Effects of Anisotropic Transformation on the Pyrolytic Carbon Layer of TRISO Fuel Particles

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1. Introduction

The pyrolytic carbon of the tristructural-isotropic (TRISO) nuclear fuel particles has a protective effect for kernel from chloride during SiC deposition and contributes to fission gas retention [1]. Any changes in the layer\s materials properties may affect the mechanical integrity of the fuel particles, especially at high burn-up conditions. Continued irradiation on the pyrolytic carbon is expected to cause anisotropic transformations of the initially isotropic graphite layer, and the following changes in mechanical properties may affect the particle durability. Yet the effect of anisotropic transformation on the pyrolytic carbon layer's and eventually the particle's mechanical properties remains to be elucidated. In this talk, we employ a fully coupled multiphysics model to analyze this problem.

2. Methods

The fuel performance model BISON currently considers that the elastic properties of the PyC layer can be described by scalar constants related to the certain Poisson's ratio and Young's modulus equations. The scalar Young's modulus for the carbon coatings is dependent upon decoupled properties of temperature, fast neutron fluence, and as-fabricated Bacon anisotropy factor (BAF_0).

In this context BAF which is a direct measure of crystallographic anisotropy of pyrolytic carbon coatings deposited on spherical fuel particles, observed to be increased with fast fluence. And also the irradiation creep of the buffer and pyrolytic carbon layer, which leads to their gradual deformation in response to irradiation-induced damage, is directly proportional to the fast neutron fluence [2].

In order to observe the anisotropic transformation, the coupled equations are to be used to analyze stress-strain relation in pyrolytic carbon.

2.1. Equations

The following heat conduction equation and thermal expansion equation which has an effect on dimensional change in anisotropic transformation are discussed to be coupled:

$$\frac{\partial \varepsilon_t}{\partial t} = \frac{1}{E}\left((1-\mu)\frac{\partial \sigma_t}{\partial t} - \mu\frac{\partial \sigma_t}{\partial t}\right) + c[(1-v)\sigma_t - v\sigma_r] \quad (1)$$

$$\frac{\partial \varepsilon_r}{\partial t} = \frac{1}{E}\left(\frac{\partial \sigma_r}{\partial t} - 2\mu\frac{\partial \sigma_t}{\partial t}\right) + c(\sigma_r - 2v\sigma_t) + \quad (2)$$

$$\rho C_p\frac{\partial T}{\partial t} + \nabla \cdot \boldsymbol{q} - E_f\dot{F} \quad (3)$$

In Eq. (1) and (2) the first term represents the elastic strain, and second, third, and fourth terms represent the creep strain, swelling strain and thermal strain respectively. And in Eq. (3) T is temperature, ρ and C_p are density and specific heat respectively, and Ef is the energy released per fission. F is the volumetric fission rate.

2.2. Elasticity

The general linear elastic response of a material to mechanical deformation is identified by Hooke's law in Eq. (4) which relates Cauchy stress to strain by the elastic stiffness tensor. In the most general situations the stiffness tensor reduces to 21 independent constants due to symmetries. Depending on texture provided discussions, pyrolytic carbon layer of TRISO particles are discussed to have isotropic properties in the circumferential directions and an axis of symmetry parallel to the radial direction, resulting in transversely isotropic symmetry. The stiffness tensor of a transversely isotropic solid can be written using Voigt notation in Eq. (5), where there are five independent elastic constants [3].

$$\sigma_{ij} = c_{ijkl}\varepsilon \quad (4)$$

$$c_{ij} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & 0 & 0 \\ & c_{11} & c_{13} & 0 & 0 \\ & & c_{33} & 0 & 0 \\ & & & c_{44} & 0 \\ & sym & & & c_{44} \end{bmatrix} \quad (5)$$

3. Conclusion

To model and analyze the coupled system of anisotropy-dependent mechanical properties such as thermal expansion and modulus of elasticity, we implement the fuel performance code based on MOOSE and BISON. The key changes in the density and anisotropy in the pyrolytic carbon will be discussed in depth.

Using the capabilities of MOOSE and BISON related to modeling the elastic properties of pyrolytic carbon, stress and strain caused by the anisotropic transformation of the material during irradiation are to be observed.

REFERENCES

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