Study on the inspection item and inspection method of HTGR fuel

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1. Introduction

The type of HTGR(High Temperature Gas-cooled Reactor) fuel is different according to the reactor type. Generally the HTGR fuel has two types. One is a block type, which is manufactured in Japan or America. And the other is a pebble type, which is manufactured in China. Regardless of the fuel type, the fuel manufacturing process started from the coated particle, which is consisted of fuel kernel and the 4 coating layers. Fig. 1 shows the schematic manufacturing process of HTGR fuel.

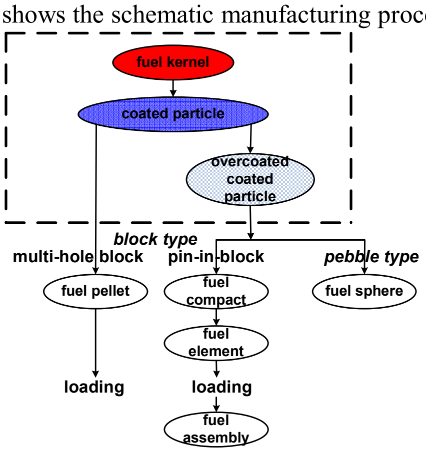

Fig. 1. Fabrication flow sheet of HTGR fuel

Korea has a plan to fabricate a HTGR fuel in near future. The appropriate quality inspection standards are requested to produce a sound and reliable coated particle for HTGR fuel. Therefore, the inspection items and the inspection methods of HTGR fuel between Japan and China, which countries have the manufacturing process, are investigated to establish a proper inspection standards of our product characteristics[1-3]

2. Inspection of fuel characteristics

The characteristics of fuel is inspected based on the design specification. The design values of fuel kernel and coated particle for HTR-10 and HTTR are listed in Table 1 and Table 2, respectively. In the following the inspection items and the inspection methods for the fuel kernel and the coated particles are briefly described. Fig. 2 shows the inspection items for the fuel kernel and the coated particles.

Table 1. Design specification of fuel kernel

Inspection item		HTR-10	HTTR
Fuel kernel	Fuel type Diameter(㎛) Density (g/cm^3) Sphericity(D_{max}/Dmin) O/U ratio EBC(ppm)	UO_2 500±50 ≥ 10.4 < 1.2 ≤ 2.01 ≤ 4	UO_2 600±75 95±3(%T.D.) < 1.2 (> 90%) 1.99~2.02 ≤ 5
	Impurities (ppm)	-	C ≤ 300 Fe ≤ 500 Ca ≤ 200
	Volatile impurities (ul/g UO_2)		≤ 80

Table 2. Inspection method for the inspection item of kernel

Inspection item		JAERI	INET
Fuel kernel	Diameter Density Sphericity O/U ratio EBC	PSA* Pycnometer PSA* gravimetry	X-ray radiograph pycnometer X-ray radiograph gravimetry emission spectrography

*PSA : Particle Size Analyzer

2.1 fuel kernel

Fig. 2 shows the inspection items for the fuel kernel. The inspection methods for inspection items of the fuel kernel are briefly describe in the following.

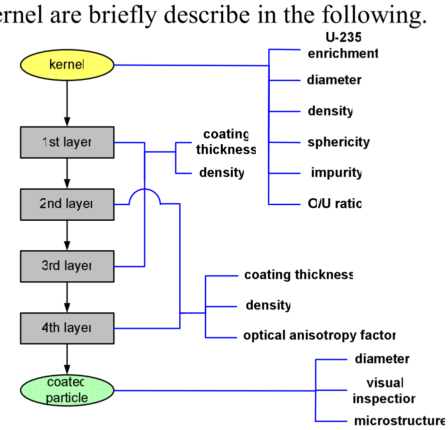

Fig. 2. Inspection item for kernel and coated particle.

1) Enrichment(if necessary) of U-235 is measured with a gamma-ray spectrum or mass spectrometry. The measuring method is determined to consider a requested precision of fuel design.

2) Diameter measurement of kernel is determined to consider a requested precision of fuel design. Japan measures the diameter of kernel with a PSA(Particle Size Analyzer) method and China measures it using a X-ray radiography method.

3) Sphericity is calculated as the ratio of the greatest and the smallest diameter of kernel. Using a measuring method of kernel diameter, the sphericity of kernel is measured.

4) Density of kernel is measured using a geometrical method. The mass of it is measured with a balance and the volume of it is measured with a picnometer. The volue and the mass gives the density.

5) O/U(Oxygen to Uranium) ratio is determined with a gravimetric method.

6) EBC(Equivalent Boron Content) and impurities are checked.

The inspection items of kernel between Japan and China are listed in Table 3.

Table 3. Design specification of coated particle

Inspection item			HTR-10	HTTR
Coating layer	layer thickness (㎛)	1st 2nd 3rd 4th r	95±45 40±20 35±19 40±20	60±36 30±12 ≥ 17 45±20
	layer density (g/cm^3)	1st 2nd 3rd 4th	≤ 1.10 1.9±0.1 ≥ 3.18 1.9±0.1	1.10±0.15 1.85±0.10 ≥ 3.18 1.85±0.10
	optical anisotropy factor	2nd 4th	≤ 1.03	≤ 1.04
Coated particle	diameter(㎛)			
	visual			no crack, no defect, no inclusion
	microstructure			normally coated

2.2 Coated particle

The role of the coating is retain the fission product in the kernel under normal operation and under accident conditions. The coating system is composed of 4 different layer. The 1st layer(innermost layer), the so-called buffer layer, is a porous(low-density) pyrocarbon. Its purpose is to absorb the damage from recoiling fission fragments, to accommodate the kernel swelling and, most importantly, to provide the free volume for gaseous fission products. The 2nd layer is a high density pyrocarbon coating, which sealed the 1st layer. This layer protects the 3rd layer(SiC coating layer) from detrimental reactions with the fuel an fission products and hinders the penetration of chlorine containing materials into the 1st layer during SiC deposition. The 4th layer, which is a high density pyrocarbon, protects the SiC layer in the chemical and mechanical sense and is an additional barrier for the gaseous fission products in case of a disruption of the SiC layer.

Fig. 2 shows the inspection items for coating layer and coated particle. The inspection methods for inspection items of coating layer and coated particle are briefly described in the following.

2.2.1 coating layer

1) the thickness of coating layer ; the inspection method is same the inspection method for fuel kernel in Japan. However, in China the thickness of the 1st and 2nd coating layer is measured using a metallographic micrograph. But the thickness of the 3rd and the 4th layer is measured by microradiography.

2) density of coating layer is measured by picnometer method in Japan. But China uses a geometrical method.

3) anisotropy factor of the 2nd and the 4th layer ; the anisotropy of two high density pyrocarbon layers is measured optically using a reflection of polarized light.

2.2.2 coated particle

1) The diameter measurement of the coated particle is determined to consider a requested precision of fuel design. There are a PSA and a X-ray radiograph method.

2) Visual and metallograph ; the target of inspection meet a criteria, in which there is no significant crack, defect or inclusions on the coated particle.

The inspection methods for the inspection items of the coated particle between Japan and China are listed in Table 4.

Table 4. Inspection method for the inspection item of coated particle

Inspection item			JAERI	INET
Coatin g layer	layer thickness (㎛)	1st 2nd 3rd 4th	PSA*	Metallographic micrograph Micro radio-graphy(X-ray)
	layer density (g/cm^3)	1st 2nd 3rd 4th	genometry float and sink float and sink float and sink	geometry float and sink float and sink float and sink
	Optical Anisotropy factor	2nd 4th		
Coated particl e	Diameter(㎛)		PSA*	
	Visual		Visual inspection	
	microstructure		metallurgy	

*PSA : Particle Size Analyzer

REFERENCES

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