Development and Application of an Evaluation Method for the Supporting Structure Characteristics of a Dual Cooled Fuel Rod

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1. Introduction

A dual cooled fuel (i.e. annular fuel) has both internal and external cooling which would allow a substantial increase in power density and safety margins compared to a solid fuel in operating PWR plants [1]. When considering the sufficient cross-sectional area of the internal cooling channel and an acceptable amount of fuel pellet, the diameter of an outer tube should be increased for applying the compatible design concept of the dual cooled fuel to current operating PWRs. However, this results in a narrow gap between a dual cooled fuel rod and its supporting structure due to a fixed fuel assembly size.

As all the fuel rods should be supported with safety and reliability for operating periods, any kinds of supporting structures should be installed in a dual cooled fuel assembly. Consequently, the positions of supporting structures around the dual cooled fuel rod should be modified from the rod-to-rod center to sub-channel regions of grid structure and their shapes are designed and improved based on the advantages of current spacer grid technologies. Even though the vibration characteristics of the dual cooled fuel rod itself were not systematically evaluated, the characteristics of designed supporting structures and their wear resistances should be evaluated at the initial development stage. In this study, the evaluation method for the characteristics of designed supporting structures is developed by using a new test rig and compared with the analytical results. The final objective is to develop the evaluation method of their fretting wear resistances which accommodates the various shape of supporting structures without actual Zirconium supporting structures.

2. Experimental Procedure

2.1 Characteristic Test

A new characteristic tester of supporting structures was developed as shown in Fig. 1(a). This system consists of a low-speed servo motor, force sensor, displacement sensor, etc. All the measured data (force, displacement, servo motor speed, etc.) is monitored and recorded on a PC on a real time basis by using LabVIEW®. Among the designed supporting structures, an embossing type was simulated as a grid spring shape by using a 304 stainless steel ball with diameter of 2.54 mm and a plate-type of Cu-Be alloy with thickness of 0.5, 1.0 and 1.4 mm as shown in Fig. 1(b).

2.2 FE Analysis

In order to compare the characteristics of supporting structures, a FE model of Cu-Be plate was created by using the commercial 3D modeler, SolidEdge V.19. Both sides of the Cu-Be plate were constrained and a normal load of 20 N was applied to a ball specimen and then calculated its stiffness with thickness variation. In this model, the 4 node linear tetrahedron elements were used.

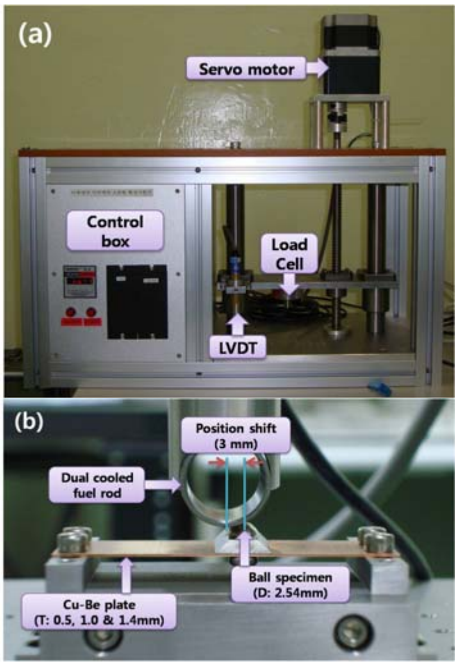


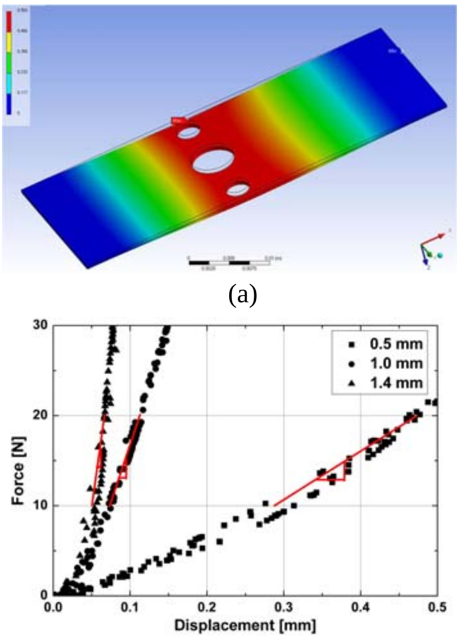
Fig. 1. (a) A schematic view of a new characteristic tester; (b) A simulated embossing type supporting structure by using a ball and Cu-Be plate.

3. Results and Discussion

The commercial code was used to post-process the model in order to calculate the stiffness of the Cu-Be plate with the variation of its thickness. The results showed that the maximum displacement was present at the ball specimen position as shown in Fig. 2(a). In this result, the ball specimen position was shift to 3 mm for the consideration of an embossing type spacer grid spring as shown in Fig. 1(b). Consequently, the shape of this force displacement curve is in good accord with that of the general spacer grid spring or dimple.

With increasing the plate thickness, the stiffness of Cu-Be alloy was rapidly increased as shown in Fig. 2(b).

At the initial stage, the contact force gradually increased during the stable contacts and then rapidly increased. In this figure, the stiffness values are calculated from the linear region (i.e. 10~20 N) of the force-displacement curve. The experimental and analytical results are summarized in Table. I.



(a)

(b)

Fig. 2. (a) FE analysis of Cu-Be plate; (b) Experimental results of simulated supporting structure characteristics.

Table I: Results of supporting structure characteristic

Plate thickness [mm]	0.5	1.0	1.4
Experimental results [N/mm]	32.1	252.5	726.9
Analytical results [N/mm]	34.4	246.9	746.3

Generally, fretting wear behaviors of a nuclear fuel rod were closely affected by the contact shape of a spacer grid spring/dimple [2] even though the material properties are regarded as a wear-governing factor. In addition, the different contact force with the same contact shape condition results in the dramatic change of its mechanism. The supporting force exerting on the fuel rod is generated by the deformation of grid spring or dimple (i.e. stiffness). So, the optimized stiffness value which was calculated by the increased weight of the dual cooled fuel rod should be evaluated by considering the vibration characteristics and fretting wear resistances between the dual cooled fuel rod and designed supporting structures. However, the considerable expenses are expected to manufacture a prototype supporting structure in order to perform the fretting wear tests. From the above results, the characteristic evaluation method of the simulated supporting structure is useful for developing the supporting structure of the dual cooled fuel rod without manufacturing actual Zirconium supporting structure.

4. Conclusions

The evaluation method by using the simulated stiffness tester can be a useful tool for developing the supporting structures for the dual cooled fuel rod. Based on this result, it is possible to evaluate the fretting wear resistances of various supporting structures at the initial design stage without actual Zirconium supporting structures.

ACKNOWLEDGEMENTS

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