Comparison of High Temperature Elastic Modulus of Selected Nuclear Graphites

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1. Introduction

Graphite is used in very high temperature gas-cooled reactors (VHTR) not only as a moderator and reflector but also as a major structural component due to its excellent neutronic, thermal and mechanical properties. During normal operation and accident, these graphite components are subjected to various mechanical and thermal stresses [1, 2]. Elastic modulus value is required for design and stress analysis of the core, the temperature dependence of elastic modulus must be examined.

In this study, the high temperature elastic modulus of selected nuclear graphites was measured in argon environment and compared one another based on the difference in pore structure.

2. Experimental

2.1 Materials and Specimen

In this study, a pyrolytic graphie (pyrographite) manufactured by GE Advanced Materials-Quartz and two grades of nuclear graphite were used: IG-110 (petroleum coke, isostatically molded) produced by the Toyo Tanso Co, Ltd, Japan and NBG-18 (pitch coke, vibrationally molded) produced by the SGL Carbon Group, Germany. The main properties of the materials are summarized in Table 1. For elastic modulus measurement, we used a bar type specimen with the dimension of 50 mm in length, 5 mm in thickness and 15 mm in width.

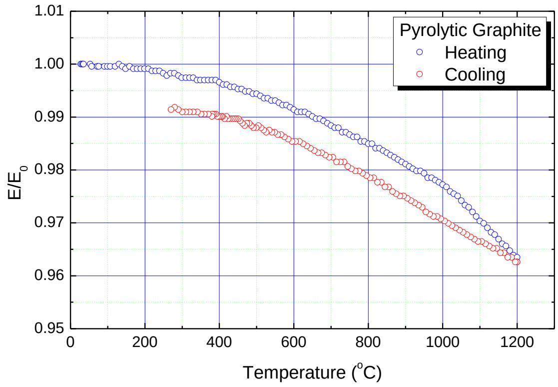
Table I: Typical properties of the graphites

Grade	Density (g/cm^3)	Coke particle size (μm)	Compressive strength (MPa)
Pyrographite	2.18-2.22	-	100
IG-110	1.77	20	81.3
NBG-18	1.85	Max. 1600	72

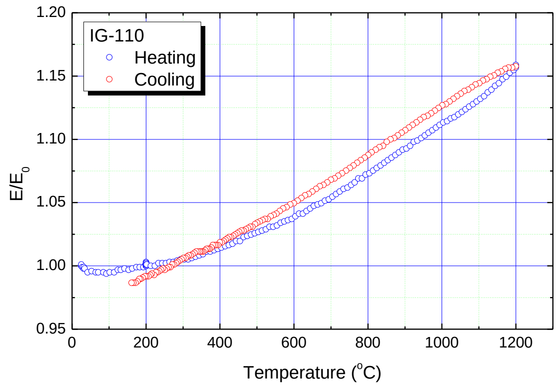
2.2 High Temperature Elastic Modulus Measurement

Elastic modulus was measured at temperature from 20 to 1200 °C using a commercialized impulse excitation apparatus (RFDA HTVP 1600, IMCE). After positioning the specimen in two nodes, the furnace was evacuated up to 0.1 mbar and then purged with Ar gas (99.999%). The specimen was heated in Ar environment at a heating rate of 4 °C/min. The specimen was gently tapped with a little hammer in the anti-node. The vibration signal emitted by the sample is captured using a microphone and sent to the resonant frequency and damping analysis software. The elastic modulus was calculated using the specimen dimensions, weight and measured resonant frequency based on the ASTM C 1259-08 [3].

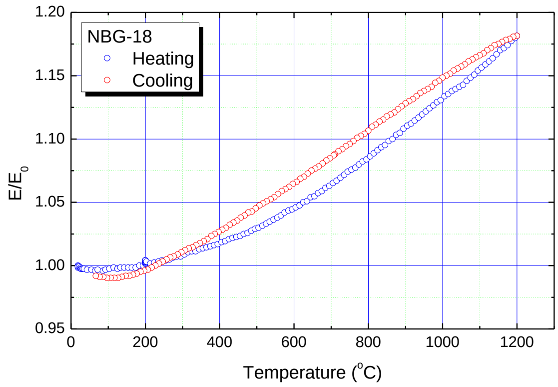
3. Results and Discussion



(a)



(b)



(c)

Fig. 1. Temperature dependence of the elastic modulus: (a) pyrolytic graphite (b) IG-110 and (c) NBG-18

Fig. 1 shows the dependence of the normalized elastic modulus. The modulus of the pyrolytic graphite decreased with increasing temperature. Fractional decrease of the modulus was less than 4 % at 1200 ^{o}C. The negative temperature dependence represents the behavior of the crystallite alone on thermodynamic grounds [4]. However, the modulus of the nuclear graphite increased with increasing temperature regardless of the grade. Fractional increases of the modulus were about 16 % for the IG-110 and 18 % for the NBG-18, respectively. The positive temperature dependence was attributed to the progressive closure of Mrozowski cracks which are result from relief of thermal stress produced by anisotropic shrinkage of graphite crystallites on cooling from graphitization temperatures [5, 6]. Changes in the elastic modulus during the heating and cooling process were also observed. It is to be noted that the hysteretic behavior observed during this process is more pronounced for the NBG-18 than for the IG-110. It is attributed thermal stresses are required to open Mrozowski cracks on the cooling process and thus there are more closed cracks than on the heating process, which would result in the higher modulus at a given temperature during the cooling process [4].

Elastic modulus of the polycrystalline graphite usually depends on its pore volume (bulk density) and the precise variation of elastic modulus with temperature depends on the nature of the graphite, since the extent and distribution of Mrozowski cracks will depend on the thermal history of the graphite as well as the microstructure of the precursor materials. The density of the NBG-18 (1.82 g/cm^3) is much higher than that of the IG-110 (1.78 g/cm^3) so that the modulus of the NBG-18 was higher than the IG-110 at all temperature. The higher positive temperature dependence and larger hysteresis change of the modulus in the NBG-18 than in the IG-110 is attributed to higher closed porosity of the NBG-18 as reported by Kim et al [7].

4. Summary

In a VHTR, if the temperature should rise the elastic modulus of graphite components would be expected to increase, which gives an even greater factor of mechanical safety than the design allows under normal operating conditions.

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REFERENCES

[1] T. Iyoku, S. Shiozawa, M. Ishihara, T. Arai, T. Oku, Nucl. Eng. Deg. Vol.132, pp.23, 1991

[2] T. Shibata, M. Eto, E. Kunimoto, S. Shiozawa, K. Sawa, T. Oku, T. Maruyama, JAEA-Research 2009-042

[3] ASTM C 1259-08, Standard Test Method for Dynamic Young’s Modulus, Shear Modulus, and Poisson’s Ratio for Advanced Ceramics by Impulse Excitation of Vibration

[4] I.B. Mason, R.H. Knibbs, Carbon Vol.5, pp.493, 1967

[5] T. Maruyama, M. Eto, T. Oku, Carbon Vol.25, pp.723, 1987

[6] D.J. Miller, P. Homerin, D.R. Ball, Proc. of the 6th International Nuclear Graphite Specialist Meeting, INGSM-6, Chamonix, France, 2005

[7] G.C. Kim, S.H. Chi, Proc. of International Symposium on Advanced Modeling and Processing of Materials, ISAMPM, Cheongju, Korea, 2006