Development Status of Surface Modified-Zr Cladding Concept for Accident Tolerant Fuel in LWRs

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1. Introduction

The Zr-based alloys used as fuel cladding in a nuclear reactor have good corrosion resistance and mechanical properties at a high temperature and neutron stability in the normal operation conditions. However, the need for accident tolerant fuel (ATF) cladding has become a major concerns in research field after the Fukushima accident [1-3]. ATF cladding is defined as those that provide considerably increased response time in the event of a reactor accident while providing similar or improved performance as the commercial Zr cladding during normal operation [1-3]. Especially, an enhanced accident tolerance include suppressed reaction with steam, resulting in lower hydrogen generation, while maintaining acceptable cladding shape by increasing strength during the accidents. Various ATF cladding concepts have been developing in many organization in the world. The target of the ATF development is insertion into a commercial reactor as part of a lead test rod or assembly in early 2020 after the selection of promising concepts. Based on this aggressive development schedule, it is necessary to prepare the material characteristics and performance evaluation data tested in an out-of pile as well as in-pile using research reactor. Here, the new concepts of cladding have to check for the feasibility assessment regarding the fuel performance code, economic, operational safety, and environmental impacts. And new AFT cladding concepts must be capable of integration into the nuclear fuel cycle system to ultimately be accepted by utilities and vendors. The major challenges to develop ATF cladding concept is depend on the proposed technologies. After considering the various ATF cladding concepts and technologies, KAERI focused on the surface modified Zr cladding as a near term application [4]. This study introduce the surface modified Zr cladding regarding the development plan, strategy, and some results at the present time.

2. Results and Discussion

Fig. 1 shows the roadmap of ATF cladding program at KAERI supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP).

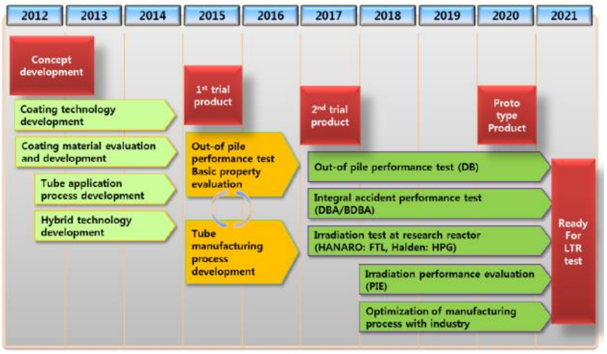

Fig. 1. Roadmap of ATF cladding development program

This project started from 2012, and the main target of this program is to develop the proto-type product for lead test rod (LTR) in the early 2020. A key point of surface modified-Zr cladding is to decrease hydrogen generation by increasing the oxidation resistance as well as to decrease the ballooning and rupture opening by increasing the strength during accident conditions. It is known that the scientific and engineering challenges associated with nuclear technology result in a long, complicated fuel cladding qualification process. The development progress of new fuel concept (surface modified-Zr cladding) deals with the design, manufacturing, testing, and evaluation. In addition, these steps will be repeated to obtain the optimum performance of the fuel cladding in the R&D strategy. This progress is summarized in Fig. 2. During last 5 years technology readiness level (TRL) for developing ATF cladding developed at KAERI was reached up to 3. Thus, the concept definition and feasibility study was performed for the surface modified-Zr cladding concept.

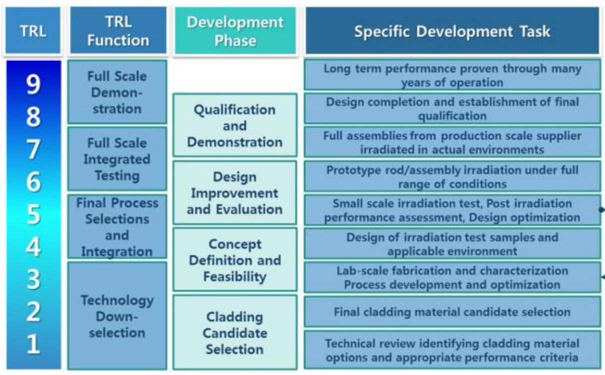

Fig. 2. Technology Readiness Level (TRL) for developing ATF cladding

The major benefit of the surface-modified Zr cladding concept is the economics when compared to other concepts such as FeCrAl cladding, Mo-lined cladding, and SiC_f/SiC cladding because the commercial Zr-based alloy and manufacturing facility can be continuously used. However, the surface-modified Zr and cladding coating concepts have to develop the coating materials and coating technology. The good corrosion/oxidation resistance is obtained by a stable coating materials and the good adhesion property can be realized by ideal coating method. In the surface modified-Zr cladding concept, the oxidation resistance and strength at high temperature can be considerably improved over commercial Zr-based alloy cladding by a combination of two types of surface modification technology of the surface coating and partial oxide dispersive strengthened (ODS) treatment. Thus, we concluded that the surface modification technology showed promise for application to ATF cladding as a near-term application concept.

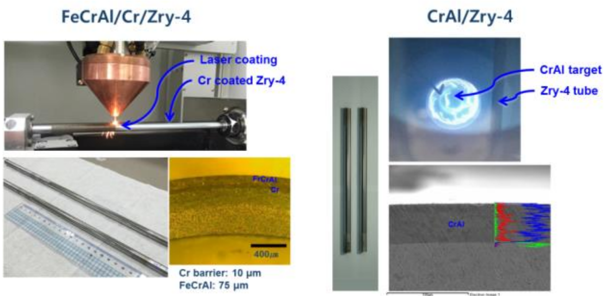

Fig. 3. Surface modification methods of 3D laser process for coating and ODS treatment and arc ion plating for coating

Fig. 3 shows the surface modification technologies of 3D laser process and arc ion plating. Here, the new material coating to improve the oxidation/corrosion resistance on Zr cladding tube is realized by using the 3D laser process and arc ion plating, and partial ODS treatment is possible by using 3D laser process.

After the sample fabrications, various tests were performed to evaluate the surface modified-Zr cladding performance. The test items are summarized as follows;

- Corrosion: 360°C, PWR simulated water
- Oxidation: 800 to 1400°C, steam
- Creep: 380°C, 120MPa (hoop stress)
- Wear: RT, water
- Integral LOCA test: 1200°C, steam, 6~8MPa (internal pressure)
- 4-point bend test after the LOCA test
- Welding performance test
- Microstructural observation
- Irradiation test at Halden research reactor

As a result of various performance tests, the surface modified-Zr cladding shows the improved performance (corrosion/oxidation, creep, wear, LOCA) and shows the reasonable performance (welding) when compared to commercial Zr cladding. An irradiation test of the surface-modified Zr cladding was reached up to 150 FPD in Halden research reactor and the irradiated samples shows a good performance without any problem such as spalling, failure et al.

3. Conclusions

From the various performance evaluations, the surface modified-Zr cladding concept shows a promising result as an ATF cladding. It may also be applied without major changes in the substrates of Zr-based alloys, because this cladding concept has a good oxidation (corrosion) resistance, as well as an improved strength at high temperatures when compared with commercial Zr alloy claddings. For 150 FPD in Halden reactor test, the surface modified-Zr cladding maintained a good performance without any problem.

Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2017M2A8A5015058)

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