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Comparison of The Thermal Conductivity of selected Nuclear Graphite Grades for High Temperature Gas-Cooled Reactor

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1. Introduction

The thermal conductivity of graphite core components in VHTR is one of the critical factors that determine the core temperature during normal as well as abnormal condition of a reactor. Thus, the thermal conductivity of selected nuclear graphite grade for the construction of the core components is an important material input data during the design, construction, operation, licensing or safety evaluation stage of a reactor.

It is well known that the thermal conductivity of nuclear graphite is influenced by factors such as phonon boundary scattering processes, Umklapp processes, electron-phonon scattering etc [1], and a lot of studies have been performed to investigate the neutron-irradiation effects on the thermal conductivity of graphite [2][3**].** However, no studies have been reported yet for the overall differences in the thermal conductivity of the nuclear graphite grades for HTGR differing in coke source (petroleum, coal), forming method and particle size.

In the present study, the thermal conductivities of seven candidate nuclear graphite grades for HTGR were determined and compared based on the microstructure of the grades.

2. Experimental

2.1 Materials and specimen

The characteristics of seven nuclear graphite grades employed in the present study are summarized in Table I. All the values reported in the Table I were obtained from the manufacturers' data sheet. Overall differences in the coke source, forming method, average coke particle size and density among the grades are noted in Table I.

Two specimens were prepared from each grade for (a) thermal diffusivity and (b) heat capacity determination (Figure 1). All the sample surfaces were prepared by polishing up to SiC paper (# 2000) and ultrasonic cleaned before thermal conductivity measurements.

2.2 *Thermal conductivity measurement.*

In this study, the thermal conductivity (TC) was measured by the laser flash method (LFM) (NETSCH, LFA 414/4, LFA 457, 450-2110 V, 0.5-0.8ms) referring ASTM E 1461-13 (Standard Test Method for Thermal Diffusivity by the Flash Method) from room temperature up to 1,100 ℃. The thermal conductivity (k) was calculated by following equation (1):

$$k = \alpha C_p \rho \ldots\ldots\ldots \quad (1),$$

where, k is the thermal conductivity, α is the thermal diffusivity, C_p is the heat capacity, and ρ is density.

Table I: Comparison of material characteristics of the selected nuclear graphite grades examined in this study.

	IC110	IG430	NBG17	NBG18	NBG25	PCEA	PPEA
Grain size (㎛)	25	10	150	300	20	360	360
Density (g/cm3)	1.77	1.82	1.89	1.873	1.81	1.85	1.83
Source coke	Petroleum	Pitch	Pitch	Pitch	Petroleum	Petroleum	Pitch
Forming method	Iso-static molding	Iso-static molding	Vibration molding	Vibration molding	Vibration molding	Extrusion	Extrusion

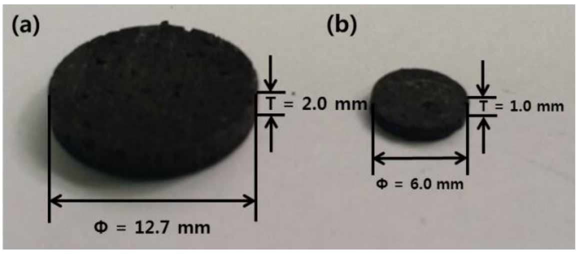

Fig. 1. Specimens for (a) thermal diffusivity and (b) heat capacity measurements.

3. Results and Discussion

All the results of thermal conductivity measured in the present study for seven candidate nuclear graphite grades for HTGR are shown in Figure 2, and Figure 3 show the results re-plotted for the forming method.

Above all, it is seen in Figure 2 that all the grades show a decrease in TC with increasing temperature owing to the increased phonon-phonon scattering, and the differences in TC among the grades at room temperature tend to decrease with increasing temperature. These observation may be understood from the following formula [4]:

$$k = 1/3\, C_p\, \lambda \nu \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where, k is thermal conductivity, C_p is heat capacity, λ is the phonon mean free path, and ν is the phonon velocity. At room temperature, where phonon-phonon scattering can be neglected, the k is proportional to λ, which will be large for large grain (PCEA) and small for small grain (IG-110). At higher temperature, the effects of λ will be diminished with an increasing phonon-phonon scattering.

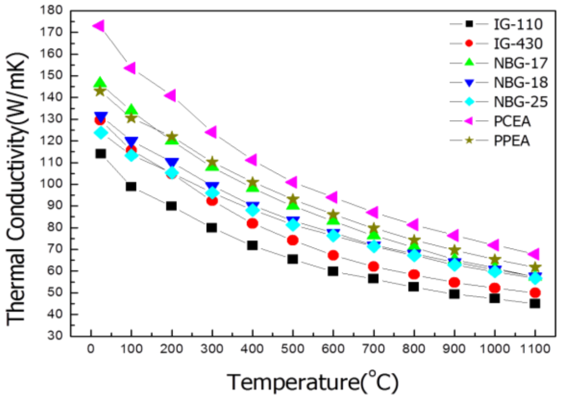

Fig. 2. The thermal conductivity of seven candidate nuclear graphite grades for HTGR measured from room temperature to 1,100℃.

Figure 2 shows that the TC decreases for 55-60 % when the temperature increases from the room temperature to 1,100℃.

Several other factors not clarified yet may be assumed to affect the TC. The examination may be exercised via Figure 3.

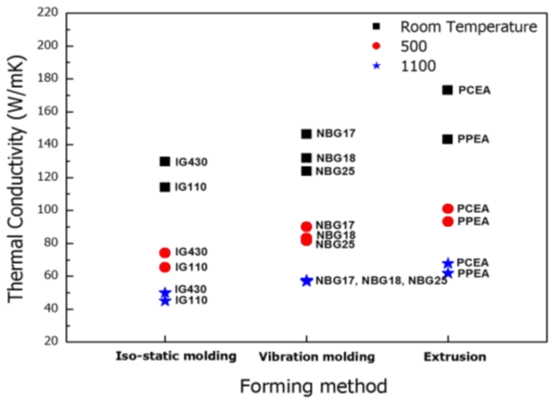

Fig. 3. The effects of forming method on thermal conductivity (TC).

It is seen that, if the data on fine grain-size of iso-static molding is not considered, no apparent effects of the forming method are assumed between the extrusion and vibration molding.

Thus, Figure 3 shows that there is no apparent effects of forming method on TC when the grain size effects are considered for the iso-molding grades (IG-110, IG-430). Figure 3 shows that the effects of temp- erature on TC are far prevailing than the material factors being considered.

Finally, it is worth noting that the effects of porosity (shape, size and distribution) are not considered in the present study under the assumption that it will be quite similar under the similar apparent density. Further studies will be performed as to the effects of porosity on TC.

4. Conclusion

The thermal conductivity is an important material input data during the design, construction and operation of HTGR. The thermal conductivities of seven nuclear graphite grades for HTGR were determined by laser flash method from room temperature to 1,100℃ and compared based on the microstructure of the grade.

Conclusions obtained from the study are as follow.

(1) The thermal conductivity of seven nuclear graphite grades appeared to be strongly influenced by the grain size at low temperature below about 500℃ and by the phonon-phonon scattering at above 800℃.
(2) All the grades show a decrease in TC of 55-60 % from their room temperature TCs with increasing temperature to 1,100℃.
(3) The PCEA of medium grain formed by extrusion shows the highest TCs for the temperature range examined in the present study.

REFERENCES

[1] B. T. Kelly, in: Chemistry and Physics of Carbon, Vol. 5 (Dekker, New York, 1969) p. 119
[2] Burchell, T. D., Radiation Damage in Carbon Materials. In Physical Processes of the Interaction of Fusion Plasmas with Solids,. Ed. J. Roth and W. O. Hoffer, Academy Press, San Diego, 1996, pp. 341-384
[3] Kelly, B. T., Physics of Graphite, Applied Science Publishers, London, 1981.
[4] Thermal Properties. In Nuclear Graphite, Ed. R. E. Nightingale, Academy Press-1962, London. P. 123.

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