Stress Analysis for Cladding Tube and Fuel Pellet with Missing Pellet Surface

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1. Introduction

In order to study the fuel rod failure mechanism caused by Pellet to Cladding Mechanical Interaction (PCMI) with a Missing Pellet Surface (MPS), the 3D Finite Element Analysis (FEA) models, which incorporates various parameters such as pellet cracking, MPS, dish, chamfer and cladding defect were developed and the stress analysis methodology was also presented [1&2].

In this paper, the parametric stress analyses were performed to figure out an effect of each small imperfection such as pellet cracking, MPS, dish depth, chamfer and cladding defect on the temperature and stress distributions of the cladding using 4 cases of power ramp conditions which represent the power histories of failed rods, reference ramp case in a research reactor and bounding ramp case for a plant.

2. Analysis Model

A general purpose FE program ANSYS[3] has been used in the heat transfer and structural analyses. First, heat transfer analysis is performed to determine the temperature distributions in the pellet and cladding. These nodal temperatures are imported into the structural analysis to calculate thermal stress. In this manner, the thermal effect is considered along with pressure loadings. Once the combined thermal and mechanical stress is obtained, the combined stress becomes initial stress for creep strain calculations[2].

The nominal dimensions of the cladding and pellet model are applied as an initial input value for the fuel performance analysis code. Then the initial geometry of 3D FEA pellet and cladding model is generated by using the fuel performance analysis code, at a specific burn up. This model simulates the entire normal power history of the fuel rod, so it can provide conditions such as the initial pellet to cracking gap at the start of the power ramp.

Based on the PIE (Post Irradiation Examination) results of cladding and pellet and the output of the fuel performance analysis code, it is evaluated that the FEA model well simulates the thermal distribution and the deformation of a perfect fuel pellet which has no MPS and no fragmentation at first. Then the model and analysis methodology are elaborated to include the geometry change such as missing chip, pellet fragmentation and cladding defect. Table 1 and 2 show the pellet and cladding defects used in this parametric study. In order to figure out the effect of each parameter on the stress distribution of the cladding inner surface, many cases of stress analyses were performed as shown in Table 3.

In the heat transfer analysis, 4 cases of power ramp conditions were applied as a constant heat source. Each linear heat generation rate (LHGR) history and power ramp condition is presented in Figure 1.

Table 1. Summary of Pellet Defects (Missing Pellet Surface)

No	Name	Type	L*, mm(inch)	D*, mm(inch)
1	W15	Wedge	1.5 (.060)	.508 (.020)
2	W25	Wedge	2.5 (.100)	.508 (.020)
3	W30	Wedge	3.0 (.120)	.508 (.020)
4	W38	Wedge	3.8 (.150)	.508 (.020)
5	C50	Column	Full Length	.508 (.020)

*See below

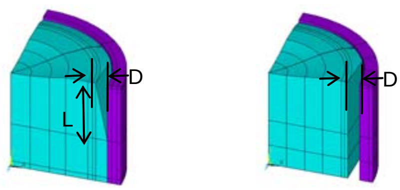

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Table 2. Summary of Cladding Defects

No	Name	Type	Length	Depth, mm
1	CC10	Column	Full Length	.057
2	CC30	Column	Full Length	.171

Table 3. Stress Analysis Matrix

FEA Model	Parameters				
	Crack	Dish	Chamfer	MPS	Cladding Defect
1	-	-	O	-	-
2	O	-	O	-	-
3	O	-	-	-	-
4	O	2x	O	-	-
5	O	-	O	W15	-
6	O	-	O	W25	-
7	O	-	O	W38	-
8	O	-	O	W38	CC10
9	O	-	O	W15	CC30
10	O	-	O	W15	CC10
11	O	-	O	W30	CC30

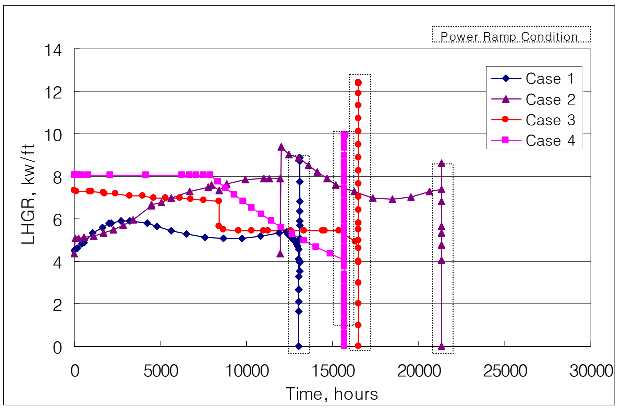

Figure 1. LHGR History and Power Ramp Region of Each Case

3. Analysis & Results

In the heat transfer analysis, cladding outer surface temperature is set by coolant temperature and pellet is assumed to be a radially constant heat source. Contact elements between pellet and cladding are implemented to transfer the heat from pellet to cladding. Contact elements enable to simulate conductive and convective heat transfer at the gap which may be closed or open. Convective coefficient at the gap is provided by the gas conductivity and distance between pellet and cladding.

In the structural analysis, the difference between rod internal gas pressure and the coolant system pressure was applied to cladding outer surface. It is assumed that the pellet is radially fragmented into several parts. The cracked surface, therefore, was modeled to be partly fixed to adjacent pellet cracks. However the pellet is free to expand radially. The bottom surface of cladding in the model is not restrained to absorb thermal expansion and axial force by the coolant system pressure. After the heat transfer analysis is performed, the missing chip part and the space between the pellet chamfer and the cladding are removed from the structural model.

From the heat transfer and structural analyses using 3D FEA model, the effect of several parameters on the temperature and hoop stress distributions are shown in Figure 2.

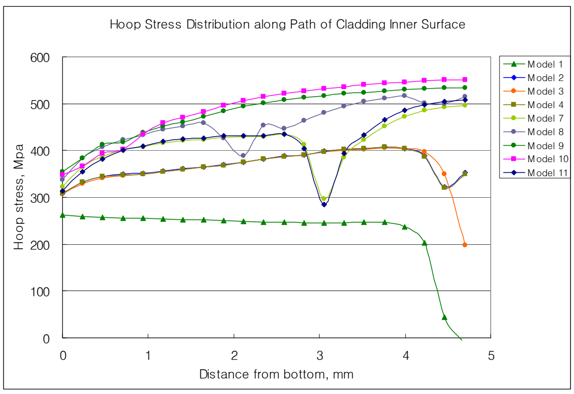

Figure 2. Hoop Stress Distribution on the Cladding Inner Surface for Each Model of Table 4.

4. Conclusion

Based on the extensive parametric study, the integrity of the fuel rod was evaluated by calculating the stress of the fuel rod cladding using the 3D PCMI finite element models which have incorporated the MPS, pellet cracking, pellet dish size, cladding defect, etc. Especially, the plant base power ramp conditions were applied to the heat transfer analysis to simulate the failed rod experience. From this stress analysis several findings are summarized as follows.

- Pellet cracking (45^o fragmentation) has no effect on the temperature distribution but increases the maximum hoop stress of cladding by 30%.
- The temperature of cladding adjacent to the chamfer of pellet tends to slightly drop but the hoop stress of cladding without pellet chamfer edge rises.
- Pellet dish depth (2 times greater than standard dish depth) has no effect on the temperature distribution and the maximum hoop stress.
- The temperature of cladding adjacent to the MPS tends to slightly drop but the temperature and hoop stress of cladding in contact with MPS edge increase.
- The MPS size slightly influences the temperature of cladding. However, the longer the MPS is, the higher the maximum hoop stress of cladding is. The MPS is more important in a structural analysis point of view rather than a thermal analysis one.

5. Acknowledgement

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REFERENCES

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