Considerations for Some Properties of Pyrolytic Carbon Coating layers in HTR Coated Particle Fuels

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1. Introduction

It is well known that the TRISO(tri-isotropic)-coated fuel particle for a HTR(High Temperature gas-cooled Reactor) has a diameter of about 1 mm, composed of a nuclear fuel kernel and four different outer coating layers. These coating layers consist of a buffer PyC (pyrolytic carbon) layer, inner PyC layer, SiC layer, and outer PyC layer as shown in Fig. 1.

The fuel kernel is a source for a heat generation by a nuclear fission of fissile uranium. The role of each of the four coating layers is different in view of retaining the generated fission products and other interactions during in-reactor service, as summarized in Table 1 [1].

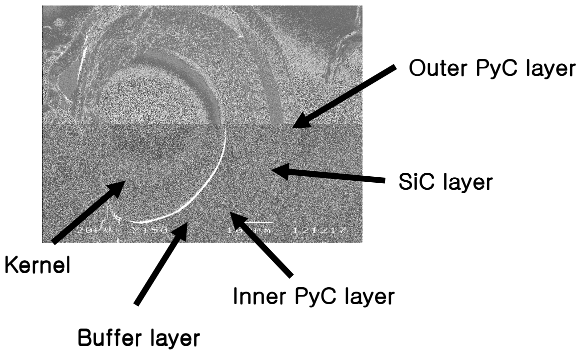

Fig. 1. Structure of a TRISO-coated fuel particle.

Table 1. The function of TRISO coating layers

Layer	function
Buffer layer	- void volume for gaseous fission products - accommodates kernel swelling - sacrificial layer for fission fragments
Inner PyC layer	- gastight coating/ protects kernel from Cl_2 during SiC coating - diffusion barrier for metallic fission products - reduces tensile stress on SiC
SiC layer	- primary metallic FP diffusion layer - primary pressure retaining layer
Outer PyC layer	- diffusion barrier gaseous and metallic FP - reduces tensile stress on SiC - provides bonding surface for overcoating

Among these coating layers, the SiC layer has been investigated mainly for its deposition mechanism and consequent properties as well as property changes during irradiation since its early utilization in coating materials for HTR fuel. A recent review on SiC has established a firm database [2]. On the other hand, PyC properties are scarcely in agreement among various investigators and the dependency of their changes upon the deposition condition is comparatively large due to their additional anisotropic properties. This work is devoted to a consideration of their properties with regard to the status of their material data and further work required for their use in material modeling.

2. Structures and Anisotropy of PyC

Since the early studies, four distinct structures have been identified which may be described as columnar, laminar, granular and isotropic [3]. In the fluidized bed coating of coated particle fuels, the isotropic structure is of most importance for its properties. Many of the PyC properties are affected by its anisotropy and thus, it is important to measure their degree of anisotropy since ideally isotropic coatings are required for coated particle fuels. An example is illustrated for its thermal conductivity variation with BAF (Bacon Anisotropy Factor) [4] in Fig. 2.

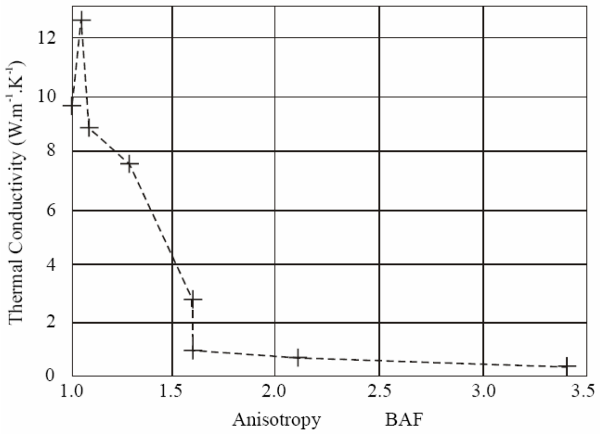

Fig.2. Variation of thermal conductivity of PyC with anisotropy

3. Properties of PyC

Density of PyC deposited by a fluidized bed CVD coating is an important parameter that must be controlled in order that particles behave satisfactorily during irradiation, as it affects and represents a number of mechanical and physical properties such as elastic constants and the thermal conductivity. Its current specifications used among several organizations range between 1.85 and 1.95 g/cm^3 for dense PyC layers and 0.85 and 1.20 g/cm^3 for buffer layer [5]. If the density of dense PyC layer is lower than 1.6 g/cm^3 the inner and outer PyC layers would densify so rapidly during irradiation that stresses would be built up which are higher than those for a fracture of the layers.

The density of a porous buffer layer seems more important than that of dense PyC layers, as it is more difficult to control during coating due to comparatively short coating time and it plays a role as the first barrier to accommodate fission gases. As a matter of fact, the porous buffer layer is not only a sacrificial layer for fission fragments but it provides porosity and accommodates kernel swelling and fission gases, as pointed out by D. Martin [6]. In this regard, open porosity of the buffer layer should be estimated for as-deposited and its variation during irradiation.

Mechanical properties of as-deposited PyC layer, interconnected somehow with its density, have been investigated extensively for its strength [7] and elastic modulus as they are required for modeling of in-reactor performance of the coated particle fuel. Studies have also been conducted for thermal properties such as the thermal conductivity [8], thermal expansion coefficient and heat capacity. As shown in Fig. 2, the highly anisotropic pyrolytic carbon exhibit lower thermal conductivity values; this indicates that the anisotropic laminar structure has high conductivity in the *a*-, compared with the *c*-direction [9].

4. Property change on irradiation

Physical properties of PyC layers change during irradiation corresponding to a modification in their structures. In particular, an initially isotropic PyC becomes anisotropic and this anisotropy can develop extensively with irradiation dose [10]. A number of studies have been performed on the dimensional changes of PyC coating layers as a function of the neutron dose due to the importance of maintaining an integrity of coating layers. Overall dimensional change of layers depends on the density (or porosity) and anisotropy. An example of the experimental results is given by Fig. 3, where J.L. Kaae [10] demonstrated the dimensional changes as a function of neutron dose, both parallel and perpendicular to the plane of deposition.

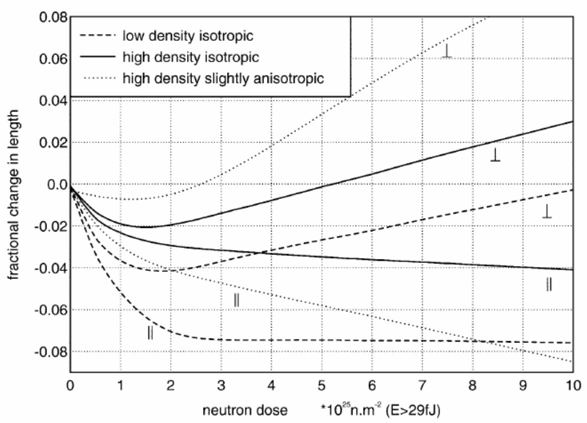

Fig. 3. Typical dimensional change of PyC on dose

These indicate both densification and swelling and also variations in densification and swelling depending on the anisotropic properties. In parallel with the dimensional change, extensive studies have been carried out on the creep behavior with neutron dose, the so-called irradiation creep. Early estimates of irradiation creep constant have been made by Price and Bokros [11] and many others.

5. Conclusion

In this review of some properties of PyC in HTR coated particle fuels, most important properties such as anisotropy and density in relation with other mechanical and thermal properties are briefly discussed. The relevant data are still not in agreement and/or in part still missing for a rigorous modeling of their performance in reactor. Further detailed experimental works are required to make up for the missing data and information. In this regard, the GIF VHTR project would be very helpful which has planned a joint irradiation program for PyC materials at Petten in 2007.

Acknowledgement

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