Modeling the Heat Treatment Response of P/M Components

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Objectives

Develop and verify a computer simulation software and strategy that enables the prediction of the effect of heat treatment on P/M components

Simulation predictions will include:

- Dimensional changes and distortion
- Residual stresses
- Type and quantity of metallurgical phases
- Hardness

Background

Need

- Model provides insight and control of processing conditions to meet
  - Dimensional tolerances .
  - Mechanical properties.

- Model can be used to design a process.
- Model can be used to optimize the process.

Methodology

- Task-1: Assessment of Dante's ability to predict heat treatment response of wrought components.
- Task-2: Adapting Dante to modeling the heat treatment response of fully dense P/M components.
- Task-3: Adapting Dante to modeling the heat treatment response on porous P/M components.
- Task-4: Computer experimentation to characterize the effect of various processing parameters on the heat treatment response of P/M parts.

Task 1- Assessment of Dante's ability to predict heat treatment response of wrought components.

- Subtask 1.1: Computer simulations for wrought 5160 steel
  - 3-D geometrical model and finite element mesh for
    1) Cylinder
    2) Thin plate with a central hole

- Subtask 1.2: Experiments and measurements
  - Verification of the model predictions for
    1) Dimensional changes and distortion
    2) Residual stresses
    3) Type and quantity of metallurgical phases
    4) Hardness

Task 2- Adapting Dante to modeling the heat treatment response of fully dense P/M components.

- Subtask 2.1: Input data generation

  - Transformation kinetics data from Dilatometry.
  - Phase specific mechanical and thermal properties as a function of temperature.
  - Heat transfer coefficient for each process step as function of temperature.

- Subtask 2.2: Computer simulations for 4600 series P/M alloy steel (fully dense)

  - 3-D geometrical model and finite element mesh

- Subtask 2.3: Experiments and measurements

  - Verification of the model predictions for

    1) Dimensional changes and distortion
    2) Residual stresses
    3) Type and quantity of metallurgical phases
    4) Hardness

Task 3- Adapting Dante to modeling the heat treatment response of porous P/M components.

- Subtask 3.1: Input data generation

  - Transformation kinetics data from Dilatometry.
  - Phase specific mechanical and thermal properties as function of temperature and porosity.
  - Heat transfer coefficient for each process step as function of temperature and porosity.

- Subtask 3.2: Computer simulations for 4600 series P/M alloy steel

  - 3-D geometrical model and finite element mesh

- Subtask 3.3: Experiments and measurements

  - Verification of the model predictions for

    1) Dimensional changes and distortion
    2) Residual stresses
    3) Type and quantity of metallurgical phases
    4) Hardness

Task 4- Computer experiments to characterize the effect of processing parameters on the heat treatment response of P/M parts.

- Subtask 4.1: Computer experiments

  - Process parameters

    1) Green density – a) Low density, b) full density, and c) Non-uniform density
    2) Heating methods - a) Conventional heating , b) Induction heating
    3) Quenching method - one, which is most commonly used.

- Subtask 4.2: Experiments and measurements

  - Verification of the model predictions for non-uniform density and conventional heating method to compare

    1) Dimensional changes and distortion
    2) Residual stresses
    3) Type and quantity of metallurgical phases
    4) Hardness

Deliverables

- A verified software tool and strategy for predicting the heat treatment response of P/M components.

  - Software predictions will include

    1) Dimensional change and distortion
    2) Residual stresses
    3) Type and quantity of metallurgical phases
    4) Hardness

- Documentation of the effect of processing conditions

  - The effect of following processing conditions will be studied

    1) Green density – a) Low density, b) full density, and c) Non-uniform density
    2) Heating methods - a) Conventional heating , b) Induction heating
    3) Quenching method - one, which is most commonly used.

Schedule

TASK 1: Assessment of Dante's ability to predict heat treatment response of wrought components. (7/1/2003 to 12/31/2003)

TASK 2: Adapting Dante to modeling the heat treatment response of fully dense P/M component (1/1/2004 to 12/31/2004)

TASK 3: Adapting Dante to modeling the heat treatment response on porous P/M components (1/1/2005 to 12/31/2005)

TASK 4: Computer experimentation to characterize the effect of various processing parameters on the heat treatment response of P/M parts (1/1/2006 to 6/30/2006)

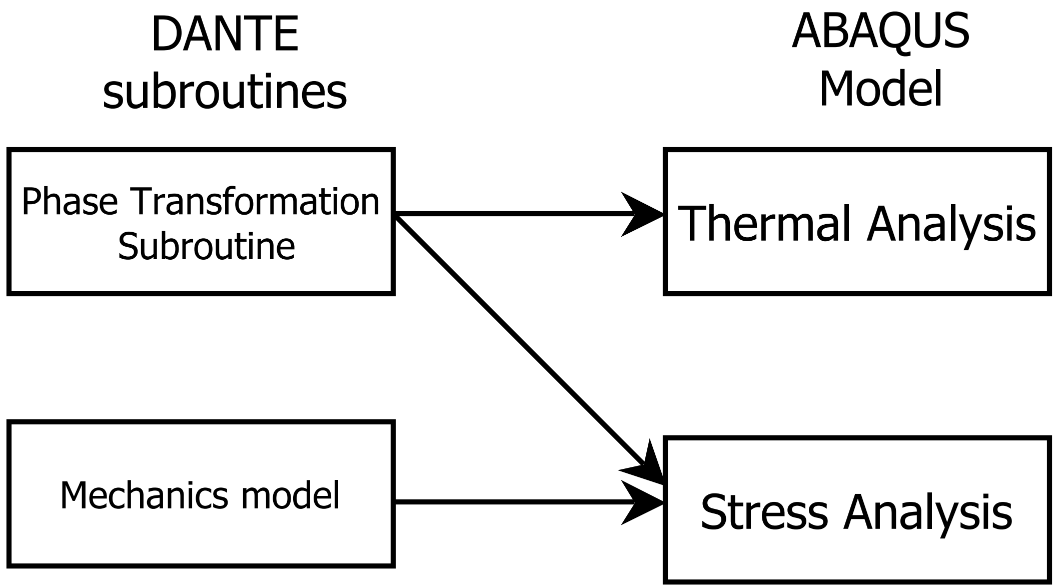
Status

Task 1 – Summary of accomplishments

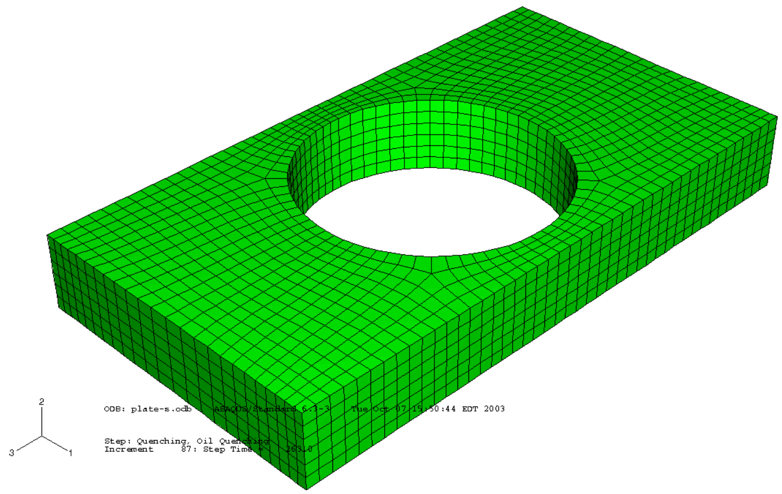
- Task-1.1:
  - DANTE and ABAQUS are installed on WPI computers.
  - DANTE/ABAQUS model is developed for thin rectangular plate made from 5160 steel

- Task-1.2:
  - Samples with same part design as used in model have been prepared from 5160 steel.
  - Samples have been quenched in Houghton-G oil.
  - Hardness has been measured and compared with the model predictions.
  - Dimensional changes has been measure and compared with the model predictions.

Overview of DANTE/ABAQUS model



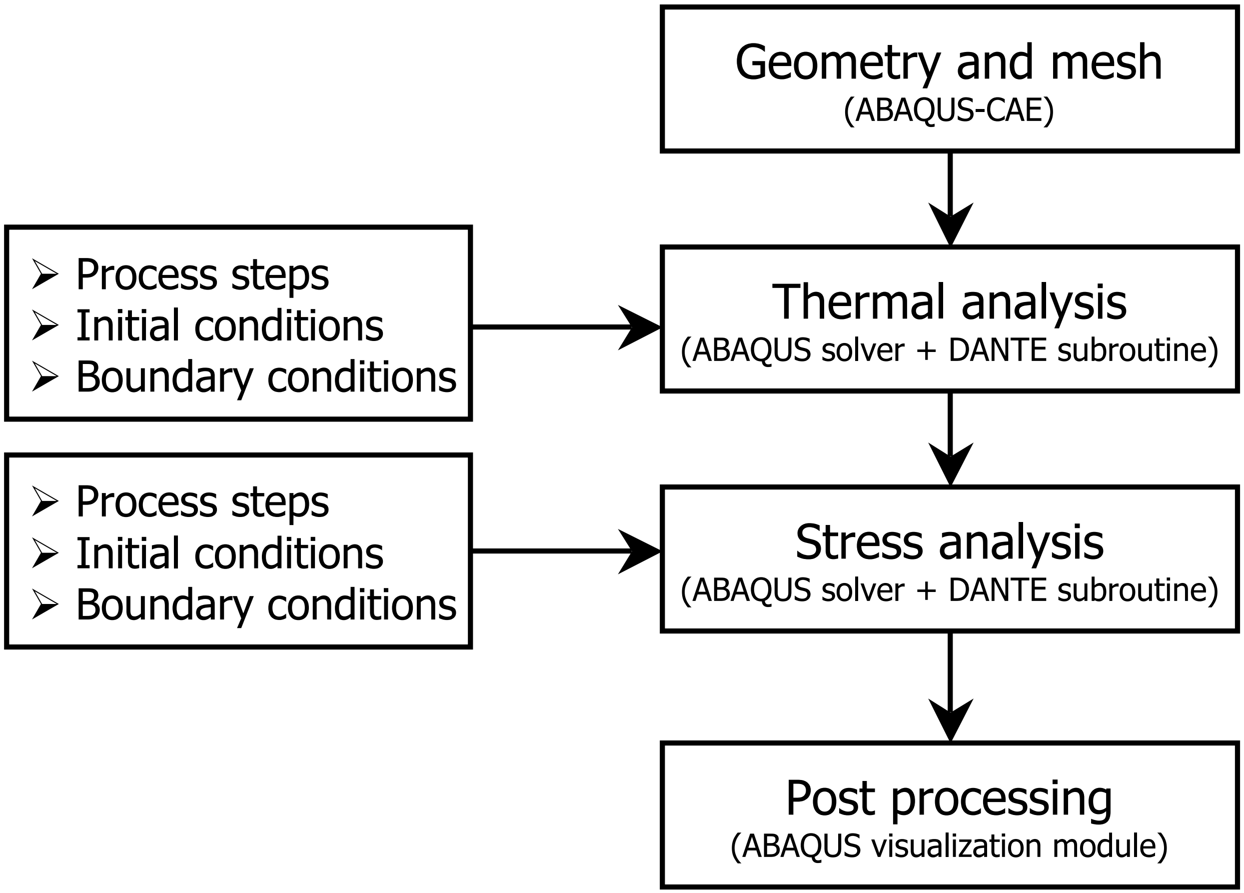
Geometry and dimensions of the part used in the model



- 3-D geometry
  - 5118 hexahedral elements
  - 6685 nodes

Dimension	Magnitude
Length	76.33 mm
Height	9.525 mm
Width	39.624 mm
Diameter of center hole	31.75 mm

Solution procedure



Process steps , and initial conditions used in the model

- Process steps:

  1) Furnace heating up to 850°C
  2) Immersion in quenching tank
  3) Quenching in oil down to room temperature

- Initial conditions:

  - Thermal analysis
    1) nodal carbon content (0.59 wt. % C)
    2) initial temperature (20°C)
    3) heat treatment modes: a) Heating , b) Cooling
  - Stress analysis
    1) initial stress level (set to zero in our case)
    2) heat treatment modes: a) Heating, b) Cooling

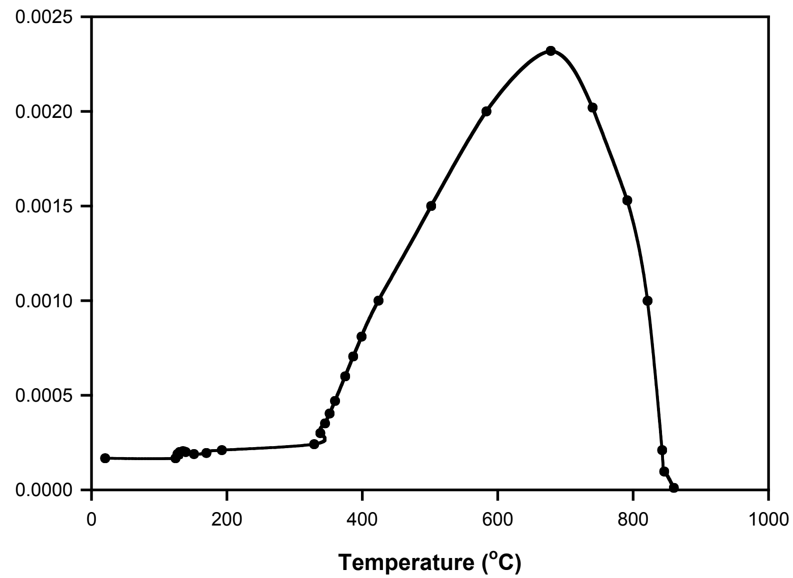
Note: Stress model must be similar to thermal model in its number of process step, process time for each step, and number of elements and nodes.

Boundary conditions

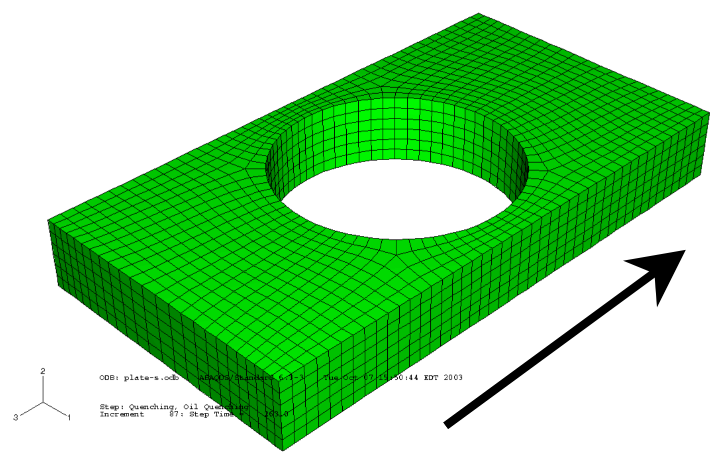
- Thermal analysis:
  1) Furnace heating:
     - Heat transfer coefficient data used from DANTE example problems.

  2) Immersion in quench tank:
     - Immersion velocity = 100 mm/s
     - Immersion direction = along length of the part

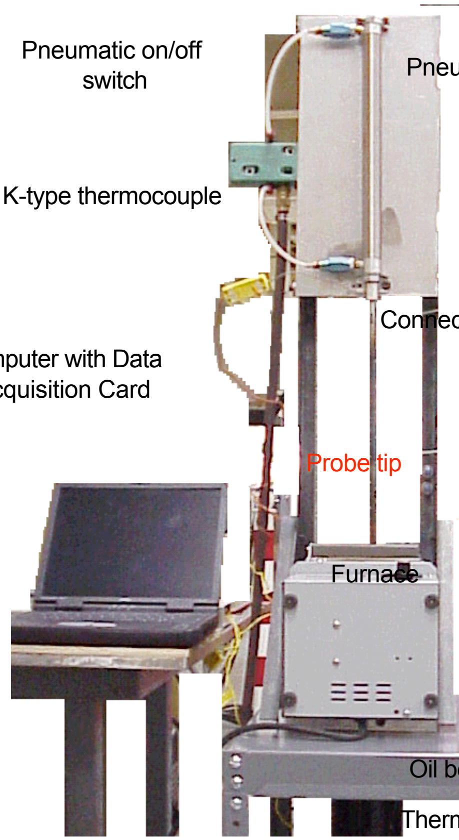
  3) Quenching in oil:
     - Heat transfer coefficient for 4140 steel quenched in Houghton-G oil is used.



- Stress analysis:
  - Nodal constraint to prevent rigid body translation and rotation.

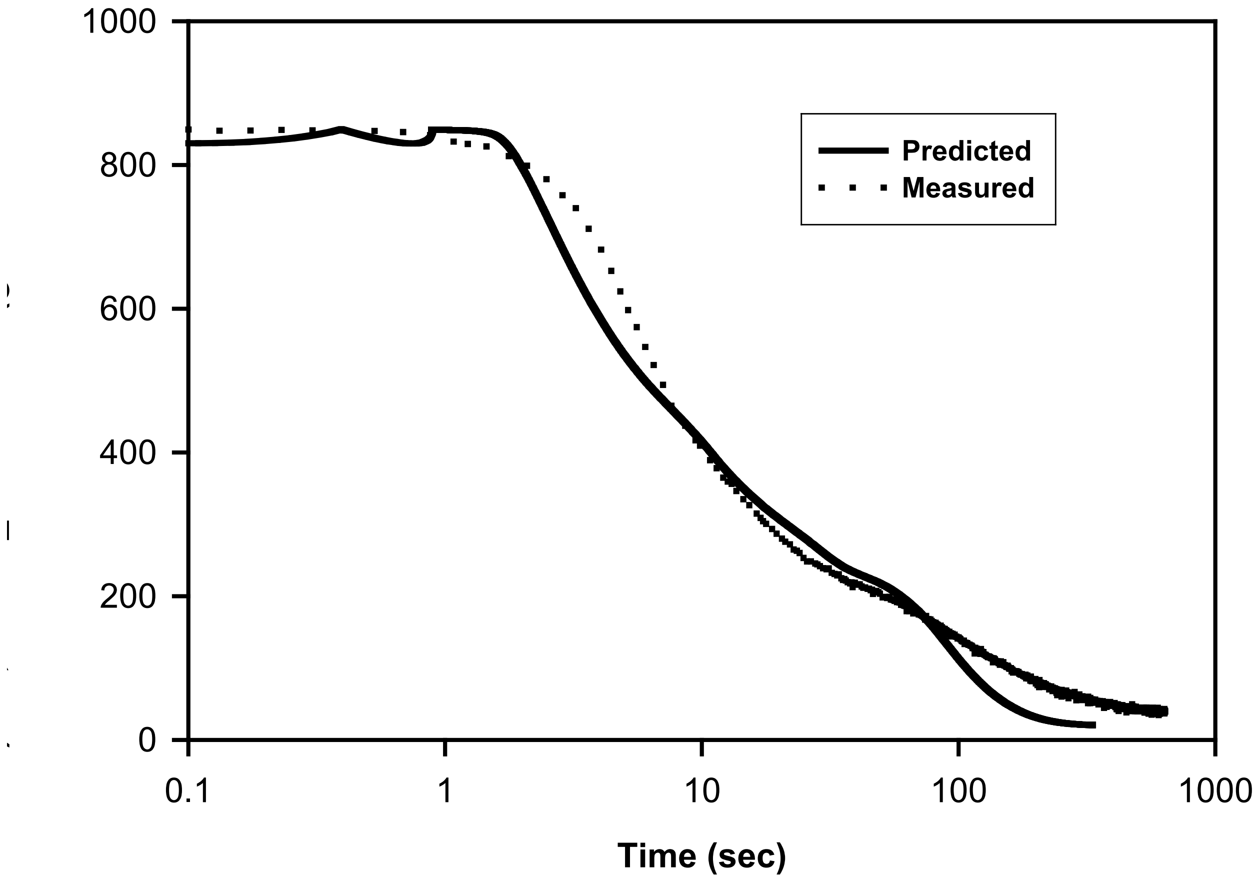


Quenching apparatus

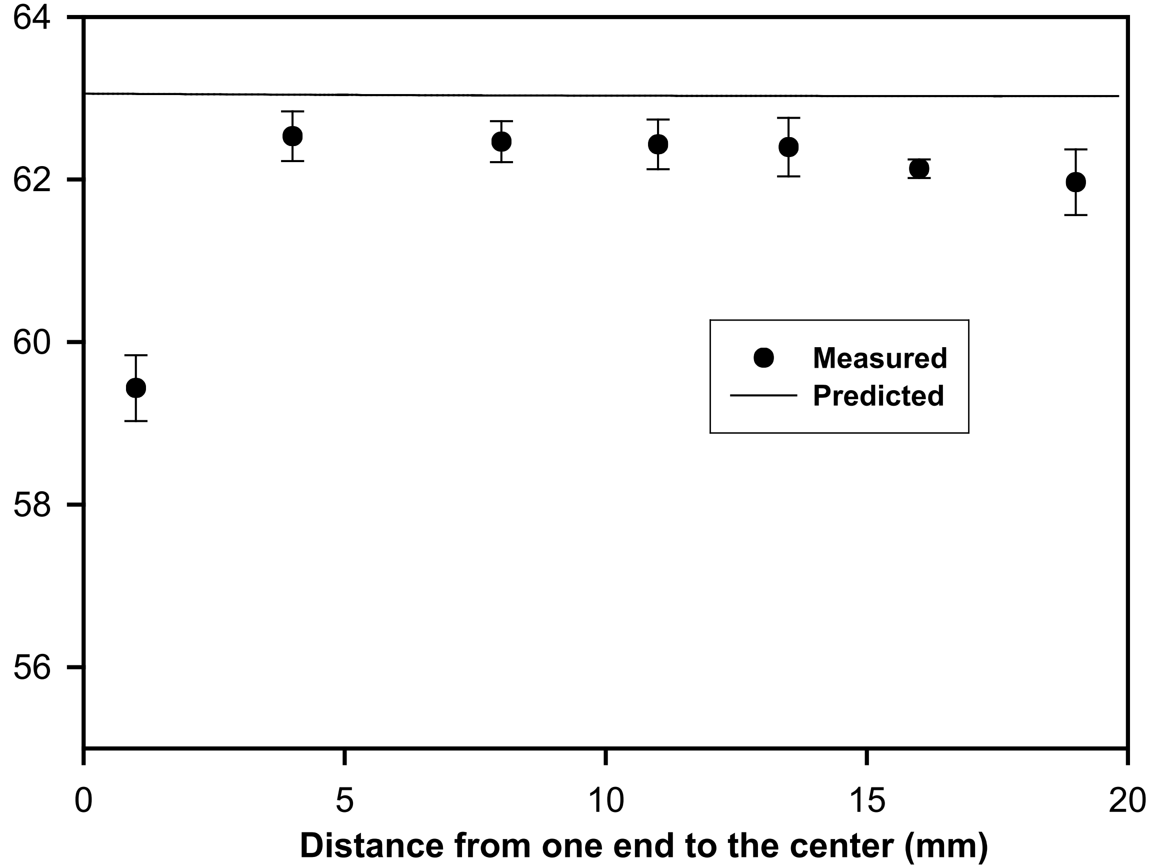


Courtesy: Center for Heat Treating Excellence (CHTE), WPI

Comparison of measured Vs. predicted cooling curves

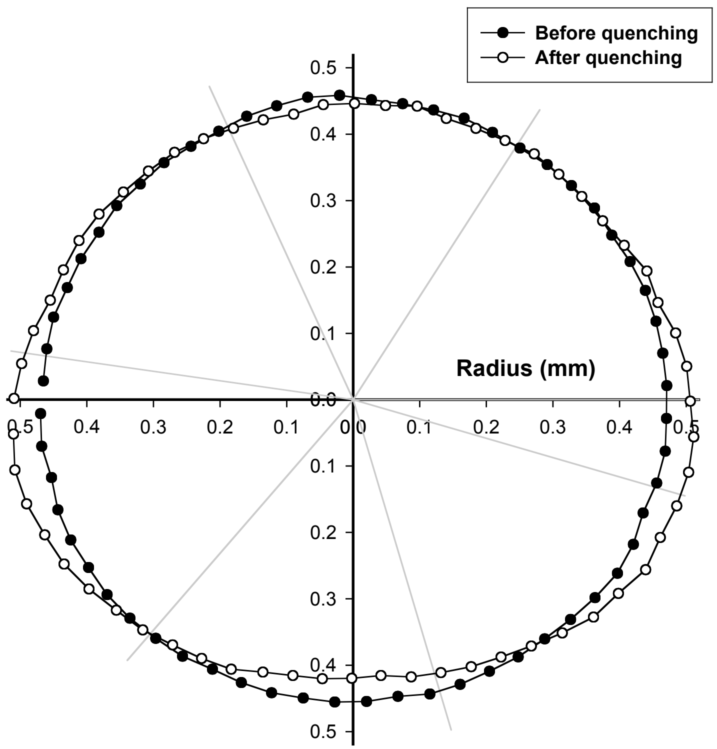


Comparison of measured Vs. predicted hardness

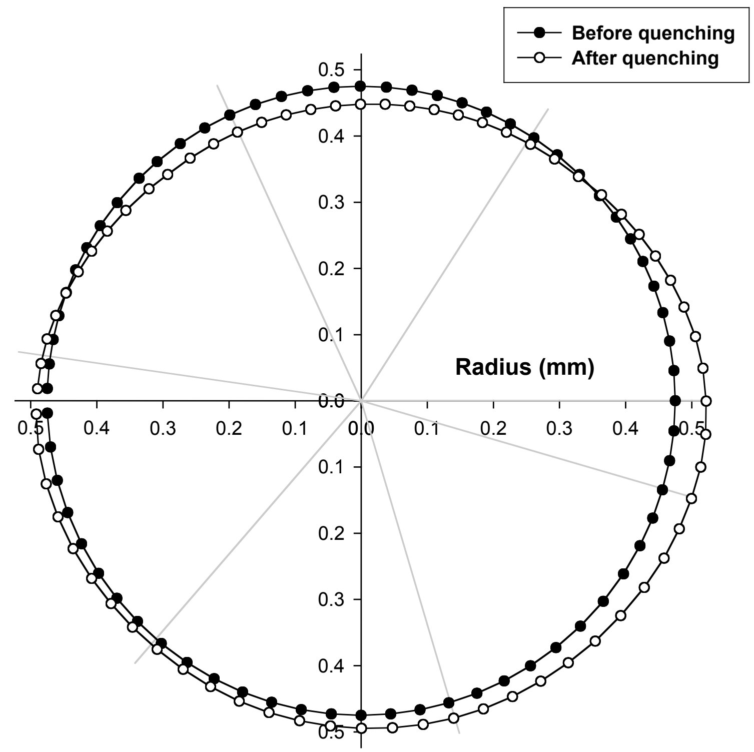


Comparison of measured Vs. predicted coordinates of circular hole before and after quenching

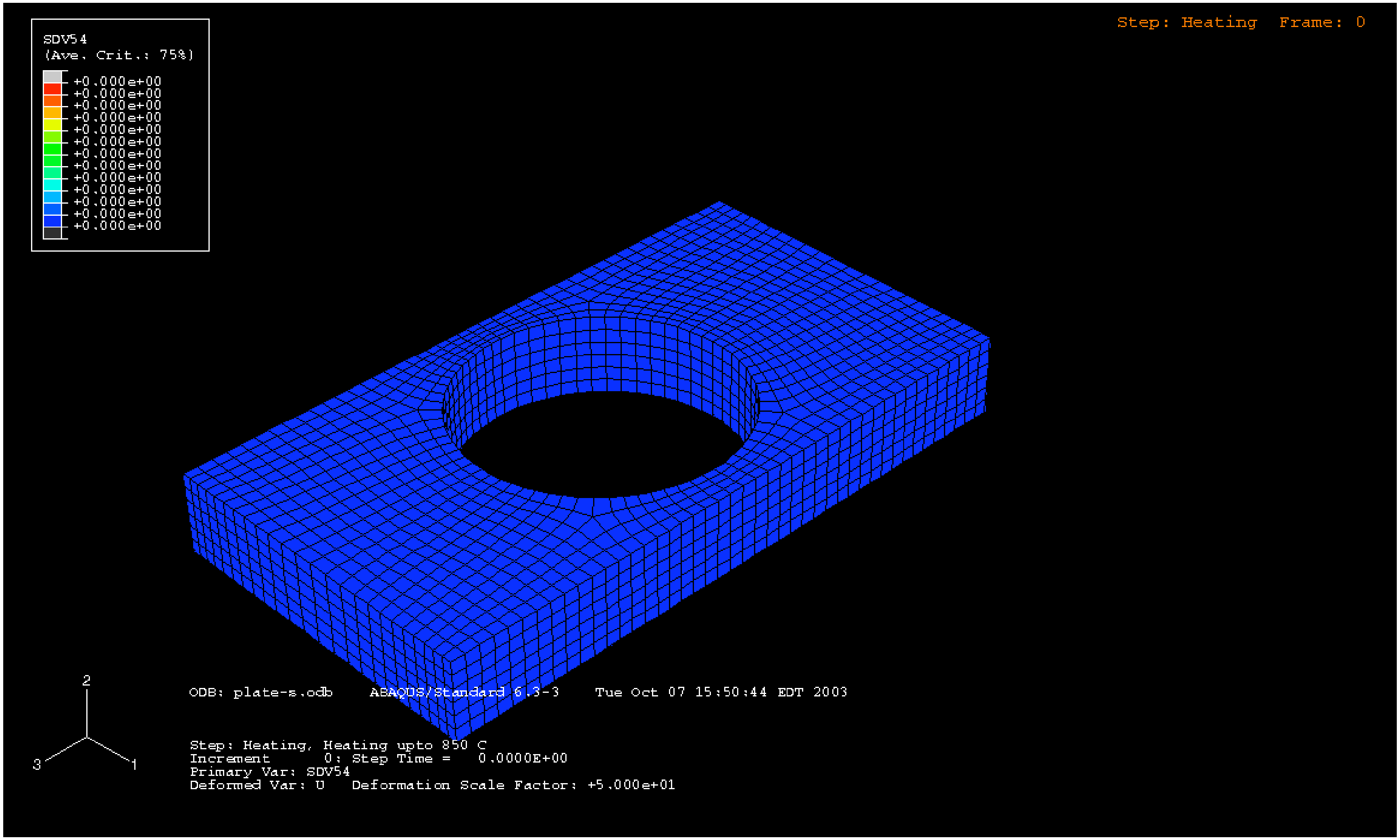
Measured by CMM



Predicted by model



Evolution of the martensite during queching



Work planned for next reporting period

- Complete Task-1
  - Subtask 1.1: Model for cylindrical part
  - Subtask 1.2: Model verification for
    1) Type and quantity of phases
    2) Residual stresses
    3) Dimensional changes and distortion (Quantitative)

- Begin Task-2
  - Subtask 2.1: Input data generation
    - Dilatometry to find transformation kinetics parameters.
    - Generation of heat transfer coefficients.
    - Mechanical and thermal properties of material.

Schedule

TASK 1: Assessment of Dante's ability to predict heat treatment response of wrought components. (7/1/2003 to 12/31/2003)

	Start	End
Subtask 1.1: Computer simulations	7/1/2003	10/1/2003
Subtask 1.2: Experiments and measurements		
➢ Measurement of dimensional changes and distortion	7/1/2003	10/1/2003
➢ Measurement of hardness	7/1/2003	10/1/2003
➢ Measurement of volume fraction of phases	7/1/2003	10/1/2003
➢ Measurement of residual stresses	7/1/2003	12/31/2003

TASK 2: Adapting Dante to modeling the heat treatment response of fully dense P/M component (1/1/2004 to 12/31/2004)

	Start	End
Subtask 2.1: Input data generation	1/1/2004	5/30/2004
Subtask 2.2: Computer simulations	6/1/2004	9/1/2004
Subtask 2.3: Experiments and measurements		
➢ Measurement of dimensional changes and distortion	9/1/2004	11/1/2004
➢ Measurement of hardness	9/1/2004	11/1/2004
➢ Measurement of volume fraction of phases	9/1/2004	11/1/2004
➢ Measurement of residual stresses	9/1/2004	12/31/2004

Schedule (contd.)

TASK 3: Adapting Dante to modeling the heat treatment response on porous P/M components (1/1/2005 to 12/31/2005)

	Start	End
Subtask 3.1: Input data generation	1/1/2005	5/30/2005
Subtask 3.2: Computer simulations	6/1/2005	9/1/2005
Subtask 3.3: Experiments and measurements		
➢ Measurement of dimensional changes and distortion	9/1/2005	11/1/2005
➢ Measurement of hardness	9/1/2005	11/1/2005
➢ Measurement of volume fraction of phases	9/1/2005	11/1/2005
➢ Measurement of residual stresses	9/1/2005	12/31/2005

TASK 4: Computer experimentation to characterize the effect of various processing parameters on the heat treatment response of P/M parts (1/1/2006 to 6/30/2006)

	Start	End
Subtask 1.1: Computer simulations	1/1/2006	3/31/2006
Subtask 1.2: Experiments and measurements		
➢ Measurement of dimensional changes and distortion	4/1/2006	6/30/2006
➢ Measurement of hardness	4/1/2006	6/30/2006
➢ Measurement of volume fraction of phases	4/1/2006	6/30/2006
➢ Measurement of residual stresses	4/1/2006	6/30/2006

Material properties required in DANTE/ABAQUS simulations

1. Elastic properties as a function of temperature.
   - Modulus of elasticity (E)
   - Poisson's ratio (_)
2. Coefficient of thermal expansion as a function of temperature for Austenite, Martenisite , Ferrite + Pearlite , and Bainite.
3. Latent heat for Austenite, Martensite , Ferrite + Pearlite , and Bainite.
4. Specific heat for Austenite, Martensite , Ferrite + Pearlite , and Bainite.
5. Thermal conductivity as a function of temperature for Austenite, Martensite , Ferrite + Pearlite , and Bainite.
6. Hardness of the material as a function of temperature.
7. Hardness of Martensite.