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Comparison between Destructive and Non-destructive Analyses of SCC of Alloy 600 SG Tubings fabricated in Various Corrosive Environments

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1. Introduction

Nickel-based alloys such as Alloy 600 and 690 have been used as steam generator (SG) tubing materials in a pressurized water reactor (PWR) due to their high corrosion resistance. However, many forms of corrosion such as pitting, intergranular attack (IGA), primary water stress corrosion cracking (PWSCC) and outer diameter stress corrosion cracking (ODSCC) have found in specific water chemistries of a crevice or a sludge pile during operation [1-5].

To evaluate the integrity of SG tubings more precisely and to detect SCC earlier, there have been many efforts to develop non-destructive examination (NDE) techniques covering a visual inspection, an eddy current test (ECT), and an ultrasonic test (UT) as in-service inspection (ISI) process. To improve those techniques for detecting and sizing SCC, it is necessary to compare NDE responses from SCC with destructive examination (DE) results [6]. This work is aimed to evaluate characteristics of SCC fabricated using various acceleration techniques such as a doped steam and a leaded caustic solution at high temperature and pressure, and an acidic solution at room temperature, and to correlate the results from DE with NDE responses of SCC.

2. Experimentals

PWSCC and ODSCC were artificially fabricated in Alloy 600 LTMA (low-temperature mill-annealed) SG tubings using three different acceleration techniques; (1) a doped steam environment containing 100 ppm of Na_2SO_4, NaF, $NaNO_3$ and 200 ppm of NaCl at 400 ^oC and 20.7 MPa with 70 kPa of H_2 partial pressure, (2) a leaded caustic solution of 1M NaOH and 10,000 ppm PbO at 340 ^oC and 14.5 MPa, (3) an acidic solution of 1M $Na_2S_4O_6$ at room temperature. Table 1 gives comparison between various techniques for SCC acceleration. Intermittent NDE was performed for detecting any crack in SG tubings every 2 weeks by ECT with a magnetic-biased/plus point motorized rotating probe coil (MRPC) at a pulling speed of 5.08 mm/s, at a rotating rate of 300 rpm, and at 300 kHz. When SCC was found to have a desired depth, the SG tubing was destructively examined using an optical microscopy (OM) and a scanning electron microscopy (SEM) to characterized SCC. Fig. 1 shows schematic diagram of SCC fabrication procedure.

Table 1 Comparison of SCC fabrication methods

Environment	**Doped steam**	**Caustic solution**	**Acidic solution**
Temperature	400^{o}C	340^{o}C	25^{o}C
Pressure	20.7MPa + 70kPa H_2	14.5MPa	14.0MPa
Chemicals	100ppm of Na_2SO_4, NaF, $NaNO_3$ and 200ppm of NaCl	1M NaOH + 10,000ppm Pb (as PbO)	1M $Na_2S_4O_6$
Susceptible materials	LTMA	LTMA	Sensitized
Typical type of flaw	pure IGSCC	pure IGSCC	IGSCC + IGA
Expected failure time	4~12 months	1~6 months	1~3 weeks

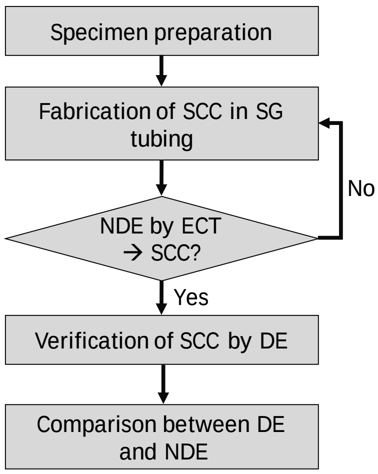

Fig. 1. Schematic diagram of SCC fabrication procedure.

3. Results and Discussions

Fig. 2 shows the C-scan plot of the SG tubing with PWSCC fabricated in the doped steam environment for 7 days. There was an indication of an inner diameter (ID) axial crack. The amplitude and phase angle of PWSCC were 3.76 V and 26 ^{o}, respectively, and the length and depth were evaluated as 9.4 mm and 100% (through-wall), respectively. From SEM analysis, the ruptured surface of the crack clearly revealed the characteristics of intergranular (IG) crack propagated from ID to outer diameter (OD) surface of tubing.

Fig. 3 gives the C-scan plot of the SG tubing with ODSCC fabricated in the caustic solution for 14 days.

There were multiple indications of ID axial cracks. The amplitude and phase angle of the largest ODSCC were 7.73 V and 33 ^{o}, respectively, and the depth was evaluated as 100% (through-wall).

Fig. 4 presents the C-scan plot of the SG tubing with ODSCC fabricated in the acidic solution for 14 days. There was an indication of an OD axial crack. The amplitude and phase angle of PWSCC were 0.55 V and 68 ^{o}, respectively, and the depth was evaluated as 48 %. It should be noted that there was a leakage through the crack during the SCC fabrication, which means that the crack was already propagated through wall, even though the depth was evaluated as 48% by NDE.

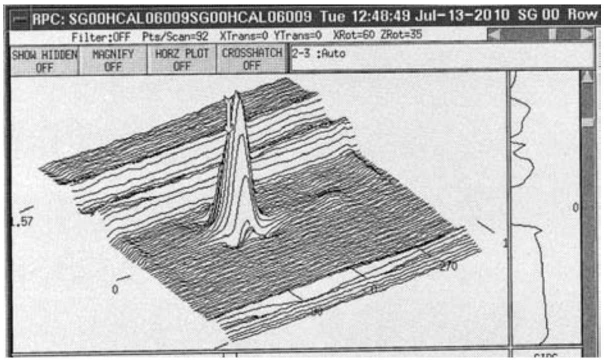

Fig. 2. C-scan plot of the SG tubing with PWSCC fabricated in the doped steam environment for 7 days.

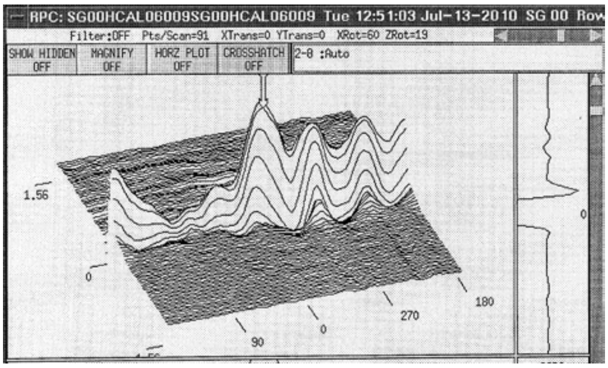

Fig. 3. C-scan plot of the SG tubing with ODSCC fabricated in the caustic solution for 14 days.

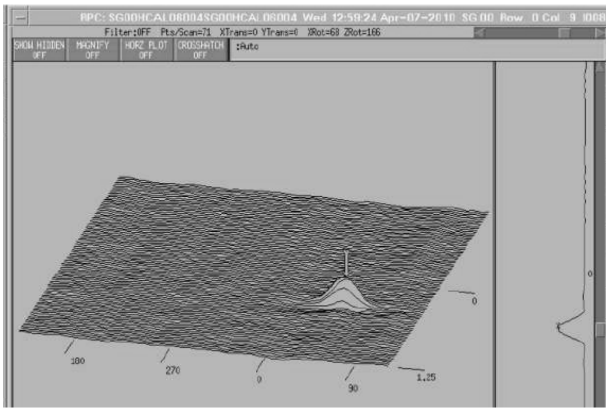

Fig. 4. C-scan plot of the SG tubing with ODSCC fabricated in the acidic solution for 14 days.

4. Conclusion

As a contribution to improvement of NDE reliability, the SG tubing specimens containing PWSCC and ODSCC were fabricated using various SCC acceleration techniques. The characteristics of different types of SCC analyzed from DE will be correlated with the NDE responses in detail.

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