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Real-Scale Failure Tests on Local Wall-Thinned Elbow under Internal Pressure

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1. Introduction

Wall thinning defect due to flow-accelerated corrosion (FAC) is one of the degradation mechanisms of carbon steel piping components in nuclear power plants (NPPs) [1]. The wall-thinning defect leads to abrupt rupture of piping components under normal operating pressure. It is important to accurately evaluate the failure pressure of piping components with local wall thinning to ensure the integrity of piping system of NPPs [2, 3]. Unfortunately, the failure pressure data on the internally wall-thinned pipe is very rear. For wall-thinned elbow, especially, the published data is nothing up to this time. Therefore, this study performs failure test using real-scale elbows containing simulated wall-thinning defect under internal pressure, and investigates the effect of wall thinning geometries on the failure pressure. Also, the reliability of existing model is examined using these data.

2. Experimental procedure

As shown in Fig. 1, an elbow connected to straight pipe at both ends was employed in the failure tests. Its nominal diameter and thickness are 114.3mm and 8.6mm, respectively. The elbow material is a carbon steel designated by ASTM A234 WPB, which generally used in the secondary piping system of NPPs. The various type of simulated wall thinning was machined inside wall of elbow, and its circumferential and axial shapes were assumed as circular. Table 1 lists the dimensions of wall thinning defect considered in the experiment.

The experimental apparatus shown in Fig. 2 is composed of pressurization system, specimen gripping stage, visible protection wall, and data acquisition system. Prior to failure tests, wall thickness at bend region of elbow was measured using ultrasonic technique to confirm the dimensions of wall thinning defect. In all tests, internal pressure is only considered as applied load, and the specimen was pressurized up to final failure by hydraulic pump with rate about 1MPa/min. During the pressurization, axial and circumferential strains at intrados, extrados, and crown of elbow, internal pressure, and displacement at end point of specimen were measured.

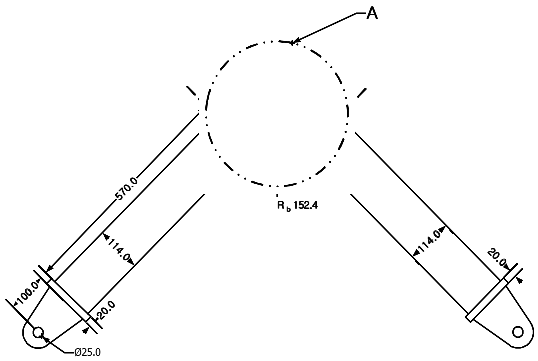

Fig. 1 Dimensions of wall-thinned elbow specimen

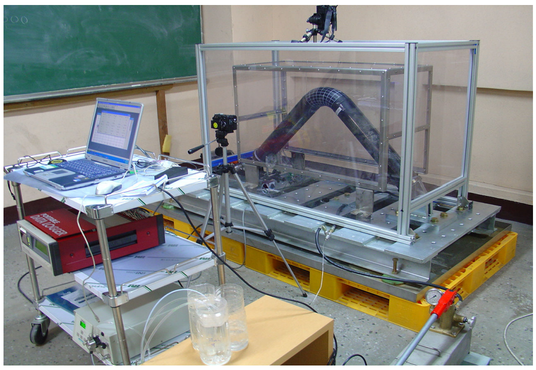

Fig. 2 Failure pressure test apparatus for wall-thinned elbow

Table 1 Matrix for failure test of wall thinned elbows

ID. No.	Thinning length, L/D_o	Thinning angle, θ/π	Min. thickness, t_p [mm]	Thinning location
SP-2	0.25	0.25	2	Extrados
SP-3	0.5			
SP-4	1.0			
SP-5A	1.0	0.125		
SP-6A		0.5		
SP-10	1.0	0.25	1.5	
SP-16A	1.0	0.125	2	Intrados
SP-15		0.25		
SP-17A		0.5		
SP-19	1.0	0.25	1.5	

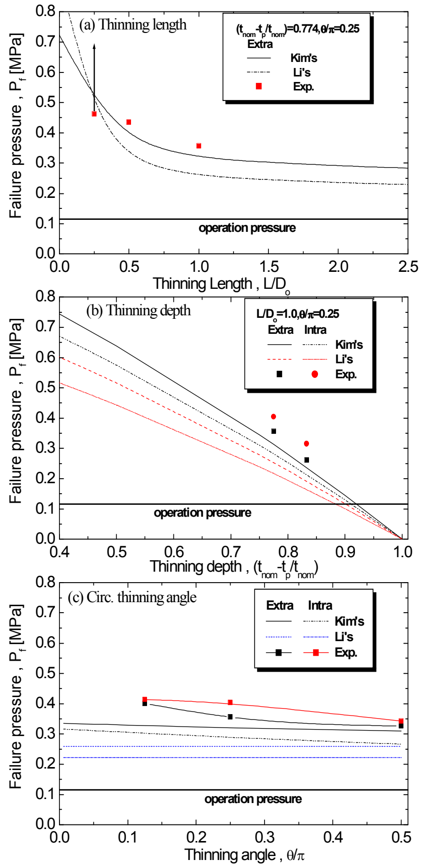

Fig. 3 Effect of wall thinning geometries on the failure pressure of locally wall thinned-elbow

3. Results and discussion

3.1 Effect of defect geometries on failure pressure

As shown in Figs. 3(a) and (b), the failure pressure decreased with increasing thinning length and depth. These behaviors are consistent with those observed in the existing studies on the wall-thinned straight pipe [2, 4~5]. In Fig. 3(c), also, the failure pressure decreased about 20% with increasing circumferential thinning angle from θ/π=0.125 to θ/π=0.5. This is different from the results on the wall-thinned straight pipe that the failure pressure is less dependent on the circumferential thinning angle [7]. This difference would be associated with that the magnitude of hoop stress at bend region of elbow is varied with circumferential location.

3.2 Effect of thinning location on failure pressure

In Figs. 3(b) and (c), it is seen that the failure pressure of intrados wall-thinned elbow is higher than that of extrados wall-thinned elbow. This is mainly related to the different actual thinning length between thinning locations. For the same equivalent thinning length that is defined at elbow crown, the actual thinning length at intrados is a half of extrados. Therefore, the effect of wall thinning length overcomes the geometric effect that intrados region shows higher hoop stress under internal pressure.

3.3 Comparison of experimental and predicted failure pressures

The existing failure pressure models [6, 7] were verified using the present experimental data. As shown in Fig 3, the existing models conservatively predict the experimental failure pressure. Also, they reasonably estimate the tendency of failure pressure with thinning length and depth. However, both models do not appropriately reflect the effect of circumferential thinning angle and thinning location on the failure pressure.

4. Conclusion

In the present study, the full-scale failure tests were carried out using wall-thinned elbow specimen. The following conclusion was derived;

(1) The failure pressure decreased with increasing axial thinning length and depth. Also, it decreased with increasing circumferential thinning angle. This behavior is different from that observed in the wall-thinned straight pipe.

(2) The failure pressure of intrados wall-thinned elbow was higher than that of extrados wall-thinned elbow, when the equivalent axial thinning length was the same.

(3) The existing models conservatively estimated the failure pressure of wall-thinned elbow, and reasonably predicted the effect of wall thinning length and depth. However, they could not appropriately consider the effect of circumferential thinning angle and thinning location on the failure pressure.

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