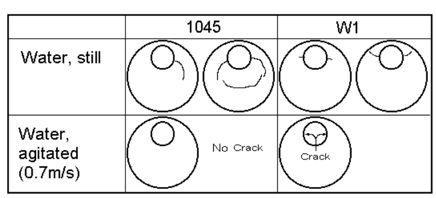
DEFORM™ Application #501

Quench Cracking Simulation

Background and Problem:

Quench cracking of engineering components is a major industrial problem, as component geometry, material properties, and/or process conditions are changed fundamentally by economical or technological demands. Fractures may be induced from excessive surface stresses during quench processes. Quenching may be the final operation in a through hardening heat treatment process and is very likely to follow an austenitizing furnace soak. Components of various size, shape and alloy are susceptible to the problem and it can result in entire batches being rejected in production.

Numerous cracks were found in a number of small disc components (shown below) after quenching. The failure patterns varied in their nature but the extent of cracking was greater when the quench medium was still as opposed to being agitated.



Failure patterns are shown in a range components. Less cracking resulted from agitated quench conditions.

Any quenching process is considered quite complex; localized boiling may occur and the formation of a vapor blanket can locally insulate parts of a component, resulting in non-uniform cooling. The photograph below illustrates typical vapor blanket activity and boiling characteristics, on one of the above disc components during non-agitated water quenching. The component illustrated below was actually cracked, but there were no pieces broken off.

Analysis:

An analysis of the AISI-W1 steel component was carried out in DEFORM™-3D-HT, in non-isothermal, elasto-plastic mode. Initially, austenitization of the component was simulated, prior to quenching in room temperature still water. Symmetry boundary conditions were applied allowing simulation of ¼ of the actual component. Heat transfer coefficients during quenching simulations were based on cooling curves from instrumented components during quench tests.

Material data consisted of elastic, plastic and thermal properties for each of the simulated phases in the steel alloys. 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:

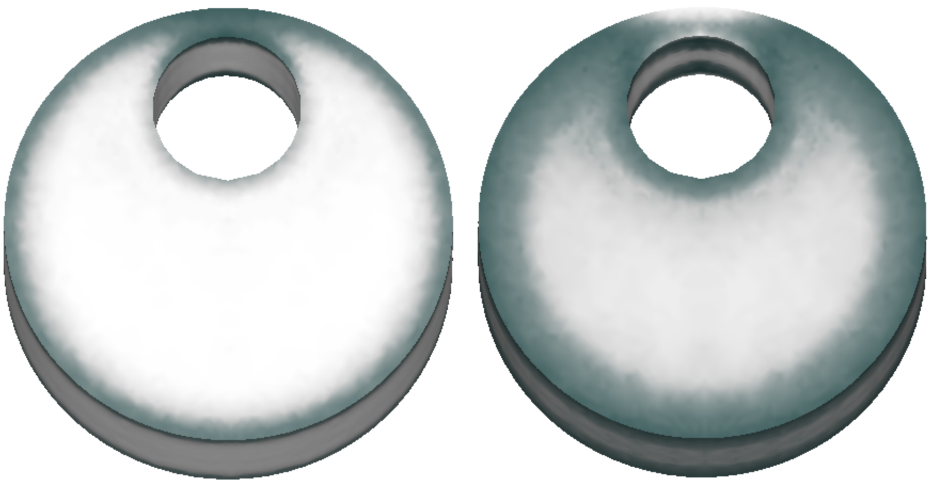
$$\Phi = 1 - \exp(-bt^{n})$$

A martensitic relationship was used for the non-diffusion type transformations. 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

Vapor blanket formation and bubbling activity at different times during the still water quenching of the AISI-W1 steel disc component.



Simulated maximum principal stress in AISI-W1 component early (left) and later (right) in the quench process. Note the locations of highest stress (dark areas).

AISI-W1 component showing quench cracks (top of figure).

Results:

During quenching, predicted temperatures fell off most rapidly in the thin sections around the hole and also around the edges of the component. The initial martensite transformation was predicted in the thin sections and eventually the entire component was martensitic. Furthermore, this was the region exhibiting some of the highest maximum principal stresses, and this is where cracking occurred on actual specimens, as shown below.

Opportunities:

DEFORM™-HT provides the environment for simulating quench processes and highlighting the susceptibility of cracking. Modified alloy composition, quenchant properties and process conditions may be analyzed on the computer without interrupting production schedules. In addition, fracture mechanics may be incorporated to determine the mode of failure of the cracking.

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