Comparison of Intergranular Attack Observed in Plant and Laboratory

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1. Introduction

The morphology of intergranular attack (IGA) is characterized by relatively uniform attack of all grain boundaries to a uniform depth over the surface of the metallic materials. This is because corrosion is localized at and adjacent to grain boundaries with relatively little corrosion of the grains.

IGA have been a form of degradation in the secondary side of pressurized water reactor steam generator tubes. It was found in tubesheet crevices, sludge piles, and tube support crevices [1].

In this work, the signal characteristics of eddy current test (ECT) are investigated using a laboratory-manufactured IGA in the outer diameter (OD) side of a tube free span. The signals are compared with those of IGA occurred in an operating steam generator. The main causes of the plant IGA are also discussed based on the microstructure, local chemistry and operation temperature.

2. Experimental Methods

Steam generator tubes of high temperature mill-annealed Alloy 600 with a nominal outer diameter of 19.05mm and a nominal wall thickness of 1.07mm, were used to manufacture IGA in laboratory.

IGA was grown in an oxidized solution at room temperature. These defects were made in the OD free span of clean tube. That is, they were not interfered from both geometry changes and sludge.

ECT was performed using a conventional rotating probe. This probe consisted of a plus point coil, a pancake coil and a high frequency pancake coil separately mounted on the same circumference.

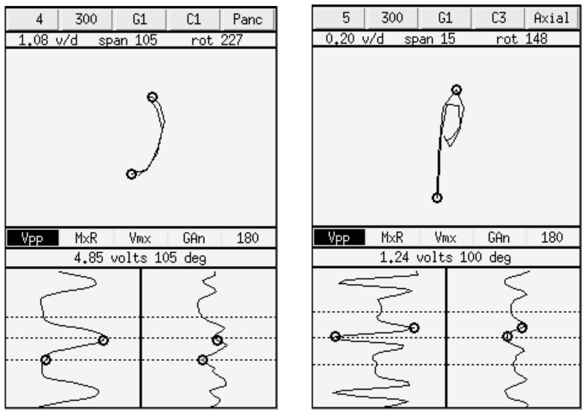
The ECT signals of the IGA specimen were obtained by the Zetec MIZ-70 digital data acquisition system with a 3-coil motorized rotating probe (M/+Point-610). The specimens were inspected at a pulling speed of 5.08 mm/sec and at a rotating rate of 600 rpm. The test frequencies were 20, 35, 100, 300, 400 and 700 kHz. The signal from an axial through-wall electric discharge machining notch with a length of 9.52 mm was calibrated to be an amplitude of 20 volts and a phase angle of 30 degrees at 300 kHz.

A defective tube with IGA in an operating steam generator was destructively examined to analyze the root causes for IGA occurrence. A detailed procedure is given elsewhere [2].

3. Results and Discussion

3.1 Signals of a drill hole

The major different characteristics of the EC signals from a drill hole were first analyzed using a 20% flat bottom hole, simulating a volumetric defect. Fig. 1 shows the impedance plane responses and the corresponding vertical and horizontal components by pancake coil and plus point coil probe. The main discriminating feature was found in the behavior of the vertical component. That is, the vertical component of the pancake coil always indicated a positive direction relative to that of the defect-free region, whereas the signals of the vertical component of the plus coil showed a zigzag pattern.



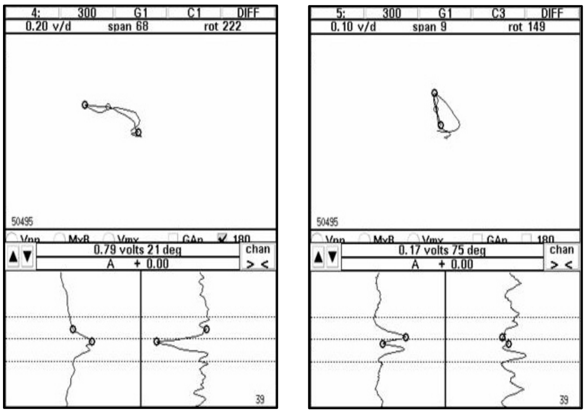
(a) (b)

Fig. 1. Impedance plane responses and the corresponding vertical and horizontal components of a drill hole by (a) pancake coil and (b) plus point coil probe at 300 kHz.

3.2 Signals of IGA

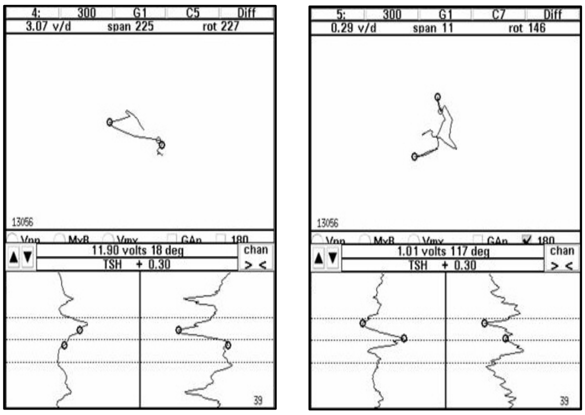
Fig. 2 shows the ECT signals of the laboratory-grown IGA. By comparison with the signals in Fig. 1, this indication showed just a characteristic feature of a drill hole, volumetric defect. From the phase angle of the signal on the impedance plane, this defect was evaluated to be located in the OD side of the tube. The maximum depth of penetration was also estimated to be about 40% of the wall thickness based on the phase angle to flaw depth correlation. It should be noted that ID noise signal was mixed in the Lissajous curve of pancake coil probe.

Fig. 3 shows the ECT signals of the IGA occurred in an operating steam generator tube. Although it was weak, the characteristic feature of a volumetric defect was observed in the vertical component of the plus coil signal. The maximum depth of the defect was measured to be 26% of the tube wall thickness by destructive metallographic examination.



(a) (b)

Fig. 2. Impedance plane responses and the corresponding vertical and horizontal components of a laboratory-grown IGA by (a) pancake coil and (b) plus point coil probe at 300 kHz.



(a) (b)

Fig. 3. Impedance plane responses and the corresponding vertical and horizontal components of IGA occurred in an operating steam generator by (a) pancake coil and (b) plus point coil probe at 300 kHz.

3.3 Analysis for the causes of IGA

IGA with a maximum penetration depth of 26% was found within the region of sludge piles in the hot-leg side of the operating steam generator. Its main causes were analyzed as follows;

- The sludge piles around the defective tube formed crevices to concentrate corrosive impurities.
- The grain boundaries of the defective tube were slightly sensitized although they were decorated with chromium carbides.
- The MRI data and relative depletion of chromium in the oxide film suggested that the local environment of the IGA was alkaline.
- Sulfur detected in the deposits could have contributed to the IGA.
- The high operating temperature of the primary side was considered to be another cause of IGA.

3. Conclusions

The ECT characteristics of IGA were analyzed using a flat bottom hole, a laboratory-grown IGA and a plant IGA. The main discriminating feature was that the signals of the vertical component of the plus coil showed a zigzag pattern. The main causes of the plant IGA were also discussed based on the microstructure, local chemistry and operation temperature. These results should be considered to evaluate a volumetric IGA defect during the in-service inspection.

ACKNOWLEDGEMENT

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[2] Do Haeng Hur et al., Nuclear Engineering and Design, Vol. 240, p.204, 2010.