# Residual Stress Evaluation of a Double Wall Tube for SFR Steam Generator

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## 1. Introduction

A steam generator has been one of the critical components determining the plant availability as well as the integrity of a sodium fast reactor (SFR). There have been many kinds of steam generators (SG) developed by several countries such as a single wall tube hockey stick shape SG, a single wall helical coil tube SG, a single wall straight tube SG, a double wall straight tube SG, and a double wall helical coil tube SG [1~7]. Each concept has advantages and disadvantages. The manufacturability, in-service inspection, economics, operating experiences, integrity, and reliability are to be considered to select a promising design concept of SG in each country.

In this study, a design concept of a double wall tube steam generator has been studied to improve the reliability of SG by reducing the possibility of a sodium-water reaction occurrence. The current focus of this research is an improvement of the heat transfer capability for a double wall tube and the development of a proper leak detection method for the failure of a double wall tube during reactor operation. The first test samples of double wall tubes are manufactured by applying a cold drawing fabrication technology, the length of which is 6 m.

The objective of this study is to measure the residual stresses of a double wall tube to confirm the desired mechanical contact between the inner and outer tubes. The neutron diffraction technology was applied to measure the residual stresses, and these results were compared with those from a numerical analysis.

## 2. Residual Stress Measurements

Three different kinds of DWT (Double Wall Tube) were prepared using a drawing fabrication technology as shown in Fig. 1. While the tube materials for three types of DWT are different, their dimensions are all the same; i.e., a length of 6 m, outer diameter of 30 mm, and inner diameter of 22 mm, and the thicknesses of both the outer and inner tubes are 2 mm. Machining rates of drawing are approximately 18.6% and 15.5% for the outer and inner tubes, respectively.

The outer and inner tube materials for type A, B, and C double wall tubes are G91/G22, G91/G22, and G91/G91, respectively, and small grooves are machined between the outer and inner tubes of type A and type C DWTs, while type B DWT has no groove at the interface between the outer and inner tubes.

A gap between the outer and inner tubes of a DWT was measured using a scanning electron microscope and an optical microscope, and their sizes are 5 – 10 μm, 5 – 11 μm, and 10 – 19 μm, respectively.

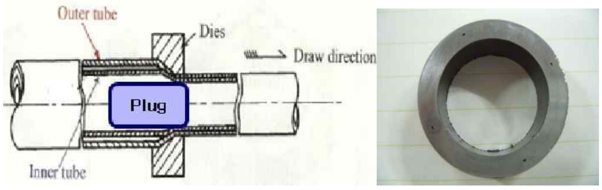


Fig. 1. Schematic of Drawing Fabrication Process of a DWT

The residual stresses of double wall tubes were measured using the neutron diffraction inspection facility at the HANARO research reactor, as shown in Fig. 2.

Fig. 2 shows the test sample arrangement at the HANARO research reactor facility where a 30 cm long test sample for each type of DWT was installed, and the residual stresses were measured at the center region of a sample to avoid the end effect.

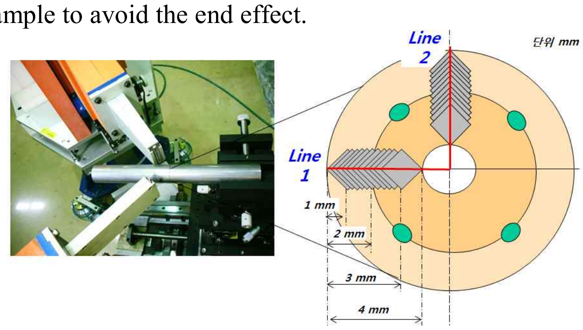


Fig. 2. Residual Stress Measurement using Neutron Diffraction Methodology (HANARO ST1 RSI)

For convenience, 2 lines at 90 degree intervals and 11 points for each line were measured as shown in Fig. 2. The residual stresses were obtained at 1 mm – 3 mm from the outer surface with 0.2 mm intervals. The measurement volume was $1\times1\times1$ $mm^3$, and the diffraction angle 2θ is 76 degrees.

Fig. 3 shows the measured residual stresses at each line of type A, B, and C double wall tubes. Dominant stresses were axial and hoop stresses, and they show a tensile behavior in the outer tube while a compressive behavior in the inner tube. A small value of compressive mechanical contact stress was observed at the interface between the outer and inner tubes.

## 3. Residual Stress Analysis

In parallel with measurements of residual stresses, a numerical analysis using ANSYS commercial finite element analysis code [8] was performed. In a numerical analysis, only a type B double wall tube was considered because it does not include non-symmetrical grooves at the interface between the outer and inner tubes.

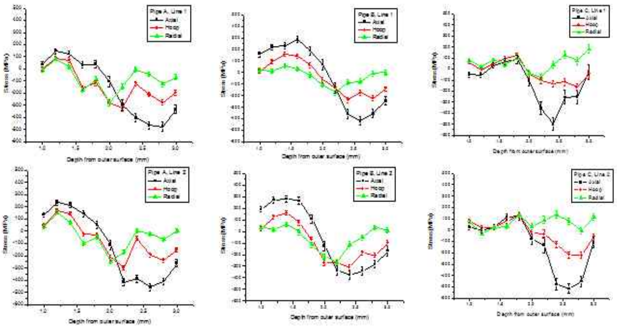

Fig. 3. Measured Residual Stress Distributions for type A, B, and C Double Wall Tubes

As shown in Fig. 4, the die and plug for a drawing process are included in the analysis model, and friction coefficients between the die and tube and between tubes are 0.05 and 0.2, respectively, by considering the lubricating condition during the fabrication process. The left side of Fig. 4 shows the outer and inner tubes at the start of the drawing process, and the right figure shows the DWT after the drawing process. Axi-symmetrical modeling was applied, and the total number of Plane 183 elements and nodes were 8,492 and 20,878, respectively. An elasto-plastic analysis was carried out to simulate the drawing process.

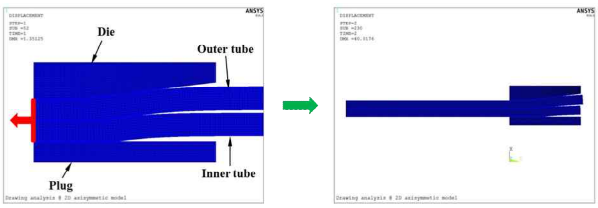


Fig. 4. FEM Modeling of a DWT Fabrication Process (Left : start of drawing, Right : after drawing)

Fig. 5 shows the computed residual stresses for type B DWT, and it was noted that a compressive contact stress of 21 MPa was observed at the interface between the outer and inner tubes.

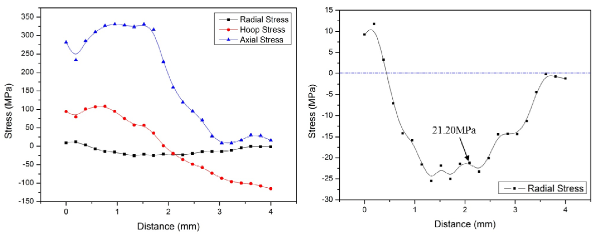


Fig. 5. Residual Stresses from the result of FEM Analysis (Type B)

## 4. Results and Discussion

The measured residual stresses for a type B double wall tube were compared with those from the FEM analysis simulating the drawing process of a DWT, as shown in Fig. 6. In Fig. 6, empty symbols with solid lines are the numerical results, and the solid symbols indicate the measured results.

The computed and measured residual stress distributions show similar trends along the radial direction but their values are different with each other. Even though a desired mechanical contact between outer and inner tubes was confirmed, it was suggested to fabricate more double wall tubes and measure the residual stresses, and to then compare those results with the computed ones for reproducibility and reliability.

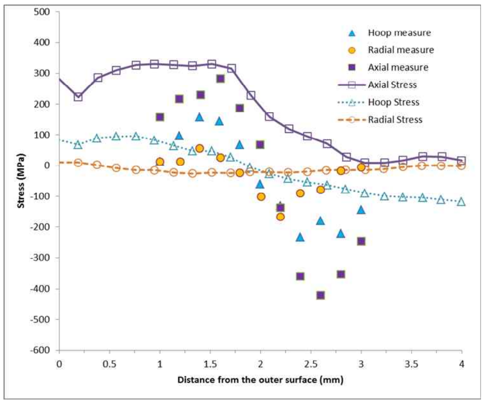


Fig. 6. Comparison of Residual Stresses between Measurement and Analysis (Type B)

## Acknowledgement

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