FATIGUE OF NEAR-ISOTROPIC GRAPHITE: INFLUENCE OF STRESS CYCLE

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Introduction

Graphite components in high temperature gas-cooled reactors (HTGRs) are subject to cyclic stresses from power cycling and possibly from seismic vibrations. Design of these components requires a knowledge of the fatigue behavior of the graphite under loading cycles which may differ in stress ratio, i.e., the ratio of the minimum stress during a cycle to the maximum stress during a cycle.

Fatigue data on extruded near-isotropic H-451 graphite (Great Lakes Carbon Company), which is a candidate for fuel and replaceable reflector blocks in large HTGRs, have been reported for a stress ratio of 0 (tension-zero stress cycle).[1] The present work consisted of uniaxial fatigue tests at ambient temperature on H-451 graphite and on a large diameter molded graphite, grade PGX (Union Carbide Corporation), under stress ratios ranging from -1 (tension-compression cycle) to +0.5 (tension-tension cycle). Grade PGX is used for core support blocks in HTGRs.

Experimental

H-451 specimens were taken in the axial orientation a quarter of the way along the parent log and between 25 and 100 mm from the edge. PGX specimens taken in both axial and radial orientations between 50 and 150 mm from the end of the log and one-third of the radius out from the log centerline. Specimens for a particular test series were spread uniformly over the sampling zone. The specimens were right cylinders 12.7 mm diameter by 25.4 mm long and were cemented between steel end-pieces using V-block jigs for alignment. The tests were run in air at ambient temperature in a modified Fatigue Dynamics fatigue machine equipped with a load cell and a special test cage in which two opposed loading rams move in coaxial linear bearings to ensure uniaxial loading in both tension and compression. Tests were run at 400 cycles/minute until the specimen fractured or 100,000 cycles were reached without fracture.

Results and Analysis

For each material and orientation, the first test series consisted of 30-35 control tensile tests on standard fatigue specimens to establish the mean tensile strength. Mean strengths were 18.9 MPa for H-451 (axial); 7.6 MPa for PGX (axial); and 9.5 MPa for PGX (radial). Fatigue tests were then run, using stress ratios of -1, -0.5, 0 and +0.5 for H-451 graphite and -1 and 0 for PGX graphite. During each series of tests, between 7 and 10 specimens were run at each of five maximum stress levels which ranged from 0.6 to 1.0 times the mean tensile strength. The stress levels were selected to avoid an excessive number of run-outs beyond 100,000 cycles.

Figure 1 is a typical S-N curve in which the logarithm of the maximum stress, S, is plotted against the logarithm of the number of cycles at failure, N. The stresses have been normalized by dividing the mean tensile strength. The tensile data and first-cycle failures are plotted at N = 0.25, and run-outs are shown as open circles at N = 100,000.

The S-N curves resemble those of metals, except that the scatter band is wider. The scatter makes unsuitable the methods of statistical analysis usually applied to fatigue measurements on metals, in which the fatigue lives for each stress setting are treated as a separate population with a log-normal or Weibull distribution. Instead the following statistical model was used:

$$\log(S) = \alpha + \beta \log (N) + \varepsilon$$

where α and β are constants and ε is a random variable distributed normally with a mean of zero. The data in the S-N curves were analyzed according to this model, counting the tensile test data but excluding run-outs. The least-squares straight line and the x/y lower tolerance limits (representing the limits above which at least x% of all observations will fall, with y% confidence) were calculated and are shown in Figure 1.

The downward slope of the S-N curves become steeper as the stress ratio decreased, i.e., as the stress became compressive during a part of the cycle. For axial specimens of H-451 graphite, the endurance limit for 50% survival to 100,000 cycles fell from 80% of the mean tensile strength at a stress ratio of 0.5 to 60% of the mean tensile strength at a stress ratio of -1. The corresponding 99/95 lower tolerance limits were 60% and 44% of the mean tensile strength. For engineering design it is convenient to plot the results on a constant life fatigue diagram (Goodman diagram), which relates the fatigue life to the following interdependent loading cycle parameters: maximum stress, minimum stress, stress amplitude, and mean stress. Figure 2 shows a Goodman diagram for axial specimens of H-451 graphite.

When normalized by dividing by the mean tensile strength, the endurance limits for PGX graphite were somewhat higher than for H-451 graphite under similar conditions. For a stress ratio of -1, the PGX endurance limit for 50% survival to 100,000 cycles was 66% of the mean tensile strength in the axial orientation and 74% in the radial orientation. Corresponding 99/95 lower tolerance limits were 52% and 56%.

Acknowledgements

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Reference

(1) R.E. Bullock, Extended Abstracts of the 12th Biennial Conference on Carbon, p. 141 (American Carbon Society, 1975).

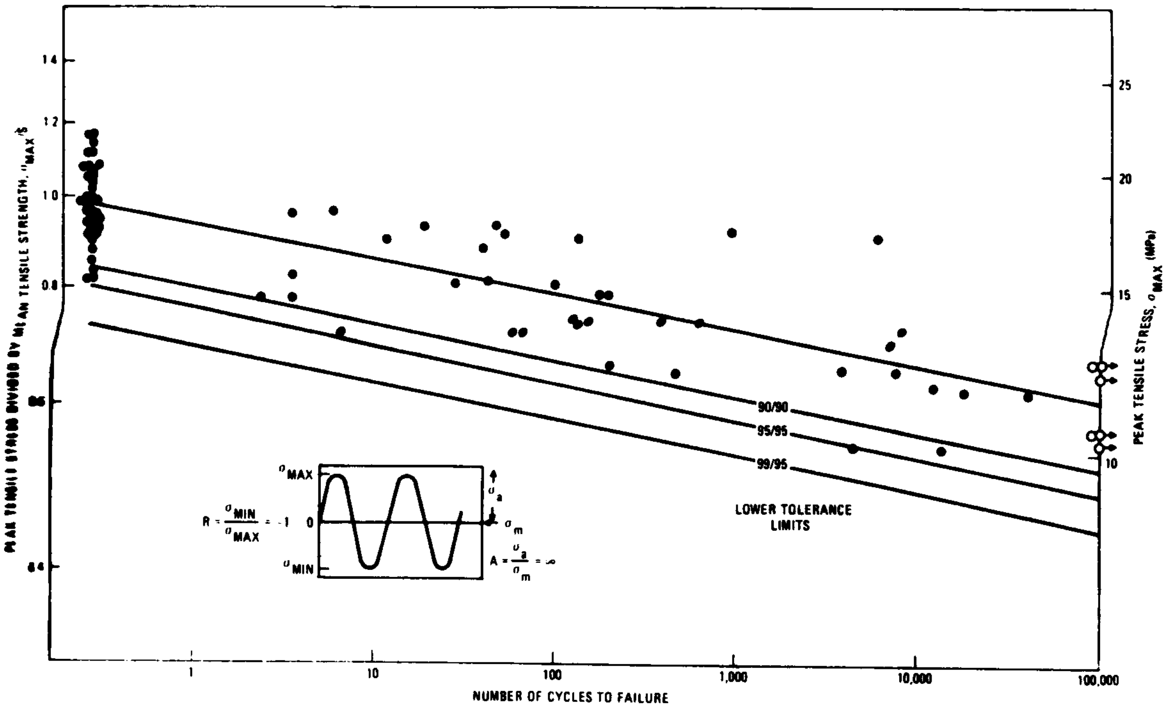

Figure 1. Log-log plot of normalized maximum stress versus number of cycles to failure. H-451 graphite, axial orientation, stress ratio, R, = -1. Lower x/y tolerance limits represent the limits above which at least x% of the points will fall, with y% confidence.

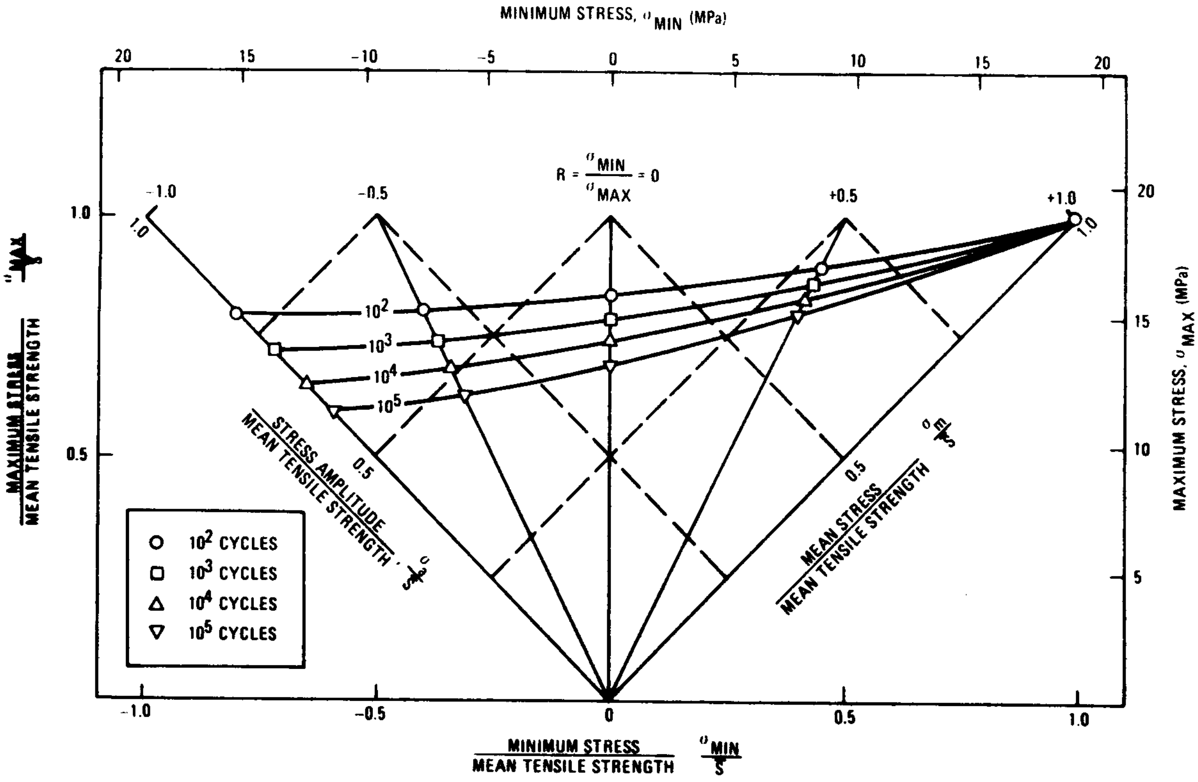

Figure 2. Constant life fatigue diagram (Goodman diagram) for H-451 graphite, axial orientation, tested in air at ambient temperature. Curves correspond to 50% survival probability.