THERMAL PROCESSING IN MOTION

Including the 4th International Conference on Heat Treatment and Surface Engineering in Automotive Applications

ASM INTERNATIONAL

Dilatometer Measurements During High Speed Heat Treatment

Measurement Errors from Temperature Gradients

MINES

Advanced Steel Processing and Products Research Center

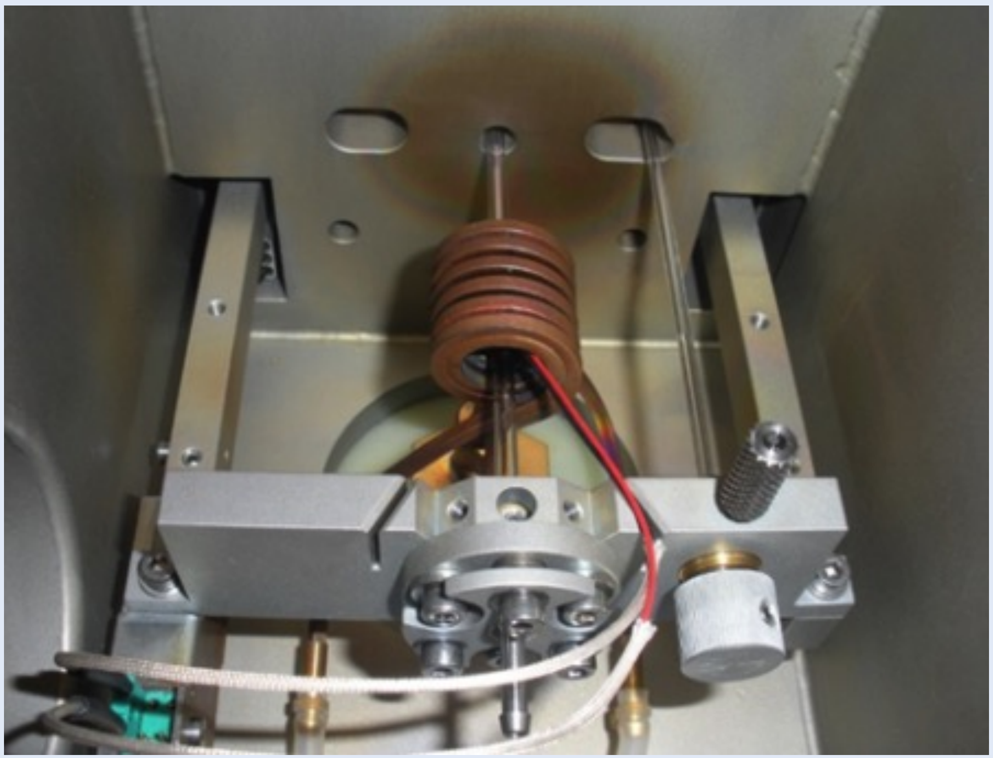
COLORADO SCHOOL OF MINES

EARTH ENERGY ENVIRONMENT

FLUXTROL

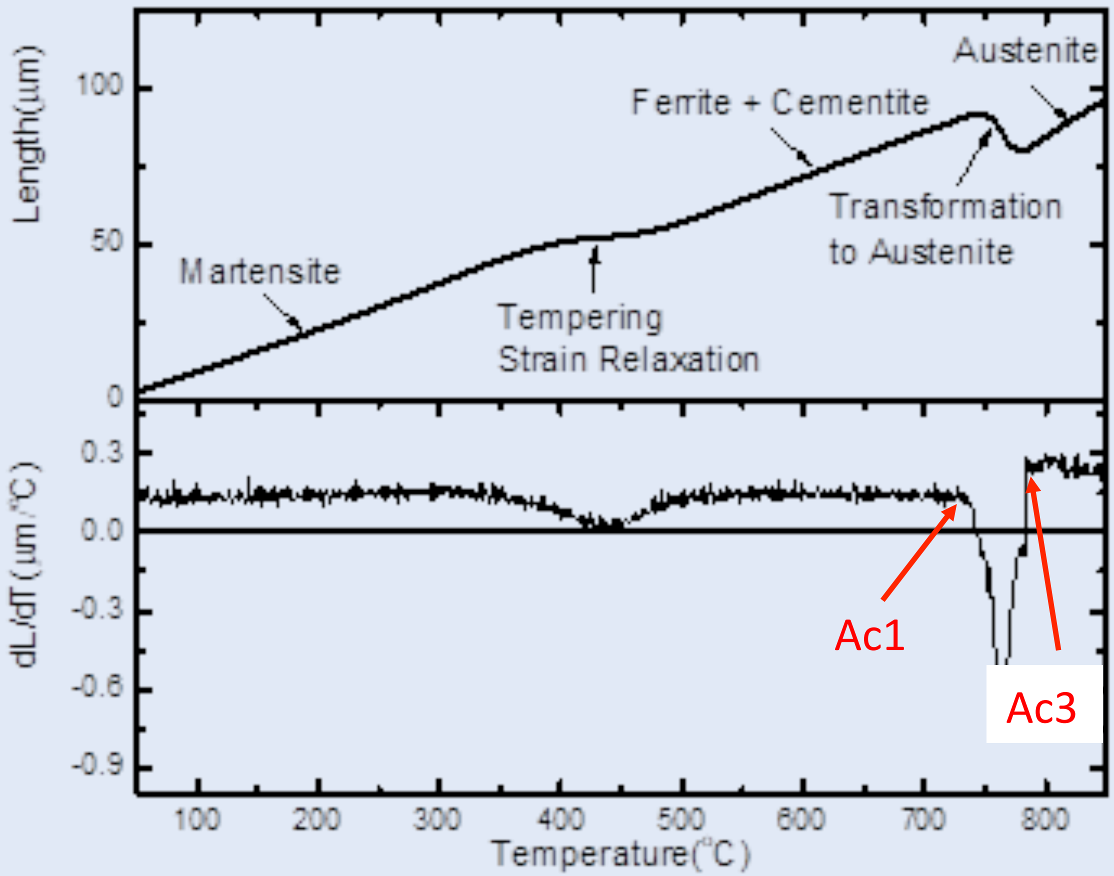
Airflow Sciences Corporation

Dilatometer Arrangement



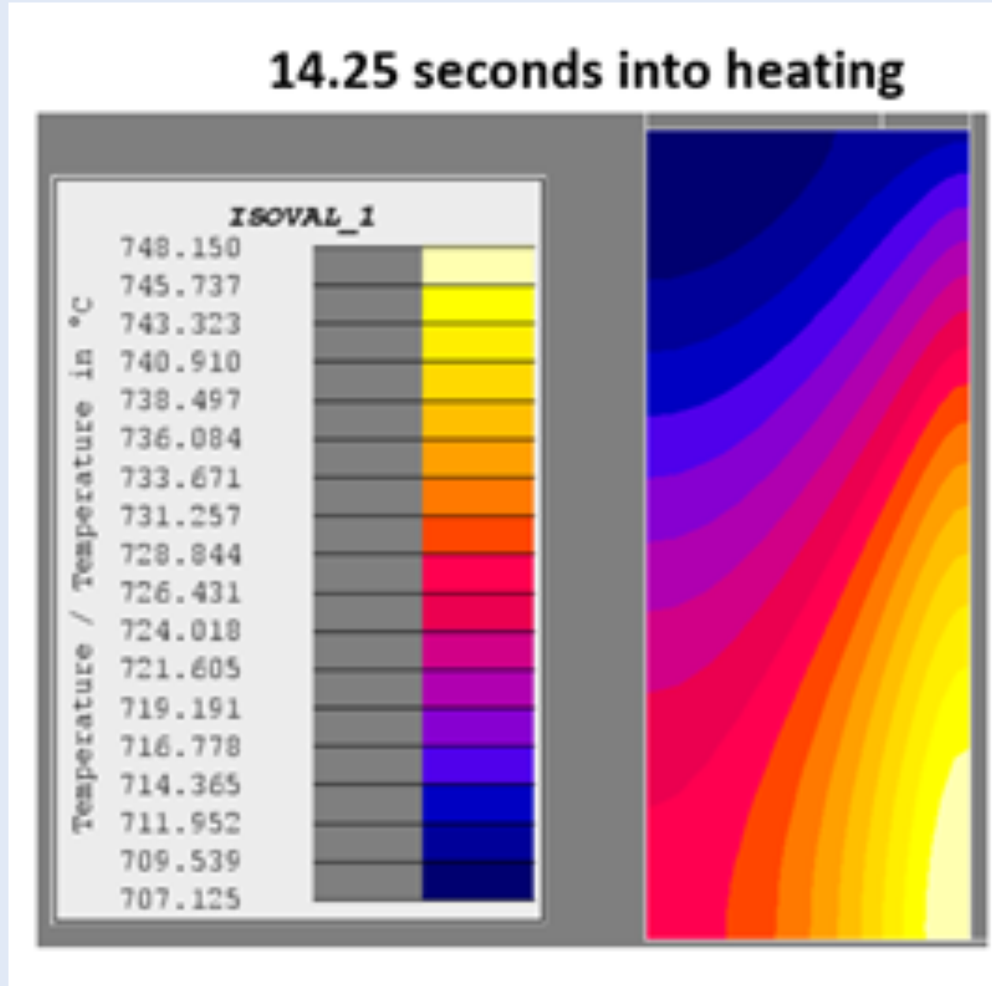
- Specimen 4 mm dia by 10 mm long
- Heating by outer induction coil
- Cooling by Gas Jets from inner coil
- Temperature measured by Single Thermocouple welded to surface at center
- Length change measured by LVDT

Dilatometry Test During Heating at 50 $^{o}C/s$



R. Cryderman and T Ballard, "Short Time Austenitizing Effects on the Hardenability of Some 0.55 wt. pct. Carbon Steels,"
IFHTSE 2017, Nice, France

Temperature Gradient During Heating at 50 $^{o}C/s$



5 mm

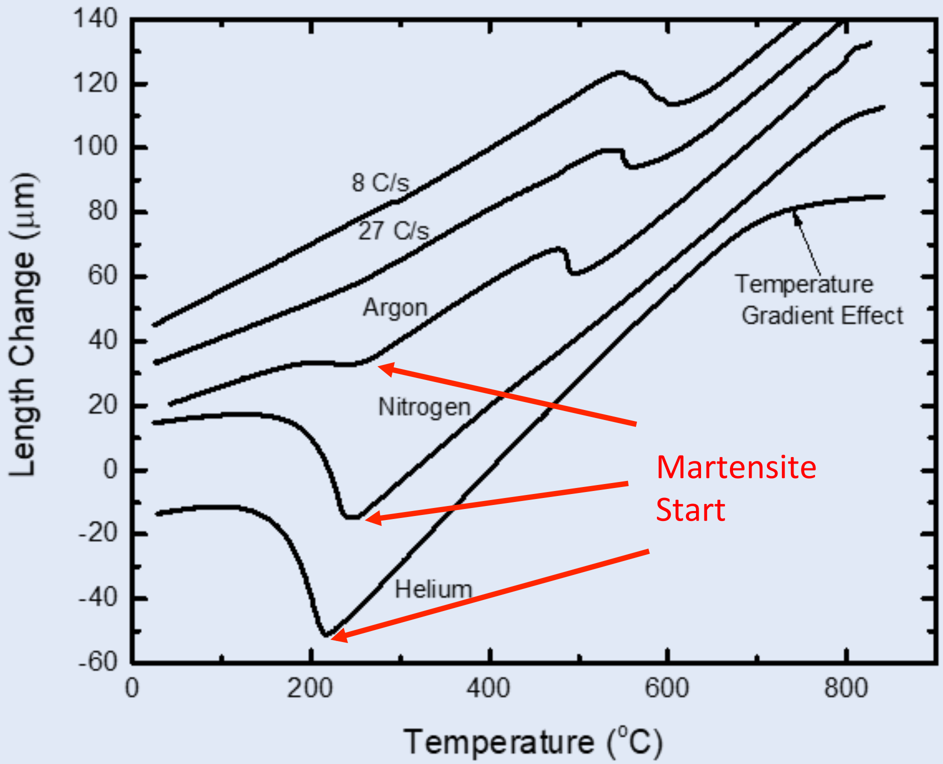
2 mm

Delta = 41 ^{o}C

Induction heating rates can be up to 10,000 $^{o}C/s$

R. Goldstein, E. Buchner, and .R Cryderman, "Modeling of Short Time Dilatometry Testing of High Carbon Steels," HTS 2017, Columbus, OH

Distortions in Length vs Temperature Plots During Cooling



Thermal Gradient implied at high quench rates

Increased Quench Rate Lowers Martensite Start Temperature ?????

Quench Rates for Induction Hardening Higher than Helium Quench Rate

R. Cryderman and T Ballard, "Short Time Austenitizing Effects on the Hardenability of Some 0.55 wt. pct. Carbon Steels," IFHTSE 2017, Nice, France

Modelling of Temperature Gradients

- Selected O1 tool steel quenched to martensite for study
- This alloy avoids transformation on cooling until martensite transformation

- Tests were conducted at Colorado School of Mines using thermocouples welded to the surface at mid, quarter, and end points to provide data for modeling

- **Tareq Eddir of Fluxtrol** will present a Model of the Influence of Heating Rate on Temperature Gradient

- **Andy Banka of Air Flow Sciences** will present a Model of the Temperature Gradients During Helium Quenching

Influence of Heating Rates on Temperature Gradients in Short Time Dilatometry Testing

Tareq Eddir, Robert Goldstein

Fluxtrol Inc.

tieddir@fluxtrol.com

Ethan Buchner, Robert Cryderman, Dr. Emmanuel De Moore

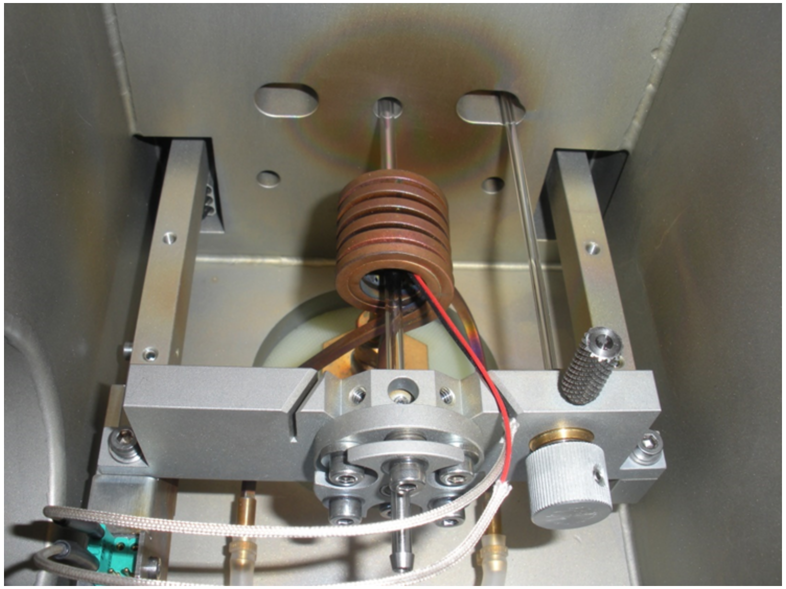
Colorado School of Mines

Outline

- Description of experiments
- Description of modelling
- Comparison methods
- Temperature Results
- Dilatometry Results
- Conclusions

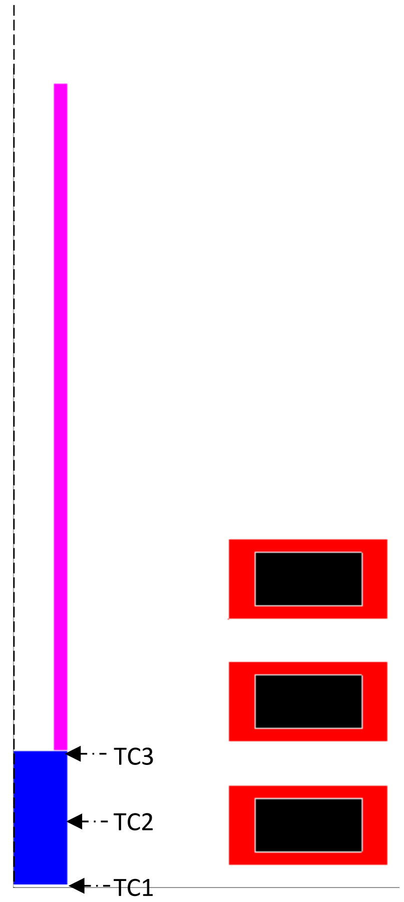
Description of Dilatometry Testing

- Manufacturer TA Instruments
- Fused silica rods hold the component
- Heat source is induction heating
  - Advertised heating rate up to 1000°C/s
- Heating is done in vacuum
- O1 Tool steel was used
- Specimen diameter is ø4.02x10.12mm
- Gas quenching through induction coil used for cooling
  - Quench not presented in this study
- Measures dimensional movement during the thermal process
- Three thermocouples attached to the sample to monitor the temperature



Description of the Induction Modelling

- Altair's Flux 2D was used
- Magnetic and thermal coupled physics
- Axisymmetric geometry was used
  - Half of the system was modelled due to symmetry
- Steel material properties were determined in a previous study*
- Three thermocouples were used to monitor the temperature, equivalent to the testing locations



*Modeling of Short Time Dilatometry Testing of High Carbon Steels

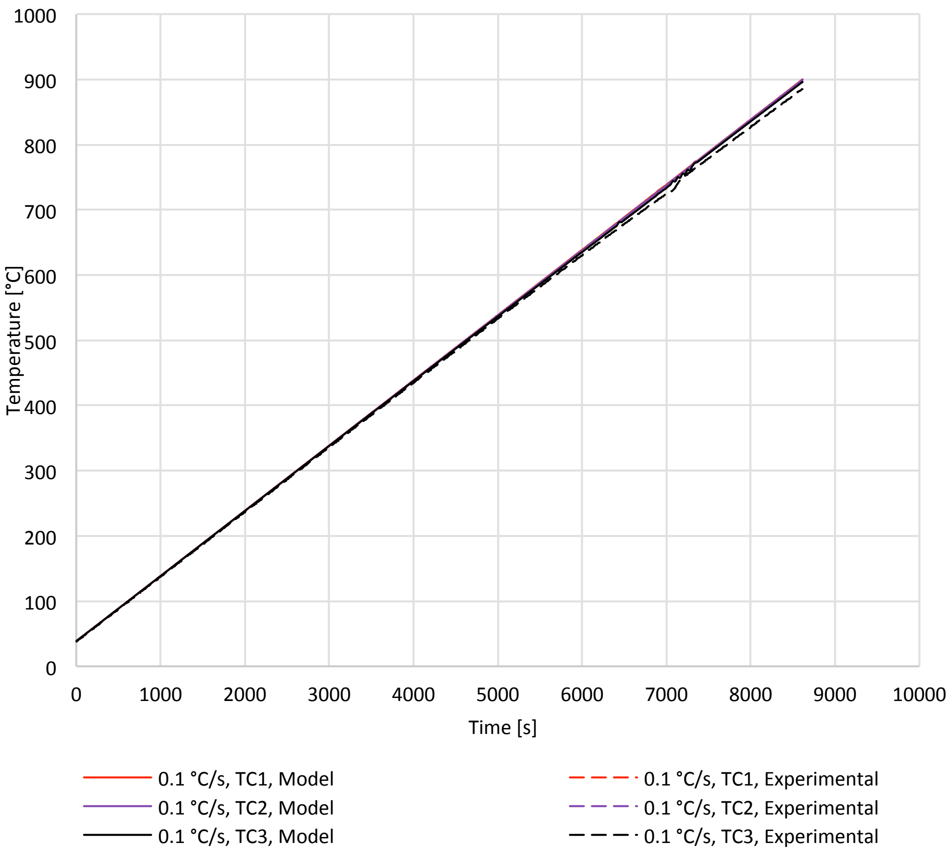
Robert Goldstein,
Fluxtrol, Inc., Detroit, Michigan, USA
rcgoldstein@fluxtrol.com

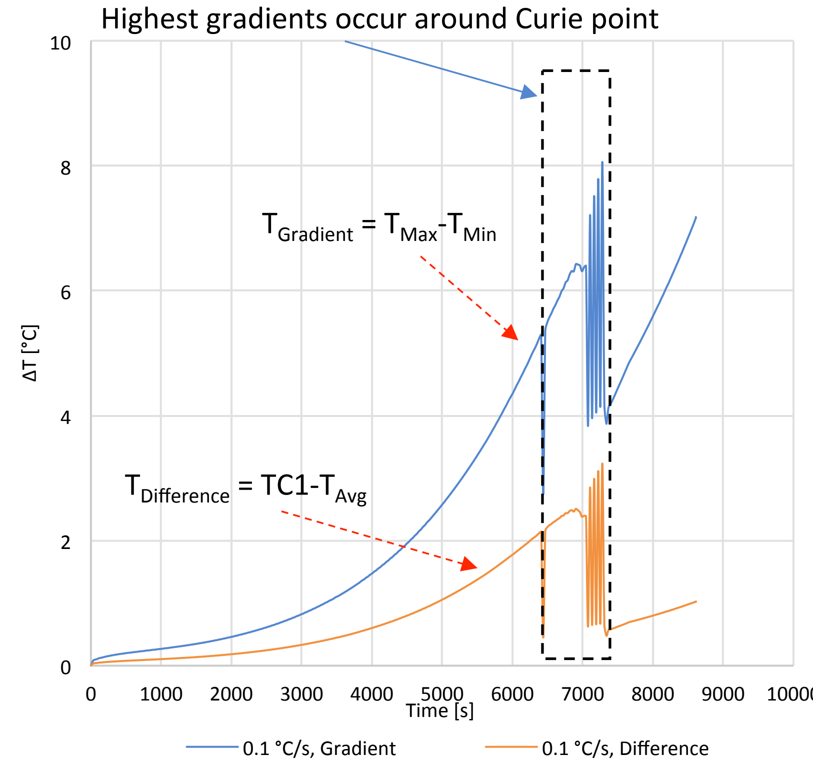
Ethan Buchner, Robert Cryderman
Colorado School of Mines, Golden, Colorado, USA

Comparison Method

- The samples were heated at different rates then gas quenched
  - TC1 was used to control temperature
  - TC2 and TC3 collected temperature data for axial gradient
  - Dilatometry data was collected
  - Quench was not modelled in this study
- Heating was modelled by matching the heating rate of the experimental and model TC1 data
  - TC2 and TC3 were compared for validation
- Samples were heated to 900°C with a 1s hold
- Heating Rates:
  - 0.1°C/s
  - 1°C/s
  - 5°C/s
  - 50°C/s
  - 250°C/s
  - 500°C/s

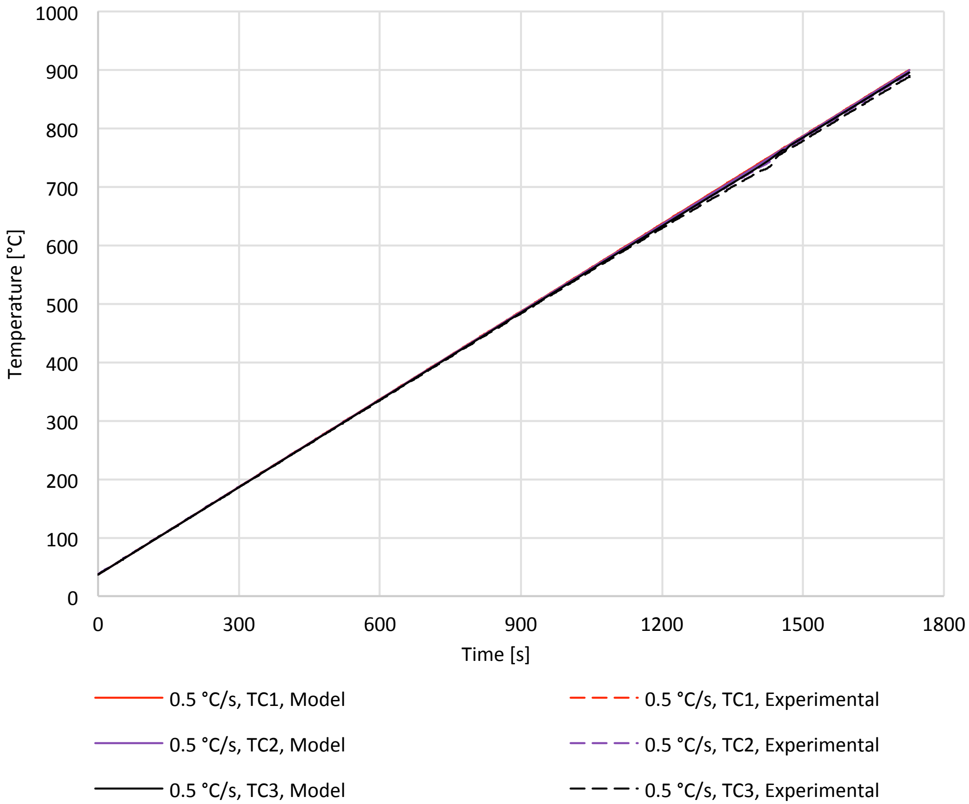
0.1 °C/s Heating Results

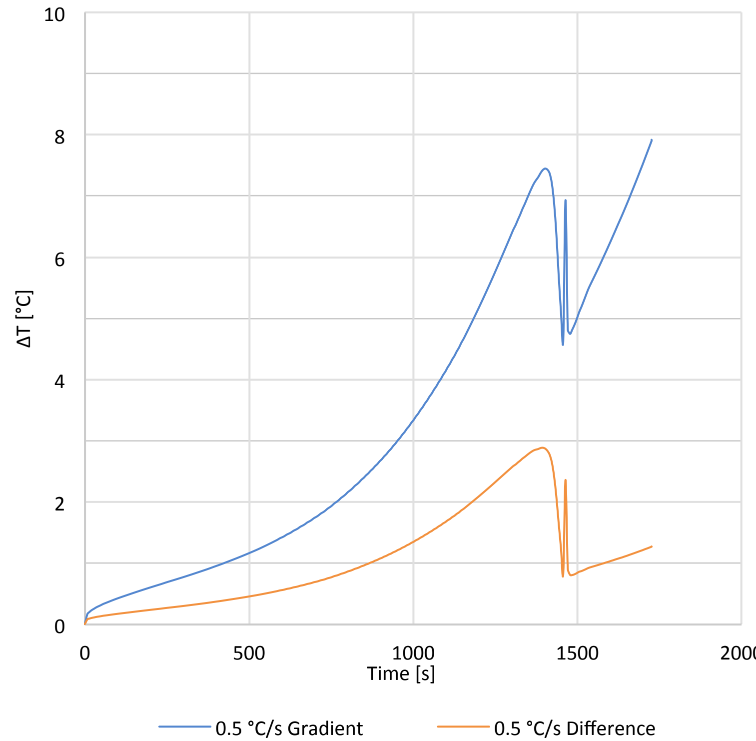




The slow heating rate results in low temperature gradients in the specimen. This can be treated as an equilibrium case.

0.5 °C/s Heating Results





The slow heating rate results in low temperature gradients in the specimen. This can be treated as an equilibrium case.

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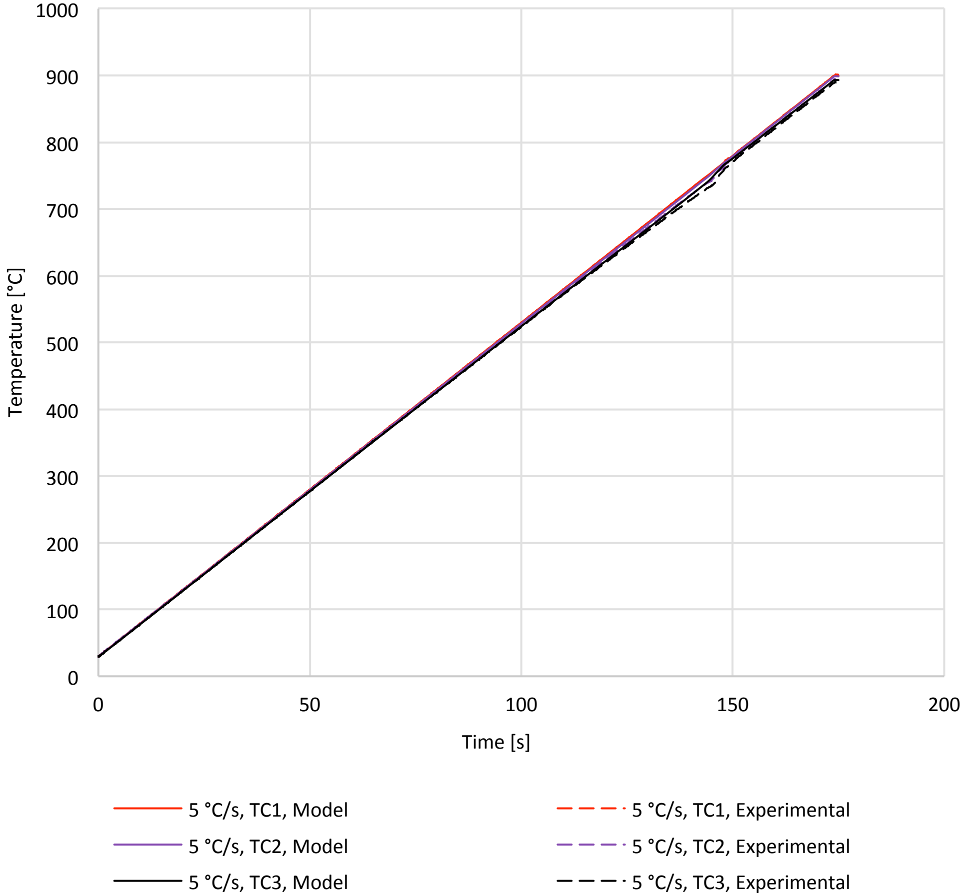
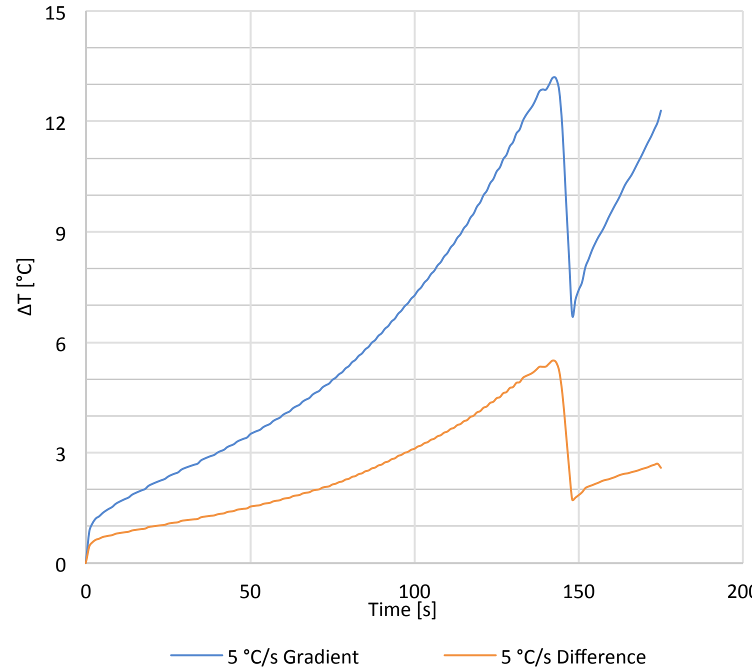
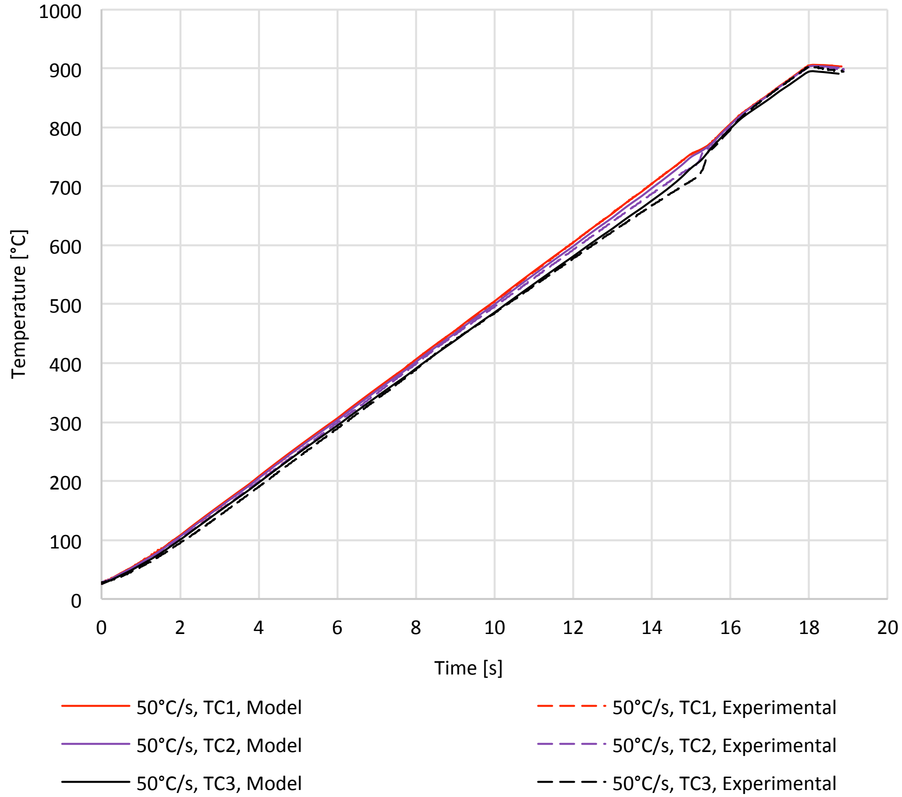
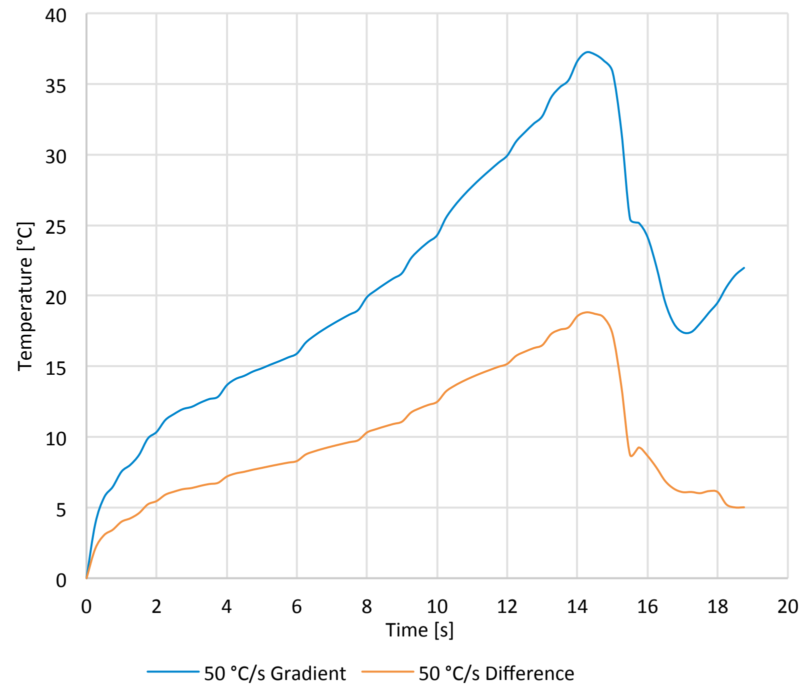
5 °C/s Heating Results





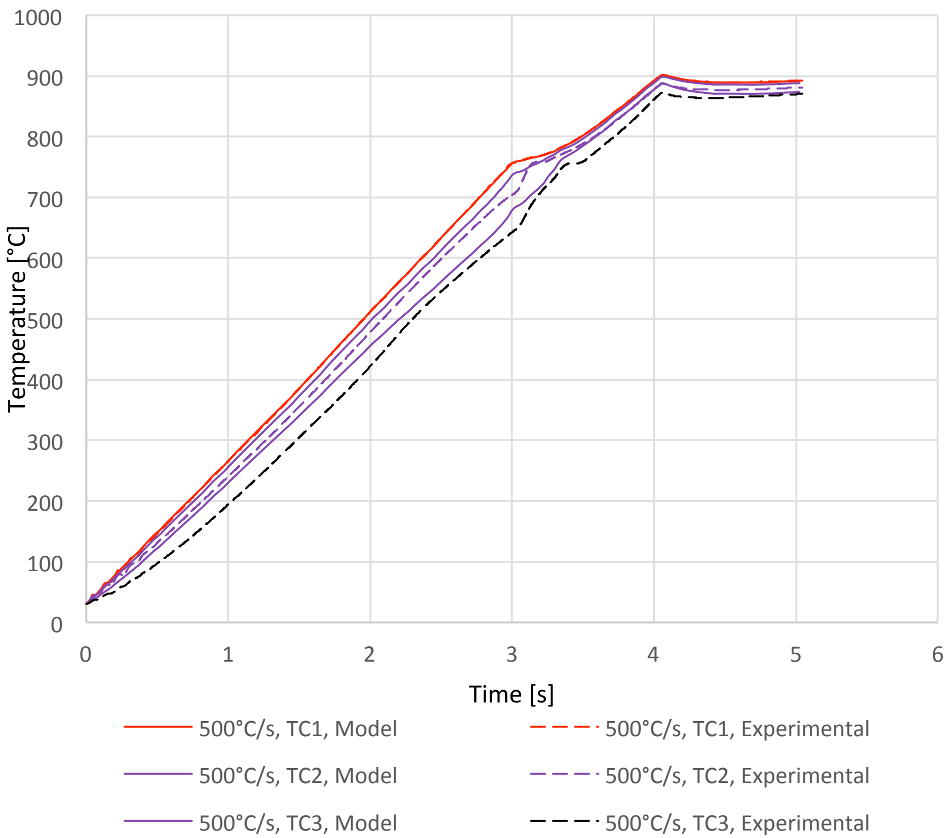
50 °C/s Heating Results

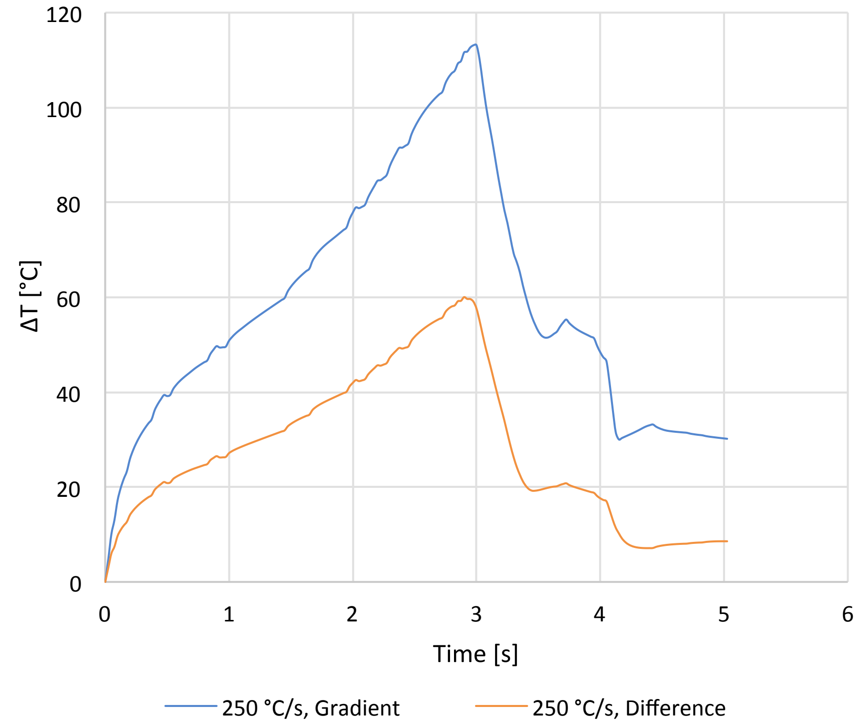




Gradients in the 50 °C/s are not insignificant and the specimen is not at uniform temperature.

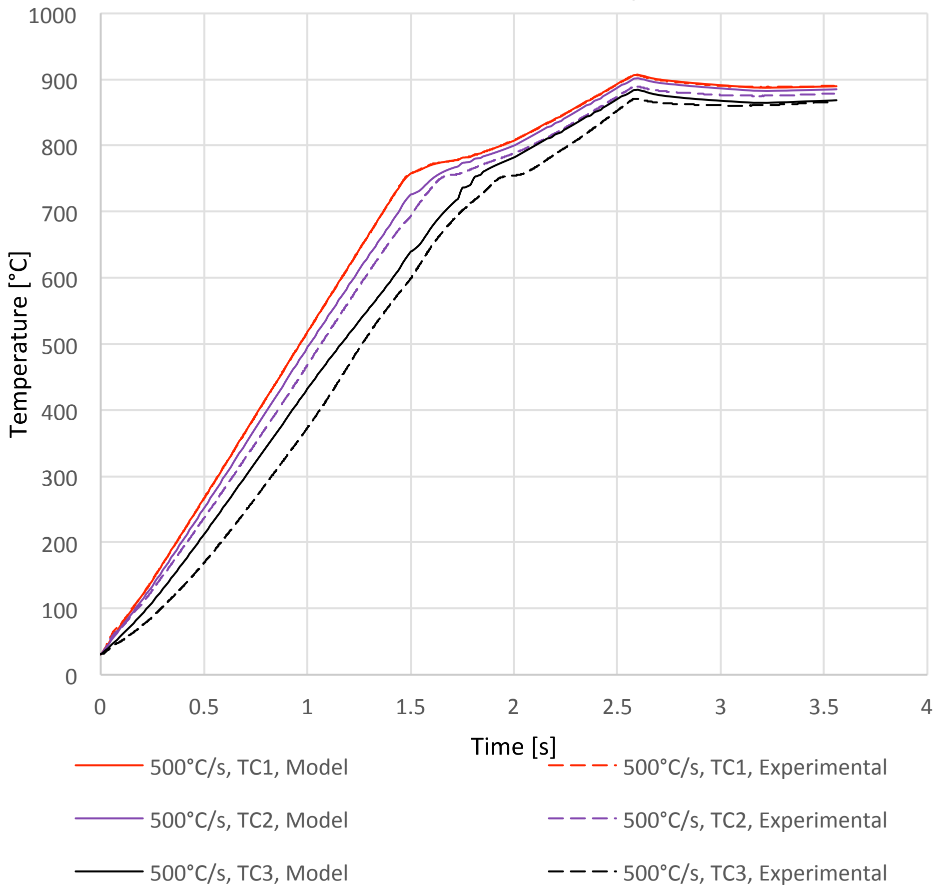
250 °C/s Heating Results

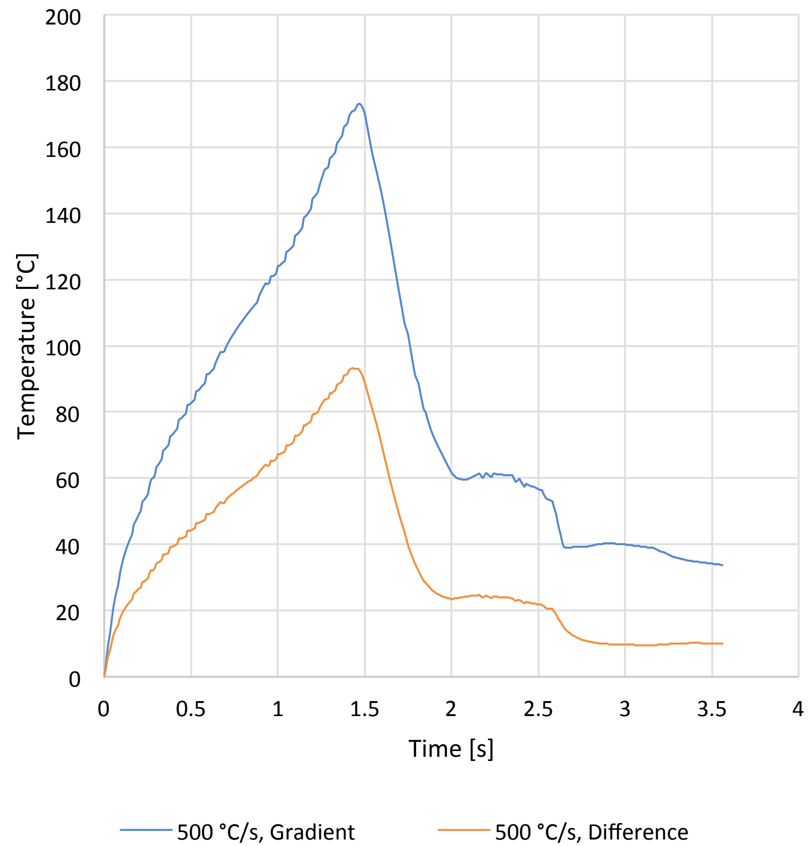




Gradients are very significant, especially around Curie point.

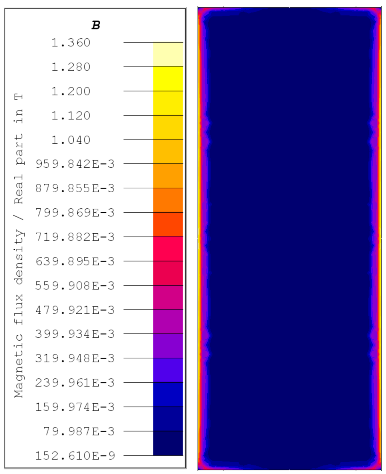
500 °C/s Heating Results



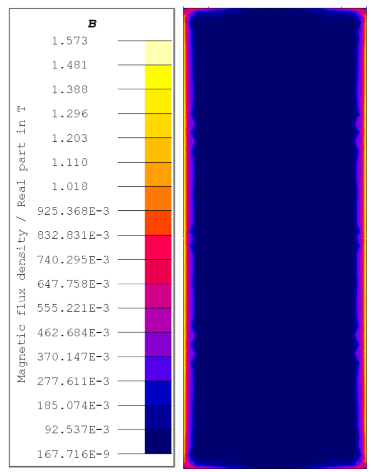


Gradients are very significant, especially around Curie point.

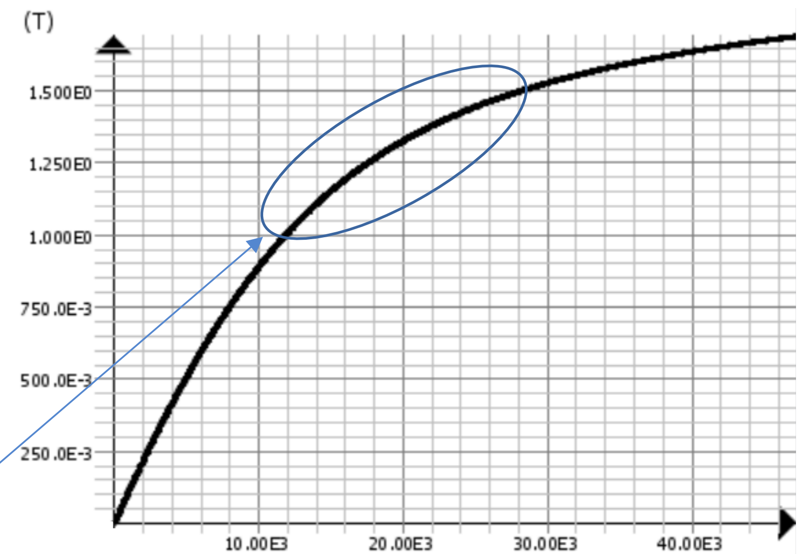
Temperature Difference at High Heating Rates



250 °C/s



500 °C/s



For the 250 °C/s and 500 °C/s heating rates B is >1.2T on the surface of the specimen. At that range the permeability (μ=B/H, slope of the BH Curve) changes more rapidly. This results in an overestimation of the end effects.

Modeling of Short Time Dilatometry Testing of High Carbon Steels

Robert Goldstein,
Fluxtrol, Inc., Detroit, Michigan, USA
rcgoldstein@fluxtrol.com

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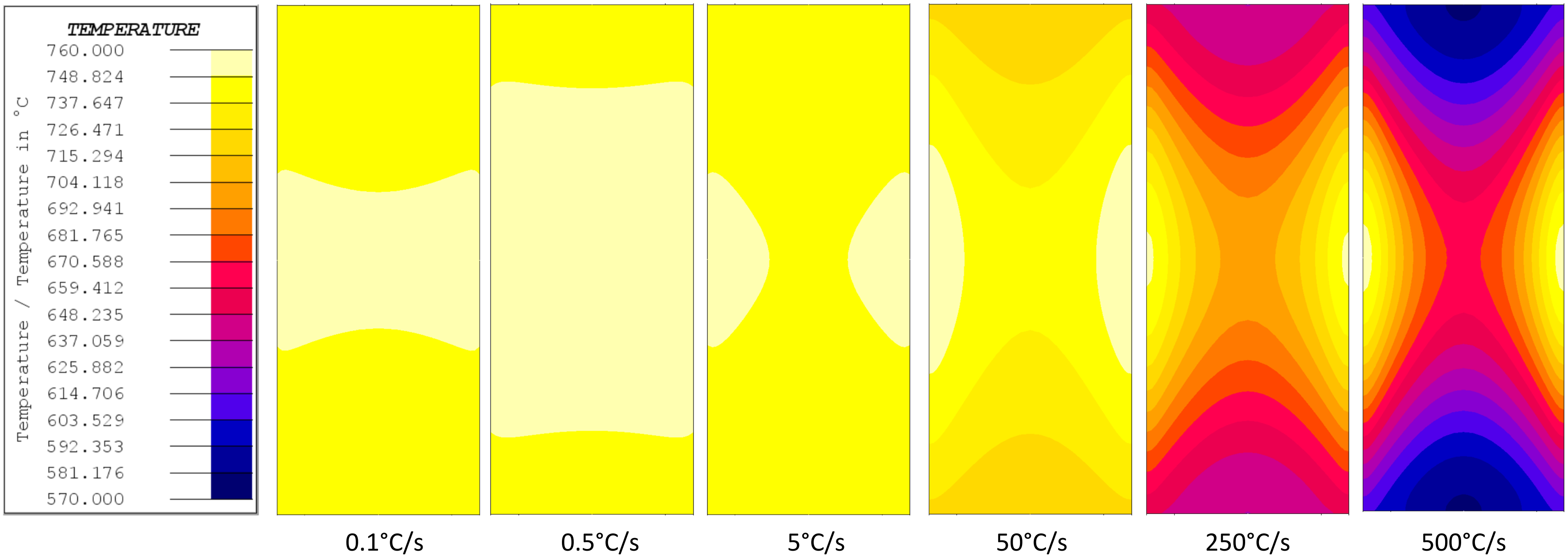
Colorado School of Mines, Golden, Colorado, USA

Future tests will look at improving material properties to better model high heating rates.

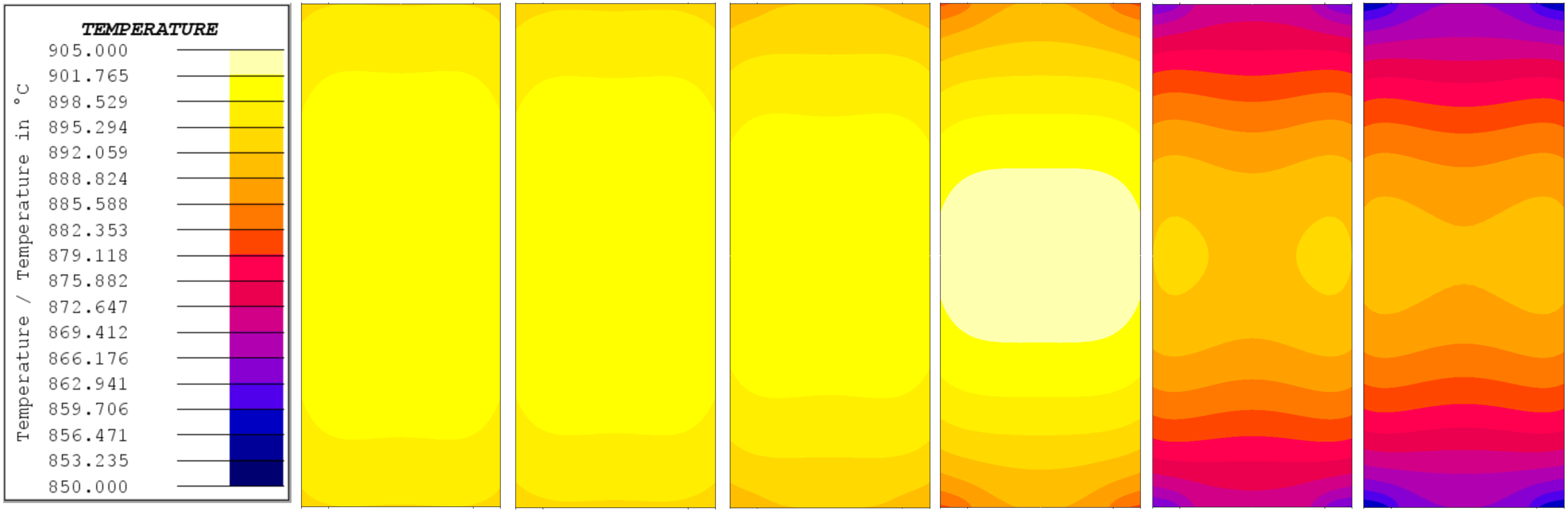
Temperature Distribution



	0.1°C/s	0.5°C/s	5°C/s	50°C/s	250°C/s	500°C/s
$T_{Gradient} = T_{Max} - T_{Min}$	7°C	7°C	13°C	36°C	113°C	173°C
$T_{Difference} = TC1 - T_{Avg}$	3°C	2°C	5°C	17°C	59°C	92°C

The temperature distribution maps were taken at TC=750 °C (Around Curie point). The highest gradients occur around this point. The gradients for the 50 °C/s, 250 °C/s, and 500 °C/s cannot be considered insignificant.

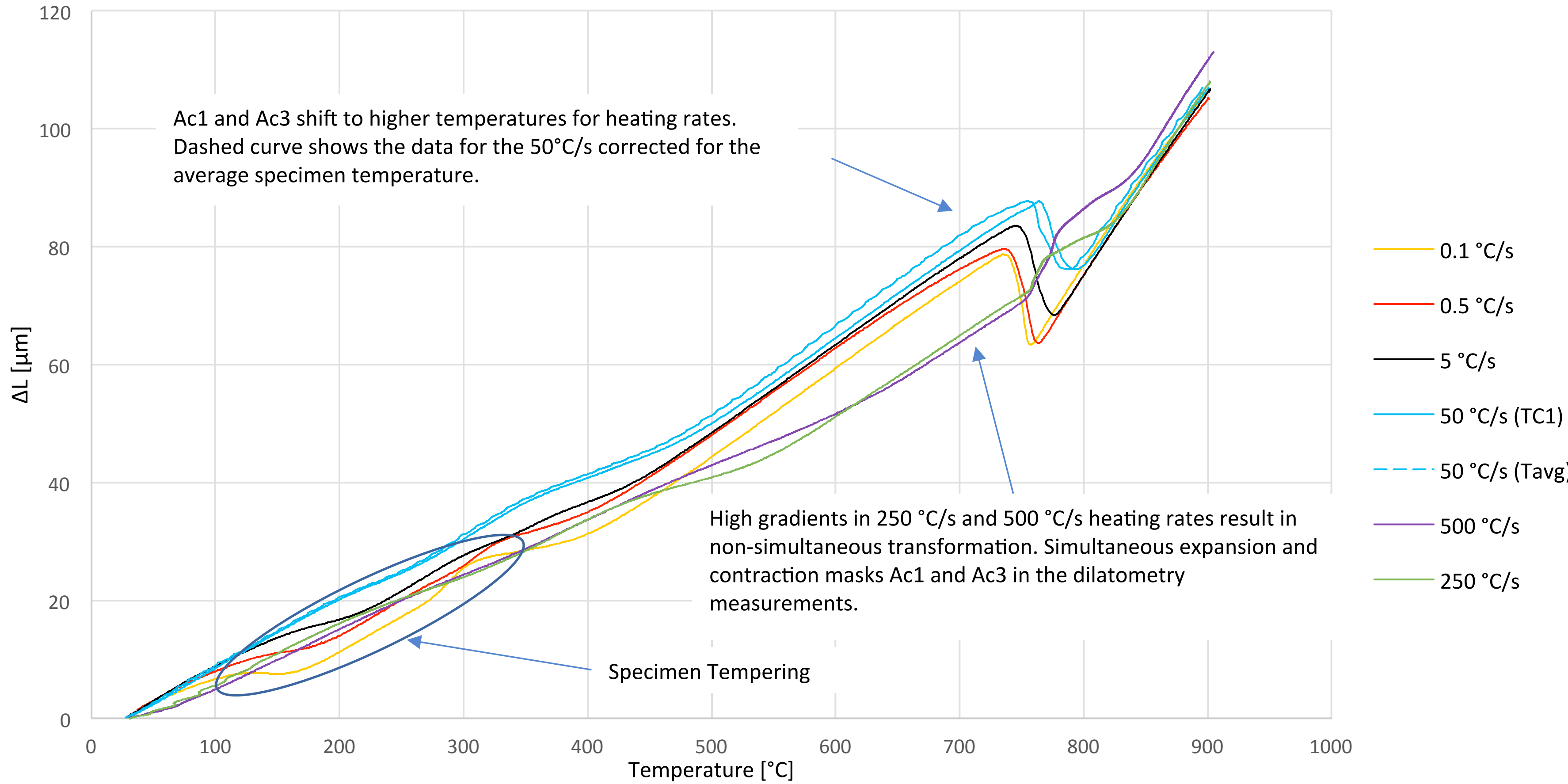
Final Temperature Distribution



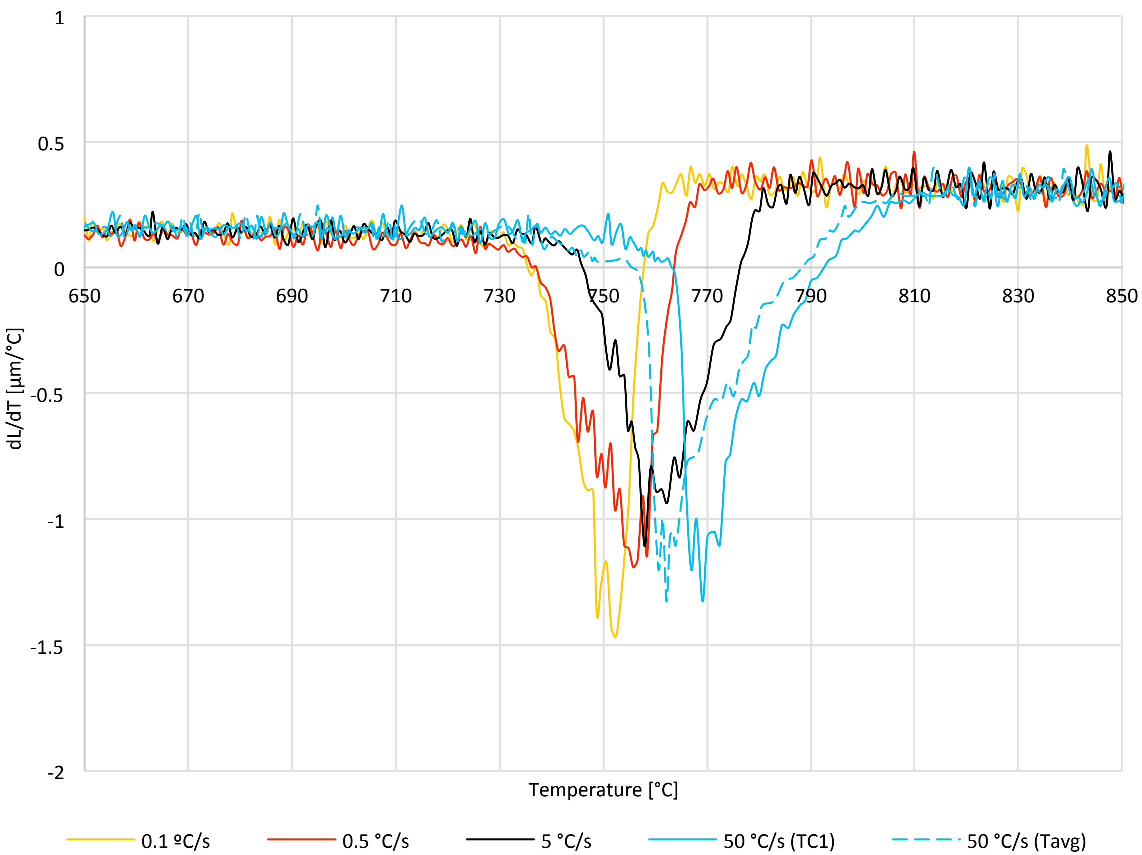
	0.1°C/s	0.5°C/s	5°C/s	50°C/s	250°C/s	500°C/s
$T_{Gradient} = T_{Max}-T_{Min}$	7°C	8°C	12°C	22°C	30°C	34°C
$T_{Difference} = TC1-T_{Avg}$	1°C	1°C	3°C	5°C	9°C	10°C

The temperature distribution maps were taken at end. The radial gradients significantly lower than the axial gradients. The 50 °C/s, 250 °C/s, and 500 °C/s heating rates show high final gradients.

Dilatometry Results



Dilatometry Results



Changes in slope of length versus temperature plot more clearly delineate transformation beginning and end.

Heating Rate [°C/s]	Measured		Corrected	
	Ac1 [°C]	Ac3 [°C]	Ac1 [°C]	Ac3 [°C]
0.1	734	760	734	760
0.5	734	766	734	766
5	746	779	746	778
50	762	800	757	794
250	N/A	N/A	N/A	N/A
500	N/A	N/A	N/A	N/A

Temperature gradients at high heating rates give erroneously high transformation temperatures.

Conclusions

- Computer models were created to predict temperature distribution during dilatometer testing
  - Low temperature gradients can be assumed for slow heating rates
  - High heating rates have high temperature gradients, especially around beginning of transformation
  - Surface welded TC measurements don't adequately describe the specimen temperature at high heating rates
- Transformation temperatures shift with heating rates
  - Quasi-Equilibrium data from slow heating rates are not appropriate for rapid heating application
- More work needs to be done to better characterize transformation at high heating rates
  - Specimen geometry change can be made to reduce gradients
  - More work needs to be done to develop accurate databases for rapid heating transformation data

Questions?

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