

Distortion and Residual Stress

Research Team

Haixuan Yu

Richard D. Sisson, Jr.

Introduction

Steel parts that are used in the automotive, aerospace and heavy-equipment industry rely on heat treatment, especially the rapid cooling process of quenching, to acquire the desired mechanical properties. Rapid phase transformation and high thermal gradients occurring during quenching can cause distortion, which can lead to costly hard machining and rejection. Residual stress and deformation induced by quenching are a consequence of complex interaction among the parameters of phase transformation, heat transfer, and strain in the steel as featured in Figure 1.

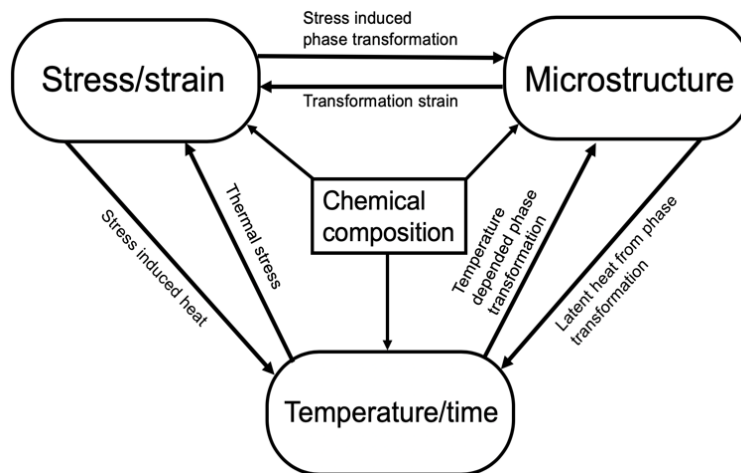


Figure 1 The interaction among stress, strain, microstructure, and temperature.

The overall goal of the present work is to identify heat treatment process parameters to control distortion and residual stress, which can help provide the manufacturing industry with heat treatment process parameters that will help to significantly reduce costs. The objective of the present project includes

- Determine the important heat-treating process parameters that impact the distortion in industrial parts.
- Develop a ranking of these processing parameters based on their impact.
- Provide processing guidelines to control distortion.

Methodology

The project focused on the following tasks:

Task 1 – Literature Review

Task 2 – Alloy Selection

Task 3 – Select part geometry for simulation

Task 4 – Conduct simulations using DANTE to identify the important process parameters that control distortion

Task 5 – Conduct sensitivity analysis to identify the process variable that leads to distortion

Task 6 – Conduct experiments to verify and modify the simulation results

Task 7 – Determine the physical properties and microstructural features that control distortion and residual stress

Task 8 – Design of experiments (DoE) coupled with analysis of variance (ANOVA) is used to rank important processing parameters based on their impact

Salient results

The measurements of the heat transfer coefficient (HTC) of alpha quench 5300 quenching oil [1] are conducted as a function of temperature with selected agitation and quench start temperature using CHTE quench probe system [2]. Figure 2 presents that HTC increases with the increase of agitation level, while the quench start temperature has no significant effect on HTC

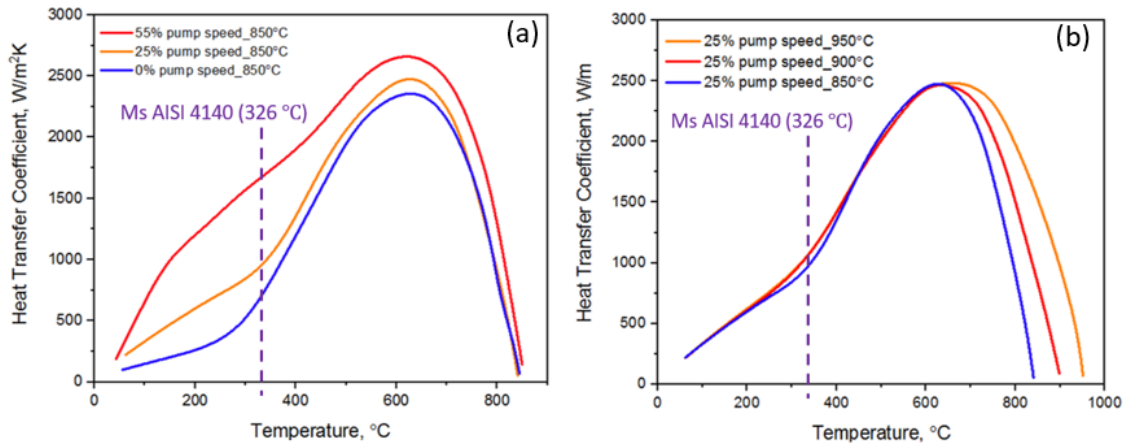


Figure 2 Heat transfer coefficient of alphaquench 5300 quenching oil with selected pump speeds (agitation level) (a), and with selected quench start temperatures (b).

The quenching experiments with the Navy C-ring specimen (Figure 3), which is selected because it offers a range of cooling rates due to its varying cross sections, are described and discussed.

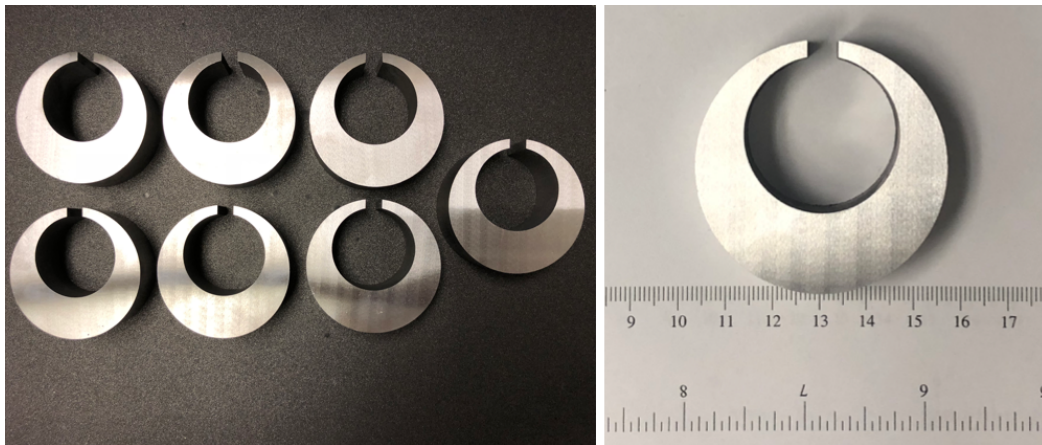


Figure 3 Fabricated specimens made by AISI 4140 steel using CNC lathe.

Heat treatment modeling, using commercial heat treatment code, DANTE, is presented. DANTE is a finite element integration package that keeps track of the thermal mechanical and phase transformations. The goal is to use this software to predict the distortion in the part, as a function of the heat-treating parameters. Figure 4 shows the three-dimensional finite element (FE) model

of the Navy C-ring for heat treatment simulation. In order to have accurate simulation results, a finer mesh was applied near the surface.

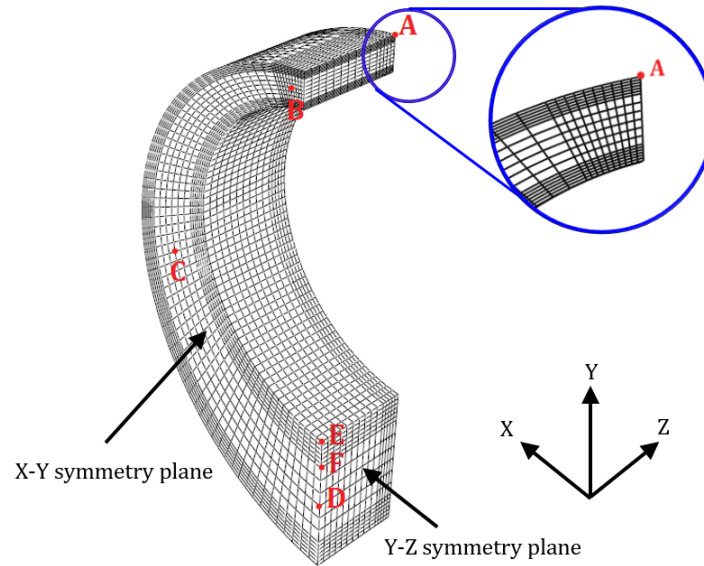


Figure 4 Solid model and finite element mesh used for heat treatment simulation.

As it is shown in Figure 5, from both modeling and experimental results, higher pump speed results in larger distortion of Navy-C rings. Selected quench start temperatures don't have significant effect on quenching distortion.

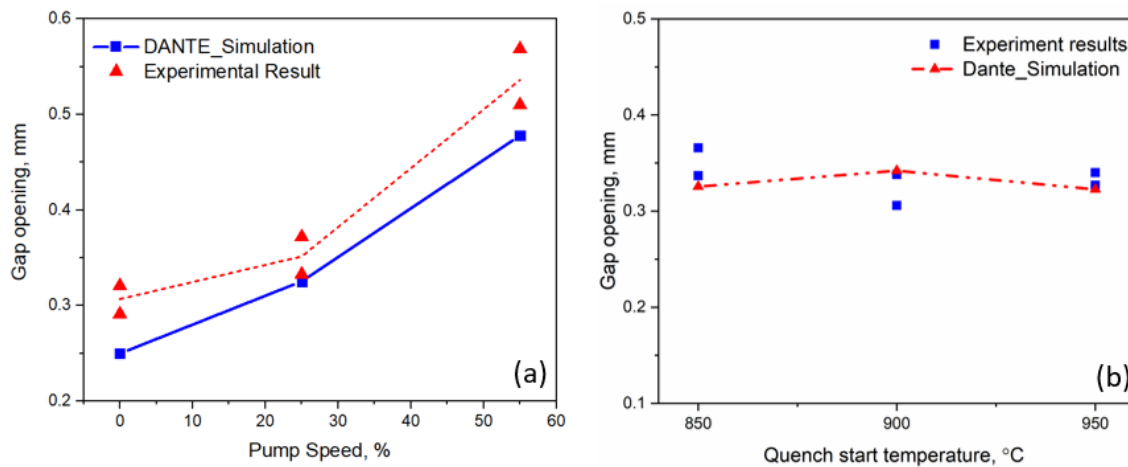


Figure 5 The gap opening with selected pump speeds and quench start temperatures after quenching.

References

1. <http://objects.eanixter.com/PD365571.PDF>
2. Maniruzzaman, M., Chaves, J., McGee, C., Ma, S., & Sisson Jr., R. (2002, July). CHTE quench probe system: a new quenchant characterization system. In 5th International Conference on Frontiers of Design and Manufacturing (ICFDM) (pp. 619-625).