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GENERATION OF LONG TIME CREEP DATA ON REFRACTORY ALLOYS AT ELEVATED TEMPERATURES

ELEVENTH QUARTERLY REPORT

Prepared for
**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
UNDER CONTRACT NAS 3-2545**

TRW EQUIPMENT LABORATORIES
CLEVELAND, OHIO

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ELEVENTH QUARTERLY REPORT

for

26 December 1965 to 26 March 1966

GENERATION OF LONG TIME CREEP DATA
OF REFRACTORY ALLOYS AT ELEVATED TEMPERATURES

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Prepared for:

National Aeronautics and Space Administration

Contract No. NAS 3-2545

Technical Management

Paul E. Moorhead
NASA - Lewis Research Center
Space and Power Systems

April 15, 1966

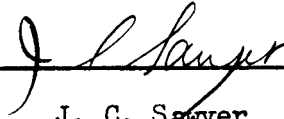
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FOREWORD

The work described herein is being performed by TRW Inc. under the sponsorship of the National Aeronautics and Space Administration under Contract NAS 3-2545. The purpose of this study is to obtain design creep data on refractory metal alloys for use in advanced space power systems.

The program is administered for TRW Inc. by E. A. Steigerwald, Program Manager. J. C. Sawyer is the Principal Investigator, and R. R. Ebert contributed to the program. The NASA technical director is Paul E. Moorhead.

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I INTRODUCTION

Space electric power systems depend upon the use of refractory metals in a variety of component areas. A critical property parameter in the design of these systems is the long-time creep strength at very low pressures. Since oxygen contamination of refractory metal alloys can occur under conditions of 1×10^{-6} Torr, vacuums better than 1×10^{-8} Torr must be used to obtain creep measurements which are employed in the design of space components. The purpose of this program is to generate long-time creep data on selected refractory alloys which have potential use in advanced power systems. Emphasis has been placed on testing sheet alloys which can be employed for cladding or tubing applications and on forgeable, high-strength turbine alloys.

This report presents the creep data obtained during the eleventh quarter on arc-cast and vapor-deposited tungsten, the molybdenum base alloys TZC, TZM, and columbium modified TZM, and the tantalum base alloys T-111 and T-222.

II MATERIALS AND PROCEDURE

A summary of the composition, heat treatments, and current tests of the alloys discussed in this report is presented in Tables 1, 2, and 3. A detailed review of the processing history and microstructure has been previously presented in the Ninth Quarterly Progress Report, NASA CR-54773. Tungsten was evaluated both as 0.030" sheet and as vapor-deposited material. Two heats of TZM and TZC material were tested. The TZM was obtained from two different vendors while the TZC came from the same vendor but had significantly different processing histories. In the TZC Heat M-91 material, three different heat treatments were evaluated at similar test conditions to provide an indication of possible effects produced by structural variations. The tantalum base alloys T-111 and T-222, were both evaluated as sheet material after selected recrystallization treatments.

The test procedure involved obtaining a vacuum of 5×10^{-10} Torr or better at room temperature, then heating the specimen at a rate so that the pressure never went above 1×10^{-6} Torr. Heat treatment was performed on the materials in situ, prior to load application. After heat treatment the specimens were cooled to room temperature and then reheated to the test temperature which was maintained for two hours to insure equilibrium. During testing the vacuum was less than 1×10^{-8} Torr and generally decreased with test time.

TABLE 1

Chemical Composition of Alloys Being Evaluated in Creep Program (Weight %)

Material	W	Mo	Ta	Hf	C	N ₂	Ti	Zr	ppm	
									O ₂	H ₂
Tungsten (arc-cast)	Bal.				.0058				9	4
Tungsten(vapor-deposited) (General Atomics)	Bal.				.0012				12-14	1-3
TZM (Climax Heat 7502)		Bal.			.013	.011	.47	.091	20	7
TZM- Heat KDTZM-1175 (AiResearch)		Bal.			.031 (.024)	.0043	.61 (.49)	.12 (.144)	34	9(note 1) (note 2)
TZC (Heat M-80)		Bal.			.140	.0018	1.02	.130	41	5
TZC (Heat M-91)		Bal.			.145	.003	1.17	.274	37	10
Cb Modified TZM (Heat 4305-4)		Bal.			.06		.50	.32		+1.62Cb
T-222	9.57		Bal.	2.93	.012	.0026			35	11
T-111	8.5		Bal.	2.30	.004	.002			55	6

Note 1 - TRW Analysis

Note 2 - AiResearch Analysis

TABLE 2
 Summary of Material Variables Being Evaluated in Creep Program¹

Material	Form	Test Temperature	Test Condition
Tungsten	Arc-Melted 0.030" Sheet	3200°F (1760°C)	Recrystallized 1 hour at 2800°F (1538°C)
Tungsten	Vapor-deposited ² 1/8" dia. Bars	3200°F (1760°C)	As-received
TZM Climax Heat 7502)	"Pancake" Forging	2000°F (1093°C)	(Cond. 1) As-received (stress-relieved condition.)(Cond. 2) Annealed 1 hour, 2850°F (1566°C)
TZM-Heat KDTZM-1175 (AIResearch) ³	"Pancake" Forging	1600-1856°F (871-1013°C)	As-received (stress-relieved, 2300°F (1260°C), 1 hour
Cb Modified TZM	5/8" dia. Bar	2000-2200°F (1093-1204°C)	As-received (stress-relieved, 2500°F (1371°C), 1 hour
TZC (Heat M-80) TZC (Heat M-91)	3/4" Plate	1800-2200°F (982-1204°C)	Three conditions: stress-relieved 2300°F (1260°C) 1 hour; annealed 3092°F (1700°C) 1 hour; or annealed 3092°F (1700°C), 1 hour age 2400°F (1315°C), 5 hours
T-222 ⁴	0.030" Sheet	1800-2200°F	Recrystallized 3000°F (1649°C), 1 hour
T-111	0.030" Sheet	1800, 2000, 2200°F (982, 1093, 1204°C)	Recrystallized 2600°F (1426°C), 1 hour or Recrystallized 3000°F (1649°C), 1 hour

1. More detailed processing history given in 9th Quarterly Report, NASA-CR 54773.
2. Vapor deposition procedure described in detail in NASA-CR 54715, GA-6522; Studies of Thermionic Mat.; October 15, 1965.
3. Forging of this material described in detail in AFAPL-TR-65-51; Materials Investigation, SNAP 50/SPUR Program, Mechanical Properties of TZM, R. L. Salley and E. A. Kovacevich, June, 1965.
4. Originally scheduled to be tested as ST-222 plate material, program plan revised to include material as T-222 grade applicable for tubing.

TABLE 3

Summary of Creep Tests Completed or in Progress During the Eleventh Quarter

Material	Unit	Test No.	Condition	Test Temperature (°F)	Test Temperature (°C)	Ksi	Stress N/m ²	Time (Hrs.)	Creep %
TZC (M-80)	2	B-9	Annealed 1700°C, 1 Hr.	2000	1093	20	1.38 x 10 ⁸	9137	0.462
TZC (M-80)	8	B-11	Annealed 1700°C, 1 Hr.	1856	1013	25	1.72 x 10 ⁸	8430	0.168
TZC (M-80)	13	B-12	Annealed 1700°C, 1 Hr.	2056	1124	19	1.31 x 10 ⁸	8207	0.228
TZC (M-91)	11	B-19	S-R, 1260°C, 1 Hr.	1800	982	44	3.03 x 10 ⁸	4604	1.015*
TZC (M-91)	9	B-20	Annealed 1700°C, 1 Hr.	2000	1093	20	1.38 x 10 ⁸	3379	0.482
TZC (M-91)	1	B-22	Annealed 1700°C, 1 Hr.	2000	1093	20	1.38 x 10 ⁸	1123	1.010*
TZC (M-91)			Aged 1316°C, 5 Hrs.						
TZC (M-91)	6	B-26	Annealed 1700°C, 1 Hr.	1800	982	44	3.03 x 10 ⁸	Broke on loading	
TZM (Climax) (7502)	6	B-3	S-R, 1204°C, 1 Hr.	2000	1093	10	6.90 x 10 ⁷	10,048	0.375*
TZM (Climax) (7502)	12	B-4	Annealed 1566°C, 1 Hr.	2000	1093	10	6.90 x 10 ⁷	10,012	0.368*
TZM (AlRes) (1175)	14	B-21	S-R, 1260°C, 1 Hr.	1600	871	65	4.48 x 10 ⁸	1630	0.085*
TZM (AlRes) (1175)	14	B-25	S-R, 1260°C, 1 Hr.	1800	982	44	3.03 x 10 ⁸	1145	0.088
Cb-TZM (4305-4)	10	B-23A	S-R, 1371°C, 1 Hr.	2000	1093	20	1.38 x 10 ⁸	686	0.032*
Cb-TZM (4305-4)	10	B-23B	S-R, 1371°C, 1 Hr.	2000	1093	28	1.93 x 10 ⁸	307	0.028*
Cb-TZM (4305-4)	10	B-23C	S-R, 1371°C, 1 Hr.	2000	1093	40	2.76 x 10 ⁸	161	0.172*
Cb-TZM (4305-4)	10	B-23D	S-R, 1371°C, 1 Hr.	1800	982	46	3.17 x 10 ⁸	403	0.078*
Cb-TZM (4305-4)	10	B-23E	S-R, 1371°C, 1 Hr.	2100	1149	34	2.41 x 10 ⁸	64	0.060
Cb-TZM (4305-4)	6	B-27	S-R, 1371°C, 1 Hr.	2000	1093	41	2.82 x 10 ⁸	401	0.162
T-111	7	S-19	Annealed 1649°C, 1 Hr.	2200	1204	8	5.51 x 10 ⁷	2395	1.290
T-111	3	S-21	Annealed 1649°C, 1 Hr.	2200	1204	12	8.26 x 10 ⁷	1865	2.092
T-111	4	S-22	Annealed 1649°C, 1 Hr.	2000	1093	20	1.38 x 10 ⁸	1099	2.010*
T-222	5	S-20	Annealed 1538°C, 1 Hr.	2200	1204	12	8.26 x 10 ⁷	1304	5.060*
W (Arc Melted)	4	S-18	Annealed 1538°C, 1 Hr.	2800	1538	3	2.06 x 10 ⁷	908	5.535*
W (Vapor Deposited)	1	S-24	Annealed 1538°C, 1 Hr.	2800	1538	2	1.38 x 10 ⁷	1313	0.915

* Test Completed

Specimen extension was measured over a two-inch gauge length with an optical extensometer that determined the distance between two reference marks to an accuracy of $\pm 50 \mu$ -inches. The program plan involves testing the plate or forged alloys at temperatures between 1600 and 2250°F (871 and 1235°C) until a 1% total elongation is obtained. The tungsten materials are being tested at 2800 and 3200°F (1566 and 1760°C) for total extensions between 3 and 5% while the tantalum-base materials are being evaluated in the 1800 to 2200°F (982 to 1204°C) range to an elongation of approximately 2 to 5%. The applied stress levels have been selected with the goal of obtaining creep data over total test times between 1000 and 10,000 hours.

III RESULTS AND DISCUSSION

In this section, creep data generated during the eleventh quarter are graphically presented as percent total elongation in the two-inch gauge section as a function of time at the applied stress. Reference marks are placed on the curves to indicate the chamber pressure during the test period. The specific data for each test which was in progress or completed during this quarter are given in detail in Appendix I.

Molybdenum Base Alloys

The three classes of molybdenum-base alloys being examined are TZC, TZM, and columbium-modified TZM.

A summary of the treatments which have been included in the evaluation during this quarter is presented below.

TZC (Heat M-80)

Annealed 3092°F (1700°C), 1 hour

TZC (Heat M-91)

Stress relieved 2300°F (1204°C), 1 hour

Annealed 3092°F (1700°C), 1 hour

Annealed 3092°F (1700°C), 1 hour; Age 2400°F (1316°C), 5 hours

TZM (Heat 7502)

Stress relieved 2200°F (1204°C), 1 hour

Annealed 2850°F (1566°C), 1 hour

TZM (Heat 1175)

Stress relieved 2300°F (1260°C), 1 hour

Columbium Modified TZM (Heat 4305-4)

Stress relieved 2500°F (1371°C), 1 hour

TZC (Heat M-80) is currently being tested at three different temperatures and stresses (see Table 3). The data given in Figure 1 show that creep does not occur in a uniform manner, but exhibits periods of rapid extension followed by an absence of creep or even contraction of the specimen. The discontinuities in the creep curve which occur over several thousand test hours are believed to be a real material effect since they are significantly greater than differences that can be attributed to variations in either temperature or extension measurements. The occurrence of the specimen contraction, coupled with the limited post-test examination indicate that strain-induced precipitation is producing the very low average creep rate in the TZC material.

TZC Heat M-91 is distinguished from Heat M-80 by the greater percent reduction per pass during the rolling operation. This processing treatment resulted in greater room temperature ductility than obtained in the Heat M-80. To determine the effect of heat treatment on the creep properties of TZC, specimens from Heat M-91 are being tested at the conditions shown in Figure 2.

A comparison between the data obtained on the annealed and aged material with the material in the unaged condition indicates that a significant increase in creep rate occurred as a result of aging five hours at 2400°F (1360°C).

Post test examination of the specimen heat treated by annealing at 3092°F (1700°C) and aging five hours at 2400°F (1360 °C) indicated that a longitudinal crack existed in the gauge section (see Figure 3). Further visual examination showed that in some areas a high degree of localized distortion had occurred which can be seen in Figure 3 located approximately 1-1/2 inches from the left side of the bottom photograph. This surface area, shown at 500X in Figure 4, consists of grains exhibiting pronounced slip. A review of the creep curve, Figure 2, gives no indication that cracking occurred during test. On the basis of this examination, plus the fact that cracking during annealing has been reported on material from this same heat*, the conclusion was reached that the creep specimen cracked during the heat treatment performed in situ prior to testing. Since the longitudinal crack did not reduce the cross-sectional area of the specimen, the possibility exists that the aging treatment was the major factor in the increased creep rate. If strain-induced precipitation during the test is a significant factor in reducing creep then this would indicate that a strain induced precipitate is more effective than the precipitate formed by the

* NAS CR-54916

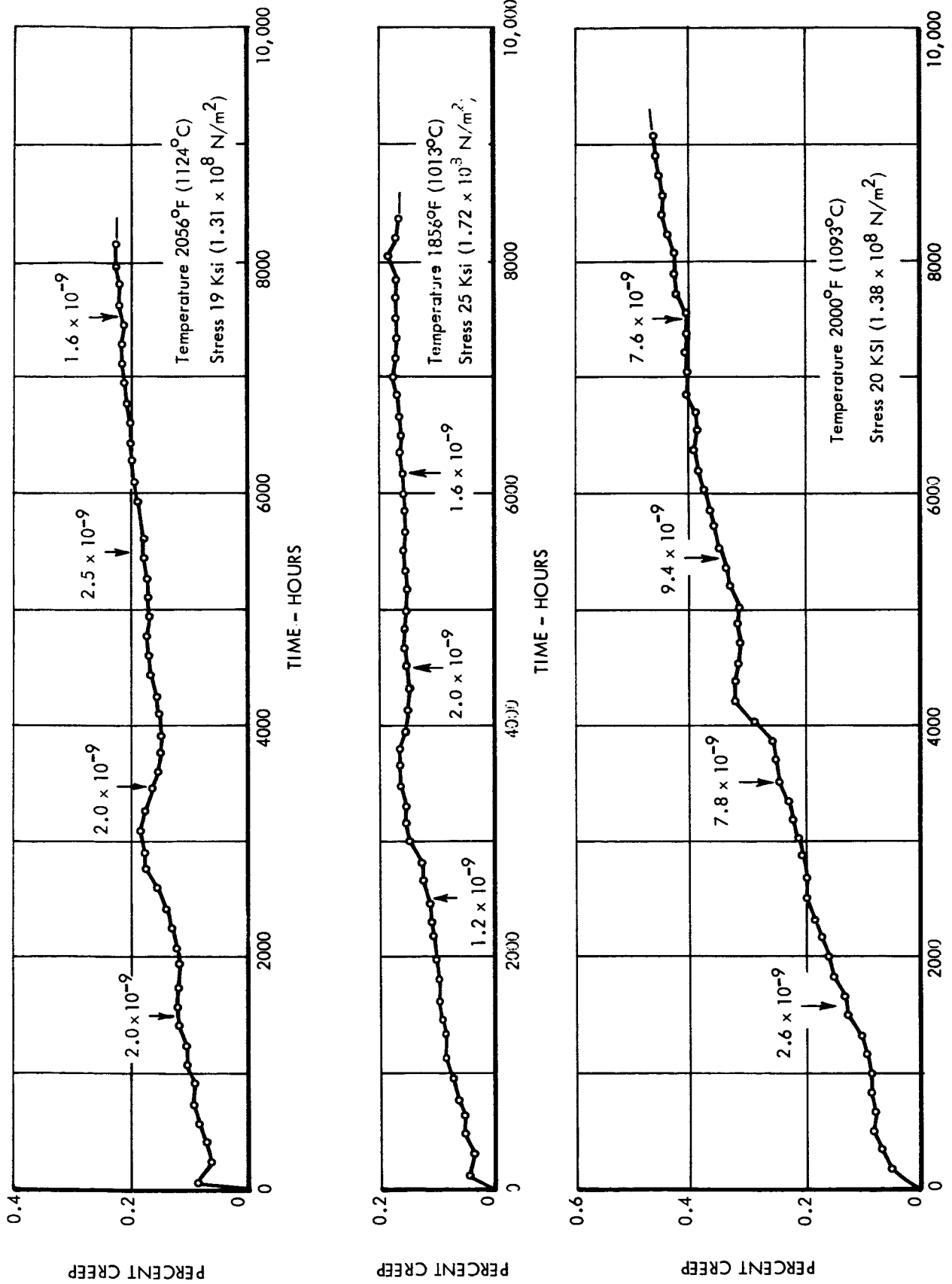


FIGURE 1. CREEP TEST DATA, TZC (HEAT M-80), ANNEALED 3092°F (1700°C) 1 HOUR TESTED IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR

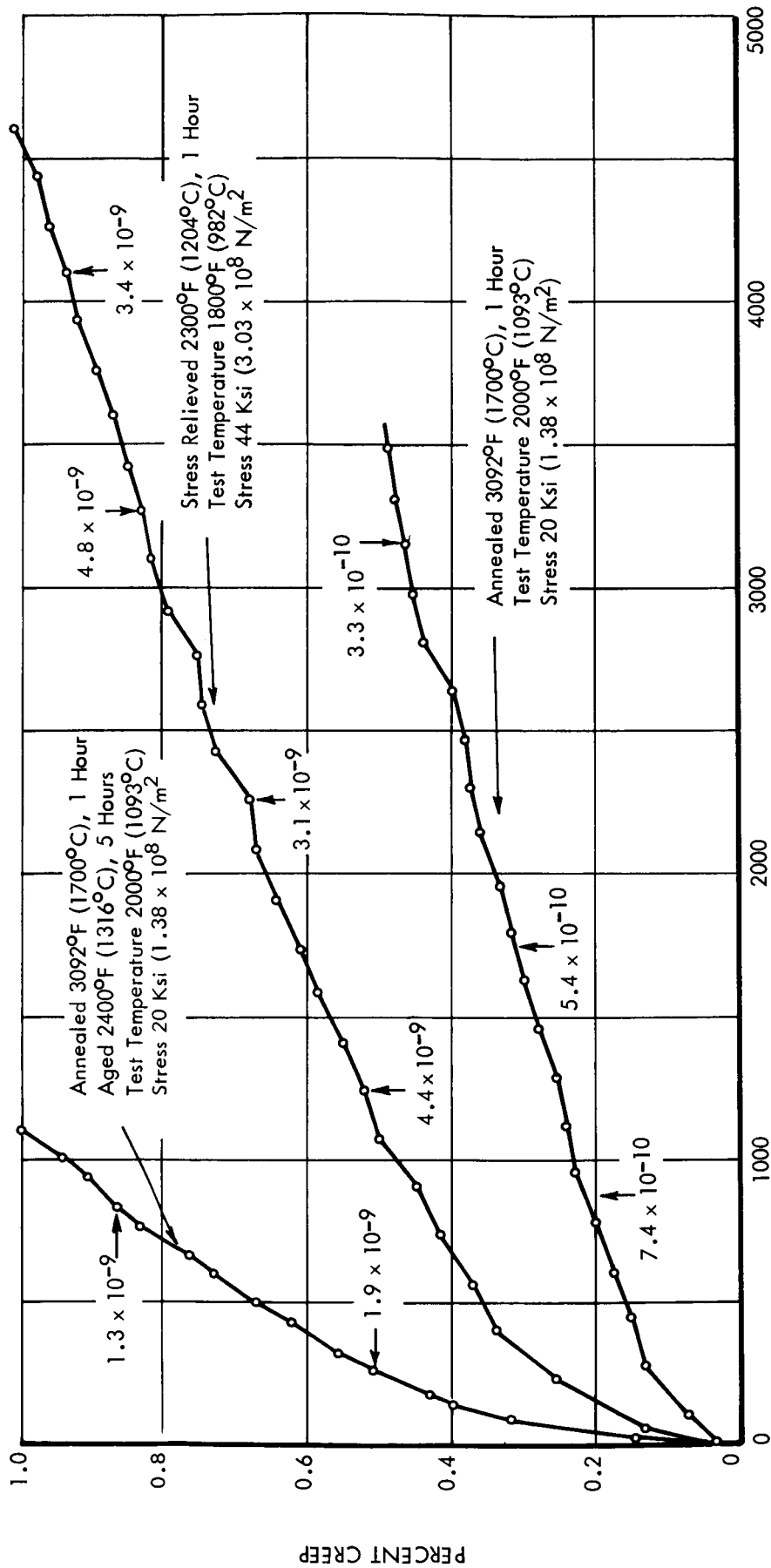
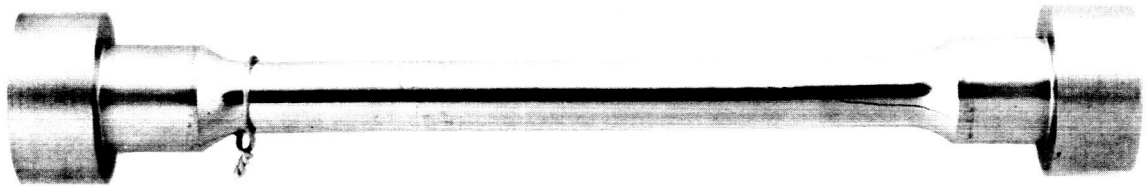
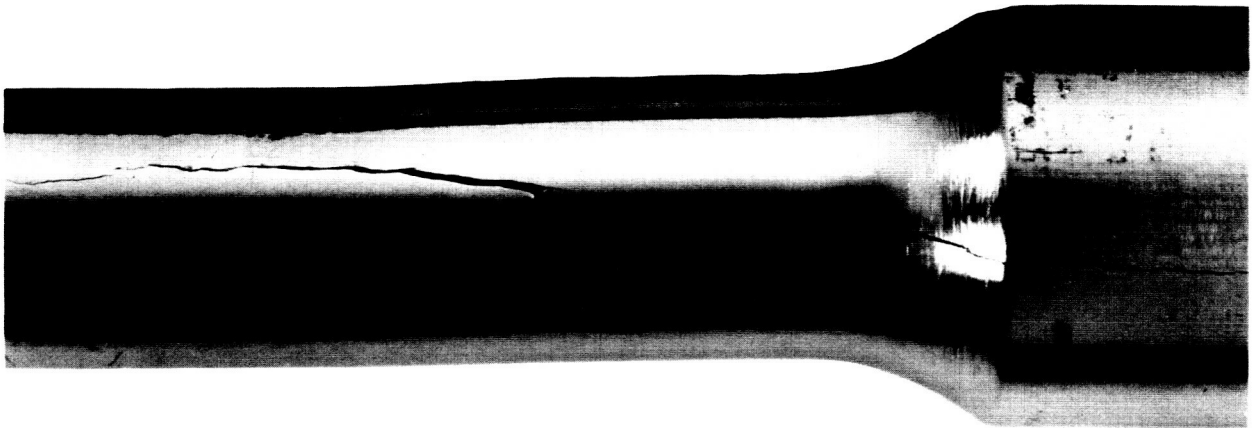


FIGURE 2. CREEP TEST DATA, TZC (HEAT M-91), TESTED IN VACUUM ENVIRONMENT < 1 x 10⁻⁸ TORR



Overall Specimen Appearance

1.5X



Close-Up of Longitudinal Crack

3X

Figure 3. TZC Specimen B-22, Heat M-91, Cracked During Creep Testing.



500X

Figure 4. Specimen B-22, Heat M-91, Micrograph Shows Local Area of Slip as Seen on Surface of Specimen After Testing, Polarized Light.

aging heat treatment. On this basis the aged material also would exhibit a higher apparent creep rate.

Microstructural examination was made in an effort to identify the mode of cracking. Figure 5, which shows the defect at 100 and 500X, indicates that the crack is preferentially located in the grain boundary. The microstructure at 6000X, shown in Figure 6, does not reveal any apparent microstructural characteristics which would account for the defect. Since the chemistry of Heat M-91 did not exhibit any abnormalities and since cracks of a similar type have not been observed in Heat M-80, it appears that the higher degree of warm working applied to Heat M-91 renders the alloy susceptible to cracking during the recrystallization operation.

During this report period two 10,000 hour tests of forged TZM (Heat 7502) were completed at 2000°F (1093°C) and 10 Ksi ($6.90 \times 10^7 \text{ N/m}^2$). In one case the specimen was stress relieved at 2200°F (1204°C) for one hour prior to testing while in the other test the specimen was recrystallized for one hour at 2850°F (1566°C). The data, shown in Figure 7A, and summarized in Table 4 indicate that after a rapid extension of almost 0.3% during the first 500 hours, the recrystallized material exhibited a relatively low creep rate and after 10,000 hours the total creep for each condition was comparable.

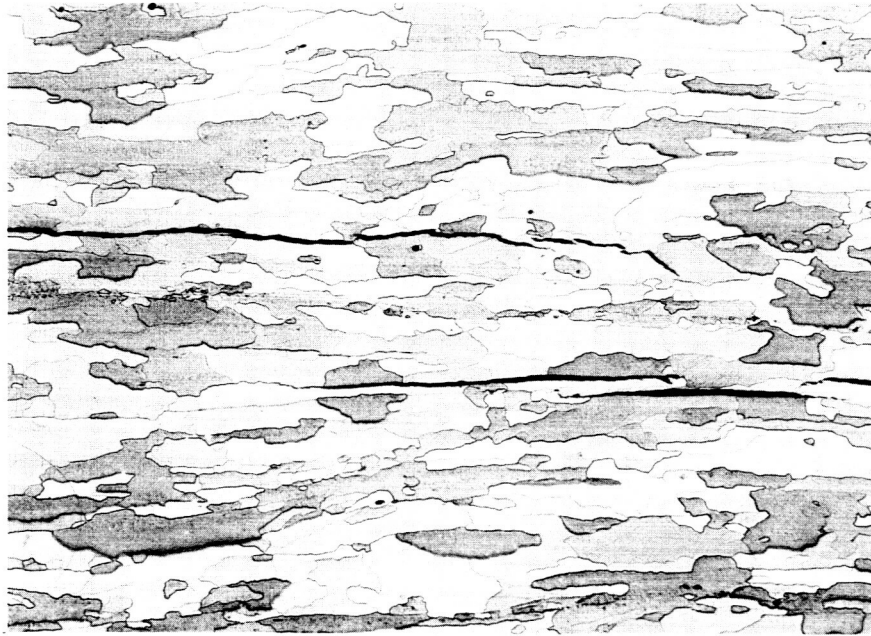
TABLE 4

Summary of Creep Data, TZM, Heat 7502

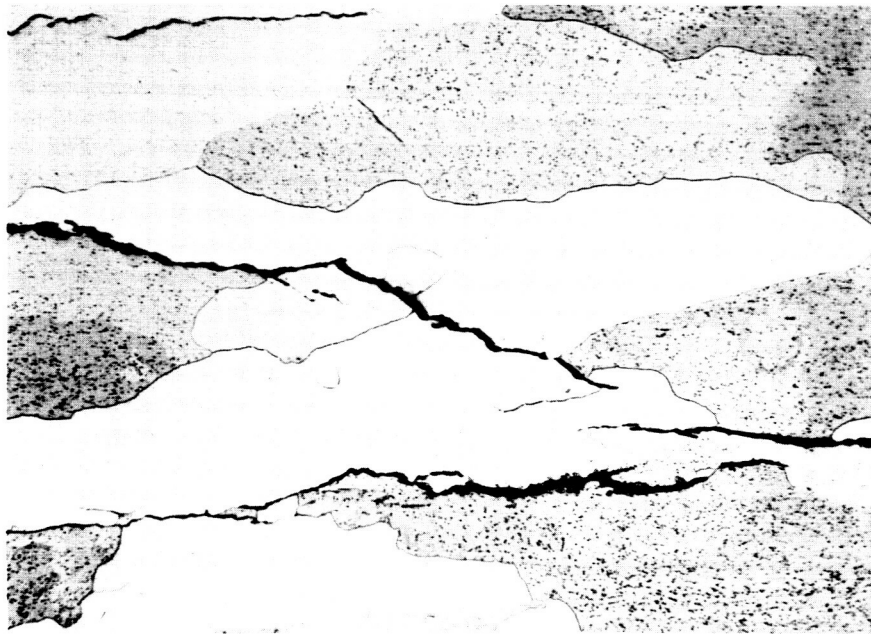
Test Temperature 2000°F (1093°C), Stress 10 Ksi ($6.90 \times 10^7 \text{ N/m}^2$)

	<u>Stress Relieved 2200°F (1204°C) 1 Hour</u>	<u>Annealed 2850°F (1566°C) 1 Hour</u>
Non-linear Creep	0.16% - 1650 Hours	0.32% - 2750 Hours
Steady State Creep Rate	2.6×10^{-7} in/in-hr.	8×10^{-8} in/in-hr.
Total Creep - 10,000 Hrs.	0.38%	0.37%

Following the 10,000 hour tests at 2000°F (1093°C) the stress relieved specimen of TZM (Heat 7502) was subjected to both chemical and metallurgical examination. A comparison of the material composition before and after test, presented in Table 5, indicates that the only differences were an increase in the nitrogen and a decrease in the zirconium content.

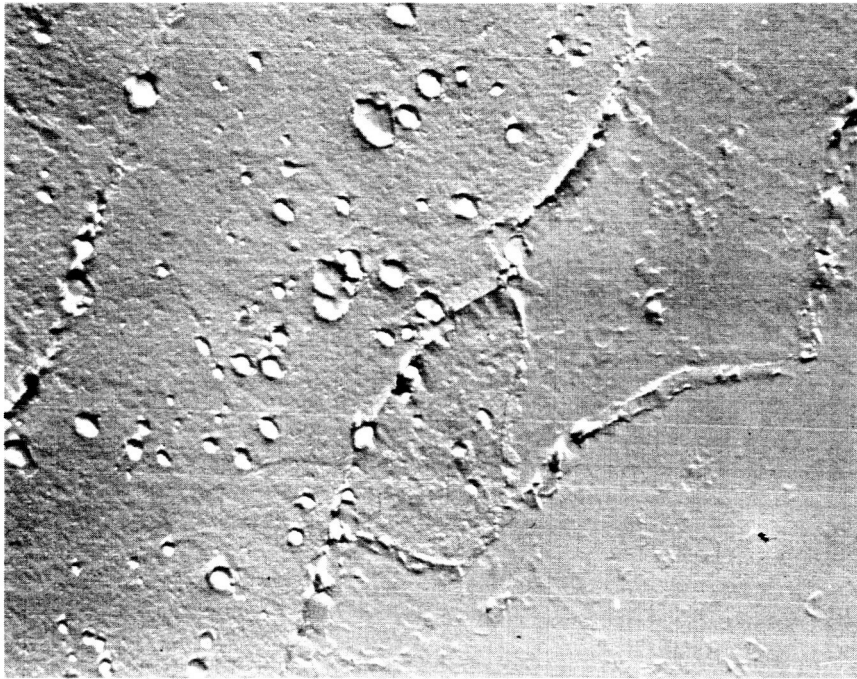


100X



500X

Figure 5. Photomicrographs of Crack in TZC (M-91) Specimen B-22,
Etchant: 15% HF, 15% H₂SO₄, 8% HNO₃, 62% H₂O



6000X

Figure 6. Microstructure of TZC (M-91) Annealed at 1700°C (3092°F),
1 Hour and Aged 1316°C (2400°F), 5 Hours.
Etchant: 15% HF, 15% H₂SO₄, 8% HNO₃, 62% H₂O

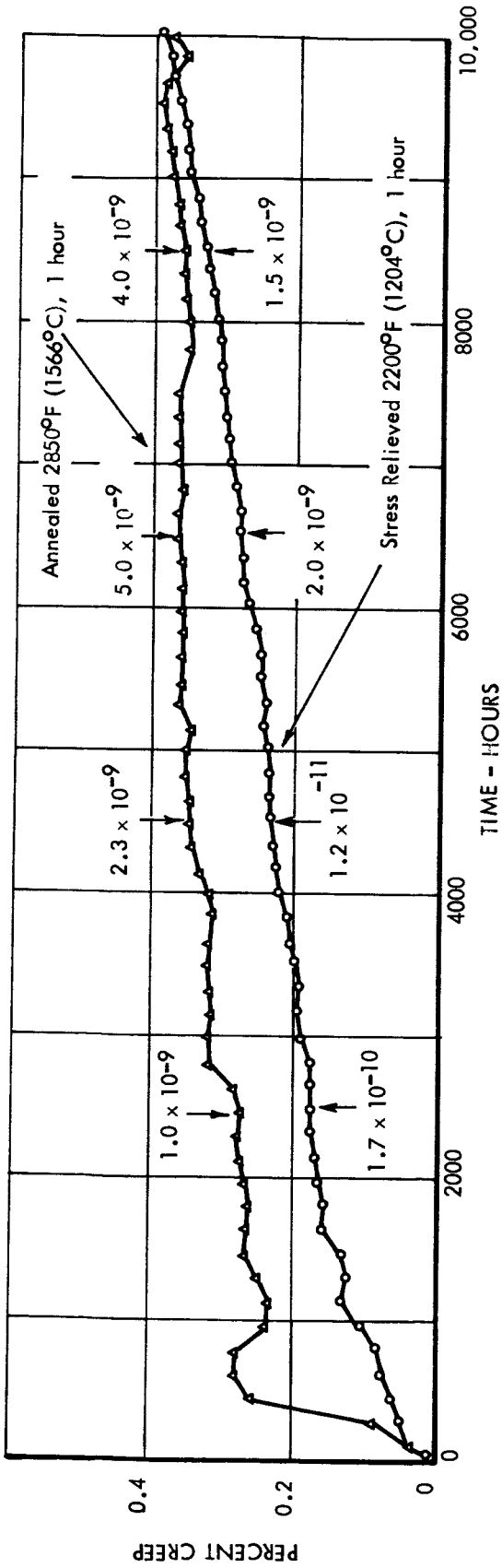


FIGURE 7A. CREEP TEST DATA, TZM HEAT 7502, TESTED AT 2000°F (1093°C) AND 10 Ksi ($6.90 \times 10^7 \text{ N/m}^2$) IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR

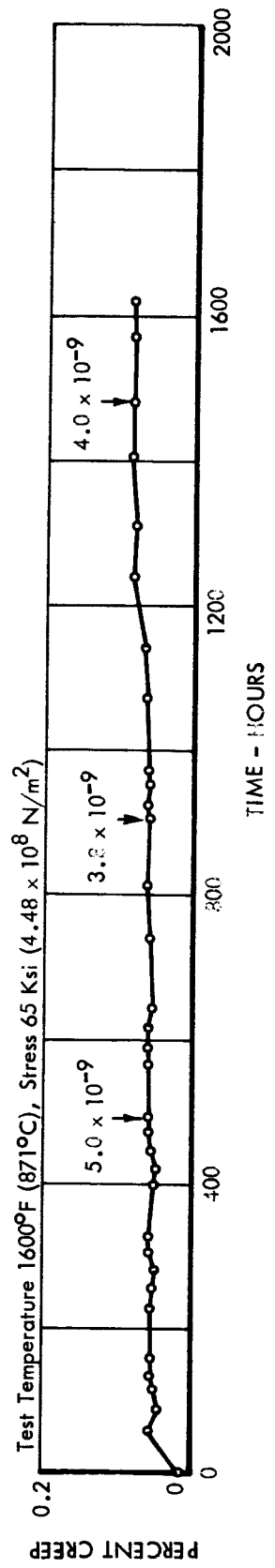
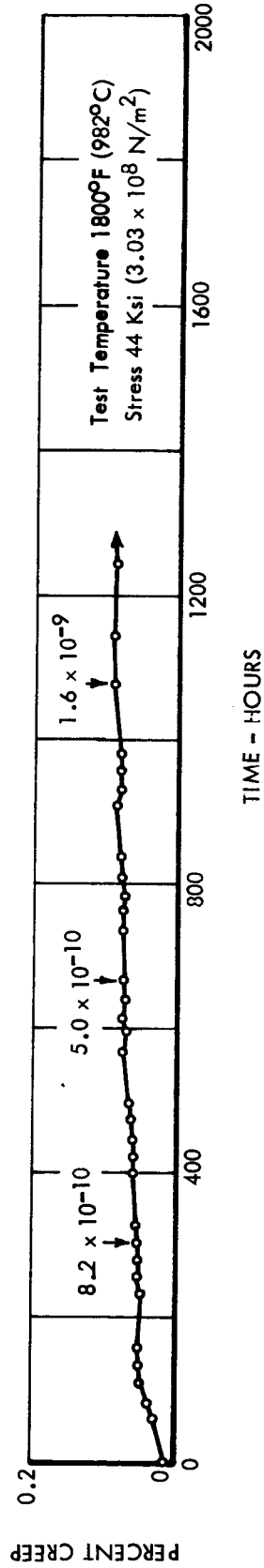


FIGURE 7B. CREEP TEST DATA, TZM HEAT 1175, STRESS RELIEVED 2300°F (1260°C) 1 HOUR, TESTED IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR

TABLE 5

CHEMICAL ANALYSIS TZM FORGED DISC (HEAT 7502)

(Weight Percent)

<u>Element</u>	<u>TAP - DMS*</u> <u>070</u>	<u>Vendor</u> <u>Certification</u>	<u>TRW</u> <u>Analysis</u>	<u>Analysis After</u> <u>10,048 hrs. at 2000°F</u> <u>(Stress-relieved specimen)</u>
Al	<0.0080	<0.001	<0.008	<0.008
C	0.01 - 0.04	0.013	0.010	0.012
Cb	<0.0100	<0.005	<0.010	<0.010
Co	<0.0025	<0.001	<0.0025	<0.0025
Cr	<0.0025	<0.001	<0.0025	<0.0025
Cu	<0.0025	<0.001	<0.0025	<0.0025
Fe	<0.0050	<0.001	<0.005	<0.005
H ₂	<0.0010	<0.0001	0.0007	0.0007
Mg	<0.0025	<0.001	<0.0025	<0.0025
Mn	<0.0050	<0.001	<0.005	<0.005
Mo	Balance	Balance	Balance	Balance
N ₂	<0.0050	0.0011	0.001	0.004
Ni	<0.0050	<0.001	<0.005	<0.005
O ₂	<0.0050	<0.0002	0.002	0.0031
Pb	<0.0050	<0.001	<0.005	<0.005
Si	<0.0050	<0.002	<0.005	<0.005
Sn	<0.0100	<0.001	<0.01	<0.010
Ti	0.40 - 0.55	0.47	0.44	0.50
V	<0.0050	<0.001	<0.005	-
Zr	0.06 - 0.12	0.091	0.10	0.05

• TRW Material Laboratory Specification

Round robin chemical analyses conducted by the Materials Advisory Board* have indicated that with TZM the following variations in composition can be expected from scatter of all combined data from cooperating laboratories.

<u>Element</u>	<u>Standard Deviation (S) ppm</u>	<u>Mean (\bar{X}) ppm</u>	<u>Coefficient of Variation (S/\bar{X})</u>
C	30.6	228	13.4%
N ₂	5.9	14	42.1%
Zr	76.0	900	8.5%

On the basis of these statistical data the differences in carbon analyses would not be significant while the changes in both the nitrogen and zirconium content shown in Table 5 are real effects.

A second lot of TZM, designated as Heat 1175, was received from NASA in the form of a forged disc. Creep tests were conducted on this material in the stress relieved condition at 1600°F (871°C), 65 Ksi ($4.48 \times 10^8 \text{N/m}^2$) and at 1800°F (982°C), 44 Ksi ($3.03 \times 10^8 \text{N/m}^2$). The results shown in Figure 7B indicate that at both conditions exceptionally low creep rates were obtained. In fact at 1800°F (982°C) the applied stress on the TZM in the stress relieved condition is actually greater than the tensile strength of the recrystallized TZC (Heat M-91) at that temperature.

Columbium modified TZM was procured from Climax Molybdenum Company to compare its creep properties to those of conventional TZM. Since disc forgings were not available, the material was obtained in the form of 5/8-inch diameter wrought bar. Chemical analyses indicated that the material had a composition comparable to the TZM shown in Table 1 with the exception that 1% columbium was added. The first test of the stress relieved alloy was carried out at 2000°F (1093°C) and 20 Ksi ($1.38 \times 10^8 \text{N/m}^2$). After 686 hours of testing only 0.032% creep occurred and the test was terminated. Because of the limited amount of material, this specimen was retested at various temperatures and stresses and the creep data were extrapolated to 1% to establish a tentative Larson-Miller curve which could be used to select future test conditions. Based upon these results a test was initiated on the stress relieved material at 2000°F (1093°C) and 41 Ksi ($2.82 \times 10^8 \text{N/m}^2$). After 400 hours a total creep of 0.162% has been obtained.

The currently available creep data on the molybdenum base alloys is summarized in Figure 8 using the Larson-Miller parameter. Although some of the data involve extrapolations to 0.5% creep, several trends are apparent.

* D. L. Chase, "Comparison of Chemical Analyses of Refractory Alloys", (MAB Survey), DMIC 220, (September 10, 1965).

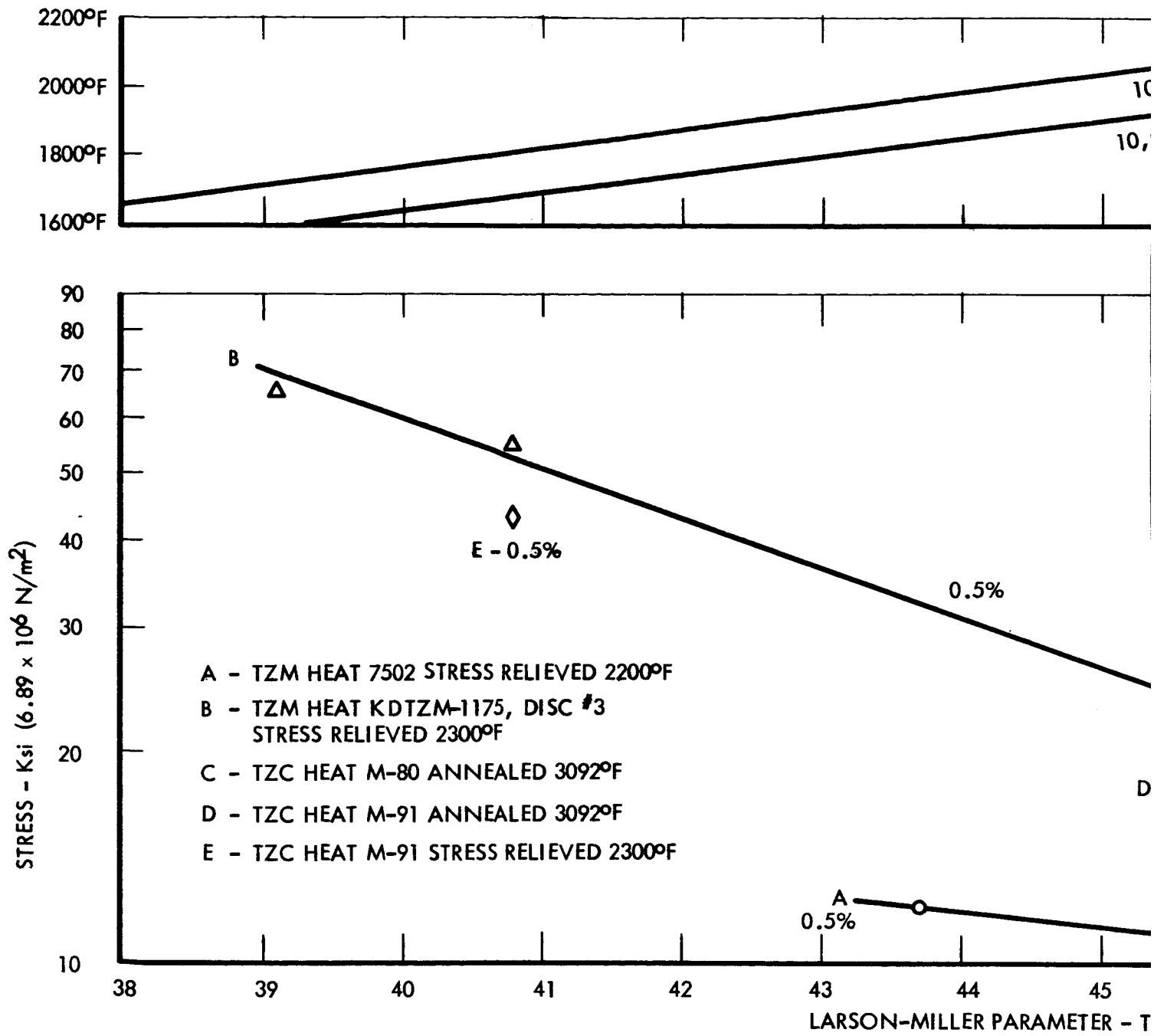
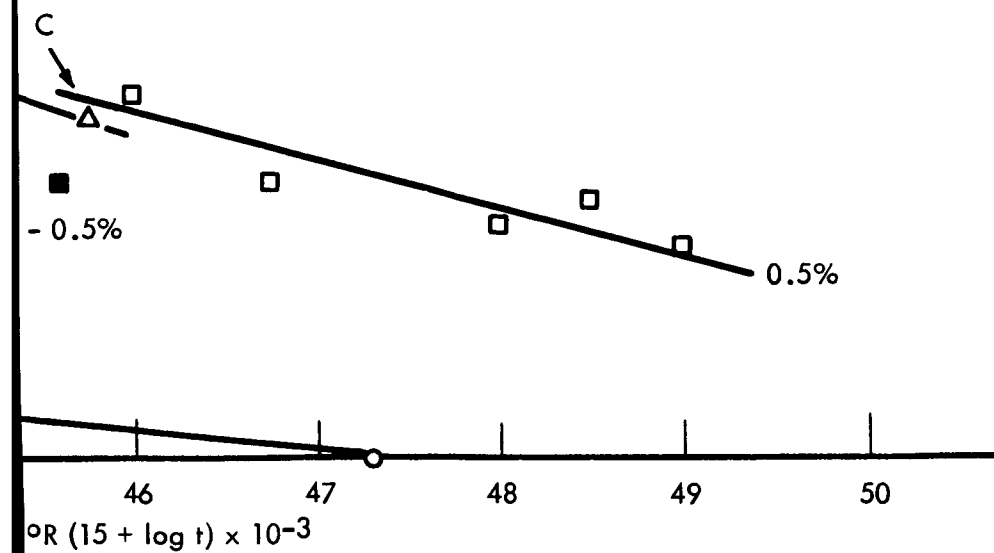


FIGURE 8 LARSON-MILLER PLOT OF DATA FOR 0.5% CREEP

17①

00 HOURS
000 HOURS



IN VARIOUS MOLYBDENUM-BASE ALLOYS



At the low values of the parameter the stress-relieved TZM material with its relatively high tensile strength exhibits the greatest creep resistance. At higher temperatures the recrystallized TZC appears to have the greatest creep resistance. Although the Cb-modified TZM appears to have good properties at higher temperature the data have been obtained from relatively long extrapolations and must be considered tentative.

Tantalum-Base Alloys

The influence of annealing temperature on the creep properties of T-111 and T-222 are evaluated in an effort to select the optimum heat treatment. A comparison of the creep properties of T-222 annealed at 2800°F (1538°C) and 3000°F (1649°C) are shown in Figure 9 while the creep data for T-111 after 2600°F (1427°C) and 3000°F (1649°C) anneals are given in Figure 10. In each case, the 3000°F (1649°C) annealing treatment produced a structure with the greatest resistance to creep extension.

Creep data for T-111 annealed at 3000°F (1649°C) and tested at a variety of conditions are summarized in Figure 11. The data show an increasing creep rate with increasing test time. A direct comparison of the creep behavior of T-111 and T-222, both annealed at 3000°F (1649°C) is presented in Figures 12 and 13. Although under specific test conditions (high temperature, low stress) the T-111 alloy had greater creep resistance. The data are not sufficient to determine whether the differences are due to compositional effects or are the result of normal heat-to-heat variations.

A comparison of the grain size variations produced by selected annealing treatments performed on the T-111 and T-222 alloys is given in Table 6. Typical microstructures for the T-111 and T-222 alloys after the 3000°F (1649°C) anneal are shown in Figure 14. The T-111 was characterized by fine grains at the surface and the appearance of darker etching striations parallel to the rolling direction. As shown by the electron micrograph in Figure 15, the striations are not typical stringers since no definite interface exists with the matrix. On this basis they are believed to be associated with a preferential etching of the microstructure. The preferential etching effect, although minimized, is not completely eliminated by recrystallization at 3000°F (1649°C).

Tungsten

The final test on the arc-melted tungsten sheet at 2800°F (1538°C) and 3 ksi ($2.07 \times 10^7 \text{N/m}^2$) has been completed and the creep curve is shown in Figure 16. The results are in agreement with the predictions obtained from the Larson-Miller plot given in the Tenth Quarterly Report.

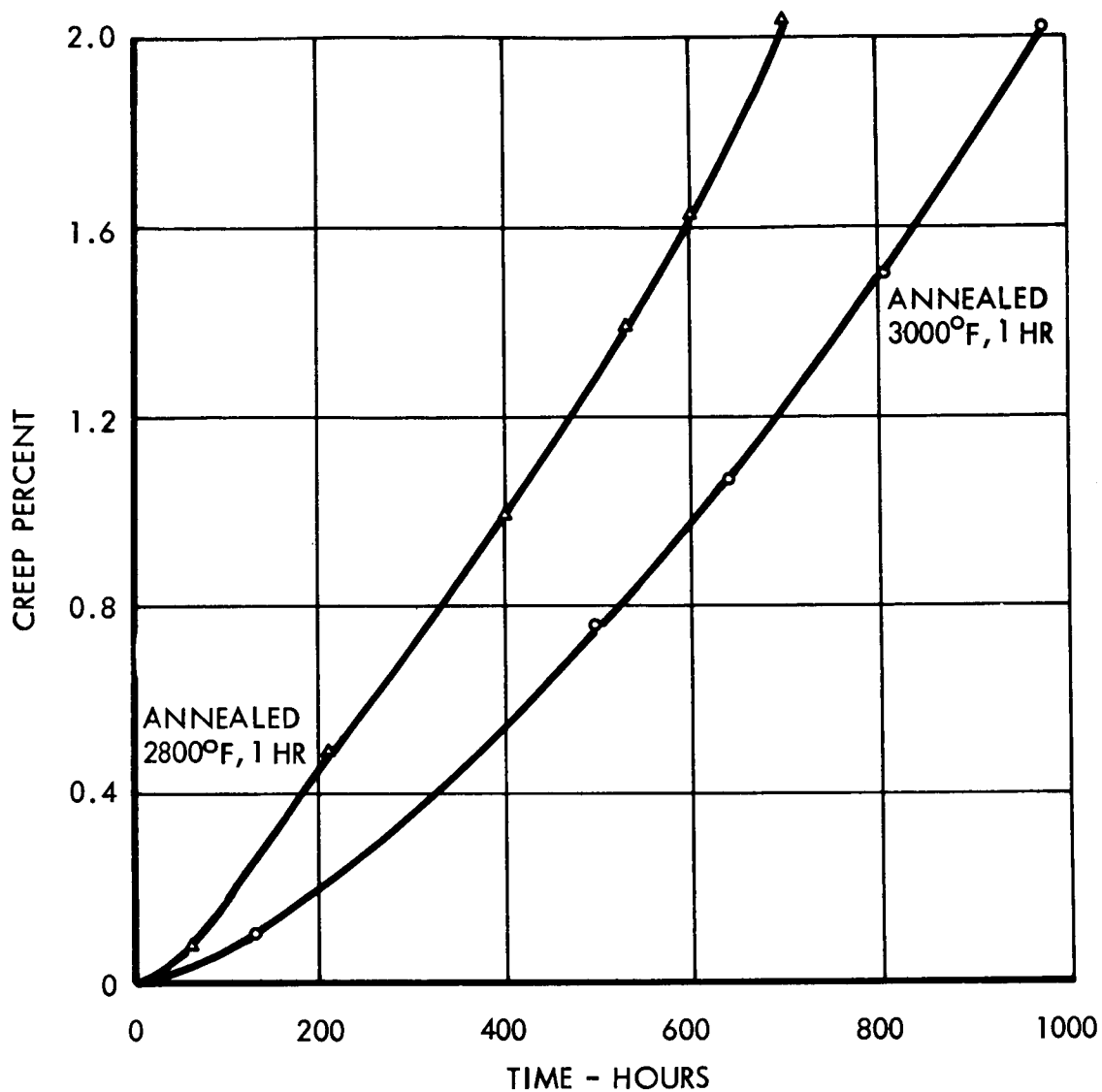


FIGURE 9. CREEP TEST DATA FOR T-222 ALLOY, TESTED AT 2000°F (1204°C), 12 KSI (8.26×10^7 N/m²) IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR

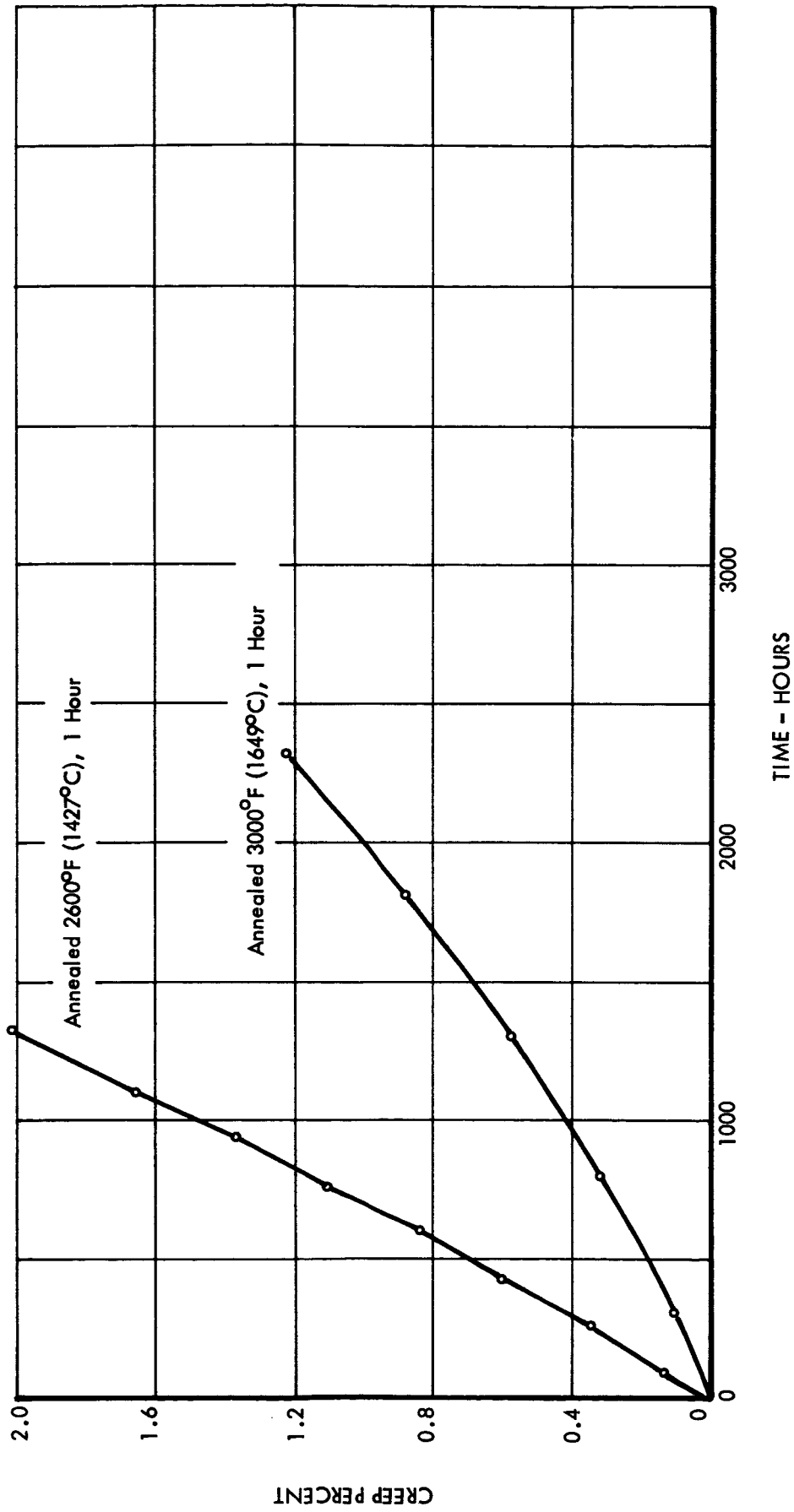


FIGURE 10. CREEP TEST DATA, T-111 ALLOY, TESTED AT 2200°F (1204°C) AND 8 Ksi, (5.51×10^7 N/m²), TESTED IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR

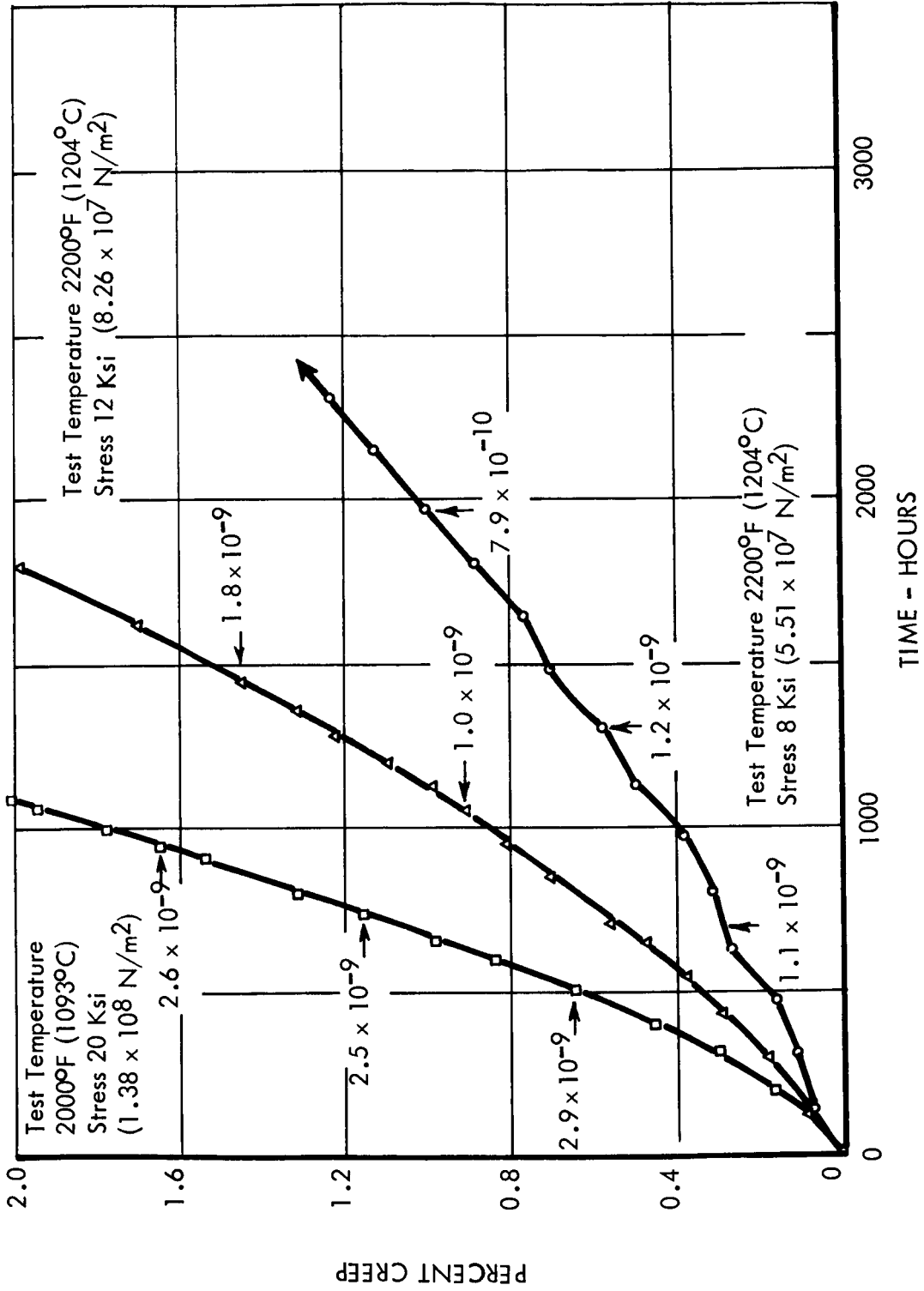


FIGURE 11. CREEP TEST DATA, T-111 (HEAT 70616) ANNEALED 3000°F (1649°C) 1 HOUR, TESTED IN VACUUM ENVIRONMENT < 1 x 10⁻⁸ TORR

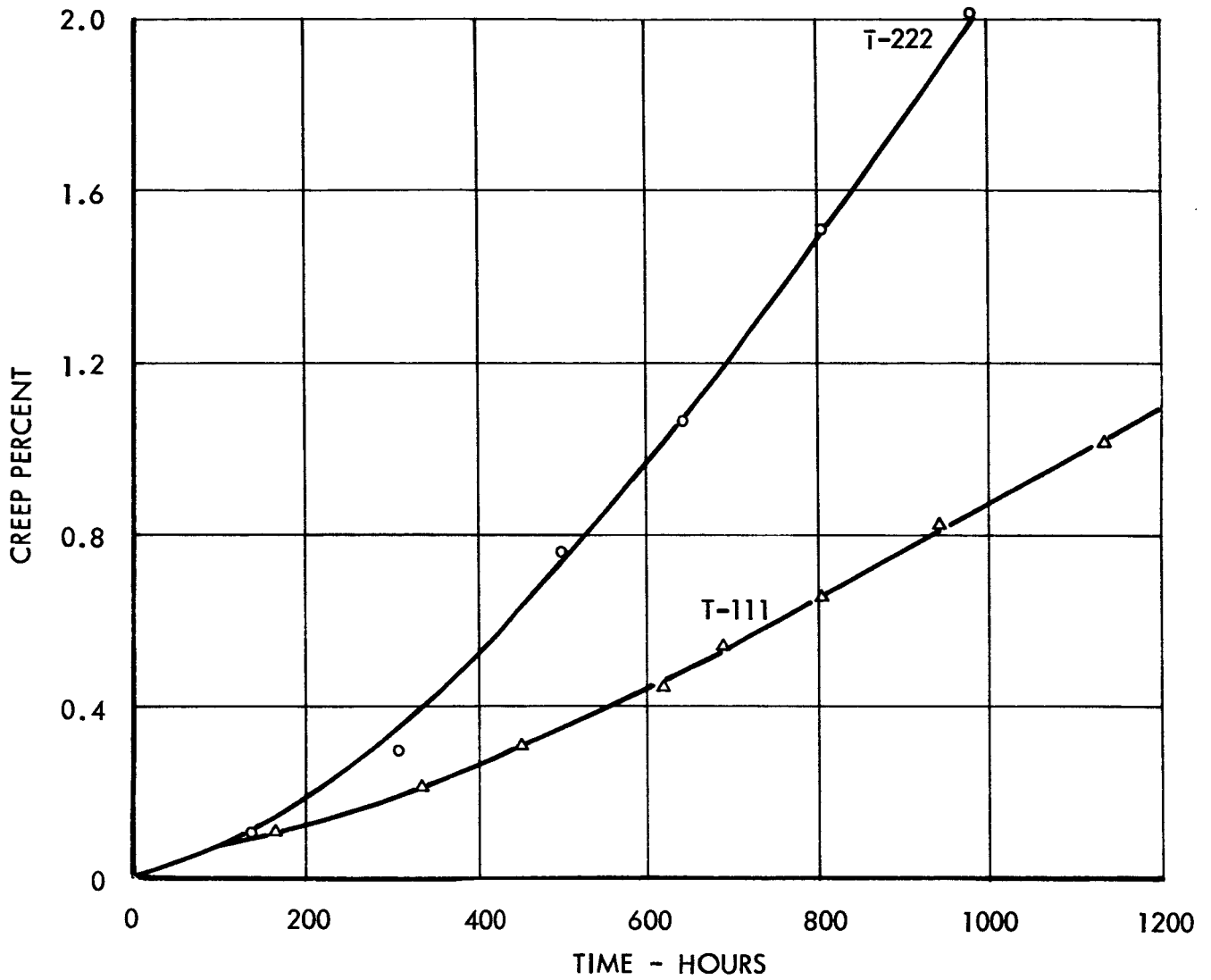


FIGURE 12. CREEP TEST DATA FOR T-222 AND T-111, ANNEALED 3000°F, (1649°C), 1 HR, TESTED AT 2200°F (1204°C), 12 ksi (8.26×10^7 N/m²) IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR

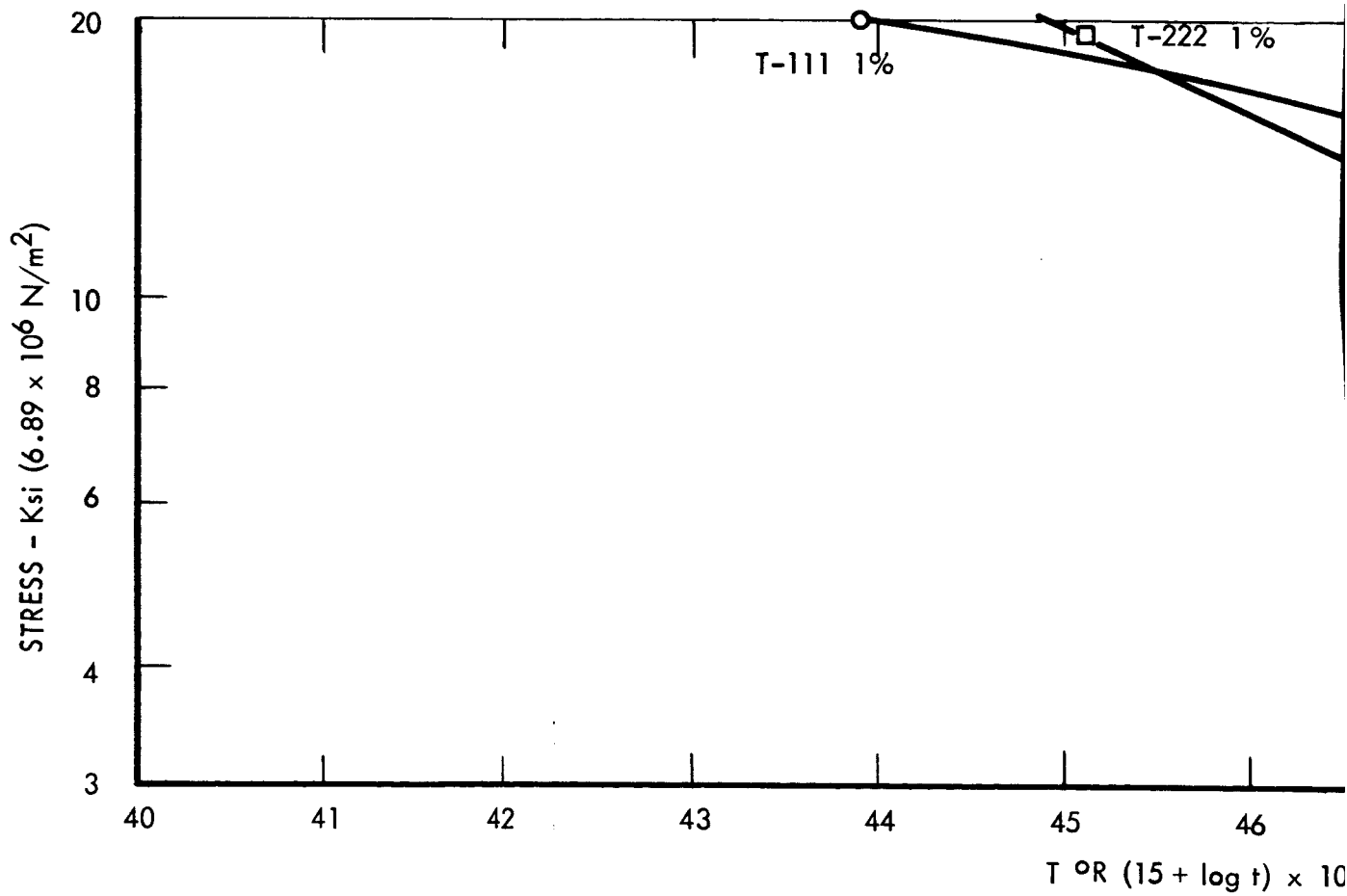
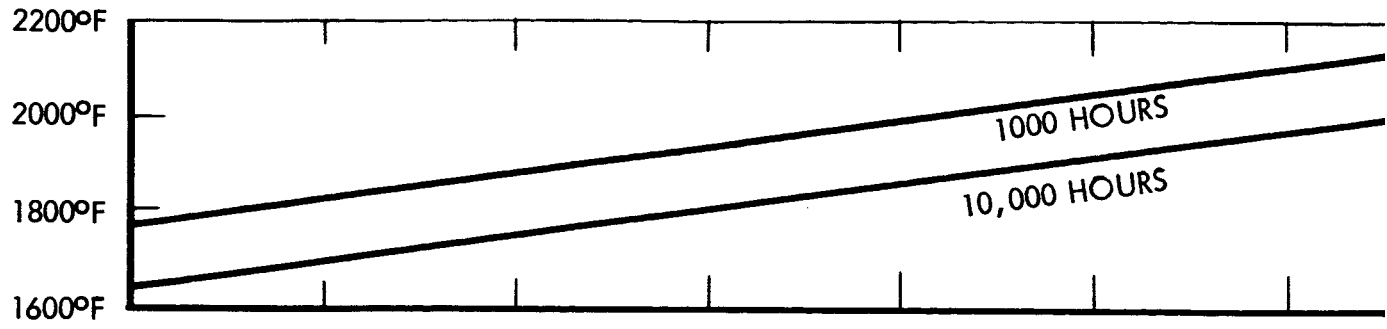
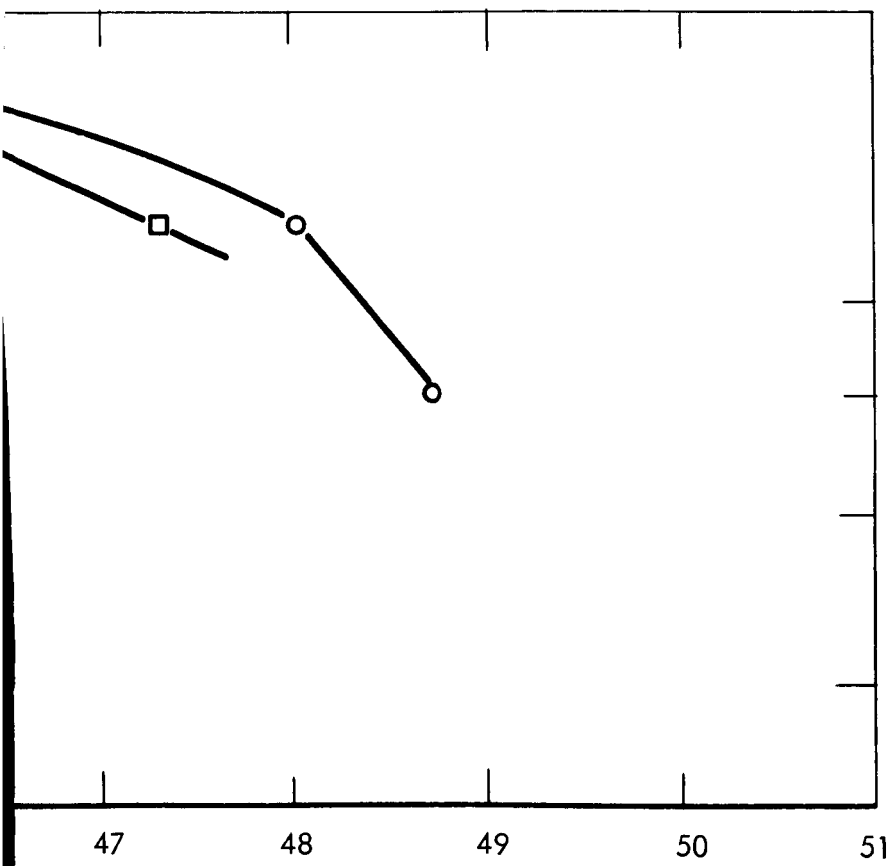
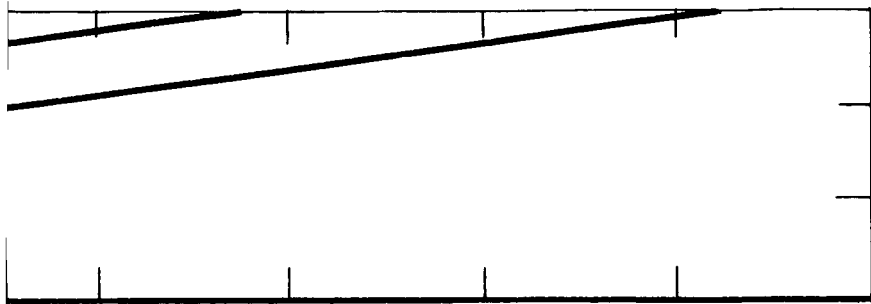
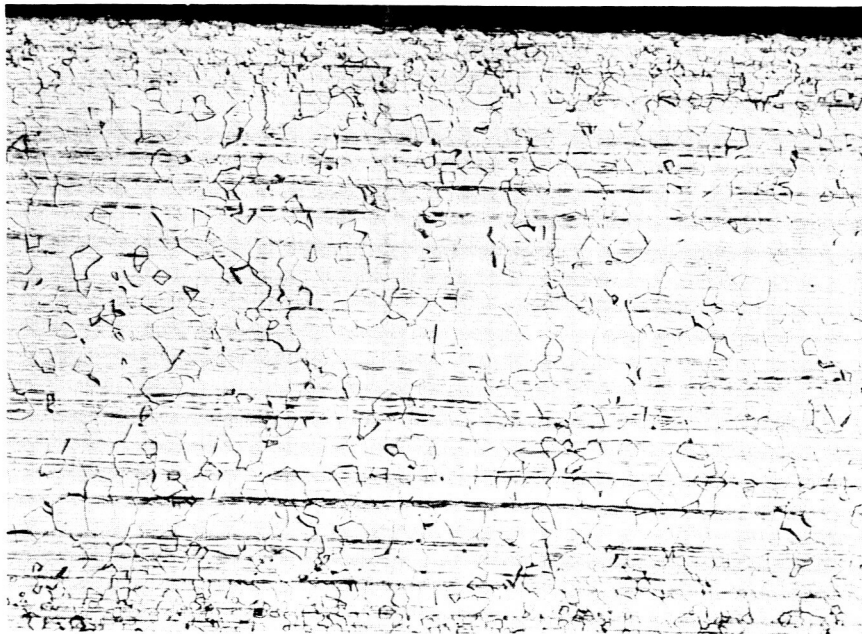


FIGURE 13 LARSON MILLER PLOT, 1% CREEP FOR T-111 AND T-222 AT 3000°F (1649°C), TESTED IN VACUUM ENVIRONMENT

2307



-3
-222 ALLOYS ANNEALED 1 HOUR
ENT $< 1 \times 10^{-8}$ TORR



T-111



T-222

100X

FIGURE 14. Cross-Sections of Tantalum Base Alloys Taken Parallel to Rolling Direction, Material Annealed at 3000°F (1649°C) for One Hour, Etchant: 15% HF, 15% H₂SO₄, 8% HNO₃, 62% H₂O

TABLE 6

Comparison of Grain Size for T-111 and T-222

Annealed at Various Temperatures

<u>Treatment</u>	<u>T-111</u> ASTM <u>Grain Size</u>	<u>T-222</u> ASTM <u>Grain Size</u>
2400°F - 1 hour	8	-
2600°F - 1 hour	7 - 8	6
2800°F - 1 hour	-	6
3000°F - 1 hour	5 - 6	5 - 6
3000°F - 16 hours	5	5 - 6
3500°F - 1 hour	2 - 3	1 - 2



6000X

Figure 15. T-111, Annealed at 2600°F (1427°C) for One Hour,
Cross Section Showing Details of Striations.
Etchant: 15% HF, 15% H₂SO₄, 8% HNO₃, 62% H₂O

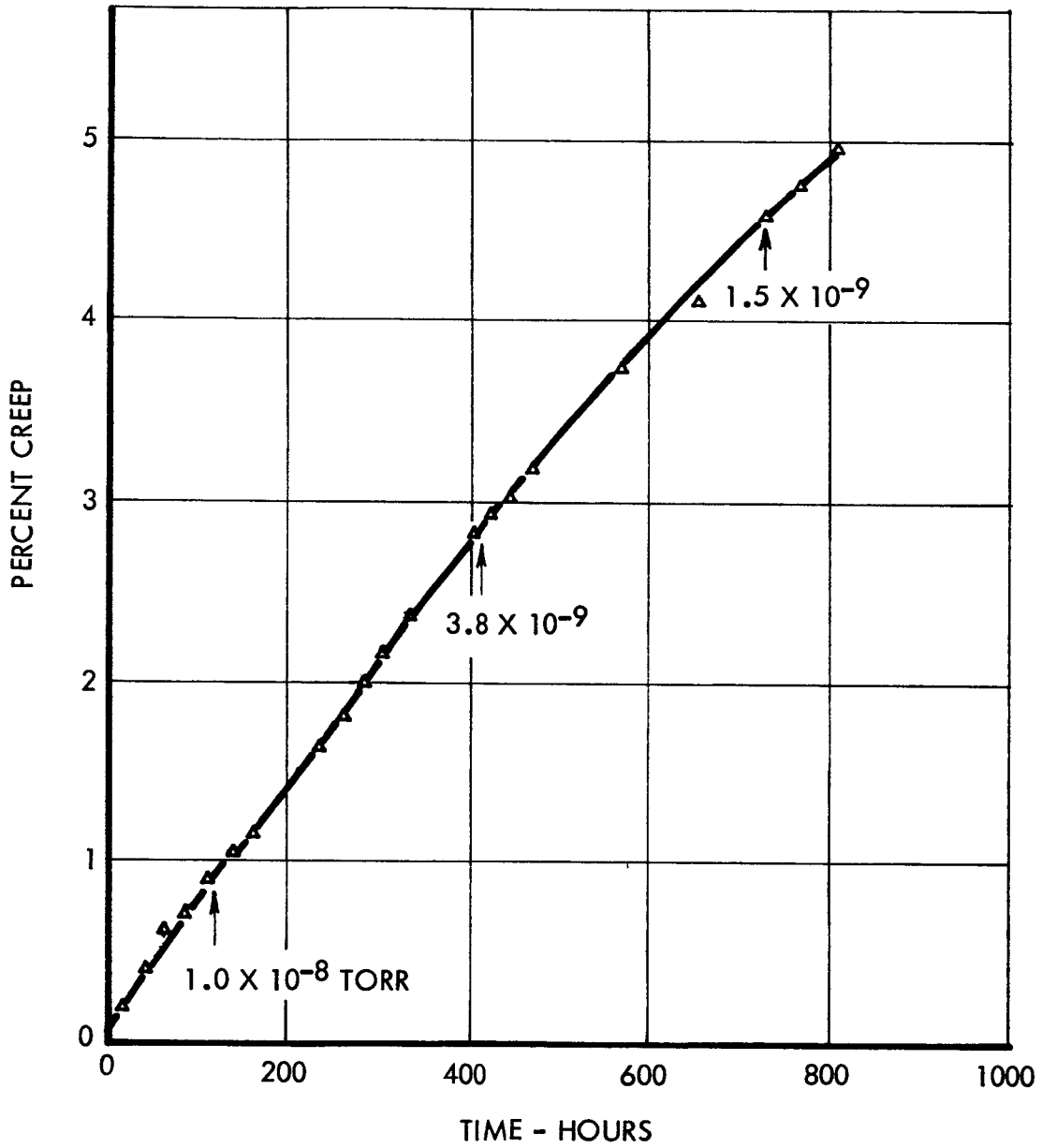


Figure 16. CREEP DATA FOR ARC-MELTED TUNGSTEN, TESTED AT 2800°F (1538°C) IN VACUUM ENVIRONMENT 1×10^{-8} TORR

Vapor deposited tungsten is currently being evaluated at 2800°F (1538°C) and a stress of 2 ksi ($1.38 \times 10^7 \text{N/m}^2$). The data shown in Figure 17 indicate the trend of slightly decreasing creep rate with increasing test time which has been characteristic of all the test conditions for the tungsten materials. A photomicrograph of the specimen of vapor deposited tungsten removed from test after 2883 hours at 3200°F (1760°C) and 1000 psi ($6.89 \times 10^6 \text{N/m}^2$) is presented in Figure 18. The microstructure is fine grained along one surface which is presumably the interface between the mandrel and deposited tungsten. The microstructure after test contains some apparent porosity which appears preferentially located at the fine grain-coarse grain interface. In addition, the microstructure after test has lost the characteristic columnar structure which is usually associated with vapor deposited materials.

IV FUTURE WORK

Tests will be continued on the molybdenum base alloys. Additional tests will be initiated on the T-111 material to allow the determination of Manson-Haferd constants.

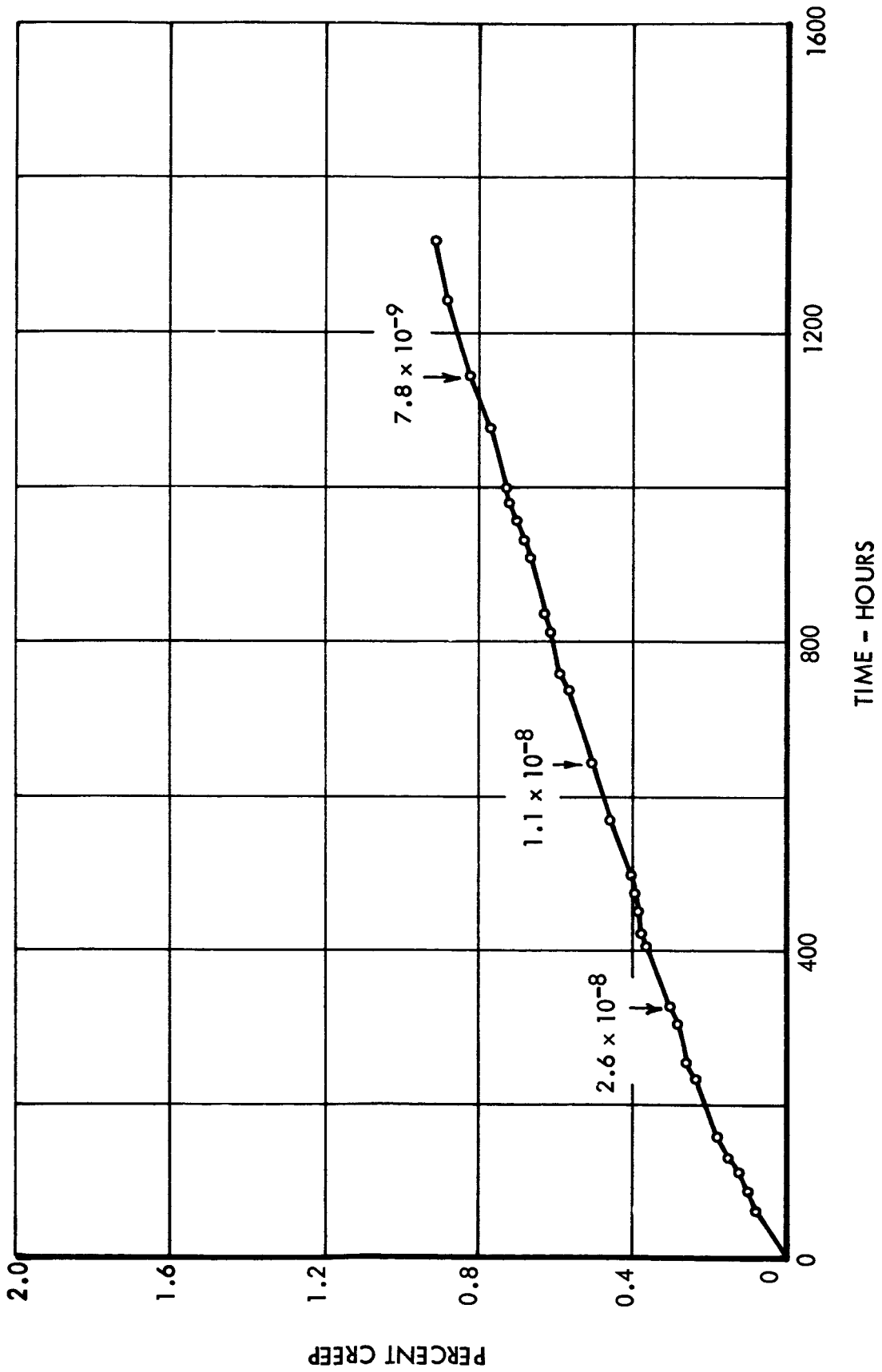
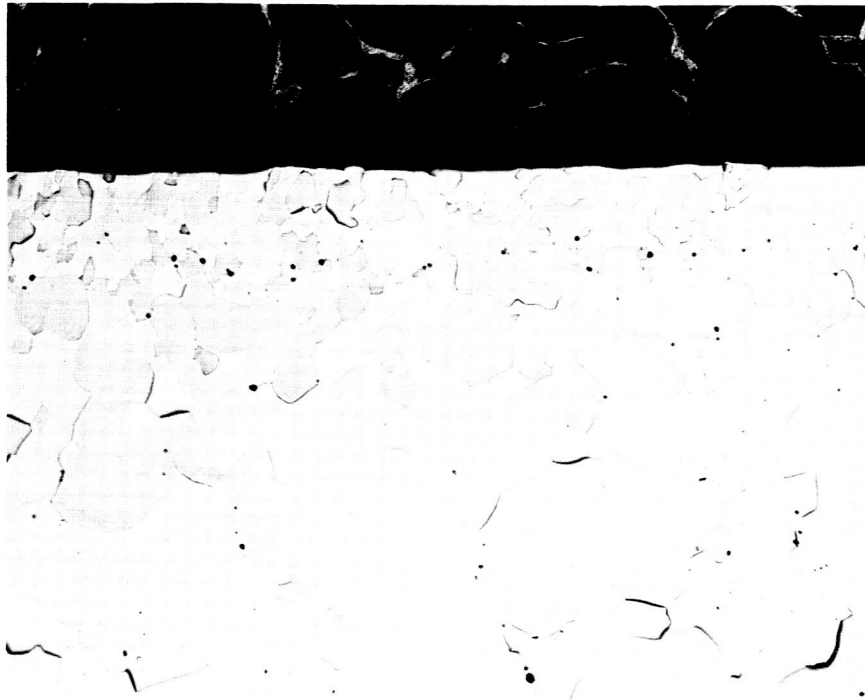


FIGURE 17. CREEP TEST DATA, VAPOR DEPOSITED TUNGSTEN, TESTED AT 2800°F (1538°C) AND 2000 PSI, (1.38×10^8 N/m²) IN VACUUM ENVIRONMENT < 1×10^{-8} TORR



413 DPH

100X

FIGURE 18. Vapor Deposited Tungsten, Creep Tested 2863 Hours at 3200°F (1760°C) and 1000 psi (6.89×10^6 N/m²), Unetched

APPENDIX I

CREEP TEST DATA

TABLE I

CREEP TEST DATA, TZC PLATE, HEAT M-80, RECRYSTALLIZED AT 3092°F (1700°C) FOR 1 HOUR,
TESTED AT 2000°F (1093°C), 20,000 PSI (1.38 x 10⁸N/m²)

<u>Time</u>	<u>Length Change</u> <u>ΔL (inch)</u> <u>(2" G. L.)</u>	<u>Creep</u> <u>(%)</u>	<u>Pressure</u> <u>(Torr)</u>
1 minutes	.00000	.000	1.2 x 10 ⁻⁹
2	-.00020	-.010	
3	-.00040	-.020	
4	-.00030	-.015	
5	-.00030	-.015	
10	-.00005	-.002	
15	.00005	.002	
20	.00005	.002	
25	.00010	.005	
30	.00010	.005	
60	.00005	.002	
90	-.00005	-.002	
17.2 hours	.00040	.020	2.6 x 10 ⁻⁹
41.3	.00060	.030	2.2 x 10 ⁻⁹
65.2	.00080	.040	2.2 x 10 ⁻⁹
89.2	.00115	.058	2.0 x 10 ⁻⁹
161.3	.00110	.055	1.3 x 10 ⁻⁹
185.7	.00130	.065	1.7 x 10 ⁻⁹
209.1	.00125	.068	1.7 x 10 ⁻⁹
233.2	.00125	.062	1.4 x 10 ⁻⁹
257.3	.00130	.065	1.3 x 10 ⁻⁹
329.2	.00140	.070	2.0 x 10 ⁻⁹
355.9	.00145	.072	3.2 x 10 ⁻⁹
377.0	.00145	.072	3.4 x 10 ⁻⁹
401.1	.00145	.072	2.4 x 10 ⁻⁹
425.0	.00150	.075	1.5 x 10 ⁻⁹
497.2	.00170	.085	1.9 x 10 ⁻⁹
521.4	.00170	.085	3.1 x 10 ⁻⁹
545.4	.00165	.082	4.8 x 10 ⁻⁹
569.2	.00170	.085	4.5 x 10 ⁻⁹
593.1	.00170	.085	4.6 x 10 ⁻⁹
665.2	.00165	.082	5.0 x 10 ⁻⁹
713.3	.00160	.080	4.6 x 10 ⁻⁹
762.8	.00170	.085	--
833.4	.00175	.088	1.5 x 10 ⁻⁸
881.4	.00185	.092	6.1 x 10 ⁻⁹
905.2	.00175	.088	5.8 x 10 ⁻⁹

TABLE I (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1001.1 hours	.00185	.092	3.9×10^{-9}
1049.2	.00185	.092	6.4×10^{-9}
1097.3	.00190	.095	--
1168.4	.00195	.098	4.2×10^{-9}
1216.2	.00200	.100	7.5×10^{-9}
1264.3	.00195	.098	7.0×10^{-9}
1336.7	.00210	.105	7.5×10^{-9}
1389.5	.00250	.125	--
1433.4	.00255	.128	7.2×10^{-9}
1504.2	.00260	.130	1.3×10^{-8}
1552.3	.00270	.135	1.2×10^{-8}
1600.2	.00265	.132	2.6×10^{-9}
1672.4	.00270	.135	5.5×10^{-9}
1720.4	.00275	.138	3.8×10^{-9}
1768.5	.00285	.142	4.6×10^{-9}
1840.1	.00305	.152	4.4×10^{-9}
1894.6	.00310	.155	4.4×10^{-9}
1936.3	.00315	.158	3.8×10^{-9}
1985.6	.00310	.155	3.8×10^{-9}
2032.2	.00325	.162	4.0×10^{-9}
2057.0	.00330	.165	4.0×10^{-9}
2104.1	.00335	.168	3.8×10^{-9}
2176.1	.00345	.172	3.5×10^{-9}
2248.4	.00370	.185	4.2×10^{-9}
2272.2	.00360	.180	7.5×10^{-9}
2344.2	.00375	.188	2.4×10^{-9}
2396.9	.00380	.190	4.6×10^{-9}
2440.2	.00390	.195	4.4×10^{-9}
2512.0	.00400	.200	2.7×10^{-9}
2584.4	.00400	.200	2.9×10^{-9}
2680.2	.00400	.200	7.4×10^{-9}
2752.2	.00405	.202	5.4×10^{-9}
2872.4	.00415	.208	3.8×10^{-9}
2920.8	.00420	.210	6.2×10^{-9}
3016.1	.00425	.212	3.8×10^{-9}
3088.4	.00435	.218	2.6×10^{-9}
3184.6	.00440	.220	4.2×10^{-9}
3256.3	.00450	.225	4.4×10^{-9}

TABLE I (Continued)

<u>Time</u>	<u>Length Change L (inch) (2" G. L.)</u>	<u>Creep %</u>	<u>Pressure (Torr)</u>
3355.4 hours	.00460	.230	--
3429.1	.00460	.230	--
3530.3	.00490	.245	--
3593.5	.00495	.247	7.8 x 10 ⁻⁹
3689.9	.00500	.250	8.0 x 10 ⁻⁹
3760.5	.00510	.255	8.0 x 10 ⁻⁹
3856.2	.00515	.257	8.2 x 10 ⁻⁹
3928.5	.00525	.262	8.2 x 10 ⁻⁹
4024.1	.00575	.282	8.7 x 10 ⁻⁹
4096.3	.00620	.310	8.2 x 10 ⁻⁹
4192.3	.00640	.320	8.2 x 10 ⁻⁹
4264.1	.00640	.320	8.2 x 10 ⁻⁹
4384.3	.00640	.320	8.4 x 10 ⁻⁹
4432.3	.00640	.320	9.0 x 10 ⁻⁹
4528.3	.00630	.315	8.6 x 10 ⁻⁹
4600.5	.00640	.320	9.4 x 10 ⁻⁹
4696.7	.00625	.312	9.5 x 10 ⁻⁹
4769.2	.00640	.320	8.5 x 10 ⁻⁹
4866.4	.00635	.318	9.2 x 10 ⁻⁹
4936.5	.00630	.315	9.2 x 10 ⁻⁹
5032.5	.00635	.318	9.2 x 10 ⁻⁹
5104.4	.00660	.330	8.4 x 10 ⁻⁹
5200.9	.00660	.330	9.5 x 10 ⁻⁹
5272.3	.00670	.335	8.8 x 10 ⁻⁹
5368.8	.00675	.338	9.4 x 10 ⁻⁹
5440.3	.00685	.342	9.4 x 10 ⁻⁹
5536.2	.00700	.350	1.0 x 10 ⁻⁸
5608.0	.00705	.352	3.4 x 10 ⁻⁹
5705.8	.00715	.358	6.4 x 10 ⁻⁹
5777.0	.00720	.360	4.9 x 10 ⁻⁹
5873.3	.00730	.365	4.9 x 10 ⁻⁹
5945.1	.00745	.372	3.4 x 10 ⁻⁹
6041.2	.00750	.375	2.8 x 10 ⁻⁹
6113.2	.00770	.385	3.4 x 10 ⁻⁹
6209.9	.00770	.385	3.3 x 10 ⁻⁹
6305.5	.00775	.388	3.5 x 10 ⁻⁹
6377.5	.00780	.390	6.3 x 10 ⁻⁹
6449.2	.00775	.388	7.0 x 10 ⁻⁹
6545.7	.00770	.385	8.2 x 10 ⁻⁹
6617.2	.00780	.390	7.4 x 10 ⁻⁹
6713.2	.00780	.390	7.9 x 10 ⁻⁹
6785.3	.00780	.390	7.8 x 10 ⁻⁹
6881.6	.00810	.405	8.0 x 10 ⁻⁹
6953.4	.00790	.395	8.3 x 10 ⁻⁹
7052.7	.00805	.402	8.2 x 10 ⁻⁹
7125.5	.00810	.405	8.1 x 10 ⁻⁹

TABLE I (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
7217.2 hours	.00810	.410	8.2 x 10 ⁻⁹
7386.0	.00815	.408	7.9 x 10 ⁻⁹
7457.2	.00825	.412	7.5 x 10 ⁻⁹
7553.3	.00830	.415	7.6 x 10 ⁻⁹
7625.7	.00835	.418	7.0 x 10 ⁻⁹
7721.9	.00845	.422	7.0 x 10 ⁻⁹
7793.6	.00845	.422	7.3 x 10 ⁻⁹
7889.4	.00850	.425	6.5 x 10 ⁻⁹
7961.2	.00855	.428	7.1 x 10 ⁻⁹
8057.4	.00855	.428	7.4 x 10 ⁻⁹
8129.4	.00860	.430	7.3 x 10 ⁻⁹
8225.3	.00870	.435	5.2 x 10 ⁻⁹
8297.5	.00875	.438	4.3 x 10 ⁻⁹
8393.2	.00880	.440	1.6 x 10 ⁻⁹
8465.6	.00885	.442	4.8 x 10 ⁻⁹
8561.4	.00890	.445	4.8 x 10 ⁻⁹
8633.1	.00895	.448	4.6 x 10 ⁻⁹
8729.1	.00900	.450	5.3 x 10 ⁻⁹
8801.3	.00905	.452	5.2 x 10 ⁻⁹
8969.3	.00915	.458	6.0 x 10 ⁻⁹
9065.3	.00920	.460	7.5 x 10 ⁻⁹
9137.2	.00925	.462	9.6 x 10 ⁻⁹

Test in progress
Specimen B-9

TABLE II

CREEP TEST DATA, TZC PLATE, RECRYSTALLIZED AT 3092°F (1700°C), FOR 1 HOUR,
 TESTED AT 1856°F (1013°C). 25,000 psi (1.72×10^8 N/m²)
 HEAT M-80

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minute(s)	-.00005	-.002	
2	.00000	.000	
3	-.00005	-.002	
4	.00005	.002	
5	.00005	.002	
6	.00010	.005	
7	.00005	.002	
8	.00000	.000	
9	.00000	.000	
10	.00005	.002	
15	-.00005	-.002	
20	.00015	.008	
25	.00015	.008	
30	.00025	.012	
60	.00065	.032	
19.3 hours	.00085	.042	1.4×10^{-8}
42.1	.00095	.048	1.3×10^{-8}
68.2	.00095	.048	1.1×10^{-8}
138.4	.00090	.045	5.8×10^{-9}
162.8	.00085	.042	6.6×10^{-9}
186.0	.00085	.042	6.8×10^{-9}
210.3	.00080	.040	5.8×10^{-9}
306.2	.00075	.038	5.2×10^{-9}
330.2	.00090	.045	4.4×10^{-9}
354.2	.00085	.042	3.4×10^{-9}
381.6	.00095	.048	--
402.4	.00095	.048	3.6×10^{-9}
460.7	.00105	.052	2.5×10^{-9}
484.5	.00105	.052	2.8×10^{-9}
508.5	.00125	.062	3.4×10^{-9}
532.4	.00105	.052	3.8×10^{-9}
556.8	.00105	.052	3.2×10^{-9}
628.9	.00105	.052	3.0×10^{-9}
681.7	.00115	.058	--
725.6	.00125	.062	3.1×10^{-9}
796.4	.00130	.065	2.0×10^{-9}
844.8	.00145	.072	2.2×10^{-9}
892.4	.00145	.072	1.6×10^{-9}
964.6	.00140	.070	2.8×10^{-9}

TABLE II (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep %</u>	<u>Pressure (Torr)</u>
1012.6 hours	.00155	.078	2.7×10^{-9}
1060.7	.00170	.085	2.6×10^{-9}
1132.3	.00165	.082	2.4×10^{-9}
1186.9	.00165	.082	2.0×10^{-9}
1228.6	.00170	.085	1.8×10^{-9}
1277.8	.00170	.085	2.2×10^{-9}
1324.4	.00165	.082	2.3×10^{-9}
1349.2	.00175	.088	1.4×10^{-9}
1396.3	.00185	.092	1.8×10^{-9}
1468.3	.00185	.092	2.5×10^{-9}
1516.4	.00180	.090	2.6×10^{-9}
1564.4	.00185	.092	3.1×10^{-9}
1636.4	.00195	.098	2.5×10^{-9}
1689.1	.00205	.102	2.2×10^{-9}
1732.4	.00195	.098	2.8×10^{-9}
1804.3	.00200	.100	2.0×10^{-9}
1876.7	.00215	.108	2.0×10^{-9}
1972.6	.00210	.105	2.3×10^{-9}
2044.4	.00225	.112	9.6×10^{-10}
2164.7	.00225	.112	2.5×10^{-9}
2213.1	.00235	.118	1.4×10^{-9}
2308.3	.00230	.115	1.2×10^{-9}
2380.7	.00235	.118	2.5×10^{-9}
2479.4	.00235	.118	1.2×10^{-9}
2548.4	.00235	.118	2.6×10^{-9}
2647.3	.00245	.122	1.8×10^{-9}
2720.0	.00245	.122	1.1×10^{-9}
2822.6	.00260	.130	9.1×10^{-10}
2886.4	.00305	.152	2.2×10^{-9}
2982.1	.00295	.148	1.6×10^{-9}
3052.8	.00320	.160	1.6×10^{-9}
3148.7	.00315	.158	1.6×10^{-9}
3220.7	.00315	.158	1.6×10^{-9}
3316.4	.00310	.155	1.9×10^{-9}
3388.8	.00315	.158	1.8×10^{-9}
3484.6	.00335	.168	1.6×10^{-9}
3556.4	.00330	.165	1.4×10^{-9}
3676.5	.00335	.168	1.5×10^{-9}
3724.5	.00330	.165	1.9×10^{-9}
3820.7	.00330	.165	1.6×10^{-9}
3892.7	.00320	.160	1.7×10^{-9}
3988.9	.00315	.158	2.8×10^{-9}
4061.4	.00315	.158	1.3×10^{-9}
4158.8	.00300	.150	1.8×10^{-9}
4228.7	.00300	.150	6.0×10^{-10}
4325.1	.00300	.150	1.5×10^{-9}
4396.7	.00315	.158	1.8×10^{-9}
4493.1	.00315	.158	2.0×10^{-9}

TABLE II (Continued)

<u>Time</u>	<u>Length Change L (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
4564.6 hours	.00310	.155	2.0×10^{-9}
4661.2	.00315	.158	1.4×10^{-9}
4732.6	.00320	.160	2.0×10^{-9}
4828.5	.00305	.152	1.7×10^{-9}
4900.3	.00310	.155	1.7×10^{-9}
4998.1	.00305	.152	1.4×10^{-9}
5069.3	.00305	.152	2.4×10^{-9}
5165.5	.00305	.152	1.6×10^{-9}
5237.4	.00310	.155	1.2×10^{-9}
5333.5	.00310	.155	1.1×10^{-9}
5405.5	.00305	.152	1.6×10^{-9}
5502.2	.00305	.152	1.1×10^{-9}
5598.0	.00310	.155	1.4×10^{-9}
5669.8	.00310	.155	1.8×10^{-9}
5741.4	.00320	.160	1.6×10^{-9}
5838.0	.00315	.158	1.6×10^{-9}
5909.4	.00325	.162	1.5×10^{-9}
6005.6	.00315	.158	1.5×10^{-9}
6077.5	.00315	.158	1.6×10^{-9}
6173.9	.00315	.158	1.6×10^{-9}
6245.7	.00320	.160	1.6×10^{-9}
6345.0	.00325	.162	1.0×10^{-9}
6417.7	.00335	.168	1.3×10^{-9}
6509.4	.00335	.168	1.5×10^{-9}
6582.0	.00340	.170	1.0×10^{-9}
6678.2	.00335	.168	1.6×10^{-9}
6749.4	.00340	.170	1.5×10^{-9}
6845.6	.00345	.172	1.6×10^{-9}
6917.9	.00350	.175	2.2×10^{-9}
7014.1	.00355	.178	1.4×10^{-9}
7085.9	.00350	.175	2.1×10^{-9}
7181.9	.00345	.172	2.3×10^{-9}
7253.6	.00355	.178	3.0×10^{-9}
7350.0	.00345	.172	1.4×10^{-9}
7421.6	.00345	.172	1.4×10^{-9}
7517.6	.00345	.172	7.8×10^{-10}
7589.7	.00350	.175	1.8×10^{-9}
7685.4	.00345	.172	1.6×10^{-9}
7757.8	.00340	.170	2.2×10^{-9}
7853.8	.00345	.172	1.8×10^{-9}
7925.4	.00340	.170	1.6×10^{-9}
8021.3	.00340	.170	1.3×10^{-9}
8093.4	.00340	.170	1.6×10^{-9}
8189.3	.00345	.172	1.7×10^{-9}
8261.5	.00345	.172	1.9×10^{-9}
8357.5	.00335	.168	1.1×10^{-9}
8429.5	.00335	.168	1.6×10^{-9}

Test in progress
Specimen B-11

TABLE III

CREEP TEST DATA, TZC PLATE, HEAT M-80, RECRYSTALLIZED AT 3092°F (1700°C), 1 HOUR,
TESTED AT 2056°F (1124°C), 19,000 PSI (1.31 x 10⁸N/m²)

<u>Time</u>	<u>Length Change</u> <u>ΔL (inch)</u> <u>(2" G.L.)</u>	<u>Creep</u> <u>(%)</u>	<u>Pressure</u> <u>(Torr)</u>
1 minutes	.00010	.005	7.0 x 10 ⁻⁸
2	.00020	.010	
3	.00030	.015	
4	.00050	.025	
5	.00055	.028	
6	.00065	.032	
7	.00085	.042	
8	.00095	.048	
9	.00105	.052	
10	.00120	.060	
12	.00130	.065	
13	.00140	.070	
14	.00150	.075	
15	.00160	.080	6.9 x 10 ⁻⁸
20	.00165	.082	
25	.00170	.085	
30	.00170	.085	6.9 x 10 ⁻⁸
40	.00175	.088	
45	.00175	.088	
60	.00180	.090	6.8 x 10 ⁻⁸
90	.00180	.090	6.7 x 10 ⁻⁸
15.7 hours	.00180	.090	3.5 x 10 ⁻⁸
87.1	.00180	.090	1.4 x 10 ⁻⁸
111.2	.00100	.050	9.8 x 10 ⁻⁹
133.4	.00140	.070	7.0 x 10 ⁻⁹
159.0	.00135	.068	3.0 x 10 ⁻⁹
181.6	.00130	.065	--
239.9	.00135	.068	4.2 x 10 ⁻⁹
263.7	.00130	.065	5.1 x 10 ⁻⁹
287.7	.00150	.075	4.5 x 10 ⁻⁹
309.9	.00140	.070	3.8 x 10 ⁻⁹
334.3	.00150	.075	3.2 x 10 ⁻⁹
406.5	.00145	.072	3.5 x 10 ⁻⁹
459.3	.00155	.078	--
503.2	.00150	.075	2.2 x 10 ⁻⁹
573.9	.00175	.088	1.2 x 10 ⁻⁹

TABLE III (Continued)

<u>Time</u>	<u>Length Change</u> <u>ΔL (inch)</u> <u>(2" G. L.)</u>	<u>Creep</u> <u>(%)</u>	<u>Pressure</u> <u>(Torr)</u>
622.5 hours	.00175	.088	1.1×10^{-9}
669.9	.00180	.090	3.8×10^{-9}
742.3	.00185	.092	2.8×10^{-9}
790.2	.00190	.095	2.8×10^{-9}
838.3	.00185	.092	1.8×10^{-9}
909.9	.00195	.098	3.2×10^{-9}
964.8	.00205	.102	2.6×10^{-9}
1006.2	.00210	.105	2.6×10^{-9}
1055.3	.00215	.108	2.7×10^{-9}
1102.0	.00220	.110	2.9×10^{-9}
1126.8	.00220	.110	1.7×10^{-9}
1173.9	.00220	.110	1.0×10^{-9}
1245.9	.00215	.108	4.2×10^{-10}
1294.0	.00225	.112	2.1×10^{-9}
1342.0	.00235	.118	2.1×10^{-10}
1414.1	.00235	.118	1.4×10^{-9}
1466.7	.00235	.118	2.5×10^{-9}
1509.0	.00225	.112	2.0×10^{-9}
1581.8	.00245	.122	7.5×10^{-10}
1654.2	.00245	.122	1.2×10^{-9}
1750.2	.00240	.120	1.3×10^{-9}
1822.1	.00235	.118	7.0×10^{-10}
1942.2	.00235	.118	8.4×10^{-10}
1990.6	.00240	.120	7.4×10^{-10}
2086.2	.00250	.125	1.6×10^{-9}
2158.2	.00260	.130	1.4×10^{-9}
2254.4	.00265	.132	7.2×10^{-10}
2326.1	.00265	.132	2.0×10^{-9}
2424.7	.00280	.140	1.4×10^{-9}
2497.4	.00305	.152	1.2×10^{-9}
2600.1	.00310	.155	8.0×10^{-10}
2664.7	.00325	.162	2.4×10^{-9}
2759.8	.00345	.172	2.6×10^{-9}
2854.3	.00355	.178	1.5×10^{-9}
2926.3	.00355	.178	1.5×10^{-9}
2998.2	.00355	.178	2.1×10^{-9}
3094.0	.00365	.182	2.1×10^{-9}
3166.4	.00360	.180	2.2×10^{-9}
3262.2	.00355	.178	9.2×10^{-9}

TABLE III (Continued)

<u>Time</u>	<u>Length Change</u> <u>ΔL (inch)</u> <u>(2" G. L.)</u>	<u>Creep</u> <u>%</u>	<u>Pressure</u> <u>(Torr)</u>
3334.1 hours	.00360	.180	2.2×10^{-9}
3454.1	.00340	.170	1.6×10^{-9}
3502.1	.00365	.182	2.0×10^{-9}
3598.2	.00315	.158	1.1×10^{-9}
3670.3	.00315	.158	1.0×10^{-9}
3766.6	.00300	.150	9.0×10^{-10}
3839.0	.00305	.152	2.5×10^{-9}
3936.4	.00300	.150	9.1×10^{-10}
4006.3	.00295	.148	2.0×10^{-9}
4102.6	.00305	.152	2.1×10^{-9}
4174.3	.00310	.155	1.9×10^{-9}
4270.6	.00320	.160	1.0×10^{-9}
4342.2	.00330	.165	2.0×10^{-9}
4438.7	.00330	.165	2.5×10^{-9}
4510.1	.00355	.178	1.4×10^{-9}
4606.2	.00340	.170	2.0×10^{-9}
4677.8	.00345	.172	1.8×10^{-9}
4775.6	.00345	.172	1.8×10^{-9}
4846.8	.00335	.168	1.6×10^{-9}
4943.1	.00335	.168	1.6×10^{-9}
5015.0	.00355	.178	1.7×10^{-9}
5111.1	.00340	.170	1.6×10^{-9}
5183.2	.00345	.172	1.0×10^{-9}
5279.7	.00350	.175	1.6×10^{-9}
5375.6	.00355	.178	1.5×10^{-9}
5447.3	.00355	.178	2.5×10^{-9}
5518.9	.00355	.178	2.5×10^{-9}
5615.6	.00355	.178	1.0×10^{-9}
5687.0	.00360	.180	2.5×10^{-9}
5783.8	.00355	.178	2.4×10^{-9}
5855.1	.00365	.182	2.4×10^{-9}
5951.5	.00375	.188	2.4×10^{-9}
6023.3	.00380	.190	2.5×10^{-9}
6122.5	.00395	.198	9.0×10^{-10}
6195.3	.00390	.195	2.4×10^{-9}
6286.9	.00400	.200	2.5×10^{-9}

TABLE III (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
6359.5 hours	.00405	.202	1.0 x 10 ⁻⁹
6455.8	.00410	.205	1.7 x 10 ⁻⁹
6527.0	.00415	.208	2.5 x 10 ⁻⁹
6623.2	.00410	.205	1.6 x 10 ⁻⁹
6695.6	.00410	.205	2.3 x 10 ⁻⁹
6791.8	.00420	.210	1.6 x 10 ⁻⁹
6864.8	.00420	.210	1.6 x 10 ⁻⁹
6959.5	.00415	.208	1.4 x 10 ⁻⁹
7031.2	.00420	.210	2.4 x 10 ⁻⁹
7127.6	.00435	.218	1.0 x 10 ⁻⁹
7199.2	.00430	.215	2.2 x 10 ⁻⁹
7295.2	.00430	.215	7.2 x 10 ⁻¹⁰
7367.3	.00430	.215	1.1 x 10 ⁻⁹
7463.2	.00425	.212	1.0 x 10 ⁻⁹
7535.5	.00430	.215	1.6 x 10 ⁻⁹
7631.3	.00440	.220	1.6 x 10 ⁻⁹
7702.9	.00440	.220	1.6 x 10 ⁻⁹
7798.9	.00440	.220	1.5 x 10 ⁻⁹
7870.9	.00440	.220	1.7 x 10 ⁻⁹
7966.8	.00445	.222	1.6 x 10 ⁻⁹
8039.1	.00440	.220	1.6 x 10 ⁻⁹
8135.2	.00450	.225	1.4 x 10 ⁻⁹
8207.0	.00455	.228	1.4 x 10 ⁻⁹

Test in progress
Specimen B-12

TABLE IV

CREEP TEST DATA, TZC PLATE, HEAT M-91, ANNEALED 2300°F (1260°C) 1 HOUR,

TESTED 1800°F (982°C), 44,000 PSI (3.03 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minutes	-.00010	-.005	3.2 x 10 ⁻⁸
2	-.00020	-.010	3.2 x 10 ⁻⁸
4	-.00025	-.012	3.2 x 10 ⁻⁸
5	-.00025	-.012	3.2 x 10 ⁻⁸
6	-.00030	-.015	3.2 x 10 ⁻⁸
7	-.00015	-.008	3.2 x 10 ⁻⁸
8	-.00015	-.008	3.2 x 10 ⁻⁸
9	-.00015	-.008	3.2 x 10 ⁻⁸
10	-.00015	-.008	3.2 x 10 ⁻⁸
15	-.00020	-.010	3.2 x 10 ⁻⁸
30	-.00015	-.008	3.2 x 10 ⁻⁸
45	-.00010	-.005	3.2 x 10 ⁻⁸
60	-.00010	-.005	3.2 x 10 ⁻⁸
67.3 Hours	.00270	.135	1.1 x 10 ⁻⁸
91.1	.00305	.152	1.0 x 10 ⁻⁸
114.9	.00385	.192	1.1 x 10 ⁻⁸
139.7	.00380	.190	1.0 x 10 ⁻⁸
162.8	.00405	.202	9.6 x 10 ⁻⁹
237.1	.00515	.258	9.0 x 10 ⁻⁹
258.7	.00530	.265	8.2 x 10 ⁻⁹
282.6	.00550	.275	3.6 x 10 ⁻⁹
307.0	.00560	.280	3.2 x 10 ⁻⁹
331.2	.00600	.300	3.1 x 10 ⁻⁹
403.4	.00675	.338	3.7 x 10 ⁻⁹
426.7	.00645	.322	3.4 x 10 ⁻⁹
450.9	.00665	.332	2.6 x 10 ⁻⁹
475.0	.00715	.358	2.4 x 10 ⁻⁹
498.9	.00775	.388	3.4 x 10 ⁻⁹
571.4	.00745	.372	3.0 x 10 ⁻⁹
595.3	.00745	.372	2.8 x 10 ⁻⁹
619.1	.00820	.410	2.8 x 10 ⁻⁹
642.9	.00795	.398	2.8 x 10 ⁻⁹
667.0	.00765	.382	2.8 x 10 ⁻⁹
739.5	.00840	.420	3.0 x 10 ⁻⁹
763.1	.00845	.422	2.5 x 10 ⁻⁹
788.4	.00875	.438	2.2 x 10 ⁻⁹
810.9	.00890	.445	2.4 x 10 ⁻⁹
835.1	.00880	.440	2.3 x 10 ⁻⁹

TABLE IV (Continued)

<u>Time</u>	<u>Length Change L (inch) (2ⁿ G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
906.9	.00890	.445	2.3 x 10 ⁻⁹
978.6	.00965	.482	2.2 x 10 ⁻⁹
1076.4	.01005	.502	2.2 x 10 ⁻⁹
1147.6	.01020	.510	4.8 x 10 ⁻⁹
1243.8	.01045	.522	4.4 x 10 ⁻⁹
1315.7	.01065	.532	4.3 x 10 ⁻⁹
1411.9	.01100	.550	4.4 x 10 ⁻⁹
1580.5	.01170	.585	2.7 x 10 ⁻⁹
1676.3	.01205	.602	4.0 x 10 ⁻⁹
1748.1	.01220	.610	4.2 x 10 ⁻⁹
1819.7	.01255	.628	2.8 x 10 ⁻⁹
1916.3	.01285	.642	3.2 x 10 ⁻⁹
1987.7	.01310	.655	2.0 x 10 ⁻⁹
2084.2	.01345	.672	3.2 x 10 ⁻⁹
2155.8	.01365	.682	2.4 x 10 ⁻⁹
2252.2	.01375	.688	3.1 x 10 ⁻⁹
2324.0	.01405	.702	2.3 x 10 ⁻⁹
2423.3	.01455	.728	2.0 x 10 ⁻⁹
2496.0	.01465	.732	1.9 x 10 ⁻⁹
2587.7	.01495	.748	2.6 x 10 ⁻⁹
2660.3	.01505	.752	1.9 x 10 ⁻⁹
2756.5	.01515	.758	2.5 x 10 ⁻⁹
2827.7	.01525	.762	2.0 x 10 ⁻⁹
2923.9	.01590	.795	3.4 x 10 ⁻⁹
2996.4	.01610	.805	5.4 x 10 ⁻⁹
3092.4	.01640	.820	1.9 x 10 ⁻⁹
3164.2	.01640	.820	2.4 x 10 ⁻⁹
3260.2	.01665	.832	4.8 x 10 ⁻⁹
3331.9	.01690	.845	2.2 x 10 ⁻⁹
3428.4	.01705	.852	2.6 x 10 ⁻⁹
3500.0	.01730	.865	1.8 x 10 ⁻⁹
3595.9	.01745	.872	1.3 x 10 ⁻⁹
3668.0	.01770	.885	2.4 x 10 ⁻⁹
3763.9	.01795	.898	2.6 x 10 ⁻⁹
3836.2	.01820	.910	3.4 x 10 ⁻⁹
3932.0	.01845	.922	3.5 x 10 ⁻⁹
4003.7	.01865	.932	3.5 x 10 ⁻⁹
4099.6	.01875	.938	3.4 x 10 ⁻⁹
4172.0	.01885	.942	3.6 x 10 ⁻⁹
4267.6	.01925	.962	3.6 x 10 ⁻⁹
4339.9	.01950	.975	3.7 x 10 ⁻⁹
4435.9	.01960	.980	3.3 x 10 ⁻⁹
4507.8	.01975	.988	3.2 x 10 ⁻⁹
4603.6	.02030	1.015	3.3 x 10 ⁻⁹

Test Terminated - 1% Creep

Specimen B-19

TABLE V

CREEP TEST DATA, TZC PLATE, HEAT M-91, ANNEALED AT 3092°F (1700°C) FOR 1 HOUR,

TESTED AT 2000°F (1093°C), 20,000 PSI ($1.38 \times 10^8 \text{N/m}^2$)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minutes	.00000	.000	8.2×10^{-9}
2	.00005	.002	8.2×10^{-9}
3	.00010	.005	8.2×10^{-9}
4	.00010	.005	8.2×10^{-9}
5	.00015	.008	8.2×10^{-9}
6	.00020	.010	8.2×10^{-9}
7	.00020	.010	8.2×10^{-9}
8	.00020	.010	8.2×10^{-9}
9	.00015	.008	8.2×10^{-9}
10	.00020	.010	8.2×10^{-9}
15	.00025	.012	8.2×10^{-9}
20	.00020	.010	8.2×10^{-9}
25	.00025	.012	8.2×10^{-9}
30	.00025	.012	8.2×10^{-9}
60	.00020	.010	8.2×10^{-9}
1.7 Hours	.00030	.015	8.2×10^{-9}
19.0	.00075	.038	8.4×10^{-9}
43.9	.00100	.050	7.2×10^{-9}
115.2	.00155	.078	4.0×10^{-9}
139.2	.00185	.092	3.2×10^{-9}
163.6	.00210	.105	2.6×10^{-9}
187.1	.00220	.110	2.4×10^{-9}
211.4	.00240	.120	2.1×10^{-9}
283.2	.00270	.135	1.4×10^{-9}
307.3	.00290	.145	1.2×10^{-9}
331.2	.00300	.150	1.1×10^{-9}
355.2	.00295	.148	9.7×10^{-10}
379.3	.00295	.148	9.6×10^{-10}
451.9	.00310	.155	7.9×10^{-10}
499.6	.00350	.175	6.7×10^{-10}
547.7	.00355	.178	6.1×10^{-10}
619.5	.00360	.180	9.2×10^{-10}
643.4	.00365	.182	6.3×10^{-10}
667.4	.00365	.182	8.1×10^{-10}
691.1	.00365	.182	8.2×10^{-10}
715.5	.00375	.188	7.8×10^{-10}

TABLE V (Continued)

<u>Time</u>	<u>Length Change L (inch) (2^m G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
787.7 Hours	.00410	.205	7.4 x 10 ⁻¹⁰
811.6	.00420	.210	7.1 x 10 ⁻¹⁰
835.3	.00435	.218	7.2 x 10 ⁻¹⁰
859.2	.00440	.220	7.0 x 10 ⁻¹⁰
883.2	.00445	.222	7.0 x 10 ⁻¹⁰
956.3	.00460	.230	6.6 x 10 ⁻¹⁰
980.0	.00470	.235	6.4 x 10 ⁻¹⁰
1003.4	.00455	.228	6.4 x 10 ⁻¹⁰
1027.2	.00465	.232	6.2 x 10 ⁻¹⁰
1123.7	.00485	.242	6.0 x 10 ⁻¹⁰
1195.5	.00490	.245	5.7 x 10 ⁻¹⁰
1294.7	.00515	.258	6.0 x 10 ⁻¹⁰
1367.4	.00525	.262	5.8 x 10 ⁻¹⁰
1459.1	.00560	.280	5.6 x 10 ⁻¹⁰
1531.7	.00585	.292	5.4 x 10 ⁻¹⁰
1627.9	.00600	.300	5.4 x 10 ⁻¹⁰
1699.2	.00620	.310	5.4 x 10 ⁻¹⁰
1795.3	.00640	.320	5.4 x 10 ⁻¹⁰
1867.8	.00655	.328	5.1 x 10 ⁻¹⁰
1963.9	.00665	.332	5.1 x 10 ⁻¹⁰
2035.6	.00695	.348	4.7 x 10 ⁻¹⁰
2131.6	.00720	.360	4.8 x 10 ⁻¹⁰
2203.3	.00740	.370	4.9 x 10 ⁻¹⁰
2299.8	.00745	.372	4.9 x 10 ⁻¹⁰
2371.4	.00755	.378	4.8 x 10 ⁻¹⁰
2467.3	.00760	.380	3.6 x 10 ⁻¹⁰
2539.5	.00770	.385	2.6 x 10 ⁻¹⁰
2635.2	.00800	.400	3.8 x 10 ⁻¹⁰
2707.6	.00820	.410	3.4 x 10 ⁻¹⁰
2803.4	.00880	.440	3.4 x 10 ⁻¹⁰
2875.1	.00900	.450	3.4 x 10 ⁻¹⁰
2971.0	.00910	.455	3.1 x 10 ⁻¹⁰
3043.1	.00920	.460	3.6 x 10 ⁻¹⁰
3139.0	.00935	.468	3.3 x 10 ⁻¹⁰
3211.3	.00930	.465	3.4 x 10 ⁻¹⁰
3307.3	.00960	.480	3.3 x 10 ⁻¹⁰
3379.2	.00965	.482	3.2 x 10 ⁻¹⁰

Test in progress

Specimen B-20

TABLE VI

CREEP TEST DATA, TZC PLATE, HEAT M-91, ANNEALED AT 3092°F (1700°C) FOR 1 HOUR

AGED AT 2400°F (1316°C) FOR 5 HOURS

TESTED AT 2000°F (1093°C) 20,000 PSI (1.38 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2nd G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minutes	-.00010	-.005	6.0 x 10 ⁻⁹
2	.00000	.000	6.0 x 10 ⁻⁹
3	.00000	.000	6.0 x 10 ⁻⁹
4	.00000	.000	6.0 x 10 ⁻⁹
5	.00000	.000	6.0 x 10 ⁻⁹
6	.00005	.002	6.0 x 10 ⁻⁹
7	.00005	.002	6.0 x 10 ⁻⁹
8	.00000	.000	6.0 x 10 ⁻⁹
9	.00000	.000	6.0 x 10 ⁻⁹
10	-.00005	-.002	6.0 x 10 ⁻⁹
15	.00000	.000	6.0 x 10 ⁻⁹
30	.00020	.010	6.0 x 10 ⁻⁹
45	.00040	.020	6.0 x 10 ⁻⁹
60	.00040	.020	6.0 x 10 ⁻⁹
2 Hours	.00085	.042	6.0 x 10 ⁻⁹
3	.00120	.060	6.0 x 10 ⁻⁹
19.2	.00295	.148	6.0 x 10 ⁻⁹
91.2	.00640	.320	3.4 x 10 ⁻⁹
115.4	.00715	.358	2.6 x 10 ⁻⁹
139.3	.00800	.400	2.5 x 10 ⁻⁹
163.3	.00840	.420	2.4 x 10 ⁻⁹
187.3	.00855	.428	2.4 x 10 ⁻⁹
259.6	.01020	.510	1.9 x 10 ⁻⁹
283.3	.01050	.525	1.7 x 10 ⁻⁹
307.3	.01070	.535	1.8 x 10 ⁻⁹
331.4	.01110	.555	1.8 x 10 ⁻⁹
430.7	.01245	.622	1.8 x 10 ⁻⁹
503.5	.01345	.672	1.7 x 10 ⁻⁹
595.2	.01465	.732	1.4 x 10 ⁻⁹

TABLE VI (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
619.6 hours	.01490	.745	1.4 x 10 ⁻⁹
643.4	.01520	.760	1.4 x 10 ⁻⁹
667.8	.01530	.765	1.4 x 10 ⁻⁹
691.3	.01570	.785	1.3 x 10 ⁻⁹
764.0	.01680	.840	1.3 x 10 ⁻⁹
811.4	.01725	.862	1.3 x 10 ⁻⁹
835.2	.01735	.868	1.3 x 10 ⁻⁹
859.4	.01760	.880	1.3 x 10 ⁻⁹
931.3	.01815	.908	1.1 x 10 ⁻⁹
955.2	.01825	.912	1.3 x 10 ⁻⁹
979.3	.01850	.925	1.1 x 10 ⁻⁹
1003.7	.01885	.942	1.1 x 10 ⁻⁹
1027.6	.01900	.950	1.1 x 10 ⁻⁹
1102.2	.02000	1.000	1.0 x 10 ⁻⁹
1123.4	.02020	1.010	1.1 x 10 ⁻⁹

Test Terminated - 1% Creep
Specimen B-22

TABLE VII

CREEP TEST DATA, STRESS-RELIEVED TZM FORGED DISC, CLIMAX HEAT NO. 7502

TESTED AT 2000°F (1093°C), 10,000 PSI (6.89 x 10⁷N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minutes	-.00030	-.015	1.6 x 10 ⁻⁷
2	-.00015	-.008	
3	-.00015	-.008	
4	-.00015	-.008	
5	-.00005	-.002	
6	.00010	.005	
7	.00005	.002	
8	.00000	.000	
9	.00010	.005	
10	.00005	.002	
15	.00005	.002	
20	.00010	.005	
25	.00005	.002	
30	.00000	.000	
45	.00010	.005	
60	.00015	.008	
75	.00005	.002	
90	.00010	.005	
20.0 hours	-.00005	-.002	
74.7	.00030	.015	
125.7	.00100	.050	
136.5	.00800	.040	
160.3	.00085	.042	
184.4	.00085	.042	
208.5	.00090	.045	
232.2	.00090	.045	
304.4	.00100	.050	
328.3	.00100	.050	
352.2	.00105	.052	
376.6	.00105	.052	
400.8	.00110	.055	
457.5	.00130	.065	
472.6	.00135	.068	
497.0	.00140	.070	

Table VII (continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
520.2 hours	.00145	.072	1.2 x 10 ⁻⁹
544.1	.00145	.072	1.2 x 10 ⁻⁹
568.2	.00150	.075	1.2 x 10 ⁻⁹
640.2	.00155	.078	1.5 x 10 ⁻⁹
664.3	.00170	.085	9.2 x 10 ⁻¹⁰
688.6	.00175	.088	6.0 x 10 ⁻¹⁰
712.3	.00175	.088	7.4 x 10 ⁻¹⁰
736.3	.00170	.085	7.6 x 10 ⁻¹⁰
810.2	.00175	.088	1.3 x 10 ⁻⁹
832.2	.00185	.092	9.0 x 10 ⁻¹⁰
856.1	.00180	.090	9.2 x 10 ⁻¹⁰
880.1	.00200	.100	7.5 x 10 ⁻¹⁰
904.0	.00205	.102	7.7 x 10 ⁻¹⁰
982.8	.00210	.105	8.1 x 10 ⁻¹⁰
1000.2	.00210	.105	7.6 x 10 ⁻¹⁰
1024.2	.00210	.105	8.2 x 10 ⁻¹⁰
1048.3	.00220	.110	8.0 x 10 ⁻¹⁰
1072.1	.00220	.110	1.3 x 10 ⁻⁹
1144.0	.00230	.115	6.9 x 10 ⁻¹⁰
1168.3	.00235	.118	6.9 x 10 ⁻¹⁰
1192.2	.00240	.120	6.6 x 10 ⁻¹⁰
1216.4	.00250	.125	6.4 x 10 ⁻¹⁰
1240.2	.00250	.125	5.8 x 10 ⁻¹⁰
1336.2	.00250	.125	5.9 x 10 ⁻⁹
1360.3	.00250	.125	5.8 x 10 ⁻¹⁰
1384.3	.00250	.125	5.2 x 10 ⁻¹⁰
1408.5	.00250	.125	4.4 x 10 ⁻¹⁰
1480.3	.00260	.130	4.6 x 10 ⁻¹⁰
1552.2	.00270	.135	4.6 x 10 ⁻¹⁰
1648.3	.00320	.160	4.0 x 10 ⁻¹⁰
1696.4	.00320	.160	3.8 x 10 ⁻¹⁰
1720.6	.00320	.160	4.4 x 10 ⁻¹⁰
1816.4	.00320	.160	5.7 x 10 ⁻¹⁰
1864.2	.00315	.158	3.8 x 10 ⁻¹⁰
1912.3	.00325	.162	4.0 x 10 ⁻¹⁰
1984.3	.00330	.165	2.6 x 10 ⁻¹⁰
2032.2	.00335	.168	3.6 x 10 ⁻¹⁰
2080.1	.00340	.170	3.1 x 10 ⁻¹⁰
2152.3	.00340	.170	2.8 x 10 ⁻¹⁰

Table VII (continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
2200.6 hours	.00335	.168	2.3 x 10 ⁻¹⁰
2248.4	.00340	.170	1.6 x 10 ⁻¹⁰
2320.4	.00350	.175	2.7 x 10 ⁻¹⁰
2369.4	.00345	.172	2.0 x 10 ⁻¹⁰
2418.3	.00355	.178	9.2 x 10 ⁻¹¹
2488.4	.00345	.172	4.0 x 10 ⁻¹⁰
2536.1	.00350	.175	1.7 x 10 ⁻¹⁰
2560.3	.00345	.172	2.6 x 10 ⁻¹⁰
2656.3	.00355	.178	2.6 x 10 ⁻¹⁰
2704.3	.00350	.175	--
2752.4	.00350	.175	--
2823.5	.00355	.178	2.5 x 10 ⁻¹⁰
2871.3	.00365	.182	1.1 x 10 ⁻¹¹
2919.5	.00375	.188	1.7 x 10 ⁻¹⁰
2991.7	.00380	.190	7.2 x 10 ⁻¹¹
3044.5	.00380	.190	--
3088.4	.00380	.190	1.8 x 10 ⁻¹¹
3159.2	.00385	.192	1.6 x 10 ⁻¹¹
3231.2	.00390	.195	1.4 x 10 ⁻¹⁰
3327.5	.00385	.192	1.2 x 10 ⁻¹⁰
3399.4	.00395	.198	2.0 x 10 ⁻¹¹
3495.1	.00400	.200	8.2 x 10 ⁻¹²
3568.1	.00400	.200	9.5 x 10 ⁻¹¹
3640.6	.00410	.205	3.4 x 10 ⁻¹¹
3687.2	.00410	.205	1.9 x 10 ⁻¹¹
3735.3	.00415	.208	1.0 x 10 ⁻¹¹
3831.1	.00420	.210	1.2 x 10 ⁻¹¹
3903.5	.00425	.212	2.1 x 10 ⁻¹¹
3999.2	.00440	.220	1.0 x 10 ⁻¹¹
4071.3	.00450	.225	2.1 x 10 ⁻¹¹
4167.1	.00450	.225	1.8 x 10 ⁻¹⁰
4239.4	.00465	.232	1.8 x 10 ⁻¹¹
4335.4	.00460	.230	1.8 x 10 ⁻¹⁰
4407.3	.00465	.232	1.0 x 10 ⁻¹¹
4527.5	.00465	.232	1.2 x 10 ⁻¹¹
4575.9	.00475	.238	1.0 x 10 ⁻¹¹

TABLE VII (Continued)

<u>Time</u>	<u>Length Change</u> <u>ΔL (inch)</u> <u>(2" G. L.)</u>	<u>Creep</u> <u>%</u>	<u>Pressure</u> <u>(Torr)</u>
4671.2 hours	.00470	.235	7.5×10^{-11}
4743.5	.00475	.238	1.0×10^{-11}
4839.7	.00470	.235	1.8×10^{-11}
4911.3	.00470	.235	1.0×10^{-11}
5010.3	.00475	.238	8.5×10^{-11}
5084.1	.00475	.238	1.8×10^{-10}
5185.4	.00485	.242	3.4×10^{-10}
5249.1	.00490	.245	9.3×10^{-10}
5344.9	.00480	.240	4.2×10^{-10}
5415.6	.00500	.250	4.2×10^{-10}
5511.5	.00505	.252	1.1×10^{-9}
5583.5	.00500	.250	1.3×10^{-9}
5679.3	.00500	.250	1.7×10^{-9}
5751.4	.00510	.255	1.7×10^{-9}
5847.5	.00515	.258	4.4×10^{-9}
5919.3	.00520	.260	2.0×10^{-9}
6039.4	.00530	.265	2.0×10^{-9}
6087.4	.00540	.270	1.8×10^{-9}
6183.4	.00545	.272	4.3×10^{-10}
6255.6	.00550	.275	4.5×10^{-10}
6351.8	.00550	.275	2.0×10^{-9}
6424.3	.00555	.278	2.4×10^{-9}
6521.5	.00560	.280	2.0×10^{-9}
6591.6	.00550	.275	2.5×10^{-9}
6687.5	.00555	.278	3.0×10^{-9}
6759.6	.00565	.282	3.7×10^{-9}
6855.9	.00570	.285	4.2×10^{-10}
6927.5	.00580	.290	3.8×10^{-10}
7024.0	.00585	.292	4.1×10^{-10}
7095.4	.00590	.295	2.5×10^{-10}
7191.3	.00595	.298	4.5×10^{-10}
7263.1	.00595	.298	3.0×10^{-10}
7360.9	.00595	.298	5.2×10^{-10}
7432.1	.00605	.302	9.4×10^{-10}
7528.3	.00600	.300	8.8×10^{-10}
7600.2	.00605	.302	9.3×10^{-10}
7696.3	.00610	.305	9.7×10^{-10}
7768.3	.00605	.302	1.0×10^{-9}
7865.0	.00615	.308	5.0×10^{-10}
7960.5	.00620	.310	1.2×10^{-9}
8032.6	.00620	.310	9.0×10^{-10}
8104.2	.00630	.315	8.6×10^{-10}

TABLE VIII

CREEP TEST DATA, TZM FORGED DISC, CLIMAX NO. 7502, ANNEALED AT 2850°F (1566°C)

FOR 1 HOUR AT 2000°F (1093°C), 10,000 PSI (6.89 x 10⁷N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00030	.015	
2	.00045	.022	
3	.00040	.020	
4	.00030	.015	
5	.00025	.012	
6	.00015	.008	
7	.00015	.008	
8	.00010	.005	
9	.00020	.010	
10	.00030	.015	
11	.00030	.015	
12	.00025	.012	
13	.00030	.015	
14	.00030	.015	
15	.00035	.018	
20	.00045	.022	
25	.00050	.025	
30	.00055	.028	
35	.00050	.025	
40	.00050	.025	
45	.00050	.025	
60	.00050	.025	
16.6 hours	.00040	.020	6.2 x 10 ⁻⁹
40.7	.00055	.028	3.1 x 10 ⁻⁹
114.5	.00095	.048	5.1 x 10 ⁻⁹
136.5	.00105	.052	3.0 x 10 ⁻⁹
160.4	.00120	.060	3.4 x 10 ⁻⁹
184.4	.00130	.065	2.4 x 10 ⁻⁹
208.3	.00140	.070	2.3 x 10 ⁻⁹
287.5	.00180	.090	2.2 x 10 ⁻⁹
304.7	.00235	.118	1.8 x 10 ⁻⁹
328.7	.00505	.252	1.6 x 10 ⁻⁹
336.5	.00485	.242	--
352.6	.00515	.258	1.6 x 10 ⁻⁹
376.4	.00525	.262	2.2 x 10 ⁻⁹
448.3	.00525	.262	1.4 x 10 ⁻⁹
472.7	.00525	.262	1.0 x 10 ⁻⁹
496.6	.00530	.265	1.0 x 10 ⁻⁹

TABLE VII (Continued)

<u>Time</u>	<u>Length Change L (Inch) (2^m G. L.)</u>	<u>Creep %</u>	<u>Pressure (Torr)</u>
8200.8 hours	.00635	.318	1.1×10^{-9}
8272.3	.00640	.320	1.1×10^{-9}
8368.3	.00650	.325	1.0×10^{-9}
8440.3	.00640	.320	1.2×10^{-9}
8536.7	.00655	.328	1.5×10^{-9}
8608.5	.00665	.332	1.6×10^{-9}
8707.8	.00665	.332	1.2×10^{-9}
8780.5	.00665	.332	1.6×10^{-9}
8872.2	.00675	.338	1.2×10^{-9}
8944.8	.00680	.340	1.6×10^{-9}
9041.1	.00700	.350	1.3×10^{-9}
9112.2	.00705	.352	1.2×10^{-9}
9208.4	.00705	.352	1.4×10^{-9}
9280.8	.00700	.350	1.5×10^{-9}
9377.0	.00715	.358	1.4×10^{-9}
9448.7	.00725	.362	1.4×10^{-9}
9544.6	.00730	.365	1.5×10^{-9}
9616.3	.00740	.370	1.7×10^{-9}
9712.5	.00745	.372	1.4×10^{-9}
9784.5	.00745	.372	1.6×10^{-9}
9880.4	.00745	.372	1.3×10^{-9}
9952.6	.00745	.372	1.8×10^{-9}
10,048.3	.00750	.375	1.7×10^{-9}

Test Terminated - 10,000 Hours

Specimen B-3

TABLE VIII (Continued)

Time	Length Change ΔL (inch) (2 ⁿ G.L.)	Creep (%)	Pressure (Torr)
520.8 hours	.00535	.268	1.6×10^{-9}
544.6	.00565	.282	1.2×10^{-9}
616.6	.00560	.280	6.2×10^{-10}
640.5	.00555	.278	7.2×10^{-10}
664.6	.00560	.280	7.2×10^{-10}
688.7	.00560	.280	7.3×10^{-10}
712.8	.00565	.282	1.3×10^{-9}
784.6	.00560	.280	5.6×10^{-10}
808.7	.00555	.278	5.5×10^{-10}
832.6	.00565	.282	5.8×10^{-10}
856.6	.00575	.288	5.8×10^{-10}
880.6	.00580	.290	6.6×10^{-10}
952.6	.00480	.240	4.3×10^{-10}
977.0	.00485	.242	1.4×10^{-9}
1000.7	.00485	.242	4.2×10^{-10}
1025.0	.00505	.252	7.2×10^{-10}
1049.3	.00440	.220	4.6×10^{-10}
1120.8	.00465	.232	3.2×10^{-10}
1145.2	.00485	.242	4.3×10^{-10}
1168.5	.00505	.252	5.0×10^{-10}
1192.7	.00515	.258	8.0×10^{-10}
1216.6	.00515	.258	3.0×10^{-10}
1288.6	.00510	.255	1.6×10^{-10}
1315.5	.00525	.262	2.2×10^{-10}
1336.5	.00525	.262	1.5×10^{-10}
1360.7	.00520	.260	1.6×10^{-10}
1384.5	.00525	.262	2.1×10^{-10}
1456.6	.00540	.270	4.4×10^{-10}
1480.9	.00520	.260	1.6×10^{-9}
1505.0	.00505	.252	9.7×10^{-11}
1528.5	.00510	.255	1.3×10^{-9}
1552.8	.00520	.260	1.3×10^{-9}
1649.0	.00530	.265	9.3×10^{-10}
1696.6	.00535	.268	--
1722.7	.00530	.265	--
1792.8	.00530	.265	3.2×10^{-12}
1840.7	.00530	.265	8.8×10^{-11}
1864.8	.00530	.265	1.2×10^{-9}

TABLE VIII (Continued)

<u>Time</u>	<u>Length Change</u> <u>ΔL (inch)</u> <u>(2" G.L.)</u>	<u>Creep</u> <u>(%)</u>	<u>Pressure</u> <u>(Torr)</u>
1960.8 hours	.00540	.270	9.6×10^{-10}
1984.8	.00545	.272	3.6×10^{-10}
2008.6	.00545	.272	1.5×10^{-9}
2056.9	.00550	.275	--
2115.2	.00555	.278	3.2×10^{-10}
2163.0	.00550	.275	8.0×10^{-10}
2211.2	.00545	.272	1.4×10^{-9}
2283.4	.00560	.280	1.1×10^{-9}
2336.3	.00560	.280	--
2380.1	.00550	.275	1.4×10^{-11}
2450.9	.00555	.278	1.4×10^{-11}
2523.0	.00570	.285	1.0×10^{-9}
2619.2	.00570	.285	8.6×10^{-10}
2691.0	.00610	.305	--
2786.8	.00635	.318	2.5×10^{-10}
2859.8	.00640	.320	8.8×10^{-11}
2932.3	.00640	.320	1.4×10^{-10}
2978.9	.00640	.320	2.2×10^{-10}
3027.0	.00580	.290	1.2×10^{-10}
3122.9	.00630	.315	2.6×10^{-10}
3195.2	.00605	.302	2.8×10^{-10}
3291.1	.00640	.320	3.5×10^{-11}
3363.0	.00650	.325	1.2×10^{-9}
3458.8	.00645	.322	2.4×10^{-10}
3531.2	.00655	.328	9.2×10^{-10}
3627.1	.00640	.320	2.4×10^{-11}
3699.0	.00655	.328	4.2×10^{-10}
3819.2	.00630	.315	5.6×10^{-10}
3891.0	.00620	.310	6.6×10^{-10}
3963.1	.00640	.320	4.3×10^{-11}
4035.2	.00640	.320	1.0×10^{-11}
4131.4	.00670	.335	8.4×10^{-10}
4203.0	.00685	.342	1.9×10^{-11}
4301.7	.00690	.345	3.0×10^{-10}
4374.3	.00680	.340	1.7×10^{-10}
4477.1	.00700	.350	2.0×10^{-10}
4541.4	.00700	.350	2.3×10^{-9}
4636.7	.00700	.350	2.4×10^{-9}
4707.2	.00700	.350	2.6×10^{-9}

TABLE VIII (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep %</u>	<u>Pressure (Torr)</u>
4803.3 hours	.00705	.352	1.2 x 10 ⁻⁹
4875.2	.00705	.352	3.1 x 10 ⁻⁹
4970.9	.00710	.355	1.7 x 10 ⁻⁹
5043.3	.00715	.358	3.0 x 10 ⁻⁹
5139.1	.00690	.345	2.6 x 10 ⁻⁹
5210.0	.00730	.365	2.6 x 10 ⁻⁹
5331.1	.00725	.362	3.4 x 10 ⁻⁹
5379.1	.00720	.360	2.1 x 10 ⁻⁹
5475.2	.00720	.360	2.0 x 10 ⁻⁹
5547.3	.00720	.360	2.1 x 10 ⁻⁹
5643.5	.00730	.365	1.9 x 10 ⁻⁹
5715.9	.00730	.365	2.3 x 10 ⁻⁹
5813.3	.00720	.360	2.0 x 10 ⁻⁹
5883.2	.00725	.362	1.9 x 10 ⁻⁹
5979.6	.00720	.360	3.2 x 10 ⁻⁹
6051.2	.00725	.362	1.9 x 10 ⁻⁹
6147.6	.00715	.358	2.6 x 10 ⁻⁹
6219.2	.00730	.365	2.6 x 10 ⁻⁹
6315.7	.00725	.362	4.4 x 10 ⁻⁹
6387.1	.00740	.370	2.6 x 10 ⁻⁹
6483.1	.00730	.365	2.6 x 10 ⁻⁹
6554.8	.00730	.365	5.0 x 10 ⁻⁹
6652.6	.00735	.368	5.4 x 10 ⁻⁹
6723.8	.00725	.362	3.2 x 10 ⁻⁹
6820.1	.00720	.360	3.2 x 10 ⁻⁹
6891.9	.00730	.365	3.2 x 10 ⁻⁹
6988.1	.00735	.368	3.4 x 10 ⁻⁹
7060.2	.00730	.365	3.2 x 10 ⁻⁹
7156.7	.00730	.365	3.8 x 10 ⁻⁹
7252.5	.00720	.360	3.5 x 10 ⁻⁹
7324.3	.00730	.365	5.8 x 10 ⁻⁹
7395.9	.00720	.360	4.0 x 10 ⁻⁹
7492.5	.00735	.368	4.8 x 10 ⁻⁹
7564.0	.00730	.365	5.0 x 10 ⁻⁹
7660.8	.00710	.355	3.7 x 10 ⁻⁹
7732.1	.00710	.355	3.8 x 10 ⁻⁹
7828.5	.00700	.350	3.7 x 10 ⁻⁹
7900.2	.00700	.350	4.0 x 10 ⁻⁹
7999.5	.00710	.355	4.9 x 10 ⁻⁹
8072.2	.00730	.365	3.7 x 10 ⁻⁹
8163.9	.00720	.360	3.8 x 10 ⁻⁹

TABLE VIII (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
8236.5 hours	.00730	.365	4.7 x 10 ⁻⁹
8332.8	.00720	.360	3.7 x 10 ⁻⁹
8404.0	.00720	.360	3.9 x 10 ⁻⁹
8500.1	.00710	.355	4.0 x 10 ⁻⁹
8572.6	.00725	.362	4.9 x 10 ⁻⁹
8668.7	.00730	.365	3.7 x 10 ⁻⁹
8740.6	.00720	.360	3.8 x 10 ⁻⁹
8836.4	.00735	.368	3.8 x 10 ⁻⁹
8908.1	.00720	.360	4.0 x 10 ⁻⁹
9004.6	.00715	.358	4.0 x 10 ⁻⁹
9076.2	.00720	.360	3.9 x 10 ⁻⁹
9172.1	.00715	.358	3.6 x 10 ⁻⁹
9244.3	.00730	.365	1.1 x 10 ⁻⁹
9304.1	.00725	.362	1.3 x 10 ⁻⁹
9412.4	.00730	.365	3.8 x 10 ⁻⁹
9508.2	.00735	.368	4.0 x 10 ⁻⁹
9579.9	.00735	.368	4.0 x 10 ⁻⁹
9675.9	.00720	.360	4.1 x 10 ⁻⁹
9747.9	.00730	.365	4.2 x 10 ⁻⁹
9843.8	.00710	.355	4.0 x 10 ⁻⁹
9916.1	.00735	.368	2.0 x 10 ⁻⁹
10,012.1	.00735	.368	2.4 x 10 ⁻⁹

Test Terminated - 10,000 Hours

Specimen B-4

TABLE IX

CREEP TEST DATA, TZM FORGED DISC, HEAT NO. 1175, TESTED AT 1600°F (871°C)

65,000 PSI ($4.48 \times 10^8 \text{N/m}^2$)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minutes	.00005	.002	5.3×10^{-6}
2	-.00005	-.002	5.3×10^{-6}
3	.00005	.002	5.3×10^{-6}
4	.00010	.005	5.3×10^{-6}
5	.00015	.008	5.3×10^{-6}
6	.00015	.008	5.3×10^{-6}
7	.00020	.010	5.3×10^{-6}
8	.00025	.012	5.3×10^{-6}
9	.00020	.010	5.3×10^{-6}
10	.00025	.012	5.3×10^{-6}
15	.00025	.012	5.3×10^{-6}
20	.00030	.015	5.3×10^{-6}
25	.00025	.012	5.3×10^{-6}
30	.00020	.010	5.3×10^{-6}
45	.00025	.012	5.3×10^{-6}
60	.00020	.010	5.3×10^{-6}
65.3 Hours	.00110	.055	1.0×10^{-5}
89.3	.00095	.048	5.5×10^{-6}
113.2	.00100	.050	6.5×10^{-6}
136.9	.00105	.052	4.3×10^{-6}
161.4	.00105	.052	4.4×10^{-6}
233.5	.00105	.052	4.7×10^{-6}
257.4	.00100	.050	4.6×10^{-6}
281.1	.00100	.050	4.5×10^{-6}
305.0	.00110	.055	4.4×10^{-6}
329.0	.00110	.055	4.6×10^{-6}
401.8	.00100	.050	4.1×10^{-6}
425.8	.00095	.048	4.0×10^{-6}
449.1	.00105	.052	4.1×10^{-6}
473.1	.00115	.058	4.0×10^{-6}
497.0	.00115	.058	4.0×10^{-6}
569.5	.00115	.058	3.9×10^{-6}
593.2	.00120	.060	4.5×10^{-6}
616.9	.00115	.058	4.3×10^{-6}
641.2	.00110	.055	4.3×10^{-6}
740.5	.00115	.058	4.0×10^{-6}
813.2	.00120	.060	4.4×10^{-6}
904.9	.00120	.060	3.8×10^{-6}
929.7	.00125	.062	3.9×10^{-6}

TABLE IX (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
953.1	.00120	.060	4.4 x 10 ⁻⁹
977.5	.00120	.060	4.1 x 10 ⁻⁹
1073.8	.00125	.062	3.8 x 10 ⁻⁹
1145.0	.00135	.068	3.8 x 10 ⁻⁹
1241.3	.00165	.082	4.0 x 10 ⁻⁹
1313.6	.00155	.078	7.6 x 10 ⁻⁹
1409.7	.00170	.085	4.3 x 10 ⁻⁹
1482.7	.00165	.082	5.0 x 10 ⁻⁹
1577.4	.00170	.085	5.2 x 10 ⁻⁹
1629.6	.00170	.085	5.0 x 10 ⁻⁹

Test Terminated - Low Creep Rate

Specimen B-21

TABLE X

CREEP TEST DATA, TZM FORGED DISC, HEAT NO. 1175, TESTED AT 1800°F (982°C)

44,000 PSI (3.03 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00000	.000	4.8 x 10 ⁻⁷
2	.00010	.005	4.8 x 10 ⁻⁷
3	.00020	.010	4.8 x 10 ⁻⁷
4	.00025	.012	4.8 x 10 ⁻⁷
5	.00015	.008	4.8 x 10 ⁻⁷
6	.00015	.008	4.8 x 10 ⁻⁷
7	.00010	.005	4.8 x 10 ⁻⁷
8	.00015	.008	4.8 x 10 ⁻⁷
9	.00020	.010	4.8 x 10 ⁻⁷
10	.00020	.010	4.8 x 10 ⁻⁷
15	.00020	.010	4.8 x 10 ⁻⁷
30	.00025	.012	4.8 x 10 ⁻⁷
45	.00025	.012	4.8 x 10 ⁻⁷
60	.00030	.015	4.8 x 10 ⁻⁷
65.5 hours	.00055	.028	3.0 x 10 ⁻⁷
89.1	.00070	.035	2.8 x 10 ⁻⁷
113.1	.00095	.048	1.1 x 10 ⁻⁸
137.1	.00100	.050	2.1 x 10 ⁻⁸
161.1	.00100	.050	1.7 x 10 ⁻⁹
233.0	.00100	.050	1.0 x 10 ⁻⁹
257.3	.00105	.052	8.4 x 10 ⁻¹⁰
280.9	.00105	.052	1.3 x 10 ⁻⁹
305.2	.00110	.055	1.6 x 10 ⁻⁹
329.4	.00110	.055	1.4 x 10 ⁻⁹
401.0	.00115	.058	1.4 x 10 ⁻⁹
426.7	.00115	.058	4.0 x 10 ⁻¹⁰
449.2	.00120	.060	5.8 x 10 ⁻¹⁰
473.4	.00130	.065	7.6 x 10 ⁻¹⁰
497.0	.00135	.068	3.8 x 10 ⁻¹⁰
569.2	.00145	.072	3.9 x 10 ⁻¹⁰
593.1	.00140	.070	5.5 x 10 ⁻¹⁰
616.9	.00145	.072	8.4 x 10 ⁻¹⁰
640.8	.00140	.070	7.8 x 10 ⁻¹⁰
664.8	.00150	.075	5.0 x 10 ⁻¹⁰

TABLE X (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure</u>
736.8	.00150	.075	8.8 x 10 ⁻¹⁰
761.7	.00150	.075	8.6 x 10 ⁻¹⁰
785.0	.00150	.075	5.0 x 10 ⁻¹⁰
808.8	.00155	.078	9.0 x 10 ⁻¹⁰
833.8	.00155	.078	5.0 x 10 ⁻¹⁰
904.7	.00160	.080	8.4 x 10 ⁻¹⁰
928.8	.00160	.080	8.9 x 10 ⁻¹⁰
953.1	.00160	.080	7.0 x 10 ⁻¹⁰
977.0	.00165	.082	6.0 x 10 ⁻¹⁰
1001.0	.00180	.090	9.2 x 10 ⁻¹⁰
1073.0	.00180	.090	9.1 x 10 ⁻¹⁰
1144.9	.00175	.088	8.2 x 10 ⁻¹⁰

Test in Progress

Specimen B-25

TABLE XI

CREEP TEST DATA, Gb MODIFIED TZM WROUGHT BAR, HEAT NO. 4305-4, TESTED AT
2000°F (1093°C), 20,000 PSI (1.38 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00000	.000	1.8 x 10 ⁻⁷
2	.00015	.008	1.8 x 10 ⁻⁷
3	.00010	.005	1.8 x 10 ⁻⁷
4	.00015	.008	1.8 x 10 ⁻⁷
5	.00010	.005	1.8 x 10 ⁻⁷
6	.00015	.008	1.8 x 10 ⁻⁷
7	.00020	.010	1.8 x 10 ⁻⁷
8	.00020	.010	1.8 x 10 ⁻⁷
9	.00025	.012	1.8 x 10 ⁻⁷
10	.00015	.008	1.8 x 10 ⁻⁷
15	.00025	.012	1.8 x 10 ⁻⁷
30	.00020	.010	1.8 x 10 ⁻⁷
45	.00025	.012	1.8 x 10 ⁻⁷
60	.00020	.010	1.8 x 10 ⁻⁷
14.3 hours	.00035	.018	2.6 x 10 ⁻⁸
86.2	.00065	.032	7.2 x 10 ⁻⁹
110.1	.00040	.020	6.2 x 10 ⁻⁹
134.2	.00045	.022	4.4 x 10 ⁻⁹
158.8	.00045	.022	4.6 x 10 ⁻⁹
182.5	.00040	.020	3.8 x 10 ⁻⁹
254.8	.00040	.020	3.0 x 10 ⁻⁹
278.5	.00040	.020	2.8 x 10 ⁻⁹
302.2	.00045	.022	2.3 x 10 ⁻⁹
326.5	.00050	.025	2.2 x 10 ⁻⁹
350.5	.00050	.025	2.1 x 10 ⁻⁹
422.5	.00055	.028	2.1 x 10 ⁻⁹
446.4	.00050	.025	2.4 x 10 ⁻⁹
470.5	.00055	.028	1.8 x 10 ⁻⁹
494.3	.00055	.028	2.0 x 10 ⁻⁹
518.4	.00050	.025	1.8 x 10 ⁻⁹
590.7	.00060	.030	1.5 x 10 ⁻⁹
614.3	.00050	.025	1.4 x 10 ⁻⁹
638.3	.00050	.025	1.4 x 10 ⁻⁹
662.3	.00055	.028	1.4 x 10 ⁻⁹
686.2	.00065	.032	1.4 x 10 ⁻⁹

Test Terminated

Specimen B-23A

TABLE XII

CREEP TEST DATA, Cb MODIFIED TZM WROUGHT BAR, HEAT NO. 4305-4, TESTED AT

2000°F (1093°C), 28,000 PSI (1.93 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00010	.005	1.3 x 10 ⁻⁹
2	.00010	.005	1.3 x 10 ⁻⁹
3	.00000	.000	1.3 x 10 ⁻⁹
4	.00000	.000	1.3 x 10 ⁻⁹
5	.00000	.000	1.3 x 10 ⁻⁹
6	-.00005	-.002	1.3 x 10 ⁻⁹
7	.00005	.002	1.3 x 10 ⁻⁹
8	.00000	.000	1.3 x 10 ⁻⁹
9	.00000	.000	1.3 x 10 ⁻⁹
10	.00005	.002	1.3 x 10 ⁻⁹
15	.00000	.000	1.3 x 10 ⁻⁹
30	.00005	.002	1.3 x 10 ⁻⁹
45	.00010	.005	1.3 x 10 ⁻⁹
60	.00010	.005	1.3 x 10 ⁻⁹
66.7 hours	.00015	.008	8.6 x 10 ⁻¹⁰
91.0	.00035	.018	8.7 x 10 ⁻¹⁰
114.6	.00035	.018	1.1 x 10 ⁻⁹
138.9	.00030	.015	5.1 x 10 ⁻¹⁰
163.1	.00035	.018	4.8 x 10 ⁻¹⁰
234.7	.00045	.022	4.9 x 10 ⁻¹⁰
259.0	.00050	.025	1.1 x 10 ⁻⁹
282.9	.00045	.022	1.5 x 10 ⁻⁹
307.0	.00055	.028	1.5 x 10 ⁻⁹

Test Terminated

Specimen B-23B

TABLE XIII

CREEP TEST DATA, Cb MODIFIED TZM WROUGHT BAR, HEAT NO. 4305-4, TESTED AT
2000°F (1093°C), 40,000 PSI (2.76 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00000	.000	1.5 x 10 ⁻⁹
2	.00005	.002	1.5 x 10 ⁻⁹
3	.00010	.005	1.5 x 10 ⁻⁹
4	.00010	.005	1.5 x 10 ⁻⁹
5	.00010	.005	1.5 x 10 ⁻⁹
6	.00015	.008	1.5 x 10 ⁻⁹
7	.00010	.005	1.5 x 10 ⁻⁹
8	.00010	.005	1.5 x 10 ⁻⁹
9	.00015	.008	1.5 x 10 ⁻⁹
10	.00020	.010	1.5 x 10 ⁻⁹
15	.00015	.008	1.5 x 10 ⁻⁹
30	.00015	.008	1.5 x 10 ⁻⁹
45	.00020	.010	1.5 x 10 ⁻⁹
60	.00020	.010	1.5 x 10 ⁻⁹
17.3 hours	.00100	.050	1.4 x 10 ⁻⁹
89.5	.00255	.128	1.4 x 10 ⁻⁹
113.4	.00270	.135	1.4 x 10 ⁻⁹
137.3	.00305	.152	1.3 x 10 ⁻⁹
161.2	.00345	.172	1.3 x 10 ⁻⁹
185.2	.00375	.188	1.3 x 10 ⁻⁹

Test Terminated

Specimen B-23C

TABLE XIV

CREEP TEST DATA, Cb MODIFIED TZM WROUGHT BAR, HEAT NO. 4305-4, TESTED AT

1800°F (982°C), 46,000 PSI (3.17 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00005	.002	1.1 x 10 ⁻⁹
2	.00010	.005	1.1 x 10 ⁻⁹
3	.00005	.002	1.1 x 10 ⁻⁹
4	.00000	.000	1.1 x 10 ⁻⁹
5	.00005	.002	1.1 x 10 ⁻⁹
6	.00000	.000	1.1 x 10 ⁻⁹
7	-.00005	-.002	1.1 x 10 ⁻⁹
8	.00000	.000	1.1 x 10 ⁻⁹
9	.00000	.000	1.1 x 10 ⁻⁹
10	.00005	.002	1.1 x 10 ⁻⁹
15	.00005	.002	1.1 x 10 ⁻⁹
30	.00000	.000	1.1 x 10 ⁻⁹
45	.00000	.000	1.1 x 10 ⁻⁹
60	.00000	.000	1.1 x 10 ⁻⁹
66.4 hours	.00010	.005	1.2 x 10 ⁻⁹
91.3	.00025	.012	1.1 x 10 ⁻⁹
114.5	.00050	.025	1.1 x 10 ⁻⁹
138.4	.00080	.040	1.1 x 10 ⁻⁹
163.4	.00110	.055	1.1 x 10 ⁻⁹
234.3	.00125	.062	1.0 x 10 ⁻⁹
258.3	.00135	.068	1.1 x 10 ⁻⁹
282.6	.00140	.070	1.1 x 10 ⁻⁹
306.6	.00140	.070	1.1 x 10 ⁻⁹
330.5	.00145	.072	9.5 x 10 ⁻¹⁰
402.6	.00155	.078	1.1 x 10 ⁻⁹

Test Terminated

Specimen B-23D

TABLE XV

CREEP TEST DATA. Cb MODIFIED TZM WROUGHT BAR, HEAT NO. 4305-4, TESTED AT
2100°F (1149°C) 34,000 PSI (2.41 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00010	.005	1.6 x 10 ⁻⁹
2	.00010	.005	1.6 x 10 ⁻⁹
5	-.00005	-.002	1.6 x 10 ⁻⁹
6	.00000	.000	1.6 x 10 ⁻⁹
7	-.00005	-.002	1.6 x 10 ⁻⁹
8	.00005	.002	1.6 x 10 ⁻⁹
9	.00010	.005	1.6 x 10 ⁻⁹
10	.00000	.000	1.6 x 10 ⁻⁹
15	.00005	.002	1.6 x 10 ⁻⁹
30	.00010	.005	1.6 x 10 ⁻⁹
45	.00005	.002	1.6 x 10 ⁻⁹
60	.00010	.005	1.6 x 10 ⁻⁹
16.1 hours	.00015	.008	1.7 x 10 ⁻⁹
40.0	.00075	.038	1.6 x 10 ⁻⁹
64.2	.00120	.060	1.4 x 10 ⁻⁹
88.2	.00160	.080	1.4 x 10 ⁻⁹
160.0	.00195	.098	1.4 x 10 ⁻⁹
184.5	.00210	.105	1.4 x 10 ⁻⁹
214.8	.00260	.130	1.2 x 10 ⁻⁹
232.4	.00270	.135	1.7 x 10 ⁻⁹
256.3	.00290	.145	1.7 x 10 ⁻⁹
328.7	.00340	.170	1.8 x 10 ⁻⁹

Test Terminated

Specimen B-23E

TABLE XVI

CREEP TEST DATA, Cb MODIFIED TZM WROUGHT BAR, HEAT NO. 4305-4, TESTED AT

2000°F (1093°C), 41,000 PSI (2.82 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00005	.002	2.5 x 10 ⁻⁷
2	.00005	.002	2.5 x 10 ⁻⁷
3	.00000	.000	2.5 x 10 ⁻⁷
4	.00005	.002	2.5 x 10 ⁻⁷
5	.00010	.005	2.5 x 10 ⁻⁷
6	.00010	.005	2.5 x 10 ⁻⁷
7	.00010	.005	2.5 x 10 ⁻⁷
8	.00015	.008	2.5 x 10 ⁻⁷
9	.00010	.005	2.5 x 10 ⁻⁷
10	.00010	.005	2.5 x 10 ⁻⁷
15	.00015	.008	2.5 x 10 ⁻⁷
30	.00015	.008	2.5 x 10 ⁻⁷
45	.00020	.010	2.5 x 10 ⁻⁷
60	.00025	.012	2.5 x 10 ⁻⁷
17.7 hours	.00070	.035	2.0 x 10 ⁻⁸
40.8	.00110	.055	9.9 x 10 ⁻⁹
64.9	.00155	.078	6.4 x 10 ⁻⁹
89.9	.00195	.098	3.9 x 10 ⁻⁹
160.7	.00250	.125	2.3 x 10 ⁻⁹
184.8	.00255	.128	2.3 x 10 ⁻⁹
208.9	.00265	.132	2.0 x 10 ⁻⁹
233.0	.00275	.138	1.7 x 10 ⁻⁹
256.9	.00285	.142	2.8 x 10 ⁻⁹
329.0	.00305	.152	2.5 x 10 ⁻⁹
352.8	.00310	.155	1.3 x 10 ⁻⁹
376.7	.00315	.158	1.1 x 10 ⁻⁹
400.9	.00325	.162	1.2 x 10 ⁻⁹

Test in progress

Specimen B-27

TABLE XVII

CREEP TEST DATA, T-111 SHEET, HEAT NO. 70616, ANNEALED 3000°F (1649°C) FOR 1 HOUR

TESTED AT 2200°F (1204°C), 8,000 PSI (5.52 x 10⁷N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00005	.002	2.6 x 10 ⁻⁹
2	.00010	.005	2.6 x 10 ⁻⁹
3	.00015	.008	2.6 x 10 ⁻⁹
4	.00010	.005	2.6 x 10 ⁻⁹
5	.00005	.002	2.6 x 10 ⁻⁹
6	.00005	.002	2.6 x 10 ⁻⁹
7	.00005	.002	2.6 x 10 ⁻⁹
8	.00000	.000	2.6 x 10 ⁻⁹
9	.00005	.002	2.6 x 10 ⁻⁹
10	.00005	.002	2.6 x 10 ⁻⁹
15	.00000	.000	2.6 x 10 ⁻⁹
30	.00010	.005	2.6 x 10 ⁻⁹
45	.00010	.005	2.6 x 10 ⁻⁹
60	.00005	.002	2.6 x 10 ⁻⁹
2.4 hours	.00005	.002	2.6 x 10 ⁻⁹
19.2	.00010	.005	2.0 x 10 ⁻⁹
43.1	.00010	.005	1.6 x 10 ⁻⁹
48.3	.00035	.018	1.6 x 10 ⁻⁹
67.1	.00060	.030	1.5 x 10 ⁻⁹
139.4	.00135	.068	1.4 x 10 ⁻⁹
163.0	.00155	.078	1.4 x 10 ⁻⁹
187.0	.00175	.088	1.2 x 10 ⁻⁹
211.3	.00190	.095	1.3 x 10 ⁻⁹
310.5	.00215	.108	1.2 x 10 ⁻⁹
383.3	.00245	.122	1.3 x 10 ⁻⁹
474.9	.00320	.160	1.3 x 10 ⁻⁹
499.3	.00370	.185	1.2 x 10 ⁻⁹
523.1	.00390	.195	1.3 x 10 ⁻⁹
547.6	.00405	.202	1.2 x 10 ⁻⁹
572.0	.00470	.235	1.3 x 10 ⁻⁹
643.8	.00530	.265	1.4 x 10 ⁻⁹
691.2	.00545	.272	1.3 x 10 ⁻⁹
714.9	.00560	.280	1.2 x 10 ⁻⁹
739.2	.00565	.282	1.2 x 10 ⁻⁹
811.1	.00625	.312	1.3 x 10 ⁻⁹
835.0	.00640	.320	1.2 x 10 ⁻⁹
859.1	.00655	.328	1.4 x 10 ⁻⁹
883.5	.00675	.338	1.3 x 10 ⁻⁹

TABLE XVII (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
907.3 hours	.00685	.342	1.3 x 10 ⁻⁹
979.7	.00750	.375	1.3 x 10 ⁻⁹
1051.4	.00835	.418	1.2 x 10 ⁻⁹
1147.3	.00975	.488	1.3 x 10 ⁻⁹
1219.0	.01050	.525	1.3 x 10 ⁻⁹
1315.7	.01125	.562	1.1 x 10 ⁻⁹
1387.2	.01150	.575	1.1 x 10 ⁻⁹
1483.1	.01375	.688	8.3 x 10 ⁻⁹
1555.3	.01410	.705	1.3 x 10 ⁻⁹
1651.0	.01515	.758	7.0 x 10 ⁻¹⁰
1723.4	.01615	.808	8.2 x 10 ⁻¹⁰
1819.2	.01755	.878	9.0 x 10 ⁻¹⁰
1890.9	.01830	.915	7.4 x 10 ⁻¹⁰
1986.9	.01980	.990	7.9 x 10 ⁻¹⁰
2059.0	.02080	1.040	8.3 x 10 ⁻¹⁰
2154.8	.02230	1.115	7.0 x 10 ⁻¹⁰
2227.1	.02315	1.158	6.9 x 10 ⁻¹⁰
2323.1	.02445	1.222	7.5 x 10 ⁻¹⁰
2395.0	.02580	1.290	7.0 x 10 ⁻¹⁰

Test in Progress

Specimen S-19

TABLE XVIII

CREEP TEST DATA, T-111 SHEET, HEAT NO. 70616, ANNEALED 3000°F (1649°C) FOR 1 HOUR,

TESTED AT 2200°F (1204°C), 12,000 PSI (8.27 x 10⁷N/m²)

Time	Length Change ΔL (Inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minute(s)	.00000	.000	2.9 x 10 ⁻⁷
2	.00005	.002	2.9 x 10 ⁻⁷
3	.00010	.005	2.9 x 10 ⁻⁷
4	.00010	.005	2.9 x 10 ⁻⁷
5	.00010	.005	2.9 x 10 ⁻⁷
6	.00015	.008	2.9 x 10 ⁻⁷
7	.00020	.010	2.9 x 10 ⁻⁷
8	.00015	.008	2.9 x 10 ⁻⁷
9	.00020	.010	2.9 x 10 ⁻⁷
10	.00020	.010	2.9 x 10 ⁻⁷
15	.00015	.008	2.9 x 10 ⁻⁷
30	.00020	.010	2.9 x 10 ⁻⁷
45	.00015	.008	2.9 x 10 ⁻⁷
60	.00015	.008	2.9 x 10 ⁻⁷
17.7 hours	.00045	.022	2.1 x 10 ⁻⁸
42.1	.00085	.042	1.1 x 10 ⁻⁸
113.9	.00180	.090	6.4 x 10 ⁻⁹
161.3	.00220	.110	4.9 x 10 ⁻⁹
185.1	.00270	.135	4.4 x 10 ⁻⁹
209.3	.00280	.140	4.4 x 10 ⁻⁹
281.3	.00300	.150	3.9 x 10 ⁻⁹
305.1	.00370	.185	3.8 x 10 ⁻⁹
329.2	.00435	.218	3.2 x 10 ⁻⁹
353.6	.00480	.240	2.6 x 10 ⁻⁹
377.5	.00510	.255	2.1 x 10 ⁻⁹
449.8	.00625	.312	2.8 x 10 ⁻⁹
473.3	.00660	.330	3.2 x 10 ⁻⁹
497.1	.00700	.350	3.1 x 10 ⁻⁹
521.5	.00735	.368	2.3 x 10 ⁻⁹
545.4	.00775	.388	2.2 x 10 ⁻⁹
617.3	.00905	.452	2.0 x 10 ⁻⁹
641.4	.00960	.480	2.1 x 10 ⁻⁹
665.2	.01040	.520	2.0 x 10 ⁻⁹
689.1	.01080	.540	2.1 x 10 ⁻⁹
713.4	.01125	.562	1.9 x 10 ⁻⁹
785.3	.01270	.635	2.5 x 10 ⁻⁹
809.2	.01300	.650	2.5 x 10 ⁻⁹
833.3	.01340	.670	1.8 x 10 ⁻⁹
857.3	.01420	.710	2.0 x 10 ⁻⁹

TABLE XVIII (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
881.1	.01435	.718	2.0 x 10 ⁻⁹
953.2	.01615	.807	5.1 x 10 ⁻¹⁰
977.5	.01680	.840	1.0 x 10 ⁻⁹
1001.1	.01740	.870	1.4 x 10 ⁻⁹
1025.4	.01790	.895	1.0 x 10 ⁻⁹
1049.2	.01840	.920	1.5 x 10 ⁻⁹
1121.1	.01985	.992	1.6 x 10 ⁻⁹
1193.5	.02205	1.102	1.8 x 10 ⁻⁹
1289.3	.02460	1.230	1.8 x 10 ⁻⁹
1361.0	.02635	1.318	8.0 x 10 ⁻¹⁰
1457.0	.02920	1.460	1.8 x 10 ⁻⁹
1529.2	.03070	1.535	1.9 x 10 ⁻⁹
1624.9	.03415	1.708	7.2 x 10 ⁻¹⁰
1697.2	.03660	1.830	8.1 x 10 ⁻¹⁰
1793.2	.03985	1.992	6.7 x 10 ⁻¹⁰
1865.1	.04185	2.092	1.8 x 10 ⁻⁹

Test in Progress

Specimen S-21

TABLE XIX

CREEP TEST DATA, T-111 SHEET, HEAT NO. 70616, ANNEALED 3000°F (1649°C) FOR 1 HOUR,

TESTED AT 2000°F (1093°C), 20,000 PSI ($1.38 \times 10^8 \text{N/m}^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minute(s)	.00015	.008	7.3×10^{-8}
2	.00010	.005	7.3×10^{-8}
3	.00010	.005	7.3×10^{-8}
4	.00005	.002	7.3×10^{-8}
5	.00010	.005	7.3×10^{-8}
6	.00015	.008	7.3×10^{-8}
7	.00015	.008	7.3×10^{-8}
8	.00015	.008	7.3×10^{-8}
9	.00015	.008	7.3×10^{-8}
10	.00015	.008	7.3×10^{-8}
15	.00020	.010	7.3×10^{-8}
30	.00015	.008	7.3×10^{-8}
45	.00015	.008	7.3×10^{-8}
60	.00015	.008	7.3×10^{-8}
67.4 hours	.00125	.062	1.1×10^{-8}
91.3	.00140	.070	9.9×10^{-9}
115.3	.00155	.078	7.2×10^{-9}
139.4	.00195	.098	6.8×10^{-9}
163.2	.00250	.125	6.6×10^{-9}
235.3	.00450	.225	4.1×10^{-9}
259.5	.00495	.248	3.3×10^{-9}
283.1	.00540	.270	3.0×10^{-9}
307.4	.00605	.302	2.6×10^{-9}
331.3	.00690	.345	1.0×10^{-9}
403.1	.00930	.465	2.5×10^{-9}
427.5	.01040	.520	3.1×10^{-9}
451.3	.01100	.550	2.8×10^{-9}
475.6	.01215	.608	2.8×10^{-9}
499.2	.01295	.648	2.9×10^{-9}
571.4	.01615	.807	2.8×10^{-9}
595.3	.01680	.840	2.7×10^{-9}
619.2	.01760	.880	2.8×10^{-9}
643.0	.01875	.938	2.6×10^{-9}
667.0	.01990	.995	2.8×10^{-9}
739.0	.02315	1.158	2.6×10^{-9}
763.9	.02435	1.218	2.5×10^{-9}
787.1	.02535	1.268	3.1×10^{-9}

TABLE XIX (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
811.2 hours	.02640	1.320	3.1 x 10 ⁻⁹
836.1	.02770	1.385	2.6 x 10 ⁻⁹
907.0	.03085	1.542	2.6 x 10 ⁻⁹
931.0	.03200	1.600	2.6 x 10 ⁻⁹
955.1	.03310	1.655	2.7 x 10 ⁻⁹
979.2	.03430	1.715	2.2 x 10 ⁻⁹
1033.1	.03570	1.785	2.4 x 10 ⁻⁹
1075.2	.03890	1.945	2.4 x 10 ⁻⁹
1099.1	.04020	2.010	2.3 x 10 ⁻⁹

Test Terminated - 2% Creep

Specimen S-22

TABLE XX

CREEP TEST DATA, T-222 SHEET, ANNEALED AT 2800°F (1538°C) FOR 1 HOUR, TESTED AT
2200°F (1204°C), 12,000 PSI (8.27 x 10⁷N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00000	.000	1.2 x 10 ⁻⁸
2	-.00010	-.005	1.2 x 10 ⁻⁸
3	-.00015	-.008	1.2 x 10 ⁻⁸
4	-.00005	-.002	1.2 x 10 ⁻⁸
5	.00000	.000	1.2 x 10 ⁻⁸
6	.00005	.002	1.2 x 10 ⁻⁸
7	.00005	.002	1.2 x 10 ⁻⁸
8	.00005	.002	1.2 x 10 ⁻⁸
9	.00010	.005	1.2 x 10 ⁻⁸
10	.00005	.002	1.2 x 10 ⁻⁸
15	.00010	.005	1.2 x 10 ⁻⁸
30	.00000	.000	1.2 x 10 ⁻⁸
45	.00000	.000	1.2 x 10 ⁻⁸
60	.00005	.002	1.2 x 10 ⁻⁸
16.3 hours	.00025	.012	8.5 x 10 ⁻⁹
40.7	.00085	.042	9.6 x 10 ⁻⁹
64.6	.00175	.088	1.2 x 10 ⁻⁹
136.6	.00490	.245	6.3 x 10 ⁻¹⁰
160.6	.00635	.318	6.4 x 10 ⁻¹⁰
184.4	.00760	.380	6.1 x 10 ⁻¹⁰
208.3	.00930	.465	1.7 x 10 ⁻⁹
232.6	.01010	.505	6.0 x 10 ⁻¹⁰
304.5	.01140	.720	6.0 x 10 ⁻¹⁰
328.5	.01560	.780	5.8 x 10 ⁻¹⁰
352.5	.01670	.835	5.7 x 10 ⁻¹⁰
376.5	.01815	.908	5.6 x 10 ⁻¹⁰
400.4	.01960	.980	6.5 x 10 ⁻¹⁰
472.4	.02430	1.215	5.0 x 10 ⁻¹⁰
496.7	.02575	1.288	3.6 x 10 ⁻¹⁰
520.3	.02730	1.365	4.7 x 10 ⁻¹⁰
544.6	.02900	1.450	2.1 x 10 ⁻¹⁰
568.5	.03035	1.518	1.6 x 10 ⁻¹⁰
640.3	.03600	1.800	2.0 x 10 ⁻¹⁰
664.7	.03780	1.890	1.6 x 10 ⁻⁹
688.5	.03955	1.978	4.9 x 10 ⁻⁹
712.8	.04100	2.050	1.2 x 10 ⁻⁹
736.4	.04290	2.145	4.5 x 10 ⁻¹⁰
808.6	.04870	2.435	1.4 x 10 ⁻⁹
832.5	.05085	2.542	1.4 x 10 ⁻⁹
856.4	.05260	2.680	1.4 x 10 ⁻⁹
880.2	.05450	2.725	1.5 x 10 ⁻⁹

TABLE XX (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
904.2	.05675	2.838	1.5 x 10 ⁻⁹
976.2	.06290	3.145	1.4 x 10 ⁻⁹
1001.1	.06535	3.268	1.4 x 10 ⁻⁹
1024.3	.06735	3.368	1.5 x 10 ⁻⁹
1048.4	.06910	3.455	1.4 x 10 ⁻⁹
1073.3	.07150	3.575	5.1 x 10 ⁻¹⁰
1144.2	.07765	3.882	4.9 x 10 ⁻⁹
1168.2	.08000	4.000	1.4 x 10 ⁻⁹
1192.3	.08280	4.140	4.8 x 10 ⁻¹⁰
1216.4	.08540	4.270	4.7 x 10 ⁻¹⁰
1240.3	.08710	4.355	4.6 x 10 ⁻¹⁰
1312.4	.09435	4.718	5.6 x 10 ⁻¹⁰
1336.3	.09635	4.818	4.8 x 10 ⁻¹⁰
1360.2	.09835	4.918	5.3 x 10 ⁻¹⁰
1389.0	.10120	5.060	5.0 x 10 ⁻¹⁰

Test Terminated - 5% Creep

Specimen S-20

TABLE XXI

CREEP TEST DATA, ARC-MELTED TUNGSTEN SHEET, ANNEALED 2800°F (1538°C)

1 HOUR, TESTED AT 2800°F (1538°C), 3,000 PSI ($2.07 \times 10^7 \text{N/m}^2$)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minute(s)	.00010	.005	2.4×10^{-7}
2	.00000	.000	2.4×10^{-7}
3	.00005	.002	2.4×10^{-7}
4	.00000	.000	2.4×10^{-7}
5	.00000	.000	2.4×10^{-7}
6	.00010	.005	2.4×10^{-7}
7	.00015	.008	2.4×10^{-7}
8	.00005	.002	2.4×10^{-7}
9	.00010	.005	2.4×10^{-7}
10	.00010	.005	2.4×10^{-7}
15	.00005	.002	2.4×10^{-7}
30	.00010	.005	2.4×10^{-7}
45	.00015	.008	2.4×10^{-7}
60	.00010	.005	2.4×10^{-7}
3.1 hour(s)	.00060	.030	2.4×10^{-7}
23.95	.00535	.218	1.0×10^{-7}
46.95	.00830	.415	2.9×10^{-8}
67.4	.01205	.602	2.0×10^{-8}
91.2	.01435	.718	1.7×10^{-8}
114.9	.01835	.918	1.0×10^{-8}
138.8	.02190	1.095	8.7×10^{-9}
162.8	.02355	1.178	8.9×10^{-9}
234.8	.03280	1.640	7.2×10^{-9}
259.0	.03665	1.832	7.4×10^{-9}
282.9	.04075	2.038	7.2×10^{-9}
306.8	.04340	2.170	6.8×10^{-9}
330.8	.04750	2.375	6.4×10^{-9}
403.2	.05605	2.802	3.8×10^{-9}
426.8	.05845	2.922	3.9×10^{-9}
450.8	.06065	3.032	4.1×10^{-9}
479.9	.06370	3.185	4.0×10^{-9}
574.3	.07495	3.748	3.0×10^{-9}
647.0	.08195	4.098	1.7×10^{-9}
738.7	.09155	4.578	1.5×10^{-9}
763.1	.09445	4.722	1.6×10^{-9}
786.9	.09690	4.845	3.1×10^{-9}
811.3	.09880	4.940	1.6×10^{-9}
835.8	.10160	5.080	1.5×10^{-9}
907.5	.11070	5.535	3.0×10^{-9}

Test Terminated - 5% Creep

Specimen S-18

TABLE XXII

CREEP TEST DATA, VAPOR DEPOSITED TUNGSTEN, RECRYSTALLIZED 1 HOUR 2800°F (1538°C)

TESTED AT 2800°F (1538°C), 2000 PSI ($1.38 \times 10^7 \text{N/m}^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minute(s)	.00020	.010	3.5×10^{-7}
2	.00025	.012	3.5×10^{-7}
3	.00025	.012	3.5×10^{-7}
4	.00025	.012	3.5×10^{-7}
5	.00025	.012	3.5×10^{-7}
6	.00030	.015	3.5×10^{-7}
7	.00040	.020	3.5×10^{-7}
8	.00035	.018	3.5×10^{-7}
9	.00040	.020	3.5×10^{-7}
10	.00035	.018	3.5×10^{-7}
15	.00000	.000	3.5×10^{-7}
30	-.00005	-.002	3.5×10^{-7}
45	.00000	.000	3.5×10^{-7}
60	-.00005	-.002	3.5×10^{-7}
64.9 hours	.00175	.088	8.0×10^{-8}
88.9	.00210	.105	6.4×10^{-8}
112.8	.00260	.130	4.6×10^{-8}
136.7	.00310	.155	4.1×10^{-8}
161.0	.00370	.185	3.8×10^{-8}
232.8	.00480	.240	3.4×10^{-8}
256.8	.00525	.262	3.1×10^{-8}
280.8	.00550	.275	2.9×10^{-8}
304.8	.00570	.285	2.7×10^{-8}
328.7	.00635	.318	2.6×10^{-8}
400.8	.00750	.375	1.6×10^{-8}
425.0	.00760	.380	1.3×10^{-8}
448.6	.00775	.388	7.8×10^{-9}
472.8	.00795	.398	6.3×10^{-9}
496.8	.00830	.415	5.6×10^{-9}
568.7	.00930	.465	5.0×10^{-9}
600.1	.00990	.495	1.1×10^{-8}
616.7	.01040	.520	1.2×10^{-8}
641.1	.01015	.508	1.1×10^{-8}
664.7	.00980	.490	1.0×10^{-8}
736.8	.01150	.575	9.9×10^{-9}
760.7	.01190	.595	8.6×10^{-9}
784.7	.01310	.655	9.7×10^{-9}

TABLE XXII (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
808.5	.01235	.618	9.4 x 10 ⁻⁹
832.5	.01270	.635	9.4 x 10 ⁻⁹
904.5	.01350	.675	9.2 x 10 ⁻⁹
929.4	.01370	.685	8.6 x 10 ⁻⁹
952.6	.01410	.705	8.5 x 10 ⁻⁹
976.8	.01445	.722	7.0 x 10 ⁻⁹
1001.8	.01460	.730	8.2 x 10 ⁻⁹
1072.5	.01540	.770	8.0 x 10 ⁻⁹
1144.8	.01660	.830	7.8 x 10 ⁻⁹
1240.7	.01775	.888	7.8 x 10 ⁻⁹
1312.7	.01830	.915	5.6 x 10 ⁻⁹

Test in Progress

Specimen B-24

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