Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

A Study on U-bending Technology using Rotary Draw Bending

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1. Introduction

The nuclear power plant, which uses pressurized water reactor (PWR) is essentially needed steam generators (SGs) to obtain dry steam for operating turbine generator. Especially, the steam generator plays an important role in producing the dry steam, and it is operated for long periods of time under the conditions of high temperature and high pressure. In the steam generator, heat transfer phenomenon for producing the steam between the primary system of the nuclear reactor and the secondary one occurs around the heat transfer tube. That is, the primary coolant with high temperature(320℃) and high pressure(157Kgf/cm2) derived from the reactor flows in the heat transfer tube, and the secondary one runs out that tube. Therefore, it is able to mention that the heat transfer tube itself is a boundary of the heat transfer phenomenon.

The heat transfer tube bundle of each steam generator used for the PWR and the PHWR(Pressurized Heavy Water Reactor) is generally composed of about 8,000~13,000 U-tubes. And these tubes are the core component as the structural and heat transfer material in the steam generator, which is in charge of cooling about 70% of the cooling surface of the primary system.

For achieving the U-bending process with the thin-walled tube, generally, a mandrel could be inserted in the tube according to the bending radius. But when the bending radius is small, the tube U-bending process could be also performed without the mandrel. In this study, numerical and experimental investigations on the U-bending process for producing the heat transfer tubes by using the straight and long tubes were carried out with the consideration of the elastic recovery after the U-bending. In the numerical approach, finite element analysis scheme was adopted with a commercial code, ABAQUS Implicit/Explicit. As the precedent study, the related experiment was also performed to verify the predicted results on the ovality and the minimum wall thickness of the U-bending heat transfer tube. Furthermore, its bending process was also conducted to analyze the deformation behavior for the Alloy 690 tube.

2. Methods

2.1 Numerical analysis

Fig. 1 shows the numerical simulation results for the U-bending when the tube blank was fully deformed. The simulation condition was set to be the total bending period of 14.5sec., the angular speed of 16.6mm/s, and the bending angle of 181°. On the whole, it was investigated that the excessive deformation at the localized regions such as the beginning area of the U-bending and the contact area between the tube and the guide mold, and then the maximum effective stress was predicted as the value of about 625MPa. On the other hand, it was noticed that the excessive deformation behavior was relieved by considering the elastic recovery. That is, the maximum effective stress was obtained as the value of about 300MPa after performing the elastic recovery as shown in Fig. 2 and Fig. 3.

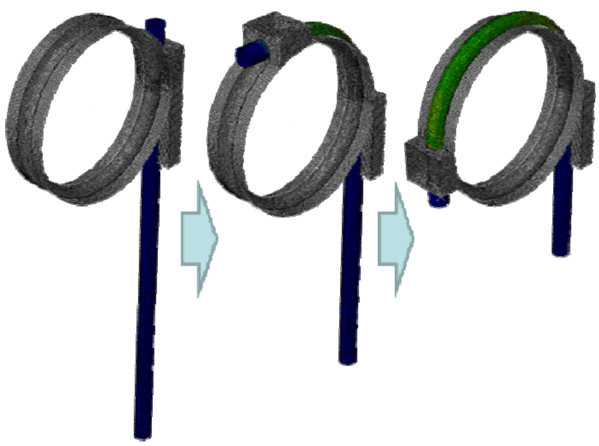

Fig. 1. Simulation procedure for U-bending

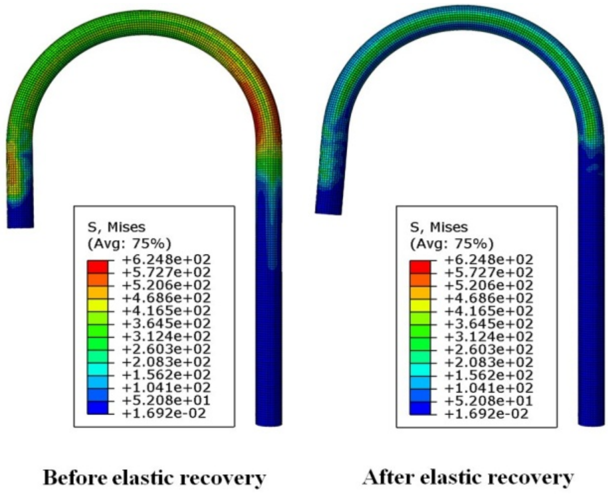

Fig. 2. Simulation result of U-bending (unit : MPa)

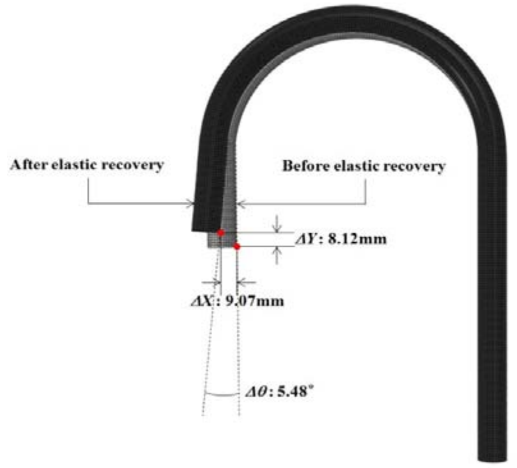

Fig. 3. Elastic recovery of U-bending

2.2 Experiments

The heat transfer tube of the steam generator used for the nuclear power plant has various bending radius from 76.2mm to 279.4mm with the U-shape. In fact, the bending radius of the heat transfer tube for the steam generator is generally chosen depending on the type of the nuclear reactor. In this study, the experimental approach was performed to verify the results of the numerical simulation. And then, the bending radius was 76.2mm, the tube diameter was 19.05mm and the wall thickness of the tube was 1.07mm. In the U-bending experiments, the process variables were selected with the values of 60%, 67% and 75% for the angular speed, those of 10.5sec, 14.5sec and 21.5sec for the rotation period and those of 180˚ , 187.5˚ and 190˚ for the bending angle, respectively.

4. Results and discussions

As the results of the numerical prediction on the tube wall thickness and the ovality as shown in Table 1, the minimum wall thickness of the deformed U-bending tube with the Alloy 690 was decreased about 6.07% of the initial tube thickness, and the minimum tube diameter was also predicted as the value of 18.28mm, which was reduced about 6.40% of the initial tube diameter. In detail, the U-bending condition of the numerical simulation was same with that of the experiment. From the experimental results, the outer diameter was measured with the value of 18.63mm in the cross-section of 0˚ , 18.28mm in the cross-section of 45˚ and 90˚ , respectively. It is shown that the numerical results were similar with the experimental one, but there are a little variation. According to the specification of the heat transfer tube for PWR, the ovality definition available and its limit is under 3%, but the value of the ovality in this study was investigated as about 4% for U-bending tube. It means that the modification on the U-bending process and the application of the inner mandrel is needed to satisfy the ovality limit.

Table 1: Summary of predicted result on ovality(unit : mm)

Section	Item	Position	Predicted	Variation
0°	Thickness	①	1.026	-0.044
		②	1.130	0.060
		③,④	1.073	0.003
	Diameter	Vertical	18.63	-0.87
		Horizontal	19.01	-0.49
45°	Thickness	①	1.005	-0.065
		②	1.149	0.079
		③,④	1.071	0.001
	Diameter	Vertical	18.28	-1.20
		Horizontal	19.04	-0.46
90°	Thickness	①	1.005	-0.065
		②	1.149	0.079
		③,④	1.071	0.001
	Diameter	Vertical	18.28	-1.22
		Horizontal	19.04	-0.46

4. Conclusions

In this study, the U-bending process was considered to simulate and manufactured the heat transfer tube used for the steam generator. To investigate the deformation behavior of the U-bending process, and a series of the experimental approach was also performed to verify the result of the numerical simulation. As the results, the U-bending results according to the numerical prediction shows a similar and reasonable tendency with the experimental one, even the comparison results have a little variation. As the future work, a series of numerical simulation combined with the experimental approach by adopting the Alloy 690 tube as the pilger one, which is heat treated, will be performed to find proper process variables such as the angular speed, the bending angle to compensate the elastic recovery.

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