Effect of Intensive Quenching on Part Residual Stress Conditions

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Abstract

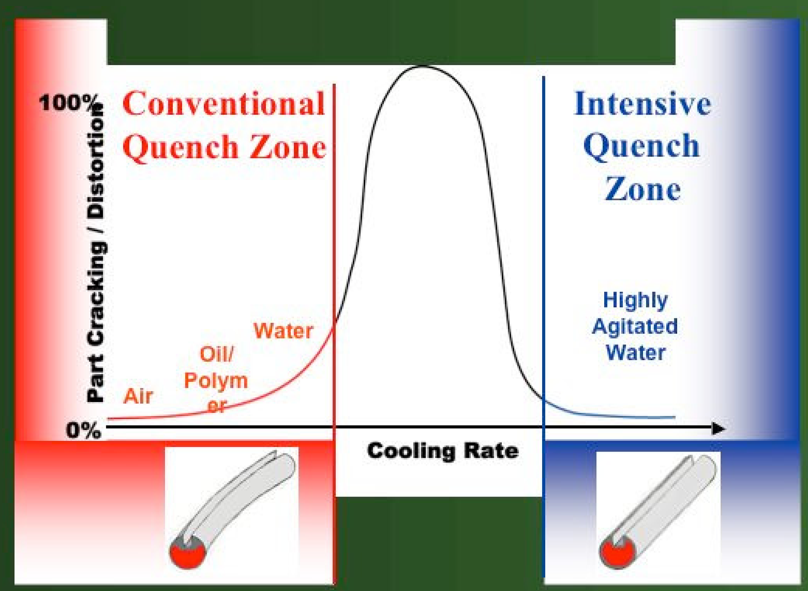
The investigation reports the results of a study conducted for evaluating the effect of the intensive quenching process on residual stress in a cylindrical part. The test specimens were 5160 steel rods 25 mm in diameter and 127 mm in length. Six sets of test samples were evaluated. The samples of three sets were quenched in highly agitated water by the Intensive Quenching process and were tempered at two different temperatures. One set of the intensively quenched samples was shot peened after tempering. Two sets of specimens were conventionally quenched in oil and then tempered. One oil quenched and tempered set of samples was then shot peened. The residual stress in test specimens at the surface and through thickness were measured by X-ray diffraction and neutron diffraction methods, respectively. The residual stress distribution was also calculated using the DANTE computer program. The results of the study demonstrate that the intensive water quenching process significantly improves the part residual stress state compared to oil quench.

Goal

Develop and validate the FEM model for Intensive Quench process.

Intensive Quench Process

The purpose of quenching steel parts is to achieve the desired metallurgical structure while keeping the distortion to a minimum. The faster the steel part is quenched, the higher the quenched hardness and the deeper into the part the hardness is driven. However, the probability of part distortion or even cracking increases. IQ Technologies, Inc. provides a IntensiQuench[SM] process, which uses environmental friendly pure water quenchant or low concentration water/salt solutions to create fast and uniform part cooling, to improve the surface hardness and durability of steel parts and creates a high compressive residual stresses on the part surface.



Non-uniform hardened layer with residual TENSILE stresses

Uniform *SupR*-STRONG hardened layer with residual COMPRESSIVE stresses

Single-part quenching high velocity IQ system

Residual Stress Measurements

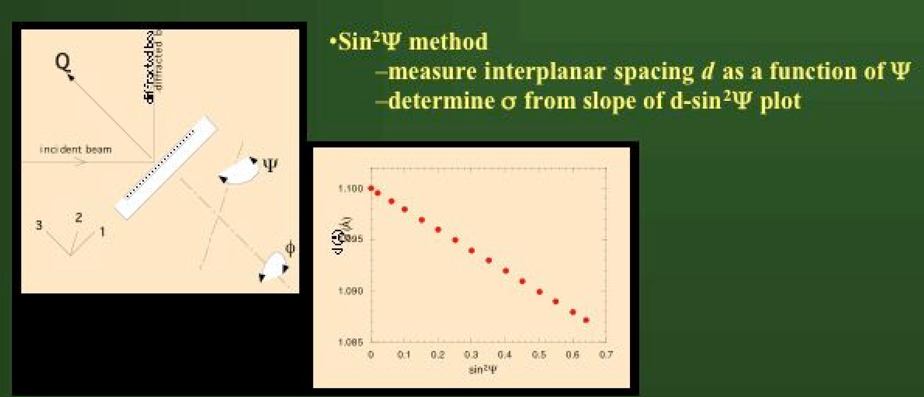
The surface and through-thickness residual stresses in the steel rods from both conventional oil quench and intensive quench processes were characterized by X-ray and neutron diffraction methods.

(1) Neutron diffraction through thickness stress mapping was performed at the ORNL High Flux Isotope Reactor's NRSF2 instrument.

Schematic of the neutron diffraction method, showing the gauge volume crossection as defined by the slits (shown at 90 degrees for convenience) and also the direction of the measured strain component (given by the scattering vector Q).

5160 steel quenched specimens were mounted on the neutron residual stress mapping facility.

(2) TEC X-ray diffraction surface stress measurement

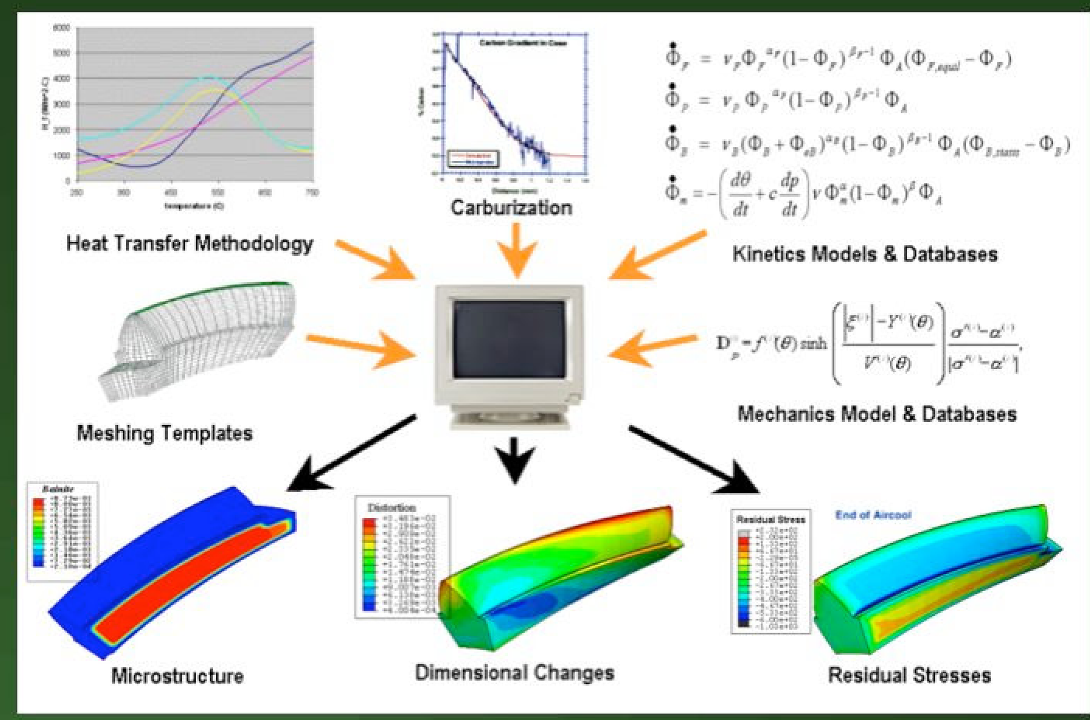


Principles Of X-ray Residual Stress Measurements

Surface residual stress of a 5160 steel quenched specimen was measured by X-ray diffraction. A 50 μm depth electro-polish was used to remove surface rust and accidental burnishing.

DANTE Heat Treat Simulation

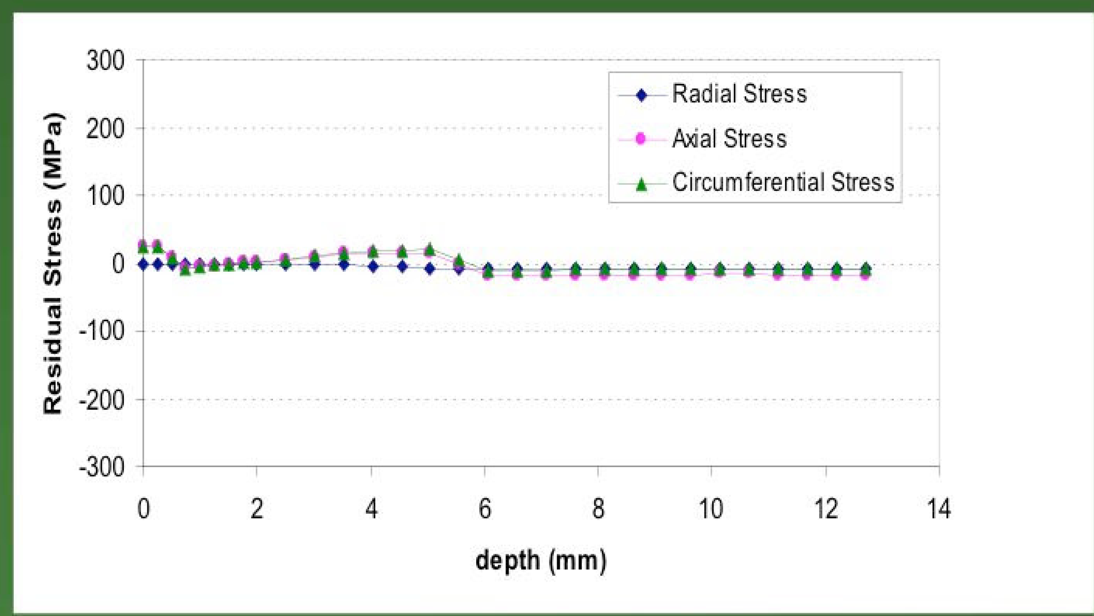
The DANTE heat treat simulation software was used to predict residual stress and microstructural phases in the heat treated bars. Using the Bammann-Chiesa-Johnson material model developed at Sandia National Laboratory, DANTE is a finite element based tool that calculates dimensional change, stress and metallurgical phase histories during heat treatment. The methodology connects thermal analysis, metallurgical phase transformation analysis, and stress/displacement analysis for these predictions. The figure on the right shows the nature of the model data and inputs and the resultant prediction results.

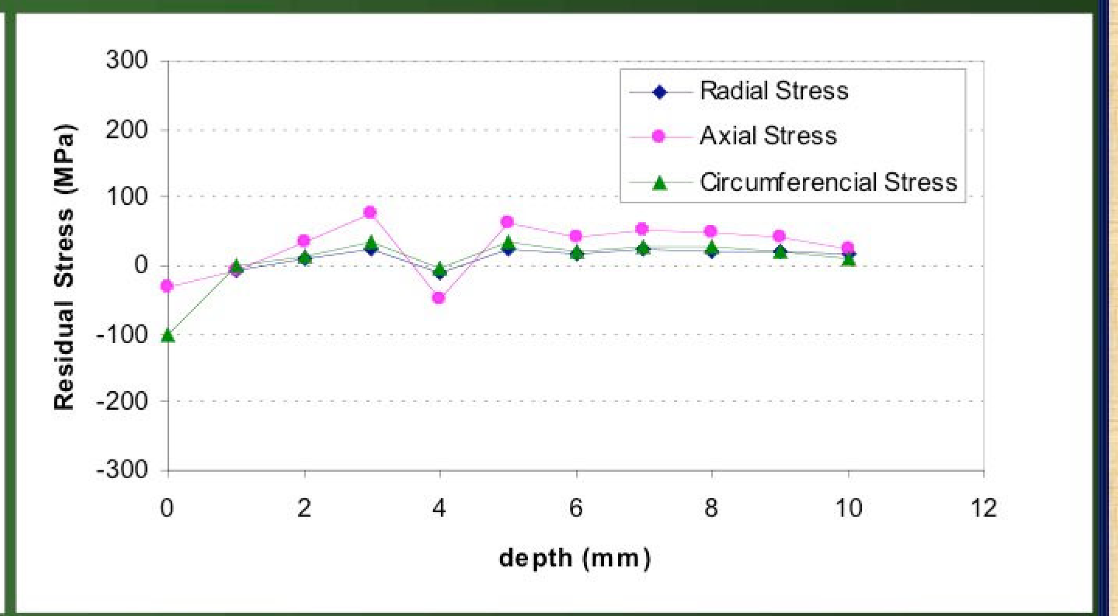


Results

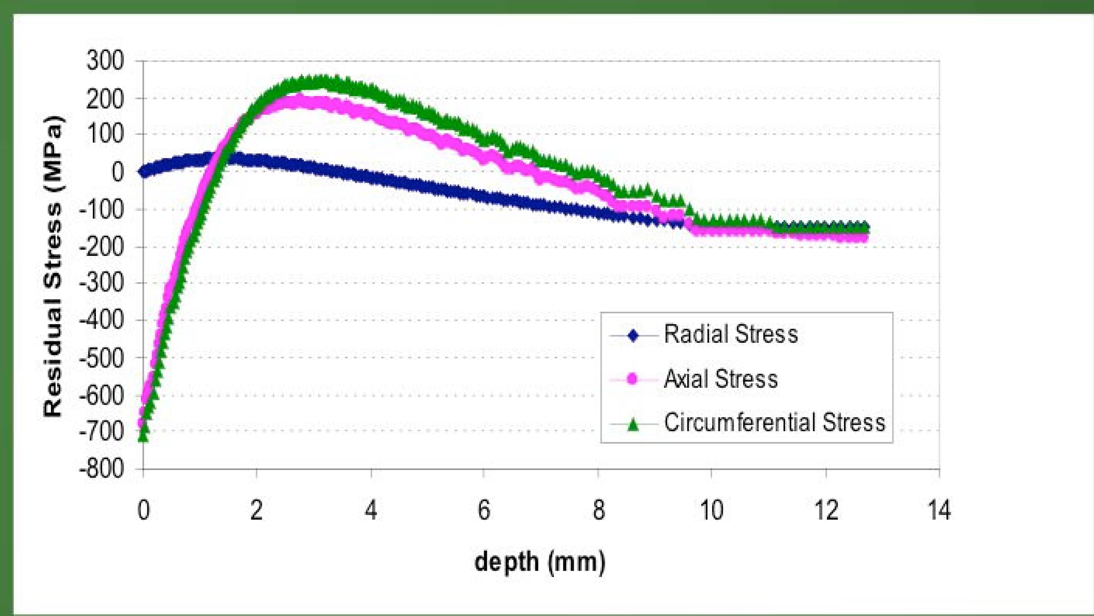
FEM residual stress modeling

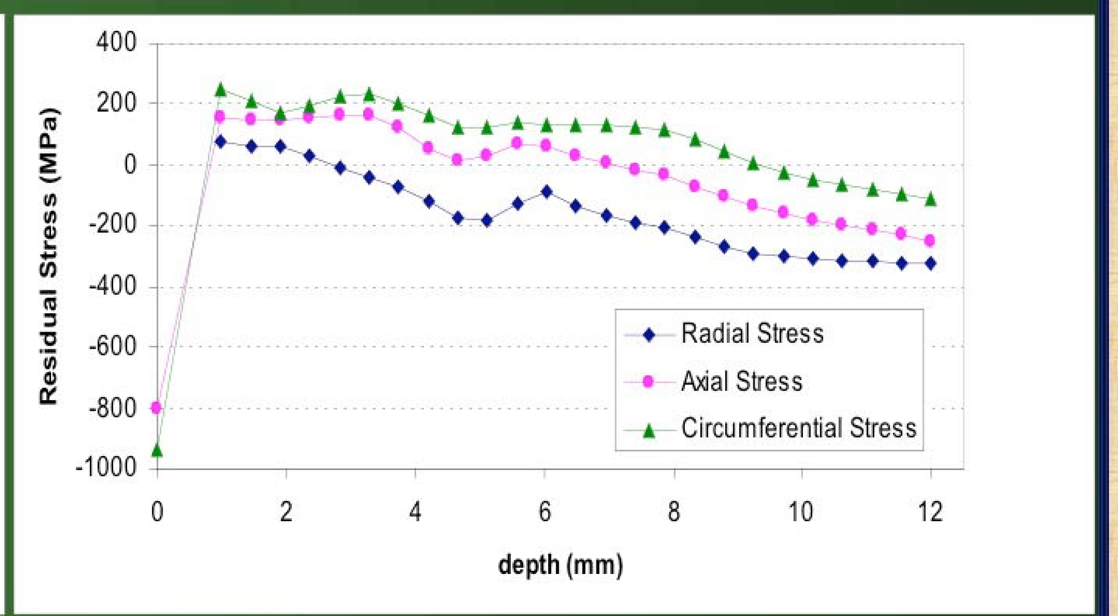
Residual stress results



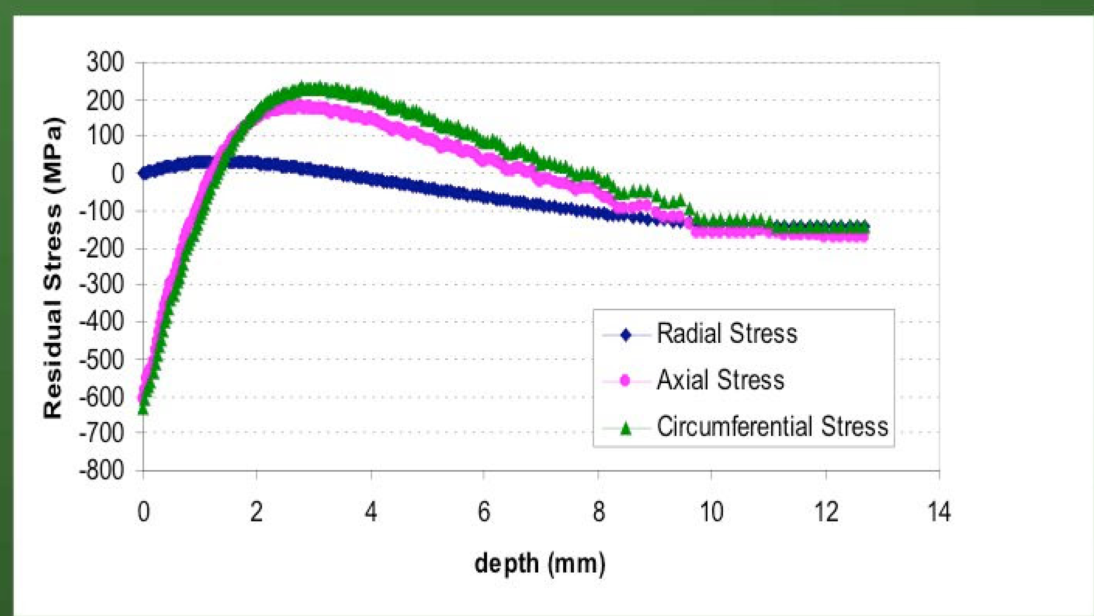


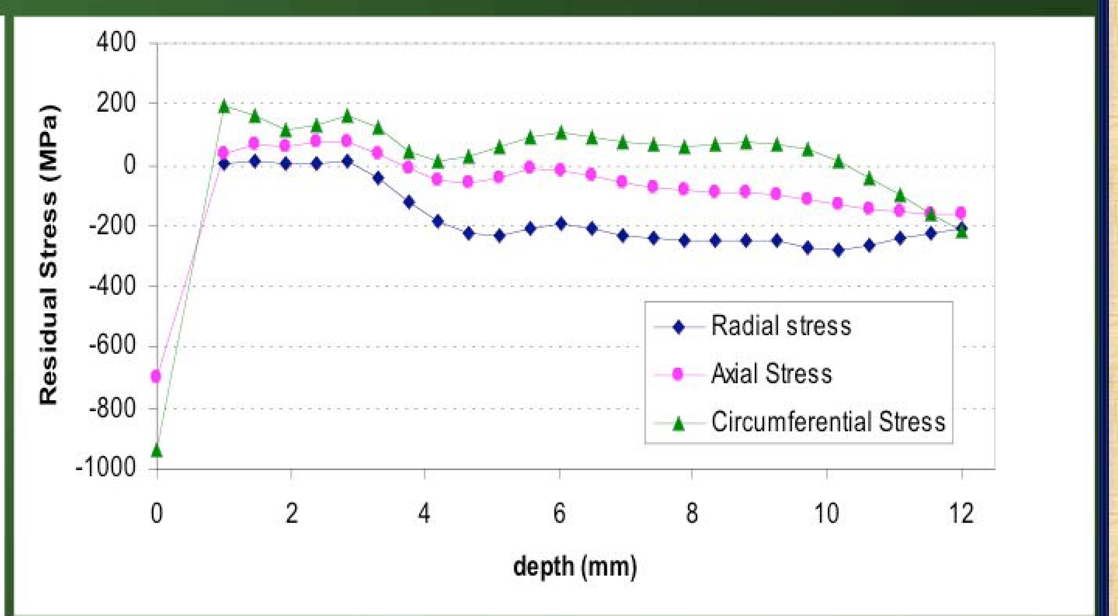
Oil Quench and Tempered at 700 degree F





Intensive Quench and Tempered at 350 degree F





Intensive Quench and Tempered at 700 degree F

Summary

- For oil quenched specimen, FEM model and measurement data are in agreement for through thickness residual stresses distribution. Measured stresses are slightly compressive when close to surface, while the model shows the opposite trend.
- For intensive quenched specimens, FEM model and measurement results show compressive stresses at the surface and extending in for about 1mm. The stresses are also compressive near the rod centerline. The radial stress from both model and experiment are very similar.
- Experimental data show some oscillation in stresses as depth increase, while model gives smooth curves, since the model assumes there are no chemistry, texture, or grain size variations across the whole sample.

Acknowledgements

Authors would like to acknowledge the Edison Material Technology Center of Dayton, Ohio for coordinating the team efforts and for getting the project approved. Residual Stress characterization sponsored by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of FreedomCAR and Vehicle Technologies, as part of the High Temperature Materials Laboratory User Program, Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract number DE-AC05-00OR22725.