Derivation of Circumferential Tensile Property of Alloy 690 Steam Generator Tube Using Inverse Analysis Method

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1. Introduction

The transverse tensile properties of the Alloy 690 steam generator tube used in a Korean PWR (pressurized water reactor) nuclear power plant is essential properties to analyze the creep rupture caused by the severe accident conditions. The transverse tensile properties of steam generator tubes cannot be directly obtained from the tubes tensile test because it have curved geometry and mixed loading condition during the test. In this paper, the circumferential tensile properties were derived using ring-type specimen and inverse analysis method. Much of this work has been published at the Korean Nuclear Society 2018 Spring Meeting and ASME 2018 Pressure Vessel & Piping Division Conference [1, 2]. In this paper, additional microstructure analysis results for axial and circumferential tensile properties are provided.

2. Experiment

The circumferential tensile specimen used in this study is depicted in Fig. 1. The ring-type specimen was used as a specimen for obtaining circumferential tensile property. Membrane and bending stresses in the loading cross-section due to the specimen geometry, an elastic bending of the loading mandrels, friction between the specimen and mandrel, initial gap between the mandrels, and so on exert an influence on the tensile test results during the test. Therefore, the stress-strain curve could not obtain directly. In this study, the circumferential tensile properties were derived using a finite element analysis and optimization technique.

3. Prediction of tensile properties

FE analyses were performed for simulating tensile tests using the general-purpose FE program, ABAQUS [3]. The number of elements and nodes in the FE mesh were 22947 elements / 56448 nodes. The contact condition for all models and the non-linear geometry condition for the elastic-plastic analyses were applied. The load-displacement curve was obtained from the FE analysis.

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 [4]. The true stress-true plastic strain values used as the input data for the finite element analysis were set to variables and the root mean square of the load-displacement curve from the test and that of finite element analysis was minimized during the optimization process.

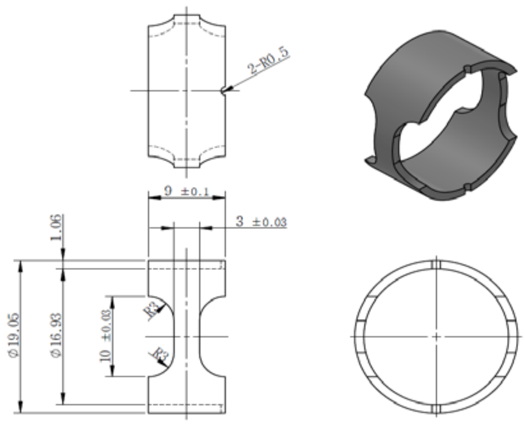

Fig. 1. Geometry of Ring-type circumferential specimen

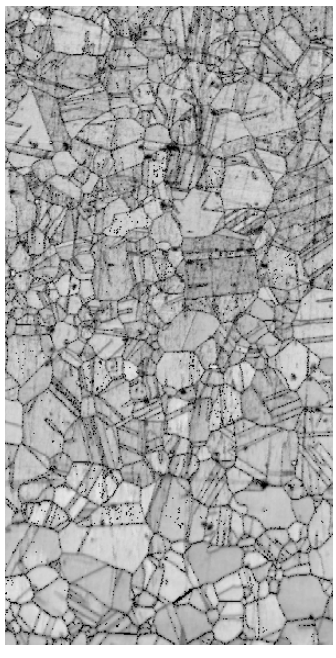

Fig. 2. Image quality map of alloy 690 SG tube

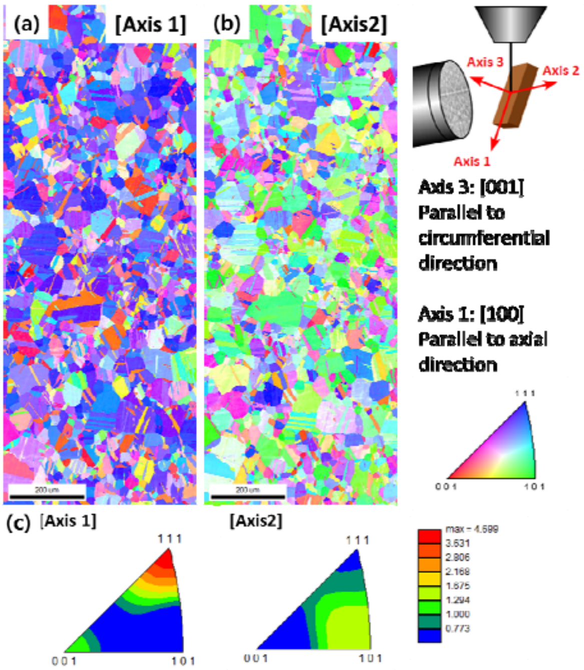

Fig 3. Inverse pole figure (IPF) map of Alloy 690 SG Tube measured to parallel to axial direction (a) and circumferential direction (b), and theirs IPF texture distribution (c)

Table 1. Tensile propeties of alloy 690 SG tube in axial and circumferential directions at room temperature

	Axial Direction		Circumferential Direction	
Yield Strength, YS [MPa]	Test	CMTR	Test	FE+Opti.
	357.4	303.37	-	310.06

4. Result and discussion

The load-displacement curves with the tensile properties determined by the finite element analysis and the optimization method are in good agreement. All effects such as bending, friction and initial gap were considered in FE analysis.

Table 1 summarizes the yield strength in the axial direction on the test and CMTR, and the yield strength in the circumferential direction using the finite element analysis and optimization method. The yield strength in axial direction was higher than that in the CMTR. The circumferential yield strength was lower than the axial yield strength.

In order to analyze difference in properties of the tensile directions, EBSD (electron backscatter diffraction) analysis was performed to explore microstructures and textures of SG tube. EBSD IQ(image quality) and IPF (inverse pole figure) map are shown in figs 2 and 3. In fig 2, grains of SG tube shows equiaxed shape. Usually, deformed grains during metal forming process are recovered by heat treatment process. However, in this study, texture of SG tube did not have random orientation as shown in fig 3. When texture was observed in axial direction, grains were strongly arranged along (111) plane. However, when texture was observed in circumferential direction, grains are slightly arranged along (101) plane. Based on the EBSD analysis, Schmid factors for axial and circumferential direction are calculated. Average Schmid factors for axial and circumferential direction are 0.417 and 0.456, respectively. From Schmid's law, the primary slip system will be the system with the greatest Schmid factor. If the same uniaxial stress is applied, the shear stress in the circumferential direction has a higher stress than the axial shear stress. Therefore, deformation in the circumferential direction is more likely to occur than the axial deformation [5]. Consequently, it can be thought that those differences in amount of deformation along directions and anisotropy textures cause the difference in tensile properties.

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 inverse analysis method. The difference of the tensile properties according to the two directions seems to be due to amount of deformation along directions and anisotropy texture.

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