Experimental Evaluation of the Burst Pressure of Steam Generator Tube with Multiple Part-through-wall Cracks

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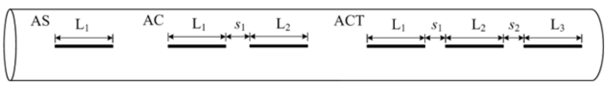
1. Introduction

Since steam generator (SG) tube is a pressure boundary of pressurized water reactor (PWR), the maintaining integrity of SG tube is very important. However, various types of defect caused by a mechanical and chemical degradations have been observed in the SG tube[1]. In particular, the outer diameter stress corrosion cracking (ODSCC) in the secondary side is a dominant type of defect, which can lead to leakage of primary coolant and burst of SG tube[2]. Thus, the integrity evaluation of SG tubes with SCC is considered to be an important issue. A number of experimental and analytical studies have been conducted to evaluate burst pressure of SG tube with defects and proposed evaluation models[3,4]. But, most of the models were developed based on single cracks, although SCC initiates and grows at multiple sites on the surface of SG tube. Therefore, this study carried out burst tests using SG tube specimens containing multiple part-trough-wall (PTW) flaws at room temperature (RT) and evaluated burst pressure of SG tubes with multiple PTW flaws.

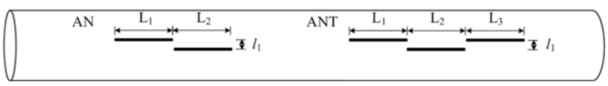
2. Experiment

2.1 Material and Specimens

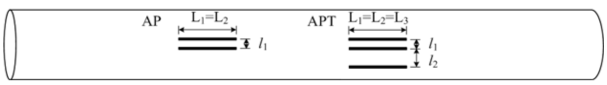
The specimens were machined from SG tube of Alloy 690TT with a nominal outer diameter of 19.05mm and a thickness of 1.067mm. Yield and tensile stresses of Alloy 690TT SG tube are 314.9MPa and 696.3MPa, respectively. The flaws were made by EDM on the outer surface of specimen of 220mm length. In the experiment, twenty eight different cases of flaw configuration were considered; single PTW flaws with different axial lengths (AS), collinear multiple PTW flaws (AC & ACT), non-aligned multiple PTW flaws (AN & ANT), and parallel multiple PTW flaws (AP & APT). Table 1 summarizes the configurations and dimensions of flaws. Regardless of flaw configuration and length (L), the shape of flaw is assumed to be rectangular with a constant depth of 50% of wall thickness (d/t=0.5). Fig. 1 illustrates the configurations of flaw considered in this experiment.



(a) AS, AC, ACT



(b) AN, ANT



(c) AP, APT

Fig. 1 Configurations of flaws regarded in the experiment.

Table 1 Dimensions of flaws considered in the specimen design

Defect type	Length of defect, $L_1/L_2/L_3$ [mm]	Axial distance, s_1/s_2 [mm]	Circ. distance, l_1/l_2 [mm]
AS	6.3, 12.7, 25.4, 50.8	N/A	N/A
AC	6.3/6.3 25.4/25.4	1, 2, 5 1,2	N/A: Collinear (l_1=l_2 =0)
ACT	6.3/6.3/6.3 12.7/25.4/12.7	2/2 1/1	
AP	6.3/6.3 25.4/25.4	N/A: Parallel (s_1=s_2=0)	1 1
APT	6.3/6.3/6.3 12.7/25.4/12.7		1/2, 1/15, 1/30 1/2, 1/15, 1/30
AN	6.3/6.3 25.4/25.4	N/A: Non-aligned (s_1=s_2=0)	1, 2, 15 1, 2, 15
ANT	6.3/6.3/6.3 25.4/25.4/25.4		1/1, 2/2 1/1

2.2 Burst Tests

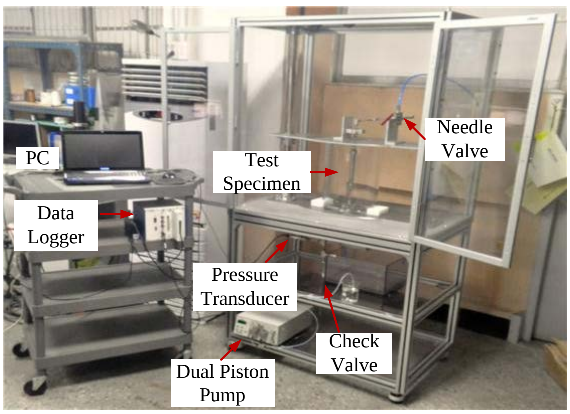


Fig. 2 Test apparatus used in experiment

Burst tests were conducted at RT using a test apparatus specially designed and fabricated. The specimen was pressurized by injection of water with a constant flow rate using high-pressure pump. During the pressurization, internal pressure was measured and recorded with sampling rate of 100/sec. The burst pressure was defined by a maximum pressure recorded up to rupture of specimen. A pressurization rate of 0.138 ~ 3.45MPa/sec was recommended by EPRI guideline for burst test of SG tube[3]. In this experiment, thus, the specimen was pressurized with a rate of 1MPa/sec by controlling flow rate of high pressure pump. Fig. 2 shows test apparatus used in experiment.

3. Result and Conclusions

The burst tests were conducted on 56 specimens and burst pressures were obtained. Also, failure mode of SG tube with multiple flaws was investigated by examining the shape of crack and tearing from post-test specimens. Fig. 2 shows a set of photographs of post-test specimens.

(a) L=6.3mm (b) L=25.4mm

Fig. 2 Photograph of post-test specimens with collinear multiple flaws

The results of tests showed that burst pressures of collinear and non-aligned multiple flaws were lower about several percent than those of single flaw of the same length. Thus, interaction of multiple flaws reduced burst pressure of SG tubes. The reduction was more pronounced for L=25.4mm than L=6.3mm and was more pronounced when three flaws were arranged than when two flaws were arranged. Burst pressure increased with increasing axial distance between flaws for collinear multiple flaws, whereas the pressure decreased and saturated with increasing circumferential distance between non-aligned multiple flaws.

For SG tubes with parallel multiple flaws, the burst pressure was influenced by circumferential distance between flaws and length of flaws. When two flaws were parallel with circumferential distance of l_1=1mm, the burst pressure was higher about 2% than that of single flaw for L=6.3mm, but it was lower about 7% than that of single flaw for L=25.4mm. Thus an interaction of multiple parallel flaws increased burst pressure for a shorter flaw, but it reduced burst pressure for a longer flaw.

When two flaws were parallel with circumferential distance of l_1=1mm and an additional flaw was parallel with circumferential distance of l_2=2, 15, and 30mm, the burst pressure decreased with increase in circumferential distance (l_2) and reached a minimum at l_2=15mm. Then it increased at circumferential distance of l_2=30mm. Regardless of circumferential distance between flaws, the reduction in burst pressure by interaction of parallel multiple flaws was more significant for L=25.4mm than L=6.3mm. Also, it was found that burst always occurred at a flaw far from adjacent two flaws when triple flaws were parallel.

AKNOWLOGEMENT

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