18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18)
Beijing, China, August 7-12, 2005
SMiRT18-C05-4

CHARACTERIZATION OF COATED NUCLEAR FUELS BY NANO-INDENTATION

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ABSTRACT

Nano-indentation technique is applied to evaluate coated layers of fuel for a high temperature gas cooled reactor. Hardness of TRISO layers are 0.52 for buffer layer, 0.874 for inner pyloric carbon layer, 9.461 for silicon carbide layer and 2.726 for outer pyloric carbon layer, respectively. Estimated density of each layer based on the hardness values is 1.08 for buffer layer, 1.15 for inner pyloric carbon layer, 3.18 for silicon carbide layer and 1.82 for outer pyloric carbon layer, respectively. Comparing the microstructure observation and density measurement, nano-indentation technique is one of useful methods to evaluate hardness and density the thin film layers of HGTR fuel.

Keywords: Nano-indentation, HGTR fuel.

1. INTRODUCTION

Recently, coated nuclear fuels have been attracted attention for their application of a high temperature gas cooled reactor for hydrogen production.[1, 2] The coated fuel consists of three types of graphite layers and one silicon layer on the spherical uranium oxide or uranium carbide fuel. In case of tri-isotropic (TRISO) coated fuel particles, the layers are low-density, porous pyrolytic carbon (PyC) buffer layer adjacent to the spherical uranium oxide fuel kernel, followed by an isotropic inner PyC layer, a silicon carbide layer and dense outer PyC layer.[1]

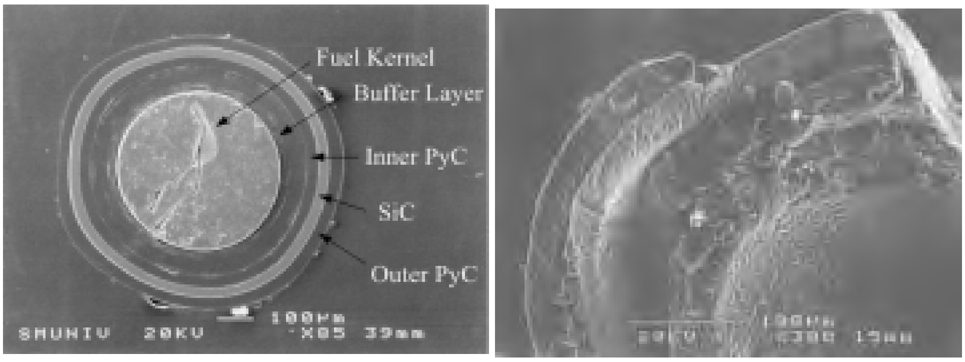
One of problems to control the quality of TRISO type coated fuel, it is difficult to determine mechanical and physical properties such as hardness and density of the thin coated layers.[2] The fuel performance under irradiation condition significantly depends on the microstructure and density of coated layers. Previous study suggests that chemical dissipation to separate the layers was suggested to determine density of the layers, however, the chemical method takes a time and need to elaborate to get data.[3] Accordingly, it is necessary to find a simple and reliable method to determine such values as mechanical properties and density. At the points of view, nano-indentation technique is one of challengeable methods in the research field of nuclear materials because small specimen with simple geometry has advantage for irradiation tests with the limits of experiments and nuclear wastes after post irradiation tests. There are lots of studies about the performance of coated fuel, most of their study has been oriented to the failure probability of the coated fuel on the point of physics, nuclear engineering and mechanical engineering.[4] Hence, the objective of this study is to apply the nano-indentation technique to evaluate hardness of TRISO coated fuel and find a method to estimate the density of each coated layer.

2. EXPERIMENTAL METHOD

Microstructure of TRISO type coated fuel was observed to determine a physical values by field emission scanning electron microscopy (Jeol JSM 6700F) and scanning electron microscopy (Jeol JSM 35-C), respectively. Micro-hardness of each coated layer was carried out with a nano-indentor (Elionix ENT-1100) at the indentor angle of 148 degree under various loadings.

3. RESULTS AND DISCUSSION

Fig. 1 is the microstructure of the coated fuel. The coated fuel is not perfect spherical shape, in which fuel kernel, buffer PyC, inner PyC, SiC and outer PyC layers were well observed. Average thickness of each coated layers is 95, 25, 30 and 28 μm, respectively. Fig. 2 is microstructure of each coated layers. As shown in Fig. 2, porous microstructures were well observed in the order of buffer, inner carbon, outer carbon and silicon carbide layers.



(a) (b)

Fig. 1 Microstructure of the coated fuel : (a) cross sectional view of fuel (b) coated layers

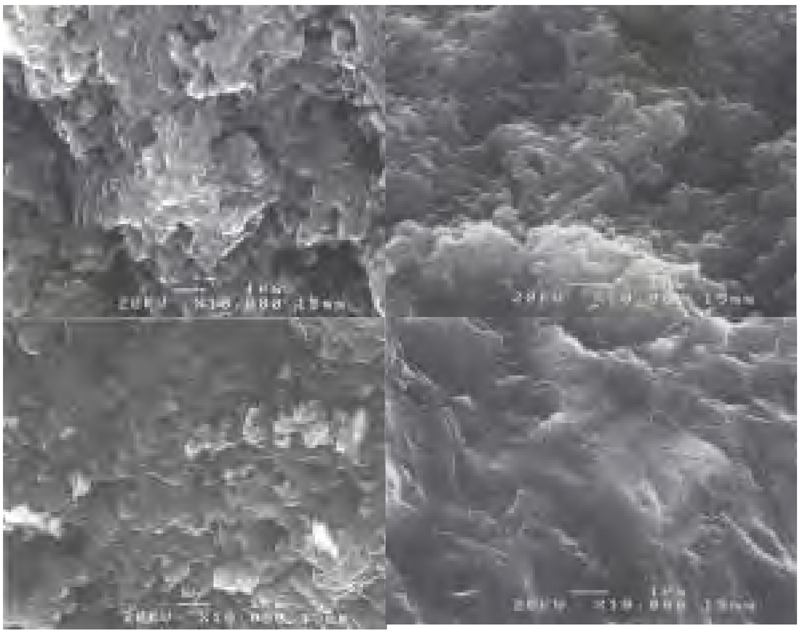


Fig. 2 Microstructure of the coated layers : (top-left) buffer (top-right) inner carbon (bottom-left) outer carbon (bottom-right) silicon carbide layer

Fig. 3 is the hardness change with maximum loading. Although the hardness values slightly decreased with load, it is clear that hardness increases in the order of buffer, inner carbon, outer carbon and silicon carbide layers for a constant load. From the relationship between hardness and density of bulk materials, we can estimate those values of the thin layers without separating each layer. In this study we determined the hardness of TRISO layers such as 0.52 for buffer layer, 0.874 for inner pyloric carbon layer, 9.461 for silicon carbide layer and 2.726 for outer pyloric carbon layer, respectively. Resultantly we estimated the density of each layer based on the hardness values such as 1.08 for buffer layer, 1.15 for inner pyloric carbon layer, 3.18 for silicon carbide layer and 1.82 for outer pyloric carbon layer, respectively. This is well agreement with microstructure observation in Fig. 2. Since it is reported that Vicker's hardness of graphite is in the range of 5-15 GPa, and that of silicon carbide is in the range of 12.65-34.14 GPa, respectively.[5] Comparing the microstructure observation and density measurement, nano-indentation technique is one of useful methods to evaluate hardness and density the thin film layers of HGTR fuel.

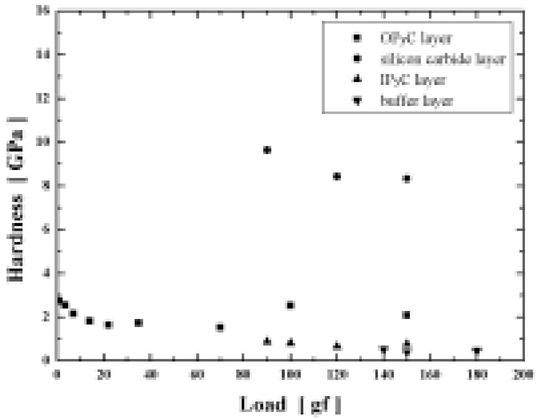


Fig. 3 Micro-hardness changes with load determined by nano-indentor

4. SUMMARY

Nano-indentation technique is applied to evaluate coated layers of HGTR fuel. Hardness of TRISO layers is 0.52 for buffer layer, 0.874 for inner pyloric carbon layer, 9.461 for silicon carbide layer and 2.726 for outer pyloric carbon layer, respectively. Based on the relationship between hardness and density, the density of each layer was estimated such values of 1.08 for buffer layer, 1.15 for inner pyloric carbon layer, 3.18 for silicon carbide layer and 1.82 for outer pyloric carbon layer, respectively. Comparing the microstructure observation and density measurement, nano-indentation technique is one of useful methods to evaluate hardness and density the thin film layers of HGTR fuel.
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ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the Ministry of Science and Technology (MOST) of the Republic of Korea for the support of this work.

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