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MATERIAL	PROPERTY
PURE TUNGSTEN	FATIGUE - CONSTANT STRAIN

Figure 1

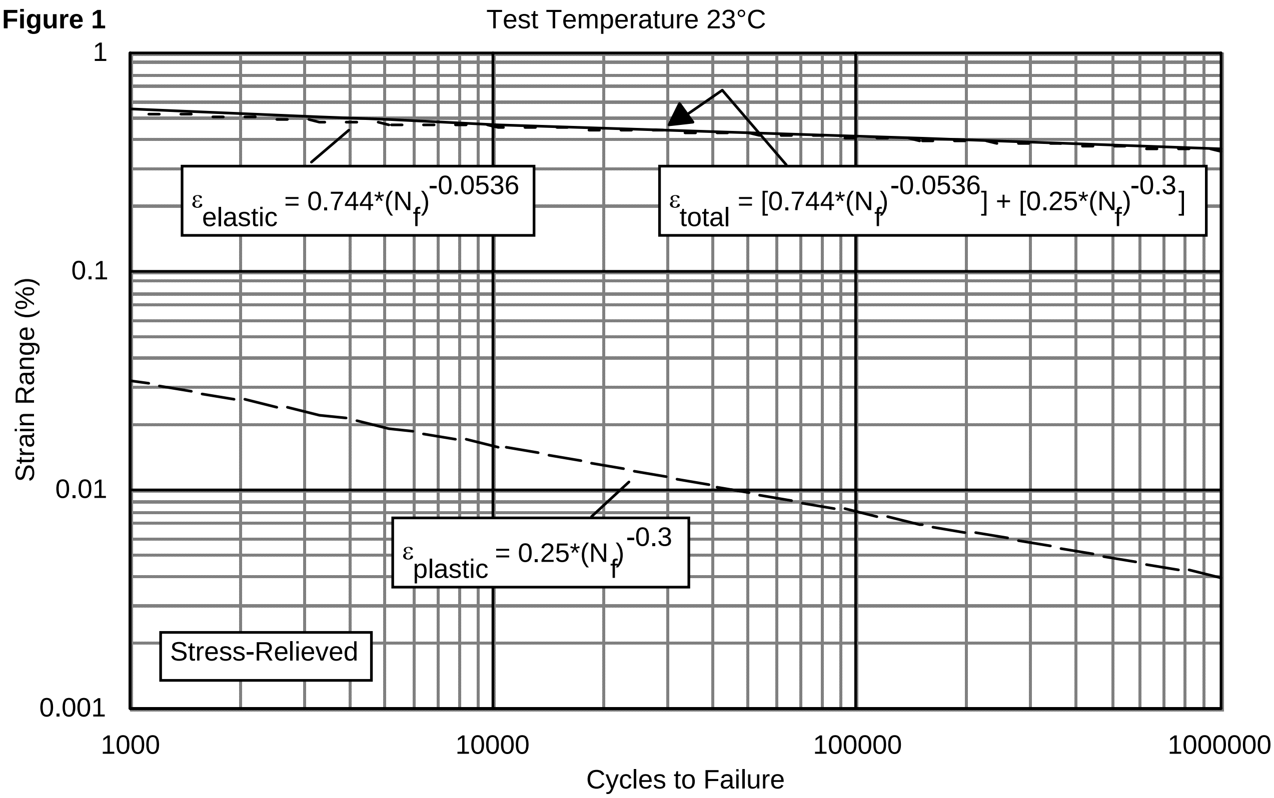
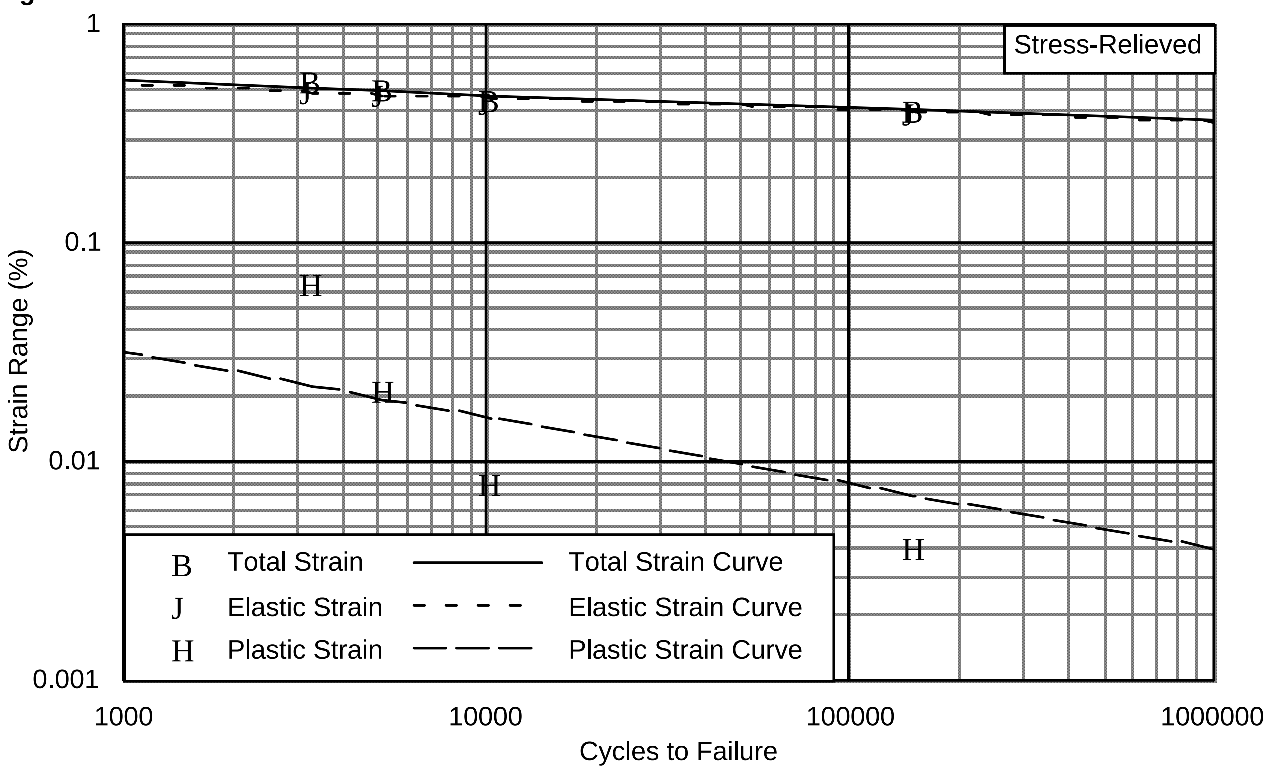


Figure 2



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PURE TUNGSTEN	FATIGUE - CONSTANT STRAIN

Table 1. Constant Strain, Low-Cycle Fatigue of Stress-Relieved Tungsten

Test Temp (°C)	Cycles to Failure (N_f)	Total Strain Range (%)	Elastic Strain Range (%)	Plastic Strain Range (%)
23	3343	0.550	0.484	0.066
"	5220	0.500	0.479	0.021
"	10337	0.450	0.442	0.008
"	150502	0.400	0.396	0.004

Authors: J. W. Davis

Comments:

Very little information is available on the fatigue strength of tungsten. Reference 1 contains limited information on both annealed and stress-relieved tungsten. This data was developed on a 14-mm-thick plate produced using the powder metallurgy process. The plate was in the cross-rolled condition, but no information was provided on the amount of cold work in the plate prior to annealing or stress-relieving. Tensile tests conducted on the plate revealed no evidence of anisotropy. Annealing was performed in a vacuum (1.33 x10^{-4} Pa [1 x 10^{-6} torr]) at 1482°C. Microstructural analysis and micro-hardness measurements after annealing indicated that the material was in the recrystallized condition.

Fatigue tests were conducted on rod specimens which had been polished to remove surface flaws prior to testing. Tests were conducted at room temperature (23°C). Strains were measured using a diametral extensometer, which was positioned at the minimum diameter of the gauge section of the specimen. The tests were fully reversed uniaxial using a servohydraulic fatigue frame. Fatigue tests were run in strain control with the frequency of the triangular wave adjusted to maintain a constant strain rate of $4 \times 10^{-3} sec^{-1}$. The test results are shown in Table 1. The results can be represented by a Manson Coffin relation in which the total strain is equal to the sum of the elastic and plastic fatigue strains. This relationship can be expressed as follows:

$$\varepsilon_{tot} = A\,N_f^a + B\,N_f^b$$

where $A\,N_f^a$ is the elastic strain, $B\,N_f^b$ is the plastic strain, N_f is the cycles to failure. The respective strains were fit to a least squares equation using the above relationships. The individual fits for the elastic and plastic strains are shown below with their respective correlation coefficients along with the total strain equation. A comparison of the data to the correlations is shown in Figure 2.

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Elastic Strain

$\varepsilon_{elastic} = 0.744*(N_f)^{-0.0536}$

$R^2 = 0.9553$

Plastic Strain

$\varepsilon_{plastic} = 0.25*(N_f)^{-0.3}$

$R^2 = 0.5232$

Total Strain

$\varepsilon_{total} = [0.744*(N_f)^{-0.0536}] + [0.25*(N_f)^{-0.3}]$

$R^2 = 0.841$

Reference

1. R. E. Schmunk and G. E. Korth, “Tensile and Low Cycle Fatigue Measurements on Cross-Rolled Tungsten”, Journal of Nuclear Materials, 103 & 104 (1981), pp. 943-948.

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Figure 1

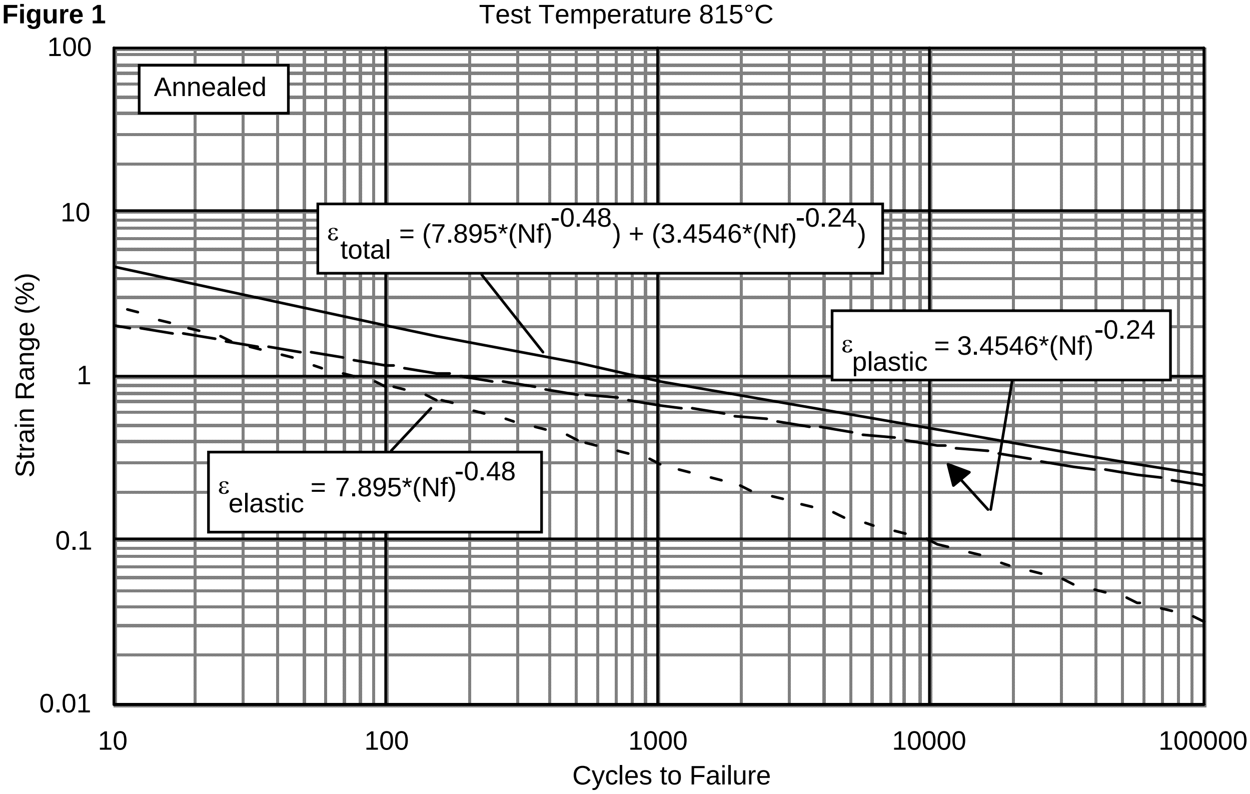

Figure 2

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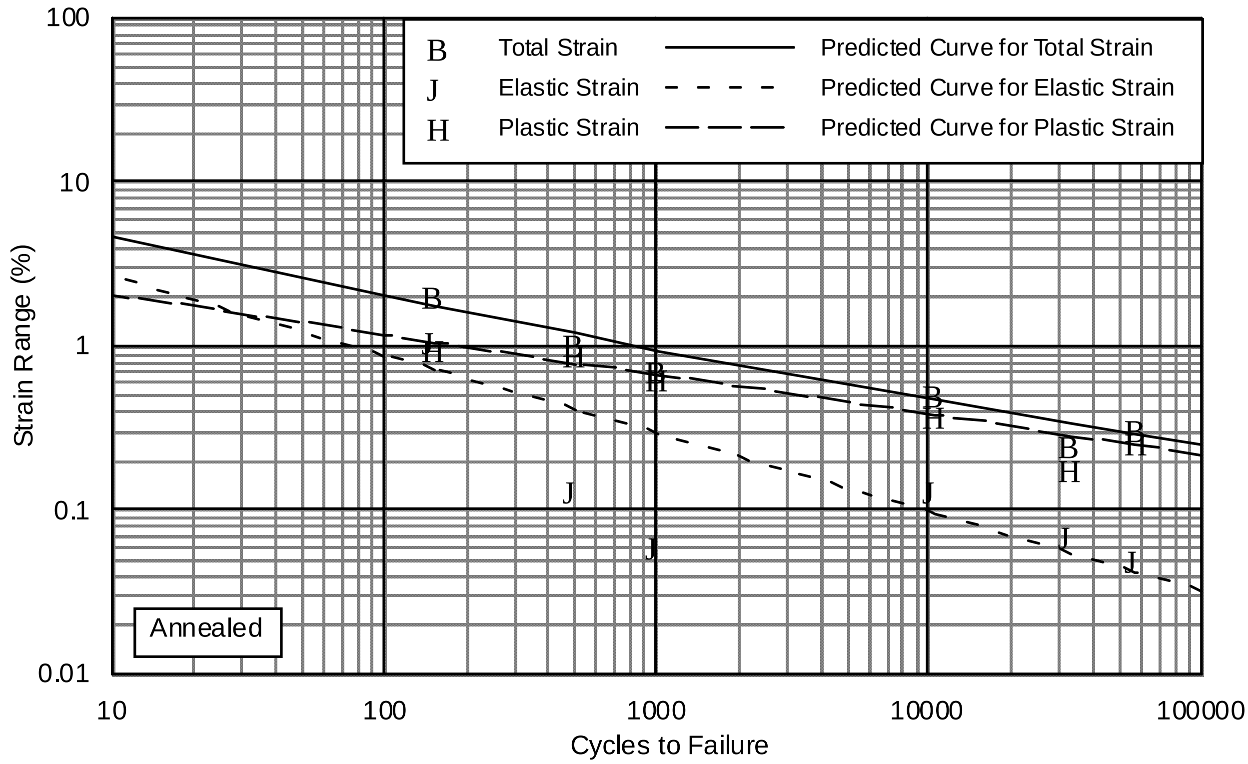
MATERIAL	PROPERTY
PURE TUNGSTEN	FATIGUE - CONSTANT STRAIN



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PURE TUNGSTEN	FATIGUE - CONSTANT STRAIN

Figure 3 Test Temperature 815°C and 1232°C

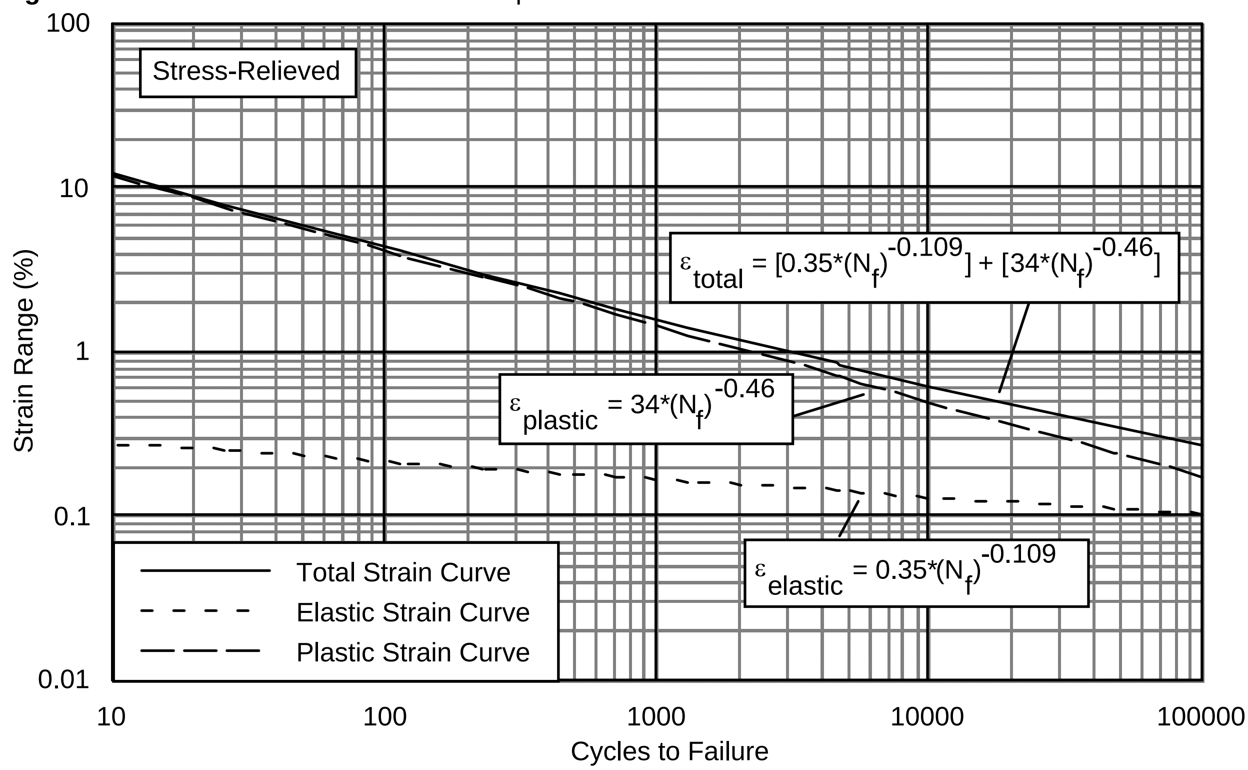
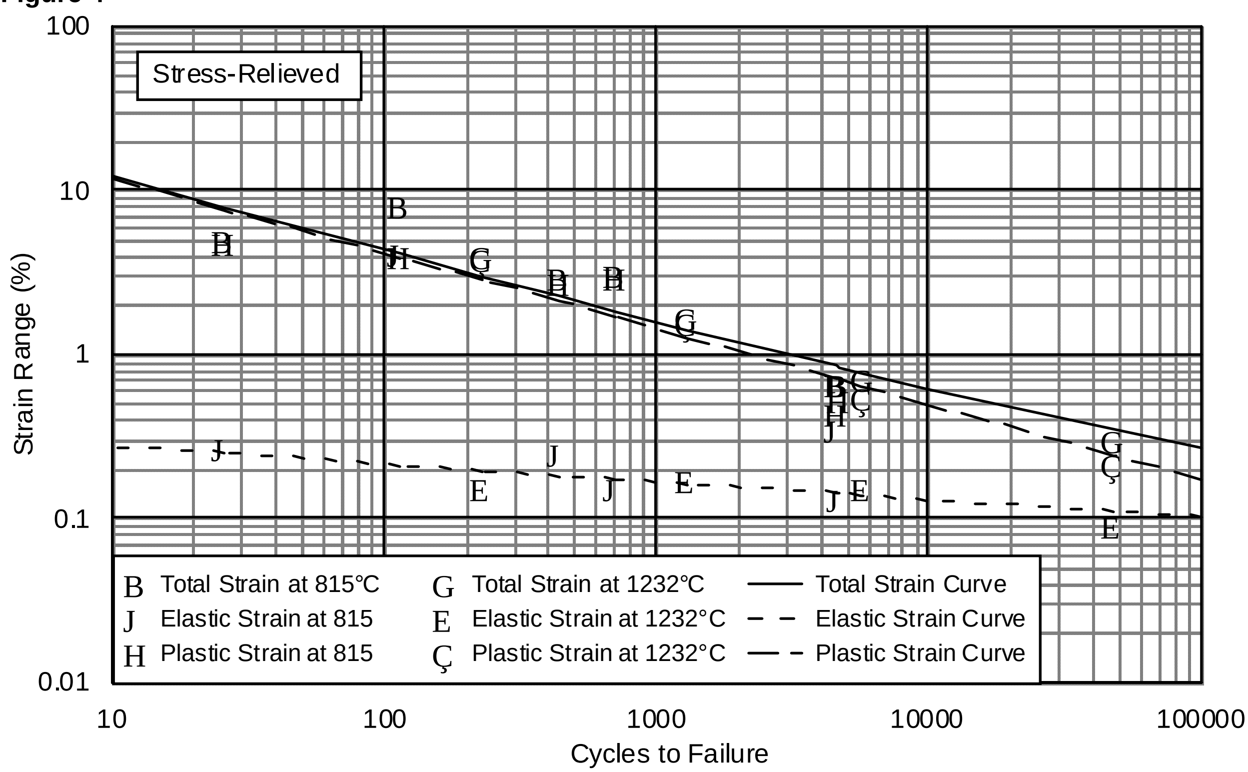


Figure 4



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PURE TUNGSTEN	FATIGUE - CONSTANT STRAIN

Table 1. Constant Strain, Low-Cycle Fatigue of Annealed Tungsten

Test Temp (°C)	Cycles to Failure (N_f)	Total Strain Range (%)	Elastic Strain Range (%)	Plastic Strain Range (%)
815	154	2.010	1.060	0.950
"	502	1.020	0.130	0.890
"	1021	0.700	0.060	0.640
"	10537	0.500	0.130	0.370
"	33139	0.250	0.070	0.180
"	58094	0.310	0.050	0.260

Table 2. Constant Strain, Low-Cycle Fatigue of Stress-Relieved Tungsten

Test Temp (°C)	Cycles to Failure (N_f)	Total Strain Range (%)	Elastic Strain Range (%)	Plastic Strain Range (%)
815	26	5.000	0.270	4.730
"	114	8.020	4.100	3.920
"	440	2.960	0.250	2.710
"	713	3.030	0.150	2.880
"	4609	0.650	0.350	0.430
"	4692	0.660	0.130	0.530
1232	231	4.02	0.15	3.87
"	1313	1.70	0.17	1.53
"	5695	0.70	0.15	0.55
"	48214	0.30	0.09	0.21

Author: J. W. Davis

Comments:

Very little information is available on the fatigue strength of tungsten. References 1 and 2 contain limited information on both annealed and stress-relieved tungsten. This data was developed on a 14-mm-thick plate produced using the powder metallurgy process. The plate was in the cross-rolled condition, but no information was provided on the amount of cold work in the plate prior to annealing or stress-relieving. Tensile tests conducted on the plate revealed no evidence of anisotropy. Annealing was performed in a vacuum (1.33 x10^{-4} Pa [1 x 10^{-6} torr]) at 1482°C. Microstructural analysis and micro-hardness measurements after annealing indicated that the material was in the recrystallized condition.

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Fatigue tests were conducted on rod specimens which had been polished to remove surface flaws prior to testing. Tests were conducted at 815°C on both annealed and stress-relieved tungsten and at 1232°C on stress-relieved tungsten only. Figure 2 shows the experimental results for the annealed tungsten along with the predictive curves. Figure 4 shows both the 815°C and 1232°C data points for stress-relieved tungsten. As can be seen from this figure, there appears to be very little temperature affect on the elevated temperature data; and, as a result, the two data sets were combined using the Manson-Coffin relationship. The elevated temperature tests were conducted in a vacuum chamber. Pressure was maintained at 1.33 x 10^{-4} Pa, prior to initiation of the tests. Examination of the specimens after testing revealed that there was no obvious evidence of scale formation and the specimens remained bright and shiny. Hence, it is believed that there was no oxidation or scale formation during the elevated temperature tests. Fracture surfaces of failed fatigue specimens were examined by scanning electron microscopy for both material conditions. Samples were taken from the extremes of the strain range. The stress-relieved material exhibited transgranular failure at both high and low strains, while the annealed material showed transgranular failure at low total strains and intergranular at high total strains. Analysis of the stress-strain hysteresis loops on stress-relieved tungsten revealed serrated yielding at 1232°C. Serrated yielding was also observed at 815°C, but considerably less than observed at 1232°C.

Annealed, constant strain at 815°C:

Elastic Strain

$\varepsilon_{elastic} = 7.895*(N_f)^{-0.48}$

R^2 = 0.7243

Plastic Strain

$\varepsilon_{plastic} = 3.4546*(N_f)^{-0.24}$

R^2 = 0.944

Total Strain

$e_{total} = (7.895*(N_f)^{-0.48}) + (3.4546*(N_f)^{-0.24})$

R^2 = 0.9337

Stress-relieved, constant strain at 815°C and 1232°C:

Elastic Strain

$e_{elastic} = 0.35*(N_f)^{-0.109}$

R^2 = 0.1376

Plastic Strain

$e_{plastic} = 34*(N_f)^{-0.46}$

R^2 = 0.7495

Total Strain

$e_{total} = [0.35*(N_f)^{-0.109}] + [34*(N_f)^{-0.46}]$

R^2 = 0.546

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Reference

1. R. E. Schmunk and G. E. Korth, “Tensile and Low Cycle Fatigue Measurements on Cross-Rolled Tungsten”, Journal of Nuclear Materials, 103 & 104 (1981), pp. 943-948.

2. R. E. Schmunk, G. E. Korth, and M. L. Ulrickson, "Tensile and Low-Cycle Fatigue Measurements on Cross-Rolled Tungsten at 1505 K," Journal of Nuclear Materials, 122 & 123 (1984), pp. 850-854.

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Figure 1

Test Temperature 23°C

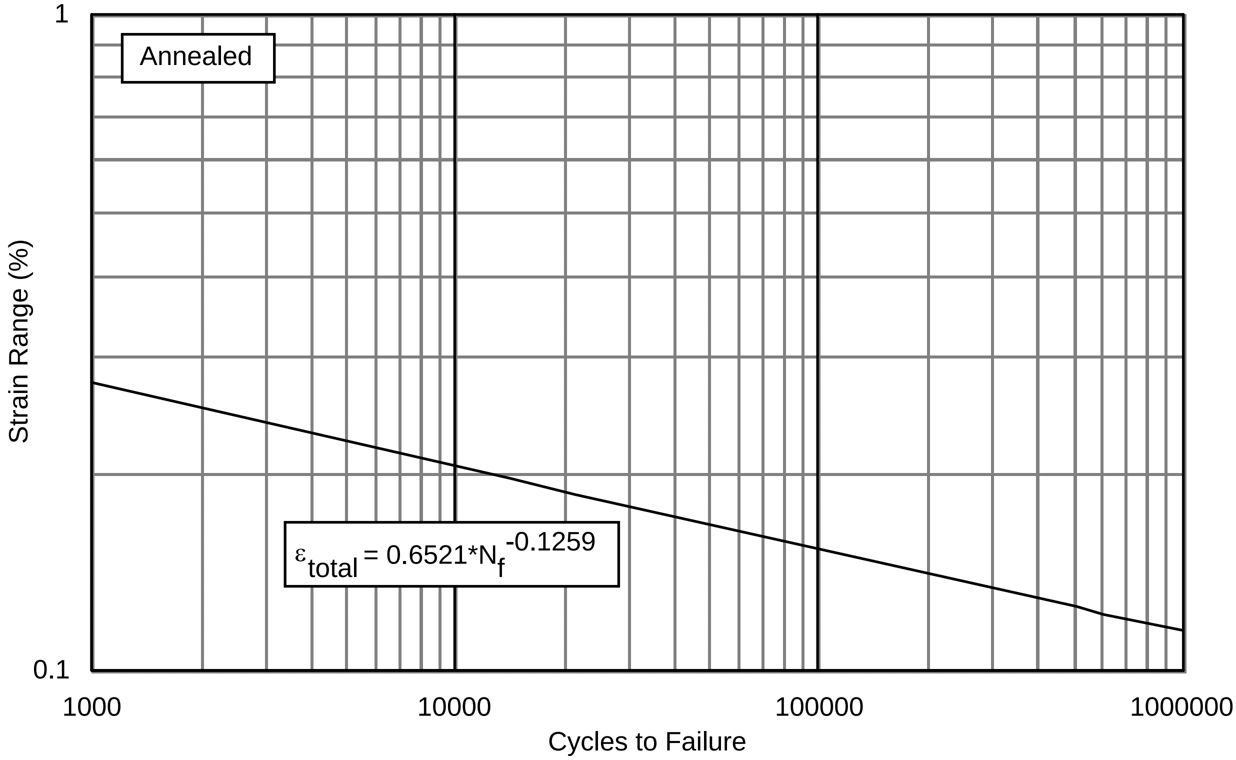
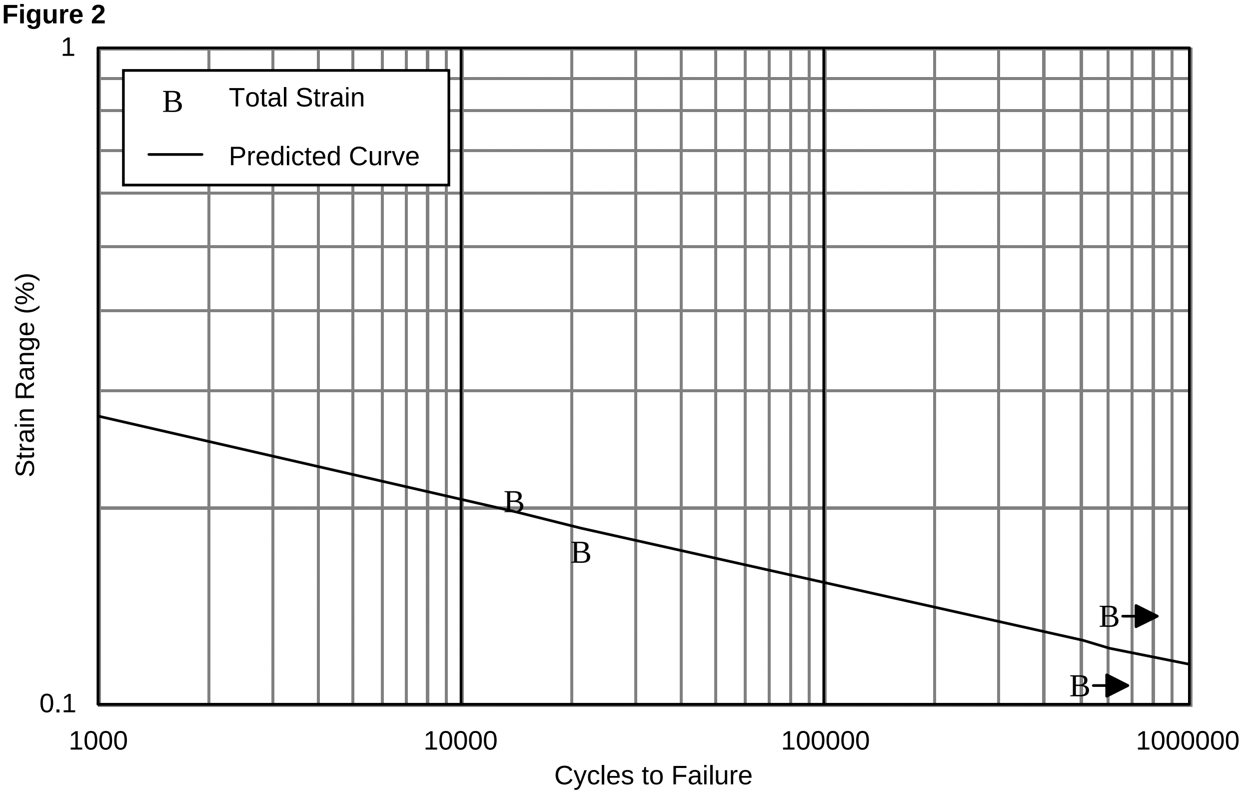


Figure 2



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PURE TUNGSTEN	FATIGUE - CONSTANT LOAD

Table 1. Constant Load, Low-Cycle Fatigue of Annealed Tungsten

Test Temp (°C)	Cycles to Failure (N_f)	Total Strain Range (%)
23	2196	0.118
"	14317	0.206
"	21535	0.172
"	512727*	0.108
"	611572*	0.137

* No failure, tests terminated

Author: J. W. Davis

Comments:

Very little information is available on the fatigue strength of tungsten. Reference 1 contains limited information on both annealed and stress-relieved tungsten. This data was developed on a 14-mm-thick plate produced using the powder metallurgy process. The plate was in the cross-rolled condition, but no information was provided on the amount of cold work in the plate prior to annealing or stress-relieving. Tensile tests conducted on the plate revealed no evidence of anisotropy. Annealing was performed in a vacuum (1.33 x10^{-4} Pa [1 x 10^{-6} torr]) at 1482°C. Microstructural analysis and micro-hardness measurements after annealing indicated that the material was in the recrystallized condition.

Fatigue tests were conducted on rod specimens which had been polished to remove surface flaws prior to testing. Tests were conducted at room temperature (23°C). These tests were done by controlling the load rather than strain because the loading was fully elastic and some anisotropy was noted at the very low strain ranges. Loading was a triangular wave at a frequency of 1 Hertz. The strain range values shown in Table 1 were calculated from the stress range values and Youngs Modulus (Ref. 1). Two of the tests (0.108 and 0.137 strain range) did not result in failure, and the tests were terminated at the specified number of cycles. There is considerable variability in the data since the 0.118 strain range test produced failure at 2,196 cycles, which is considerably below the number of cycles observed in the 0.108 and 0.137 strain tests. The calculated strain range values are plotted in Figure 2 along with the predictive equation which was determined using regression analysis techniques which produced the following equation.

$$\varepsilon_{total} = 0.6521 * N_f^{-0.1259}$$

R^2 = 0.8521

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where ε_{total} is the total strain range in per cent and N_f is the number of cycles.

Reference

1. R. E. Schmunk and G. E. Korth, “Tensile and Low Cycle Fatigue Measurements on Cross-Rolled Tungsten”, Journal of Nuclear Materials, 103 & 104 (1981), pp. 943-948.