Dose Rate Effects in the 2 MeV C$^+$ Ion Irradiated Nuclear Graphite

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1. Introduction

In HTGRs, graphite acts as a moderator and reflector as well as a major structural component that may provide channels for the fuel and coolant gas, channels for the control and shutdown, and a thermal and neutron shielding. Additionally, graphite components are employed as supports

In the case of the HTGR, some parts of the core structure receive a higher dose than the other parts of different graphite components under the same temperature condition during an operation. In the PBMR design, for example, the volume ratio of a graphite of a low dose to an intermediate and high dose are roughly 9.5: 1.0 (Haag, 1990) and (Mitchell, 2003).

In the present study, to obtain firsthand information on the dose rate effects on the change of the mechanical property and internal molecular bonding structure of nuclear graphite, specimens prepared from the IG-110 grade isotropic nuclear graphite were irradiated with varying dose rates of 2 MeV C$^+$ ions to several dose levels at room temperature, and the changes in the hardness and Raman spectrum due to an irradiation were measured and evaluated in terms of the dose rate effects.

2. Experimental

2.1 Material

The material used in the present study is the Toyo Tanso manufactured Grade IG-110 isotropic nuclear graphite. Thermal and physical properties specified in the manufacturer's material test sheet are reproduced in Table 1. Specimens with a size of 10 x 10 x 2 (mm^3) were prepared by cloth polishing for an irradiation and the as-received baseline hardness and Raman spectrum measurements.

Table 1 Selected IG-110 nuclear graphite material property

Density	Mg.m^{-3}	1.77
Shore Hardness	Shore D	53
Specific Resistivity	$\mu\Omega$.m	10.2
Bending Strength	MPa	39
Compressive	MPa	80
Strength	ppm	≤ 10
Ash Content		

2.2 Irradiation

The prepared specimens were irradiated by a 2 MeV C$^+$ ion irradiation (Tandem Vande-Graff Accelerator, NEC 5SDH-2, NEC, SNICS) at room temperature.

2.3 Micro-hardness and Raman Spectrum Measurements

An ultra-micro-hardness tester (model: Shimadzu DUH-200) and the Raman spectroscopy (Model: Jobin-Yvon Ramanor U-1000) were used to trace the changes in the micro-hardness and the Raman spectrum due to an irradiation, respectively. Analysis of the irradiation-induced changes in the Raman spectrum was performed by evaluating the peak intensity ratio between the peak at about 1357cm^{-1} (D band) and 1581 cm^{-1} (G band), i.e., I_D / I_G , and the ratio of the full width at a half maximum (FWHM) of the D and G bands, i.e., (FWHM (D/G)), which were obtained by using a Gaussian multi-peak analysis method. The Raman band at 1581 cm^{-1} is known as the graphite band (G band), and the band at about 1357cm^{-1} is known as the D band because it is associated with the defective and disorder structures (Cataldo, 2000)

3. Results and Discussion

3.1 Hardness Change in Depth

Results observed in the present micro-hardness test may be understood in terms of the difference in the defect density due to the difference in the dose rate, i.e., the difference in the rate of the defect removal by an annealing (recombination of interstitial and vacancies) and the rate of the defect production by an irradiation (Nightingale, 1962). The higher chances of a recombination of a higher dose rate may result in a relatively lower defect survival, while a relatively small number of defects due to a lower dose rate may have a greater chance of survival from an annihilation. Observation of the hardness peak around 0.25 in depth irrespective of the dose rate imply that the peak range (calculated to be formed at 2.40 in depth) affects the location of the hardness peak. In the present result, the ratio of relative distance from the surface appeared to be 0.25/ 2.40 ( ) = 0.10.
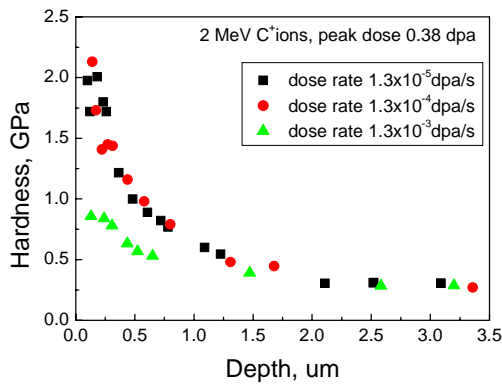
FIG. 1 The change of the hardness in depth of the IG-110 graphite specimens irradiated to 0.38 dpa by three different dose rates.

3.2 Raman Spectroscopy

The increase in the FWHM with a decreasing dose rate in Fig. 2 may be understood in terms of the time available for a defect diffusion which will be increased with a decreasing dose rate. From the observation of the somewhat large difference in the hardness between the 1.10×10^{-3} dpa/s and the other two dose rates, i.e., 1.30×10^{-4} dpa /s and 1.30×10^{-5} dpa /s, suggest the possibility of the threshold dose rate effects. Observation of the relative increase in the defected phase, i.e., the relative increase in the radiation-induced sensitivity in the D-phase compared to the G-phase with a decreasing dose rate in Fig. 2 and 3 can be understood in terms of the relative increase in the vibrational energy absorption in the defected lattice structure system, i.e., D-phase, compared to the normal graphite lattice structure, i.e., the G-phase, which, in turn, results in an increase in the FWHM, spectrum area, and the Raman shift down (Chi, 2003). It is worth noting that, even with an order of magnitude of difference in the dose of the specimen examined and a large difference in the examined volume, the implications obtained from Fig. 2 and 3 are the same in that the irradiation sensitivity of the graphite is increased with a decreasing dose rate. 0.04mm/year)
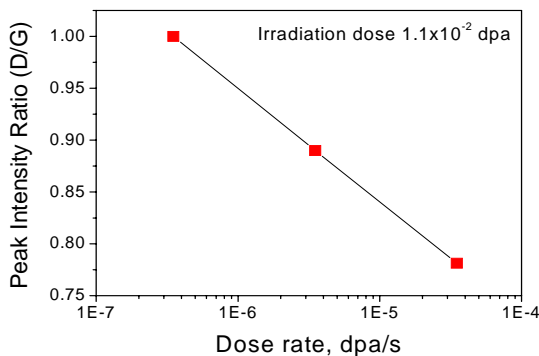

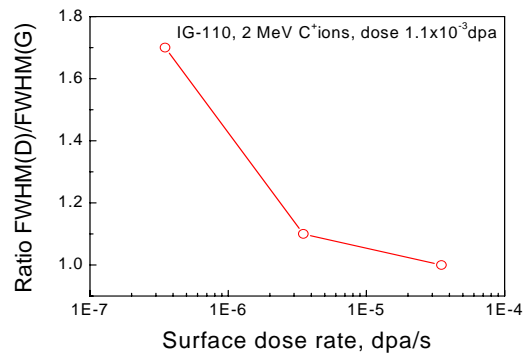FIG. 2 Change of the peak intensity ratio (I_D /I_G)

FIG. 3 Change of the FWHM of D and G peaks, Ratio FWHM(D)/FWHM(G)

4. Conclusion

Dose rate effects of IG-110 isotropic nuclear graphite were evaluated by the micro-hardness test and Raman spectroscopy for specimens irradiated with varying dose rates of 2 MeV C^+ ions. The irradiation sensitivity of IG-110 nuclear graphite showed an increase with decreasing dose rate. The increase of the irradiation sensitivity appeared as an increase in the hardness from the micro-hardness test, and an increase in the peak intensity ratio (D/G) and in the ratio of the FWHM of the D and G peaks from the Raman spectroscopy, respectively.

REFERENCES

[1] Haag, G . , 1990. Development of Reactor Graphite. Journal of Nuclear Materials 71, 41 – 48.
[2] Mitchell, M., 2003. Graphite thermal conductivity and heat-removal paths for PBMR, Pro. Fourth. Int. Nuclear Graphite Specialist Meeting, Marugame, Japan, to appear.
[3] Cataldo, Franco., 2000. A Raman study on radiation-damaged graphite by γ-rays. Carbon 38, 623 – 641.
[4] Nightingale, R. E., 1962, Nuclear Graphite, Academic Press, New York, pp. 231 – 232.
[5] Chi, S. H., Kim, G. C. and Chang, J. H., 2003. Dose and Dose Rate Effects in Raman Spectrum of 2 MeV C^+ Ion-Irradiated IG -110 Graphite, Pro. Fourth. Int. Nuclear Graphite Specialist Meeting, Marugame, Japan, to appear.