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TENTH QUARTERLY REPORT

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LEWIS RESEARCH CENTER

UNDER CONTRACT NAS 3-2545

TRW EQUIPMENT LABORATORIES

CLEVELAND, OHIO

NASA-CR 54895

TENTH QUARTERLY REPORT

FOR

September 26, 1965 to December 26, 1965

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

Prepared by:

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Prepared for:

National Aeronautics and Space Administration
Contract No. NAS 3-2545

Technical Management

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January 8, 1965

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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

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 partial 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 tenth quarter on arc-cast and vapor-deposited tungsten, the molybdenum base alloys TZM and TZC, and the tantalum base alloys T-111 and T-222. In addition to the creep test results, residual gas analyses of the vacuum environment are given for several test systems after extended test periods.

II. MATERIALS AND PROCEDURE

A summary of the composition and heat treatments of the alloys discussed in this report is presented in Tables 1 and 2. A detailed review of the processing history and microstructure has been previously presented in the Ninth Quarterly Progress Report. 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 in 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.

Specimen extension was measured over a 2 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

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	ppm H_2	
Tungsten (arc-cast)	Bal.				.0058				9	4	
Tungsten (vapor-deposited) (General Atomics)	None available										
TZM (Climax Heat 7502)		Bal.			.013	.011	.47	.091	20	7	
TZM-Heat KDTZM-1175 (Air Research)		Bal.			.031 (.024)	.0043	.61 (.49)	.12 (.114)	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	
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 - Air Research Analysis

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TABLE 2

Summary of Material Variables Being Evaluated in Creep Program[1]

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 (Air Research)[3]	"Pancake" Forging	1600-1856°F (871-1013°C)	As-received (stress-relieved, 2300°F) (1260°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 (982-1204°C)	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.

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or forged alloys at temperatures between 1600 and 2250°F (871 and 1235°C) until a 1% total elongation is attained. The tungsten materials are being tested at 3200°F (1760°C) and 2800°F (1566°C) for total extensions between 3 and 5% while the tantalum base materials are being evaluated in the 1800 and 2200°F (982 to 1240°C) range to an elongation of approximately 2%. 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 are graphically presented as percent total elongation in the 2 inch gauge section as a function of the time at the applied stress. Reference marks indicating the chamber pressure during the test period are also placed on the curves. The specific data for each test which is in progress or completed during this test period are given in detail in Appendix I.

1. Tungsten

The creep test data for the vapor-deposited tungsten are shown in Figure 1, which also presents for comparison the results obtained on arc-melted material at the 3200°F (1700°C) test temperature. The tungsten produced by vapor-deposition exhibited less creep than the arc-melted material. Results obtained on arc-cast tungsten tested at 2800°F (1538°C) are shown in Figure 2. A decrease in the applied stress from 4 Ksi to 3 Ksi (2.06×10^7 to 2.75×10^7 $N/_{M}2$) produced a marked decrease in the creep behavior. The data obtained on the tungsten base alloys examined in the program are given in Figure 3 in terms of the Larson-Miller parameter for 1% creep. The W-25 Re alloy exhibited significantly less creep than the arc-cast material at low values of the parameter where a deviation from linearity was apparent for the unalloyed tungsten.

2. Molybdenum-Base Alloys

The creep behavior of the TZM alloy (Heat 7502) tested at 2000°F (1093°C) is shown in Figure 4. After an initially high creep rate, virtually no extension has occurred in the recrystallized material over the last 3500 hours of test time. The as-received, stress-relieved material, however, has exhibited a relatively constant creep rate of 1.86×10^{-5}/hour from approximately 2000 to 9000 hours. As a result, at very long test times the total extension in the recrystallized material is less than that obtained in the stress-relieved condition. In tests conducted on the TZM from heat KDTZM-1175 (see Table 3) at 1856°F (1013°C) and 1600°F (871°C) relatively little creep was evident. The results indicate that the material from this heat has exceptionally good creep resistance at the lower temperatures. Additional tests will be conducted to determine whether the behavior shown by the Heat 1175 is primarily produced by the low test temperature or is a unique property of the particular heat being evaluated.

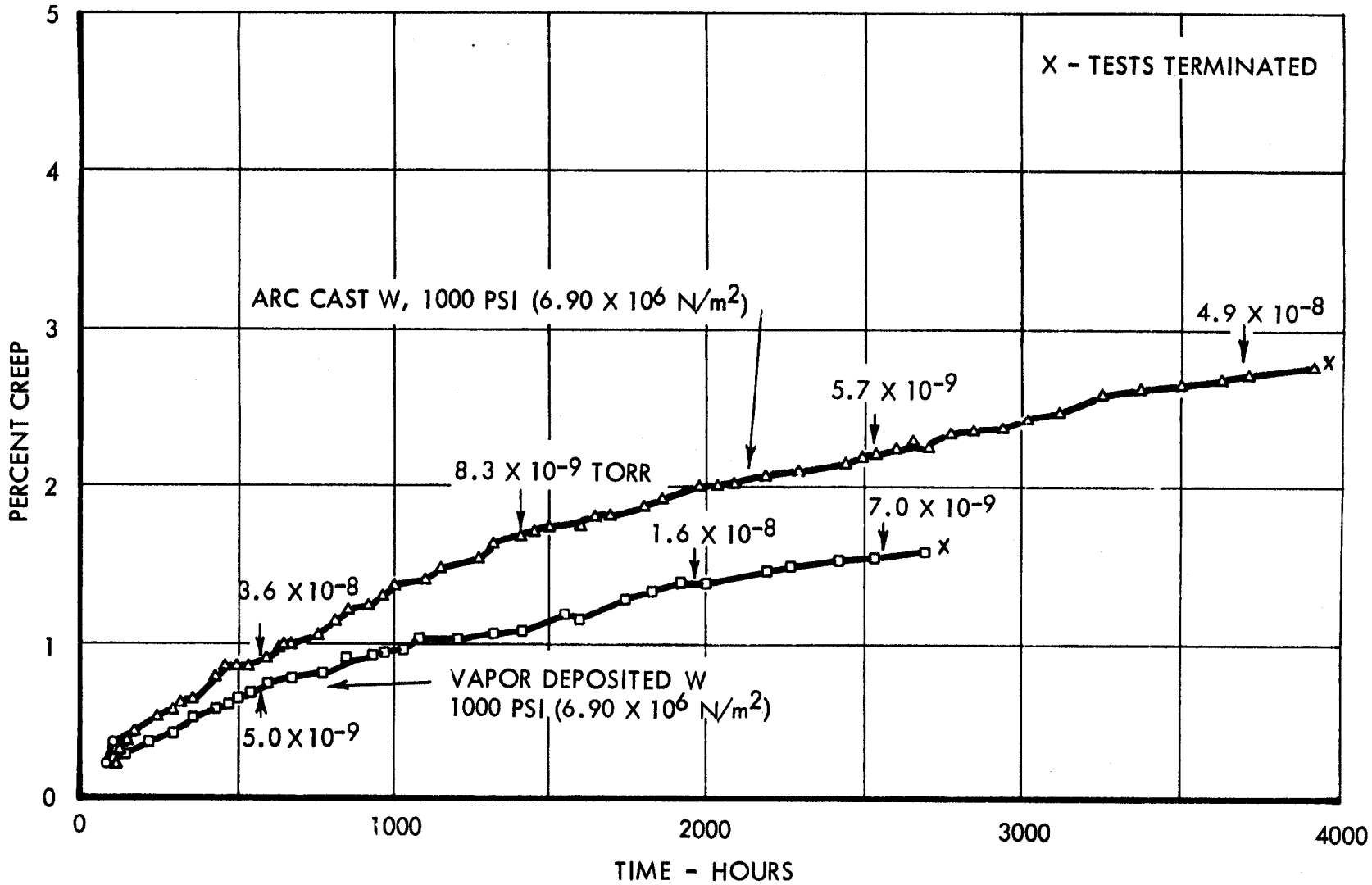

FIGURE 1 CREEP DATA FOR TUNGSTEN, TESTED AT 3200°F (1760°C) IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR

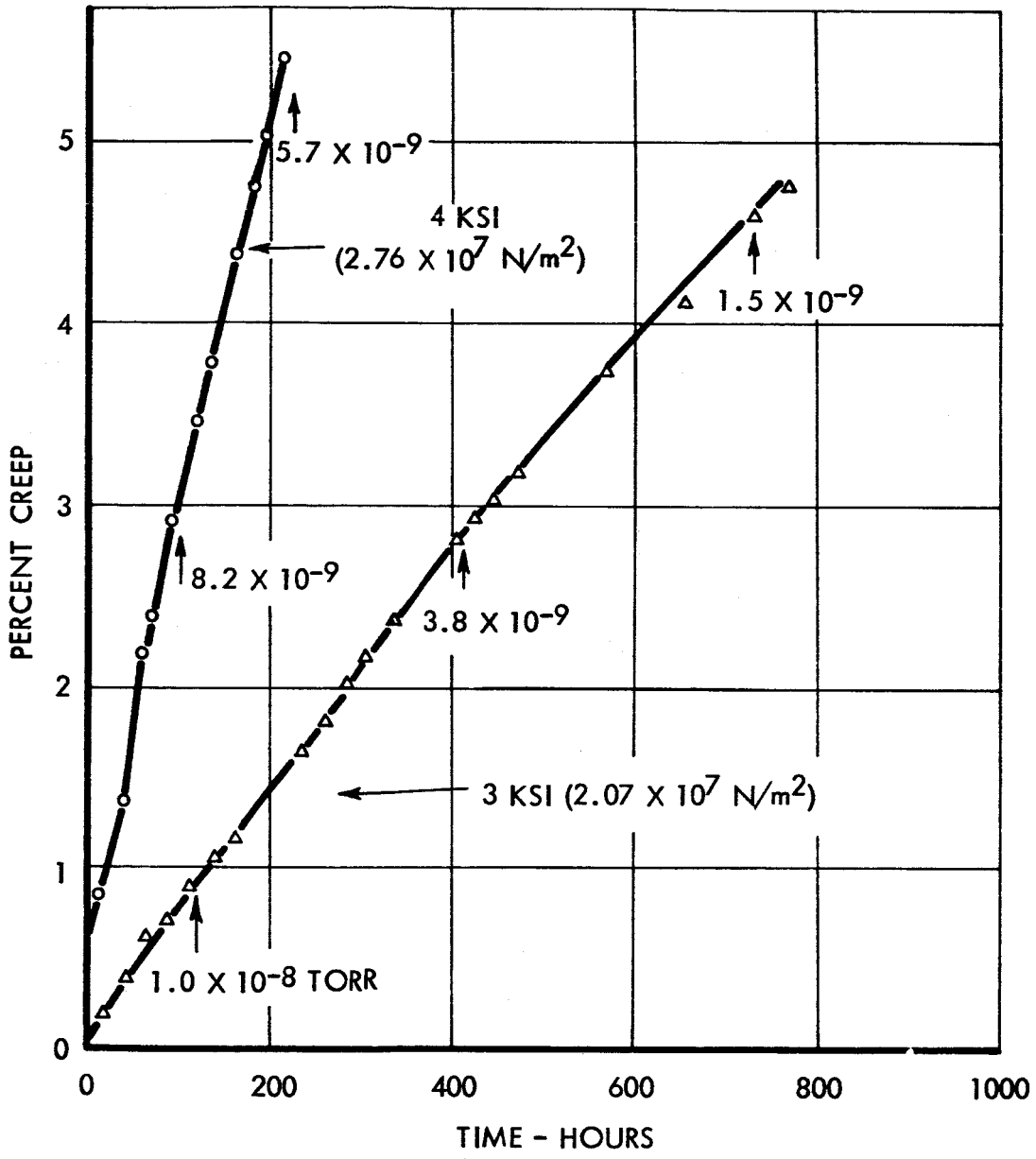

FIGURE 2 CREEP DATA FOR ARC-MELTED TUNGSTEN, TESTED AT 2800°F (1538°C) IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR

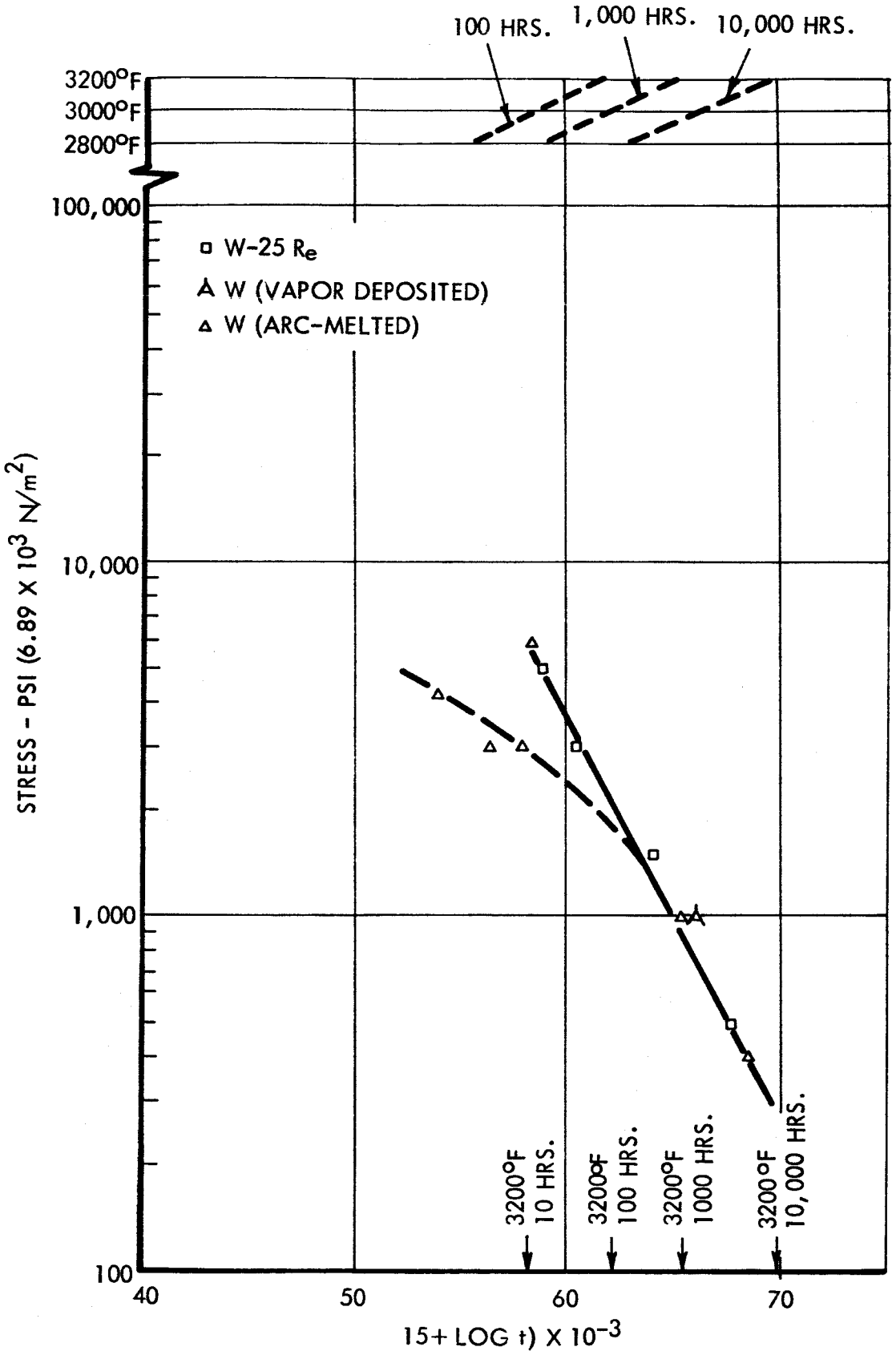

FIGURE 3 LARSON-MILLER PLOT OF TUNGSTEN AND TUNGSTEN-25% RHENIUM 1% CREEP DATA, (T = TEST TEMPERATURE °R, t = TEST TIME, HOURS) VACUUM ENVIRONMENT $<10^{-8}$ TORR

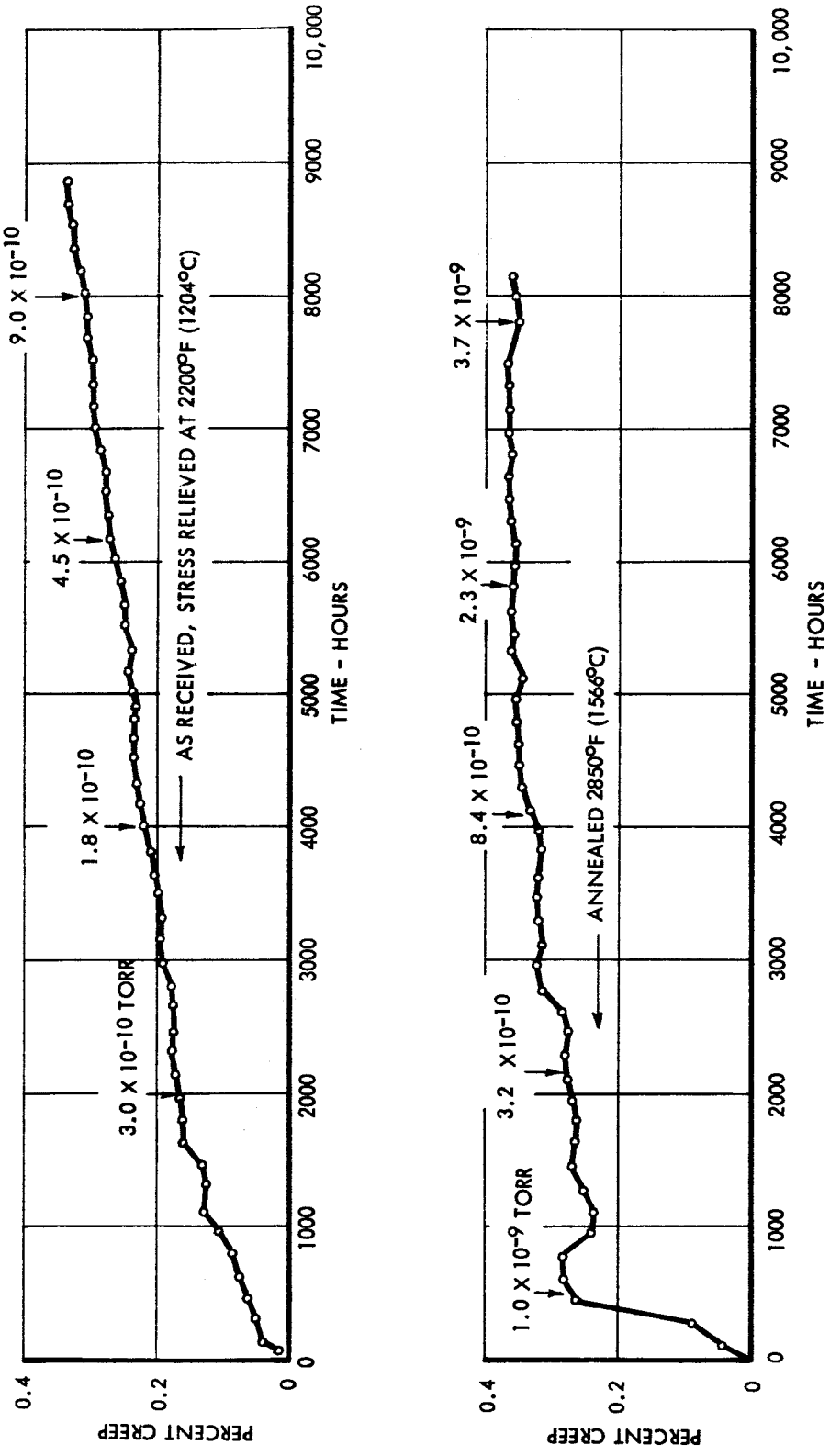

FIGURE 4 CREEP DATA FOR TZM DISC FORGINGS, (HEAT 7502), TESTED AT 2000°F (1093°C), 10 KSI (6.90 X 10^7 N/m^2), VACUUM ENVIRONMENT <10^{-8} TORR

TABLE 3

SUMMARY OF CREEP DATA ON TZM FROM HEAT 1175 (DISC 3)

Material	Condition	Test Temperature °F	Test Temperature °C	Applied Stress Ksi	Applied Stress N/m^2	Time (Hours)	% Creep	Status
TZM	Stress Relieved*	1856	1013	23.4	16.1×10^7	4376	0.035	Terminated
TZM	Stress Relieved*	1600	871	55.0	37.9×10^7	2159	0.018	Terminated
TZM	Stress Relieved*	1600	871	65.0	44.7×10^7	978	0.060	In progress

* 2300°F (1260°C), 1 hour

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Specimens of TZC from Heats M-80 and M-91 are being investigated and the test results are presented in Figures 5, 6, 7, 8, and 9. In the tests on Heat M-80 material conducted at 2056°F (1124°C) and 1856°F (1013°C), the appearance of "negative" creep which occurred between 3000 and 4000 hours has stopped and changed to a very low positive creep rate (see Figure 5). In the data shown in Figure 6 for the test conducted at 2000°F (1093°C), 20 Ksi ($1.38 \times 10^8 N/m^2$) a plateau occurred in the creep curve at times between 4000 and 5000 hours which also suggested the presence of a "negative" creep effect. Since TZC is known to exhibit strain-induced precipitation, the obvious explanation for the "negative" creep is the formation of a precipitate which produces specimen contraction and a resultant decrease in the total elongation measurement. The presence of the "negative" creep in the TZC alloys after long test times illustrates the errors which can occur in predicting creep values from relatively short time data.

In order to integrate the beneficial strengthening effects that strain-induced precipitation may impart on the TZC alloys with design predictions a relationship between applied stress, temperature and time should be selected to enable "negative" creep to be predicted from a knowledge of the test conditions. The Larson-Miller parameter has been initially used as a method for correlating the test parameters with "negative" creep effects. A plot of this parameter for the start of "negative" creep in the TZC alloys tested at 1856°F (1013°C), 2000°F (1093°C), and 2056°F (1124°C) is presented in Figure 7. The data, although limited, can be represented by a linear relationship over the temperature range evaluated. On this basis the time at which "negative" creep might be expected to occur can be determined from a knowledge of the applied stress and test temperature. Test data on TZC for temperatures of 2200°F (1204°C) reported in the Ninth Quarterly Report indicated that at these higher temperatures the "negative" creep phenomenon was not apparent despite the fact that the Larson-Miller plot shown in Figure 7 would predict such an effect. The results imply that the precipitation which is assumed to be producing the extensive decrease in creep is not the predominate mechanism above 2200°F (1204°C).

The creep of TZC (Heat M-91) in the stress relieved condition is presented in Figure 8 for a test temperature of 1800°F (982°C) and an applied stress of 44 Ksi ($3.03 \times 10^8 N/m^2$). The creep behavior is conventional and shows no apparent anomalies. The influence of heat treatment on the creep of the TZC material from Heat M-91 is presented in Figure 9. The material annealed at 3092°F (1700°C) and aged 5 hours at 2400°F (1316°C) showed a considerably greater rate of creep than material annealed at 3092°F (1700°C) but not aged.* The results can be rationalized on the basis that the prior aging treatment at 2400°F has formed a stable precipitate so that no strain-induced precipitation is occurring during the test to minimize the degree of creep. Figure 9 also presents a comparison of the two heats of TZC material in the 3092°F (1700°C) annealed condition.

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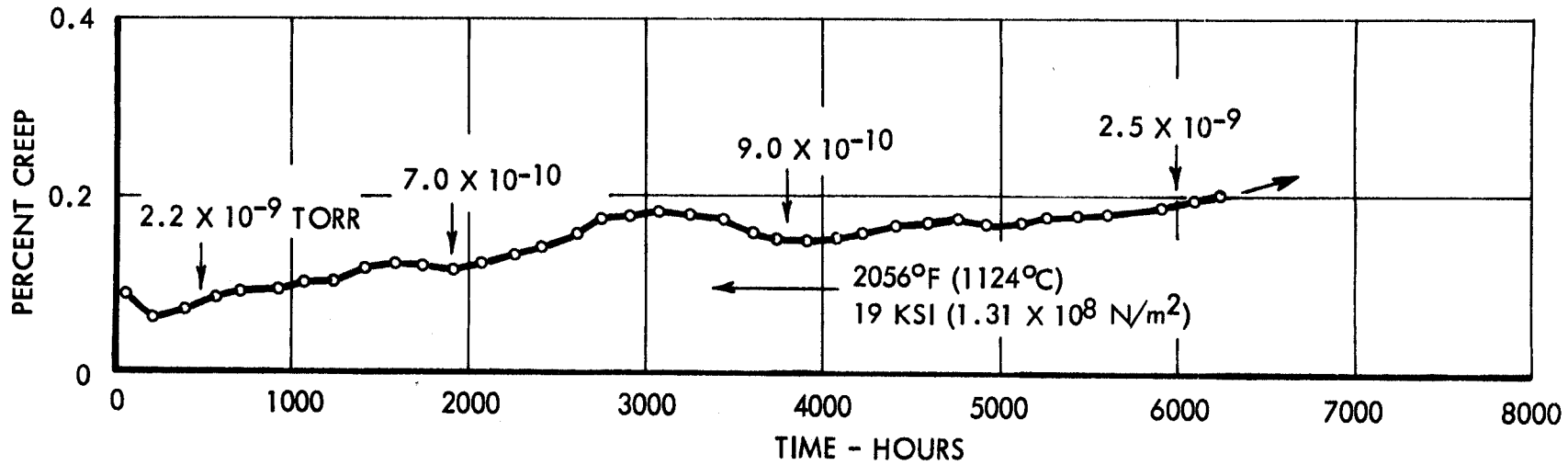
* This specimen was subsequently found to be cracked.



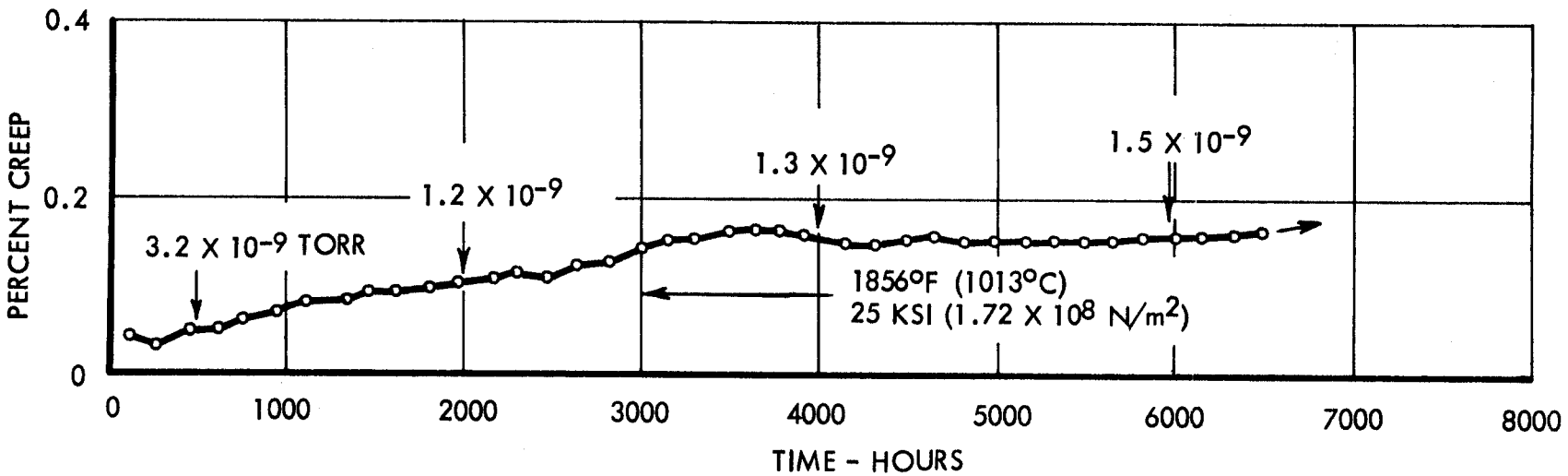


FIGURE 5 CREEP DATA FOR TZC PLATE (HEAT M-80) ANNEALED AT 3092°F (1700°C) TESTED IN VACUUM ENVIRONMENT < 1 X 10^{-8} TORR

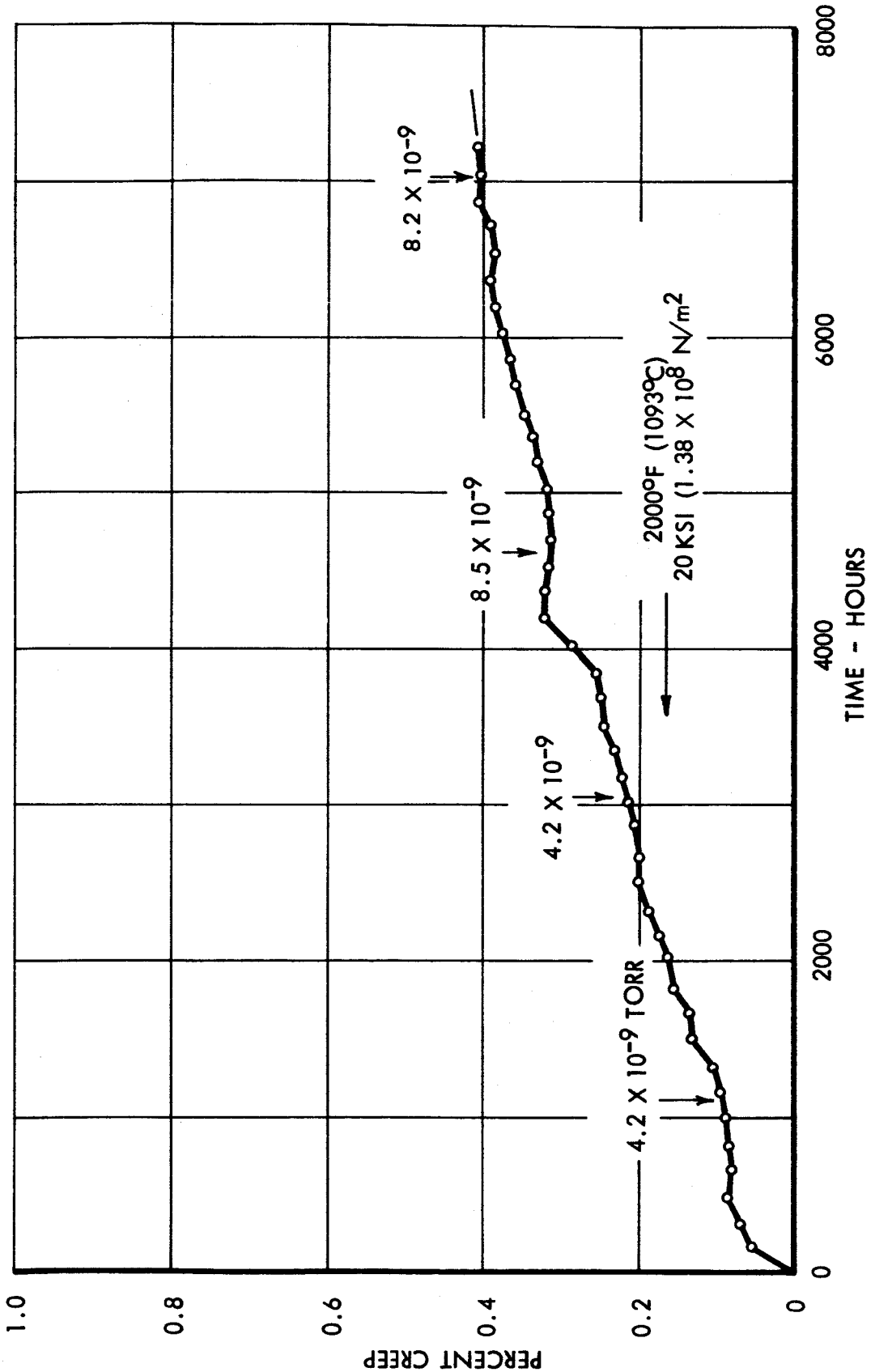


FIGURE 6 CREEP DATA FOR TZC PLATE (HEAT M-80) ANNEALED AT 3092 F (1700°C), TESTED IN VACUUM ENVIRONMENT < 1 X 10⁻⁸ TORR

135da

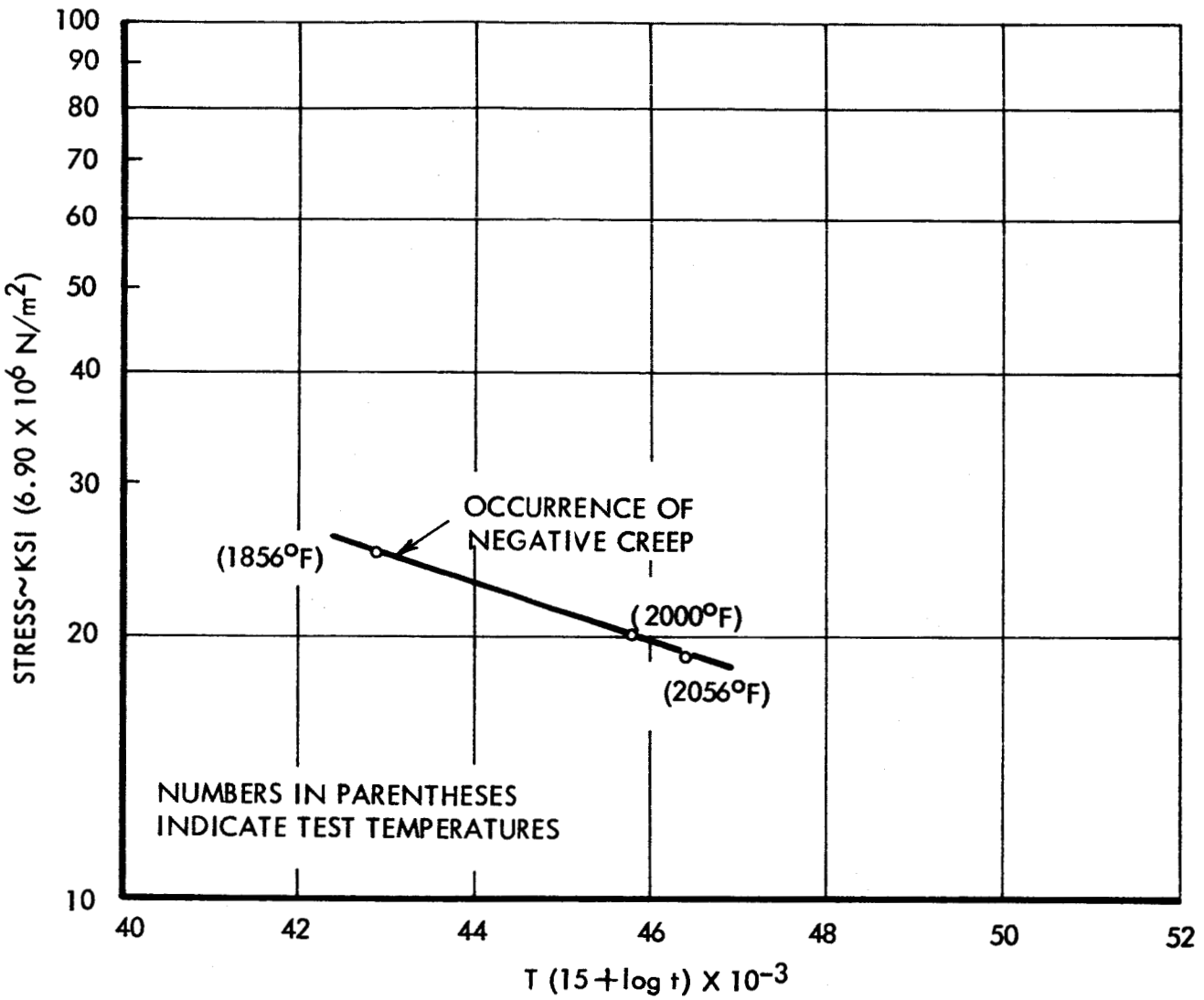


FIGURE 7 LARSON-MILLER PLOT OF CREEP DATA FOR TZC ALLOY SHOWING PARAMETER WHERE "NEGATIVE" CREEP IS INITIALLY OBSERVED, TZC ALLOY (HEAT M-80) IS ANNEALED AT 3092°F (1700°C), 1 HR. TESTED IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR

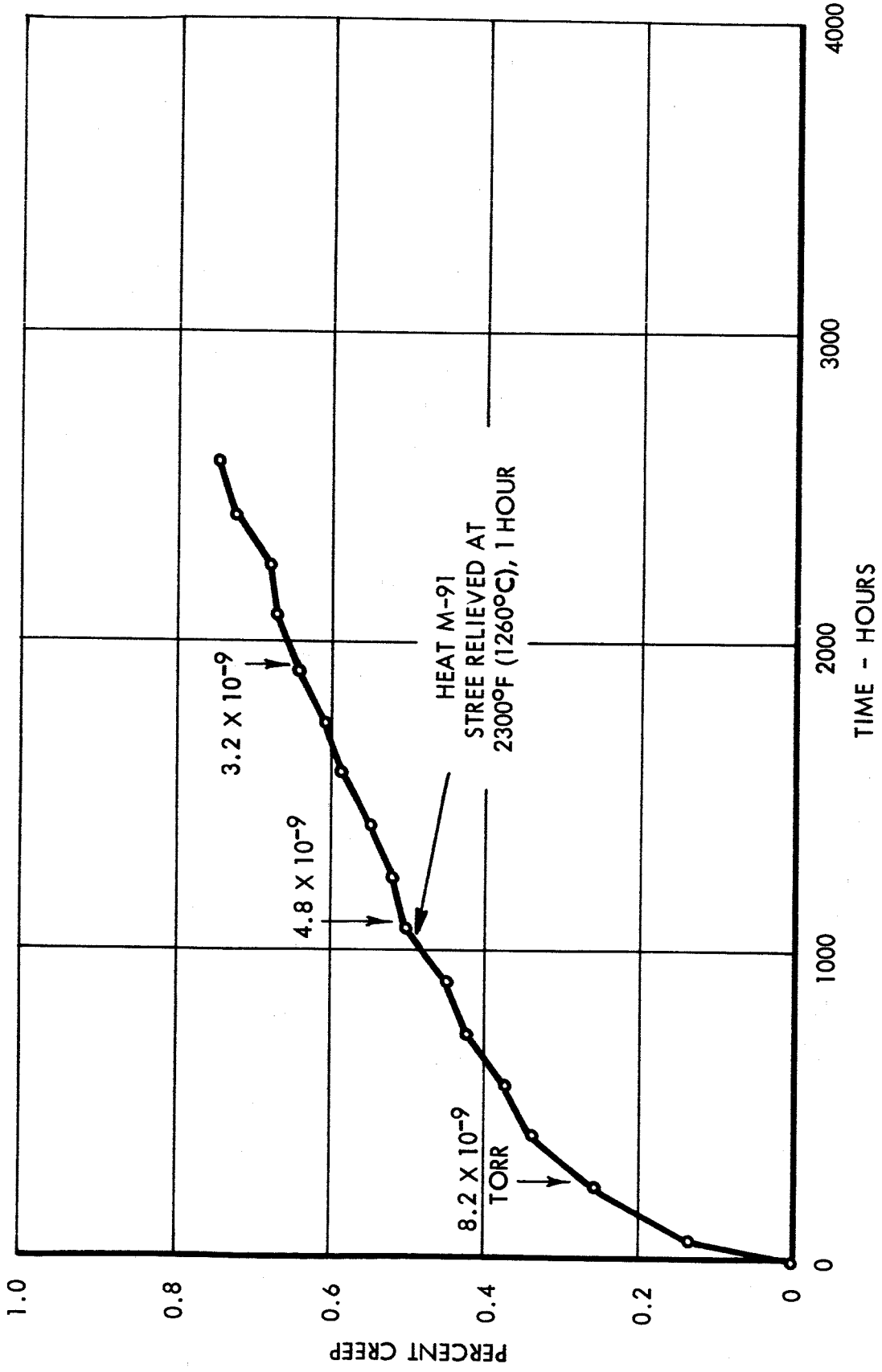


FIGURE 8 CREEP DATA FOR TZC ALLOY, TESTED AT 1800°F (982°C), 44 KSI (3.03 X 10^3 N/m^2) IN VACUUM ENVIRONMENT <1 X 10^{-8} TORR

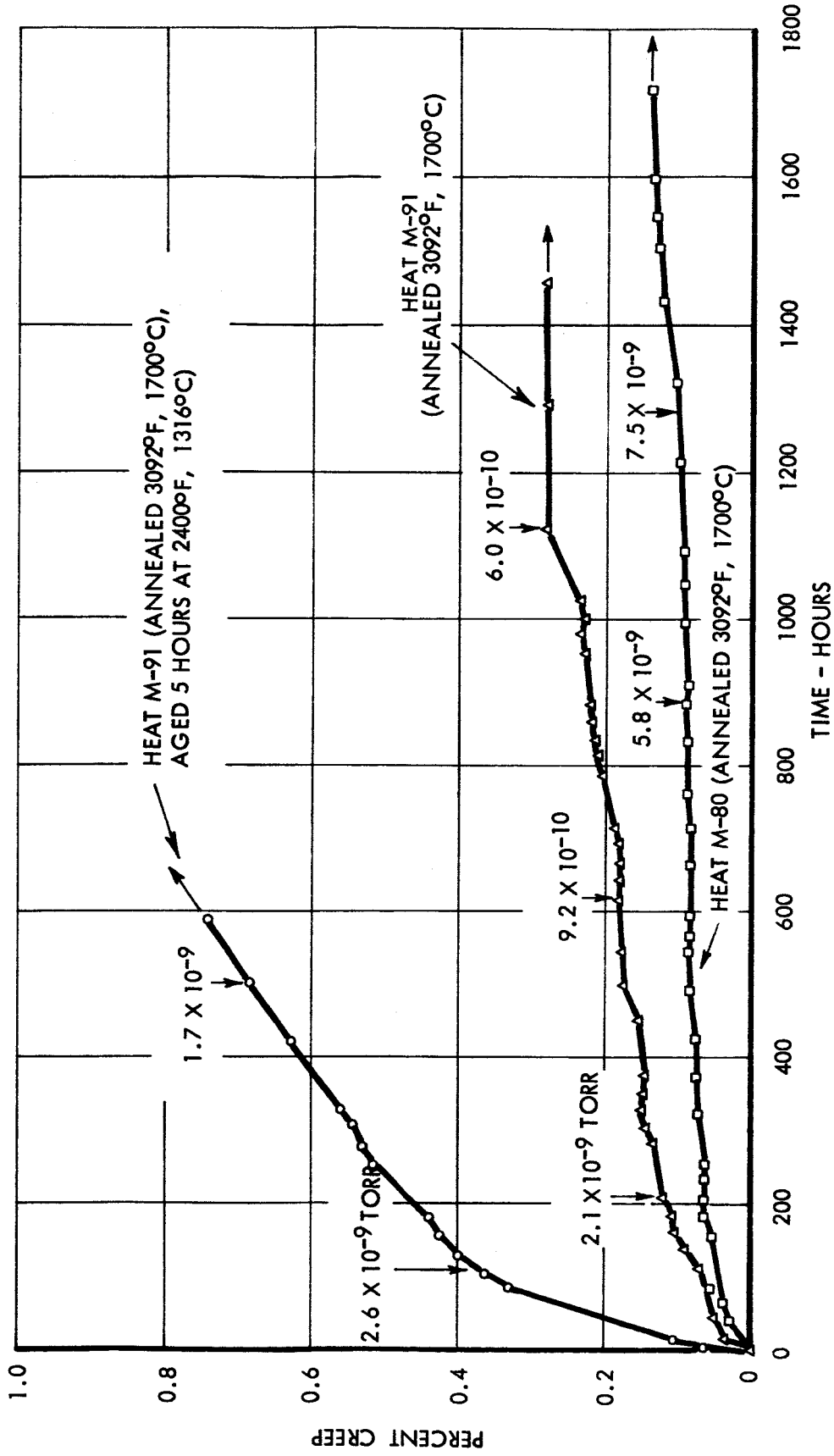


FIGURE 9 CREEP DATA FOR TZC ALLOY, TESTED AT 2000°F, (1093°C), 20 KSI (1.38×10^8 N/m^2) IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR

1353A

Over the current test duration at 2000°F (1093°C) and 20 Ksi ($1.38 \times 10^8 N/m^2$) the amount of creep in the specimens from Heat M-91 is greater than that experienced in Heat M-80 being tested under identical conditions. The variation between the heats can be partially attributed to the variation in processing treatments. Heat M-91 was heavily worked so that the annealing treatment at 3092°F (1700°C) produced a completely recrystallized structure with room temperature strength properties that were lower than those obtained in Heat M-80 material which was only partially recrystallized after the same anneal. The variation in creep rate at test times below 2000 hours is probably a result of the differences in degree of recrystallization.

3. Tantalum Base Alloys

Creep test data for both T-111 and T-222 tantalum base alloys are shown in Figures 10 and 11. The T-111 data indicate that a 3000°F (1649°C) annealing treatment produces a substantial improvement in creep resistance when compared to material annealed at 2600°F (1427°C). Creep data for the T-222 alloy tested at 2200°F (1204°C) and 2056°F (1124°C) presented in Figure 11 indicates a continuously increasing creep rate with increasing test time. Results obtained by post-test metallographic examination of the surface of the T-222 material tested for 1890 hours at 2200°F (1204°C) (5.72% creep) are shown in Figures 12 and 13. Appreciable grain boundary sliding is indicated in Figure 12 by the displacement of the scribe mark as it crosses the grain boundary. In addition to the grain boundary sliding, very fine slip lines were apparent in selected grains when the specimen was viewed with polarized light (Figure 13).

4. Residual Gas Analysis

Six of the vacuum creep units employed for creep testing are equipped with residual gas analyzers. These units which are based on the time-of-flight principle have been discussed in the Third Quarterly Report (CR 54048). During the course of the various creep tests, periodic recordings have been made of the residual gas in selected systems.

When the gas analyzer was first placed in use, no set procedure for operation was available. The measurement method consisted of connecting the electronic equipment to the analyzer head, making the recommended voltage adjustments, and finally recording the oscilliscope trace. During the course of the measurements it was found that the sensitivity of the response of the flight tube and the indicated composition of the residual gas was influenced by the time allowed for warm-up of the tube. The results, shown in Table 4, indicate that as the tube becomes warm from the filament, water vapor and possible CO_2 and CH_4-O_2 are released with the result that the relative amount of these gases in the analyzer ionization section continuously increases during the first 30 minutes of operation. At the same time, the amounts of H_2, H_2-CO, and argon decreases to half of their original values probably as a result of a dilution effect.

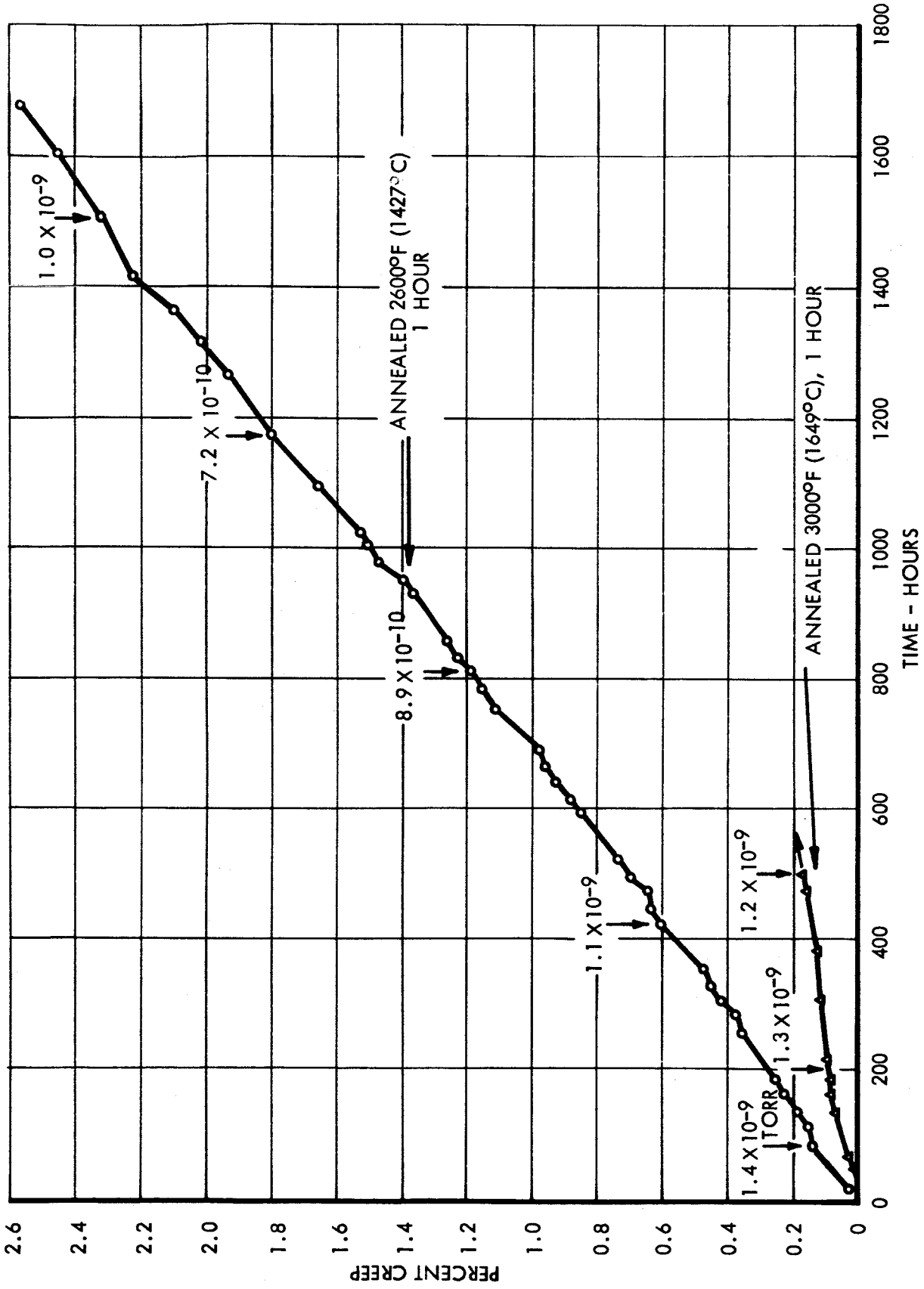


FIGURE 10 CREEP DATA FOR T-111 ALLOY, TESTED AT 2200°F, (1204°C), 8 KSI (5.52 X 10^7 N/m^2) IN VACUUM ENVIRONMENT <1 X 10^{-8} TORR

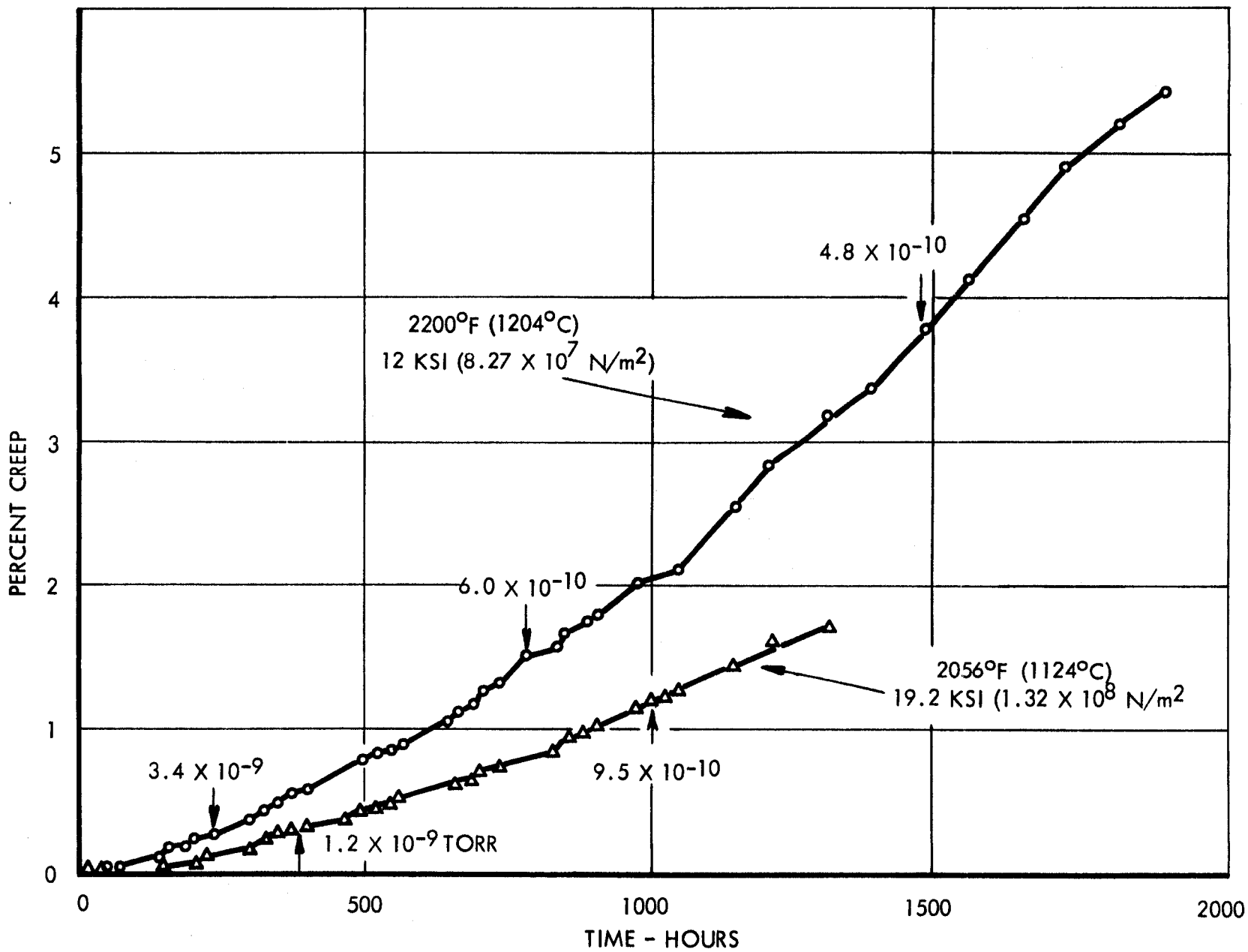


FIGURE 11 CREEP DATA FOR T-222 ALLOY, ANNEALED 3000°F (1649°C) FOR 1 HOUR TESTED IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR

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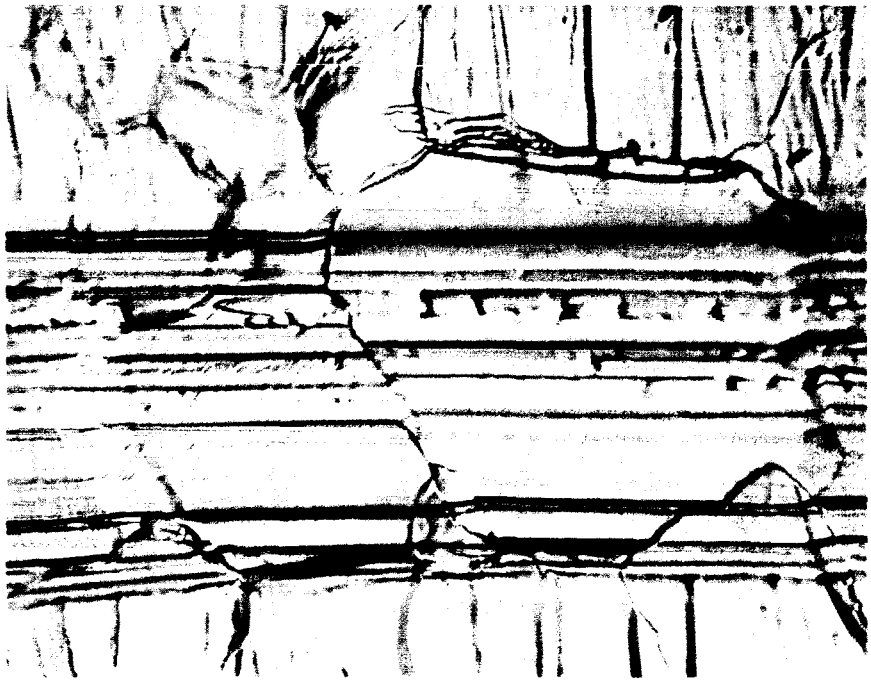

750X

Figure 12. Surface of T-222 specimen after testing at 2200°F (1204°C), 12 Ksi ($8.27 \times 10^7 N/m^2$) for 1890 Hours, 5.72% total extension. Photomicrograph shows grain boundary sliding.

1000X

Figure 13. Surface of T-222 specimen after testing at 2200°F (1204°C), 12 Ksi (8.27 x 107 N/m^2) for 1890 hours 5.72% total extension, polarized light. Photomicrograph illustrates fine slip present in the grain.

The residual gas analyses of current tests taken after a fixed tube warm-up time are given in Table 5 through 10. The results show that with few exceptions the major components of the residual gas are H_2O, CO-N_2 and CO_2. The appearance of CO and CO_2 has been attributed to reactions taking place in the ion pumps.

It will be noted in Table 5 that a line appears at mass number 34 and 35. Examination of various gases fails to show a particular specie which could be responsible for the appearance of the line in this position. Tests have shown similar lines appearing in this position when the sensitivity of the amplifier is reduced to the point where all lines are attentuated. The appearance of lines in this position, probably represents an artifact produced by the equipment rather than an unknown gas component.

At present no systematic trend in the variation in gas content as a function of test time can be established.

IV. FUTURE WORK

The long-time tests on the molybdenum-base alloys will be continued. Additional tests will be performed with the molybdenum alloys to further define the effects of heat treatment on the creep properties. Tests will be also initiated on columbium-modified TZM, vapor-deposited tungsten, and T-111. Primary emphasis will be placed on running long-time tests on TZC and T-111.

TABLE 4

Composition of Residual Gases as a Function of Analyzer Operating Time, Unit No. 10, Vapor Deposited Tungsten Specimen, 3200°F, (1760°C)

Warm-up Time-Min.	Residuals - % of Total Pressure (6.6×10^{-9} Torr)							
	H_2	He	C	CH_4 / O_2	H_2O	N_2 / CO	A	CO_2
0	9	1	2	1	4	60	13	10
5	8	1	2	2	7	57	12	11
21	5	1	2	3	19	38	7	25
30	4	1	2	3	25	32	7	26
40	5	1	1	3	24	31	7	28
50	5	1	2	2	24	30	7	29
52	3	-	1	4	31	33	6	32
70	3	1	3	3	29	33	5	23
73	5	1	2	3	28	32	5	24

TABLE 5

Composition of Residual Gases in Vacuum Chamber, Unit #1, TZM Specimen, 1800°F (982°C)

Time (Hrs.)	Pressure (Torr)	Residuals - % of Total Pressure								
		H_2	He	C	O_2 / CH_4	H_2O	CO / N_2	34-* / 35	A	CO_2
72	3.7×15^{-8}	52	-	-	2	16	8	4	-	18
671	1.6×15^{-9}	3	-	2	4	17	20	4	-	50
1459	1.1×10^{-9}	4	-	-	-	26	32	12	-	26
2008	1.0×10^{-9}	-	-	-	-	38	31	21	-	10

* No gas species for these mass numbers. Probably artifacts of analyzer.

TABLE 6

Composition of Residual Gases in Vacuum Chamber, Unit #2, TZC Specimen, 2000°F(1093°C)

Time (Hrs.)	Pressure (Torr)	Residuals - % of Total Pressure							
		H_2	He	C	O_2 CH_4	H_2O	CO N_2	A	CO_2
384	3.4×10^{-9}	19	4	1	4	18	35	11	8
1535	4.4×10^{-9}	24	2	-	6	28	22	11	6
2952	7.2×10^{-9}	14	2	1	8	34	28	6	7
3741	8.3×10^{-9}	15	2	1	11	30	28	7	7
4288	8.2×10^{-9}	17	2	-	8	26	31	7	9
5467	9.6×10^{-9}	16	2	-	5	30	27	10	10

TABLE 7

Composition of Residual Gases in Vacuum Chamber, Unit #3, T-222 Specimen, 2056°F(1124°C)

Time (Hrs.)	Pressure (Torr)	Residuals - % of Total Pressure							
		H_2	He	C	O_2 CH_4	H_2O	CO N_2	A	CO_2
189	1.8×10^{-9}	9	-	1	7	56	8	-	19
736	1.3×10^{-9}	24	-	-	3	27	30	-	16
1912	6.8×10^{-10}	13	-	-	2	31	27	-	27

TABLE 8

Composition of Residual Gases in Vacuum Chamber, Unit #6, TZM Specimen, 2000°F (1093°C)

Time (Hrs.)	Pressure (Torr)	Residuals - % of Total Pressure							
		H_2	He	C	O_2 CH_4	H_2O	CO N_2	A	CO_2
0	3.5×10^{-9}	65	-	-	3	11	12	-	12
1175	6.9×10^{-10}	40	-	-	3	17	31	-	9
2039	3.6×10^{-10}	20	-	-	4	22	32	-	19
5397	3.5×10^{-10}	11	-	2	7	26	34	-	20
5943	2.0×10^{-9}	17	2	2	4	18	34	17	6

TABLE 9

Composition of Residual Gases in Vacuum Chamber, Unit #8, TZC Specimen, 1856°F (1013°C)

Time (hrs)	Pressure (Torr)	Residuals - % of Total Pressure							
		H_2	He	C	O_2 CH_4	H_2O	CO N_2	A	CO_2
0	5.8×10^{-9}	20	1	2	6	15	35	3	18
3340	1.9×10^{-9}	16	1	1	7	18	34	14	9

TABLE 10

Composition of Residual Gases in Vacuum Chamber, Unit #8, Tungsten Specimen, 3200°F (1760°C)

Time (hrs)	Pressure (Torr)	Residuals - % of Total Pressure							
		H_2	He	C	O_2 CH_4	H_2O	CO N_2	A	CO_2
286	7.9×10^{-9}	1	-	1	4	49	18	4	23
520	6.6×10^{-9}	4	1	1	4	30	34	6	20

APPENDIX I

CREEP TEST DATA

TABLE A-I

CREEP TEST DATA, VAPOR DEPOSITED TUNGSTEN, RECRYSTALLIZED 2 HOURS 3200°F (1760°C), TESTED AT 3200°F (1760°C), 1000 PSI ($6.90 \times 10^6 N/m^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	.00010	.005	
2	.00070	.035	
3	.00110	.055	
6	.00120	.060	
14	.00100	.050	
20	.00105	.052	3.8×10^{-7}
40	.00110	.055	
60	.00160	.080	
16.3 hours	.00220	.110	1.2×10^{-7}
88.4	.00460	.230	7.2×10^{-8}
117.4	.00550	.275	6.7×10^{-8}
136.6	.00675	.338	1.8×10^{-8}
160.3	.00755	.378	3.0×10^{-8}
184.1	.00795	.398	8.9×10^{-9}
256.0	.00960	.480	1.4×10^{-8}
280.0	.00940	.470	7.9×10^{-9}
304.1	.01045	.522	6.7×10^{-9}
328.4	.01095	.548	8.2×10^{-9}
352.2	.01115	.558	1.2×10^{-8}
424.3	.01190	.595	5.2×10^{-9}
448.1	.01280	.640	4.7×10^{-9}
472.1	.01190	.595	6.5×10^{-9}
496.0	.01310	.655	6.6×10^{-9}
520.2	.01350	.675	6.0×10^{-9}
616.2	.01395	.698	5.9×10^{-9}
640.7	.01410	.705	5.6×10^{-9}
664.2	.01430	.715	7.8×10^{-9}
688.2	.01460	.730	4.9×10^{-9}
760.3	.01520	.760	4.0×10^{-9}
784.1	.01580	.790	5.4×10^{-9}
808.1	.01625	.812	5.2×10^{-9}
832.3	.01640	.820	5.0×10^{-9}
856.4	.01725	.862	--
928.5	.01750	.875	5.2×10^{-9}
952.4	.01760	.880	8.4×10^{-9}
976.2	.01710	.855	9.8×10^{-9}
991.0	.01800	.900	9.8×10^{-9}
1014.2	.01800	.900	9.5×10^{-9}

TABLE A-I (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1088.4	.01845	.922	8.4×10^{-9}
1158.3	.02030	1.015	8.0×10^{-9}
1254.7	.02030	1.015	9.2×10^{-9}
1326.3	.02080	1.040	7.8×10^{-9}
1422.7	.02190	1.095	2.6×10^{-7}
1494.2	.02330	1.165	1.0×10^{-8}
1590.8	.02290	1.145	6.8×10^{-9}
1662.2	.02510	1.255	8.0×10^{-9}
1758.2	.02540	1.270	9.0×10^{-9}
1829.9	.02605	1.302	8.0×10^{-9}
1927.7	.02660	1.330	1.4×10^{-8}
1998.9	.02700	1.350	1.6×10^{-8}
2095.1	.02825	1.412	1.4×10^{-8}
2191.3	.02910	1.455	1.4×10^{-8}
2263.2	.02950	1.475	1.5×10^{-8}
2259.2	.03000	1.500	1.2×10^{-8}
2431.8	.03050	1.525	1.2×10^{-8}
2527.6	.03065	1.532	1.1×10^{-8}
2599.4	.03090	1.545	7.0×10^{-9}
2671.0	.03140	1.570	4.6×10^{-9}

Test terminated because of inability to see scribe lines.

Specimen B-17

TABLE A-II

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

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

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	--

Test in Progress

Specimen S-18

TABLE A-III

CREEP TEST DATA, ARC-MELTED TUNGSTEN SHEET, ANNEALED AT 2800°F (1538°C), 1 HOUR, TESTED AT 2800°F (1538°C), 4,000 PSI (2.76×10^7 N/m^2)

Time		Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1	minute(s)	.00000	.000	1.4×10^{-7}
2		-.00030	-.015	1.4×10^{-7}
3		.00000	.000	1.4×10^{-7}
4		.00005	.002	1.4×10^{-7}
5		.00010	.005	1.4×10^{-7}
10		-.00005	-.002	1.4×10^{-7}
15		.00010	.005	1.4×10^{-7}
30		.00005	.002	1.4×10^{-7}
45		.00015	.008	1.4×10^{-7}
60		.00030	.015	1.4×10^{-7}
17.0	hours	.01720	.860	2.2×10^{-8}
41.0		.03150	1.375	1.3×10^{-8}
65.1		.04385	2.192	1.1×10^{-8}
73.3		.04785	2.392	--
98.6		.05900	2.950	8.2×10^{-9}
122.5		.06905	3.452	7.2×10^{-9}
137.7		.07605	3.802	7.2×10^{-9}
163.7		.08790	4.395	6.8×10^{-9}
185.4		.09500	4.750	6.6×10^{-9}
194.1		.10050	5.025	6.5×10^{-9}
218.1		.10905	5.452	5.7×10^{-9}

Test Completed at 5% Elongation

Specimen S-17

TABLE A-IV

CREEP TEST DATA, STRESS-RELIEVED TZM FORGED DISC, HEAT NO. 7502, TESTED AT 2000°F (1093°C), 10,000 PSI ($6.89 \times 10^7 N/m^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	-.00030	-.015	1.6×10^{-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	6.7×10^{-8}
74.7	.00030	.015	1.0×10^{-8}
125.7	.00100	.050	1.4×10^{-8}
136.5	.00800	.040	1.0×10^{-8}
160.3	.00085	.042	5.7×10^{-9}
184.4	.00085	.042	4.4×10^{-9}
208.5	.00090	.045	4.0×10^{-9}
232.2	.00090	.045	3.4×10^{-9}
304.4	.00100	.050	2.2×10^{-9}
328.3	.00100	.050	2.0×10^{-9}
352.2	.00105	.052	1.9×10^{-9}
376.6	.00105	.052	1.3×10^{-9}
400.8	.00110	.055	2.1×10^{-9}
457.5	.00130	.065	1.3×10^{-9}
472.6	.00135	.068	1.2×10^{-9}
497.0	.00140	.070	1.2×10^{-9}

TABLE A-IV (Continued)

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

TABLE A-IV (Continued)

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

TABLE A-IV (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep %	Pressure (Torr)
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 A-IV (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep %	Pressure (Torr)
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}
Test in Progress			

Specimen B-3

TABLE A-V

CREEP TEST DATA, TZM FORGED DISC HEAT # 7502, ANNEALED AT 2850°F (1566°C), FOR 1 HOUR, TESTED AT 2000°F (1093°C) 10,000 PSI (6.89×10^7 N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
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	6.2×10^{-9}
40.7	.00055	.028	3.1×10^{-9}
114.5	.00095	.048	5.1×10^{-9}
136.5	.00105	.052	3.0×10^{-9}
160.4	.00120	.060	3.4×10^{-9}
184.4	.00130	.065	2.4×10^{-9}
208.3	.00140	.070	2.3×10^{-9}
287.5	.00180	.090	2.2×10^{-9}
304.7	.00235	.118	1.8×10^{-9}
328.7	.00505	.252	1.6×10^{-9}
336.5	.00485	.242	--
352.6	.00515	.258	1.6×10^{-9}
376.4	.00525	.262	2.2×10^{-9}
448.3	.00525	.262	1.4×10^{-9}
472.7	.00525	.262	1.0×10^{-9}
496.6	.00530	.265	1.0×10^{-9}

TABLE A-V (Continued)

CREEP TEST DATA, TZM FORGED DISC HEAT #7502, ANNEALED AT 2850°F (1566°C), FOR 1 HOUR, TESTED AT 2000°F (1093°C) 10,000 PSI (6.89×10^7 N/m^2)

Time	Length Change ΔL (inch) (2" 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 A- V

CREEP TEST DATA, TZM FORGED DISC HEAT #7502, ANNEALED AT 2850°F (1566°C), FOR 1 HOUR, TESTED AT 2000°F (1093°C) 10,000 PSI (6.89×10^7 N/m^2)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
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 A-V (Continued)

CREEP TEST DATA, TZM FORGED DISC HEAT #7502, ANNEALED AT 2850°F (1566°C)

FOR 1 HOUR, TESTED AT 2000°F (1039°C), 10,000 PSI (6.89×10^7 N/m^2)

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

Test in progress
Specimen B-4

TABLE A-VI

CREEP TEST DATA, TZM MATERIAL, HEAT KDTZM 1175, TESTED AT 1600°F (871°C)

65,000 PSI (4.48×10^8 N/m^2)

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

Test in Progress
Specimen B-21

TABLE A-VII

CREEP TEST DATA, TZM MATERIAL, HEAT KDTZM 1175, TESTED AT 1600°F (871°C)

55,000 PSI ($3.79 \times 10^8 N/m^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	.00000	.000	6.3×10^{-9}
2	.00000	.000	
3	.00005	-.002	
4	.00005	.002	
5	.00005	.002	
6	.00000	.000	
7	.00000	.000	
8	.00010	.005	
9	.00015	.008	
10	.00010	.005	
15	.00030	.015	
30	.00015	.008	
60	.00020	.010	
21.2 hours	.00020	.010	3.4×10^{-9}
45.5	.00025	.012	2.6×10^{-9}
69.2	.00015	.008	2.2×10^{-9}
141.2	.00020	.010	1.6×10^{-9}
165.1	.00035	.012	1.6×10^{-9}
189.2	.00030	.015	1.4×10^{-9}
213.2	.00030	.015	1.3×10^{-9}
237.2	.00035	.018	1.4×10^{-9}
333.2	.00035	.018	1.2×10^{-9}
357.7	.00025	.012	1.1×10^{-9}
381.1	.00030	.015	1.1×10^{-9}
405.2	.00025	.012	1.1×10^{-9}
477.3	.00030	.015	1.1×10^{-9}
501.1	.00025	.012	9.5×10^{-10}
525.1	.00030	.015	1.1×10^{-9}
549.4	.00035	.018	1.1×10^{-9}
573.4	.00040	.020	—
645.7	.00035	.018	1.1×10^{-9}
669.4	.00030	.015	1.1×10^{-9}
693.2	.00030	.015	1.1×10^{-9}
741.2	.00030	.015	1.1×10^{-9}

TABLE A-VII (Continued)

CREEP TEST DATA, TZM MATERIAL, HEAT KDTZM 1175, TESTED AT 1600°F (871°C)

55,000 PSI ($3.79 \times 10^8 N/m^2$)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
815.4	.00030	.015	1.0×10^{-9}
837.2	.00025	.012	1.0×10^{-9}
861.0	.00020	.010	1.0×10^{-9}
885.4	.00030	.015	1.0×10^{-9}
909.5	.00035	.018	1.0×10^{-9}
981.7	.00040	.020	1.0×10^{-9}
1053.3	.00035	.018	1.0×10^{-9}
1149.7	.00045	.022	8.8×10^{-10}
1221.3	.00040	.020	8.8×10^{-10}
1317.8	.00035	.018	9.0×10^{-10}
1393.3	.00035	.018	8.6×10^{-10}
1485.3	.00030	.015	8.7×10^{-10}
1556.9	.00030	.015	9.5×10^{-10}
1654.7	.00025	.012	8.2×10^{-10}
1725.9	.00030	.015	6.6×10^{-10}
1822.2	.00025	.012	6.2×10^{-10}
1894.0	.00040	.020	6.2×10^{-10}
1990.2	.00035	.018	6.8×10^{-10}
2062.3	.00030	.015	3.6×10^{-10}
2158.8	.00035	.018	6.2×10^{-10}

Test terminated because of slow creep rate.

Specimen B-18

TABLE A-VIII

CREEP TEST DATA FOR TZM MATERIAL HEAT KDTZM 1175, TESTED AT 1856°F

55,000 PSI ($3.79 \times 10^8 N/m^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	-.00010	-.005	3.2×10^{-7}
2	-.00015	-.008	
3	-.00010	-.005	
4	-.00005	-.002	
5	-.00010	-.005	
6	-.00010	-.005	
7	-.00010	-.005	
8	-.00005	-.002	
9	-.00010	-.005	
10	-.00005	-.002	
15	-.00020	-.010	
30	-.00020	-.010	
60	-.00015	-.008	
66.9 hours	-.00010	-.005	3.7×10^{-8}
88.5	-.00005	-.002	2.2×10^{-8}
117.1	-.00005	-.002	2.3×10^{-8}
136.4	.00000	.000	1.6×10^{-8}
160.4	.00005	.002	1.6×10^{-9}
232.2	.00020	.010	9.8×10^{-9}
256.7	.00015	.008	8.8×10^{-9}
280.6	.00020	.010	5.6×10^{-9}
304.5	.00020	.010	6.7×10^{-9}
329.8	.00030	.015	6.1×10^{-9}
400.4	.00025	.012	4.2×10^{-9}
424.4	.00030	.015	3.7×10^{-9}
448.7	.00035	.018	3.4×10^{-9}
472.4	.00040	.020	2.6×10^{-9}
496.5	.00040	.020	1.5×10^{-9}
592.6	.00040	.020	1.8×10^{-9}
616.5	.00045	.022	1.4×10^{-9}
640.7	.00035	.018	1.6×10^{-9}
664.3	.00030	.015	1.6×10^{-9}
736.3	.00035	.018	1.1×10^{-9}
760.9	.00030	.015	1.0×10^{-9}
784.4	.00030	.015	1.3×10^{-9}
808.7	.00035	.018	1.4×10^{-9}
832.1	.00050	.025	1.0×10^{-9}
904.8	.00045	.022	1.2×10^{-9}
928.5	.00050	.025	1.0×10^{-9}
952.6	.00060	.030	8.2×10^{-10}
976.5	.00050	.025	5.2×10^{-10}

1600A

TABLE A-VIII (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1075.2 hours	.00050	.025	--
1149.3	.00050	.025	8.4×10^{-10}
1250.5	.00045	.022	6.8×10^{-10}
1313.6	.00065	.032	3.6×10^{-10}
1410.1	.00055	.028	5.7×10^{-10}
1504.7	.00055	.028	1.2×10^{-9}
1576.4	.00060	.030	5.5×10^{-10}
1648.7	.00080	.040	1.1×10^{-9}
1744.3	.00080	.040	1.1×10^{-9}
1816.5	.00085	.042	1.1×10^{-9}
1912.5	.00080	.040	1.1×10^{-9}
1984.4	.00080	.040	1.0×10^{-9}
2104.5	.00075	.038	1.1×10^{-9}
2152.5	.00070	.035	5.0×10^{-10}
2248.5	.00075	.038	4.9×10^{-10}
2320.7	.00070	.035	1.0×10^{-9}
2416.9	.00065	.032	1.0×10^{-9}
2498.3	.00065	.032	5.7×10^{-10}
2586.6	.00070	.035	1.0×10^{-9}
2656.7	.00070	.035	1.1×10^{-9}
2752.7	.00070	.035	1.2×10^{-9}
2824.6	.00070	.035	1.0×10^{-9}
2921.1	.00065	.032	1.1×10^{-9}
2992.5	.00065	.032	1.0×10^{-9}
3189.0	.00065	.032	1.0×10^{-9}
3260.4	.00060	.030	1.1×10^{-9}
3356.4	.00060	.030	1.0×10^{-9}
3428.3	.00070	.035	8.2×10^{-10}
3536.0	.00060	.030	4.4×10^{-10}
3607.1	.00065	.032	6.6×10^{-10}
3703.4	.00060	.030	4.6×10^{-10}
3775.3	.00060	.030	5.6×10^{-10}
3871.3	.00070	.035	6.0×10^{-10}
3943.3	.00070	.035	5.6×10^{-10}
4040.0	.00075	.038	7.1×10^{-10}
4135.3	.00070	.035	6.3×10^{-10}
4207.3	.00065	.032	4.7×10^{-10}
4279.0	.00075	.038	9.4×10^{-10}
4375.5	.00070	.035	7.9×10^{-10}

Test terminated because of low creep rate.

Specimen B-16

TABLE A-IX

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/m^2)
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 A-IX (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep %	Pressure (Torr)
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 A-IX (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep %	Pressure (Torr)
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}

Test in progress

Specimen B-11

TABLE A-X

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 ($1.31 \times 10^8 N/m^2$)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minutes	.00010	.005	7.0×10^{-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	6.9×10^{-8}
20	.00165	.082	
25	.00170	.085	
30	.00170	.085	6.9×10^{-8}
40	.00175	.088	
45	.00175	.088	
60	.00180	.090	6.8×10^{-8}
90	.00180	.090	6.7×10^{-8}
15.7 hours	.00180	.090	3.5×10^{-8}
87.1	.00180	.090	1.4×10^{-8}
111.2	.00100	.050	9.8×10^{-9}
133.4	.00140	.070	7.0×10^{-9}
159.0	.00135	.068	3.0×10^{-9}
181.6	.00130	.065	—
239.9	.00135	.068	4.2×10^{-9}
263.7	.00130	.065	5.1×10^{-9}
287.7	.00150	.075	4.5×10^{-9}
309.9	.00140	.070	3.8×10^{-9}
334.3	.00150	.075	3.2×10^{-9}
406.5	.00145	.072	3.5×10^{-9}
459.3	.00155	.078	—
503.2	.00150	.075	2.2×10^{-9}
573.9	.00175	.088	1.2×10^{-9}

TABLE A-X (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
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 A-X (Continued)

Time	Length Change ΔL (inch) (2" G. L.)	Creep %	Pressure (Torr)
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}

Test in progress

Specimen B-12

TABLE A-XI

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 ($1.38 \times 10^8 N/m^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	.00000	.000	1.2×10^{-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	2.6×10^{-9}
41.3	.00060	.030	2.2×10^{-9}
65.2	.00080	.040	2.2×10^{-9}
89.2	.00115	.058	2.0×10^{-9}
161.3	.00110	.055	1.3×10^{-9}
185.7	.00130	.065	1.7×10^{-9}
209.1	.00125	.068	1.7×10^{-9}
233.2	.00125	.062	1.4×10^{-9}
257.3	.00130	.065	1.3×10^{-9}
329.2	.00140	.070	2.0×10^{-9}
355.9	.00145	.072	3.2×10^{-9}
377.0	.00145	.072	3.4×10^{-9}
401.1	.00145	.072	2.4×10^{-9}
425.0	.00150	.075	1.5×10^{-9}
497.2	.00170	.085	1.9×10^{-9}
521.4	.00170	.085	3.1×10^{-9}
545.4	.00165	.082	4.8×10^{-9}
569.2	.00170	.085	4.5×10^{-9}
593.1	.00170	.085	4.6×10^{-9}
665.2	.00165	.082	5.0×10^{-9}
713.3	.00160	.080	4.6×10^{-9}
762.8	.00170	.085	--
833.4	.00175	.088	1.5×10^{-8}
881.4	.00185	.092	6.1×10^{-9}
905.2	.00175	.088	5.8×10^{-9}

TABLE A-XI (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
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 A-XI (Continued)

Time	Length Change L (inch) (2" G. L.)	Creep %	Pressure (Torr)
3355.4 hours	.00460	.230	—
3429.1	.00460	.230	—
3530.3	.00490	.245	—
3593.5	.00495	.247	7.8×10^{-9}
3689.9	.00500	.250	8.0×10^{-9}
3760.5	.00510	.255	8.0×10^{-9}
3856.2	.00515	.257	8.2×10^{-9}
3928.5	.00525	.262	8.2×10^{-9}
4024.1	.00575	.282	8.7×10^{-9}
4096.3	.00620	.310	8.2×10^{-9}
4192.3	.00640	.320	8.2×10^{-9}
4264.1	.00640	.320	8.2×10^{-9}
4384.3	.00640	.320	8.4×10^{-9}
4432.3	.00640	.320	9.0×10^{-9}
4528.3	.00630	.315	8.6×10^{-9}
4600.5	.00640	.320	9.4×10^{-9}
4696.7	.00625	.312	9.5×10^{-9}
4769.2	.00640	.320	8.5×10^{-9}
4866.4	.00635	.318	9.2×10^{-9}
4936.5	.00630	.315	9.2×10^{-9}
5032.5	.00635	.318	9.2×10^{-9}
5104.4	.00660	.330	8.4×10^{-9}
5200.9	.00660	.330	9.5×10^{-9}
5272.3	.00670	.335	8.8×10^{-9}
5368.8	.00675	.338	9.4×10^{-9}
5440.3	.00685	.342	9.4×10^{-9}
5536.2	.00700	.350	1.0×10^{-8}
5608.0	.00705	.352	3.4×10^{-9}
5705.8	.00715	.358	6.4×10^{-9}
5777.0	.00720	.360	4.9×10^{-9}
5873.3	.00730	.365	4.9×10^{-9}
5945.1	.00745	.372	3.4×10^{-9}
6041.2	.00750	.375	2.8×10^{-9}
6113.2	.00770	.385	3.4×10^{-9}
6209.9	.00770	.385	3.3×10^{-9}
6305.5	.00775	.388	3.5×10^{-9}
6377.5	.00780	.390	6.3×10^{-9}
6449.2	.00775	.388	7.0×10^{-9}
6545.7	.00770	.385	8.2×10^{-9}
6617.2	.00780	.390	7.4×10^{-9}
6713.2	.00780	.390	7.9×10^{-9}
6785.3	.00780	.390	7.8×10^{-9}
6881.6	.00810	.405	8.0×10^{-9}
6953.4	.00790	.395	8.3×10^{-9}
7052.7	.00805	.402	8.2×10^{-9}
7125.5	.00810	.405	8.1×10^{-9}
7217.2	.00810	.405	8.4×10^{-9}

Test in progress

Specimen B-9

TABLE A-XII

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 ($1.38 \times 10^8 N/m^2$)

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

Test in Progress

Specimen B-22

TABLE A-XIII

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 ($1.38 \times 10^8 N/m^2$)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
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 A-XIII (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
787.7 Hours	.00410	.205	7.4×10^{-10}
811.6	.00420	.210	7.1×10^{-10}
835.3	.00435	.218	7.2×10^{-10}
859.2	.00440	.220	7.0×10^{-10}
883.2	.00445	.222	7.0×10^{-10}
956.3	.00460	.230	6.6×10^{-10}
980.0	.00470	.235	6.4×10^{-10}
1003.4	.00455	.228	6.4×10^{-10}
1027.2	.00465	.232	6.2×10^{-10}
1123.7	.00485	.242	6.0×10^{-10}
1195.5	.00490	.245	5.7×10^{-10}
1294.7	.00515	.258	6.0×10^{-10}
1367.4	.00525	.262	5.8×10^{-10}
1459.1	.00560	.280	5.6×10^{-10}

Test in Progress

Specimen B-20

TABLE A-XIV

CREEP TEST DATA, TZC PLATE, HEAT M-91, ANNEALED 2300°F (1260°C) 1 HOUR, TESTED 1800°F (982°C), 44,000 PSI ($3.03 \times 10^8 N/m^2$)

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

TABLE A-XIV (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
906.9	.00890	.445	2.3×10^{-9}
978.6	.00965	.482	2.2×10^{-9}
1076.4	.01005	.502	2.2×10^{-9}
1147.6	.01020	.510	4.8×10^{-9}
1243.8	.01045	.522	4.4×10^{-9}
1315.7	.01065	.532	4.3×10^{-9}
1411.9	.01100	.550	4.4×10^{-9}
1580.5	.01170	.585	2.7×10^{-9}
1676.3	.01205	.602	4.0×10^{-9}
1748.1	.01220	.610	4.2×10^{-9}
1819.7	.01255	.628	2.8×10^{-9}
1916.3	.01285	.642	3.2×10^{-9}
1987.7	.01310	.655	2.0×10^{-9}
2084.2	.01345	.672	3.2×10^{-9}
2155.8	.01365	.682	2.4×10^{-9}
2252.2	.01375	.688	3.1×10^{-9}
2324.0	.01405	.702	2.3×10^{-9}
2423.3	.01455	.728	2.0×10^{-9}
2496.0	.01465	.732	1.9×10^{-9}
2587.7	.01495	.748	2.6×10^{-9}

Test in progress

Specimen B-19

TABLE A-XV

CREEP TEST DATA, T-111 SHEET, ANNEALED 3000°F (1649°C) FOR 1 HOUR, TESTED AT 2200°F (1204°C), 8,000 PSI ($5.52 \times 10^7 N/m^2$)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (5)	Pressure (Torr)
1 Minutes	.00005	.002	2.6×10^{-9}
2	.00010	.005	2.6×10^{-9}
3	.00015	.008	2.6×10^{-9}
4	.00010	.005	2.6×10^{-9}
5	.00005	.002	2.6×10^{-9}
6	.00005	.002	2.6×10^{-9}
7	.00005	.002	2.6×10^{-9}
8	.00000	.000	2.6×10^{-9}
9	.00005	.002	2.6×10^{-9}
10	.00005	.002	2.6×10^{-9}
15	.00000	.000	2.6×10^{-9}
30	.00010	.005	2.6×10^{-9}
45	.00010	.005	2.6×10^{-9}
60	.00005	.002	2.6×10^{-9}
2.4 Hours	.00005	.002	2.6×10^{-9}
19.2	.00010	.005	2.0×10^{-9}
43.1	.00010	.005	1.6×10^{-9}
48.3	.00035	.018	1.6×10^{-9}
67.1	.00060	.030	1.5×10^{-9}
139.4	.00135	.068	1.4×10^{-9}
163.0	.00155	.078	1.4×10^{-9}
187.0	.00175	.088	1.2×10^{-9}
211.3	.00190	.095	1.3×10^{-9}
310.5	.00215	.108	1.2×10^{-9}
383.3	.00245	.122	1.3×10^{-9}
474.9	.00320	.160	1.3×10^{-9}
499.3	.00370	.185	1.2×10^{-9}

Test in Progress

Specimen S-19

TABLE A-XVI

CREEP TEST DATA, T-111 SHEET ANNEALED 2600°F (1427°C) FOR 1 HOUR, TESTED AT 2200°F (1204°C), 8,000 PSI ($5.52 \times 10^7 N/m^2$)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minutes	.00010	.005	6.2×10^{-9}
2	-.00015	-.008	6.2×10^{-9}
3	-.00010	-.005	6.2×10^{-9}
4	-.00005	-.002	6.2×10^{-9}
5	.00010	.005	6.2×10^{-9}
6	.00010	.005	6.2×10^{-9}
7	.00005	.002	6.2×10^{-9}
8	.00015	.008	6.2×10^{-9}
9	.00015	.008	6.2×10^{-9}
10	.00010	.005	6.2×10^{-9}
15	.00020	.010	6.2×10^{-9}
30	.00015	.008	6.2×10^{-9}
45	.00010	.005	6.2×10^{-9}
60	.00020	.010	6.2×10^{-9}
2 Hours	.00015	.008	5.7×10^{-9}
18.5	.00070	.035	2.8×10^{-9}
90.3	.00280	.140	1.4×10^{-9}
113.9	.00320	.160	1.4×10^{-9}
138.1	.00395	.198	1.4×10^{-9}
162.3	.00455	.228	1.3×10^{-9}
186.1	.00500	.250	2.2×10^{-9}
258.6	.00700	.350	1.2×10^{-9}
282.5	.00745	.372	1.2×10^{-9}
306.3	.00830	.415	1.1×10^{-9}
330.2	.00895	.448	3.8×10^{-9}
354.3	.00950	.475	1.0×10^{-9}
426.7	.01200	.600	1.1×10^{-9}
450.2	.01270	.635	1.0×10^{-9}
475.1	.01280	.640	1.1×10^{-9}
498.1	.01400	.700	1.0×10^{-9}
522.3	.01465	.732	1.1×10^{-9}
594.0	.01690	.845	1.2×10^{-9}
617.8	.01750	.875	1.0×10^{-9}
642.1	.01840	.920	1.0×10^{-9}
665.8	.01900	.950	1.1×10^{-9}
690.9	.01970	.985	1.0×10^{-9}

TABLE A-XVI

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
763.6	.02225	1.112	9.8×10^{-10}
787.0	.02290	1.145	8.9×10^{-10}
811.0	.02375	1.188	8.9×10^{-10}
834.8	.02445	1.222	8.1×10^{-10}
859.7	.02470	1.235	7.8×10^{-10}
931.0	.02745	1.372	7.2×10^{-10}
955.2	.02785	1.392	7.4×10^{-10}
979.4	.02940	1.470	7.2×10^{-10}
1022.9	.03025	1.512	7.1×10^{-10}
1027.1	.03030	1.515	7.7×10^{-10}
1099.0	.03320	1.660	7.1×10^{-10}
1171.0	.03600	1.800	7.2×10^{-10}
1267.7	.03875	1.938	6.6×10^{-10}
1315.4	.04035	2.018	6.6×10^{-10}
1363.5	.04200	2.100	7.0×10^{-10}
1435.3	.04445	2.222	1.0×10^{-9}
1506.9	.04640	2.320	1.0×10^{-9}
1603.5	.04885	2.442	9.5×10^{-10}
1675.0	.05140	2.570	9.5×10^{-10}

Test Completed

Specimen S-16

TABLE A-XVII

CREEP TEST DATA, T-222 SHEET, ANNEALED 3000°F (1649°C), 1 HOUR, TESTED AT 2200°F (1204°C), 12,000 PSI ($8.27 \times 10^7 N/m^2$)

HEAT AL TA 43

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minutes	.00020	.010	2.8×10^{-9}
2	.00070	.035	
3	.00060	.030	
4	.00060	.030	
5	.00065	.032	
6	.00060	.030	
7	.00070	.035	
8	.00060	.030	
9	.00060	.030	
10	.00070	.035	
15	.00070	.035	
45	.00080	.040	
1.0 hours	.00075	.038	2.8×10^{-9}
17.7	.00110	.055	2.0×10^{-9}
41.2	.00120	.060	1.6×10^{-9}
65.0	.00140	.070	1.5×10^{-9}
136.9	.00230	.115	1.5×10^{-9}
160.9	.00345	.172	1.2×10^{-9}
184.9	.00370	.185	1.3×10^{-9}
209.0	.00435	.218	3.2×10^{-9}
232.9	.00505	.252	3.4×10^{-9}
305.1	.00775	.388	1.0×10^{-9}
328.9	.00865	.432	2.5×10^{-9}
353.0	.00980	.490	8.7×10^{-10}
376.8	.01080	.540	2.5×10^{-9}
401.0	.01165	.582	2.4×10^{-9}
497.0	.01535	.768	8.0×10^{-10}
521.6	.01625	.812	8.0×10^{-10}
545.0	.01715	.858	8.1×10^{-10}
569.0	.01785	.892	7.8×10^{-10}
641.0	.02145	1.072	2.1×10^{-9}
664.9	.02250	1.125	2.0×10^{-9}
688.9	.02360	1.180	2.0×10^{-9}
713.2	.02540	1.270	2.0×10^{-9}
737.0	.02640	1.320	—
809.4	.03035	1.518	6.0×10^{-10}
833.2	.03140	1.570	1.8×10^{-9}
857.1	.03320	1.660	1.7×10^{-9}
881.8	.03440	1.720	5.0×10^{-9}
905.0	.03580	1.790	5.5×10^{-10}

TABLE A-XVII (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
979.1 hours	.04055	2.028	5.6×10^{-10}
1049.2	.04445	2.222	1.0×10^{-9}
1145.1	.05110	2.555	9.8×10^{-10}
1217.2	.05660	2.830	8.8×10^{-10}
1313.5	.06350	3.175	9.2×10^{-10}
1385.1	.06770	3.385	4.6×10^{-10}
1481.5	.07575	3.788	4.8×10^{-10}
1553.0	.08275	4.138	8.2×10^{-10}
1648.9	.09085	4.542	8.4×10^{-10}
1720.7	.09800	4.900	5.0×10^{-10}
1818.4	.10710	5.355	7.2×10^{-10}
1889.7	.11440	5.720	9.5×10^{-10}

Test completed at 5% elongation.

Specimen S-13

TABLE A XVIII

CREEP TEST DATA, T-222 SHEET, ANNEALED 300°F (1649°C), 1 HOUR, TESTED AT 2056°F (1124°C), 19,200 PSI ($1.32 \times 10^8 N/m^2$)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minute(s)	.00000	.000	
3	.00015	.008	
8	.00015	.008	
13	.00015	.008	
1.0 hour(s)	.00015	.008	3.0×10^{-9}
18.6	.00015	.008	--
40.5	.00030	.015	5.7×10^{-9}
137.2	.00065	.032	1.6×10^{-9}
159.8	.00090	.045	1.4×10^{-9}
183.6	.00140	.070	1.4×10^{-9}
207.8	.00190	.095	3.3×10^{-9}
231.8	.00230	.115	3.1×10^{-9}
303.7	.00340	.170	1.2×10^{-9}
328.9	.00480	.240	1.3×10^{-9}
351.5	.00540	.270	9.5×10^{-10}
375.8	.00565	.282	8.4×10^{-10}
399.5	.00610	.305	1.2×10^{-9}
471.4	.00755	.378	1.4×10^{-9}
495.5	.00845	.422	1.0×10^{-9}
519.5	.00915	.458	1.0×10^{-9}
543.6	.00965	.482	1.2×10^{-9}
567.6	.01005	.502	1.2×10^{-9}
663.6	.01230	.615	1.4×10^{-9}
687.6	.01305	.652	1.3×10^{-9}
711.5	.01410	.707	1.3×10^{-9}
735.7	.01485	.742	1.4×10^{-9}
831.6	.01830	.915	1.4×10^{-9}
856.2	.01895	.948	9.2×10^{-10}
879.6	.01970	.985	1.0×10^{-9}
903.6	.02095	1.042	9.5×10^{-10}
975.6	.02310	1.155	9.2×10^{-10}
999.6	.02385	1.192	9.5×10^{-10}
1023.5	.02465	1.232	1.0×10^{-9}
1047.8	.02550	1.275	9.0×10^{-10}
1144.0	.02935	1.468	9.5×10^{-10}
1216.4	.03215	1.608	5.4×10^{-10}
1313.7	.03385	1.692	8.3×10^{-10}

Test Terminated

Specimen S-14

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