

# Development of an ANSYS-Based FE Analysis Methodology for Simulating Neutron-Irradiation-Induced Deformation in Reactor Core Components

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## 1. Introduction

Research reactor core structures are exposed to neutron irradiation over extended periods, which leads to the accumulation of material deformations such as irradiation growth, swelling, and irradiation creep; these deformations directly affect integrity assessments of the structures. Previous studies [1] have presented implementation procedures for incorporating neutron-irradiation-induced material deformation into finite element analyses using ABAQUS; however, implementation and validation cases in ANSYS, which is widely used in industrial practice, remain limited. Accordingly, this study implemented the deformation prediction model proposed in the previous work within an ANSYS-based finite element analysis framework.

## 2. Material Deformation Behavior under Neutron Irradiation

This study selected the neutron-irradiation-induced deformation behavior of zirconium alloys, which are widely used in research reactor core structures, as the subject of analysis.

### 2.1. Irradiation Growth and Swelling under Neutron Irradiation

Irradiation growth and swelling refer to dimensional changes that accumulate under neutron irradiation even in the absence of external loading. Previous studies [1] formulated this behavior as being proportional to the accumulated neutron fluence. The length variation is defined as follows:

$$\frac{\Delta L}{L} = C_{ir} \cdot \phi \cdot t \quad (1)$$

where  $\phi$  is the neutron flux;  $t$  is the exposure time;  $C_{ir}$  denotes the irradiation-induced deformation coefficient.

### 2.2. Neutron Irradiation Creep

Irradiation creep is a phenomenon in which creep strain accumulates in a time-dependent manner when stress is applied under neutron irradiation [2]. For zirconium alloys, the irradiation creep strain rate  $\dot{\epsilon}_{cr}$  is defined as a function of the neutron flux and the effective equivalent stress  $\tilde{\sigma}$ , as follows:

$$\dot{\epsilon}_{cr} = C_{cr} \cdot \phi \cdot \tilde{\sigma} \quad (2)$$

where  $C_{cr}$  denotes the irradiation creep coefficient of the zirconium alloy.

## 3. ANSYS-based Neutron-Irradiation Deformation Prediction Method

### 3.1. Growth and Swelling Simulation via Thermal Expansion Analysis in ANSYS

In the commercial FEA program ANSYS, dedicated material models or analysis functions for directly accounting for neutron-irradiation growth and swelling are limited. Therefore, this study incorporated the effects of irradiation growth and swelling into the FE analysis by applying the thermal-expansion equivalence method proposed in previous work [1].

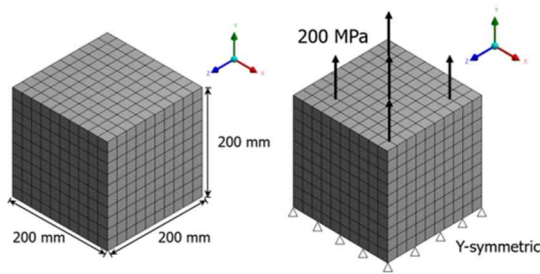
### 3.2. Implementation of Creep Models via ANSYS User Programmable Features (UPFs)

ANSYS provides built-in models for conventional creep analysis. However, there are limitations in directly applying the irradiation creep strain-rate equation in Eq. (2) in the same equation [5]. Therefore, this study implemented the irradiation creep model by using ANSYS user defined functionality (UPFs).

## 4. Validation of the ANSYS Simulated Results

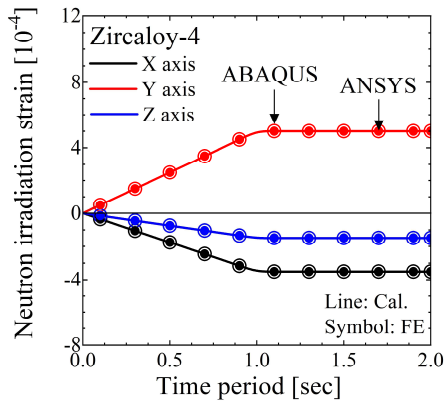
### 4.1. Validation of the Growth and Swelling Analysis Method

The FE model used to verify the ANSYS-based analysis method for neutron-irradiation growth and swelling is presented in Fig. 1. Following the previous study, a cubic model with a side length of 200 mm was employed. The model consisted of 4,961 nodes and 1,000 elements, using SOLID186 elements. No additional loads were applied, and all six degrees of freedom at the node located at the center of the bottom face were constrained. The material properties, neutron-irradiation coefficients, and neutron fluence were set to the same values as those reported in the previous study.



**Fig. 1.** Finite Element Analysis (FEA) Conditions for Neutron Irradiation

Figure 2 shows comparison of ANSYS results with theoretical value in previous study. The ANSYS results using thermal expansion analogy show in good agreement with both the theoretical predictions and the ABAQUS predicted results in the previous study [1].

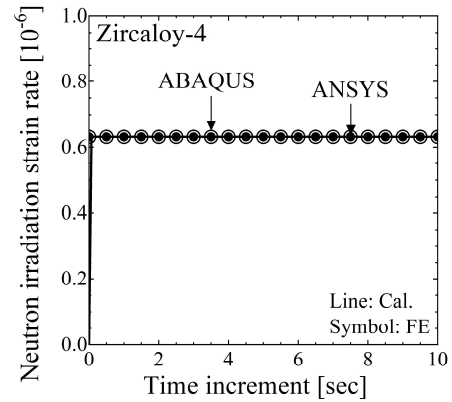


**Fig. 2.** FE analysis results for neutron-irradiation growth and swelling using ANSYS thermal expansion analogy.

#### 4.2. Validation of the Creep Analysis Method Using ANSYS UPFs

The FE model used to verify the neutron irradiation creep analysis method employed the same FE geometry as that used for the irradiation growth and swelling analysis, but with modified loading and boundary conditions. A stress of 200 MPa was applied on the top surface in the *Y*-direction, and a *Y*-direction symmetry boundary condition was imposed on the bottom surface. The creep model in Eq.(2) was incorporated into the analysis using ANSYS UPFs.

Figure 3 show comparison of the accumulated irradiation creep deformation behavior obtained using the ANSYS UPF-based approach with theoretical value in previous study [1]. As a result, the ANSYS simulation results agreed with both the theoretical predictions and the ABAQUS results in the previous study [1]. This confirms the applicability and reproducibility of the ANSYS UPFs-based implementation procedure for irradiation creep established in this study.



**Fig. 3.** FE analysis results for neutron-irradiation creep

## 5. Conclusion

This study implemented and validated prediction methodology using ANSYS for neutron-irradiation growth, swelling and irradiation creep in zirconium alloys. The simulation results are compared with theoretical predictions and the ABAQUS predicted results in previous study [1]. The ANSYS results show in good agreement with both the theoretical predictions and the ABAQUS predicted results. The proposed procedure was validated for applicability in evaluating reactor core components under neutron irradiation conditions

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