Changes in Material Properties of PyC Coating Layers by Neutron Irradiation in HTR Coated Particle Fuel: II. Change in Mechanical Properties

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1. Introduction

The TRISO(tri-isotropic)-coated fuel particle for a High Temperature gas-cooled Reactor has a diameter of about 1 mm, composed of a nuclear fuel kernel and four different outer coating layers, successively coated with a buffer PyC (pyrolytic carbon) layer, inner PyC layer, SiC layer, and outer PyC layer in different layer dimensions and properties following a specific fuel design.

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

Among these coating layers, PyC properties are scarcely in agreement among various investigators and their changes upon neutron irradiation is not firmly established due to their little data available. Indeed, there have been little investigations on the behavior of PyC during irradiation and an integration of the data and modeling on the irradiation behavior of PyC coating layers remains at the preliminary stage since the middle of 1970's for the early BISO design.

Recently, an attempted was made by the authors [2] to analyze the existing data of the experimental results of the dimensional change upon neutron irradiations of PyC coating layers obtained from various experiments performed in the early periods of the HTR coated particle development by collecting and comparing the different data . In this work, the change in mechanical properties of the PyC are reviewed and analyzed with a few literatures available, of which the relevant data were judged reliable and comparatively complete in view of the experimental method and data acquisition. [3, 4]

2. Mechanical properties of PyC

Mechanical properties of an as-deposited PyC layer, connected somehow with its density and other structural parameters, have been investigated extensively along with the works performed for the structural studies of its strength and elastic modulus. In early works carried out in the 1960's, most experiments for a PyC coating were concerned with methane as a source hydrocarbon gas, and the mechanical properties investigated with these experiments were based on a methane-derived PyC. [5, 6, 7] Particularly, Kaae compared relationships between the structure and properties of different PyC's by taking the experimental data with methane from the work by Bokros and Price [6] and Price [7], and those with propane from his work.[8] For a acetylene-propylene gas mixture, he used unpublished data.[9] The Young's modulus generally increases with the density of PyC coating layer for LTI-PyC, showing higher modulus than HTI-PyC with lower fraction of source gas. The dependency of a fracture stress on the density seems unclear. When propane was used as a source gas, the LTI-PyC obtained at temperatures below 1823 K showed a tendency of an increasing fracture stress together with modulus with an increasing density.[2]

3. Change in Young's modulus and fracture stress of PyC coating layer by neutron irradiation

As the mechanical properties vary considerably depending on the source gas, i.e., methane and propane or propylene, the change in mechanical properties should be analyzed considering the source gas used as well.

3.1 Young's modulus

Fig. 1 shows the variation of the Young's modulus of PyC layer deposited from propane as a function of pre-irradiation density in different neutron irradiation conditions; with neutron fluences of 3.7×10^{25} and 8.3×10^{25} n/m^2 at two different temperatures of each fluence level. As can be noticed, the modulus increases with increasing the pre-irradiation density of PyC as well as the neutron dose. It should be noted that the difference in temperature at the same fluence level has little effect on the modulus at the range of temperature investigated.

Fig. 2 shows the variation of the Young's modulus of PyC layer deposited from methane as a function of pre-irradiation density in different neutron irradiation conditions; with neutron fluences of 1.5×10^{25}, 1.6×10^{25}, 2.2×10^{25} and 2.4×10^{25} n/m^2 at different temperatures of each fluence level. In comparison with the data obtained from the propane as the source gas, the change in Young's modulus of PyC shows different behavior: The modulus of PyC as deposited decreases slightly with density increase. The general tendency of the change in the modulus is nearly constant and not as distinct as in the case of propane as the source gas. This can be attributed to the lower fluence irradiation conditions and the temperatures compared with the previously mentioned data above.

3.2 Fracture stress

Fig. 3 shows the variation of the fracture stress of PyC layer deposited from propane as a function of pre-irradiation density in different neutron irradiation conditions. Generally, the fracture stress shows an increasing tendency with increasing density and neutron fluence level. However, the data obtained from these literatures scattered to a larger extent than the modulus measurement data probably due to the difficulties in the measurement and sample preparation skills.

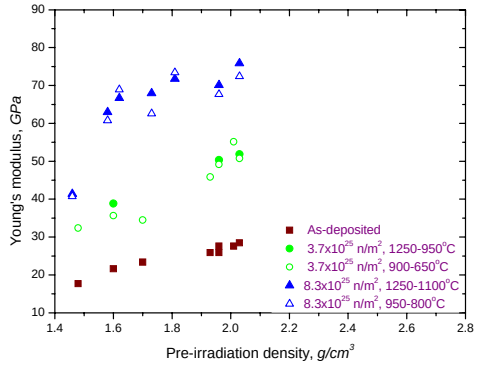

Fig. 1. Variation of the Young's modulus of PyC layer deposited from propane as a function of pre-irradiation density in different neutron irradiation conditions.

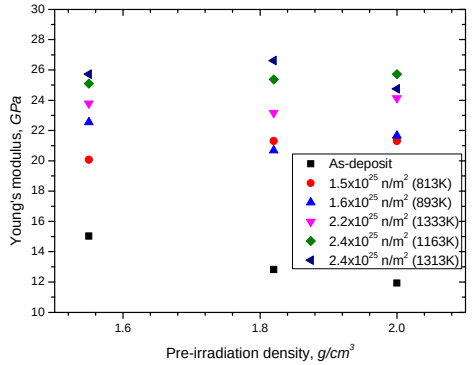

Fig. 2. Variation of the Young's modulus of PyC layer deposited from methane as a function of pre-irradiation density in different neutron irradiation conditions.

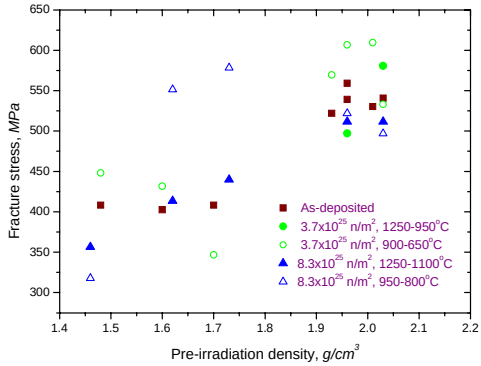

Fig. 3. Variation of the fracture stress of PyC layer deposited from propane as a function of pre-irradiation density in different neutron irradiation conditions.

3. Conclusions

From the review and analysis in this work, the following conclusions can be drawn.

- The behaviors of the change in Young's modulus and the fracture stress of PyC on irradiation are different when different source gases are used.
- The Young's modulus increases with increasing the pre-irradiation density of PyC as well as the neutron dose with propane as source gas. The difference in temperature at the same fluence level has little effect on the modulus at the range of temperature investigated.
- Generally, the fracture stress shows an increasing tendency with increasing density and neutron fluence level. However, the data obtained from these literatures scattered to a larger extent than the modulus measurement data
- It is suggested that these changes be re-evaluated with the source gas currently used and that the modeling work be performed with the data to be obtained thereof.

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