RESULTS OF IRRADIATION CREEP TESTING GRAPHITE AT 900°C*

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The displacement damage of graphite under neutron irradiation causes graphite to change dimensions. The dimensional instability requires careful attention when graphite is used as the moderator and reflector structure in nuclear devices. The neutron flux and temperature gradients in the graphite blocks result in time-varying differential growth with resulting stresses similar to thermal stresses with an ever-increasing temperature gradient. Graphite fortunately has the ability to creep under irradiation, allowing the stress intensity to relax below critical levels for fracture. The creep strain also serves to average the radiation-induced strains, thus contributing to the dimensional stability of the core.

Several experimental programs have been undertaken to study radiation-induced creep, but always with the emphasis on creep strain and induced stresses.[1–3] Of secondary interest has been the study of the potentially, equally important dependence of other physical properties upon the creep deformation.[1] It is the purpose of this study to describe the results of the first of a series of creep experiments run in the Oak Ridge Research Reactor (ORR). The details of the elaborate irradiation experiment are described by Senn *et al.*[4] The graphite specimens were compression creep tested in two identical columns at 900°C under design stresses of 13.8 and 20.7 MPa. The grades tested were H-327, H-451, and AXF-5QBG. All of the specimens were stressed in the extrusion direction except for one radial specimen of both grades H-451 and H-327. The AXF-5QBG specimen has been previously compression creep tested by Gray[2] at 800°C, 10.4 MPa, to a fluence of 1×10^{18} (n/m^2). Dimensional changes, electrical resistivities, sonic velocities, and the coefficient of thermal expansion (CTE) to 800°C were measured on each stressed and control specimen in the experiment.

The dimensional measurements of the specimens clearly indicated ratchetting by the load cell readout during the experiment. It appears that each time the reactor shut down, the specimen column shrank, the loading system followed the shrinkage, and jammed solid. Upon startup, the column expanded against the jammed load system to fairly high stresses which then relaxed due to the irradiation creep. Thus, we have three sets of specimens, one set of controls under zero stress, one set of specimens under a constant 13.8 MPa and 20.7 MPa, and one set experiencing creep relaxation of thermal stresses. The latter is an exaggerated condition similar to actual service requirements. The specimens subjected to the ratchetting exhibited deformation several times greater than those under constant stress.

The creep coefficients calculated from the constant stress specimens are given in Fig. 1. These values include corrections for elastic modulus and CTE changes and assumes the primary creep equal to the initial elastic strain. These corrections are confirmed by the H-451 axial data with a wide spread in fluence levels to allow an extrapolation back to

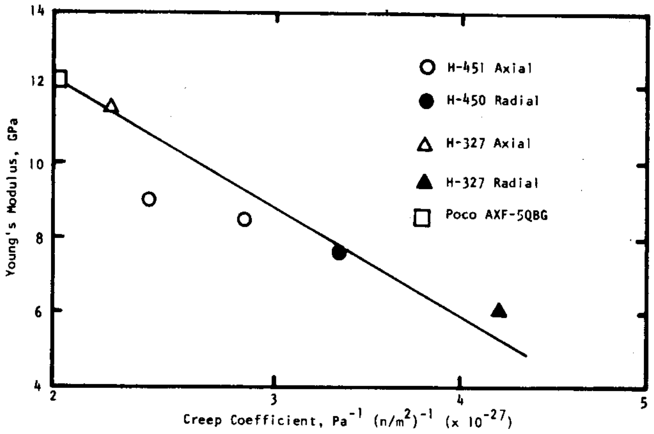

Fig. 1. The Creep Coefficient at 900°C under Compression.

the "O" intercept. These results, shown in Fig. 1, are obviously in good agreement with the creep coefficient decreasing linearly with increasing modulus of elasticity. The value of the creep coefficients is also in good agreement with values given by Veringa and Blackstone[3] considering the flux level effect. The uncertainty in the load cell output by irradiation damage precludes accurate calculations of the creep coefficient by the relaxation behavior. However, the total strain introduced into the specimens indicates a creep coefficient of a similar value to the constant stress specimens.

Diameter measurements of the stressed specimens indicate a significant reduction in volume by the compressive stresses. The ratio of the increase in diameter to the axial compressive strain varied from −0.1 to −0.2, significantly less than −0.5 required for no volume change. The decrease in volume was close to 2% for several of the higher strained specimens.

The effect of compressive creep deformation did increase the CTE in a manner similar to the results of Brocklehurst and Brown.[1] The increase in the CTE appears to be linear with the creep deformation as shown in Fig. 2. The values of A and B in the figure are the constants of the equation

$$\text{mean CTE} = A + BT \qquad (1)$$

The values of B are generally similar for all graphites relatively independent of grade, method of fabrication, and preferred orientation. As seen in Fig. 2, the value of B retains this independence of grade and orientation, but increases sharply with deformation. The value of A, of course, is a function of grade and preferred orientation. Therefore, the ratio A/A_0 is used for comparison rather than the actual value as for B. As seen in Fig. 2, the values of A do not increase with deformation as significantly as the value of B.

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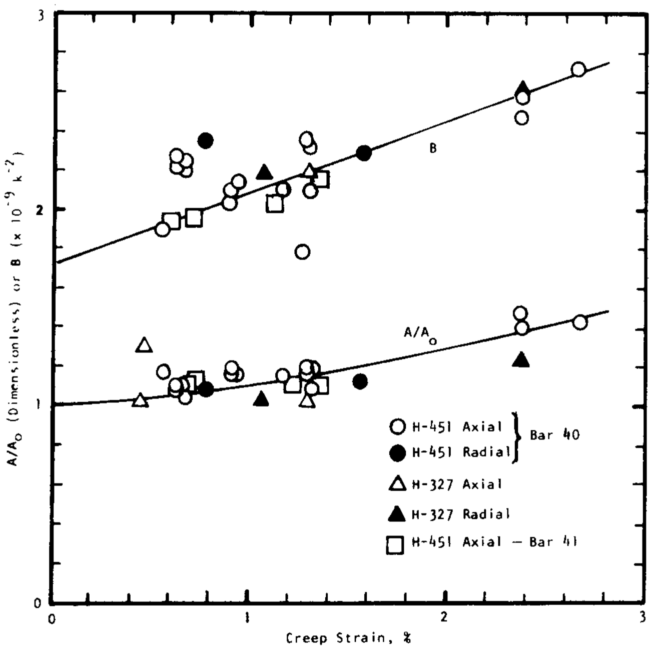

Fig. 2. Compressive Strain at 900°C Increases the Mean Coefficient of Thermal Expansion ($\bar{\alpha}$=A+BT).

The decrease in Young's modulus from the unstressed irradiated control samples by compressive deformation is given in Fig. 3. Apparently, like the CTE, the alteration is independent of the fluence and dependent only upon the total deformation. Poisson's ratio, while virtually unchanged by irradiation without stress, is dramatically reduced to essentially zero by the compressive deformation. This is shown in Fig. 4 for grade H-451.

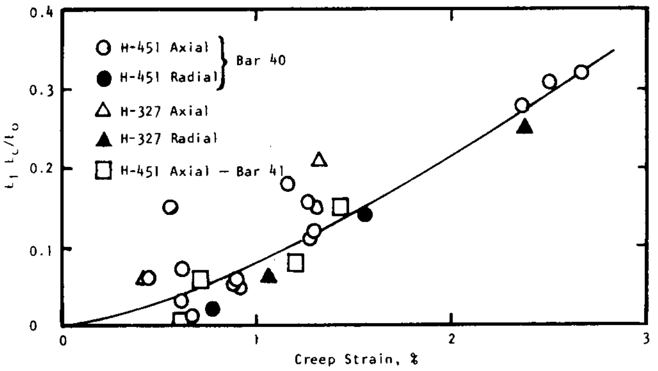

Fig. 3. The Reduction of Young's Modulus by Creep Strain.

The ability of the graphite to sustain compressive strains up to 2.5% have been demonstrated at 900°C. The mechanism of the deformation is at least uncertain; however, it is clear from the physical property measurements that the initial structure has been altered. The reduction in Young's modulus can result from two causes. The first is a flattening of the void volume to reduce the overall spring constants, and the second is a reorientation to increase the anisotropy of the graphite. Both of these events

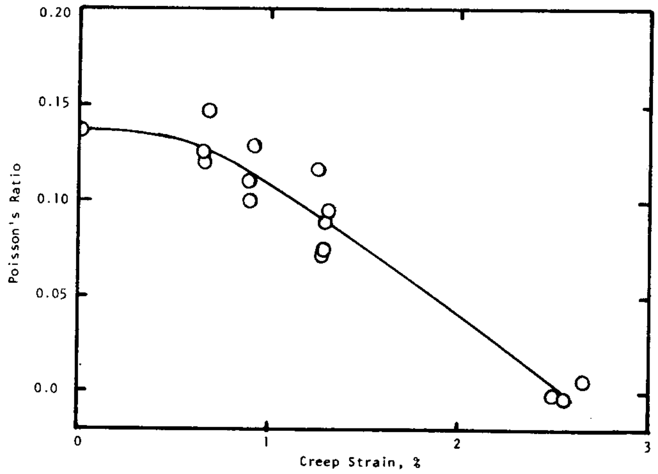

Fig. 4. The Reduction of Poisson's Ratio of Grade H-451 by Creep Strain.

will also increase the CTE as observed. However, the effect of deformation was to slightly and uniformly increase A with a significant increase in the value of B of Eq. (1). This implies that void flattening is the dominant feature in reducing the CTE. This does not infer a healing of the voids, but, to the contrary, the reduction in Poisson's ratio describes an actual decrease in the continuity of the structure. The major implications of these results are:

1. Compressive strains increase the CTE and tensile strains decrease the CTE. The actual magnitudes are larger than reported in the literature in that the creep deformation has a greater influence upon B than A in Eq. (1).

2. The effect of pore collapse and/or reorientation by compressive strains decreases the elastic moduli and very likely the tensile strength of the graphite. This will be of importance in withstanding the reverse thermal stresses during shut-down operations.

References

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(2) W. J. Gray, *Carbon* 11, 383 (1973).

(3) H. J. Veringa and R. Blackstone, *Carbon* 14, 279 (1976).

(4) R. L. Senn, J. A. Conlin, W. H. Cook, and W. P. Eatherly, this conference.