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Burst Behavior for Mechanically Machined Axial Flaws of Steam Generator Tubings

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It has been reported that some events of a rupture of seam generator tube have occurred in nuclear power plants around the world. Main causes of the leakage are from various types of corrosion in the steam generator(SG) tubings. Primary water stress corrosion cracking(PWSCC) of steam generator tubings have occurred in many tubes in Korean plant, and they were repaired using sleeves or plugs. In order to develop proper repair criteria, it is necessary to ascertain the leak behavior of the tubings. A high pressure leak and burst testing system was manufactured. Various types of Electro Discharged Machined (EDM) notches were developed on the SG tubes. Leak rate and burst pressure were measured on the tubes at room temperature. Burst pressure of the part through wall defected tubes depends on the defect depth. Water flow rates after the burst were independent of the flaw types; tubes having 20 to 60 mm long EDM notches showed similar flow rates regardless of the defect depth. A fast pressurization rate gave the tube a lower burst pressure than the case of a slow pressurization.

Keywords : *SG tubes, stress corrosion cracking, leak test, burst test, burst pressure*

1. Introduction

For many years, steam generators of a Pressurized Water Reactor(PWR) have suffered from many types of corrosion, such as pitting, wastage and stress corrosion cracking (SCC) in the primary and secondary sides.[1),2)] In order to prevent the primary coolant from leaking into the secondary side, the tubes are repaired by sleeving or plugging.[3)] It is important to establish the repair criteria to maintain the plugging ratio within a plugging limit to operate the plant successfully.

In the international steam generator tube integrity program (ISG TIP) supported by the US NRC (Nuclear Regulatory Commission), tasks such as in-service inspection technology development, and studies on a steam generator tube degradation mode have been undertaken. As a part of the cooperation work, leak and burst tests were carried out, and the burst behavior of axial mechanical flaws were studied.

This article aims to evaluate the burst behavior of axial EDM defects of alloy 600 SG tubes in various pressurization modes.

2. Experimental

Various types of axial (tube longitudinal) EDM notches were developed on SG tubes as shown in Table 1. The tubes were 19.05 mm in outside diameter, and 1.07 mm in thickness. They were high temperature mill annealed alloy 600, of which the yield strength and tensile strength are 35 ksi and 95 ksi respectively. Leak rate and ligament rupture pressure for the part through wall defect were measured for the tubes at room temperature. The length of the part through wall defects was 5 mm to 62 mm.

Tests with a 100 % axial through wall defect tube were carried out to measure the burst pressure at room temperature. The length of the 100% through wall defects was 12 mm to 30 mm. A flexible plastic tube is usually used for the through wall defect tubes[4)] to ensure leak tightness during the pressurization. In this test, however, it was attempted to see a crack opening displacement(COD) variation during a slow pressurization. Flexible Tygon™

Table 1. Information about the test tubes

Number of test tubes	Tube dimension	Flaw type	Flaw length, mm	Flaw depth, %TW	Bladder
33	19.05OD × 1.07t	EDM notch Axial or Axial+Cir	5~62	50, 60, 75, 80, 100	With or Without

tubes(bladder) were used only for the fast pressurization rate test for the 100% through wall tubes.

To determine the effect of the pressurization rate on the burst pressure, different pressurization rates were applied for the same types of tubes. Water leak rates just after the ligament rupture or burst were measured by scale, and the water flow rate through the tubes and the pressures with time were recorded on a personal computer. Evolutions of the crack opening during the pressurization were recorded using a conventional digital camera.

The length and depth of the defects of the tubes were conservatively checked by the eddy current method, and the tubes were transferred to the leak and pressure test.

3. Results and discussion

3.1 Crack opening displacement

COD as a function of pressure is important in the modeling of a ligament rupture or burst pressure in the tubes. In the preliminary test, the COD increased a little as the pressure increased during the slow pressurization as shown in Fig. 1. It was not so distinguishable though, the COD of a 36 MPa was larger than that of a 10 MPa. While the tube integrity was sustained before the burst, a small pressure increase of 1 MPa gave the tube a ligament rupture followed by a burst. Finally, the tube showed a fish mouth like opening as shown in Fig. 1.

Through wall defect tubes showed a larger COD than that of part though wall defect tubes. The bladder of the 12 mm long 100% TW defect tube (KY56039) was torn at 20.7 MPa, a water jet came out of the bladder. The bladder extruded out when the pressure arrived at 21.4 MPa. A hole in the bladder enlarged at a constant pressure, and then the opening of the tube increased with time for 2 to 3 seconds. There was an extrusion of the bladder throughout the tube opening followed by a tube rupture. The opening was not evaluated quantitatively in this test.

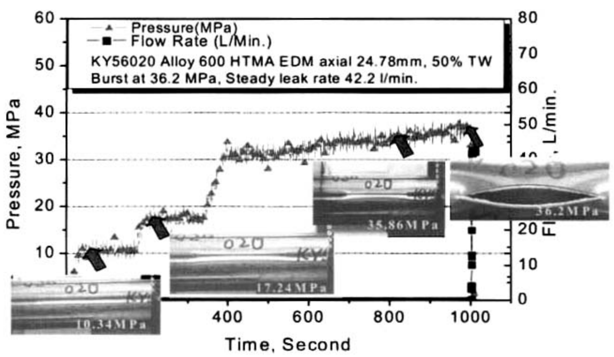


Fig. 1. Crack opening behavior of a part through wall defect tube

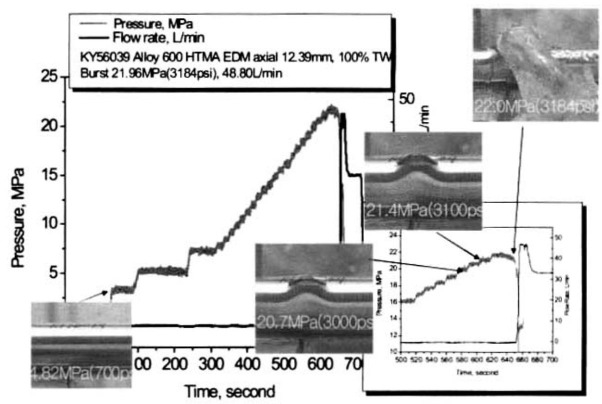


Fig. 2. Crack opening behavior of a 100% through wall defect tube

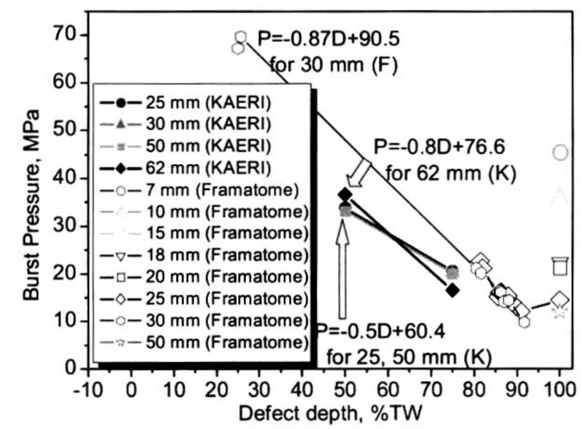


Fig. 3. Effect of the defect depth on the burst pressure

3.2 Effect of the defect depth on the burst pressure

Burst pressures as a function of the defect depth are plotted in Fig. 3. Closed symbols are obtained in this test. Burst pressure dependency of the long (62 mm) defects is a little stronger than that of the short defects (25, 50 mm). Open symbols represent other group's data.[4] This data suggests that the burst pressure of the part through wall tubes depends rather on the defect depth than on defect length.

In the case of the 100% through wall defects, they showed a strong length dependency from about 12 MPa of a 50 mm long defect to 45 MPa of a 7 mm long defect.

3.3 Effect of the defect length on the burst pressure

Fig. 4 shows the burst pressures as a function of the defect length. Closed symbols are obtained in this test. Burst pressure of 50 % TW defect and 75 % TW are

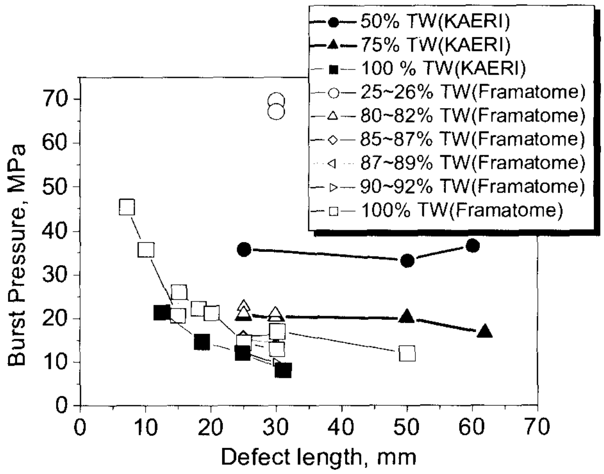


Fig. 4. Effect of the defect length on the burst pressure

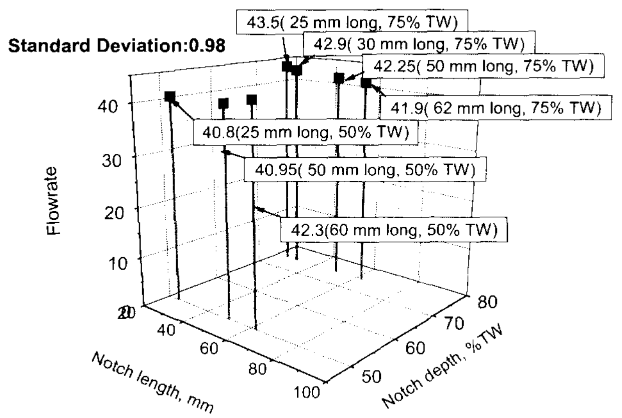


Fig. 5. Relationship among the length, depth and flow rate of the part through wall defects

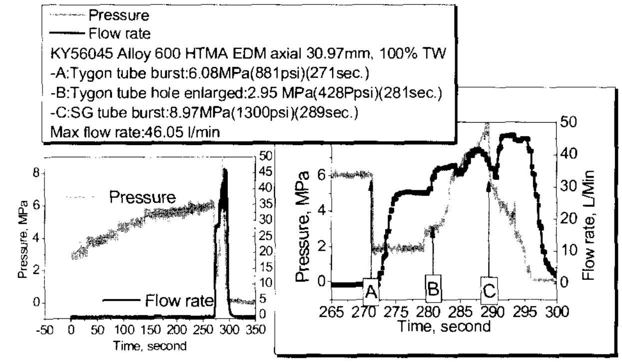


Fig. 6. Burst behavior of a through wall defect tube in a slow pressurization

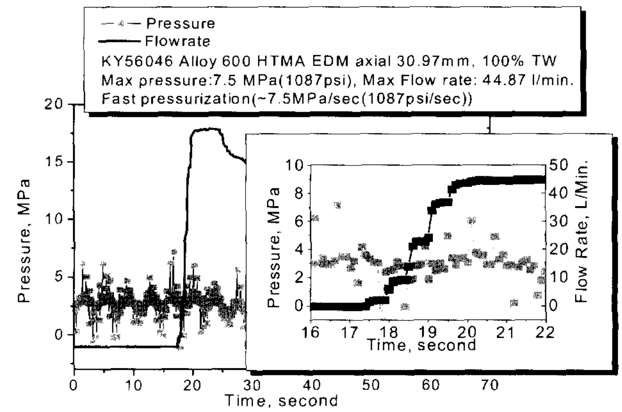


Fig. 7. Burst behavior of the through wall defect in a fast pressurization

around 35 MPa and 20 MPa respectively regardless of their length from 25 mm to 62 mm. Short defects below 25 mm, however, show a dependency of the defect length.

3.4 Relationship among the flow rate, defect depth and defect length

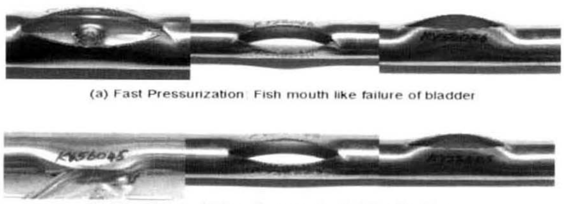
Flow rates after the burst of the part through wall defect tubes were measured. Defect depths were 50% and 75 % of the through wall, and the defect lengths were 25 mm to 62 mm. Regardless of the defect types, the flow rates were similar for all the tubes as shown in Fig. 5.

3.5 Effect of the pressurization rate on the burst pressure of a through wall defect

A through wall defected tube showed three stages of rupture behavior as presented in Fig. 6; flexible plastic tube burst(stage A), the tube hole enlarged(stage B), and finally, the SG tube burst(stage C). A pressure of 6 MPa dropped to 2 MPa when the flexible plastic tube burst. When the internal water pressure increased a little as in stage B, the flow rate increased. The tube burst at about 9 MPa.

Fast pressurization gave the tube a different burst behavior as shown in Fig. 7. The pressurization rate was about 7.5 MPa/sec(1087 psi/second). A pressure fluctuation between 3 MPa and 7 MPa was recorded. Maximum flow rate was achieved 2 seconds after the tube burst. Burst pressure of the tube was about 7.5 MPa, which is smaller than that of a slow pressurization (9 MPa).

Failure morphologies after the burst of the through wall defect with a bladder in two the pressurization modes are shown in Fig. 8. The flexible plastic tube extruded out of the SG tube after the burst in the slow pressurization mode, while the plastic tube was torn like a fish mouth. The SG tube failure morphologies, however, are similar. For that reason, the flow rates after the SG tube burst are similar at about 45 l/min.



(a) Fast Pressurization: Fish mouth like failure of bladder

(b) Slow Pressurization: Squeezed out of the bladder

Fig. 8. Failure morphologies of the through wall defects at a different pressurization mode.

4. Conclusions

(1) While the tube integrity was sustained before the burst, a small pressure increase of 1 MPa gave the tube a ligament rupture followed by a burst.

(2) Burst pressure of the part through wall tubes depends rather on the defect depth than on the defect length.

(3) Flow rates after a ligament rupture of the part through wall defect or a burst of the through wall defect tubes were similar.

(4) Burst pressure of a through wall defect in a fast pressurization was smaller than that of a slow pressurization.

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