

Electrochemical Behavior of i-SMR Structural Materials in Simulated Soluble Boron-free KOH or LiOH Environments

Wonjun Choi ^a, Seung Heon Baek ^b, Geun Dong Song ^b, Dong Seok Lim ^b,
Yeongho Son ^b, Young-Jin Kim ^b, Chi Bum Bahn ^{a*}

^a*School of Mechanical Engineering, Pusan National Univ., Busan, 43241, South Korea*

^b*FNC Technology Co. Ltd, Yongin-si, Gyeonggi-do, 16954, South Korea*

*Corresponding author: bahn@pusan.ac.kr

1. Introduction

Nuclear power plants (NPPs) are acknowledged as a potential solution for mitigating air pollution and addressing climate change, as it produces electricity in an environmentally friendly manner while ensuring stable and reliable energy production. There is a growing interest in the development of Small Modular Reactors (SMRs), which have a maximum power output below 300 MW, and can be used for coal replacement, distributed power, and hydrogen production, etc. Currently, more than 70 SMR designs are being developed in 16 countries worldwide, with 31 of them adopting a pressurized water reactor design that uses water as a coolant [1].

Recently, South Korea has also been actively developing the innovative SMR (i-SMR) by adopting the boron-free coolant water chemistry [2,3]. The boron-free core design offers several advantages, such as reducing the amount of liquid radioactive waste, mitigating crud induced power shift (CIPS), and simplifying the chemical and volume control system (CVCS) used to regulate boron concentration. In addition, the use of KOH is being explored as an alternative pH control agent for the reactor cooling system, as it offers advantages in terms of both price and supply compared to the previously used LiOH.

Electric Power Research Institute (EPRI) has carried out extensive research to explore the use of KOH as a replacement for LiOH, which is a pH control agent for the primary coolant system in commercial pressurized water reactors [4]. The VVER, which operates in Russia, has verified that stainless steel and Zr-alloy fuel cladding have good corrosion resistance in a water chemistry environment where KOH is used as the pH control agent [5,6]. Most recently, Kai Chen et al. [7] found that replacing LiOH with KOH as a pH control agent in simulated PWR primary water had no significant effect on the irradiation-assisted stress corrosion cracking (IASCC) crack growth rate of the 304 stainless steel. However, research on the corrosion characteristics of i-SMR structural materials in the boron-free KOH environment has not been extensively conducted.

The purpose of this study is to evaluate and compare the electrochemical corrosion behavior of significant structural materials in the coolant chemistry of i-SMR. The materials under investigation are 316L stainless steel, Alloy 690, and Zr alloy, and the comparison will

be carried out in a simulated boron-free water chemistry environment, where KOH or LiOH is used as the pH control agent.

2. Experimental Procedures

2.1 Materials and test conditions

The test materials used were 316L stainless steel, Alloy 690, and Zr alloy, which are considered as main structural materials for i-SMR. 316L stainless steel and Alloy 690 were cut by electro-discharge machining into 10 mm × 10 mm × 2 mm specimens. The edges of the specimens were mechanically ground using 400 grit silicon carbide paper. All surfaces were mechanically polished with colloidal silica suspension up to 0.04 μm. In the case of the Zr alloy, a ring-shaped specimen with a diameter of 10 mm, height of 5 mm, and thickness of 1 mm was used. All specimens were ultrasonically cleaned with acetone, ethanol, and distilled water in sequence.

The experiments were conducted in an autoclave equipped with a high temperature water circulation system. The test solution was prepared by dissolving either potassium hydroxide (KOH) or lithium hydroxide (LiOH) powder in distilled water, and subsequently adjusting the pH to 7.2 at the operating temperature.

Before the experiments, the test solution was deaerated by purging with pure Ar gas to reduce the dissolved oxygen (DO) concentration to below 5 ppb. Then, pure H₂ gas was continuously injected to maintain a dissolved hydrogen (DH) concentration 25 cc/kg·H₂O. The experiments were carried out under the conditions of a temperature of 320°C and a pressure of 150 bar.

2.2 Electrochemical tests

The electrochemical experiments were conducted using the three-electrode technique on a GAMRY 1010E potentiostat. Each test specimens, Pt mesh and Cu/Cu₂O/YSZ electrode were used as the working electrode, counter electrode, and reference electrode, respectively.

Electrochemical impedance spectroscopy (EIS) was carried out at the open-circuit potential (OCP) with an amplitude of 10 mV and a frequency range from 2 × 10⁴ Hz to 10⁻² Hz. Potentiodynamic polarization tests were

conducted following the EIS measurement at a scanning rate of 0.167 mV/s. The anodic and cathodic polarization curves were obtained from -0.3 V to $+1.5$ V (vs. OCP) separately. Each experiment was repeated at least three times to ensure the reproducibility and reliability of the results.

3. Conclusions

To achieve the goals of this study, experimental equipment is being prepared, and experiments will be conducted in the future. An overview of the ongoing project will be presented, along with experimental data. The resulting database from this study has the potential to aid in establishing a water chemistry management strategy to ensure corrosion resistance of the significant materials used in i-SMR.

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