

Applying CFD to Characterize Gear Response During Intensive Quenching Process

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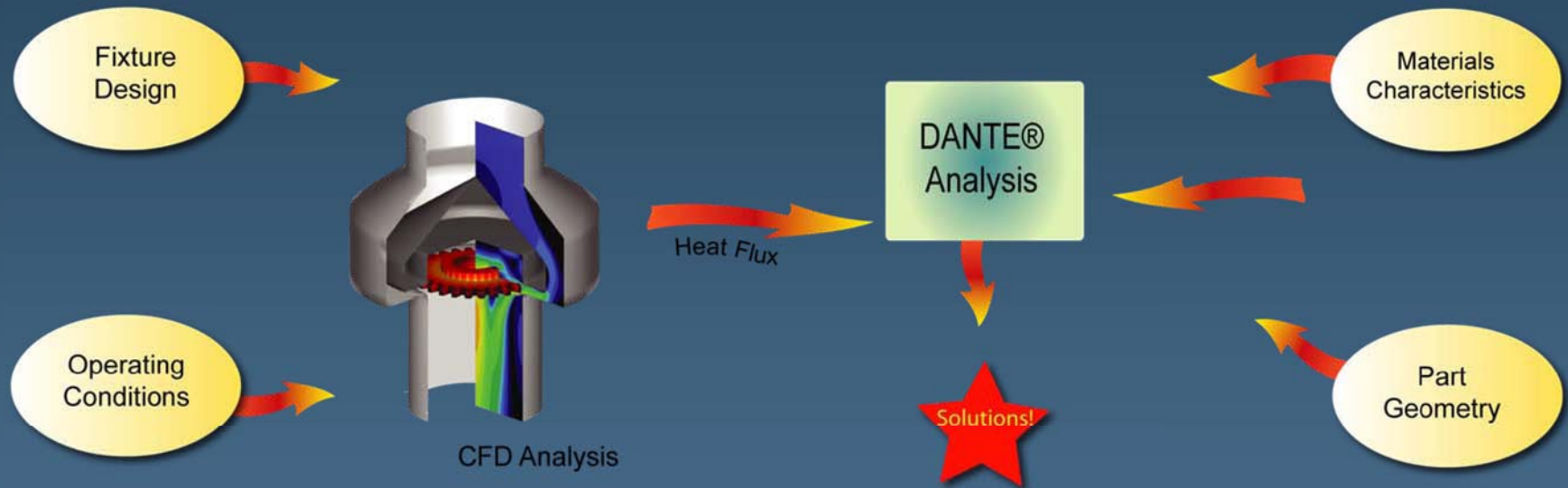
Overview

The fluid flow field that exists in any quenching operation can lead to variations in surface heat flux that lead to distortion, as well as variations of residual stress, phase and hardness distributions, etc.

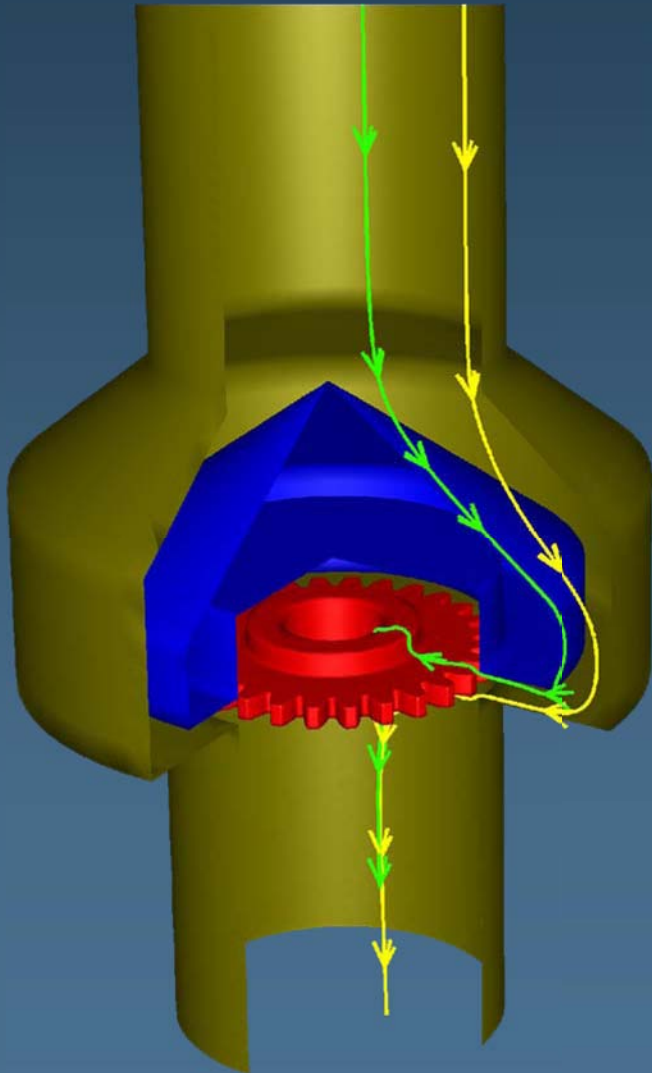
Flow field and heat flux predicted by CFD (Fluent).

Applying CFD results as thermal boundary condition, DANTE transient thermal/stress analysis is used to predict distortion, residual stress, hardness and phase distributions.

Analysis Workflow



Fixture Design



Quench flow is radially inward toward the gear teeth to provide the best quenching to the wear surfaces.

Water flow rate: 500 GPM

CFD Goal

Provide accurate surface heat flux rates for use in FEA (DANTE) modeling

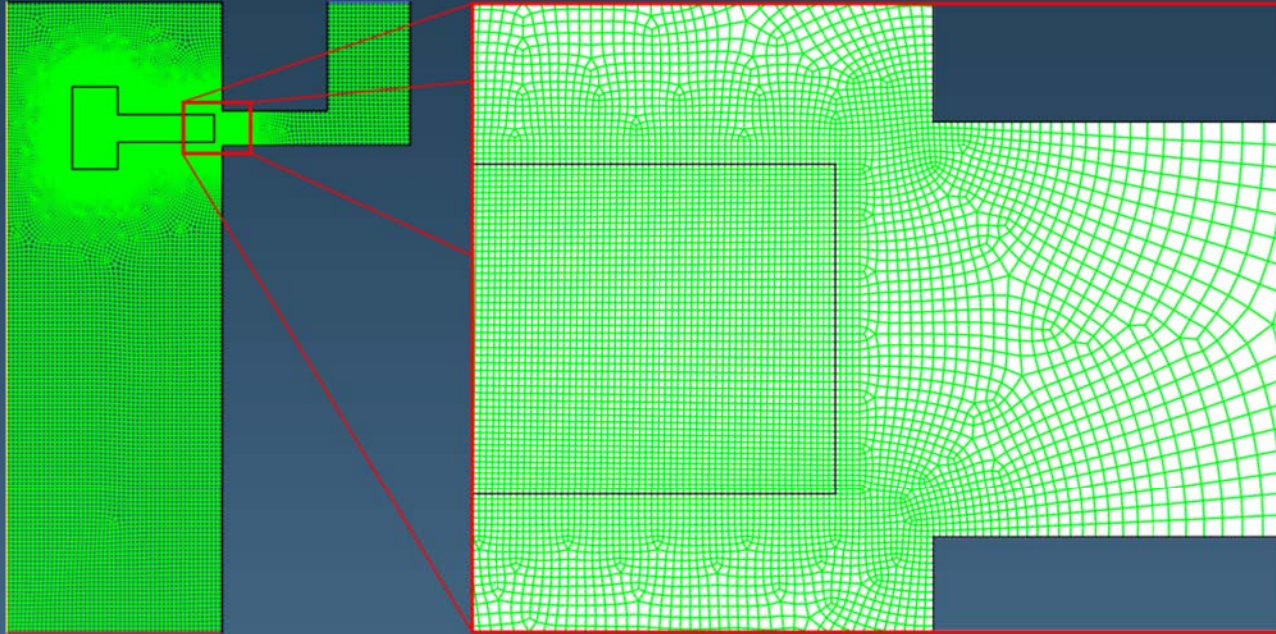
Challenges

Full transient 3D simulation of real geometries would take too long to be a practical engineering tool

How do heat fluxes vary in space in time?

Investigate with 2D model

2D Analyses - Computational Grid



2D representation of gear (no teeth)

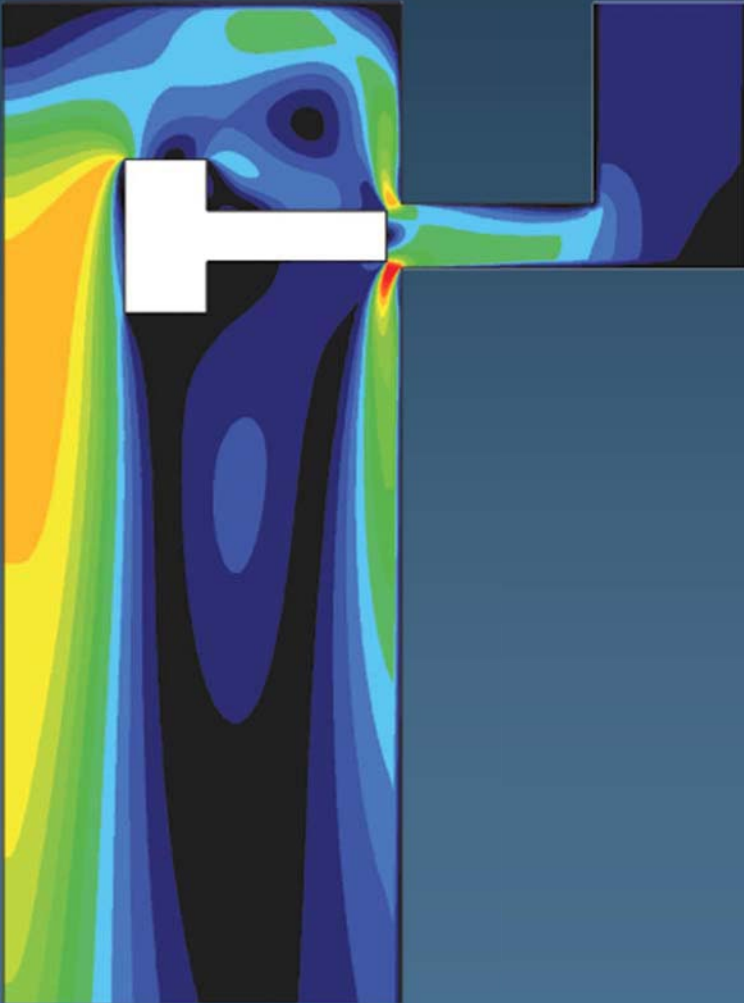
Solid included in simulation

50,391 cells, with 22,121 in the solid

Transient simulation with time step of 0.001 seconds

10 seconds of time simulated

2D Analyses - Flow Field



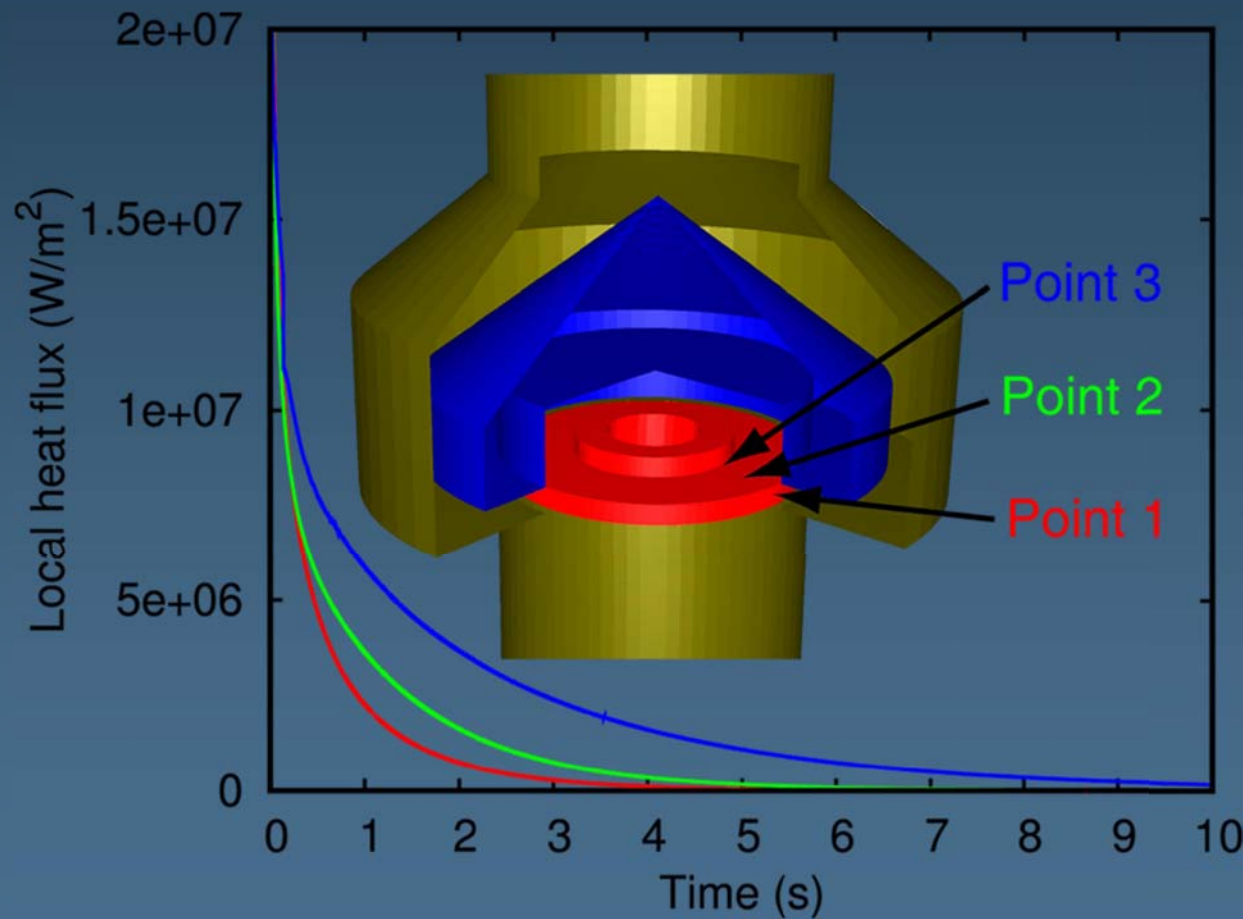
Impingement on gear tooth face provides good heat transfer

High velocity around "corners" of gear disk also provide high heat transfer

Asymmetry on top and bottom corners

Velocities on faces of gear disk are lower

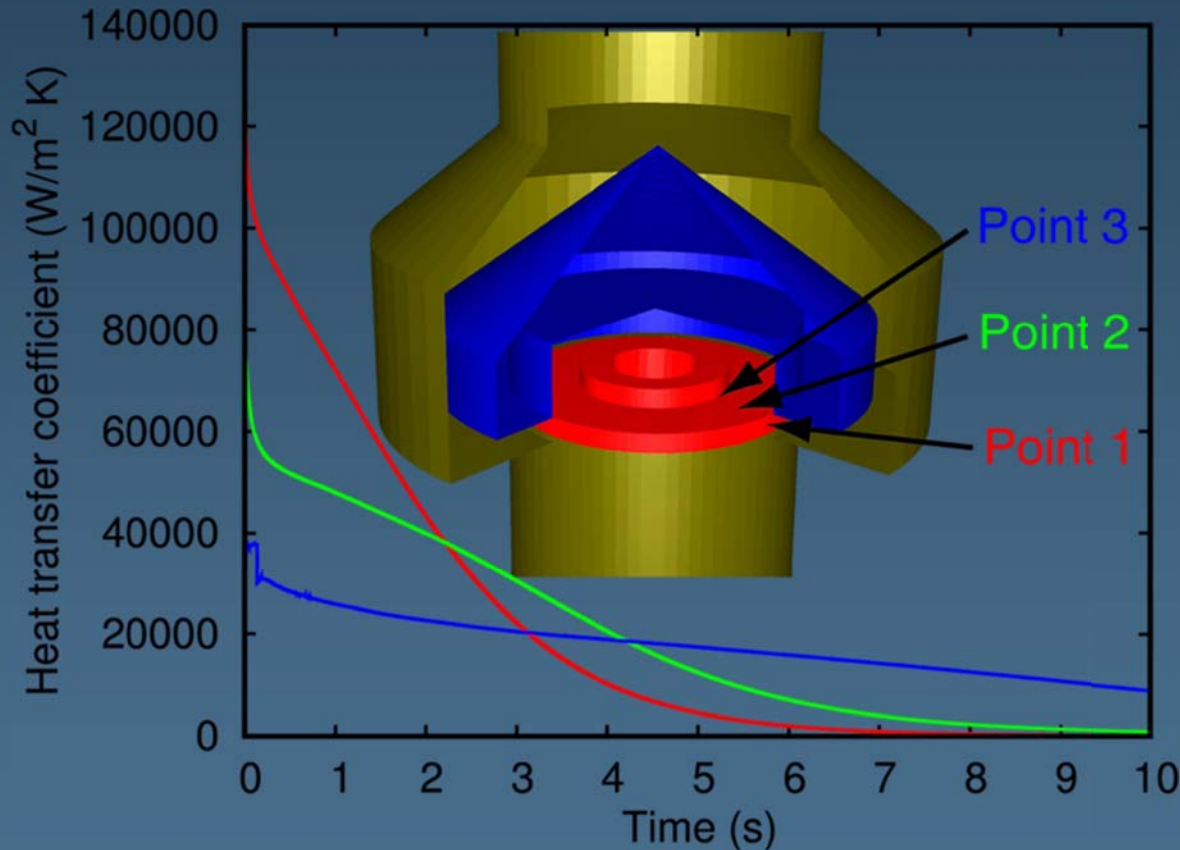
2D Analyses - Transient Heat Flux



For three representative points on the gear blank, heat flux rate varies considerably

An assumption of equal heat flux everywhere would not be appropriate

2D Analyses - Transient Heat Flux



Heat transfer coefficient for same three points varies both with location and with time

Assumption of constant and equal heat transfer coefficient is not appropriate

2D Analyses - Correlation Method

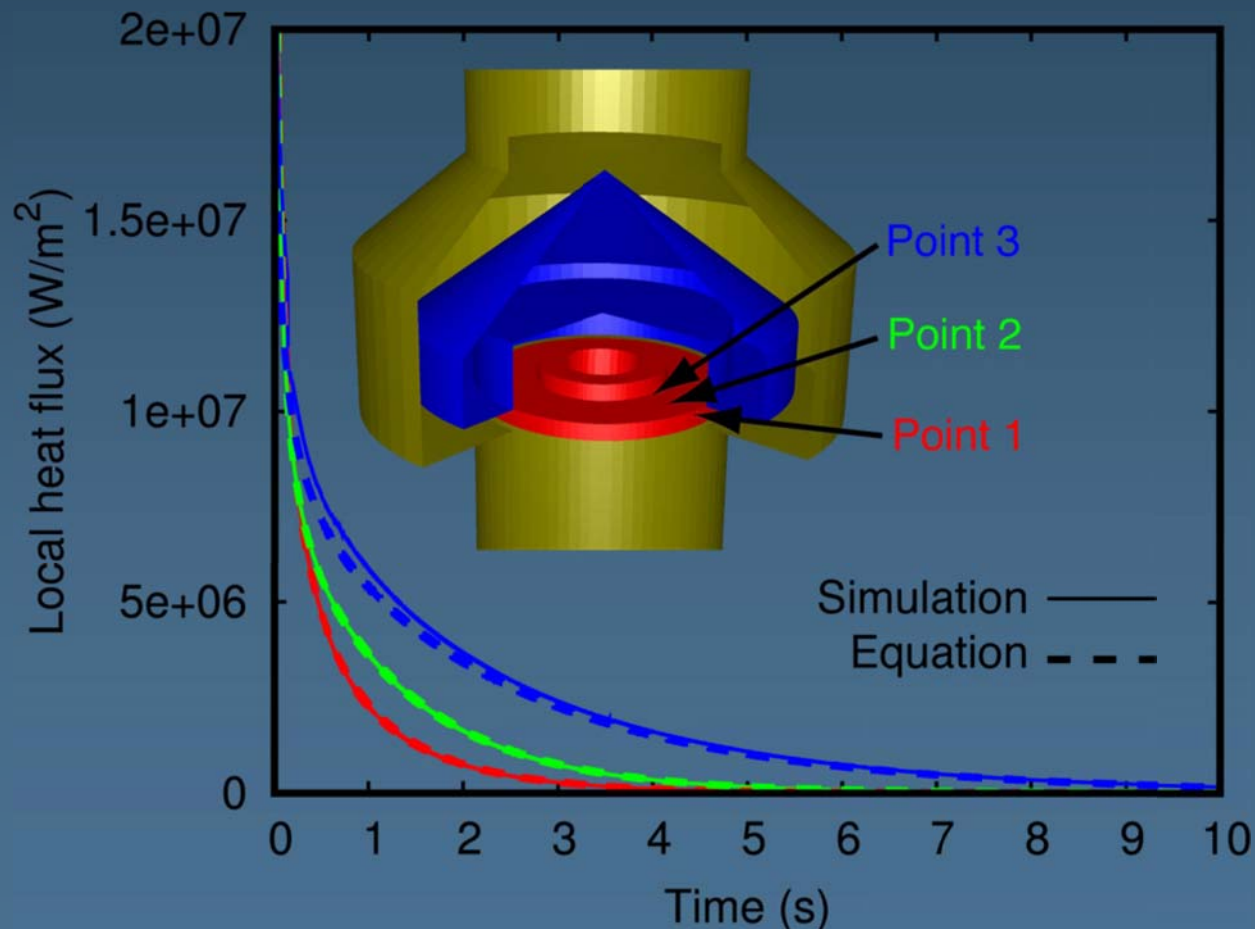
Is it possible to approximate the transient heat flux from steady state simulations?

$$q = \left\{ h^o \frac{T_w - T_r}{T_w^o - T_r} + h^f \frac{T_w^o - T_w}{T_w^o - T_r} \right\} \left[T_w - \left\{ T_o \frac{T_w - T_r}{T_w^o - T_r} + T_r \frac{T_w^o - T_w}{T_w^o - T_r} \right\} \right]$$

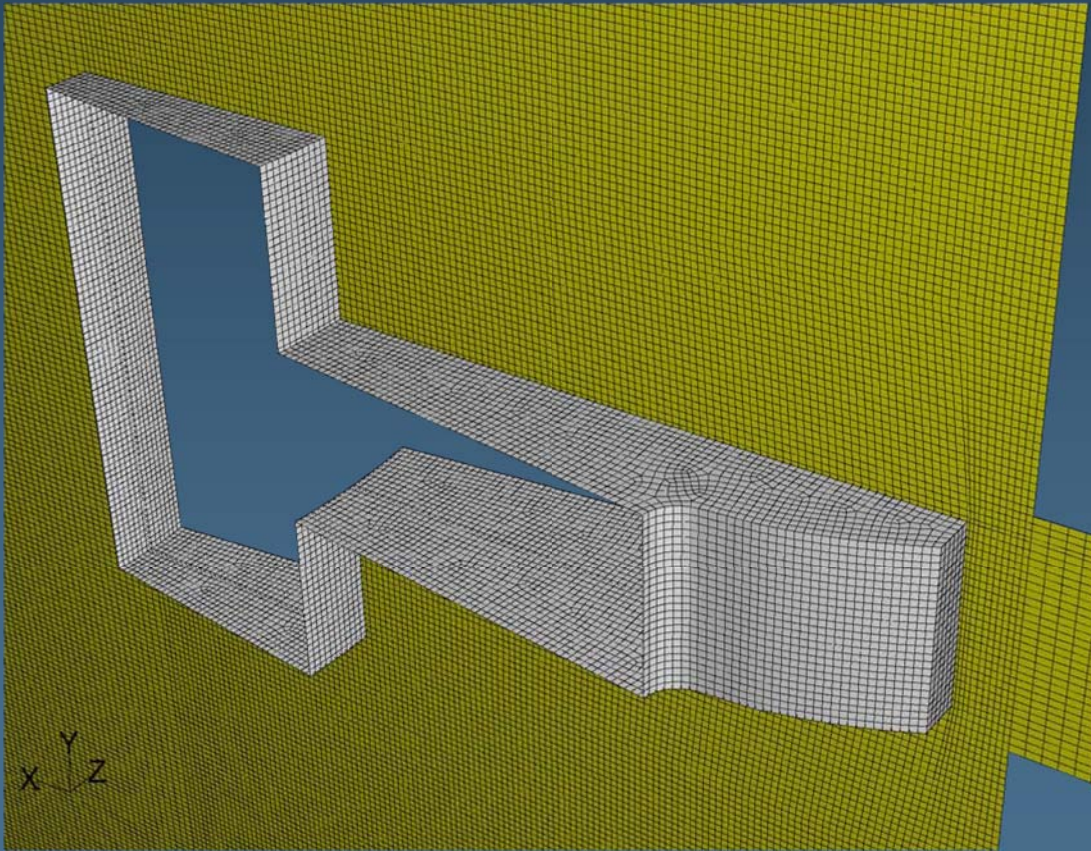
- h^o is the initial local heat transfer coefficient;
- h^f is the final local heat transfer coefficient (when the part is fully cooled);
- T_w^o is the initial temperature of the part;
- T_r is the reference fluid temperature (inlet fluid temperature);
- T_o is the initial near surface characterization temperature; and
- T_w is the current wall temperature.

2D Analyses - Correlation Method

Is it possible to approximate the transient heat flux from steady state simulations?



3D Analyses - Computational Grid

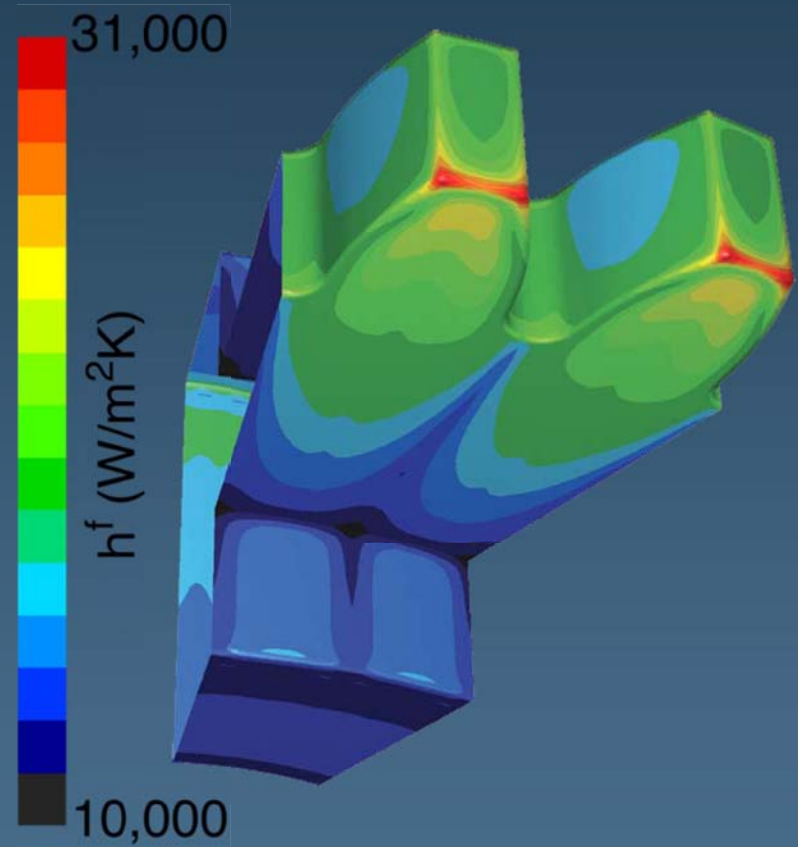
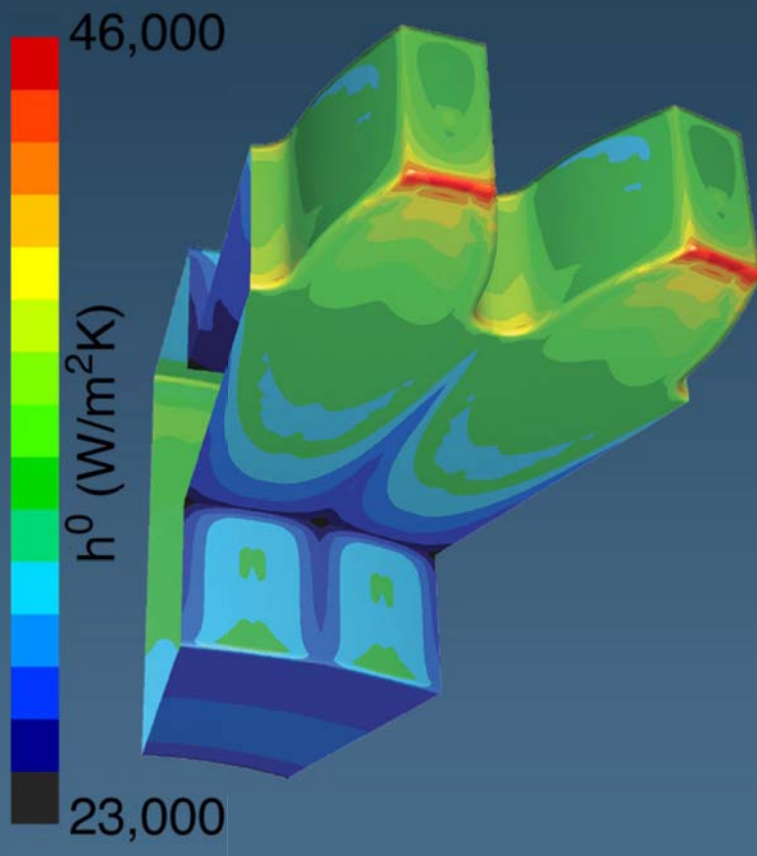


1,721,070
computational
cells (fluid only)

Gear surface
temperature held
constant

Hot surface and
ambient surface
simulations made

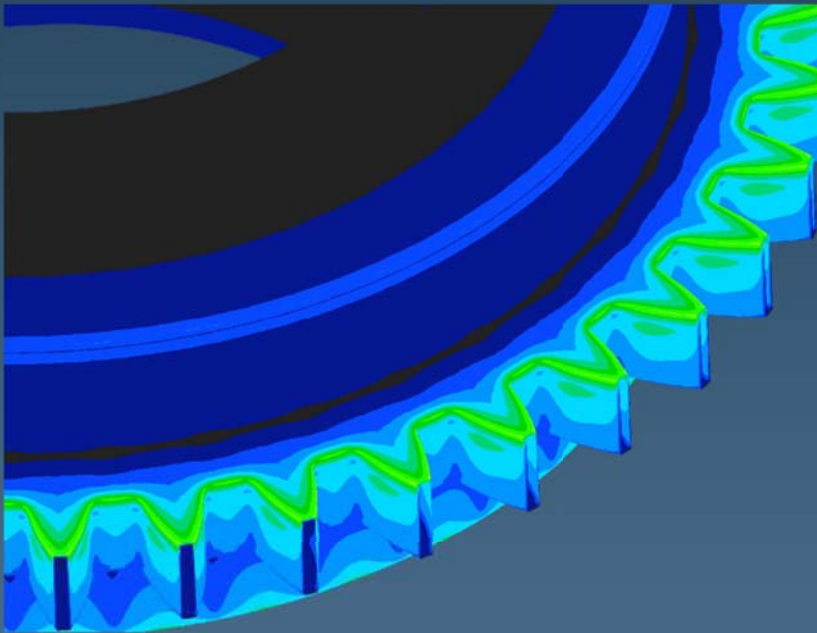
3D Analyses - Results



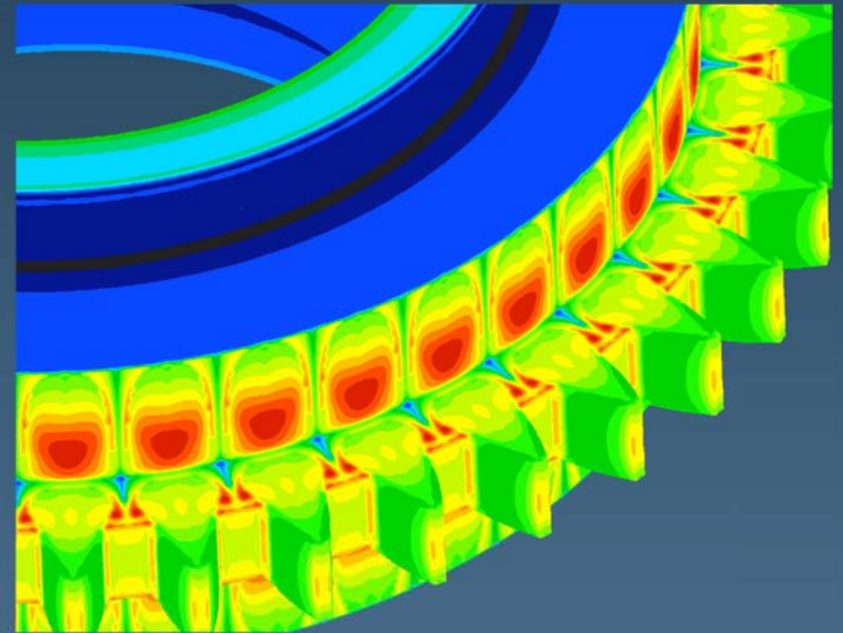
Local heat transfer coefficients displayed
(related to film temperature, not inlet fluid temperature)

CFD As Design Tool

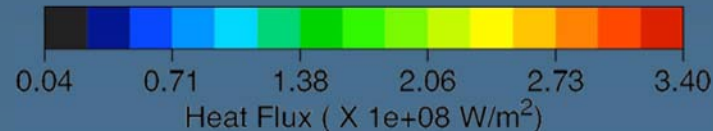
Design of quench fixture improved through CFD iterations



Axial Flow Fixture



Radial Flow Fixture



Interface with DANTE

Computational grids for CFD and DANTE do not necessarily match

Data exported for each gear surface node in the CFD model, including position, and three governing parameters

Data are interpolated by DANTE boundary condition routine

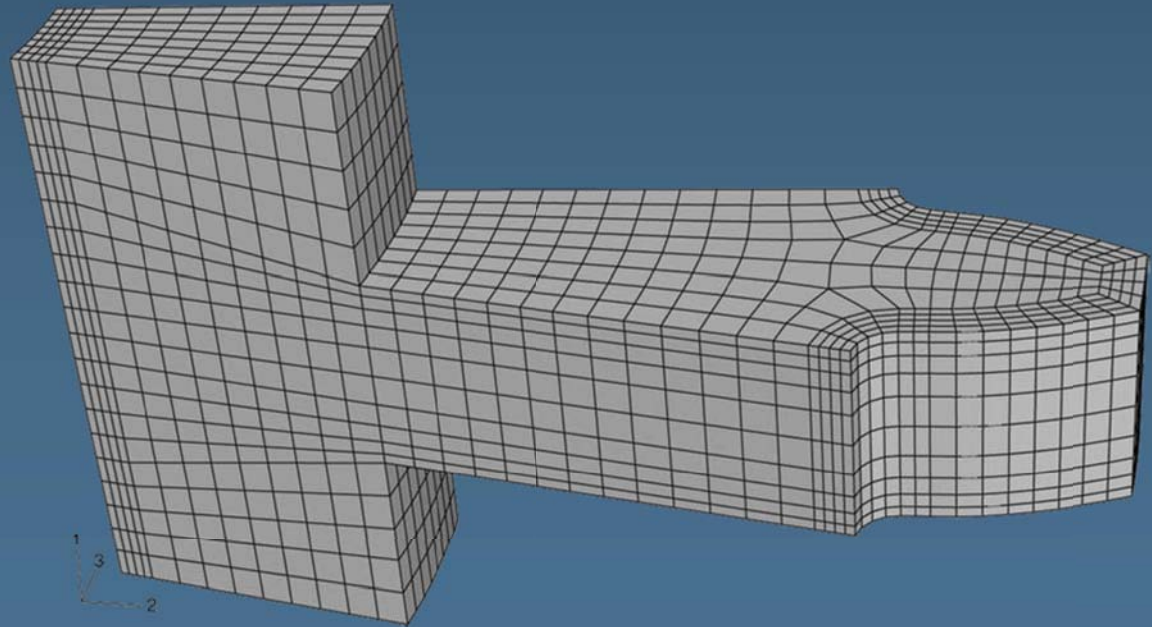
At each time step, the current local wall temperature is used to compute the wall heat flux

$$q = \left\{ h^o \frac{T_w - T_r}{T_w^o - T_r} + h^f \frac{T_w^o - T_w}{T_w^o - T_r} \right\} \left[T_w \left\{ T^o \frac{T_w - T_r}{T_w^o - T_r} + T_r \frac{T_w^o - T_w}{T_w^o - T_r} \right\} \right]$$

DANTE Finite Element Meshing

3D single gear tooth model

- Material: Pyro53
- Fine surface elements are used to more accurately catch the thermal and carbon gradients in the surface
- Cyclic boundary condition is applied



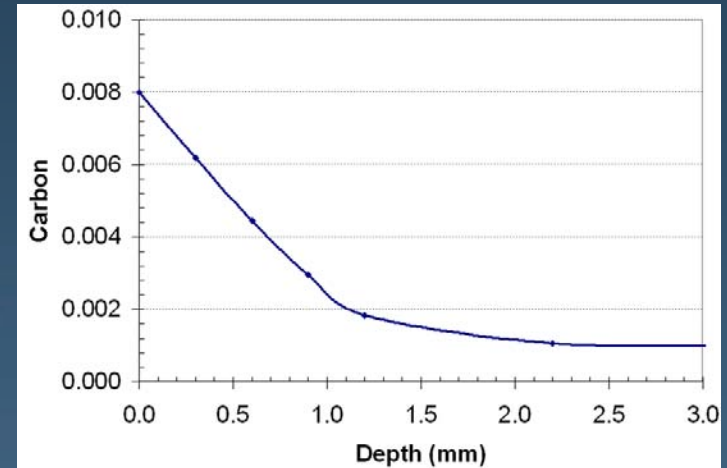
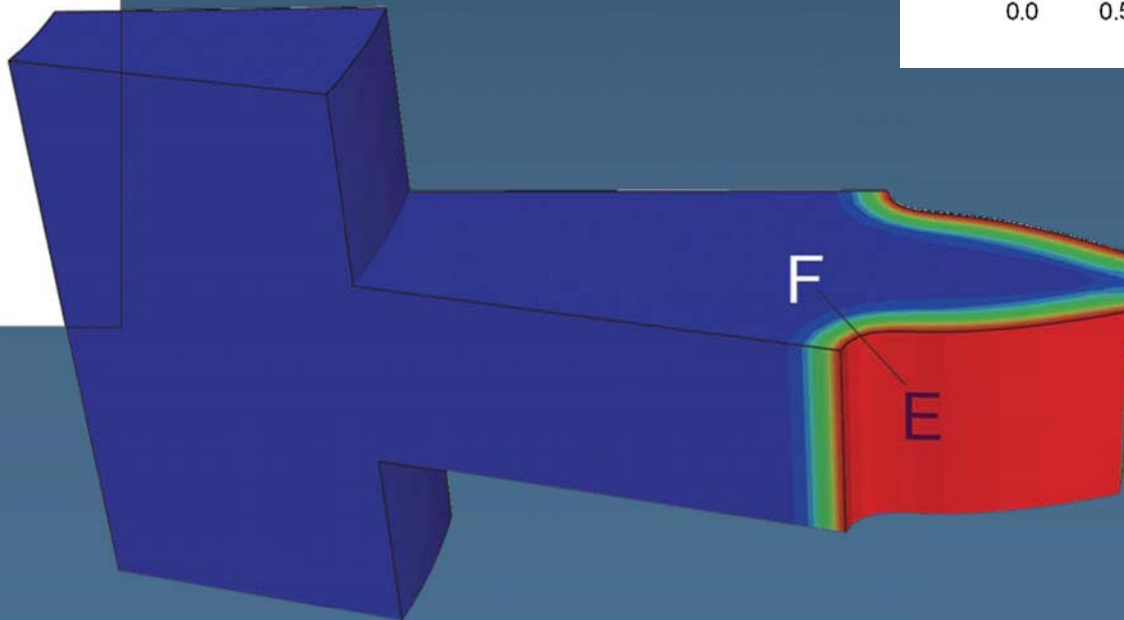
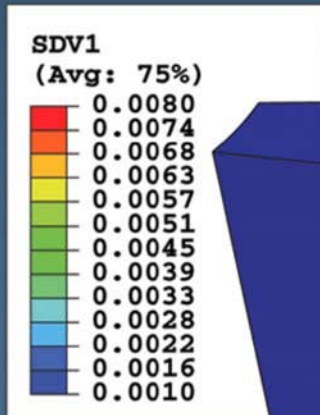
5959 nodes

4820 elements

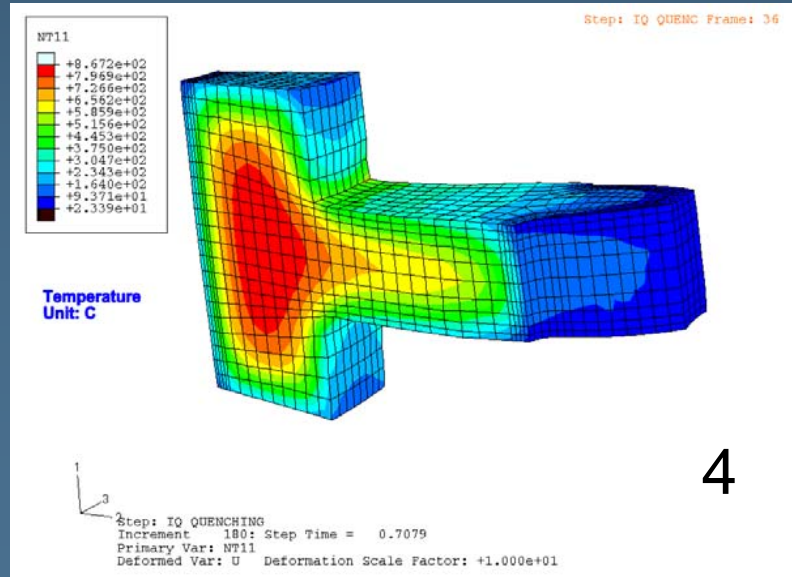
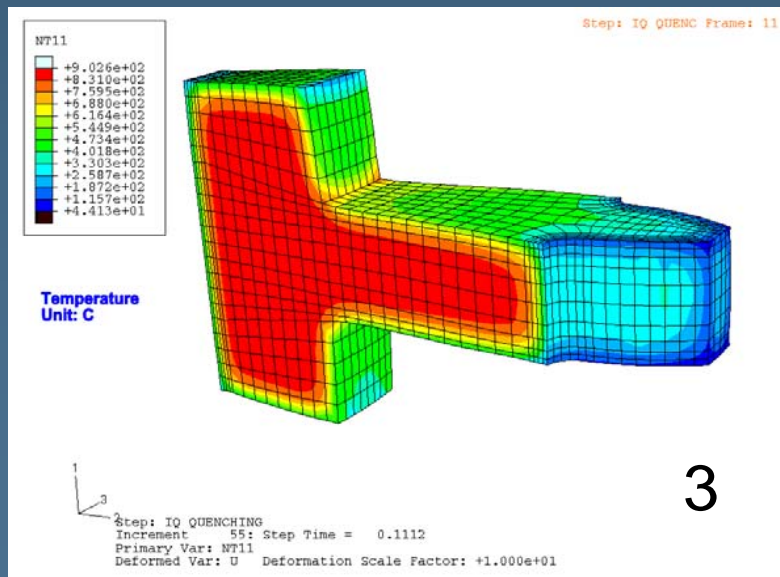
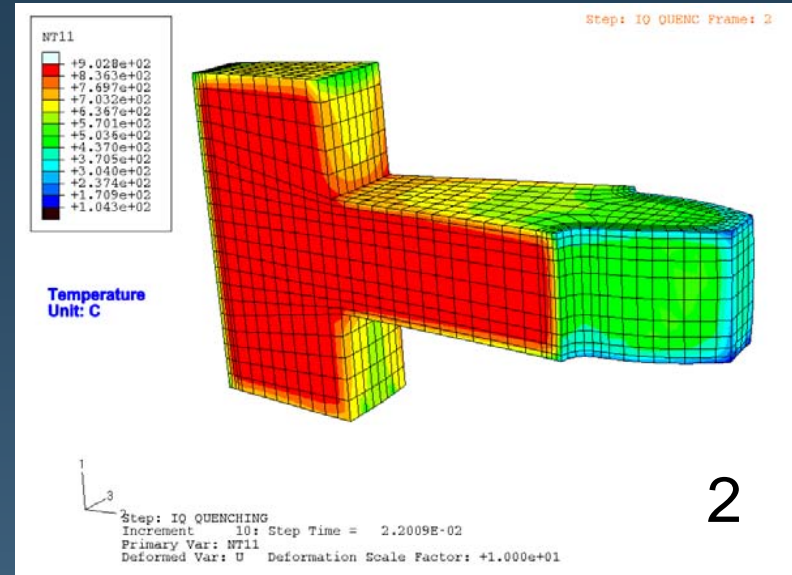
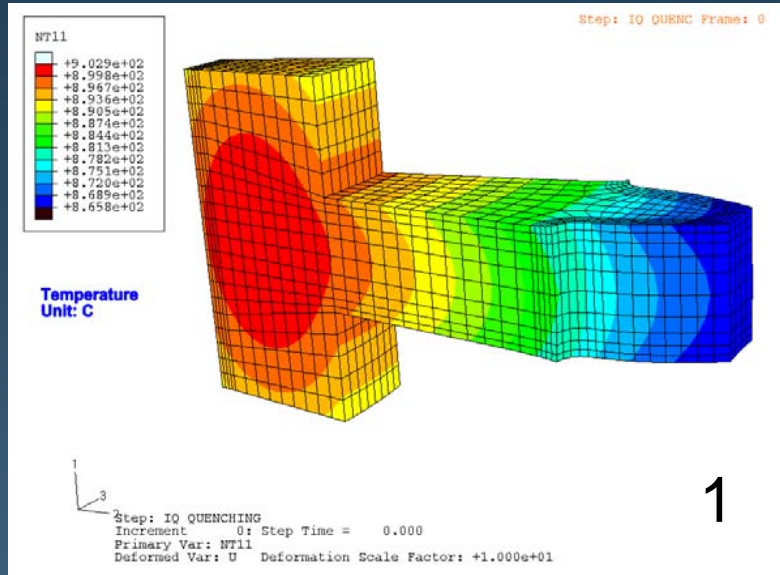
Carbon Distribution

Carburization Schedule:

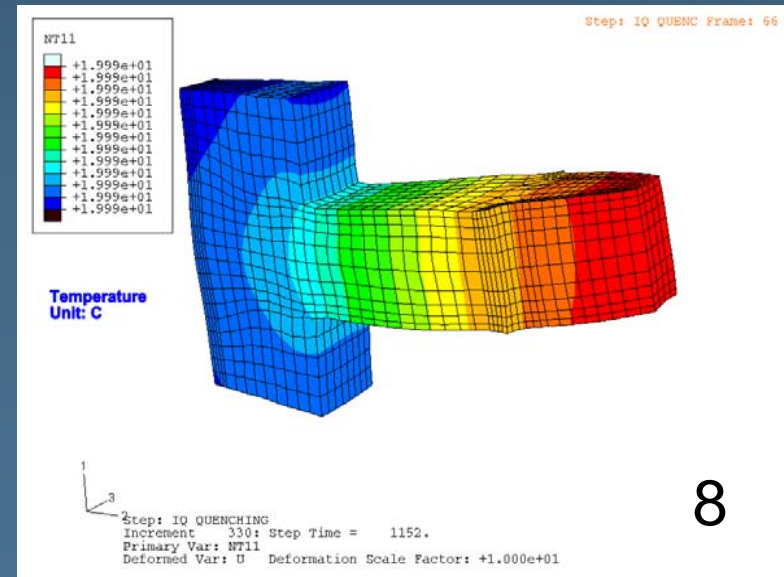
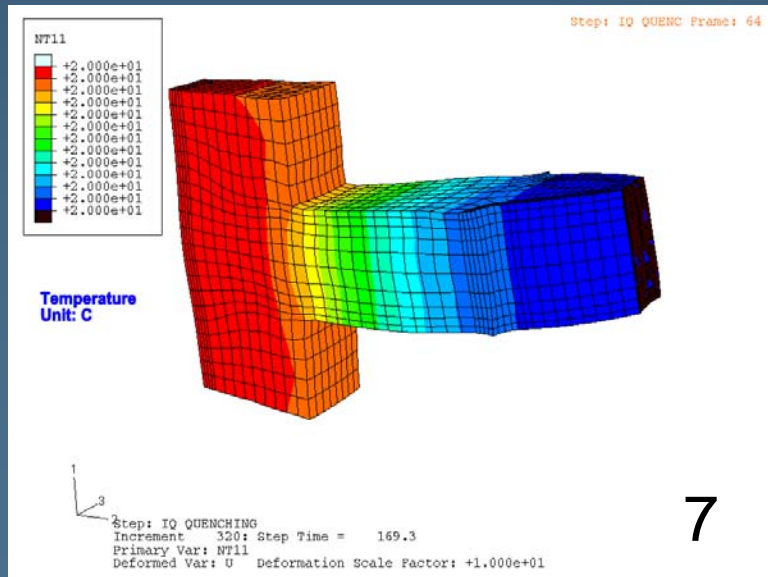
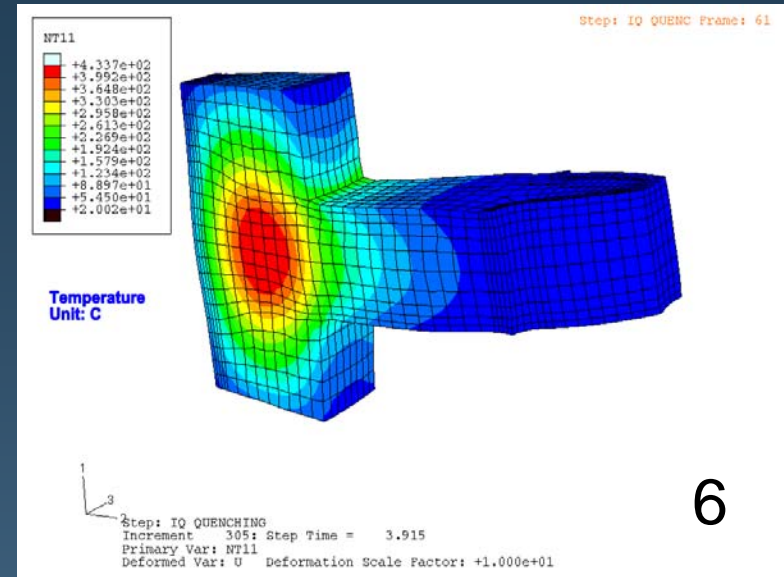
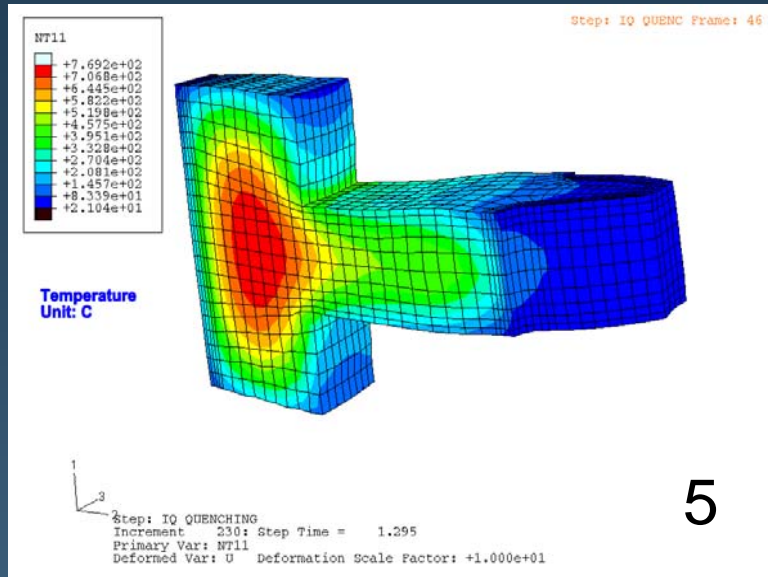
- Carburization temperature is 926.7° C,
- Carbon potential is 0.8%,
- Carburization time period is 8 hours.
- Only the gear tooth surface is carburized.



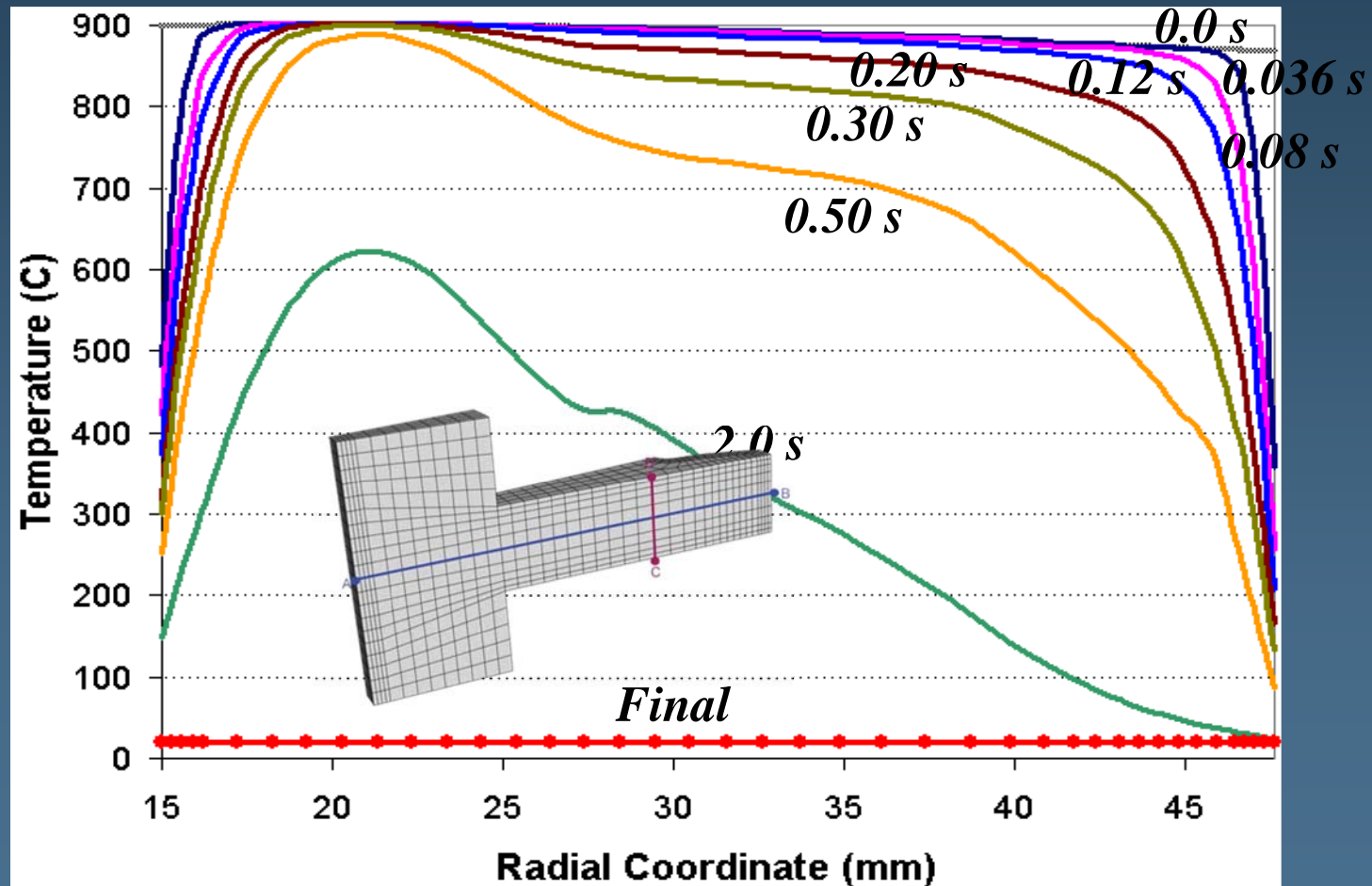
Temperature During Quenching



Temperature During Quenching (cont.)

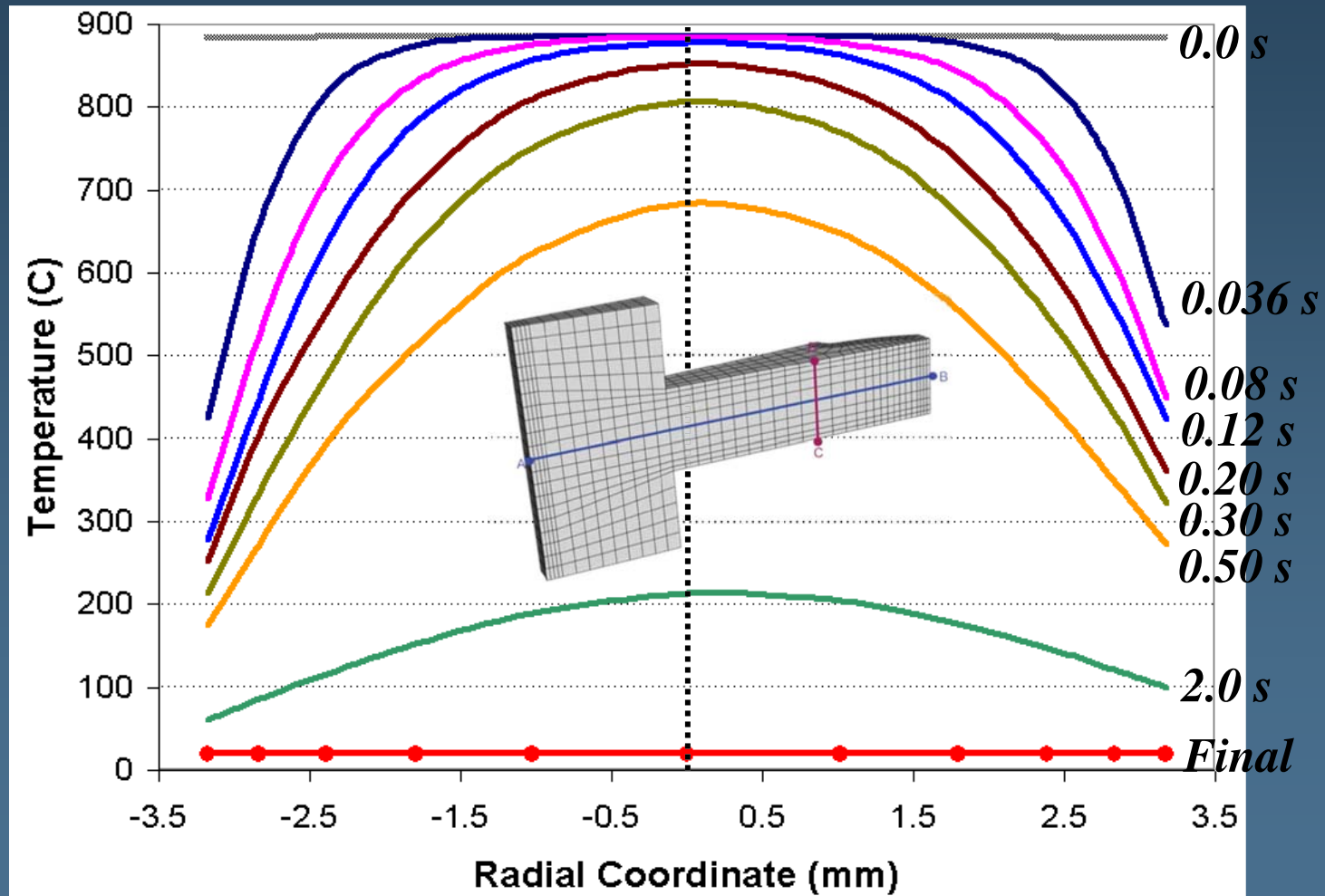


Along the Radial Line

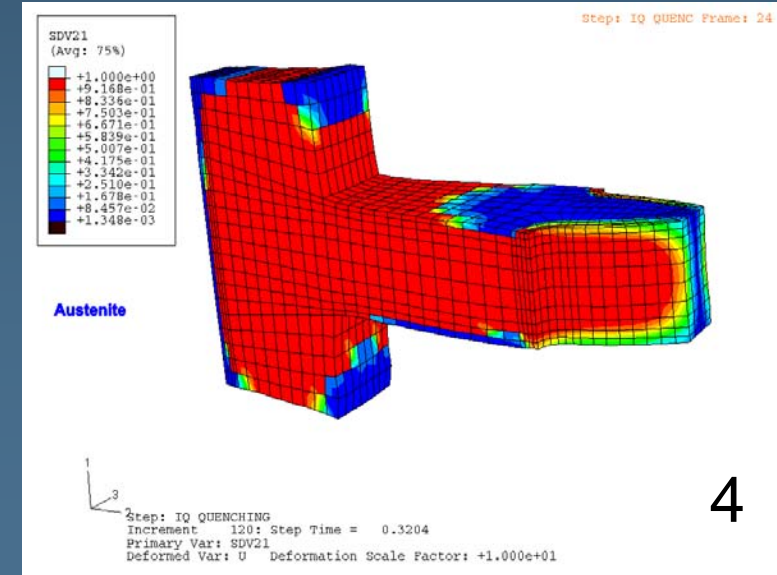
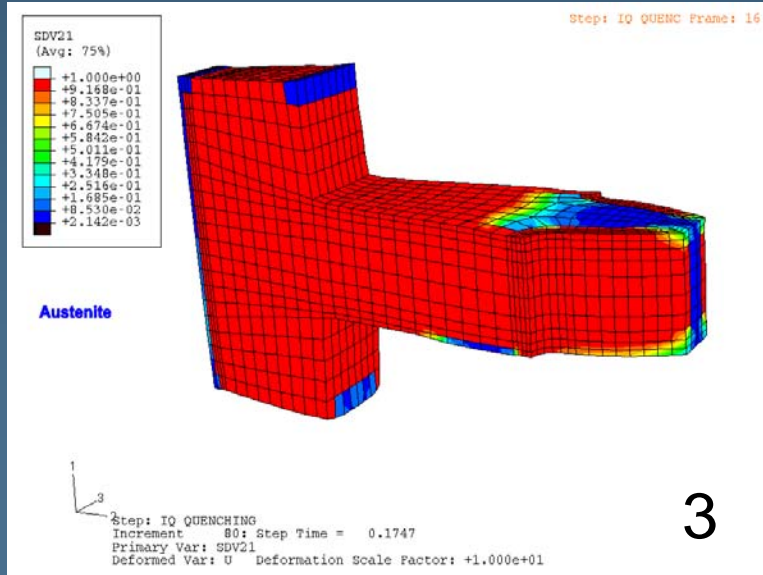
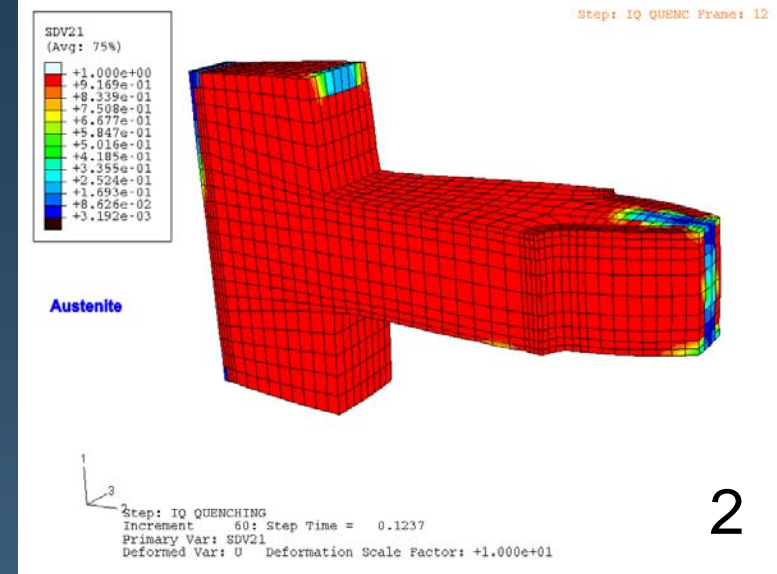
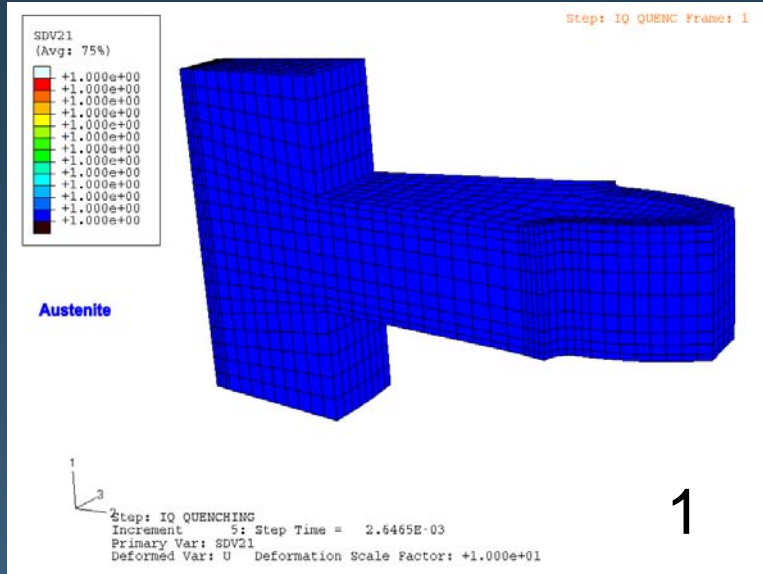


Temperature History During Quenching

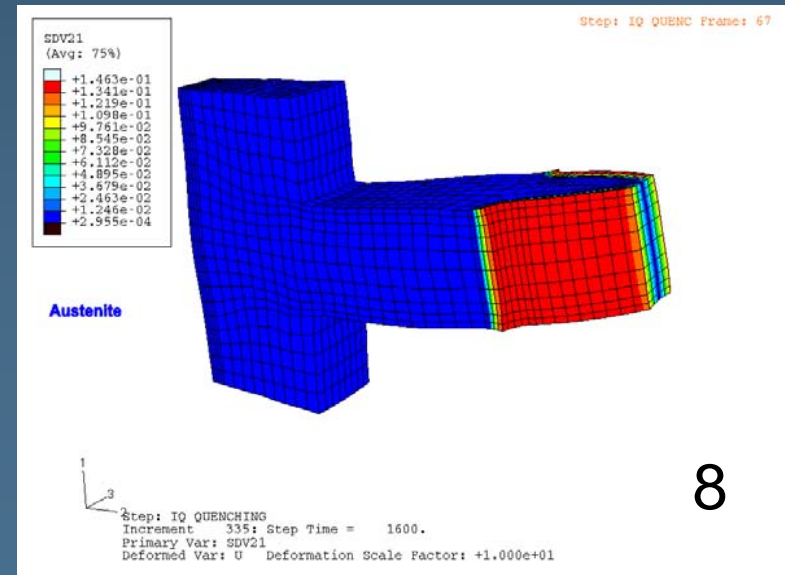
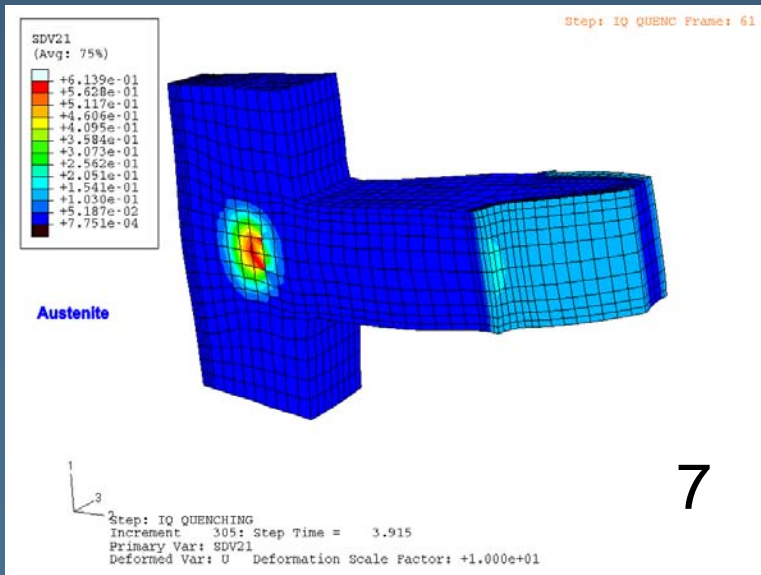
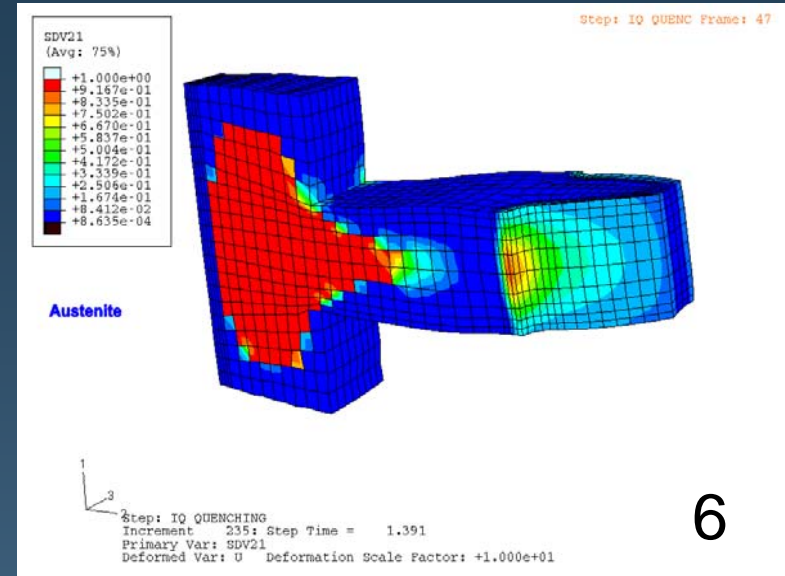
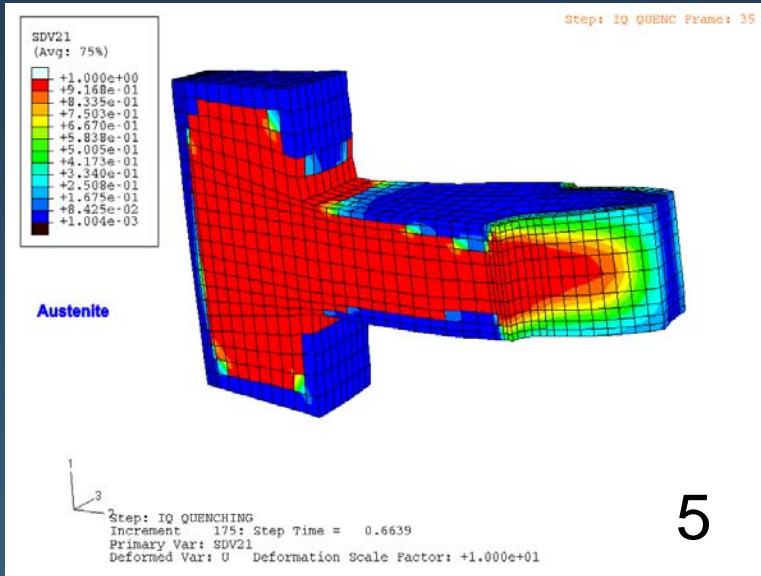
Along the Vertical Line



Austenite Phase Transformation

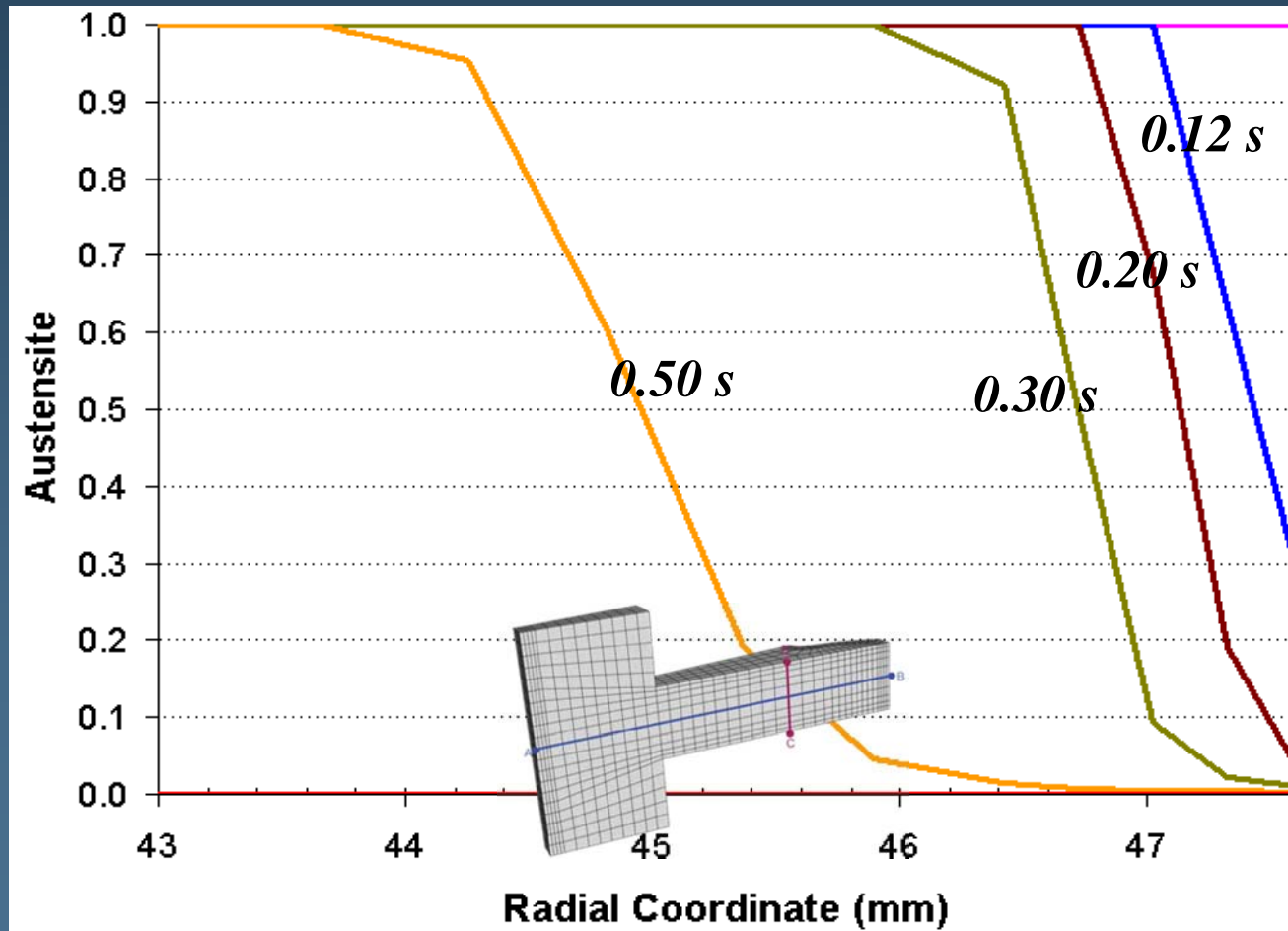


Austenite Phase Transformation (cont.)



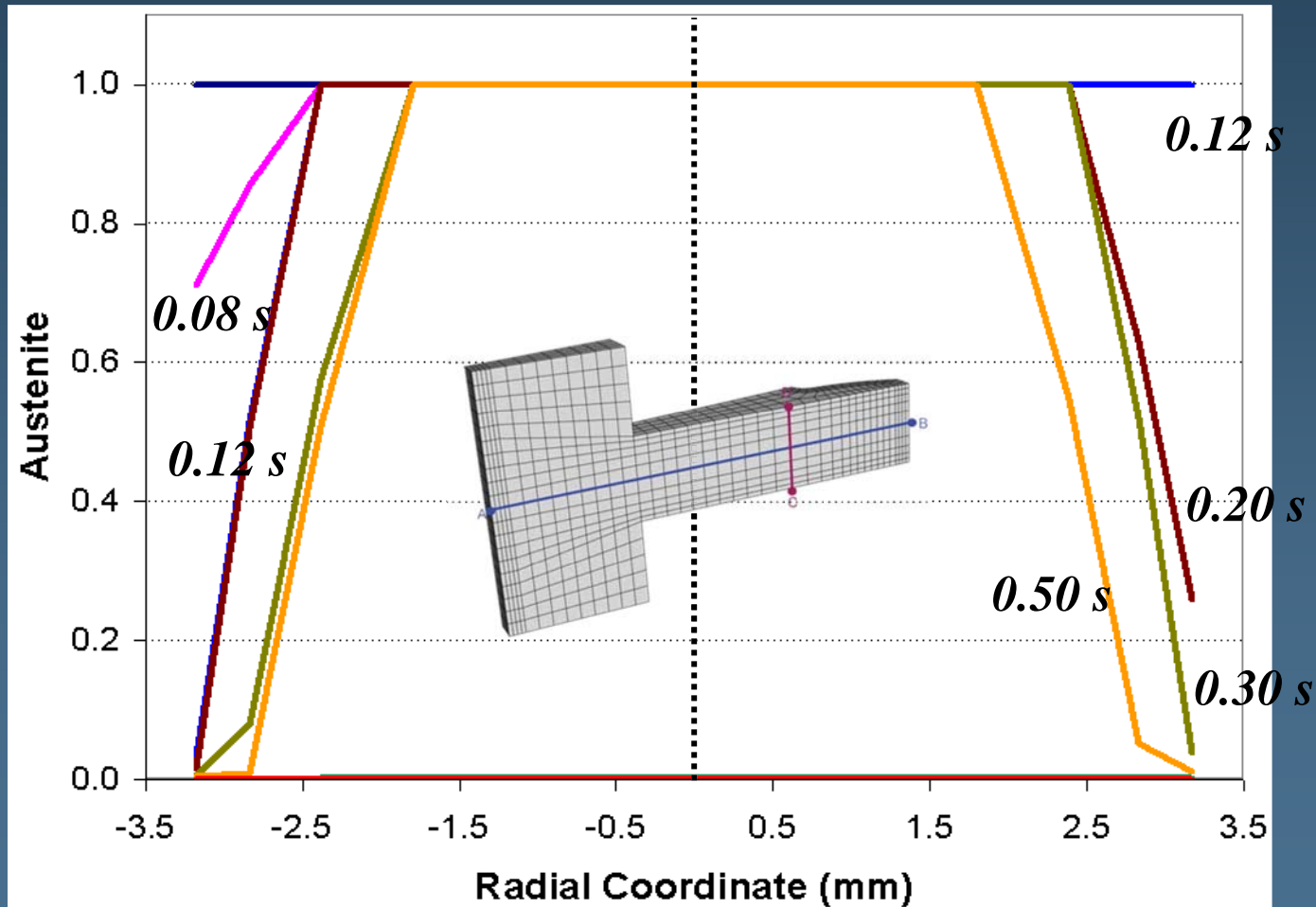
Phase History During Quenching

Along the Radial Line

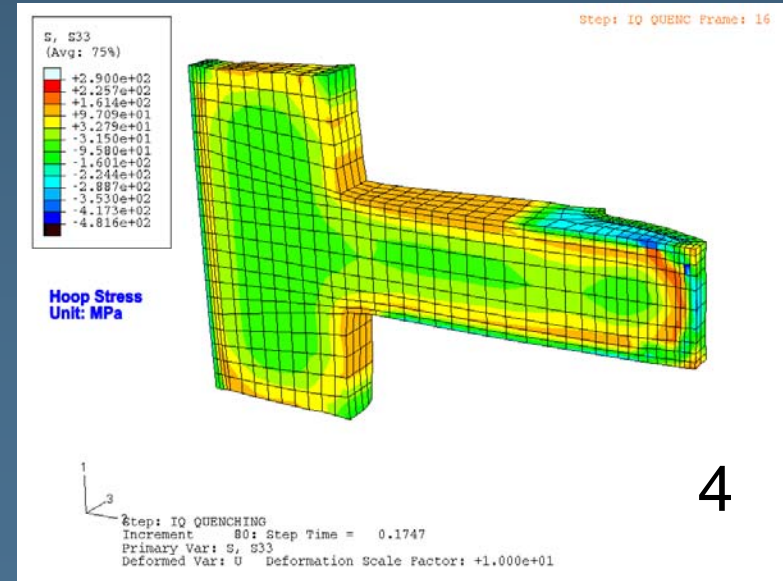
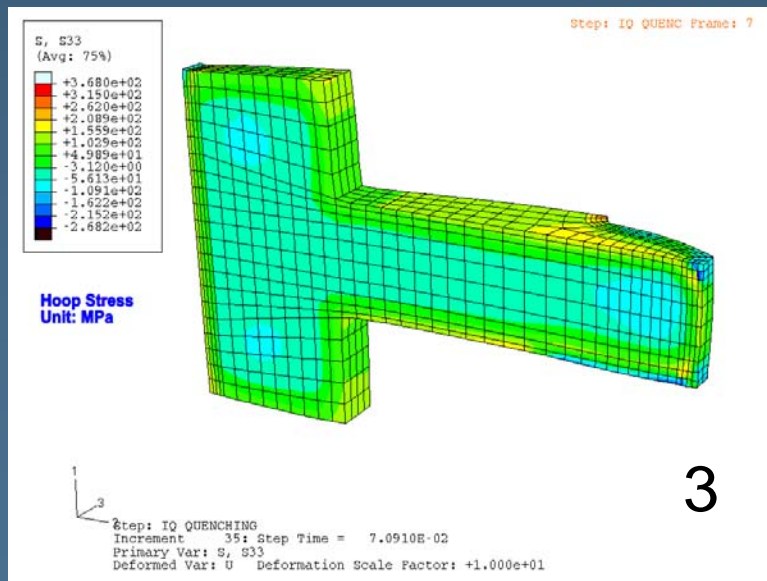
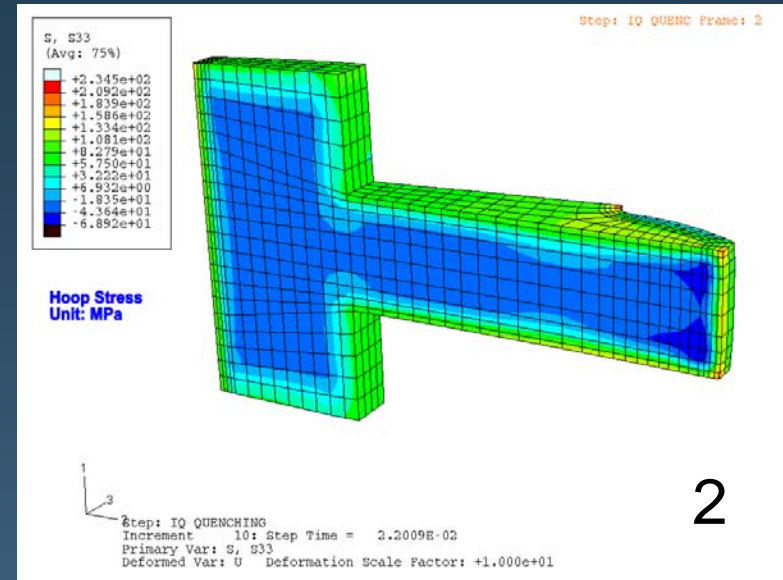
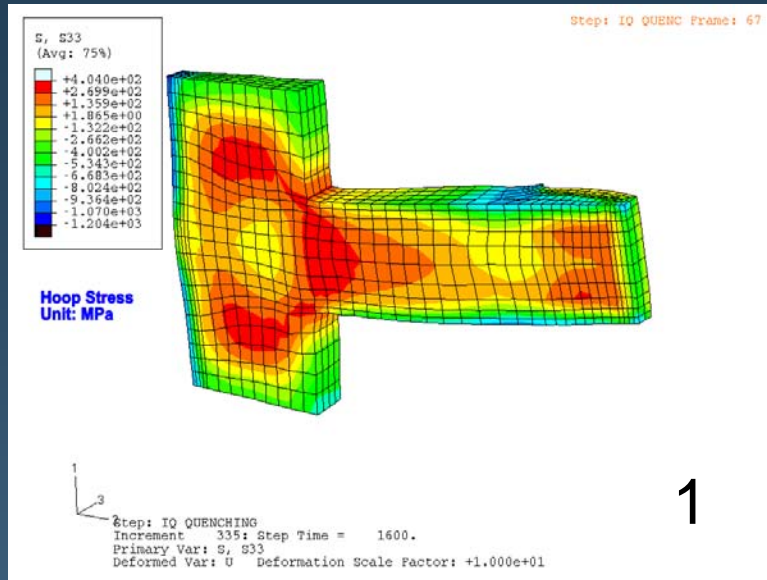


Phase History During Quenching

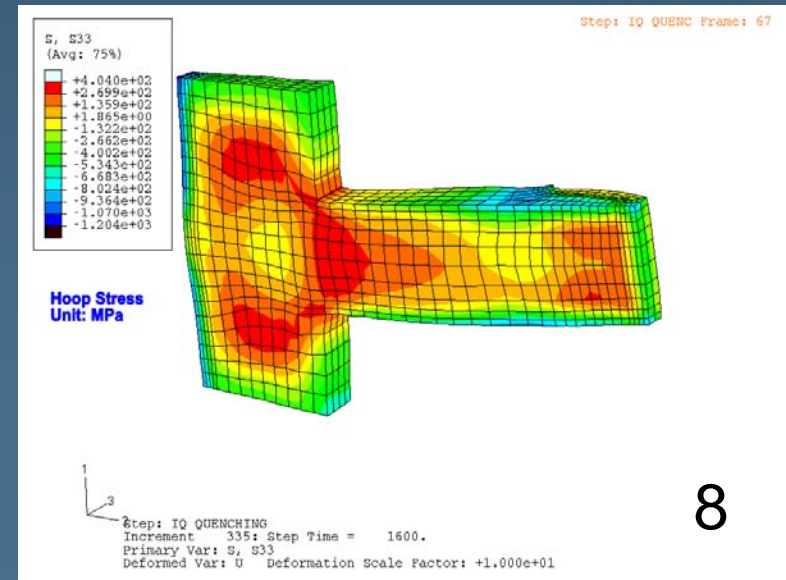
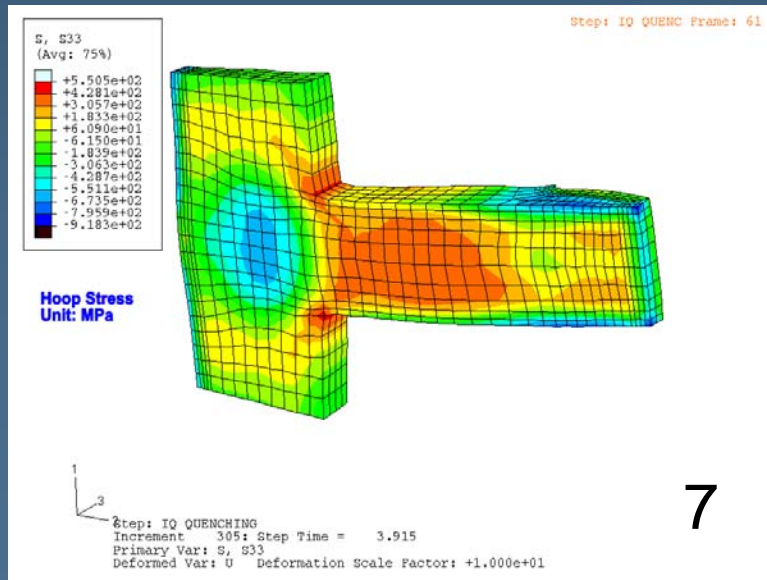
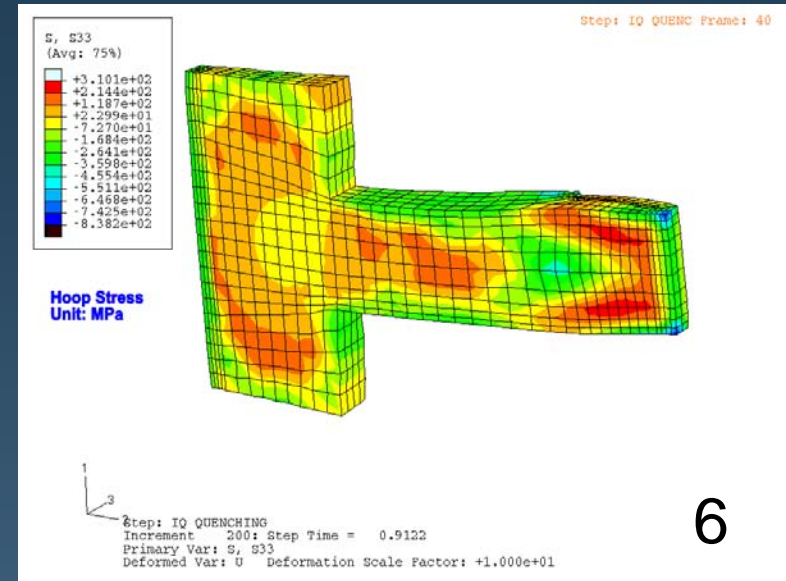
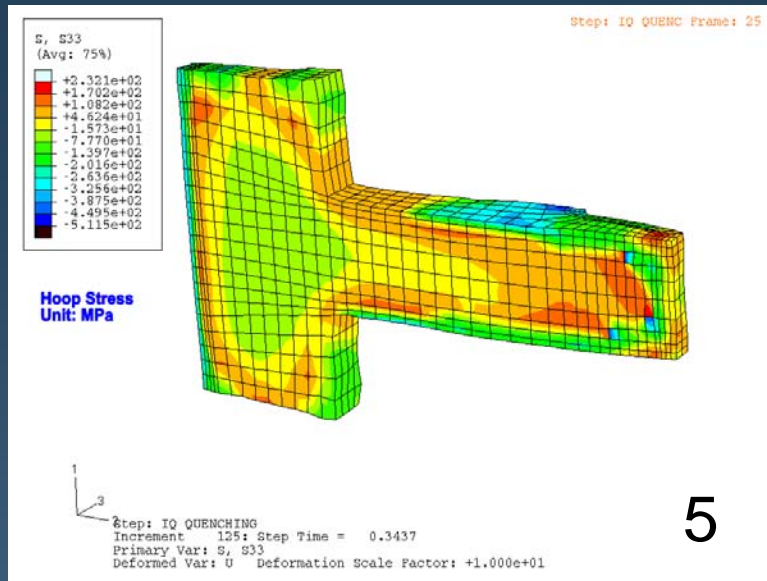
Along the Vertical Line



Hoop Stress Evolution

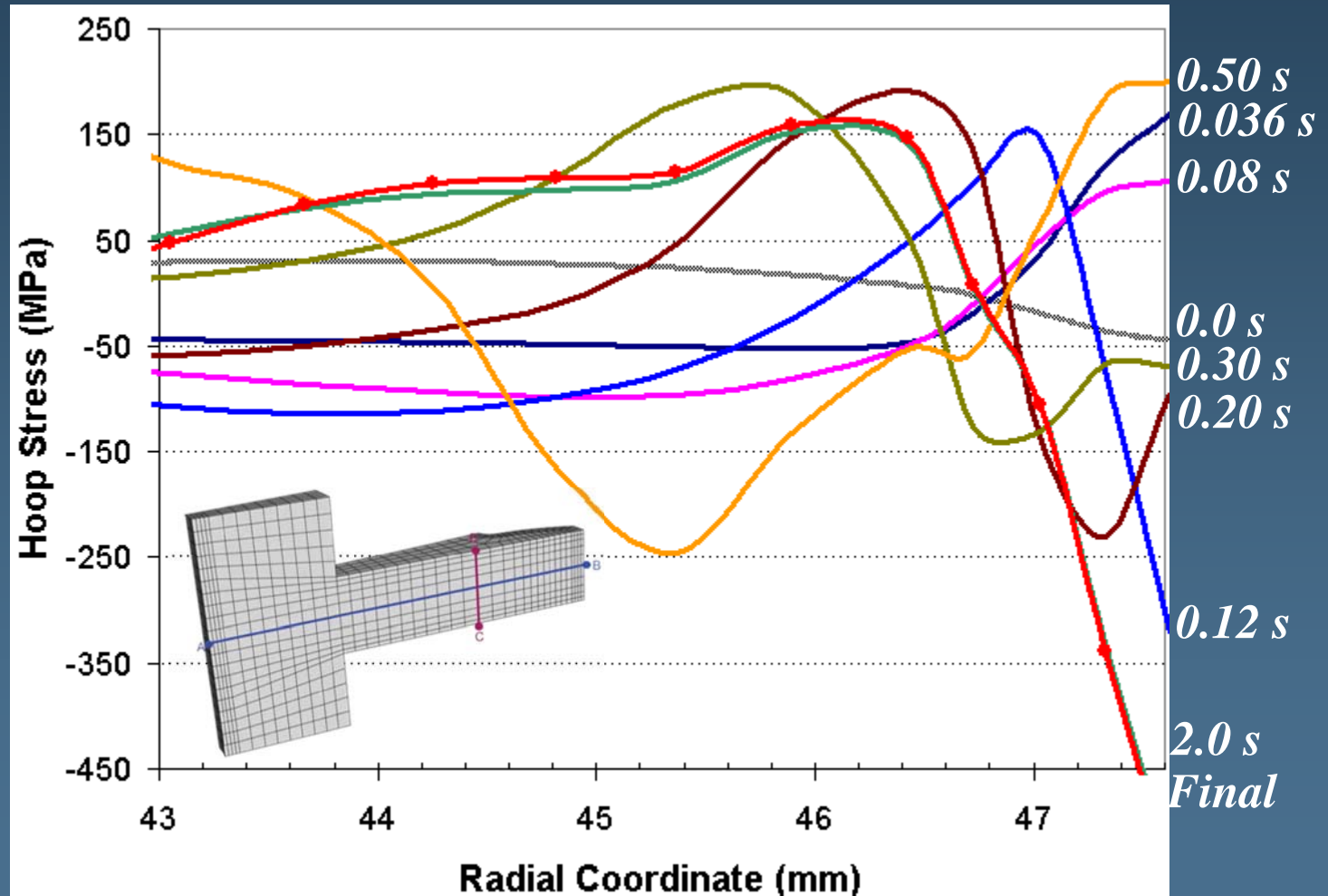


Hoop Stress Evolution (cont.)

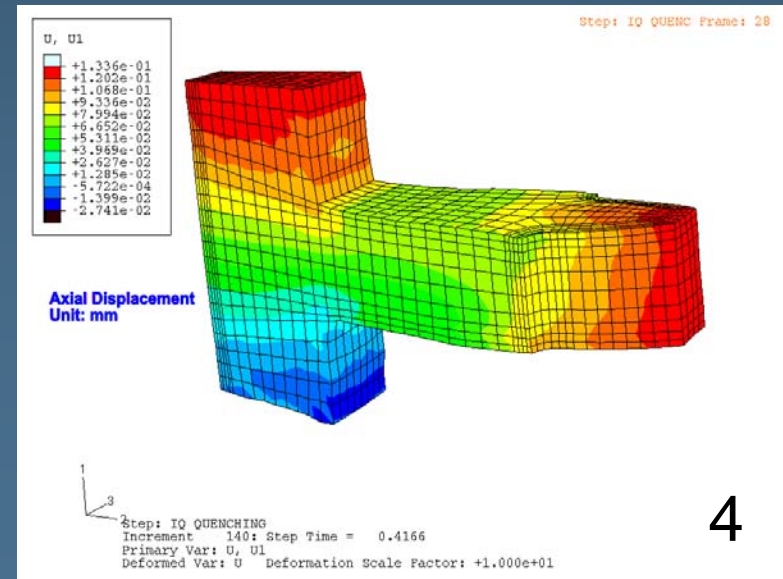
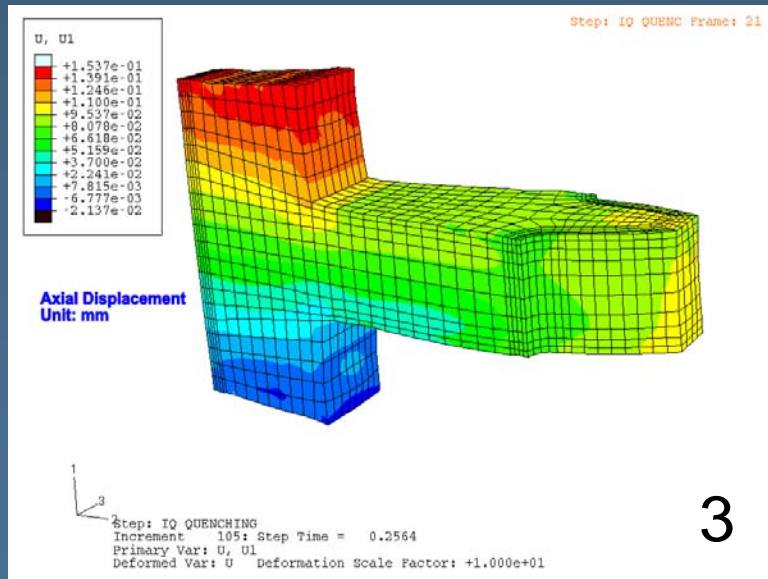
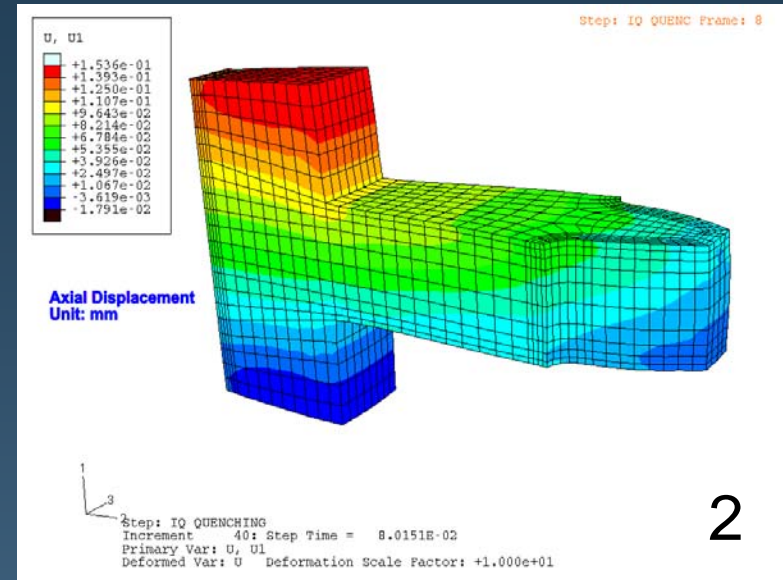
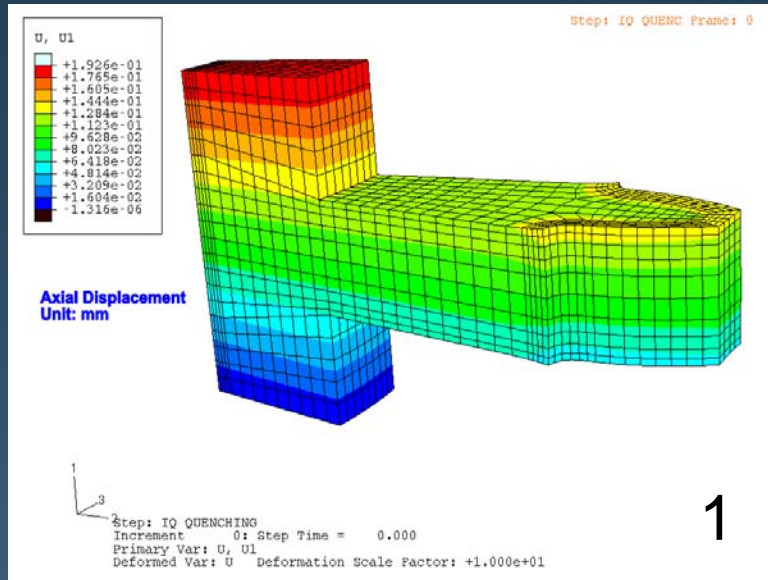


Hoop Stress Evolution During Quenching

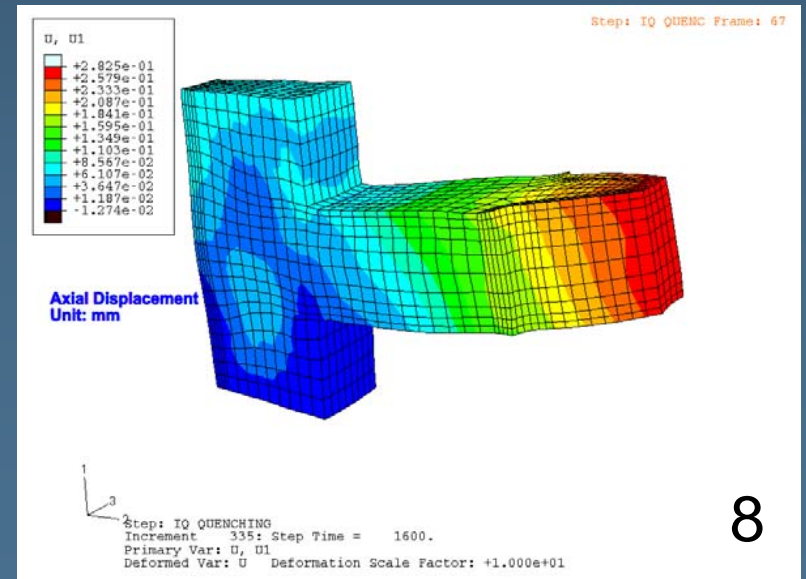
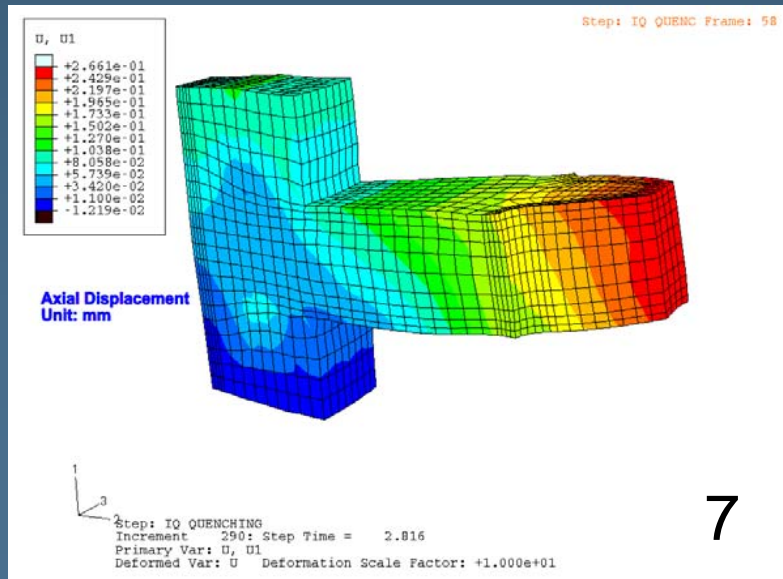
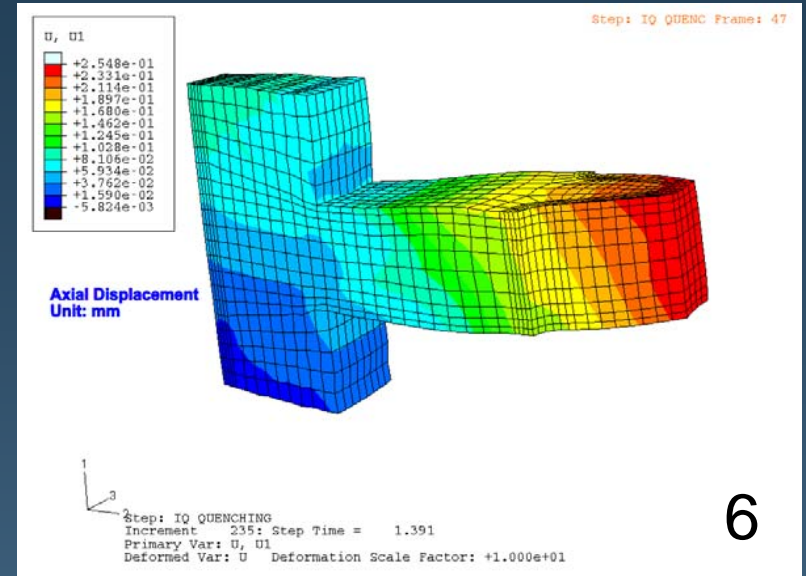
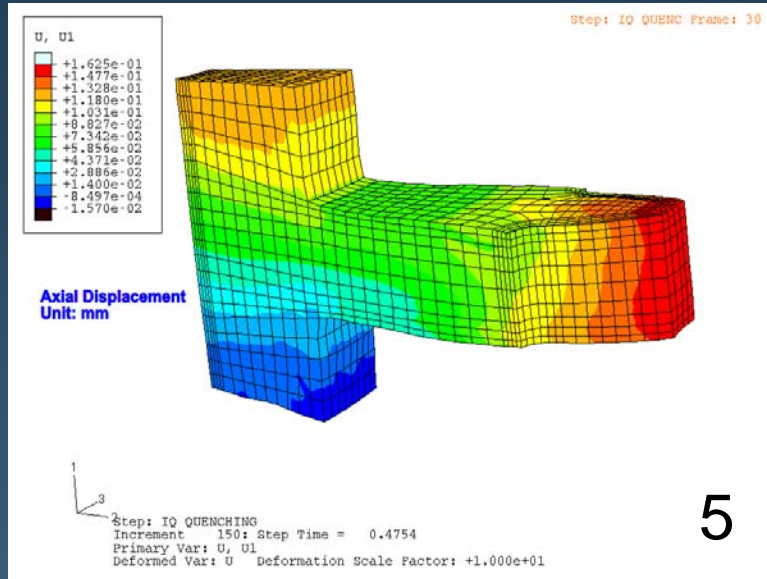
Along the Radial Line



Axial Displacement During Quenching

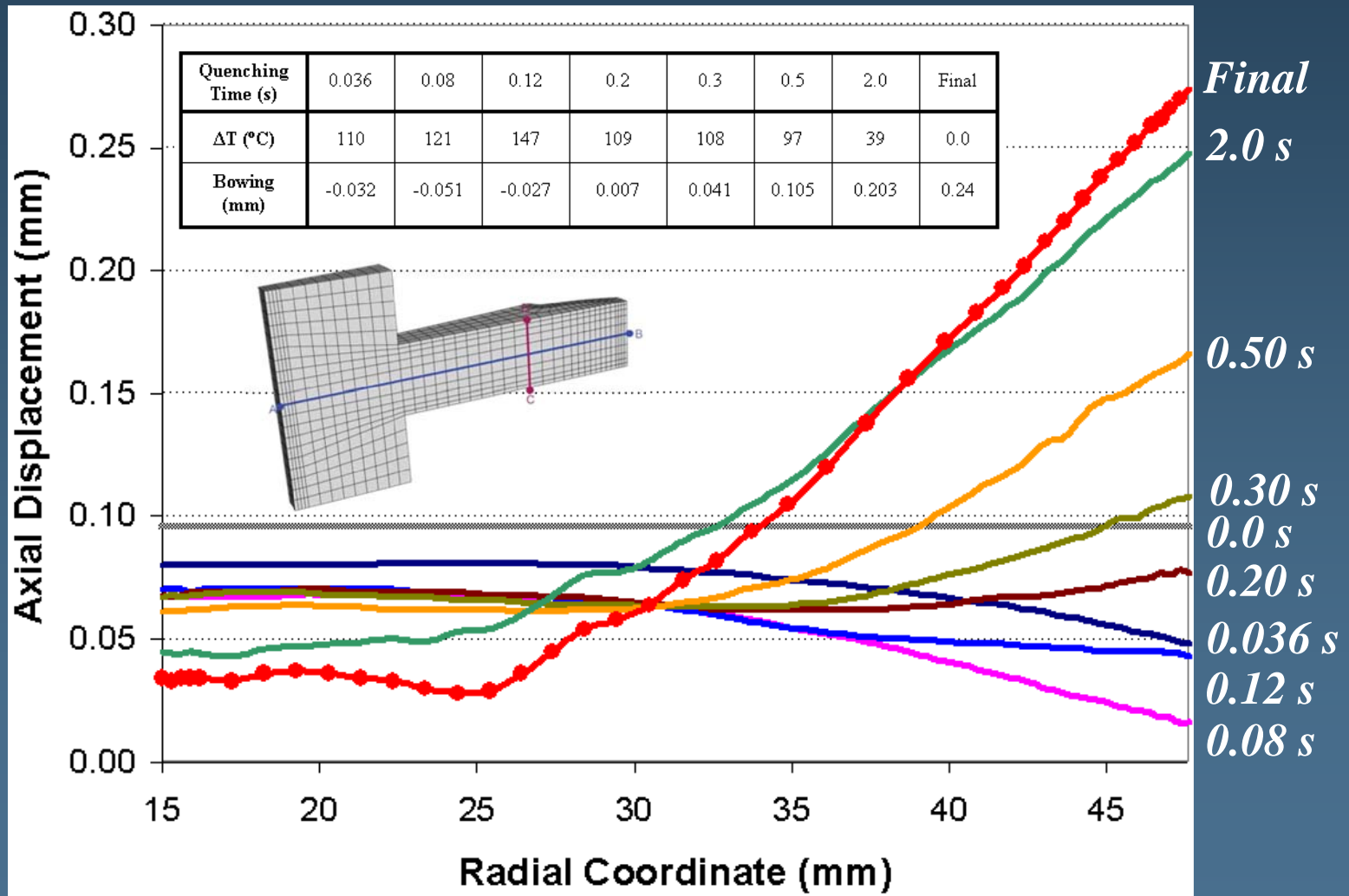


Axial Displacement During Quenching (cont.)



Axial Displacement During Quenching

Along the Radial Line



Summary & Conclusions

A method was developed to closely predict the transient 3D surface heat fluxes from a pair of steady-state CFD analyses.

Those heat fluxes were supplied to a DANTE model for a more complete analysis of the quenching process.

The DANTE results show that inclusion of the CFD predicted heat flux rates has a significant effect on distortion, compared to the assumption of constant heat transfer coefficient.

A combination of CFD and DANTE provides more accuracy of the simulations.

Acknowledgments

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