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Pellet-Clad Mechanical Interaction Analysis with ANSYS Mechanical Module

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1. Introduction

Pellet-Clad Mechanical Interaction (PCMI) has been known as a potential threat in fuel cladding integrity during power ramp conditions and high burn-up scenario. As the fuel outer surface contact with clad inner surface, the local stress become increased. Moreover, fuel pellet have much higher temperature in operation and have much greater expansion effects than clad, which occur additional contact pressure on clad inner surface, the cladding pellet deforms into a shape reflecting that of the pellet [1]. This mechanical interaction between fuel pellet and clad depends on gap size, burn-up, friction coefficient between clad and pellet [2]. Moreover, recent field result shows that nearly PCI-induced failures are thought to have developed at a missing pellet surface (MPS), where the tangential stress has its maximum and the cladding temperature has its minimum [3].

For the additional study on PCMI, it is very important and valuable to find geometric parameters of MPS which make critical safety issue on cladding material safety. Followings are result and conclusion of the parametric studies.

2. Methods and Results

To simulate and predict MPS effect on fuel pellet and clad, ANSYS APDL 3D mechanical modeling and analysis were conducted.[4]

2.1 3D Modeling

The 3D modeling of fuel pellet and clad geometry was conducted in 1/8 fuel model with axi-symmetric assumption. For the finite element model, the 3D 20-node SOLID90 element was used for the thermal analysis. And the interfaces between pellet and clad tube were simulated with TARGE170 and CONTA 174 contact element for the conduction, convection heat transfer analysis and surface to surface contact for the structure analysis. Additionally, FEMAXI-6 PWR test case was selected for the reference parameters of fuel and clad with dish and chamfer. The graphical feature of this 3D modeling is on Fig. 1.

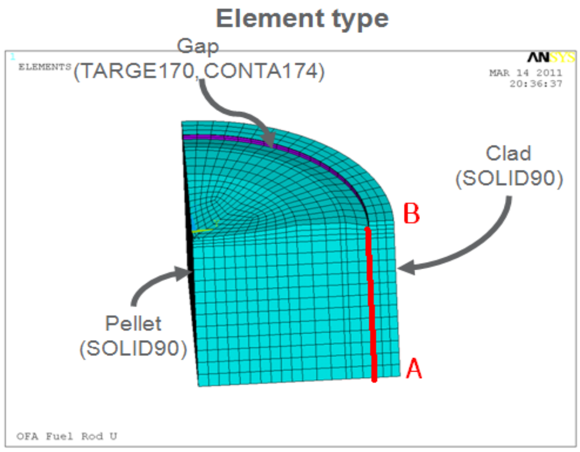

Fig. 1. 3D 1/8 axi-symmetric fuel model

2.2 Thermal Analysis

Model	Name	Brief descriptions
Case 1	NCND	No pellet crack, No missing chip
Case 2	180CND	180° axi-symmetric pellet crack, No missing chip
Case 3	180C50D	180° axi-symmetric pellet crack, 0.05 in. missing chip
Case 4	180C100D	180° axi-symmetric pellet crack, 0.1 in. missing chip

Table 1. Modeling descriptions

Four kinds of model were selected to analyze missing pellet effects. Case 1 is perfect fuel case. However, from case 2 to 4 have a small defect on fuel pellet surface, which is crack in case 2 and missing pellet in case 3 and 4. The difference between case 3 and 4 is the depth of missing pellet fragment starting from B in fig.1 to A, which are 0.5in. and 1in. respectively. Crack geometry in case 2 to 4 are 180° axi-symmetric. Table. 1 describes brief descriptions of the modeling cases.

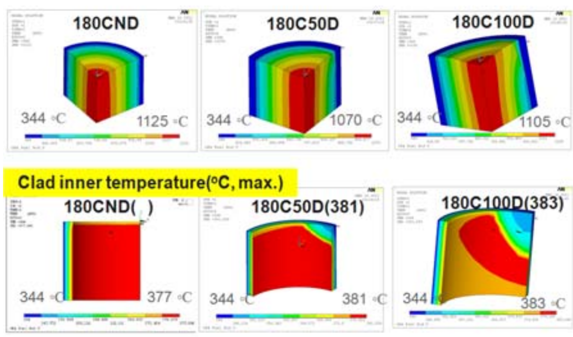

Fig. 2. Temperature distribution over 1/8 axi - symmetric fuel model with MPS

Thermal analysis result described in Fig. 2 shows that the local temperature of missing pellet part has lower temperature than other parts. The temperature difference between hottest and coolest part is over 30°C.

2.3 Structural analysis

The temperature difference would make thermal gradient over the clad surface and make excessive stress and strain on clad surface over the missing pellet fragment. The displacement and hoop strain result are illustrated in Fig. 3.

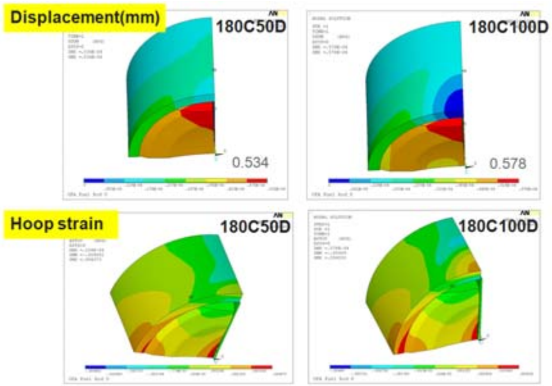

Fig. 3. Displacement and Hoop strain distribution for fuel model with MPS

Moreover, comparing hoop strain through the missing pellet fragment depth study, missing pellet depth moved the highest point of strain over the clad inner surface like Fig. 4. These results show that the missing pellet defect have much impact on clad inner surface hoop strain than dish and chamfer geometry on the upper surface and edge of fuel pellet.

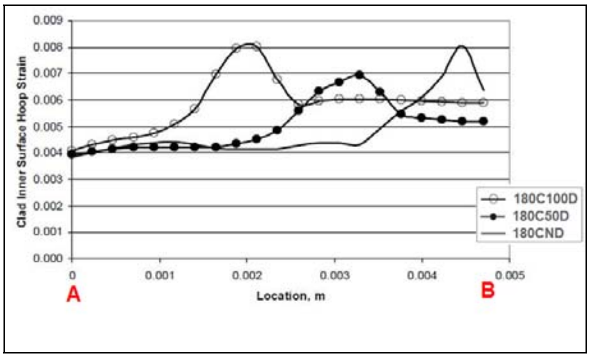

Fig. 4. Hoop strain on clad inner surface (MPS start from B to A as Fig. 1.)

3. Conclusions

Comparing perfect and missing pellet surface case in temperature analysis, there exists temperature decrease on the clad inner surface in MPS cases. Moreover, the MPS makes more significant strain and stress effect than fuel dish and chamfer.

Acknowledgement

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