Diametral Compressive Strength and Elastic Modulus of Flattened Disc using Diametral Compressive Test

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1. Introduction

The nuclear grade graphite is the candidate materials for the in-core components of the very high temperature gas-cooled reactor (VHTR) due to its very high conductivity, melting temperature, chemical resistance and mechanical stability. Nuclear graphite undergoes dimensional change and mechanical properties change because of irradiation damage. To estimate the irradiation damage, surveillance capsule would be inserted in reactor. Surveillance capsule sizes were limited because it would be located inside of a reactor vessel. Thus, a new test method using small specimen is needed and diametral compressive test is one of them [1-2]. However, various circular anvils are needed according to the specimen size. A flattened disc specimen were proposed to overcome such a problem and applied for determination of mechanical properties for brittle rocks. In this study, the applicability of such specimens was investigated. In addition, minimum specimen size for test was determined and diametral compressive strength of nuclear graphite was measured.

2. Experimental

In this study, four different nuclear graphite grades were investigated. Physical properties of graphite are summarized in Table I. Fig. 1 shows the dimensions of the flattened specimen. The dimension of the flattened disc specimen was from 5mm to 25mm in radius (R), from 3mm to 15mm in thickness (t), from 2.59mm to 12.94mm in contact width (2b), respectively. To perform diametral compressive strength test at room temperature, Instron 4204 screw driven mechanical testing machine with the load cell capacity of 50 kN was used. Diametral compressive strength test were carried out with the cross-head speed of 0.1mm/min.

Table I: Typical physical properties of nuclear graphite from manufacturer's data

Manufacturer	**Toyo Tanso**	**SGL**		
Grade	IG-110	NBG-17	NBG-18	NBG-25
Coke	Petroleum	Pitch	Pitch	Petroleum
Fabrication	Isomolded	Vibro-molded	Vibro-molded	Isomolded
d_{avg} (μm)	10	Max. 800	Max. 1600	20

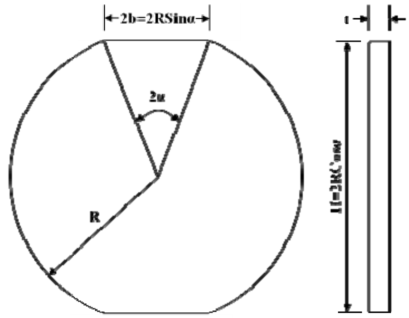

Fig. 1. Flattened disc specimen

3. Results and Discussion

3.1 Specimen geometry effect on failure mode

According to the FEM analysis [3] disc center region experience the largest tensile stress, during compressive test at flattened disc specimen. Therefore, crack initiates at the center of specimen. However, stress was also concentrated at contact edge between jig and specimen which was used by specimen geometry [3]. In that case, failure occurs prior to apply maximum stress at center region and diametral compressive strength can't be calculated. Fig. 2 shows that effect of contact angle on disc specimen failure mode. According to theoretical analysis of Q. Z. Wang et al. [3], failure occurred at center region when 2α is between 20° and 30°. However, experimental result is different. In case of 2α=20°, 25°, failures happened at contact edge region. However, failures happened at center region for 2α=30°. It would seem that nuclear grade graphite have pores, binder and anisotropy material.

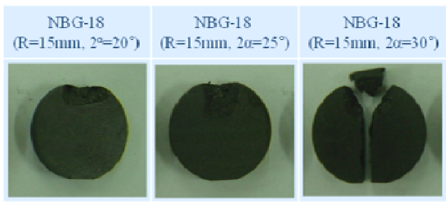

Fig. 2. Effect of contact width on failure mode

Increment of contact width is restricted, because lose their original disc shape. So, we increase the specimen thickness to get the valid result. Fig. 3 shows the effect of thickness on specimen failure mode. When t/R ratio is 0.4 and 0.5, failure happened at contact edge region. However, for the rest of specimens, failure occurred at center region.

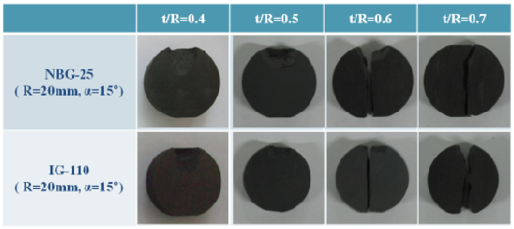

Fig. 3. Effect of specimen thickness on failure mode

3.2 Diametral compressive strength

Diametral compressive strength at center region could be calculated using the following equation [1].

$$\sigma_{Hc} = \{1 - 1.15(b/R)^2 + 0.22(b/R)^3\}\sigma_p$$

where σ_{Hc} is diametral compressive strength, b is contact half width, R is radius of specimen and σ_p is uniformly distributed tensile stress on the loading axis in the disk. Fig. 4 shows the calculated diametral compressive strength of flattened disc specimen vs. specimen diameter. In case of NBG grade, diametral compressive strength decreased up to 30mm and showed steady value at larger values. In contrast, that of IG-110 diminished with increasing diameter. As diameter increased, many IG-110 specimens were broken at contact edge region and failure happened before maximum stress at center region was reached. That is the reason why diametral compressive strength value of IG-110 decrease with specimen diameter. Standard deviation for NBG-18 is the largest among tested nuclear graphite grades. Meanwhile, NBG-25 has lowest standard deviation. The difference in grain size might have something to do with the standard deviation of diametral compressive strength.

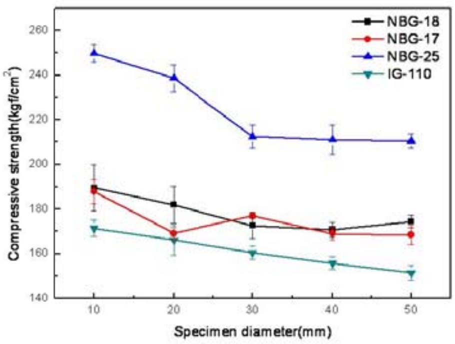

Fig 4. Diametral compressive strength vs. specimen diameter curves of nuclear graphite

3.3 Deduced elastic modulus

Elastic modulus was deduced using approximate formula for the compression displacement Δw along the vertical diameter of a flattened disc [3].

$$E = \frac{2P}{\pi t \Delta w}\left\{(1-\mu) + \ln\left(1 + \frac{4}{\sin^2\alpha}\right)\right\}$$

where P is the resultant of the distributed force, t is the thickness, μ is the poison's ratio, α is the half the load angle. Fig. 5 shows the deduced elastic modulus. Except NBG-18, elastic modulus showed somewhat constant values at diameters greater than 30 mm. Unlike compressive strength, IG-110 did not show abnormal behaviors.

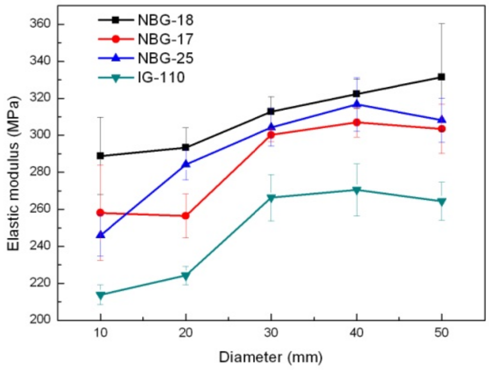

Fig 5. Elastic modulus vs. specimen diameter curves of nuclear graphite

4. Conclusions

The applicability of flattened disc specimen for compressive test of nuclear graphite were investigated. Contact edge width and thickness of specimen affected the failure mode. Optimum specimen size for the valid test result was determined such that contact angle, 2α, is 30° and t/R ratio is 0.6.

Diametral compressive strength decrease up to 30mm but showed less change at larger specimen diameters. In case of IG-110, however, the strength continuously decreased with increase in specimen diameter mainly because many specimens were broken at contact edge region instead of center region.

Elastic modulus was also determined from the tests. Except NBG-18, elastic modulus showed somewhat constant values at diameters greater than 30 mm.

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