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Relationship between SCC of Alloy 600 Tubes and Sludge Pile in a Retired Steam Generator

Seong Sik Hwang, Man Kyo Jung, Dong Jin Kim, Jangyul Park, Hong Pyo Kim
Korea Atomic Energy Research Institute, 1045 Daeduckdae-ro (150 Deokjin-dong), Yuseong-Gu, Daejeon 305-353, Korea
sshwang@kaeri.re.kr

1. Introduction

The Kori-1 retired steam generator (RSG) had been affected with various types of corrosion degradation in the alloy 600 tubes such as pitting and stress corrosion cracking (SCC). [1] The degradation occurred in the regions of the tube expansion and the crevices where corrosive environment and high stress/strain could have existed. The non-destructive eddy current technology (ECT) is used for detection of degradation in the SG tubes. The capability and the performance of the ECT are of utmost importance for safe operation of SGs and establishment of the guide lines for it. Fifty alloy 600 tubes were extracted from the RSG. The tubes were re-inspected with a comprehensive laboratory non-destructive ECT examination and the SCC defects were destructively analyzed using the metallographic techniques. Type and size (length and depth) of the defects were determined. The data were analyzed for possible correlations among the defect location, type and size, location of the top of the tube sheet (TTS) and the sludge height. The results of the present investigation are to be utilized for development of countermeasures for SCC degradation and improvement of the ECT performance.

The present work was mainly focused on analyzing spatial distribution of the different types of the defects, and possible correlations with sludge accumulation.

2. Experimental Procedures

Alloy 600 tubes were extracted from the RSG based on the field ECT and transferred to a hot laboratory of Korea Atomic Energy Research Institute (KAERI) for examination. Comprehensive laboratory nondestructive ECT analysis was performed and the exact locations of the ECT defect indication were marked on the tube specimens for the subsequent destructive examinations.

Metallographic examinations were carried out in a hot laboratory using the procedures in accordance with the Electric Power research Institute (EPRI) tube examination guidelines. [2]

Types of the defects were characterized and the sizes were measured by using a high magnification contact camera and a scanning electron microscope (SEM). The chemical compositions at the outer diameter (OD) of the tubes were also analyzed by using energy dispersive x-ray spectroscopy (EDS). A SG degradation data base was constructed from the analyses. A relationship among the SCC defect location, defect depth, and sludge height was explored.

3. Results and Discussion

While the RSG has other kinds of defects such as pitting, only the SCC defects were analyzed for the present work. Two types of SCC defects have been detected; the primary water stress corrosion cracking (PWSCC) and the outer diameter stress corrosion cracking (ODSCC). The SCCs occurred at or near the TTS and the tube support plate (TSP). Some SCCs were also found at the free span region. Circumferential cracks were mainly distributed near the TTS and TSP in a form of band, while axial cracks were distributed mainly at the TSP. The maximum penetration depth was about 90% of the tube wall thickness for both the circumferential and the axial cracks.

Figure 1 shows an example of analysis for the PWSCC. The nondestructive ECT examination, optical microscopy, SEM, and a schematic of the crack penetration are presented. A 1.54 mm long crack was located 5.3 mm above the TTS with the penetration depth of 60% tube wall.

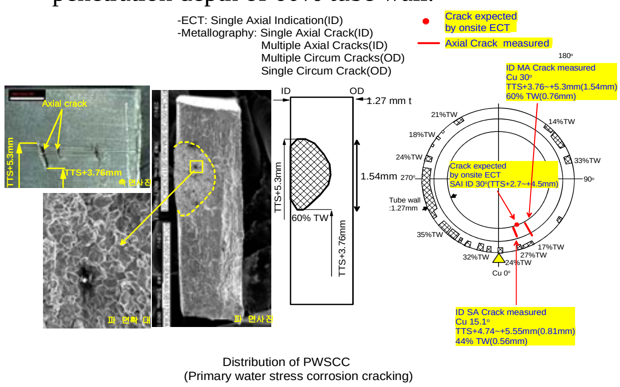

Figure 1 Destructive and non-destructive analysis of an axial SCC.

The vertical position of the axial cracks and sludge height is depicted in Figure 2. Most axial cracks were located at the sludge region.

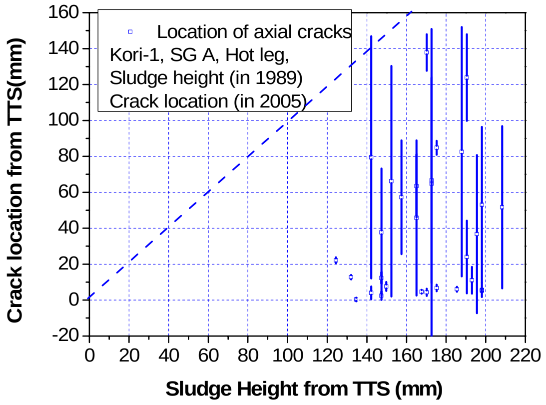

Figure 2 Relationship between the location of axial cracks and sludge accumulation

Residual stresses evaluated by X-ray show that relatively higher hoop stresses exist compared with the axial stresses. [3] The typical maximum values for standard roll-transitions were 370 MPa (54 Ksi) and 340 MPa (49 Ksi) for the hoop stress and the axial stress, respectively. It is considered from these findings that a corrosive environment inside the sludge as well as relatively high hoop stress caused the axial cracks.

On the other hand, the circumferential cracks were in the sludge pile and below the TTS and TSP region as shown in Figure 3. It has been reported that tube sheet dents and phosphate chemistry caused OD circumferential cracks at TTS region. [4] A. Mcilree discussed that the causes of the circumferential ODSCC at the TTS were sludge pile and residual plus operating stresses at the TTS region. [4] Though the RSG had not operated with the phosphate treatments, denting could also be considered as an additional factor for the cracking at the TTS.

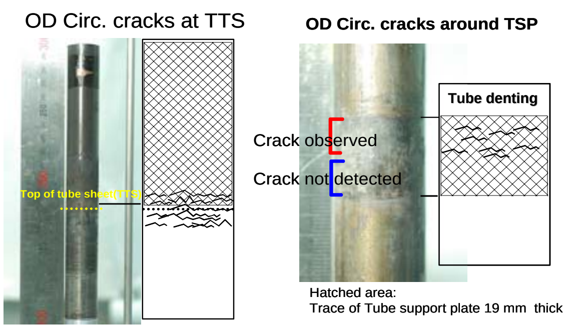

Figure 3 Schematics of the circumferential cracks around top of tube sheet and TSP region

Circumferential cracks were found in the shape of a band around the TTS and the TSP. The sludge accumulation may not be the only cause for the circumferential cracks. The axial stresses caused by the tube expansion process are considered to promote the circumferential cracks around the TTS. In case of the TSP region, the circumferential cracks were detected at the upper part of the TSP crevice. The tube denting due to oxidation of the carbon steel TSP material is a causative factor of the cracking.

4. Conclusions

(1) Many types of corrosion damage occurred in SGs of a Korean NPPs such as pitting, PWSCC, ODSCC, intergranular attack (IGA) and denting.

(2) Most axial SCCs were in the sludge pile, whereas the circumferential ones were around the TTS or upper area of the TSP.

(3) No appreciable correlation was observable between the distribution of the circumferential SCCs and the sludge height.

(4) Average defect depth of the axial cracks was deeper than that of the circumferential ones.

REFERENCES

[1] J.S. Kim, S.S. Hwang, et al., ‘Destructive analysis on pulled tubes from Kori-1 ’ Korea Atomic Energy Research Institute, 1989.

[2] EPRI TR-016743 V4 R1, ‘Guidelines for PWR steam generator tubing specification and repair Guidelines for Tube Section Removal and Examination’, December, 1997.

[3]R.Comby, B.Flesch, F de Keroulas, ‘Circumferential cracking of French reactor steam generator tubes in the roll transition zones under the effect of stress corrosion’, EPRI NP-7198-S, Proceedings of 1990 EPRI Workshop on Circumferential Cracking of steam Generator Tubes. Feb. 22-23, 1990, p. A6-1, March, 1991.

[4] A.R. Mcilree, ‘Purposes of workshop and review of past experience with circumferential cracking of steam generator tubes’ EPRI NP-7198-S, Proceedings of 1990 EPRI Workshop on Circumferential Cracking of steam Generator Tubes. Feb. 22-23, 1990, p. A1-1, March, 1991.