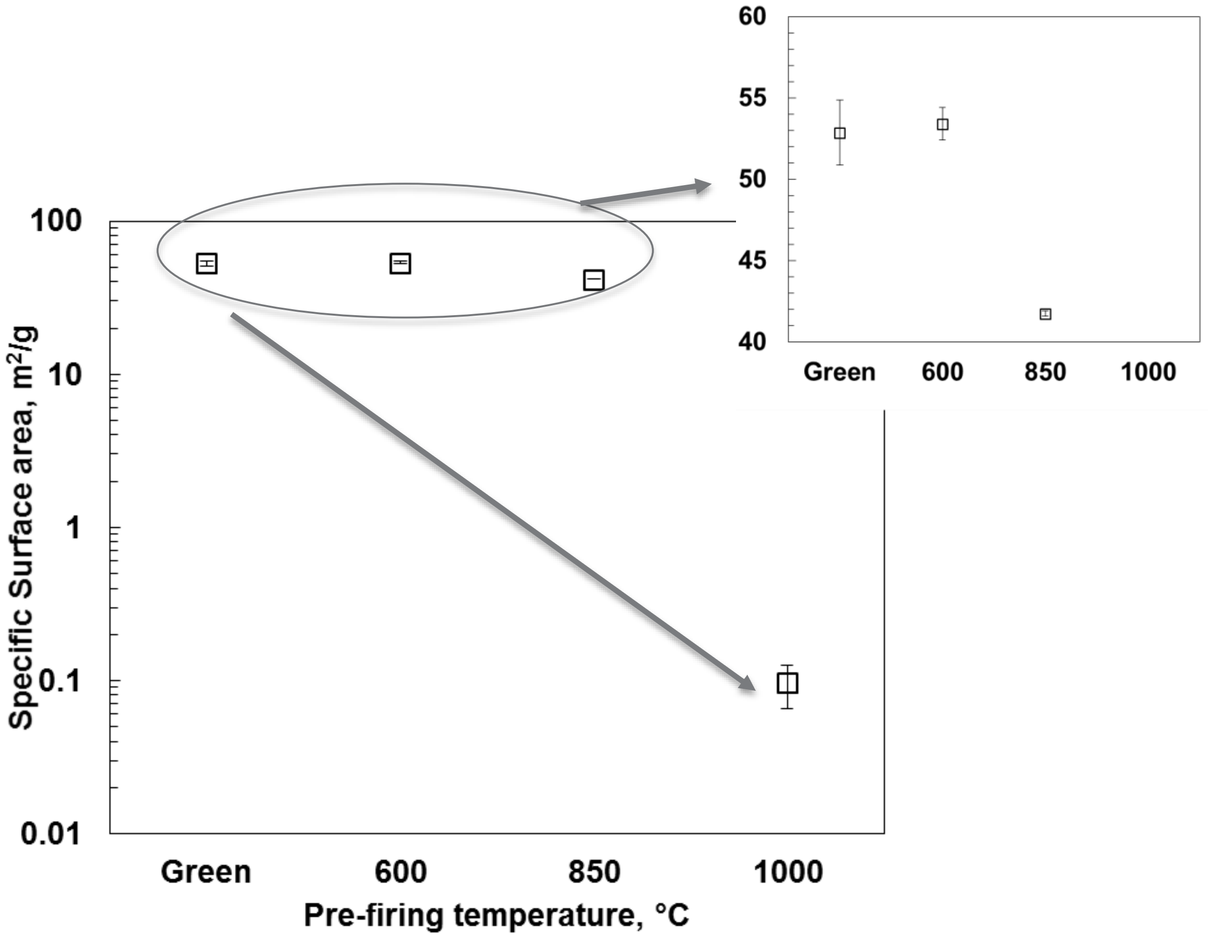
# What Caused the Change

- During firing/sintering
  - Grain boundary migration
  - Grain growth

→

- Surface area reduction
  - Surface energy to activate
  - Kinetical favorable path

# Specific Surface Area of Silica Binder

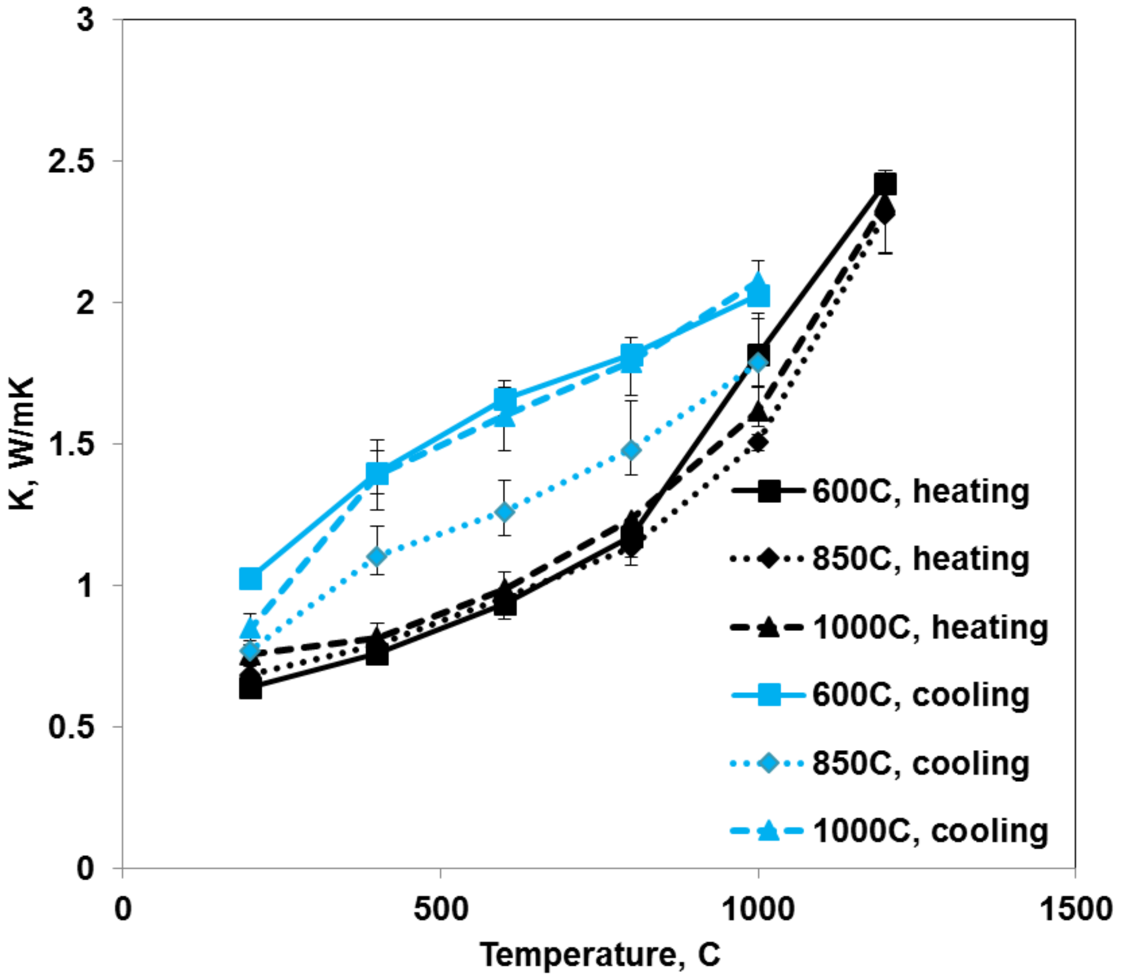



0.26J/$m^2$ surface energy*
~1,000 J/g surface energy loss

*Brunauer, S., Kantro, D. L., Weise, C. H., "The Surface Energies of Amorphous Silica and Hydrous Amorphous Silica", Canadian Journal of Chemistry, 1956, 34(10): 1483-1496, 10.1139/v56-190.

# Thermal Conductivity

- Crystalline silica has better thermal conductivity
- Amount of crystalline silica
  - 600C > 1000 > 850C



# Summary

- Ways to determine thermal properties
  - Modified LF: steady-state thermal properties
  - Inverse method: transit
- Firing parameters have a significant effect on thermal properties

# Current Work

- Funded by American Foundry Society
  - Develop silica devitrification kinetical model
- Future work
  - Silica reclamation

# Acknowledgements


- My wife Dr. Jingjing Qing
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- Shelly Dutler
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# For More Information

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