Nuclear Engineering and Design 278 (2014) 222–228

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Effect of cyclic loading on the relaxation of residual stress in the butt-weld joints of nuclear reactor piping

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HIGHLIGHTS

- The accuracy of welding simulation is confirmed by comparing with experiments.
- Relaxation of residual stress for piping weld due to cyclic load is investigated.
- High tensile stress that occurs in front of crack tip is reduced by cyclic loading.
- Mechanism of relaxation of residual stress due to cyclic loading is discussed.
- Cyclic loading on the piping welds affects the suppression of crack growth.

ARTICLE INFO

Article history:
Received 9 August 2013
Received in revised form 10 July 2014
Accepted 13 July 2014

ABSTRACT

Weld residual stress is among the most important factors in stress corrosion cracking (SCC) of the austenitic stainless steels used for pressure boundary piping in nuclear power plants. To assess the integrity of piping, particularly over long-term operation, it is necessary to understand the effects of cyclic loading, such as that caused by an earthquake, on residual stress. In this study, finite element analyses were performed using an axisymmetric model of a 250A pipe butt weld composed of low-carbon Type 316L stainless steel. The moving heat source was simulated by a double ellipsoid model. The accuracy of the method was verified by comparing the calculated results with experimental measurements. Subsequent to the welding simulation and residual stress analysis, the effects of cyclic loading were studied by applying several axial cyclic loading patterns to the model, varying the maximum load. Higher loading caused greater relaxation of the weld residual stress near the piping welds. It was concluded that cyclic loading on piping butt welds suppresses the SCC growth by reducing the tensile residual stress at the inner surface.

1. Introduction

In Japan, nuclear power plants have experienced multiple large earthquakes such as the Niigataken Chuetsu-oki Earthquake in 2007 and the Tohoku District-off the Pacific Ocean Earthquake in 2011. These experiences have shown that the occurrence of large earthquakes should be treated as probabilistic methodology. Furthermore, recognizing the importance of the effect of residual risks on the evaluation of seismic resistance, i.e., the seismic safety margin, is suggested. Additionally, during the past few decades, stress corrosion cracking (SCC) has been observed at the welds of the reactor coolant pressure boundary piping in nuclear power plants (Takamori et al., 2004; Suzuki et al., 2004; Yamashita et al., 2008). SCC has been chiefly attributed to material sensitization from heat input due to welding, a corrosive environment, and the tensile residual stress caused by welding. Tensile residual stress is the most important factor for assessing the structural integrity of piping related to SCC because high tensile stresses at the inner surface and through-thickness distribution in the pipe wall affect the initiation and growth of SCCs. These events have attracted attention toward the need to assess the effect of large-scale earthquakes beyond the previous design basis on the seismic structural integrity of reactor components. Several experimental and analytical studies of crack growth behavior due to excessive loading have been performed in recent years (Yamaguchi et al., 2013; Saito et al., 2013; Mohanty et al., 2013).

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http://dx.doi.org/10.1016/j.nucengdes.2014.07.024
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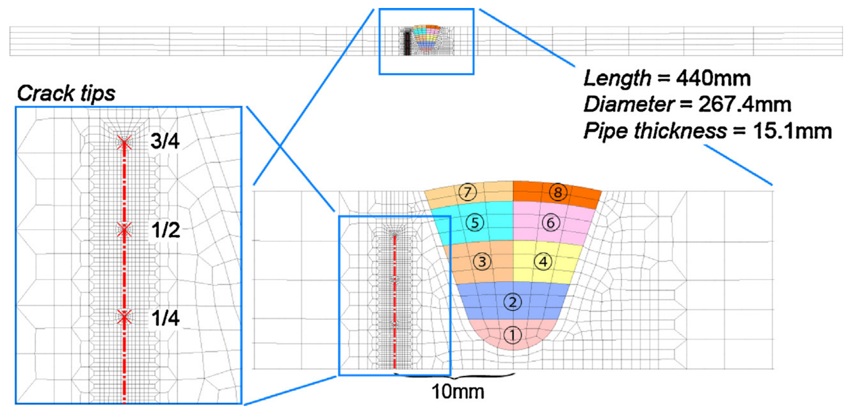

Fig. 1. Axisymmetric FEA model.

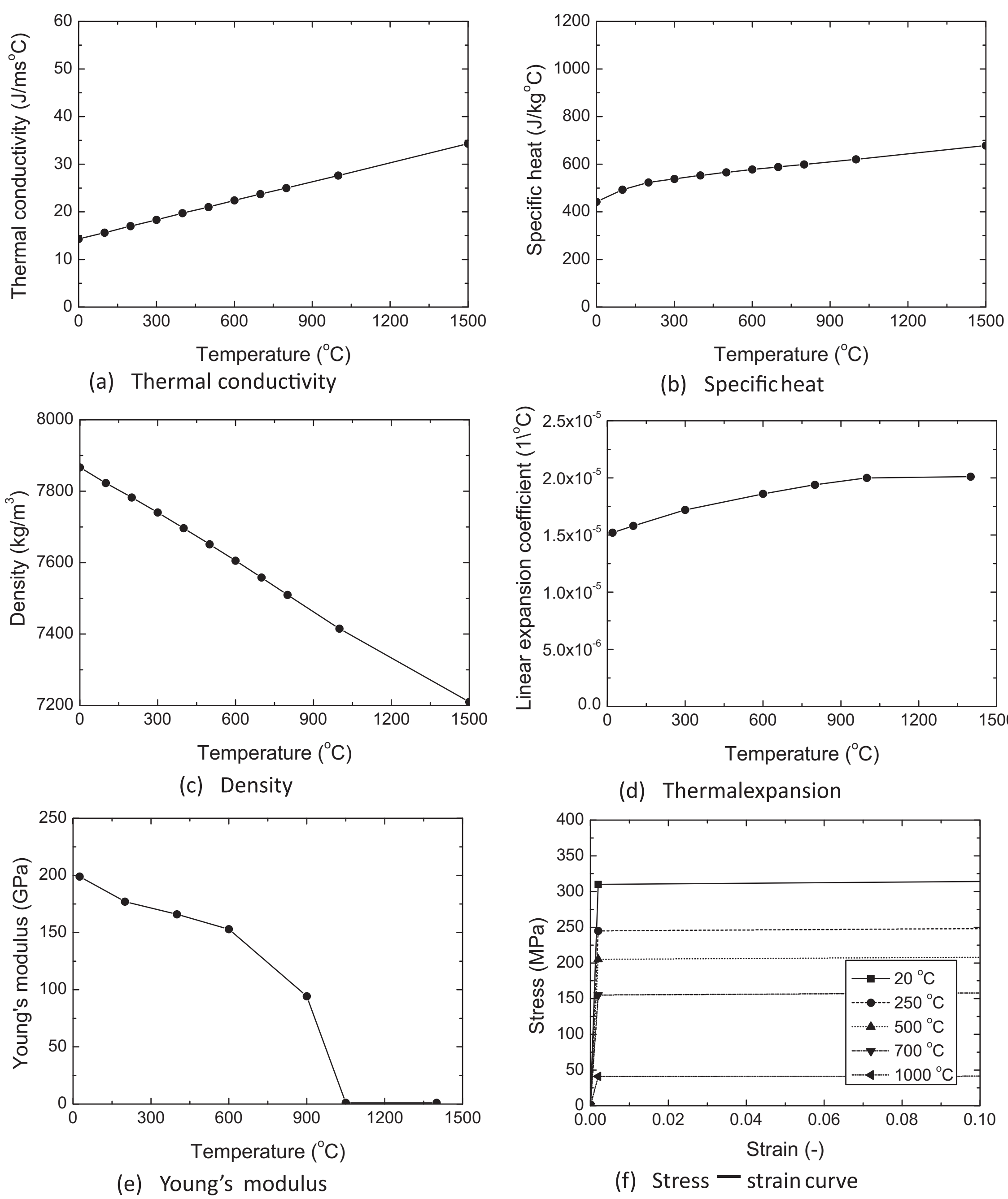

Fig. 2. Material properties of Type 316L low-carbon stainless steel.