

RELAXATION OF TENSILE STRESS IN A REACTOR GRAPHITE AT 2000° to 2700°C*

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ABSTRACT

Relaxation of tensile stress has been studied in longitudinal ("across-grain") specimens of molded H4LM graphite at initial stresses of 1000 to 3000 lb/in² and temperatures of 2000° to 2700°C. Tests were made by suspending cylindrical specimens from a strain-gage load cell, heating them in a static helium atmosphere by thermal radiation, extending them mechanically to develop the desired initial stresses, then holding them at constant temperatures and total extensions while the decay of stress with time was observed continuously.

Except at very short times (less than 5 minutes) and relatively long times (beyond a few hours or days), the variation of stress, σ , with time, t , was found to be well described by the equation

$$\sigma = \sigma_1 - \sigma_0 s \log_{10} t, \quad (1)$$

where σ_0 is initial stress, σ_1 is stress at $t = 1$ minute, and s is a constant. The principal data collected were values of s determined by least-squares fitting of lines to the essentially linear regions of experimental curves of σ/σ_0 vs $\log_{10} t$. From equation (1), s must vary as $1/\sigma_0$, so that a plot of s vs σ_0 should produce a hyperbola. Accordingly, for each experimental temperature, the curve of s vs σ_0 was smoothed by least-squares fitting to the data the equation

$$s^2 = b\sigma_0^2 + c\sigma_0. \quad (2)$$

Values of s taken from this family of hyperbolas were then plotted as $\log_{10} s$ vs $1/T$ (with temperature in degrees Kelvin) to produce an "Arrhenius plot" for each of a series of values of σ_0 . At each level of initial stress, these data were well represented by one line segment from 2000° to 2400°C and by a second line segment of distinctly lower slope from 2400° to 2700°C. This was taken to mean that, in each of these temperature regions, the steady-state relaxation rate represented by s was controlled by a single thermally activated process, but that the process was different above and below 2400°C. Therefore a group of lines was least-squares fitted to the $\log_{10} s$ vs $1/T$ data representing each initial stress level and each temperature interval. From the slopes of these lines and the Arrhenius relation, apparent activation energies for the steady-state relaxation processes were calculated. They were about 53 ± 6 kcal/mole for the range 2000° to 2400°C and about 10 ± 2 kcal/mole for the range 2400° to 2700°C, with a weak dependence of energy on initial stress in both ranges.

Analysis of equation (1) in terms of the Arrhenius relation reveals the existence of a second activation-energy term, which is "time-dependent" in the sense that its calculation is based on a ratio of times (t_2/t_1) rather than of rates (s_1/s_2). This has often been interpreted in terms of "a spectrum of relaxation times". In the present work,

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however, the interest was in stress itself, and so the alternative concept of "a stress-dependent activation energy" was accepted. The times, t , appearing in the calculation were related through equation (1) to rates and stresses. Then, for the same values of s and q_0 previously used to calculate the rate-dependent energy requirement, the time-dependent (or, as now expressed, "stress-dependent") part of the apparent activation energy was calculated. For each temperature and initial stress, this is linear with the fractional stress decrease, $(\sigma_1 - \sigma)/\sigma_0$, which has already occurred, increasing from zero when relaxation begins ($\sigma = \sigma_1$) to a maximum value reached at the hypothetical time when relaxation is complete ($\sigma = 0$). The maximum stress-dependent energy requirement was found to depend strongly on both temperature and initial stress, typical values being: at 2000°C, about 4300 kcal/mole when initial stress was 1000 lb/in², and about 2300 kcal/mole when it was 2000 lb/in²; at 2700°C, about 150 kcal/mole when initial stress was 1000 lb/in², and about 75 kcal/mole when it was 3000 lb/in². The rapid increase in activation energy which accompanies stress decay--especially at the lower temperatures and initial stresses--indicates the existence of a physical reason for stress to relax only to some limiting value of "persistent stress", after which the relaxation mechanism should become at least extremely slow. This concept was examined in a series of relatively long relaxation experiments, continued for as much as ten days at the lowest temperature and at least a few hours at the highest temperatures. Because of experimental difficulties, data collected from these tests are not of high quality. They indicate, however, that at the temperatures and times considered relaxation rate at least diminishes to a relatively low value after a few days or hours, leaving a "persistent stress" which ranges from about 1100 or 1200 lb/in² at 2000°C down to about 700 or 800 lb/in² at and above 2400°C. The apparent total activation energy (rate-dependent plus stress-dependent terms) at which relaxation appears to cease could not be calculated accurately, but diminished from approximately 1500 to 1600 kcal/mole at 2000° - 2100°C to about 35 kcal/mole at and above 2400°C. The latter value is consistent with certain reported values of the activation energy for creep of graphite, suggesting that in time relaxation processes give way to slower and somehow physically different creep processes. The significance of the very high energy values reached at temperatures below 2400°C is not clear.

A few relaxation tests on other reactor graphites indicated behavior qualitatively similar to that here reported, but with relaxation rates different from one graphite to another at the same temperature and initial load.