Visco-elastic Analysis of PyC Coated Surrogate Fuel Particles For an Irradiation Test

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1. Introduction

KAERI has been carrying out the Korean VHTR (Very High Temperature modular gas cooled Reactor) project since 2004 and with the long-term aim to localize the TRISO fuel technology in Korea, KAERI has been endeavoring to research and develop the coated particle fuel technologies. The fundamental safety of a gas-cooled reactor largely relies on the mechanical integrity of the coated particle fuel. In this regard an irradiation test plan is being carried out by using surrogate coated particles to investigate thermo mechanical behavioral changes of coatings and coating combinations under irradiation. To eliminate the complicated influence of fissile material, the coatings were applied to dummy kernels composed of inert materials (zirconia) as shown in Figure 1. Test results will be useful in understanding and modeling of the thermo mechanical behavior of the PyC layer and can be used for validation purposes of High Temperature Reactor (HTR) fuel concepts.

In this study, an attempt was made to predict the mechanical integrity of the test specimen by calculating the stress levels of the coating layer under the irradiation conditions. Used were an ABAQUS based finite element (FE) model which is being developed by KAERI to cover the linear and the non-linear behaviors of a coated particle fuel subject to creep, swelling, and pressures[1]. This paper shows the stress calculation results of PyC coated surrogate fuel particles subject to an irradiation condition as assumed in the IAEA-CRP-6 benchmark case 6 to predict the mechanical integrity of the coating layers[2].

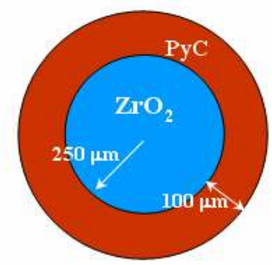

Figure 1. Test Specimen with Dummy Kernel

2. Methods and Results

2.1 ABAQUS Finite Element Model

The finite element (FE) model deals with the stresses in the PyC layer of the surrogate coated particle. The two-dimensional finite element model is shown in Figure 2 by representing a quarter of a sphere.

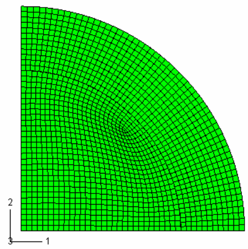

Figure 2. ABAQUS 2-D finite element model for PyC coated surrogate fuel particle

The elements are four-noded axisymmetric quadrilaterals (CAX4R in ABAQUS)[3]. 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 the kernel and the PyC. 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 not considered because dummy kernels are used in the test.

The particle is assumed to be irradiated to a fluence (E>0.18 MeV) level of 3.0×10^{25} n/m^2 in the problem.

2.2 Calculation Results

Stress contour of the test specimen at the fluence of 3.0×10^{25} n/m^2 is presented in Figure 3. As the PyC layer shrinks due to the neutron fluence the pellet shows compressive stress condition. The PyC layer on the other hand is subjected to tensile stress.

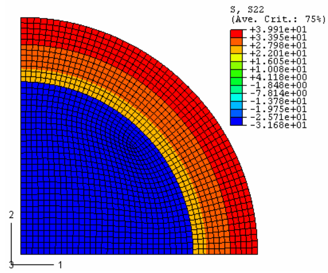

Figure 3. Stress Contour of PyC coated surrogate fuel particle

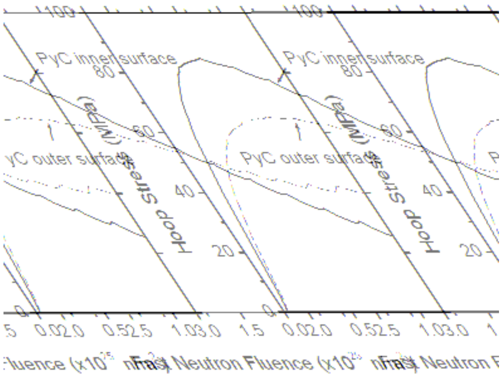

Figure 4. Hoop stresses on PyC layer as functions of fast neutron fluences

Figure 4 shows hoop stresses on the PyC layer in its inner and outer surfaces as functions of fast neutron fluences. Peak stress of the single layer in its tangential direction is approximately 83 MPa. The stresses show similar trend as they shows peaks at the fluence level around 0.6×10^{25} n/m^2 and decrease thereafter. The peak stress in PyC inner surface is bigger than that of outer surface because inner surface is bonded to the pellet and constrained firmly. However, the rate at which the stress decreases is bigger in inner surface than the outer surface. It is considered that the effect of irradiation creep is bigger in the inner surface of the PyC layer.

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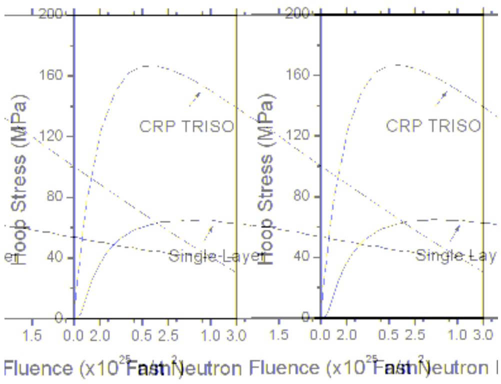

Figure 5.Hoop stresses on PyC layer of TRISO and single layer coated particle as functions of fast neutron fluences

Figure 5 compares the hoop stresses on the PyC layer of the PyC coated surrogate fuel particle with the hoop stress on the IPyC layer of the TRISO particle as in the IAEA-CRP-6 benchmark case 6. It should be noted that the stress values for the TRISO particle is those of outer surface of the IPyC because only 3-layer model was used in the IAEA-CRP-6 benchmark case 6 and the outer surface of IPyC was bonded to the SiC layer. Therefore, the difference of stress level between both cases mainly comes from the difference of material properties of the two PyC layers. Table 1 shows the elastic properties of the PyC layers of the IAEA-CRP-6 benchmark case 6 TRISO fuel particle and the PyC coated surrogate fuel particle.

Table 1. ABAQUS results vs. Millers's derivation

Cases	Young's Modulus (PyC)	Poisson's Ratio (PyC)
Single layer[4]	25.9 GPa	0.3
IAEA TRISO	39.6 GPa	0.33

3. Summary

An attempt was made to predict the mechanical integrity of the PyC coated surrogate fuel particle by calculating the stress level of the coating layer under the irradiation conditions. Peak stress of the PyC coating layer in its tangential direction is around 83 MPa at the fluence level around 0.6×10^{25} n/m^2.

In a comparison with the IAEA-CRP-6 TRISO case, the PyC stress level of the PyC coated surrogate fuel particle was lower than that of the TRISO particle mainly due to the difference in their material properties.

Acknowledgement

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