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The Effect of Magnetite Scales on the Eddy Current Signals of Cracks in the Secondary Side of Steam Generator Tube

Deok-Hyun Lee *, Se-Beom Oh, Soon-Hyeok Jeon, Hee-Sang Shim, Kyung-Mo Kim and Sung-Woo Kim
Nuclear Materials Safety Technology Research Div., Korea Atomic Energy Research Institute,
Daedeok-daero 989 Beon-gil, Yuseong-gu, Daejeon, 34057, Korea
**Corresponding author: dhlee1@kaeri.re.kr*

1. Introduction

The integrity of steam generator tubes in pressurized water reactors are verified by the periodic in-service inspection using eddy current test methods. During the operation of steam generator, magnetite scales from corrosion of carbon steel components are deposited cumulatively on the secondary side of tube. They may cause the eddy current noise signals and affect the reliability of defect detection and sizing [1]. In this work, the changes of eddy current signals of cracks from the presence of magnetite scales on the secondary side of steam generator tube are investigated in order to evaluate the performance of eddy current test inspection in the same condition of operating steam generator.

2. Methods and Results

2.1 Manufacturing of Artificial Cracks in Tube

Artificial cracks were manufactured on the outer surface of Alloy 690TT archive steam generator tube with outer diameter of 19.05mm and wall thickness of 1.07mm. The cracks with a length of 3mm were machined by laser ablation method [2]. Two sets of 5 axial cracks and one set of 5 circumferential cracks with different penetration depths of 20, 30, 40, 50, and 60% wall thickness were arranged in a row along the axial direction of tube, as shown in Fig. 1.

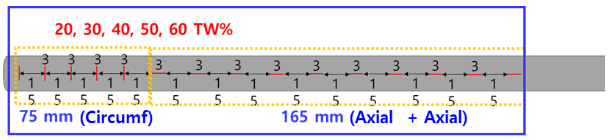

Fig. 1. Arrangement of artificial cracks in tube specimen.

2.2 Magnetite Scale Deposition on Outer Surface of Tube

Magnetite scales were deposited on the outer surface of tube specimen with artificial cracks in a simulated condition of operating steam generator. An internal electrical heater was inserted into the inside of tube specimen and the outer surface was exposed to the secondary coolant so that boiling condition need for magnetite scale deposition can be introduced. The pH of the secondary coolant was maintained at 9.0 with addition of ethanolamine (ETA) and Fe-acetate was injected into the coolant in order to supply Fe ions, the source of magnetite scale formation. The temperature of the secondary coolant was maintained at 270^{o}C in saturated water pressure condition. Fig. 2 shows the photo of tube specimen with magnetite scale deposition. It shows that the tube span of artificial cracks are fully covered with uniform magnetite scales, and the thickness of the scales is approximately estimated to be over several tens microns.

Fig. 2. Tube specimen with artificial cracks after magnetite scale deposition.

2.3 Eddy Current Test

Before and after magnetite scale deposition, the tube specimen with cracks was inspected with a ZETEC MRPC (Motorized Rotating Pancake Coil) probe and MIZ-70 eddy current data acquisition system. Plus-point coil signals at test frequency of 300 kHz, which have been used for field data analysis in operating power plants, were analyzed principally

2.3 Results and Discussion

Fig. 3 shows an example of c-scan graph of plus-point coil eddy current signal distribution from a set of 5 axial cracks with various wall penetration depth before magnetite scale deposition. The amplitude of crack signal increased proportionally with the crack depth.

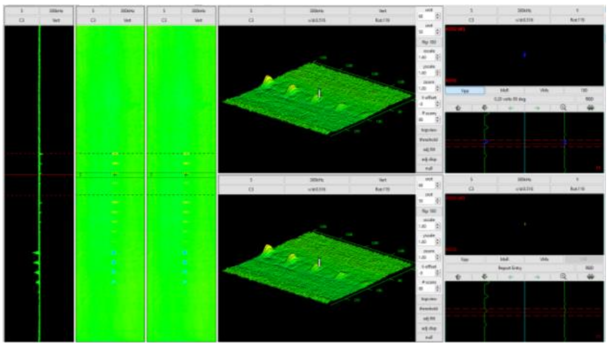

Fig. 3. C-scan graph of eddy current signal distribution from a set of axial cracks before magnetite scale deposition.

The amplitude and phase angle of plus-point coil eddy current signals at 300kHz were analyzed for three sets of artificial cracks, and their changes before and after magnetite scale deposition were quantitatively compared. Fig. 4 shows the results of signal amplitude changes for three sets of cracks. It is observed that the effect of magnetite scale deposition on the crack signal amplitude was minor for all depth of axial and circumferential cracks.

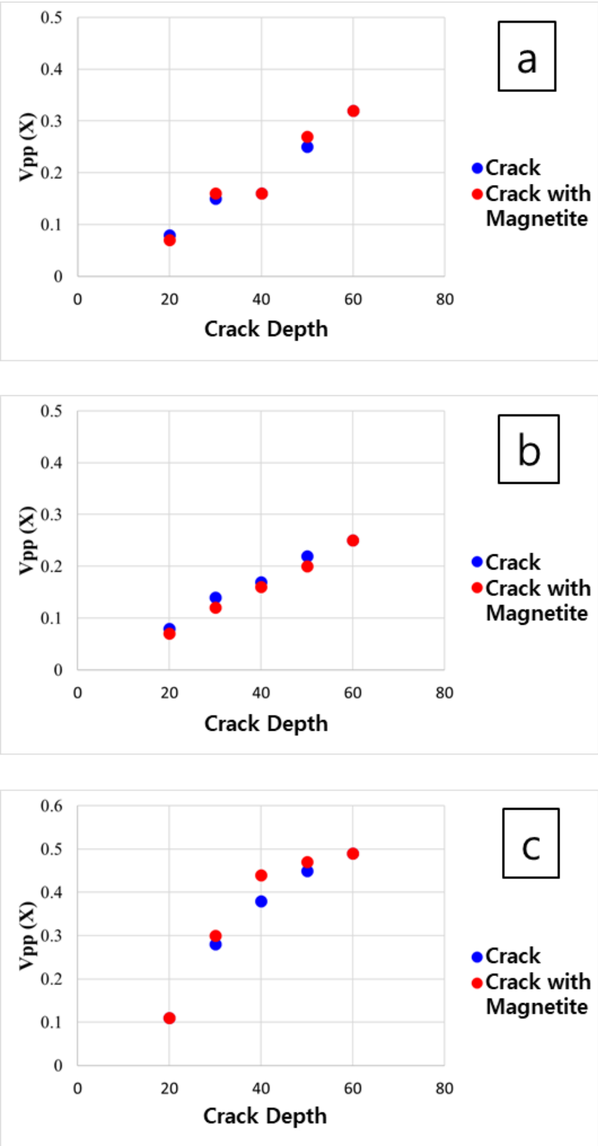

Fig. 4. Changes of plus-point coil signal amplitude with magnetite scale deposition, a) set I of axial cracks, b) set II of axial cracks, and c) set of circumferential cracks.

The changes of phase angle in plus-point coil crack signal with magnetite scale deposition were shown in Fig. 5. The noticeable changes of phase angle are observed only in both axial and circumferential cracks with smaller depth of 20~40%. The opposite trend of changes in phase angle values appeared in axial and circumferential cracks with smaller crack depth, and the cause of these results could not be explained. Thus, it is suspected that the deposition of magnetite scales may affect the sizing capability of cracks with smaller depth, that is, the accuracy of crack depth estimation.

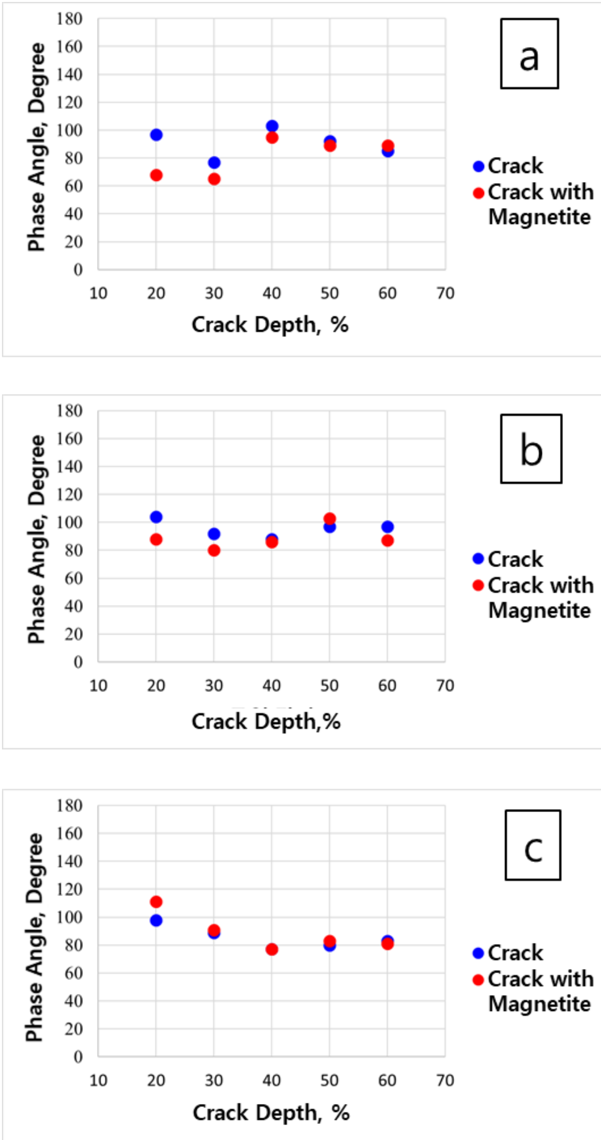

Fig. 5. Changes of plus-point coil signal phase angles with magnetite scale deposition, a) set I of axial cracks, b) set II of axial cracks, and c) set of circumferential cracks.

The background noise levels of plus-point coil signals in the tube zones free from cracks were analyzed before and after magnetite scale deposition, and the results were summarized in Table 1. It is evident that the amplitude of background noises in the tube specimen are increased by ~ 2 times with magnetite scale deposition and these noise signals are thought to affect the phase angle changes of smaller depth crack signals in Fig. 5.

Table 1. Changes of background noise levels of plus-point coil signals in tube zones free from cracks with magnetite scale deposition.

Tube Zones Free From Cracks	Before Magnetite Scale Deposition	After Magnetite Scale Deposition	Changes, Volts
Above Set of Axial Cracks	0.08	0.22	Δ 0.14
Between 2 Sets of Axial Cracks	0.09	0.12	Δ 0.03
Between Axial/ Circum. Cracks	0.08	0.16	Δ 0.08
Average	0.08	0.16	Δ 0.08

3. Conclusions

In a simulated condition of operating steam generator, uniform magnetite scales were deposited successfully on the outer surface of Alloy 690TT archive tube specimen with artificial cracks. The effect of magnetite scale deposition on the crack signal amplitude of plus-point coil was minor for all depth of axial and circumferential cracks machined. However, uniform magnetite scales increased the background noise levels of plus-point coil signals in the tube and resulted in the noticeable changes of signal phase angle in both axial and circumferential cracks with smaller depth of 20~40%. These changes of phase angle may affect the reliability in depth sizing of cracks with smaller depth. Finally, it can be concluded from this study that background noise signals are introduced and the small crack signals can be distorted, depending upon the thickness and distribution of magnetite scales deposited.

ACKNOWLEDGEMENTS

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