

Building the Materials Database to Unlock the Potential of Induction Heat Treating

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Overview

- Market Demands for New Product Development
- Advantages/Drawbacks of Induction Heat Treating Compared to Other Methods
- Tools Available for Material Characterization
- Opportunities for Improved Measurement Methods
- Conclusions

Market Demands

- Lighter
- Stronger
- Cleaner
- Cheaper
- Quicker to Market



Due to Unique Features of Induction Heating, We Have a Better Opportunity to Be Magicians than Other Technologies

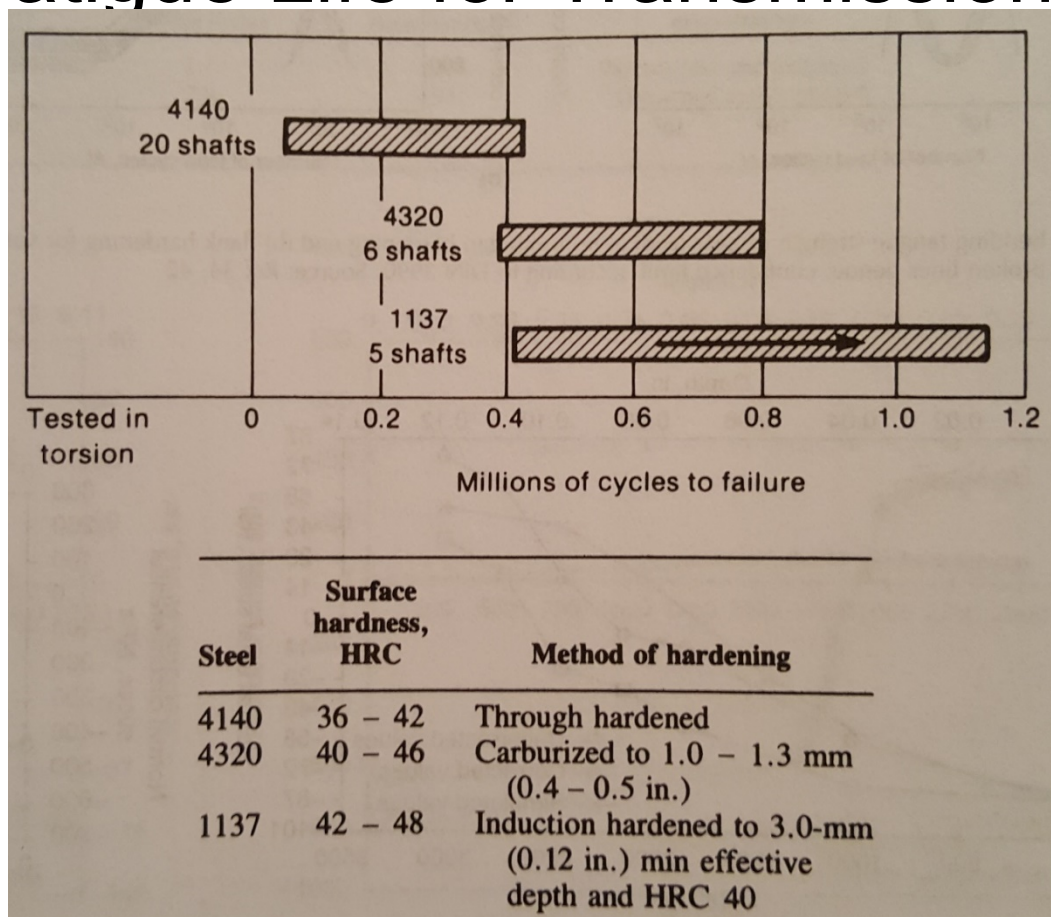
Specific Features of Induction Heating

- Heat generation occurs inside the part
- Heating is contactless
- Method can provide very high power densities
- Any processing atmosphere (air, protective gas, vacuum)
- Very high temperatures may be created
- Heating may be highly selective in the depth and along the surface
 - ***Very Important Feature, especially for multi-material components***

Advantages of Induction Heating

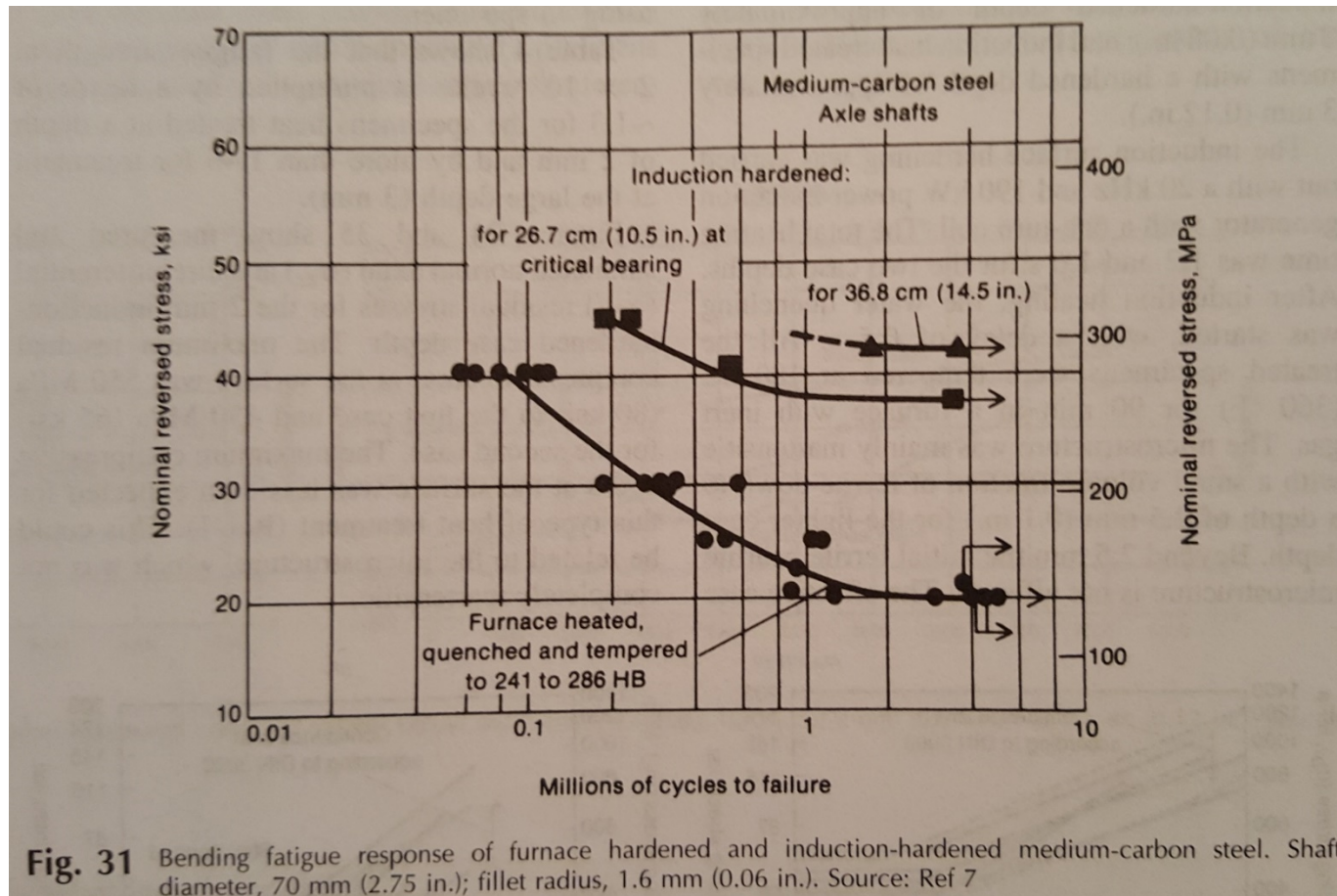
- Short heating cycles and high production rates
- Electromagnetic forces can be used in combination with heating to stir or contain molten metal
- Better metallurgical results due to fast and clean heating
- Energy savings due to selectivity and high efficiency
- Good control and repeatability
- Minimal or no surface oxidation and decarburization
- Lower distortions for surface or local hardening
- Favorable Distributions of Residual Stresses (Better loading capability)
- Much less Alloy Required (lower cost)
- Finer Grain Structures Possible
- Favorable for industrial environment (in-line heating, no pollution, “push button” performance)
- Some processes may not be accomplished other than by induction

Comparison of Through, Case and Induction Hardened Fatigue Life for Transmission Shafts



Source – ASM Handbook Volume 4C - Grum

Comparison of Through and Induction Hardened Bending Fatigue



Source – ASM Handbook Volume 4C - Grum

Improved Mechanical Properties Possible when Using Non-Equilibrium Structures



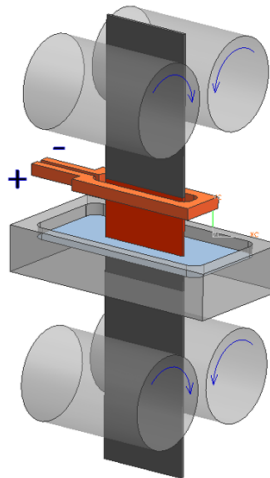
What is *Flash® Processing*?

... Flash Processing starts with commercial off the shelf steels like AISI1010, 1020, or 4130

... using Induction Heating technology the steel is rapidly heated in approx 2-3 seconds to temperatures over 1000C, typically 1070C to 1200C

... within a few seconds, the austenized steel is quenched with a water spray or bath.

... by limiting austenization time, the natural heterogeneity of the steel is preserved to create an engineered micro-segregation of both chemistry and phase in a matrix that combines the strength of martensite with the ductility of bainite.



Why can Flash® Bainite form parts this Strong?

Heterogeneous complexity can lead to ~

“Maximum Strength” in Steel

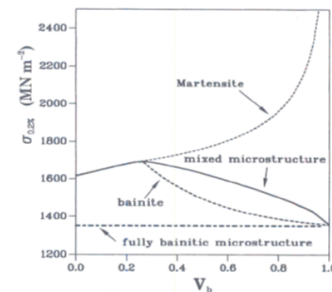
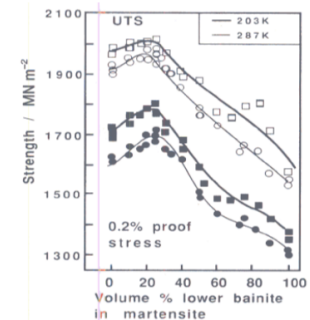


Illustration of contributions of bainite and martensite to overall strength of mixed microstructure

Research by: Tomita and Okabayashi



Young and Bhadeshia

It has been known for 30 years that ~25% Bainite and ~75% Martensite is stronger than ~100% Martensite

Courtesy of SFP Works dba FlashBainite

Cold Formed AHSS Components

Current Production Design Seating Components

Flash® 1550 Room Temp “Crash Formed” in Prototype Steel Tools



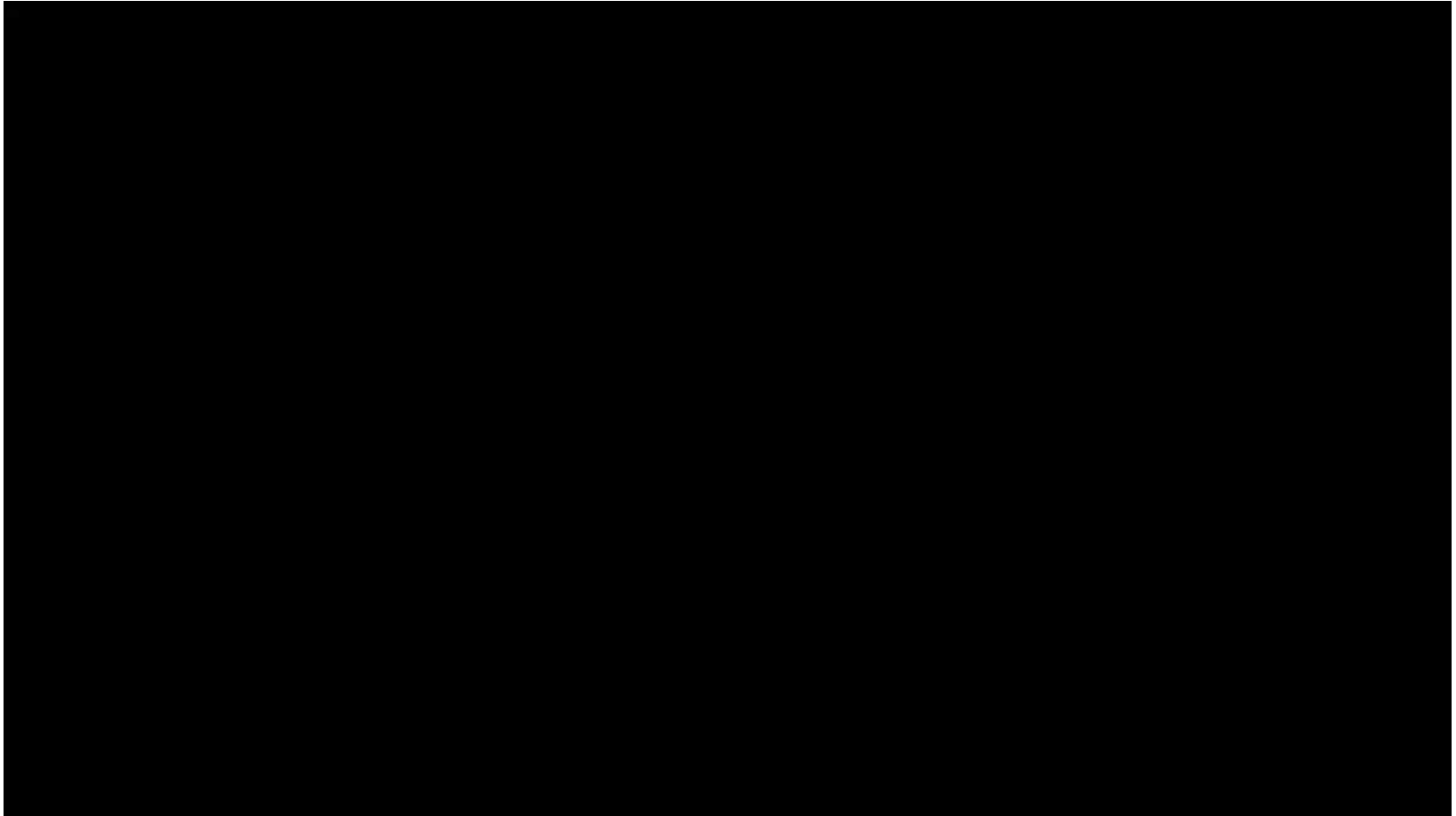
No noticeable
“Thinning”



Courtesy of
SFP Works
dba
FlashBainite

**\$\$\$\$ - Opportunity for
1/3 weight reduction
compared to other cold
formable steels at lower
cost or nearly 50% cost
reduction over hot
stamped steel.**

Gear Contour Hardening

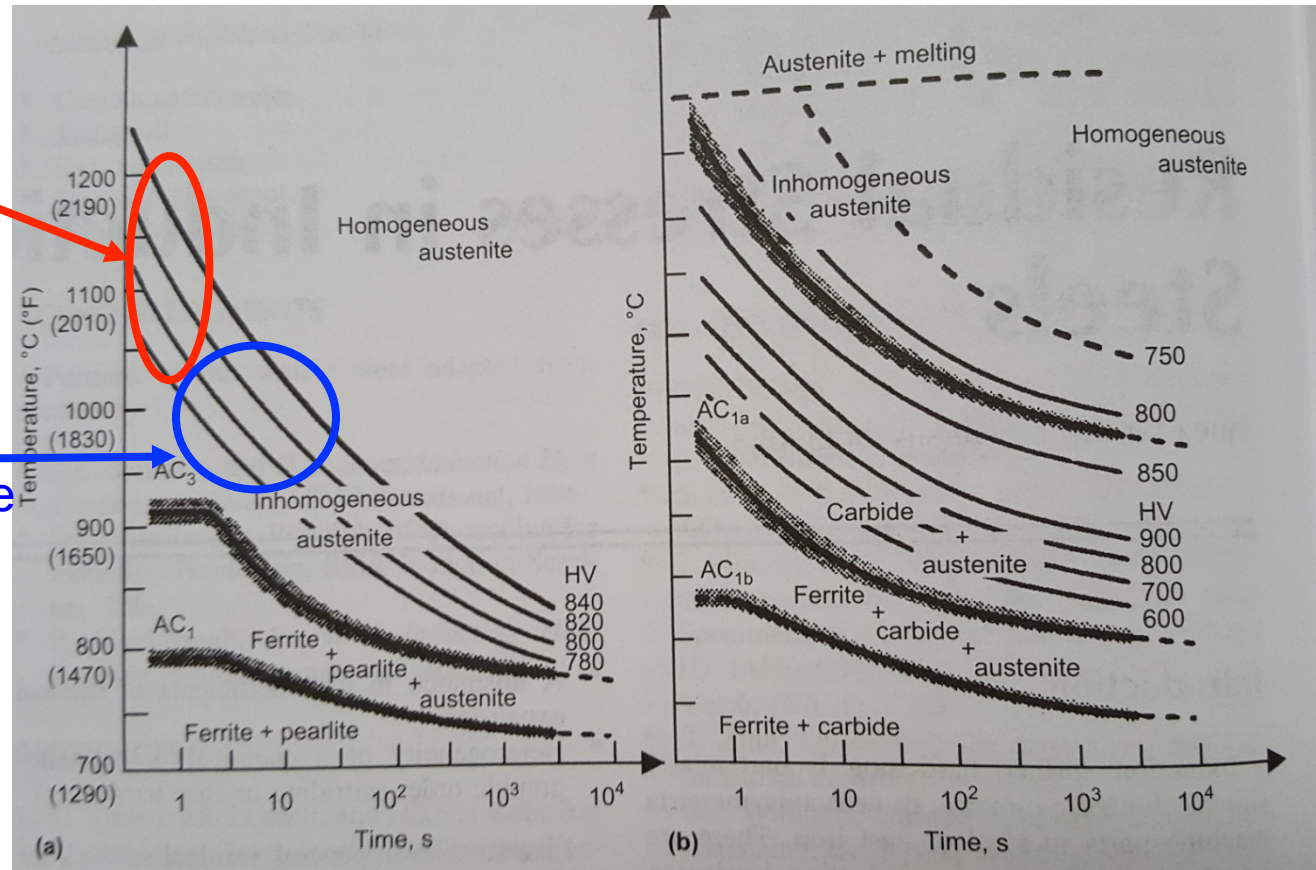


Courtesy of Inductoheat

Effect of Short Time Heat Treatment on Transformation Temperature

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

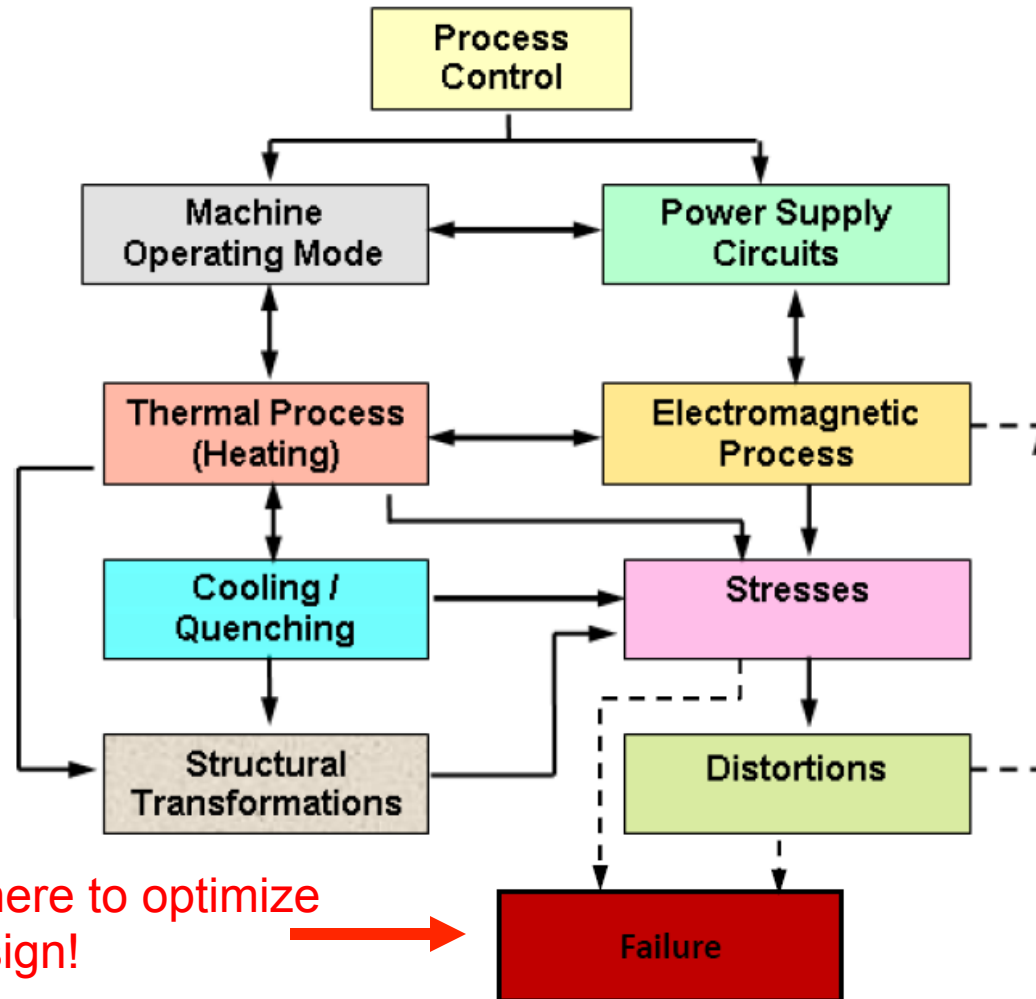
Drawbacks of Induction Heat Treating

- Process is more complicated than furnace heat treatment (more variables), and empirical development can be challenging
- Product Designers Do Not Understand the Process
- Limited Materials Database
 - Even more limited understanding of tempering and other sub-critical processes such as rapid spheroidization developed by COMTES



Modeling is the Key to Bridging the Gap, but Modeling Requires the Necessary Database

Mutually Coupled Phenomena in Induction Heating Process

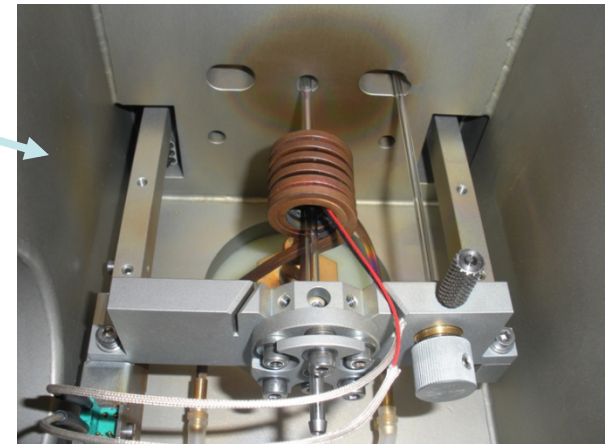


Need to be able to get here to optimize component/process design!

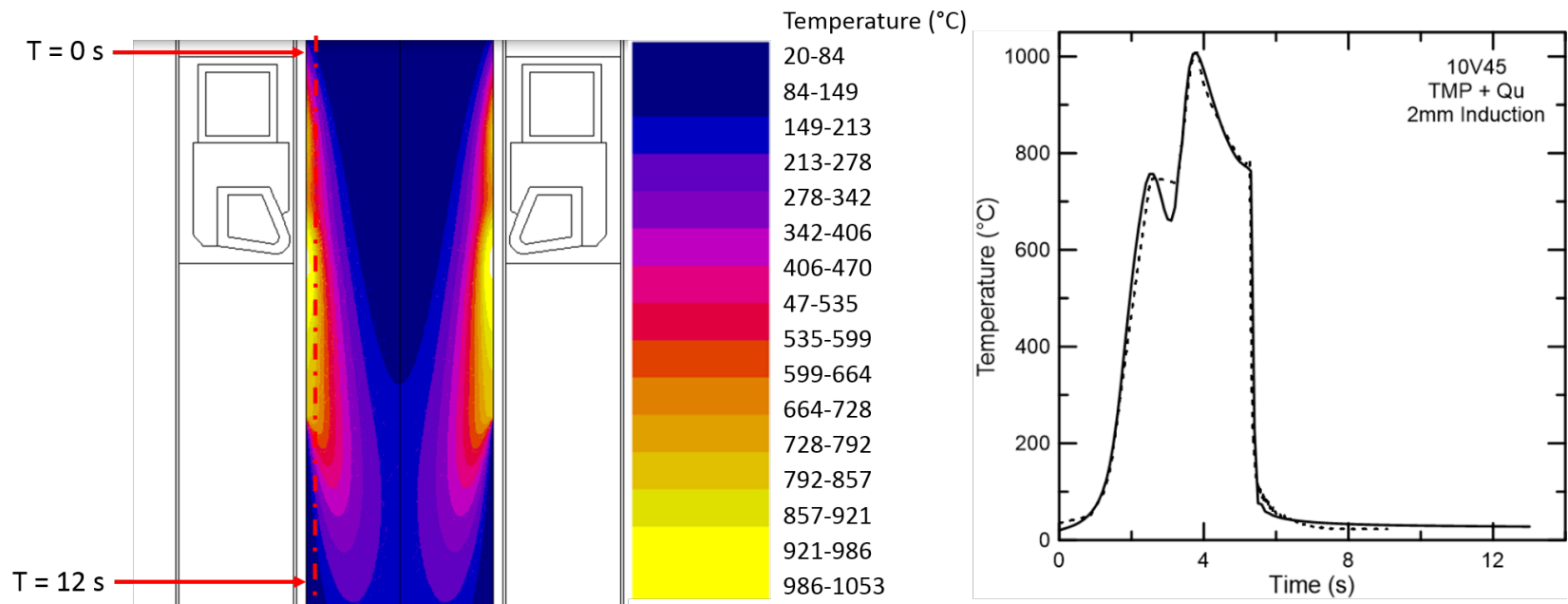


Tools Available for Materials Response Testing at CSM ASPPRC

- Transient metallurgical and physical response to rapid thermal processing
 - Gleeble (resistance heater capable of 10 k Cps)
 - Dilatometers (induction heating system with 1 k Cps)
- Quenchant characterization
 - Inverse Calculations
- Numerous mechanical property and microstructural analysis tools

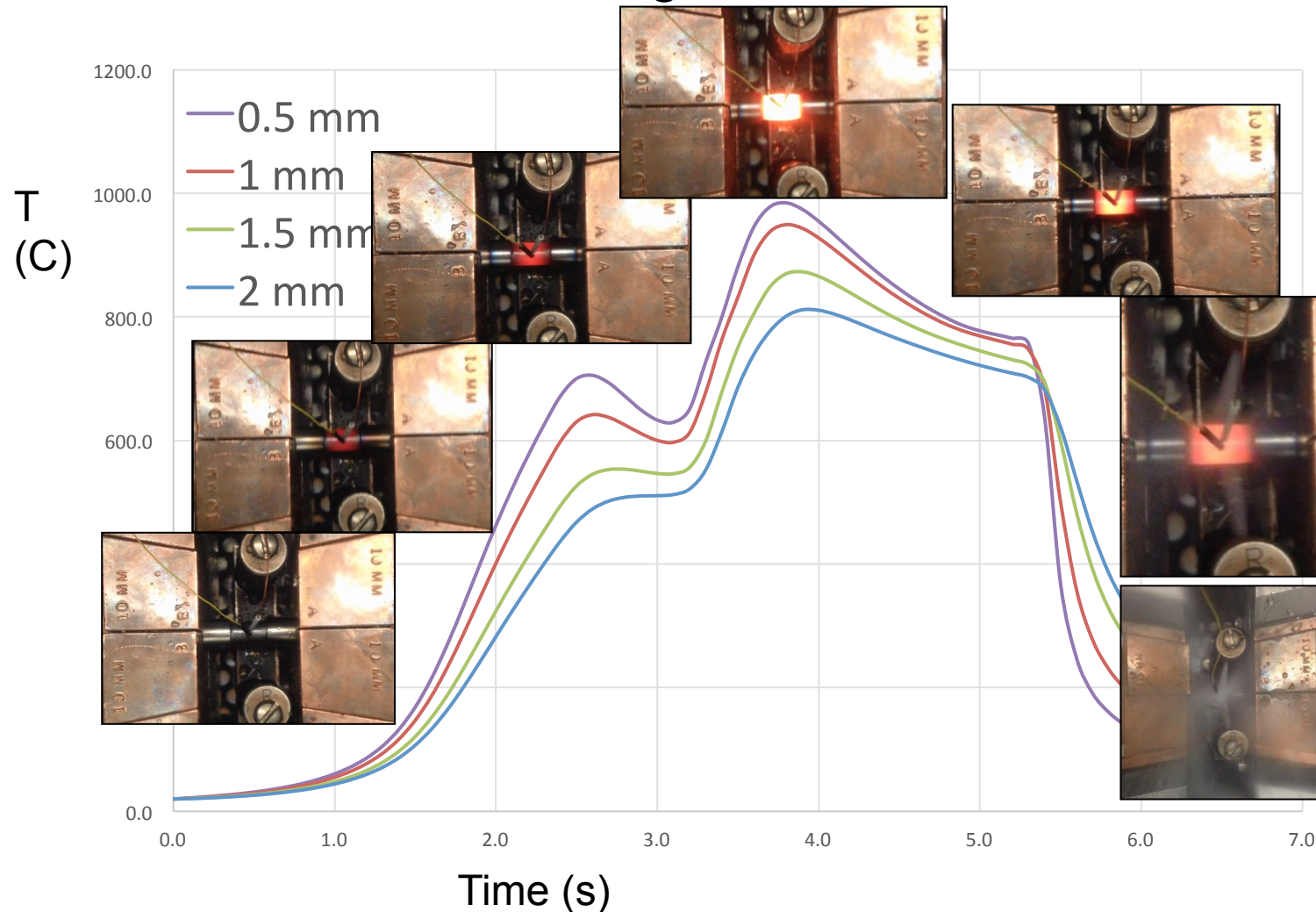


Comparison of Gleeble Tests with Computer Simulation using Flux



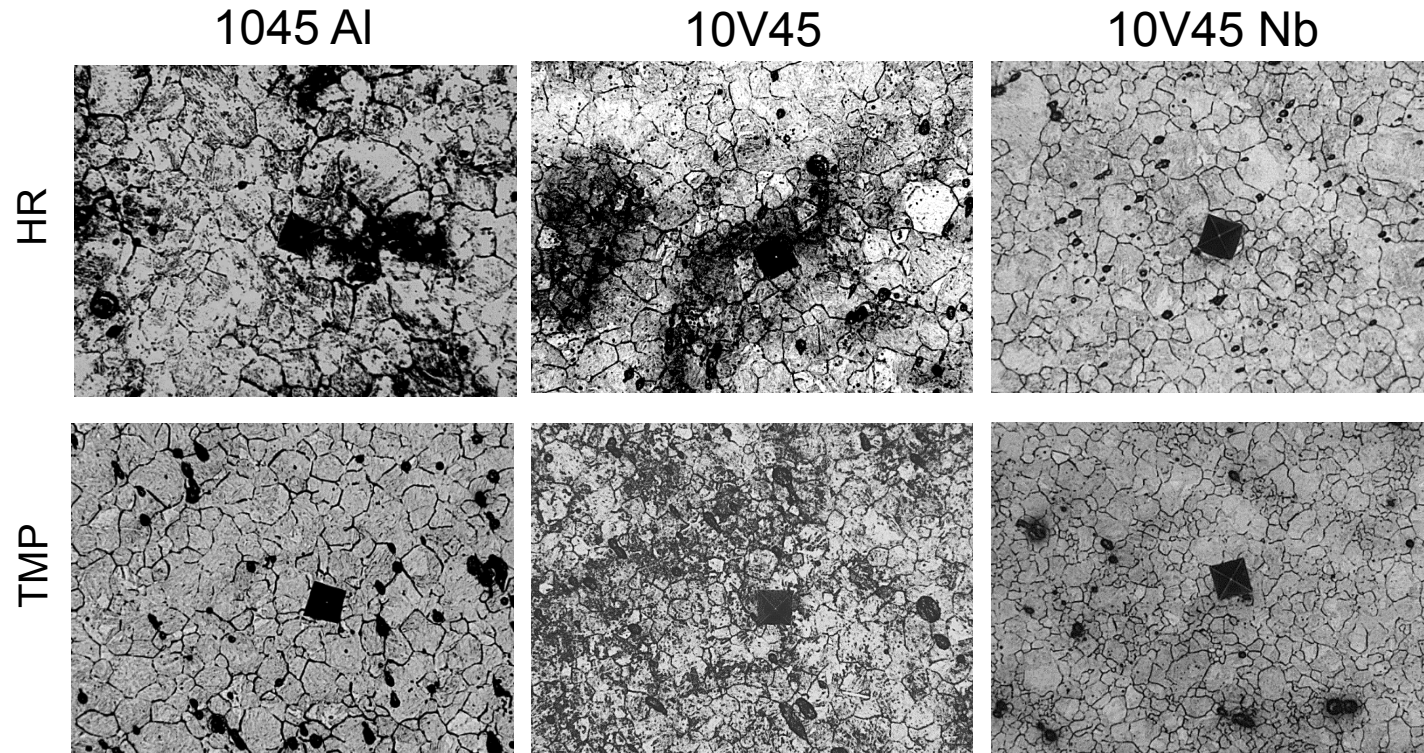
Thermec 2016 Whitely, et. al., Simulation of 2 turn axle scan hardening process (left), Comparison of surface temperature vs. time from simulation and Gleeble test (right)

Induction Hardening – Gleeble Simulation



Thermec 2016 Whitely, et. al., Simulation of thermal profiles experienced at different depths of steel in 2 turn axle scan hardening process

Post Induction Hardening PAGs (Direct Quench Conditions)

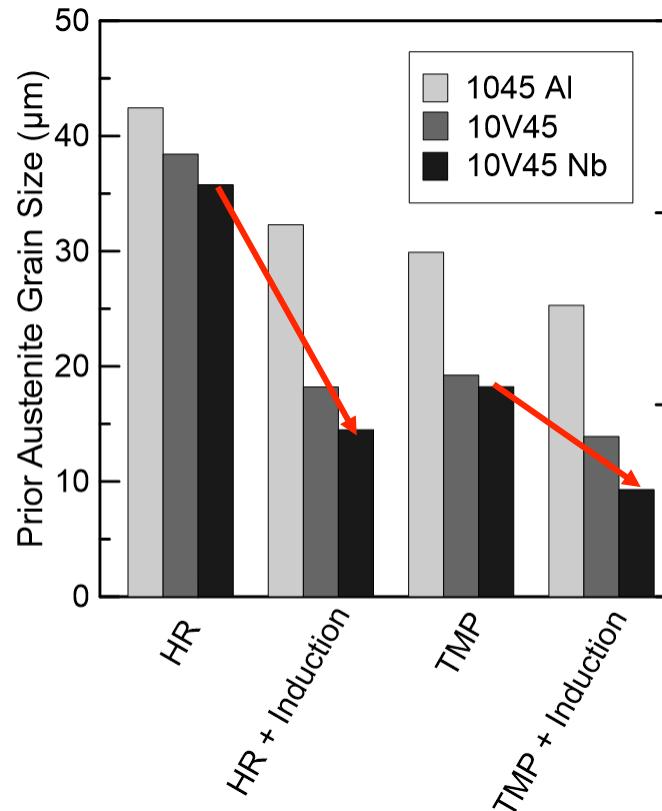


Light optical micrographs of each experimental steel alloy following hot torsion simulation of bar rolling, direct quenching to room temperature, induction hardening simulation, sectioning in the cross-sectional orientation, and metallographic etching to reveal prior austenite grain boundaries.

Thermec 2016 Whitely, et. al.

Induction Hardening – Gleeble Simulation

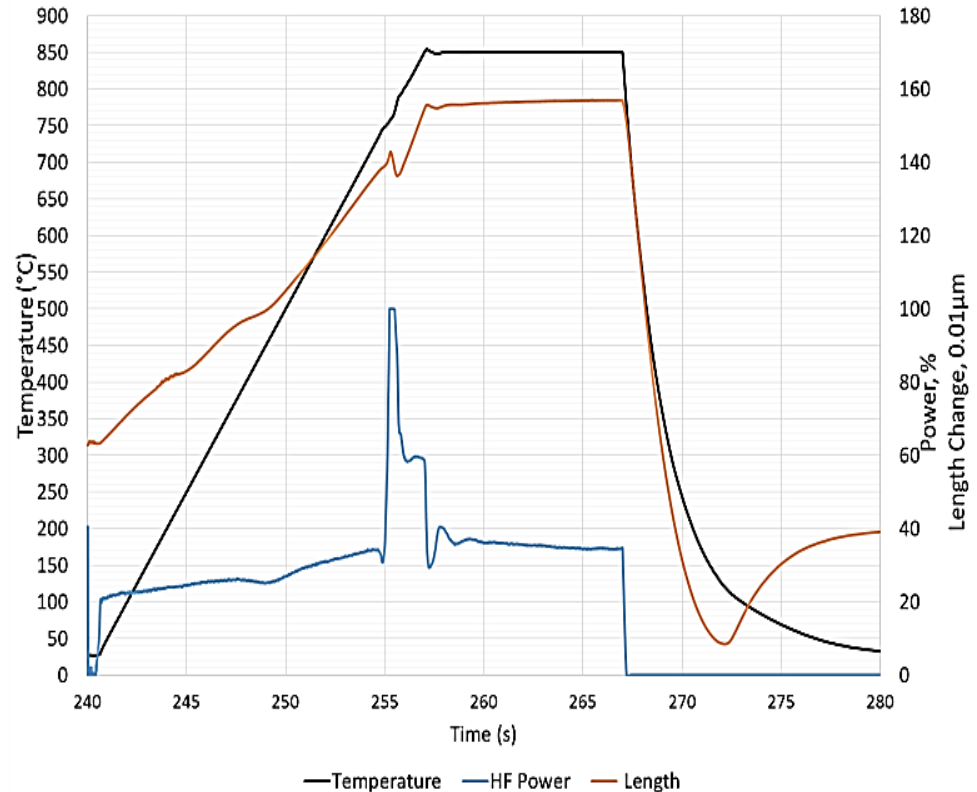
	Prior Austenite Grain Sizes (microns)		
	1045 Al	10V45	10V45 Nb
Austenitized	94.87	113.92	99.28
Hot Roll	42.45	38.43	35.76
TMP	29.9	19.23	18.24
HR+Qu+2mm Ind. Sim	32.3	18.2	14.5
TMP+Qu+2mm Ind. Sim	25.3	13.9	9.3



Thermec 2016 Whitely, et. al.

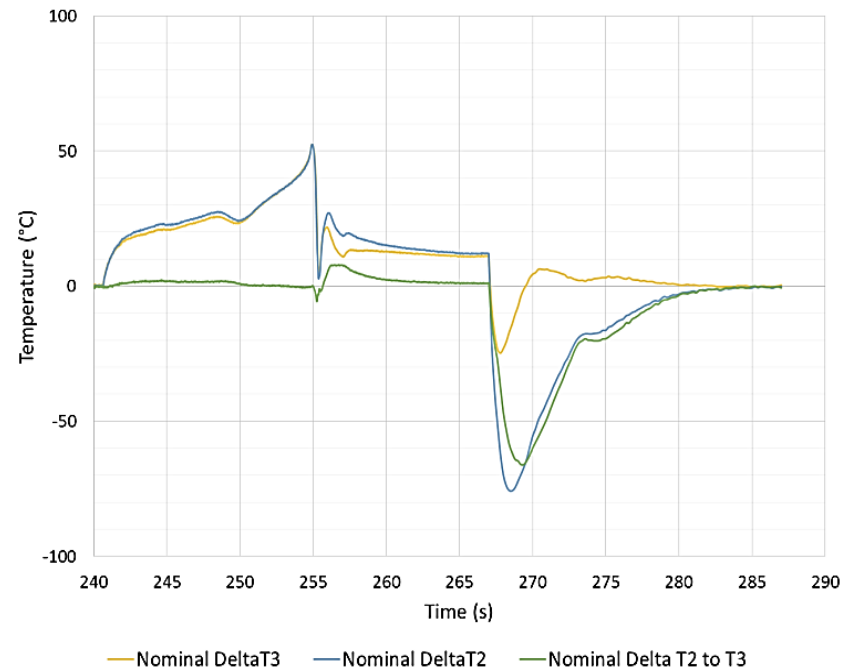
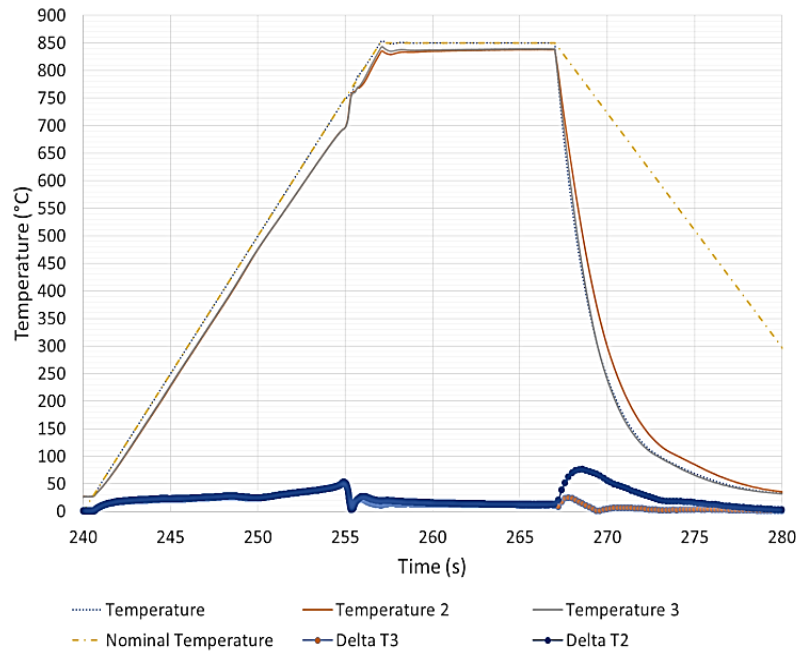
Dilatometer Testing

- 4 mm tool steel sample
- Proposed cycle
 - 50 Cps heating rate
 - 850 C target temperature
 - Hold at 850 C for 10 s
 - Helium quench



Will be presented at ASM HTS
2017 Goldstein, et. al.

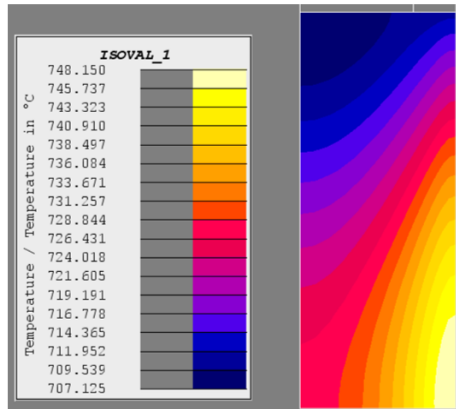
End to End Gradients in Sample Temperature During Trials



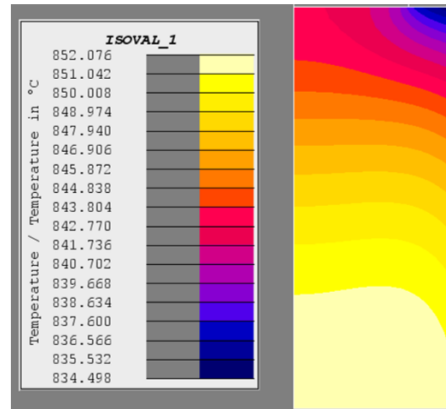
Even with relatively slow induction heating and cooling process, substantial gradients present in the sample. Will be presented at ASM HTS 2017 Goldstein, et. al.

Modeled Temperature Distributions Agree with Test Results

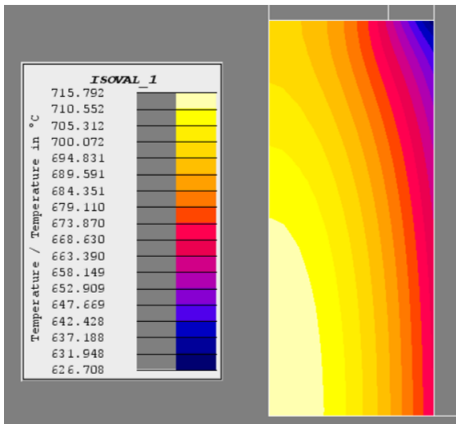
14.25 seconds into heating



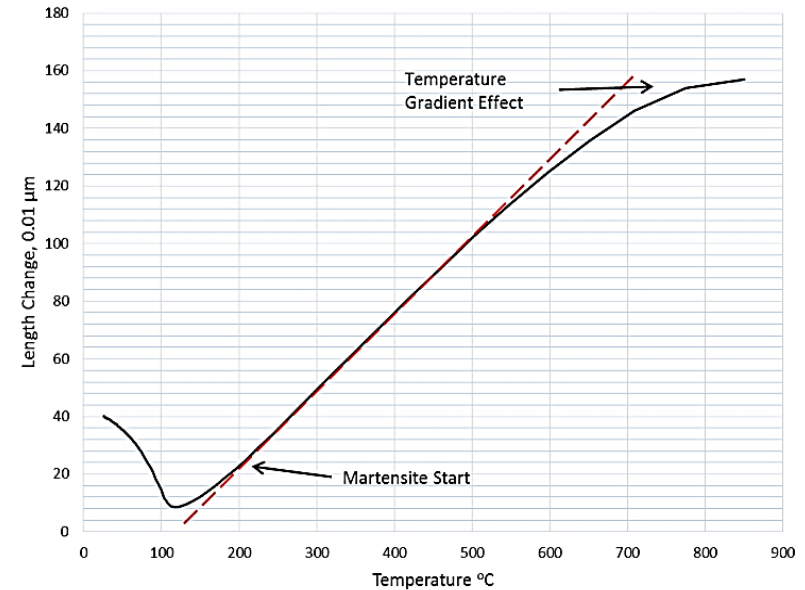
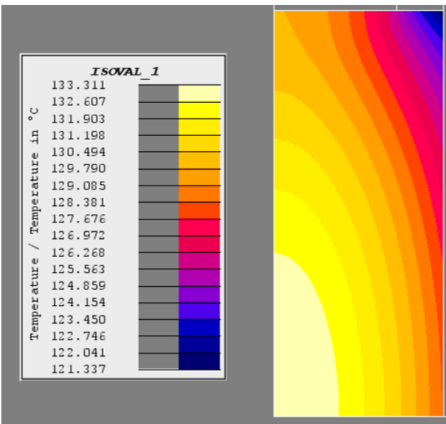
End of Holding



0.5 seconds into Cooling



During Phase Transformation



One Drawback of Flux is that there is currently no good option to simulation different phase transformations occurring on heating (austenite) and cooling (martensite)

Will be presented at ASM HTS 2017 Goldstein, et. al.

Conclusions

- Induction heating is a widely used technology for heat treating
- Many induction heat treated components are known to have superior properties compared to components heat treated using other technologies, however, exactly why they perform as well as they do in some conditions is not fully understood
- Despite the widespread use of the technology, the materials database for induction heat treating needs to be improved to maximize the potential of the technology
- It is important to couple experimental tools with computer models to understand true temperature dynamics in the samples to properly interpret experimental results

Acknowledgements

- Some of the slides in this presentation were taken from the “Basics of Induction Heating Parts I & II” prepared by Dr. Valentin Nemkov (www.fluxtrol.com)
- Video Courtesy of Inductoheat (www.inductoheat.com)
- Physical Simulation Data provided by Advanced Steel Products and Processing Center at Colorado School of Mines