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Orr-Sherby-Dorn Creep Strengths of the Refractory-Metal Alloys C-103, ASTAR-811C, W-5Re, and W-25Re

Robert E. English
Lewis Research Center
Cleveland, Ohio

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ORR-SHERBY-DORN CREEP STRENGTHS OF THE REFRACTORY-METAL ALLOYS C-103, ASTAR-811C, W-5Re, AND W-25Re

Robert E. English
National Aeronautics and Space Administration
Lewis Research Center
21000 Brookpark Road, MS AAC-2
Cleveland, OH 44135
(216) 977-7078

Abstract

Available creep data for the refractory-metal alloys C-103 (Nb-10%Hf-1%Ti-0.7%Zr), ASTAR-811C (Ta-8%W-1%Re-0.7%Hf-0.025%C), W-5Re (W-5%Re), and W-25Re (W-25%Re) were correlated by the Orr-Sherby-Dorn method and extrapolated to 1 percent creep over 10 years. In addition, useful life was specified to be two standard estimates of error below the mean surface through the data. Over the temperature range of 1200 to 1800 K, ASTAR-811C was found to be the strongest of these alloys. In particular, ASTAR-811C was found to have at 1800 K the same creep strength as W-25Re at 1420 K. The difference between these results and those of Horak and Booker (1990) likely devolves from the comparative lack of long-time data on the tungsten alloys.

INTRODUCTION

The long powerplant lives (at least 7 years) necessary to enable use of nuclear space power systems pose special problems for technologists. Inasmuch as nearly all tests of materials are for time periods substantially less than the powerplant endurance actually sought, extrapolation from these shorter tests is naturally required. Herein the test data are treated in the following ways: The criterion for evaluation is 1-percent creep, not rupture, and the service life sought is 10 years (87 660 hr). The test data are correlated by the Orr-Sherby-Dorn (OSD) method. The standard estimate of error (SEE) of the test data from the correlating surface is computed, and the logarithm of the useful life is specified to be two SEEs below the correlating surface. On this basis, the following alloys are compared: C-103 (Nb-10%Hf-1%Ti-0.7%Zr), ASTAR-811C (Ta-8%W-1%Re-0.7%Hf-0.025%C), W-5Re (W-5%Re), and W-25Re (W-25%Re).

DATA ANALYSIS

For the Orr-Sherby-Dorn correlation,

$$t_{1\%} = a\, s^{-m} \exp\left(\frac{q}{T}\right) \tag{1}$$

where $t_{1\%}$ = hours to 1 percent creep, s = stress (MPa), T = temperature (K), and a, m, and q are constants selected to fit the data. Because of the limited data for the tungsten alloys, linear creep was assumed, when necessary, in estimating their times to 1 percent creep. Linear regression was applied to the logarithm (to the base 10) of Equation (1), that is,

$$\log(t_{1\%}) = b - m \log(s) + \frac{Q}{T} \tag{2}$$

where $b = \log(a)$ and $Q = q \log(e)$.

Analysis of C-103

The 35 creep tests of C-103 (Titran and Klopp 1980) totaled 118 806 hr and spanned the temperature range of 1100 to 1477 K. One data point was ignored inasmuch as that test did not continue to 1 percent strain. For the OSD correlation, the correlation coefficient r^2 was 0.92.

Analysis of ASTAR-811C

Although the 98 long-term creep tests of ASTAR-811C (Klopp et al. 1980) continued for a total of 314 140 hr (35.8 years), 41 data were set aside in this analysis for the following reasons: For 29 tests, the time to 1 percent creep was not measured. Annealing at temperatures as low as 1811 K was found to be detrimental to creep strength. And the OSD correlation was improved by ignoring imposed stresses over 190 MPa. The remaining 57 data points spanned a total of 123 916 measured hours to 1 percent creep, total test duration of 153 485 hr, and test temperatures of 1366 to 1811 K. For the OSD correlation, the correlation coefficient r^2 was 0.76.

Analysis of W-5Re

A severely limited source of creep data on W-5Re was found in Table 13 in Horak and Booker (1990). The 28 test durations totaled only 96 hr, and the longest was 89 hr. The test temperatures spanned 1673 to 2473 K. For the OSD correlation, the correlation coefficient r^2 was 0.84.

Analysis of W-25Re

The data sources on W-25Re were Conway and Flagella (1971, pp. 396 and 402) and Sheffler and Ebert (1973, Table II-3). The 67 tests spanned the wide temperature range of 1144 to 3073 K. Although the tests were continued to rupture, the test times totaled only 6447 hr, averaging less than 100 hr apiece; one other test continued to 2686 hr without rupture. For the OSD correlation, the correlation coefficient r^2 was 0.96.

Results

For these four alloys, the parameters for substitution into Equation (2) are listed in Table 1. The SEE for $\log(t_{1\%})$ is also listed.

TABLE 1. Statistical Results for Orr-Sherby-Dorn Creep Correlation of Four Refractory-Metal Alloys.[a]

Alloy	b	m	Q	S.E.E.[b]
C-103	-5.944	3.077	17 855	0.129
ASTAR-811C	-4.989	3.567	23 497	.290
W-5Re	-4.405	4.109	23 017	.407
W-25Re	-2.963	2.726	14 939	.339

[a]Refer to Equation (2).
[b]Standard estimate of error for $\log(t_{1\%})$.

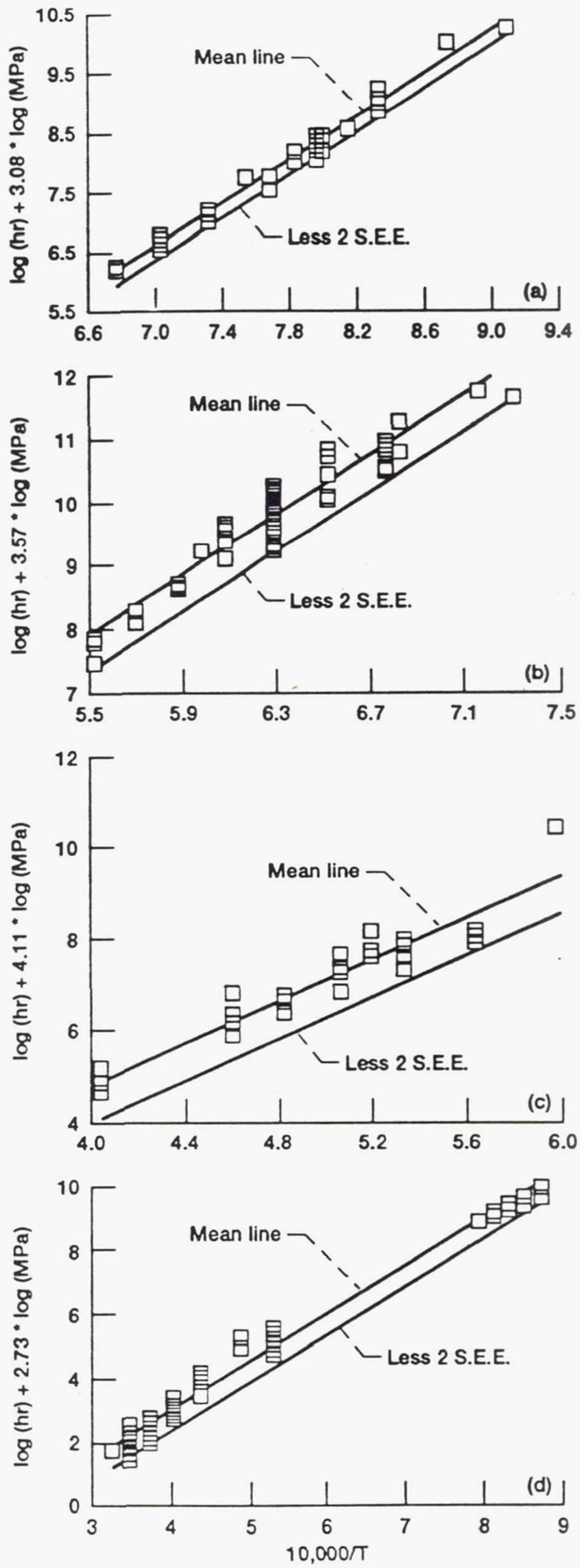

Figure 1.—OSD correlations of 1% creep of 4 refractory-metal alloys. (a) C-103, (b) ASTAR-811C, (c) W-5Re, (d) W-25Re.

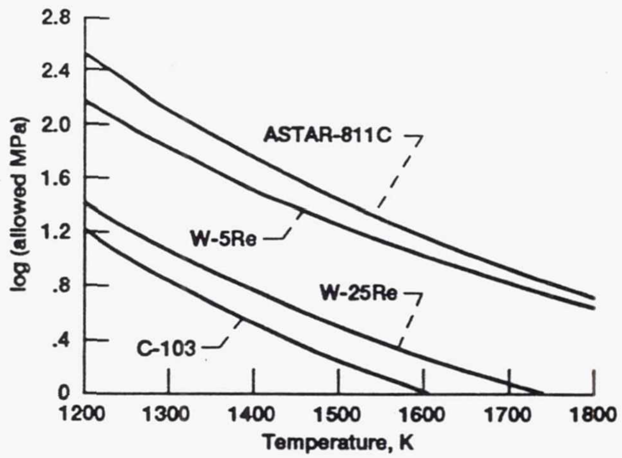

Figure 2.—Comparative creep strengths for 1% creep in 10 years with 2 S.E.E.

Figure 1 shows for each alloy the measured data, the mean line through these data, and the line for which $\log(t_{1\%})$ has been reduced by two SEEs. Just as anticipated, the two-SEE allowance pretty well delineates the lower bound of the test data, for, statistically, approximately 98 percent of the data should have strengths above this line.

DISCUSSION OF RESULTS

The results of this OSD analysis were employed in order to determine the stresses producing 1 percent creep over 10 years for each of these alloys, the allowable stresses being shown in Figure 2 and in Table 2. In each determination of allowable stress, the $\log(t_{1\%})$ (in Equation (2)) was decreased by two SEEs from the mean surface through the data. These four alloys have very similar trends of strength versus use temperature, and their comparative strengths are about constant over the temperature range of 1200 to 1800 K. C-103 exhibits the low strengths characteristic of Nb alloys; even at 1200 K, its allowable stress producing 1 percent creep in 10 years is only 16 MPa.

ASTAR-811C has superior creep strength over this entire range, but W-25Re has creep strength only slightly better than C-103. For example, the long-time creep strength of ASTAR-811C at 1800 K (5.2 MPa) is equal to that for W-25Re at 1420 K, a 380-K advantage. In addition, the derivative alloys ASTAR-1211C (Ta-12%W-1%Re-0.7%Hf-0.025%C) and -1511C (Ta-15%W-1%Re-0.7%Hf-0.025%C) offer the possibility of a further 200-K increase in operating temperature over ASTAR-811C at the same strength (Buckman and Ammon 1990). W-5Re, less highly alloyed than W-25Re, appears to have superior strength and rivals

TABLE 2. Allowable Stresses (MPa) to Produce 1 Percent Creep over 10 Years

Temperature, K	1200	1300	1400	1500	1600	1700	1800
C-103	16	7.0	3.3	1.8	1.0	0.62	0.40
ASTAR-811C	(a)	130	57	28	15	8.5	5.2
W-5Re	156	68	34	18	11	6.6	4.4
W-25Re	26	12	5.8	3.2	1.9	1.2	.79

[a]Outside the range of the correlation.

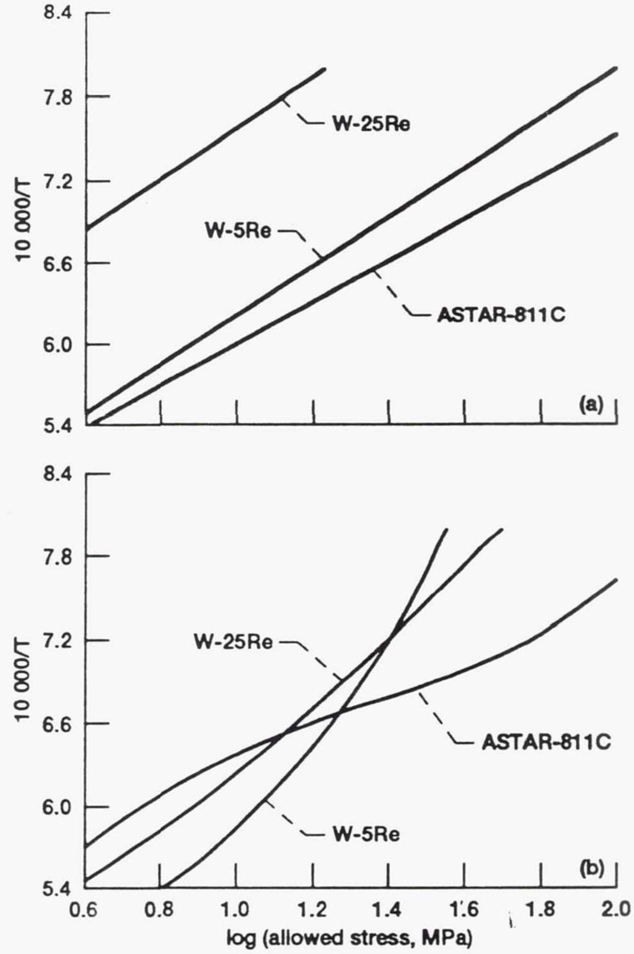

Figure 3.—1% creep of 3 alloys over 10 years. (a) Orr-Sherby-Dorn and 2 S.E.E. (b) Horak's data and method; 2 S.E.E.

ASTAR-811C in this OSD correlation. I infer that the creep of either of these tungsten alloys over 10 years is very uncertain because of the gross extrapolation required from its very limited, short-time creep tests, especially so for W-5Re. The range of creep strengths found for the W-Re family is, I judge, representative of this family for Re contents ranging from 5 to 25 percent. With present knowledge, the ASTAR family thus appears to be more promising than the W-Re family as a focus for a program on materials technology to evolve adequate creep strength at high temperature.

For the three alloys ASTAR-811C, W-5Re, and W-25Re, Figure 3 contrasts these OSD results with those of Horak and Booker. Rather than using the straight lines in Figure 3(a), Horak and Booker elected to use polynomials for their correlations, their data correlations being the basis for Figure 3(b). From their analysis for a 7-years service period and with no allowance for scatter in the test data, they conclude (p. 39) that "ASTAR-811C has the highest long-term creep strength of the six materials (they) evaluated over the temperature range 1300 to 1650 K." In contrast with this result, Figure 3(b) (for a 10-years service period and with two-SEE allowance for scatter of the test data) shows ASTAR-811C and W-25Re to have equal allowable stresses at about 1500 K. Overwhelming the modest differences between results from OSD and from Horak-Booker are the scanty data base for the W-Re family and the gross extrapolation to 10-year duration that that limited data base requires.

Admittedly, the specification of 1 percent creep over 10 years as the criterion for selection of materials and operating temperatures is conservative, these materials deforming 20 percent or more in short-time tests before rupturing. In addition, my election to reduce the logarithm of the useful life by two standard estimates of error (SEE) of the test data from the correlating surface is a more severe allowance than is common in assessment of candidate materials and nuclear power systems. In my view, confidence of success in developing a nuclear powerplant that will operate for 10 years requires that its design and development be based on (1) an extensive, long-time data base on material properties and on (2) just such a conservative approach to design as I outline.

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