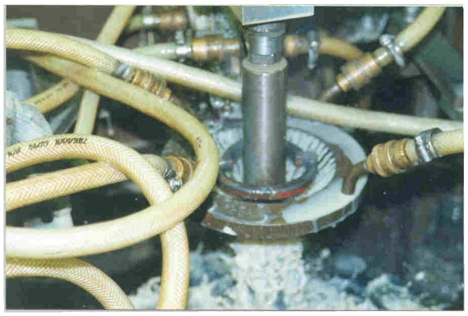
DEFORM™ Application #502

Simulation of Induction Hardening

Background

Engineering components rely on good mechanical properties for adequate performance in service; heat treatment is usually the method utilized to impart these mechanical properties. Induction hardening is a popular and efficient method for the rapid heating and cooling of a workpiece surface to achieve desired microstructural and mechanical properties. The surface hardening of long, slender components such as shafts can be conveniently carried out by scanning through an induction hardening unit, comprising of an induction heating coil and a water quench jacket. Tight control of process conditions is important in order that problems such as insufficient case depth do not result. In addition, the phase transformations involved in the process inevitably mean an increased volume and distortion. Furthermore, insufficient balance between the heating and cooling processes can cause the already quenched martensitic surface to become softened from the tempering effect of the still hot core.



Industrial scanning induction hardening equipment. The induction coil is located above the quench jacket and unit translates up the rotating shaft.

Analysis

An SAE-1055 steel shaft was analyzed in DEFORM™-HT together with a two turn copper induction coil and a water quench jacket. All components were axisymmetric and the analysis was carried out in 2D.

The workpiece and coil each contained an FEM mesh, the water jacket took the form of a user defined heat transfer window and the Boundary Element Method (BEM) was coupled to the Finite Element Method (FEM) to allow for easy movement between coil and workpiece. The required material data consisted of elastic, plastic, thermal, and electromagnetic properties for each phase of the workpiece; electromagnetic properties were also specified for the copper coil. Transformation kinetics characteristics were used to describe the phase transformation behavior between metallic phases. The Johnson-Mehl equation was used for the diffusion type transformations with (TTT) diagrams:

$$\Phi = 1 - \exp(-bt^{n})$$

Additionally, a martensitic relationship was used for the non-diffusion type transformations.

15kW of power was applied to heat the workpiece, at a frequency of 20kHz, to concentrate the heating in the surface layers. The heat transfer cooling window, representing the quench jacket, was specified a temperature of 20C and a convection coefficient of 20kW/(m^{2}K), representative of a water quench. The heat transfer temperature field was governed by the Laplace equation:

$$\rho c\dot{T} = \frac{\partial}{\partial X}\left(K\frac{\partial T}{\partial X}\right) - \sigma_{ij}\dot{\varepsilon}_{ij}^{p} + L_I\dot{\xi}_I + \dot{Q}$$

Design Environment for FORMing

The governing equations to be solved for the electromagnetic field, involving magnetic permeability, electric conductivity, source current density, and magnetic vector potential are shown below:

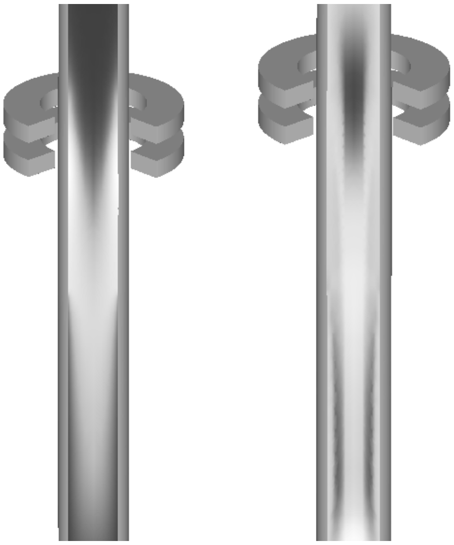
$$\nabla \times \left(\frac{1}{\mu} \nabla \times A \right) = Jo - \sigma \left(\frac{\partial A}{\partial t} + \nabla \phi \right)$$

$$\nabla \bullet \sigma \left[\frac{\partial A}{\partial t} + \nabla \phi \right] = 0$$

The FEM discretization allowed the formulation of algebraic equations which were then solved by the standard methods.

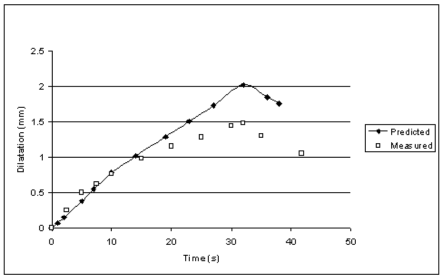
Results

The DEFORM™ predicted temperature-time variations at the exit of the coil were very close to those measured via optical pyrometer in the actual process.



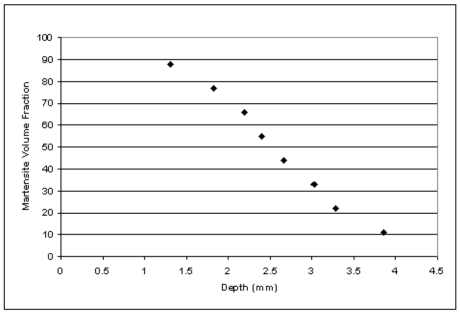
Simulated workpiece temperature distribution (left) and maximum principal stress (right) during scanning induction hardening process.

Applying boundary conditions to lock one end of the shaft and allow the other end to move freely facilitated the prediction of axial dilatation.



Axial dilatation of free end of workpiece

Effective case depth, defined as the region with 50% or greater martensite volume fraction, was determined across the radial section of the simulated shaft. These predictions were taken after cooling the workpiece to room temperature.



Simulated volume fraction of martensite vs. depth from surface

Applications

Predictions from DEFORM™-HT can provide designers and metallurgists with valuable information on the scanning induction hardening process. Shaft temperature, case depth, residual stresses and resultant distorted geometry are just some of the results available from simulation. In addition, induction coil design can be facilitated by the DEFORM™-HT system. The process simulation of shafts, stub axles, gears and bearing components which are hardened by the scanning induction hardening method will allow automotive, aerospace, oilfield and specialist industries to analyze the process on the computer and reduce shop floor trial and error.

**Scientific
Forming
Technologies
Corporation**

5038 Reed Road
Columbus, Ohio
43220-2514
Tel: (614)451-8330
Fax: (614)451-8325

www.deform.com
email: sales@deform.com