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Nondestructive Measurement of the Coating Thickness in the Simulated TRISO-coated Fuel Particle by X-ray Imaging

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1. Introduction

The TRISO(tri-isotropic)-coated fuel particle is widely utilized owing to its higher stability at a high temperature and its efficient retention capability for fission products in the HTGR(high temperature gas-cooled reactor). The typical spherical TRISO-coated fuel particle with a diameter of about 1 mm is composed of a nuclear fuel kernel and outer coating layers. The coating layers consist of a buffer PyC(pyrolytic carbon) layer, inner PyC(I-PyC) layer, SiC layer, and outer PyC(O-PyC) layer as shown in Fig. 1.[1]-[4]. X-ray radiography can be one of the nondestructive alternatives without generating radioactive wastes.[1],[5]-[10] The coating thickness for the simulated TRISO-coated fuel particle with a ZrO_2 kernel instead of a UO_2 kernel was measured by using a micro X-ray imaging system.

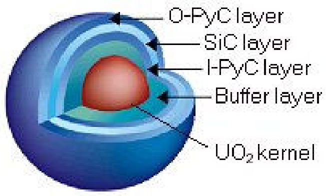


Fig. 1. Structure of a TRISO-coated fuel particle.

2. X-ray Imaging System

The used X-ray imaging system is Harmony 130 developed at the DRGEM Corporation in Korea. The focus spot size of the X-ray generator is 5 μm. The number of pixels of the used flat panel X-ray detector is 1024x1024. The size of a pixel is 48x48 μm^2. In the experiment, the tube voltage/current was 40 kV/100 μA under the inspection condition. The radiographic image was enhanced by an image processing technique to acquire clear boundary lines between the coating layers. The thickness of the coating layers was computed by measuring the distance between the boundary lines.

3. Coating Thickness Measurement

3.1 Calculation of the Coating Thickness

A fuel particle is projected by an X-ray cone beam. The radius of each layer can be calculated by equation (1) in case the where the distance from the source to the object is large enough by using the measured distances, d_1, d_2, , , d_5, for the projection image on the screen.[9]

$$r_n = d_n \, R / D, \quad n=1, 2, 3, 4, 5. \qquad (1)$$

Where,

- D : distance from source to screen
- R : distance from source to the center of a particle
- r_1 : radius of kernel
- r_2~r_5 : radius of buffer PyC, I-PyC, SiC, O-PyC layer
- d_1 : measured distance for radius of kernel
- d_2~d_5: measured distance for radius of buffer, I-PyC, SiC, O-PyC layer

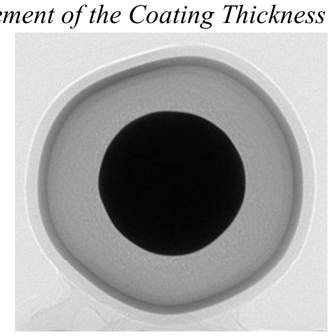
3.2 Acquisition of Radiographic Images for the Simulated TRISO-coated Fuel Particle

We are developing a TRISO coating process by using a simulated kernel made of ZrO_2 instead of UO_2. The radiographic image of the simulated TRISO-coated fuel particle was acquired by the micro focus X-ray system. The X-ray power was minimized to maintain a good contrast in an image. 20 images were integrated to control the exposure for an object. The random noises were reduced by an integration due to an average effect. The histogram was controlled to enhance the brightness and contrast for the integrated image.

Fig. 2 shows the histogram adjusted image. The adjusted image was treated by an edge sharpening process to intensify the boundaries.

Fig. 2. The histogram adjusted image for the radiographic image.

3.3 Measurement of the Coating Thickness



The coating thickness was calculated by using the measured radius of the boundary according the coordinate of the center of the object on the image. The distance between the boundary position and the center of a TRISO particle image is the radius of the coating layer. The radii of the coating layers were circularly measured by rotating them 360 degrees with a step of 10 degrees on the X-ray radiographic image.

The coating thickness was computed by using the measured radii as shown in Fig. 3. The abrupt peaks were excluded for the measurement process to reduce the measurement error. The mean value and the standard deviation for the coating thickness were calculated for a fabricated TRISO particle.

As a result of the experiment, the thickness of buffer layer ranged from 129 to 157 μm. That of the I-PyC layer ranged from 31 to 43 μm. The SiC layer thickness ranged from 31 to 39 μm. And, the O-PyC layer thickness ranged from 31 to 59 μm. The standard deviation of each layer ranged from 2.4 μm to 6.6 μm. The thickness deviation for the buffer layer was large, but the thickness of the other layers was relatively uniform. The outer shape of a coated fuel particle was mainly determined by the buffer layer.

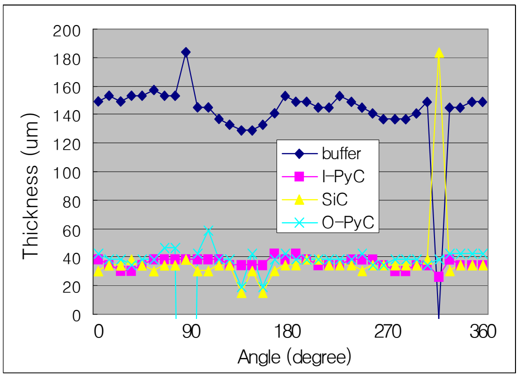


Fig. 3. The coating thickness for a simulated TRISO-coated fuel particle.

4. Conclusion

In this study, micro X-ray radiographic imaging technology as well as digital image processing technology was established to measure the coating thickness in the TRISO-coated fuel particles. The experimental results are as follows.

- The used micro X-ray imaging system consisted of a micro focus X-ray generator with a focus spot less than 5 μm and a flat panel detector with a high resolution of 48μm.

- The coating thickness was measured for the simulated TRISO-coated fuel particle with a kernel made of ZrO_2 instead of UO_2.

- The acquired image was enhanced by the digital image processing techniques.

- The coating thickness was automatically measured by the image processing algorithm.

- The coating thickness of the TRISO-coated fuel particles could be effectively measured by applying the micro X-ray radiography and the developed image processing technology.

Acknowledgement

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