

Integrity Evaluation Methodologies of Secondary System Materials in Nuclear Power Plants during Long-Term Layup

Seong-Jun Ha ^a, Hee-Sang Shim ^a, Do Haeng Hur ^a, Hyuk-Chul Kwon ^b, Byung-Hoon Kim ^b, Soon-Woo Kwon ^b,
Soon-Hyeok Jeon ^{a*}

^a Korea Atomic Energy Research Institute

^b Korea Hydro & Nuclear Power Co, Ltd.

*Corresponding author: junsoon@kaeri.re.kr

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1. Introduction

The management of nuclear power plants (NPPs) is significantly important during long-term layup periods with respect to the integrity of the secondary system. These layups, essential for maintenance and safety evaluations, expose the plant to atmospheric conditions that can lead to the accumulation of impurities such as sodium, chloride, and sulfate [1-3]. In special, the surfaces of carbon steel piping in secondary system of NPPs can also susceptible to corrosion. This exposure poses risks to operational soundness of the plant by potentially accelerating corrosion and affecting secondary coolant systems [4-6]. Therefore, it is essential to carry out an evaluation of the integrity of NPPs involving identification and mitigation of these risks, ensuring long-term operational safety of the plants.

To evaluate the corrosion rate and impurity accumulation during layup periods, this study introduces an innovative approach. It focuses on the comparative analysis of surveillance specimens collected at the start of the overhaul and at the end of long-term layup periods. By comparing the surveillance specimens collected at these two specific periods, this method provides a detailed evaluation of the changes induced by the layup period on the materials within the secondary system of the NPPs. In this study, bare metal and oxidized specimens as surveillance specimens introduce to simulate the oxidized surface of piping in the secondary system. This approach is anticipated to offer essential insights into the corrosion rate and impurity accumulation during layup periods, thereby aiding in the enhancement of maintenance and safety standards.

2. Methods

To evaluate the atmospheric corrosion rate during the layup period, surveillance specimens were fabricated using three steel types: SA106 Gr.B, SA516 Gr.70, and A335 P22. The chemical compositions of the steels were listed in Table I. These specimens were prepared not only their bare metal but also pre-oxidized state such as magnetite and hematite. Specifically, the

magnetite formation was carried out by controlling the dissolved oxygen level to below 5 ppb using argon purging for 2 h. The hematite formation was carried out by purging oxygen for 2 h to establish a saturated dissolved oxygen environment. These oxide formations were carried out in an autoclave at a temperature of 230 °C for 240 h. After the oxide formation process, weight of the surveillance specimens was measured three times to ensure accuracy. The macroscopic appearance of the oxidized specimens was observed. Subsequently, X-ray diffraction (XRD) analysis was carried out to identify the phases of oxides formed on the surface of each material. To evaluate the corrosion rate during the layup period, these surveillance specimens were assembled onto a specimen holder and subsequently installed in specific position such as a condenser, low-pressure heater, high-pressure heater, deaerator, and moisture separator and reheater.

Table I: Chemical compositions of SA106 Gr.B, SA516 Gr.70, and A335 P22 (wt. %).

Alloys	C	Si	Cr	Mn	Ni	Cu	Mo	Fe
SA106	0.19	0.23	0.04	1.05	0.02	0.01	0.01	Bal.
SA516	0.21	0.19	0.06	1.04	0.07	0.17	0.02	Bal.
P22	0.12	0.31	2.12	0.45	-	-	0.94	Bal.

3. Results

Fig. 1 shows the macroscopic appearance of the surveillance specimens oxidized under various conditions. The appearance of the surveillance specimens revealed distinct color variations indicative of their oxidation states. For SA106 Gr.B and SA516 Gr.70 specimens showed a dark gray color under magnetite-forming condition, while turning red in hematite-forming condition. However, A335 P22 specimens maintained a dark gray appearance in both conditions. This differential color indicates that SA106 Gr.B and SA516 Gr.70 prefer the formation of hematite compared to A335 P22 under high dissolved oxygen condition due to the difference of Cr content.

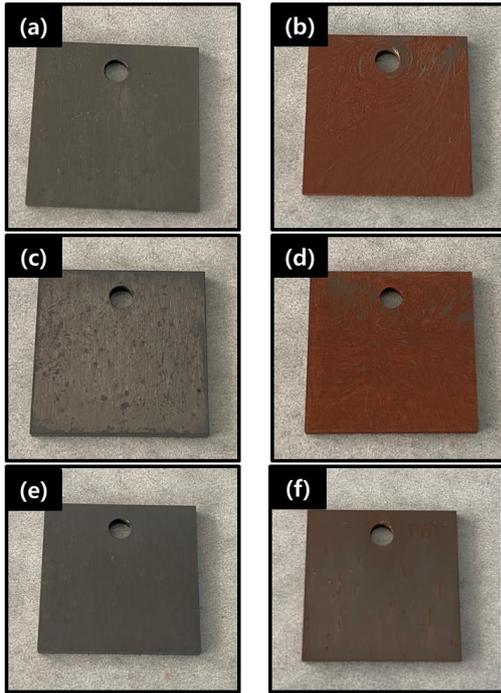


Fig. 1. Macroscopic appearance of surveillance specimens under various oxidation conditions:(a) SA106 Gr.B with magnetite formation, (b) SA106 Gr.B with hematite formation, (c) SA516 Gr.70 with magnetite formation, (d) SA516 Gr.70 with hematite formation, (e) A335 P22 with magnetite formation, and (f) A335 P22 with hematite formation.

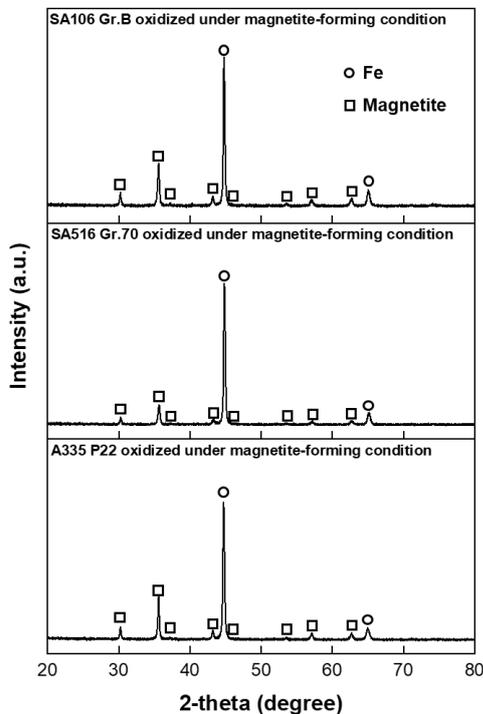


Fig. 2. XRD Results of surveillance specimens containing SA106 Gr.B, SA516 Gr.70, and A335 P22 oxidized under magnetite-forming condition.

Fig. 2 shows the XRD results for surveillance specimens after surface oxidation under conditions with dissolved oxygen levels below 5ppb. The XRD analysis distinctly identified only magnetite formation on all specimens. This distinct identification of magnetite on the specimens indicates that the process to fabricate magnetite-oxidized surveillance specimens was performed with precision.

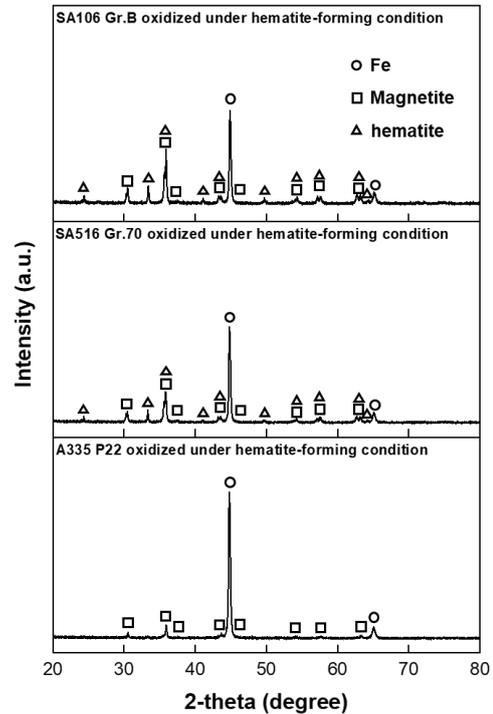


Fig. 3. XRD Results of surveillance specimens containing SA106 Gr.B, SA516 Gr.70, and A335 P22 oxidized under hematite-forming condition.

Fig. 3 shows the XRD results for surveillance specimens after surface oxidation under the high dissolved oxygen condition. The XRD analysis identified both hematite and magnetite on the SA106 Gr.B and SA516 Gr.70 specimens, indicating the formation of multiple oxide types under these conditions. However, the A335 P22 specimen only identified the magnetite with no hematite detected. Despite the aim of forming the hematite on all specimens under the high dissolved oxygen conditions, the lack of hematite on the A335 P22 specimen indicates a need for refining the oxidation process.

The fabricated surveillance specimens were assembled on a specimen holder and then installed in the secondary coolant system of the NPPs to evaluate atmospheric corrosion during long-term layup periods. The specimen holder after assembling the surveillance specimens is shown in Fig. 4. Prior to the restart of operations, the surveillance specimens will be collected to evaluate potential atmospheric corrosion and the accumulation of impurities that could adversely affect the operation of the NPP. It is expected that these evaluations will ensure the long-term safety of the plant

by identifying any corrosion-related issues that may have occurred during the layup period.

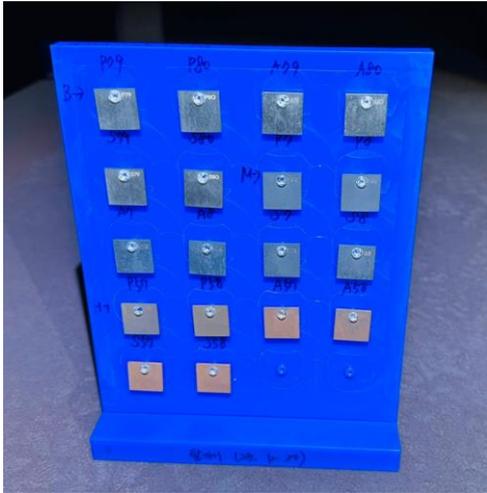


Fig. 4. Assembled surveillance specimens on a specimen holder for evaluation of atmospheric corrosion rate during long-term layup periods.

4. Conclusions

This study newly introduced the use of surveillance specimens to evaluate atmospheric corrosion rate during long-term layup periods of NPP. The focus of this research was on fabricating surveillance specimens that formed magnetite and hematite on the SA106 GrB, SA516 Gr.70, and A335 P22 steels. While magnetite was successfully formed on all specimens, hematite did not achieve the optimal conditions, indicating a need for further optimization. The application of these surveillance specimens for monitoring and managing corrosion is expected to significantly enhance the safety and efficiency of power plant operations by providing the effect of atmospheric corrosion under layup conditions.

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