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An Investigation on the Structural Behavior of the PWR Fuel Assembly due to Irradiation

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1. Introduction

The structural behavior of the PWR fuel assembly is affected by the fuel assembly length change in the core. The fuel assembly length will be increased due to the irradiation and decreased due to the creep down. The hold-down spring forces will be increased as the irradiation induced growth increase. The amount of the creep down will be increased with the higher downward hold-down spring forces and upward hydraulic force. These irradiation growths and creep downs are main parameters for the evaluation of the fuel assembly axial growth and lateral bow. In this study, the effects of the irradiation growth on the fuel assembly structural behavior and the mechanism of the irradiation growth and bow are investigated. And, the measured structural behaviors of the PWR fuel assembly, irradiation induced growth and bow, are presented.

2. Effects on the Structural Behavior

2.1 Material Effects

The irradiation growth is defined as a change in shape without a volume change during irradiation in the absence of applied stress. The characteristics of the irradiation growth and creep down for the zirconium alloy are affected by the material dependent parameters, such as texture, cold work, heat treatment, corrosion, etc. and core conditions dependent parameters, such as neutron fluence, temperature, etc.[1,2] The main phenomenon which can be caused by irradiation growth is the fuel assembly bow. The fuel assembly bow is the loss of straightness caused by differential temperatures and strains between opposite faces of a fuel assembly.

2.2 Fuel Assembly Design Effects

The spacer grids of nuclear fuel assembly support the fuel rods along their length and maintain the lateral spacing between the rods throughout the design life of the fuel assembly[3]. The support system allows for different thermal expansion, creep and growth of the fuel rods, while maintaining sufficient spring contact force to prevent coolant flow-induced vibration damage.

Generally the irradiation growth of the fuel rod is higher than that of the fuel assembly because of the higher neutron fluence and temperature. The higher irradiation growth of the fuel rod will cause tensional stress through a spacer grid spring force on the guide thimble within a span of the fuel assembly until the sliding takes place between the grid spring and fuel rod. The effect of the fuel rod irradiation growth on the fuel assembly growth will be increased for the fuel assembly design with higher grid spring forces. The spacer grid spring forces are decreased as a function of the fluence due to the irradiation induced stress relaxation. The spacer grid spring with Inconel alloy has less stress relaxation than zirconium alloy. The fuel assembly design with all Inconel grid has strong fuel rod growth effect on the fuel assembly growth.

The hold-down springs provide a downward load on the top of the fuel assembly in the core. This compressive load causes a creep down of the fuel assembly axial length. The fuel assembly with higher hold-down forces has more downward creep down.

2.3 Core Design Effects

The fuel assemblies are loaded vertically in the reactor core and stand upright on the lower core plate. After all fuel assemblies are set in place on the lower core support structure, the upper core support structure is installed. The upper core plate compresses the fuel assembly hold-down springs to hold the fuel assemblies in place. The upper and lower core plates will be deflected due to the weight of the fuel assemblies and the hold-down forces. The irradiation growth and bow of the fuel assemblies can be affected by the deflections of the core support plates.

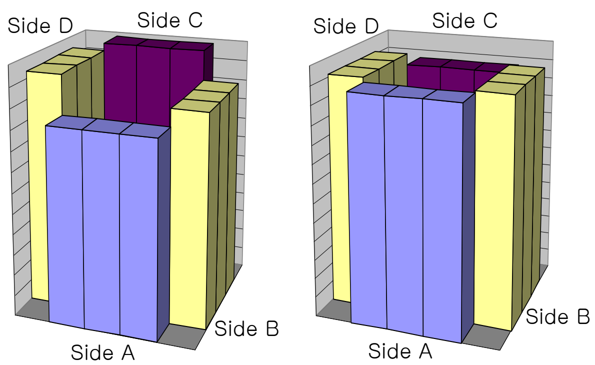
Three different groups of the fuel assemblies are loaded in the core according to the loading pattern. Some fuel assemblies can be surrounded by the fuel assemblies with different burnup. The non-uniform irradiation growth in a fuel assembly can be caused by different burnup distribution among the surrounding fuel assemblies.

3. Typical Structural Behavior of Fuel Assembly

3.1 Irradiation Growth

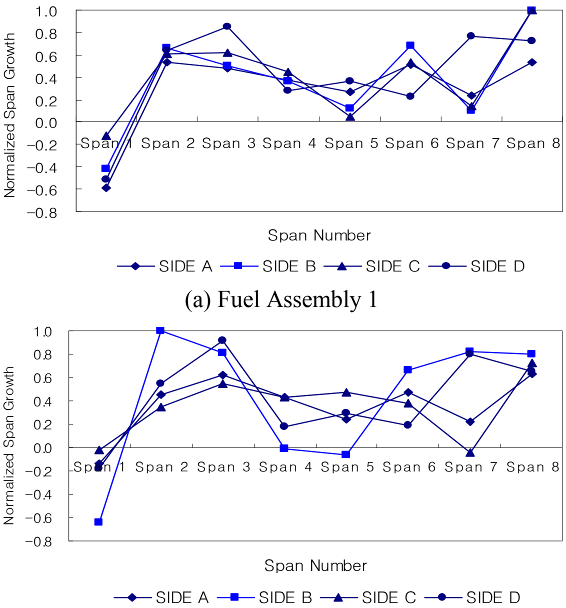
The fuel assembly length changes in axial direction are measured and the irradiation growths of the fuel assembly are evaluated. Fig. 1 shows a normalized fuel assembly growth at each side of the fuel assembly. It was evaluated that the fuel assembly irradiation growth differences of each side of the fuel assembly are mainly due to the burnup distribution of the surrounding fuel assemblies. When a certain side of the fuel assembly is faced with higher burnup fuel assembly in the core, the fuel assembly growth of that side is higher than that of the other side of the fuel assembly.

Fig. 2 shows a fuel assembly span growths in a fuel assembly. The fuel assembly span growths are relatively small at the middle location of the fuel assembly compared to the span growth at the upper and lower part of the fuel assembly. It was evaluated that the larger span growths at the upper and lower part of the fuel assembly are due to the larger friction forces between fuel rod and spacer grid spring at these locations. The friction forces of the top and bottom Inconel grids are larger than that of the mid zircaloy grids because of less irradiation relaxation of the top and bottom Inconel grid.



(a) Fuel Assembly 1 (b) Fuel Assembly 2

Fig. 1. Fuel assembly growth at each side of the fuel assemblies

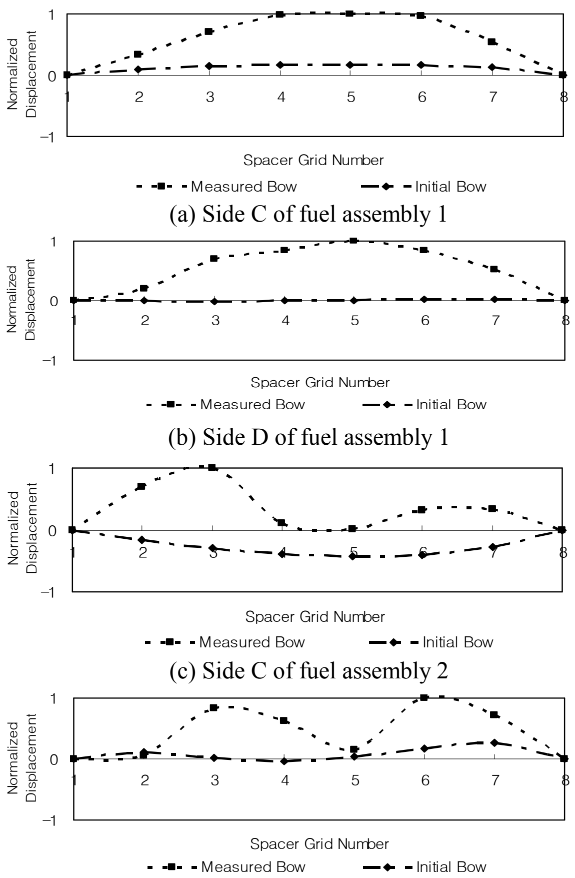


(b) Fuel Assembly 2

Fig. 2. Fuel assembly span growth in a fuel assembly

3.2 Bow

The fuel assembly lateral displacements at each grid locations are measured and the bow characteristics of the fuel assembly are evaluated. Fig. 3 shows the fuel assembly bow compared with initial bow. Fig. 3 (a), (b), (c), and (d) shows the fuel assembly bow at side C and D of fuel assembly 1 and side C and D of fuel assembly 2, respectively. It seems that the fuel assembly growth of each side and bow directions has some relationship and little relationship between initial bow and measured bow.



(d) Side D of fuel assembly 2

Fig. 3. Fuel assembly bow

4. Conclusion

(1) The effects of the spacer grid spring forces and hold-down spring forces need to be considered for the evaluation of the structural behavior of the PWR fuel assembly in the core.

(2) It is evaluated that the effects of burnup distribution of the surrounding fuel assemblies need to be included for the evaluation of the fuel assembly bow and growth.

(3) It seems that the bow directions are affected by the fuel assembly growth of each side and some relationship between initial and measured bow. Further study will be performed for the effect of fuel assembly initial bow and growth on the measured bow.

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