Static analysis of a dual-cooled fuel with different elongations of an inner and outer cladding tube

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1. Introduction

Innovative water reactor fuel center of the Korea Atomic Energy Research Institute (KAERI) recently started a new project for developing a dual-cooled fuel technology through a National R&D Program by the Ministry of Science and Technology. The key feature of the dual-cooled fuel is its annular cross-section of a fuel rod. The fuel rod has an internal coolant passage in addition to an external one so that a fuel rod consists of coaxial inner and outer cladding tubes in which donut-shaped pellets are stacked. An intrinsic purpose of this shape is to increase the surface area of heat transfer which results in a reduction of the fuel temperature. The important effects of this idea are to enhance the fuel safety and to achieve a power uprating[1].

A cladding tube is elongated by heat and neutron irradiation. The inner and outer cladding tubes of a dual-cooled fuel rod can be extended differently by in-core environmental factors. If these two tubes are lengthened differently, a dual-cooled fuel rod and the assembly could be tilted. The tilted fuel assembly will interact with a neighboring fuel assembly, which is one of the critical issues for a dual-cooled fuel development. So it is necessary to investigate the length behavior of the inner and outer tubes. It is also important to know how to reduce this phenomenon if it actually happens.

In this paper, static analyses are performed to predict the elongation behavior of these two tubes.

2. FE model & properties

Three assumptions are used to perform a static analysis. First, the cladding tube is elongated only in the axial direction. Second, a cladding growth happens linearly by temperature rise. Finally, cladding growth gradient along the thickness direction is ignored. The cladding tubes have a symmetric geometry about a center line, so the FE model is created by an axi-symmetric model as shown figure 1. This schematic drawing used geometry data of a 12x12 dual-cooled fuel named KAERI LTFA-1 and geometry data of the end plug used in the KSNP fuel. Numbers of 8-node bi-quadratic axi-symmetric reduced elements (CAX8R) were used for the two cladding tubes and an axi-symmetric discrete rigid element was used for a pellet stack. Total number of nodes and elements used in the FE model was 488,605 and 182,368, respectively. The used material properties of Zircaloy-4 were the elastic-plastic characteristic values.

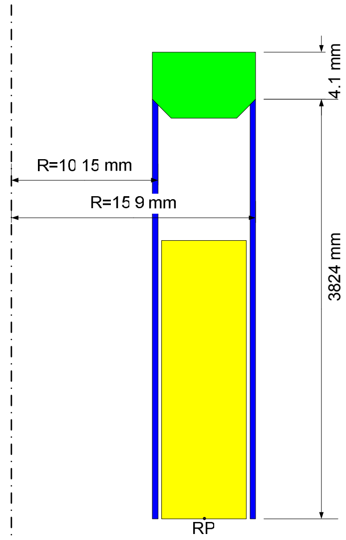

Fig. 1 The schematic geometry of a dual-cooled fuel.

Because a cladding tube is elongated about a whole length of a tube, we used different thermal expansion coefficients (pseudo) for each tube to simulate a distinct tube growth. It means that two tubes will be lengthened differently at the same temperature condition due to the different thermal expansion coefficients. In the case of a solid fuel rod, the elongation rate about a rod is 0.4 to 1 % of the whole rod length. For a conservative analysis, the growth difference between the inner and outer tubes is maximized by using the elongation rate of a solid rod, that is, the elongation rate for the inner tube is 1 % of the whole rod length and the outer tube has a 0.4 % elongation rate in this research.

$$\Delta L = \alpha \cdot \Delta T \cdot L$$
$$\alpha = \frac{\Delta L}{\Delta T \cdot L} , \qquad (1)$$

Where
$\Delta L / L$: Elongation rate
ΔT : Arbitrary temperature rise (100℃)
α : Thermal expansion coefficient.

The thermal expansion coefficient is calculated by using Eq. 1. The coefficients of the inner and outer tubes are 3.33E-5 and 1.33E-5, respectively. Contact definitions are applied between two cladding tubes and a pellet stack to prevent those from penetrating each other.

3. The results of analysis

Figure 2 shows the axial displacement (U2) of a dual-cooled fuel. After performing a static analysis, the inner and outer tubes are elongated without bending in any direction. Axial displacement of the right corner of an end plug is 24.086 mm and 24.098 mm for the left corner of an end plug.

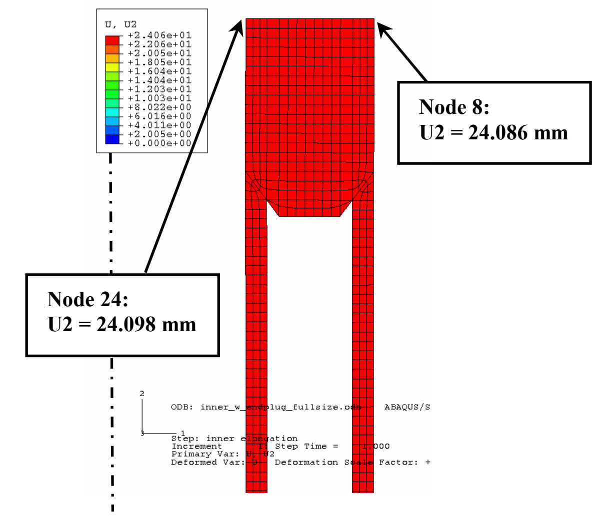

Fig. 2 Axial displacement of a dual-cooled fuel (unit: mm).

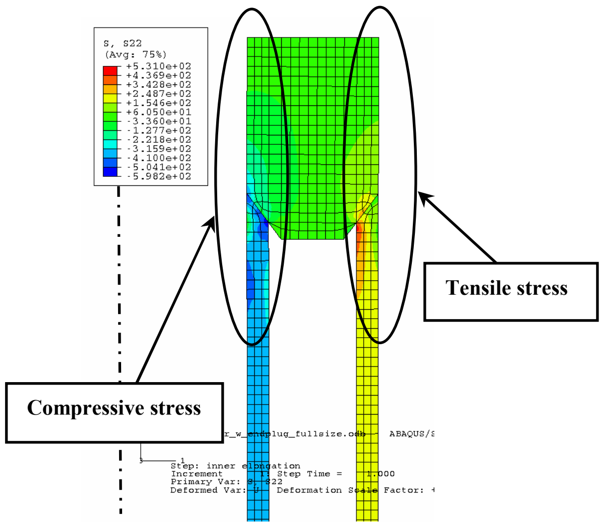

Fig. 3 Axial stress of a dual-cooled fuel (unit: MPa).

The reason for an elongation without a bending is that the end plug blocks an extension of an inner tube and promotes an elongation of an outer tube; that is, compressible stress occurs at the inner area of an end plug and tensile stress for the outer area of an end plug. These phenomena are verified by figure 3, axial stress distribution of the fuel (S22). Von-Mises stress of a dual-cooled fuel is shown in figure 4. The stress at the intersection of an inner tube and an end plug exceeds the yield strength. It is due to considerably conservative conditions applied in the analysis such as sudden loading and maximum of the growth difference. Although the yield happens due to a conservative condition used in the analysis, more attention is needed during a welding between a cladding tube and an end plug.

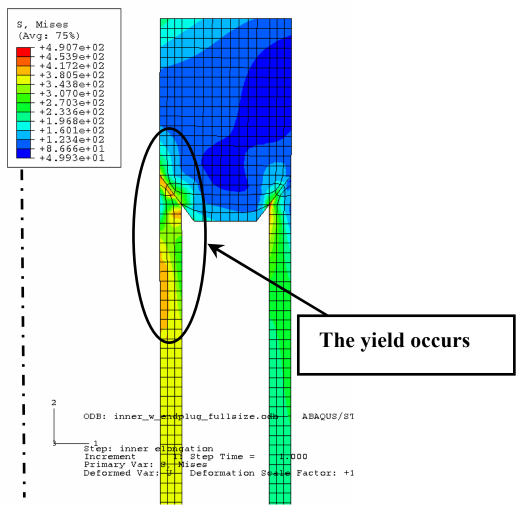

Fig. 4 Von-Mises stress of a dual-cooled fuel (unit: MPa).

4. Conclusion

Static analysis of a dual-cooled fuel was performed with concerning different elongations of an inner and outer cladding tube by using a computational analysis method. The conclusions of this study are

1. The different extension of the two cladding tubes has no effect on a bending of a dual-cooled fuel even in the case of a conservative extension difference.
2. The axial displacement of a dual-cooled fuel is very similar to the average value of the inner and outer tubes' displacement.
3. Although a tube in a real core condition is elongated slowly according to a change of core environmental factors, the tube is extended suddenly in this static analysis. It is the reason that a larger stress than the yield strength of Zircaloy-4 happens around the joint of an inner tube and an end plug.

ACKNOWLEDGEMENTS

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