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Original Article

Round Robin Analyses on Stress Intensity Factors of Inner Surface Cracks in Welded Stainless Steel Pipes

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ABSTRACT

Austenitic stainless steels (ASSs) are widely used for nuclear pipes as they exhibit a good combination of mechanical properties and corrosion resistance. However, high tensile residual stresses may occur in ASS welds because postweld heat treatment is not generally conducted in order to avoid sensitization, which causes a stress corrosion crack. In this study, round robin analyses on stress intensity factors (SIFs) were carried out to examine the appropriateness of structural integrity assessment methods for ASS pipe welds with two types of circumferential cracks. Typical stress profiles were generated from finite element analyses by considering residual stresses and normal operating conditions. Then, SIFs of cracked ASS pipes were determined by analytical equations represented in fitness-for-service assessment codes as well as reference finite element analyses. The discrepancies of estimated SIFs among round robin participants were confirmed due to different assessment procedures and relevant considerations, as well as the mistakes of participants. The effects of uncertainty factors on SIFs were deducted from sensitivity analyses and, based on the similarity and conservatism compared with detailed finite element analysis results, the R6 code, taking into account the applied internal pressure and combination of stress components, was recommended as the optimum procedure for SIF estimation.

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1. Introduction

As operating years of nuclear power plants have increased, various aging degradations have been reported in major components and piping systems so that establishment of appropriate evaluation methods are required. Austenitic stainless steels (ASSs) are widely used in nuclear pipes of nuclear power plants as they exhibit a good combination of mechanical properties and corrosion resistance. Since post-weld heat treatment of ASS welds has not been carried out to avoid sensitization [1], high tensile residual stresses may occur in the ASS welds and the resulting high tensile residual stress field contributes to one of the crack driving forces [2]. Furthermore, recent research has reported that ASS welds lose toughness due to thermal aging embrittlement [3,4]. However, since there has been significant deviation among well-known fitness-for-service (FFS) codes and equations, as well as analysts, due to the inherent complexity of the welding, the effects of residual stresses on cracking behavior in ASS welds should be evaluated rigorously prior to dealing with the embrittlement phenomenon.

Fracture mechanics parameters, such as stress intensity factors (SIFs), are commonly used to evaluate the integrity of cracked pipes and other components in the nuclear industry. While a lot of research works on SIFs and welding residual stresses of Ni-based alloy steels have been carried out [5–8], there were few investigations into welded ASS pipes. This is because they have sufficiently high ductility and resistance to brittle fracture. FFS assessment codes such as American Society of Mechanical Engineers (ASME)

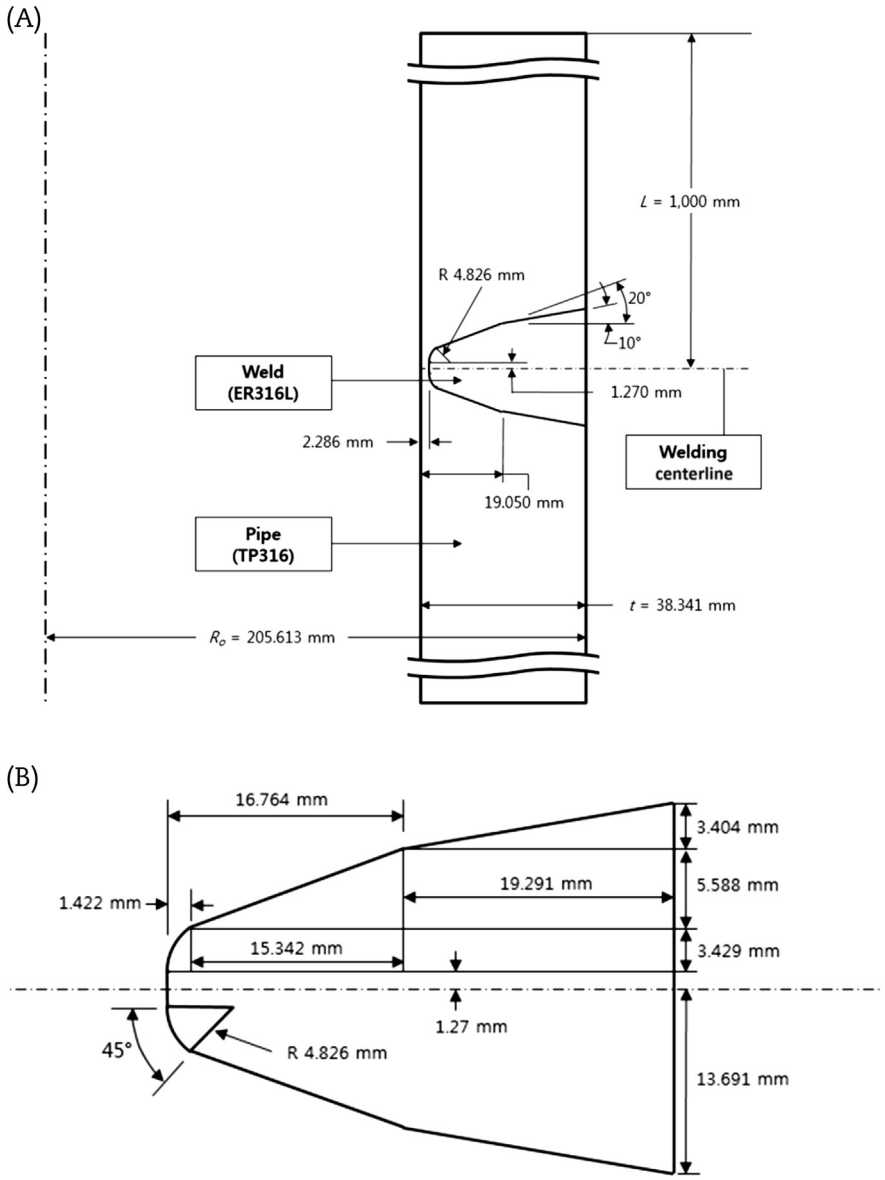

Fig. 1 – Schematics of an ASS pipe and its weldment [14]. (A) Geometry of an ASS pipe. (B) Enlarged geometry of a weldment. ASS, austenitic stainless steel.

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