Experiment, modeling and evaluation of ATF in the frame of IAEA CRP ATF-TS

Hyochan Kim [a*], Sunguk Lee [a], Jangsoo Oh [a], Changhwan Shin [a], Jongdae Hong [a], Jae-ho Yang [a], Dong-Joo Kim [a], Sunghoon Joung [b], Youho Lee [b]
[a]*LWR fuel technology research division, Korea Atomic Energy Research Institute, 111 Daedeok-daero 989 Beon-gil, Yuseong-gu, Daejeon, Republic of Korea*
[b]*Department of Nuclear Eng., Seoul National Univ., 1 Gwanak-ro, Gwanak-gu, Seoul, Republic of Korea*
[*]*Corresponding author: hyochankim@kaeri.re.kr*

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1. Introduction

Nuclear fuel technology is currently being developed to improve the reactor safety. It is desirable that improvements in accident tolerance are simultaneously accompanied by improvements to normal operations in terms of compatibility with current power plants and operations, economics, and impact on fuel cycles. For this reason, technology regarding accident tolerant fuel (ATF) has been developed worldwide.

Since the 1990s, the IAEA (International Atomic Energy Agency) has continuously organized CRP (Coordinated Research Project) fuel code benchmarking activities to develop fuel models and enhance the relationship among fuel model developers. In FUMEX-II and FUMEX-III, the extended burnup fuel models were benchmarked to improve the predictive capability of fuel performance codes with respect to higher burnup fuel [1, 2]. In the revised ECCS acceptance criteria, the fuel model for accident conditions should be considered for safety analysis. To investigate fuel behavior under design basis accident and design extension conditions, FUMAC CRP was performed [3]. Simultaneously, ACTOF CRP was initiated to obtain data through experiments on new fuel types [4]. Following FUMAC and ACTOF, in order to make synergy of experimental part and modeling part, a new CRP, called ATF-TS (Testing and Simulation for Advanced Technology and Accident Tolerant Fuels), has been launched since 2021.

In this paper, the activities in the frame of ATF-TS will be introduced in Korea. In the ATF-TS, the fabrication of the coated cladding, the experiments with the fabricated specimen, modeling ATF with the experiment data, code benchmark among participants' result with the model and LOCA evaluation are included. Those activities are significant as international guidance in terms of modelling and evaluation of near-term ATF. Korea consortium (KAERI and SNU) contributes all work tasks in the CRP. The recent result with respects to work tasks that we contribute will be introduced in this paper.

2. Frame of ATF-TS CRP

The number of participants in the ATF-TS CRP is 29 organizations from 22 countries. ATF-TS consists of 4 work tasks as shown in Figure 1. In Work task (WT) 1, some of the participants fabricate the specimen (e.g. coated cladding) and some of the participants carry out experiments such as corrosion, ballooning and burst, oxidation at high temperature etc. In WT 2, model developments based on WT1 experiments are performed. As well as code benchmark results simulated by participants' codes are compared for Cr-doped pellet in-pile experiment and coated cladding experiment. In WT 3, ATF behaviors are evaluated for LOCA scenario. IFA650.9 and 10 tests are used and nuclear power plant scenario is applied with ATF model. UA (Uncertainty analysis) and SA (Sensitivity Analysis) are also investigated. In WT 4, ATF material properties library will be constructed based on publicable references and experimental data in WT1. KAERI and SNU participate the ATF-TS as Korea consortium.

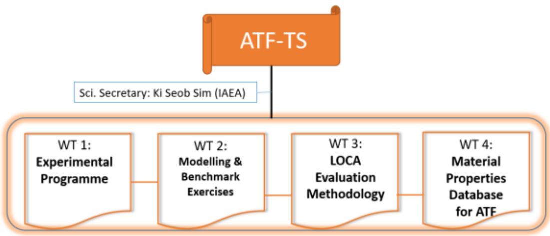

Fig. 1. Frame of ATF-TS and its work tasks

3. Contribution by KAERI/SNU

3.1 Worktask 1 (Experiment)

In WT1, SNU/KAERI conducts PQD (Post Quench Ductility) assessment of Cr-coated cladding fabricated by the participants. Typically, PQD characteristics of fuel cladding assess cladding embrittlement for accident conditions. Complying with the procedure that regulatory proposed, PQD test was conducted with the coated cladding. As shown in figure 1, cladding embrittlement of coated cladding become worse compared to reference cladding. However, the coated cladding takes more time to reach the certain weight gain ECR. As well as eutectic behavior of the Cr coated cladding above 1200 C has been investigated via experiment.

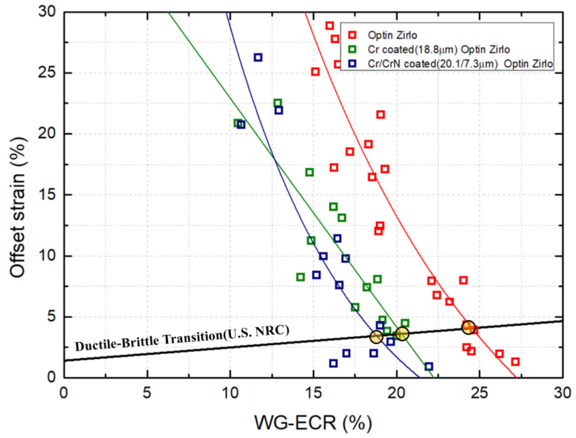

Fig. 2. Experimental results regarding PQD of the coated cladding [5]

To obtain mechanical properties of the coated layer for the application in high fidelity code, micro-pillar experiment has been conducted [6].

3.2 Worktask 2 (Modeling and benchmark)

Based on ballooning and burst experiment result with the coated cladding in WT1, creep coefficients at high temperature of the coated material (Cr) are extracted using MERCURY [7] for simulation of ballooning behavior. The extracted coefficients do a good job to predict the experiment results [8]. In addition, strain-based burst criteria including isothermal and isobaric 26 burst experiments is also built with uncertainty range as shown in figure 2.

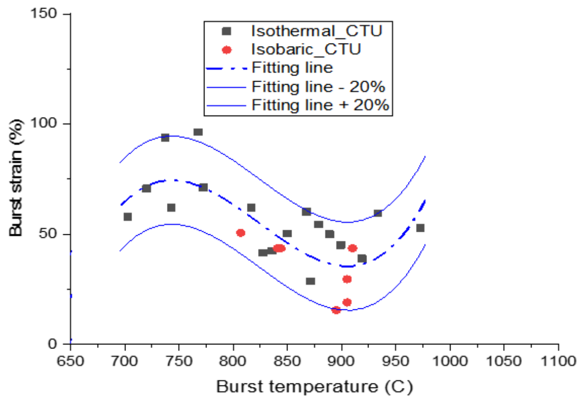

Fig. 3. Strain-based burst criteria of the Cr-coated cladding

As a near-term ATF pellet, it is concerned that amount of fission gas release of Cr-doped pellet can be increased compared to typical UO2. IFA716 which is in-pile test in halden reactor demonstrate that the Cr-doped pellet release fission gas more compared to reference case in consideration of uncertainty amount of FGR. Participants in WT2 simulate IFA 716 rod 1 FGR behavior with modification of FGR model that takes into account high diffusivity of doped pellet. Figure 4 shows the simulation result of IFA 716 rod1 where the higher FGR was measured [9].

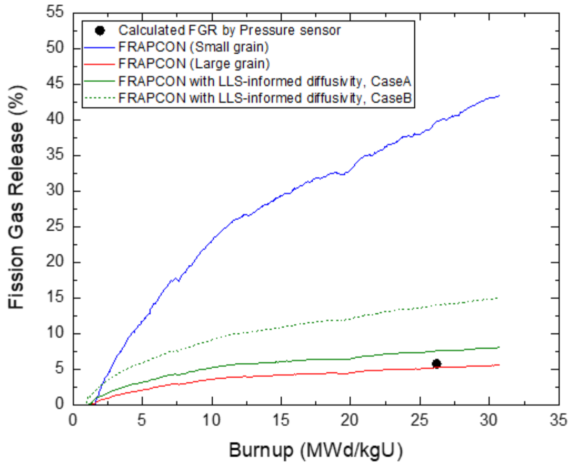

Fig. 4. Amount of FGR of Cr-doped pellet simulated by the modified FRAPCON4.0P1

With the developed models, single effect tests are simulated by each participant code. The simulation results are compared for code benchmark.

3.3 Worktask 3 (LOCA evaluation)

By developing ATF models over WT1 and WT2 activity, ATF is evaluated under LOCA scenario. IFA650.9 and 10 scenario that were conducted in Halden reactor are used with consideration of ATF model. For the NPP case, TRACE [10] which has been developed by US NRC for the safety analysis, generates the thermal-hydraulic boundary conditions which will be imposed for fuel analysis for a typical European nuclear power plant (NPP). The NPP scenario consists of LBLOCA, SBLOCA and DEC. UA and SA will be investigated. KAERI will perform fuel behavior simulation with MERCURY and ATF models under IFA650.9 and 10 as well NPP scenario.

3.4 Worktask 4 (ATF material properties)

Material properties of nuclear fuel are significant when the fuel rod behaviors are simulated and evaluated. Therefore, so far UO2 and Zircaloy material properties has been accumulated in material library. As new fuel concept, material properties of ATF should be built as same manner of UO2 and Zircaloy. One of the promising ATF pellet, micro cell pellet which has been developed by KAERI [11] has been tested in-pile and out-of-pile. Based on the experiment, thermal conductivity correlation of Cr vol. 5% microcell pellet and Mo vol. 5% microcell pellet were obtained as shown in figure 5 [12]. The correlation and literatures that were published are added to ATF material library as activity of WT4.

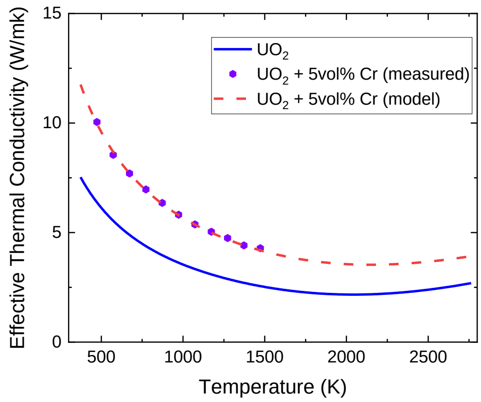

Fig. 5. Thermal conductivity of Cr metallic micro cell pellet

4. Conclusions

Throughout worldwide, fabrication, experiment and modelling of ATF actively have been carried out. IAEA coordinates activities (fabrication, experiment, modeling, evaluation) regarding ATF in order to initiate guidance of ATF model and evaluation. Korea consortium (KAERI/SNU) contributes all work tasks. In WT1, PQD analysis, eutectic investigation and mechanical properties of Cr coated cladding are conducted. In WT2, creep coefficient and strain based burst criteria are obtained from other participants' experiments. Code benchmark for single effect test is participated with MERCURY code. In WT3, MERCURY with ATF models simulates fuel behavior with thermal hydraulic boundary condition under LOCA scenarios. In WT4, thermal conductivity correlations of Cr and Mo metallic microcell pellet are added to ATF material library where IAEA will maintain. End of 2024, it is expected that 4 TECDOCs regarding worktasks will be published as a guidance of ATF models and evaluation.

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