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Limit load analysis of heat induction bending pipe (90°) with thinning on the extrados

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1. Introduction

Application of heat induction bending technology could reduce the number of welds, thus time and cost can be decreased dramatically during installation, maintenance and repair. For this reason, Department of Energy, USA has recommended application of this technology to construction of nuclear power plant in 2004[1]. Recently, the technology has been applied to non-safety-related systems in Shin-Hanul Unit 1 and 2. However, application to the safety-related systems is not decided yet due to lack of application cases and Code & Standard as well as not confirmed safety performance. For application of this technology, several researches are being performed in Korea [2]. In this paper, as a part of those researches, limit load of pipe bend with thinning on the extrados is compared with the other paper which performed same analysis for normal elbow [3], and applicability of bending technology is reviewed.

2. Analysis Methods

In this section, configuration of heat induction pipe bend (90°), and its FE model and analysis method are described.

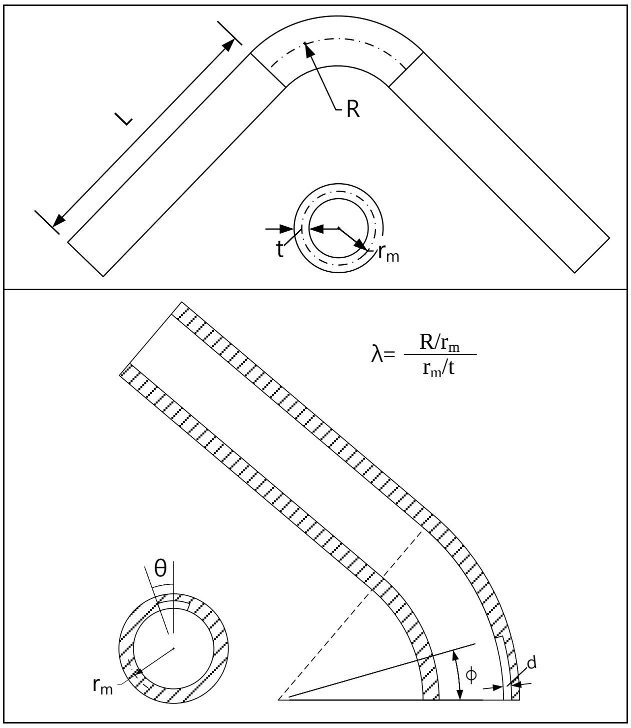

Figure 1. Schematic illustration of half bending pipe

2.1 Model of heat induction pipe bend

Figure 1 depicts the model of heat induction pipe bend used for analysis. Since heat induction bending is a manufacturing process which bends straight pipe to the required angle by applying heat and compressive axial load, the bent pipe has thinner extrados and thicker intrados than normal elbow. The thickness of the extrados is assumed to be $0.875t_n$ which is the minimum design thickness. Then thickness of intrados was obtained on the assumption that the volume is not changed after bending. It is assumed that angle between straight and curved pipe in the transient portion is 30°, and straight pipe with length $15 \cdot r_m$ is considered together in order to minimize 'end effect'[4].

R/r_m, r_m/t and λ are used as the parameters which determine shape of curved pipe, and d/t, θ/π and ϕ are used to determine the shape of thinning.

2.2 FE model

ANSYS 13.0 is used for this analysis. Figure 2 depicts the FE model and its mesh. EPP (Elastic Perfectly Plastic) material is used, and the analysis is performed with large deformation option. Using arc-length method, limit load is obtained in the point that the tangent stiffness matrix becomes singular.

Shape of thinning is modeled like rectangle, considering easiness of modeling and conservatism. Solid186, 3D 20 nodes structural solid elements, is used with uniform reduced integration option. 4 elements to thickness direction, 2 elements in thinning depth are used.

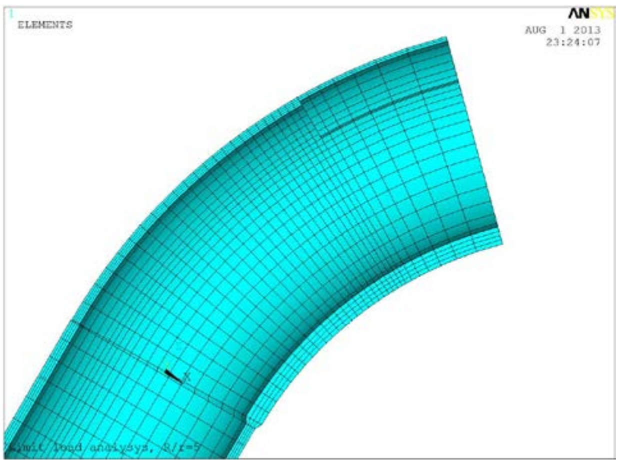

Figure 2. Finite Element of pipe bends

3. Results

The limit load of pipe bend with longitudinal and circumferential thinning is calculated and compared with those of normal elbow [3]. The calculated limit load is normalized by dividing limit load of pipe bend (P_L) by theoretical limit load of normal elbow (P_0) [5].

$$P_0 = \left(\frac{2}{\sqrt{3}}\sigma_0\frac{t}{r}\right)\left[\frac{1-r/R}{1-r/(2R)}\right] \quad \text{(1)}$$

3.1 Longitudinal thinning ($\phi \leq 40$, $\theta/\pi=0.3$)

Figure 3 depicts limit load of pipe bend when longitudinal thinning increases. Curved lines in the figures show approximate expressions, Eq.(2) of limit load for normal elbow which is presented in reference [3]. In the Eq.(2), f_0 and f_∞ can be obtained from Eq.(3) through. Eq.(5).

$$\frac{P_L}{P_0} = (f_0 - f_\infty)exp\left(-\beta\frac{\ell}{d_0}\right) + f_\infty$$
$$\beta = -2.76 + 18.3\frac{d}{t} \quad \text{(2)}$$

As seen in the figure, limit load usually becomes converged to certain value as longitudinal thinning increases in $\phi \geq 15°$, which is same behavior in normal elbow case.

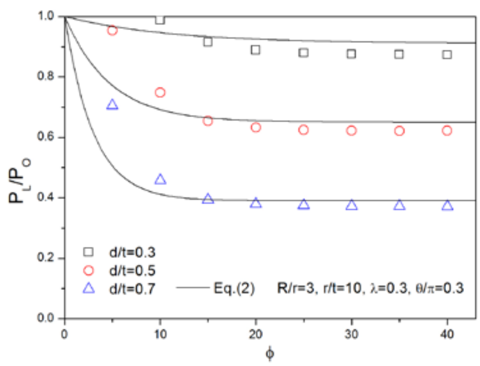

Figure 3. Effects of Longitudinal Thinning

3.2 Circumferential thinning

In this case, d/t_{ex}=0.3, 0.5 and 0.7 are considered in the basis of extrados thickness (t_{ex}). Figure 4 depicts limit load of pipe bend for circumferential thinning. Dotted line and solid line in the figures show approximate expressions (Eq.4 and Eq.5) for limit loads of normal elbow which are circumferentially thinned by 90°, 180°, respectively [3].

$$\frac{P_L}{P_0} = f_0 = 1 \quad \text{for no thinning} \cdots \text{(3)}$$

$$\frac{P_L}{P_0} = f_\infty = min\left[1, (1.6-\lambda)\left(1-\frac{d}{t}\right)\right] \quad \text{for } \theta/\pi \leq 0.5 \cdots\cdots \text{(4)}$$

$$\frac{P_L}{P_0} = f_\infty = \left(1-\frac{d}{t}\right) \quad \text{for } \theta/\pi = 1 \cdots\cdots\cdots \text{(5)}$$

Limit load of pipe bend decreases with thinning depth, however, it's not significantly affected by amount of circumferential thinning. In addition, it does not decrease so much even though pipe bend is fully thinned in circumferential direction, while it does in normal elbow case.

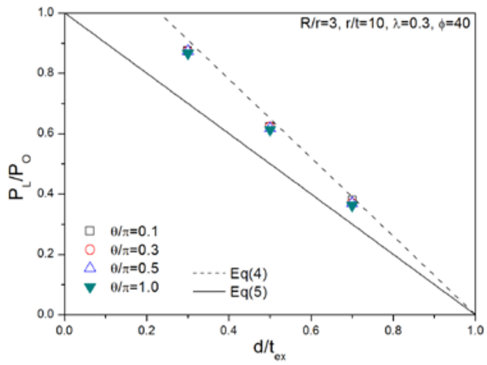

Figure 4. Effects of Circumferential Thinning

3. Conclusions

As discussed earlier, limit load of pipe bend with thinning is not significantly different with normal elbow. When the thinning increases into longitudinal direction, limit load is reduced but converged to specific value, and when it increases into circumferential direction, maximum value of limit load is smaller than normal elbow but not significantly, whereas minimum value is larger. Thus it can be said that there is no serious problem to apply pipe bending technology to the safety-related piping system instead of elbow, even though thickness of extrados is reduced when it is fabricated.

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