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May 1963

to

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

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EFFECT OF 1200°F SODIUM
ON AUSTENITIC AND FERRITIC STEELS
Physical Properties of Materials
Contract AT(11-1)-765
Modification No. 1

June 21, 1963

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MSA Research Corporation

Subsidiary of Mine Safety Appliances Company

Callery, Pennsylvania

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Signed:

R. C. Andrews
R. C. Andrews
Project Engineer

Approved:

R. C. Werner
R. C. Werner
Associate Director
Engineering and
Development

Signed:

K. R. Barker
K. R. Barker
Project Supervisor

MSA RESEARCH CORPORATION
Callery, Pennsylvania

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SUMMARY

Tests 1 and 2 which consisted of the determination of the physical properties of Type 316 stainless steel and 2 1/4 Cr-1 Mo steel specimens in low oxide sodium, helium and air at 1200 F and 1100 F respectively have been completed except for three Type 316 ss and two Cr-Mo steel creep tests in helium, one Type 316 ss creep-to-rupture test in helium, and two pre-exposed Cr-Mo steel creep-to-rupture tests in air. These remaining tests are being conducted at the University of Michigan.


Metallurgical examination of the specimens generated under Tests 1 and 2 is continuing. A topical report on the findings of Tests 1 and 2 is being written. Preliminary conclusions based on the results of these tests to date are presented in this report.

A comparison between the incomplete physical property data and the environment in which the specimens were run indicates the following:

For Type 316 stainless steel, 1200°F

1. The creep rates in helium and sodium are higher than in air.
2. The number of cycles to failure in fatigue is extended by helium followed by sodium as compared to air. However, at low strains all three environments may show equal life.
3. All other physical properties showed little effect.

For 2 1/4 Cr-1 Mo steel, 1100°F

1. The tensile strength was lower in helium than in air.
 2. The stress-rupture strength in sodium was slightly lower than for helium or air.
 3. Pre-exposing the specimens for 4000 hr (in sodium) lowered the stress-rupture strength.
 4. The creep rate in sodium is higher than in air.
 5. The number of cycles to failure in fatigue is extended by both helium and sodium.
 6. The effect of helium on creep is too premature for a comparison.
- 12
- 

It is noted that some of the above differences occur in a relatively short time, indicating possible surface effects. Thermodynamics will be used to see if the different oxygen content of the various environments may contribute to different surface compositions.

Test 3 is the determination of the physical properties of 316 ss specimens in 1200 F sodium saturated with carbon. Shake-down operations of this test loop will begin during the next report period.

Test 4 is the measurement of the physical properties of 2 1/4 Cr-1 Mo steel specimens in sodium having 200 to 300 ppm sodium oxide. The test is underway with two of the short time creep-to-rupture tests completed.

Progress Report 33

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 air and helium tests and examining the specimens generated under Tests 1 and 2. At the same time, Test 3 is ready to begin its shakedown operations and Test 4 has been initiated.

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 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 Table 2.

Preliminary conclusions based on test results of Tests 1 and 2 to date are included in this report.

2. TEST 1 - STAINLESS STEEL SPECIMENS
IN 1200 F LOW OXIDE SODIUM, HELIUM AND AIR

The operating history of Test 1 can be found in Progress Report 31, Fig. 2. A summary of all the test data from Test 1 is tabulated in Table 3 of this report. All tests at MSAR and the University of Michigan have been completed with the exception of one creep-to-rupture test in helium and the three creep tests in helium. These tests are in progress at this time. A discussion of test results of Test 1 follows:

2.1 STAINLESS STEEL FATIGUE TESTS

Before summarizing the fatigue results on stainless steel it might be best to review the method used for the fatigue tests.

The fatigue tests conducted throughout this program are based on bending the specimens over a mandrel having a specific controlled radius. In each case the mandrel and specimen is in an

isothermic environment of 1200 F sodium, helium or air. This technique is based on the assumptions that contact between the specimen and mandrel will not affect its fatigue life and that the strain distribution in bending will be as predicted by fundamentals of strength of materials. The definition of cyclic strain used in this program is derived from page 119 of Elements of Strength of Materials by Timoshenko and MacCullough, 3rd Edition, 1949. The strain is depicted therein as $Y/\rho = e_x$ where Y equals one-half the thickness and ρ equals the radius of curvature on the mandrel. In this case, where bending is reversed, using two mandrels, the strain must be multiplied by two to obtain the total change in strain or, in other words, the cyclic strain. Therefore, the cyclic strain in our case can be obtained by dividing the specimen thickness by the radius of the mandrel, or $T/\rho = e_x$ where T equals the thickness of the specimen. Three strain levels were to be used and, after preliminary testing, mandrels having radii of 3.125, 6.75 and 12 in. were chosen to give a high, medium and low level strain respectively.

The ASTM does not have a standard fatigue test and this method, used and suggested by W. F. Anderson (Atomics International), is believed to give good reproducible results and to be a relatively simple method for comparing the effects of environments on fatigue life.

All the Type 316 stainless steel fatigue tests have been completed for Test 1. Results of these tests are tabulated in Table 3 and shown graphically in Fig. 1, as percent of cyclic strain vs the number of cycles. Fig. 2 shows curves of averaged data for the tests in air, helium and sodium. These curves include both plastic and elastic strain and, therefore, do not appear as straight line functions.

Metallographic examination of the 316 ss fatigue specimens is incomplete at this time, but the following conclusions can be made concerning the effects of the three environments (air, helium and sodium) on the fatigue life of 316 stainless steel.

- a. The fatigue life of 316 ss in 1200 F helium is considerably longer than in 1200 F air throughout the range of cyclic strains tested.
- b. The fatigue life of 316 ss in 1200 F sodium is the same as in air at high cyclic strains, but is the same as in 1200 F helium at the low cyclic strains.
- c. The shapes of the fatigue curves indicate the possibility that at very low cyclic strains the differences between the three environments may not be significant.
- d. The pre-exposure of 316 ss for 286 hours in 1200 F sodium showed generally, when compared to the

original material in the same environment: a shorter life when tested in 1200 F air, a trend towards longer life in 1200 F sodium, and no change in 1200 F helium.

2.2 STAINLESS STEEL CREEP-RUPTURE TESTS

All the stainless steel creep-rupture tests have been completed for Test 1 with the exception of one test in 1200 F helium at a load of 17,500 psi which has been in progress 1870 hours. Results of these tests are tabulated in Table 3. The results of all the creep rupture tests on the original material are shown graphically in Fig. 3. The comparison of the pre-exposure tests against the original material tests is shown in Fig. 4.

Metallographic examination of the specimens generated in these tests is not complete, but from the data available the following conclusions can be reached as to the effect of the three test environments (air, helium, sodium) at 1200 F on the creep rupture properties of 316 ss:

1. The data for the tests in all three environments is in such good agreement that there appears to be no significant differences in the creep-rupture properties of 316 ss in air, sodium or helium at 1200 F.
2. Specimens that had been exposed for 4000 hours in 1200 F sodium showed no significant change in creep rupture properties when tested in 1200 F air.
3. There appears to be a trend for the pre-exposed specimens to have extended life when tested in 1200 F sodium.
4. The pre-exposed specimens showed considerable scatter in 1200 F helium and no trends were noted other than that the results were within range of the original material.

2.3 STAINLESS STEEL CREEP TESTS

All stainless steel creep tests have been completed in air and sodium at 1200 F. The three tests in 1200 F helium are in progress at loads of 12,000 psi, 11,000 psi, and 10,500 psi respectively.

The specimen at a load of 12,000 psi reached a minimum rate of 0.23%/1000 hours at 700 hours and has been increasing until

its rate is 0.40%/1000 hours at 3200 hours. The specimen at 11,000 psi load has been steadily decreasing until at 1000 hours it has a rate of 0.18%/1000 hours. The final test at 10,000 psi has decreased to a rate of 0.076%/1000 hours after 1000 hours.

The results of all 316 ss creep tests to date are found in Table 3, and Figs. 5, 6, and 7 compare the creep rates in the three environments at comparable stress levels. Fig. 8 shows a summary of the minimum creep rate %/1000 hours vs stress for the three environments.

Although the helium tests are continuing, the data to date indicates the following:

- a. The creep rates of 316 ss in 1200 F sodium and helium are substantially higher than in 1200 F air.
- b. The preliminary helium data indicate minimum creep rates in the same range as the sodium minimum creep rates.

2.4 STAINLESS STEEL TENSILE TESTS

Tensile tests of the 316 ss have been completed for Test 1. The results are tabulated in Table 3. Conclusions based on the results of these tests are as follows:

- a. There was no significant difference in the tensile properties when tested in air or helium at 1200 F.
- b. Specimens exposed for 4000 hours in 1200 F sodium indicated no significant tensile property change when tested in 1200 F helium regardless as to whether the specimens were washed or unwashed after exposure.
- c. Specimens exposed for 4000 hours in 1200 F sodium indicated no significant tensile property change when tested in room temperature helium and compared to unexposed specimens tested under the same conditions.

3. TEST 2 - 2 1/4 Cr-1 Mo STEEL SPECIMENS IN 1100 F LOW OXIDE SODIUM, HELIUM AND AIR

The operational history of Test 2 can be found in Progress Report 31, Fig. 3. A summary of all the test data from Test 2 is tabulated in Table 3 of this report. All the tests at MSAR have been completed. The University of Michigan has two creep rupture pre-exposed specimens to run in 1100 F air and the completion of two creep tests in 1100 F helium.

3.1 Cr-Mo FATIGUE TESTS

All the 2 1/4 Cr-1 Mo steel fatigue tests have been completed for Test 2. Results of these tests are tabulated in Table 3 and shown graphically in Fig. 9 as the percent of cyclic strain vs the number of cycles. Fig. 10 shows curves of averaged data for the tests in air, helium and sodium at 1100 F. The curves include both plastic and elastic strain and therefore do not appear as straight line functions.

Preliminary conclusions resulting from metallographic examination are discussed below. The bulk of photomicrographs are not shown but will be discussed in depth in a forthcoming topical report.

Figures 11, 12 and 13 show specimens fatigue tested in air, helium and sodium. A transgranular fatigue crack is evident in Fig. 11, and such cracks do not appear in specimens tested in 1100 F helium or sodium. Air corrosion products appear to fill the numerous fatigue cracks observed in air-tested specimens.

It is apparent that a different mode of failure is exhibited in air-tested specimens as compared to non-oxidizing environments, which results in earlier fatigue failure in an air environment. The oxidizing environment permits formation of surface oxides (or possibly nitrides) within surface cracks. The presence of such corrosion products enhances stress concentration at a crack-tip during the compression cycle and the crack-tip is extended into the matrix as a result of the "wedging" action of the corrosion product. Fatigue failure in the non-oxidizing environment (He and Na) does not result in surface coatings, and fatigue failure occurs at a single site, and only after more prolonged cycling.

Fig. 14 shows a specimen that had been pre-exposed in sodium prior to fatigue-testing in air. While the fatigue cracks appear to be essentially transgranular, the irregularity of the cracks suggests some degree of intergranular attack particularly near the surface. Stress-corrosion initiated fatigue cracking apparently occurs in pre-exposed specimens. This is probably a

result of residual caustic retained even after prolonged water wash, which eventually results in localized caustic attack during fatigue testing.

Fig. 15 shows the fracture area of an air-fatigued 2 1/4 Cr-1 Mo specimen. Two modes of fracture are evident. The upper half of the failure is associated with transgranular fatigue cracking, and no plastic deformation is evident. Below the crack-tip (center of photomicrograph), plastic deformation is apparent. Plastic failure of the specimen results after the effective cross-sectional area has been reduced by extension of opposing fatigue cracks in toward the center of the specimen. All of the specimens examined show less plastic deformation with decreasing cyclic strain, irrespective of test environment. No changes in grain size were observed in any of the fatigue specimens examined.

It is concluded that the failures observed in the fatigue tests were surface initiated, and that air testing results in earlier failure as a result of air oxidation product.

From these tests the following conclusions can be made as to the effect of the three test environments (air, helium and sodium):

- a. The fatigue life of the 2 1/4 Cr-1 Mo steel is increased considerably in 1100 F helium compared to 1100 F air throughout the range of strain in which the tests were conducted.
- b. The fatigue life of 2 1/4 Cr-1 Mo is almost identical in 1100 F sodium as in 1100 F helium, considering the scatter in data and the few number of tests conducted.
- c. Specimens exposed for 323 hours in 1100 F sodium did not indicate a change in fatigue life when tested in 1100 F air or sodium.
- d. Specimens exposed for 323 hours in 1100 F sodium followed by fatigue tests in 1100 F helium showed widely scattered results but in most cases indicated a shorter fatigue life after exposure.

3.2 Cr-Mo STEEL CREEP RUPTURE TESTS

All the Cr-Mo steel creep rupture tests in sodium and helium have been completed. Two exposed specimens (4000 hours in 1100 F sodium) being tested in air and helium failed during this report period. The exposed specimen being tested in air failed after 1209 hours at a stress of 10,000 psi. An exposed specimen being tested in helium failed after 1078 hours at a stress of 10,000 psi. Two creep-to-rupture tests in air are in progress.

The results of the tests completed are tabulated in Table 3 and are shown graphically in Fig. 16.

Metallographic examination of the Cr-Mo creep to rupture specimens is complete.

Fig. 17 shows a longitudinal section of a specimen stressed to rupture in air. An oxide coating approximately 4 mil thick is apparent. Intergranular cracking is also evident in the microphotograph.

Fig. 18 shows a section of a specimen stressed at 7500 psi in sodium for 6624 hours, at which time the test was terminated without failure. Surface coatings are absent. Fig. 19 shows a pre-exposed specimen (4000 hrs in Na) tested in helium. Intergranular cracking is evident.

With the exception of coatings apparent in air test specimens, no differences are observed in metallographic examination of creep-to-rupture 2 1/4 Cr-1 Mo specimens.

The following conclusions have been made based on the above tests:

- a. The scatter of data was greater for the Cr-Mo tests than in the tests of stainless steel.
- b. The creep-to-rupture tests of Cr-Mo in air and helium at 1100 F showed no significant difference.
- c. The creep-to-rupture tests of Cr-Mo in 1100 F sodium indicated shorter rupture times at the higher stresses.
- d. Specimens exposed to 1100 F sodium for 4000 hours and then tested in sodium and helium at 1100 F gave similar results. In both cases the rupture times were much shorter than for the original material.

3.3 Cr-Mo STEEL CREEP TESTS

All the 2 1/4 Cr-1 Mo creep tests in air and sodium have been completed. Two tests in helium are now in progress at loads of 7000 and 5500 psi. The test at 6000 psi has been terminated after 4008 hours.

The terminated test at 6000 psi had exhibited a creep rate of 0.085%/1000 hours since 1500 hours. The 7000 psi test has decreased to a rate of 0.26%/1000 hours at the end of 1000 hours and is still decreasing. The 5500 psi test decreased to 0.045%

per 1000 hours at the end of 1000 hours of testing and continued to decrease to 0.036% at the end of 2000 hours.

The results of all tests to date are found in Table 3, and Figs. 20, 21 and 22 show the creep rates in the three environments at comparable stress levels. Fig. 23 is a summary of the minimum creep rate (%/1000 hrs) vs stress.

Fig. 24 shows a longitudinal section of a creep specimen tested in air, while Fig. 25 shows a sample tested in sodium. A heavy oxide coating is apparent in Fig. 24. No change in grain size is evidenced in any of the creep or stress-to-rupture tests performed to date.

Preliminary conclusions based on the above tests follow:

- a. The minimum creep rates of 2 1/4 Cr-1 Mo steel in 1100 F air are substantially lower (better) than in 1100 F sodium.
- b. The minimum creep rates of 2 1/4 Cr-1 Mo steel in 1100 F helium are incomplete at this time.

3.4 2 1/4 Cr-1 Mo STEEL TENSILE TEST

Tensile tests of the 2 1/4 Cr-1 Mo steel have been completed. The results are found in Table 3. Conclusions based on this data are as follows:

- a. There was considerably more scatter in the Cr-Mo tensile tests than obtained in the stainless steel tests.
- b. Tests conducted in 1100 F air showed a higher tensile strength and an increase in the yield strength over those tests in 1100 F helium.
- c. Exposed specimen (4000 hrs - 1100 F sodium) tests in helium showed considerably less tensile and yield strength than the original material.
- d. There was no difference in the exposed tests as to whether the specimens were washed or unwashed after exposure.
- e. The results of the tensile tests of Cr-Mo were surprising and no explanation for this behavior is available at this time, but it is suspected that lack of oxidation may have contributed to the findings.

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

The bypass tank installation for the addition of carbon was completed and the system charged. After some difficulty, the six test pots were charged. The immersion heater in one test pot failed during the charging procedure. All test pots were isolated from the system and the system drained. The test pot with the bad heater was cut out of the system and a new heater installed. At this time it was found that a solid plug had formed in the pot inlet line. This line was cut out, washed and put back into the system. After installation of the repaired pot, the system was then recharged. An improperly seated valve at the repaired pot caused a leak at this area, and necessitated draining of the system. Wiring was damaged by the leaking sodium in this area as well as the insulation on this pot. When repairs were completed, the system was recharged and flow established through the test pots.

During the next report period the oxide level will be reduced to a saturation temperature of less than 300 F. The carbon level will be determined and then brought to test conditions by the use of the bypass carbon pot. After it has been determined that the proper carbon level has been reached and that it can be maintained, the foils (2 1/4 Cr-1 Mo, 316 ss, 304 ss and Armco pure iron) will be installed for a 2-3 week period. After data obtained from these foils has been correlated, Test 3 will be initiated.

5. TEST 4 - 2 1/4 Cr-1 Mo STEEL SPECIMENS IN 1100 F, HIGH OXIDE SODIUM

With completion of runs in which foils were exposed for various lengths of time, the pots were drained and the test machine calibrations were checked. Test 4 was initiated by installing the three creep specimens and three creep-rupture specimens. Fig. 26 is a graph showing the operational history of Test 4.

5.1 2 1/4 Cr-1 Mo STEEL FATIGUE TESTS

Fatigue tests have not yet been started. These tests will be initiated during the next report period.

5.2 2 1/4 Cr-1 Mo STEEL CREEP-RUPTURE TESTS

The three creep-to-rupture tests in the high oxide sodium were loaded at stresses of 18,000 psi, 14,000 psi, and 12,000 psi. The specimen at a load of 18,000 psi failed after 48.5 hours. This

specimen was removed and a new specimen installed. It was placed under a load of 16,000 psi. The specimen at a load of 14,000 psi failed after 240.6 hours. This specimen will be removed and a fifth test started at a load of 10,000 psi.

If the results of these two tests are indicative of a trend, then the creep-to-rupture in high oxide sodium will show failures in shorter times.

5.3 2 1/4 Cr-1 Mo STEEL CREEP TESTS

The three creep tests in the high oxide sodium were loaded at stresses of 7000 psi, 6000 psi and 4500 psi. Specimens for the exposed creep rupture tests were installed with these specimens. The tests have not been in progress a sufficient length of time to report results.

5.4 2 1/4 Cr-1 Mo STEEL TENSILE TESTS

Tensile tests are not scheduled until the end of the 4000 hour creep tests.

5.5 ANALYTICAL RESULTS

Extraction of samples from Loop 2 (Test 4) on a weekly basis has continued. Analyses have been run for carbon and for trace elements by emission spectrograph. The results of these carbon analyses are as follows:

<u>Date</u>	<u>Results</u> <u>ppm C</u>	
*3/22/63	22.2	} Average 29 ppm C
*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	
5/15/63	- -	} Improved trapping procedure for carbon dioxide Instrumentation failure (Back particles noted in sample in water solution)
5/22/63	130.0	

* Last month's results.

Average result on Loop 2 to 5/7/63 was 29 ppm C. Results after this date are thought to be due to operational changes made in the loop.

Standard samples were again run as a check on operation of equipment and methods. Results are listed below:

<u>Date</u>	<u>Std. Sample ppm C</u>	<u>Result ppm C</u>
5/2/63	50	45
5/2/63	50	48
5/3/63	50	48
5/9/63	50	61
5/9/63	50	50
5/10/63	50	48
5/10/63	50	49
5/13/63	50	55
5/13/63	50	62
5/15/63	50	45
5/15/63	50	57
Average =		51

Results substantiate previous standard results given in last month's report. The standard material was lampblack in sodium sulfate as in previous tests.

Results on the emission spectrograph samples are now available and are reported in Table 4.

A chemical oxygen analysis of the loop sodium showed 424 ppm O. This indicates a saturation level of 715°F and agrees with the plugging temperature of 715-720°F.

5.5.1 Particulate Carbon

The cause of variation in carbon content has been attributed to particulate carbon in the sample. Samples taken last month through a 40-60 μ frit showed inconsistent carbon values. During the past month, samples were extracted at 600°F through a 4-8 μ glass frit. Results of these tests are given in the following table:

<u>Sample No.</u>	<u>Carbon Content</u> <u>ppm C</u>
*1 (end near frit 40-60 μ)	108
*2	65.6
*3	53
*4	46.2

5 (end near frit 4-8 μ)	55
6	86
7	-- (tube cracked during digestion)
8	37
9	151

* Previous results

Results do not indicate a segregation of carbon within the tube as previously thought. The cause of variation is at present undetermined.

6. FUTURE WORK

While preliminary conclusions have been presented in the above sections, final conclusions will not be made on Tests 1 and 2 until carbon analyses and microhardness determinations have been completed. Metallographic examination reveals the significance of surface effects on fatigue. Changes in specimen carbon content are necessary to correlate compositional effects with the small differences in creep and stress-to-rupture tests observed with the variation in test environment.

Topical reports on Tests 1 and 2 are now in progress and will be completed in the near future on work to date. Since it appears that oxygen, or rather the lack of oxygen, may be a contributing factor, a short study will be made of the thermodynamics involved.

TABLE I
 REVISED MECHANICAL TEST PROGRAM - March 26, 1962
 Tests 1 and 2

Loop No. 1 - Type 316 ss - 1200 F

Test Conditions	Creep Test			Tensile Test				Stress to Rupture						Fatigue											
	UE			E	UE	PE	UE RT	PE RT	PE			Uniformity			UE			1000 Cycles	10,000 Cycles	100,000 Cycles	PE 1,000 Cycles				
	#1	#2	#3						#1	#2	#3	#1	#2	#3	#4	#5	#6			E					
Test 1																									
Na, He	1	1	1	21		3			1	1	1				1	1	1	1	1	1	3	3	3	9-3	3
				6	6	3-3																		3	3
Air	1	1	1		3				1	1	1	2	2	2	1	1	1	1	1	1	3	3	3		3
Helium	1	1	1		3	6	3	6	1	1	1				1	1	1	1	1	1	3	3	3		3

Loop No. 2 - 2-1/4 Cr - 1 Mo 1100 F

Test Conditions	Creep Test			Tensile Test		Stress to Rupture						Fatigue								
	UE			E	UE	PE	PE			UE			1,000 Cycles	10,000 Cycles	100,000 Cycles	PE 1,000 Cycles				
	#1	#2	#3				#1	#2	#3	#1	#2	#3	#4	#5	#6			E		
Test 2																				
Na, He	1	1	1	12-3			1	1	1	1	1	1	1	1	1	3	3	3	9-3	3
				6-3																
Air	1	1	1		3											3	3	3		3
Helium	1	1	1		3	6	1	1	1	1	1	1	1	1	1	3	3	3		3

UE - Unexposed
 E - Unstressed Specimens Being Exposed
 RT - Room Temperature
 PE - Pre-exposed
 # - Stress Values

Table 2 - Mechanical Tests 3 and 4 - October 31, 1962
 Revised December 31, 1962

Loop No. 1 - Type 316 ss (1200 F)

Test 3

Test Medium	Creep Test				Tensile Test		Stress to Rupture Test						Fatigue Test						
	T				PE	PE RT	PE						High Stress	Med. Stress	Low Stress		PE High Stress		
	#1	#2	#3	E			#1	#2	#3	#4	#5	#6			T	E			
Na, Sat C, He Air He	1	1	1	21			1	1	1	1	1	1	3	3	3	9	3	3	3
					6	6	1	1	1										

Loop No. 2 - 2-1/4 Cr-1 Mo (1100 F)

Test 4

Test Medium	Creep Test				Tensile Test		Stress to Rupture Test						Fatigue Test						
	T				PE	PE RT	PE						High Stress	Med. Stress	Low Stress		PE High Stress		
	#1	#2	#3	E			#1	#2	#3	#4	#5	#6			T	E			
Na, 200-300 ppm O ₂ , He Air He	1	1	1	18			1	1	1	1	1	1	3	3	3	9	3	3	3
					6	6	1	1	1										

- T - Under Test
- UE - Unexposed
- E - Unstressed Specimens Being Exposed
- RT - Room Temperature
- PE - Pre-exposed
- # - Stress Values

Table 3 - Test Data Summary
Tests 1 and 2A. Fatigue Tests

<u>316 ss</u>	<u>Condition</u>	<u>Specimen Thickness In.</u>	<u>% Cyclic Strain</u>	<u>Cycles to Failure</u>	<u>Time at Temperature Hrs</u>
3FAX2	Air-1200 F	.0680	2.18	599	14.7
3FAX3	Air-1200 F	.0680	2.18	600	15.5
3FAX4	Air-1200 F	.0680	2.18	570	16.6
3HAL1	(1)Air-1200 F	.0660	2.11	296	1.8
3HAL2	(1)Air-1200 F	.0663	2.12	302	2.5
3HAL3	(1)Air-1200 F	.0662	2.12	326	2.0
3FHX4	He-1200 F	.0665	2.13	1325	17.7
3FHX5	He-1200 F	.0685	2.19	848	5.5
3FHX6	He-1200 F	.0670	2.14	1122	7.5
3HHL1	(1)He-1200 F	.0665	2.13	1116	16.8
3HHL2	(1)He-1200 F	.0675	2.16	1233	7.0
3HHL3	(1)He-1200 F	.0660	2.11	749	4.5
3FLX1	Na-He-1200 F	.0675	2.16	615	17.5
3FLX2	Na-He-1200 F	.0680	2.18	275	2.0
3FLX3	Na-He-1200 F	.0678	2.16	492	20.0
3FLX4	Na-He-1200 F	.0675	2.16	475	14.0
3HLL1	(1)Na-He-1200 F	.0680	2.18	700	21.8
3HLL2	(1)Na-He-1200 F	.0675	2.16	751	42.0
3HLL3	(1)Na-He-1200 F	.0675	2.16	545	65.5
3GAX7	Air-1200 F	.0680	1.00	1498	8.5
3GAX8	Air-1200 F	.0680	1.00	1663	9.5
3GAX9	Air-1200 F	.0675	1.00	1500	8.5
3GHX2	He-1200 F	.0680	1.00	9693	63.0
3GHX3	He-1200 F	.0670	0.99	9058	51.5
3GHX4	He-1200 F	.0678	1.00	7816	59.5
3GLX1	Na-He-1200 F	.0665	.985	2385	32.5
3GLX2	Na-He-1200 F	.0675	1.00	2110	22.5
3GLX3	Na-He-1200 F	.0672	.995	3914	23.5
3GLX4	Na-He-1200 F	.0682	1.01	4112	44.0

(1) Specimen pre-exposed to 1200 F sodium for 286 hours

Table 3 - Test Data Summary - Cont'd

<u>316 ss</u>	<u>Condition</u>	<u>Specimen Thickness In.</u>	<u>% Cyclic Strain</u>	<u>Cycles to Failure</u>	<u>Time at Temperature Hrs</u>
3JAX5	(4) Air-1200 F	.0665	.554	8956	49.8
3JAX6	(4) Air-1200 F	.0682	.568	8060	44.8
3JAX7	Air-1200 F	.0678	.565	8556	48.0
3JHX1	He-1200 F	.0670	.558	50,004	277.8
3JHX2	He-1200 F	.0685	.571	38,804	217.5
3JHX3	He-1200 F	.0688	.573	37,011	230.5
3JLX1	Na-He-1200 F	.0680	.565	55,925	333.5
3JLX2	Na-He-1200 F	.0668	.556	29,400	160.0
3JLX3	Na-He-1200 F	.0670	.558	33,055	212.5
<u>2-1/4 Cr-1 Mo</u>					
2FAX1	Air-1100 F	.0685	2.15	474	16.5
2FAX2	Air-1100 F	.0675	2.16	392	16.5
2FAX3	Air-1100 F	.0678	2.17	365	28.2
2HAL1	(3) Air-1100 F	.0670	2.14	353	2.5
2HAL2	(3) Air-1100 F	.0670	2.14	371	2.5
2HAL3	(3) Air-1100 F	.0670	2.14	449	2.8
2FHX5	He-1100 F	.0670	2.14	1725	15.8
2FHX6	He-1100 F	.0672	2.15	2360	10.5
2FHX7	He-1100 F	.0670	2.14	2440	14.3
2HHL1	(3) He-1100 F	.0675	2.16	843	5.0
2HHL2	(3) He-1100 F	.0675	2.16	2129	11.8
2HHL3	(3) He-1100 F	.0675	2.16	196	2.0
*2HHL4	(3) He-1100 F	.0672	2.15	1614	20.0
*2HHL5	(3) He-1100 F	.0668	2.14	999	7.5
2FLX1	Na-He-1100 F	.0672	2.15	1931	34.0
2FLX2	Na-He-1100 F	.0675	2.16	2134	41.5
2FLX3	Na-He-1100 F	.0672	2.15	2280	17.5
2HLL1	(3) Na-He-1100 F	.0675	2.16	2448	33.8
2HLL2	(3) Na-He-1100 F	.0672	2.15	1770	21.5
2HLL3	(3) Na-He-1100 F	.0672	2.15	2140	25.5

(3) Specimen pre-exposed to 1100 F sodium for 323 hours.

(4) Specimens 3JAX3 and 3JAX4 tested on different mandrel design have been voided.

Table 3 - Test Data Summary - Cont'd

<u>2-1/4 Cr-1 Mo</u>	<u>Condition</u>	<u>Specimen Thickness In.</u>	<u>% Cyclic Strain</u>	<u>Cycles to Failure</u>	<u>Time at Temperature Hrs</u>
2GAX1	Air-1100 F	.0675	1.00	998	5.8
2GAX2	Air-1100 F	.0675	1.00	1011	5.5
2GAX3	Air-1100 F	.0672	.995	1017	6.0
*2GHX1	He-1100 F	.0675	1.00	12,400	101.5
*2GHX2	He-1100 F	.0672	.997	10,388	58.3
*2GHX3	He-1100 F	.0665	.985	9,878	63.0
2GLX1	Na-He-1100 F	.0672	.995	6727	94.0
2GLX2	Na-He-1100 F	.0672	.995	7300	42.0
2GLX3	Na-He-1100 F	.0672	.995	9249	64.5
2JAX1	Air-1100 F	.0668	.556	2710	16.5
2JAX2	Air-1100 F	.0665	.554	2768	16.5
2JAX3	Air-1100 F	.0665	.554	2850	16.0
2JHX1	He-1100 F	.0675	.562	18,454	104.0
2JHX2	He-1100 F	.0675	.562	32,390	185.8
*2JHX3	He-1100 F	.0665	.554	56,522	326.0
*2JHX4	He-1100 F	.0665	.554	43,200	254.0
2JLX1	Na-He-1100 F	.0672	.560	44,458	305.0
2JLX2	Na-He-1100 F	.0668	.556	42,555	256.0
2JLX3	Na-He-1100 F	.0672	.560	53,400	323.0

B. Tensile Tests

<u>316 ss</u>	<u>Condition</u>	<u>Tensile Str. (Psi)</u>	<u>0.2% Offset Yield Strength (Psi)</u>	<u>Elong %</u>	<u>Reduction of Area %</u>
3BAX4	Air-1200 F	49,400	26,100	43	47
3BAX3	Air-1200 F	50,250	25,650	41	48
3BAX1	Air-1200 F	51,200	26,300	47	44
3BHX1	He-1200 F	47,200	26,600	46	58
3BHX2	He-1200 F	47,500	25,900	52	54
3BHX3	He-1200 F	48,600	25,300	44	53
3BHL1C	(5)He-1200 F	48,850	24,500	39	46
3BHL2C	(5)He-1200 F	46,900	24,800	52	52
3BHL3C	(5)He-1200 F	50,000	26,200	41	46

Table 3 - Test Data Summary - Cont'd

<u>316 ss</u>	<u>Condition</u>	<u>Tensile Str. (Psi)</u>	<u>0.2% Offset Yield Strength (Psi)</u>	<u>Elong %</u>	<u>Reduction of Area %</u>
3BHL1U	(11)He-1200 F	49,100	26,750	41	56
3BHL2U	(11)He-1200 F	46,400	25,200	46	55
3BHL3U	(11)He-1200 F	49,900	25,650	46	51
3BHX4	(5)He-RT	93,200	44,600	47	46
3BHX5	(5)He-RT	92,000	43,750	48	50
3BHX6	(5)He-RT	92,500	42,000	46	40
3BHX7	(5)He-RT	91,400	43,700	49	52
3BHX8	(5)He-RT	92,500	43,900	49	52
3BHX9	(5)He-RT	95,500	45,600	46	40
*3BHX10	He-RT	89,500	49,700	65	59
*3BHX11	He-RT	88,500	49,400	66	59
<u>2-1/4 Cr-1 Mo</u>					
2BAX4	Air-1100 F	49,170	25,800	28	64
2BAX1	Air-1100 F	56,800	28,800	32	57
2AAX4	Air-1100 F	59,400	29,370	32	62
2BHX3	He-1100 F	39,700	24,500	39	46
2BHX4	He-1100 F	38,120	24,800	52	52
2BHX5	He-1100 F	37,820	26,200	41	46
2BHL1C	(6)He-1100 F	26,620	17,200	45	54
2BHL2C	(6)He-1100 F	25,230	(10) --	46	55
2BHL3C	(6)He-1100 F	26,580	16,800	47	41
2BHL4C	(6)He-1100 F	26,160	17,300	41	50
2BHL1U	(12)He-1100 F	25,800	16,150	40	65
2BHL2U	(12)He-1200 F	26,410	17,950	42	56
2BHL3U	(12)He-1100 F	29,200	19,400	38	57

Table 3 - Test Data Summary - Cont'd

C. Creep Tests

<u>316 ss</u>	<u>Condition</u>	<u>Stress Psi</u>	<u>Rate %/1000 hrs</u>
3AAX2	Air-1200 F	13,000	0.215 Terminated 3692 hrs
3BAX2	Air-1200 F	12,500	0.15 Terminated 4242 hrs
3AAX3	Air-1200 F	11,500	0.035 Terminated 3986 hrs
*3AHX1	He-1200 F	12,000	0.40 (IP 3532 hrs)
*3AHX2	He-1200 F	11,000	0.18 (IP 1174 hrs)
*3AHX3	He-1200 F	10,500	.076 (IP 1030 hrs)
3ALX1	Na-He-1200 F	13,500	0.67 Terminated 4000 hrs
3ALX2	Na-He-1200 F	12,500	0.31 Terminated 4000 hrs
3ALX3	Na-He-1200 F	11,500	0.17 Terminated 4000 hrs

2-1/4 Cr-1 Mo

2BAX2	Air-1100 F	8,000	.395 Terminated 3957 hrs
2AAX2	Air-1100 F	6,000	.12 Terminated 4010 hrs
*2AAX1	Air-1100 F	5,500	.07 (IP 3720 hrs)
*2AHX1	He-1100 F	6,000	.085 Terminated 4009 hrs
*2AHX2	He-1100 F	5,500	.036 (IP 2181 hrs)
*2AHX3	He-1100 F	7,000	.260 (IP 1173 hrs)
2ALX1	Na-He-1100 F	10,000	**Terminated 1839 hrs
2ALX2	Na-He-1100 F	8,000	**Terminated 4000 hrs
2ALX3	Na-He-1100 F	6,000	.28 Terminated 4000 hrs
2ALX4	Na-He-1100 F	8,000	.57 Terminated 2587 hrs

D. Stress-Rupture Tests

<u>316 ss</u>	<u>Condition</u>	<u>Stress (Psi)</u>	<u>Elong %</u>	<u>Reduction of Area %</u>	<u>Rupture Time (Hrs)</u>
3CAX10	Air-1200 F	27,500	61	45	173.6
3CAX2	Air-1200 F	27,500	58	49	152.8
3CAX9	Air-1200 F	27,500	52	46	146.5
3CAX3	Air-1200 F	27,500	63	50	143.0
3DAX4	Air-1200 F	24,000	40	38	476.2
3CAX6	Air-1200 F	24,000	60	43	426.2
3CAX7	Air-1200 F	24,000	44	39	349.7
3CAX1	Air-1200 F	22,000	33	31	863.0
3CAX8	Air-1200 F	21,500	33	28	1000.6
3CAX5	Air-1200 F	21,500	35	38	971.0
3DAX3	Air-1200 F	20,500	35	29	1387.8
3DAX1	Air-1200 F	18,500	34	29	2363.0

Table 3 - Test Data Summary - Cont'd

<u>316 ss</u>	<u>Condition</u>	<u>Stress (Psi)</u>	<u>Elong %</u>	<u>Reduction of Area %</u>	<u>Rupture Time (Hrs)</u>
3DAX2	Air-1200 F	17,750	39	20	1969.5(9)
3AAX4	Air-1200 F	17,750	18	18	3695.1
3EAL1	(5) Air-1200 F	27,500	62	46	144
3EAL2	(5) Air-1200 F	24,000	54	44	574
3EAL3	(5) Air-1200 F	21,500	49	42	985.2
3CAX4	He-1200 F	27,500	63	46	166.3
3CHX2	He-1200 F	27,500	53	49	152.8
3CHX3	He-1200 F	24,000	48	49	697.7
3DHX3	He-1200 F	24,000	65	54	483.1
3CHX1	He-1200 F	21,500	52	47	894.3
3DHX1	He-1200 F	20,000	34		1509.5
3DHX2	He-1200 F	18,000	44	32	2619.9
*3DHX4	He-1200 F	17,750			IP (1870)
3EHL1	(5) He-1200 F	27,500	57	52	57.6
3EHL2	(5) He-1200 F	24,000	48	44	675.0
3EHL3	(5) He-1200 F	21,500	49		822.2
3CLX1	Na-He-1200 F	27,500	74	50	144.6
3CLX2	Na-He-1200 F	24,000	62	49	445.0
3CLX3	Na-He-1200 F	21,500	70	46	890.7
3DLX2	Na-He-1200 F	20,000	53	36	1437.0
3DLX3	Na-He-1200 F	18,500	33	17	2489.5
3DLX1	Na-He-1200 F	17,750	27	16	2942.2
3ELL3(7)	(5) Na-He-1200 F	24,000	73	53	632.0
3ELL2	(5) Na-He-1200 F	21,500	73	53	902.5
3ELL1(7)	(5) Na-He-1200 F	20,000	65	44	1869.7
3ELL4	(5) Na-He-1200 F	27,500	71	45	236.0
<u>2-1/4 Cr-1 Mo</u>					
2CAX4	Air-1100 F	20,000	64	58	90.8
2CAX2	Air-1100 F	17,500	42	36	139.2
2CAX3	Air-1100 F	15,000	41	32	302.3
2CAX1	Air-1100 F	12,000	23	--	1390.5
2EAL1	(6) Air-1100 F	10,000			1290.0
2CHX1	He-1100 F	20,000	55	55	108.0
2CHX3	He-1100 F	20,000	56	40	86.5
2DHX1	He-1100 F	16,500	47	41	246.6
2DHX3	He-1100 F	16,500	47	54	98.4
2DAX1	He-1100 F	14,500	36	41	303.8
2DAX4	He-1100 F	12,500	24	27	1545.0
2DAX5	He-1100 F	10,500	22	27	624.0(8)
2CHX4	He-1100 F	10,500	27		1398
2EHL1	(6) He-1100 F	14,000	36	31	78.8
2EHL2	(6) He-1100 F	12,500	31		180.4
*2EHL3	(6) He-1100 F	10,000	27		1078.4

Table 3 - Test Data Summary - Cont'd

<u>2-1/4 Cr-1 Mo</u>	<u>Condition</u>	<u>Stress (Psi)</u>	<u>Elong %</u>	<u>Reduction of Area %</u>	<u>Rupture Time (Hrs)</u>
2CLX1	Na-He-1100 F	20,000	88	66	30.1
2CLX4	Na-He-1100 F	20,000	68	60	71.7
2CLX5	Na-He-1100 F	20,000	77	60	41.9
2CLX2	Na-He-1100 F	16,500	71	58	146.6
2CLX3	Na-He-1100 F	14,000	53	58	298.8
2DLX1	Na-He-1100 F	12,000	34	36	1116.0
2DLX2	Na-He-1100 F	10,000	36	28	2106.6
2DLX3	Na-He-1100 F	7,500			6623.8(Term)
2ELL2	(6)Na-He-1100 F	16,500	67	53	20.0
2ELL1	(6)Na-He-1100 F	14,000	53	42	71.7
2ELL3	(6)Na-He-1100 F	12,000	56	41	159.7
2ELL4	(6)Na-He-1100 F	10,000	52	34	932.2

- * - Results obtained since last report
 ** - Creep rate too high to determine a minimum rate
 IP - Indicates tests in progress for indicated time
 (5) - Specimen pre-exposed to 1200 F sodium for 4000 hours
 (6) - Specimen pre-exposed to 1100 F sodium for 4000 hours
 (7) - Specimen code corrected
 (8) - Specimen failed prematurely at gage mark
 (9) - Molybdenum sheet used accidentally as shielding.
 (10) - Operational strain measurement difficulties, stress-strain data not available.
 (11) - Specimen pre-exposed to 1200 F sodium for 4000 hrs - not washed.
 (12) - Specimen pre-exposed to 1100 F sodium for 4000 hrs - not washed.

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

<u>Date</u>	<u>Fe</u>	<u>B</u>	<u>Co</u>	<u>Mn</u>	<u>Al</u>	<u>Mg</u>	<u>Sn</u>	<u>Cu</u>	<u>Pb</u>	<u>Cr</u>	<u>Si</u>	<u>Ti</u>	<u>Ni</u>	<u>Mo</u>	<u>V</u>	<u>Be</u>	<u>Ag</u>	<u>Zr</u>	<u>Li</u>	<u>Ca</u>
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

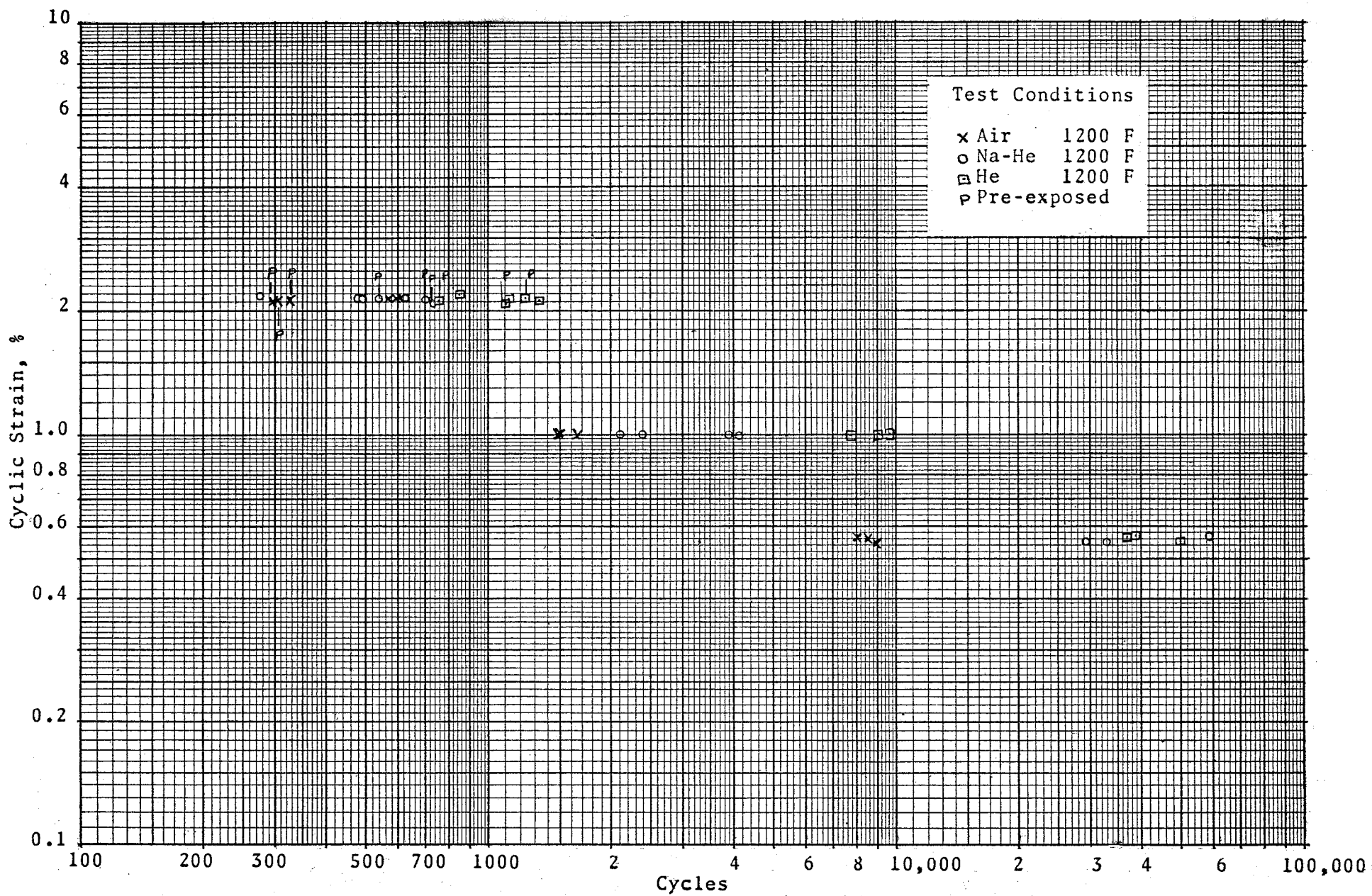


FIG. 1 - FATIGUE TESTS OF 316 STAINLESS STEEL SPECIMENS

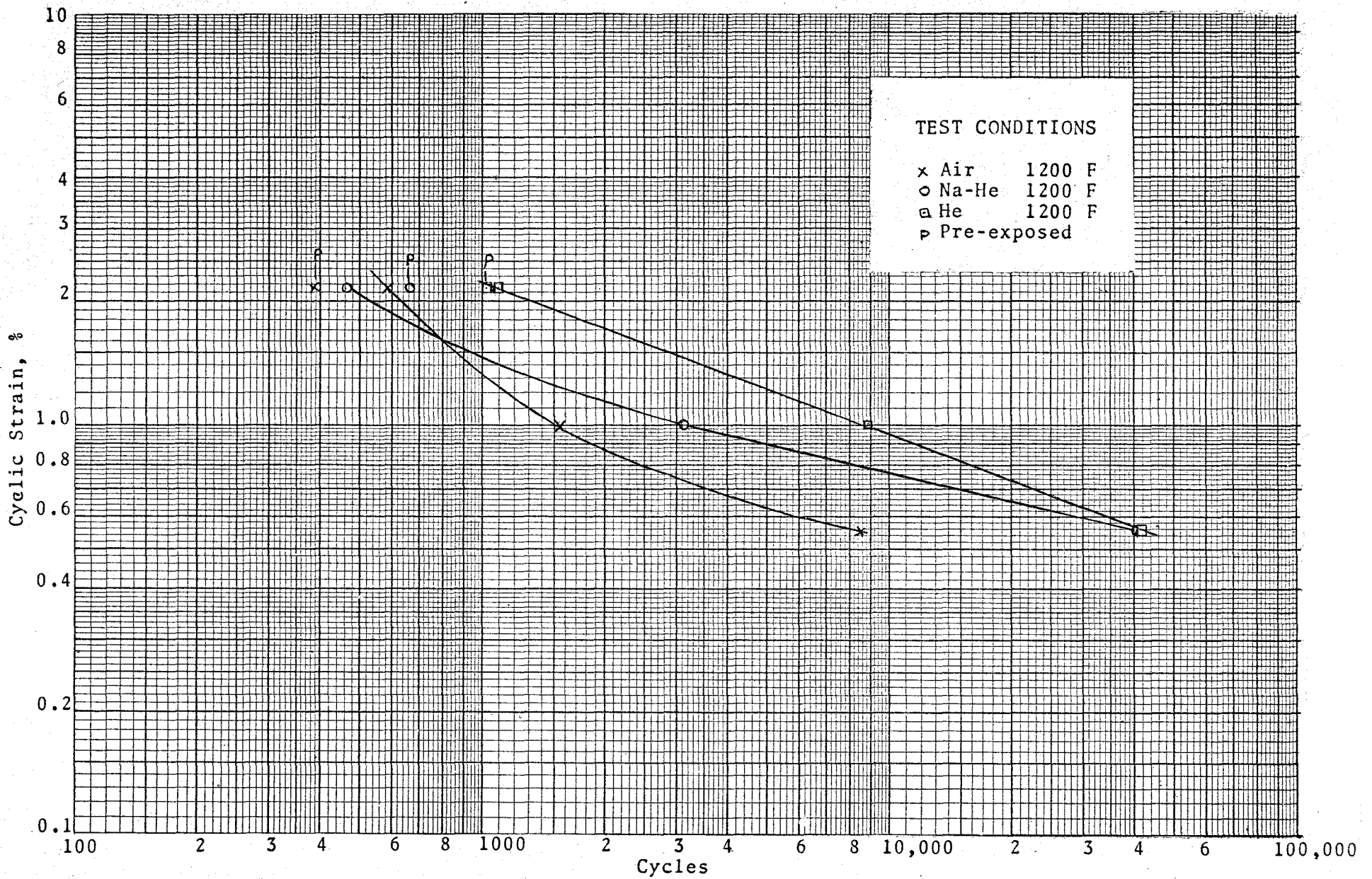


FIG. 2 - FATIGUE CURVES OF AVERAGED DATA FOR 316 STAINLESS STEEL FATIGUE TESTS

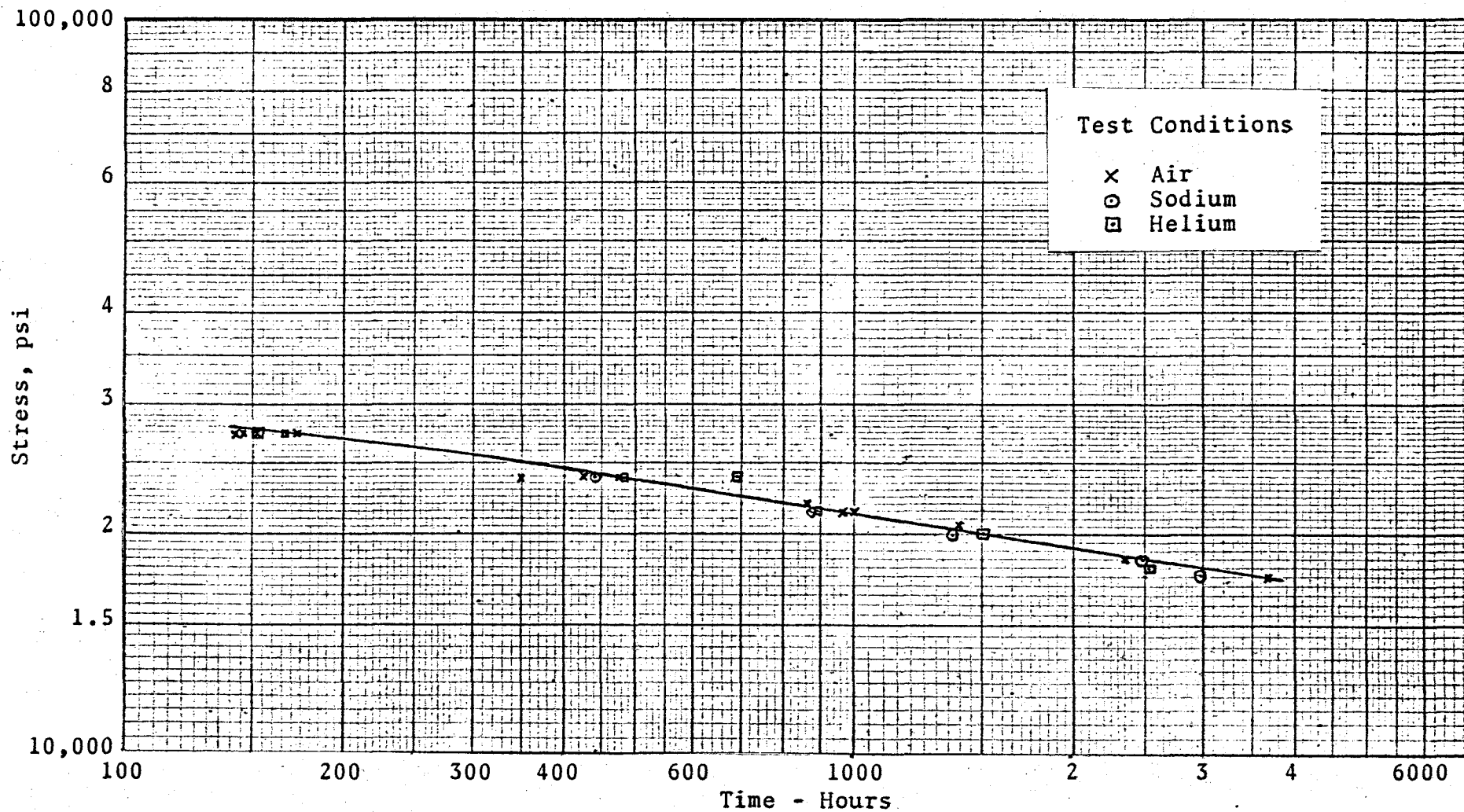


FIG. 3 - CREEP TO RUPTURE OF 316 STAINLESS STEEL SPECIMENS

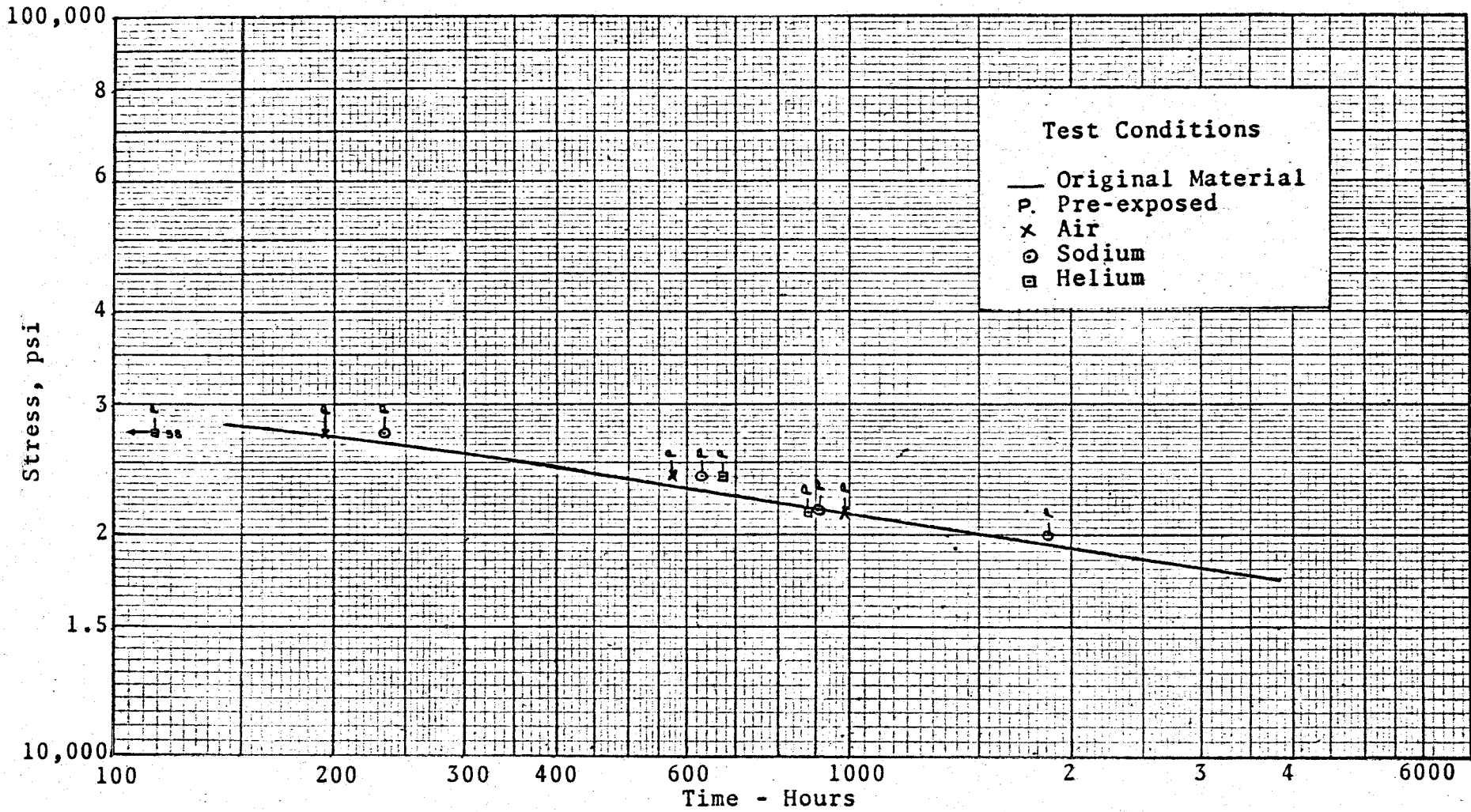


FIG. 4 - CREEP RUPTURE OF PRE-EXPOSED STAINLESS STEEL SPECIMENS

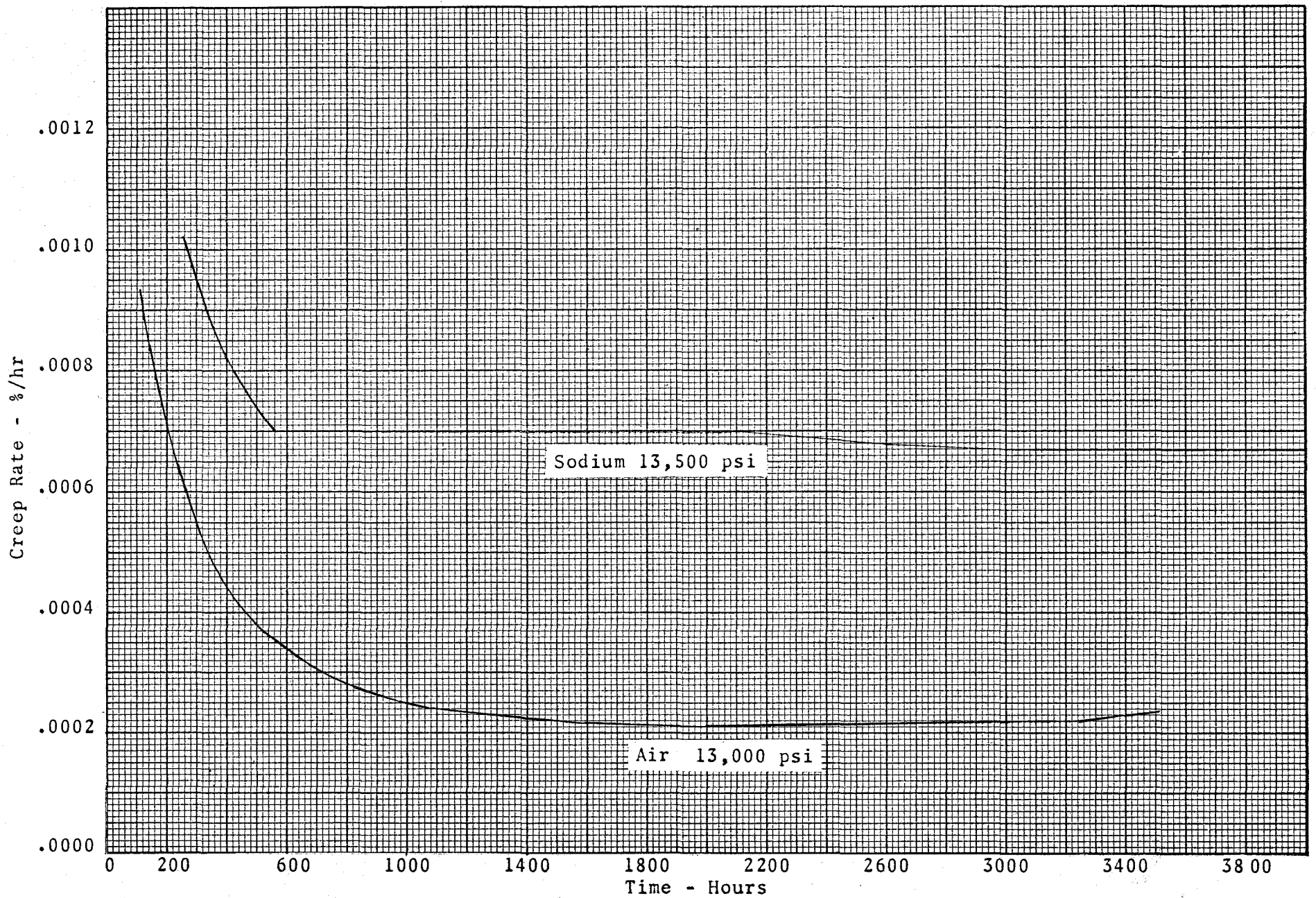


FIG. 5 - CREEP RATE, 316 STAINLESS STEEL SPECIMENS

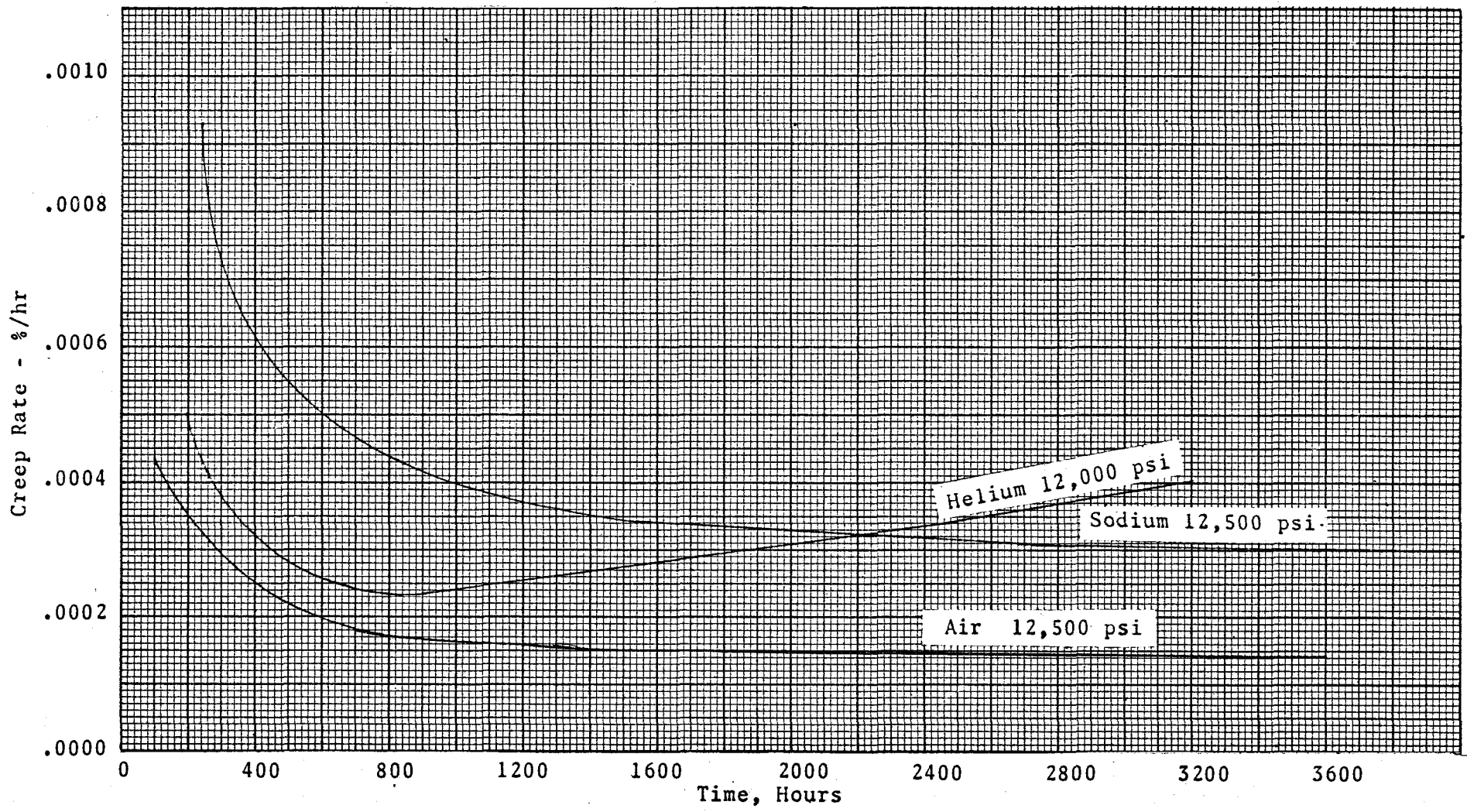


FIG. 6 - CREEP RATE, 316 STAINLESS STEEL SPECIMENS

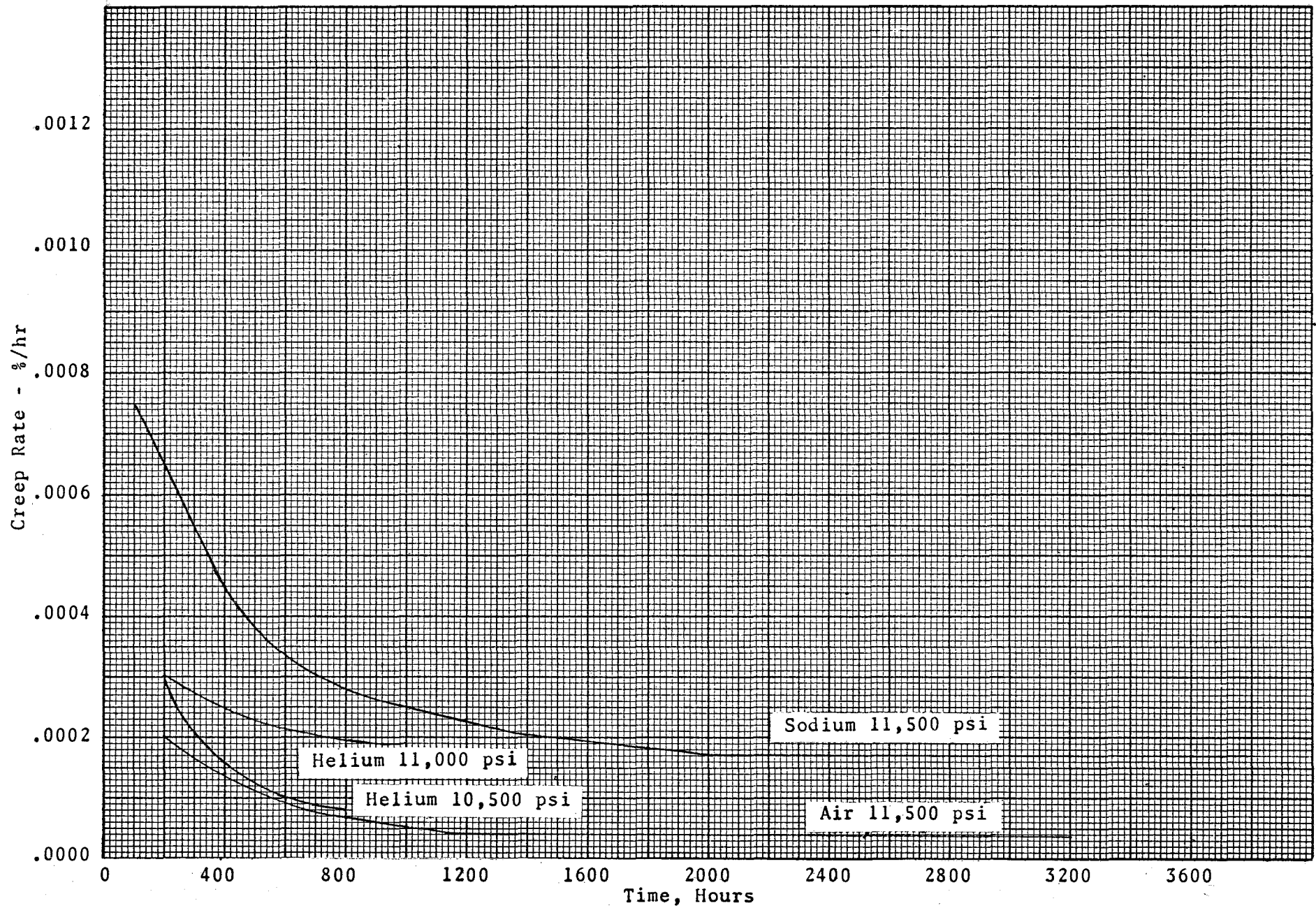


FIG. 7 - CREEP RATE, 316 STAINLESS STEEL SPECIMENS

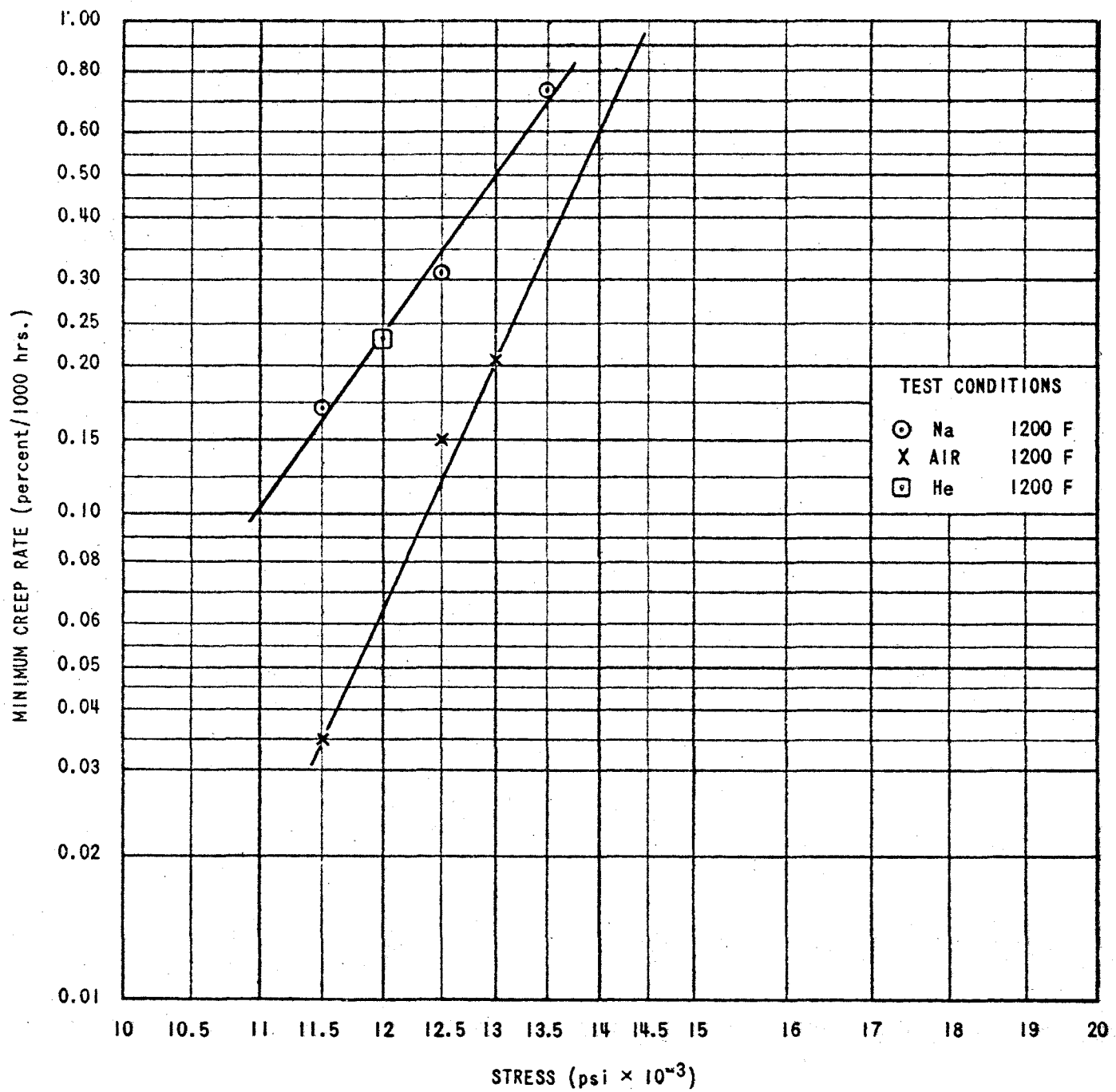


FIG. 8 - CREEP RATE VS STRESS, 316 STAINLESS STEEL SPECIMENS

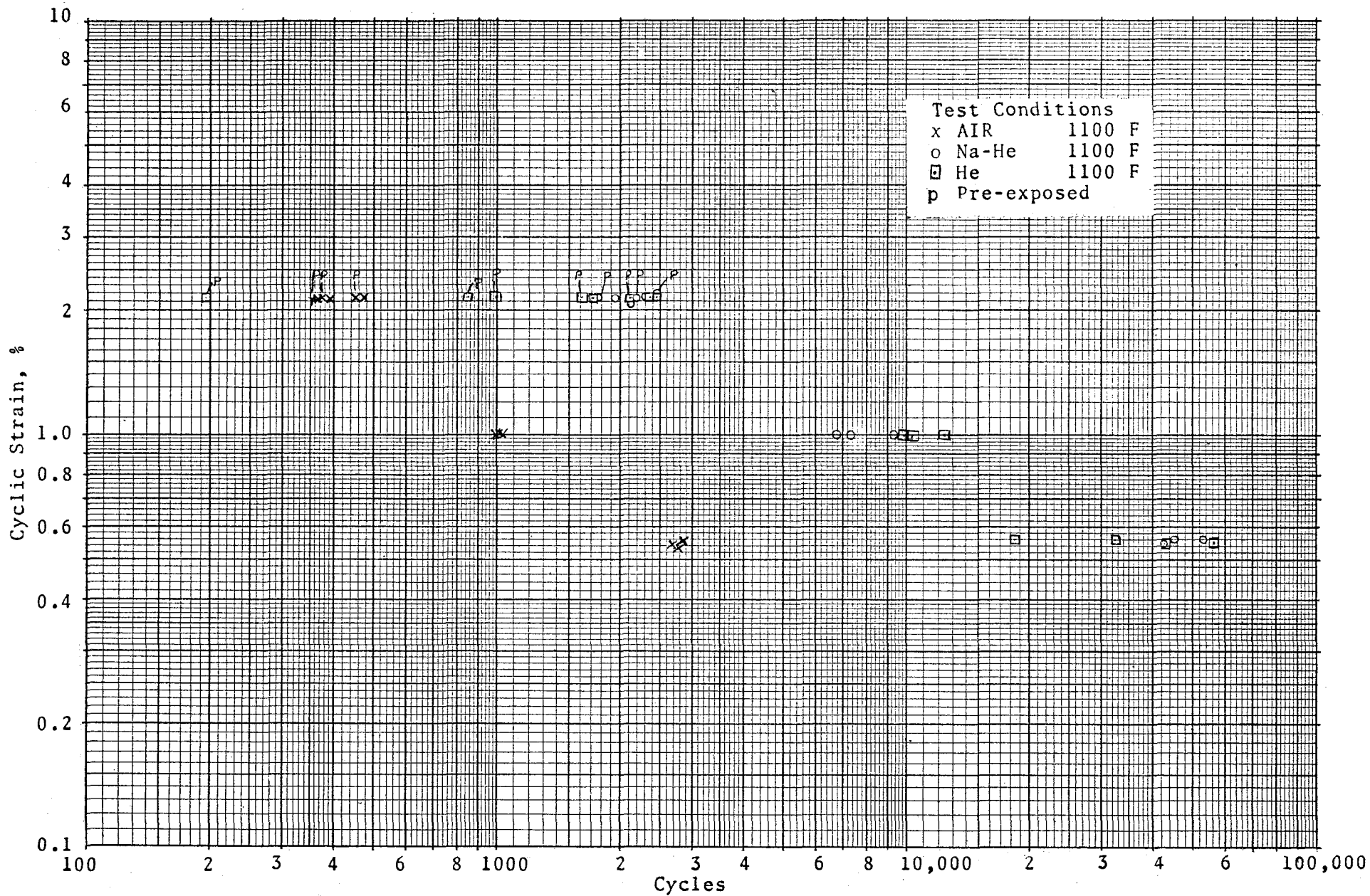


FIG. 9 - FATIGUE TESTS OF 2 1/4 Cr - 1 Mo CARBON STEEL SPECIMENS

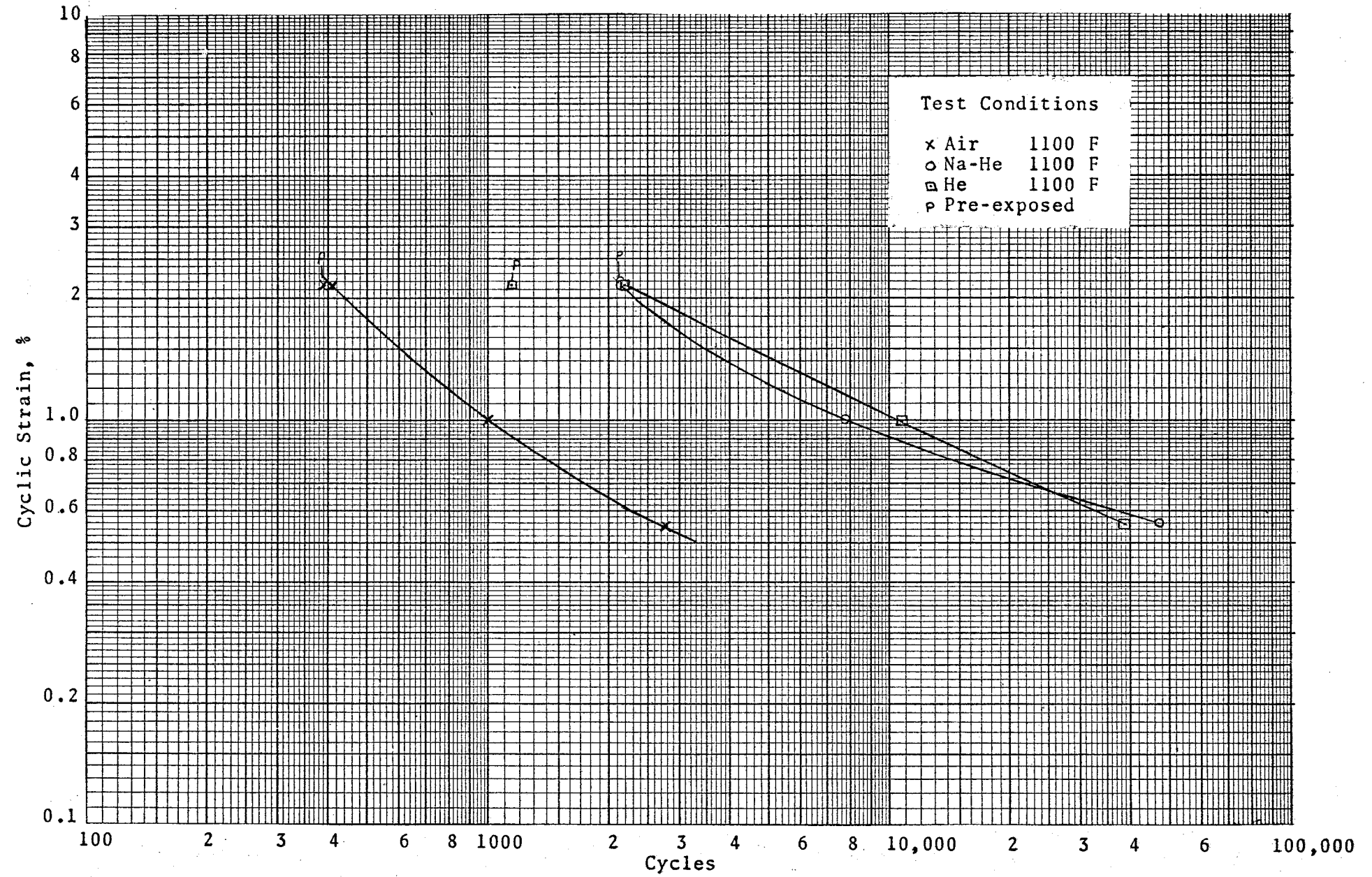


FIG. 10 - FATIGUE CURVES OF AVERAGED DATA FOR 2 1/4 Cr - 1 Mo CARBON STEEL FATIGUE TESTS



FIG11 - 2 1/4 Cr-1 Mo #2JAX2
Fatigue in 1100°F Air

Cyclic Strain = 0.55% Cycles to failure = 2768
Time at Temperature = 16.5 hrs
Longitudinal section near fracture 266X-Nital etch



FIG12 - 2 1/4 Cr-1 Mo #2JHX2
Fatigue in 1100°F Helium

Cyclic Strain = 0.56% Cycles to failure 32,390
Time at Temperature = 185.8 hrs
Longitudinal section near fracture 266X-Nital etch



FIG13 - 2 1/4 Cr-1 Mo #2JLX1
Fatigue in 1100°F Sodium

Cyclic Strain = 0.56% Cycles to failure = 44,458
Time at Temperature = 305 hrs
Longitudinal section near fracture 266X-Nital etch

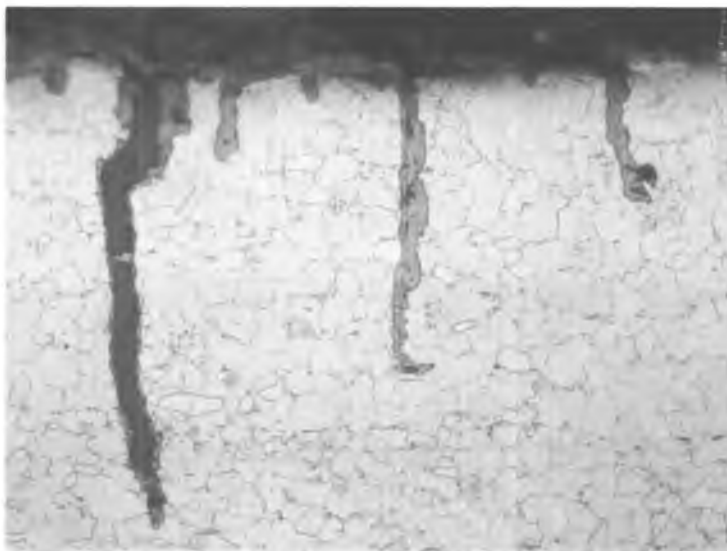


FIG14 - 2 1/4 Cr-1Mo #2HAL2
Pre-exposed in Sodium(323 hrs) and Fatigued in 1100°F Air

Cyclic Strain = 2.14% Cycles to failure = 371
Time at Temperature = 2.5 hrs
Longitudinal section near fracture 266X-Nital etch



FIG15 - 2 1/4 Cr-1 Mo #2FAX2
Fatigue in 1100°F Air

Cyclic Strain = 2.16% Cycles to failure = 392
Time at Temperature = 16.5 hrs
Longitudinal section at fracture 266X-Nital etch

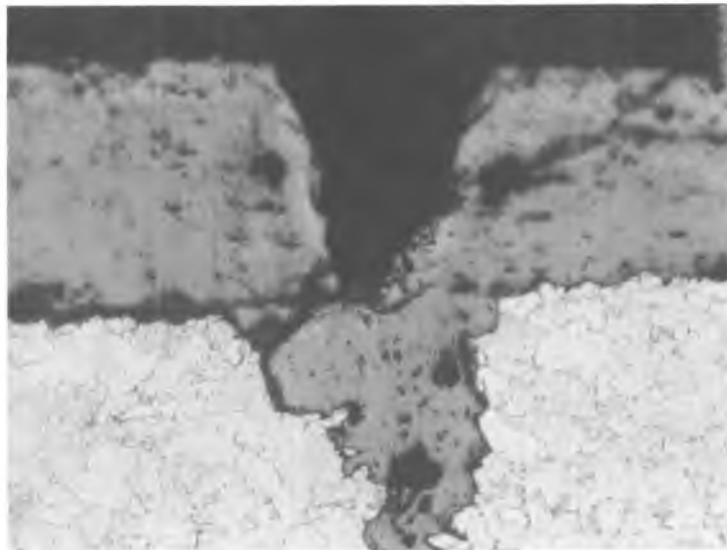


FIG 17- 2 1/4 Cr-1 Mo #2CAX1
Stress to rupture in 1100°F Air

Stress = 12,000 psi Elongation = 23%
Rupture Time = 1390.5 hrs
Longitudinal section near fracture 266X-Nital etch

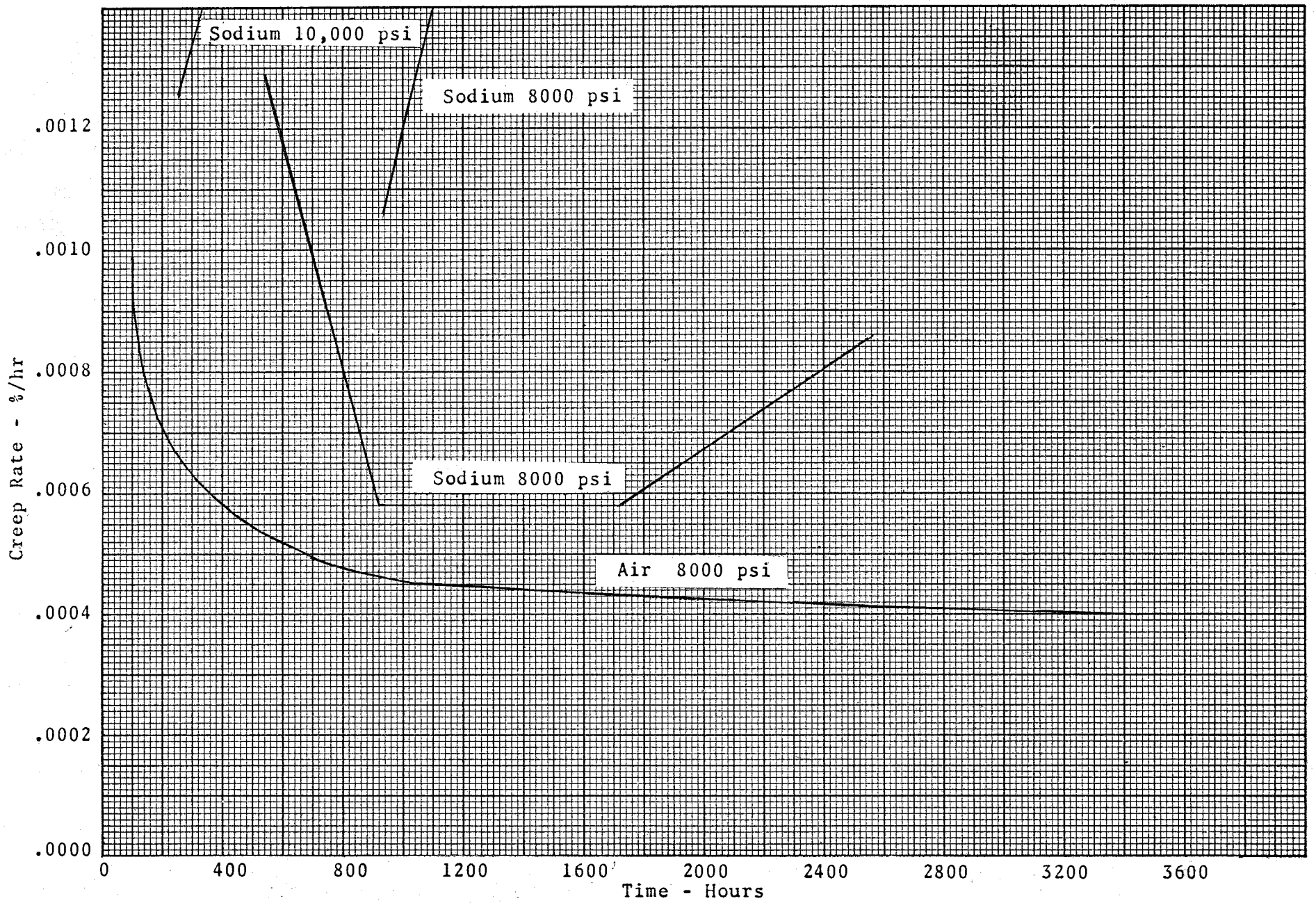


FIG. 20 - CREEP RATES OF 2 1/4 Cr-1 Mo CARBON STEEL

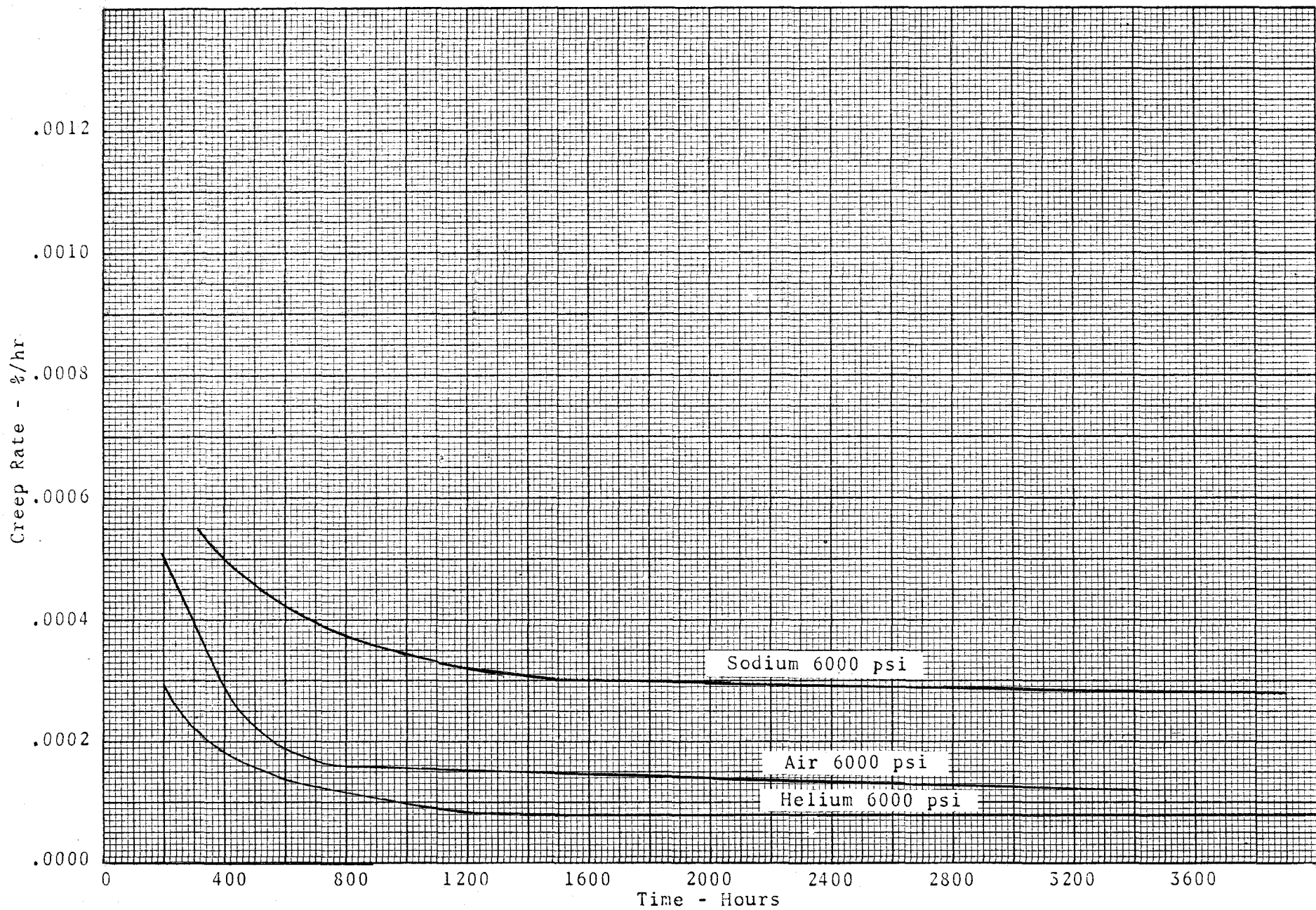


FIG. 21 - CREEP RATES OF 2 1/4 Cr-1 Mo CARBON STEEL

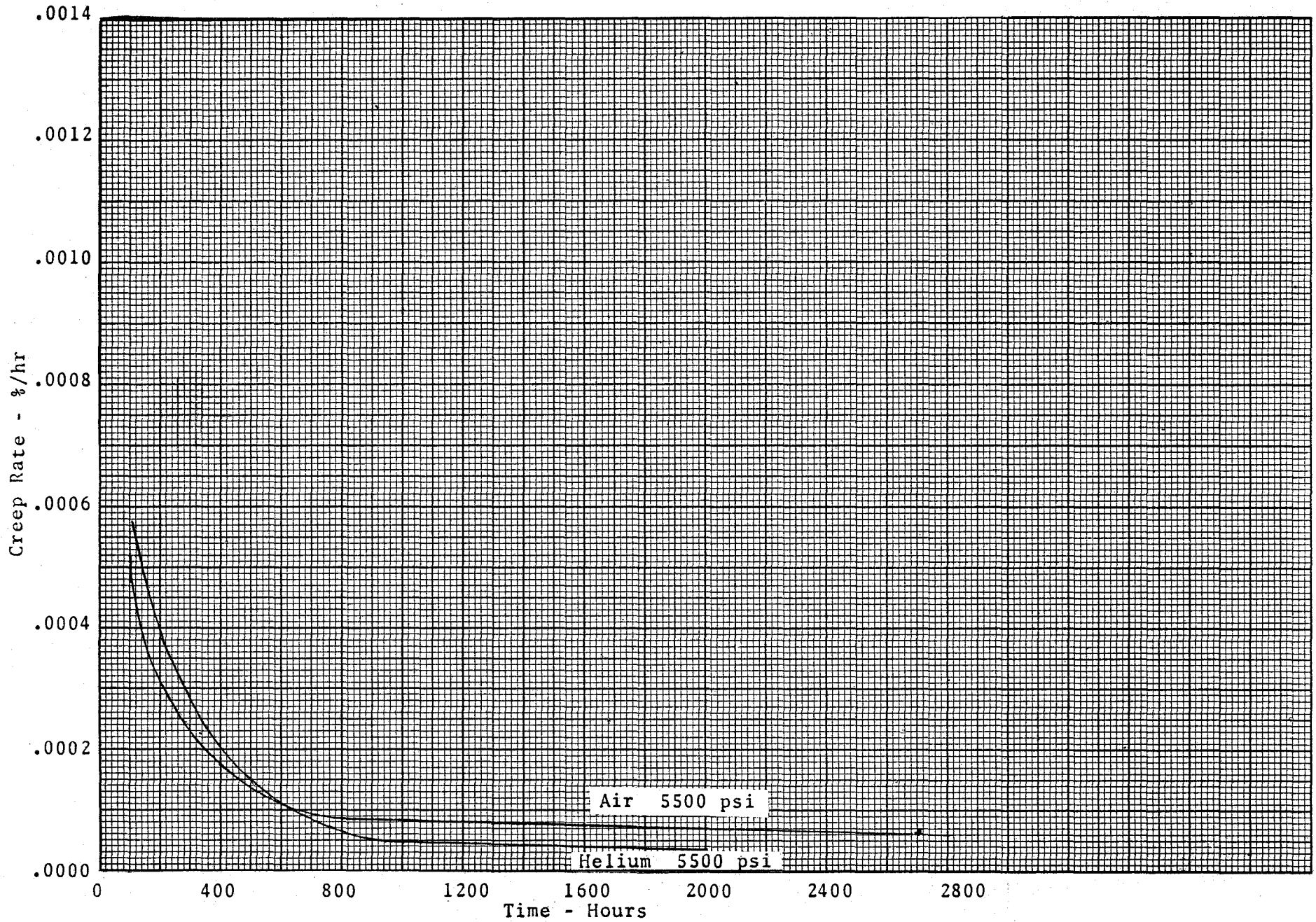


FIG. 22 - CREEP RATES OF 2 1/4 Cr-1 Mo CARBON STEEL

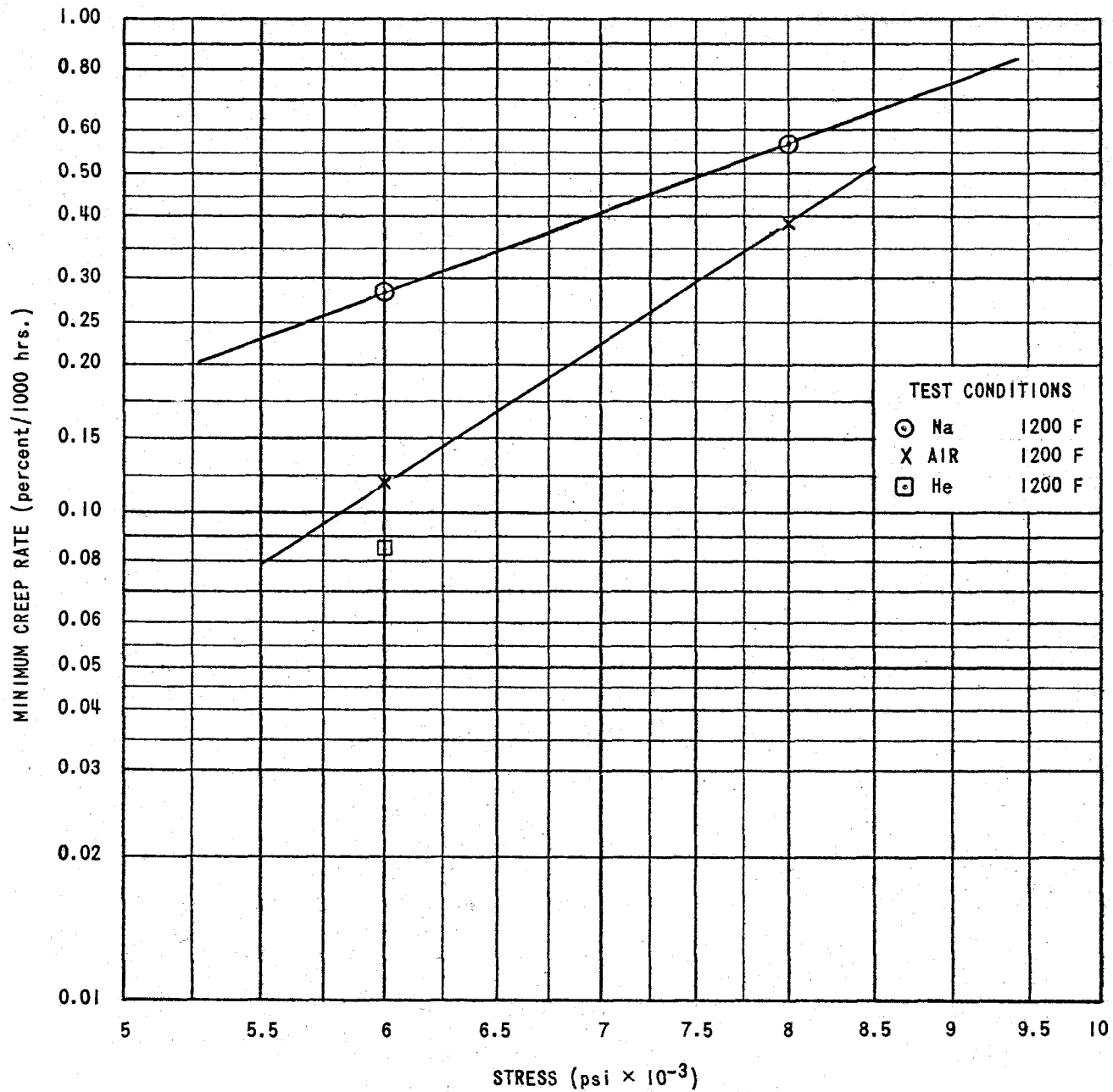


FIG. 23 - CREEP RATE VS STRESS, 2 1/4 Cr-1 Mo CARBON STEEL SPECIMENS

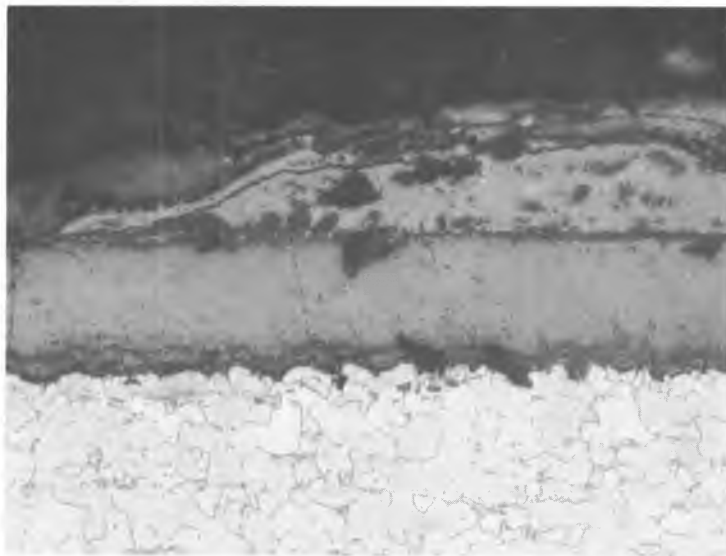


FIG 24 - 2 1/4 Cr-1 Mo #2AAX2
Creep in 1100°F Air

Stress = 6,000 psi
Test Duration = 4010 hrs
Longitudinal section

Elongation = 1.07%
266X-Nital etch



FIG 25 - 2 1/4 Cr-1 Mo #2ALX4
Creep in 1100°F Sodium

Stress = 8,000 psi
Test Duration = 2587 hrs
Longitudinal section

Elongation = 1.3%
266X-Nital etch

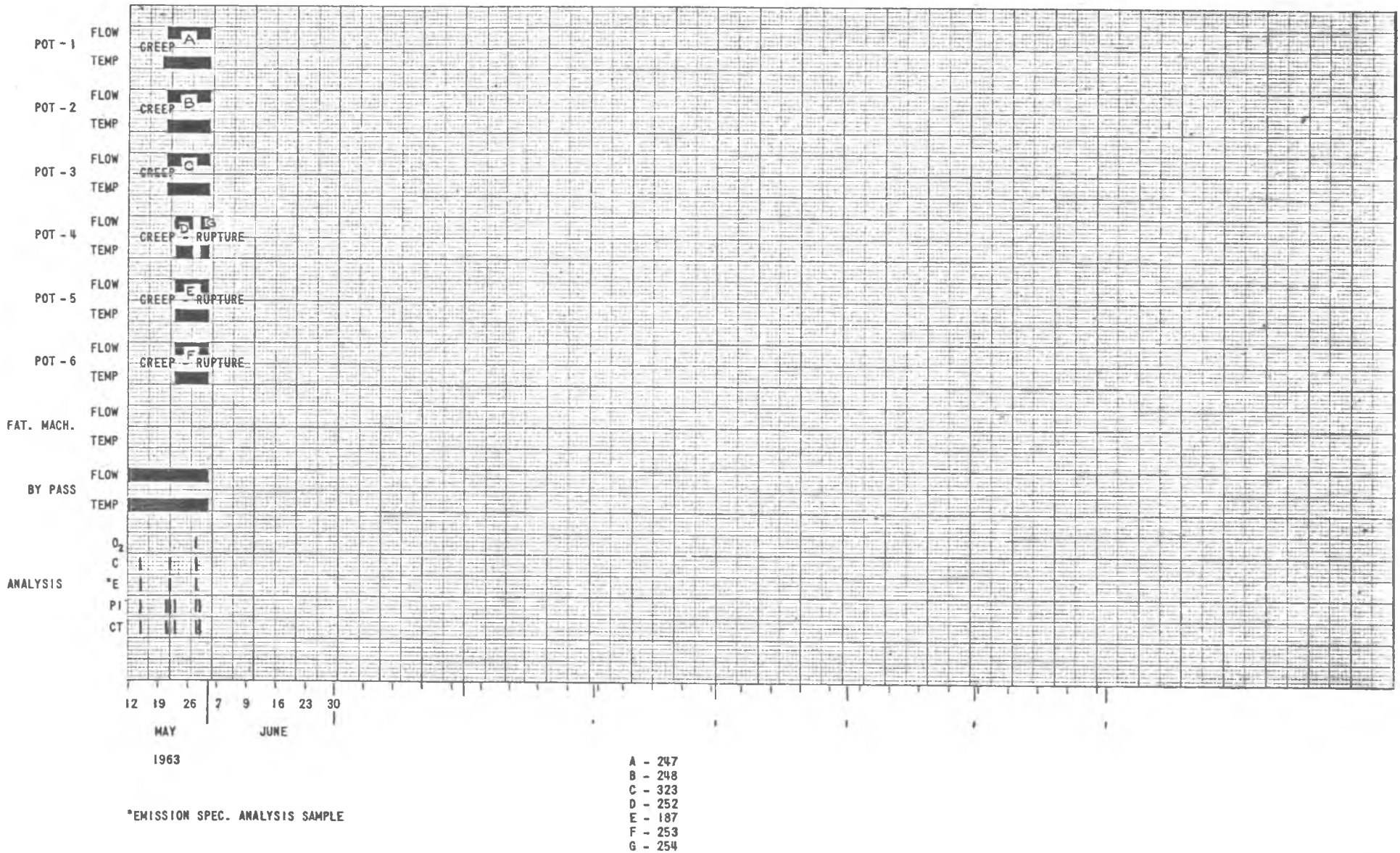


FIG. 26 - OPERATIONAL HISTORY OF LOOP 2 TEST 4 (Cr-Mo Test Specimens)