Integrated Computational Development of Induction Heat Treatment Process for Automotive Axle Shafts

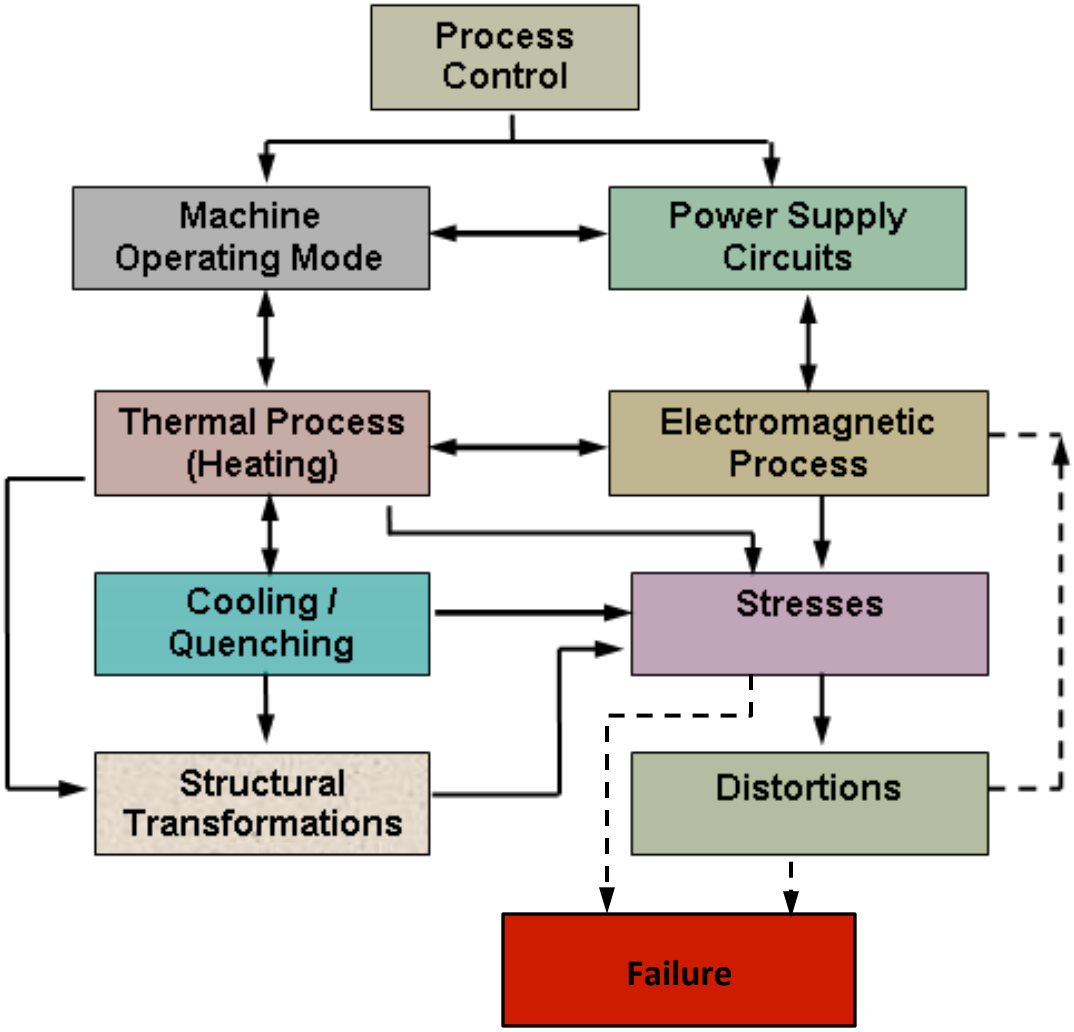
Robert Goldstein[(1)], Dr. Valentin Nemkov[(1)],
Dr. Lynn Ferguson[(1)], Dr. Zhichao Li[(1)]

[(1)] Fluxtrol, Inc., Auburn Hills, MI, USA
[(2)] DANTE SOFTWARE, Cleveland, OH, USA

Introduction

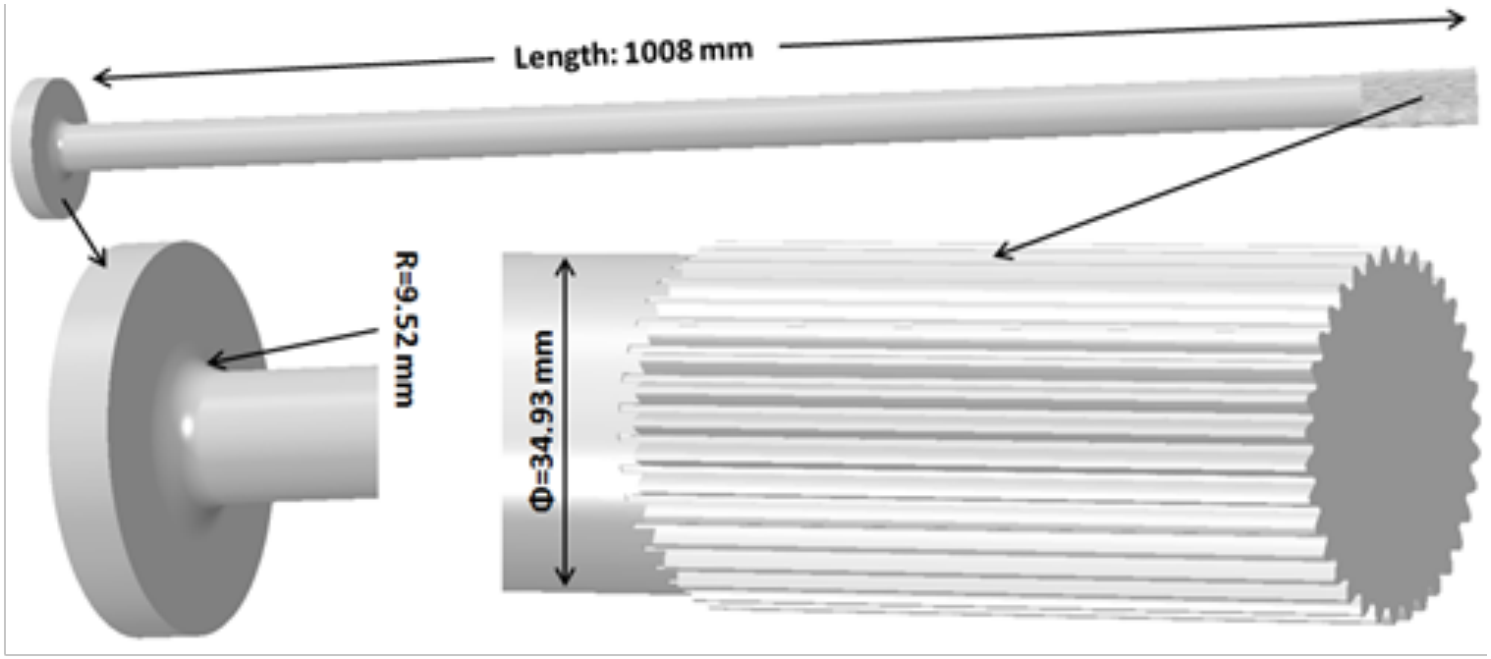
- Induction hardening involves multiple phenomena, including: electromagnetic, thermal, metallurgical, stress and deformation
- State of the art method is developed to couple these physics together
- Flux software (electromagnetic and thermal capabilities) is coupled with DANTE (thermal, stress, distortion and applied load capabilities)
- Case chosen for study is a full-float axle, dimensions typical for axles manufactured and hardened by induction heating

Mutually coupled phenomena in induction heating process



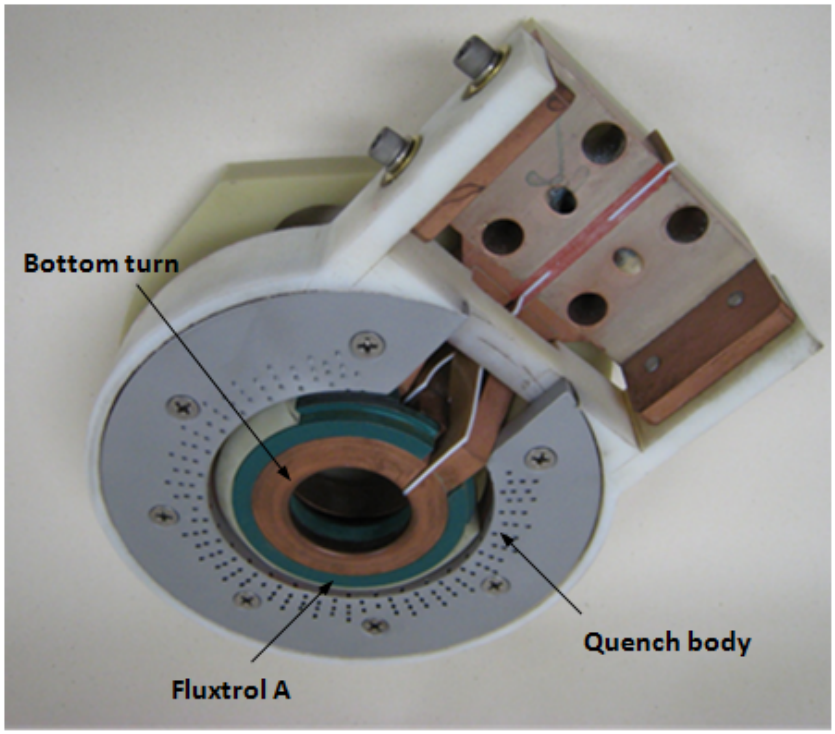
Axle Dimensions Used in Model

Axles can be broken into 3 main regions: Radius and Flange, Shaft, and Spline

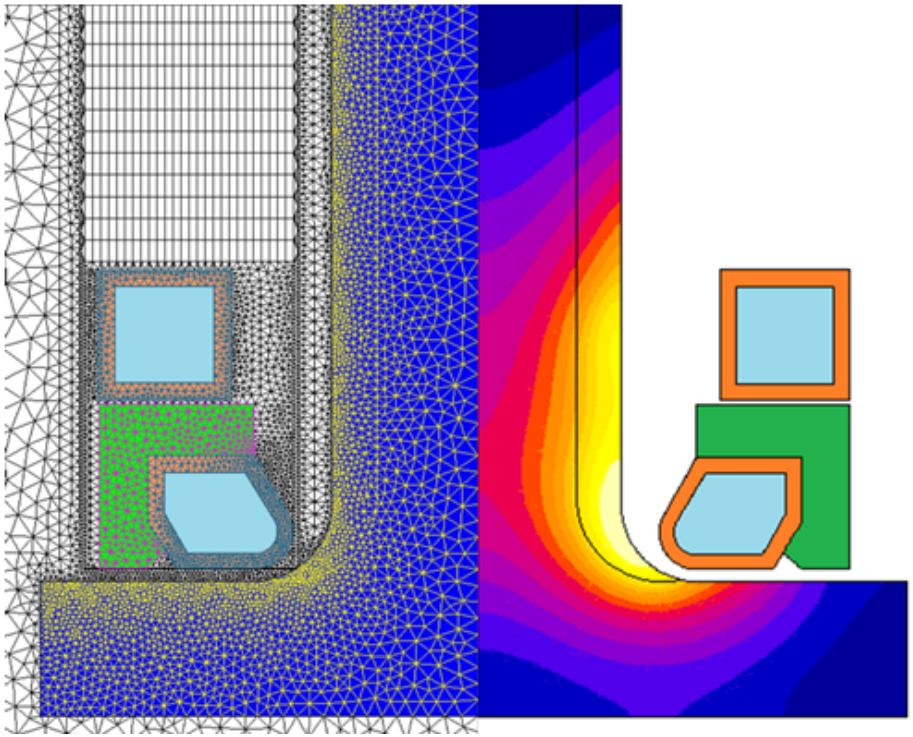


Case Depths to 40 HRC		
Shaft:	Radius:	Run-out:
5.36 mm	2.7 mm	to end of radius

2-Turn Coil Design

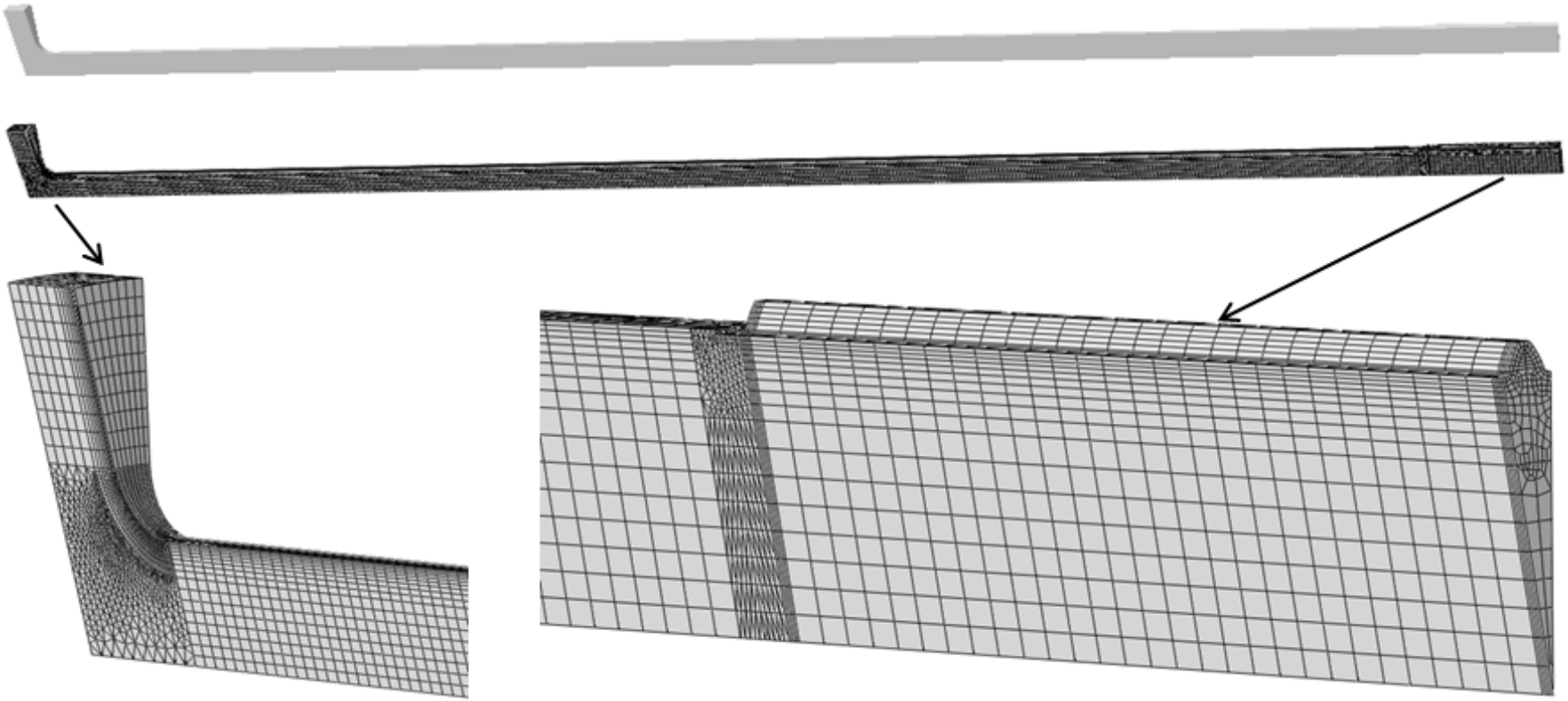


Example of fully assembled axle coil



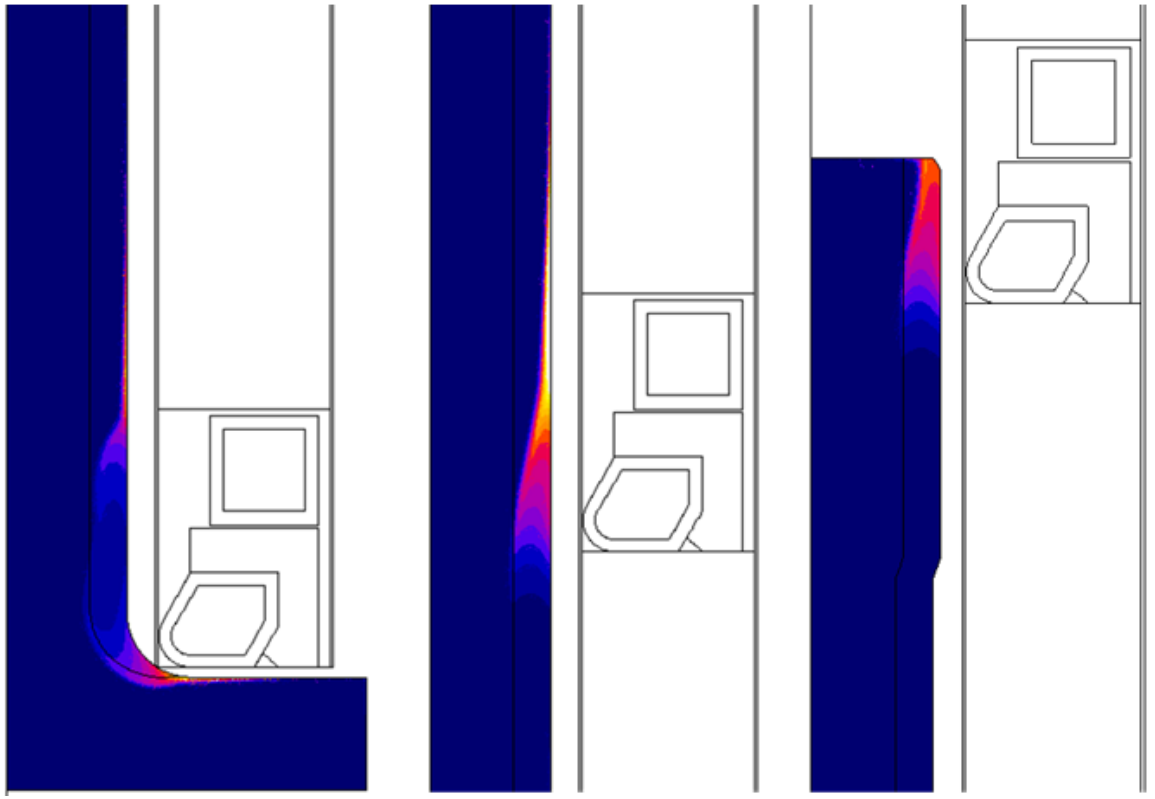
Flux 2D model showing mesh (left) and temperature (right) at end of dwell

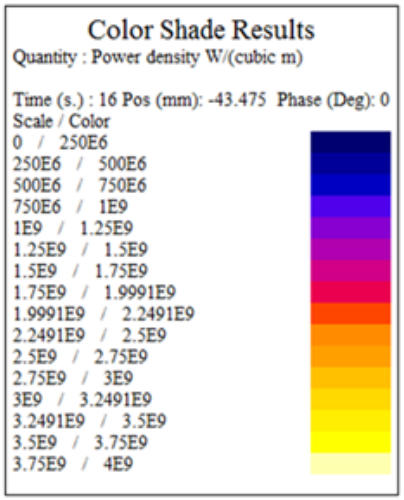
Due to Symmetry, Single Tooth of Spline is Modeled in DANTE



Finite element meshing in DANTE is displayed

Power Density in 3 Regions (Flux 2D)

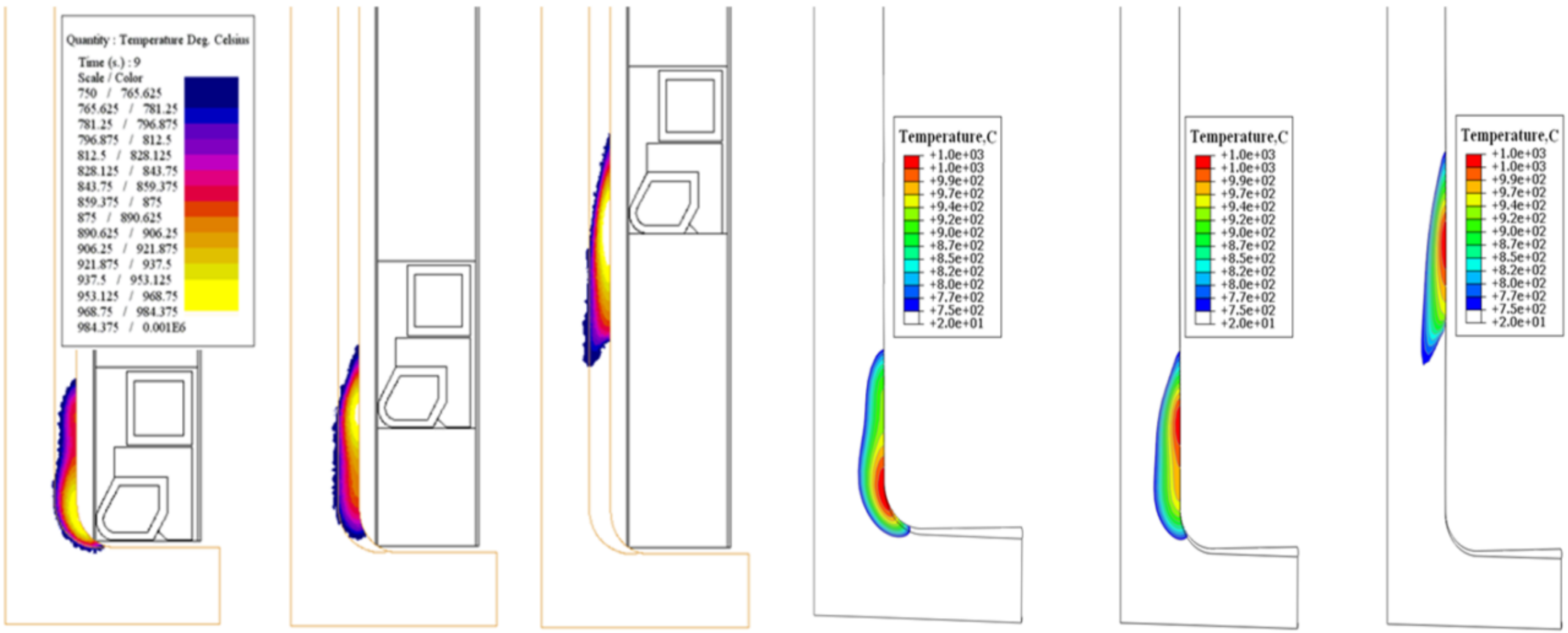




Radius Shaft Spline

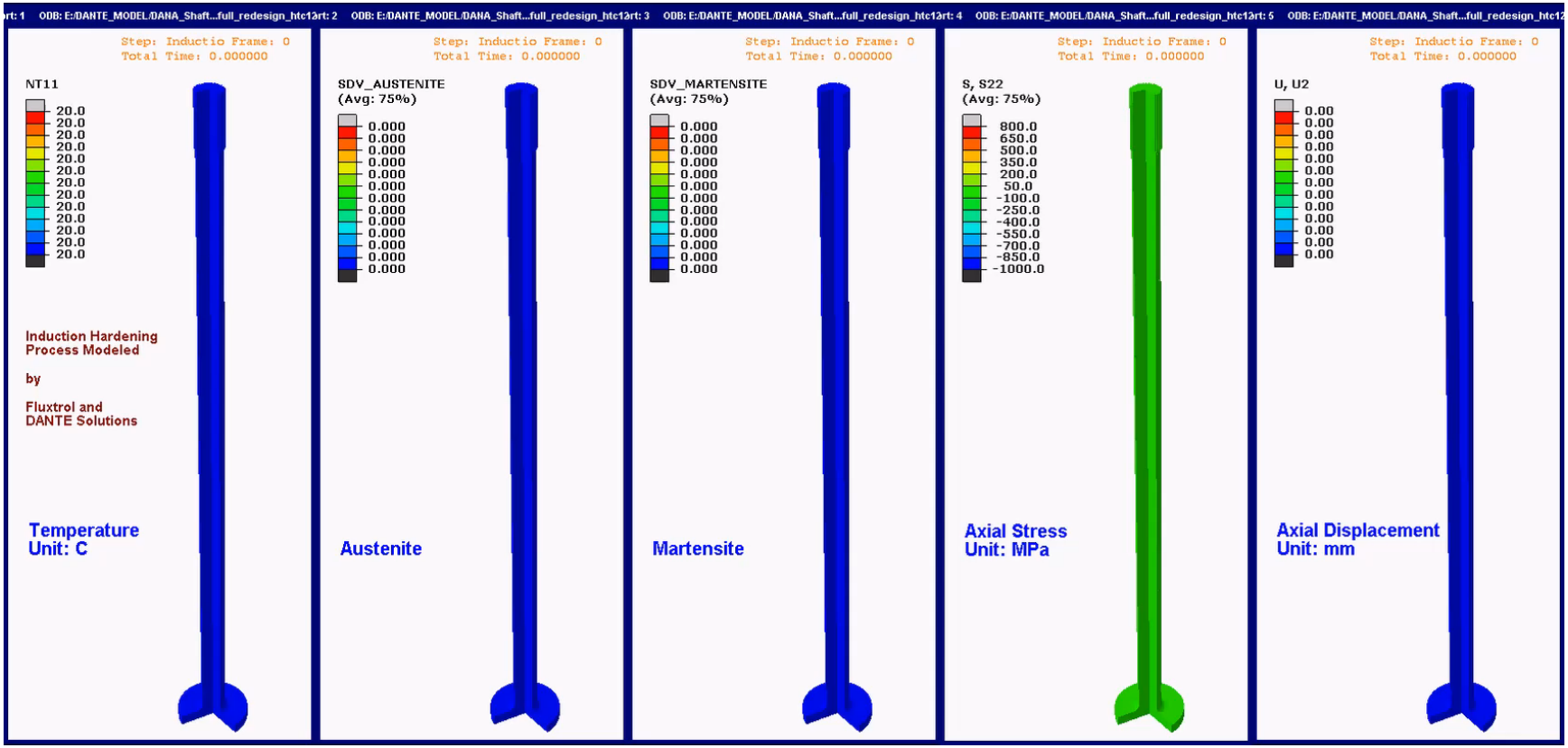
Power densities are extracted from Flux 2D and imported to DANTE

Temperature Validation Between Flux and DANTE

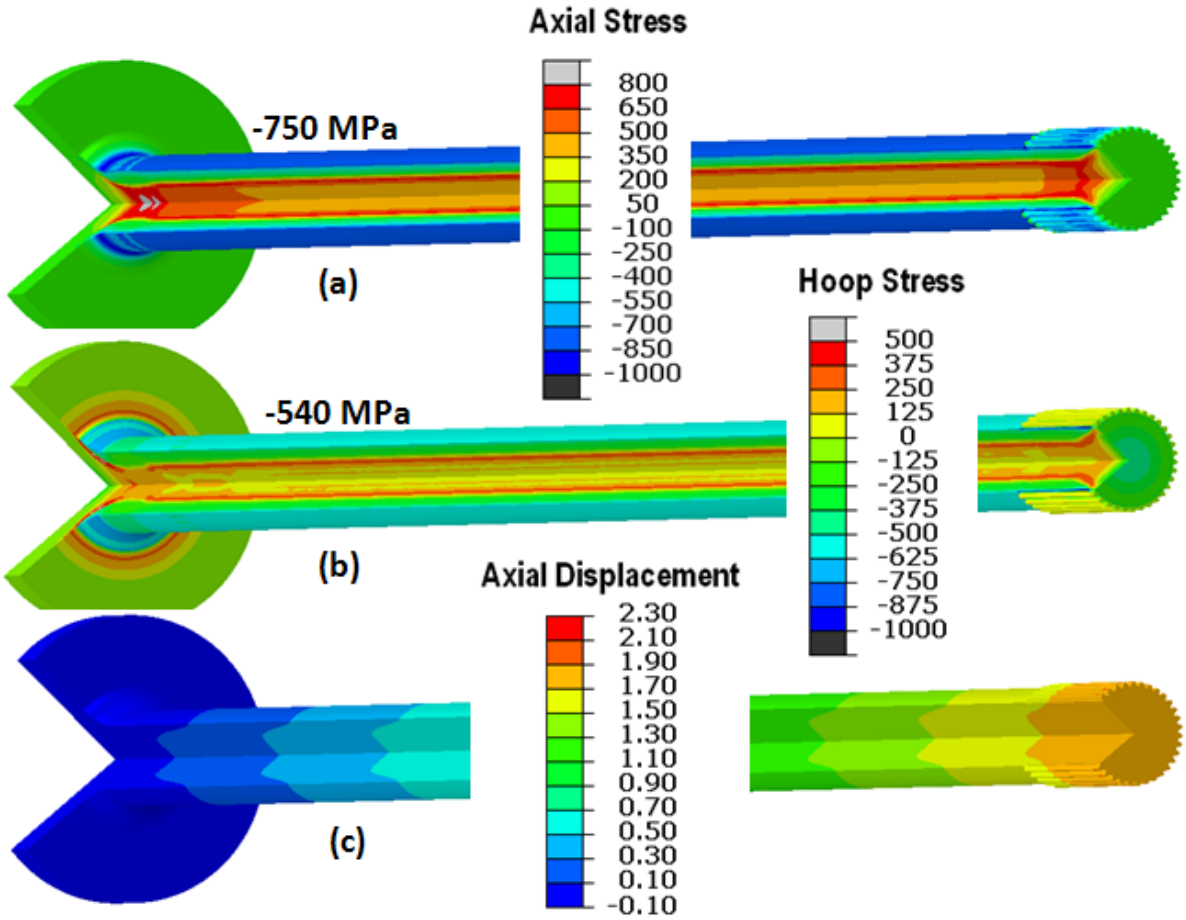


Flux 2D DANTE

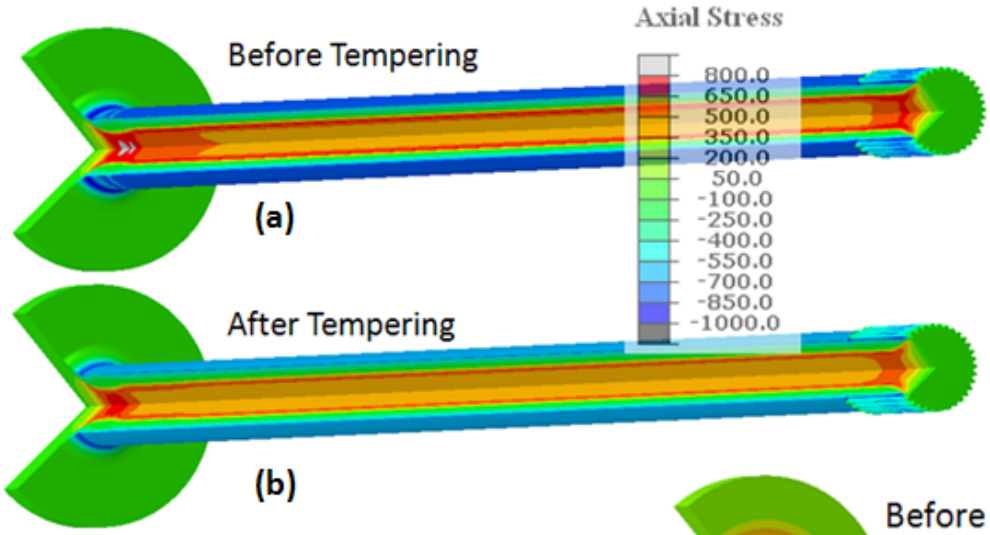
DANTE Simulation of Scanning Process

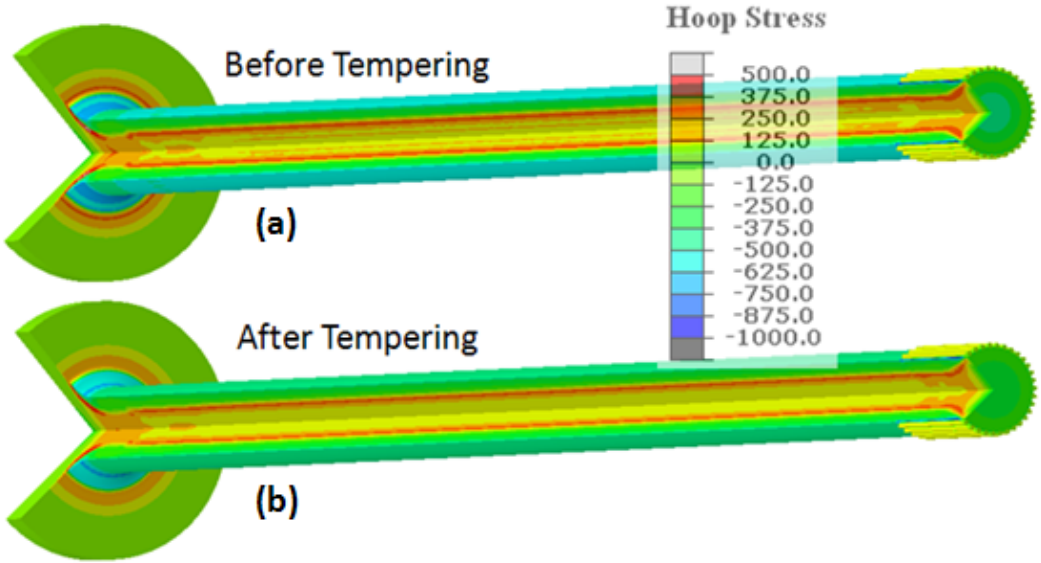


Stresses and Dimensional Movement after Hardening

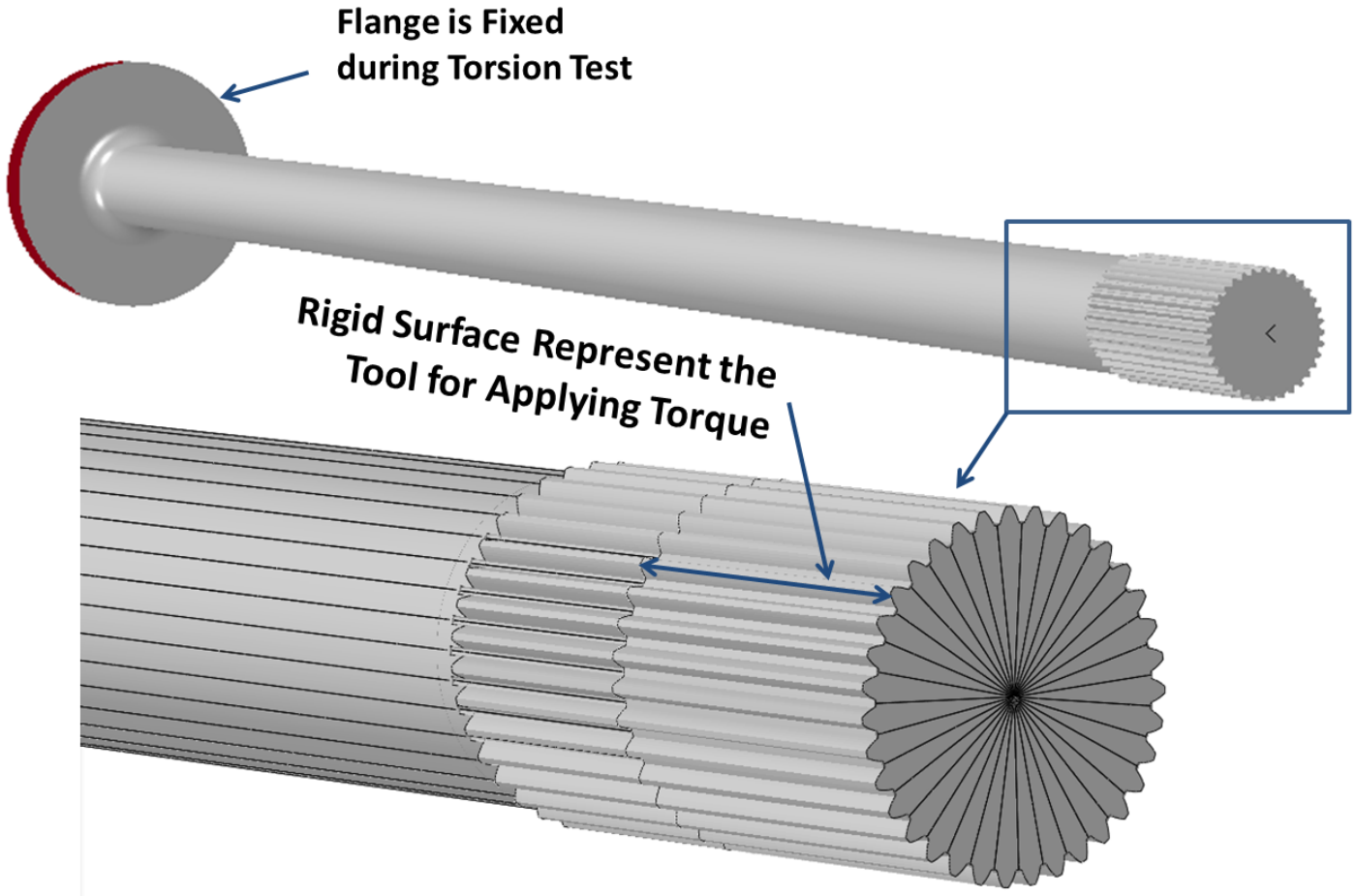


Effect of Tempering on Residual Stresses



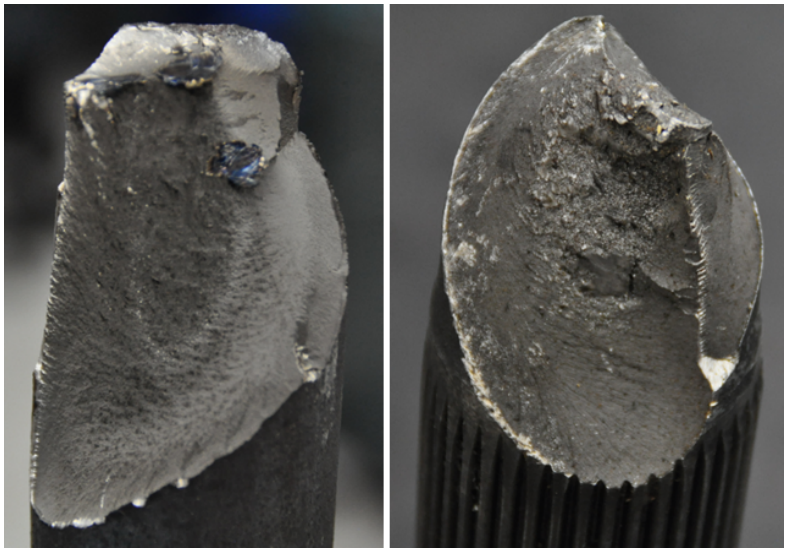


Simulation of Torsional Loads

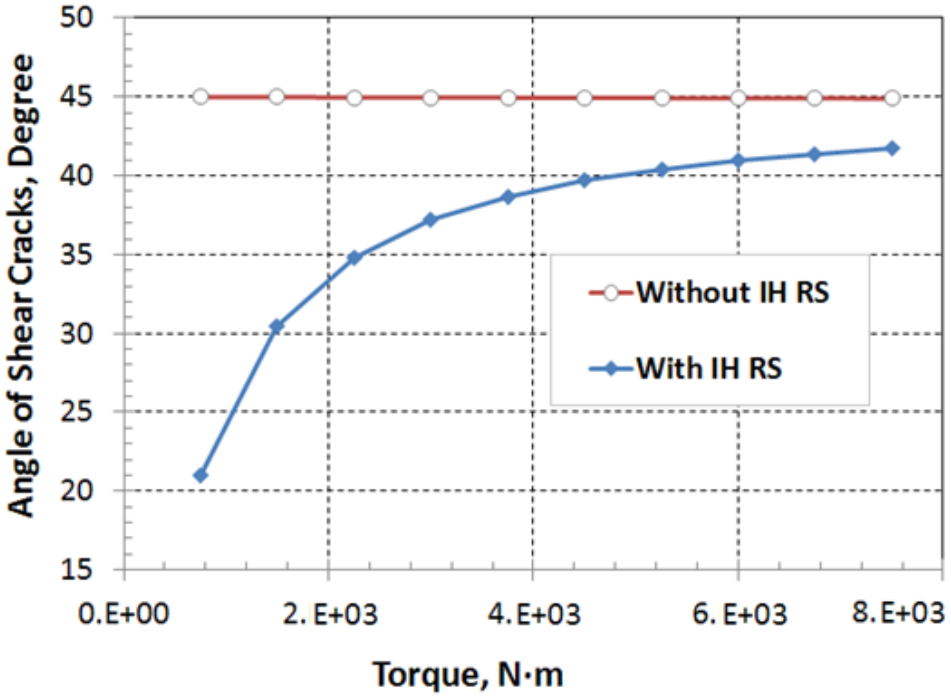


Dante Simulation of Torsional Loads

Failure Prediction



(Left) Fatigue crack, and
(Right) Overload crack.
Courtesy of Dana Corp.



Conclusions

- Electromagnetic modeling by Flux and thermal-stress modeling by DANTE were successfully coupled
- High surface compression and high tensile stresses in core were predicted in model
- The largest tensile stresses occur at the base of the shaft and at the spline
- Total axial growth is 2.3 mm and radial shrinkage in shaft is 4µm. The authors have shown other papers that the axial growth and stress profiles are strongly influenced by the quenching severity.
- Virtual Loads were applied to the axle that simulate torsional testing equipment used in industry. Failure mode predictions are similar to what has been found while testing real components, showing that the residual stresses from the heat treating process have a strong influence on the component performance.
- Additional work needs to be done to incorporate residual stresses from manufacturing operations prior to the induction heat treating process to improve the accuracy of the predictions.