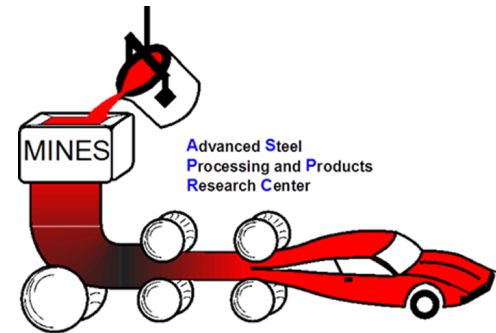


Modeling of Short Time Dilatometry Testing of High Carbon Steels

*Robert Goldstein,
Fluxtrol, Inc.
rcgoldstein@fluxtrol.com*

*Ethan Buchner, Robert Cryderman
Colorado School of Mines*



Overview

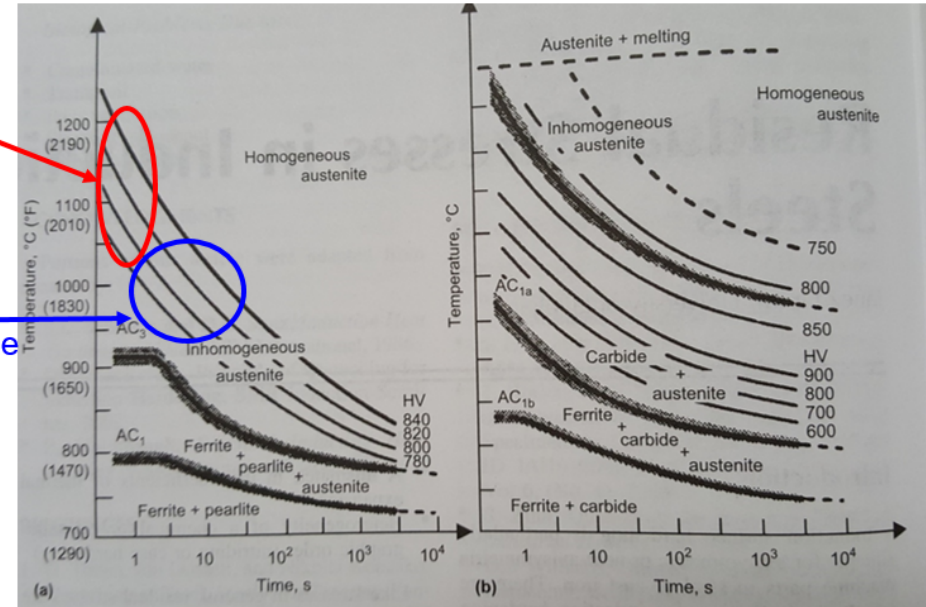
- Effect of Short Time Heat Treatment on Transformation Phenomena
 - Test Results That Led to the Study
- Dilatometer Description
- Modeling Dilatometer Performance
- Comparison Between Simulation and Experiments
- Conclusions/Future Research

Effect of Short Time Heat Treatment on Transformation Temperature

Superior Performance of Components Has Been Achieved in Many Cases Using Non-Equilibrium Thermal Processes (NETP), but There Is Very Little Quantitative Data Available on Material Response to Rapid Thermal Processing

Creating Non-Homogeneous Austenite in this range, creates Flash Bainite® Structure, good elongation, reasonable hardness

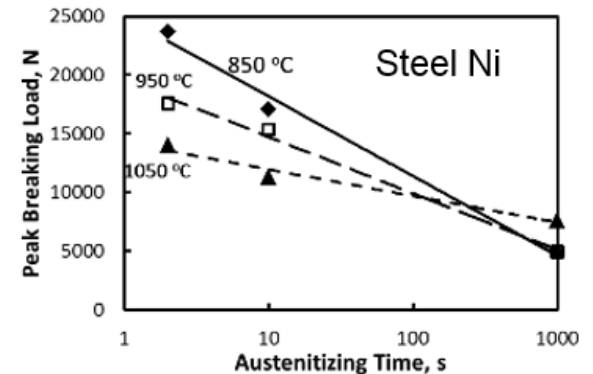
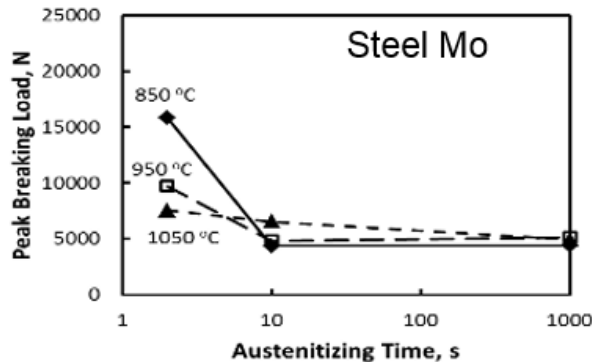
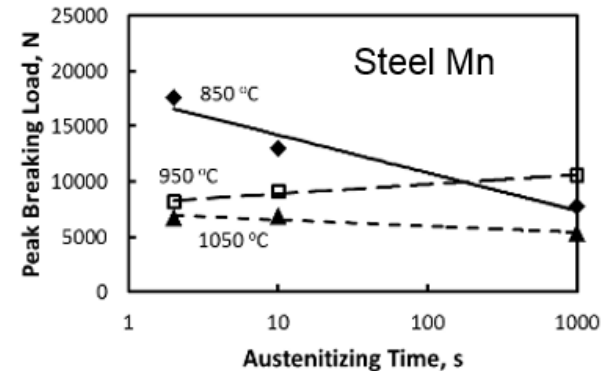
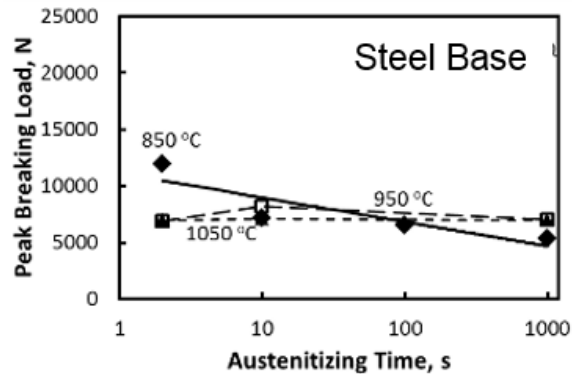
Creating Non-Homogeneous Austenite in this range common in industry and is part of near surface structure of many induction heat treated components and creates good hardness



Hypoeutectoid steel CK45 left, hypereutectoid steel 100Cr6 right
Source – ASM Handbook Volume 4C - Grum

Recent Findings at ASPPRC of Improved Mechanical Properties with NETP

Up to 3X better properties demonstrated using appropriate alloying elements and relatively short, low temperature heat treatment



Microstructure and Notched Fracture Resistance of 0.56% C Steels After Simulated Induction Hardening

Robert Cryderman and John Speer

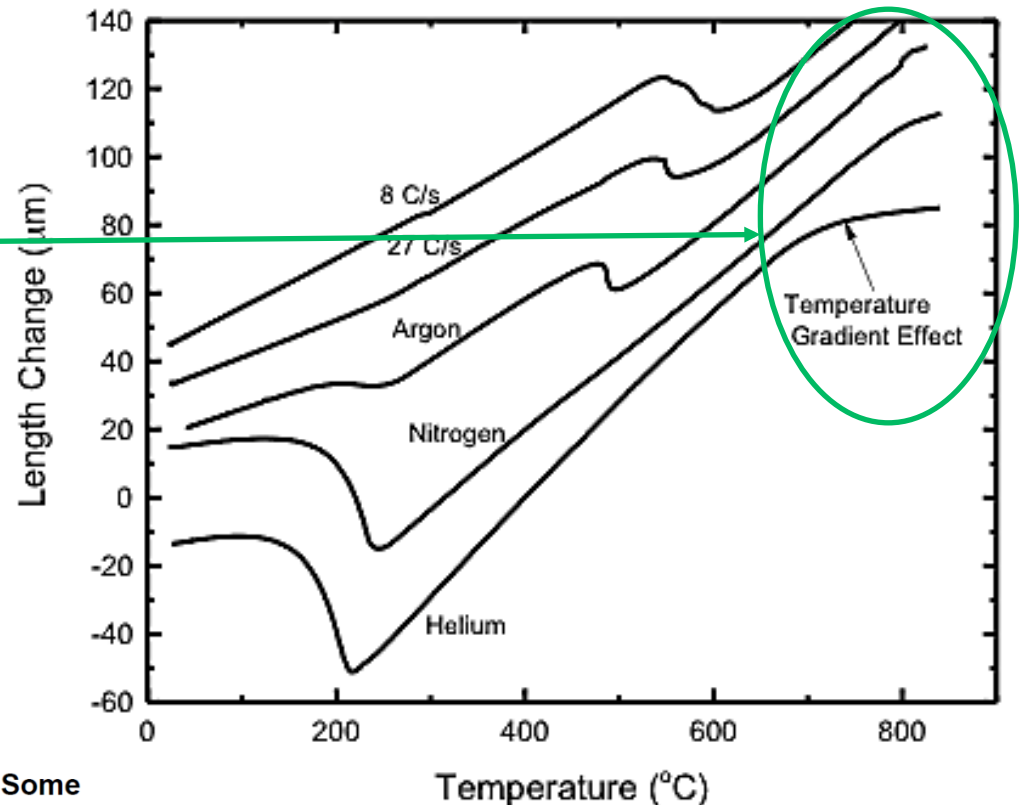
Advanced Steel Processing and Product Research Center, Colorado School of Mines, Golden, Colorado, 80401, USA, rcryderm@mines.edu

Dilatometer Testing of the Steel for Materials Characterization

Effect of Reduced Pre-Transformation Expansion with Increasing Cooling Rate called Temperature Gradient Effect and Led to Impression There Was Non-Uniform Temperature in the Sample

Cooling Rates:

- He: 235 °C/s
- N: 91 °C/s
- Ar: 52 °C/s



Short Time Austenitizing Effects on the Hardenability of Some 0.55 wt. pct. Carbon Steels

Robert Cryderman and Trevor Ballard

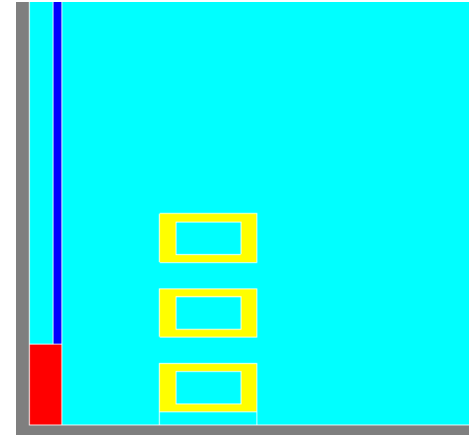
Dilatometer Description

- Measures dimensional movement during thermal procession
- Heating is in a vacuum
- Heat source is induction heating
 - Advertised heating rate up to 1000 C/s
- Gas quenching through induction coil used for cooling
- Fused silica rods hold the component
- Manufacturer TA Instruments



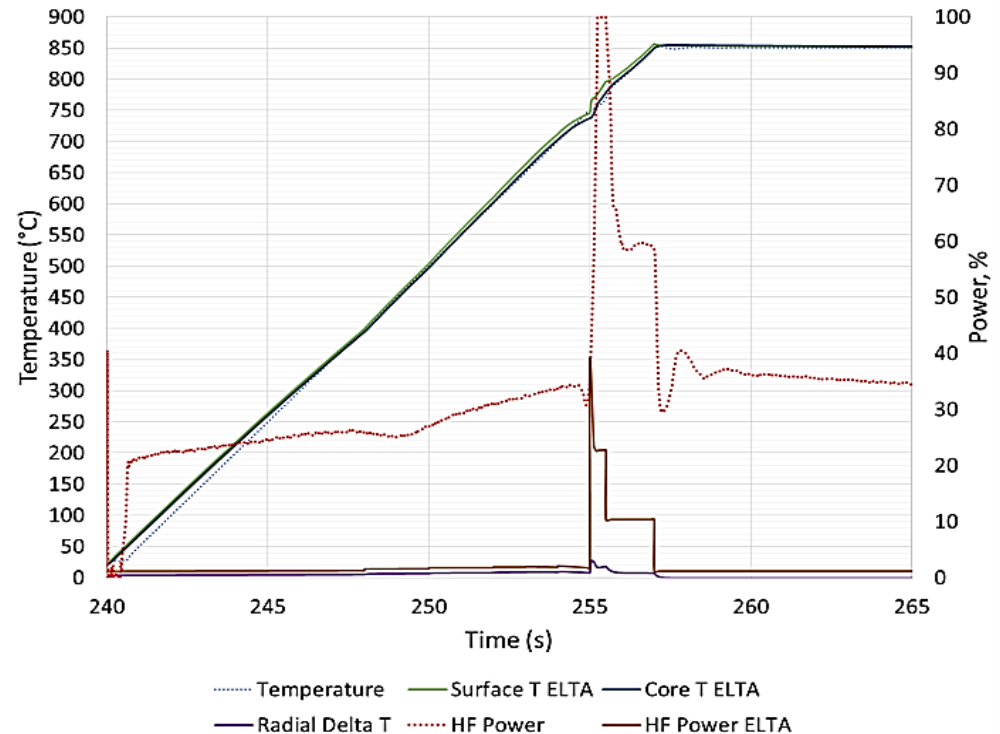
Modeling of Dilatometer Tests

- Heating and Cooling simulations separated due to differences in enthalpy of phase transformations
- 1 D Program ELTA used initially to determine radial gradients and inverse calculations of material properties
- 2D Program Flux Used for Determining Full Temperature Distributions
- For Flux – $\frac{1}{2}$ of axisymmetric system used

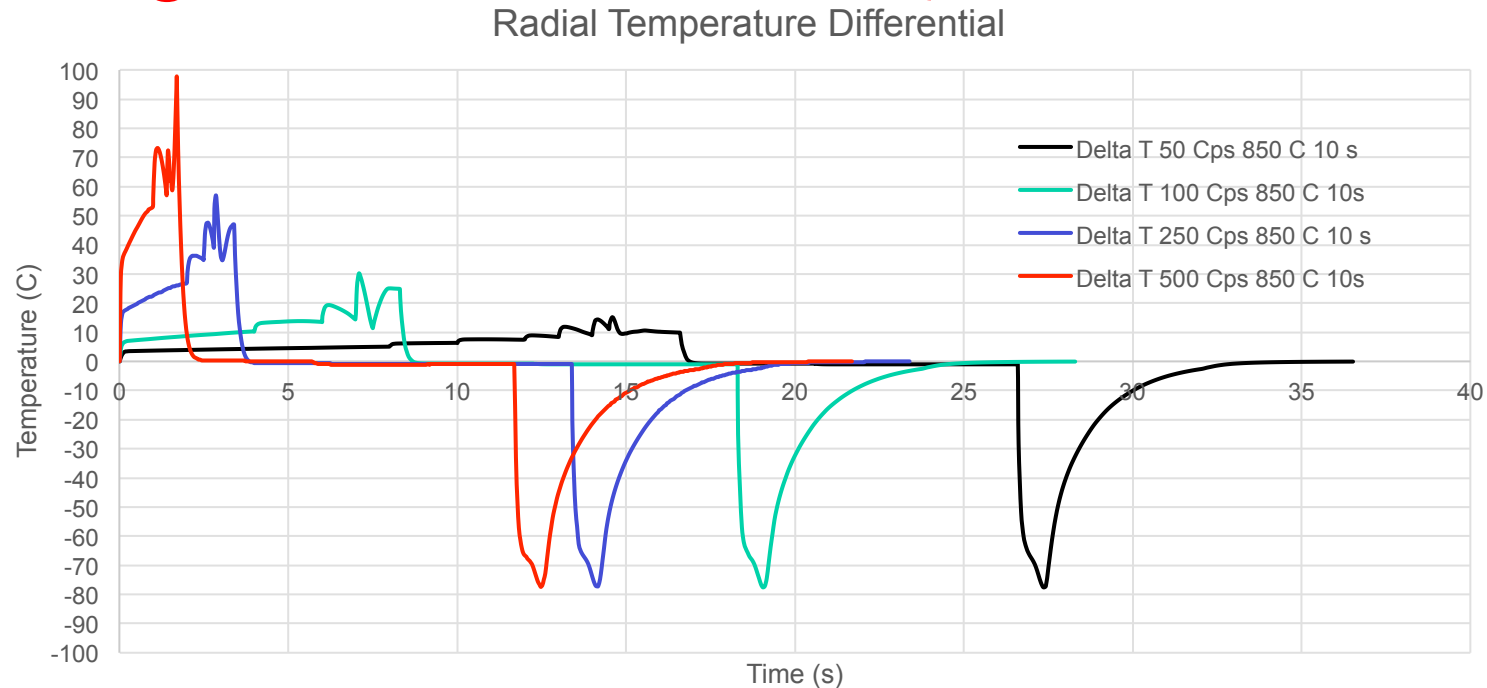


Comparison of ELTA with Experimental Data

- Surface Temperature tracks closely
- Dynamics of power change very similar
- Big discrepancy in power level, measured substantially higher than calculated



Radial Temperature Gradients for Different Heating Rates with Helium Quench

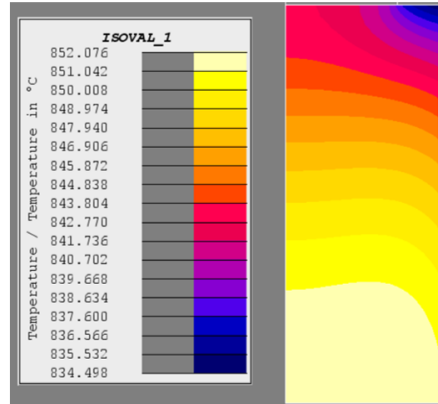
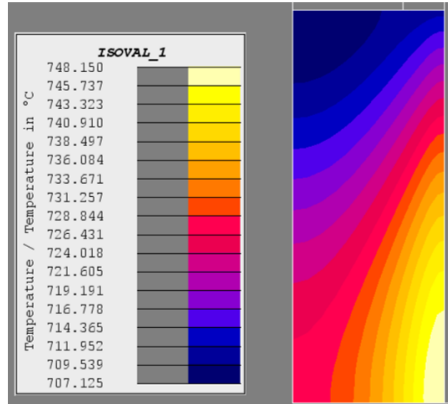


For 50 CPS, radial gradients much larger during cooling than heating. As heating rate increases, gradients during initial heating approach those from the rapid cooling. After Curie Point, radial temperature difference close to 0 for all samples during heating and holding phase

2D Modeling with Flux

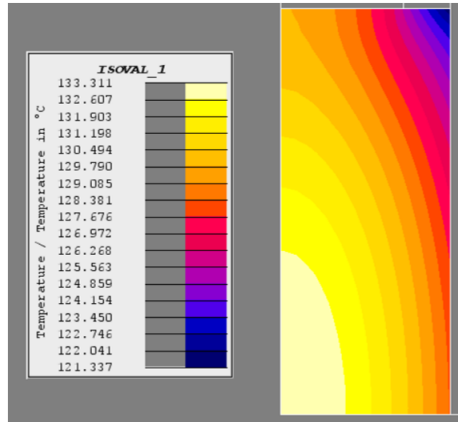
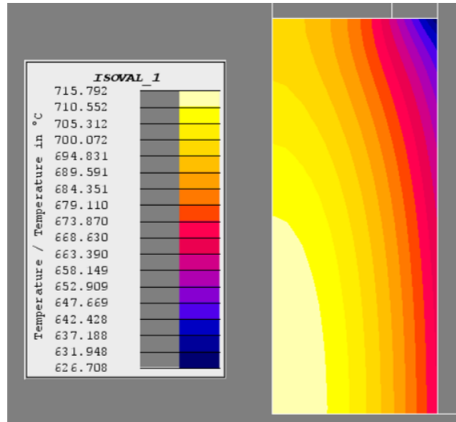
14.25 seconds into heating

End of Holding



0.5 seconds into Cooling

During Phase Transformation

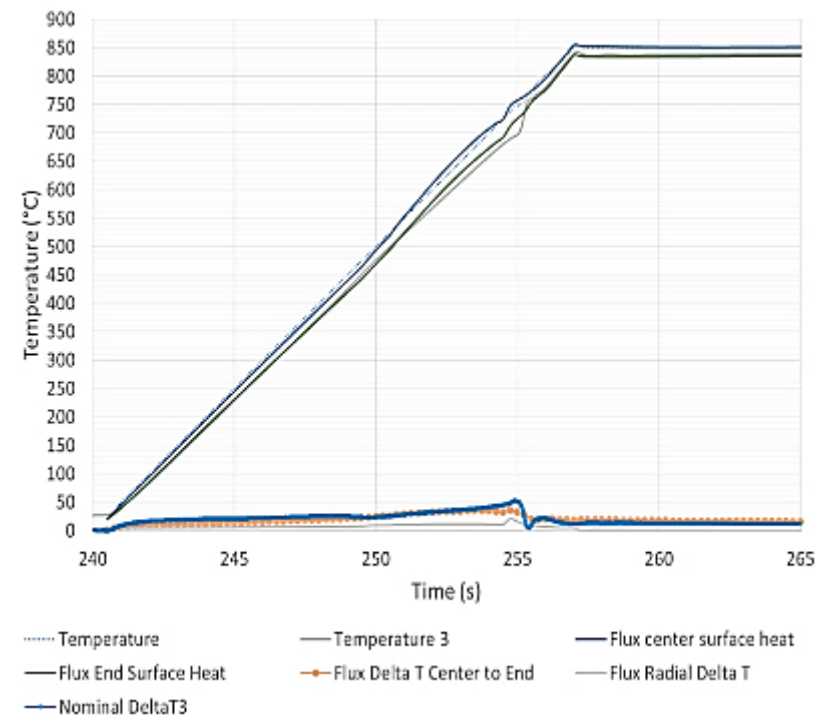
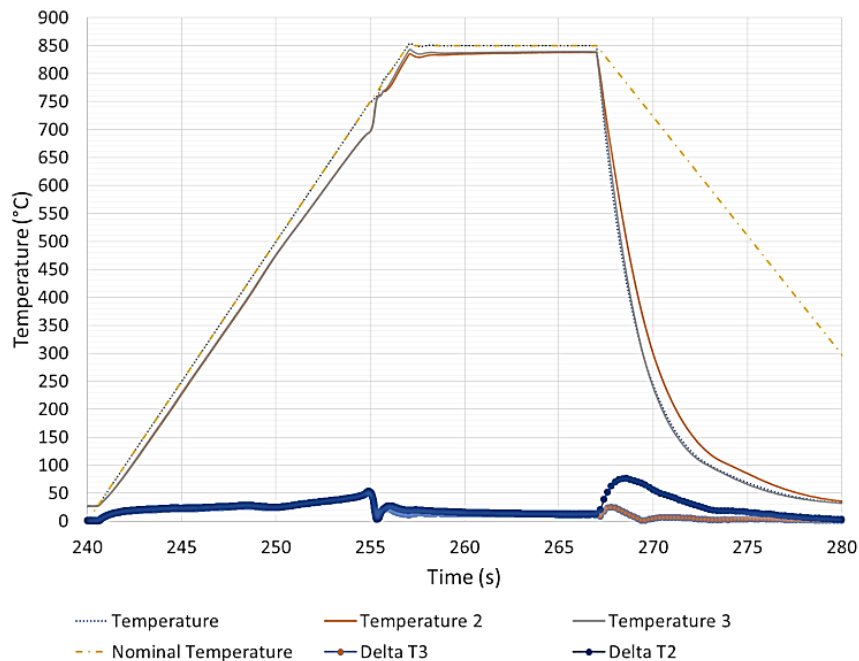


- Axial Gradients are Larger than Radial Gradients on Heating According to Models
- Axial Gradients Also Exist on Cooling, with ends being colder than center for uniform heat transfer coefficient on surface

3 TC Testing and Comparison to Models

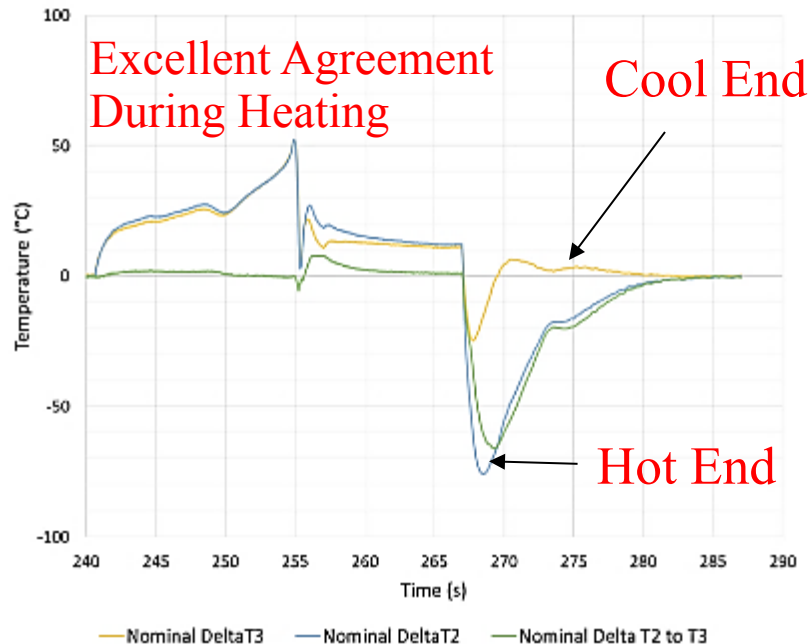
Heating Experiments

Models

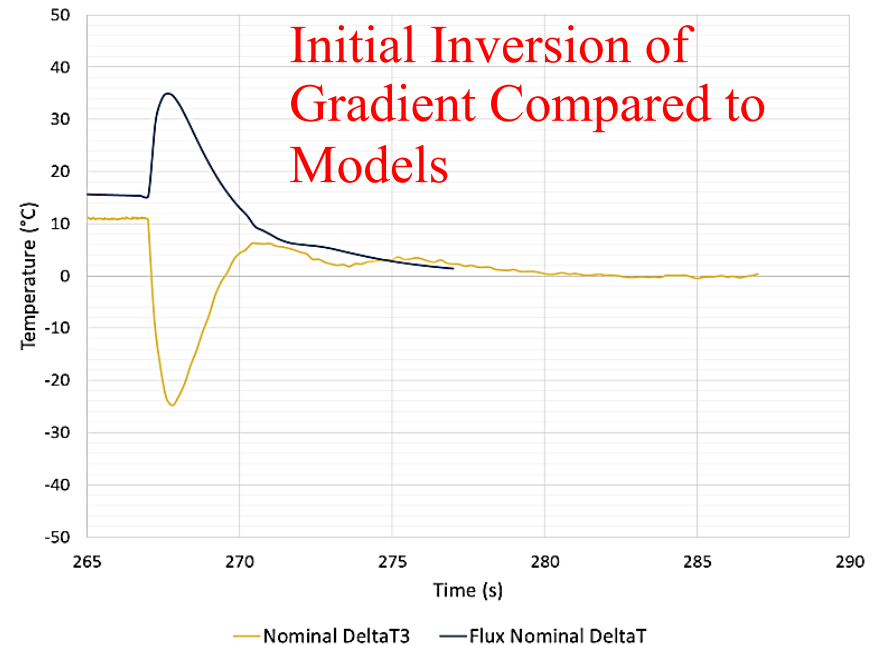


3 TC Testing Cooling Comparison

Experimental End to End

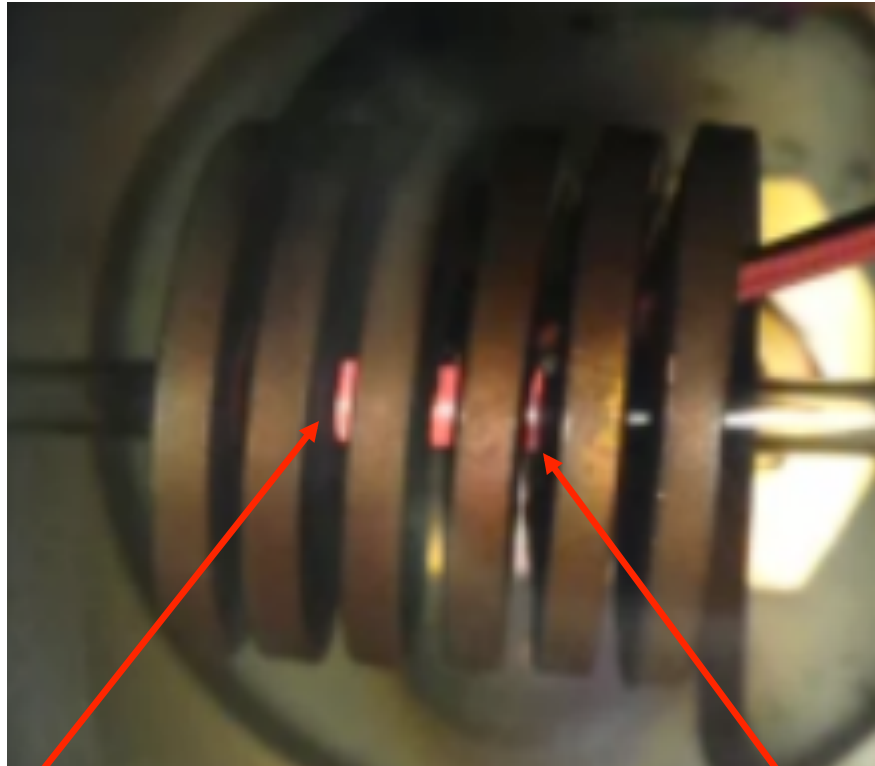


Experimental Cool End to Models



Axial Variation in Temperature is High, End to End Cooling Different, Initial Inversion Relative to Models Means We Have Significant HTC Variation in Length and Time!

Image During Cooling



Hot End

Cool End

Conclusions

- Models have been created to determine temperature distributions which occur during dilatometer testing
- Once the steel started transforming from magnetic to non-magnetic, the generator power level rises dramatically, limiting the ability to deliver high heating rates
 - Need to understand better as there is a significant variance from calculated power levels and need to determine how to increase power delivery
- For rapid heating and cooling rates, there are significant gradients (both axial and radial) in the part which need to be considered when evaluating dimensional movement data
- More work still needs to be done to better characterize/improve the cooling dynamics in the system