Qualitative approach to understand irradiation growth behavior of ODS ATF fuel

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1. Introduction

The Irradiation growth is the most important phenomenon that causes longitudinal change among the various causes of dimensional changes that occur in fuel in a nuclear reactor.

Detailed mechanism of irradiation growth is still studying, a definition of Irradiation growth is that the irradiation growth is a change in the dimensions of a zirconium alloy reactor component even though the applied stress is nominally zero. It is approximately a constant volume process, so if there is, for example, an increase in the length of a component, the width and/or thickness must decrease to maintain constant volume [1].

In SRP(Standard Review Plan) 4.2, it is stated that "the irradiation growth can result in a significant interference fit between the rod upper end cap and the tie plate (in a boiling-water reactor (BWR)) or the upper nozzle (in a pressurized-water reactor (PWR)), resulting in rod bowing". [2] Due to this reason, an irradiation growth should be limited to avoid fuel damage or failure.

In case of the Zr-based cladding, an amount of irradiation growth as a function of neutron fluence is well known, but irradiation growth of ATF(Accident Tolerant Fuel) nuclear fuel, which are currently being developed, are not yet known.

This paper summarizes the irradiation growth related part of the PIRT(Phenomenon Identification and Ranking Table) development study which is performed for the development of the ATF nuclear fuel performance model and code including the ODS(Oxide Dispersion Strengthened) and CrAl alloy coating layer.

In this paper, the ATF's irradiation growth is qualitatively studied and its effect on fuel in-reactor behavior is discussed.

2. ODS ATF Fuel

Fig. 1 shows an approximated structure of ATF fuel cladding[3]. Based on zirconium base cladding, Y_2O_3 particles are dispersed by 3D printing technique. The role of Y_2O_3 particles are to enhance the mechanical strength under high temperature condition such a LOCA(Loss Of Coolant Accident). The outer most layer is CrAl alloy which is coated by AIP(Arc Ion Plate) methods. Due to the high corrosion resistance characteristics of CrAl alloy, ATF cladding can endure high temperature oxidation period and maintain its ductility during accident.

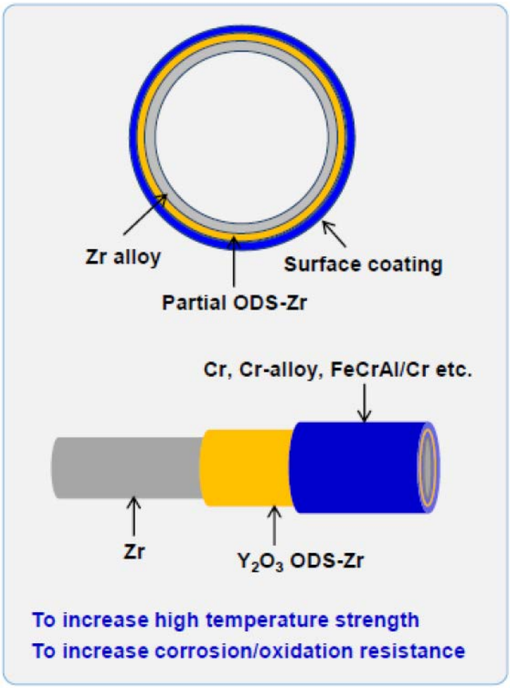

Fig. 1 Structure of Zr-ODS-CrAl cladding

3. Irradiation growth of ODS ATF cladding

As mentioned in chapter 1, the ATF cladding consists of three layers. Therefore, in this paper, an irradiation growth of each layer are reviewed.

3.1. Zirconium alloy layer

An irradiation growth of zirconium is caused by HCP structure characteristics. An irradiation growth model for Zr based alloy was suggested as follows by Geelhodd et al[4].,

$$ax\,[mm/mm] = 2.1800 \times 10^{-21} \Phi^{0.845} \quad \text{for SRA}$$
$$ax\,[mm/mm] = 7.0130 \times 10^{-21} \Phi^{0.81787} \quad \text{for M5}$$
$$ax\,[mm/mm] = 9.7893 \times 10^{-25} \Phi^{0.98239} \quad \text{for Zirlo}$$

Above models are applicable temperature range 700K~900K, maximum burnup level 65MWd/kgU and under 12×10^{25} n/m^2 fast fluence level. However, above presented correlation is only applicable relatively low stress case, in case of high stress region such as a guide tube joining with spacer grid or top/bottom nozzle, our knowledge on irradiation growth is still uncertain.

3.2. ODS layer

There are very poor study results are available for an irradiation growth behavior of ODS alloy due to lack of usage of ODS ally to reactor materials. But, due to the HAZ(Heat Affected Zone) formation during ODS manufacturing process, it is expected that an entire irradiation growth will be less than that of matrix material(Zirconium alloy). As can be seen in Fig. 2, HAZ formation result in more random microstructure than as-fabricated cladding's one and axial growth can be shortened.

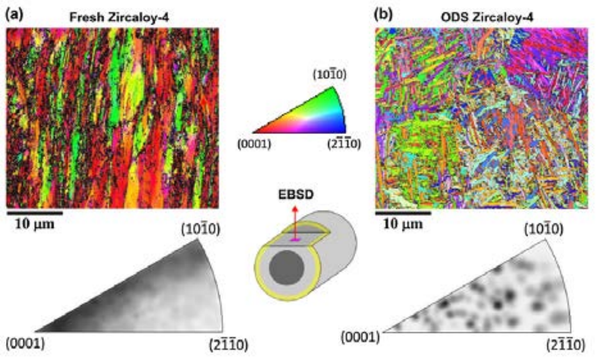

Fig. 2 HAZ formation in ODS region[5]

In a knowledge level point of view with regarding irradiation growth, as mentioned in chapter 3.1, in high stress region, current available irradiation growth correlation is not applicable. In Fig. 3, a stress analysis results of ODS cladding is shown. Due to the uneven material property in ODS region, a sharp stress increase is expected and current irradiation model's applicability should be re-estimated for ODS cladding.

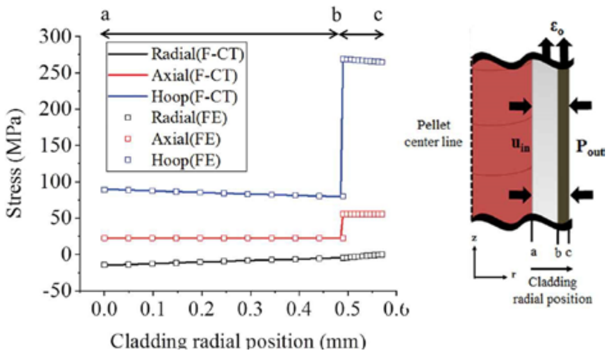

Fig. 3 Stress distribution in ODS cladding[6]

3.3. CrAl coating layer

The outermost layer is CrAl alloy which is coated by AIP method for increasing corrosion resistance. It can be easily imagined that a CrAl coating layer shows no growth behavior due to its isotropic characteristics

4. Results and Discussion

The irradiation growth of newly developed ATF fuel, Zr-ODS-CrAl coating cladding, has been studied by qualitative approach.

As a results of this study,

- An overall axial growth of ODS cladding may reduce.
- Maxtrix(Zriconium alloy layer)'s growth is same with current clading's one.
- Irradiation growth of ODS layer will be decrease due to HAZ formation during manufacturing process.
- CrAl alloy has no potential of irradiation growth due to its isotropic characteristics.
- High stress concentration in ODS region, the applicability of current known growth model should be reviewed.
- In regulatory or design point of view, current irradiation growth limit will be applicable to Zr-ODS-CrAl ATF Fuel.

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