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Finite element prediction of crack formation induced by quenching in a forged valve

Davide Gallina *

University of Brescia, via Branze 38, Brescia 25123, Italy

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ABSTRACT

Quenching treatment is commonly used to improve the mechanical properties of steel components. However, in these components, quench cracks are often observed as a result of improper material choice and thermal treatment process. Prediction of quench cracks is important to reduce production cost and to prevent in-service component failure; however, a generally accepted criterion for their formation has to be still established. In this study, finite element prediction of crack formation induced by quenching in a forged valve used in the offshore oil drilling field, is performed by means of the commercial finite element software Abaqus®. Microstructures (austenite, martensite, bainite, pearlite and ferrite) which can be formed during the thermal treatment are taken into account. The simulation results, compared with the effects of the quenching on the actual component, indicate that this type of simulation can effectively predict the quench cracks formation in 3D components.

1. Introduction

It is well known that quenching treatment is commonly used to improve the mechanical properties of steel components. In quenched components, cracking is often observed as a result of improper material choice and thermal treatment process. Prediction of quench cracking is important to reduce production cost and also to delay the in-service failure due to fatigue propagation from latent quench cracks [1].

One of the main causes of quench crack formation is the high stress level reached in the component during quenching in conjunction with its surface finishing, massive geometry and defects. In turn, the stress distribution in the component strongly depends on the phase transformations occurring during quenching [2] and, therefore, a reliable prediction of the phase transformations is essential for the prediction of crack induced by quenching, such as by means of finite element analysis (FEA).

Koistinen and Marburger's equation [3] is still widely used by several researchers to evaluate the martensite volume fraction of several low-alloy steels even though the equation was originally developed using iron-carbon steels [4]. In addition, their equation predicts only the percentage of martensite and not the percentage of different microstructures which can be formed during the thermal treatment.

In the last two decades, the modeling of residual stress and distortion induced by quenching has received considerable attention and the finite element method (FEM) is used more and more often to compute temperature and stress during quenching. Denis et al. [2] investigated the effects of stress on the phase transformation kinetics and transformation plasticity using a coupled model of a cylinder. Inoue and Arimoto [5] developed a CAE system for heat treatment simulation based on Metallo-Thermo-Mechanics theory. Lee and Lee [4] investigated the relationship between transformation kinetics,

* Tel.: +39 030 371 5807; fax: +39 030 370 2448.
E-mail address: davide.gallina@ing.unibs.it

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