DEFORM™ Application #507

Heat Treat Distortion

Heat treatment modeling of complex components can require large models. The ideal model frequently exceeds computer limitations. Several techniques are available to reduce the number of elements while providing resolution to simulate case depth, thermal gradients and stress concentrations:

Symmetry - If parts have planar or rotational symmetry, modeling techniques are available to reduce the problem size without sacrificing accuracy. Symmetry is usually a preferred modeling option.

Geometry abstraction - Minor geometric features can frequently be simplified or removed without influencing the results in the regions of interest, requiring fewer elements.

Local mesh refinement - The mesh in critical locations can be refined, with larger elements used in other areas. This provides excellent resolution in important areas, with a manageable model size.

Submodeling - This technique models only a local region or subset of the full part. Boundary conditions are used to simulate the remainder of the component. A detailed submodel can provide excellent local resolution.

This project demonstrated a strategy to manage model size, while retaining an accurate solution.

Design Environment for FORMing

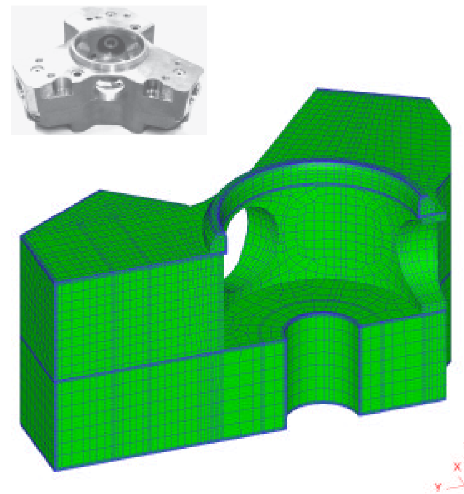
Heat Treatment Modeling:

Predicting and managing heat treatment distortion of complex parts is a huge challenge. DEFORM-HT is a powerful tool for simulating heat treatment processes. The system predicts heat treat distortion, residual stresses and phase volume fraction. Heat treatment modeling helps to achieve hardness and strength requirements while minimizing heat treat distortion and residual stresses.

Kistler-IGeL GmbH, the DEFORM distributor in Germany, worked with Rob. Bosch GmbH, DaimlerChrysler AG, Institute of Material Science and Engineering of Karlsruhe and other partners on a Computer Aided Simulation of Heat Treatment project (CASH), funded by the German Federal Ministry for Education and Research. The objective was to establish a modeling methodology for the heat treatment of complex parts.

Bosch was interested in the heat treatment modeling of a fuel injection pump housing made of AISI 5120 steel alloy. It is a thick-walled part with a piston guide and complex geometric features. To accurately predict the case depth and distortion, a very fine

fuel injection pump housing (Bosch)



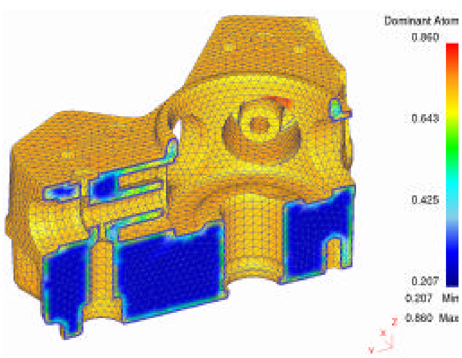
The mesh used to simulate case hardening (green) and actual pump housing (gray) are shown.

mesh, on the order of one million elements would be required. Models of this size are impractical to analyze in the current computing environment.

In order to retain the resolution required for an accurate solution, the geometry was simplified. The use of symmetry, and the elimination of very small features, resulted in a manageable model size. This compromise was the result of multiple simulation trials using different levels of geometric abstraction. Thin layers of highly refined elements were used to model the surface effects during carburization. For modeling distortion, geometric features at noncritical locations were simplified without modifying the mass of the part. In this case, volumetric effects are important to accurately capture thermal changes and phase transformation. Prediction accuracy was compared for various levels of geometric detail.

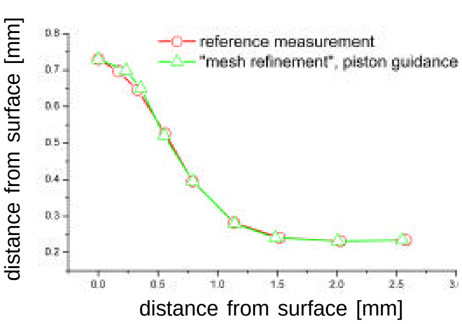
Detailed material data was generated for two different case hardening steels, AISI 5120 and 18CrNiMo7-6. Transformation kinetics, along with thermal and mechanical properties as a function of temperature and c-content, were determined. Local heat transfer coefficients as a function of temperature and location were generated for the quenching process.

Case depth after carburization of the fuel injection pump housing was validated. The model predictions matched the shop floor observation. Temperature profile predictions during the quenching process, at key thermo-coupled locations, matched well with experimental data. The modeled prediction of volume fraction of retained austenite matched the actual part with excellent accuracy.

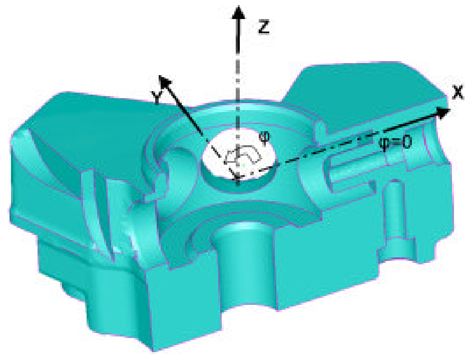


carbon content after carburization

Heat treat distortion varies with the part's position in the batch during quench. A sensitivity analysis was modeled to study this effect. The distortion at the piston guide hole was measured and the model predictions matched the characteristic change of shape and dimension very well.

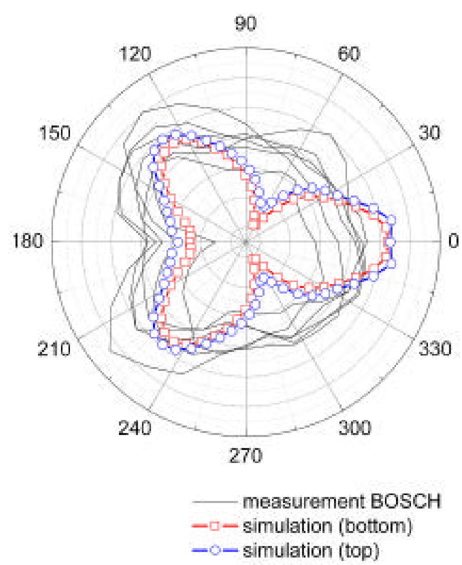


Measured case depth correlated well with simulation results.



The measurement coordinate system for hole roundness is shown in a sectioned solid model.

This project demonstrated the capabilities and accuracy of DEFORM in predicting heat treatment process responses. Heat treat modeling makes it possible to achieve an optimum balance of mechanical properties (for example, hardness vs. ductility). Critical process variables can be identified and their effects on heat treat distortion and residual stresses can be readily analyzed.



Validation of heat treat distortion is shown.

The quality of heat treat modeling results is dependant on the fidelity of the material data. DEFORM requires four sets of material related input data for heat treatment analysis – thermal, mechanical, transformation and process conditions.

Thermal properties include thermal conductivity, heat capacity and thermal expansion. Mechanical properties include Young's modulus, stress-strain curves and Poisson's ratio. Transformation data consists of beginning and end of transformation along with transformation kinetics. Transformation enthalpy and volumetric change can also be supplied. Process related boundary conditions such as heat transfer coefficients and diffusion constants are also needed. Material data should be a function of temperature or other significant dependencies.

All of the required data for a specific material may not always be available. Fortunately, much of the data is available in the public domain for common materials. Engineering assumptions and extrapolation of incomplete data sets have been successful for many cases over the years. As the applications for modeling become more popular, the data availability will continue to improve.

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