Review of Data on Irradiation Creep of Monolithic SiC - F. A. Garner, G. E. Youngblood and M. L. Hamilton (Pacific Northwest National Laboratory)

Summary

An effort is now underway to design an irradiation creep experiment involving SiC composites and SiC fibers. In order to successfully design such an experiment, it is necessary to review and assess the available data for monolithic SiC to establish the possible bounds of creep behavior for the composite. The data available show that monolithic SiC will indeed creep at a higher rate under irradiation compared to that of thermal creep, and surprisingly, it will do so in a temperature-dependent manner that is typical of metals.

Introduction

At the outset of the SiC development program it was not obvious that irradiation creep would indeed occur in such a non-metal. The published irradiation creep data on monolithic SiC were acquired by General Atomics as part of the High Temperature Gas Reactor Base Program. Although limited, the data are quite revealing.

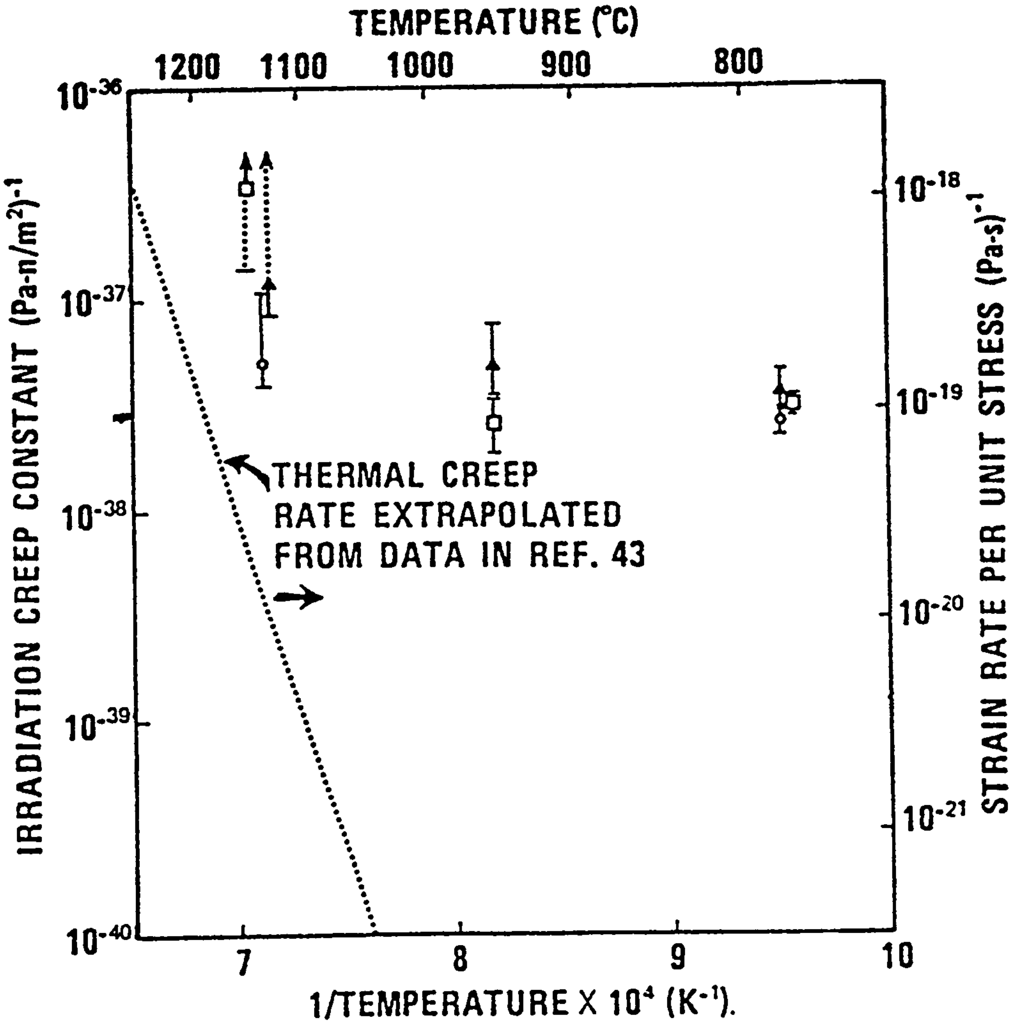
In the first set of experiments[(1)], oriented graphite substrates measuring about 6 x 1 x 1 mm were overcoated with pyrolytic SiC and then irradiated in the ETR reactor (ORNL) at 640 and 900°C to exposures of 3.2 and 3.8×10^{21} nvt (E>0.18 MeV) respectively. Irradiation-induced expansion of the graphite substrate put the SiC in tension. Very rough estimates of the steady state creep constant K were inferred from the resultant strain and the presence or absence of cracks. A linear creep equation, $\varepsilon = K\sigma\gamma$, was developed where ε is the strain, σ is the stress and γ is the neutron fluence.

For irradiation at 650°C a creep constant K on the order of 2×10^{-37} $(\text{Pa-n/m}^2)^{-1}$ was estimated. At 900°C an upper limit of 4×10^{-37} $(\text{Pa-n/m}^2)^{-1}$ was inferred. These values are two orders of magnitude lower than those found in pyrolytic carbons. Due to the nature of this test, these estimates must be considered to be very rough, however. It is quite possible that plastic strain may have occurred or that some chemical interaction may have occurred between the SiC and graphite.

While the first set of experiments provides at least an upper bound to the creep behavior, the second set of experiments appears to be much more useful. In an unpublished beta-SiC experiment by Price (that was reviewed briefly in ref. 2), strips of pyrolytic beta-SiC measuring about 6 x 1 x 0.1 mm were bent to about half their fracture strain in four-point straining fixtures and irradiated in the ETR reactor at 780, 950 and 1130°C. The specimens were in three starting conditions, having been vapor deposited at 1400, 1750 and 1800°C to produce grain sizes of 1, 5, and 10 microns, respectively.

The strips were removed from their fixtures after irradiation and their residual curvature was measured. Using a method developed to study thermal creep on the same type of specimens[(3)], it was possible to derive creep coefficients. The insensitivity of the fractional strain relaxation to the initial elastic strain confirmed that the creep rate was linearly proportional to stress.

The steady-state irradiation creep constant K, calculated from the strain relaxation assuming a linear creep law, is shown in Fig. 1 as a function of irradiation temperature. For some specimens irradiated at the highest temperature, relaxation was almost complete and only a lower limit for the creep constant could be



SYMBOL	DEPOSITION TEMP (K)	APPROX GRAIN SIZE (μm)
○	1673	1
▲	2023	5
□	2073	10

Fig. 1. Irradiation creep constant and strain rate for pyrolytic β-SiC strips restrained in bending as a function of irradiation temperature.(2)

established. The right scale in Fig. 1 shows the approximate creep rate per unit time, and the dashed line indicates the calculated thermal creep rate extrapolated from data in Ref. 2. The irradiation creep data are subject to substantial errors because of uncertainty and fluctuations in the temperatures of 100 to 150°C and the neglect of transient creep in the analysis.

Several conclusions can be drawn from these data, however.

1) The creep rate is enhanced by irradiation at all temperatures compared to that developed by thermal creep alone. The creep rates are significantly smaller than those measured in the first set of experiments, however.

2) Surprisingly, the creep behavior below ~1050°C is very nearly independent of temperature, as would be expected by analogy with the sink-dominated regime of metals. Above ~1050°C the creep behavior is directly analogous to that of thermal-dominated behavior in metals.

3) In the thermally dominated regime above ~1050°C there is a tendency of the creep rate to increase with initial grain size, especially as the irradiation temperature increases.

It is instructive to examine the creep rate in the temperature-insensitive regime and compare it to that of typical metals. This rate is roughly 3×10^{-38} $(Pa\text{-}n/m^2)^{-1}$. If we assume that roughly ~5 dpa were produced per 10^{26} n m^{-2} (E > 0.18 MeV), we obtain $K \sim 0.6 \times 10^{-6}$ MPa^{-1} dpa^{-1}, which is close to that of typical metals at ~1×10^{-6} MPa^{-1} dpa^{-1}. Since the details of the spectrum are not known and thus the true dpa conversion is also not known, this must be considered only a rough agreement. However, it does indicate that the creep behavior of SiC has many similarities to that of metals and alloys.

References

1. R. J. Price, in "HTGR Base Program Quarterly Progress Report for the Period Ending August 31, 1967," GA-8200, p. 91, General Atomic Division of General Dynamics (1967).

2. R. J. Price, Nuclear Technology 35 (1977) 320.

3. . D. Gulden and C. F. Driscoll, "Creep of Chemically Vapor-deposited β-SiC With an Analysis of Creep in Bending", GA-10366, General Atomic Company (1971).