Analysis of a Dual Cooled Fuel Rod Behavior during Different Elongation of an Inner and Outer Cladding Tube

JaeYong Kim *, KyungHo Yoon, HyungKyu Kim and KunWoo Song
Innovative Nuclear Fuel Division, KAERI, 1045 Daedeok-daero, Yuseong-gu, Daejeon
**Corresponding author: kjykjy@kaeri.re.kr*

1. Introduction

In a dual cooled fuel, double cladding tubes exist to increase heat-transfer surface area and decrease the centerline temperature of a fuel rod. In the case of a solid fuel rod, it consists of pellets, single cladding tube and end-plugs. Fuel rods are sustained by the friction force of the supports (springs and dimples) located in 10~11 spacer grids. The diameter and length of a fuel rod are altered due to neutron irradiation and high temperature in a reactor. If the friction forces exceed a critical buckling load of a tube, the rod will bow. It is a design method to check a fuel rod's bowing. But this methodology couldn't be applied for a dual cooled fuel if two tubes are deformed differently. Although two independent tubes are welded with end plugs, they could elongate differently. Different elongation of two cladding tubes could bring about a different moment at the joints between the end-plugs and tubes. And the soundness of a fuel rod could be harmed. The deformation can cause the narrow gap between the dual cooled fuel rods to be much closer. In the previous research [1], different elongation was just considered. In this paper, we suggest an advanced methodology that accommodates system pressure, rod's inner pressure and the friction forces of supports. The deformed behavior of a dual cooled fuel rod is discussed.

2. Method

2.1 Analysis procedure

Fuel rods are pressurized by system pressure from BOL (beginning of life). Because the system pressure is greater than the rod's inner pressure in this stage, a fuel rod contracts. Then, elongation due to neutron irradiation and temperature increase happens. Friction forces at the fuel rod's supports are simultaneously activated to block the rod elongation, also. To simulate these phenomena, analysis is composed of two steps, i.e. pressurization and elongation steps. During the pressurization step, inner and outer pressures are applied to the outer surface and inner surface of a dual cooled fuel rod. After satisfying force equilibrium, elongation is simulated by using artificial thermal expansion coefficients [1]. These coefficients do not have physical meaning but are pseudo-expansion coefficient. It is just introduced to control elongation difference. It is assumed that only the outer cladding tube was extended in this analysis for simulating a growth difference. We attempted three elongation differences, 0.5 mm, 3 mm, and 5.5 mm. The used artificial thermal expansion coefficients for each case are summarized in Table I. These values were calculated with some assumptions: temperature rise of 100℃ (no physical meaning) and the length of a dual cooled fuel being the same as that of a CE-type fuel rod, 4093.7 mm.

Table I: Artificial thermal Expansion Coefficient

Elongation difference (mm)	Thermal expansion coefficient (1/℃)
0.5	1.3031E-06
3	7.81861E-06
5.5	1.43341E-05

The friction force was derived from the Coulomb friction law. The normal force was obtained by using FE analysis. The friction coefficient between a fuel rod and supports was set as 0.3.

2.2 FE model

The geometry of a dual cooled fuel is axisymmetry about Y axis. So FE model was made by 2nd order axisymmetric element, CAX8. The chamfers of end-

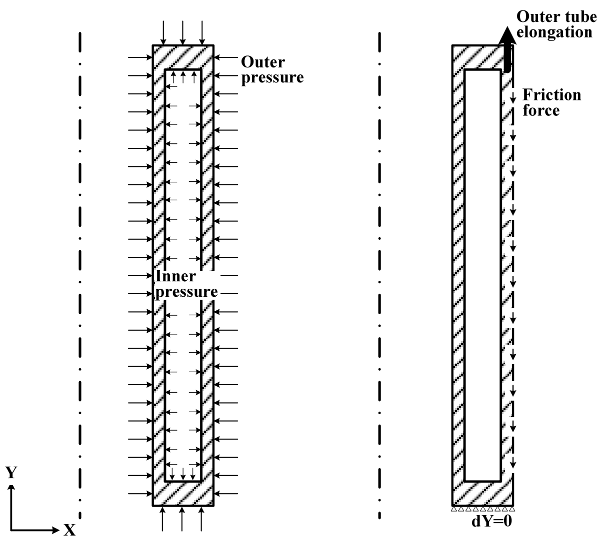

Fig. 1 Analysis procedure and model.

plugs were ignored. The FE model was composed of about 46,000 elements and 160,000 nodes. The material of two tubes is Zicaloy-4. The elastic- plastic properties of Zry-4 were measured by unidirectional tensile tests according to ASTM E8M-99 [2]. The Young's modulus and yield stress are 73.3 GPa and 163.45 MPa, respectively. And the Poisson's ratio is 0.37. HyperMesh V10.0 was used for a preprocessor and ABAQUS V6.8-5 was used for a solver and postprocessor [3, 4].

3. Result

During the 1st step, because the system pressure is greater than the rod's inner pressure about 10 MPa, the inner cladding is deformed in the direction of +x and the outer cladding is deformed in the direction of –x. Gray parts represent the un-deformed state. A legend shows y-directional displacement. Because this value is too small to recognize the change of shape, a scale factor for the deformed shape is applied.

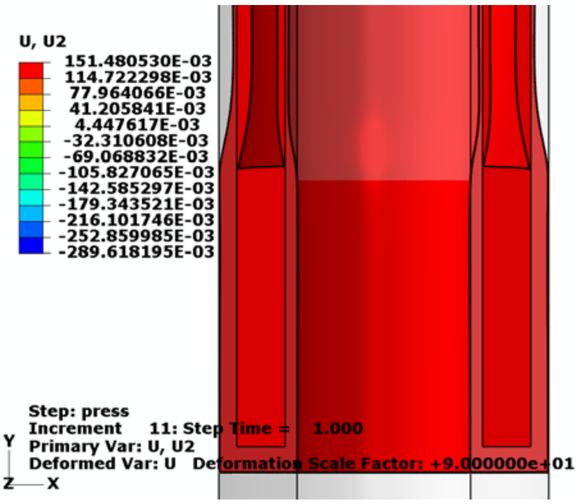

Fig. 2 Multiple plot of the un-deformed and deformed shape after the 1st step analysis.

After the 2nd step, inner and outer cladding tubes are moved in the direction of -x and +x, respectively.

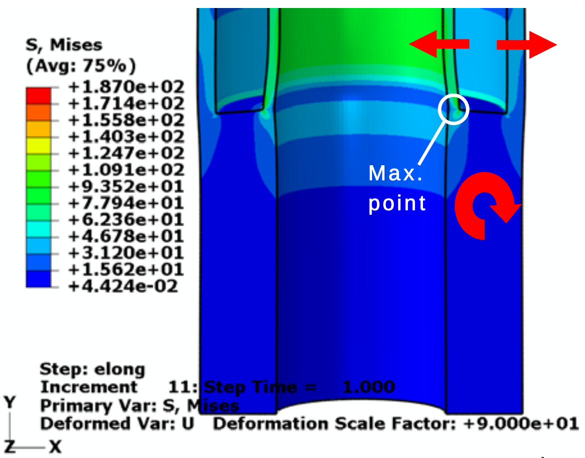

Fig. 3 Perspective plot of the deformed shape after the 2nd step analysis.

The lower end-plug is rotated in clockwise direction. Then the intersection area between the end-plug and inner tube is shrunk and the maximum Von-Mises stress is measured in this area. In the case of an upper end-plug, the analysis result is almost the same as one of the lower end-plug. The overall growth of the inner and outer tubes is summarized in Table II. The difference of overall growth between inner and outer tubes is in the order of 1/1000 mm and the outer tube is expanded more than the inner tube.

Table II: Overall growth (unit: mm)

Elongation difference	Inner edge of inner tube	Outer edge of outer tube
0.5	3.599140E-01	3.605160E-01
3	2.294569E+00	2.298075E+00
5.5	4.229214E+00	4.235625E+00

4. Conclusions

The conclusions of this study are

1. Advanced methodology for a deformed behavior of a dual cooled fuel rod is suggested. Pressure difference and friction force of supports are considered.
2. Euler's buckling equation couldn't be applied for a dual cooled fuel rod, because the deformed shape is mixing of an hourglass shape of inner tube and balloon shape of outer tube.
3. The maximum Von-Mises stress is happened at the junction area of a lower end-plug and an inner tube but it is much lower than yield strength until 5.5 mm elongation difference.

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