Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Observation of Compressive Deformation Behavior of Nuclear Graphite by Digital Image Correlation

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1. Introduction

Polycrystalline nuclear graphite has been proposed as a fuel element, moderator and reflector blocks, and core support structures in a very high temperature gas-cooled reactor [1]. During reactor operation, graphite core components and core support structures are subjected to various stresses. It is therefore important to understand the mechanism of deformation and fracture of nuclear graphites, and their significance to structural integrity assessment methods. Digital image correlation (DIC) is a powerful tool to measure the full field displacement distribution on the surface of the specimens [2]. In this study, to gain an understanding of compressive deformation characteristic, the formation of strain field during a compression test was examined using a commercial DIC system.

2. Experiments

The material used in this study was a high purity, super fine-grained isotropic nuclear grade graphite, IG-110, made by Toyo Tanso Co. Ltd. Japan. For compression tests, we used a square column type specimen with a size of 20 mm in length and 10 mm on its side.

The DIC equipment (VIC-2D, Correlated Solutions) shown in Fig. 1, included one charge-coupled device camera (1392 x 1040 pixels), a high intensity light illumination source, and a data acquisition (DAQ) box. Using the DAQ box, an input signal from the test machine was synchronized with the camera trigger.

Fig. 1 Digital image correlation (VIC-2D) setup.

As shown in Fig. 2, prior to DIC measurement, a speckle pattern was made to one surface of the test specimen by first applying a layer of white paint on the surface and then a mist of black paint to creat the black speckles. After the specimen and universal testing machine (30kN Instron 5867) were settled, an accesible position for the digital camera was selected and the focal length was adjusted to fix and acquire a clear image. The aperture range of the camera lens was set with the lowest f-number as possible to let in the maximum amount of light. Before starting the test, a picture is taken for a non-deformed reference image.

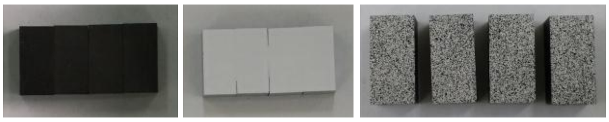

Fig. 2 Speckle patterns applied on specimen surfaces.

Compression tests were performed at a controlled displacement rate of 0.5 mm/min. Three specimens were loaded continuously to a final fracture. Based on the test results, one specimen was subjected to several loading-unloading cycles. The selected field of view was divided into a square subet that could be displaced, rotated, sheared, and strained. After accumulating images at various stages of loading and unloading, the relative displacements between the two subset were quantified and a full field displacement for the area of interest was obtained using VIC-2D software. The strain was then calculated from the measured displacements and the partial derivatives of the displacment.

3. Results and Discussion

A typical load-displacement curve is shown in Fig. 3. It is notable that the load-displacement curve was relatively linear up to 3200 N and then became more non-linear as the load increased. Full strain field distributions at the points during continuous loading are shown in Fig. 4. Generally, the strain fields were non-uniform, and much higher strains were accumulated more rapidly in localized regions. The macrocrack initiation sites and propagation paths observed in Fig. 4 (e) were inconsistent with the localized region at $0.95P_{max}$ observed in Fig. 4 (d). However, the crack propagation paths were inclined at ±45 degrees to the loading axis.

The measured strains and loads in the initial linear portion of the load-displacement curve were used to determine the Young's modulus of elasticity, E, using Hook's law. The calculated Young's modulus was found to be about 9.4 GPa. This value is comparable with the static Young's modulus value of 9.8 GPa reported for IG-110 [3].

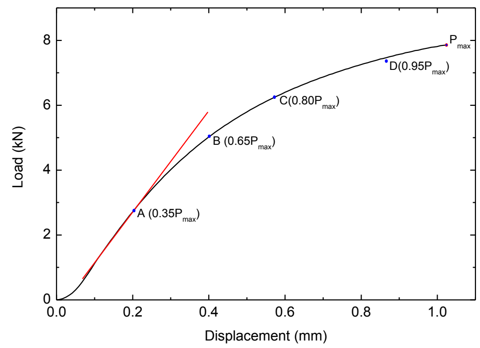

Fig. 3 Typical load-displacement curve.

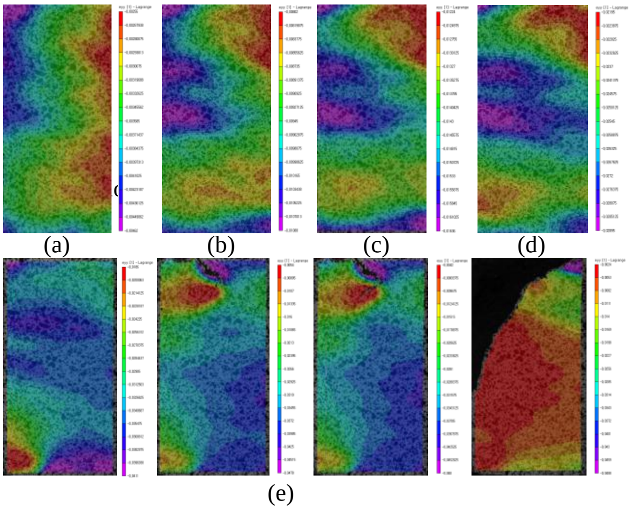

Fig. 4 Full field strain distributions at (a) $0.35P_{max}$, (b) $0.65P_{max}$, (c) $0.80P_{max}$, (d) $0.95P_{max}$ and (e) near P_{max}.

There was permanent displacement on complete unloading to a zero load at points B, C and D, as summarized in Table 1. Also, as shown in Fig. 5, the residual strains after the unloading were detected regardless of the load levels.

Table 1 Permanent displacement after the unloading

Load level	0	$0.35P_{max}$	$0.65P_{max}$	$0.85P_{max}$	$0.95P_{max}$
Sample length	20.04	20.04	20.02	20.01	19.96

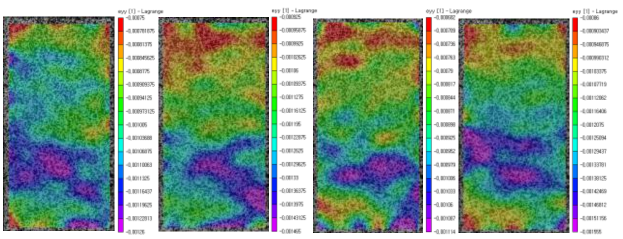

Fig. 5 Residual strain distributions after unloading to zero load at (a) $0.35P_{max}$, (b) $0.65P_{max}$, (c) $0.80P_{max}$ and (d) $0.95P_{max}$.

Polycrystalline graphite consists of filler grains and a binder region, including pores and microcracks. Inherent pores and microcracks between the basal planes nearly perpendicular to the loading axis would be closed or shrunk during compressive loading [4]. The localized strain during loading and the permanent displacement after unloading result from the closure and shrinkage of inherent defects.

4. Conclusions

An examination was made to characterize the compressive deformation behavior of nuclear graphite by a digital image correlation. The non-linear load-displacement characteristic prior to the peak load was shown to be mainly dominated by the presence of localized strains, which resulted in a permanent displacement. Young's modulus was properly calculated from the measured strain.

Acknowledgement

This study was supported by Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIP) (Grant code: NRF-2012M2A8A2025682).

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