

FATIGUE CRACK PROPAGATION IN NIOBIUM

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Fatigue cracks may start early in the life of cyclically loaded structural components and the useful life is determined by the rate at which these fatigue cracks propagate in the component. Fatigue crack propagation rate has been shown to be a function of the elastic stress intensity range and stress ratio, R , (ratio of the minimum stress to the maximum stress) for constant amplitude loading.

Tests must be performed to determine these fatigue crack propagation rates and associated material constants for each distinct material. Accordingly, a series of tests was conducted to measure fatigue crack growth rates in niobium. This material is one of the body-centered cubic refractory metals and its properties make it increasingly useful as a structural material in nuclear applications (because of its low thermal neutron cross-section and corrosion resistance) and energy conversion devices (see papers in Reference 1 for range of applications).

Axial load fatigue crack growth tests were conducted with pure niobium sheets. The data were analyzed using the elastic stress intensity method, and the material constants in the power law were determined.

MATERIALS AND METHODS

Fatigue crack growth tests were conducted on ten specimens of commercially pure niobium (in the as received condition) sheet specimens 2 inches (51 mm) wide, 8 inches (204 mm) long and with a nominal thickness of 0.050 inch (1.27 mm). Each specimen had a crack starter notch 0.10 in (2.54 mm) long by 0.01 in (0.25 mm) wide cut into the center. A reference grid with lines spaced 0.050 in (1.27 mm) apart was photographically printed on the surface of each specimen to measure crack growth. The longitudinal axis of the specimen was parallel to the rolling direction of the sheets.

The niobium was supplied by the Wah Chang Corporation and was from heat number 501020 CB with impurities as follows, in ppm: Al, 20; B, 1; C, 30; Ca, 10; Cd, 5; Co, 10; Cu, 40; Fe, 50; H, 5; Hf, 50; Mg, 20; Mn, 20; N, 31; Ni, 20; O, 50; Pb, 20; Si, 50; Sn, 10; Ta, 230; Ti, 40; V, 20; W, 20; and Zr, 100. The tensile properties of the material were determined in monotonic tensile tests of two ASTM sheet specimens with a 2-inch (51 mm) gage length at a cross head rate of 0.025 in/min. and average values are: tensile strength 50.4 ksi (348 mN/m²), yield strength (0.2% offset) 44.0 ksi (304 mN/m²), and percent elongation of 6 percent.

Axial load fatigue crack propagation tests were conducted at a stress ratio, R , of approximately zero and at stress levels from 15 ksi (103 mN/m²) to 25 ksi (174 mN/m²). The load was not changed as the test progressed. All tests were conducted using a Sontag Model SF-1-U constant-force testing machine with a 5:1 multiplying figure operating at 30 Hz. The specimens were lightly clamped between guide plates to prevent out-of-plane buckling. All tests were completed during the early summer in a laboratory without temperature or humidity control; temperature was approximately 79 F (26 C) and relative humidity 60 percent.

Fatigue crack growth data were obtained with a 10-power microscope and a stroboscopic light. The number of cycles necessary to propagate the fatigue cracks to each of the reference lines were recorded. Accurate crack length-versus-cycles curves were obtained from these data.

RESULTS AND DISCUSSION

Fatigue crack growth rates were shown to be related to the elastic stress intensity factor by Paris and his associates (2, 3) and are given by:

$$da/dN = C \Delta K^m \quad \text{Eq. 1}$$

where a is the half crack length, N is the

number of cycles, C and m are material constants and

$$\Delta K = K_{\max} - K_{\min} \quad \text{Eq. 2}$$

For the centrally cracked sheet specimens subjected to uniform axial load used in this investigation

$$K_{\max} = \alpha S_{\max} (\pi a)^{1/2} \quad \text{Eq. 3}$$

$$K_{\min} = \alpha S_{\min} (\pi a)^{1/2} \quad \text{Eq. 4}$$

where S_{\max} and S_{\min} are applied maximum and minimum stresses respectively.

The term α is a factor which corrects for the finite width of the specimen (proposed by Feddersen (4)) and is given by

$$\alpha = (\sec \pi a / w)^{1/2} \quad \text{Eq. 5}$$

where w is the width of the specimen.

Fatigue crack growth rates from this investigation are plotted against the elastic stress intensity range, ΔK , in Figure 1. All values as shown indicate a fatigue crack growth power relation. A least squares fit of the form of equation 1 to these data gives

$$da/dN = 7.248 \times 10^{-12} \Delta K^{4.486} \quad \text{Eq. 6}$$

over the range of the data shown. Equation 6 is shown as the solid line in Figure 1.

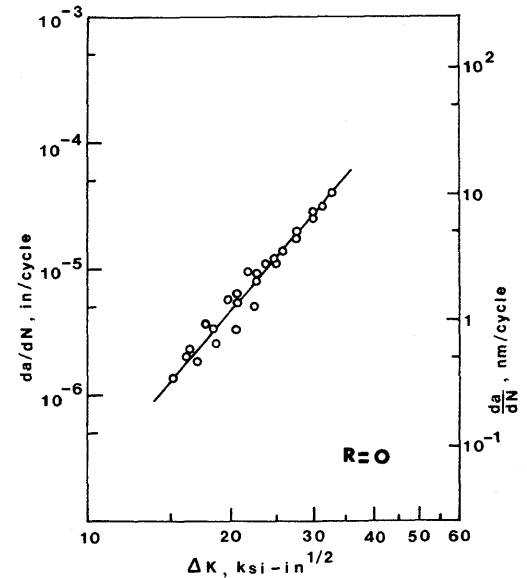


FIGURE 1. Relationship between fatigue growth rates and elastic stress intensity range.

CONCLUSIONS

Fatigue crack growth tests were conducted on 2 in (51 mm) wide, 0.050 inch thick (1.27 mm) specimens of pure niobium under axial loading. These tests were performed to determine the relation between fatigue crack growth rate and elastic stress intensity. The analysis of these tests supports the following conclusions: (a) For R approximately equal to zero, fatigue crack growth rates in pure niobium were nominally a single-valued function of the elastic stress intensity range; and, (b) the material constants in the Paris relationship were found to be C equal to 7.248×10^{-12} and m equal to 4.486.

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