MSAR 63-125

PROGRESS REPORT 36
August 1963

to

U. S. Atomic Energy Commission
Chicago Operations Office
Lemont, Illinois

EFFECT OF 1200°F SODIUM ON AUSTENITIC AND FERRITIC STEELS

Physical Properties of Materials

Contract AT(11-1)-765
Modification No. 1

September 17, 1963

MSA Research Corporation

Subsidiary of Mine Safety Appliances Company

Callery, Pennsylvania

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Progress Report 36

EFFECT OF 1200°F SODIUM ON AUSTENITIC AND FERRITIC STEELS

PHYSICAL PROPERTIES OF MATERIALS

SUMMARY

The physical properties research program was initiated for the purpose of determining the effects of reactor grade sodium, and normally anticipated contaminants, upon Type 316 stainless steel and 2 1/4 Cr-1 Mo steel. For comparison, the physical properties of these same materials were to be determined in air and helium. The test temperatures selected were 1200°F for the austenitic and 1100°F for the ferritic. The contaminants to be intentionally introduced into the sodium after the reactor grade sodium tests were completed would be oxygen, carbon, and nitrogen. The types of tests selected for revealing any possible effects of the environments upon the materials were tensile, creep, stress-to-rupture, and fatigue.

TEST 1 - STAINLESS STEEL (316) SPECIMENS IN 1200°F, LOW OXYGEN (30 ppm) SODIUM, AIR AND HELIUM

The two remaining specimens in helium are essentially complete, having reached and passed their minimum creep rate. The minimum creep rates for specimens in all three environments are compared and the creep rate curves included. The stress necessary to produce a creep rate of 0.1% per 1000 hours for 316 ss in 1200°F sodium and helium are 11 and 13.5% respectively lower than the stress necessary to produce the same creep rate in 1200°F air.

All other tests for these conditions have been completed. Microprobe analysis of selected stainless steel specimens was performed. The iron, chromium, nickel, and molybdenum images at the surfaces of the specimens are included. Quantitative line profiles of iron, chromium and nickel composition from the matrix to the exposed surface are included and show no effect within 10 microns of the surface. It is concluded that specific metallic mass transfer is not significant in 4000 hours for the conditions of this test.

TEST 2 - 2 1/4 Cr-1 Mo STEEL SPECIMENS IN 1100°F, LOW OXYGEN (30 ppm), SODIUM, AIR AND HELIUM

Only one creep test in helium remains in operation and it has passed its minimum rate. The creep rate curves are shown and the minimum creep rates versus stresses are compared for the three environments. The results indicate the stresses to produce 0.10% minimum creep in 1000 hours in 1100°F sodium and 1100°F helium are 32% lower and 6% higher respectively than in 1100°F air. The lowest creep rate reached in sodium, however, was 0.3% per 1000 hours with the creep rate of 0.1% being obtained by extrapolating a two-point curve.

All other tests for these conditions have been completed.

TEST 3 - STAINLESS STEEL (316) SPECIMENS IN 1200°F, HIGH CARBON SODIUM

The shakedown operation of this system is in progress. The carbon concentration has not reached equilibrium and no additional carbon or specimens have been added. Frequent carbon samples are being taken and the results of these analyses are included and show a range from 20 to 180 ppm.

TEST 4 - 2 1/4 Cr-1 Mo STEEL SPECIMENS in 1100°F, HIGH (300 ppm) OXYGEN SODIUM

The operational history of this test to date is shown graphically. The creep-to-rupture tests have been completed on original specimens. The results indicate shorter rupture times in sodium with high oxygen than in low oxygen sodium. These rupture times range from being 12% shorter under high stress to 46% shorter at the lower stresses. The greater difference at the lower stresses is due to the two curves having different slopes. Data scatter may have exaggerated the differences between these two mediums. Elongation curves for each specimen are included.

The creep tests are still in progress, but preliminary data indicate the creep rates in high oxygen sodium will be lower than in sodium with low oxygen.

The fatigue tests are in progress with the initial results showing agreement with the low oxygen sodium tests.

Progress Report 36

EFFECT OF 1200°F SODIUM ON AUSTENITIC AND FERRITIC STEELS

PHYSICAL PROPERTIES OF MATERIALS

1. INTRODUCTION

MSA Research Corporation and the University of Michigan are in the process of completing the final helium tests and examining the specimens generated under Tests 1 and 2. At the same time, Test 3 is in its shakedown operations and Test 4 is in progress.

The test program for Tests 1 and 2 under AEC Contract AT(11-1)-765 and modified by letters from F. C. Mattmueller (Director Contracts Division) to Dr. R. C. Werner (MSAR), dated February 12, 1962, and to C. H. Staub (MSAR) on October 24, 1962, and January 8, 1963, is summarized in Progress Report 33 (Table 1).

The test program for Tests 3 and 4 under this contract, as outlined in a letter from F. C. Mattmueller to C. H. Staub, dated October 24, 1962, and revised by letter from F. C. Mattmueller to C. H. Staub, dated January 8, 1963, is summarized in Progress Report 33 (Table 2).

2. OPERATION

L. H. Kirschler
J. W. Freeman (University of Michigan)

2.1 TEST 1 - STAINLESS STEEL (316) SPECIMENS IN 1200°F, LOW (30 ppm) OXYGEN SODIUM, AIR AND HELIUM

The following tests have been completed:

1. All air tests
2. All sodium tests
3. All fatigue tests
4. All tensile tests
5. All creep-rupture tests

The only operations remaining in Test 1 are the completion of two creep rate measurements in 1200°F helium at loads of 11,000 and 10,500 psi. The creep rate of the specimen at 11,000 psi decreased to 0.18%/1000 hours in 1000 hours and held constant to 2400 hours, at which time it began increasing. It has now reached

0.27%/1000 hours after 3000 hours. The creep rate of the specimen at 10,500 psi decreased to a rate of 0.08%/1000 hours at 800 hours, and then increased to 0.11%/1000 hours to the present 3000 hours. The third specimen has been removed after 4008 hours and exhibited a minimum creep rate of 0.23%/1000 hours at 800 hours, then increased to a termination rate of 0.48%/1000 hours.

Complete data from Test 1 is tabulated in Table 1 of Progress Report 34. Preliminary conclusions were also included in Progress Report 34. A graphic illustration of the operational history of Test 1 is shown in Fig. 1. Plots of the creep rates showing the latest helium data are found in Figs. 2, 3, and 4. Plots of the minimum creep rates exhibited by the stainless steel specimens in all three enrivonments versus the stress applied are shown in Fig. 5.

The determination of the stress necessary to produce a minimum creep rate of 0.1% in 1000 hours was to be the means of comparing the test environments. These tests have indicated some influence of the environment on the creep rates. This is illustrated below, showing the variation of the stress necessary to produce 0.1% creep in 1000 hours of stainless steel specimens in air, helium and sodium.

Test Environment	Stress to Produce 0.1% Minimum Creep in 1000 Hours
Air - 1200°F	12,250 psi
Helium - 1200°F	10,600 psi
Sodium (30 ppm O_2) - 1200°F	10,900 psi

If the differences can be considered significant, the data indicates 316 ss specimens in 1200°F sodium with 30 ppm oxygen and 1200°F helium require 11 and 13.5% respectively lower stresses to produce 0.1% creep per 1000 hours than in air.

2.2 TEST 2 - 2 1/4 Cr-1 Mo STEEL SPECIMENS IN 1100°F, LOW (30 ppm) OXIDE SODIUM, AIR AND HELIUM

The following tests have been completed and the data from these tests summarized in Table 1 of Progress Report 34:

1. All air tests
2. All sodium tests
3. All fatigue tests
4. All tensile tests
5. All creep-rupture tests

The operational history of Test 2 is graphically illustrated in Fig. 6.

One creep rate measurement in 1100°F helium under 5500 psi stress was terminated during this report period after 3929 hours. The creep rate had decreased to 0.02%/1000 hours and was still decreasing when terminated. A second creep specimen in 1100°F helium under 7000 psi stress is still in progress after 3000 hours, but a minimum rate of 0.245%/1000 hours was reached after 1400 hours. A third specimen under 6000 psi stress was removed after 4000 hours after reaching a minimum creep rate of 0.085%/1000 hours. Figs. 7, 8, and 9 show the plots of the creep rates including the latest helium data. The minimum creep rates versus applied stress are shown for all three environments in Fig. 10.

Here also the objective was to be the comparison of the stresses necessary to obtain minimum creep rates of 0.1% in 1000 hours in air, helium and sodium (30 ppm O_2). The creep tests in helium are essentially complete and the minimum creep rates established at this time. The comparison of these minimum creep rates is shown below:

Test Environment	Stress to Produce 0.1% Creep in 1000 Hours
Sodium (30 ppm O_2) - 1100°F	4000 psi
Air - 1100°F	5850 psi
Helium - 1100°F	6200 psi

It would appear that the stresses to produce 0.1% creep in 1000 hours in 1100°F sodium and 1100°F helium are 32% lower and 6% higher respectively than in air under the same conditions. The lowest creep rate actually reached in sodium, however, was 0.3% per 1000 hours. The stress value for the creep rate of 0.1% per 1000 hours was obtained by extrapolation of a two-point curve.

Two creep-to-rupture measurements in 1100°F air were completed during this report period on specimens previously exposed to 1100°F sodium for 4000 hours. One specimen at 12,500 psi failed after 195.2 hours and another at 14,000 psi failed after 74.3 hours. This completes all the creep-rupture measurements for Test 2. Results are shown graphically in Fig. 11.

These recently completed creep and creep-rupture operations only confirm the conclusions as previously stated in Progress Report 33.

2.3 TEST 3 - STAINLESS STEEL (316) SPECIMENS IN 1200°F, HIGH CARBON SODIUM

Loop 1 will be utilized for this test and is in operation without specimens. The fluctuation of the carbon level is to such a degree that start of the actual test is being delayed until there is a better understanding of the variables involved. The analytical and engineering groups are actively engaged in the clarification of the complete carbon picture.

Circulation of Loop 1 continued this month with the outlet line that failed the previous month being replaced. Samples of sodium were taken daily for carbon analysis. Two samples were taken for oxide determination to check the plugging indicator results. The results of the analyses are discussed in Section 4.

After establishing a carbon equilibrium in the system, the carbon addition bypass system will be put into operation. The test conditions will be obtained and foil samples will be installed for a 2-3 week period. Following the analysis of the foil data, Test 3 will be initiated.

2.4 TEST 4 - 2 1/4 Cr-1 Mo STEEL SPECIMENS IN 1100°F, HIGH OXIDE (300 ppm) SODIUM

This test is well underway with three creep specimens, two creep-rupture specimens, and a fatigue specimen in progress. Suffucient creep rupture data is available to show results.

Operational history of Loop 2 during Test 4 is shown graphically in Fig. 12.

2.4.1 2 1/4 Cr-1 Mo Steel Fatigue Runs

One fatigue specimen had been previously completed under low cyclic strain and, after about 45,000 cycles, the fatigue machine motor failed, ending the second run. After repairs, a new specimen was installed and this specimen ran to failure at 45,890 cycles. The third specimen failed after 48,551 cycles. The mandrel will be changed and the intermediate strain runs initiated during the next report period. The results of the low cyclic strain tests are found in Table 1.

2.4.2 2 1/4 Cr-1 Mo Steel Creep-Rupture Runs

The creep-rupture specimen at a load of 9500 psi failed after 1846 hours. Since the previous test at 16,000 psi stress was run with a temperature differential, due to malfunction, it was decided to rerun this point. The new run failed after 142 hours and completes the creep-rupture runs for Test 4 on original material.

The results of these runs are found in Table 2 and are also plotted in Fig. 11, with curves obtained from Test 2 (low oxide sodium) for comparison. From this curve it appears that the creep-rupture times for Cr-Mo in sodium with high oxide are shorter than in sodium with low oxide. The specimen elongations, as taken from externally mounted dial gages, are plotted against time in Fig. 13. Metallurgical examinations of these specimens are not complete at this time.

2.4.3 2 1/4 Cr-1 Mo Steel Creep Runs

The determination of creep rates of the three 2 1/4 Cr-1 Mo specimens continued with stresses of 7000 psi, 6000 psi and 4500 psi. These runs have been in progress approximately 1700 hours.

The creep rate of the 7000 psi specimen decreased to 0.06%/1000 hours at 2200 hours and is still decreasing. The preliminary curve is plotted in Fig. 7 with the results from Test 2 for comparison.

The creep rate of the 6000 psi specimen decreased to 0.25%/1000 hours after 400 hours and has now increased to 0.69%/1000 hours after 2200 hours. The preliminary curve is plotted in Fig. 8 with the results obtained from Test 2 for comparison.

The creep rate of the 4500 psi specimen decreased to 0.05%/1000 hours after 1000 hours and has increased to 0.23%/1000 hours after 2200 hours, as shown in Fig. 9.

2.4.4 2 1/4 Cr-1 Mo Tensile Tests

The 2 1/4 Cr-1 Mo tensile tests are not scheduled until the completion of the creep tests.

3. METALLURGICAL RESULTS

3.1 TEST 1 - 316 ss IN LOW OXIDE (30 ppm) SODIUM

Evaluation of metallurgical effects occurring in stainless steel specimens is near completion. Analysis of surfaces of specimens for carbon is presently underway, in attempts to correlate carbon diffusion rates in stressed versus unstressed specimens. Microprobe analysis of selected stainless steel specimens has been performed, and a topical report, which will include results on Test 1, is in preparation.

Microprobe analysis of two stainless steel specimens that had been exposed to high purity sodium was performed at the Mellon Institute, Pittsburgh, Pa. Sample number 3ALX1 was a 316 specimen that had been creep tested at a stress of 13,500 psi for 4000 hours in 1200°F high purity sodium. Sample number 99 was exposed to 1200°F sodium for 4000 hours in an unstressed condition.

Fig. 14 is an iron image at the surface of sample number 99. Each of the grid squares shown in Fig. 14 is 1.77 mils on edge, and the spacing between center grid markings is 0.35 mils. The iron content within the field is quite homogeneous, although the lower left corner appears to show a lower iron content. Examination of all microprobe photographs shows the same low density effect in the same portion of the field, indicating that this effect is a characteristic of the instrument.

Figs. 15 and 16 show respectively the chromium and nickel images of the same sample, which also indicate no significant inhomogeneities with respect to these elements. Examination of Ni, Cr and Fe images (not shown) of as-received 316 did not show any inhomogeneities and appeared to be identical to images of the creep specimen (not shown) as well as those of sample number 99. Fig. 17 shows a molybdenum image at the surface of the creep specimen. No inhomogeneities appear to exist for molybdenum.

Quantitative line profiles of Fe, Cr and Ni composition from the matrix to the exposed surface were obtained for both exposed samples. Fig. 18 is a plot of metallic compositions versus distance from the surface. The iron, chromium and nickel values were found to be uniform on both samples, with the exception of a surface-affected layer approximately 8 microns ($\sim$0.0003 in.) thick. The matrix chromium content was found to be 23% as compared to a chemical Cr analysis of 18.1%, while microprobe Ni analysis was approximately 10.5% as compared to a chemical analysis of the heat of 12.7%. The differences between microprobe results versus those obtained by chemical analysis are thought to be the result of interferences of foreign elements in microprobe analysis.

The microprobe line profiles show a depletion of chromium, which is not apparent on the qualitative photographs shown in Fig. 15. A slight enrichment of iron, probably as a result of chromium removal is also apparent in Fig. 18.

It is concluded that metallic mass transfer is not significant in 4000 hours under the relatively isothermal conditions and low oxygen content existing in the systems. Chromium removal with subsequent enrichment of the remainder of the constituents of the surface has occurred, but the affected zone is significantly less than 1 mil. The application of a load to the Type 316 ss specimens did not markedly affect mass transfer. The differences in removal of chromium from the stressed versus unstressed sample is thought to be within experimental error in determination of the exact location of the surface.

3.2 TEST 2 - 2 1/4 Cr-1 Mo STEEL IN HIGH PURITY SODIUM

Carbon analysis of surface sections of sodium exposed croloy specimens are in progress.

3.3 TEST 4 - 2 1/4 Cr-1 Mo STEEL IN OXYGEN-CONTAMINATED SODIUM

Evaluation of tabs and foils exposed unstressed to sodium with an oxygen content of 200-300 ppm is near completion. Metallographic examination of croloy specimens stressed in oxygen-contaminated sodium has shown a surface film that was not apparent in specimens exposed in Test 2.

4. ANALYTICAL RESULTS

Samples have been extracted from Loop 1 for carbon analysis and the results are shown in Table 3. These results continue to show scattered carbon levels; however, the elimination of the four highest values leaves results that are fairly consistent.

Extraction of samples from Loop 2, Test 4, on a weekly basis has continued. Analyses for carbon, complete to this date, are shown in Table 4. Results of emission spectrograph samples from Loop 2 are shown in Table 5.

The overall problems associated with the analyses of carbon in sodium and particularly the understanding of the contributing factors affecting the carbon concentration in Loop 1 have been examined during this report period. In addition to the relatively routine analyses of samples taken from the two liquid metal systems, additional considerations have been given to possible factors which contribute to the behavior of carbon in sodium. These activities include an innovation with respect to the possible separation of particulate carbon, the statistical analyses of the carbon samples taken to date, and the effect of freezing on carbon distribution in a sodium sample.

Samples are also being run to determine if CO is released during any stage of analysis; this has been reported by General Electric with the major release of CO occurring during acidification of the sample. These studies are in progress at the time of this report writing. The results of these studies and their value to the carbon program will be discussed in detail in the next report.

5. FUTURE WORK

The metallurgical studies for Tests 1 and 2 will be concluded and a topical report issued as soon as possible.

The stabilization of the carbon content in Loop 1 will be given a high priority in order that Test 3 can be started.

Test 4 will continue as scheduled. The metallography of the specimens generated under this test will begin.

TABLE 1 - FATIGUE TEST DATA SUMMARY
2-1/4 Cr-1 Mo STEEL - TEST 4 - HIGH OXIDE SODIUM

Specimen No.	Condition	Specimen Thickness in.	% Cyclic Strain	Cycles to Failure	Time at Temp. Hrs
153	High Oxide Na-1100 F	0.0672	.560	63,270	405.5
317	High Oxide Na-1100 F	0.0670	.558	45,890	284.5
318	High Oxide Na-1100 F	0.0655	.545	48,551	333.5

TABLE 2 - CREEP-RUPTURE TEST DATA SUMMARY
2-1/4 Cr-1 Mo STEEL - TEST 4 - HIGH OXIDE SODIUM

Specimen No.	Condition	Stress Psi	Elong %	Reduction of Area %	Rupture Time (Hrs)
252	High Oxide Na-1100 F	18,000	73	38	48.5
254	High Oxide Na-1100 F	16,000	60	50	(1)234.4
253	High Oxide Na-1100 F	14,000	66	52	240.6
187	High Oxide Na-1100 F	12,000	51	42	588.7
251	High Oxide Na-1100 F	10,500			(2)973.6
250	High Oxide Na-1100 F	9,500			1846.6
255	High Oxide Na-1100 F	16,000			141.5

(1) Loss of flow after 65 hours - Temperature gradient across specimen
*IP Test in progress
(2) Loss of flow for 56 hours - Temperature gradient across specimen

TABLE 3 - CARBON CONCENTRATION - LOOP 1

Date	Carbon Content (ppm C)
6-17-63	77
6-18-63	85
	232
	114
	88
6-19-63	88
	119
	113
6-25-63	52
6-28-63	228
	112
7-2-63	150
7-9-63	115
7-16-63	114
7-23-63	148
7-24-63	62
7-25-63	37
7-26-63	43
7-29-63	86*
7-30-63	76*
8-7-63	63
8-8-63	54
8-9-63	128
8-12-63	67
8-13-63	44
8-15-63	184
8-16-63	56
8-19-63	127
8-20-63	70
8-23-63	220
8-26-63	43

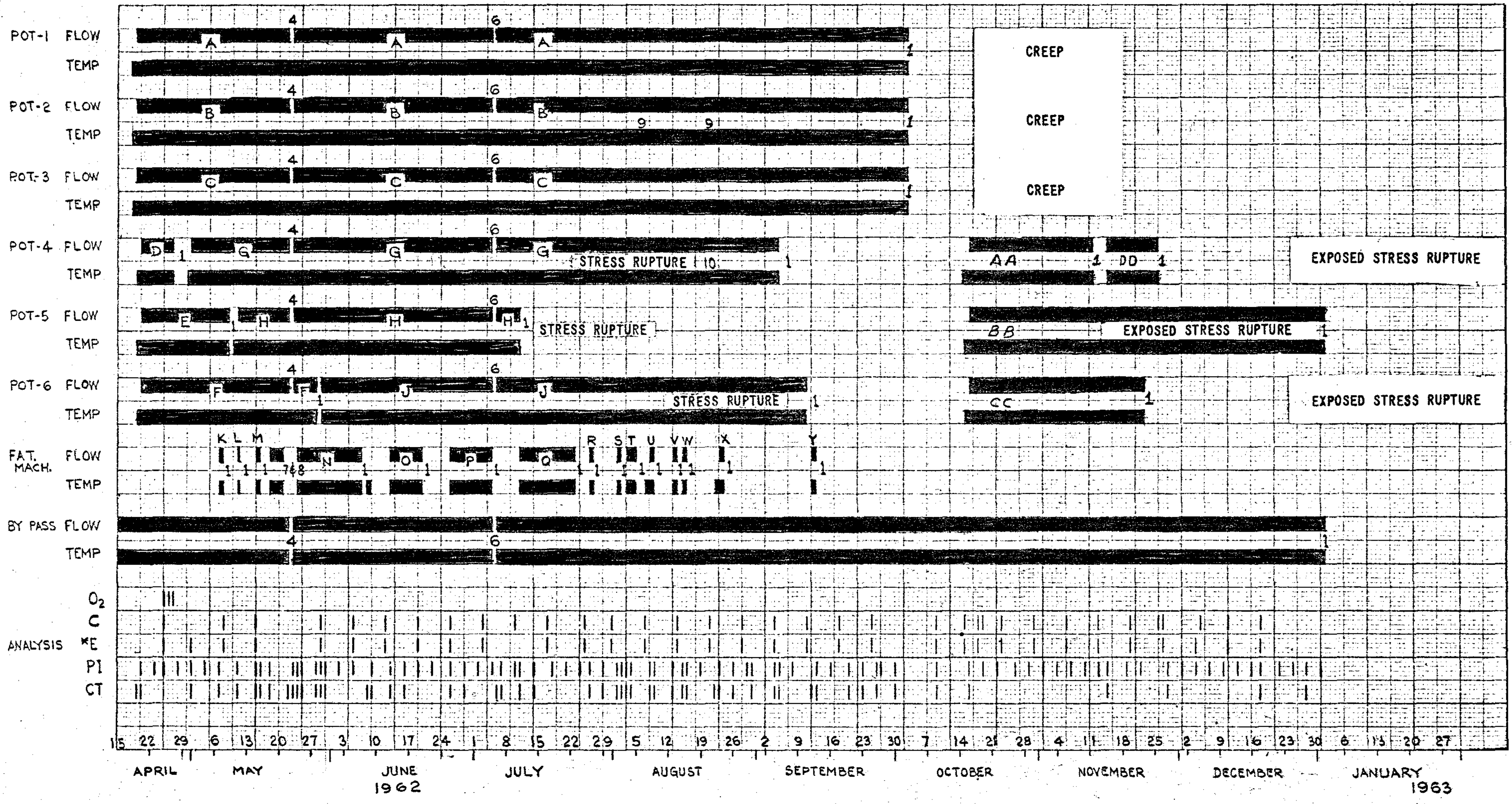
* Sampled at 600° F

TABLE 4 - CARBON CONCENTRATION - LOOP 2
(TEST 4 - SODIUM 300 ppm O_2)

Date	Carbon Content (ppm C)
3-22-63	22.2
3-25-63	33.9
4-1-63	48.2
4-9-63	25.4
4-15-63	20.2
4-24-63	35.4
4-30-63	25.0
5-7-63	18.0
5-22-63	130.0
5-28-63	63
6-4-63	52
6-11-63	59
6-18-63	91
6-25-63	123
7-9-63	170
7-16-63	137
7-23-63	94
7-30-63	54
8-6-63	81
8-13-63	70
8-20-63	50
Standard Samples (50 ppm C)	
7-10-63	53.0
	45.0
7-12-63	55.0
	54.0
	52.0 Avg. ppm

Table 5 - Chemical Analysis of Sodium From Test 4 (Cr-Mo Test Specimens) - in ppm

Date	Fe	B	Co	Mn	Al	Mg	Sn	Cu	Pb	Cr	Si	Ti	Ni	Mo	V	Be	Ag	Zr	Li	Ca
3-22-63	<1	<5	<5	<1	<1	<1	<5	1	<5	<1	<10	<5	<1	<5	<1	<1	<1	<10	<1	2
3-25-63	5	<5	<5	<1	<1	<1	<5	2	<5	1	15	<5	<1	<5	<1	<1	<1	<10	<1	3
4-1-63	<1	<5	<5	<1	<1	<1	<5	1	<5	<1	15	<5	<1	<5	<1	<1	<1	<10	<1	<1
4-9-63	<1	<5	<5	<1	<1	<1	<5	<1	<5	<1	<10	<5	<1	<5	<1	<1	<1	<10	<1	<1
4-15-63	5	<5	<5	<1	<1	3	<5	2	<5	2	<10	<5	<1	<5	<1	<1	<1	<10	<1	20
4-24-63	<1	<5	<5	<1	<1	<1	<5	<1	<5	<1	10	<5	<1	<5	<1	<1	<1	<10	2	<1
4-30-63	<1	<5	<5	<1	2	3	<5	<1	<5	<1	<10	<5	<1	<5	<1	<1	<1	<10		6
5-7-63	1	<5	<5	<1	2	4	<5	<1	<5	<1	12	5	<1	<5	<1	<1	<1	<10		6
5-15-63	2	<5	<5	<1	1	2	<5	5	<5	<1	<10	20	<1	<5	<1	<1	<1	<10		6
5-22-63	3	<5	<5	1	1	2	<5	3	<5	<1	10	<5	<1	<5	<1	<1	<1	<10		5
5-28-63	2	<5	<5	1	2	5	<5	<1	<5	<1	11	<5	<1	<5	<1	<1	<1	<10		7
6-4-63	2	<5	<5	<1	1	3	<5	<1	<5	<1	10	<5	<1	<5	<1	<1	<1	<10		7
6-11-63	1	<5	<5	<1	2	2	<5	1	<5	<1	10	<5	<1	<5	<1	<1	<1	<10		3
6-18-63	<1	<5	<5	<1	2	1	<5	<1	<5	<1	10	<5	<1	<5	<1	<1	<1	<10		2
6-25-63	<1	<5	<5	<1	2	1	<5	<1	<5	<1	<10	<5	<1	<5	<1	<1	<1	<10		3
7-9-63	<1	<5	<5	<1	2	1	<5	<1	<5	<1	<10	<5	<1	<5	<1	<1	<1	<10		1
7-16-63	<1	<5	<5	<1	2	2	<5	<1	<5	<1	10	<5	<1	<5	<1	<1	<1	<10		2
7-23-63	2	<5	<5	<1	2	2	<5	<1	<5	<1	10	5	<1	<5	<1	<1	<1	<10		6
7-30-63	1	<5	<5	<1	1	1	<5	<1	<5	<1	10	<5	<1	<5	<1	<1	<1	<10		5
8-6-63	2	<5	<5	<1	2	5	<5	<1	<5	<1	12	<5	<1	<5	<1	<1	<1	<10		12



1. TEST COMPLETED
2. FLANGE LEAK
3. FATIGUE MOTOR FAILURE
4. VALVE LEAK
5. BELLOW FAILURE
6. PIPE FAILURE
7. IMPROPER SPECIMEN INSTALLATION
8. TEST NOT COMPLETED
9. HEATER LEAD FAILURE
10. CONTROLLER FAILURE

* EMISSION SPEC.

A-3ALX1
B-3ALX2
C-3ALX3
D-3CLX1
E-3CLX2
F-3CLX3
G-3DLX1
H-3DLX2
J-3DLX3
K-3FLX1
L-3FLX2
M-3FLX3
N-3JLX1
O-3JLX2
P-3JLX3
Q-EXPOSED SAMPLES
R-3HLL1
S-3HLL2
T-3HLL3
U-3GLX1
V-3GLX2
W-3GLX3
X-3GLX4
Y-3FLX4
AA-3ELL3
BB-3ELL1
CC-3ELL2
DD-3ELL4

FIG. 1 - OPERATIONAL HISTORY OF LOOP 1 DURING TEST 1 in SODIUM (30 ppm O_2)

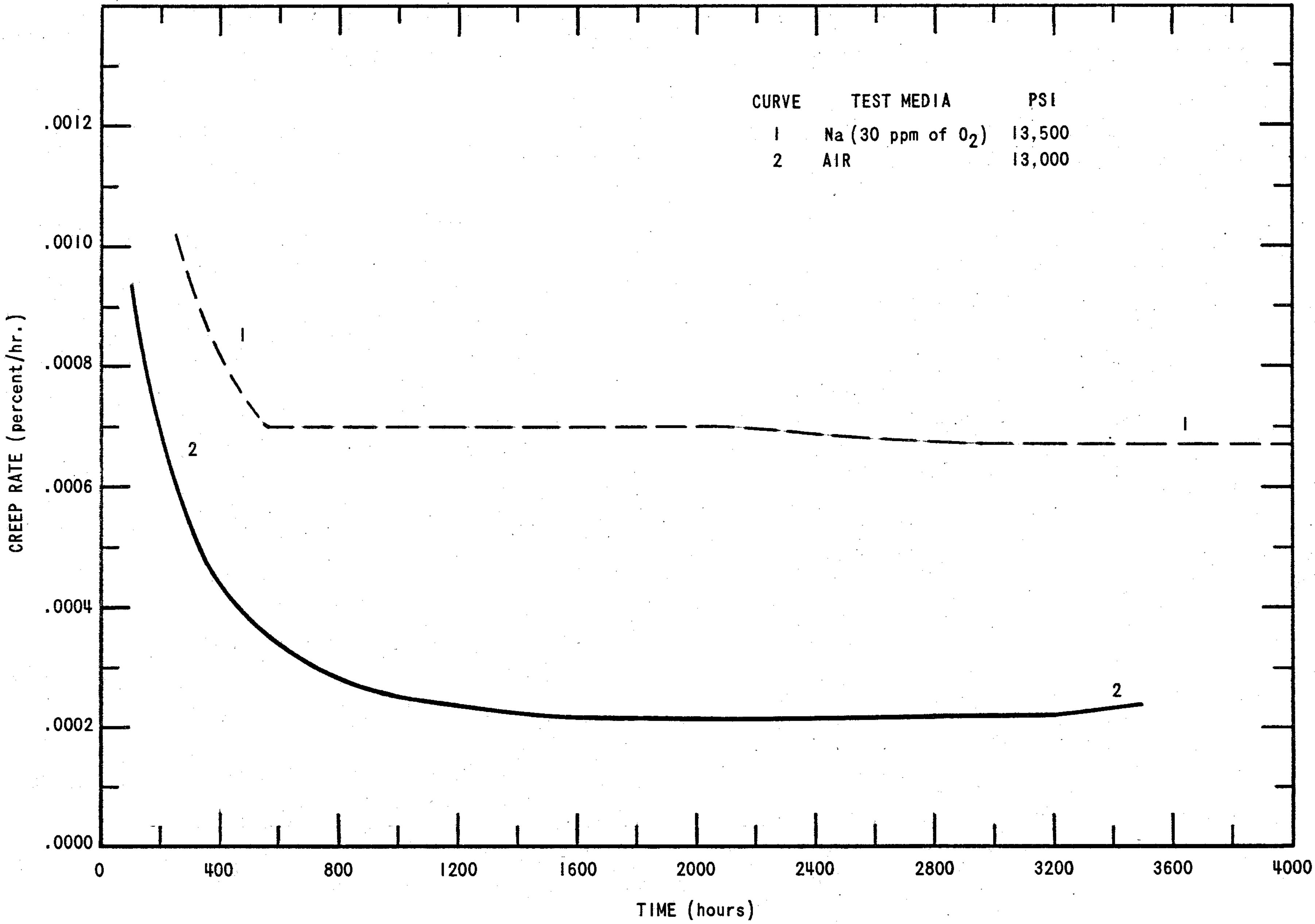


FIG. 2 - CREEP RATES, 316 STAINLESS STEEL SPECIMENS - 1200°F

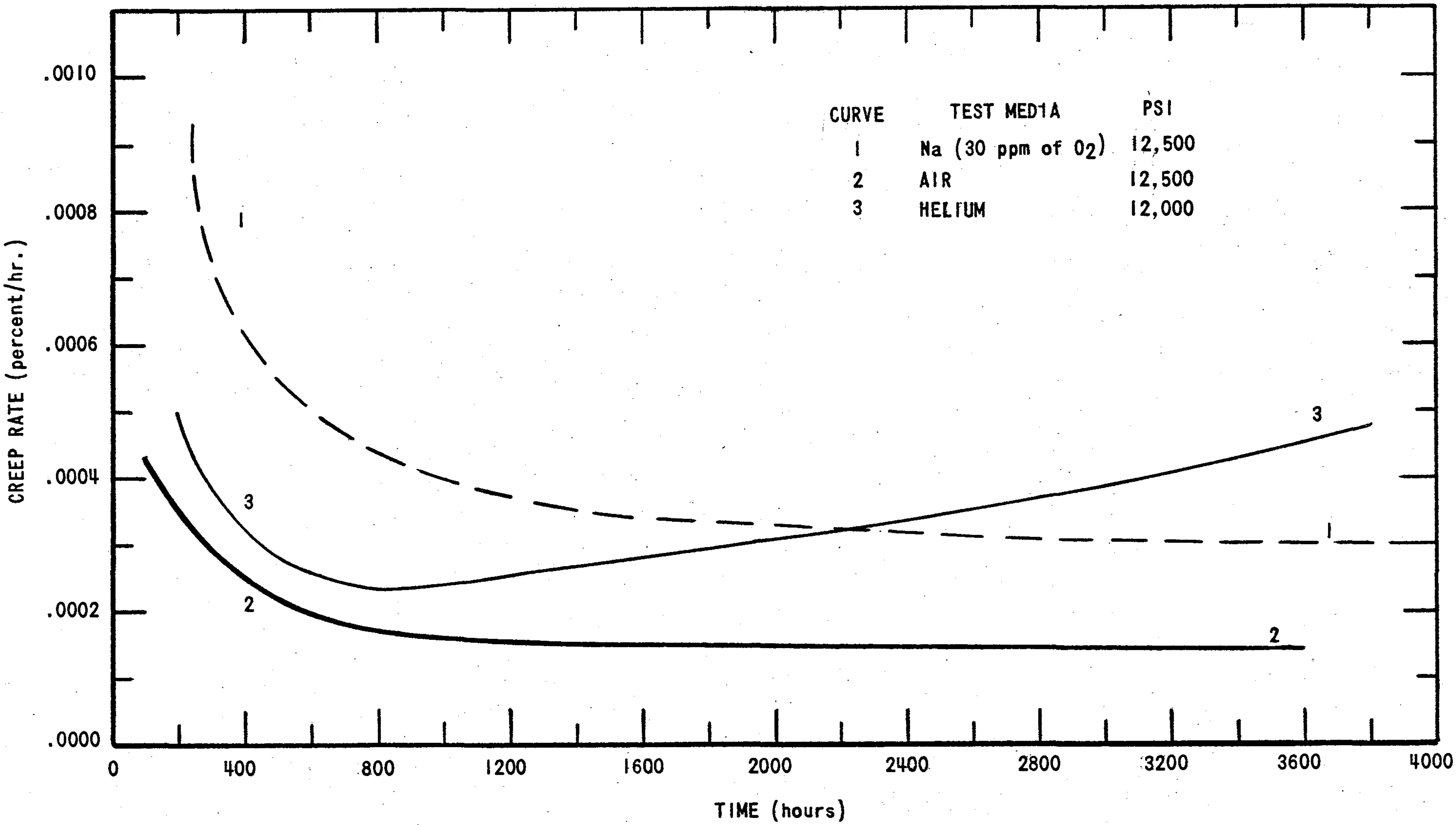


Fig. 3 - Creep Rates, 316 Stainless Steel Specimen - 1200 F

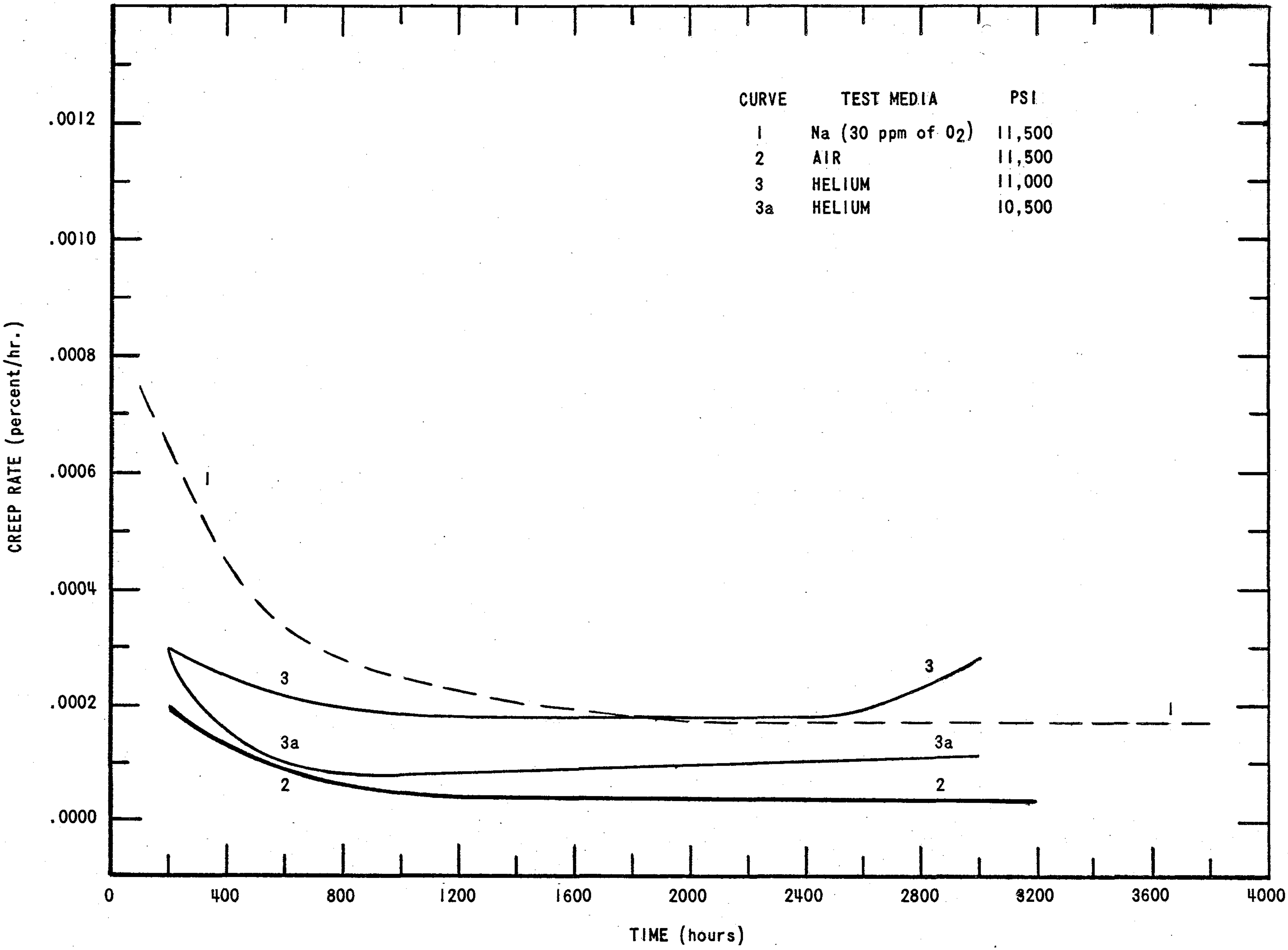


FIG. 4 - CREEP RATES, 316 STAINLESS STEEL SPECIMENS - 1200°F

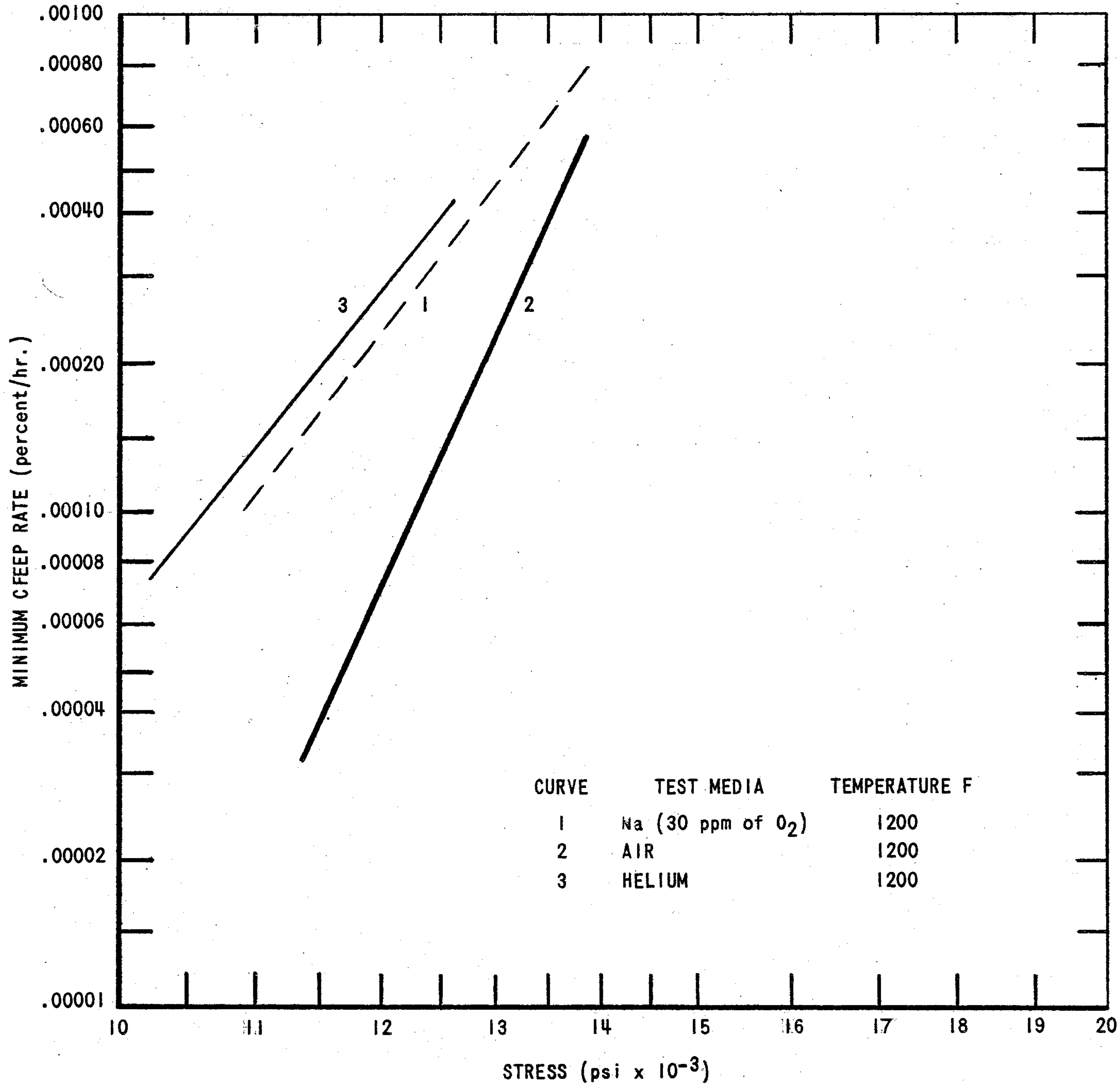
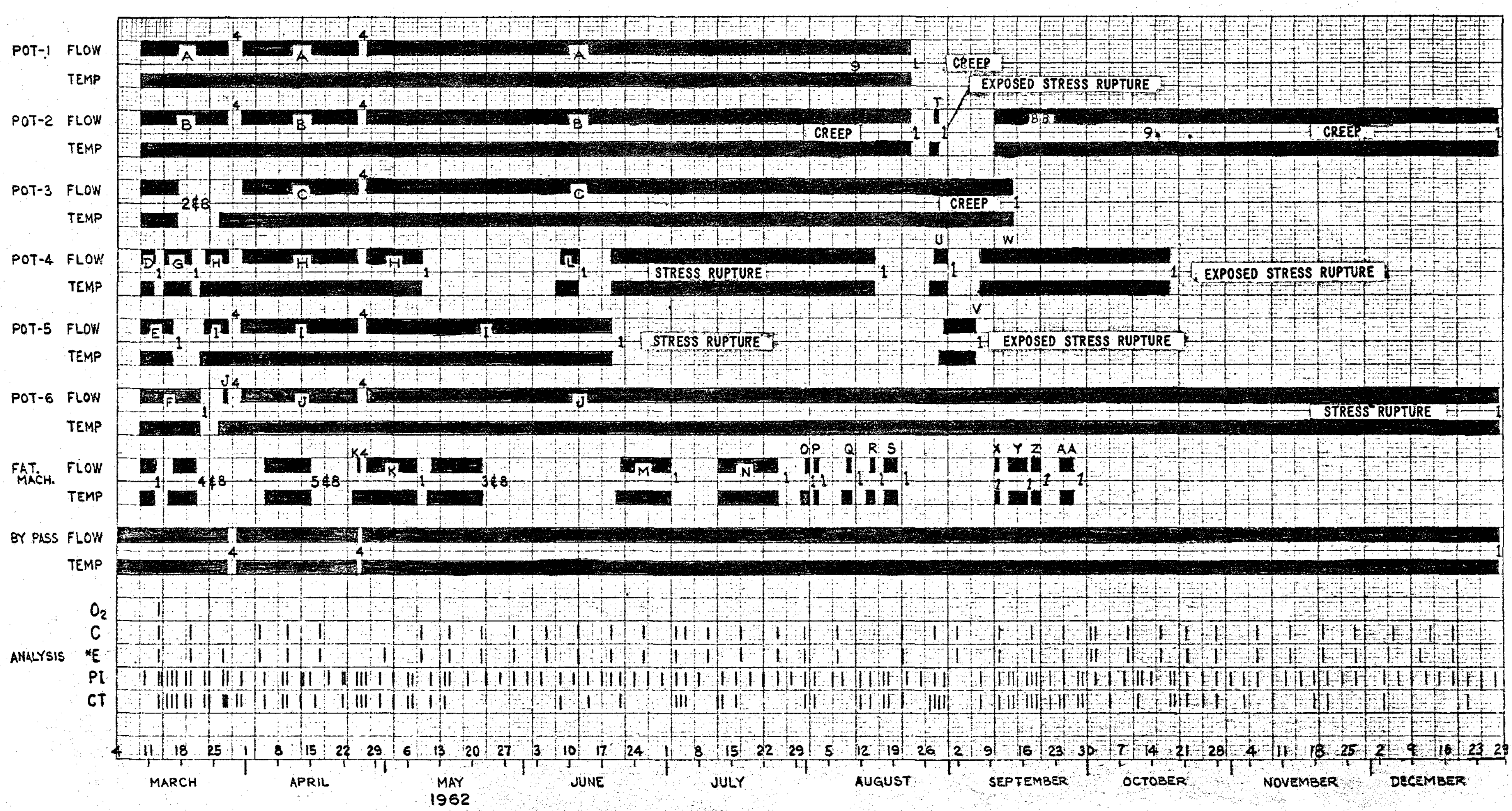


FIG. 5 - MINIMUM CREEP RATES vs STRESS, 316 STAINLESS STEEL SPECIMENS



1. TEST COMPLETED
2. FLANGE LEAK
3. FATIGUE MOTOR FAILURE
4. VALVE LEAK
5. BELLOW FAILURE
6. PIPE FAILURE
7. IMPROPER SPECIMEN INSTALLATION
8. TEST NOT COMPLETED
9. HEATER LEAD FAILURE
10. CONTROLLER FAILURE

*EMISSION SPEC.

A-2ALX1
B-2ALX2
C-2ALX3
D-2CLX1
E-2CLX2
F-2CLX3
G-2CLX4
H-2DLX1
I-2DLX2
J-2DLX3
K-2JLX1
L-2CLX5
M-2JLX2
N-238 & EXPOSED SAMPLES

O-2HLL1
P-2HLL2
Q-2HLL3
R-2FLX1
S-2FLX2
T-2ELL2
U-2ELL1
V-2ELL3
W-2ELL4
X-2FLX3
Y-2GLX1
Z-2GLX2
AA-2GLX3
BB-2ALX4

FIG. 6 - OPERATIONAL HISTORY OF LOOP 2 DURING TEST 2
(Cr-Mo Test Specimens in Sodium 30 ppm O_2)

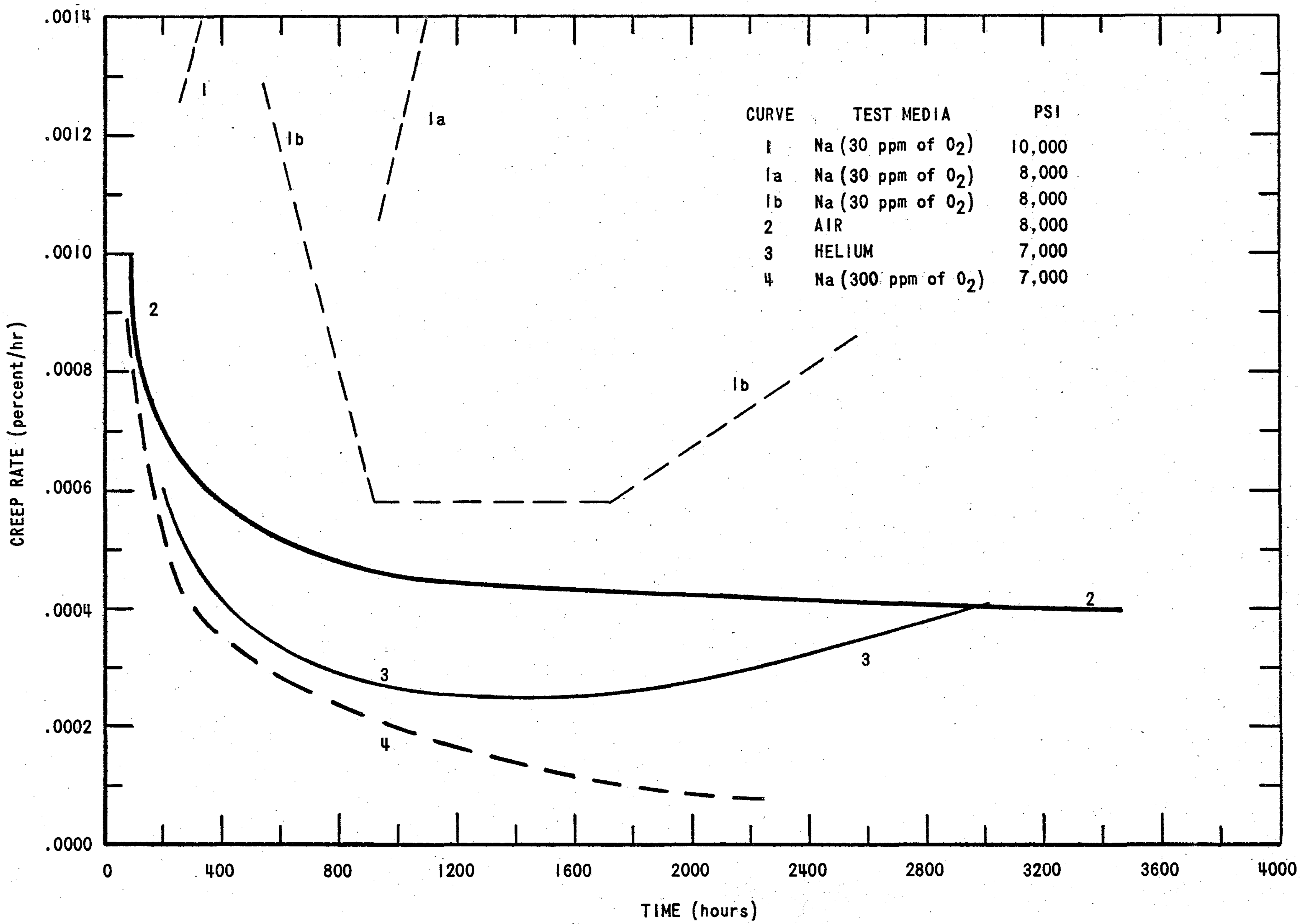


FIG. 7 - CREEP RATES, 2 1/4 Cr-1 Mo CARBON STEEL - 1100°F

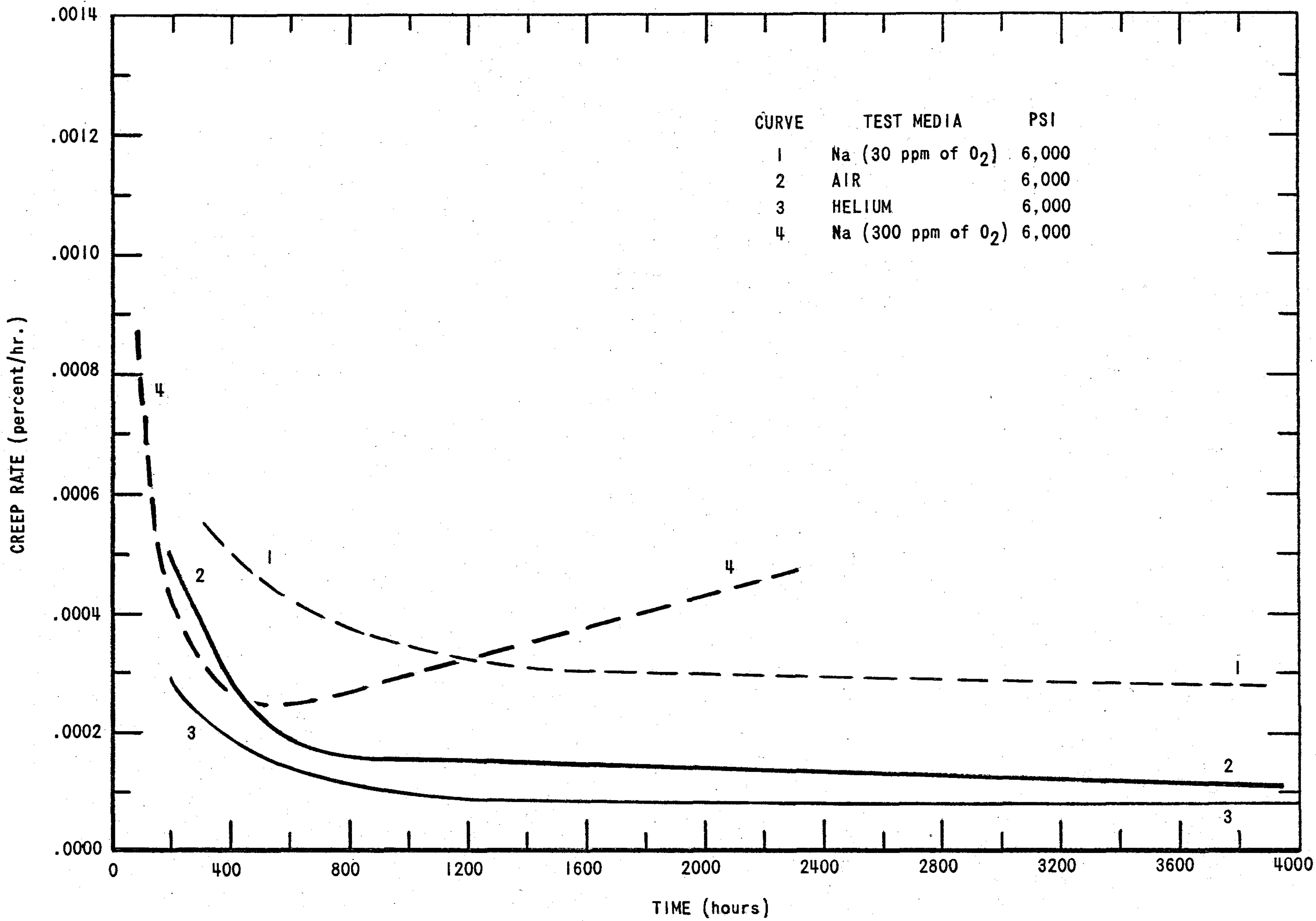


FIG. 8 - CREEP RATES, 2 1/4 Cr-1 Mo CARBON STEEL - 1100°F

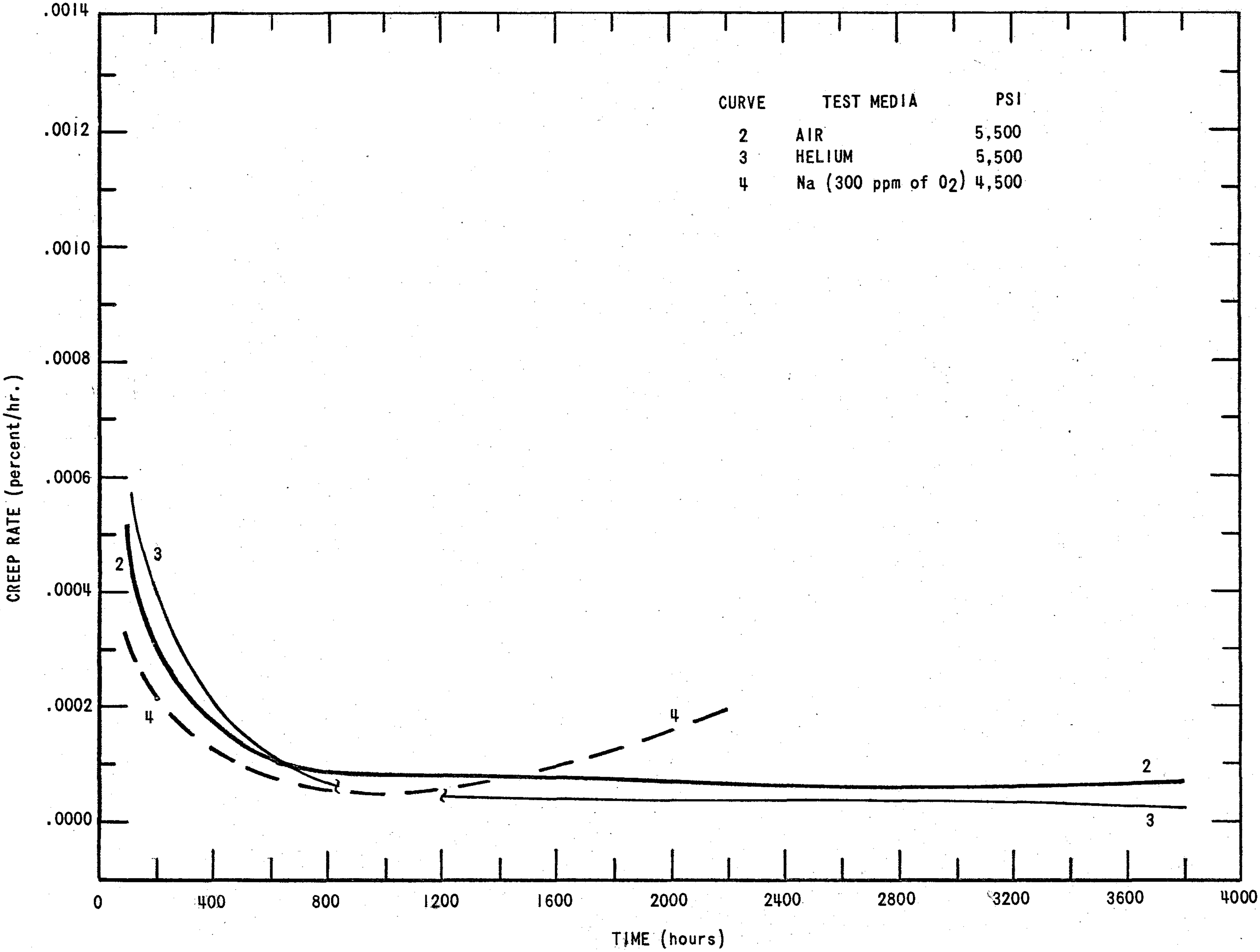


FIG. 9 - CREEP RATES, 2 1/4 Cr-1 Mo CARBON STEEL - 1100°F

R-1602

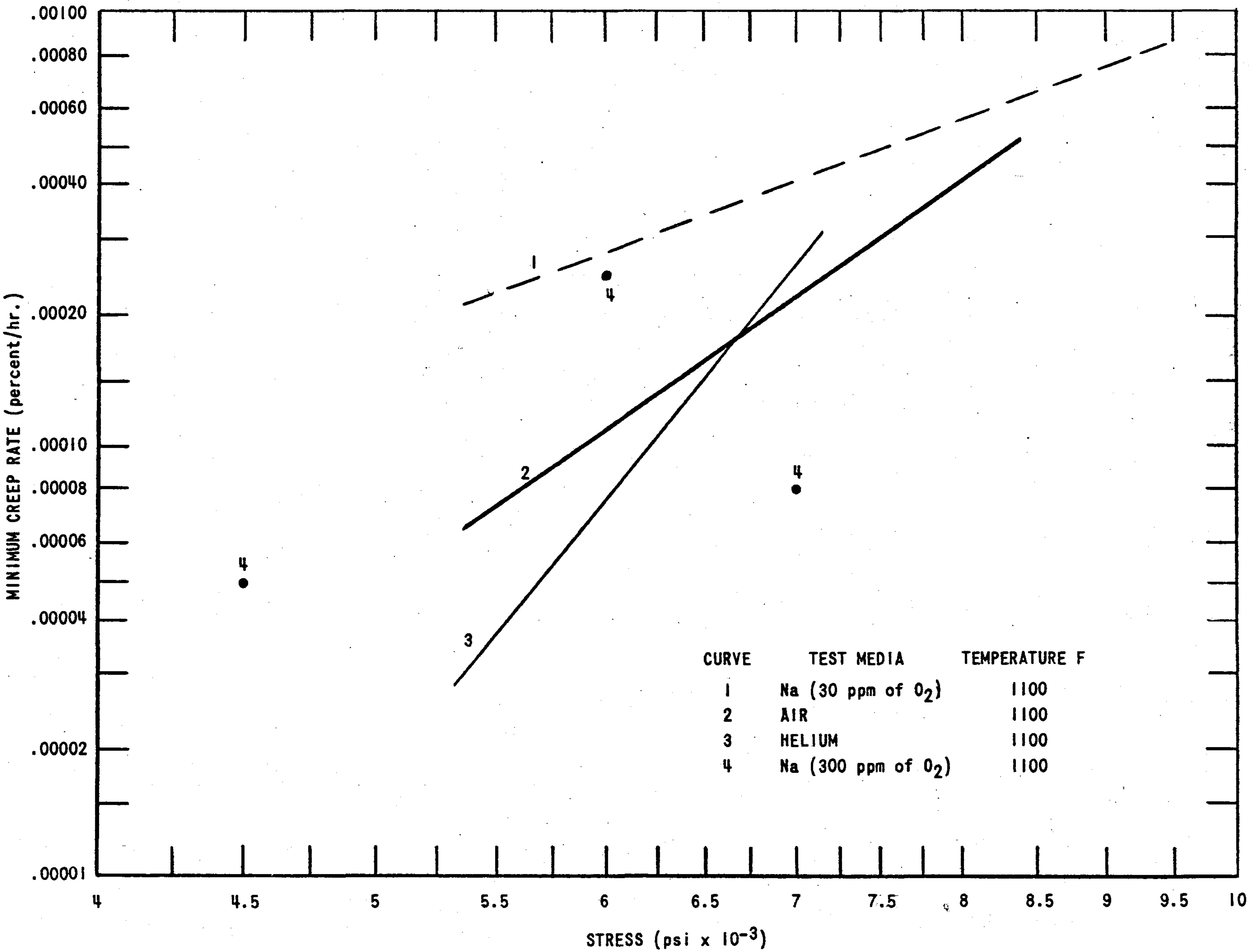


FIG. 10 - MINIMUM CREEP RATE vs STRESS, 2 1/4 Cr-1 Mo CARBON STEEL SPECIMENS

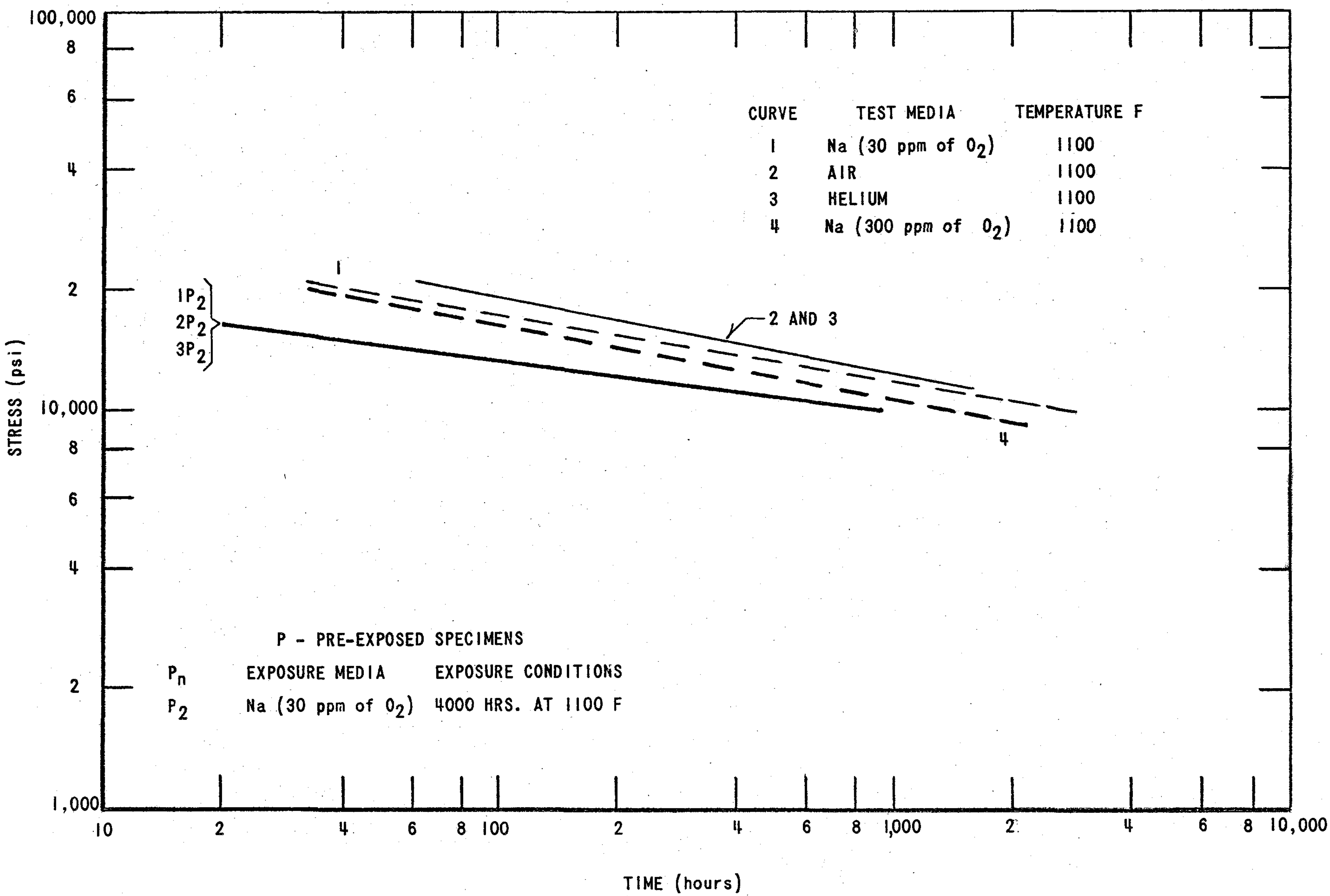


FIG. 11 - CREEP-TO-RUPTURE OF 2 1/4 Cr-1 Mo CARBON STEEL SPECIMENS

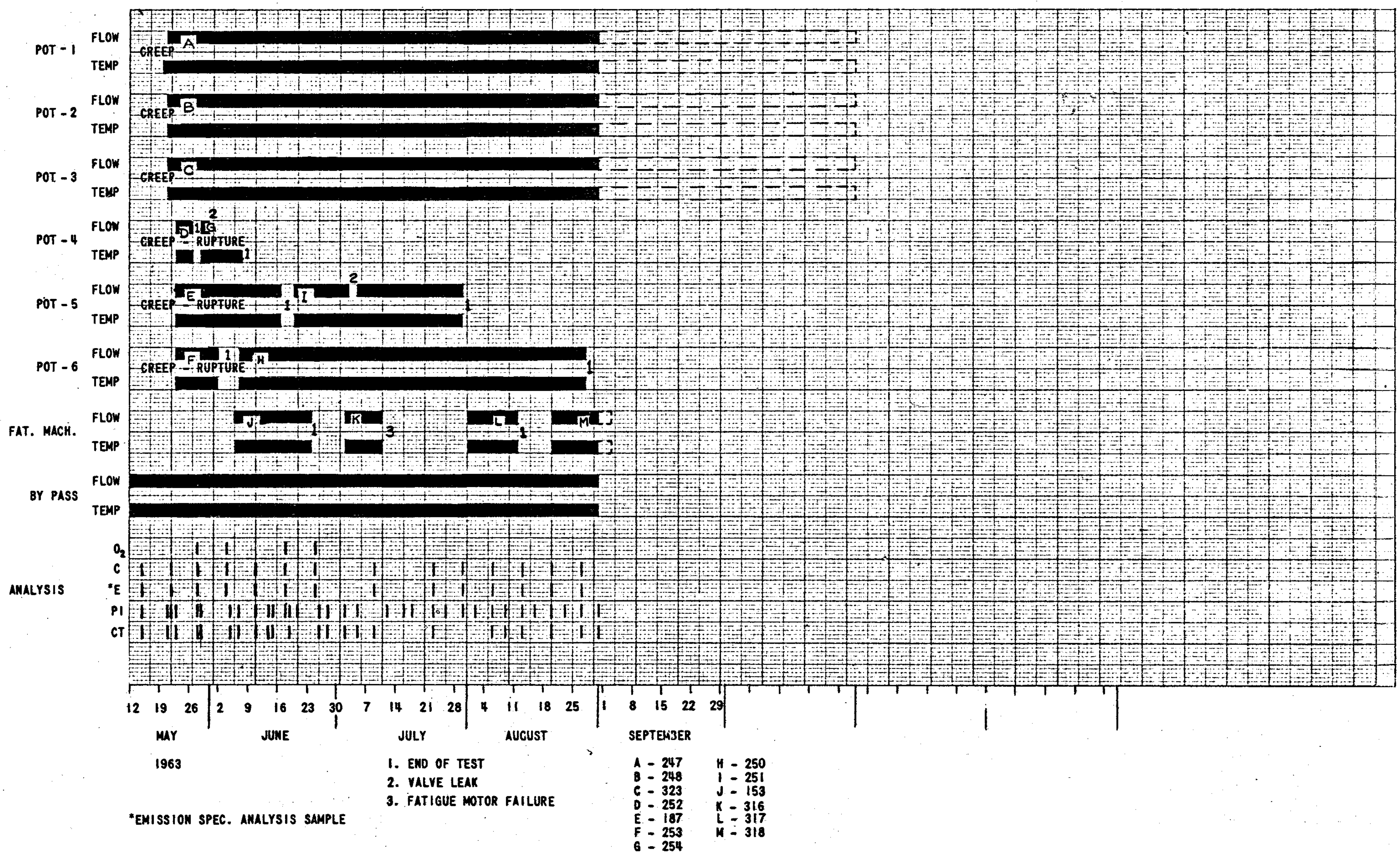


FIG. 12 - OPERATIONAL HISTORY OF LOOP 2 - TEST 4 (Cr-Mo TEST SPECIMENS)

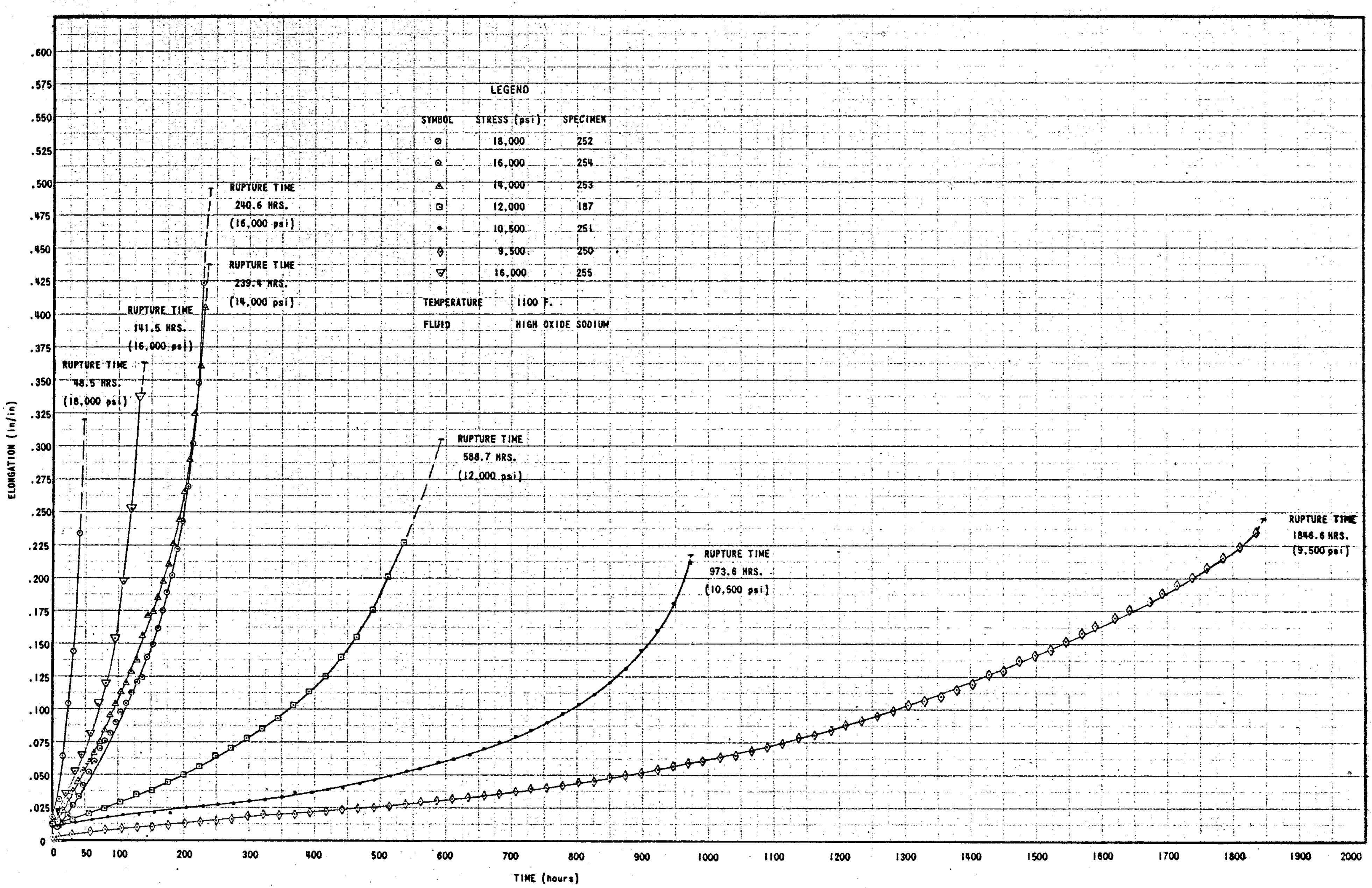


FIG. 13 - ELONGATION OF 2 1/4 Cr-1 Mo STEEL - CREEP RUPTURE SPECIMENS

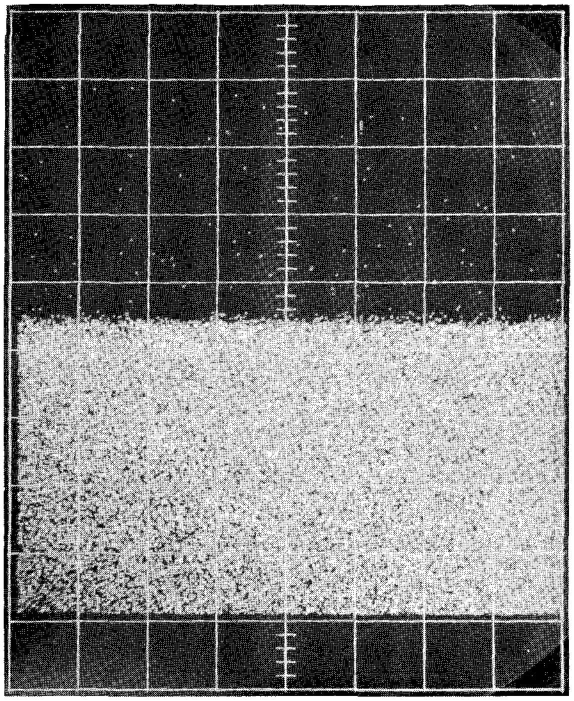


FIG. 14 - IRON IMAGE
Type 316 ss - Specimen No. 99

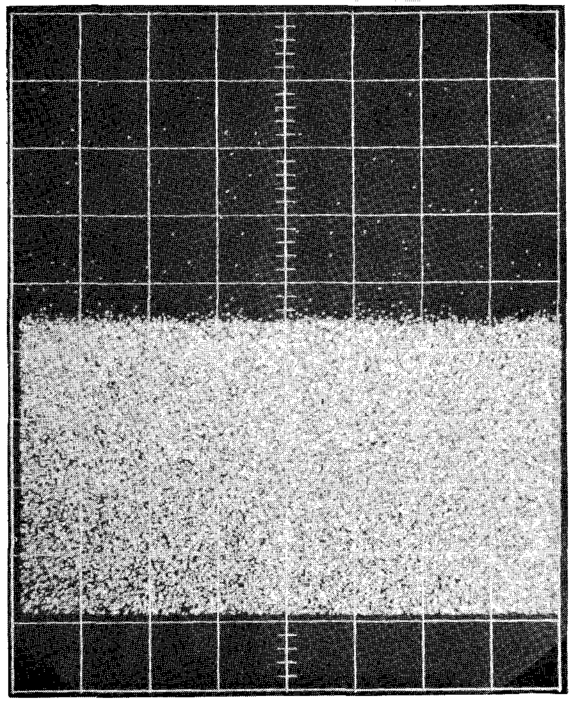


FIG. 15 - CHROMIUM IMAGE
Type 316 ss - Specimen No. 99

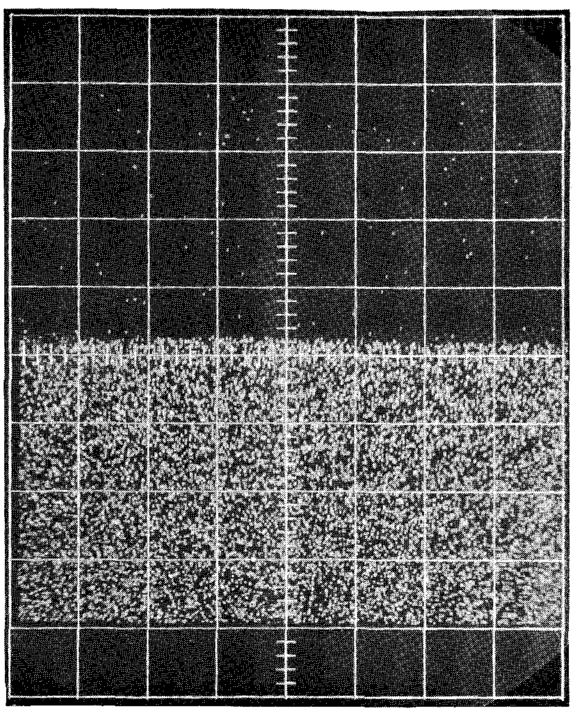


FIG. 16 - NICKEL IMAGE
Type 316 ss - Specimen No. 99

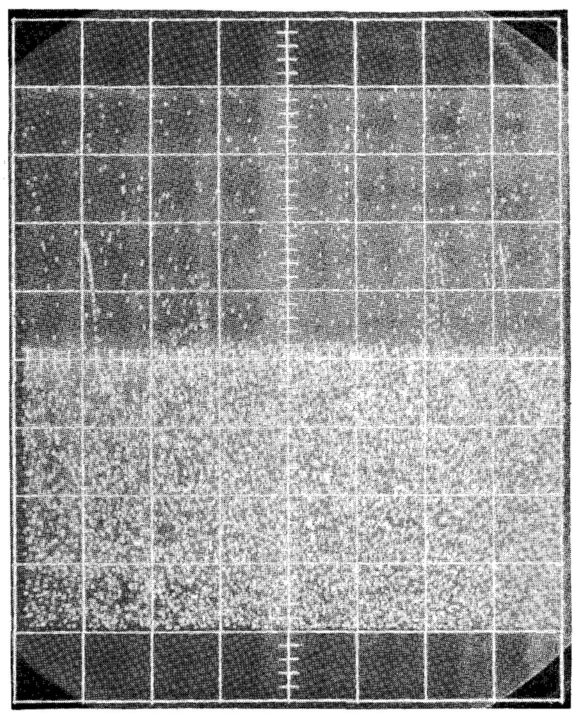


FIG. 17 - MOLYBDENUM IMAGE
Type 316 ss - SPECIMEN 3ALX2

Note: Field is 360 microns (approximately 0.014 in.) wide.

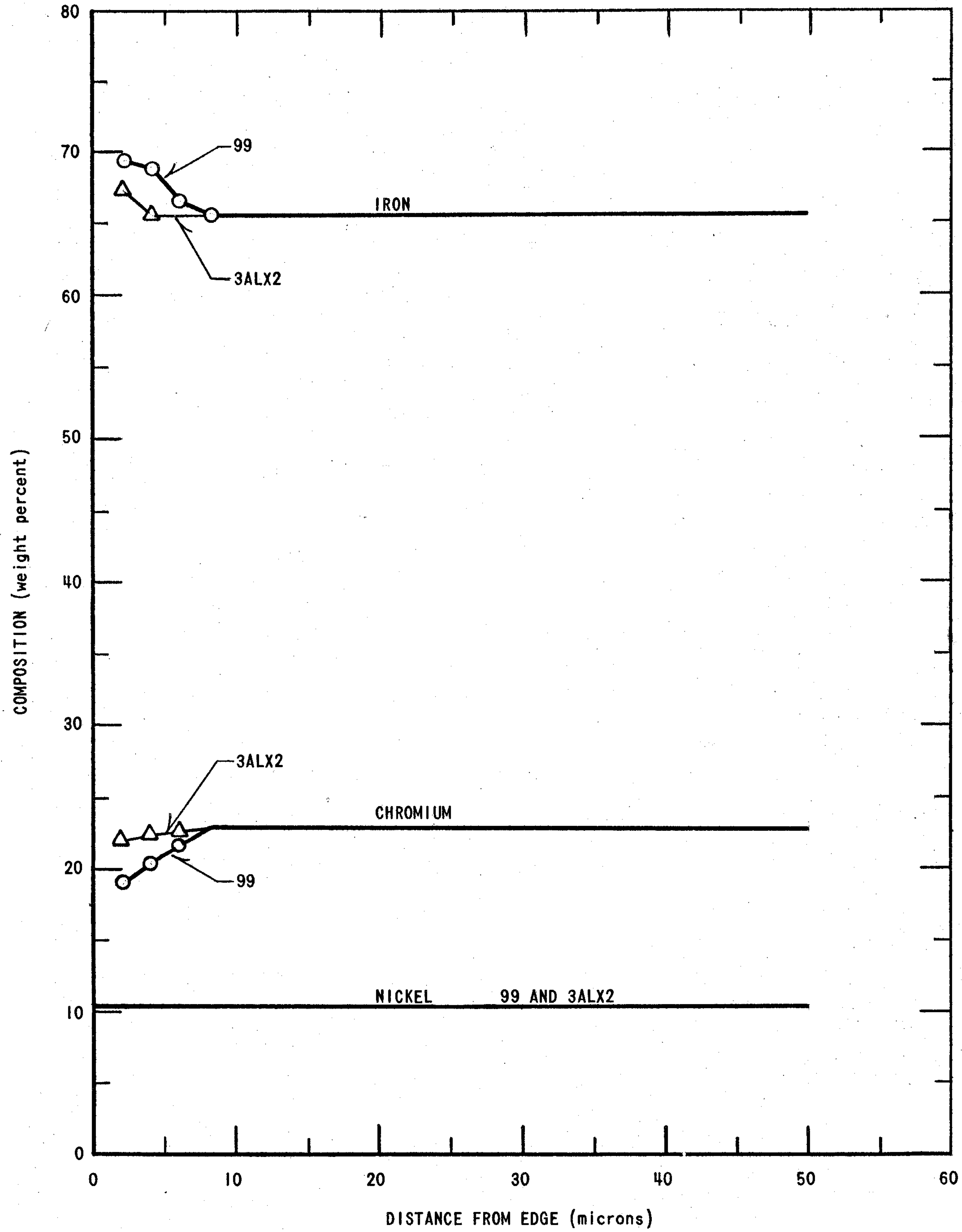


FIG. 18 - MICROPROBE LINE PROFILE FOR TYPE 316 STAINLESS STEEL SPECIMENS 99 and 3ALX2