An investigation of wall thinning and cross sectional geometry change of bent tube of small diameters

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1. Introduction

In general, bent tube has widely been using in nuclear power plants (NPPs) such as steam generator U-tubes and in-core instrumentation (ICI) tubes, etc. One of the most troublesome problems is change of tube wall thickness after bending process. In the extrados, the tube wall is subjected to tensile stress and it becomes thin, while in the intrados is subjected to compressive stress resulting in thick wall. Moreover, the ununiformed deformation of cross section of bent tube also occurs, which is not perfectly circular and uniform but a significant ovality can result in from the fabrication process.

In this study, an investigation of the deformation profile of bent tube such as wall thickening/thinning and cross-sectional distortion in cold bending process will be performed. The finite element model, using ANSYS 14.5, is developed and simulated the bending process. The results will be investigated for any change of diameter and circularity perpendicular to the bending axis.

2. Considerations of bending method

There are several types of bending methods. This study will use press bending method, which has commonly been used in reality. The features of press bending method are sketched simply as shown in Fig. 1.

The model consists of three rollers which have same mechanical parameters, rollers 2 and 3 which are in a straight line and fixed on the table of a press or adjust the distance between two rollers if change of bending radius is required, while roller 1 is fixed by the battering ram of the same press and moves up or down depending on required bend radius of tubes.

In order to get desired bend radius, tube 4 is placed on rollers 2 and 3, while roller 1 moves vertically on the tube causing plastic deformation. The bending radius is adjusted by changing horizontally distance a between two rollers 2 and 3 and vertically stroke b of roller 1.

Some terminologies are used in this study such as thinning, thickening, and ovality will be described as follows:

Thinning, which occurs at extrados of the tube bend, is defined as the ratio of the difference between the nominal thickness and the minimum thickness to the nominal thickness of the tube bend and is expressed in percentage as given in Eq. (1).

$$C_{th} = \frac{t - t_{min}}{t} x100 \quad (1)$$

Thickening, which occurs at intrados of the tube bend, is defined as the difference between the maximum thickness and the nominal thickness divided by the nominal thickness of the tube bend. The percentage thickening is given in Eq. (2).

$$C_t = \frac{t_{max} - t}{t} x100 \quad (2)$$

Ovality, which is determined by the difference between the major and minor diameters divided by the nominal diameter of the tube as given in Eq. (3).

$$C_0 = \frac{D_{max} - D_{min}}{D} x100 \quad (3)$$

where $$D = \frac{D_{max} + D_{min}}{2} \quad (4)$$

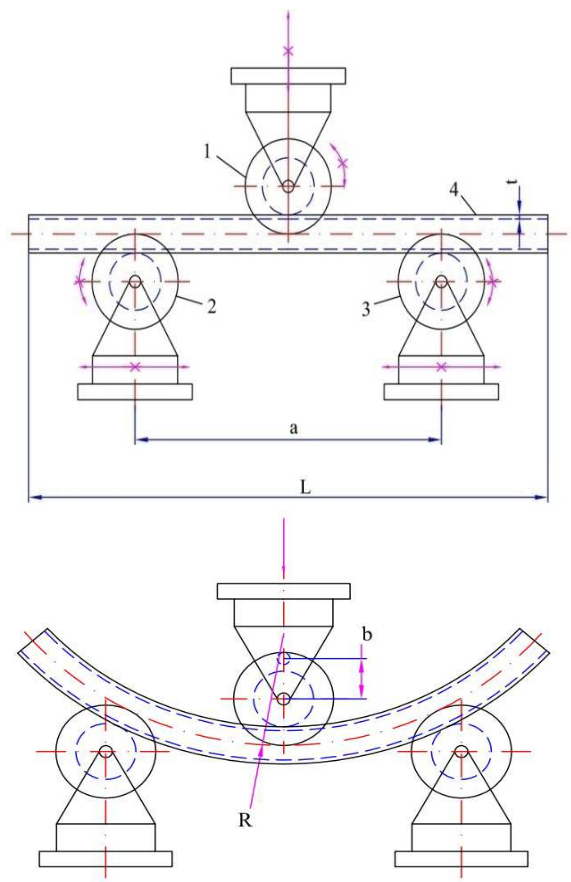

Fig. 1. Sketch of the principle of press bending method: 1-upper roller; 2, 3-lower rollers; 4-tube; b-the distance covered by the upper roller during the bending; R-the bending radius.

3. Bending process analysis with FEM

3.1 Modeling and Meshing

In this study, three different tube sizes will be used with main parameters as given in table I:

Table I: Dimension of welded and seamless stainless steel pipe–SI units

Nominal Pipe Size in.	Pipe Outside Diameter, mm	Nominal Wall Thickness, mm Sch. 40S
3/8	17.1	2.31
1/2	21.3	2.77
1	33.4	3.38

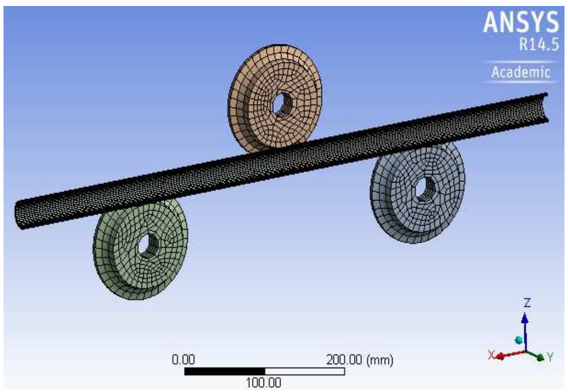

Fig. 2.Geometric and meshing of tube bending

To reduce the size of FEM model and simulation time, the symmetric model of press bending method is created as shown in Fig. 2. It consists of three rollers and one tube where contact between tube and rollers were defined to reflect actual contact condition.

The bending of tube due to vertical movement of roller 1 was specified as "PATH" that produces bending as spring back as well.

Refinement of mesh was done to get more accurate solution of bending process.

3.2. Boundary Conditions

For the material of bending tubes, austenitic stainless steel F316L was selected which is used in the nuclear power plant broadly, with mechanical properties of Young's modulus E=2.83x10^7 psi and Poisson's ratio v=0.3. The tube is defined as a deformable body, while three rollers are assumed as solids have absolute stiffness by using "RIGID" option.

For the scope of this study, the material is assumed to be elastic perfectly plastic. Therefore strain hardening effect was not considered and results in conservative solution.

Contact between various pairs of surfaces: tube 4 and the rollers 1, 2, and 3 were all defined with friction condition of 0.1.

The stroke b of roller 1 is defined to produce displacement resulting in required bending radius.

4. Results and discussion

Distribution of total mechanical strain of bent tube wall is presented for bending radius R=300mm and diameter D=33.4 mm.

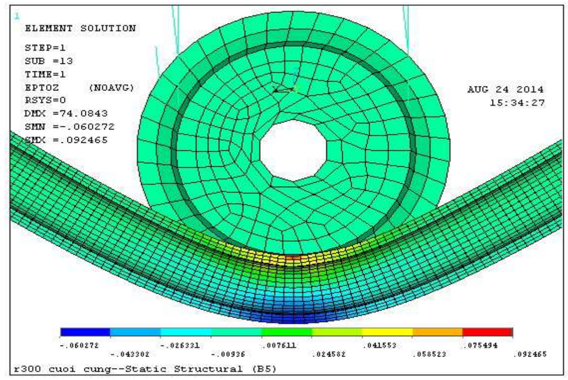

Fig. 3. Distribution of total mechanical strain of bent tube wall

As shown in Fig. 3 the extrados region becomes thinner, and intrados wall thickens.

Both the wall thinning and thickening changes tube cross-sectional geometric profile as shown in Fig. 4 and Fig. 5. The results indicated that when bending radius increases, the wall thickness decreases as well.

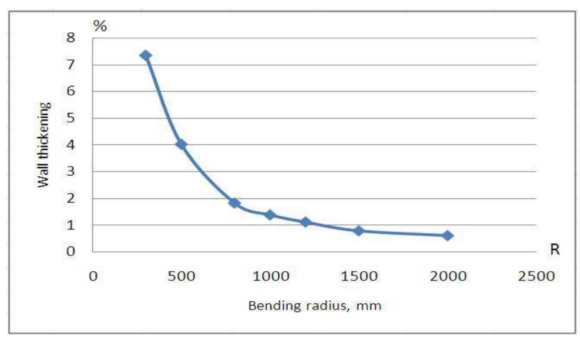

Fig. 4. Effect of bending radius for wall thickening of tube for diameter D=33.4mm

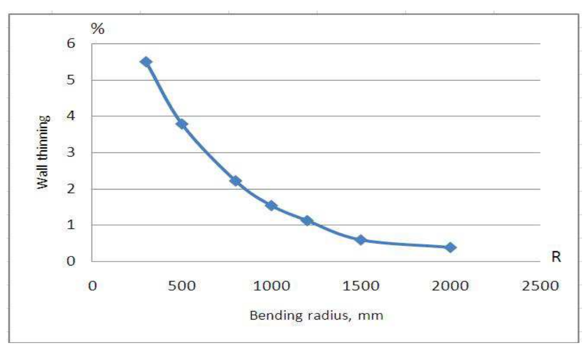

Fig. 5. Effect of bending radius for wall thinning of tube for diameter D=33.4mm

Figure 6 shows the effects of tube diameter in bending. If the diameter of tube increases, the wall thickness increases as well. The maximum equivalent strain for different tube diameters corresponding to Fig. 6 is shown in Fig. 7.

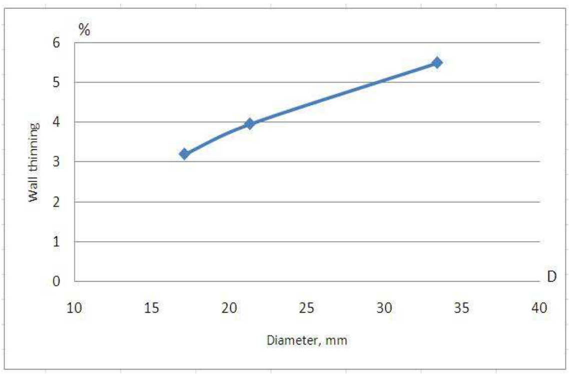

Fig. 6. Effect of diameter for wall thinning for bending radius R=300mm

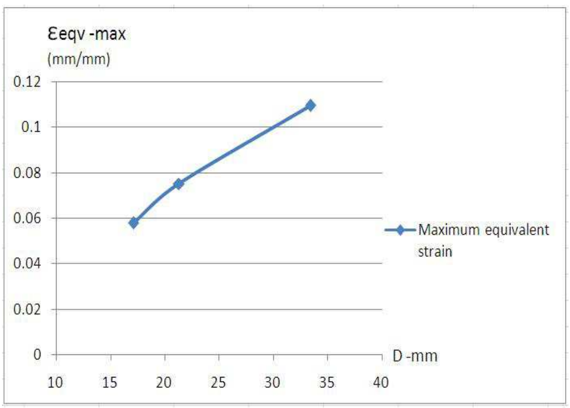

Fig. 7. Effect of diameter for maximum equivalent strain for bending radius R=300

Fig. 8 presents the ovality change according to the tube diameter. It shows that the larger diameter of tube causes the larger change of ovality percentage. This results show that the tolerance of tube inner diameter be carefully specified if ICI probe is to be inserted through the tube.

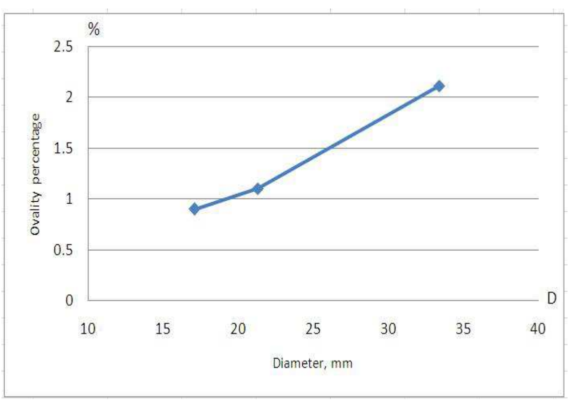

Fig. 8. Change of ovality for bending radius R=300mm

5. Conclusions

The analyses showed that the change of wall thickness of tube will happen in bending process. Consequently, the bend region of tube appears thicker wall at intrados and thinner wall at extrados. Moreover, bending process affects the ovality of tube cross section at bend region.
From these results, wall thinning and cross-sectional ovality change need to be considered in the application and design of tube. In case of ICI guide tube, the inner circularity very important since ICI probe has to pass through the bend elbow, and any deviation from the tolerance causes stuck of ICI probe in the bend region. This is one of the particular applications where geometric deviations need to be carefully monitored. In fluid application of tube, the thinning is more of concern than the ovality of cross section. Hence there is also limit on how much wall thinning be allowed. The simulation presented in this paper is focused on the estimation of geometric variation resulted in bending process of tube with typical bending process.

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