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Implementation of Physical and Post-Irradiation Characterization Facilities For High-Temperature Nuclear Structural Materials at KRID

Mun-ho JO*, Juhan Ka, Jung-hyun Park, Seoha Kim, Yeong-su Ha

569, Haemaji-ro, Jangan-eup, Gijang-gun, Busan, Korea
Korea Research Institute of Decommissioning (KRID)
**Corresponding author: moon@krid.re.kr*

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1. Introduction

To achieve global carbon neutrality, the role of nuclear power is becoming increasingly important, with its utilization steadily increasing worldwide. High-temperature gas-cooled reactor (HTGR) and molten salt reactor (MSR), which are classified as Generation IV nuclear reactors, have attracted significant attention due to their high thermal efficiency, excellent safety features, and potential to address the issue of spent nuclear fuel. However, in order to ensure the long-term integrity of reactor structures under extreme high-temperature and radioactive environments, it is essential to obtain highly reliable verification data for high-temperature structural materials and to develop design technologies based on these data. It is also essential to establish appropriate regulations and guidelines for these materials.

For this purpose, the Korea Research Institute of Decommissioning (KRID) is conducting a research project titled "Development of Verification Element Technologies for Structural Integrity of High-Temperature Reactors (HTGR, MSR) Based on Demonstration Experiments," under the supervision of the Nuclear Safety and Security Commission of Korea.

2. Research Objectives

The purpose of this study is to select structural materials capable of maintaining stable performance under conditions such as high temperature and radiation exposure, and to establish a roadmap for the verification of these materials in accordance with the requirements of domestic and international regulatory authorities. Subsequently, the suitability of the selected candidate structural materials for high-temperature reactors will be evaluated through demonstration experiments. The final goal of this study is to develop key technologies for the verification of structural integrity and the establishment of regulatory guidelines for structural materials used in high-temperature reactors.

Among these objectives, this paper focuses on the establishment of an experimental laboratory for investigating the physical properties of candidate materials and building a database based on demonstration tests.

3. Material Analysis Lab Status

The Korea Research Institute of Decommissioning is currently constructing a demonstration/analysis building equipped with hot cells, in addition to operating its existing research building where radiochemical analyses are conducted. The research building was completed in 2024, and, following the facility inspection approval for radioisotope (RI) use in March 2025, radiochemical analyses of intermediate- and low-level radioactive waste have been conducted since April 2025.

3.1 Mechanical Properties

Prior to analyzing irradiated samples, equipment for the analysis of the mechanical properties of selected candidate materials will be installed on the first floor of the research building to enable comprehensive characterization within the institute. The main equipment to be installed on the first floor of the research building for the analysis of mechanical properties includes a universal testing machine (UTM), scanning electron microscope (SEM), X-ray fluorescence spectrometer (XRF), polishing machine, mounting machine, microhardness tester, and optical microscope.

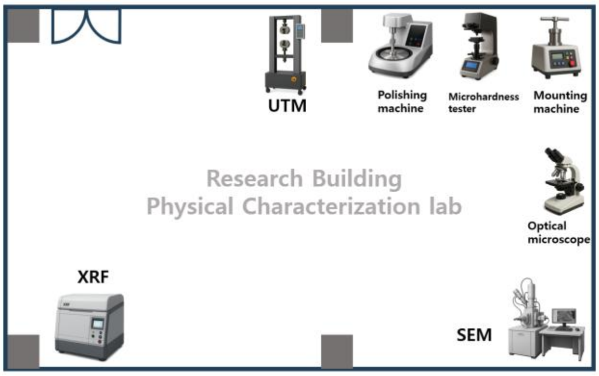

Fig. 1. Mechanical properties Lab Layout.

Using these instruments, comprehensive analyses will be performed to evaluate the fatigue behavior, tensile strength, creep properties, and microstructural analysis of selected structural materials. This approach allows for the generation of reliable data required for performance evaluation under high-temperature environments, as well as the establishment of degradation mechanisms. Especially, microstructural analyses using SEM and optical microscopy will provide critical insights into the relationship between mechanical properties and structural changes during high-temperature operation. These instruments will enable acquisition of fundamental data necessary for the accurate evaluation of material properties under high-temperature conditions. In particular, the results of mechanical and chemical property analyses will provide critical reference information for the design, performance assessment, and development of regulatory standards for structural materials used in high-temperature nuclear reactors.

3.2 Post-Irradiation mechanical Properties

The hot cells are scheduled to be used for the evaluation of irradiated samples during the second and third years of the project. There are seven cells in the hot cell facility; experimental activities will primarily be performed in sample processing cell, sample preparation and characterization cell. The sample processing cell houses equipment for basic specimen preparation, such as circular saws, band saws, CNC machines, and lathes. Following precision preparation using tools such as precision cutters and polishing machines in the sample preparation cell, the irradiated specimens will be assessed for material properties in the characterization cell, employing a universal testing machine (UTM) capable of operation at temperatures over 700°C.

In particular, the mechanical properties of irradiated specimens—such as high-temperature tensile strength and creep—will be directly demonstrated using a universal testing machine (UTM) equipped with a high-temperature chamber located within the hot cells. This approach will facilitate the acquisition of real-world performance data under actual irradiation conditions, which is essential for verifying the structural integrity of materials intended for use in advanced reactors.

Fig. 2. Demonstration/Analysis Building Under Construction.

3. Future Plans

The mechanical properties laboratory is scheduled for completion by the end of 2025, with experimental activities set to begin in early 2026. The hot cell facility is also scheduled for completion by the end of 2026. The data and results from this study are expected to be directly and indirectly utilized by domestic and international regulatory authorities in the design and implementation of regulations for next-generation high-temperature reactors. The details are as follows.

- Establishment of a materials property database for high-temperature gas-cooled reactor (HTGR) and molten salt reactor (MSR)
- Development of structural material design evaluation criteria based on demonstration data
- Creation of data-driven guidelines that meet the requirements of domestic regulatory authorities
- Reduction of verification costs through elucidation of high-temperature structural material degradation mechanisms

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