Study on the properties of the fuel compact for High Temperature Gas-cooled Reactor

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1. Introduction

Generation-IV reactors have been developed for the advanced safety, higher burn-up, long-term irradiation cycle and /or additionally for the hydrogen production. High Temperature Gas-cooled Reactors (HTGR), one of the Gen-IV reactors, have been using the fuel element which is manufactured by the graphite matrix, surrounding Tristructural-isotropic (TRISO)-coated Uranium particles. Factors with these characteristics effecting on the matrix of fuel compact are chosen and their impacts on the properties are studied.

The fuel elements are considered with two types of concepts for HTGR, which are the block type reactor and the pebble bed reactor [1]. In this paper, the cylinder-formed fuel element for the block type reactor is focused on, which consists of the large part of graphite matrix [2]. One of the most important properties of the graphite matrix is the mechanical strength with the high reliability because the graphite matrix should be enabled to protect the TRISO particles from the irradiation environment and the impact from the outside.

In this study, the three kinds of candidate graphites and the two kinds of candidate binder (Phenol and Polyvinyl butyral) were chosen and mixed with each other, formed and heated to measure mechanical properties. The objective of this research is to optimize the materials and composition of the mixture and the forming process by evaluating the mechanical properties before/after carbonization and heat treatment.

2. Experimental Procedure

The several types of binder, graphite and different process were applied to form the matrix mixture and compared with the commercial process. In this study, the different preparation process such as pulverization and wet milling was carried out to improve the commercial production. Fig. 1 shows the manufacturing flow diagram for fuel element fabrication process. The eight (8) kinds of samples were manufactured with the conditions according to flow diagram in Fig. 1.

Three kinds of graphite (G, R and S) among the several candidate graphite were chosen for this study. (G, R : Natural graphite, S : Artificial graphite)

As shown in Table I, four kinds of graphite matrix (G : S or R : S = 4 : 1 based on wt%) are mixed with 2 % or 6 % of PVB binder and 10 or 20 wt% of Phenol binder, and milled by the planetary ball mill with solvent for 2 hours, respectively. Then, the graphite mixture was dried for over 12 hours. The particle size of mixed graphite was measured by CILAS 1064 particle size analyzer.

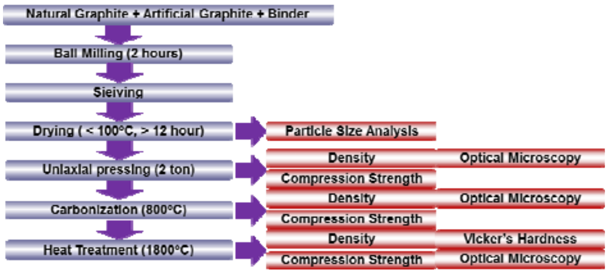

Fig. 1. Manufacturing flow diagram of pellet-type graphite sample

Table I: Compositions of the various mixing conditions

SAMPLE	Mixed Graphite Ratio		Binder (PVB)	Binder (Phenol)
	Natural Graphite (G or R)	Artificial Graphite (S)		
Condition 1, 2	4	1	2 %	
Condition 3, 4			6 %	
Condition 5, 6				10 %
Condition 7, 8				20 %

The dried graphite mixtures are pressed into the pellet-type (green pellets) by applying compressive pressures of 2 ton/cm^2. The green pellets were carbonized at 800°C for 2h in N_2 atmosphere (1 liter/min). In addition, the compressive strength of the samples was measured by INSTRON SFL with same condition. Also, after heat-treatment at 1800°C for 2 hr, the measurements was conducted as listed above. The bulk density of the pellets was measured before and after carbonization and after heat treatment. And the Vicker's hardness test was conducted with the heat-treated pellets by micro Vicker's hardness tester in the condition of 0.3 kgf for 15 sec.

3. Results

The results of the particle size analyze (PSA) of the wet-milled graphite powder was shown in Fig 2. It shows that the kinds and contents of binder affect mainly to the particle size distribution. Small differences of particle size was measured in the results of PSA of PVB-added powder. However, it shows large difference in the results of Phenol-added powder, Diameter at 50 % is increased from about 20 to 30 μm, as the contents of Phenol binder increased from 10 to 20 wt%.

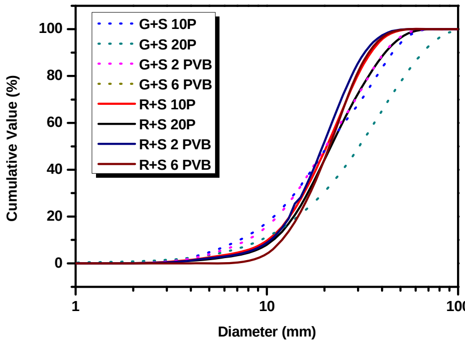

Fig. 2. Particle Size Analyze of mixed graphite powder (P : Phenol)

Fig. 3 shows the density of the green graphite pellets, the carbonized pellets and the heat treated pellets. As shown in Fig. 3, the density of pellets, PVB-added pellets and Phenol-added pellets are mostly decreased according to the carbonization and the heat treatment. The pellets, 20 wt% phenol added, has low density about 1.7 g/cm^3, but the density of other pellets are about 1.95 g/cm^3.

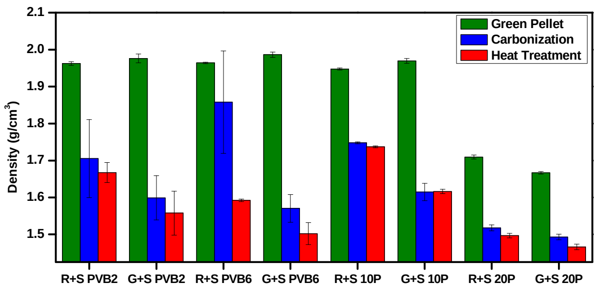

Fig. 3. Density of the pellets (Green pellets, Carbonized pellets and Heat treated pellets)

Fig. 4 shows results of the compressive strength test of the pellets. The compressive strength of the phenol-added pellets are certainly shown the higher compressive strength than the PVB-added pellets. The phenol added pellets are shown that smaller degradation than the PVB-added pellets after the carbonization and the heat treatment.

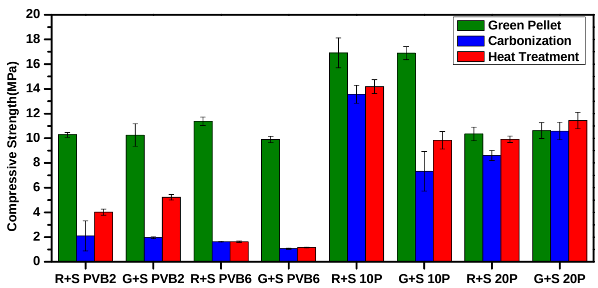

Fig. 4. The result of compressive strength test

Vicker's hardness test has conducted with the heat-treated pellets. In Fig. 5, shows the PVB-added pellets has lower hardness value than Phenol-added pellets. Because of the many pore in the pellet, the hardness of G+S PVB 6 pellet was not able to observe the indentation.

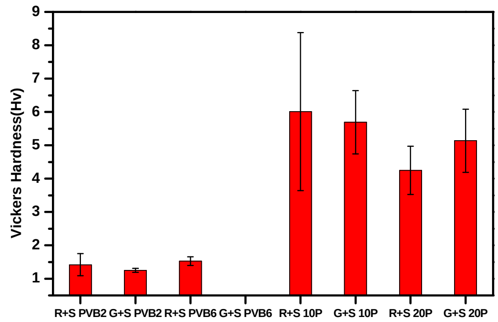

Fig. 5. Vicker's hardness of heat-treated pellets

4. Conclusion

For the aspects of fuel elements of HTGR, the mechanical integrity of graphite matrix is one of the main factor to evaluate the mechanical properties. In this study, the effect of binder and heat treatment on graphite matrix was studied in terms of the density, the compressive strength and Vicker's hardness.

The diameter and length of pellets are increased by heat treatments. However, the density of graphite pellet is decreased about 0.2 ~ 0.4 g/cm^3 due to the vaporization of binder.

From the mechanical test results, the mechanical properties of graphite pellets was related to the various conditions such as the contents and kinds of binder, the kinds of graphite and the heat treatments. In the result of the compressive strength and Vicker's hardness, the 10 wt% phenol binder added R+S graphite pellet was relatively higher mechanical properties than other pellets.

The contents of Phenol binder, the kinds of graphite powder and the temperature of carbonization and heat treatment are considered important factors for the properties.

To optimize the mechanical properties of fuel elements, the role of binders and the properties of graphites will be investigated as further study.

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