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AXIAL AND TORSIONAL FATIGUE BEHAVIOR OF A COBALT-BASE ALLOY

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The wrought cobalt-base alloy, Haynes 188 is used in high temperature, high thermal stress aerospace components. Some applications include combustor liners for gas turbine engines and liquid oxygen carrying tubes within the Space Shuttle Main Engine. Typically, during the engine start up and shutdown transients, these components are subjected to multiaxial states of stress. Fatigue life estimation under multiaxial stress states is necessary for safe and reliable operation of these components. In order to develop elevated temperature multiaxial fatigue life prediction models, a multiaxial fatigue data base is required. To satisfy this need, an elevated temperature experimental program on Haynes 188 which consists of axial, torsional, inphase and out-of-phase axial-torsional fatigue experiments has been designed. As a part of this experimental program, elevated temperature axial and torsional fatigue experiments were conducted under strain-control on thin-wall tubular specimens of Haynes 188 in air.

The tensile ductility of Haynes 188 exhibits a minimum around 760 °C [1]. Since ductility governs low-cycle fatigue behavior, the axial and torsional fatigue experiments were conducted at 760 °C. The thin-wall tubular specimens were heated to the test temperature with induction heating. The thermal gradient in the gage section of the specimen was kept to within 1% of the test temperature. Axial and torsional strains were measured by a commercially available high temperature extensometer. A data acquisition and control program developed specifically for axial-torsional fatigue tests was used to conduct the axial and torsional tests on a servo-hydraulic testing machine [2]. Test data were acquired at logarithmic intervals by the computer. Failure of the specimen was defined as a 10% drop in the peak axial or torsional loads referenced to a previously recorded cycle.

The axial and torsional fatigue life data were used to determine the elastic, plastic and total life relationships for Haynes 188 at 760 °C. Cyclic axial and shear engineering stress-engineering strain curves were also determined from the data acquired by the computer. The fatigue lives obtained from the [illegible] torsional fatigue experiments were compared against the predictions of three multiaxial fatigue life parameters. The following parameters were evaluated for this material: 1) von Mises Equivalent Strainrange, 2) Multiaxiality factor of Manson-Halford [3], and 3) Modified Smith-Watson-Topper [4]. Constants for the three parameters were derived from the axial fatigue life data generated also with thin-wall tubular specimens. The Fatemi-Socie parameter [5] which represents both the axial and torsional fatigue data by a single life relation was also evaluated for its applicability to Haynes 188 at 760 °C. The predictive and correlative capabilities of all parameters are presented.

REFERENCES

[1] Nickel Base Alloys. International Nickel Company, Inc., New York, 1977.

[2] Kalluri, S. and Bonacuse, P. J., "A Data Acquisition and Control Program for Axial-Torsional Fatigue Testing," Applications of Automation Technology to Fatigue and Fracture Testing, ASTM STP 1092, A. A. Braun, N. E. Ashbaugh, and F. M. Smith, Eds., American Society for Testing and Materials, Philadelphia, 1990, pp. 269-287.

[3] Manson, S. S. and Halford, G. R., Discussion to the paper "Multiaxial Low Cycle Fatigue of Type 304 Stainless Steel" by J. J. Blass and S. Y. Zamrik., Journal of Engineering Materials and Technology, Vol. 99, No. 3, July 1977, pp. 283-285.

[4] Socie, D. F., "Multiaxial Fatigue Damage Models", Journal of Engineering Materials and Technology, Vol. 109, No. 4, 1987, pp. 293-298.

[5] Fatemi, A., and Socie, D. F., "A Critical Plane Approach to Multiaxial Fatigue Damage Including Out-of-Phase Loading", Fatigue and Fracture of Engineering Materials and Structures, Vol. 11, No. 3, 1988, pp. 149-165.

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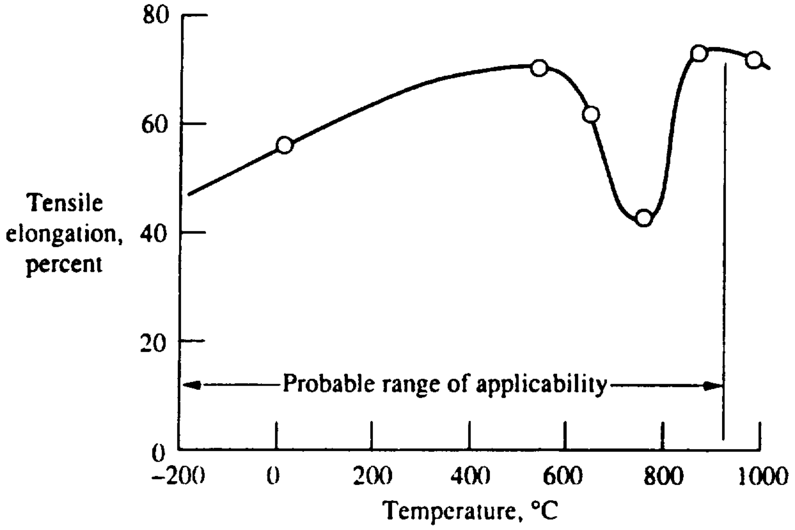
Tensile Elongation Versus Temperature

Haynes 188



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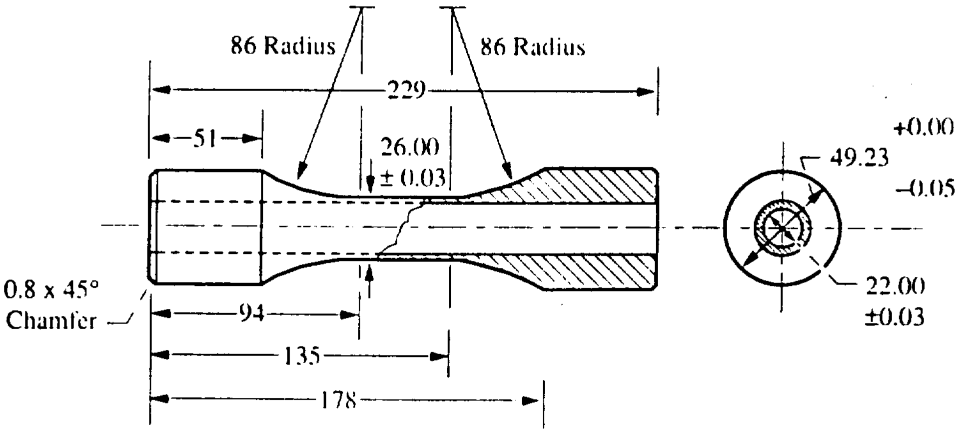
Axial-Torsional Fatigue Specimen



All dimensions in millimeters

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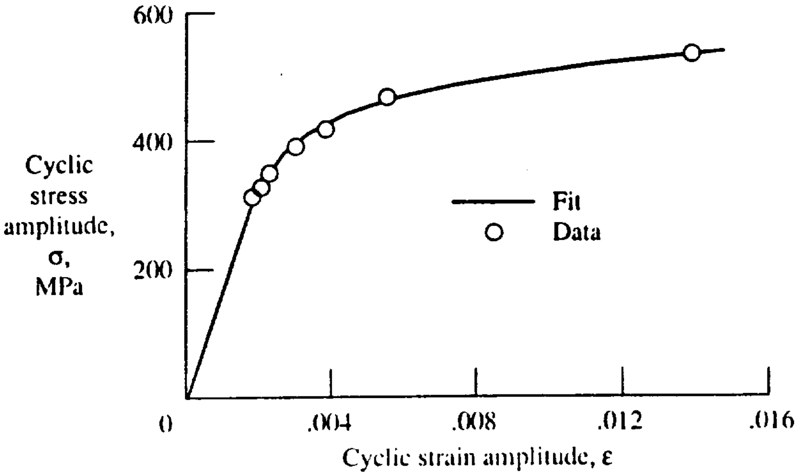
Cyclic Stress Amplitude Versus Cyclic Strain Amplitude for Haynes 188 at 760 °C



$$\varepsilon = \frac{\sigma}{170\ 200} + \left(\frac{\sigma}{860}\right)^{9.48};\ \sigma \text{ in MPa}$$

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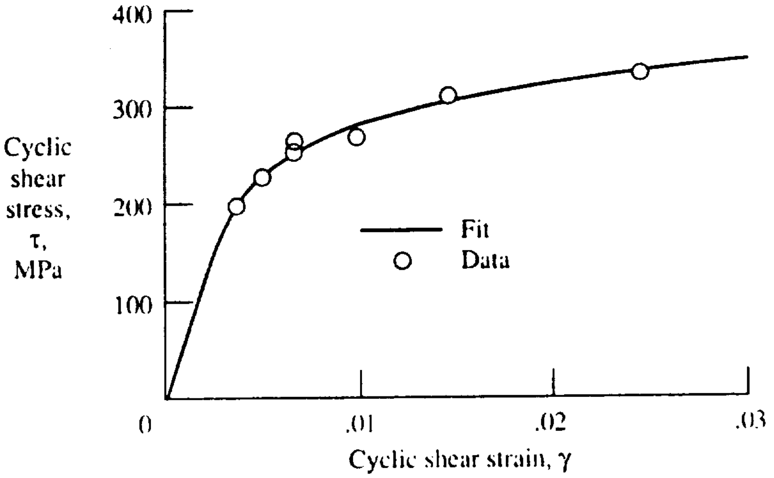
Cyclic Shear Stress Versus Cyclic Shear Strain for Haynes 188 at 760 °C



$$\gamma = \frac{\tau}{63\ 490} + \left(\frac{\tau}{591}\right)^{6.99};\ \tau \text{ in MPa}$$

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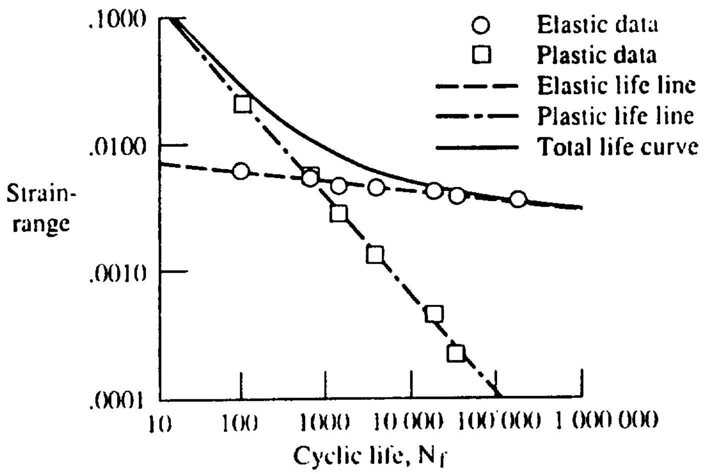
Axial Strainrange Versus Cycles to Failure for Axial Tests on Haynes 188 at 760 °C



$$\Delta\varepsilon = \underbrace{0.00863\,N_f^{-0.074}}_{\text{Elastic}} + \underbrace{0.689\,N_f^{-0.754}}_{\text{Plastic}}$$

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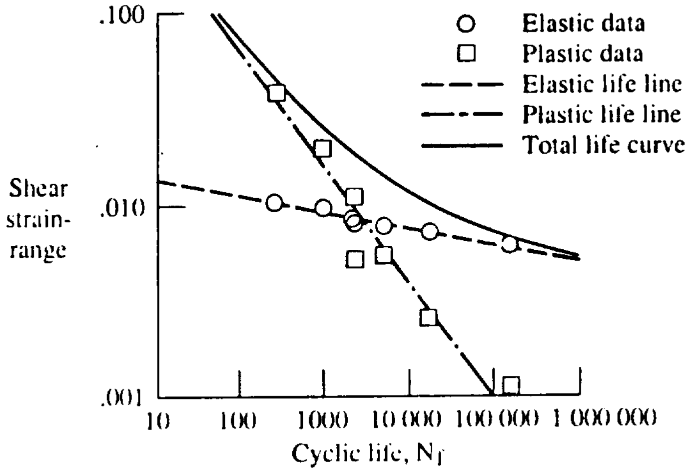
Shear Strainrange Versus Cycles to Failure for Haynes 188 at 760 °C



$$\Delta\gamma = \underbrace{0.0166\,N_f^{-0.086}}_{\text{Elastic}} + \underbrace{1.002\,N_f^{-0.601}}_{\text{Plastic}}$$

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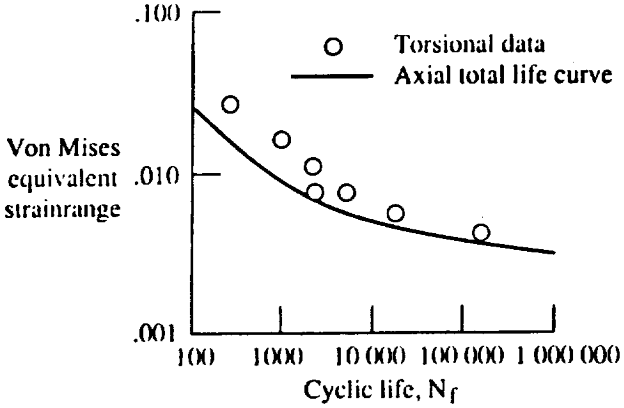
Von Mises Equivalent Strainrange Versus Cycles to Failure for Haynes 188 at 760 °C



$$\Delta\varepsilon_{eq} = 0.00863\, N_f^{-0.074} + 0.689\, N_f^{-0.754}$$

For torsion:

$$\Delta\varepsilon_{eq} = \left[\frac{3}{4}\,\frac{\Delta\gamma^2}{(1+\nu^*)^2}\right]^{1/2}$$

Where:

$\nu^* = 0.5$

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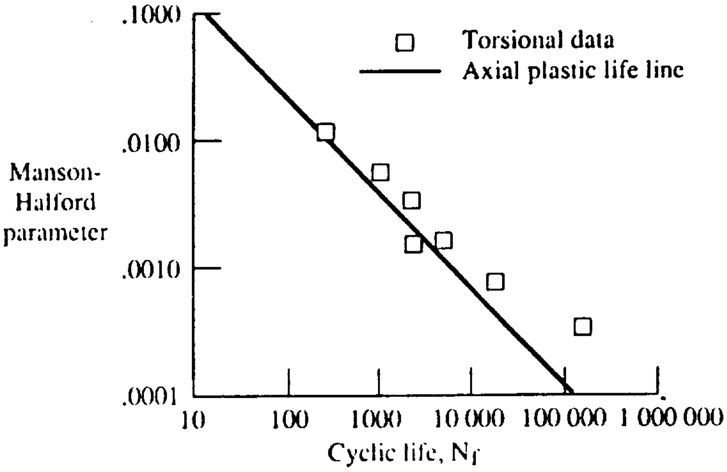
Manson-Halford Parameter Versus Cycles to Failure for Haynes 188 at 760 °C



$$MF\,(\Delta\varepsilon_{in})_{eq} = 0.689\, N_f^{-0.754}$$

For torsion:

$$MF = \frac{1}{2}$$

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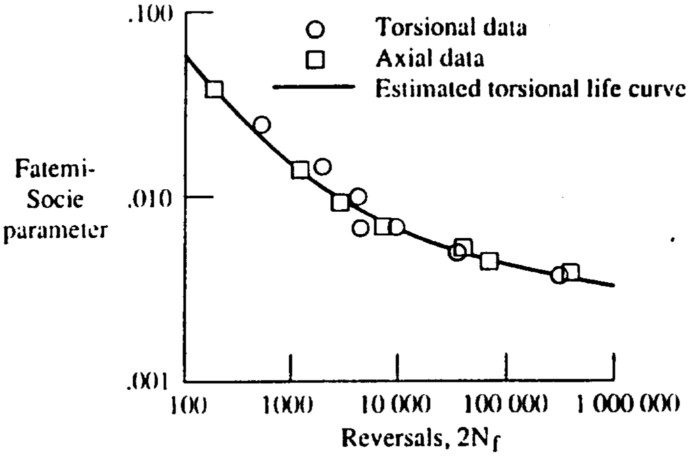
Fatemi-Socie Parameter Versus Reversals to Failure for Haynes 188 at 760 °C



$$\frac{\Delta\gamma_{max}}{2}\left(1 + 0.00335\,\sigma_n^{max}\right) = \left[0.006\,(2N_f)^{-0.074} + 0.872\,(2N_f)^{-0.754}\right]$$
$$\left[1 + 1.296\,(2N_f)^{-0.074}\right]$$

Value for k = 0.9

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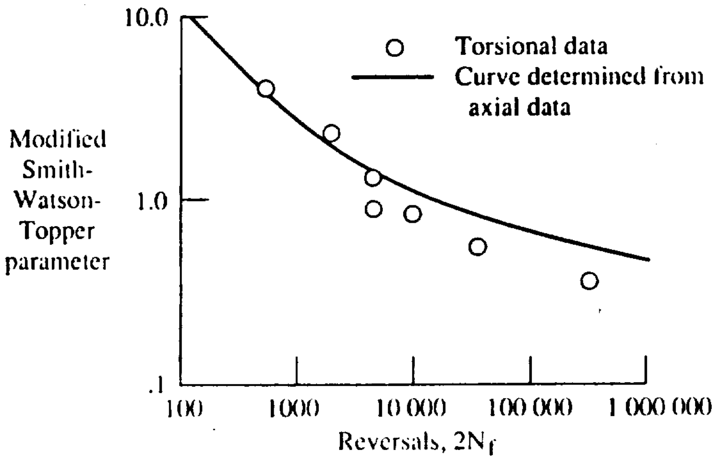
Modified Smith-Watson-Topper Parameter Versus Reversals to Failure for Haynes 188 at 760 °C



$$\sigma_1^{max}\,\frac{\Delta\varepsilon_1}{2} = 449\,(2N_f)^{-0.828} + 3.51\,(2N_f)^{-0.147}$$

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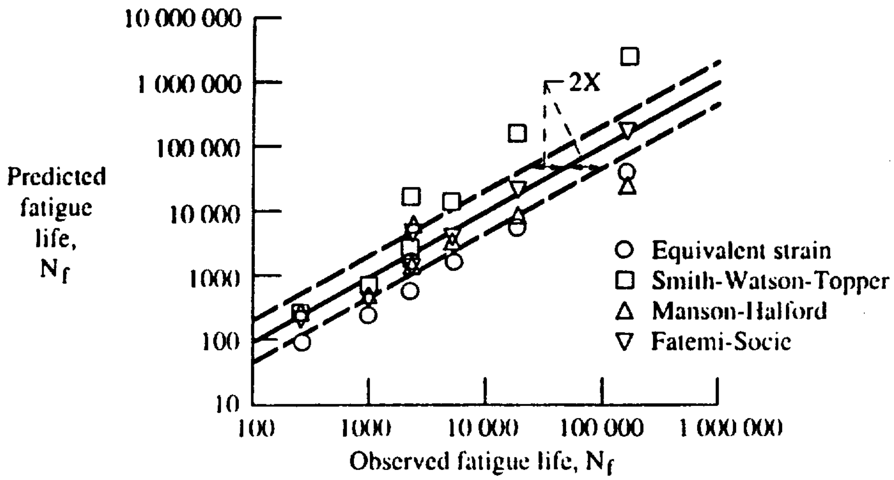
Comparison of Fatigue Life Models

Torsional Fatigue Data of Haynes 188 at 760 °C



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