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A Study on the Engineering Estimation for Obtaining Circumferential Tensile Property of Alloy 690 Steam Generator Tube Using Optimization and Finite Element Method

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1. Introduction

After the Fukushima Daiichi accident, the SG tube integrity may be challenged by high temperature and high pressure conditions and may have a potential to fail due to creep rupture in a broad category of station blackout severe accident scenarios. For design and safety analysis of the steam generator tube rupture (SGTR) under severe accident conditions, a creep rupture model for the steam generator tube material is needed, and it is essential to evaluate the mechanical properties in the as-manufactured material conditions [1]. However, transverse tensile properties of steam generator tube cannot be obtained directly from the tensile test using ring-type tensile specimen due to its geometry limitation [2-4]. In this paper, the circumferential tensile properties were derived using finite element analysis and optimization technique.

2. Tensile Test

Figure 1 shows the circumferential tensile specimen. The ring-type specimen was used as a specimen for circumferential tensile property.

An Insight 50 static machine manufactured from MTS was used for the tensile test. Strain rate in circumferential tensile tests is 0.1 mm/min (strain rate : 4.2×10-4/s). The COD gauge was attached to the front of the test jig to measure the displacement. The load-displacement curves that were calibrated the machine compliance were used in the data analyses.

Figure 2 shows the failure mode of tensile specimens. In the circumferential tensile test using ring-type specimens, the final fracture occurred after necking in the reduced section. Particularly, fracture occurred only in one side in reduced section of the ring-type specimen, and the fracture occurred at the bottom or upper part of the center instead of the center part of the reduced section as shown in Fig. 2.

3. FE Analysis and Optimization

3.1 FE Analysis

FE analyses were performed for simulating tensile tests using the general-purpose FE program, ABAQUS [5]. Fig. 3 shows a quarter model for the circumferential tensile test. The specimen was loaded by displacement control on the upper mandrel. All mandrels were modeled as a rigid body. The contact condition for all models and the non-linear geometry condition for the elastic-plastic analyses were applied.

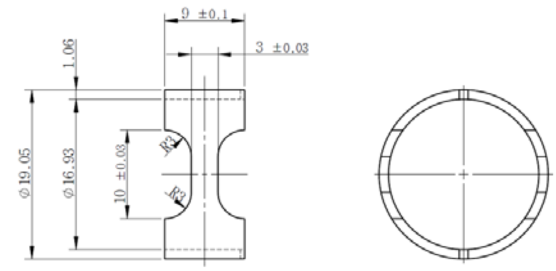

Fig. 1. Geometry of Ring-type circumferential specimen

Fig. 2. Typical specimen after failure

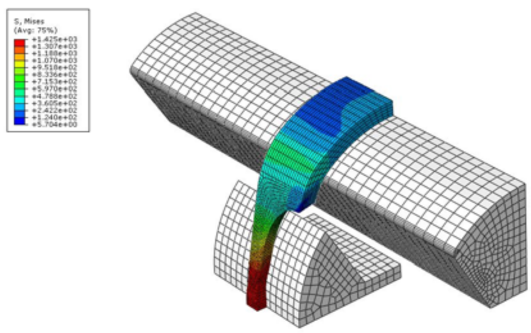

Fig. 3. FE model for simulation of circumferential tensile test

3.2 Optimization

In this study, a finite element analysis of the ring-type specimen was performed and an optimization method was used to determine the tensile properties that best predict the load-displacement curve obtained from the test. As an optimization method, a pattern search method was used. The pattern search was developed by Hooke and Jeeves [6]. The Hooke & Jeeves method incorporates the past history of a sequence of iterations into the generation of a new search direction. One such pattern search method is convergence, which is based on the theory of positive bases. Optimization attempts to find the best match (the solution that has the lowest error value) in a multidimensional analysis space of possibilities. The true stress-true plastic strain values used as the input data for the finite element analysis were used as variables and the root mean square of the load-displacement curve from the test and that of finite element analysis was minimized.

4. Result and discussion

Figure 4 compares the load-displacement curves obtained in the circumferential tensile test, the load-displacement curves with the tensile properties determined by the finite element analysis and the optimization method, and the two results are in good agreement. Since the 3-piece loading mandrels were treated as a rigid body in the finite element analysis, the load-displacement curve was corrected considering the machine compliance, and the initial gap of the finite element analysis and the test were also considered.

Comparing the results of the finite element analysis of Fig. 2 with those of Fig. 3, it can be observed that the fracture occurs at the bottom or upper part, not at the center of the reduced section. In addition, the initial bending of the ring-type specimen is well simulated. Figure 5 shows the true stress - true plastic strain curves in the circumferential direction using finite element analysis & optimization process. The tensile properties in the circumferential direction were found to be lower than those in the axial direction. However, the cause of the difference will be clarified through analysis of the microstructural analysis.

5. Conclusions

The purpose of this study is to derive the tensile properties of the alloy 690 steam generator tube which is used as the basic data for evaluating the creep rupture properties of the steam generator tube under severe accident condition. The axial tensile properties were directly derived through tests, and the tensile properties in the circumferential direction were derived using finite element analysis and optimization process. The difference of the tensile properties according to the two directions will be investigated by microstructural analysis. And the gauge length position will be compared with the current 9 o'clock position and 12 o'clock position. In addition, the effects of bending of specimen during the test and initial gap between specimen and mandrels on the results will be analyzed in detail.

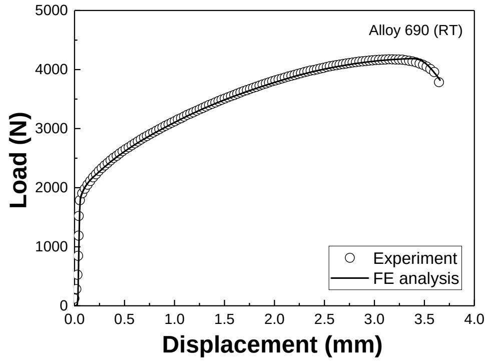

Fig. 4. Comparison of L-d curves from FE analysis and test

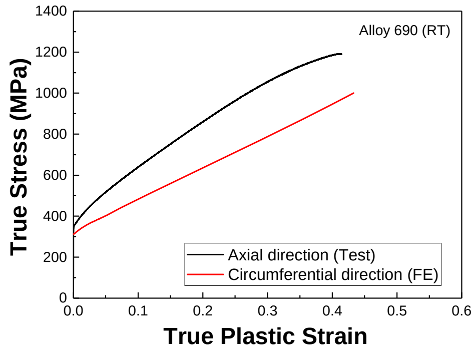

Fig. 5. True stress-true plastic strain curves for axial direction from the test and for circumferential direction from the FE simulation & optimization technique

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