A Study on Residual Stress of U-Bending Heat Transfer Tube using Rotary Draw Bending Processing

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1. Introduction

Most of the nuclear power plant that has been operating in our country, has adopted PWR (Pressurized Water Reactor). PWR nuclear reactor does not generate a change of state of the primary coolant at inside the reactor. For that reason, PWR is necessary steam generator to obtain high-temperature and high-pressure dry steam for driving the turbine and the power generator.

The heat of high temperature generated by the nuclear fuel fission reaction, apply heat to the primary coolant about 320 ℃, and pressurize to about 157kgf/cm^2. Since then, the primary coolant flows into the heat transfer tube of the steam generator. The outside of the heat transfer tubes is flowed the secondary coolant of about 220℃ and about 60kgf/cm^2 state. The secondary coolant is converted to steam state of about 270℃ and 60kgf/cm^2, through the heat exchange of the boundary of the heat transfer tubes. The secondary coolant turned into steam through this heat exchange process, convert to dry steam of about 99.5% through the moisture separator and moisture dryer, flow to the turbine system.

As above, the heat transfer tubes can be considered a kind of heat exchange boundary that is direct heat exchange from inside the steam generator.

The heat transfer tubes of the steam generator have various bending radius. The heat transfer tubes have the U-shape and L-shape, depending on installed location and arrangement. The forming of the heat transfer tubes can be applied to process of rotary draw bending, roll bending, ram bending and etc. The rotary draw bending process is mainly used, when the bending radius is small.

Recently, Alloy 600 or Alloy 690 tubes have been used as material for the heat transfer tubes of the steam generator. The purpose of this study is to evaluate the residual stress of the heat transfer row-1 tubes for deriving the remaining residual stress after U-Bending processing, as a primary study.

In this study, the samples of U-Bending tube were made using Rotary Draw Bending Machine by Alloy690 straight tube. Finite Element Method (FEM) analysis for the U-Bending process was performed using the ABAQUS Explicit. Furthermore, it was measured to the test of the Hole Drilling Method (HDM), and compared the FEM and HDM results.

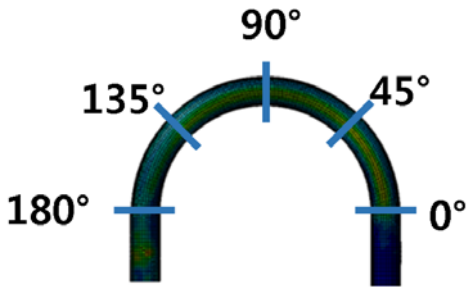

Fig. 1. Location of Residual Stress Evaluation

2. Residual Stress and Target of Measurement

Residual stresses in structural materials are stresses that exist in the objective without the application of any service or other external loads. Manufacturing processes are the most common causes of residual stress. Residual stress is one of the causes which make defects in engineering components and materials. And it is interested in the measurement of residual stress in many industries. There are commonly used methods by which residual stresses are currently measured. The residual stresses are determined by the amount of strain.

In this study, Alloy 690 straight tube for U-Bending process is manufactured through mechanical-thermal process. The final dimensions of Alloy 690 straight tube is outer diameter of 19.05mm, tube wall thickness of 1.067mm. The method of U-Bending process was used for Rotary Draw Bending that is processed tangential bending with mandrel and tube at bending point. The internal mandrel is fixed in the vicinity of the bending point, the clamp for straight tube is rotated with the Bend Die. The material of mandrel is used Mono Cast Nylon, it was to prevent the damage such as scratch caused on the inner surface.

The heat transfer tubes used in the experiment is row-1 heat transfer tube which is bending radius of 76.2mm, which is the same dimensions used in Uljin Nuclear Power Plant Unit 3 and 4. The row-1 heat transfer tube takes a lot of stress during plastic deformation because bending radius is the smallest. It is expected to remain the biggest residual stress. It is the reason that is used row-1 heat transfer tube.

For the reliability of the measured data, it was compared using the analytical method and experimental methods. The measured location is the flank of 0,45,90,135,180 degree positions, in the 45-degree interval from the starting position to the finish position. The experimental method will be mentioned later is impossible to measure all of the location. Therefore, measurement was performed at the 45-degree interval.

3. Measurement Method of Residual Stress

3.1 Analytical Method

Measurement methods were used two types as the finite element analysis method and the experimental method.

The first, finite element method (FEM) analysis was performed using ABAQUS. The common conditions in analysis and experiment are Bend Die Radius 76.2mm, Mandrel Outer Diameter 16.50mm, Total Bending Time 14.5sec. The residual stress values were derived from U-Bent Tube that is completed elastic recovery after bending process. The schematic results by analytical method were shown in Figure 2 and 3.

3.2 Experimental Method

Residual stress measurement can be used several ways, however this study was used Hole Drilling Method (HDM) using the Strain Gauge. HDM is the method for converting the stress from relieved strain that was occurred when drill fine holes (small cylindrical hole) in strain gauge attached to the specimen. HDM is a quasi-destructive method that is tinily destroyed the specimen. HDM is commonly method used for measurement of Residual Stress. It is impossible to measures all of the locations, because require to attach the strain gauge and need to destruct the specimen. Therefore, this study was performed to evaluate the tendency of residual stress values depending on the location selected areas in 45-degree interval. The strain gauge used in the experiment is the three-axial Rosette Strain Gauge.

3.3 Results of Analytical and Experimental Method

The FEM results are as follows; The minimum value is about 76MPa in the location of 180-degree and the maximum value was predicted to be about 238MPa at 90-degree. The value of other location is around 150MPa. The HDM results are as follows; The maximum value was obtained to be about 324 MPa at 90-degree. The value of other location is around 200MPa. Thus, FEM and HDM both methods showed compressive residual stresses. It is difference of 37 ~ 140MPa between FEM and HDM method. The two methods were all had maximum value at 90-degree, showed tendency to decrease the value around the 90-degree location. The entire analytical and experimental results were shown in Figure 5.

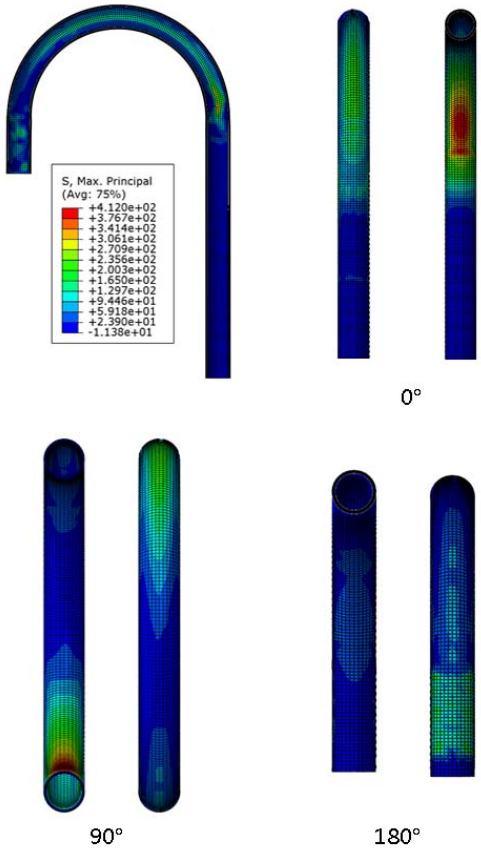

Fig. 2. Results of analytical method (FEM)

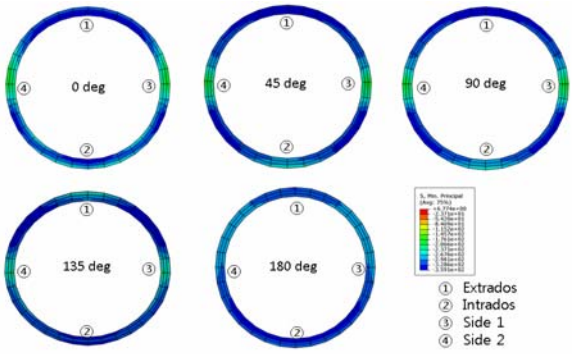

Fig. 3. Residual Stress of each section (FEM)

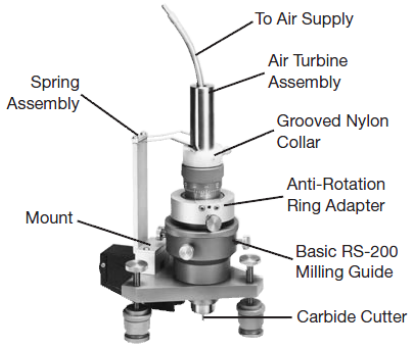

Fig. 4. Equipment of Residual Stress Measurement (HDM)

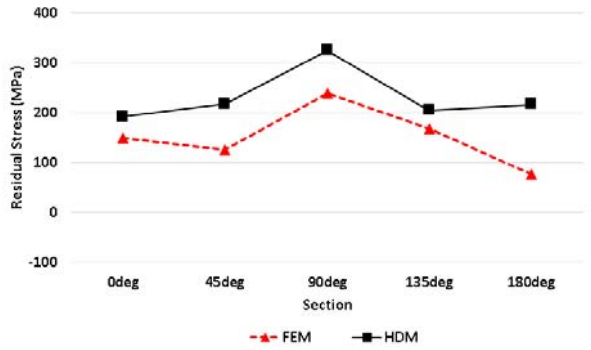

Fig. 5. Comparison of FEM and HDM

4. Conclusions

This study was measured Residual Stresses of the Row-1 Heat Transfer Tube in Steam Generator. The measurement methods are used two type of the analytical method (FEM) and experimental method (HDM).

It was confirmed that the correlation of the measurement of the FEM and HDM methods. The FEM and HDM both methods showed compressive residual stresses. In numerical terms, the HDM is shown that higher value than the FEM. The values showed difference of +37MPa ~ +140MPa. Even though the FEM results came out relatively small, but it was known the usefulness of the analysis in trend terms.

The measurement results of both methods were showed maximum value at 90-degree location. The maximum value in the experimental method is 324MPa. This value is nearly 80% of Alloy690 Yield Strength 412MPa.

Acknowledgment

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