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Effects of an IPyC Crack on the Mechanical Behavior of the TRISO Coating Layers

Moon-Sung Cho, Y. M. Kim, Y. W. Lee, K. C. Jeong, Y. K. Kim, S. C. Oh
Korea Atomic Energy Research Institute, 150 Dukjin, Yuseong, Daejeon, Korea, mscho1@kaeri.re.kr

1. Introduction

The fundamental design of a gas-cooled reactor relies on an understanding of the behavior of a coated particle fuel. KAERI, which has been carrying out the Korean VHTR (Very High Temperature modular gas cooled Reactor) Project since 2004, is developing a fuel performance analysis code for a VHTR named COPA (COated Particle fuel Analysis) [1]. COPA predicts temperatures, stresses, a fission gas release and failure probabilities of a coated particle fuel in normal operating conditions.

COPA code consists of nine sub-codes and every sub-code has its own functions and models. Each sub-code can be inserted into other sub-codes or can be used to generate input data for other sub-codes. COPA-ABAQ is one of the nine sub-codes to calculate cracks or de-bondings in the coating layers of TRISO-coated particle fuel. Cracks and de-bondings can cause stress concentrations in the coating layers and increase the failure probability of the coated particle fuel. The COPA-ABAQ, which is in the process of being developed, is written in ABAQUS [2].

In this study, a mechanical stress analysis was carried out by using the finite element analysis program, ABAQUS to evaluate the effect of a crack at the IPyC inner surface on the mechanical behavior of the TRISO coating layers.

2. Methods and Results

2.1 ABAQUS Finite Element Model for Crack Analysis

The finite element model used for the PyC crack analysis is an improvement of the previous ABAQUS FE model that dealt with CRP-6 TRISO coated particle benchmark problems involving creep, swelling, and pressure [3]. The finite element(FE) model deals with the stresses in three load-bearing layers of the TRISO coated particle: the inner pyrocarbon (IPyC) layer, the SiC barrier layer, and the outer pyrocarbon (OPyC) layer.

The two-dimensional finite element model for the PyC crack analysis is shown in Figure 1 by representing a quarter of a sphere. The crack was modeled as a line embedded in a face that cuts across the cross-section of the IPyC layer in this two-dimensional model. The elements in all of the three layers are four-node axisymmetric bilinear (CAX4R in ABAQUS) elements. The nodes along the bottom surface extend along the equator of the sphere. To enforce a spherical symmetry of the model, the nodes along the horizontal and the vertical surface of the model are constrained to move only in the radial direction. Elements are grouped together in logical sets to allow for a specification of the material properties for

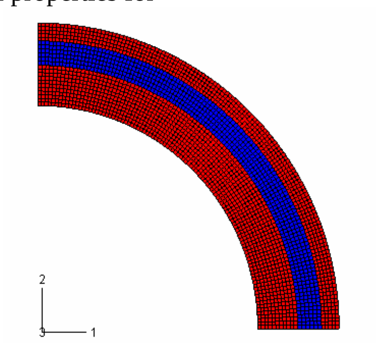


Figure 1. ABAQUS 2-D Finite Element Model for PyC Crack Analysis

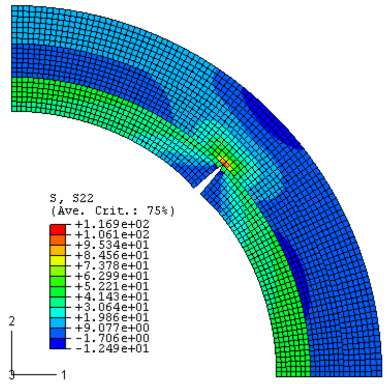
the PyC and the SiC. Because of the anisotropic nature of the PyC irradiation induced dimensional changes, the material properties are evaluated at the integration points in a spherical coordinate system: The first component direction is aligned along the radial direction, and the second and the third are aligned in the hoop direction. The stresses reported below are taken from this intrinsic spherical coordinate system. Fission gas pressure is applied to the inner surface of the IPyC layer and the external ambient pressure is applied to the outer surface of the OPyC layer.

2.2 Effect of an IPyC Crack on the Stress Distributions of TRISO Coating Layers

To evaluate the effect of an IPyC crack on the mechanical behavior of the TRISO coated particle fuel, calculation results from ABAQUS FE crack model was compared with the results from the ABAQUS FE no-crack model used for the calculation of the IAEA-CRP-6 benchmark case 5.

IAEA-CRP-6 benchmark case 5 assumes a TRISO coated fuel particle with a 350 μm diameter kernel and 215 μm thick coating layers under realistic service conditions.

Figures 2 shows a hoop stress contour of the TRISO coating layers at a fluence of 3.0×10^{25} n/m^2. Stress concentration is found on the inner surface elements adjacent to the crack point of IPyC layer. It means that a crack in the PyC layer affect the stress distribution of the SiC layer, significantly.



Figures 2. Hoop Stress Contour of the TRISO Coating Layers at the fluence of 3.0×10^{25} n/m^2

Figure 3 shows the hoop stress of the SiC layer inner surface element obtained from IPyC crack case as a function of the fast neutron fluence in comparison with the results from no-crack case at the equivalent location. The most significant difference is found in the direction of the hoop stress. The SiC layer of no-crack case is normally subject to compressive stress due to the irradiation shrinkage of the PyC layers as is shown in the Figure 2. The inner surface element of crack case, however, is under tensile stress condition. It is because the fractured IPyC layer can not exert compressive force to the SiC layer while the internal pressure from fission gas causes the tensile stress in the SiC layer. Maximum stress occurs at around a fluence of 0.4×10^{25} n/m^2 regardless of crack existence, but the intensity is bigger in crack case.

3. Conclusion

A mechanical stress analysis was carried out by using the ABAQUS finite element model to evaluate the effect of a crack at the IPyC inner surface on the mechanical behavior of the TRISO coating layers.

The most significant difference is found in the direction of the hoop stress. The inner surface element of crack case showed tensile stress condition. While the SiC layer of no-crack case is normally subject to compressive stress due to the irradiation shrinkage of the PyC layers. Maximum stress occurred at around a fluence of 0.4×10^{25} n/m^2 regardless of crack existence, but the intensity is bigger in crack case.

Acknowledgement

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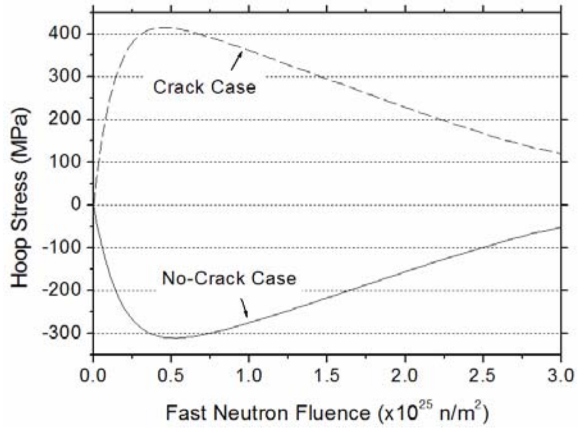

Figure 3. Hoop stress of the SiC layer inner surface with an IPyC crack in comparison with no-crack case

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