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INTERMITTENT CREEP AND STABILITY OF MATERIALS FOR SST APPLICATIONS

Oscar N. Thompson and Richard L. Jones

General Dynamics Corporation
Fort Worth Division

TECHNICAL REPORT AFML-TR-66-407

January 1967

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NOTICES

The information contained herein is in support of a national undertaking sponsored by the Federal Aviation Agency with administrative and technical support provided by the Department of Defense, Aeronautical Systems Division, Air Force Systems Command with contributing basic research and technical support provided by the National Aeronautics and Space Administration.

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INTERMITTENT CREEP AND STABILITY OF MATERIALS FOR SST APPLICATIONS

Oscar N. Thompson and Richard L. Jones

FOREWORD

This report was prepared by personnel of the Structural Loads, Dynamics and Materials section of Aerospace Technology and the Metallurgical section of the Engineering Test Laboratory of General Dynamics Corporation, Fort Worth Division. The work was conducted under Air Force Contract No. AF33(657)-11687 as an extension of Contract No. AF33(657)-8907. The work was initiated under Project No. 7381, "Materials Application," Task No. 738106 "Materials Information Development." All work was administered under the direction of Mr. Clayton L. Harmsworth, Air Force Materials Laboratory, Research and Technology Division Project Engineer.

This report covers the work performed under Contract No. AF33(657)-11687 from its starting date of 1 July 1963 to its completion data of 31 December 1966. This report repeats some of the descriptive information and all of the test data and results gathered under the initial Contract No. AF33(657)-8907 and previously published as Technical Report AFML-TDR-64-138.

The authors would like to acknowledge the assistance of Chief Metallurgist F. C. Nordquist throughout the duration of the program and Engineering Metallurgist Ray J. Schiltz, Jr., for his assistance in reading creep.

This technical report has been reviewed and approved.

D. A. Shinn
Chief, Materials Information
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ABSTRACT

This report covers an investigation of the creep rate and metallurgical stability of candidate materials for a supersonic transport airplane when exposed to heat alone and to creep loading at temperatures of 550° or 650°F. Specimens were exposed to intermittent heating and to creep loading for times of 1000, 5000, 10,000 and 30,000 hours and, also, to steady heating and to creep loading for 30,000 hours. The materials tested were Ti-8Al-1Mo-1V (duplex annealed) and Ti-6Al-4V (mill annealed) titanium alloys, René 41 (20% cold rolled + 16 hours at 1400°F) superalloy, and AM-350 SCT (825) and PH 14-8 Mo (SRH 1050) stainless steels. The 30,000 hour creep stress level for the two titaniums and René 41 was 40,000 psi, whereas, 67,000 psi was used for the 30,000 hour creep stress level of the two stainless steels. The creep stress levels for the 1000 hours exposures were set below the yield stress of each material at the exposure temperature and intermediate stress levels were used for the 5,000 and 10,000 hour creep loadings to give a range of creep rates. The influence of each of these conditions on the tensile, fracture toughness, and metallurgical properties of materials was determined. Plastic deformation due to creep was measured throughout the duration of the exposure.

The results indicated that all five materials would be satisfactory for use at 550°F for 30,000 hours at the 30,000 hour creep test stress levels. The creep behavior of Ti-6Al-4V titanium makes it undesirable for long time use at 650°F. Also, the AM-350 SCT (825) stainless steel is embrittled by long time exposure to 650°F. The PH 14-8 Mo stainless steel was not tested at 650°F. The exposure to creep loading at 650°F did not reveal any characteristics of the René 41 superalloy or the Ti-8Al-1Mo-1V titanium that would make these alloys undesirable for use in a supersonic transport airplane.

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SECTION I

INTRODUCTION

Two factors are of concern when materials are to be used at the operating temperature and for the long life expectancy of a supersonic transport airplane. They are the amount of creep strain accumulated and the influence of the exposure on the mechanical properties of the materials. Current life expectancy of a supersonic transport airplane is in excess of 30,000 hours of flight time with skin temperatures reaching the 550° to 650°F range during cruise conditions. To further complicate the exposure, the heating and loading is intermittent following the ground-air-ground flight cycle of the airplane.

This testing program was planned to resolve these questions with regard to five candidate materials for a supersonic transport (SST) airplane. The specific questions were:

1. How much does the material creep?

2. Is the creep rate the same for intermittent heating and loading as for steady heating and loading?

3. What changes, if any, are produced in the mechanical properties of the materials as a result of heating and loading?

4. Is it the heating or the loading or both that causes the changes?

The five materials tested were:

1. Ti-8Al-1Mo-1V (duplex annealed) titanium alloy

2. Ti-6Al-4V (mill annealed) titanium alloy

3. AM-350 SCT (825) stainless steel

4. PH 14-8 Mo (SRH 1050) stainless steel

5. Rene' 41 (20% cold worked + 16 hours at 1400°F) superalloy.

The test was started with PH 15-7 Mo (RH 1100) stainless steel as one of the five materials but after approximately 4000 hours of creep loading the PH 15-7 Mo steel was replaced with the newer PH 14-8 Mo (SRH 1050) steel because its increased toughness made it more desirable for SST applications.

Initially, creep was of primary concern for a SST airplane. As the test progressed, other sources of data became available indicating that the magnitude of creep strain accumulated over 30,000 hours at cruise flight conditions would not be a problem with any of the candidate materials. However, the metallurgical stability of the candidate materials after 30,000 hours of exposure remained unknown and became the prime concern for this program.

SECTION II

SUMMARY

A testing program was initiated in July 1962 to determine the magnitude of creep strain accumulated on specimens of five SST candidate materials after times of 1000, 5000, 10,000 and 30,000 hours of exposure to stress at temperatures of 550° and 650°F. The creep exposure was applied intermittently by cyclicly heating the specimens to temperature in 10 minutes, applying the load and holding the load and temperature constant for 2.5 hours followed by a release of the load and then cooling the specimens to approximately room temperature in 20 minutes. Also, creep was measured during 30,000 hours of steady exposure to heat and stress to determine if there was any difference between the creep rate due to intermittent exposure and the creep rate due to steady exposure. Following the creep exposure, the effects of creep on the tensile properties and fracture toughness of the materials was determined. Soon after the start of the program the scope was enlarged to include exposure of unstressed materials so that a comparison could be made between the influence of heat alone and heat plus stress on their mechanical properties.

During the program time span, creep rate data from other sources indicated that creep would not be excessive at 550°F, if any of the candidate materials was used for the construction of a supersonic transport, and the Ti-6Al-4V titanium was the only material, of the five being tested, that showed an excessive creep rate at 650°F. However, the tensile strength and fracture toughness stability after exposure was a growing concern with fracture toughness occupying the major importance.

The specimens used in the program were cut from .025 inch thick sheet with the length of the specimens laid out parallel to the longitudinal grain direction. The candidate materials were selected as skin materials for use in sheet form and the .025 inch thickness was expected to be in the range of gages used.

An overall summary of the results is shown in bar graph form in Figures 1 through 5. Figure 1 shows the ratio of ultimate strength divided by density for all of the materials tested after each exposure condition. There are some small changes existing between ultimate strength of each alloy after various exposures. There are only slight trends and it is believed the differences measured are within experimental scatter.

Figure 2 shows the ratio of tensile yield strength to density. The only definite trend is a slight increase in tension yield of the AM-350 SCT (825) stainless steel after exposure to 650°F. Figure 3 compares the percent elongation of the materials after various exposures. The exposure to 650°F appears to increase the percent elongation of the AM-350 SCT (825) steel. The other materials show erratic behavior with no definite trends. The maximum variation of percent elongation with exposure time, for any one material including AM 350 steel, is within 5 percent which could be attributed to experimental scatter.

The specimen size used for fracture toughness testing was within the ASTM recommended standard specimen proportions at the time the program was formulated. It has since been established that the thin gage used will show an upper limit of toughness rather than a toughness value that is a constant for the material. However, the aim in this program was to determine if changes in toughness resulted from the creep or heat exposure. For this purpose the residual gross fracture stress measured using a constant specimen size offers the best basis for comparison. Figure 4 compares the residual gross fracture stress divided by density of all of the materials tested at room temperature using center notched, fatigue cracked, specimens. Again, no significant change with respect to exposure was found. However, Figure 5 shows the residual gross fracture stress divided by density when the same materials with the same exposure conditions and specimen configuration were tested at -65°F. The AM-350 SCT (825) stainless steel shows a very definite embrittlement after 30,000 hours exposure to heat alone and after 10,000 hours to creep loading at 650°F. The creep loaded specimens showed the most embrittlement.

Throughout the testing no significant differences were observed between results obtained after steady creep loading compared to results obtained after intermittent creep loading on an equal exposure time basis. It should be noted that the intermittently exposed specimens were under heat and load for 5/6 of the test time.

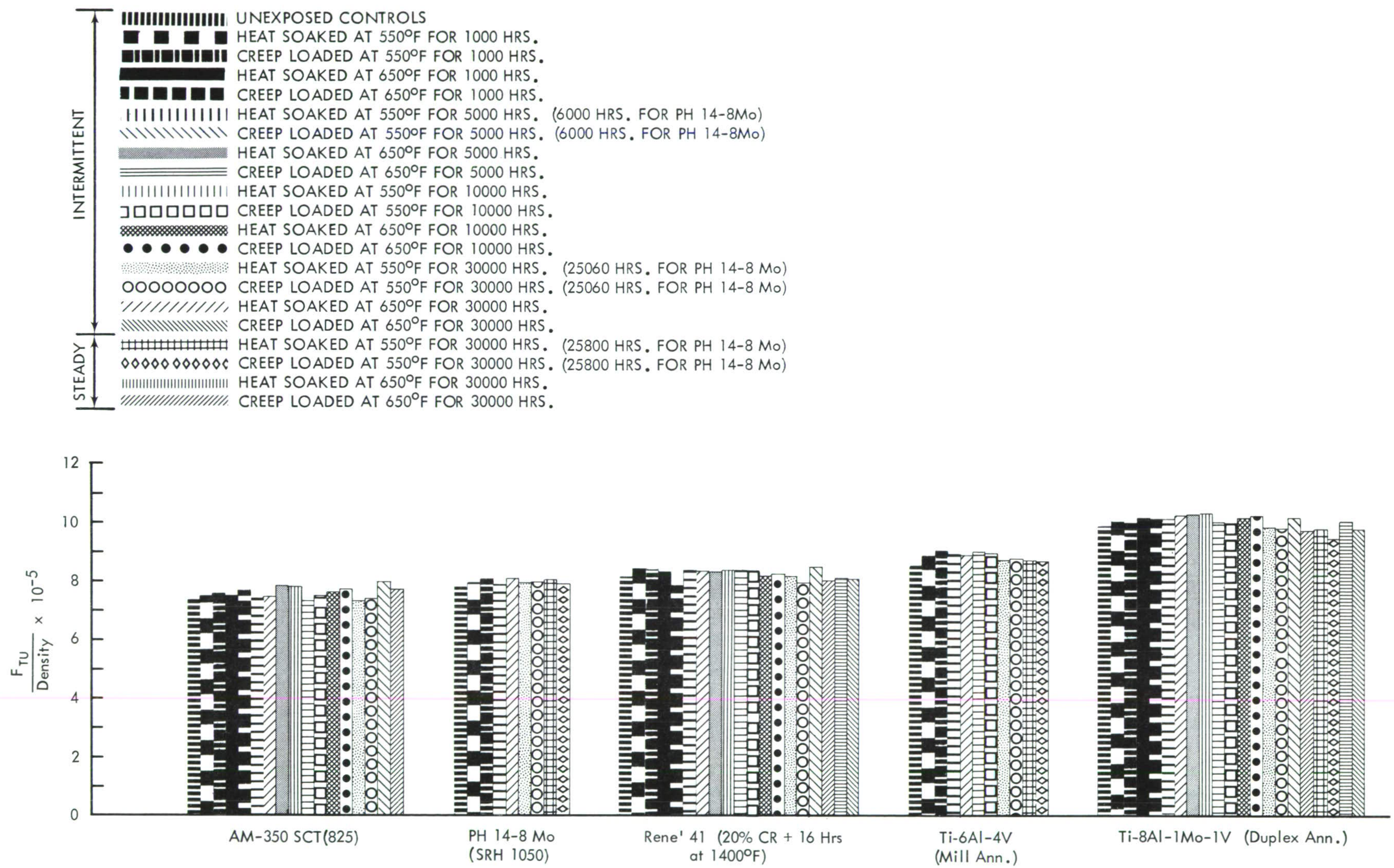


Figure 1 COMPARISON OF F_{TU}/DENSITY OF UNNOTCHED SPECIMENS TESTED AT ROOM TEMPERATURE AFTER VARIOUS EXPOSURE TO INTERMITTENT HEAT OR CREEP

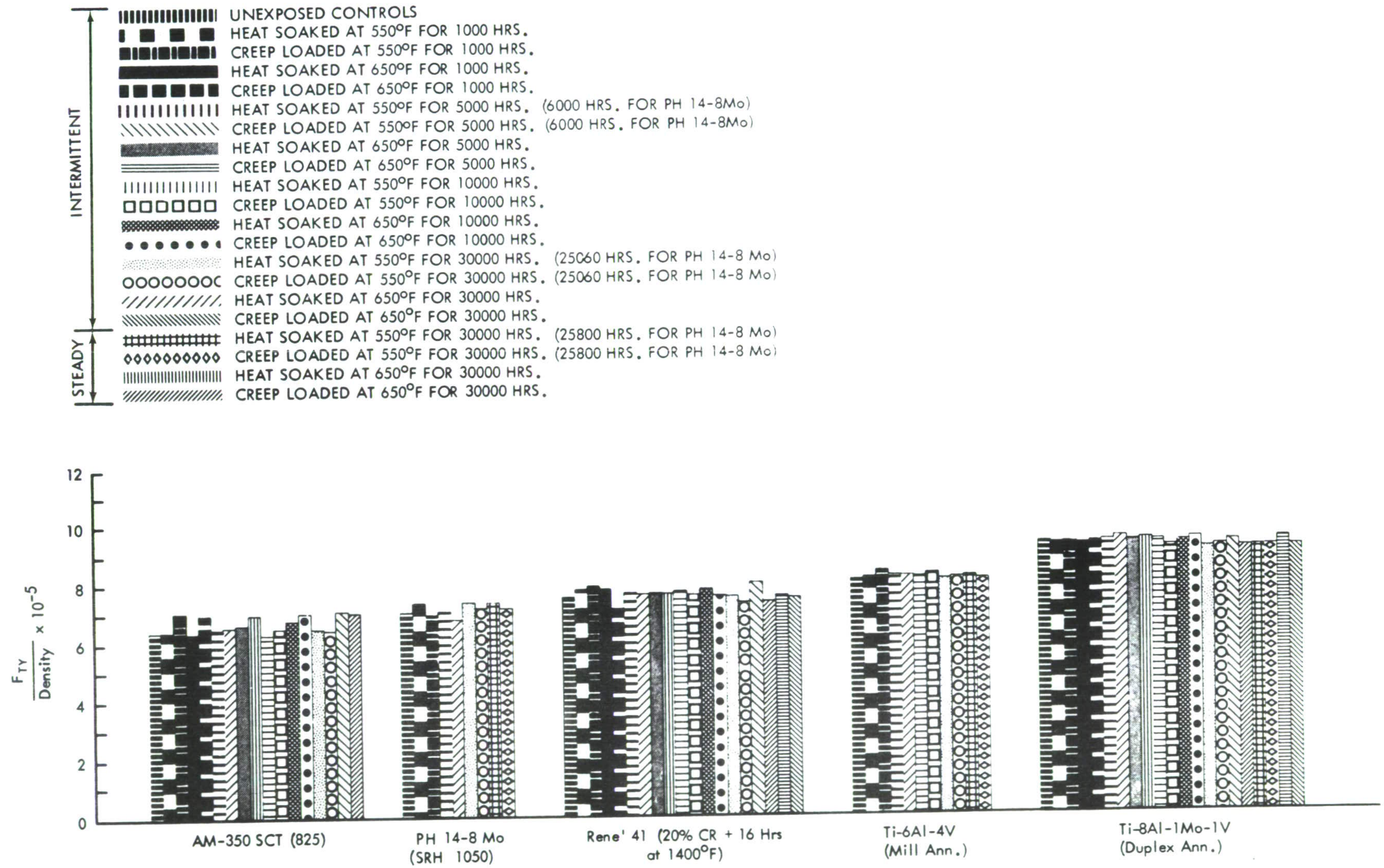


Figure 2 COMPARISON OF F_{TY}/DENSITY OF UNNOTCHED SPECIMENS TESTED AT ROOM TEMPERATURE AFTER VARIOUS EXPOSURES TO INTERMITTENT HEAT OR CREEP

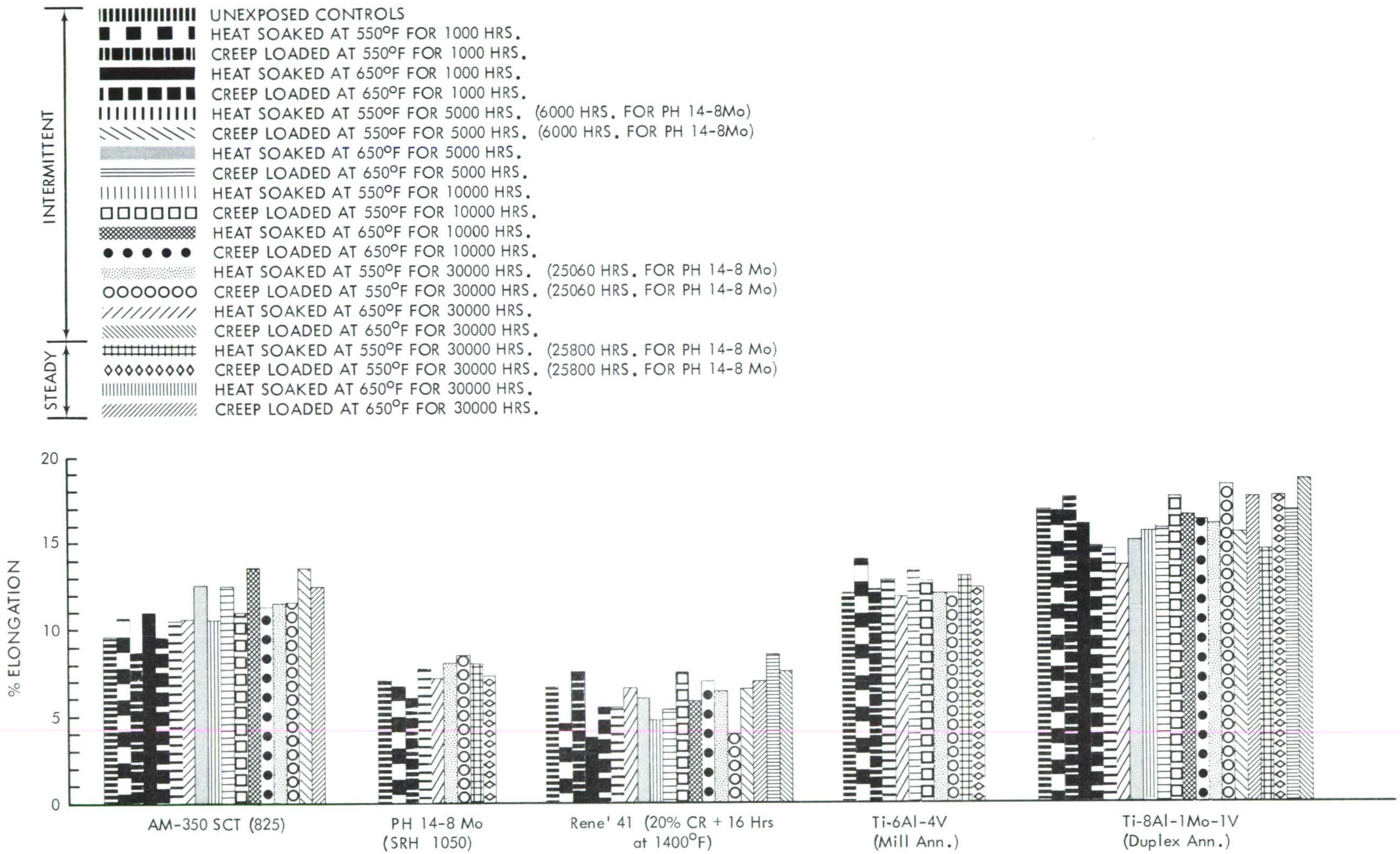


Figure 3 COMPARISON OF PERCENT ELONGATION OF UNNOTCHED SPECIMENS TESTED AT ROOM TEMPERATURE AFTER VARIOUS EXPOSURES TO INTERMITTENT HEAT OR CREEP LOADING

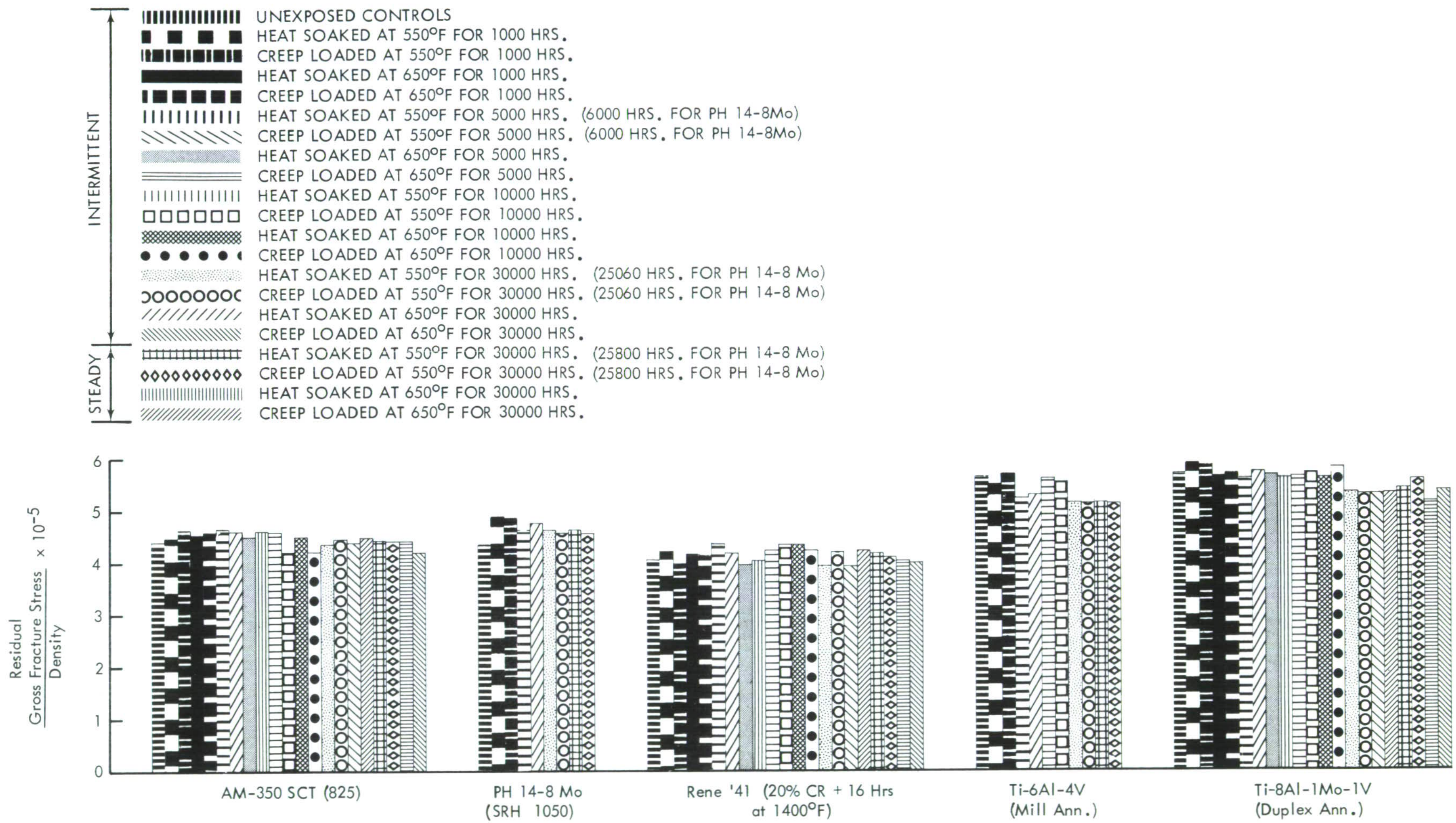


Figure 4 COMPARISON OF GROSS FRACTURE STRESS OF FATIGUE CRACKED NOTCHED SPECIMENS TESTED AT ROOM TEMPERATURE AFTER VARIOUS EXPOSURES TO HEAT OR CREEP LOADING

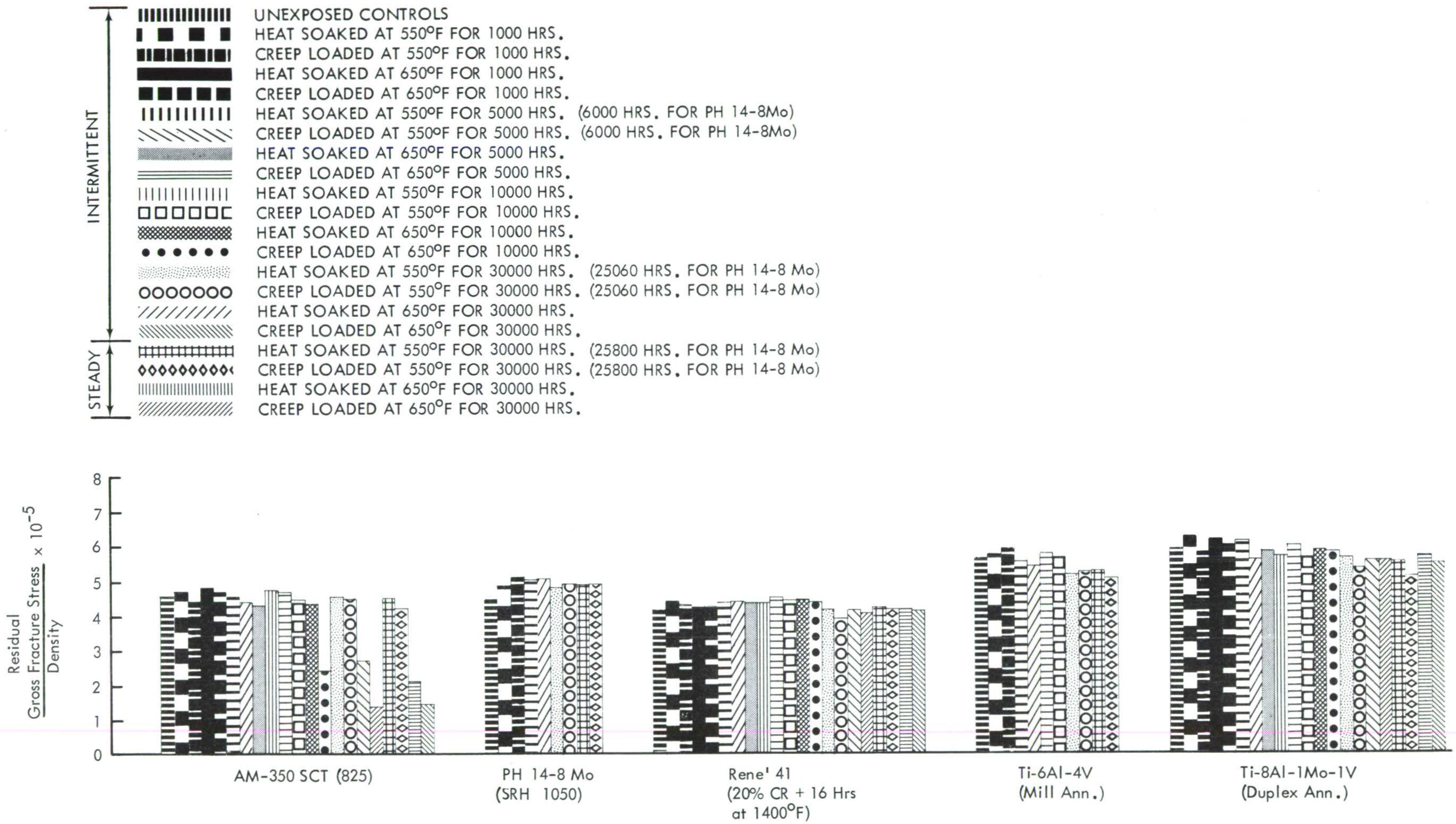


Figure 5 COMPARISON OF GROSS FRACTURE STRESS OF FATIGUE CRACKED NOTCHED SPECIMENS TESTED AT -65°F AFTER VARIOUS EXPOSURES TO HEAT OR CREEP LOADING

SECTION III

TEST REQUIREMENTS

Test Conditions

The program consisted of four parts:

1. Evaluation of the materials prior to creep straining
2. Measurement of creep during, and evaluation of the materials after 1000, 5000, 10,000 and 30,000 hours of intermittent creep testing
3. Measurement of creep during, and evaluation of the materials after 30,000 hours of steady creep
4. Evaluation of the materials after 1000, 5000, 10,000 and 30,000 hours of heating without loading.

Creep Stress Levels

In order that a range of creep rates be measured, a creep stress level slightly below tension yield of the material at temperature was used for the 1000 hour exposure of each material. Lesser stresses were used for the 5000 and 10,000 hour exposures and a stress level expected to be used for design at cruise flight condition was used for the 30,000 hour exposure. These stress levels are shown for the five materials in Table I.

Evaluation of Material

Unexposed control specimens, specimens exposed to heat alone and specimens exposed to creep loading were tested to determine any change in tensile properties or fracture toughness resulting from the exposure. Also, an examination was made by means of the optical and electron microscopes to determine if any metallurgical changes to the microstructure could be found.

Table 1 STRESS LEVELS FOR CREEP LOADING IN PSI

	CREEP TIME SPAN (HOURS)							
MATERIAL	1000		5000		10,000		30,000	
Temp (^{o}F)	550°	650°	550°	650°	550°	650°	550°	650°
Titanium 8Al-1Mo-1V	94,000	88,600	80,000	80,000	60,000	60,000	40,000	40,000
Titanium 6Al-4V	85,000		71,500		60,000		40,000	
AM-350 SCT (825)	120,000	118,000	103,000	101,000	85,000	85,000	67,000	67,000
PH 14-8 Mo (SRH 1050)	120,000		103,000		85,000		67,000	
Rene' 41 (20%) Cold Worked +1400^{o}F for 16 Hours)	138,500	124,000	110,000	100,000	70,000	70,000	40,000	40,000

Number of Specimens per Creep Condition

To evaluate the tensile properties and the fracture toughness after each exposure condition, different types of specimens were exposed. The number of specimens of each type exposed to creep is shown in Table II. Strips of material sufficient to make exactly the same number of specimens as exposed to creep were hung in the ovens for exposure to heat without load.

Intermittent Creep Cycle

A comparison between the influence of creep applied during steady state heating and loading with the influence of creep applied intermittently was a primary aim of this testing program. The intermittent creep would represent the exposure of a supersonic transport airplane to heat and stress during the ground-air-ground flight cycle. The intermittent creep test cycle used consisted of 10 minutes to heat the unloaded specimens to test temperature, load the specimens and hold under steady heat and stress for 2.5 hours, and then remove the load and drop the temperature to approximately room temperature in 20 minutes. A typical heating cycle as recorded by a Brown recorder is shown in Figure 6.

Table II SPECIMENS PER CREEP CONDITION

	EXPOSURE HOURS	STEADY CREEP TESTS: Tensile Test		STEADY CREEP TESTS: Fracture Toughness		INTERMITTENT CREEP: Tensile Test		INTERMITTENT CREEP: Fracture Toughness	
	CREEP TEMP. (°F)	550°	650°	550°	650°	550°	650°	550°	650°
Ti-8Al-1Mo-1V	1000					5	5	5	5
	5000					5	5	5	5
	10,000					5	5	5	5
	30,000	5	5	5	5	5	5	5	5
Ti-6Al-4V	1000					5		5	
	5000					5		5	
	10,000					5		5	
	30,000	5		5		5		5	
AM-350 SCT	1000					5	5	5	5
	5000					5	5	5	5
	10,000					5	5	5	5
	30,000			5	5	5	5	5	5
PH 14-8 Mo	1000					5		5	
	5000					5		5	
	10,000					5		5	
	30,000	5		5		5		5	
Rene 41	1000					5	5	5	5
	5000					5	5	5	5
	10,000					5	5	5	5
	30,000		5	5	5	5	5	5	5
TOTAL		15	10	25	15	100	60	100	60

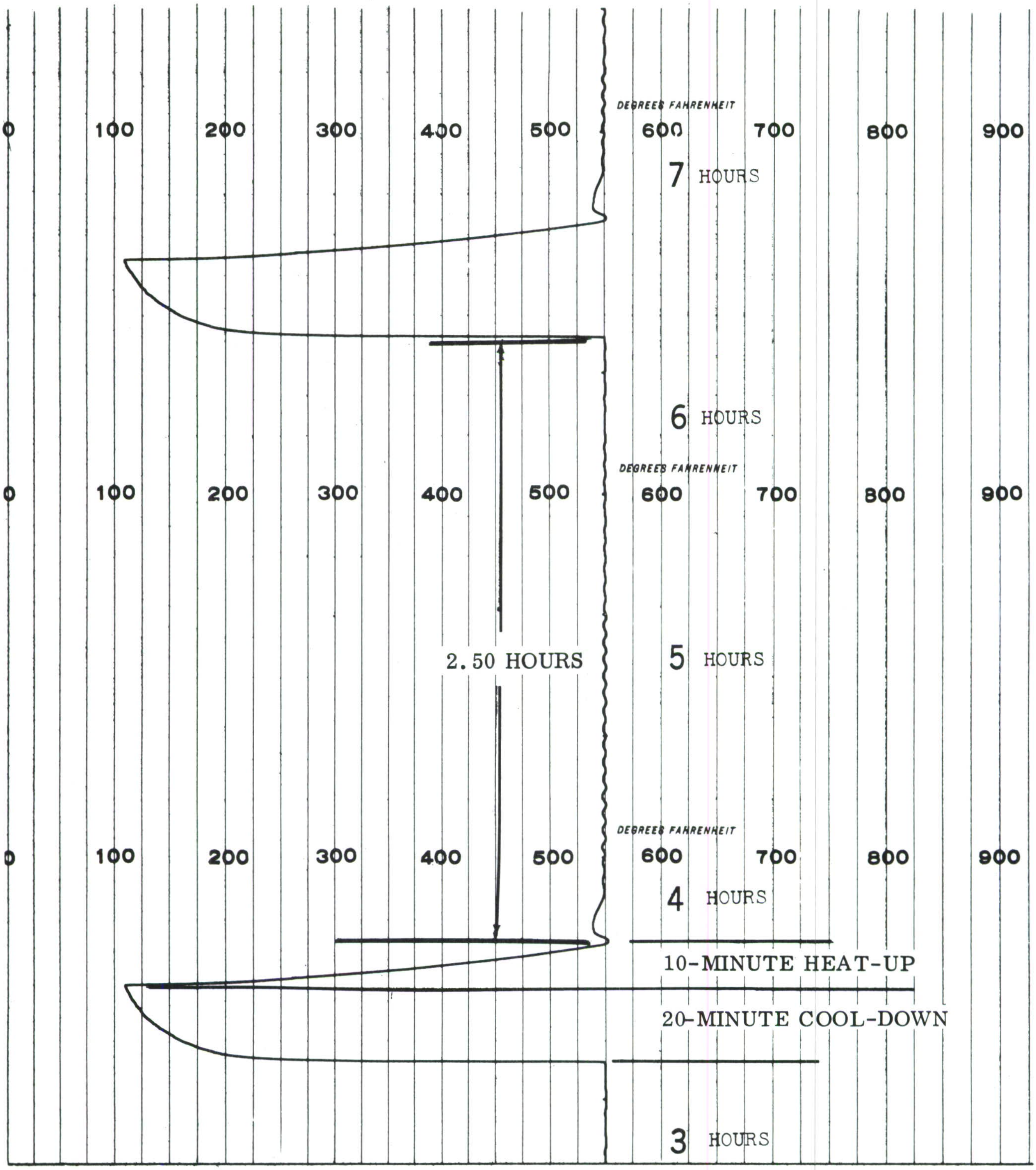


Figure 6 CHART OF OVEN TEMPERATURE DURING A 550°F INTERMITTENT HEATING AND COOLING CYCLE

SECTION IV

TEST SPECIMENS

Specimen Materials

All materials for this program were procured under their trade name to vendor specifications. Each of the materials is typical of a production run with no special requirements added. The materials purchased, the vendors, and the heat numbers are shown below:

AM-350 Condition H from Allegheny-Ludlum, heat number 89324

PH 14-8 Mo (SRH 1050) from Armco, heat number 31562

Rene 41 (20% cold rolled) from Cannon Muskegon, heat number V-2146

Ti-8Al-1Mo-1V (duplex annealed) from TMCA, heat number D-1237

Ti-6Al-4V (mill annealed) from TMCA, heat number M7858. This material was supplied to the Fort Worth Division of General Dynamics for this program by courtesy of Bureau of Naval Weapons from the sheet rolling program stock.

The AM-350 stainless steel was transformed from Condition H to Condition SCT (825) at the Fort Worth Division by following Allegheny-Ludlum's published heat treat procedure. The René 41 was given a 1400°F soak for 16 hours to bring it to its final condition. All other alloys were tested as received.

Specimen Configuration

All specimens were cut from 0.025-inch (nominal) thick sheet stock with the length of the specimens parallel to the longitudinal grain direction.

All of the creep specimens used for tensile properties evaluation after creep had a conventional tensile test configuration as shown in Figure 7. Each set of five specimens was machined in a continuous sequence as shown in Figure 8. The holes were drilled and the side contours were cut on the "Fosdamatic" tape-controlled jig bore during one setup. This jig bore has a tolerance of less than 0.001 inch; therefore, the centerline through the loading pin holes should correspond to the centerline of the gage length to a high degree of accuracy.

The fracture toughness test specimens were proportioned to agree with the 1960 recommendations of the ASTM Committee on Fracture Testing of High-Strength Sheet Materials (Ref. 1). These recommendations were current when this program was planned. A view of the specimen is shown in Figure 9. The material exposed to creep, for fracture toughness evaluation, was loaded in the ovens in 1-inch-wide strips as shown in Figure 10. Results in preliminary tests indicated that if the center notches were added prior to creep exposure the specimens would fail in fatigue because of the intermittent loading and unloading cycle.

Following creep exposure, the loading pin holes were drilled along the centerline of the strips on the "Fosdamatic" jig bore and then the strips were cut into 4-inch specimen lengths.

The center notch was formed by first cutting a slot 0.005 inch wide by 1/4-inch long with the "Elox" electric discharge erosion process. Care was taken to assure symmetry of the notch, with respect to the centerline through the loading pin holes, by locating the specimen on a holding fixture by pins through the loading holes. The "Elox" electrode was passed through the specimen. The specimen was then relocated on the holding fixture by rotating it about the centerline through the loading pin holes and the electrode was again passed through the specimen. Any eccentricity of the electrode with respect to the centerline through the loading pin holes was offset by the double machining. After the "Elox" notch was formed, the crack was extended to a nominal 3/8-inch length by tension-tension fatigue cracking using a minimum/maximum stress ratio of +0.5. The maximum stress used for each of the materials is shown below:

AM-350 SCT - 54,000 psi

PH 14-8 Mo - 50,900 psi

René 41 - 67,800 psi

Ti-8Al-1Mo-1V - 43,500 psi

Ti-6Al-4V - 39,000 psi.

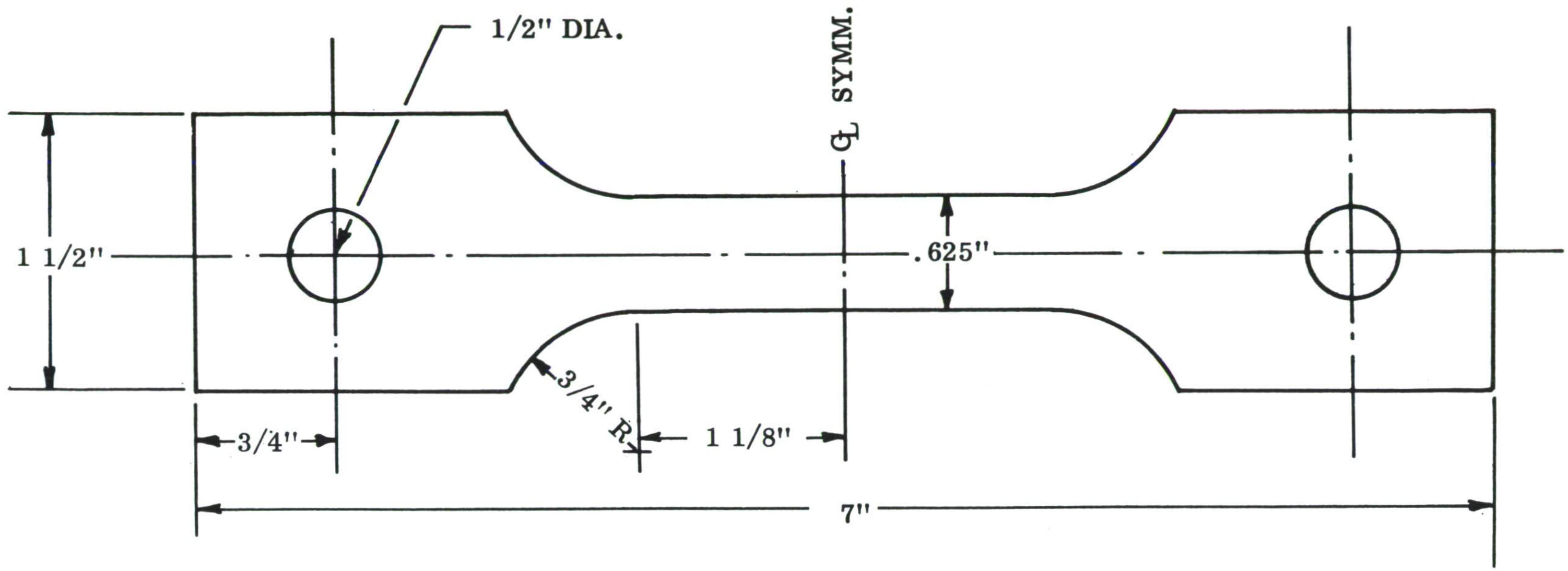


Figure 7 CREEP SPECIMEN FOR TENSILE PROPERTIES TEST AFTER CREEP LOADING

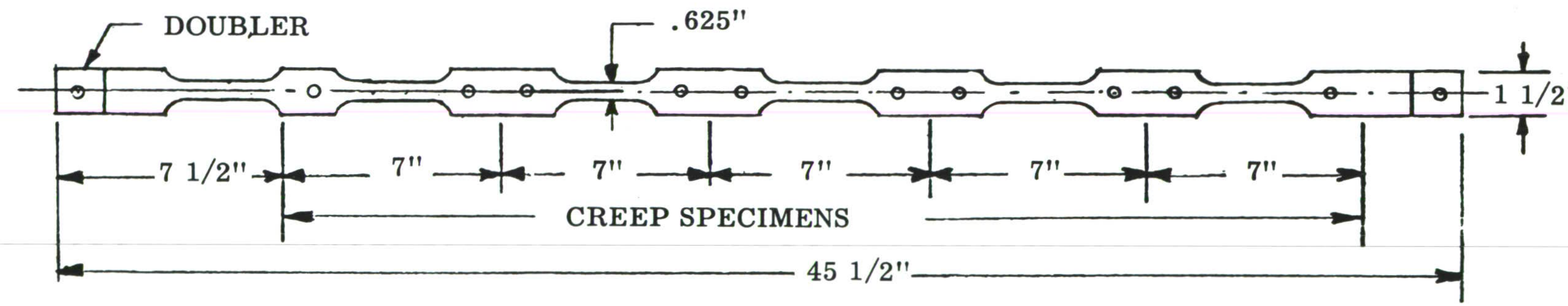


Figure 8 TANDEM CREEP SPECIMENS FOR MEASURING CREEP STRAIN DURING, AND TENSILE PROPERTIES AFTER, CREEP EXPOSURE

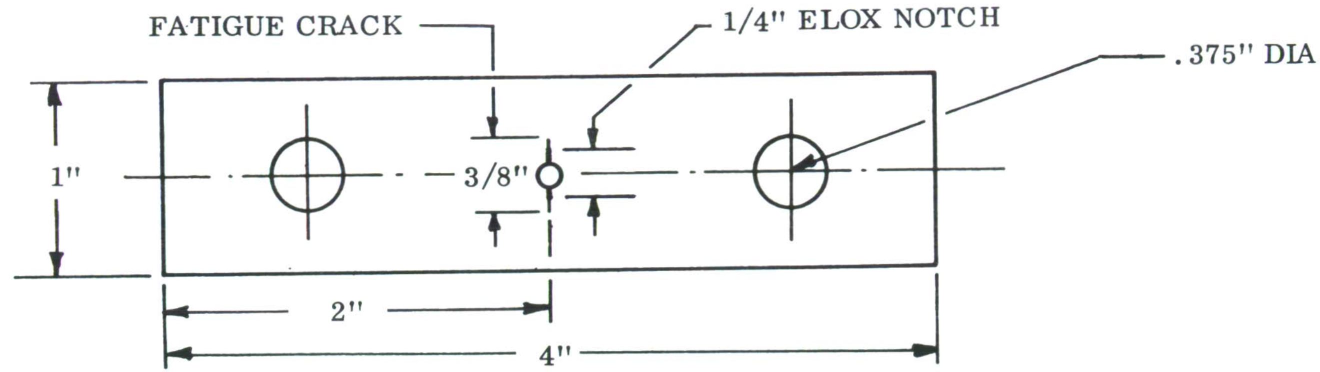


Figure 9 CREEP SPECIMEN FOR FRACTURE TOUGHNESS TESTING AFTER CREEP LOADING (SPECIMEN NOTCHED AFTER CREEPING)

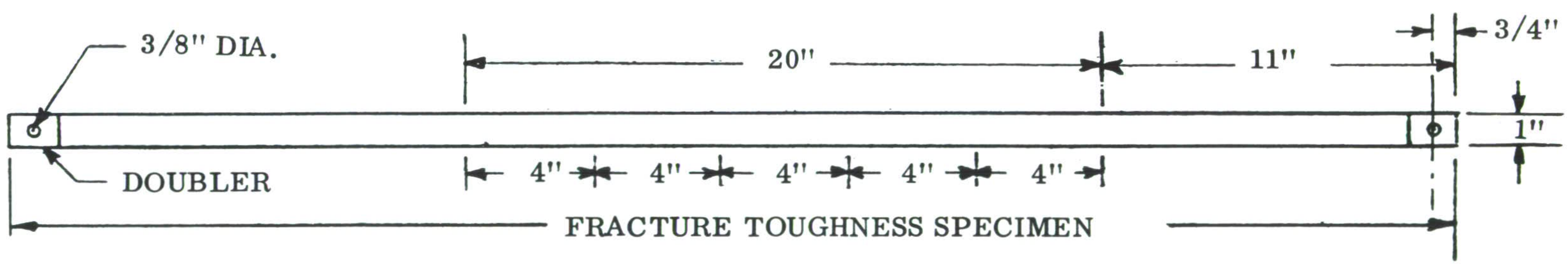


Figure 10 TANDEM CREEP SPECIMENS FOR MEASURING FRACTURE TOUGHNESS AFTER CREEP EXPOSURE

These stresses and the stress ratio were selected to propagate the crack the desired amount in 15 to 20 minutes. By trial and error it was found that the crack length could be controlled under these conditions.

After fatigue cracking, the specimens were again placed in the holding fixture on the "Elox" machine and a center hole was added for attaching the compliance gage. A 3/16-inch diameter hole was used for the control specimens, but this was changed to 1/8-inch diameter for the remainder of the specimens.

The material used for heat-soaked specimens was hung in the ovens in 1-1/2-inch-wide strips. After heat exposure this material was machined into tensile specimens and fracture toughness specimens using the same technique as that used to machine the specimens exposed to creep.

SECTION V

CREEP TESTING

Ovens

To creep load the large number of specimens for such long time spans required a maximum utilization of the creep machines. This was accomplished by building special ovens and adapting them to existing Arcweld Model C creep machines. The ovens were heated by circulating hot air heated in a heater box by electrical resistance heating elements. The hot air was drawn from the heater box by a blower through a connecting duct and discharged at the bottom of the oven. The air moved upward and was returned to the heater box through a duct connecting the top of the oven with the heater box. The length and cross section of the ovens were proportioned to accommodate four tanden sets of five specimens. Automatically controlled flapper valves in the oven air inlet and exhaust ducts isolated the heater boxes from the ovens and allowed room temperature air to circulate through the ovens during the cool-down portion of the cycle of intermittent heating and loading. The temperature during the heating portion of the cycle was sensed by a thermocouple mounted in contact with a specimen in the center of the oven and controlled by a Brown "Electronik" recorder controller. A timer and relay system provided the controls to make the heat-up, hold at temperature, cool-down cycle completely automatic. The steady creep loaded specimens were exposed in similar ovens except without flapper valves and automatic cycling controls.

A temperature survey of the ovens showed a variation of 20^{o} from the hottest specimen to the coolest specimen. By adding deflector vanes and channeling air from hot spots to cooler regions the maximum variation between hottest and coolest specimens was reduced to 5^{o}F.

Load Divider

Four tanden sets of specimens were loaded by each creep machine. To develop the desired stress in the specimens, the single deadweight load applied by the creep machine was distributed to each set of specimens by a whiffletree load divider. The bottom of the specimens were anchored to the creep machine by pin-ended links.

A complete description of the oven construction, temperature controls and load dividers can be found in Reference 2.

Creep Measurements

Creep strain measurements were made on the specimens used for tensile testing after creep exposure. This required measurements to be made on 10 specimens in each oven. It was considered desirable to measure creep without attaching anything to the specimens. The method selected was to indent each specimen with a pair of marks giving a 2-inch gage length. The marks were made by a Tukon micro-hardness machine with a 500-gram-load indenter. Creep strains were then determined by comparing the distance between indentations with the distance between similar indentations in a standard block as read with a Gaertner Scientific Dual Creep Microscope. Creep measurements were made prior to exposure; when the exposure temperature was reached; immediately after loading and then after 1 hour, 6 hours, 24 hours, every 168 hours thereafter for the first 10,000 hours and once a month until 30,000 hours was accumulated.

The creep microscope was mounted on a movable stand with sufficient vertical adjustment to allow creep reading on all five specimens through windows in the front of the ovens while the chain of five specimens was mounted in an oven. A horizontal adjustment was built into the stand to allow ease in focusing the microscope on the specimens.

All measurements reported as creep in this report were made while the specimens were stabilized at the creep exposure temperature. The magnitude of creep reported for any time is the difference between the dual microscope reading at that time and the initial dual microscope reading at the beginning of the test (after the oven temperature had stabilized and load had been applied to the specimens). Only the time-dependent strain is reported as creep.

Some difficulties were experienced in using the dual creep microscope. Since creep measurements were made while the specimens were stabilized at the creep exposure temperature, measurements had to be made while air was blowing over the specimens. The airflow produced a slight flutter which made it difficult to focus on the gage marks. Another difficulty occurred in measuring creep on the bottom specimen of the series of five specimens. When the bottom specimen was read, the lower creep microscope barrel was in contact with or very near the insulation covering the plenum chamber at the bottom of the oven. The unequal heating produced an error in the instrument. It was, therefore, decided to omit measuring creep on the bottom specimen in each set. As time progressed, the specimens oxidized adding to the difficulty of reading creep through the windows in the ovens. The indentations are approximately .001 inch in width which is approximately the width of the crosshair in the microscope. If it is assumed that the error in aligning the top and bottom gage marks with the crosshairs in the dual instrument is one crosshair width, this would produce a possible error between individual reading in a two inch gage length of $\frac{.001}{2} \times 100 = .05\%$. Such tolerance would be acceptable for usual creep measurements of .5 to 2%, but it is a large error compared to the small amount of creep found for the candidate materials under the planned test conditions.

After two of the special ovens became available, a new creep test of Ti-6Al-4V and Ti-8Al-1Mo-1V titanium specimens was started under General Dynamics Corporate sponsored research and is reported here as related information. The purpose of the research was to develop a method for more accurately measuring creep as well as to gain additional creep data on the two titanium alloys. In this test, 30 inch gage length specimens as shown in Figure 11 were used. Each specimen had a strip of Ti-8Al-1Mo-1V titanium attached at one end by a single rivet as shown in Figure 12. The unloaded strip served as a reference for measuring the change in the specimen length. The strip had holes at zero, 7.5, 15, 22.5, and 30 inches spacing. Again the indenter of a Tukon microhardness tester was used to indent the specimen near the center of each hole and indent the strip at each side of the hole as shown in Figure 12. Before placing the specimen in the oven, a measurement was made of the difference between the mark on the specimen and the marks at the edge of hole on the reference strip for the initial zero, 7.5, 15, 22.5, and 30 inch lengths using one element of the dual creep microscope. The specimens were then exposed to intermittent creep for time intervals of one hour, increasing to time intervals of one month. At the end of each time interval the specimens were removed from the oven, clamped in a holding fixture to assure flatness of the strip, and again were measured to determine the difference in gage marks on the specimen with reference to the gage marks on the unloaded strip as shown in Figure 13.

With this system, the possibility of parallax error in the dual microscope readings is completely eliminated. Again assuming a reading error of .001-inch in 30 inches the error is only $\frac{.001}{30} \times 100 =$ .0033%. An error of this magnitude can be considered negligible.

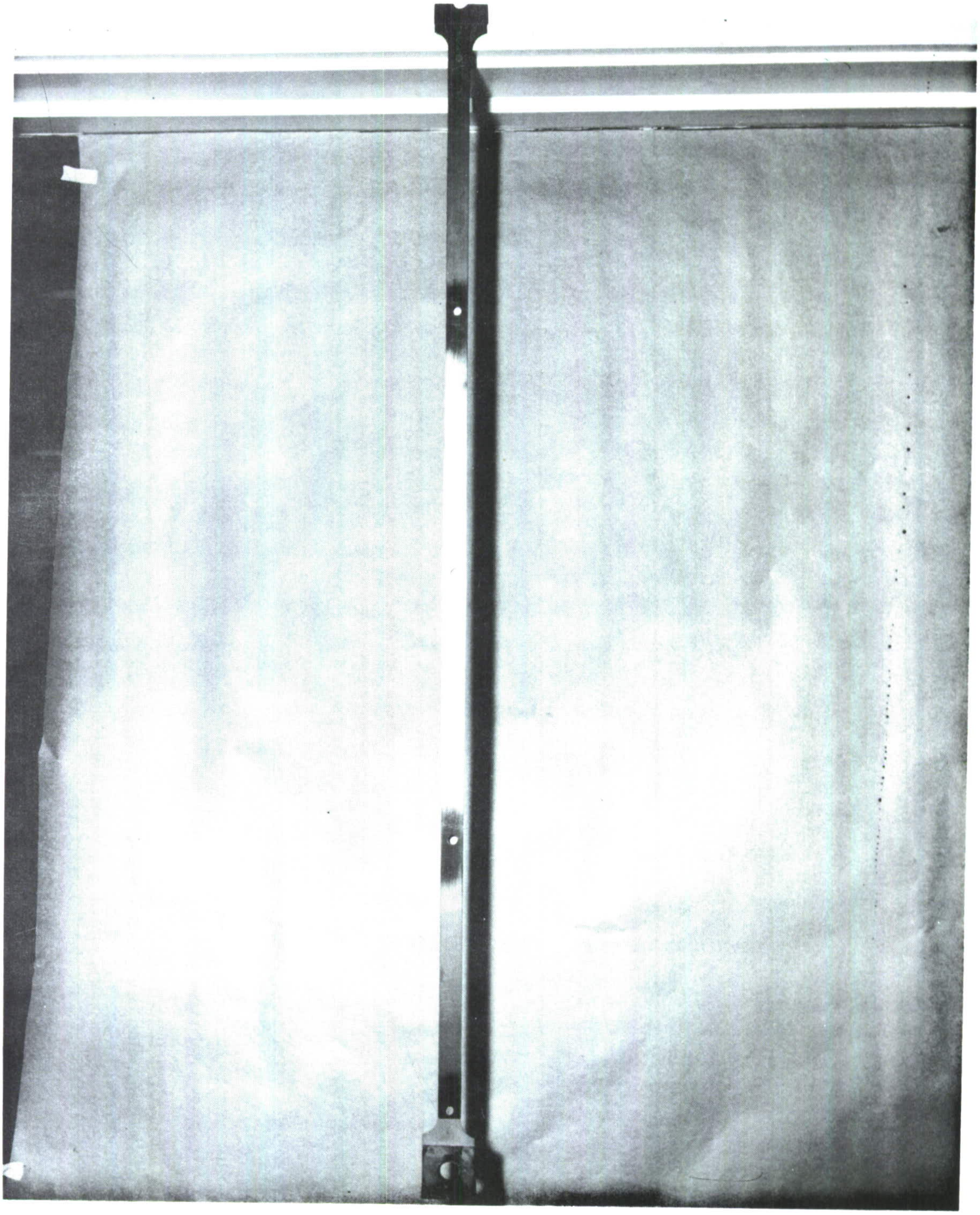


Figure 11 30-INCH GAGE LENGTH CREEP SPECIMEN

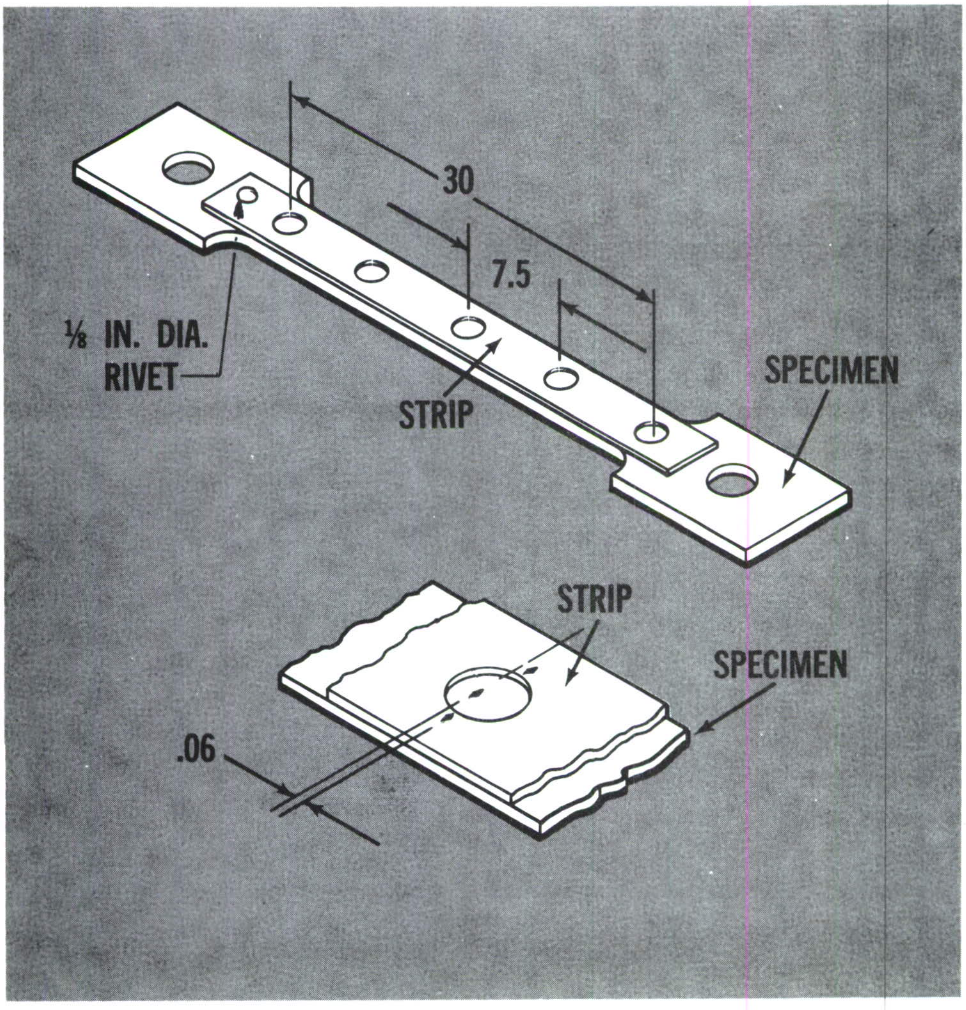


Figure **12** DIAGRAM OF 30-INCH GAGE LENGTH CREEP SPECIMEN WITH REFERENCE STRIP ATTACHED

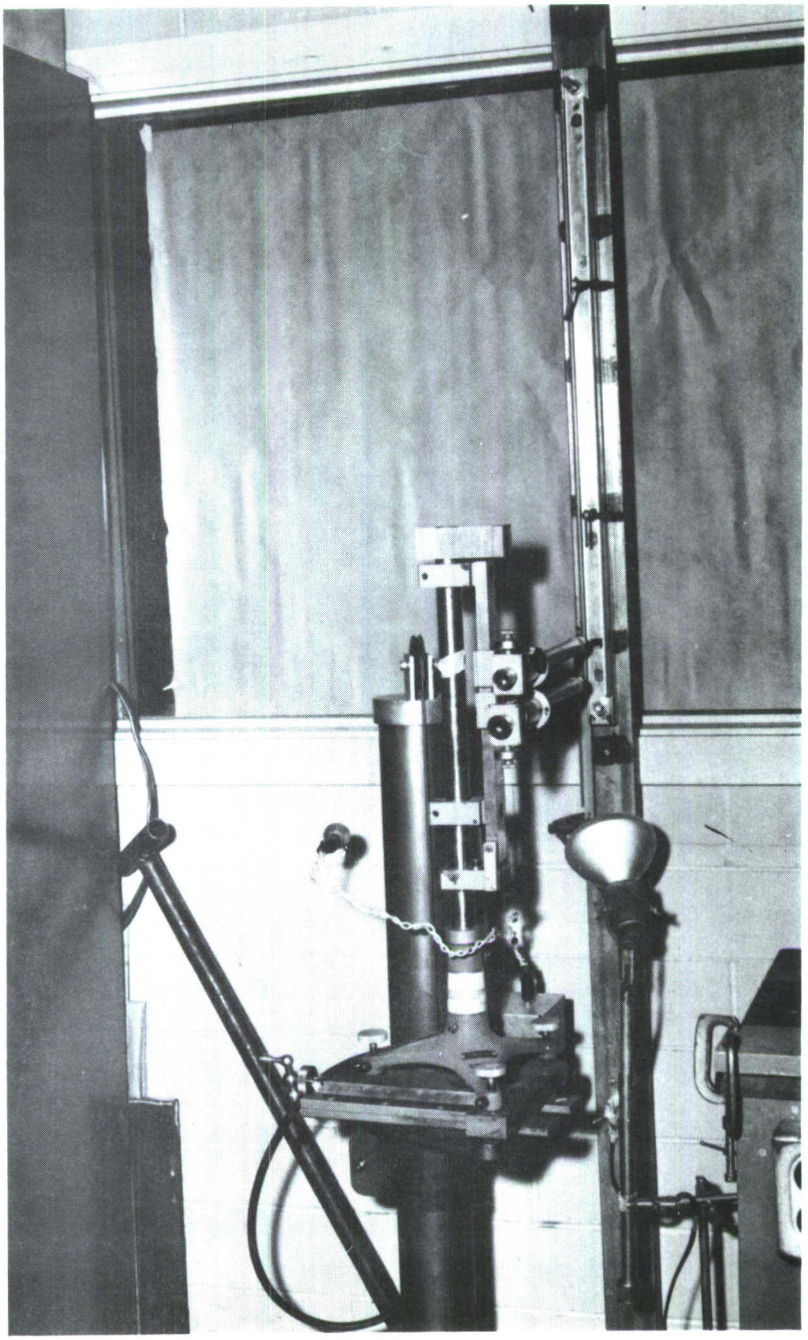


Figure 13 30-INCH GAGE LENGTH CREEP SPECIMEN IN HOLDING FIXTURE FOR MEASURING CREEP

The most likely error with this system is due to variations in heating over the 30-inch strip. Unequal heating can be detected by thermocouples located throughout the oven. Any effects from unequal heating will be shown by variations in creep rate between the 0 to 7.5, 7.5 to 15, 15 to 22.5, and 22.5 to 30-inch lengths. The creep measured will be an average creep for an average temperature and an average sheet thickness over the 30-inch gage length and is realistic for aircraft structural design information.

The intermittent cycle of heating to temperature, applying load, and holding load and temperature constant for 2.5 hours, and then relieving the load and cooling to approximately room temperature was the same for the 30-inch specimens as used for the 2-inch specimens.

SECTION VI

TENSILE PROPERTIES TESTING

Except for the measurement of modulus of elasticity, all tests to determine the tensile properties of the materials were performed in accordance with Federal Test Method Standard 151, Tension Test 211. The specimens were loaded in a 5000-pound capacity Baldwin Universal Test Machine at a strain rate of 0.005 inch per inch per minute to yield and at approximately 0.05 inch per inch per minute from yield to failure. The load-deformation curve was autographically recorded on a Baldwin Model MA-1B recorder; an averaging type Class B-1 extensometer was used to measure strain over a two-inch gage length.

The modulus of elasticity of the materials was determined from the slope of the load-deformation curve. It is included in the data for information only and should not be used for design. Federal Test Method Standard 151 requires a Class A-1 extensometer to be used for determining modulus of elasticity.

The reduction in area was determined by measuring the width and thickness of the necked down section. The width was measured on an optical comparitor with a 20X magnification. In those specimens failing in a line perpendicular to the load, no problem was encountered in determining the necked down area. In specimens failing at an angle to the centerline, the fractured specimens were rejoined and the minimum width of the neck was measured on a micrometer stage using a 100X magnification microscope. The thickness of the final fracture surface was measured by differentiating between the rough fracture surface and the relatively smooth necked down outer surface.

SECTION VII

FRACTURE TOUGHNESS TESTING

Requirements

The test plan required five fracture toughness specimens to be exposed for each creep loading condition and each corresponding heat soaking condition. Three of each set of five exposed specimens were to be tested to measure K_c at room temperature for comparison with K_c measured on unexposed specimens. The remaining two of each set of five specimens were spares. With the permission of the Air Force Project Engineer the two spare specimens for each exposure condition through 10,000 hours were tested at -65°F under a General Dynamics Corporate sponsored research program. The two spare specimens for each 30,000 hour exposure condition were tested at -65°F as part of this program. The test set-up for testing the specimens at -65°F was the same as used during the room temperature tests except that the specimen was surrounded by a styrafoam box. Air was blown over solid carbon dioxide and then into the styrafoam box until a thermocouple attached to the specimen indicated the desired temperature had been reached. The light used to illuminate the specimen for photographing had a warming action. Therefore the temperature at the start of loading was held below -65°F so that failure would occur at the time the thermocouple indicated a specimen temperature of -65°F. A variation of ±3°F resulted in trying to syncronize the failure with the -65°F temperature.

Procedure and Instrumentation

The original intent in this program was to follow the recommended procedures of the ASTM Committee on Fracture Toughness Testing of High-Strength Sheet Materials (Ref. 1) in measuring the fracture toughness of the materials. However, the ASTM recommendations have been modified since the conception of this program and several deviations exist between the current ASTM recommendations (Ref. 3) and the test procedure described in Reference 1.

At the time of the program planning, December 1961, the 1-inch wide by 0.025-inch thick specimen size was in accord with the ASTM recommendations of 1960. A small specimen size was essential to accomplishing the simultaneous creep loading of the large number of specimens required for this program. It has since been shown that plane stress fracture toughness is a function of specimen size. Ideally, a very wide specimen width should have been used. As stated by Dr. J. M. Krafft in a report to the ASTM Committee for Fracture Testing of Metallic Materials (Ref. 4), "From the fracture mechanics viewpoint, an ideal fracture specimen is a very large one." The current recommendations are that a specimen size should be of a width and thickness such that the stress on the net section at fracture is less than 0.8 yield stress. This condition is definitely not met in this test. The materials for this program were selected for their outstanding toughness and in most cases, the net stress at fracture is greater than 0.8 yield stress. However, inasmuch as K_c is not a material property and this test program was planned to compare the toughness of each alloy before and after exposure to heat and to creep for various times, the small specimen size is entirely adequate.

Various techniques were investigated for testing this small specimen. A compliance gage technique seemed the most promising for detecting pop-in. The first attempt was to use a semicircular compliance gage attached to one side of the specimen and record load versus compliance on an x-y recorder. This approach gave very poor results with the thin specimens. The eccentricity of the compliance gage, with respect to the neutral axis of the specimen, produced slight bending in the unloaded specimen. On loading the specimen, the curvature was removed, but application of axial load resulted in a very nonlinear trace plotted by the x-y recorder. The x-y recorder itself created an objection to this method. The recorder trace lacked smoothness and it was felt that should a "pop-in" occur, it would be undetectable.

After consideration, a modified technique was devised which departed in some respects from the technique commonly used for fracture toughness testing. The first consideration was given to the design of a new compliance gage. Requirements for the gage were these:

1. Gage must not bend the specimen

2. It must have high sensitivity

3. It must not be damaged by the rapid fracture of the specimen

4. It must be capable of responding to rapid changes.

A compliance gage was built which satisfied all of these conditions. The gage is a 1.4-inch inside diameter ring 0.1-inch thick, machined from 7075-T6 aluminum alloy bar stock. The width is 0.25 inch to allow for strain gages to be mounted on the inside and the outside of the ring. Diametrically opposite the strain gages, a section 0.2-inch wide was removed and steel prongs were attached, as shown in Figure 14, to be inserted in the hole in the specimen as shown in Figure 15. The gage was calibrated in the Fort Worth Division of General Dynamics Standards Laboratory and was shown to have a linear response of less than 2 percent variation when prong deflection was plotted versus strain gage reading from fully closed to fully open. This gage design was selected for the following reasons: First, a single gage that loads the specimen on the neutral axis is the surest means of eliminating bending. Second, by loading at a small center hole, the gage does not pick up the error introduced by a warped specimen being pulled straight. Third, a gage in contact with the free boundary of the crack is the most sensitive to changes in crack width. If a compliance gage extends over a length L, the response is a function of two terms, the PL/AE elongation in the gross section over the gage length and the elongation due to the distortion of the material in the neighborhood of the crack. Only the change in compliance with respect to crack length contributes to the information desired. The elongation in the gross section away from the crack only serves to mask the information desired. It is obvious that if L becomes very large the compliance gage would have a response consisting of a negligible term due to the crack as compared to the large term due to PL/AE. If L is reduced to zero, the entire response of the compliance gage is due to change in crack width. Therefore, the most sensitive gage for pop-in detection is one that bears on the surface of the crack along its minor axis. Fourth, since the gage bears on the crack inner surface, it will spring free of the specimen without damage when the specimen fractures. Fifth, a compliance gage using strain gages is capable of rapid response to crack growth.

Consideration was next given to the method of recording the load versus the compliance gage output. A Consolidated Engineering Co. oscillograph was selected to record load cell output and compliance gage output versus time. The oscillograph was capable of recording extremely rapid changes in load or compliance and was free of the mechanical difficulties found in the x-y plotter. Examples of the oscillograph records are shown in Figures 16 through 21. The top trace shows the load cell input; the center trace shows the compliance gage output with normal amplification; and the bottom trace shows the compliance output fed through a preamplifier with approximately a 10 factor amplification.

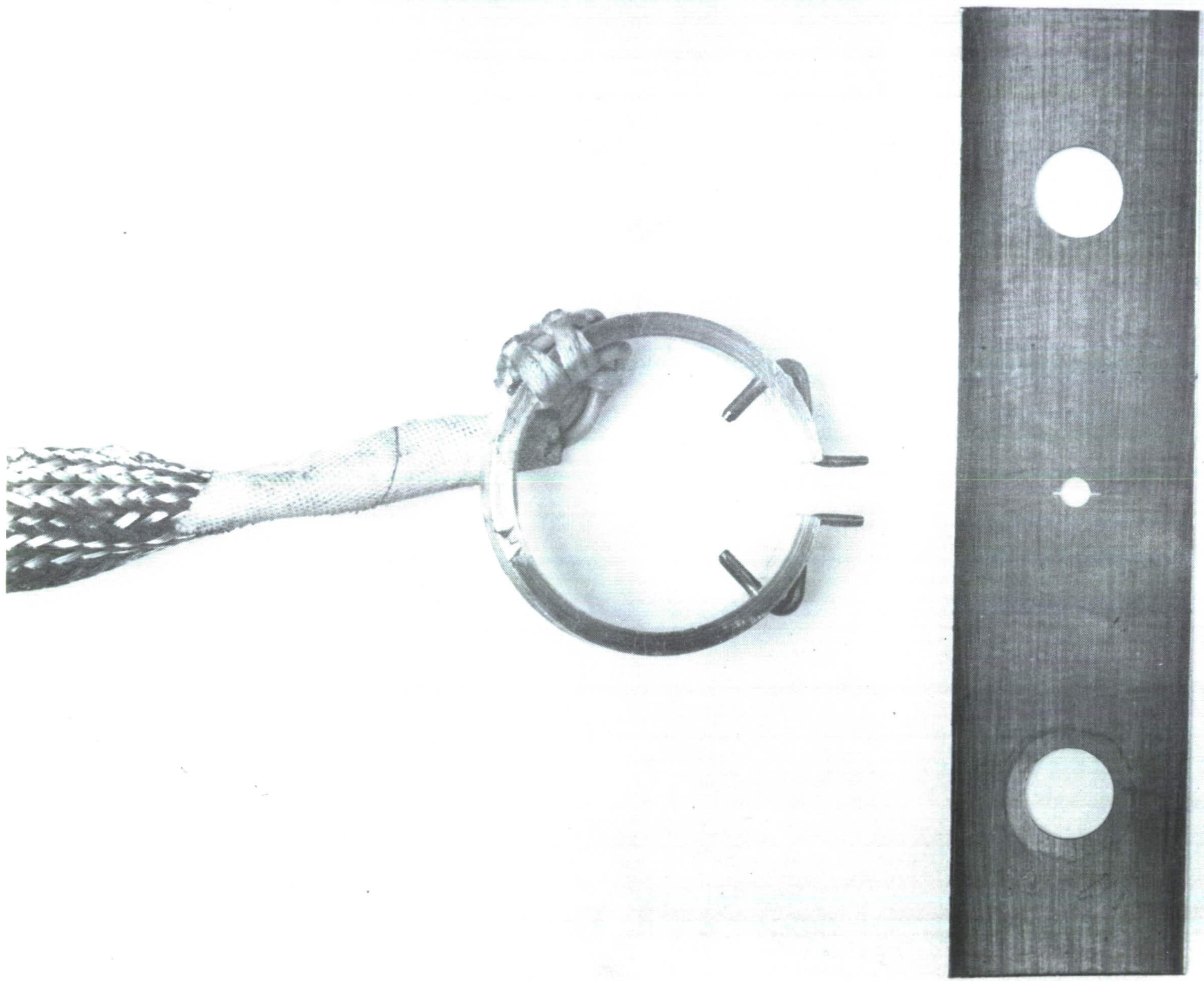


Figure 14 COMPLIANCE GAGE AND FRACTURE TOUGHNESS SPECIMEN

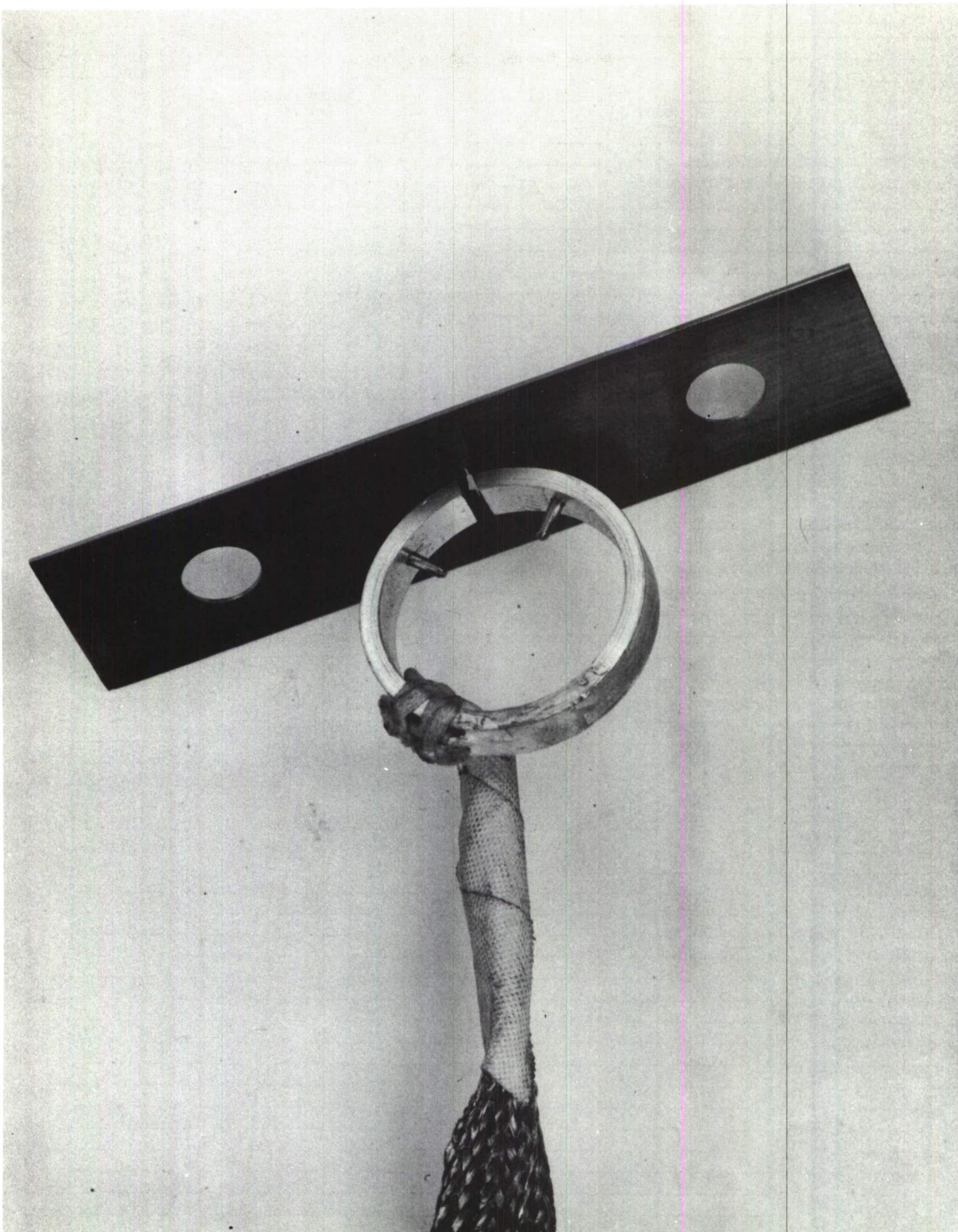


Figure 15 COMPLIANCE GAGE ATTACHED TO FRACTURE TOUGHNESS SPECIMEN

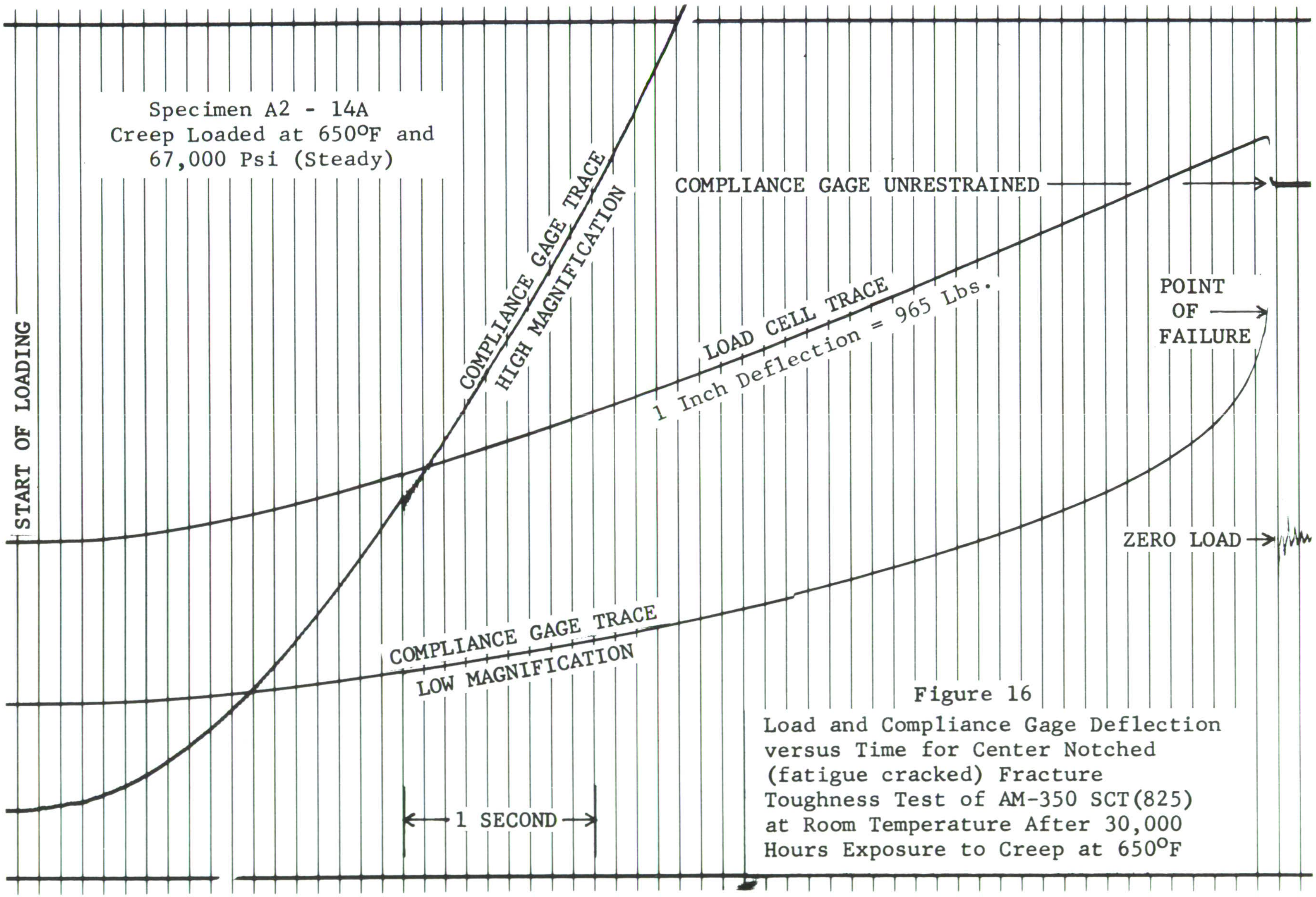


Figure 16

Load and Compliance Gage Deflection versus Time for Center Notched (fatigue cracked) Fracture Toughness Test of AM-350 SCT(825) at Room Temperature After 30,000 Hours Exposure to Creep at 650°F

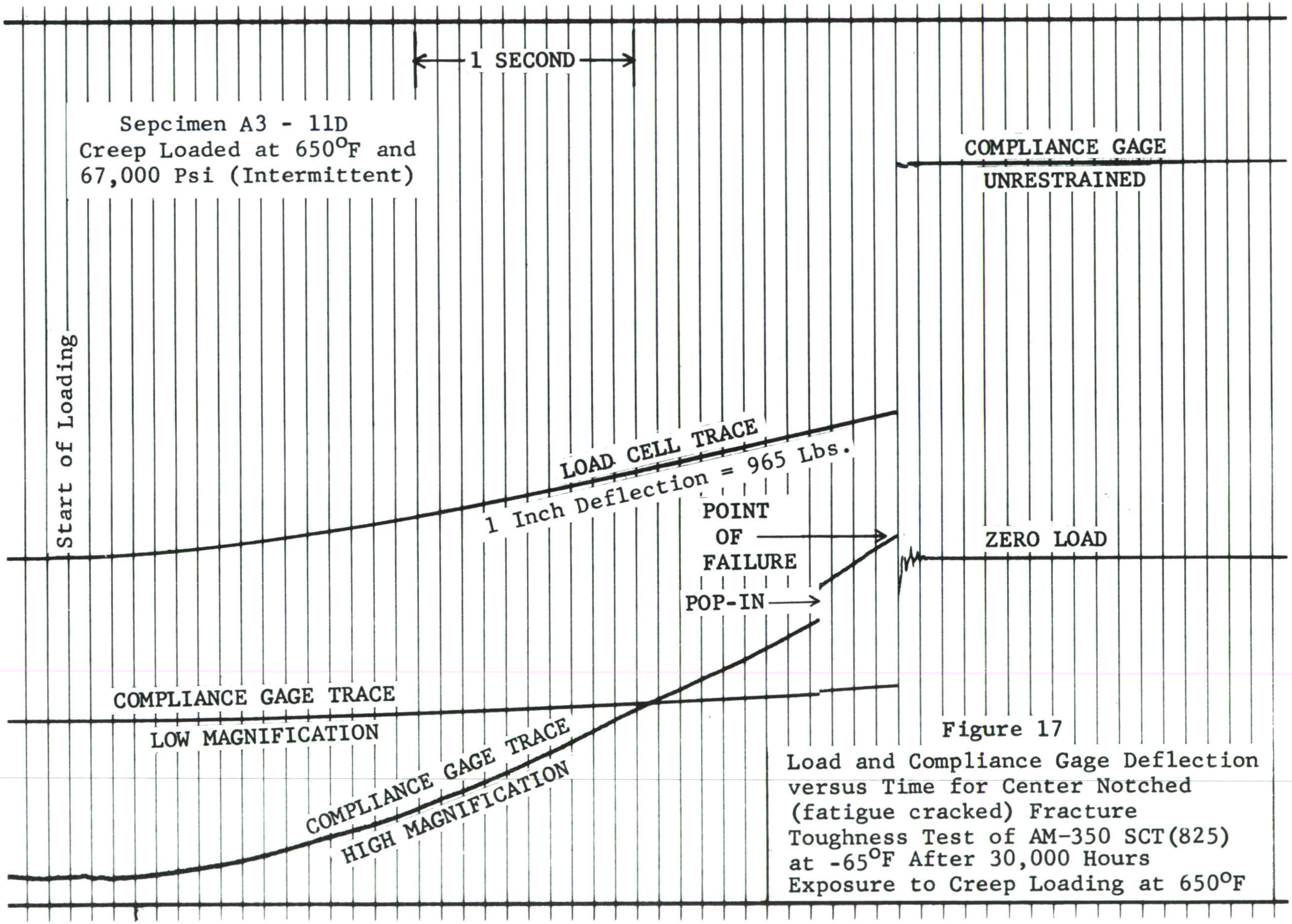


Figure 17

Load and Compliance Gage Deflection versus Time for Center Notched (fatigue cracked) Fracture Toughness Test of AM-350 SCT(825) at -65°F After 30,000 Hours Exposure to Creep Loading at 650°F

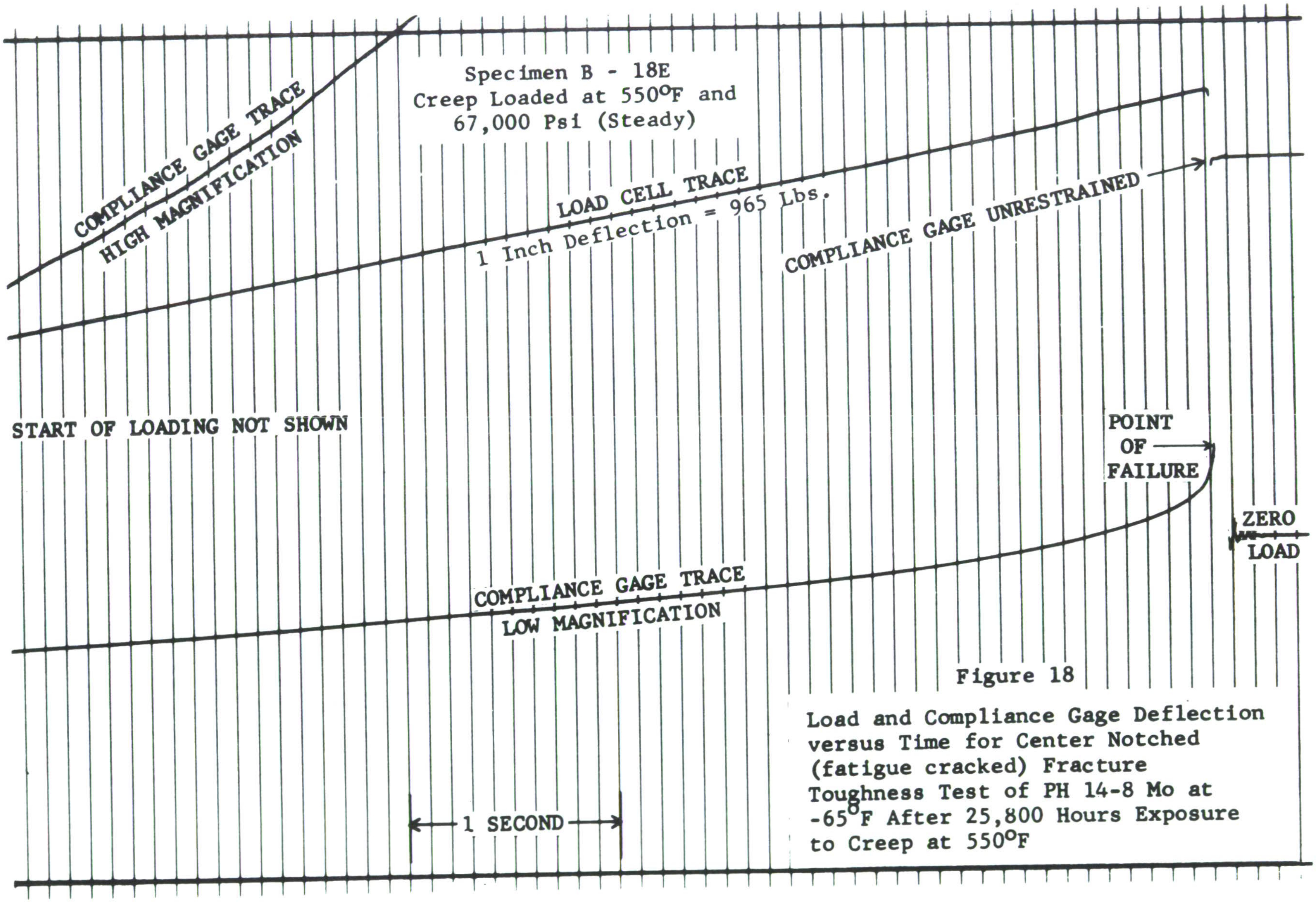


Figure 18

Load and Compliance Gage Deflection versus Time for Center Notched (fatigue cracked) Fracture Toughness Test of PH 14-8 Mo at -65°F After 25,800 Hours Exposure to Creep at 550°F

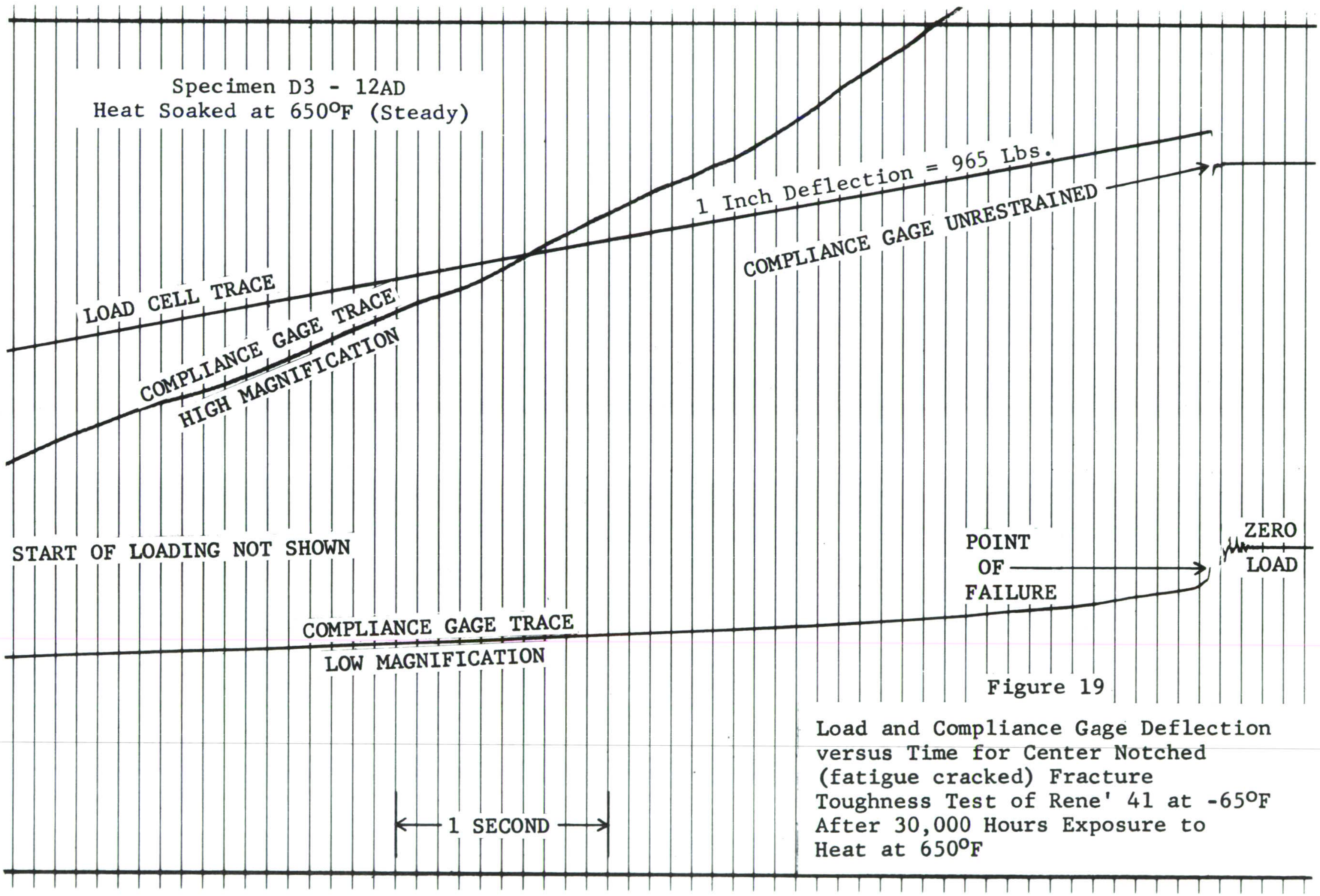


Figure 19

Load and Compliance Gage Deflection versus Time for Center Notched (fatigue cracked) Fracture Toughness Test of Rene' 41 at -65°F After 30,000 Hours Exposure to Heat at 650°F

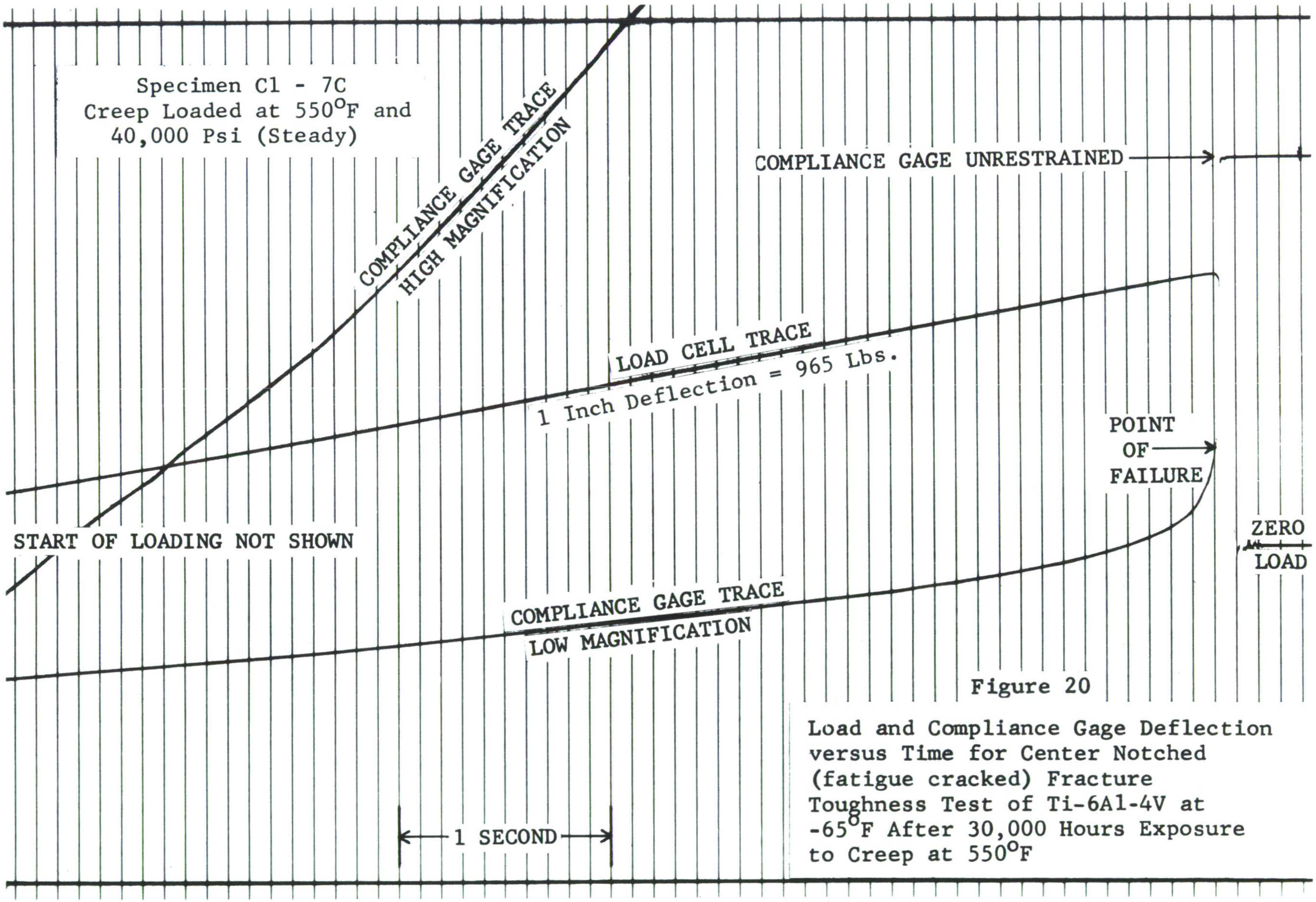


Figure 20

Load and Compliance Gage Deflection versus Time for Center Notched (fatigue cracked) Fracture Toughness Test of Ti-6Al-4V at -65°F After 30,000 Hours Exposure to Creep at 550°F

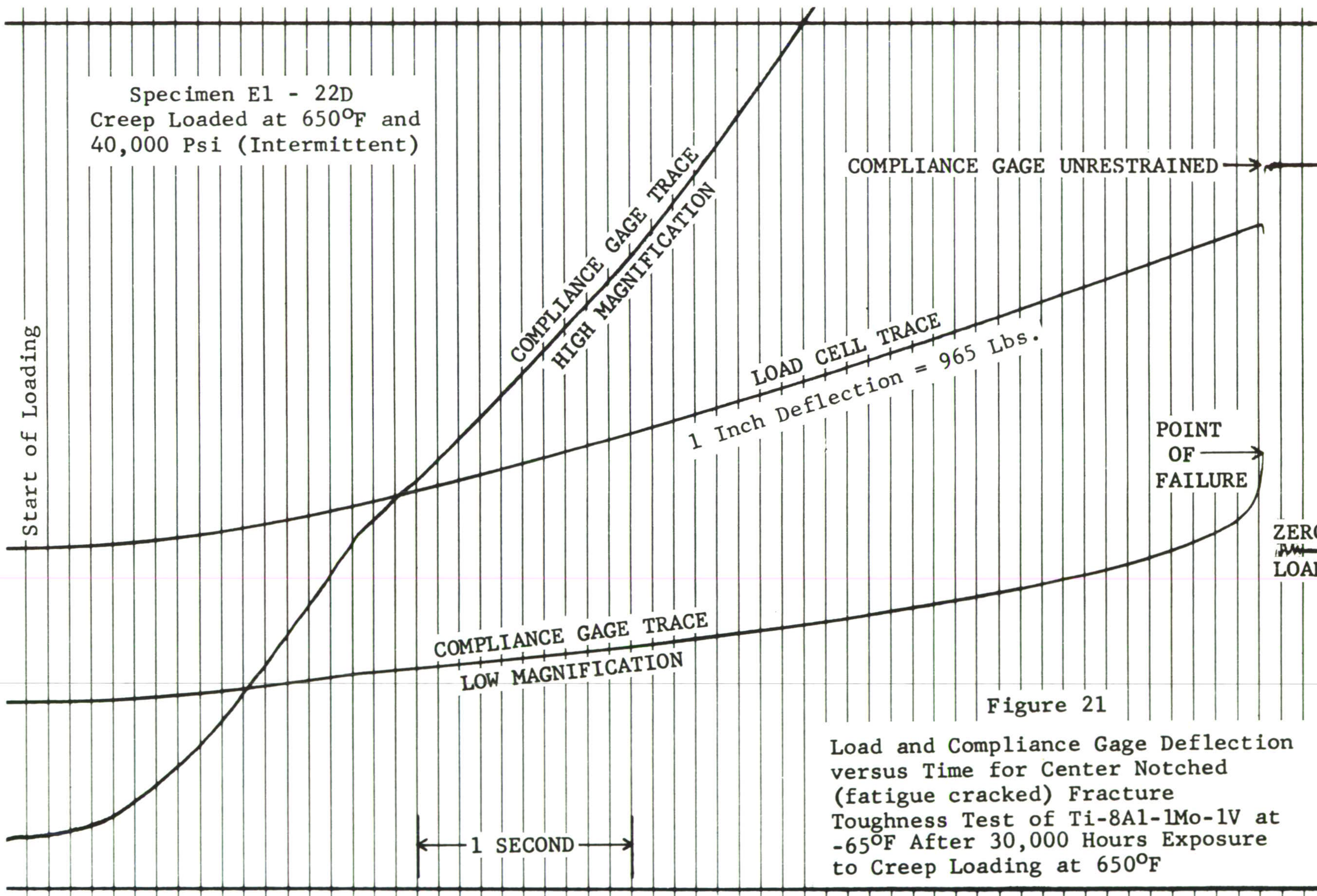


Figure 21

Load and Compliance Gage Deflection versus Time for Center Notched (fatigue cracked) Fracture Toughness Test of Ti-8Al-1Mo-1V at -65°F After 30,000 Hours Exposure to Creep Loading at 650°F

After some preliminary investigations, it was decided that photographic recording was the best method of measuring crack length at the point of slow crack growth to fast fracture transition. A 16 mm movie camera was used to photograph the crack growth at approximately 40 frames per second. With the loading rate used, each frame corresponded to a change in load of approximately 10 pounds. The maximum crack length for slow crack growth, measured from the photographs, is within one frame of failure and, therefore, was the crack length existing in the specimen when the load was within 10 pounds of maximum.

A further deviation from usual testing practice was the addition of a spring in series with the specimens. The spring was added to provide sufficient energy in the system to allow the crack to propagate without a drop in load. When a specimen was large in length and width, the strain energy stored in the specimen was large compared to the strain energy released as a result of a small increment of crack propagation. For a fixed grip system, any release in strain energy caused a drop in the load. When a small specimen was tested, the stored strain energy was small. The same increment of crack propagation as before might then require a release of a large percentage of the stored strain energy, thus causing an appreciable drop in the load. This drop in load could be sufficient to allow crack arrest. The preliminary tests without the spring showed a slow buildup in load and then a gradual drop. There was no sudden "pop-in" or fast fracture. Neither the stored energy in the specimen nor the test machine was capable of supplying energy to the crack fast enough to produce fast crack propagation. The load would build up to a maximum and then slowly drop off as slow tearing of the specimen progressed. The rate of tearing depended on the test machine head travel speed rather than an energy instability condition. When the spring was added, the load increased at a very uniform rate and then suddenly dropped to zero at the onset of fast fracture.

The spring consisted of 18 Belleville washers stacked in series, giving a spring constant of 5000 pounds per inch. The energy stored in the spring was approximately 50 times the strain energy in the specimen.

SECTION VIII

DISCUSSION AND RESULTS

Creep Testing

The average percent creep measured for the AM-350 SCT (825) stainless steel is shown in Figure 22. There is very little difference between the intermittent creep recorded for 550°F and for 650°F at the same stress levels. The creep measured by the Joliet Metallurgical Laboratory (Reference 5) up to 20,000 hours on AM-350 SCT (850) specimens exposed at 650°F and 67,000 psi steady loading is shown for comparison. There is as much as .03% variation between the Joliet curve for steady loading and the General Dynamics curve for intermittent loading. This could be attributed to differences in technique in reading creep. However, it is questionable that true creep can ever be measured on AM-350 with this degree of accuracy. This material grows approximately .47% during heat treatment from the H condition to the SCT condition. The dimensional instability of the material at 650°F may be affecting the accuracy of the measurements. Regardless of the cause, the deformation measured up to 30,000 hours is not enough to prevent the use of AM-350 in a supersonic transport design.

The average percent creep of PH 14-8Mo (SRH 1050) stainless steel is shown in Figure 23. The curves fall short of 30,000 hours since this material was added to the program after creep loading had started. There seems to be no difference between the intermittent creep and the steady creep. The magnitude of creep is approximately the same as was measured for the AM-350 SCT (825) stainless steel. The PH 14-8Mo is another precipitation hardening alloy that grows during heat treatment and the same dimensional problems exist in determining creep deformation.

The René 41 (20% cold rolled + 16 hours at 1400°F) showed the most peculiar behavior of the five alloys tested. As shown in Figure 24, at low stress levels there was a slight shrinkage for the first 5000 to 6000 hours and thereafter some creep was measured. The shrinkage was probably due to relaxation of the cold work remaining after the 16 hours at 1400°F. In an alloy as complex as René 41 the small amount of deformation measured as creep could easily be due to undetectable metallurgical changes rather than

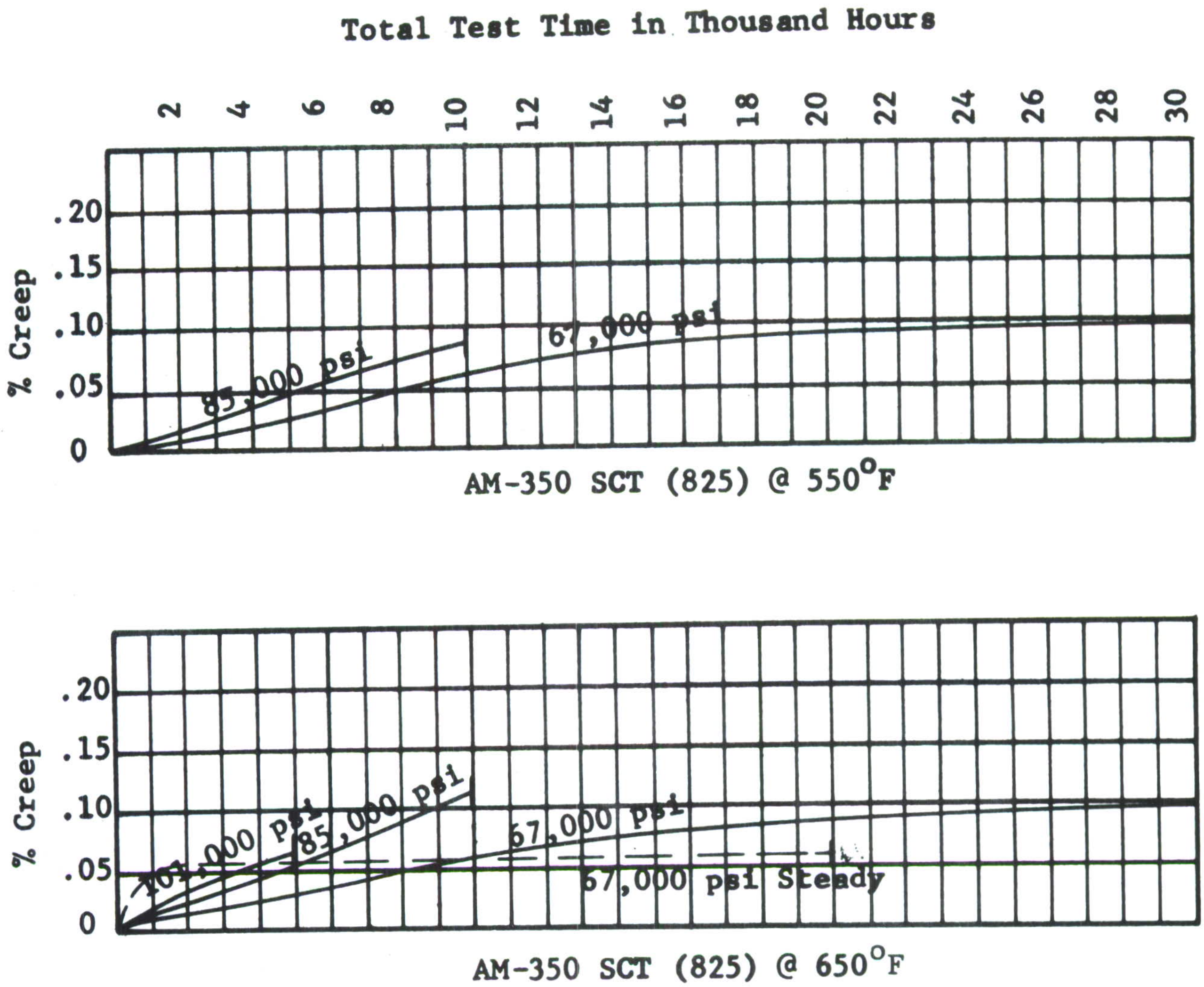


Figure 22 AVERAGE PERCENT CREEP OF AM-350 SCT (825) STAINLESS STEEL SHEET. (INTERMITTENT HEATING AND LOADING UNLESS OTHERWISE SHOWN).

— — — — JOLIET MET. LAB. DATA
FOR AM-350 SCT (850) STEEL
AVERAGE OF FOUR SPECIMENS
REF AFML-TR-65-18

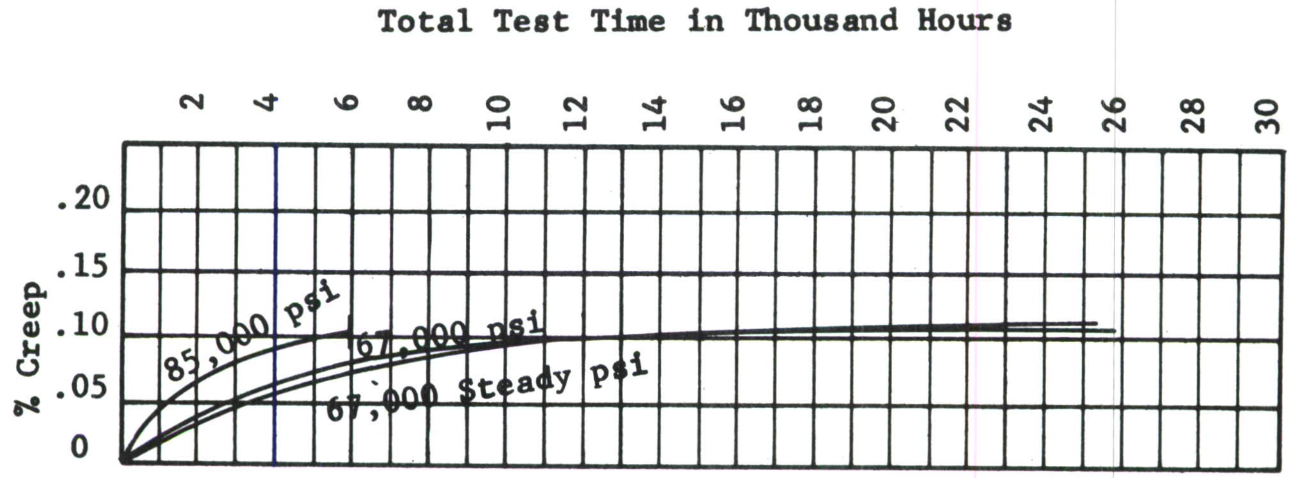


Figure 23 AVERAGE PERCENT CREEP OF PH 14-8 Mo (SRH 1050) @ 550°F STAINLESS STEEL SHEET. (INTERMITTENT HEATING AND LOADING UNLESS OTHERWISE SHOWN).

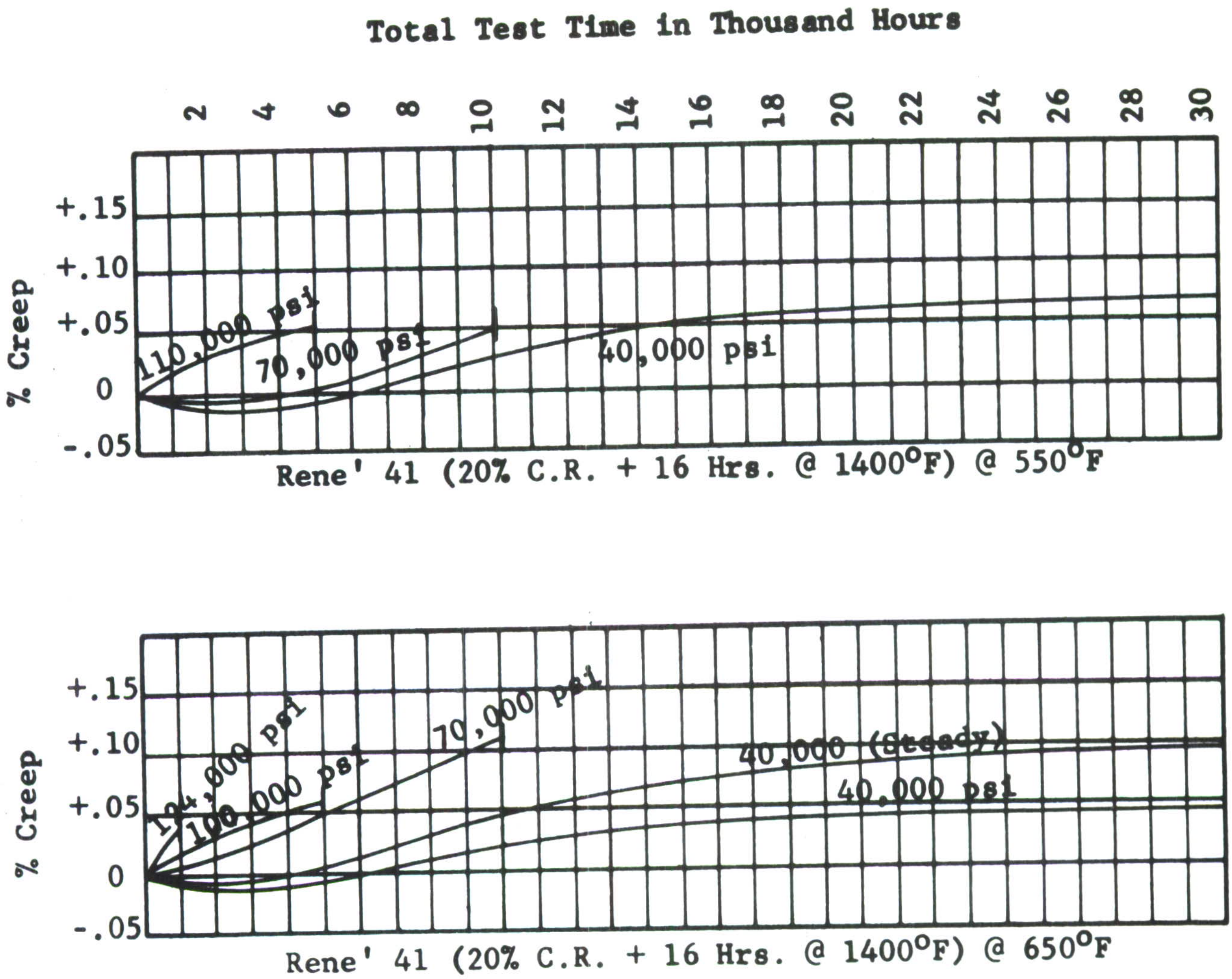


Figure 24 AVERAGE PERCENT CREEP OF RENE' 41 SHEET. (INTERMITTENT HEATING AND LOADING UNLESS OTHERWISE SHOWN).

plastic deformation due to load. R. Widmer, et.al. (Ref. 6) has shown that Udimet 500, which is a complex nickel base alloy similar to Rene' 41, at 1200°F under no load shrinks .06% in 1800 hours due to phase changes, whereas, at 1500°F and no load, there is very little shrinkage in 2000 hours. Only by measuring changes in unloaded as well as loaded specimens can the full significance of the observed small changes in length be determined. Regardless of the cause, the deformation shown in Figure 24 should be well within design requirements for an SST.

The 30 inch gage length specimen data is shown in Figures 25 and 26 for the titanium alloys in lieu of the 2 inch gage length data since it is considered to be more precise. Neither the Ti-6Al-4V (mill annealed) or the Ti-8Al-1Mo-1V (duplex annealed) creeped appreciably at 550°F even at stresses as high as 65,000 psi. The creep of the steady loaded Ti-8Al-1Mo-1V (mill annealed) at 550°F and 67,000 psi, as measured by the Joliet Metallurgical Laboratory (Ref. 5), is shown in Figure 25 for comparison. The amount of creep of the mill annealed Ti-8Al-1Mo-1V more nearly corresponds to the creep of the mill annealed Ti-6Al-4V than it does to the duplex annealed Ti-8Al-1Mo-1V. At 650°F the Ti-6Al-4V creep rate increases rapidly whereas the duplex annealed Ti-8Al-1Mo-1V shows only a moderate increase in creep rate. At 550°F creep of either titanium alloy would be of no consequency in the design of a SST. At 650°F the Ti-8Al-1Mo-1V (duplex annealed) would be satisfactory, whereas, the use of Ti-6Al-4V (mill annealed) should be restricted to very low stresses or short exposure time.

Tensile Testing

AM-350 SCT (825) Stainless Steel

Both heat alone and creep loading at 650°F has a slight tendency to raise the ultimate tensile strength. Specimens tested at room temperature after exposure showed a more definite upward trend than specimens tested at 650°F after exposure as shown in Figure 27. It appears the heat is the predominant factor causing the increase rather than creep. The 550°F exposure had no effect on the ultimate tensile strength.

The increase in tensile yield strength after exposure to 650° (heat or creep) was more pronounced than the increase in ultimate strength, as shown in Figure 28. Except for an increase in yield

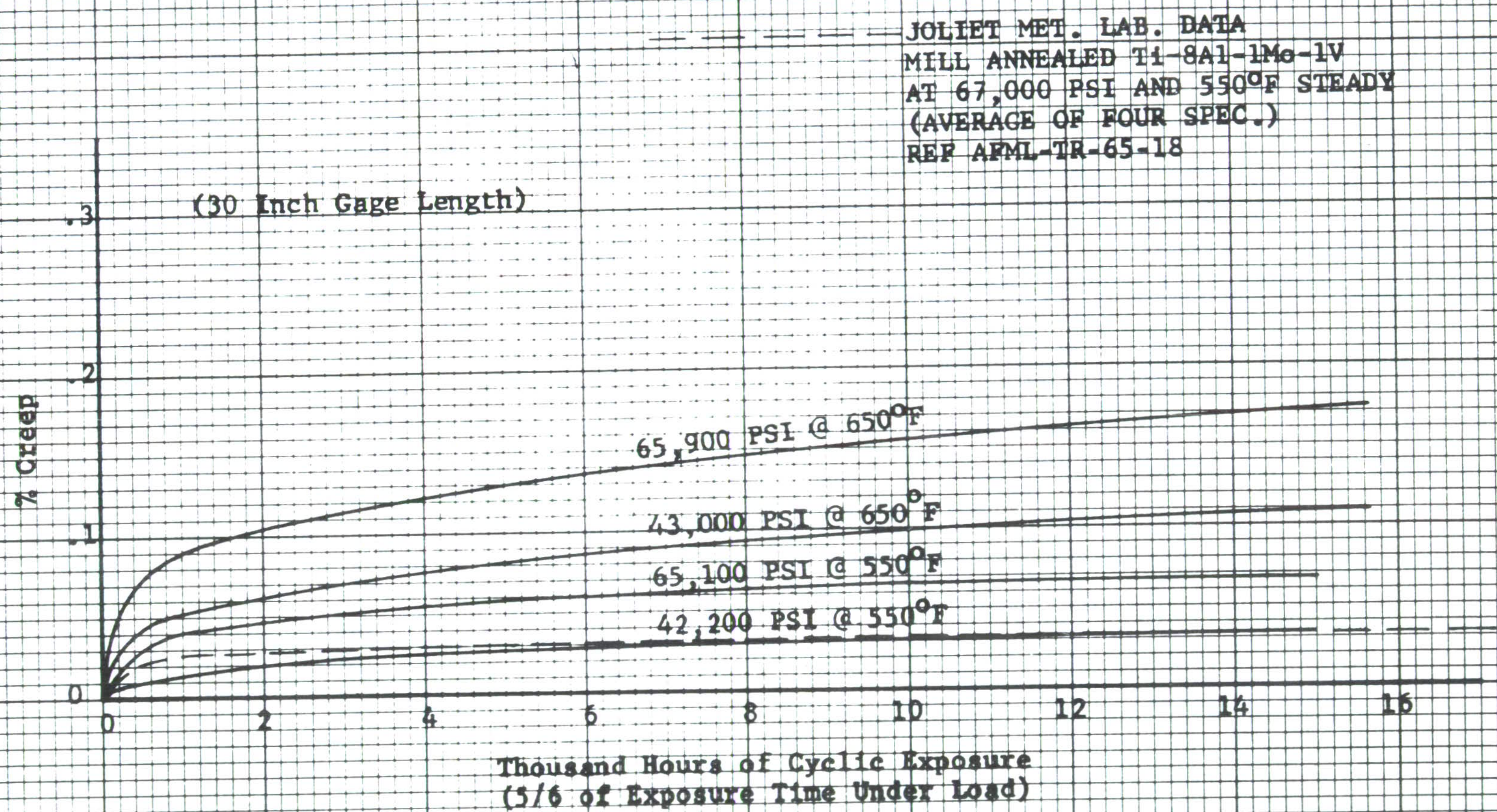


Figure 25 INTERMITTENT CREEP OF Ti-8Al-1Mo-1V TITANIUM

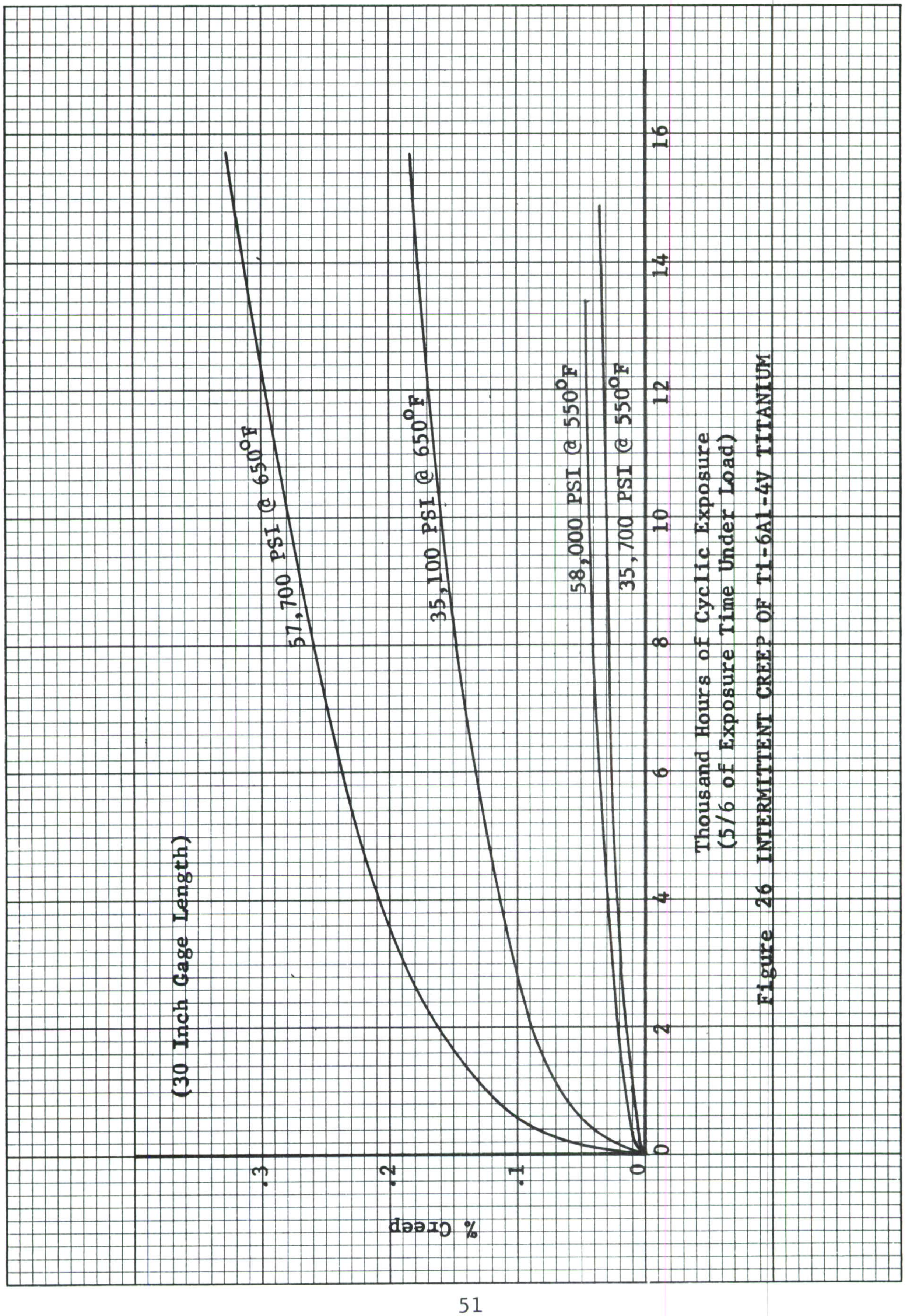


Figure 26 INTERMITTENT CREEP OF Ti-6Al-4V TITANIUM

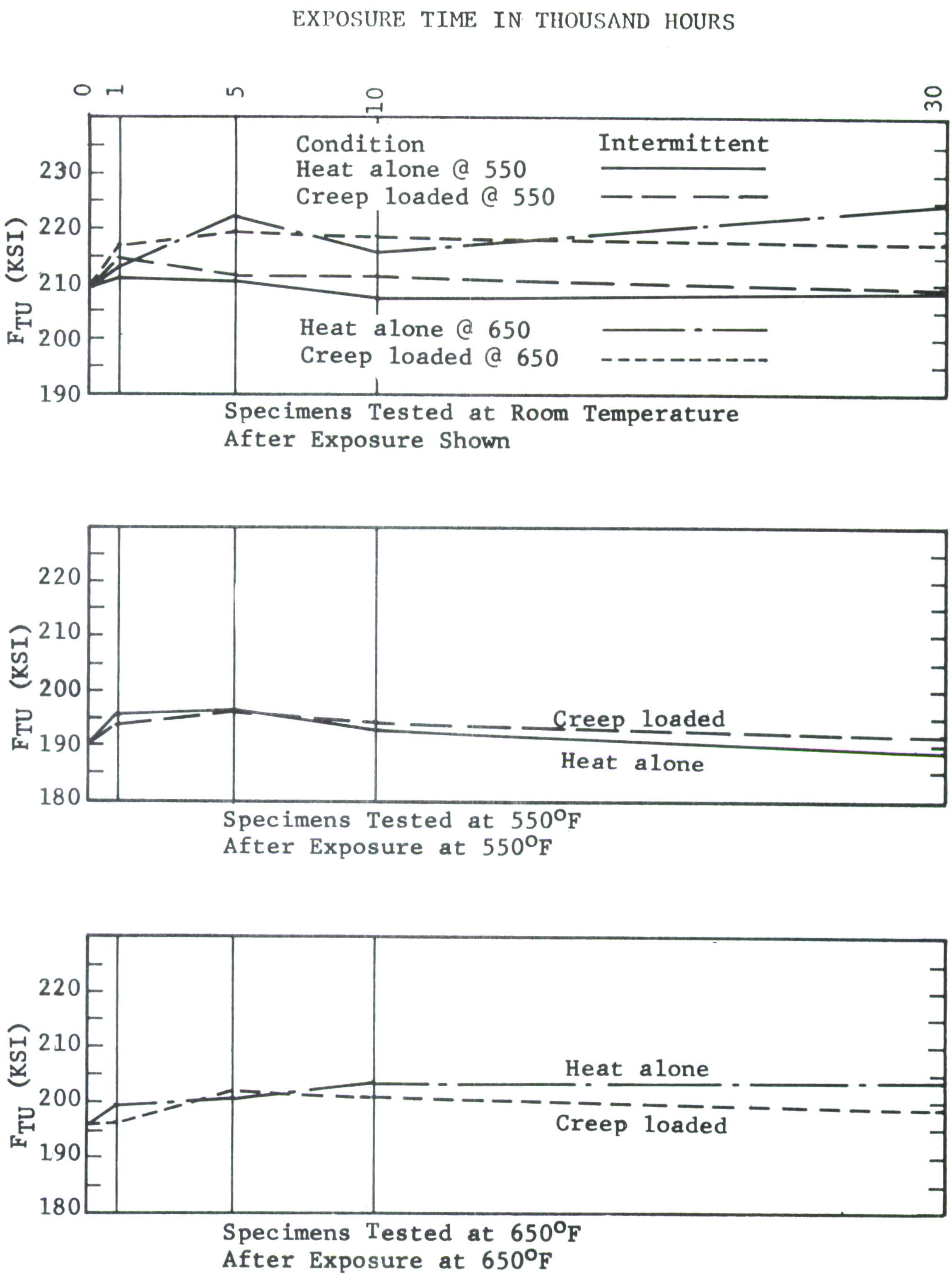
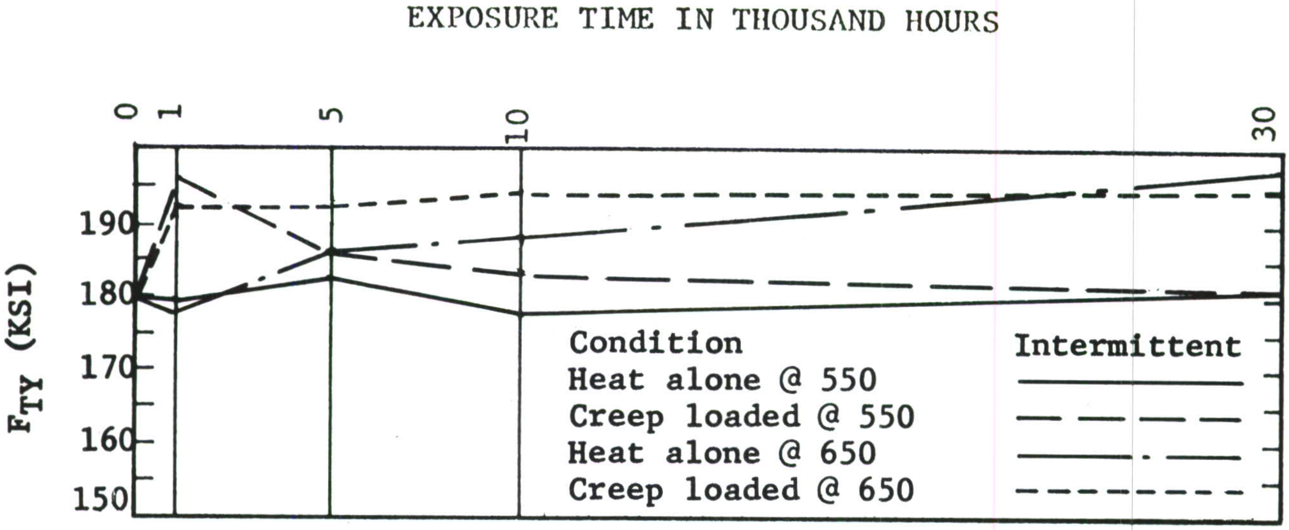
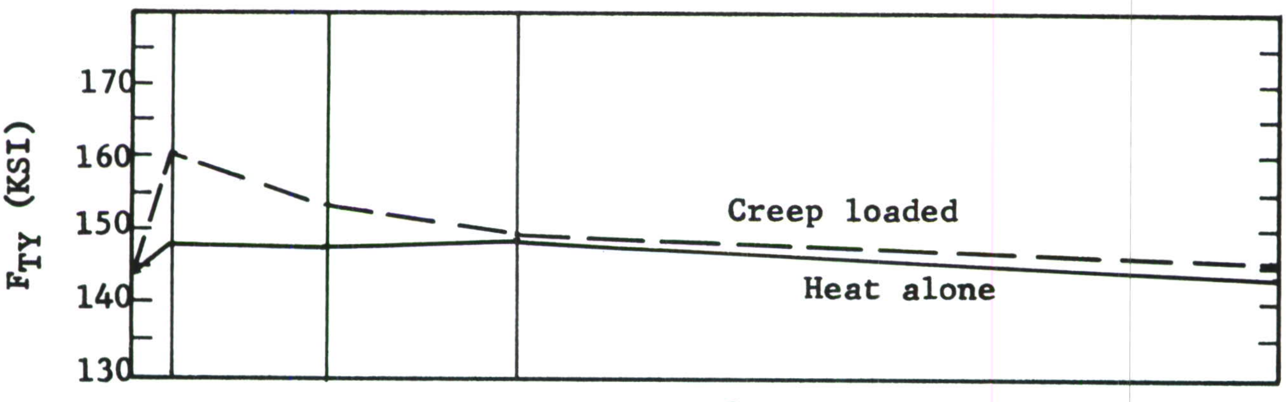


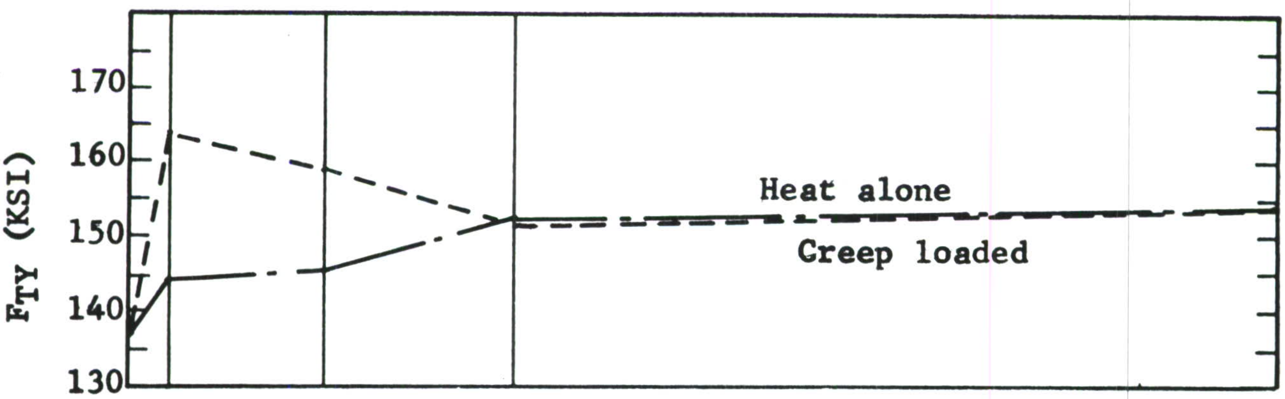
Figure 27 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON F_{TU} of AM-350 SCT (825) STEEL



Specimens Tested at Room Temperature
After Exposure Shown



Specimens Tested at 550°F After
Exposure at 550°F



Specimens Tested at 650°F After
Exposure at 650°F

Figure 28 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON F_{TY} OF AM-350 SCT (825) STEEL strength after 1000 hours of creep loading at 550°F, the 550° exposure had no influence on the yield strength. The stress for 1000 hours of creep loading was near the 550°F yield strength of the material. This singular increase in yield strength after 1000 hours of intermittent exposure to 550°F and 120,000 psi stress could indicate that working the material in the plastic range at 550°F would increase its yield strength.

The percent elongation of specimens tested at room temperature after exposure showed a slight tendency to increase after all exposure conditions. However, when specimens were tested at 650°F after exposure to heat or creep at 650°F, the percent elongation had a downward trend. No definite trend up or down was evident when specimens exposed at 550°F were tested at 550°F as seen in Figure 29.

The percent reduction in area of AM-350 SCT (825) specimens appears to be independent of exposure condition as shown in Figure 30. Only the percent reduction in area of specimens exposed to creep for 30,000 hours at 650°F and then static tested at room temperature appears significantly lower with a drop from 51.3% for the unexposed control specimen to 37.6% for the creep loaded specimen.

In summary, a comparison between the tensile properties of AM-350 SCT (825) specimens tested with no prior exposure and the tensile properties of similar specimens tested after exposure to heat alone or to creep loading indicates the alloy is slightly affected by heating at 650°F. However, all of the trends are small and the actual magnitude of the change is of no design significance.

PH 14-8Mo (SRH 1050)

There is some scatter in the data but there is no definite trend in any of the tensile properties toward an increase or a decrease with exposure time. This material was only exposed at 550°F for 25,060 hours intermittently and 25,800 hours steady. The tensile properties measured after intermittent exposure agree with the tensile properties measured after steady exposure within experimental scatter. The comparisons in tensile properties versus exposure time are shown in Figures 31 through 34.

René 41 (20% cold rolled + 16 hours at 1400°F)

The tensile properties data for the René 41 scatters more than the data for any of the other materials due to its tendency to fail at the extensometer grips. The most definite change noticed

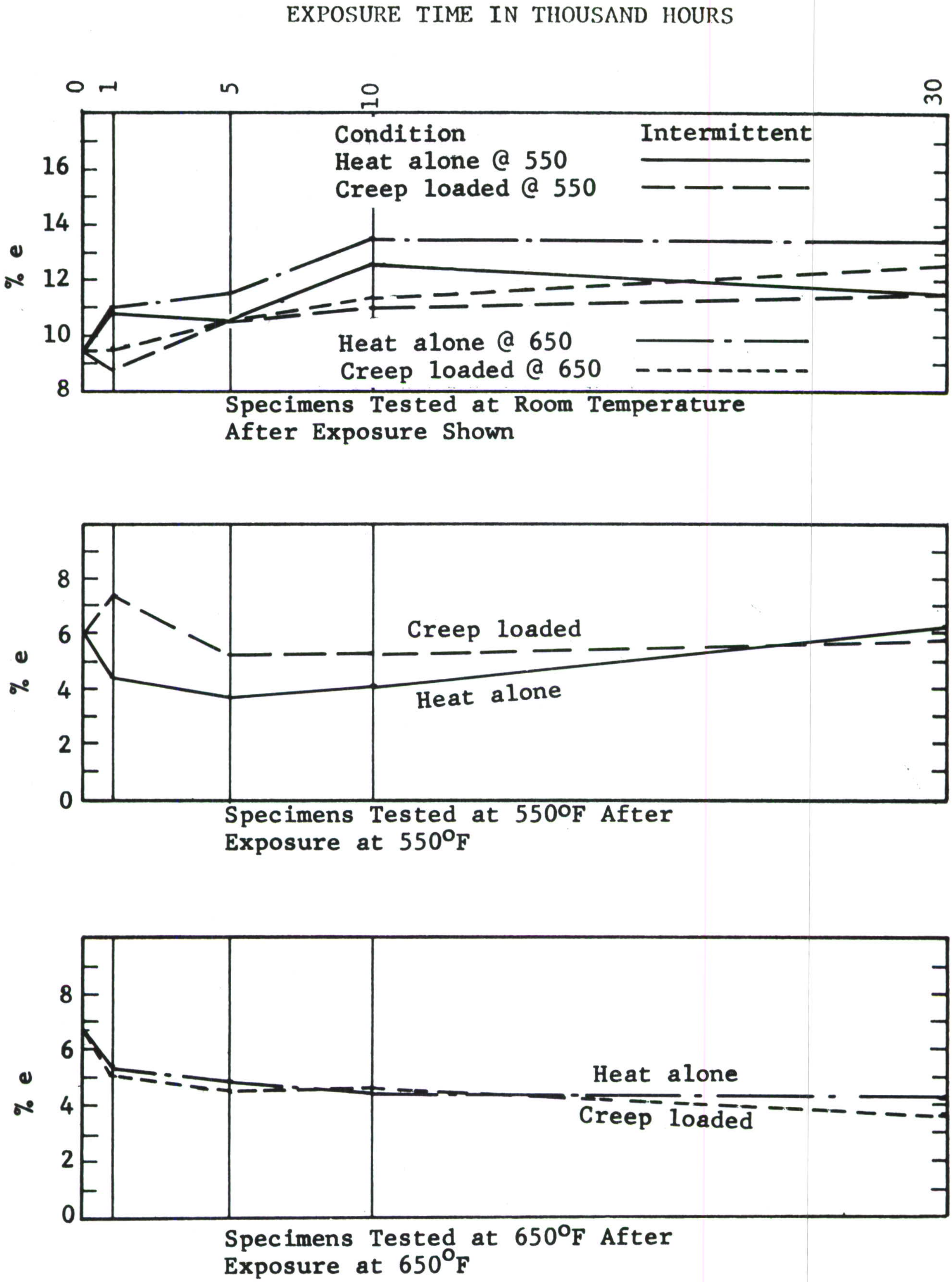


Figure 29 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON % e OF AM-350 SCT (825) STEEL

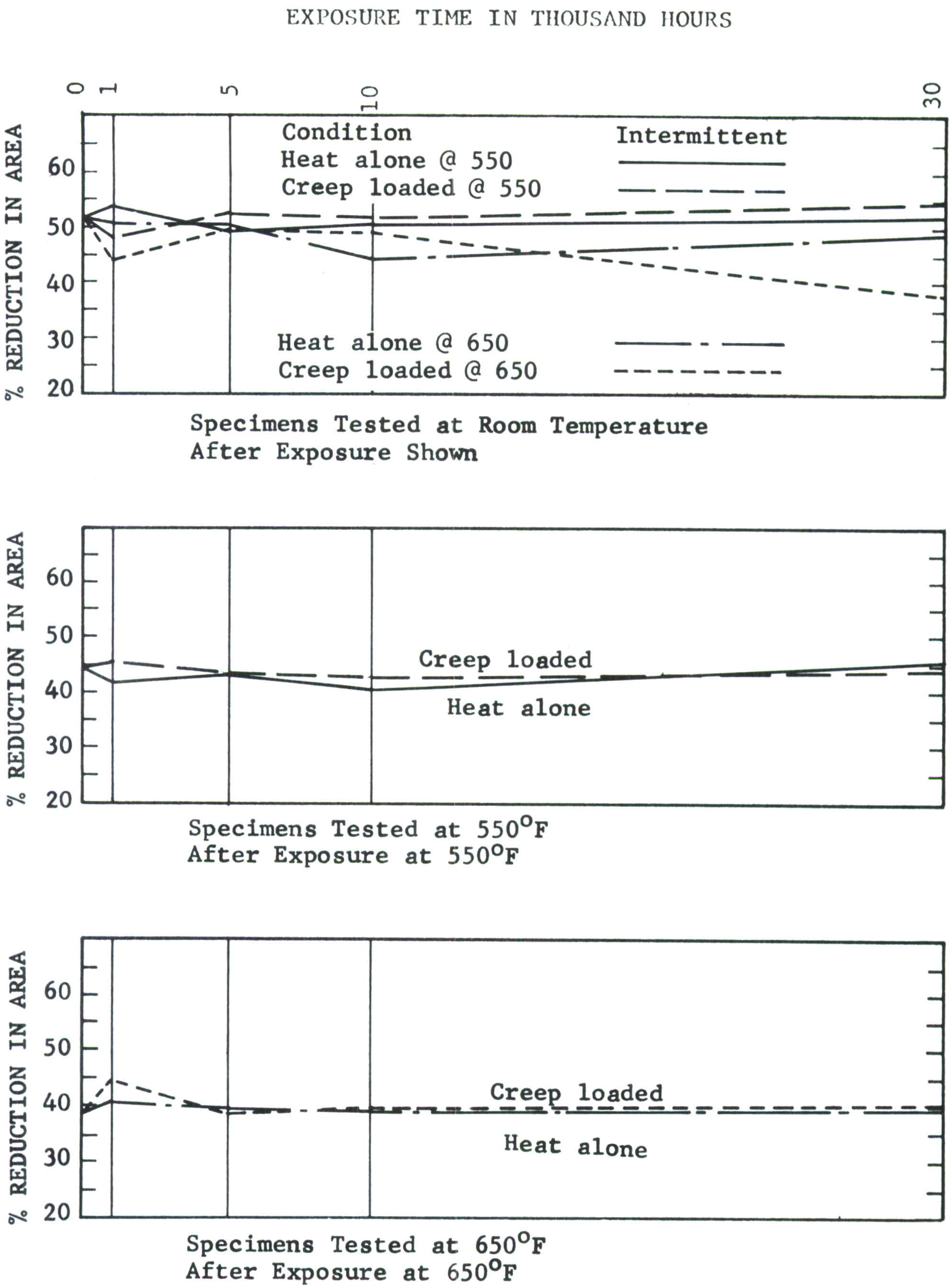


Figure 30 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON % REDUCTION IN AREA OF AM-350 SCT (825) STEEL

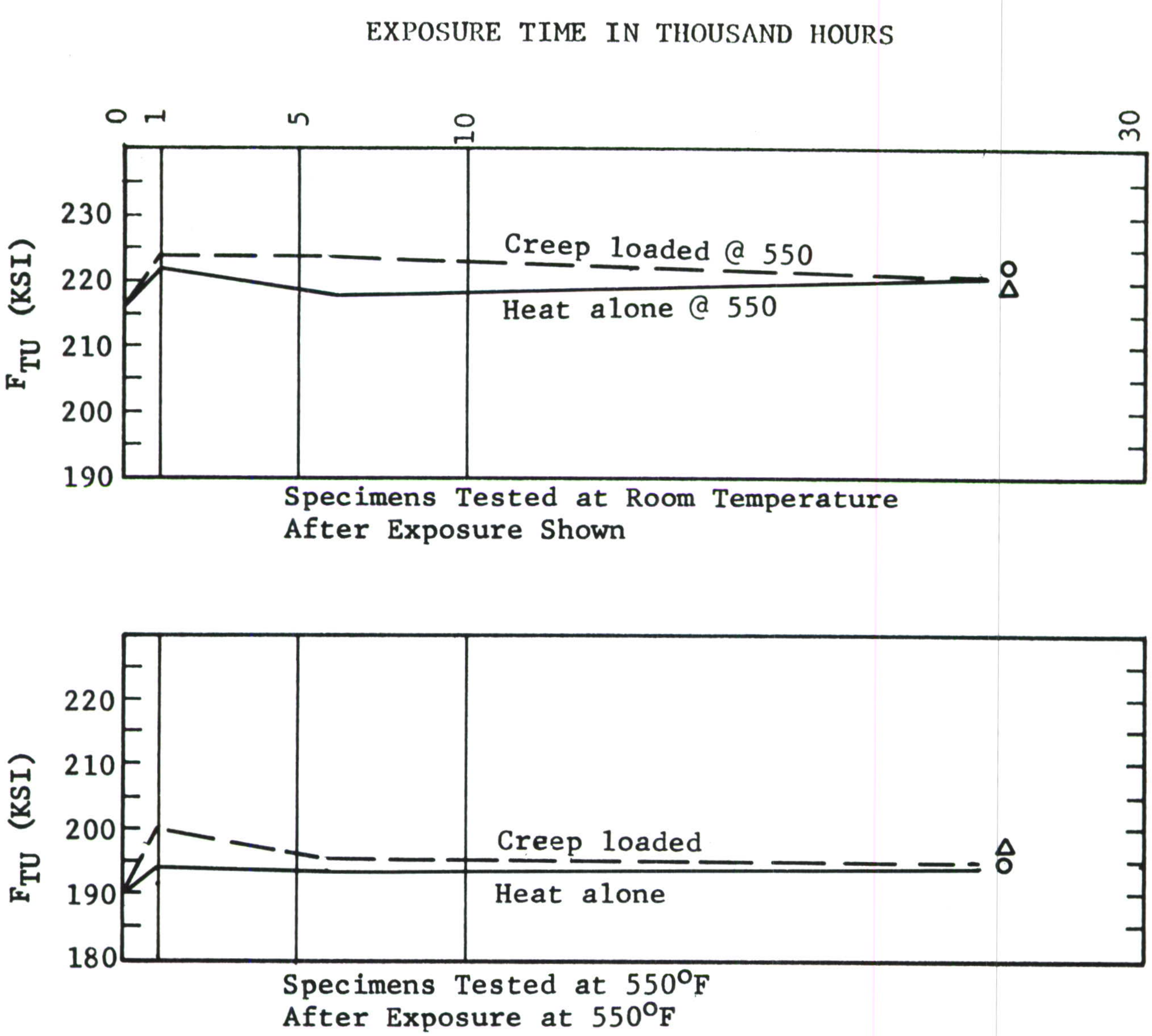


Figure 31 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON F_{TU} OF PH 14-8 Mo (SRH 1050)

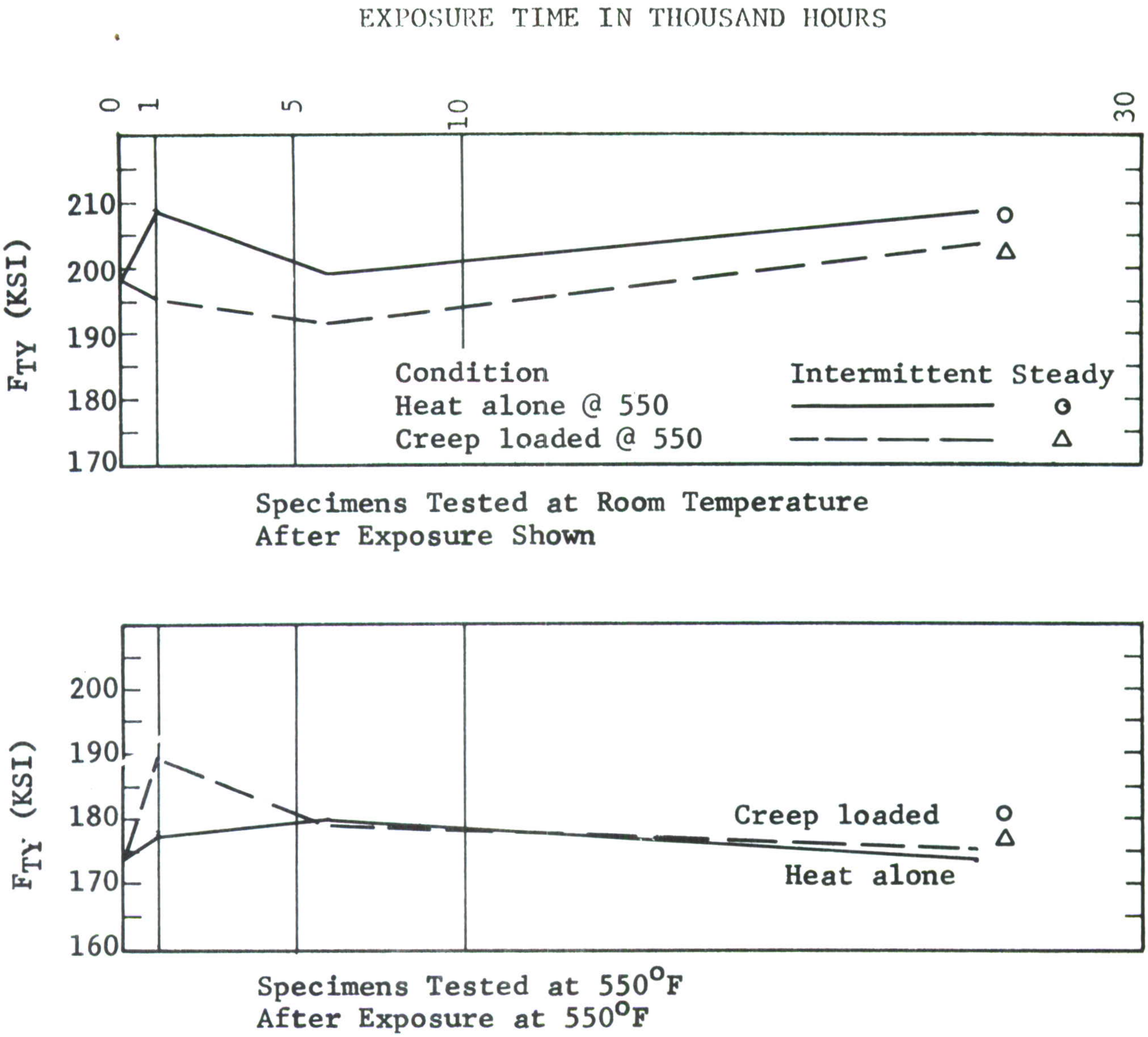


Figure 32 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON F_{TY} OF PH 14-8 Mo (SRH 1050)

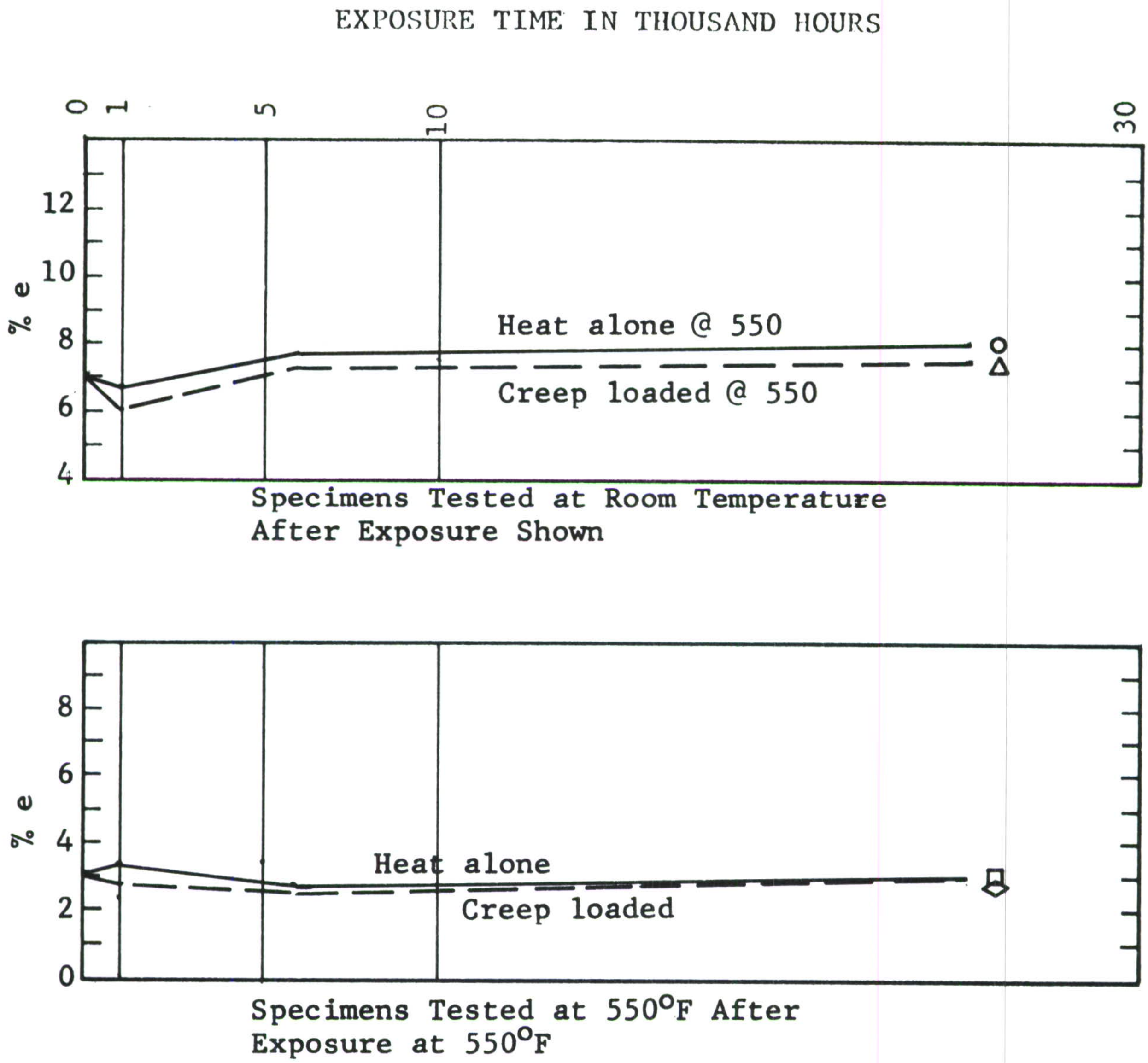


Figure 33 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON % e OF PH 14-8 Mo (SRH 1050)

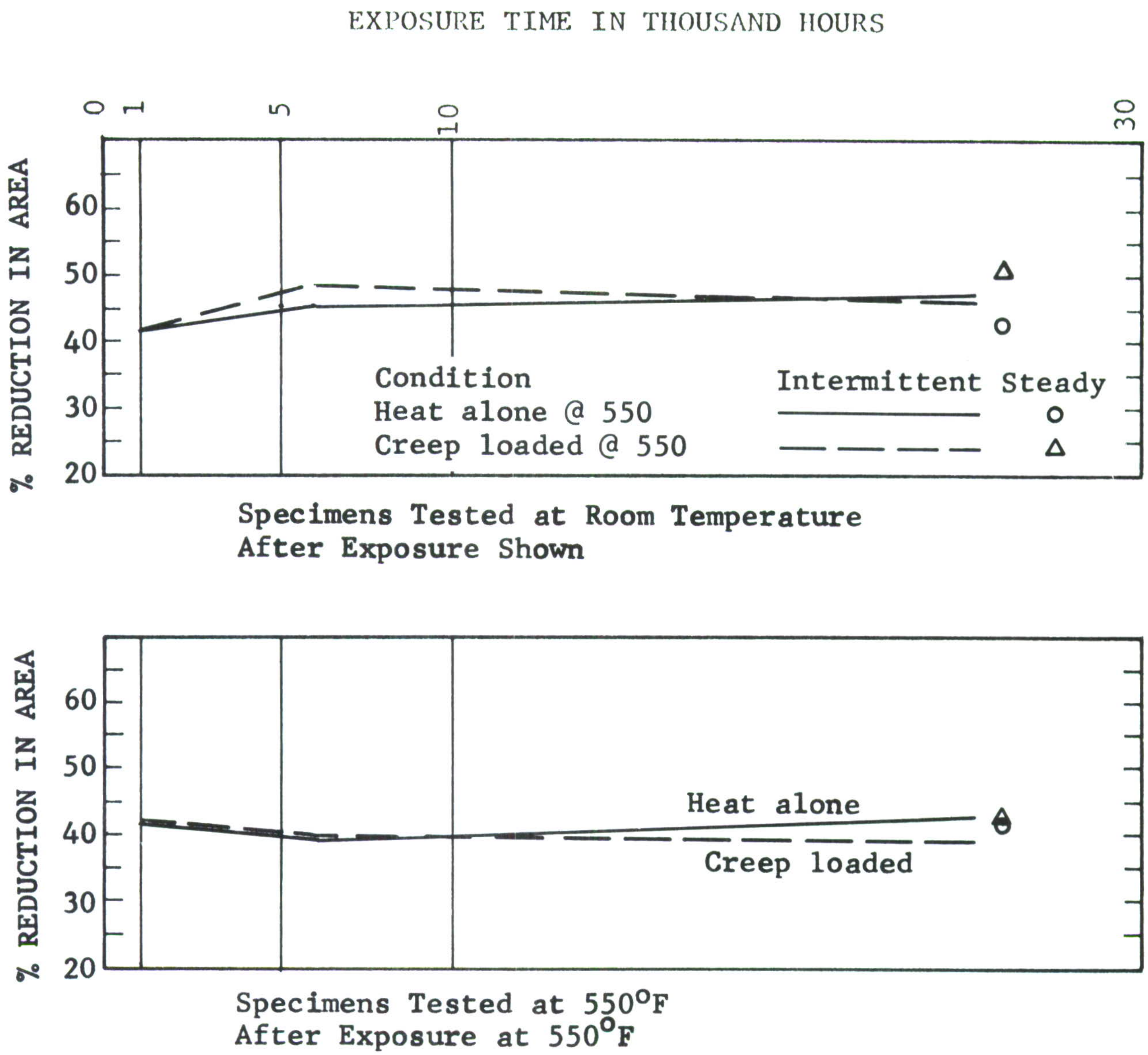


Figure 34 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON % REDUCTION IN AREA OF PH 14-8 Mo (SRH 1050)

was a rise in the yield and ultimate tensile strength after 1000 hours of exposure to heat or to creep. The F_{TU} and F_{TY} of specimens tested at room temperature after 1000 hours of creep at 650° are low as shown in Figures 35 and 36, but it should be pointed out that two of the three specimens tested failed at the extensometer grips whereas the third specimen had a yield and ultimate tensile strength in agreement with specimens tested after the other exposure conditions. Exposure time greater than 1000 hours tends to decrease the strength below the unexposed control level. The percent elongation of specimens static tested at their creep exposure temperature drops with exposure time up to 10,000 hours and back to the unexposed control percent elongation for 30,000 hours exposure as shown in Figure 37. The percent reduction in area does not appear to be influenced by exposure condition as shown in Figure 38. There is very good agreement between the tensile properties of the steadily exposed and the intermittently exposed specimens.

Ti-6Al-4V Titanium Alloy

The yield and ultimate tensile strength of Ti-6Al-4V titanium alloy appears to be independent of exposure at 550°F as shown in Figure 39 through 40. The percent elongation shown in Figure 41 shows some variations without any definite trends and it is believed the variations are due to experimental scatter. The percent reduction in area shown in Figure 42 is exceptionally constant. The 30,000 hour steadily exposed specimen data agrees very closely with the intermittently exposed specimen data.

Ti-8Al-1Mo-1V Titanium Alloy

The ultimate strength of the Ti-8Al-1Mo-1V appears to increase slightly up to 5000 hours of exposure to all conditions and from there on to decrease very slightly as shown in Figure 43. The variation is so slight that it could well be ignored. The tensile yield strength remains very constant as shown in Figure 44. The percent elongation has the usual scatter in data but there appears to be a slight drop in the values measured at room temperature after 5000 hours exposure as shown in Figure 45. The reduction in area shown in Figure 46 is constant within experimental error for all exposure conditions. There is very good agreement between the tensile properties measured after steady exposure and the tensile properties measured after intermittent exposure.

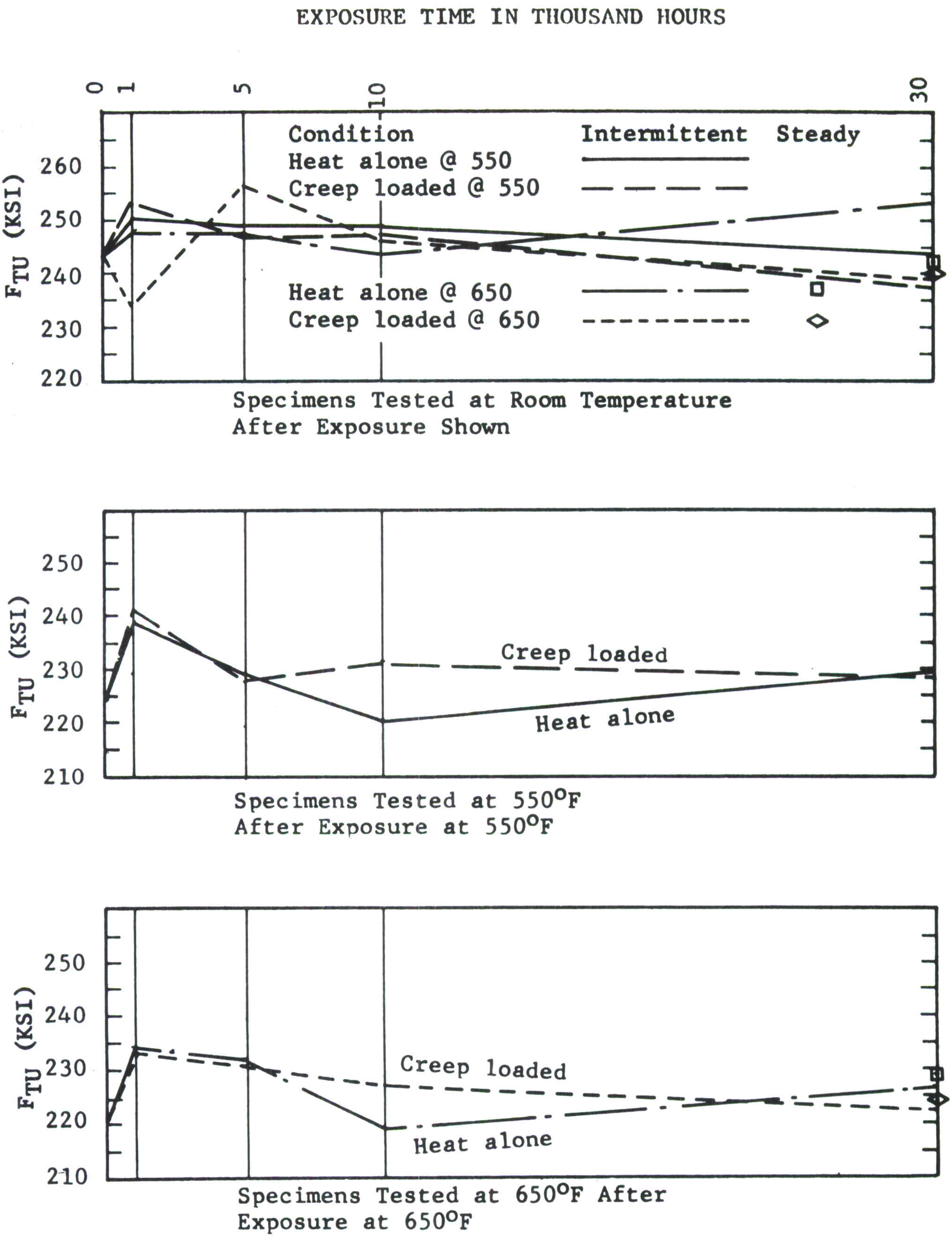


Figure 35 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON F_{TU} OF RENE' 41 (20% C.R. + 16 HRS. @ 1400°F)

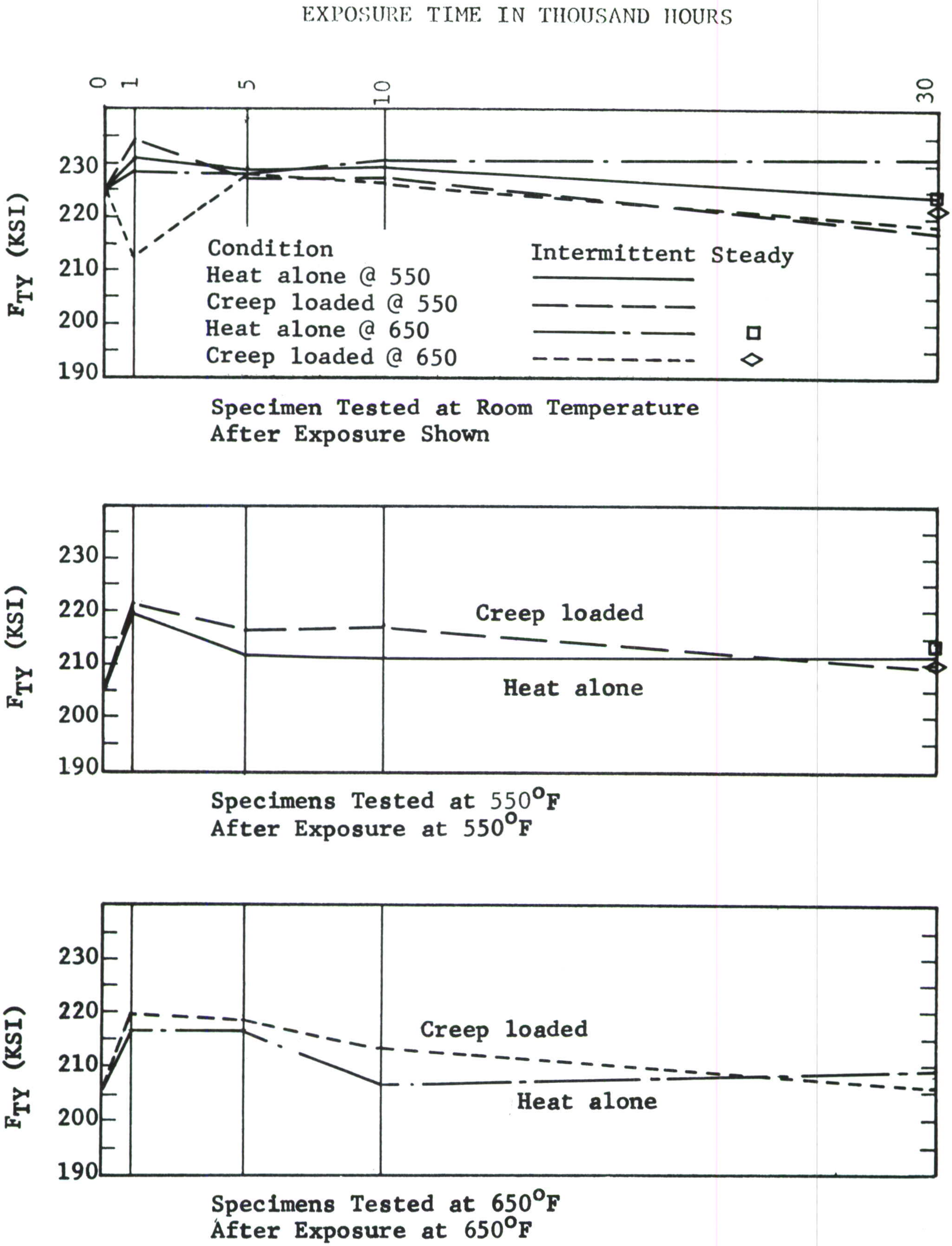


Figure 36 **INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP OF F_{TY} OF RENE' 41 (20% C.R. + 16 HRS. AT 1400°F)**

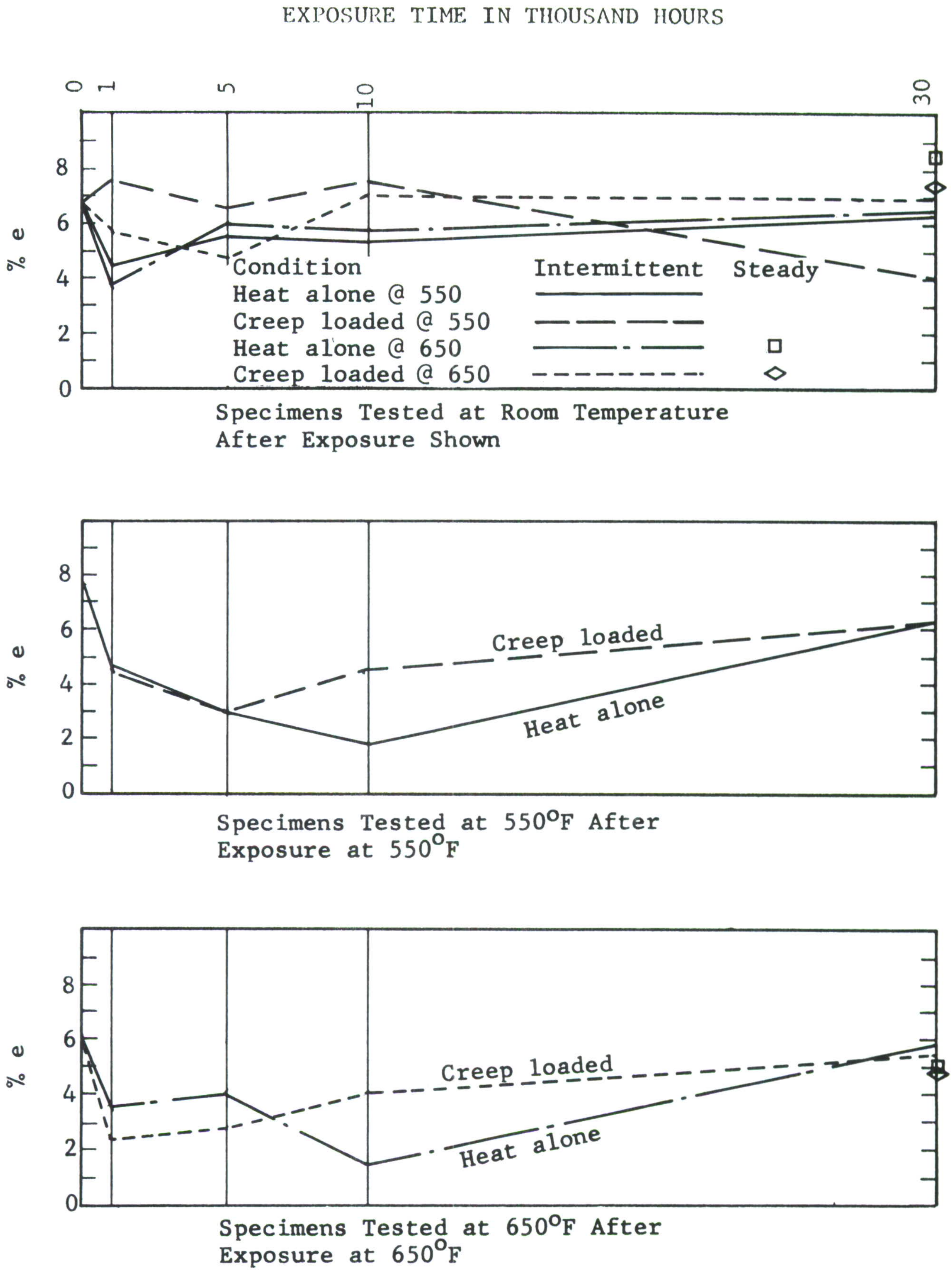


Figure 37 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON % e OF RENE' 41 (20% C.R. + 16 HRS. @ 1400°F)

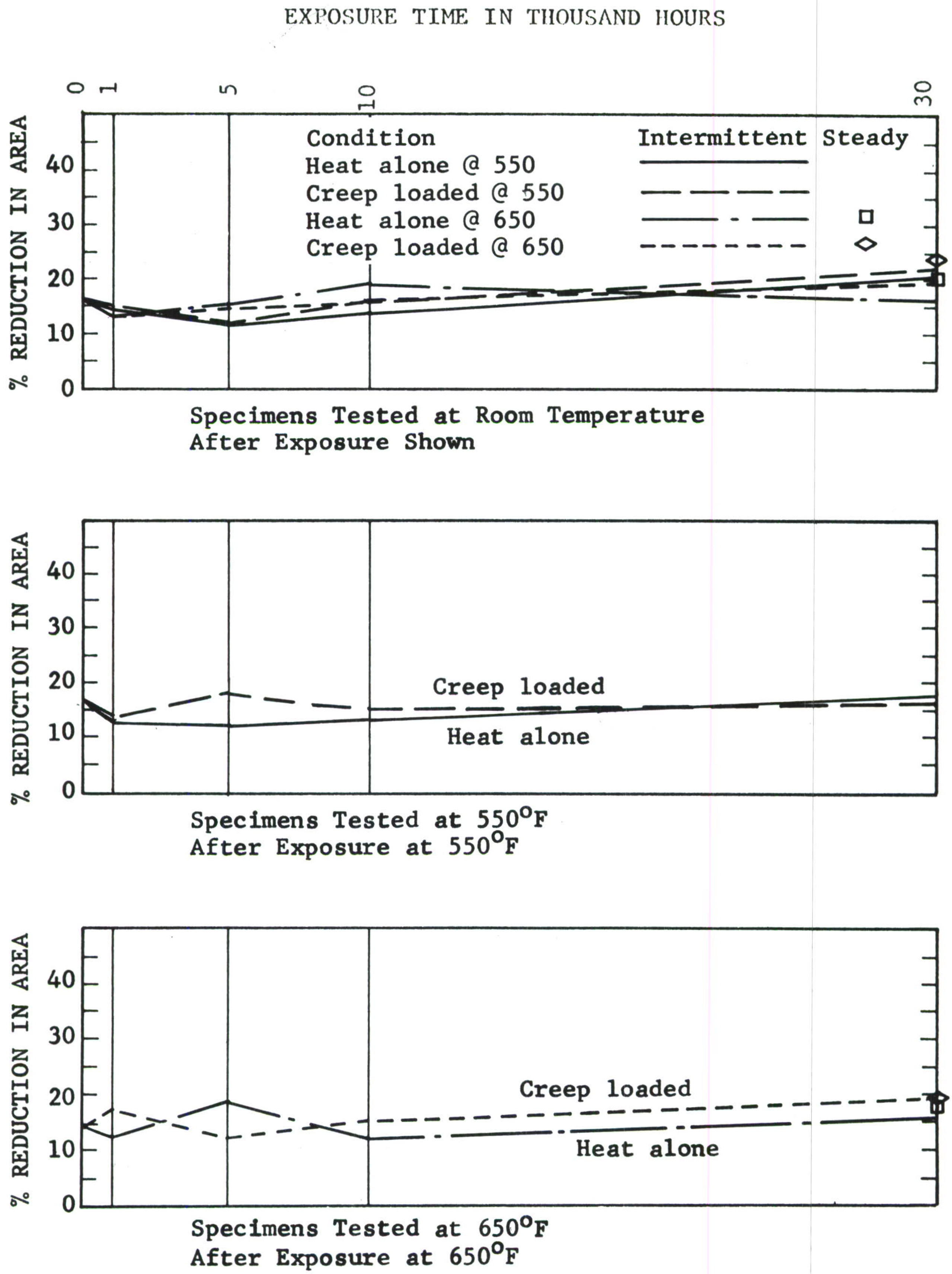


Figure 38 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON % REDUCTION IN AREA OF RENE' 41 (20% C.R. + 16 HRS. @ 1400°F)

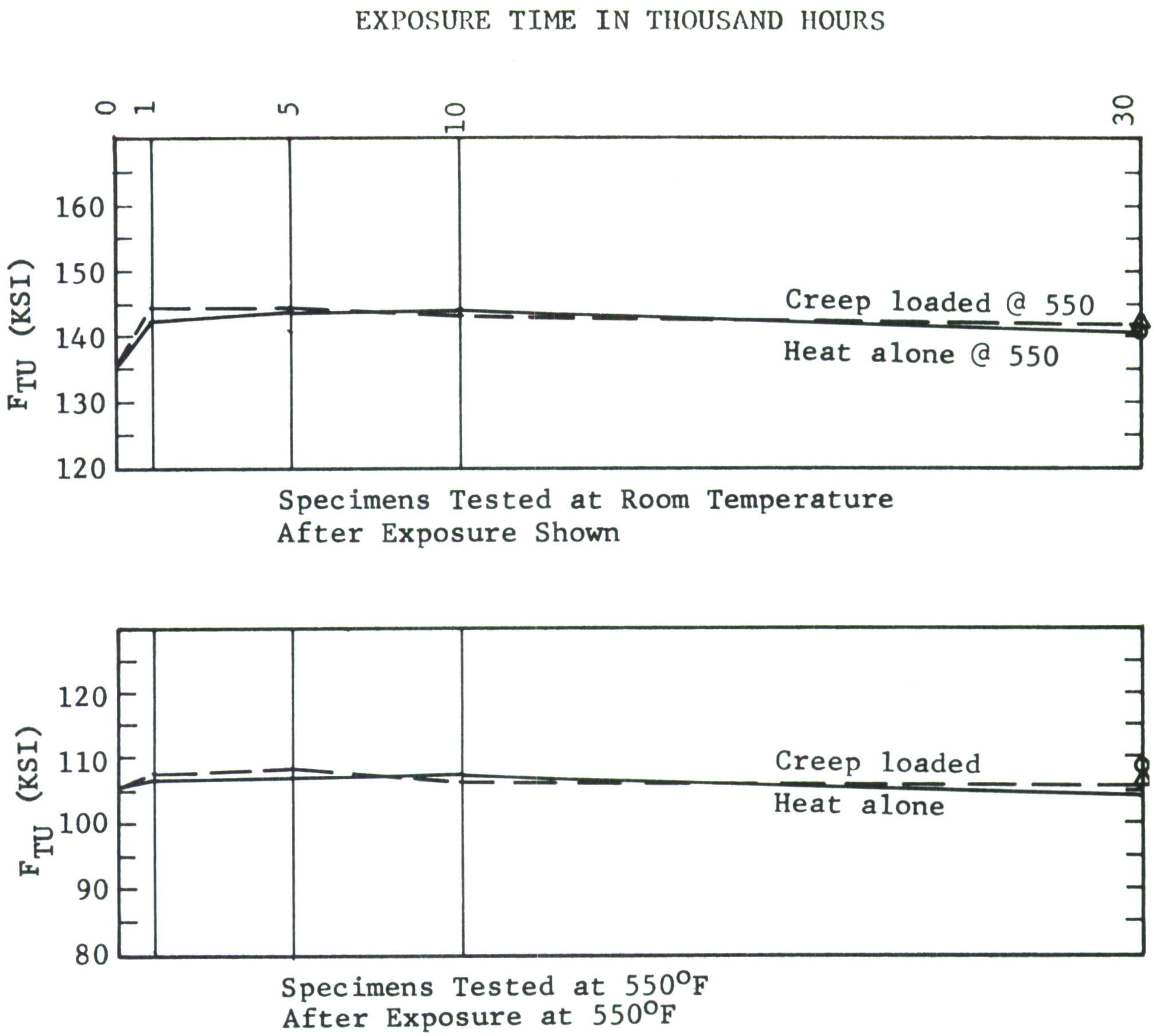


Figure 39 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON F_{TU} OF Ti-6Al-4V (MILL ANNEALED)

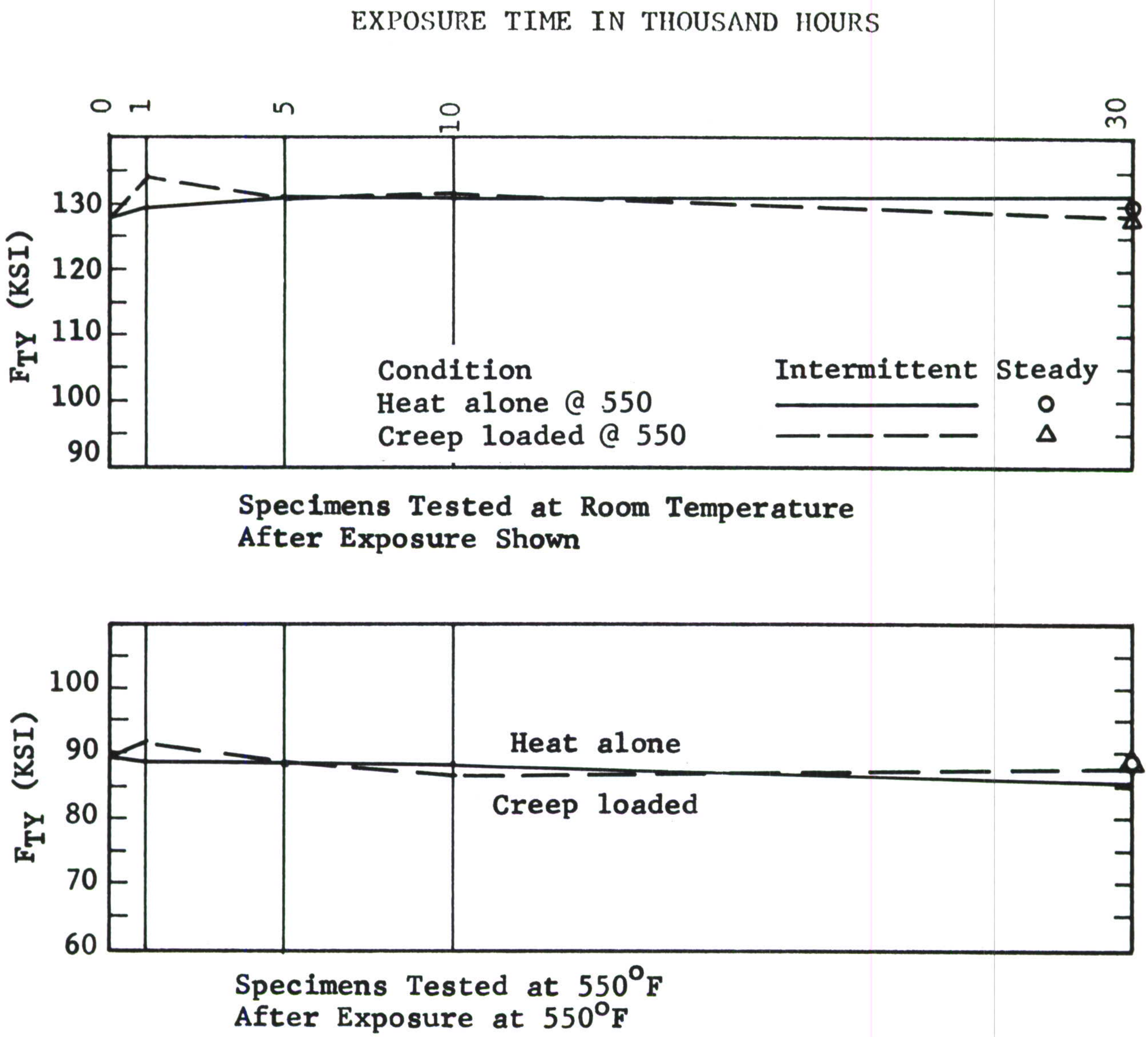


Figure 40 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON F_{TY} OF Ti-6Al-4V (MILL ANNEALED)

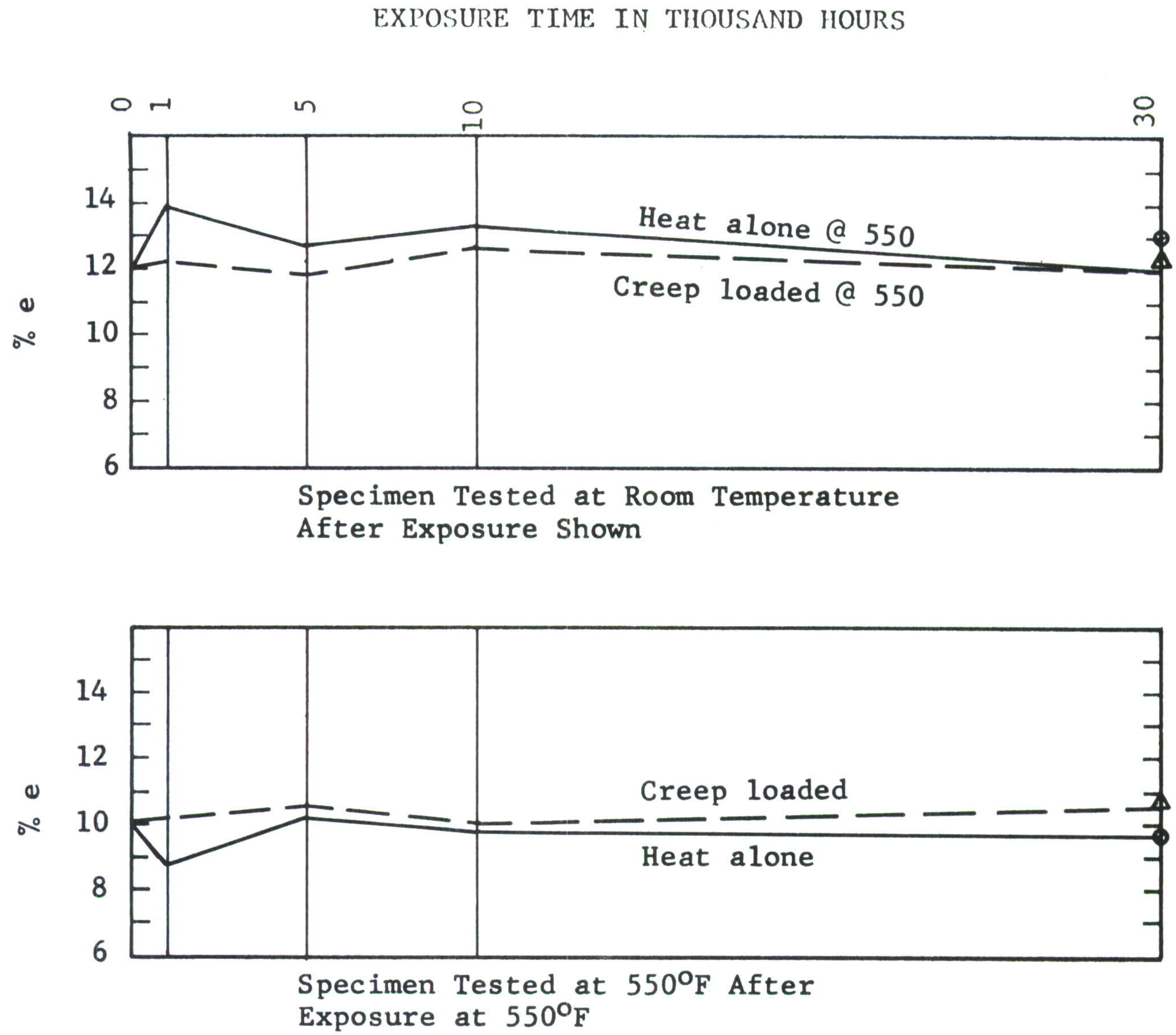


Figure 41 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON % e OF Ti-6Al-4V (MILL ANNEALED)

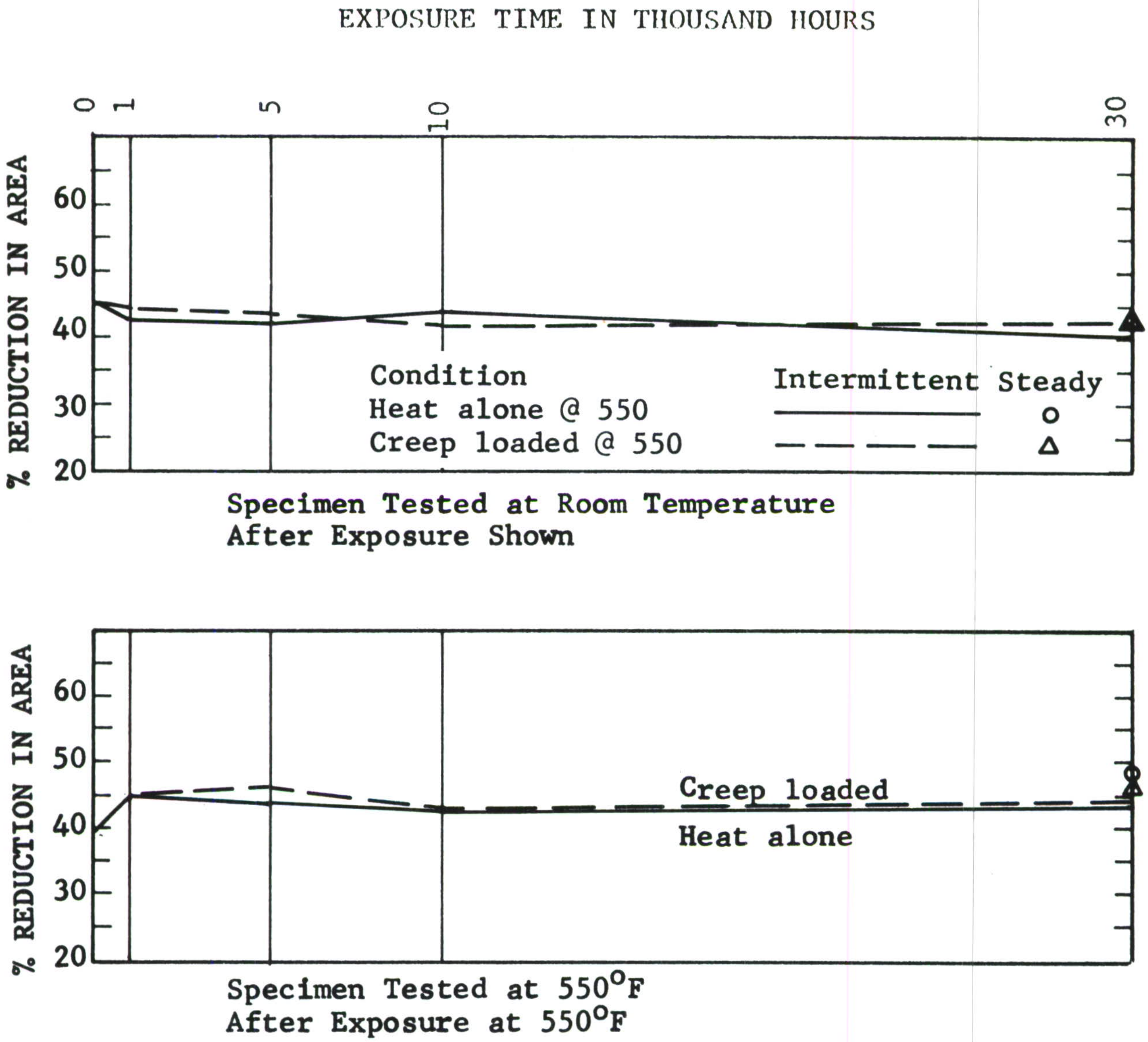


Figure 42 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON % REDUCTION IN AREA OF Ti-6Al-4V (MILL ANNEALED)

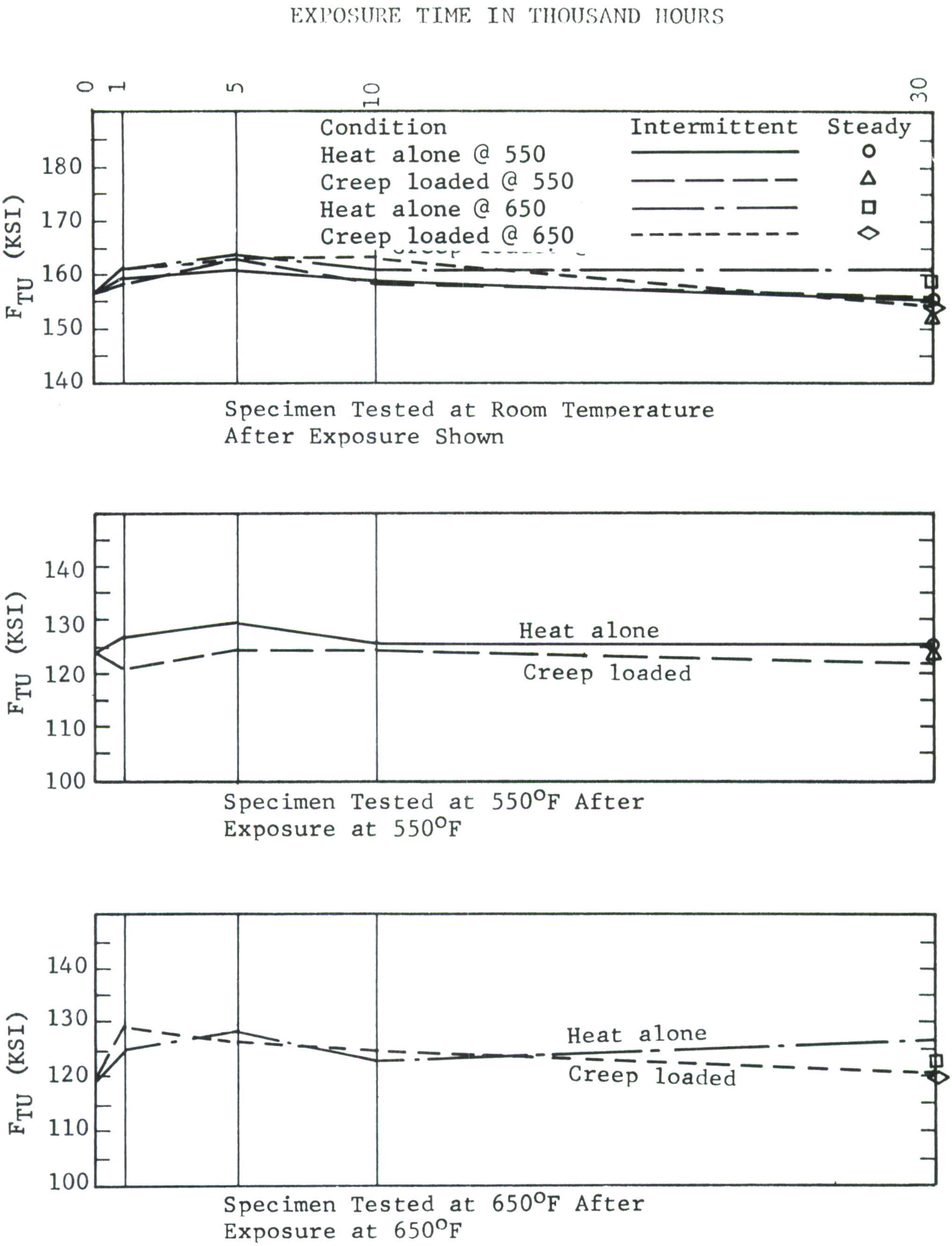


Figure 43 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON F_{TU} OF Ti-8Al-1Mo-1V (DUPLEX ANNEALED)

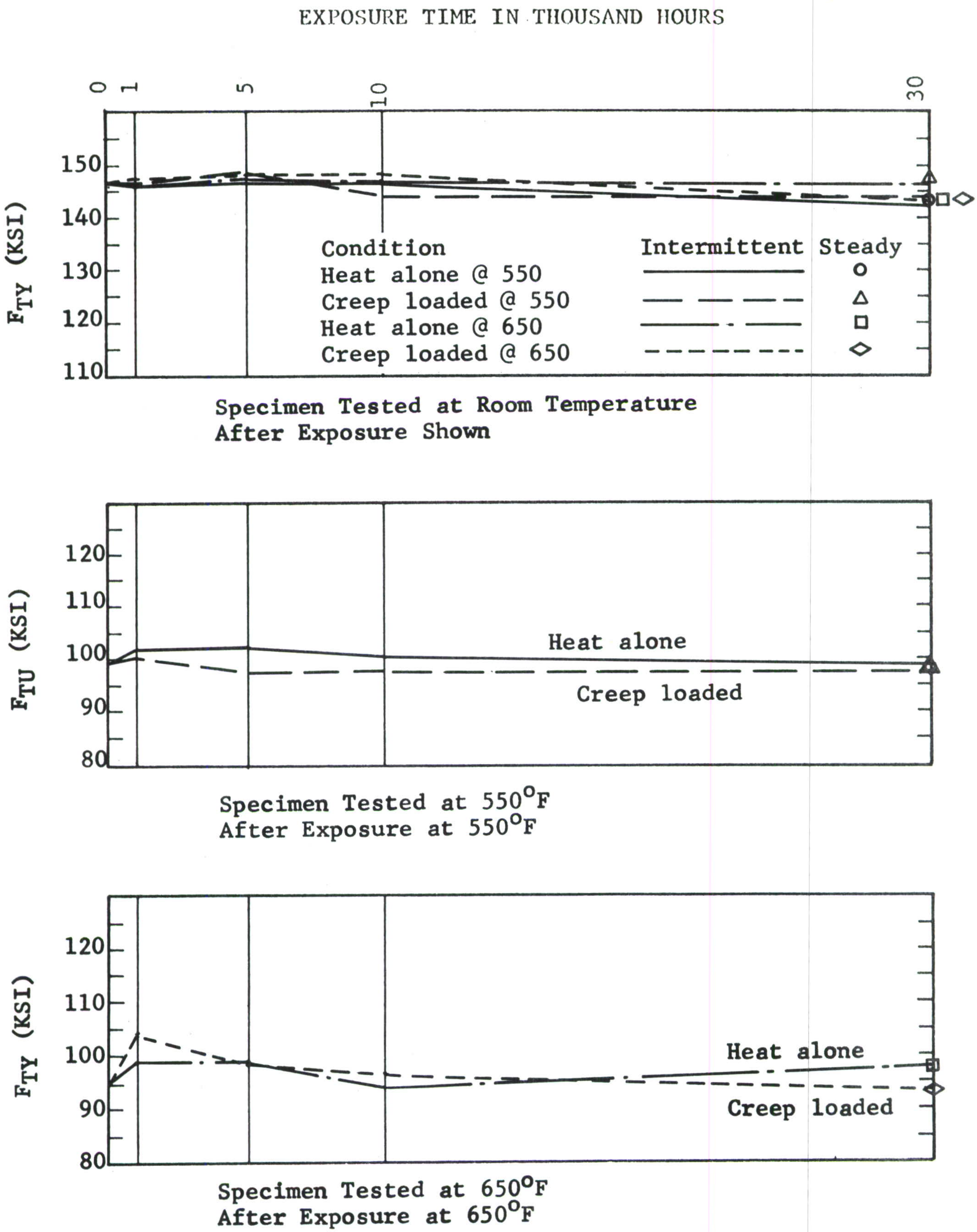


Figure 44 **INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON F_{TY} OF Ti-8Al-1Mo-1V (DUPLEX ANNEALED)**

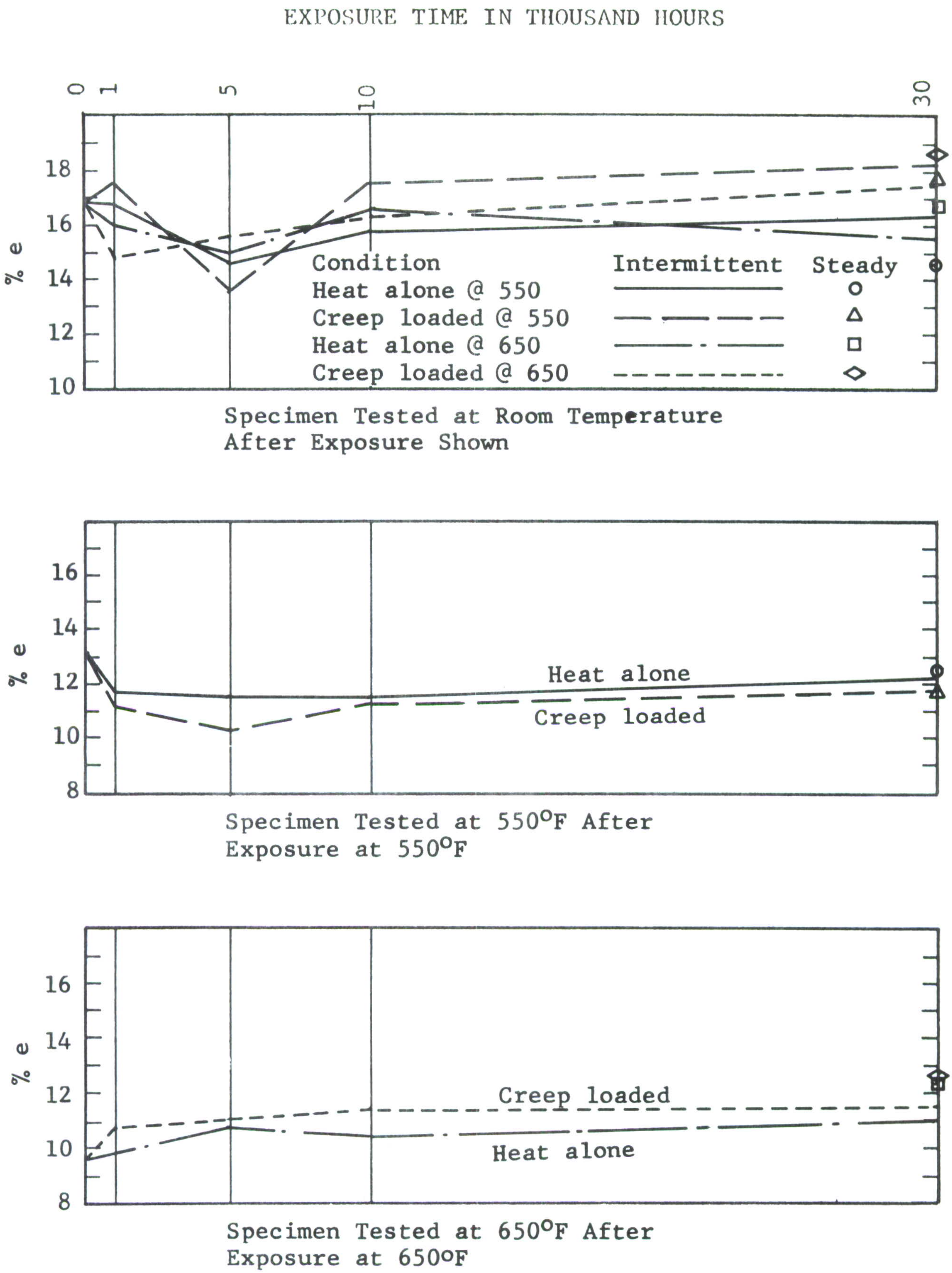


Figure 45 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON % e OF Ti-8Al-1Mo-1V (DUPLEX ANNEALED)

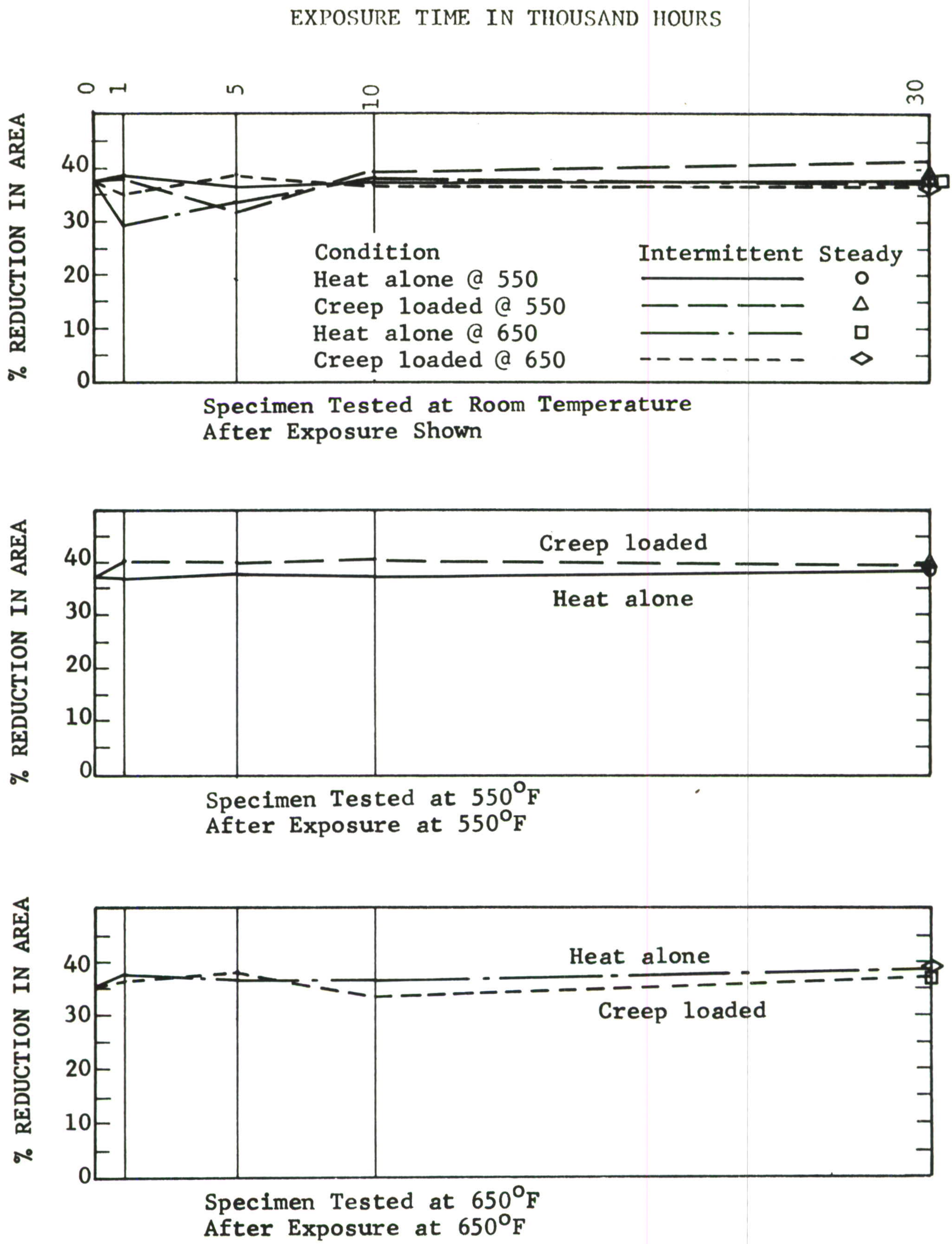


Figure 46 INFLUENCE OF EXPOSURE TO HEAT AND TO CREEP ON % REDUCTION IN AREA OF Ti-8Al-1Mo-1V (DUPLEX ANNEALED)

Fracture Toughness

One requirement of this program was to compare the stress intensity factor for onset of fast crack propagation, K_c, versus time for each material after each exposure condition. At the time this program was formulated (1961), the specimen size selected was within the existing recommendations of the ASTM Special Committee on Fracture Testing of High-Strength Metallic Materials (Reference 1). There has been considerable advancement in the field of fracture mechanics since that time. It has since been agreed that K_c is not a material property but varies with specimen geometry. Larger specimens than were tested in this program should be used for determining minimum values of K_c. Since the specimen size was kept constant throughout the program, the K_c determined is quite valid for comparison purposes within the test conditions for each alloy. However, discretion should be exercised in using the values of K_c obtained in this investigation or in comparing them with K_c values measured in other tests.

K_c was calculated using Irwin's tangent formula

$$K_c = \sigma \left[W \tan \frac{\pi a}{W} \right]^{\frac{1}{2}}$$

where σ = gross stress at rupture

W = specimen width

$a = \dfrac{\text{Crack length}}{2}$ at the transition

from slow crack growth to fast fracture.

Recommended calculation of K_c is by the modified formula

$$K_c = \sigma \left[W \tan \frac{\pi}{W} \quad (a + r_p) \right]^{\frac{1}{2}}$$

where r_p is the plastic zone radius given by

$$r_p = \frac{1}{2\pi} \left(\frac{K_c}{\sigma_y} \right)^2 \quad \text{in inches}$$

and σ_y = yield stress

Irwin (Reference 7) originally proposed this plastic zone radius correction for K_c with the assumptions that it would be small with respect to ½x(crack length). A test is considered valid if the net stress at fracture (σ_N) is equal to or less than 0.8 σ_y. Now assume

$$K_c = \sigma_N$$

Using 0.8 for K_c/σ_y then

$$r_p = \frac{1}{2\pi} (0.8)^2 = 0.102 \text{ inch}$$

The initial ½x(crack length) used was approximately 0.18 inch. Thus, r_p, so calculated, is not small compared to ½x(crack length) and it is approximately four times the 0.025 inch thickness of the specimen. Therefore, the basic assumptions for calculating r_p were exceeded and the use of r_p as the plastic zone size is not justified for this size specimen.

Each crack length, 2a, was measured from the enlarged photograph of the last frame of 16 mm movie film exposed just before catastrophic crack propagation occurred. Examples of the last two frames, photographed prior to rupture, for each material are shown in Figures 47 through 51. Measurements made of the crack length included the dimple at the end of the crack to allow for tunneling and plastic zone correction.

The reasonableness of this approach as applied to the 0.025 inch thick specimens is demonstrated in Figure 52. Measuring to the apex of the crack in Figure 52C includes the plastically deformed material along the triangular sides of the crack and should be a sufficient plastic zone correction.

In addition to K_c it was desired that K_{Ic} be calculated if the data permitted. The compliance gage output as recorded on the oscillograph record was used to detect "pop-in" if it occurred. Only the tests performed at -65°F on the AM-350 SCT (825) steel showed any signs of "pop-in." However, all of the records showed a deviation from linearity when compliance gage deflection was plotted versus load. In the initial report on this program, AFML-TDR-64-138, the load at the point of deviation from linearity was used for calculating the stress for onset of slow crack growth. The validity of this stress was suspect and K_{Ic} was not shown.

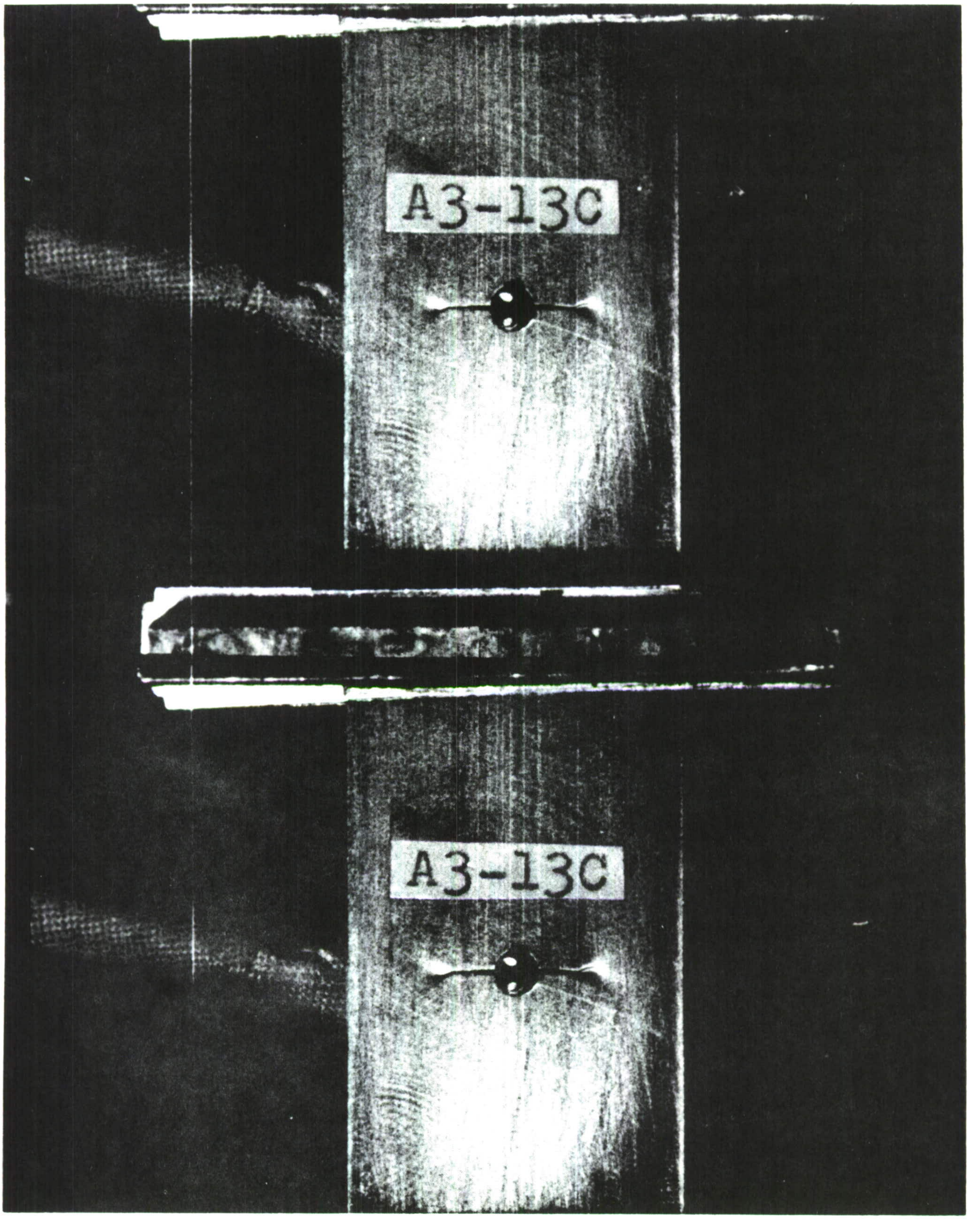


Figure 47 AM-350 SCT (825°) STAINLESS STEEL FRACTURE TOUGHNESS SPECIMEN JUST PRIOR TO COMPLETE RUPTURE (MAG. 2.65)

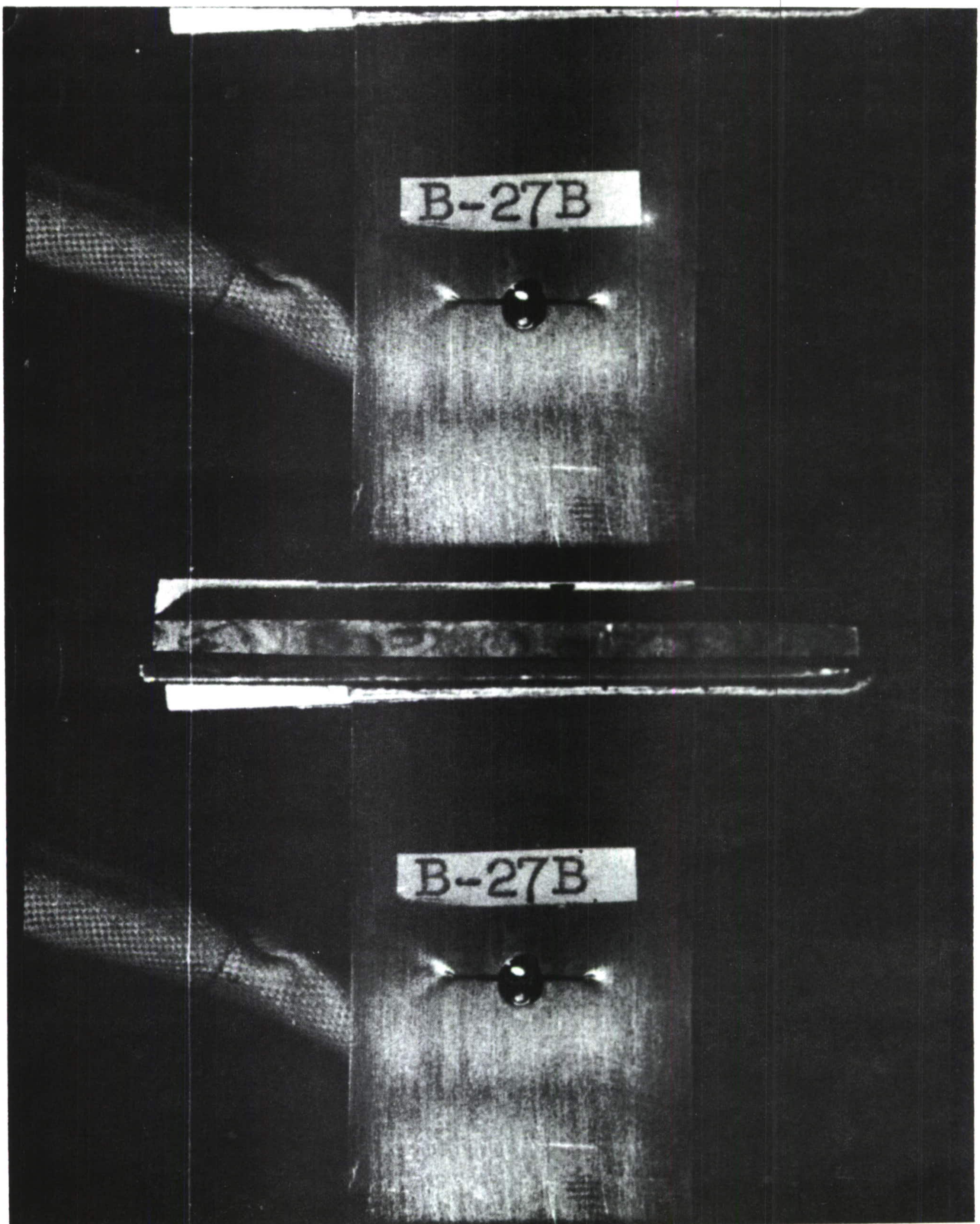


Figure 48 PH 14-8 Mo (SRH 1050) STAINLESS STEEL FRACTURE TOUGHNESS SPECIMEN JUST PRIOR TO COMPLETE RUPTURE (MAG. = 2.65)

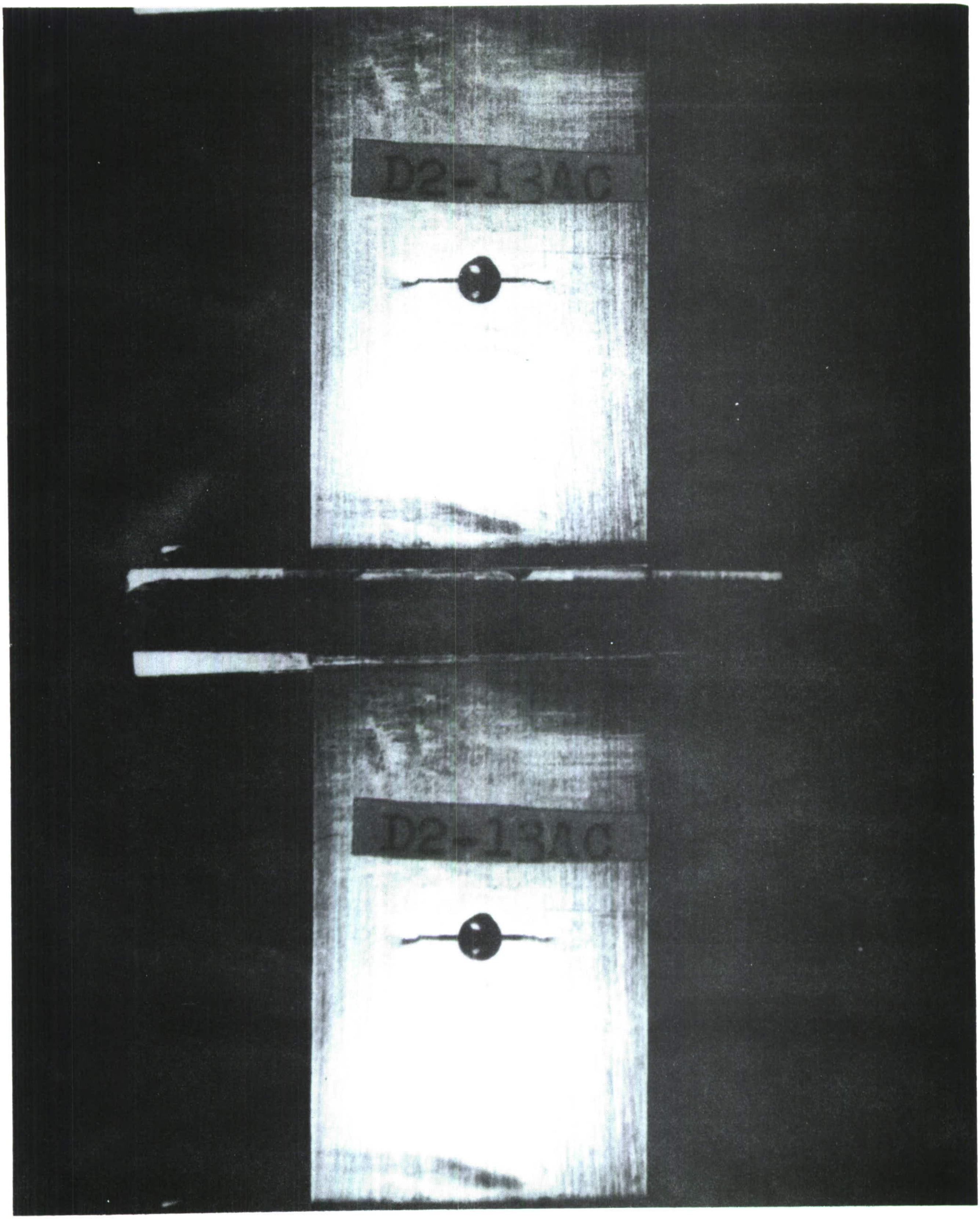


Figure 49 RENE' 41 (20% C. R. + 16 HRS. @ 1400^{o}F) SUPERALLOY FRACTURE TOUGHNESS SPECIMEN JUST PRIOR TO COMPLETE RUPTURE (MAG. = 2.60)

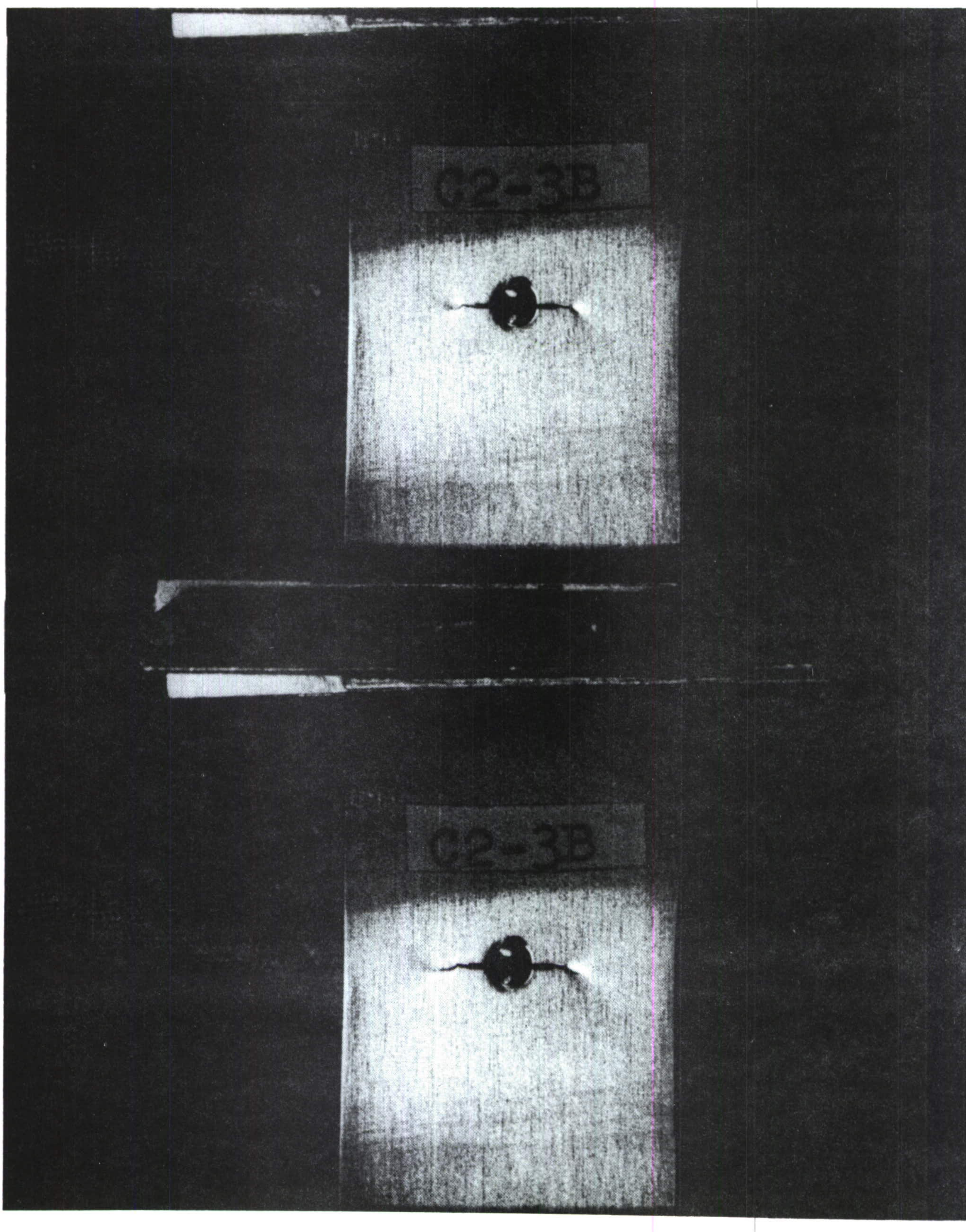


Figure 50 Ti-6Al-4V (MILL ANNEALED) TITANIUM ALLOY FRACTURE TOUGHNESS SPECIMEN JUST PRIOR TO COMPLETE RUPTURE (MAG. = 2.60)

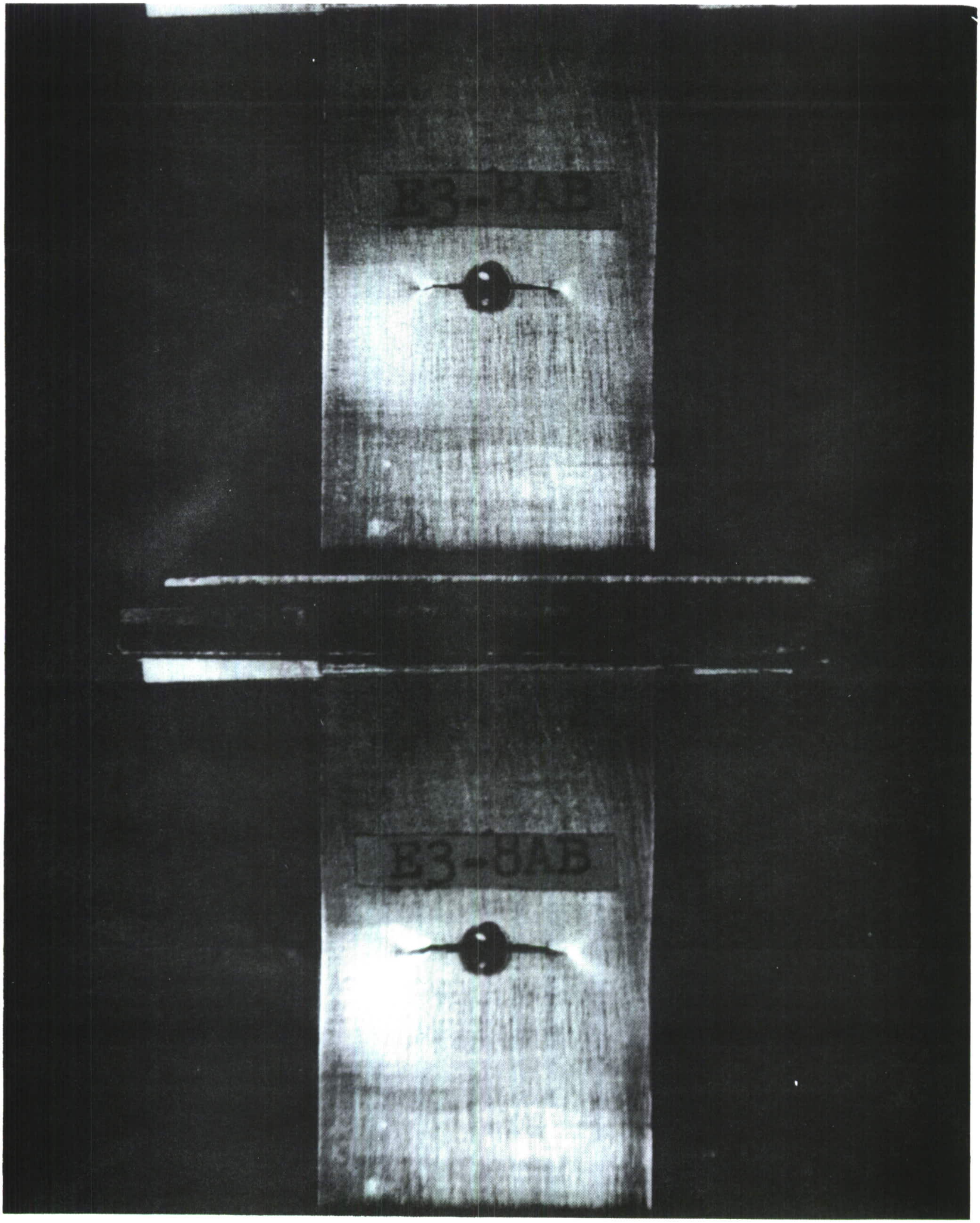


Figure 51 Ti-8Al-1Mo-1V (DUPLEX ANNEALED) TITANIUM ALLOY FRACTURE TOUGHNESS SPECIMEN JUST PRIOR TO COMPLETE RUPTURE (MAG. = 2.60)

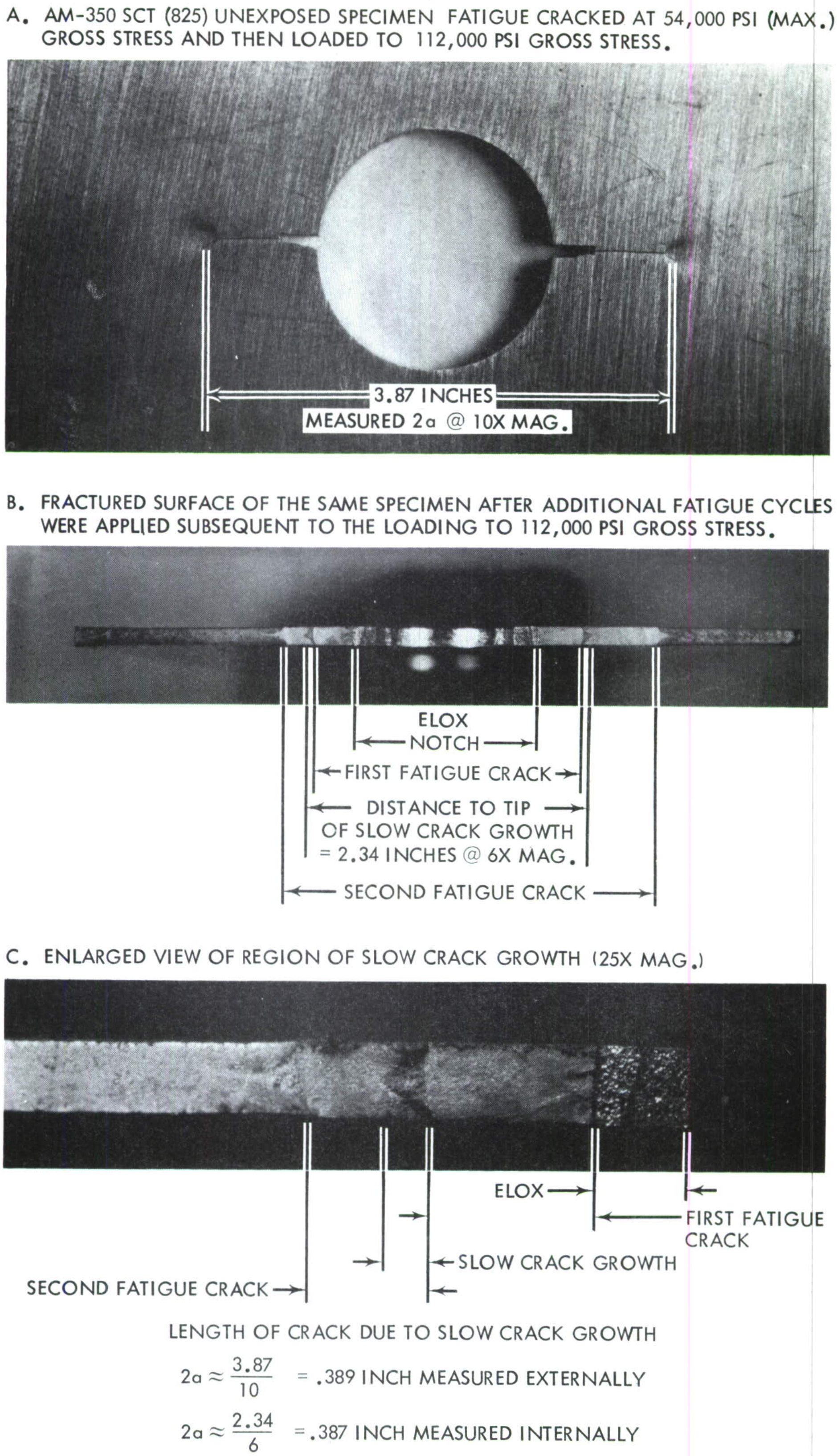


Figure 52 AM-350 Specimen A3-5 Showing Plastic Deformation And Well Defined Slow Crack Growth After Loading To 2800 Pounds

Since that time, further investigations have been made of the significance of the deviation from linearity. This investigation consisted of preparing groups of 3 unexposed specimens exactly the same as the control fracture toughness specimens, loading one to the point of deviation from linearity, another to a load half way between the point of deviation from linearity and failure and the third to a load approximately ten percent below the expected failing load. These specimens were then returned to the fatigue machine and the fatigue crack propagated for another 30,000 cycles. Finally, the specimens were loaded to failure. (Note: This is the technique as used to produce the photographs in Figure 52.) The initial slow crack growth was isolated between two fatigue cracked regions. Oscillographic time histories of load and compliance gage deflection were made while the one high stress cycle was being applied. AM-350 SCT (825) steel and René 41 were tested in sets of 3. Only one PH 14-8 Mo (SRH 1050) specimen was available so two PH 15-7 Mo (RH 1100) specimens were used to make up that set of 3.

The load versus compliance gage deflection plots and photographs of the fractured surface of each of the three AM-350 specimens is shown in Figure 53. Similar plots and photographs for the René 41 are shown in Figure 54 and the plots and photographs for the PH 15-7 Mo and PH 14-8 Mo are shown in Figure 55. The pertinent data is as follows.

Specimen	Material	Initial Crack Length (inches)	Max. Load (pounds)
A1-2	AM-350 SCT/825	.365	1590
A3-4	AM-350 SCT/825	.356	2200
A3-5	AM-350 SCT/825	.367	2800
D3-7	René 41	?	1780
D3-10C	René 41	.356	2240
D2-15C	René 41	.367	2580
B1-13B	PH 15-7 Mo (RH 1100)	.367	1600
B5	PH 14-8 Mo (SRH 1050)	.372	2200
B1-13C	PH 15-7 Mo (RH 1100) (Photograph not shown)	.350	Failed at 2310

Specimen A1-2 of the AM-350 set was loaded just beyond the point of deviation from linearity whereas specimens A3-4 and A3-5 were loaded well beyond. In every case the load-deflection diagrams indicate plastic deformation occurring. The photograph of specimen A1-2 shows a very small indication after the one time, high-load

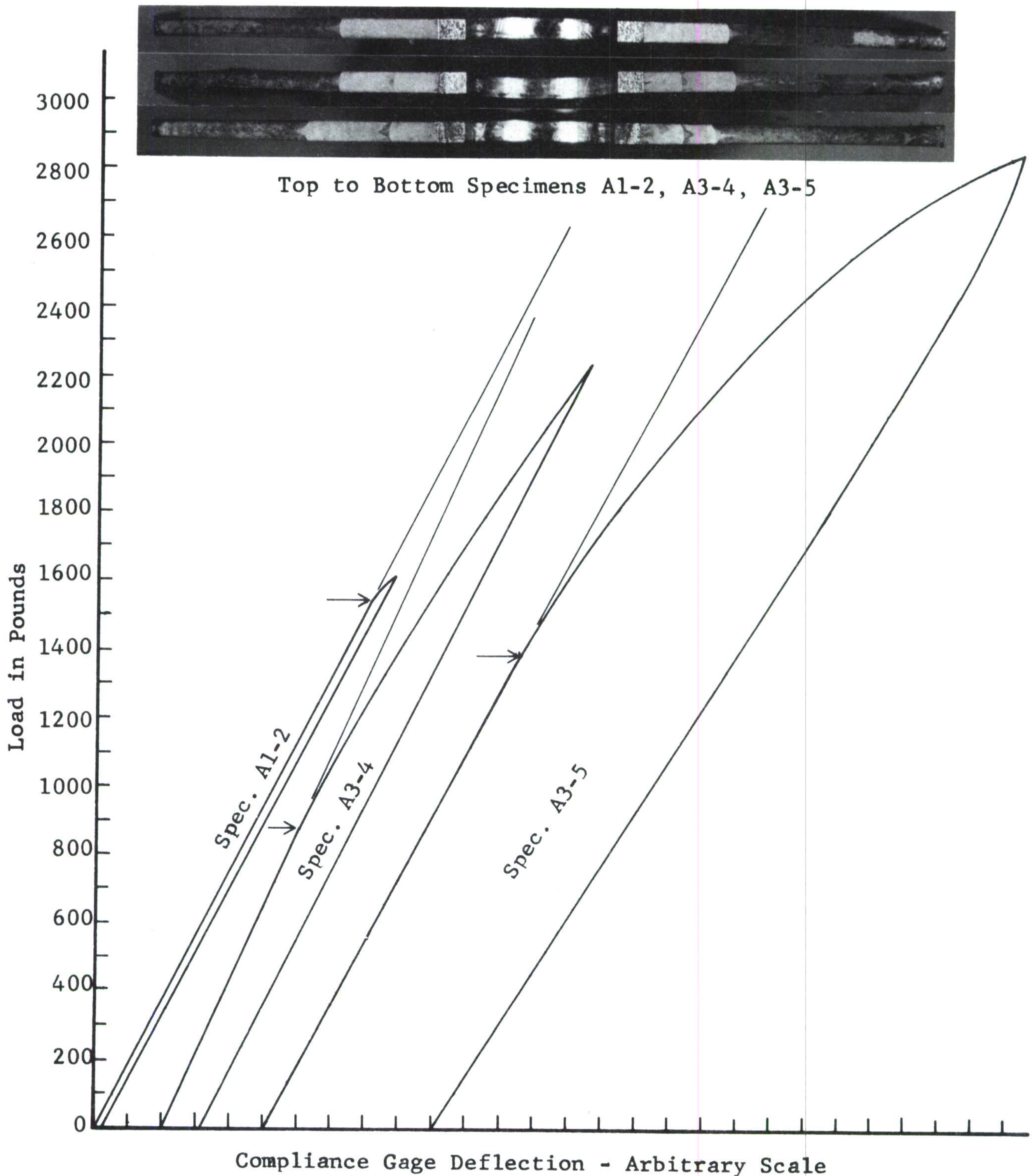


Figure 53 Comparison of Effects of Loading on Crack Propagation in AM-350 SCT (825) Stainless Steel.

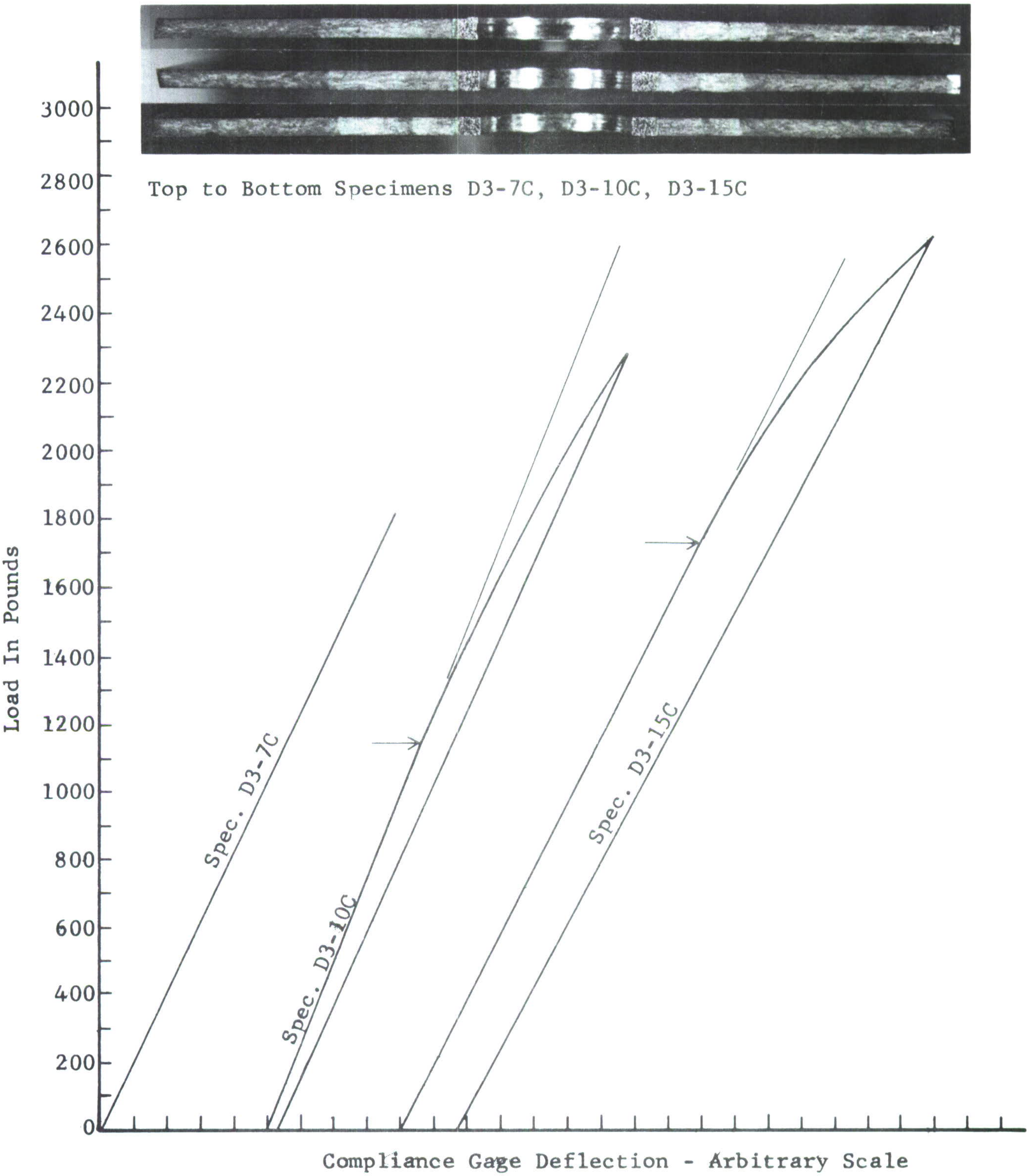


Figure 54 Comparison of Effects of Loading on Crack Propagation in Rene' 41 (20% Cold Rolled + 16 Hours @ 1400°).

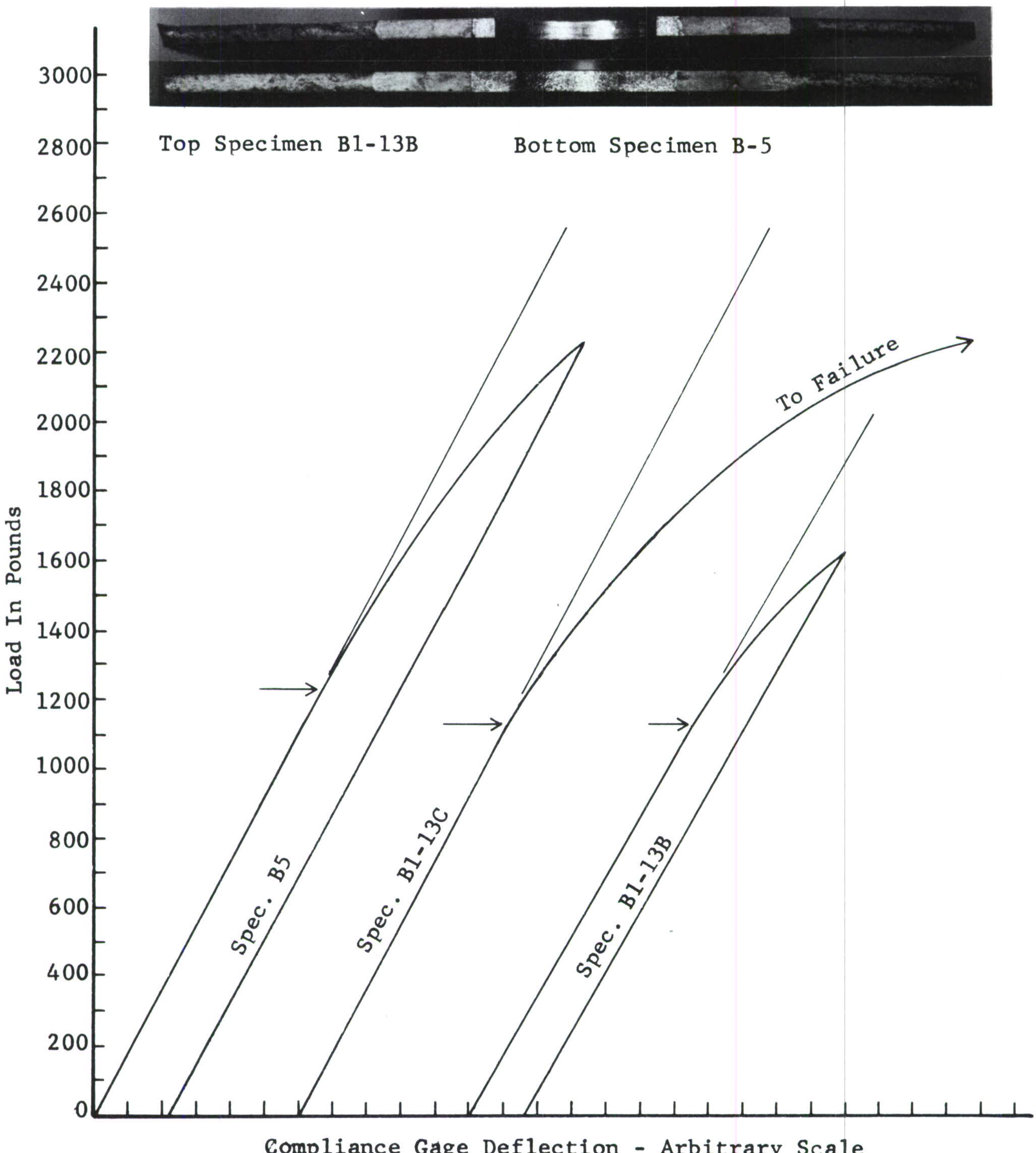


Figure 55 Comparison of Effects of Loading on Crack Propagation in PH 14-8 Mo (SRH 1050) and PH 15-7 Mo (RH 1100) Stainless Steel.

cycle between the two fatigue cracked regions. Specimen A3-4 shows some slow crack growth and there is very definite slow crack growth shown in the photograph for specimen A3-5. An enlarged view of the slow crack growth (triangular, dark area) along with the permanent separation of the fatigue crack and plastic dimples at the end of the crack are shown in Figure 52. This photograph clearly shows that the deviation from the straight line is resulting from a mixed mode of crack propagation plus plastic flow.

The load-deflection diagram for the René 41 specimen D3-7C in Figure 54 is a straight line with no indication of inelastic behavior. The corresponding photograph of the fractured surface shows no evidence of crack growth. The load-deflection curve for specimen D3-10C shows inelastic behavior but it is not evident as slow crack growth in the photograph. There is definite inelastic behavior shown by the load deflection diagram for specimen D2-15C and some evidence of slow crack growth shown in the photograph but it does not have the usual triangular pattern as found in the AM-350 steel. A photograph in Figure 56 of specimen D2-15C taken after the application of the 2580 pound load shows plastic dimples at the end of the fatigue crack but only a slight crack separation.

The PH 15-7 Mo specimen (B1-13B) tested to 1600 pounds shows evidence of plastic dimple formation but indiscernible slow crack growth. The load-deflection curve and the photograph of the fractured surface also indicate this. The PH 14-8 Mo specimen loaded to 2200 pounds shows inelastic behavior in the load-deflection diagram as well as slow crack growth in the accompanying photograph of Figure 55. The side photograph of the specimen shown in Figure 57 definitely shows plastic deformation at the end of the fatigue cracks with only a slight separation in the crack. Specimen B1-13C failed prematurely and did not yield any information.

With this evidence at hand it was concluded that the point of deviation from linearity was more likely to be the point of onset of plastic flow than the onset of slow crack growth and K_{Ic} could not be calculated using this value.

Perhaps the most meaningful and least controversial interpretation of the data can be had by comparing the residual gross fracture stress after each exposure condition. The residual gross fracture stress is the failing load divided by the unnotched cross-sectional area of the specimen. Since all specimens had nominally the same thickness and width, variations in geometry are excluded and the comparison of results after various exposure conditions is a valid one.

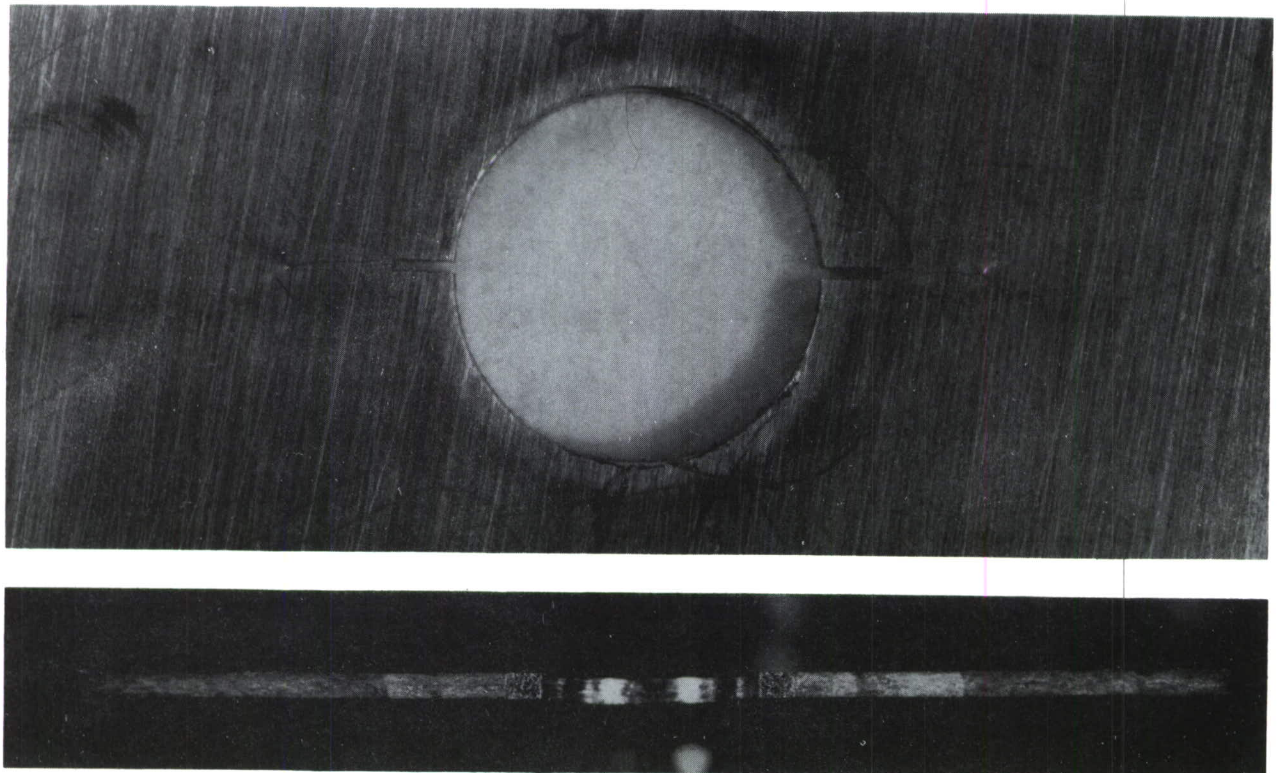


Figure 56 Rene' 41 Specimen D2-15C Showing Plastic Deformation But Poorly Defined Slow Crack Growth After Loading To 2580 Pounds

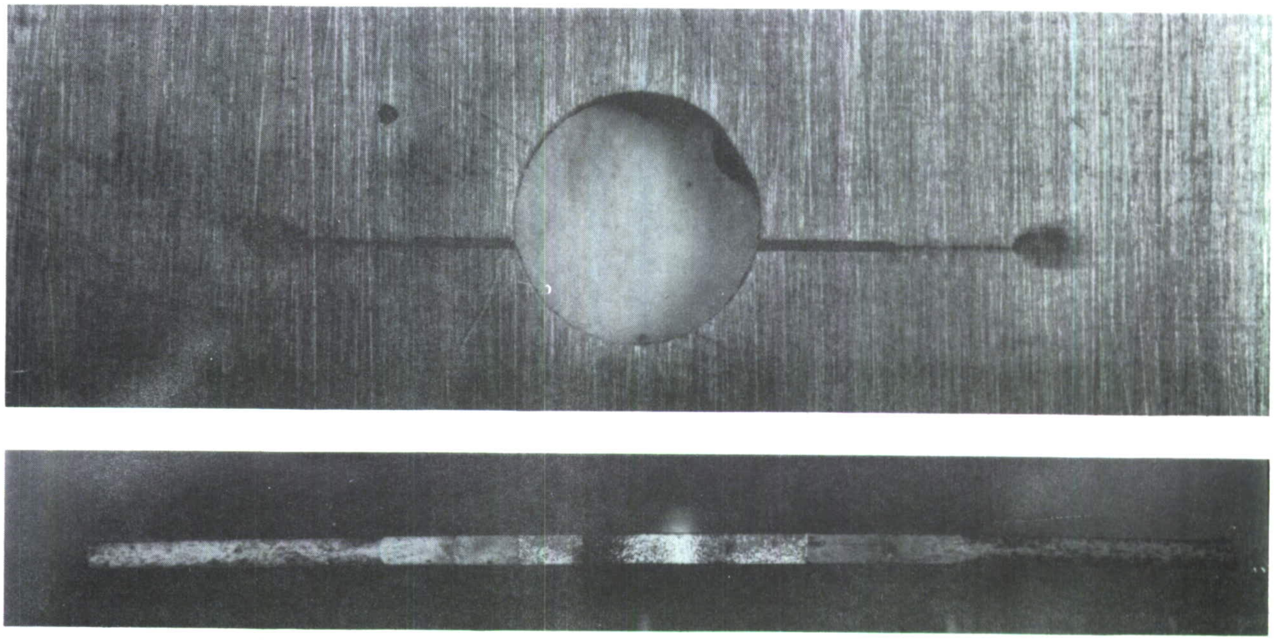


Figure 57 PH 14-8 Mo Specimen B5 Showing Plastic Deformation And Start Of Slow Crack Growth After Loading To 2200 Pounds

A similar method of evaluating the effects of exposure is by comparing the residual net fracture stress, (σ_{net}). This value was calculated by

$$\sigma_{net} = \frac{\text{Failing load}}{\text{Thickness (width -2a)}}$$

where 2a is the crack length at onset of fast crack propagation. This calculation contains the uncertainty of accuracy of 2a as measured from the photographs.

The final method of evaluating the effects of exposure on the materials is by a comparison of notched to unnotched strength ratios. This ratio is determined by calculating σ_{net}/F_{TU}.

It should be noted that this ratio is calculated differently from the usual notched to unnotched strength ratio in that the net stress is based on the area at the point of maximum load rather than the unloaded net area.

AM-350 SCT (825) Stainless Steel

A comparison of the effects of exposure on K_c as shown in Figure 58 and on the residual gross and net fracture stresses as shown in Figure 59 for AM-350 SCT (825) steel indicates that the room temperature fracture toughness is unaffected by the exposure. However, an examination of Figures 60 and 61 for K_c and residual gross and net fracture stresses measured at -65^{o}F definitely indicates a ductile to brittle transition occurring with time as the specimens are exposed to 650^{o}F. The first indication occurred after 10,000 hours of creep loading at 85,000 psi. No embrittlement was noted after 10,000 hours of heat alone. After 30,000 hours the creep loaded specimens showed further embrittlement, whether exposed intermittently or steadily. Also, the specimens exposed to heat alone were embrittled but to an extent lesser than the creep loaded specimens, indicating that both heat and stress contribute to the embrittlement.

This transition to brittle fracture is also clearly shown by the oscillograph recordings of load and deflection time histories and the appearance of the specimen fracture surface. Comparing the oscillograph record of Figure 16 for specimen A2-14A, tested at room temperature after steady exposure to 67,000 psi at 650^{o}F with the oscillograph record of Figure 17 for specimen A3-11D, tested

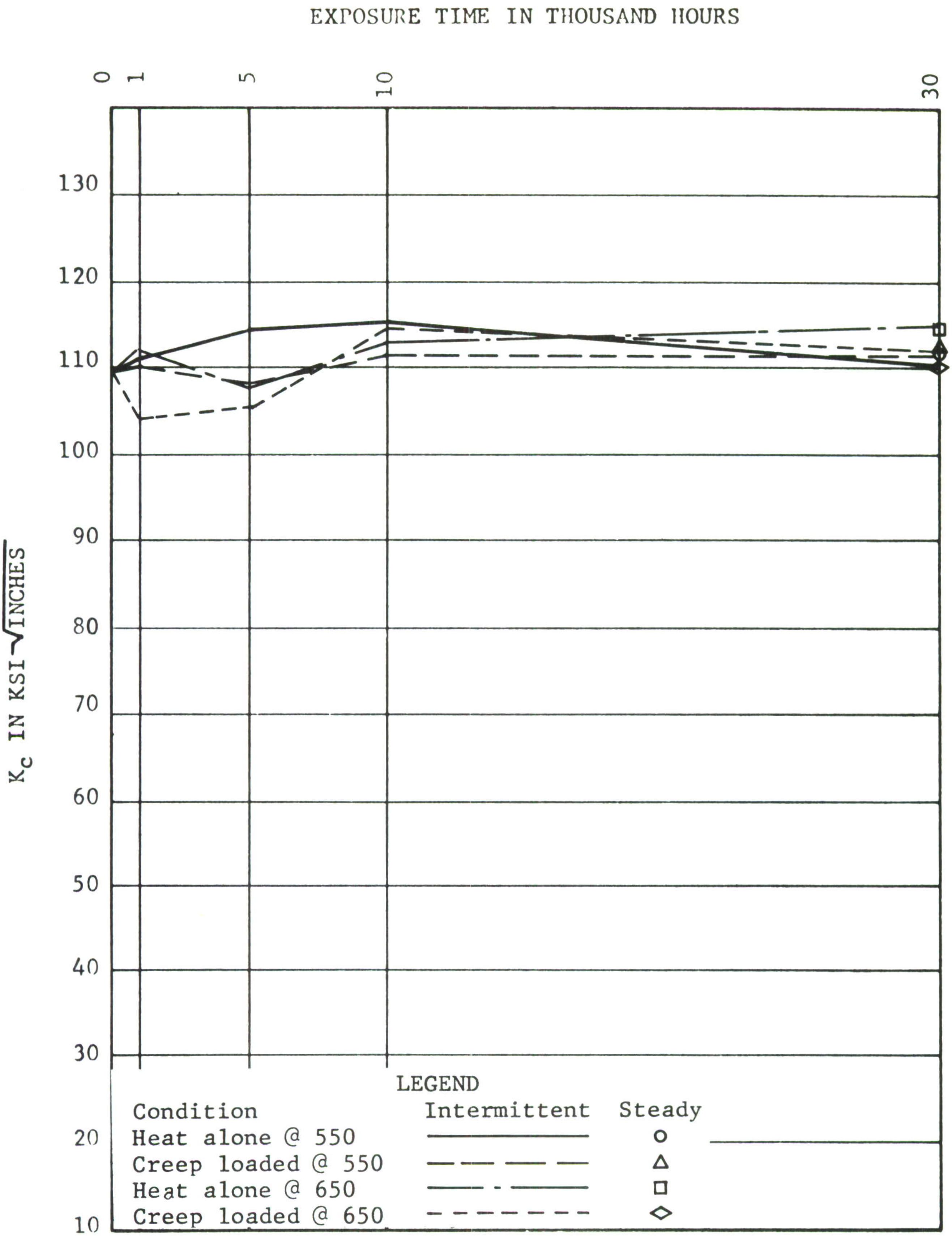


Figure 58 AM-350 SCT (825) K_c versus Time for Center Notched (fatigue cracked) Specimens Tested at Room Temperature After Exposure as Indicated

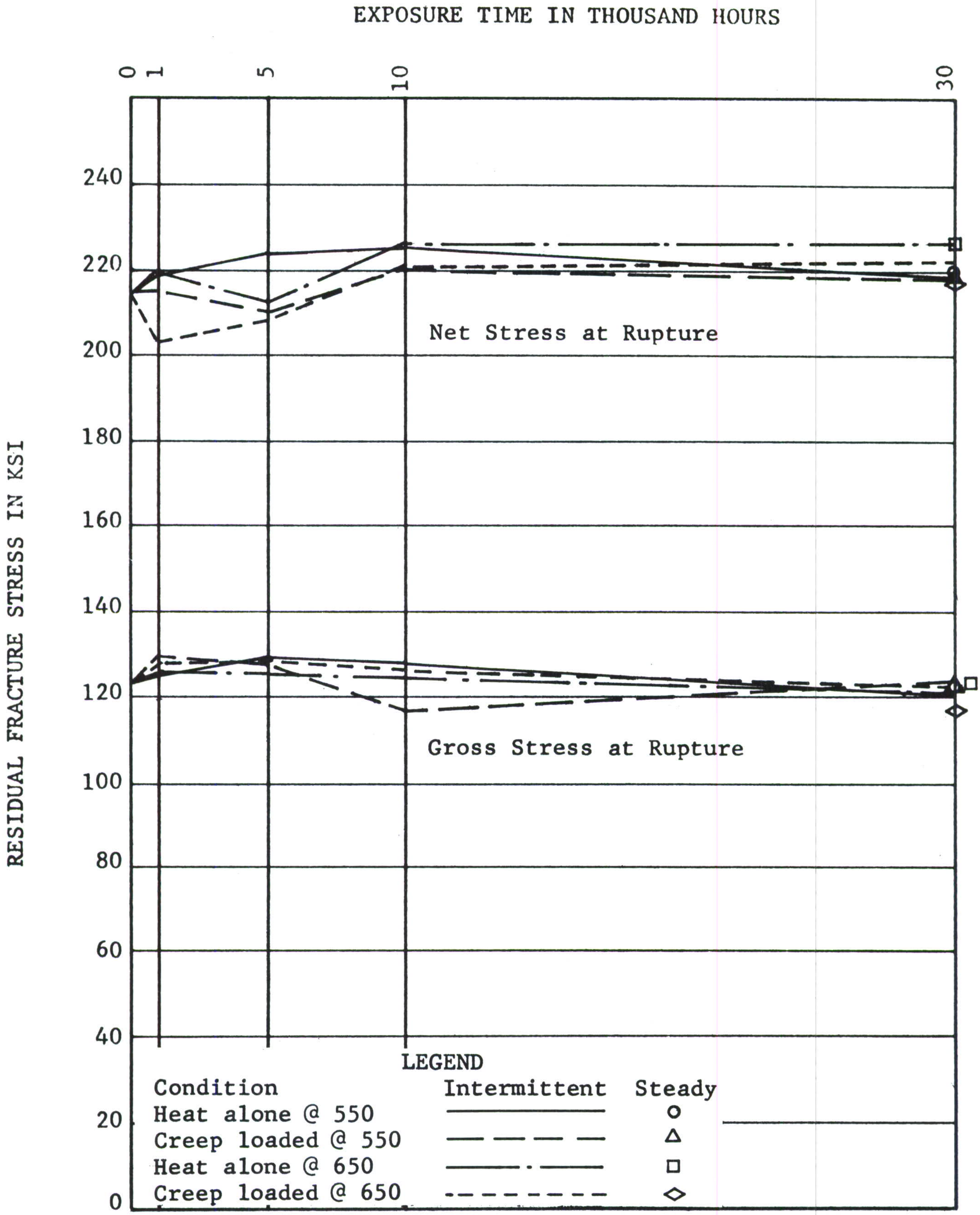


Figure 59 AM-350 SCT (825) Fracture Stress versus Time for Center Notched (fatigue cracked) Specimens Tested at Room Temperature After Exposure

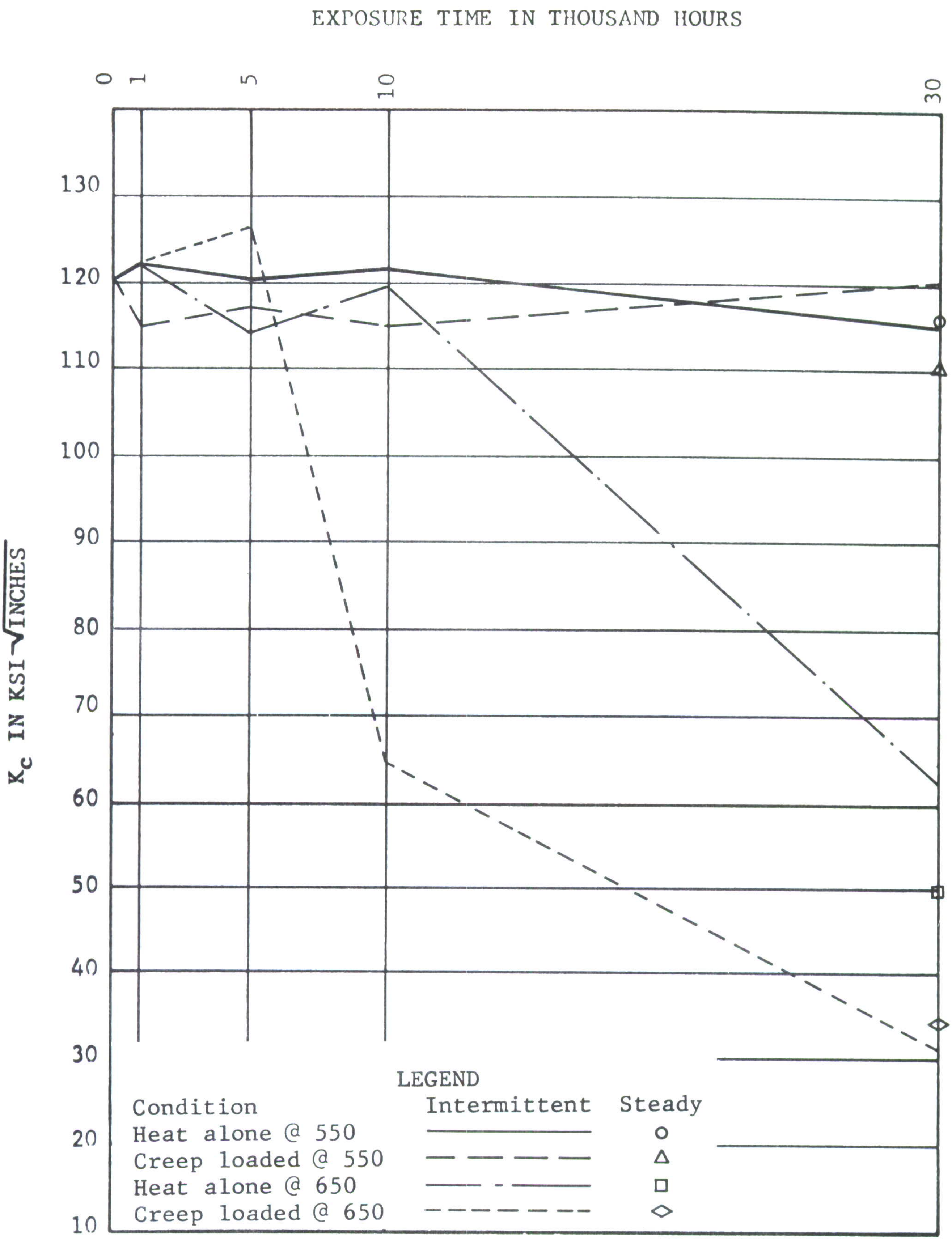


Figure 60 AM-350 SCT (825) K_c versus Time for Center Notched (fatigue cracked) Specimens Tested at -65° After Exposure as Indicated

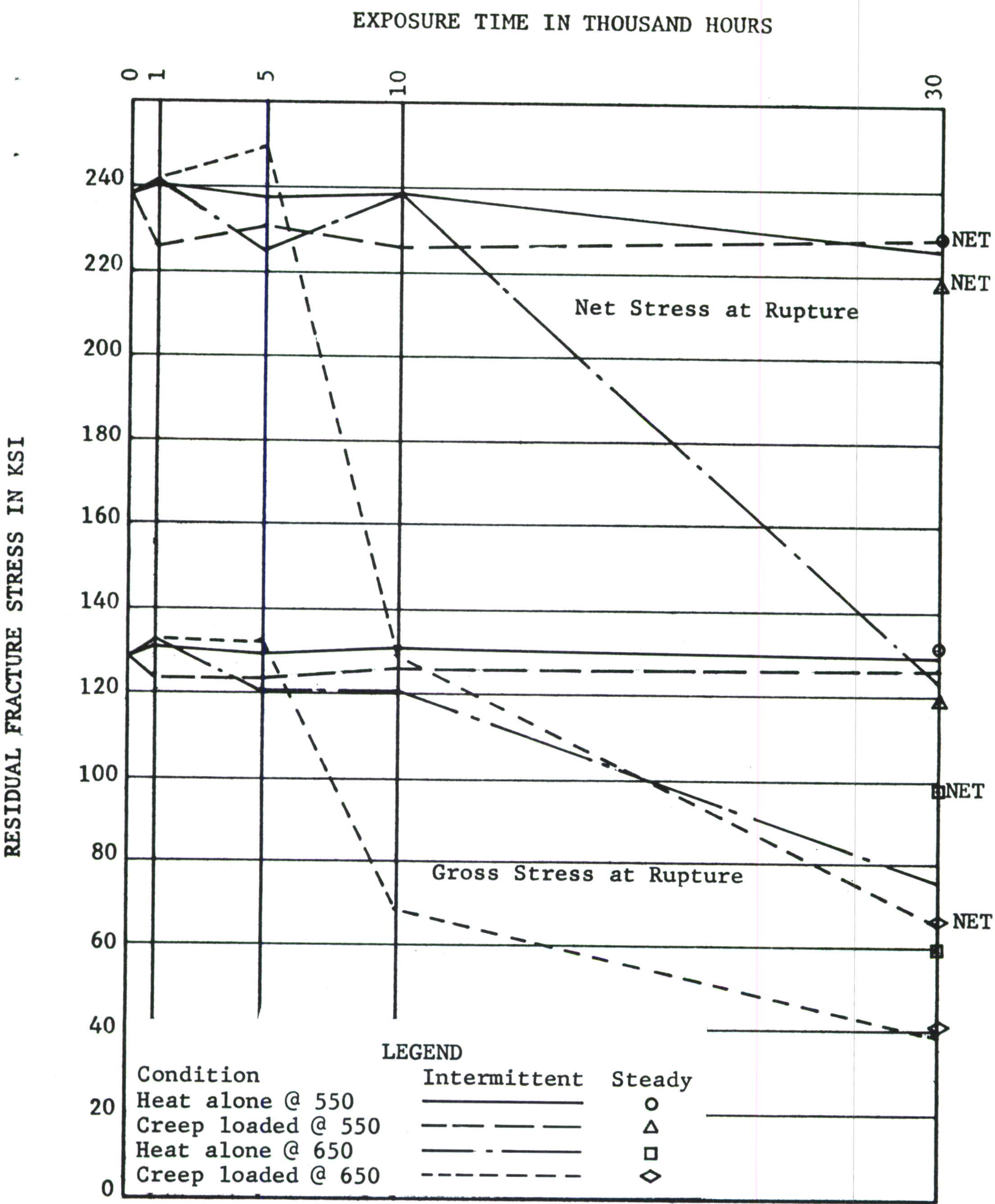


Figure 61 AM-350 SCT (825) Fracture Stress versus Time for Center Notched (fatigue cracked) Specimens Tested at -65°F After Exposure

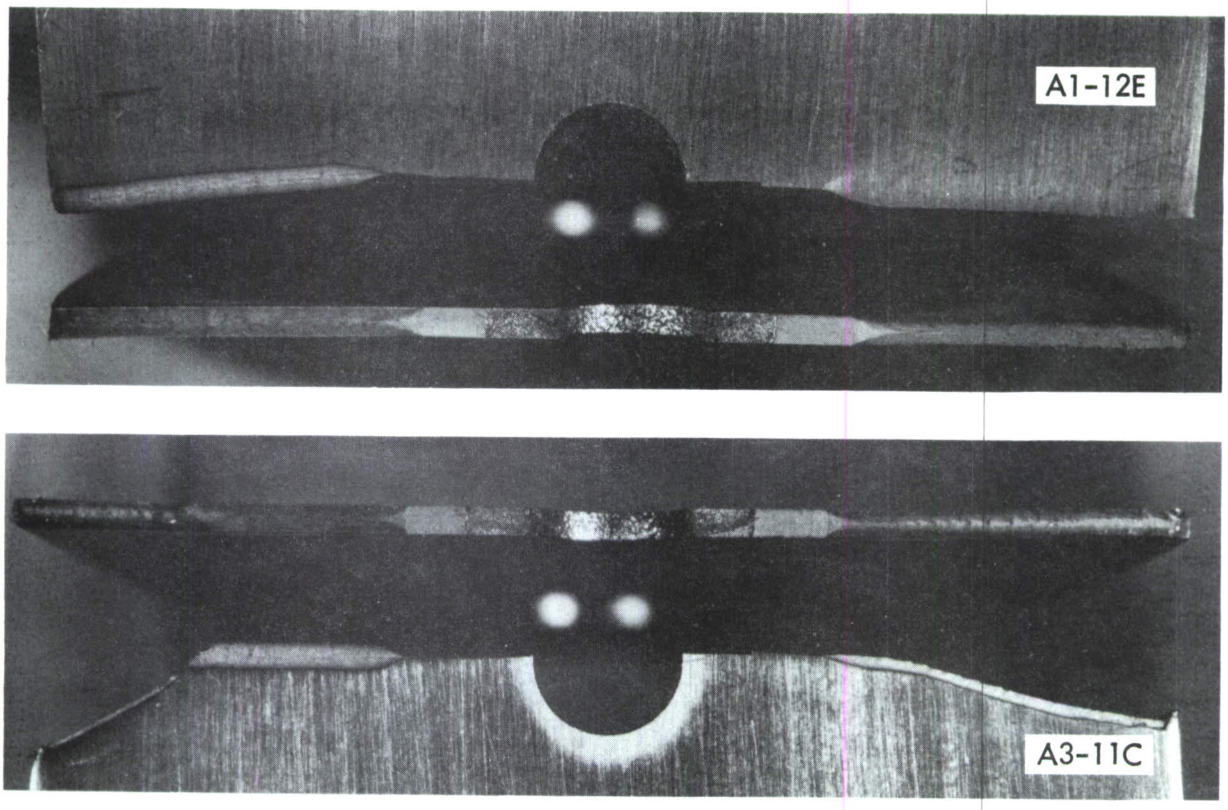
at -65°F after a similar exposure, a drastic change in maximum load and compliance gage deflection is easily seen. At room temperature there is a large smooth deflection of the compliance gage trace, even at low magnification, except for one slight discontinuity that might be a pop-in. At -65°F failure of specimen A3-11D occurred at a very low load with only a slight deflection of the compliance gage. The high magnification compliance gage trace shows one "pop-in" followed by sudden failure with no sign of plastic flow.

The ductile to brittle transition of the AM-350 SCT (825) steel is further confirmed by examining the specimens. Figure 62 shows the mode of failure of two specimens tested at room temperature after 30,000 hours of exposure compared with the mode of failure of specimens tested at -65°F after similar exposure. The specimens tested at room temperature failed ductilly with necking both in the thickness direction and the width direction. In the descriptive terms of Srawley and Brown (Reference 8) the fracture was of the slant type. The specimens tested at -65°F, failed with no signs of plastic flow with a square fracture.

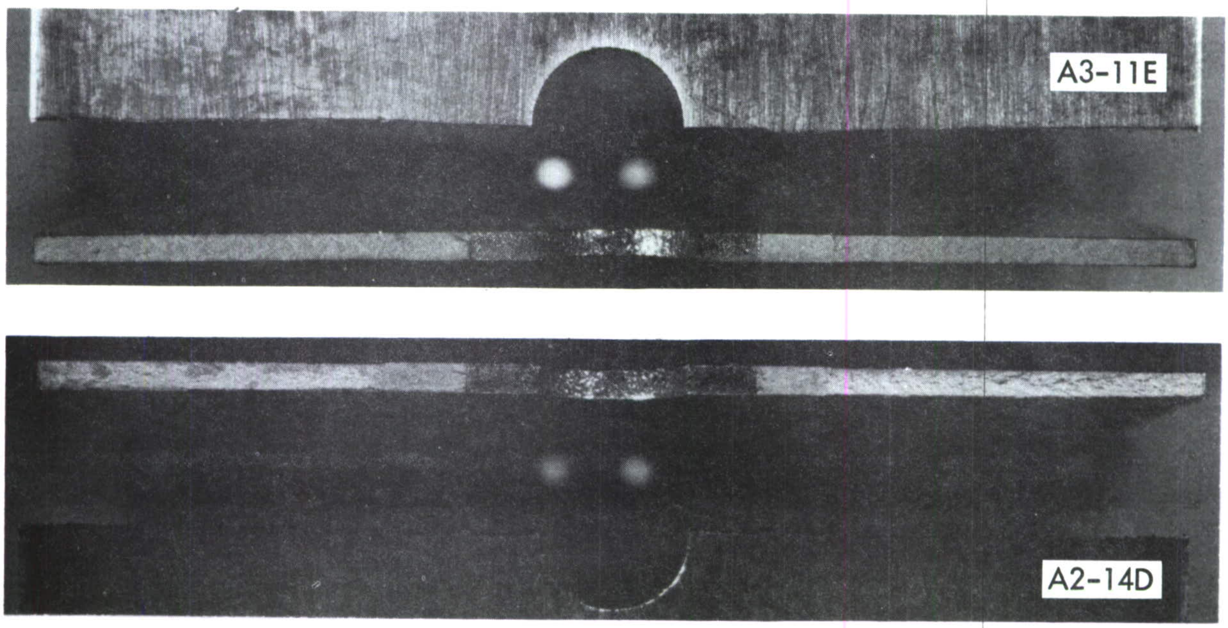
In summary, it can be said that exposure to heat alone at 650°F raises the ductile to brittle transition temperature of AM-350 SCT (825) stainless steel from well below to well above -65°F. Stress in addition to heat augments the embrittlement mechanism causing greater loss in toughness. Steady heat produced a greater effect than intermittent heat, probably due to the increased time at temperature. (Note: The intermittent specimens were under load and elevated temperature 5/6 of the total exposure time.) There seems to be no difference between the embrittling effect of steady versus intermittent exposure to creep loading. The embrittling effects were not evident until the 650°F exposure time reached 10,000 hours and it became more pronounced as time at temperature accumulated.

PH 14-8 Mo (SRH 1050) Stainless Steel

This material was only exposed at 550°F. At room temperature, K_c and the residual net fracture stress was raised by all exposures to heat or creep but the residual gross fracture stress remained almost constant as shown in Figures 63 and 64. The net fracture stress was increased by approximately 18 percent. Tests made at -65°F show a slight increase in K_c, residual gross and residual net fracture stress which seems to confirm that the exposure is having a slight toughening effect on the material as shown in Figures 65 and 66.



ROOM TEMPERATURE TESTS - NOTE DUCTILE FAILURES



-65° TESTS - BRITTLE FAILURES, VERY LITTLE SHEAR LIP

Figure 62 Comparison of Mode of Failure of Fracture Toughness Specimens of AM-350 Tested at Room Temperature and -65°F.

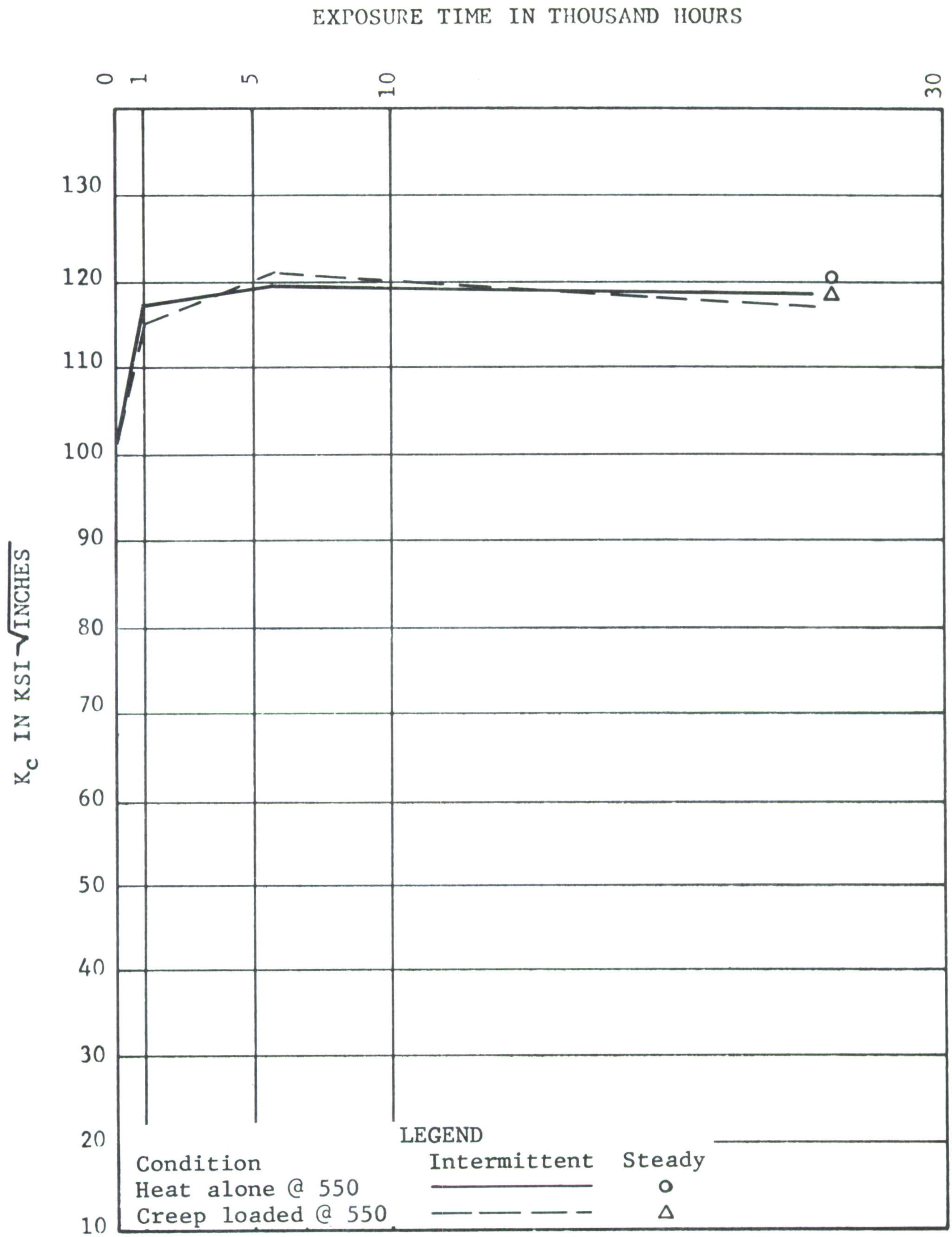


Figure 63 PH 14-8 Mo (SRH 1050) K_c versus Time for Center Notched (fatigue cracked) Specimens Tested at Room Temperature After Exposure as Indicated

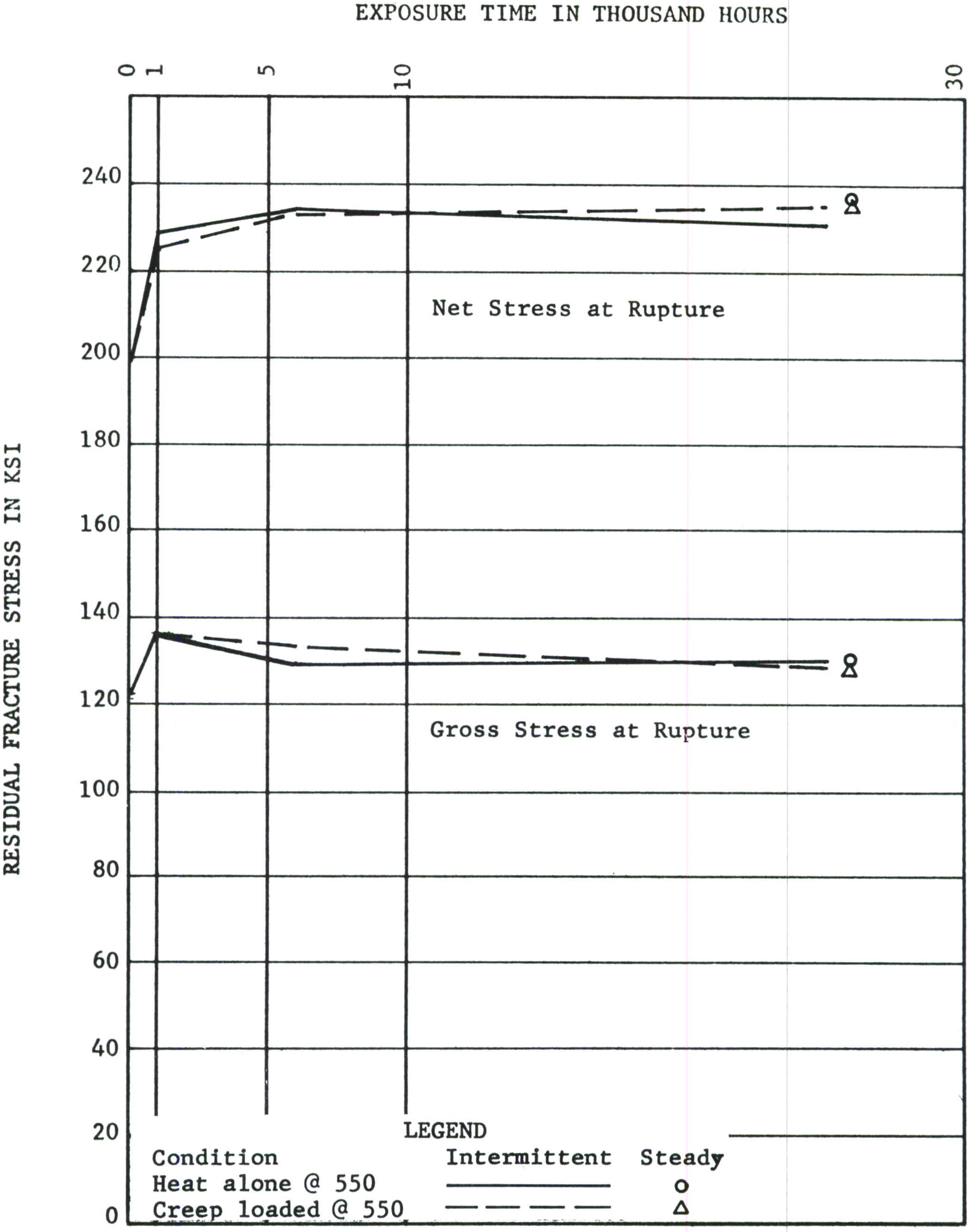


Figure 64 PH 14-8 Mo (SRH 1050) Fracture Stress versus Time for Center Notched (fatigue cracked) Specimens Tested at Room Temperature After Exposure

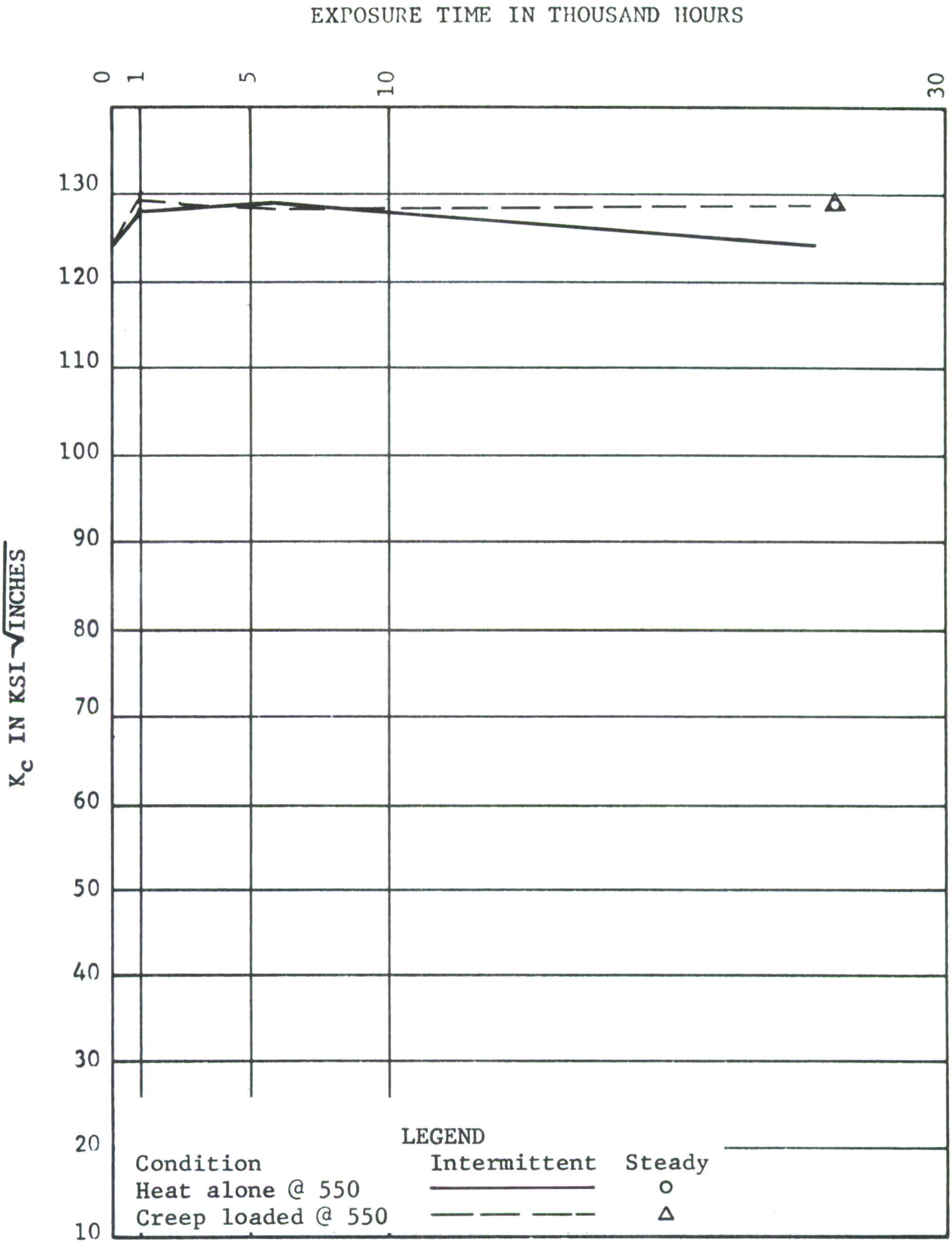


Figure 65 PH 14-8 Mo (SRH 1050) K_c versus Time for Center Notched (fatigue cracked) Specimens Tested at -65^{o}F After Exposure as Indicated

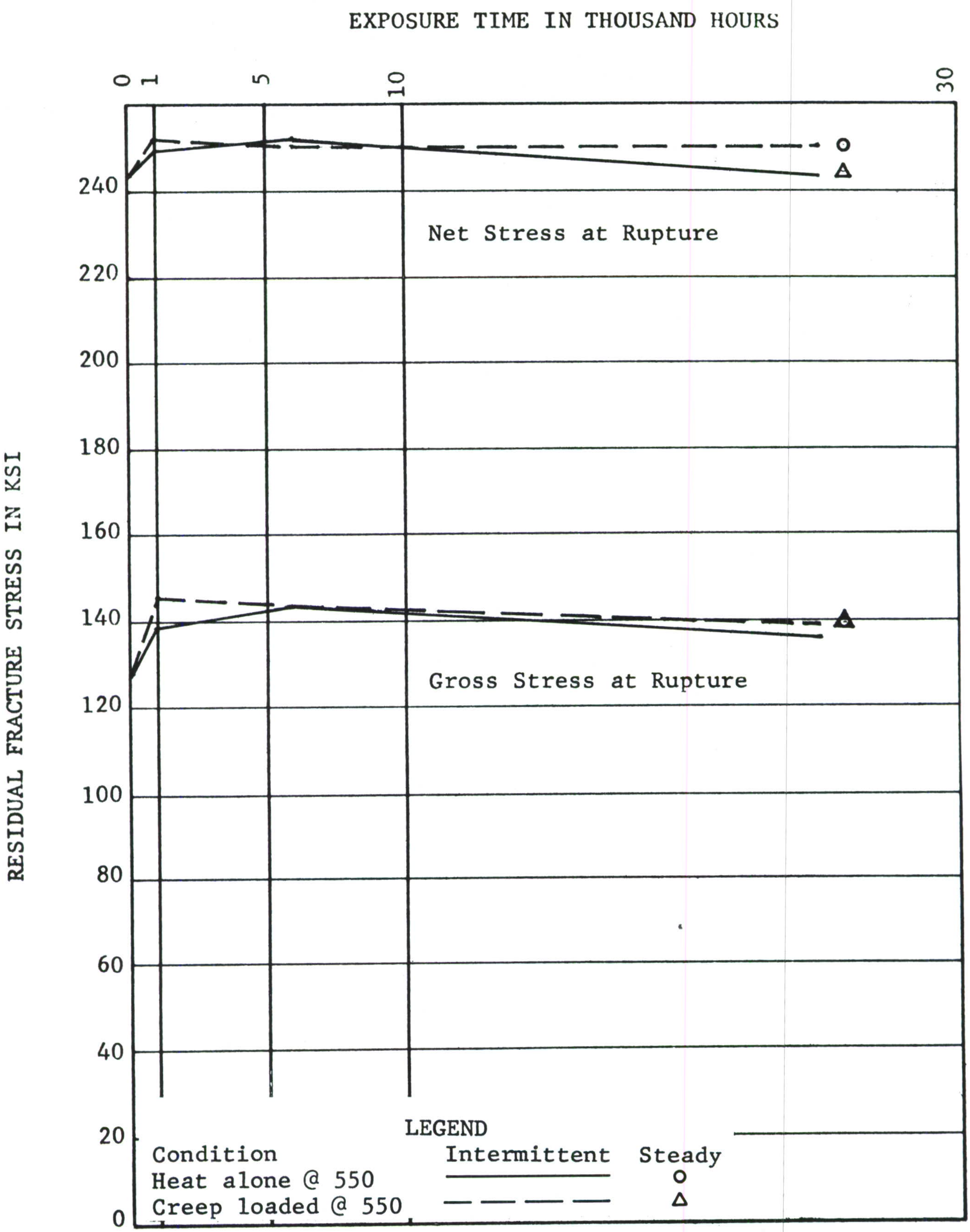


Figure 66 PH 14-8 Mo (SRH 1050) Fracture Stress versus Time for Center Notched (fatigue cracked) Specimens Tested at -65°F After Exposure

The oscillograph time histories of load and compliance gage deflection, as shown in Figure 18, as well as the fracture appearance of the specimens indicates a ductile failure after all exposure conditions. There were no signs of "pop-in" on the oscillograph compliance gage traces. There was no difference between the results obtained from steady and intermittent exposures.

Rene' 41 (20% cold rolled + 16 hours at 1400°F)

The Rene' 41 had a slight rise in K_c and residual net fracture stress after 1000 hours when tested at room temperature but this rise was not shown by the residual gross fracture stress. There is a sharp peak in K_c and residual net fracture stress after 5000 hours of heat alone at 650°F. This peak could easily be due to error in measuring the crack length at onset of fast fracture from the photographs. Film magazine difficulties caused the loss of one loading sequence and very poor photographs of the other two out of three 5000 hour heat soaked specimens tested at room temperature. Similiarly exposed specimens tested at -65°F did not show any such peak after 5000 hours but there was a slight decrease in K_c and residual net fracture stress after 30,000 hours of heat at 650°F and creep at both 550° and 650°F. Results from specimens exposed for 30,000 hours under steady heating or creep loading agreed quite closely with results from specimens exposed to intermittent heating or creep loading as shown in Figures 67 through 70.

The oscillograph records like shown in Figure 19 for Rene' 41 indicated less plastic flow occurred during loading than was found in any of the other materials except the embrittled AM-350. The failure takes place fairly abruptly but there is no evidence of "pop-in" occurring. Examination of the failed specimens showed a slant fracture along a line normal to the center line of the specimens. The Rene' 41 did not neck-down in the width direction.

Ti-6Al-4V (Mill Annealed)

Except for a slight drop after 5000 hours of exposure, the Ti-6Al-4V titanium specimens tested at room temperature showed no significant variation in K_c or residual gross or net fracture stress as shown in Figures 71 and 72. When similar specimens were tested at -65°F there was a slight loss in all three values with time as shown in Figures 73 and 74. The 30,000 hour intermittently exposed and steadily exposed specimen gave results in very close agreement, when specimens were tested at room temperature, and the residual gross fracture stresses were in close agreement when specimens were

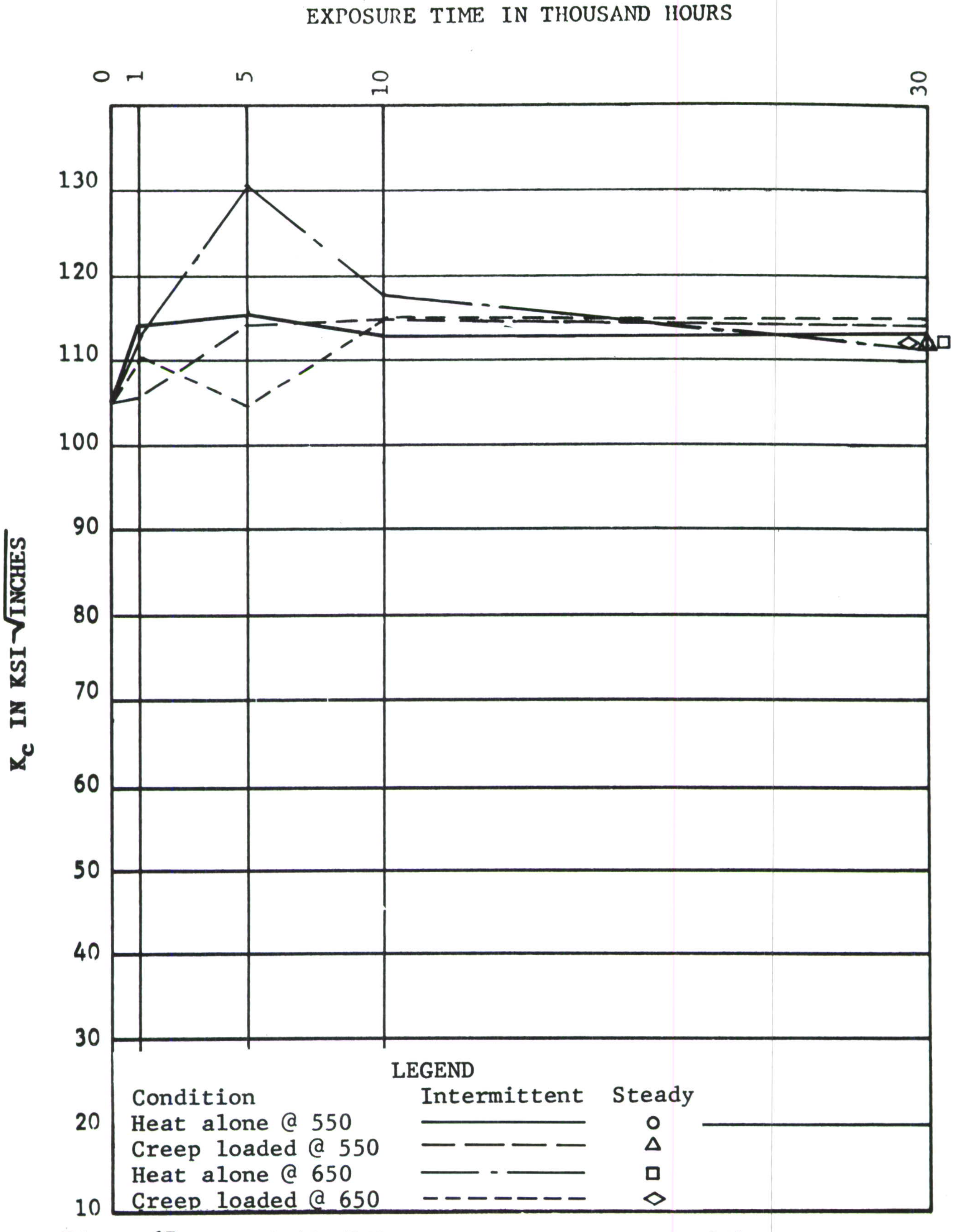


Figure 67 Rene' 41 (20% C.R. + 16 Hours @ 1400°F) K_c versus Time for Center Notched (fatigue cracked) Specimens Tested at Room Temperature After Exposure as Indicated

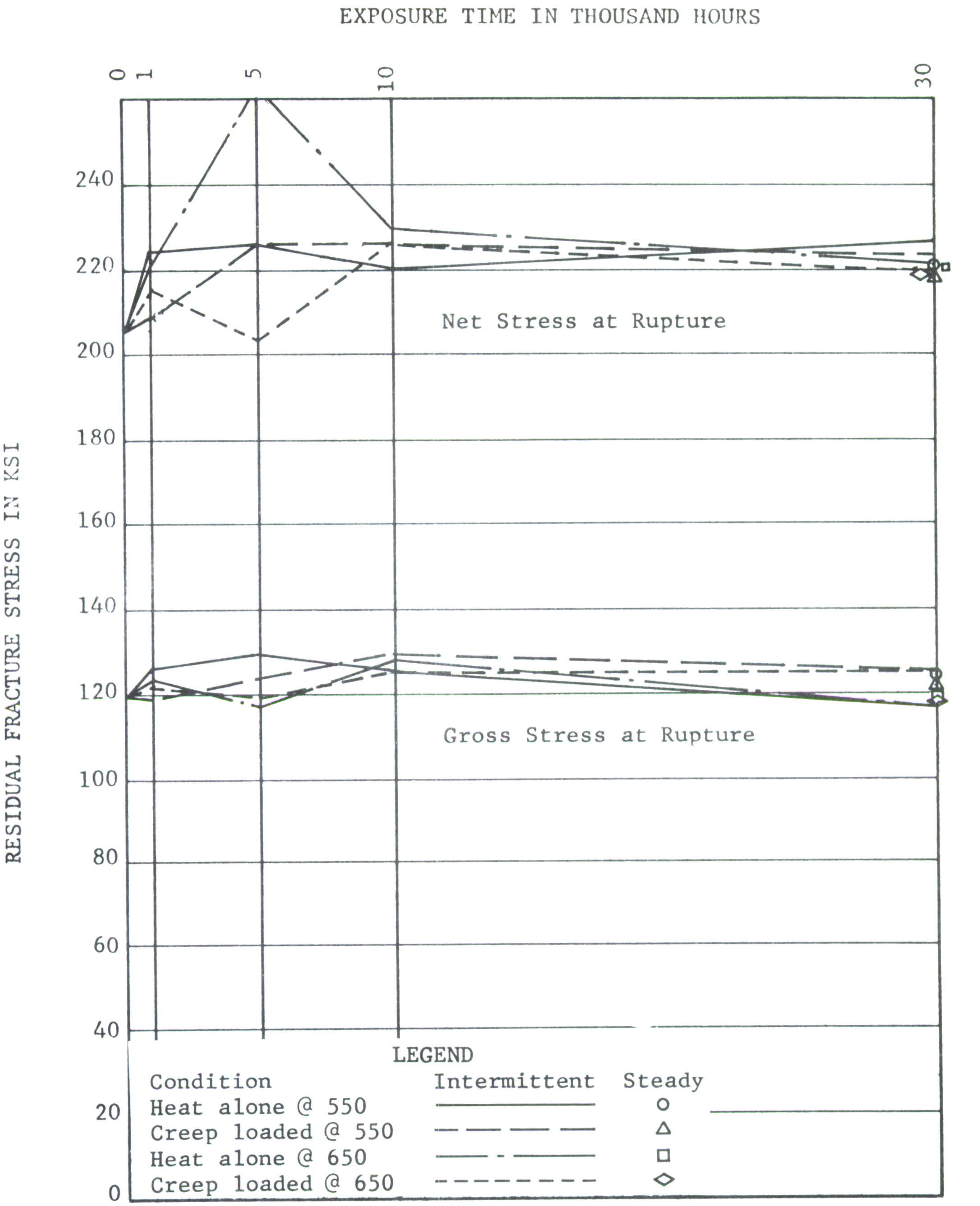


Figure 68 Rene' 41 (20% C.R. + 16 Hours @ 1400°F) Fracture Stress versus Time for Center Notched (fatigue cracked) Specimens Tested at Room Temperature After Exposure

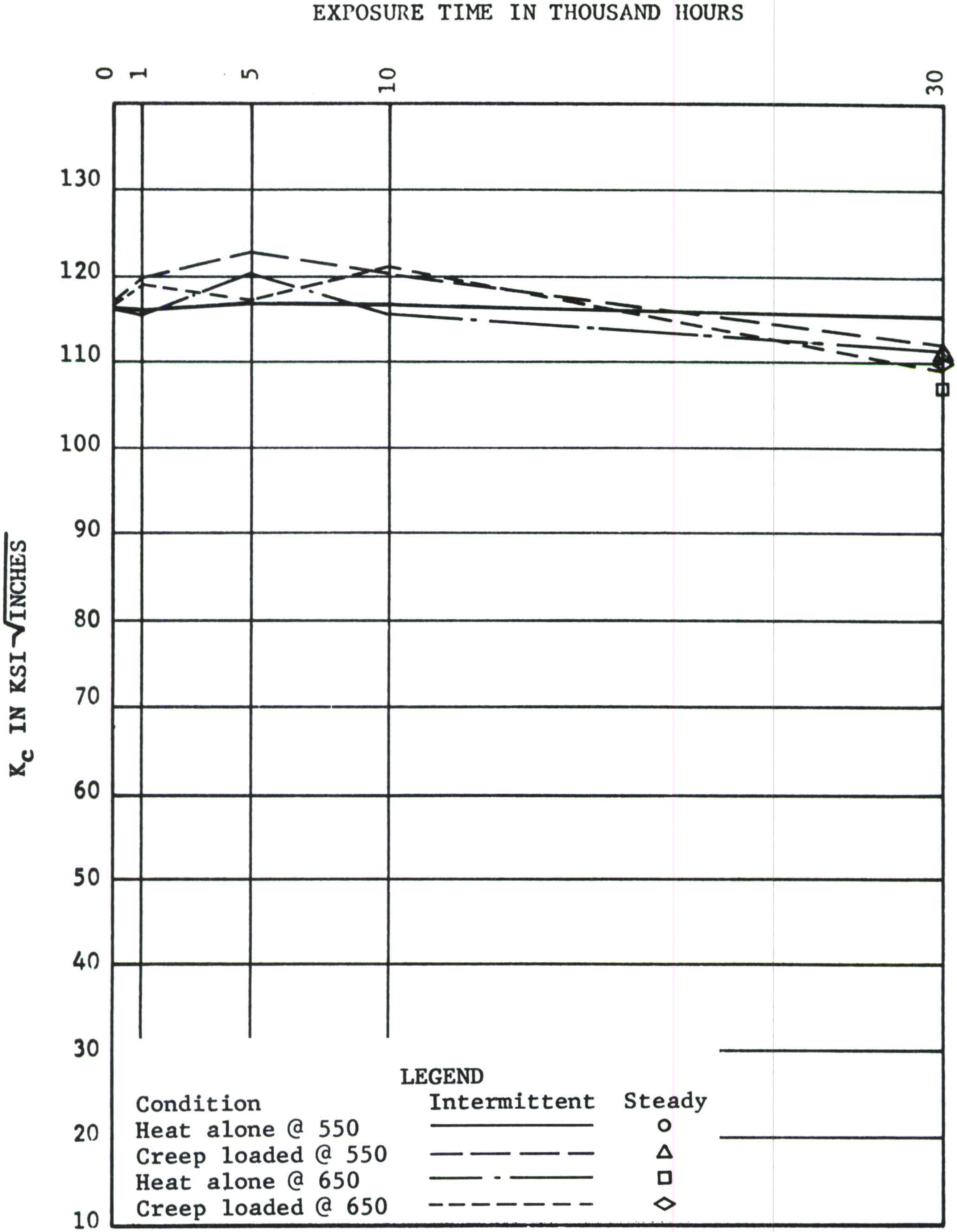


Figure 69 Rene' 41 (20% C.R. + 16 Hours @ 1400°F) K_c versus Time for Center Notched (fatigue cracked) Specimens Tested at -65°F After Exposure as Indicated

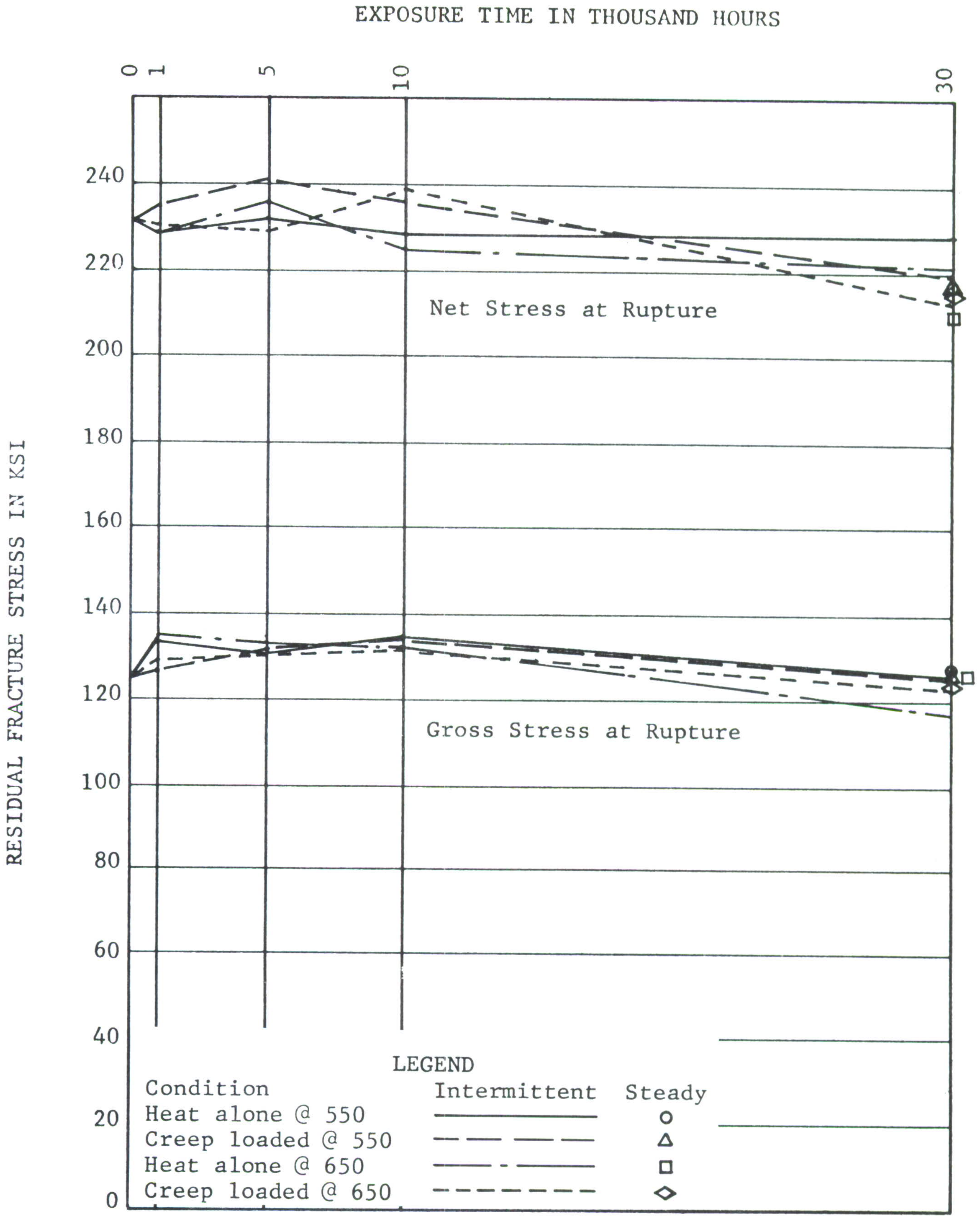


Figure 70 Rene' 41 (20% C.R. + 16 Hours @ 1400°F) Fracture Stress versus Time for Center Notched (fatigue cracked) Specimens Tested at -65°F After Exposure

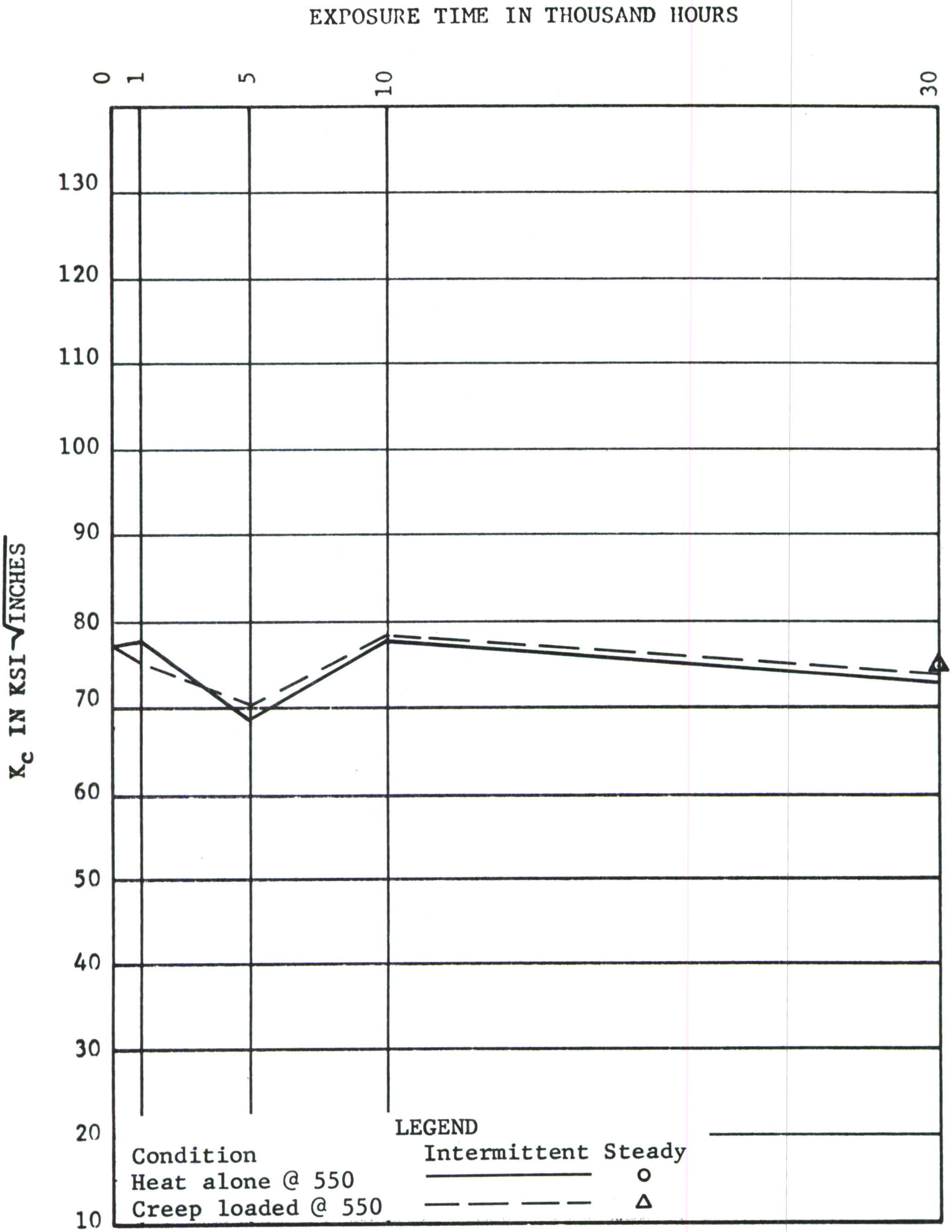


Figure 71 Ti-6Al-4V (Mill Annealed) K_c versus Time for Center Notched (fatigue cracked) Specimens Tested at Room Temperature After Exposure as Indicated

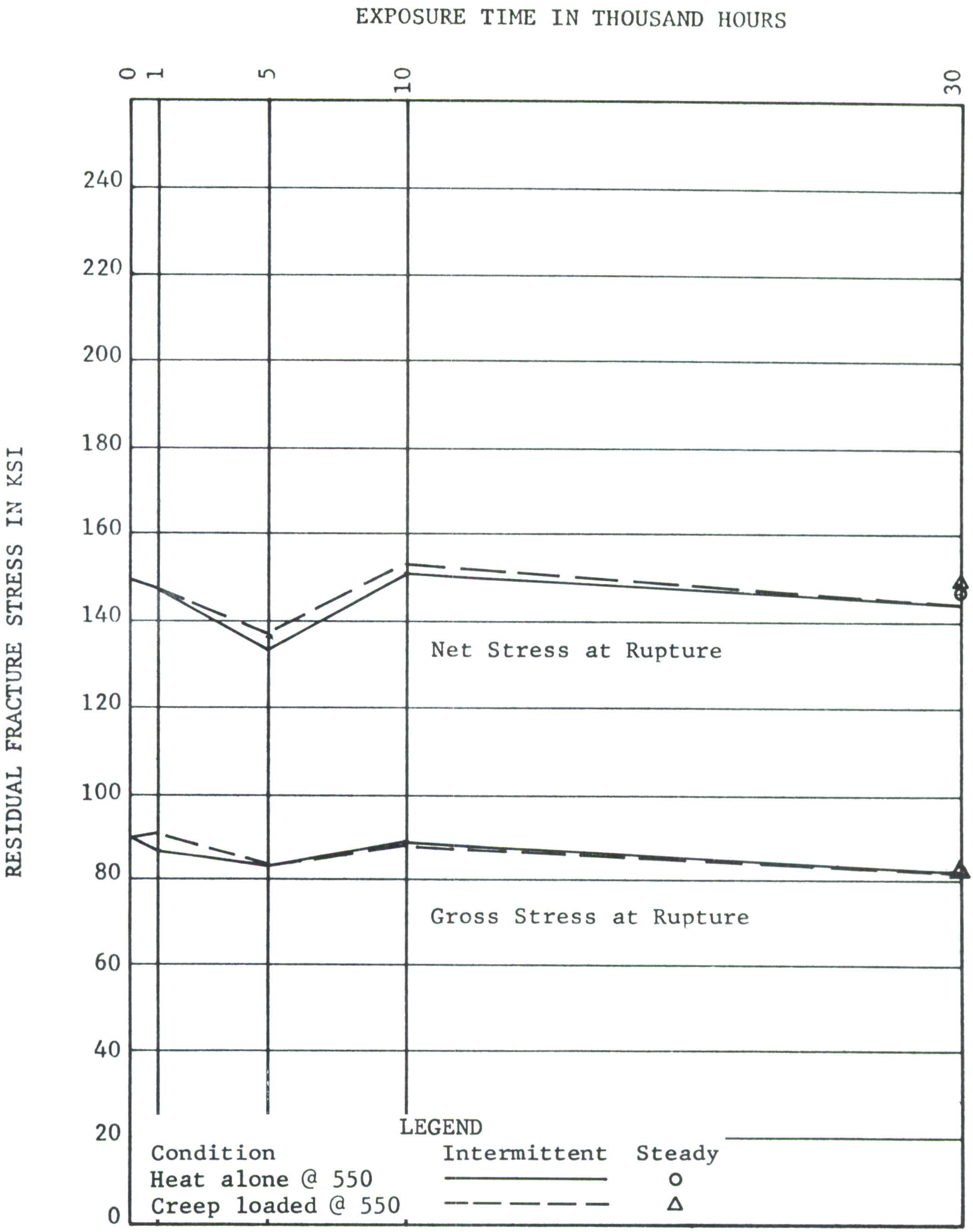


Figure 72 Ti-6Al-4V (Mill Annealed) Fracture Stress versus Time for Center Notched (fatigue cracked) Specimens Tested at Room Temperature After Exposure

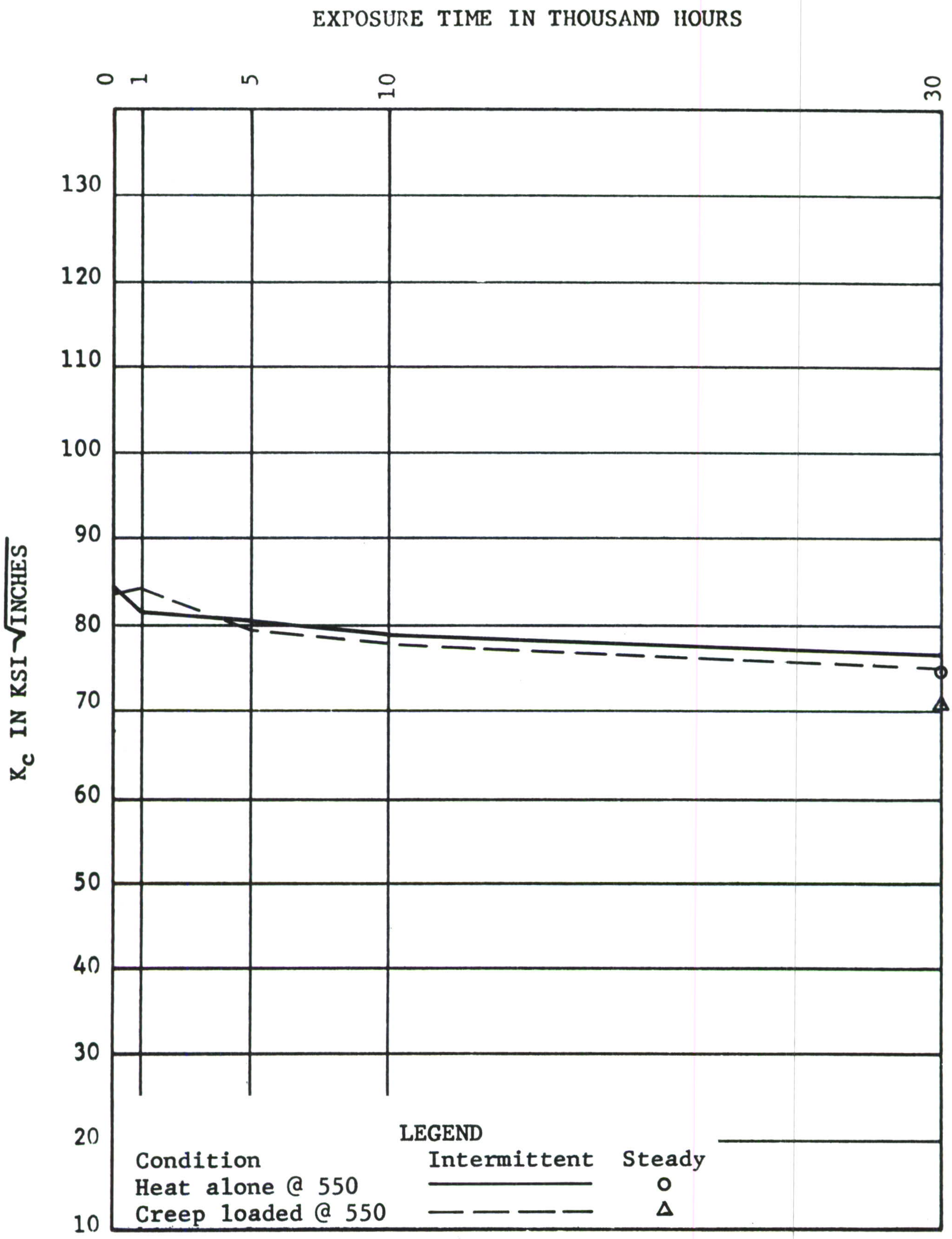


Figure 73 Ti-6Al-4V (Mill Annealed) K_c versus Time for Center Notched (fatigue cracked) Specimens Tested at -65°F After Exposure as Indicated

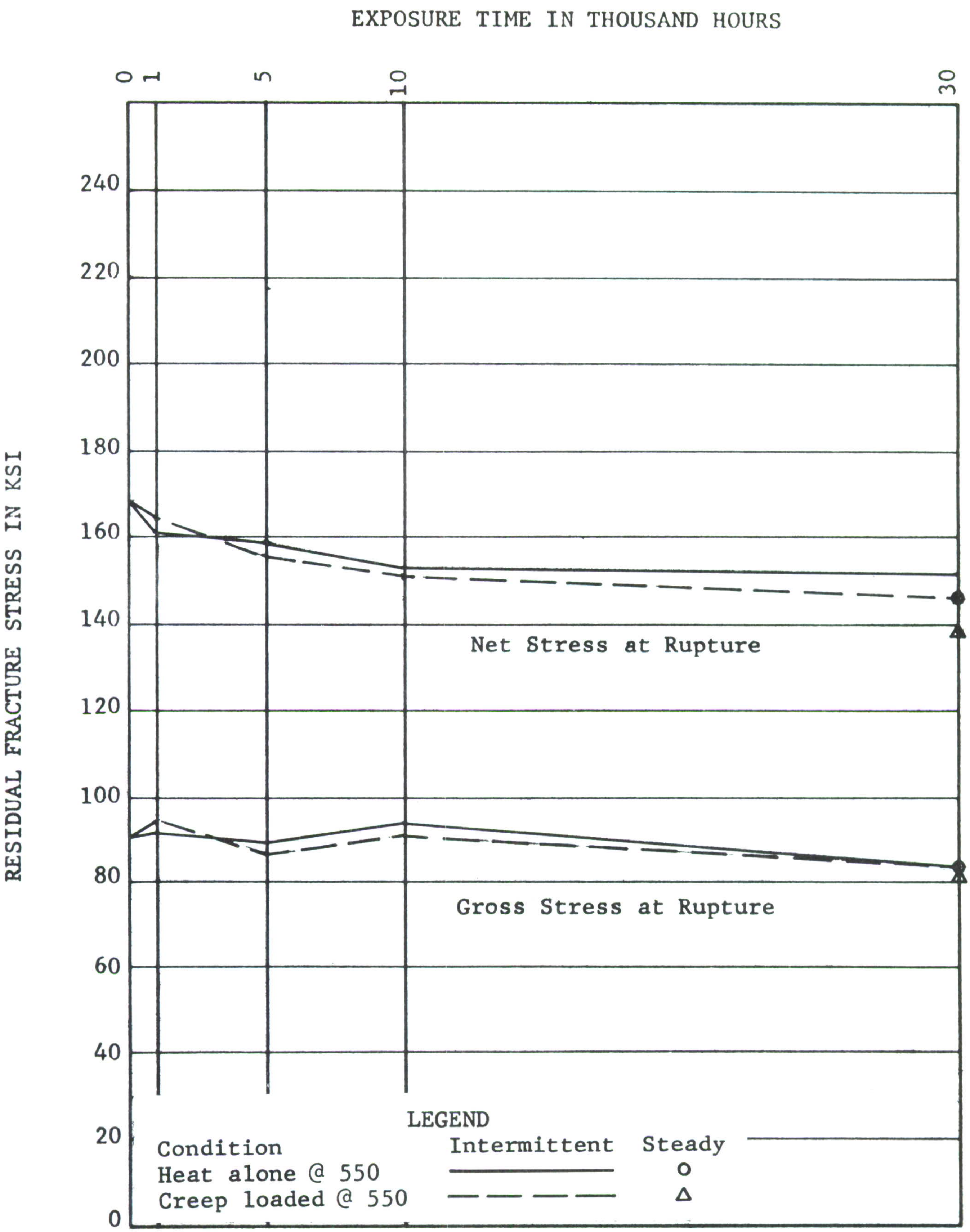


Figure 74 Ti-6Al-4V (Mill Annealed) Fracture Stress versus Time for Center Notched (fatigue cracked) Specimens Tested at -65° After Exposure

tested at -65°F. However, the steadily exposed specimens showed a slightly greater reduction in K_c and residual net fracture stress when specimens were tested at -65°F after 30,000 hours of exposure. This is probably due to the greater time at temperature experienced by the steadily exposed specimens. Both the oscillograph records, as illustrated in Figure 20, and the specimens fractured surfaces indicate considerable plastic flow prior to failure. No "pop-in" was found. The specimens failed with a slant fracture with some necking in the width direction much the same as the AM-350 specimens failed at room temperature.

Ti-8Al-1Mo-1V (Duplex Annealed)

The Ti-8Al-1Mo-1V titanium produced very consistent results with no significant variations in fracture toughness at room temperature after any of the exposure conditions whether intermittent or steady as shown in Figures 75 and 76. Tests performed at -65°F show a slight decrease in toughness with time as shown in Figures 77 and 78. Apparently heat is the cause of the decrease in toughness since the residual fracture stress (net and gross) curves for creep loaded specimens lie between the curves for specimens exposed to heat alone with the curve for the 650 heat alone exposure being the lowest. The specimens exposed to steady creep for 30,000 hours gave results slightly less than was measured for the intermittently exposed specimens; however, the difference is within experimental error.

The load and deflection time histories, as recorded on the oscillograph records for Ti-8Al-1Mo-1V titanium, were very similar to the load and deflection time histories as recorded for Ti-6Al-4V as seen by comparing Figure 21 with Figure 20. Likewise, the failure mode as shown by the fractured surfaces of the specimens is very similar.

Notched Strength Ratio

A final comparison between types of materials is shown in Figures 79 through 84 for the ratio of net fracture stress divided by ultimate strength. The AM-350 SCT (825) and the PH 14-8Mo (SRH 1050) stainless steels, when tested at room temperature after exposure, are compared in Figure 79. Within experimental error, the ratios are very near 1.0 regardless of the exposure condition for both alloys. When these alloys are tested at -65°F after exposure the ratio for AM-350 remains approximately 1.0 while the ratio for the PH 14-8 Mo is slightly above 1.0 as shown in Figure 80. After creep loading AM-350 for 10,000 hours at 650°F and subsequently testing at -65°F, the notched to unnotched ratio drops

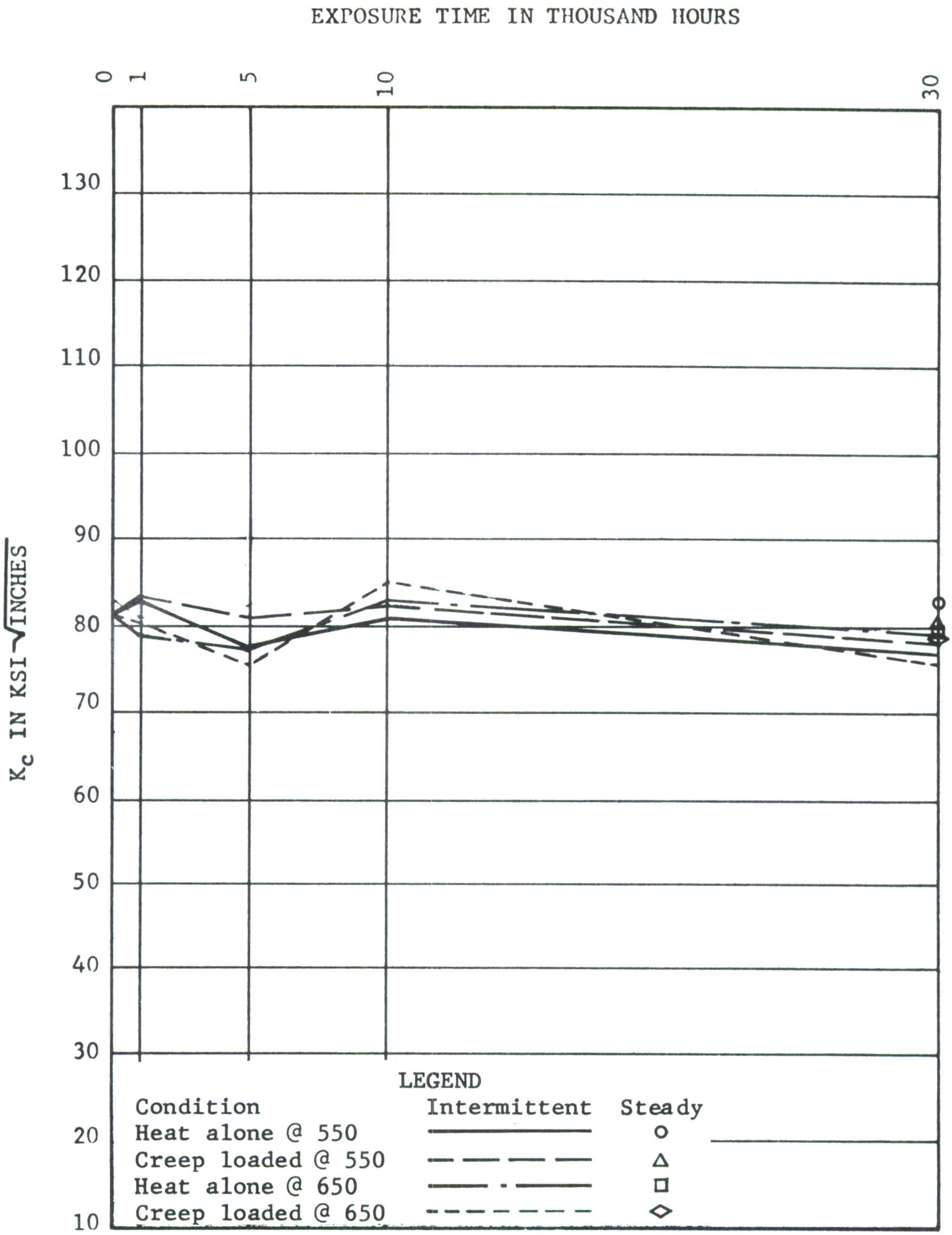


Figure 75 Ti-8Al-1Mo-1V (Duplex Annealed) K_c versus Time for Center Notched (fatigue cracked) Specimens Tested at Room Temperature After Exposure as Indicated

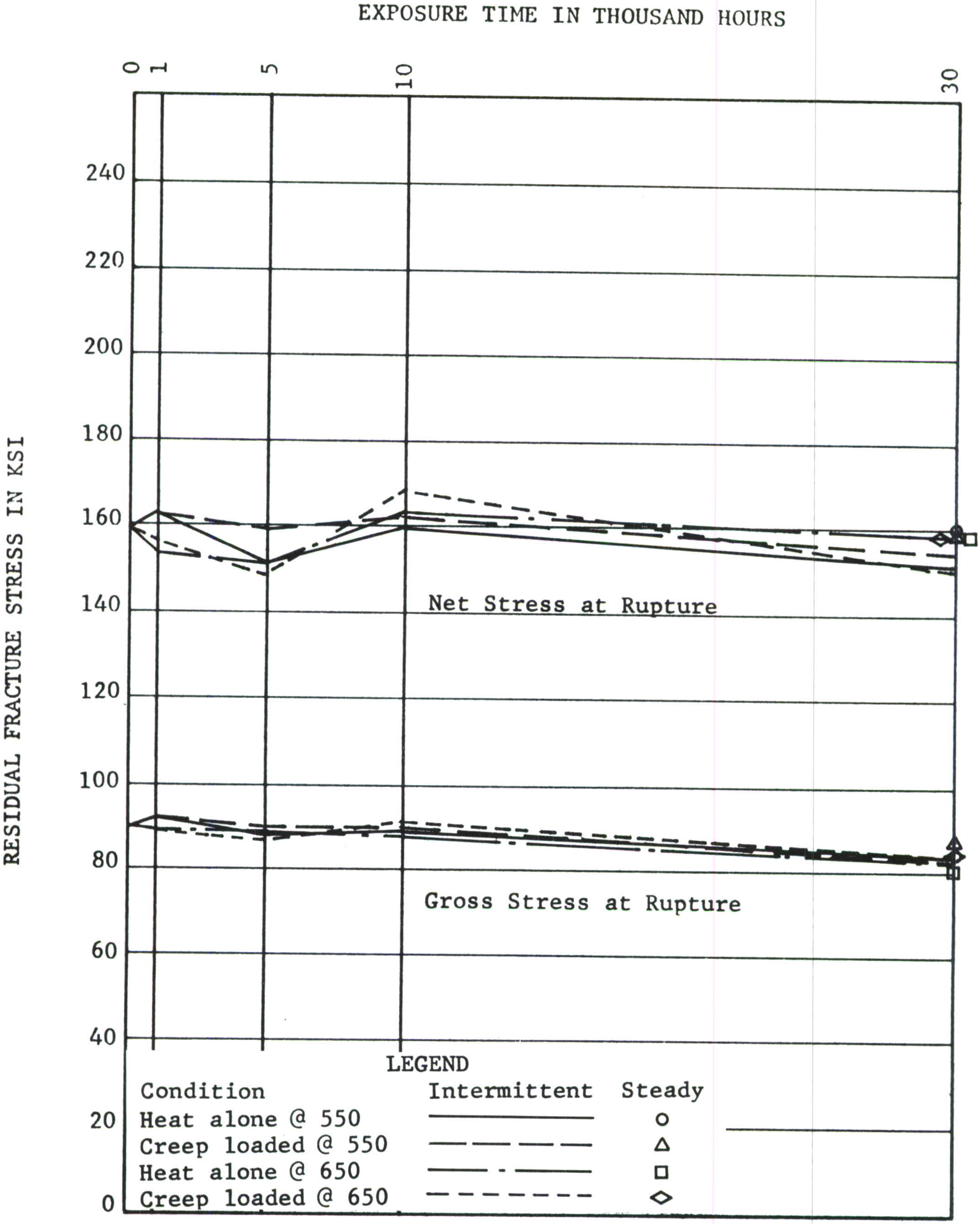


Figure 76 Ti-8Al-1Mo-1V (Duplex Annealed) Fracture Stress versus Time for Center Notched (fatigue cracked) Specimens Tested at Room Temperature After Exposure

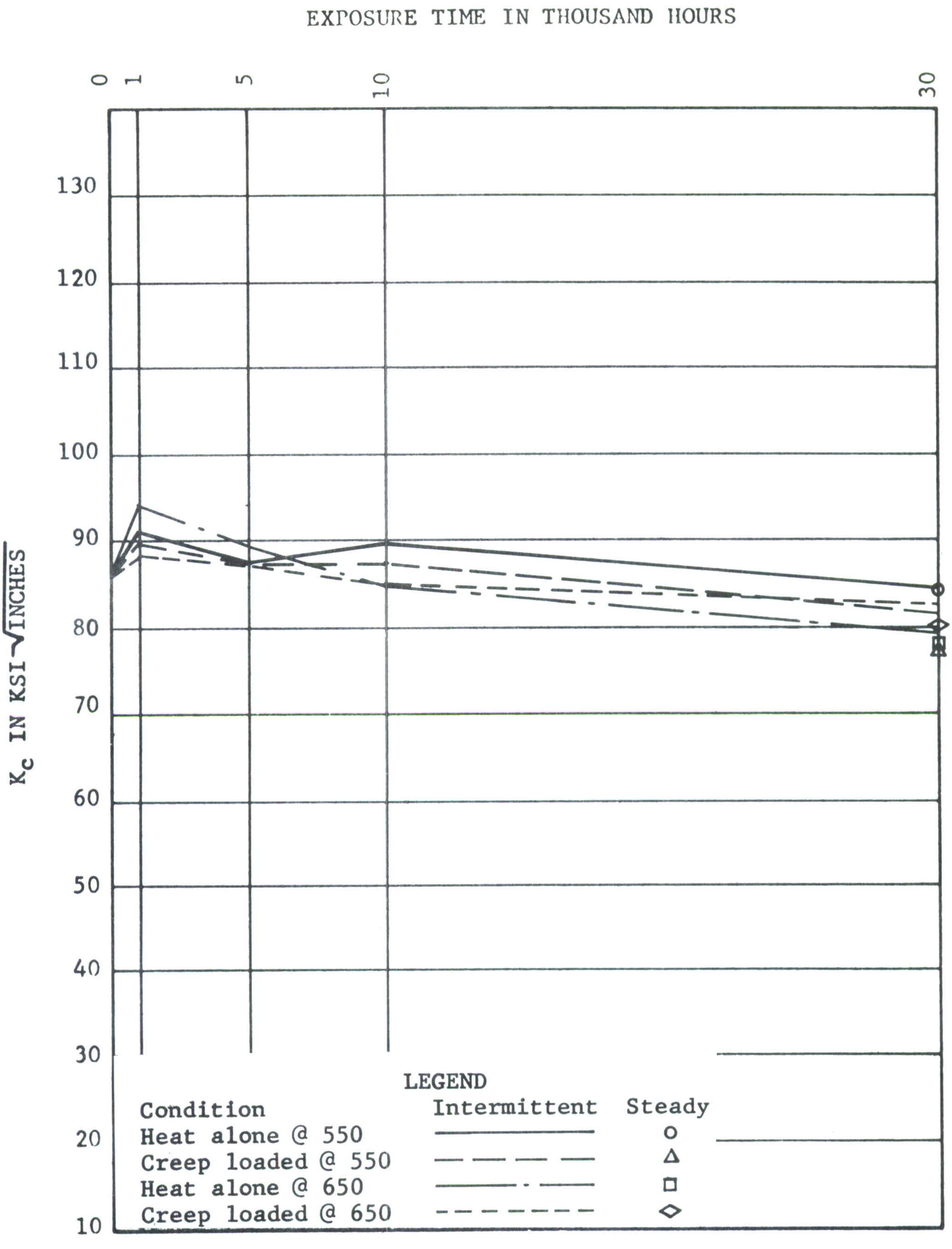


Figure 77 Ti-8Al-1Mo-1V (Duplex Annealed) K_c versus Time for Center Notched (fatigue cracked) Specimens Tested at -65°F After Exposure as Indicated

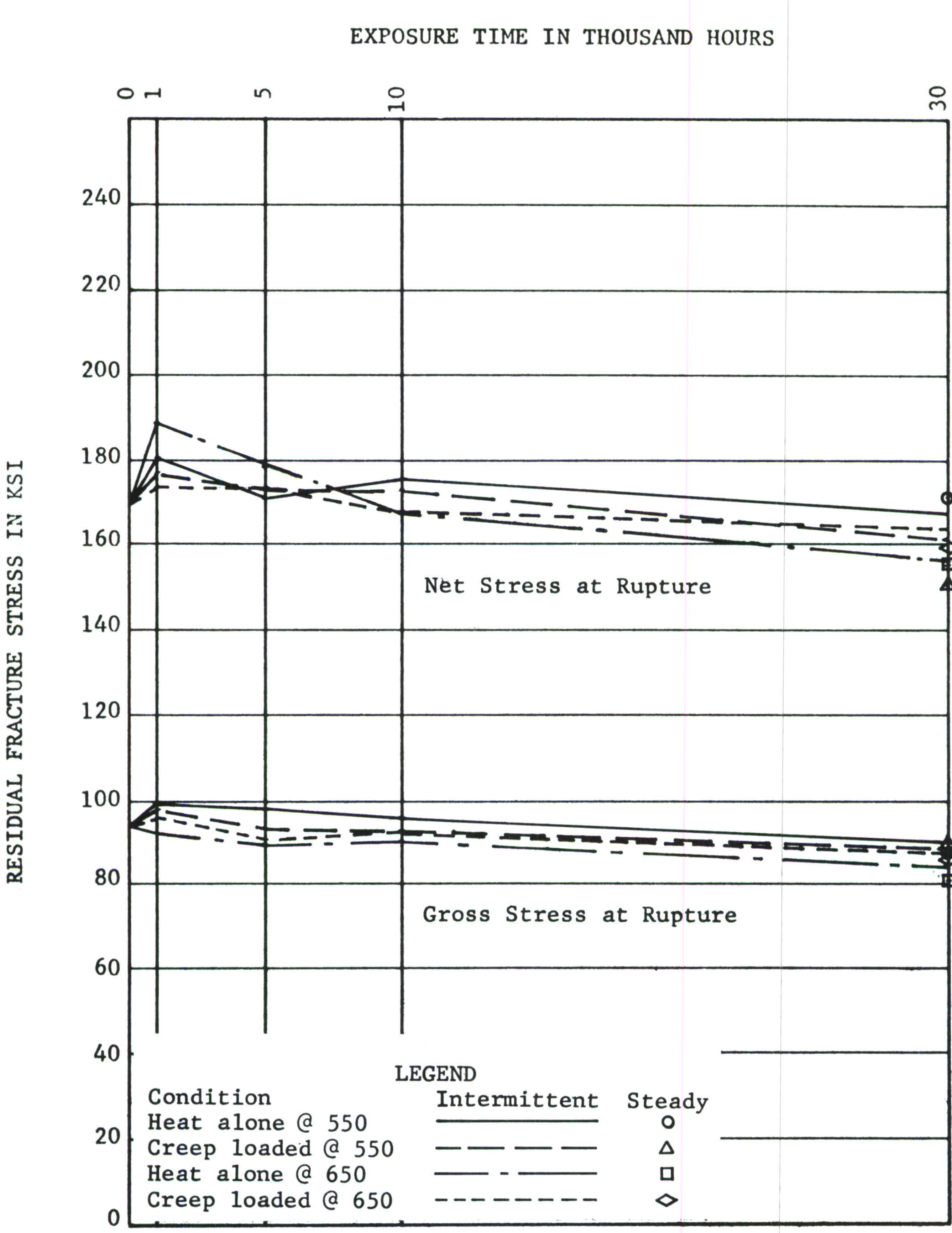


Figure 78 Ti-8Al-1Mo-1V (Duplex Annealed) Fracture Stress versus Time for Center Notched (fatigue cracked) Specimens Tested at -65° After Exposure

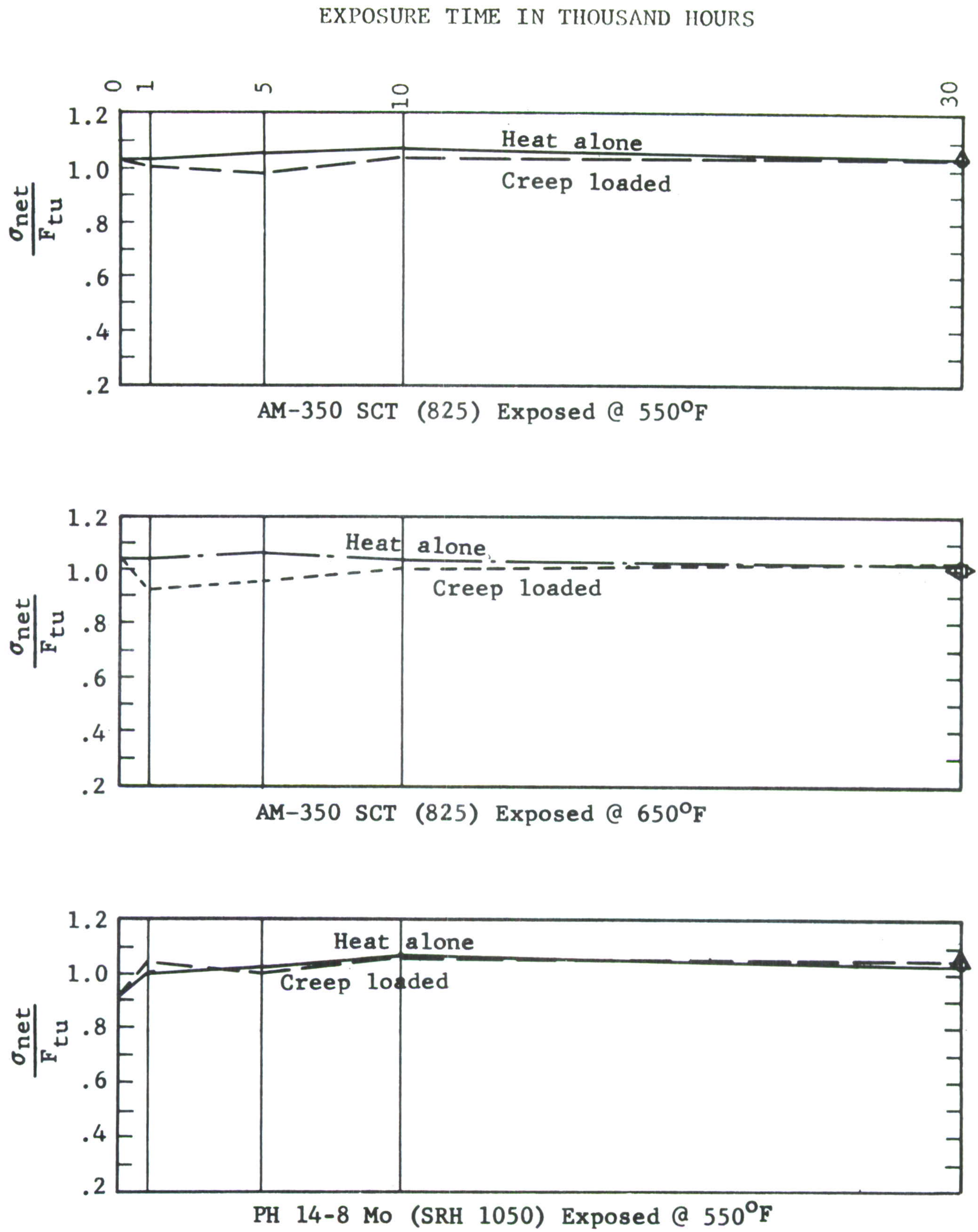


Figure 79 Ratio of Net Fracture Stress (σ_{net}) to Ultimate Tensile Strength (F_{tu}) versus Exposure Time for Stainless Steels After Exposure Indicated and Then Tested at Room Temperature

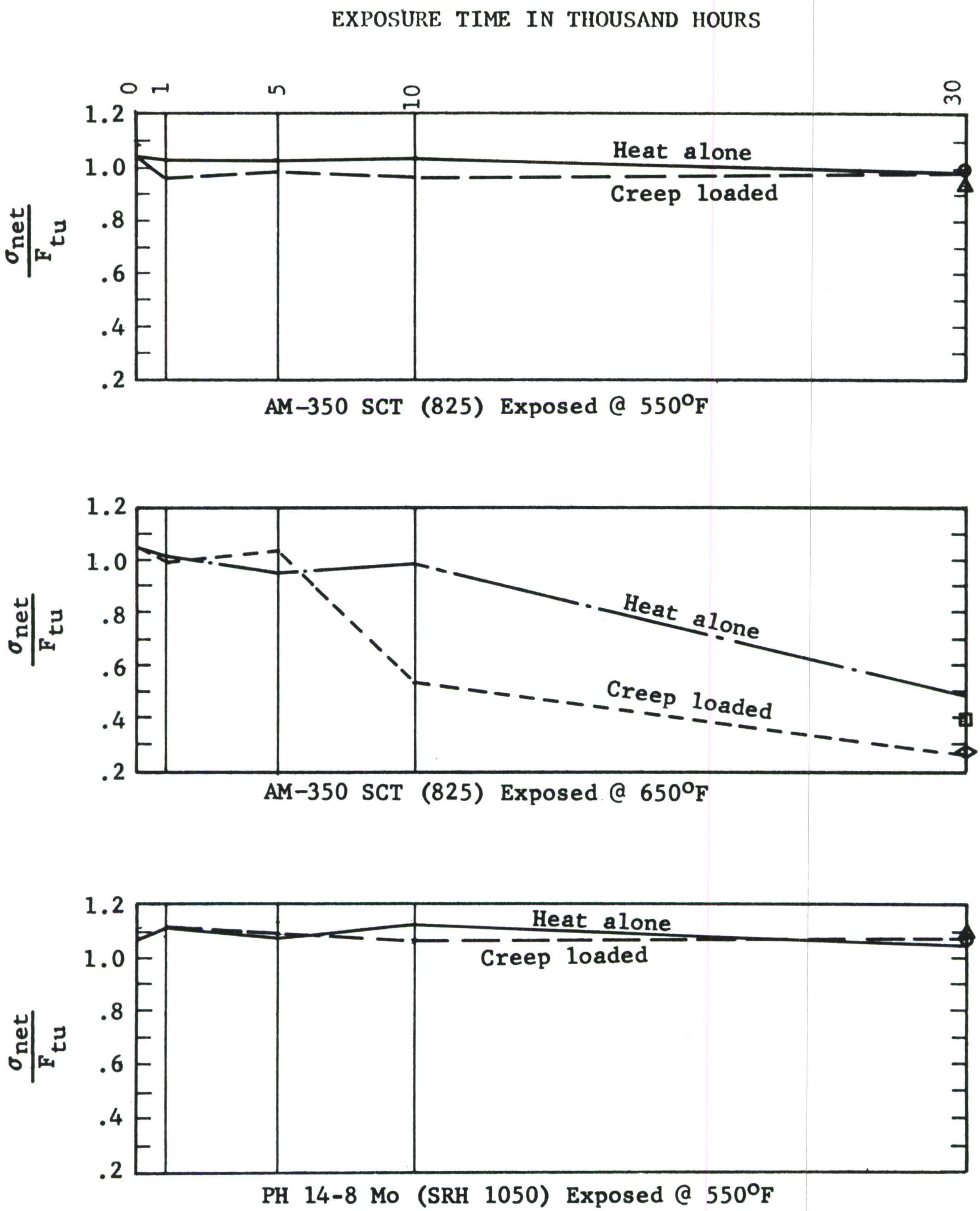


Figure 80 Ratio of Net Fracture Stress (σ_{net}) to Ultimate Tensile Strength (F_{tu}) versus Exposure Time for Stainless Steels After Exposure Indicated and Then Tested at -65°F

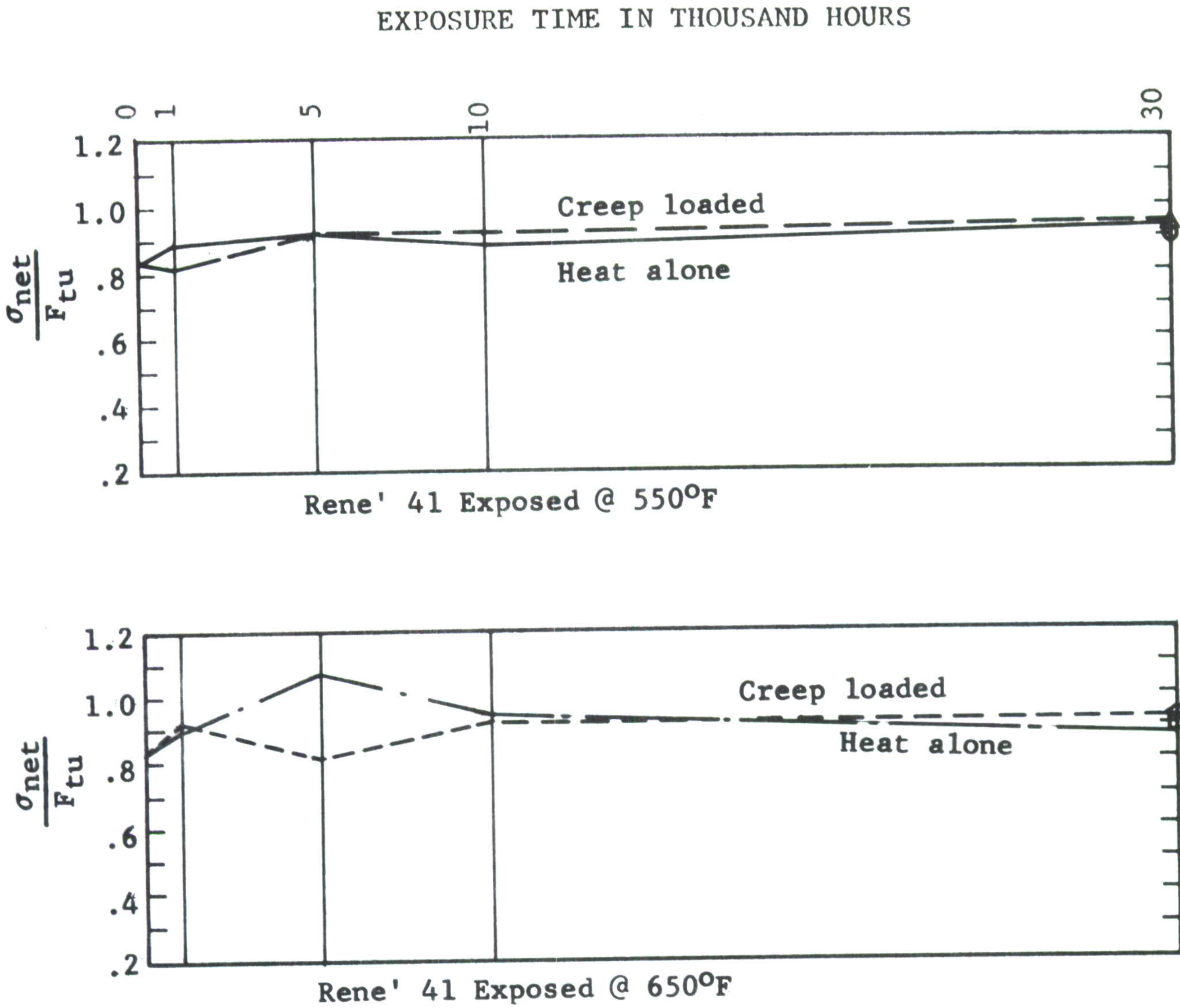


Figure 81 Ratio of Net Fracture Stress (σ_{net}) to Ultimate Tensile Strength (F_{tu}) versus Exposure Time for Rene' 41 (20% C.R. + 16 Hours @ 1400°F) After Exposure Indicated and Then Tested at Room Temperature

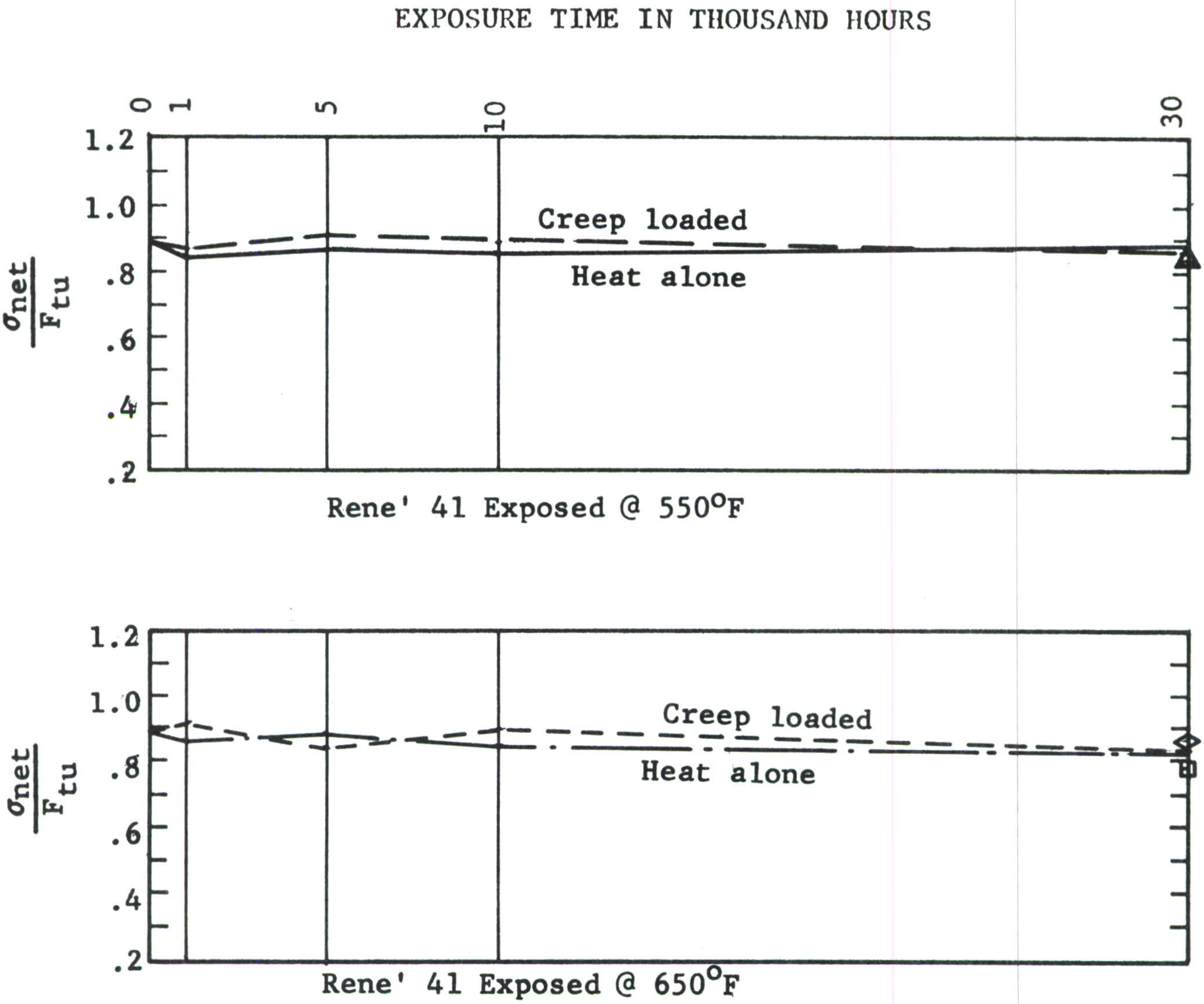


Figure 82 Ratio of Net Fracture Stress (σ_{net}) to Ultimate Tensile Strength (F_{tu}) versus Exposure Time for Rene' 41 (20% C.R. + 16 Hours @ 1400°F) After Exposure Indicated and Then Tested at -65°F

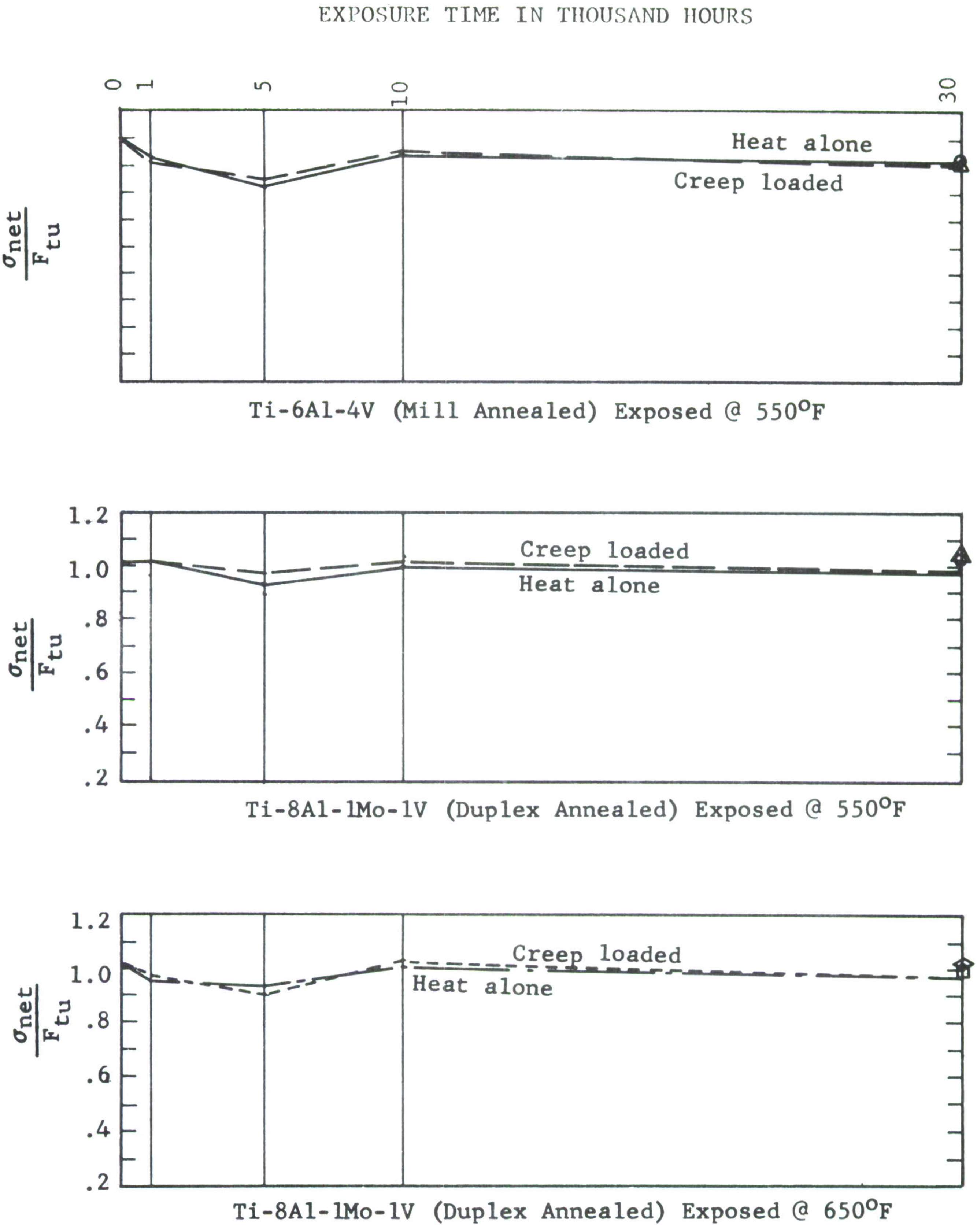


Figure 83 Ratio of Net Fracture Stress (σ_{net}) to Ultimate Tensile Strength (F_{tu}) versus Exposure Time for Titanium Alloys After Exposure Indicated and Then Tested at Room Temperature

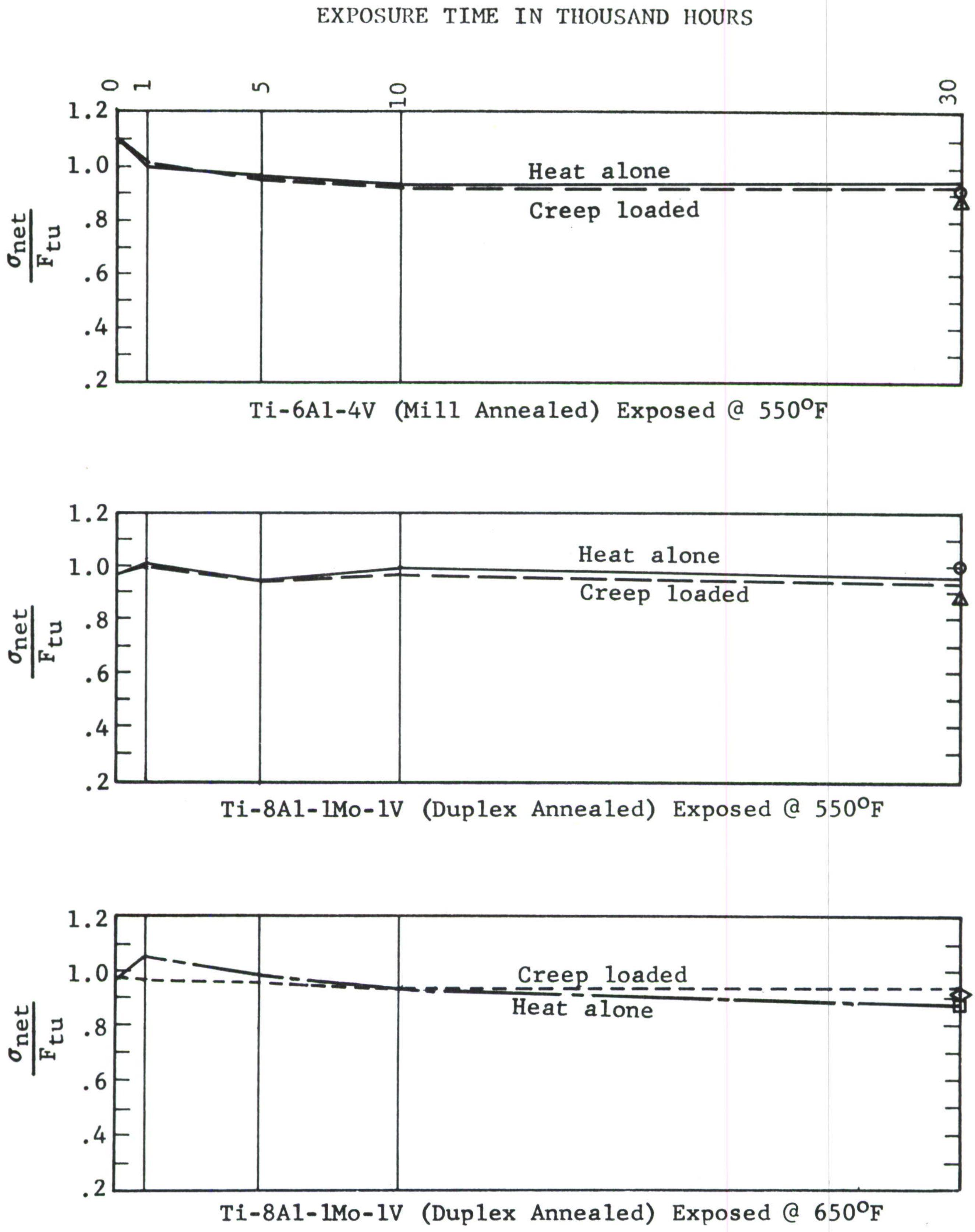


Figure 84 Ratio of Net Fracture Stress (σ_{net}) to Ultimate Tensile Strength (F_{tu}) versus Exposure Time for Titanium Alloys After Exposure Indicated and Then Tested at -65°F

rapidly. After 10,000 hours of exposure to either heat or to creep the ratio is lowered until it reaches .27 for the creep loaded specimens. There is very little difference between the notched to unnotched strength ratio of specimens tested after intermittent exposure and steady exposure.

The notched to unnotched strength ratio of René 41 as shown in Figures 81 and 82 is slightly less than 0.9 regardless of exposure condition or static test temperature.

The notched to unnotched strength ratio of Ti-6Al-4V and Ti-8Al-1Mo-1V is very nearly the same and only slightly affected by exposure at 550°F. The ratio starts around 1.0 and drops about 5 percent after 30,000 hours. At 650°F the Ti-8Al-1Mo-1V notched to unnotched ratio drops to approximately 0.90 after 30,000 hours indicating temperature and time are having a slight effect on the titanium, as shown in Figures 83 and 84.

Metallographic Studies

Longitudinal sections from all material exposed to both intermittent and steady heat and stress were examined on a B & L Research Metallograph. Photographs at 500 X were made of representative sections which had received the severest test conditions. That is, where a material was exposed to either 550° or 650°F, the 650°F exposure was considered to be the most likely to show microstructural changes if any existed. The creeped material was compared to the material which was exposed to temperature only.

To further amplify and clarify any structural changes which might have occurred in the five materials evaluated in this investigation, electron microscope studies were made using a JEM-6a instrument. Replication of the metal surfaces was made using nitrocellulose acetate tape softened in acetone. The replica was chromium shadowed at 45° followed by evaporated carbon backing. Electron micrographs were taken at 3500 and 11,000X magnifications of the sample of each material which was intermittently stressed at the highest exposure temperature.

AM-350 SCT (825) Stainless Steel

The microstructures of the AM-350 (SCT 825) semimartensitic stainless steel exposed to the various periods of temperature and stress are shown by optical microscopy in Figure 85 and by electron microscopy in Figure 86. Basically, the microstructure consists of stringers of ferrite in a martensite matrix with retained austenite interspersed in the matrix. Small particles of chromium carbide have precipitated at the ferrite-martensite interface and at grain boundaries. Normally AM-350 contains approximately 10 percent ferrite, 70 percent martensite, and 20 percent retained austenite in the solution treated and aged condition. The unexposed material has a microstructure which would correspond approximately to this composition.

Referring to Figure 85, the most noticeable changes in the microstructure are to the light etching islands of ferrite and the dark etching carbide particles. After 10,000 hours of exposure at 650°F, the almost continuous ferrite stringers had changed into nearly equiaxed ferrite grains. However, the stringers reappeared in the 30,000 hour exposure material. It was concluded that the equiaxed condition observed in the 10,000 hour material was a localized condition in the sheet of AM-350 rather than being an effect of time at temperature. The sections photographed for the 30,000 hour exposure contained more ferrite. However, the ferrite was not uniformly distributed across the thickness of the sheet and the photomicrographs contained the maximum density of ferrite. The material exposed to the 550°F environment showed no microstructural changes.

The basic change that occurred to the AM-350 resulted in the chromium carbide precipitation. Although an increase in the dark etching constituent is apparent in Figure 85, the increase in carbide precipitation is more evident in the electron micrographs of the 10,000 and 30,000 hour material in Figure 86. This precipitation occurred primarily at the ferrite-martensite interface. The mechanism involved was an agglomeration of small carbides already present in the material as verified by extraction replication techniques.

To summarize, the effect of the 650°F exposure on AM-350 was to cause an agglomeration of the chromium carbides, primarily at the ferrite-martensite interface. This agglomeration became detrimental to the -65°F fracture toughness properties after 10,000 hours of exposure, causing a 60 percent drop in strength. After 30,000 hours of exposure, both the creeped and non-stressed AM-350 were adversely affected. In addition, the carbide agglomeration caused an increase in the yield strength and a slight decrease in 650°F ductility.

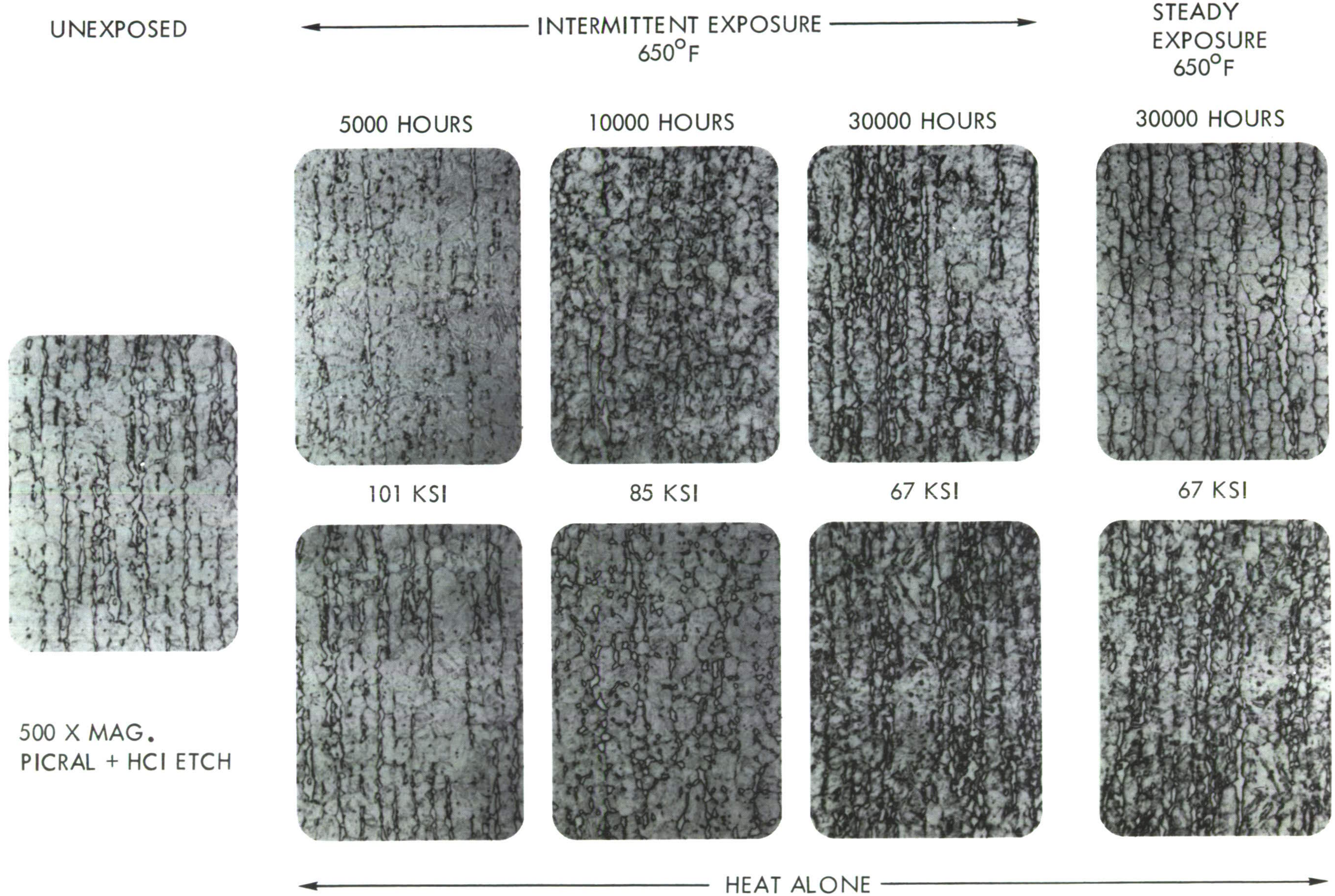


Figure 85 MICROSTRUCTURE OF AM-350 SCT (825) AFTER LONG TIME EXPOSURE TO HEAT ALONE AND CREEP LOADING

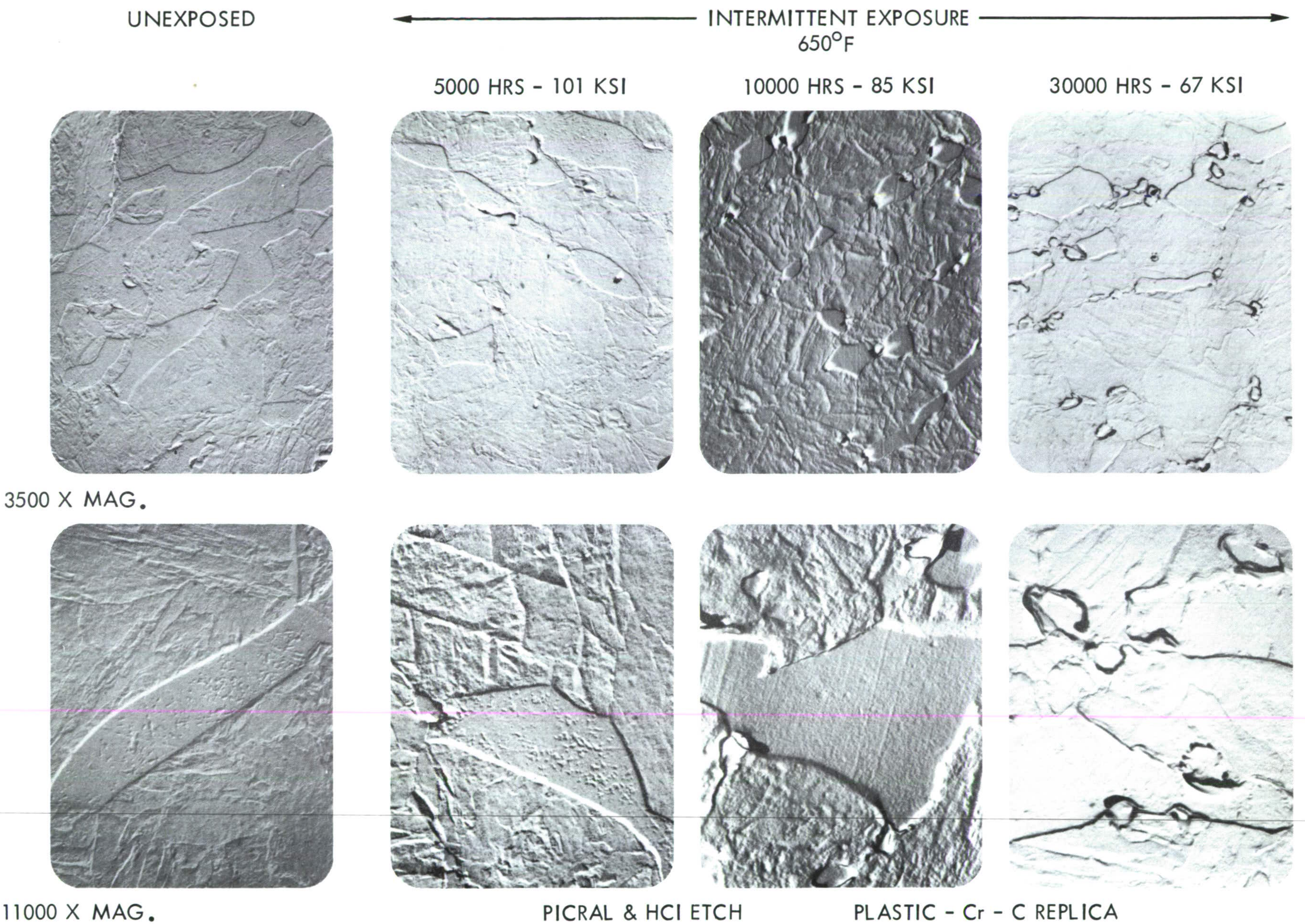


Figure 86 ELECTRON MICROGRAPHS OF AM-350 SCT (825) AFTER LONG TIME EXPOSURE TO CREEP LOADING

PH 14-8 Mo (SRH 1050) Stainless Steel

The PH 14-8 Mo (SRH 1050) evaluated in this program represents an improvement by Armco Steel to increase the toughness of PH 15-7 Mo. Originally, PH 15-7 Mo was part of this investigation but specimens were changed to PH 14-8 Mo after about 4000 hours of exposure. This is the reason for the microstructural comparison being made at 1000, 6000, and 25,000 hours whereas all the other materials were compared at 5000, 10,000 and 30,000 hours. A comparison of microstructures is shown as observed on the metallograph in Figure 87 and on the electron microscope in Figure 88.

PH 14-8 Mo is quite similar in composition and microstructure to AM-350. It contains less carbon, manganese, silicon, phosphorus, sulfur and nitrogen than AM-350. These elements are considered to lower the toughness of a stainless steel. The main difference in composition is that the PH 14-8 Mo contains a nominal 1.2 percent aluminum which combines with nickel to form precipitation hardening intermetallics, Ni_3Al and NiAl. In the heat treatment of the AM-350, the final heating operation consisted of tempering at 825°F which reduced the strength of the martensite. In the final heating operation of the PH 14-8 Mo at 1050°F, an increase in the strength of the semimartensitic steel resulted because of precipitation hardening. These precipitates can not be detected by observation of the etched surface even with the electron microscope, but require diffraction techniques which were beyond the scope of this program.

In the aged condition, PH 14-8 Mo nominally contains 77 percent martensite, 8 percent ferrite and 15 percent retained austenite. That this condition exists in the material evaluated in this program is shown in Figure 87. The ferrite exists mostly in small, isolated islands with occasional short stringers, surrounded by the martensitic matrix. Non-metallic inclusions were more predominant in the PH 14-8 Mo than in the AM-350. Retained austenite is difficult to discern in the optical photomicrographs but can be observed in the electron micrographs of Figure 88. The enlarged electron micrograph of Figure 89 shows the "veined" structure of the martensite phase compared to the relatively smooth appearance of the retained austenite. The ferrite phase has the same smooth texture but appears to stand out in relief due to the difference in etch rate of this constituent to the electrolytic oxalic acid etchant. No observable change in the microstructure was detected in the PH 14-8 Mo after 25,060 hours exposure to 550°F. This includes both intermittent and steady exposure to temperature and with and without creep stress.

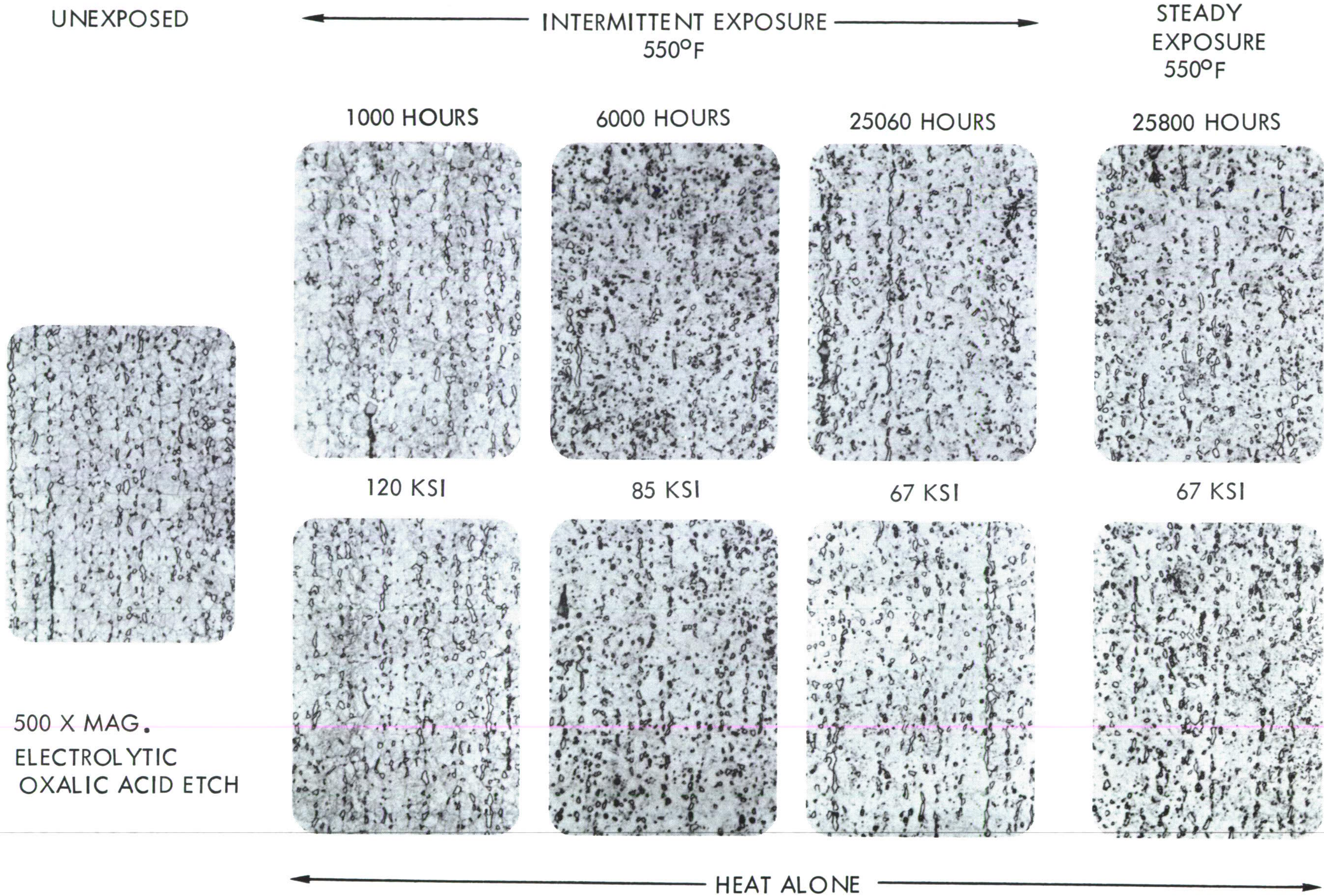


Figure 87 MICROSTRUCTURE OF PH 14-8 Mo (SRH 1050) AFTER LONG TIME EXPOSURE TO HEAT ALONE AND CREEP LOADING

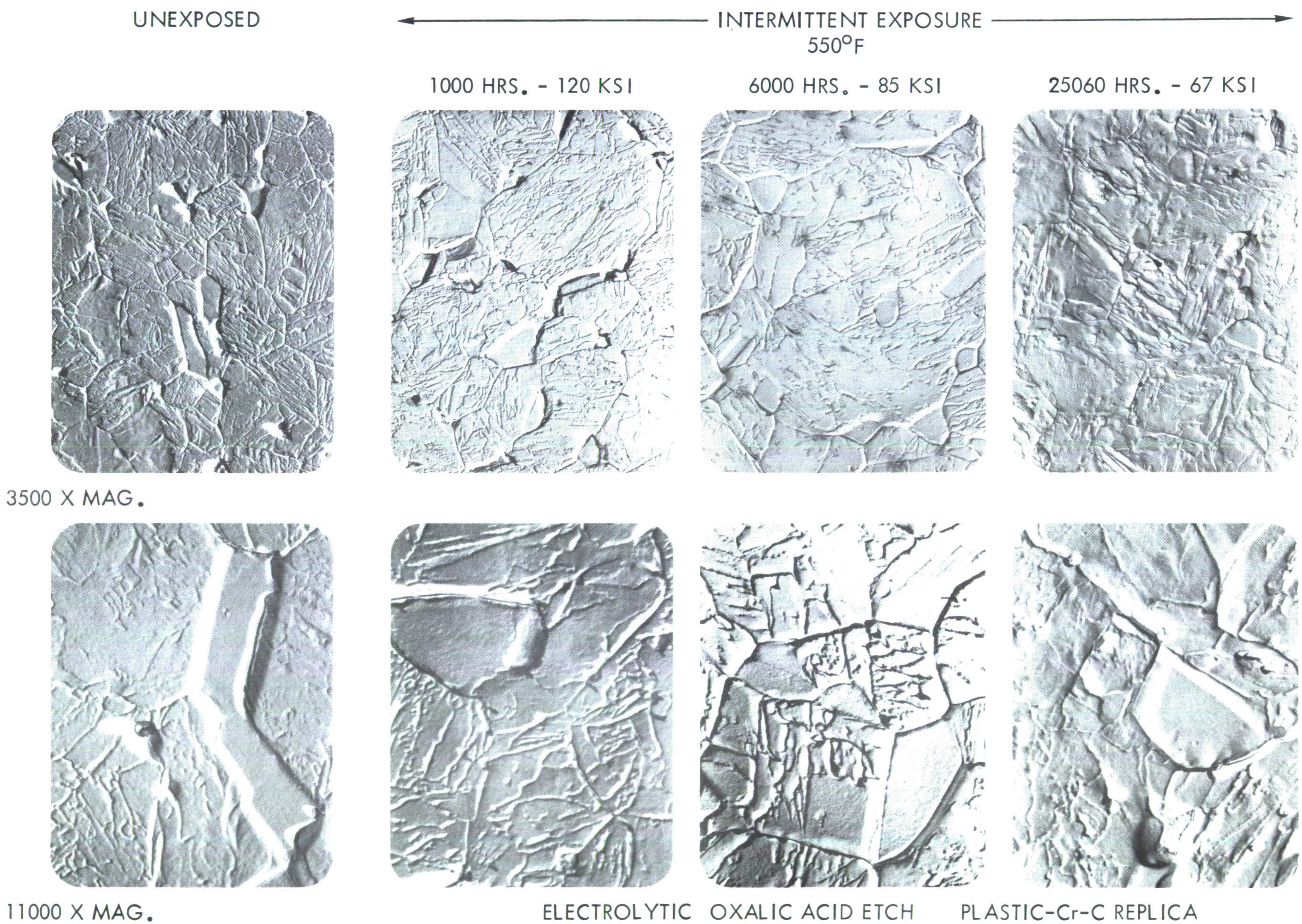


Figure 88 ELECTRON MICROGRAPHS OF PH 14-8 Mo (SRH 1050) AFTER LONG TIME EXPOSURE TO CREEP LOADING

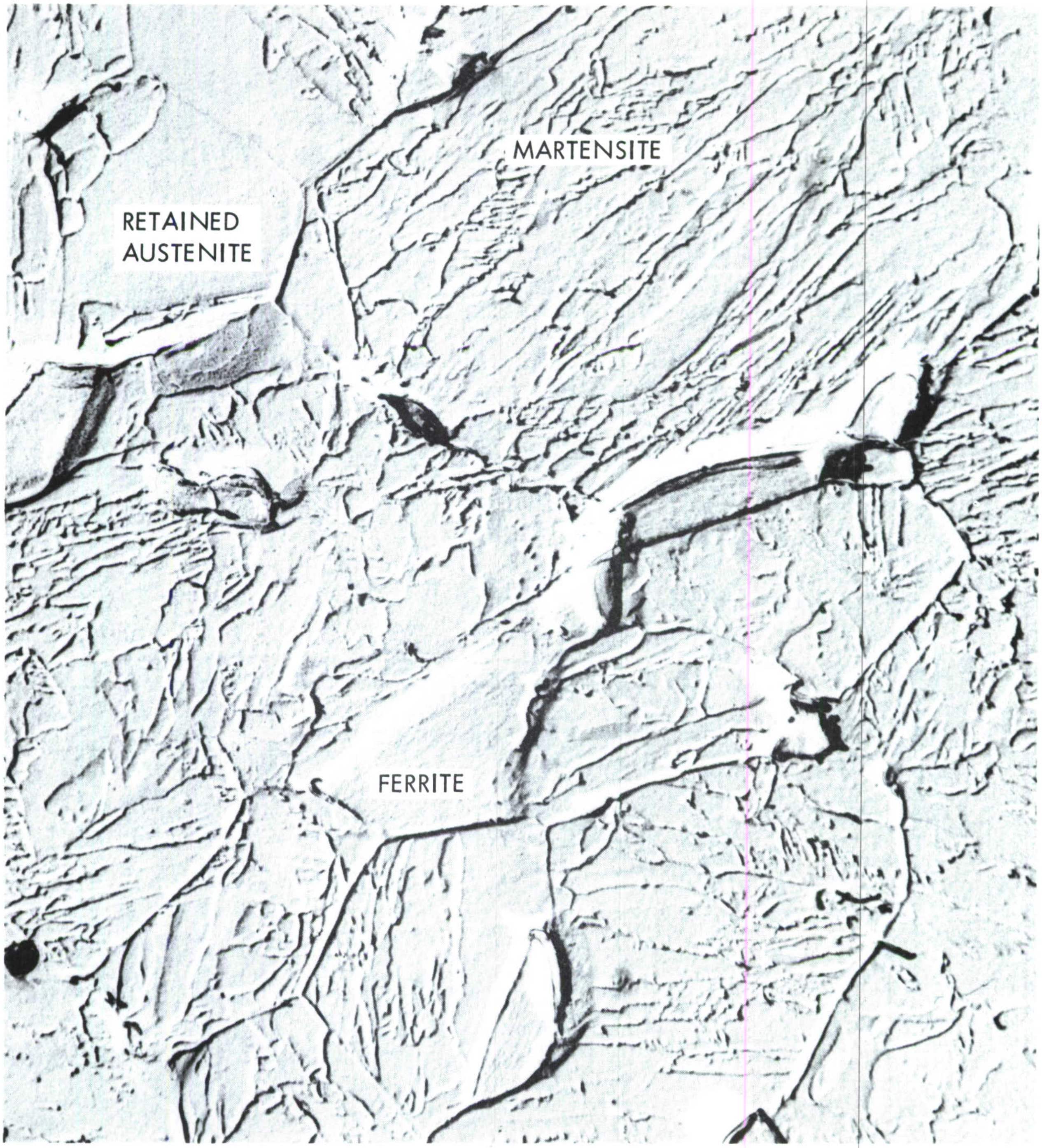


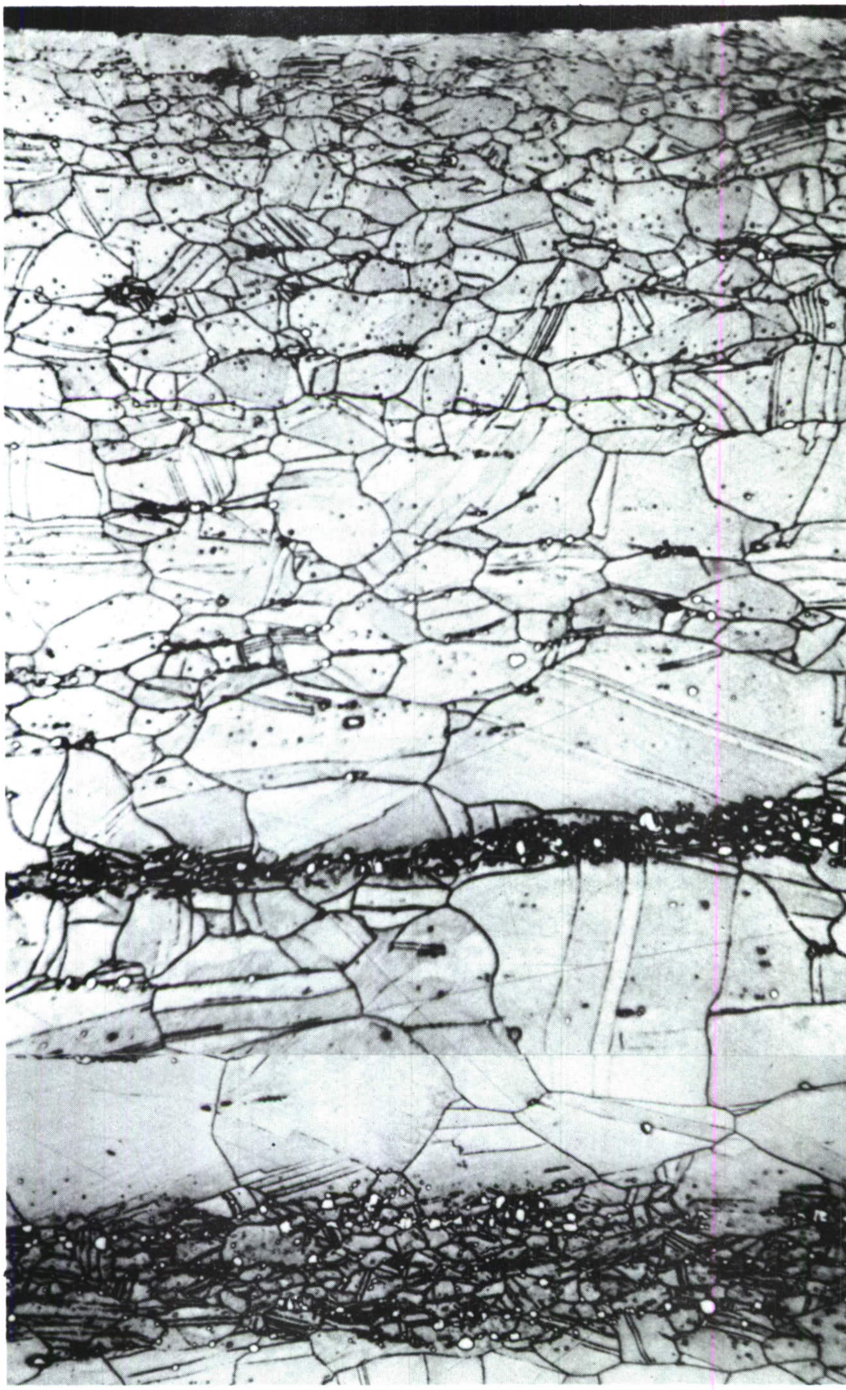
Figure 89 ELECTRON MICROGRAPH OF PH 14-8 Mo (SRH 1050) AFTER 1000 HOURS INTERMITTENT EXPOSURE TO 120 KSI AND 550°F (Major phases are identified)

Those specimens under conditions of steady exposure received a total of 25,800 hours at temperature with no cool-down to room temperature (except for a few shut-downs due to equipment repair). The intermittent specimens were exposed to maximum temperature for 2.5 out of every 3 hours of exposure. Thus, the intermittent specimens were at temperature for a total of 22,483 hours with 8,353 cool-downs to at least 125°F.

Rene' 41 (20% Cold Rolled + 16 Hours at 1400°F)

The complex microstructure of the Rene' 41 evaluated in this investigation was further compounded by the extreme amount of cold work, 20 percent reduction, put into the material by Sendzimir rolling to the 0.025-inch thickness. This severe rolling resulted in a very small grain size at the outer 1/4 thicknesses of the sheet. The center of the sheet had a larger grain size as shown in Figure 90, but was still a relatively small grain size of ASTM 6. A considerable amount of twinning is also evident in the photomicrographs of Figures 90 and 91. This cold work raised the normal ultimate strength of the 1400°F aged Rene' 41 from 185 ksi to 243 ksi.

The effect of the long time exposure at 650°F is shown in the photomicrographs of Figure 91 and the electron micrographs of Figure 92. No significant change is readily discernable. The etchant has revealed a considerable quantity of carbide precipitation at the grain boundaries and dispersed throughout the nickel-base matrix. The large white appearing carbides are TiC and were not affected by the exposure at 650°F, both for the stressed condition as well as the heat-soaked only material. The smaller carbides are M_6C. The electron micrographs did not reveal any obvious embrittling films of $M_{23}C_6$ carbides. Generally, extraction replica procedures are necessary to detect carbide films. The electron micrographs did show the primary strengthening constituent, gamma-prime precipitate, $Ni_3(Al, Ti)$ as a fine dispersion in the matrices in Figure 92. Carbides can also be seen at the grain boundaries and within the matrix. A very slight increase (5%) in the precipitated carbides was observed in the initially (1000 hours) exposed material which did not increase with exposures up to 30,000 hours. It was also observed that randomly scattered throughout the sheets of Rene' 41 were bands of severely segregated alloy concentration such as that shown in Figure 90. These bands of carbides undoubtedly accounted for the occasional extremely low ductility measured in the tensile tests.



$92HCl + 5H_2SO_4 + 3HNO_3$ 500 X MAG.

OUTER EDGE OF SHEET AT TOP OF PHOTO HAS SMALL GRAIN SIZE AND CONSIDERABLE TWINNING ASSOCIATED WITH 20% COLD ROLLING OF MATERIAL.

Figure 90 A CROSS SECTION OF HALF THE THICKNESS OF A RENE 41 .025" SHEET SHOWING BANDS OF SEVERE CARBIDE AND ALLOY SEGREGATION.

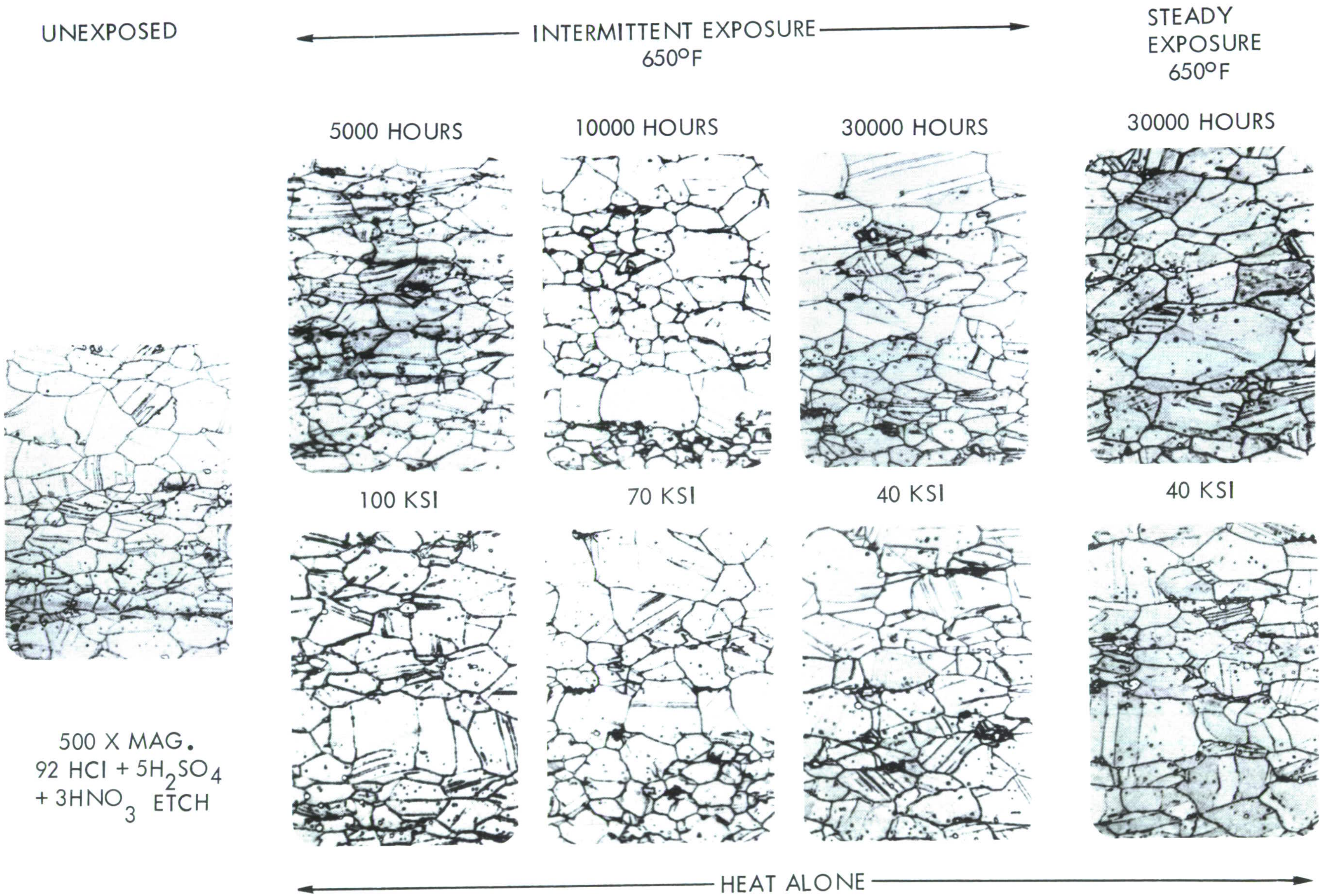


Figure 91 MICROSTRUCTURE OF 20% COLD ROLLED RENE 41 AFTER LONG TIME EXPOSURE TO HEAT ALONE AND CREEP LOADING

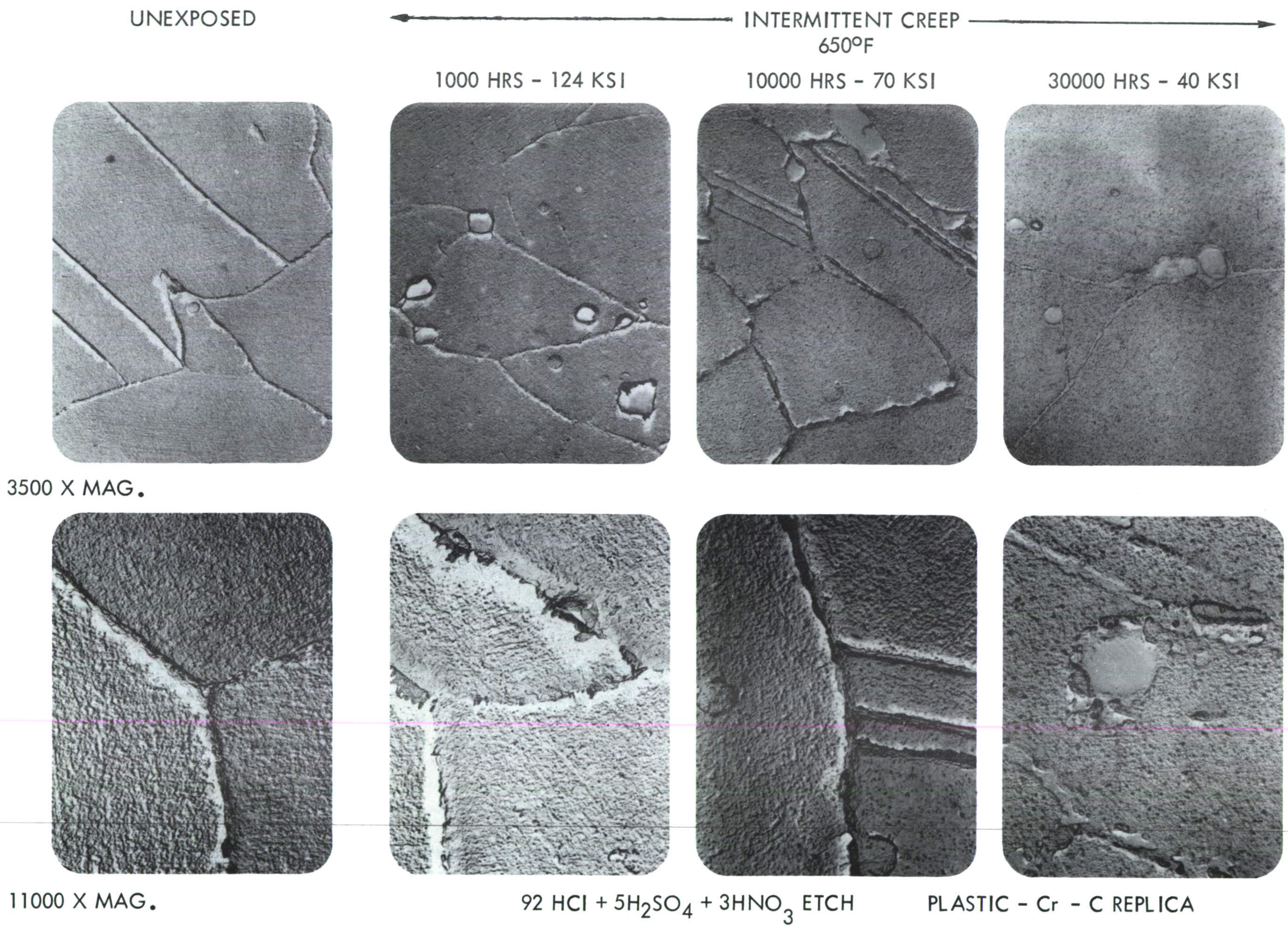


Figure 92 ELECTRON MICROGRAPHS OF 20% COLD ROLLED RENE 41 AFTER LONG TIME EXPOSURE TO CREEP LOADING

It would appear that the initial heating of the René 41 caused a slight secondary precipitation of carbides which resulted in some strengthening. After extended exposures to temperature and repeated cool-downs by the intermittent nature of the test, the strengthening was offset by some relaxation of the cold work.

Metallographically, no difference could be observed in the material which was exposed to steady heat as compared to that of the intermittent heat.despite the fact that the time at temperature was actually 30,000 hours instead of the 25,000 hours for the intermittently exposed René 41.

Ti-6Al-4V (Mill Annealed)

The microstructure of the mill annealed Ti-6Al-4V for conditions of intermittent and steady exposure with and without creep stress, are shown in Figures 93 and 94. It is evident that exposures up to 30,000 hours at 550°F with creep stresses of 40 ksi did not significantly cause any change in the alpha-beta titanium alloy. The optical micrographs show a light etching primary alpha matrix surrounding areas of stable beta. The elongated grains of alpha indicate that the annealing operation did not remove all of the effects of the sheet rolling operation. The electron micrographs of Figure 94 show the substructure of the alpha matrix and the beta particles and platelets.

This lack of microstructural change from temperature and stress exposure collaborates with the mechanical property results previously discussed.

Ti-8Al-1Mo-1V (Duplex Annealed)

The stability of the microstructure of the duplex annealed Ti-8Al-1Mo-1V is indicated in the optical and electron micrographs of Figures 95 and 96. The effect of 30,000 hours at either 550°F or 650°F for steady or intermittent exposure was nil in so far as metallographic changes were concerned. Essentially, neither the primary alpha phase (light etching) nor the transformed alpha-beta phase (dark etching - lamellar structure) were altered by the long time exposure. No transformation of beta could be detected despite the fact that the alloy contains only a small amount of beta-stabilizing elements, molybdenum and vanadium, and a relatively large amount of aluminum, an alpha-stabilizing addition. Unlike the Ti-6Al-4V, the duplex annealing operation was effective in removing the effects of

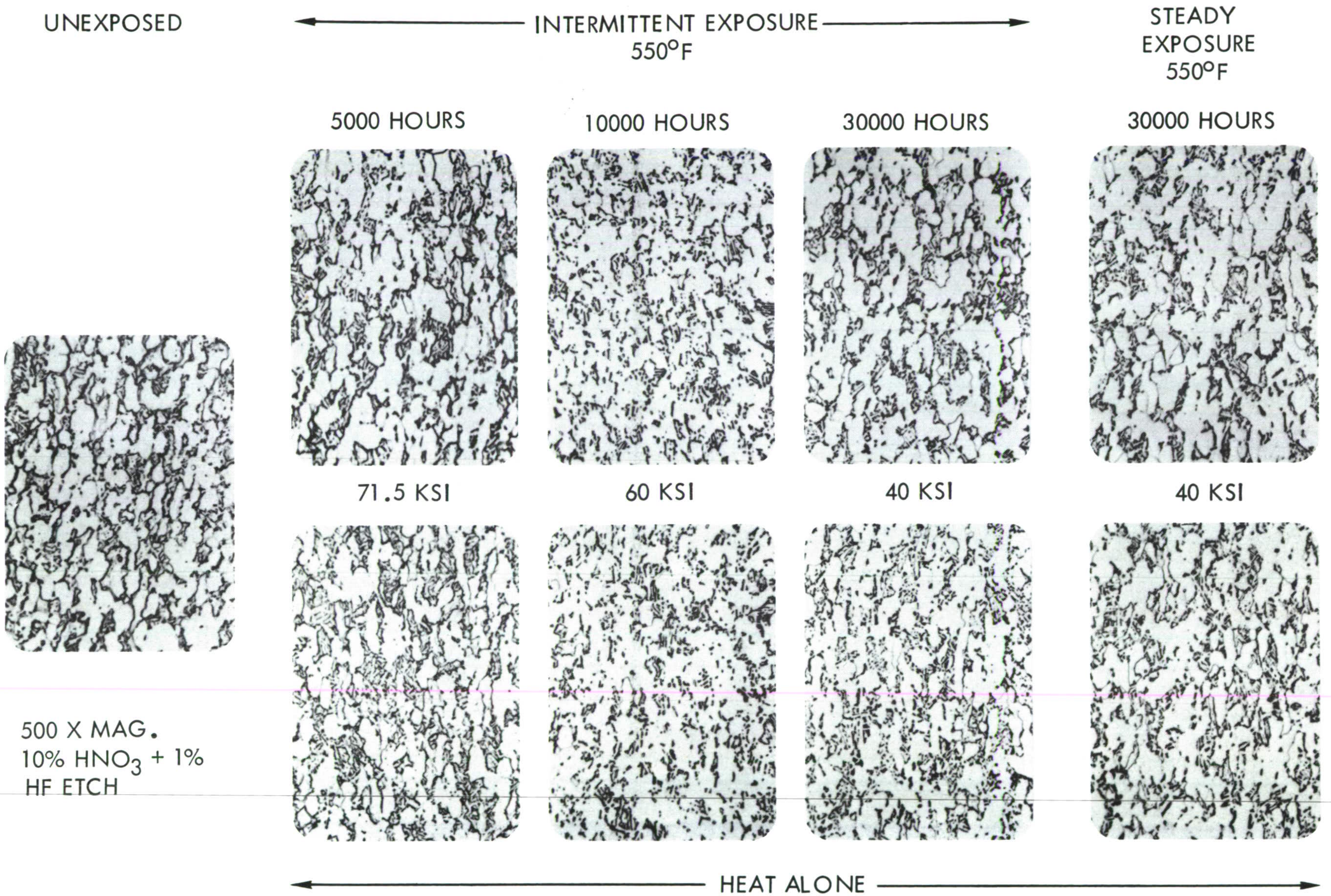


Figure 93 MICROSTRUCTURE OF MILL ANNEALED Ti-6Al-4V AFTER LONG TIME EXPOSURE TO HEAT ALONE AND CREEP LOADING

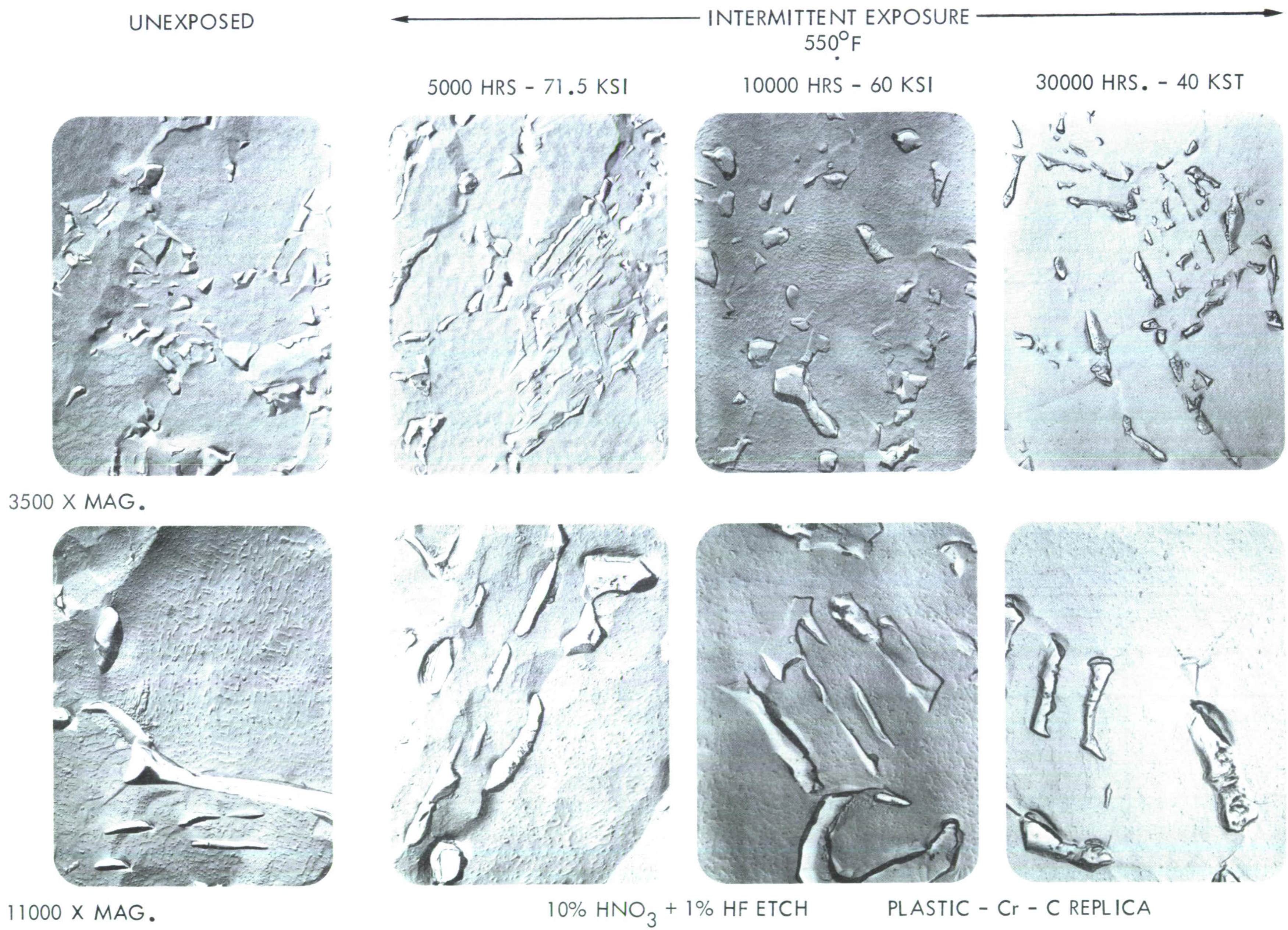


Figure 94 ELECTRON MICROGRAPHS OF MILL ANNEALED Ti-6Al-4V AFTER LONG TIME EXPOSURE TO CREEP LOADING

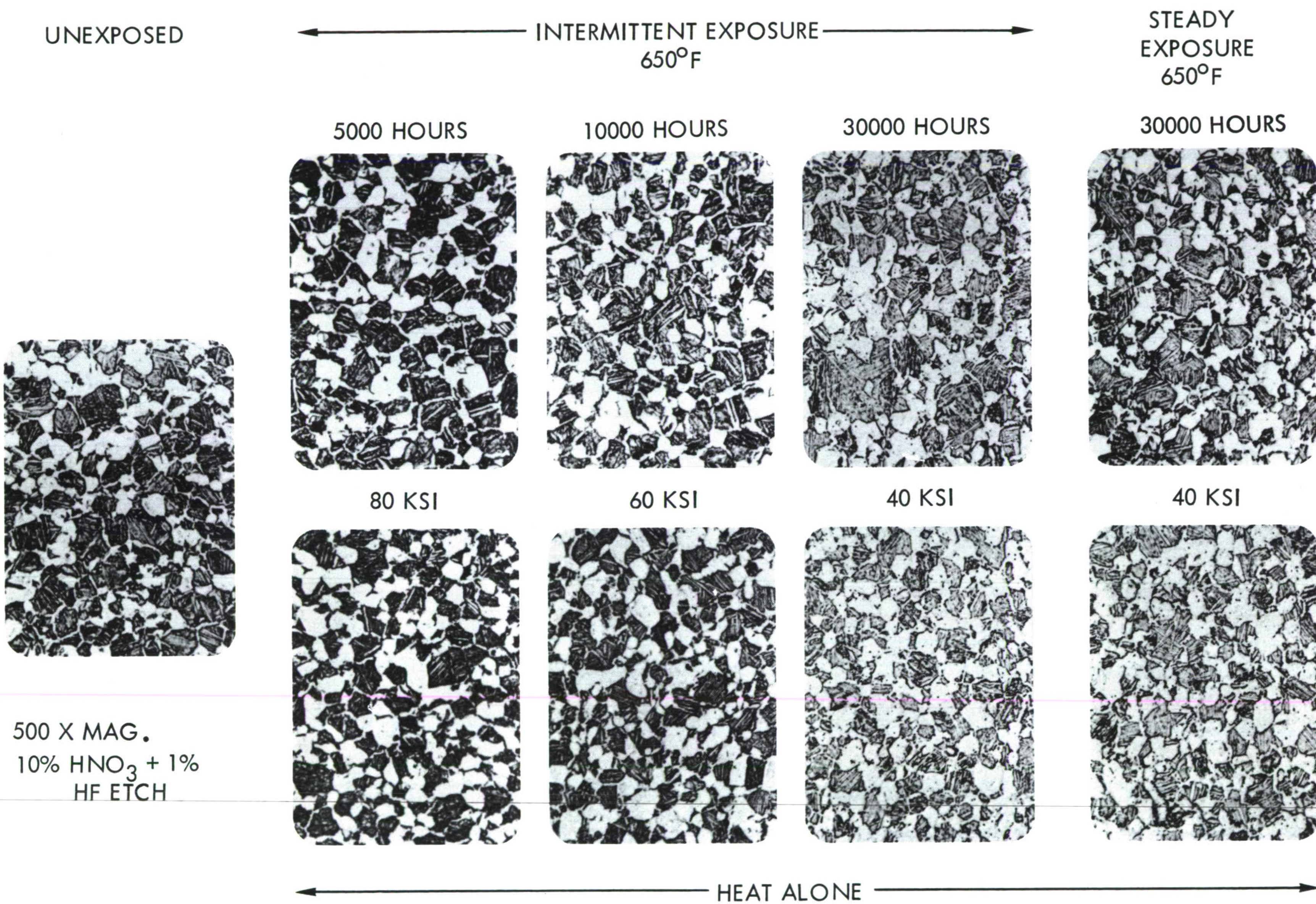
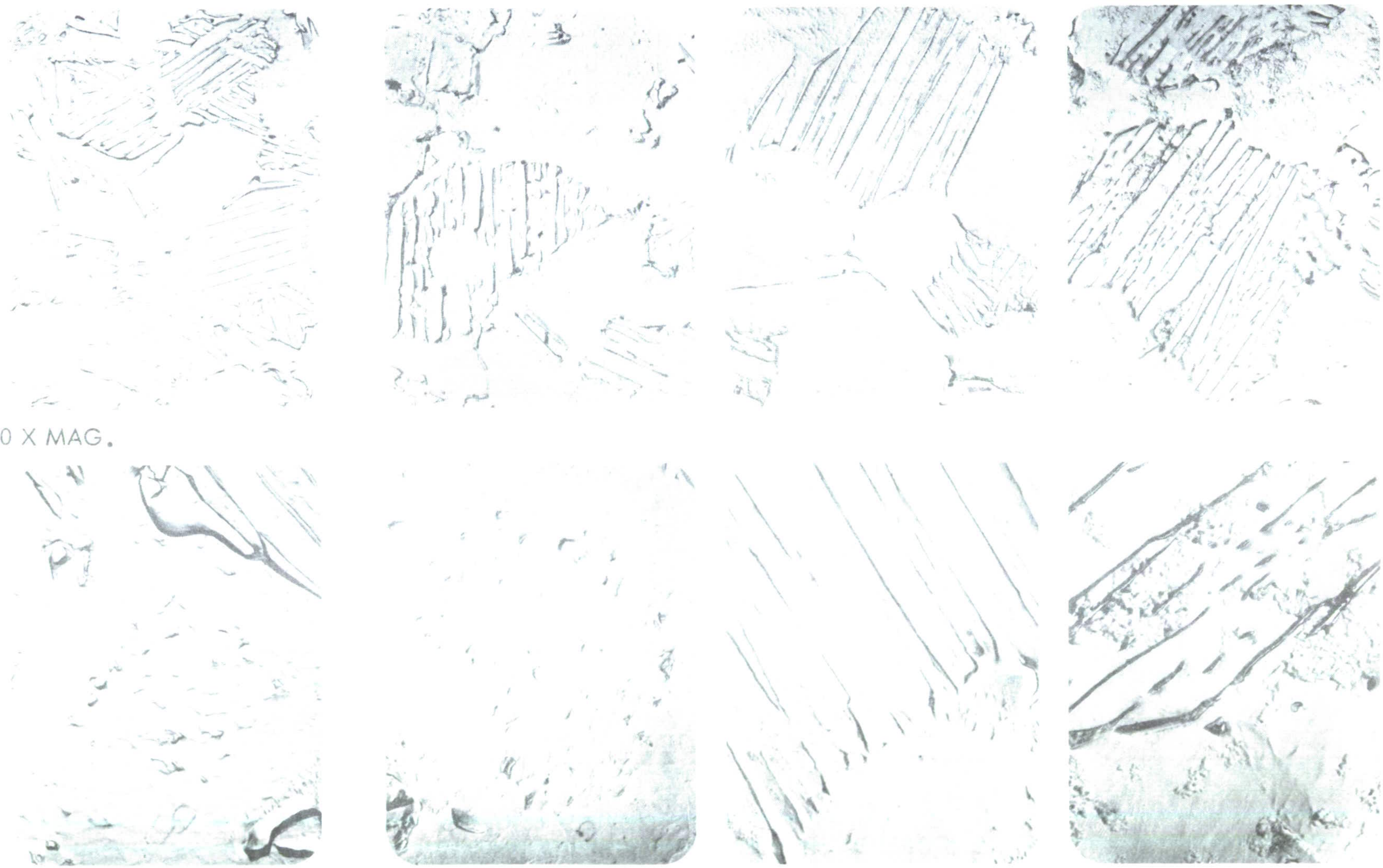


Figure 95 MICROSTRUCTURE OF DUPLEX ANNEALED Ti-8Al-1Mo-1V AFTER LONG TIME EXPOSURE TO HEAT ALONE AND CREEP LOADING

UNEXPOSED ←— INTERMITTENT EXPOSURE 650°F —→

5000 HRS. - 80 KSI | 10000 HRS. - 60 KSI | 30000 HRS - 47 KSI



3500 X MAG.

11000 X MAG.

10% HNO_3 + 1% HF ETCH   PLASTIC - Cr - C REPLICA

Figure 96 ELECTRON MICROGRAPHS OF DUPLEX ANNEALED Ti-8Al-1Mo-1V AFTER LONG TIME EXPOSURE TO CREEP LOADING the rolling operation and an equiaxed grain structure resulted. Isotropic properties would be expected from the Ti-8Al-1Mo-1V sheet.

SECTION IX

CONCLUSIONS

1. The magnitudes of creep deformation measured after 30,000 hours of loading at 550°F should not create a problem in the design of a supersonic transport airplane. The Ti-6Al-4V titanium alloy showed a rapid increase in creep rate as the exposure temperature increased from 550° to 650°F and, therefore, its use should be limited to low stress levels for short times at 650°F. Otherwise, the magnitude of creep measured at 650°F at the 30,000 hour creep loading stress levels on the AM-350 steel, the René 41 superalloy and the Ti-8Al-1Mo-1V titanium specimens should be within the allowable creep deformation for 30,000 hours of flight of a supersonic transport airplane.

2. Creep loading applied intermittently produces the same magnitude of plastic strain per unit of time as steadily applied creep loading when measured at 550° and 650°F on the candidate alloys.

3. a. Based on fracture toughness measurements, it was found that the ductile to brittle transition temperature of AM-350 SCT (825) stainless steel was raised from below -65°F to between -65°F and room temperature by exposure to creep loading at 650°F for 10,000 hours. The fracture toughness of the AM-350 stainless steel tested at -65°F continued to decrease as the creep exposure time increased to 30,000 hours. Exposure to heat alone at 650°F for 30,000 hours also raised the ductile to brittle transition temperature above the -65°F test temperature. Exposure to heat alone or to creep loading at 550°F had a negligible effect on the AM-350 steel up to 30,000 hours.

   b. The exposure of PH 14-8 Mo (SRH 1050) stainless steel to heat alone or creep loading at 550°F did not reveal any important changes in this alloy when exposed up to 25,800 hours. There was a slight increase in toughness shown when exposed fracture toughness specimens were static tested at -65°F.

   c. The variations in tensile and fracture toughness properties of René 41 with exposure at 550° and 650°F are slight and are of no design significance.

d. Neither Ti-6Al-4V nor Ti-8Al-1Mo-1V titanium alloys are significantly affected by heat alone or creep loading as applied in the program.

4. The only alloy of the five tested that showed any appreciable degradation with exposure was the AM-350 SCT (825) stainless steel. This degradation was a result of applying heat alone or heat plus stress at 650°F. The stress added to the effect of heat in producing lower fracture toughness at an earlier exposure time than caused by heat alone.

5. a. Of the five materials tested, only the AM-350 showed any significant change in microstructure. After 10,000 hours exposure, a growth in carbides at the martensite-ferrite interface was noted in the creeped material only. An electron microscope study of extraction replicas revealed that an agglomeration of smaller precipitated carbides was occurring. This same condition was observed in the heat-soaked only material as well as the creeped material after 30,000 hours exposure. Primarily, the effect of the agglomerated carbides was to drastically reduce the -65°F fracture toughness strength and slightly increase the yield strength of the AM-350.

   b. The René 41 (20% cold rolled + 16 hours at 1400°F) showed a very slight (5%) increase in precipitated M_6C carbides which could be metallographically detected only by careful study of the microstructure. This increase in carbide concentration occurred after the initial 1000 hours of exposure to 650°F and no further increase was observed for exposures up to 30,000 hours. Tensile properties were affected by an initial increase in yield and ultimate which gradually lessened with longer periods of exposure.

   c. The stability of the mill annealed Ti-6Al-4V and the PH 14-8 Mo (SRH 1050) stainless steel was not affected by intermittent or steady exposures at 550°F for 30,000 and 25,000 hours, respectively. Likewise, the duplex annealed Ti-8Al-1Mo-1V alloy was not affected by 30,000 hours at temperatures of 650°F.

SECTION X

RECOMMENDATIONS

1. Where small magnitudes of creep are to be measured, such as was found in this program, creep should be measured over a long gage length to minimize the error in physically making the measurement. Accompanying the specimen throughout its entire exposure duration, there should be an unloaded specimen measured precisely the same as the creep specimen to determine how much of the deformation measured was actually plastic strain and how much was growth due to metallurgical instability of the material.

2. AM-350 SCT (825) stainless steel should not be used above 550°F for long periods of time until the temperature required to start embrittlement is determined and should not be used more than 5000 hours at 650°F wherever brittle fracture would cause catastrophic failure.

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APPENDIX

TABLES III THRU XVII

Table III AM-350 SCT (825)
TENSILE PROPERTIES TEST DATA

(ALLEGHENY LUDLUM HEAT 89324, AIR MELTED) (SHEET 1 of 4)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	% e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
A1-1	R.T.	UNEXPOSED CONTROLS			.0247	.4809	.01188	2490	209,600	178,500	9.5	51.3	28.9
A1-2	R.T.				.0247	.4821	.01191	2505	210,300	181,800	10.0	50.3	29.1
A1-3	R.T.				.0249	.4845	.01206	2510	208,100	178,700	9.0	52.4	27.4
AVG.									209,300	179,700	9.5	51.3	28.5
A1-6	550				.0247	.6137	.01516	2900	191,300	143,500	6.5	45.2	25.4
A1-7	550				.0248	.6145	.01524	2880	189,000	146,000	6.5	44.8	26.2
A1-9	550				.0249	.6143	.01530	2925	191,200	142,500	5.0	42.2	23.7
AVG.									190,500	144,000	6.0	44.1	25.1
A2-18A	R.T.	HEAT SOAKED ONLY	550	1000	.0248	.6268	.01554	3280	211,100	179,200	11.5	53.7	27.4
A2-18E	R.T.				.0247	.6267	.01548	3270	211,200	179,600	10.0	52.8	27.9
AVG.									211,100	179,400	10.7	53.2	27.6
A2-18B	550				.0248	.6255	.01551	2970	191,500	145,700	5.0	46.5	23.6
A2-18C	550				.0248	.6275	.01556	3100	199,200	149,400	4.0	40.0	24.9
A2-18D	550				.0250	.6270	.01568	3055	194,800	147,000	4.0	39.4	24.4
AVG.									195,200	147,400	4.3	42.0	24.3
A3-19A	R.T.			5000	.0250	.6280	.01570	3290	209,600	182,200	11.0	47.8	27.2
A3-19E	R.T.				.0249	.6264	.01560	3300	211,500	182,200	10.0	50.0	29.2
AVG.									210,500	182,400	10.5	48.9	28.2
A3-19B	550				.0250	.6275	.01569	3085	196,600	146,000	4.0	41.5	25.8
A3-19C	550				.0250	.6285	.01571	3090	196,700	145,800	3.0	43.0	25.9
A3-19D	550				.0250	.6280	.01570	3080	196,200	150,300	4.0	45.2	22.2
AVG.									196,500	147,400	3.7	43.2	24.6
A1-16A	R.T.			10,000	.0252	.6252	.01576	3290	208,800	176,400	13.0	50.3	27.2
A1-16B	R.T.				.0253	.6288	.01591	3290	206,800	178,600	12.0	50.9	26.9
AVG.									207,900	177,500	12.5	50.6	27.0
A1-16C	550				.0252	.6316	.01592	3020	189,700	-	5.0	43.4	-
A1-16D	550				.0252	.6335	.01596	3080	193,000	146,600	4.0	37.5	27.5
A1-16E	550				.0252	.6343	.01598	3110	194,600	150,300	3.3	40.0	23.0
AVG.									192,400	148,500	4.1	40.3	25.2
A1-18A	R.T.			30,000	.0252	.5850	.01474	3055	207,300	179,100	12.0	53.4	27.2
A1-18B	R.T.				.0252	.5839	.01471	3065	208,400	183,200	11.0	50.4	28.2
AVG.									207,800	181,100	11.5	51.9	27.7
A1-18C	550				.0253	.5837	.01477	2820	190,900	142,200	5.5	47.7	28.1
A1-18D	550				.0253	.5844	.01479	2770	187,300	144,700	6.0	44.2	29.4
A1-18E	550				.0253	.5819	.01472	2760	187,500	143,300	7.0	44.1	31.0
AVG.									188,600	143,400	6.2	45.3	29.5

*DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY

Table III AM-350 SCT (825)
TENSILE PROPERTIES TEST DATA

(SHEET 2 of 4)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	%e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
A1-1	R.T.	UNEXPOSED CONTROLS			.0247	.4809	.01188	2490	209,600	178,500	9.5	51.3	28.9
A1-2	R.T.				.0247	.4821	.01191	2505	210,300	181,800	10.0	50.3	29.1
A1-3	R.T.				.0249	.4845	.01206	2510	208,100	178,700	9.0	52.4	27.4
AVG.									209,300	179,700	9.5	51.3	28.5
A1-6	550				.0247	.6137	.01516	2900	191,300	143,500	6.5	45.2	25.4
A1-7	550				.0248	.6145	.01524	2880	189,000	146,000	6.5	44.8	26.2
A1-9	550				.0249	.6143	.01530	2925	191,200	142,500	5.0	42.2	23.7
AVG.									190,500	144,000	6.0	44.1	25.1
A2-19A	R.T.	120,000	550	1000	.0248	.6238	.01547	3325	214,900	197,800	8.5	49.6	28.0
A2-19E	R.T.				.0250	.6273	.01568	3370	214,900	194,200	9.0	45.8	28.3
AVG.									214,900	196,000	8.7	47.7	28.1
A2-19B	550				.0250	.6245	.01561	3055	195,700	162,700	7.5	44.7	24.6
A2-19C	550				.0250	.6254	.01564	2985	190,900	159,800	7.5	46.9	28.0
A2-19D	550				.0250	.6261	.01565	3025	193,300	160,700	7.0	44.4	25.0
AVG.									193,500	161,100	7.3	45.3	25.9
A3-17A	R.T.	103,000		5000	.0248	.6238	.01547	3255	210,400	183,600	11.0	52.2	28.7
A3-17E	R.T.				.0248	.6275	.01556	3305	212,400	187,600	10.0	53.1	28.7
AVG.									211,400	185,300	10.5	52.7	28.7
A3-17B	550				.0248	.6249	.01550	3065	197,700	151,900	5.0	43.5	24.4
A3-17C	550				.0250	.6258	.01565	3085	197,100	156,500	4.0	45.0	28.2
A3-17D	550				.0250	.6264	.01566	3050	194,800	153,600	6.5	43.2	29.0
AVG.									196,500	154,000	5.2	43.9	27.2
A2-16A	R.T.	85,000		10,000	.0248	.6242	.01548	3230	208,700	180,600	11.0	55.0	29.3
A2-16B	R.T.				.0250	.6250	.01563	3350	214,300	185,500	11.0	48.0	28.2
AVG.									211,500	183,100	11.0	51.5	28.7
A2-16C	550				.0250	.6255	.01564	3040	194,400	149,900	6.0	47.5	26.1
A2-16D	550				.0250	.6262	.01566	3025	193,200	148,500	5.5	41.5	25.6
A2-16E	550				.0249	.6275	.01562	3070	196,500	150,400	4.0	38.3	25.6
AVG.									194,700	149,600	5.2	42.4	25.8
A1-17A	R.T.	67,000		30,000	.0254	.6248	.01587	3295	207,600	182,100	12.0	57.2	28.1
A1-17B	R.T.				.0252	.6250	.01575	3320	210,800	178,400	11.0	52.4	29.5
AVG.									209,100	180,300	11.5	54.8	28.8
A1-17C	550				.0253	.6263	.01585	3030	191,200	147,900	6.0	43.7	30.2
A1-17D	550				.0253	.6268	.01586	3095	195,100	142,800	5.0	43.1	31.0
A1-17E	550				.0253	.6280	.01589	3015	189,700	146,300	6.5	46.4	28.2
AVG.									192,000	145,700	5.8	44.4	29.8

*DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY

Table III AM-350 SCT (825)

TENSILE PROPERTIES TEST DATA

(SHEET 3 of 4)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	%e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
A1-1	R.T.	UNEXPOSED CONTROLS			.0247	.4809	.01188	2490	209,600	178,500	9.5	51.3	28.9
A1-2	R.T.				.0247	.4821	.01191	2505	210,300	181,800	10.0	50.3	29.1
A1-3	R.T.				.0249	.4845	.01206	2510	208,100	178,700	9.0	52.4	27.4
AVG.									209,300	179,700	9.5	51.3	28.5
A2-6	650				.0249	.6128	.01526	3015	197,600	135,000	6.0	36.7	27.7
A3-6	650				.0251	.6146	.01543	3035	196,700	139,300	7.0	38.0	23.6
A4-6	650				.0249	.6118	.01523	2975	195,300	137,900	7.0	39.5	23.8
AVG.									196,500	137,400	6.7	38.1	25.0
A4-16A	R.T.	HEAT SOAKED ONLY	650	1000	.0245	.6270	.01536	3280	213,500	177,700	10.0	49.9	28.9
A4-16E	R.T.				.0248	.6284	.01558	3320	213,100	177,800	12.0	51.2	27.9
AVG.									213,300	177,700	11.0	50.6	28.4
A4-16B	650				.0246	.6283	.01546	3095	200,200	141,700	6.0	39.8	25.3
A4-16C	650				.0248	.6290	.01560	3115	200,000	146,800	5.0	37.8	24.5
A4-16D	650				.0248	.6278	.01570	3070	195,500	144,900	5.0	45.2	24.8
AVG.									198,600	144,500	5.3	40.9	24.9
A4-19A	R.T.			5000	.0246	.6283	.01535	3430	223,400	182,400	13.0	49.8	28.7
A4-19E	R.T.				.0249	.6270	.01561	3460	221,700	189,600	12.0	50.5	27.9
AVG.									222,500	186,000	12.5	50.2	28.3
A4-19B	650				.0250	.6277	.01569	3150	200,800	145,600	4.0	39.5	24.1
A4-19C	650				.0250	.6280	.01570	3160	201,300	145,200	5.0	33.8	26.2
A4-19D	650				.0251	.6279	.01576	3140	199,200	145,600	5.5	39.4	25.3
AVG.									200,400	145,500	4.8	39.2	25.2
A3-16A	R.T.			10,000	.0251	.6258	.01571	3420	218,300	189,200	14.0	43.9	27.7
A3-16B	R.T.				.0252	.6306	.01589	3425	215,500	187,100	13.0	45.3	27.0
AVG.									216,800	188,100	13.5	44.6	27.3
A3-16C	650				.0250	.6331	.01583	3205	202,500	159,500	3.5	38.0	23.0
A3-16D	650				.0250	.6362	.01591	3250	204,300	148,700	4.5	38.4	22.3
A3-16E	650				.0250	.6362	.01591	3245	204,000	149,400	5.0	40.0	22.5
AVG.									203,600	152,300	4.3	38.8	22.7
A4-17A	R.T.			30,000	.0249	.5852	.01457	3275	224,800	196,300	13.0	49.0	30.6
A4-17B	R.T.				.0250	.5857	.01464	3295	225,100	198,800	14.0	47.5	31.8
AVG.									225,000	197,600	13.5	48.3	31.2
A4-17C	650				.0255	.5841	.01489	3000	201,500	151,800	4.0	39.4	27.2
A4-17D	650				.0252	.5838	.01471	3000	203,900	154,700	5.0	38.9	27.9
A4-17E	650				.0251	.5805	.01457	2975	204,200	156,800	4.0	39.4	27.0
AVG.									203,200	154,400	4.3	39.2	27.4

*DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY

Table III AM-350 SCT (825)

TENSILE PROPERTIES TEST DATA

(SHEET 4 of 4)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	% e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
A1-1	R.T.	UNEXPOSED CONTROLS			.0247	.4809	.01188	2490	209,600	178,500	9.5	51.3	28.9
A1-2	R.T.				.0247	.4821	.01191	2505	210,300	181,800	10.0	50.3	29.1
A1-3	R.T.				.0249	.4845	.01206	2510	208,100	178,700	9.0	52.4	27.4
AVG.									209,300	179,700	9.5	51.3	28.5
A2-6	650				.0249	.6128	.01526	3015	197,600	135,000	6.0	36.7	27.7
A3-6	650				.0251	.6146	.01543	3035	196,700	139,300	7.0	38.0	23.6
A4-6	650				.0249	.6118	.01523	2975	195,300	137,900	7.0	39.5	23.8
AVG.									196,500	137,400	6.7	33.1	25.0
A3-18A	R.T.	118,000	650	1000	.0250	.6235	.01559	3400	218,100	190,500	9.5	46.0	27.9
A3-18E	R.T.				.0250	.6268	.01567	3400	217,000	194,600	9.5	42.6	28.4
AVG.									217,500	192,500	9.5	44.3	28.1
A3-18B	650				.0249	.6247	.01555	3120	200,600	165,900	5.0	45.3	25.1
A3-18C	650				.0249	.6255	.01575	3040	193,000	161,600	5.0	45.4	25.5
A3-18D	650				.0250	.6260	.01565	3055	195,200	163,900	5.0	41.9	28.7
AVG.									196,300	163,800	5.0	44.2	26.4
A4-18A	R.T.	101,000		5000	.0246	.6235	.01559	3400	220,300	197,200	11.0	48.8	28.4
A4-18E	R.T.				.0248	.6268	.01567	3400	218,300	188,500	10.0	50.5	29.4
AVG.									219,300	192,400	10.5	49.7	28.9
A4-18B	650				.0249	.6246	.01555	3135	201,600	154,700	4.5	37.6	26.0
A4-18C	650				.0248	.6254	.01551	3160	203,700	156,700	5.0	35.7	25.7
AD-18D	650				.0250	.6260	.01565	3145	201,000	164,500	4.0	43.1	27.3
AVG.									202,100	158,600	4.5	38.8	26.3
A2-17A	R.T.	85,000		10,000	.0250	.6245	.01561	3405	218,100	194,700	12.0	48.5	27.4
A2-17B	R.T.				.0250	.6252	.01563	3420	218,800	194,800	10.5	49.8	32.4
AVG.									218,400	194,700	11.3	49.1	29.9
A2-17C	650				.0251	.6259	.01571	3200	203,700	153,100	4.5	39.3	27.2
A2-17D	650				.0251	.6269	.01574	3160	200,800	149,000	5.0	42.4	24.2
A2-17E	650				.0250	.6272	.01568	3120	199,000	152,400	4.0	37.4	26.0
AVG.									201,200	151,500	4.5	39.7	25.8
A1-19A	R.T.	67,000		30,000	.0254	.6243	.01586	3455	217,800	195,800	13.0	27.7	27.8
A1-19B	R.T.				.0254	.6248	.01587	3440	216,800	193,800	12.0	47.5	28.6
AVG.									217,300	194,800	12.5	37.6	28.2
A1-19C	650				.0253	.6250	.01581	3140	198,600	151,500	4.0	42.6	32.6
A1-19D	650				.0252	.6259	.01577	3135	198,800	155,400	3.5	38.3	28.3
A1-19E	650				.0253	.6272	.01587	3160	199,100	156,000	3.5	39.7	28.4
AVG.									198,800	154,300	3.7	40.2	29.8

*DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY

Table IV PH 14-8 Mo (SRH 1050)
TENSILE PROPERTIES TEST DATA

(ARMCO HEAT NO. 31562) (SHEET 1 of 3)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	%e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
1	R.T.								219,200	200,000	7		
2	R.T.								209,800	186,200	10		
3	R.T.								216.500	203,100	5		
4	R.T.								219,200	202,000	7		
5	R.T.								218,800	202,400	6		
		UNEX	POSED	CONTROL		SPECIMEN							
		TEST	DATA	SUPP	LIED	BY	ARMCO						
6	550								192,000	175,200	3		
7	550								191,500	180,300	4		
8	550								185,500	165,700	3		
9	550								188,800	-	3		
10	550								192,000	175,200	3		
B9-A	R.T.	HEAT SOAKED ONLY	550	754	.0250	.6279	.01570	3455	220,100	-	6.0	47.1	26.4
B9-D	R.T.				.0249	.6300	.01569	3450	220,000	206,500	7.0	48.4	25.4
B9-E	R.T.				.0248	.6276	.01556	3425	220,100	210,500	7.0	51.9	26.9
AVG.									220,100	208.500	6.7	49.1	26.2
B9-B	550				.0250	.6276	.01569	3005	191,500	178,100	2.0	40.1	21.5
B9-C	550				.0249	.6276	.01563	3000	191,900	176,900	2.5	40.5	22.4
AVG.									191,700	177,500	2.2	40.3	21.7
B14-D	R.T.			1000	.0249	.6252	.01557	3535	222,700	211,500	7.0	40.3	25.4
B14-E	R.T.				.0249	.6250	.01556	3450	221,700	206,900	6.5	42.8	25.0
AVG.	R.T.								222.200	209.200	6.7	41.5	25.2
B14-A	550				.0250	.6262	.01566	3025	193,200	177,200	4.0	41.9	23.9
B14-B	550				.0250	.6254	.01564	3010	192,500	174,900	3.0	42.4	20.9
B14-C	550				.0250	.6253	.01563	3070	196,400	179,000	3.0	41.8	24.4
AVG.									194,000	177,000	3.3	42.0	23.0
B-4A	R.T.			6000	.0248	.6268	.01554	3375	217,200	198,800	7.5	48.5	29.2
B-4B	R.T.				.0246	.6272	.01543	3390	219,700	200,900	8.0	42.4	26.4
AVG.									218.400	199.800	7.7	45.5	27.8
B-4C	550				.0246	.6277	.01544	3055	197,900	184,600	3.0	35.9	22.0
B-4D	550				.0250	.6293	.01573	3010	191,400	175,800	2.5	41.9	22.5
B-4E	550				.0251	.6272	.01574	302)	191,900	179,500	3.0	40.4	22.6
AVG.									193,700	180,000	2.8	39.4	22.4
B-6A	R.T.			25060	.0252	.6270	.01580	3500	221,500	210,800	8.0	46.5	25.2
B-6B	R.T.				.0253	.6277	.01588	3515	221,300	208,800	8.0	48.9	26.3
AVG.									221,400	209.800	8.0	47.7	25.7
B-6C	550				.0253	.6285	.01590	3130	196,900	173,300	3.0	43.1	26.4
B-6D	550				.0251	.6300	.01581	3040	192,300	174,600	3.0	43.5	24.2
B-6E	550				.0252	.6276	.01582	3075	194,400	176,000	3.0	42.2	21.4
AVG.									194,500	174,600	3.0	42.9	24.0

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY

Table IV PH 14-8 Mo (SRH 1050)
TENSILE PROPERTIES TEST DATA

(SHEET 2 of 3)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	%e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
1	R.T.								219,200	200,000	7		
2	R.T.								209,800	186,200	10		
3	R.T.								216,500	203,100	5		
4	R.T.								219,200	202,000	7		
5	R.T.								218,800	202,400	6		
		UNEXPOSED CONTROL SPECIMEN TEST DATA SUPPLIED BY ARMCO											
6	550								192,000	175,200	3		
7	550								191,500	180,300	4		
8	550								185,500	165,700	3		
9	550								188,800	-	3		
10	550								192,000	175,200	3		
B10-A	R.T.	103,000	550	754	.0243	.6263	.01522	3310	217,500	189,900	6.5	48.1	27.3
B10-E	R.T.				.0248	.6272	.01555	3435	220,900	198,400	6.5	42.5	28.8
AVG.									219,200	194,100	6.5	45.3	28.0
B10-B	550				.0242	.6271	.01518	3045	200,600	187,700	2.0	44.6	27.0
B10-C	550				.0242	.6288	.01522	3055	200,700	187,200	2.0	43.1	26.6
B10-D	550				.0248	.6296	.01561	3190	204,400	190,900	2.5	41.7	23.8
AVG.									201,900	189,300	2.2	43.1	25.8
B1-A	R.T.	120,000		1000	.0246	.6255	.01539	3440	223,500	194,300	5.0	-	28.9
B1-E	R.T.				.0246	.6262	.01540	3455	224,400	196,400	7.0	41.6	27.8
AVG.									223,900	195,300	6.0	41.6	28.4
B1-B	550				.0245	.6267	.01535	3065	199,700	190,900	2.0	44.0	25.9
B1-C	550				.0242	.6270	.01517	3030	199,700	187,900	3.0	39.4	26.0
B1-D	550				.0243	.6282	.01527	3065	200,700	189,300	3.0	43.7	26.2
AVG.									200,000	189,400	2.7	42.4	26.0
B-2A	R.T.	85,000		6000	.0247	.6260	.01546	3465	224,100	196,300	7.0	48.2	31.5
B-2B	R.T.				.0246	.6266	.01541	3445	223,600	186,900	7.5	49.4	33.2
AVG.									223,800	191,600	7.2	48.8	32.4
B-2C	550				.0245	.6270	.01536	3010	196,000	178,100	2.0	-	24.7
B-2D	550				.0244	.6290	.01535	3025	197,100	182,400	3.0	39.1	22.9
B-2E	550				.0248	.6262	.01553	3010	193,800	178,400	2.5	41.1	23.8
AVG.									195,600	179,600	2.5	40.1	23.8
B-3A	R.T.	67,000		25,060	.0253	.6270	.01586	3480	219,400	198,000	8.5	50.3	30.1
B-3B	R.T.				.0252	.6275	.01581	3530	223,300	210,000	8.5	43.2	27.3
AVG.									221,300	204,000	8.5	46.7	28.7
B-3C	550				.0251	.6281	.01577	3130	198,500	175,600	3.0	35.9	20.7
B-3D	550				.0248	.6304	.01563	3005	192,300	174,000	3.0	35.4	27.5
B-3E	550				.0250	.6276	.01569	3045	194,100	176,500	3.0	46.1	29.9
AVG.									195,000	175,400	3.0	39.1	26.0

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY

Table IV PH 14-8 Mo (SRH 1050)
TENSILE PROPERTIES TEST DATA

(SHEET 3 of 3)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	% e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
1	R.T.								219,200	200,000	7		
2	R.T.								209,800	186,200	10		
3	R.T.								216,500	203,100	5		
4	R.T.								219,200	202,000	7		
5	R.T.								218,800	202,400	6		
		UNEXPOSED CONTROL SPECIMEN											
6	550								192,000	175,200	3		
7	550	TEST DATA SUPPLIED BY ARMCO							191,500	180,300	4		
8	550								185,500	165,700	3		
9	550								188,800	-	3		
10	550								192,000	175,200	3		
B-7A	R.T.	HEAT SOAKED ONLY	550 STEADY	25800	.0246	.6270	.01542	3465	224,700	211,400	8.0	-	27.5
B-7B	R.T.				.0246	.6273	.01543	3405	220,700	206,400	8.0	42.7	26.1
AVG.									222,700	208,900	8.0	42.7	26.8
B-7C	550				.0243	.6281	.01526	2975	195,000	177,900	3.0	40.1	24.8
B-7D	550				.0251	.6303	.01582	3065	193,700	179,200	3.0	41.6	24.2
B-7E	550				.0252	.6277	.01582	3110	196,600	182,700	3.0	42.5	27.3
AVG.									195,100	181,100	3.0	41.4	25.4
B-5A	R.T.	67000 STEADY			.0253	.6270	.01586	3460	218,200	201,100	7.0	50.9	27.7
B-5B	R.T.				.0251	.6274	.01575	3480	221,000	204,400	7.5	50.5	29.4
AVG.									219,600	202,800	7.3	50.7	28.5
B-5C	550				.0252	.6280	.01583	3145	198,700	**	2.5	44.7	**
B-5D	550				.0246	.6302	.01550	3020	194,800	173,900	3.0	43.8	27.7
B-5E	550				.0248	.6275	.01556	3090	198,600	178,700	3.0	37.5	28.9
AVG.									197,400	175,300	2.8	42.0	28.3

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY
** EXTENSOMETER MALFUNCTIONED

Table V RENÉ 41 (20% C. R. + 16 HRS @ 1400°F)
TENSILE PROPERTIES TEST DATA

(CANNON MUSKEGON HEAT V-2146) (SHEET 1 of 5)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	%e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
D3-15B	R.T.	UNEXPOSED CONTROLS			.0241	.4927	.01187	2920	246,000	229,100	5.5	13.5	31.5
D3-15C	R.T.				.0239	.4929	.01178	2900	246,200	230,500	5.5	15.1	32.5
D3-15E	R.T.				.0238	.4908	.01168	2850	244,000	226,900	6.0	16.3	31.9
D2-17E1	R.T.				.0221	.4982	.01101	2650	240,700	222,100	9.0	16.9	32.4
D2-17E2	R.T.				.0216	.4962	.01072	2570	239,700	221,100	7.5	17.6	31.2
AVG.									243,300	225,900	6.7	15.9	31.9
D3-3B	550				.0238	.6201	.01476	3335	225,900	208,000	**	-	28.5
D3-4B	550				.0241	.6217	.01498	3400	227,000	206,600	6.5	10.4	30.4
D3-6B	550				.0249	.6225	.01550	3415	220,300	203,900	**	-	28.9
D2-15B	550				.0223	.6183	.01379	2805	224,800	203,400	8.0	19.4	30.3
D2-13B	550				.0229	.6193	.01418	3170	223,600	203,800	8.5	18.8	29.8
AVG.									224,300	205,100	7.7	16.2	29.8
D3-1AA	R.T.	HEAT SOAKED ONLY	550	1000	.0225	.6290	.01415	3545	250,500	231,400	2.0	11.8	32.6
D3-1AE	R.T.				.0228	.6269	.01429	3575	250,200	231,900	7.0	16.7	30.9
AVG.									250,300	231,600	4.5	14.3	31.8
D3-1AB	550				.0230	.6280	.01444	3440	238,200	220,200	3.5	10.0	30.6
D3-1AC	550				.0233	.6277	.01463	3520	240,600	219,800	4.5	11.8	26.0
D3-1AD	550				.0231	.6282	.01451	3450	237,800	217,800	6.0	13.8	30.9
AVG.									238,900	219,300	4.7	11.9	29.2
D3-6A	R.T.			5000	.0241	.6244	.01505	3745	248,800	231,000	6.0	12.0	30.7
D3-6B	R.T.				.0243	.6292	.01529	3790	247,800	227,400	5.0	10.5	31.1
AVG.									248,800	229,200	5.5	11.2	30.9
D3-6C	550				.0250	.6315	.01579	3625	229,600	212,700	3.0	12.7	27.4
D3-6D	550				.0248	.6350	.01575	3570	226,700	212,700	2.5	12.1	32.9
D3-6E	550				.0245	.6356	.01557	3555	228,300	209,600	3.5	11.5	27.9
AVG.									228,500	211,700	3.0	12.1	29.4
D3-8A	R.T.			10,000	.0240	.6275	.01506	3715	246,700	228,500	5.5	15.2	30.5
D3-8B	R.T.				.0243	.6328	.01538	3845	250,000	231,200	5.0	12.3	30.9
AVG.									248,400	229,900	5.3	13.8	30.7
D3-8C	550				.0248	.6357	.01577	3500	221,900	214,600	1.0	13.3	29.8
D3-8D	550				.0248	.6380	.01582	3360	212,400	210,400	-	-	27.3
D3-8E	550				.0246	.6390	.01572	3550	225,800	210,500	2.5	12.7	31.3
AVG.									220,000	211,800	1.8	13.0	29.5
D1-13A	R.T.			30,000	.0228	.5875	.01340	3275	244,400	225,700	7.0	20.1	32.2
D1-13B	R.T.				.0231	.5860	.01354	3285	242,600	222,700	5.5	20.8	29.4
AVG.									243,500	224,200	6.3	20.4	30.8
D1-13C	550				.0230	.5858	.01347	3110	230,900	213,100	7.0	17.7	31.3
D1-13D	550				.0231	.5852	.01352	3095	228.900	210,400	6.5	17.7	31.6
D1-13E	550				.0235	.5837	.01372	3150	229,600	212,100	5.5	17.1	31.3
AVG.									229,800	211,900	6.3	17.5	31.4

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY
** FAILED AT EXTENSOMETER GRIPS

Table V RENE'41 (20% C. R. + 16 HRS @ 1400°F)
TENSILE PROPERTIES TEST DATA

(SHEET 2 of 5)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	% e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
D3-15B	R.T.	UNEXPOSED CONTROLS			.0241	.4927	.01187	2920	246,000	229,100	5.5	13.5	31.5
D3-15C	R.T.				.0239	.4929	.01178	2900	246,200	230,500	5.5	15.1	32.5
D3-15E	R.T.				.0238	.4908	.01168	2850	244,000	226,900	6.0	16.3	31.9
D2-17E1	R.T.				.0221	.4982	.01101	2650	240,700	222,100	9.0	16.9	32.4
D2-17E2	R.T.				.0216	.4962	.01072	2570	239,700	221,100	7.5	17.6	31.2
AVG.									243,300	225,900	6.7	15.9	31.9
D3-3B	550				.0238	.6201	.01476	3335	225,900	208,000	**	-	28.5
D3-4B	550				.0241	.6217	.01498	3400	227,000	206,600	6.5	10.4	30.4
D3-6B	550				.0249	.6225	.01550	3415	220,300	203,900	**	-	28.9
D2-15B	550				.0223	.6183	.01379	2805	224,800	203,400	8.0	19.4	30.3
D2-13B	550				.0229	.6193	.01418	3170	223,600	203,800	8.5	18.8	29.8
AVG.									224,300	205,100	7.7	16.2	29.8
D1-10A	R.T.	138,500	550	1000	.0239	.6292	.01504	3765	250,300	235,400	**	-	30.7
D1-10B	R.T.				.0232	.6303	.01462	3675	251,400	232,200	7.0	13.9	31.0
D1-10E	R.T.				.0230	.6358	.01462	3695	252,700	233,900	8.0	15.9	31.0
AVG.									251,500	233,800	7.5	14.9	30.9
D1-10C	550				.0233	.6312	.01471	3545	241,000	223,000	6.0	16.3	32.2
D1-10D	550				.0234	.6357	.01488	3590	241,300	219,100	3.0	11.3	34.4
AVG.									241,100	221,100	4.5	13.8	33.3
D1-5A	R.T.	110,000		5000	.0242	.6286	.01521	3770	247,900	228,100	6.0	10.1	32.6
D1-5B	R.T.				.0235	.6295	.01479	3645	246,500	226,500	7.0	13.1	33.9
AVG.									247,200	227,300	6.5	11.6	33.2
D1-5C	550				.0236	.6311	.01489	3445	231,400	**	4.0	17.2	**
D1-5D	550				.0236	.6366	.01502	3390	225,700	219,000	2.0	17.8	31.2
D1-5E	550				.0232	.6258	.01452	3290	226,600	214,000	-	-	27.2
AVG.									227,900	216,500	3.0	17.5	29.1
D1-1A	R.T.	70,000		10,000	.0233	.6250	.01456	3615	248,300	229,100	7.0	-	30.8
D1-1B	R.T.				.0228	.6274	.01430	3530	246,900	225,500	8.0	15.9	31.7
AVG.									247,600	227,300	7.5	15.9	31.3
D1-1C	550				.0228	.6298	.01436	3325	231,500	214,100	6.0	19.2	33.5
D1-1D	550				.0226	.6328	.01430	3285	229,700	**	4.0	-	**
D1-1E	550				.0222	.6289	.01396	3260	233,500	220,600	3.5	11.2	32.2
AVG.									231,600	217,300	4.5	15.2	32.8
D1-6A	R.T.	40,000		30,000	.0245	.6270	.01536	3665	238,600	222,000		-	30.7
D1-6B	R.T.				.0242	.6293	.01523	3595	236,000	212,100	4.0	22.1	28.8
AVG.									237,300	217,100	4.0	22.1	29.8
D1-6C	550				.0240	.6275	.01506	3425	227,400	208,500	7.0	17.2	30.1
D1-6D	550				.0237	.6295	.01492	3400	227,900	208,800	6.5	15.2	31.8
D1-6E	550				.0233	.6365	.01483	3405	229,600	212,100	6.0	16.4	33.7
AVG.									228,300	209,800	6.5	16.3	31.9

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY
** FAILED AT EXTENSOMETER GRIPS

Table V RENE'41 (20% C. R. + 16 HRS @ 1400°F)
TENSILE PROPERTIES TEST DATA

(SHEET 3 of 5)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	% e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
D3-15B	R.T.	UNEXPOSED CONTROLS			.0241	.4927	.01187	2920	246,000	229,100	5.5	13.5	31.5
D3-15C	R.T.				.0239	.4929	.01178	2900	246,200	230,500	5.5	15.1	32.5
D3-15E	R.T.				.0238	.4908	.01168	2850	244,000	226,900	6.0	16.3	31.9
D2-17E1	R.T.				.0221	.4982	.01101	2650	240,700	222,100	9.0	16.9	32.4
D2-17E2	R.T.				.0216	.4962	.01072	2570	239,700	221,100	7.5	17.6	31.2
AVG.									243,300	225,900	6.7	15.9	31.9
D1-13B	650				.0228	.6205	.01415	3240	229,000	211,000	7.0	12.2	28.5
D3-2B	650				.0225	.6148	.01383	3090	223,400	205,400	6.0	21.2	28.8
D3-7B	650				.0250	.6244	.01561	3290	210,800	206,000	**	-	29.6
D3-9B	650				.0245	.6190	.01517	3300	217,500	204,400	**	-	31.6
D3-10B	650				.0241	.6148	.01482	3300	222,700	204,500	5.0	10.4	28.7
AVG.									220,700	206,300	6.0	14.6	29.5
D3-5AA	R.T.	HEAT SOAKED ONLY	650	1000	.0238	.6274	.01493	3690	247,200	234,100	3.0	11.2	31.1
D3-5AB	R.T.				.0240	.6292	.01510	3810	252,300	232,500	5.0	14.7	31.4
D3-5AE	R.T.				.0241	.6300	.01518	3720	245,100	228,300	3.0	15.7	32.4
AVG.									248,200	231,600	3.7	13.9	31.6
D3-5AC	650				.0245	.6297	.01543	3510	227,500	212,200	4.0	12.4	29.0
D3-5AC	650				.0241	.6290	.01516	3650	240,800	230,100	3.0	12.3	29.7
AVG.									234,100	216,100	3.5	12.3	29.3
D3-7AA	R.T.			5000	.0239	.6298	.01505	3740	248,500	230,600	6.0	12.3	30.9
D3-7E	R.T.				.0243	.6282	.01527	3765	246,600	227,200	6.0	18.1	30.4
AVG.									247,500	228,900	6.0	15.2	30.6
D3-7AB	650				.0242	.6289	.01522	3520	231,300	216,800	3.0	19.2	31.1
D3-7AC	650				.0246	.6293	.01548	3640	235,100	217,100	5.5	17.2	30.1
D3-7AD	650				.0246	.6288	.01547	3565	230,400	214,900	3.5	17.4	30.5
AVG.									232,300	216,300	4.0	18.6	30.6
D3-3A	R.T.			10,000	.0240	.6330	.01519	3730	245,600	227,300	7.5	19.1	30.2
D3-3B	R.T.				.0238	.6278	.01494	3760	251,700	235,200	4.0	18.9	31.0
AVG.									243,700	231,200	5.8	19.0	30.6
D3-3C	650				.0246	.6352	.01563	3435	219,800	211,900	1.0	14.7	27.7
D3-3D	650				.0240	.6382	.01532	3420	223,300	207,500	2.0	10.5	31.4
D3-3E	650				.0241	.6389	.01540	3300	214,300	200,600	1.5	10.4	29.9
AVG.									219,100	206,700	1.5	11.9	29.7
D3-4A	R.T.			30,000	.0230	.5866	.01349	3405	252,400	235,400	6.0	17.9	33.0
D3-4B	R.T.				.0233	.5855	.01364	3465	254,000	273,500	7.0	15.7	35.0
AVG.									253,200	236,400	6.5	16.8	34.0
D3-4C	650				.0247	.5855	.01416	3175	224,200	203,400	5.5	16.4	31.0
D3-4D	650				.0243	.5844	.01420	3165	222,900	206,300	6.0	16.3	29.5
D3-4E	650				.0243	.5841	.01419	3300	232,500	217,800	6.0	14.7	33.0
AVG.									226,500	209,200	5.8	15.8	31.2

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY
** FAILED AT EXTENSOMETER GRIPS

Table V RENE'41 (20% C. R. + 16 HRS @ $1400^{\circ}F$)
TENSILE PROPERTIES TEST DATA

(SHEET 4 of 5)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	% e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
D3-15B	R.T.	UNEXPOSED CONTROLS			.0241	.4927	.01187	2920	246,000	229,100	5.5	13.5	31.5
D3-15C	R.T.				.0239	.4929	.01178	2900	246,200	230,500	5.5	15.1	32.5
D3-15E	R.T.				.0238	.4908	.01168	2850	244,000	226,900	6.0	16.3	31.9
D2-17E1	R.T.				.0221	.4982	.01101	2650	240,700	222,100	9.0	16.9	32.4
D2-17E2	R.T				.0216	.4962	.01072	2570	239,700	221,100	7.5	17.6	31.2
AVG.									243,300	225,900	6.7	15.9	31.9
D1-13B	650				.0228	.6205	.01415	3240	229,000	211,000	7.0	12.2	28.5
D3-2B	650				.0225	.6148	.01383	3090	223,400	205,400	6.0	21.2	28.8
D3-7B	650				.0250	.6244	.01561	3290	210,800	206,000	**	-	29.6
D3-9B	650				.0245	.6190	.01517	3300	217,500	204,400	**	-	31.6
D3-10B	650				.0241	.6148	.01482	3300	222,700	204,500	5.0	10.4	28.7
AVG.									220,700	206,300	6.0	14.6	29.5
D1-11A	R.T.	124,000	650	1,000	.0238	.6246	.01487	3415	229,700	205,100	**	-	30.2
D1-11B	R.T.				.0231	.6261	.01446	3640	251,700	232,700	5.5	13.2	31.2
D1-11E	R.T.				.0230	.6258	.01439	3285	228,300	200,500	**	-	31.7
AVG.									234,300	212,800	5.5	13.3	31.0
D1-11C	650				.0232	.6244	.01449	3450	238,100	220,800	3.5	17.2	31.8
D1-11D	650				.0235	.6213	.01460	3345	229,100	218,200	1.0	-	29.4
AVG.									233,600	219,500	2.3	17.2	30.6
D1-12A	R.T.	100,000		5,000	.0234	.6252	.01463	3565	243,700	216,300	2.0	-	31.5
D1-12B	R.T.				.0230	.6291	.01447	3625	250,500	231,900	7.0	13.6	31.0
D1-12E	R.T.				.0228	.6333	.01444	3700	256,200	238,900	5.0	14.9	31.1
AVG.									250,100	229,000	4.7	14.2	31.2
D1-12C	650				.0232	.6311	.01464	3460	236,300	220,600	3.5	12.6	30.4
D1-12D	650				.0231	.6366	.01471	3305	224,700	215,200	2.0	11.6	30.0
AVG.									230,500	217,900	2.7	12.1	30.2
D1-4A	R.T.	70,000		10,000	.0240	.6290	.01510	3730	247,000	225,800	6.0	13.3	36.1
D1-4B	R.T.				.0234	.6276	.01469	3615	246,100	226,300	8.0	17.8	33.1
AVG.									246,600	226,100	7.0	15.5	34.6
D1-4C	650				.0234	.6310	.01477	3310	224,100	211,200	4.0	16.6	30.3
D1-4D	650				.0232	.6350	.01473	3350	227,400	**	4.0	13.6	**
D1-4E	650				.0228	.6390	.01438	3295	229,100	215,000	-	-	30.3
AVG.									226,900	213,100	4.0	15.1	30.3
D1-3A	R.T.	40,000		30,000	.0241	.6291	.01516	3605	237,800	223,000	6.0	19.1	31.9
D1-3B	R.T.				.0235	.6293	.01479	3540	239,400	214,000	8.0	19.9	30.1
R.T.									238,600	218,500	7.0	19.5	31.0
D1-3C	650				.0235	.6313	.01484	3305	222,700	204,900	5.5	14.2	30.8
D1-3D	650				.0231	.6344	.01465	3275	223,500	206,800	6.0	22.7	32.1
D1-3E	650				.0231	.6357	.01468	3245	221,000	207,100	5.0	21.3	32.0
AVG.									222,400	206,300	5.5	19.4	31.6

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY
** FAILED AT EXTENSOMETER GRIPS

Table V RENE'41 (20% C. R. + 16 HRS @ 1400°F)

TENSILE PROPERTIES TEST DATA

(SHEET 5 of 5)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	%e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
D3-15B	R.T.	UNEXPOSED CONTROLS			.0241	.4927	.01187	2920	246,000	229,100	5.5	13.5	31.5
D3-15C	R.T.				.0239	.4929	.01178	2900	246,200	230,500	5.5	15.1	32.5
D3-15E	R.T.				.0238	.4908	.01168	2850	244,000	226,900	6.0	16.3	31.9
D2-17E1	R.T.				.0221	.4982	.01101	2650	240,700	222,100	9.0	16.9	32.4
D2-17E2	R.T.				.0216	.4962	.01072	2570	239,700	221,100	7.5	17.6	31.2
AVG.									243,300	225,900	6.7	15.9	31.9
D1-13B	650				.0228	.6205	.01415	3240	229,000	211,000	7.0	12.2	28.5
D3-2B	650				.0225	.6148	.01383	3090	223,400	205,400	6.0	21.2	28.8
D3-7B	650				.0250	.6244	.01561	3290	210,800	206,000	**	-	29.6
D3-9B	650				.0245	.6190	.01517	3300	217,500	204,400	**	-	31.6
D3-10B	650				.0241	.6148	.01482	3300	222,700	204,500	5.0	10.4	28.7
AVG.									220,700	206,300	6.0	14.6	29.5
D3-2A	R.T.	HEAT SOAKED ONLY	650 STEADY	30,000	.0238	.5868	.01397	3360	240,500	222,600	8.0	24.9	31.0
D3-2B	R.T.				.0239	.5845	.01397	3395	243,000	225,500	9.0	16.6	31.4
AVG.									242,200	224,100	8.5	20.7	31.2
D3-2C	650				.0239	.5834	.01394	3190	228,800	215,200	3.5	15.0	29.6
D3-2D	650				.0237	.5831	.01382	3160	228,700	212,000	6.5	19.3	31.8
D3-2E	650				.0240	.5828	.01399	2980	213,000	**	**	-	27.4
AVG.									228,700	213,600	5.0	17.1	29.6
D1-7A	R.T.	40,000 STEADY			.0244	.6254	.01526	3670	240,500	222,100	8.0	28.1	31.3
D1-7B	R.T.				.0241	.6258	.01508	3610	239,400	223,500	7.0	27.9	31.3
AVG.									239,900	222,800	7.5	28.0	31.3
D1-7C	650				.0241	.6290	.01516	3350	221,000	211,700	3.5	13.7	31.9
D1-7D	650				.0239	.6315	.01509	3400	225,300	212,700	5.5	16.4	28.9
D1-7E	650				.0236	.6273	.01480	3330	225,000	207,100	5.5	25.1	30.3
AVG.									223,800	210,500	4.8	18.4	30.4

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY
** FAILED AT EXTENSOMETER GRIPS

Table VI Ti 6Al-4V (MILL ANNEALED)
TENSILE PROPERTIES TEST DATA

(TMCA HEAT NO. M7858) (SHEET 1 of 3)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	%e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
C1-1A	R.T.	UNEXPOSED CONTROLS			.0237	.4961	.01176	1570	133,500	126,700	12.5	47.0	14.3
C1-1B	R.T.				.0242	.4932	.01194	1665	139,400	131,500	12.5	45.5	14.8
C1-1C	R.T.				.0238	.4934	.01174	1630	138,800	129,500	12.5	44.5	15.0
C1-1D	R.T.				.0235	.4955	.01164	1570	134,900	125,900	10.5	44.4	14.9
C1-1E	R.T.				.0230	.4953	.01139	1535	134,800	127,300	**	44.1	14.9
AVG.									136,300	128,200	12.0	45.1	14.8
C1-15A	550				.0224	.6212	.01391	1465	105,300	89,900	9.5	37.3	12.3
C1-15C	550				.0244	.6207	.01515	1595	105,300	88,800	11.5	40.3	12.0
C1-15D	550				.0233	.6213	.01448	1530	105,700	89,400	10.5	39.8	12.5
C1-15E	550				.0223	.6212	.01385	1455	105,100	89,200	8.0	40.5	12.9
C1-15F	550				.0253	.6208	.01570	1640	104,500	87,900	11.0	41.4	12.5
AVG.									105,200	89,000	10.0	39.9	12.4
C1-10B	R.T.	HEAT SOAKED ONLY	550	1000	.0259	6252	.01619	2305	142,400	130,200	14.0	43.2	14.6
C1-10C	R.T.				.0238	6261	.01490	2120	142,300	129,900	14.0	41.6	14.4
AVG.									142,300	130,000	14.0	42.4	14.5
C1-10A	550				.0243	.6212	.01509	1620	107,300	89,100	8.5	45.0	12.8
C1-10D	550				.0235	.6280	.01476	1580	107,000	87,800	8.5	42.6	12.6
C1-10E	550				.0239	.6293	.01504	1580	105,000	88,300	9.5	45.3	13.3
AVG.									106,400	88,400	8.8	44.3	12.9
C2-10A	R.T.			5000	.0260	.6270	BROKE AT IDENTIFICATION STAMP						
C2-10E	R.T.				.0278	.6257	.01739	2495	143,500	131,700	13.5	42.0	14.6
C2-10D	R.T.				.0276	.6275	.01732	2495	144,100	131,900	12.0	41.7	14.6
AVG.									143,900	131,800	12.7	41.8	14.6
C2-10B	550				.0275	.6259	.01721	1850	107,500	87,400	10.0	40.7	9.9
C2-10C	550				.0280	.6269	.01755	1885	107,400	89,200	10.5	47.6	13.2
AVG.									107,400	88,300	10.2	44.1	11.6
C2-8B	R.T.			10,000	.0269	.6275	.01688	2415	143,100	129,600	12.5	43.2	14.3
C2-8C	R.T.				.0274	.6294	.01725	2495	144,600	132,600	14.0	44.2	14.6
AVG.									144,300	131,100	13.3	43.7	14.4
C2-8A	550				.0253	.6237	.01578	1700	107,700	88,000	10.0	43.0	13.2
C2-8D	550				.0272	.6372	.01733	1840	106,200	88,100	10.0	43.6	13.1
C2-8E	550				.0271	.6331	.01716	1850	107,800	88,400	9.5	41.3	12.7
AVG.									107,600	88,200	9.8	42.6	13.0
C1-14A	R.T.			30,000	.0235	.5812	.01366	1825	133,600	127,000	**	-	14.0
C1-14B	R.T.				.0245	.5828	.01428	2010	140,800	131,700	12.0	40.5	14.5
AVG.									140,800	129,300	12.0		14.2
C1-14C	550				.0239	.5837	.01395	1415	101,400	85,300	8.0	46.1	13.4
C1-14D	550				.0240	.5839	.01401	1475	105,300	86,400	10.5	45.3	13.8
C1-14E	550				.0255	.5860	.01494	1585	106,100	85,700	10.5	39.5	13.1
AVG.									104,300	85,800	9.7	43.6	13.4

* DETERMINED FROM SLOPE OF LOAD - DEFORMATION CURVE - FOR INFORMATION ONLY
** FAILED AT EXTENSOMETER GRIP

Table VI Ti 6Al-4V (MILL ANNEALED)
TENSILE PROPERTIES TEST DATA

(SHEET 2 of 3)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	% e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
C1-1A	R.T.	UNEXPOSED CONTROLS			.0237	.4961	.01176	1570	133,500	126,700	12.5	47.0	14.3
C1-1B	R.T.				.0242	.4932	.01194	1665	139,400	131,500	12.5	45.5	14.3
C1-1C	R.T.				.0238	.4934	.01174	1630	138,800	129,500	12.5	44.5	15.0
C1-1D	R.T.				.0235	.4955	.01164	1570	134,900	125,900	10.5	44.4	14.9
C1-1E	R.T.				.0230	.4953	.01139	1535	134,800	127,300	**	44.1	14.9
AVG.									136,300	128,200	12.0	45.1	14.8
C1-15A	550				.0224	.6212	.01391	1465	105,300	89,900	9.5	37.3	12.3
C1-15C	550				.0244	.6207	.01515	1595	105,300	88,800	11.5	40.3	12.0
C1-15D	550				.0233	.6213	.01448	1530	105,700	89,400	10.5	39.8	12.5
C1-15E	550				.0223	.6212	.01385	1455	105,100	89,200	8.0	40.5	12.9
C1-15F	550				.0253	.6208	.01570	1640	104,500	87,900	11.0	41.4	12.5
AVG.									105,200	89,000	10.0	39.9	12.4
C2-7A	R.T.	85,000	550	1000	.0260	.6219	.01617	2340	144,700	134,200	12.0	43.8	14.7
C2-7B	R.T.				.0259	.6187	.01602	2305	143,900	134,800	12.5	44.3	16.8
AVG.									144,300	134,500	12.2	44.0	15.7
C2-7C	550				.0258	.6192	.01598	1750	109,500	92,600	11.0	45.9	13.0
C2-7D	550				.0266	.6193	.01647	1765	107,200	91,700	10.0	44.1	12.5
C2-7E	550				.0262	.6196	.01623	1720	106,000	91,500	9.5	43.4	12.8
AVG.									107,600	91,900	10.2	44.5	12.8
C2-9A	R.T.	71,500		5,000	.0265	.6223	.01649	2375	144,000	132,200	11.0	43.0	14.6
C2-9D	R.T.				.0279	.6196	.01729	2475	143,100	130,100	12.5	43.3	14.6
C2-9E	R.T.				.0272	.6198	.01686	2430	144,100	131,900	12.0	43.1	14.8
AVG.									143,700	131,400	11.8	43.1	14.7
C2-9B	550				.0272	.6180	.01681	1810	107,700	88,300	10.5	45.9	15.7
C2-9C	550				.0272	.6200	.01686	1825	108,200	89,000	10.5	46.6	19.2
AVG.									107,900	88,600	10.5	46.2	17.4
C1-17A	R.T.	60,000		10,000	.0250	.6111	.01528	2165	141,700	131,900	12.5	42.7	16.1
C1-17B	R.T.				.0243	.6158	.01496	2185	146,100	132,400	13.0	41.4	16.0
AVG.									143,900	132,200	12.7	42.1	16.0
C1-17C	550				.0241	.6148	.01482	1585	107,000	87,400	10.0	43.7	12.7
C1-17D	550				.0238	.6171	.01469	1585	107,900	87,800	10.0	42.1	14.1
C1-17E	550				.0258	.6170	.01592	1680	105,500	86,100	10.0	43.4	13.4
AVG.									106,800	87,100	10.0	43.1	13.4
C1-13A	R.T.	40,000		30,000	.0251	.6230	.01564	2200	140,700	129,200	12.5	41.4	15.3
C1-13B	R.T.				.0258	.6200	.01600	2270	141,900	130,000	11.5	43.3	14.9
AVG.									141,300	129,600	12.0	42.4	15.1
C1-13C	550				.0241	.6205	.01495	1605	107,400	87,600	11.0	41.7	13.6
C1-13D	550				.0237	.6205	.01471	1510	102,700	85,700	10.5	48.7	13.7
C1-13E	550				.0245	.6208	.01521	1615	106,200	88,400	10.0	44.1	11.6
AVG.									105,400	87,200	10.5	44.8	13.0

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY
** FAILED AT EXTENSOMETER GRIP

Table VI Ti 6Al-4V (MILL ANNEALED)
TENSILE PROPERTIES TEST DATA

(SHEET 3 of 3)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	%e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
C1-1A	R.T.	UNEXPOSED CONTROLS			.0237	.4961	.01176	1570	133,500	126,700	12.5	47.0	14.3
C1-1B	R.T.				.0242	.4932	.01194	1665	139,400	131,500	12.5	45.5	14.8
C1-1C	R.T.				.0238	.4934	.01174	1630	138,800	129,500	12.5	44.5	15.0
C1-1D	R.T.				.0235	.4955	.01164	1570	134,900	125,900	10.5	44.4	14.9
C1-1E	R.T.				.0230	.4953	.01139	1535	134,800	127,300	**	44.1	14.9
AVG.									136,300	128,200	12.0	45.1	14.8
C1-15A	550				.0224	.6212	.01391	1465	105,300	89,900	9.5	37.3	12.3
C1-15C	550				.0244	.6207	.01515	1595	105,300	88,800	11.5	40.3	12.0
C1-15D	550				.0233	.6213	.01448	1530	105,700	89,400	10.5	39.8	12.5
C1-15E	550				.0223	.6212	.01385	1455	105,100	89,200	8.0	40.5	12.9
C1-15F	550				.0253	.6208	.01570	1640	104,500	87,900	11.0	41.4	12.5
AVG.									105,200	89,000	10.0	39.9	12.4
C2-6A	R.T.	HEAT SOAKED ONLY	550 STEADY	30,000	.0239	.5799	.01386	1940	140,000	129,500	13.5	44.6	14.5
C2-6B	R.T.				.0252	.5812	.01465	2070	141,300	130,700	12.5	40.4	14.0
AVG.									140,600	130,100	13.0	42.5	14.2
C2-6C	550				.0259	.5820	.01507	1625	107,800	87,900	10.5	46.4	13.0
C2-6D	550				.0258	.5825	.01503	1675	111,400	88,200	9.0	48.4	13.3
C2-6E	550				.0257	.5841	.01501	1610	107,300	87,900	9.5	51.5	13.2
AVG.									108,800	88,000	9.7	48.8	13.2
C1-11A	R.T.	40,000 STEADY			.0252	.6197	.01562	2165	138,600	126,400	12.0	43.5	15.1
C1-11B	R.T.				.0252	.6200	.01562	2215	141,800	130,300	12.5	41.4	15.0
AVG.									140,200	128,400	12.3	42.4	15.0
C1-11C	550				.0235	.6204	.01458	1570	107,700	87,800	10.5	46.9	13.1
C1-11D	550				.0233	.6204	.01446	1535	106,200	87,800	10.5	45,1	14.1
C1-11E	550				.0243	.6208	.01509	1615	107,000	88,500	11.0	46.8	15.2
AVG.									107,000	88,000	10.7	46.3	14.1

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY
** FAILED AT EXTENSOMETER GRIP

Table VII Ti 8Al-1Mo-1V (DUPLEX ANNEALED)

TENSILE PROPERTIES TEST DATA

(TMCA HEAT NO. D-1237) (SHEET 1 of 5)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	% e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
E3-7B	R.T.	UNEXPOSED CONTROLS			.0264	.5006	.01322	2040	154,300	146,700	20.0	35.0	17.8
E3-8B	R.T.				.0268	.5009	.01342	2095	156,100	145,300	17.0	35.7	17.8
E3-9B	R.T.				.0267	.5006	.01337	2105	157,400	146,200	17.0	37.3	18.0
E3-10B	R.T.				.0267	.4994	.01333	2095	157,200	146,700	15.0	38.3	17.4
E3-11B	R.T.				.0264	.4985	.01316	2100	159,600	148,200	15.0	37.2	18.1
AVG.									156,900	146,600	16.8	37.7	17.8
E2-5A	550				.0265	.6255	.01658	2090	126,100	100,700	13.5	38.1	15.6
E2-5C	550				.0272	.6242	.01698	2065	121,600	98,600	13.5	36.4	15.4
E2-6A	550				.0272	.6251	.01700	2110	124,100	99,100	13.5	37.3	15.1
E2-6B	550				.0275	.6253	.01720	2135	124,100	99,100	13.0	36.5	14.4
AVG.									124,000	99,400	13.1	37.1	15.1
E3-19A	R.T.	HEAT SOAKED ONLY	550	1000	.0264	.6211	.01640	2570	156,700	145,400	16.5	40.9	16.5
E3-19B	R.T.				.0261	.6230	.01626	2615	160,800	146,600	17.0	37.4	17.2
AVG.									158,700	146,000	16.7	39.1	16.8
E3-19C	550				.0265	.6263	.01660	2105	126,800	102,700	11.0	37.3	15.7
E3-19D	550				.0270	.6271	.01693	2130	125,800	100,600	12.0	35.5	15.1
E3-19E	550				.0266	.6274	.01669	2120	127,000	101,200	12.0	37.7	15.5
AVG.									126,600	101,500	11.7	36.8	15.4
E3-20AA	R.T.			5000	.0260	.6278	.01632	2620	160,500	145,800	14.0	37.5	17.1
E3-20AE	R.T.				.0261	.6268	.01636	2660	162,600	148,800	15.0	35.2	17.3
AVG.									161,500	147,300	14.5	36.3	17.2
E3-20AB	550				.0265	.6265	.01660	2170	130,700	102,400	12.0	38.0	16.5
E3-20AC	550				.0267	.6286	.01678	2160	128,700	103,400	11.5	38.6	17.5
E3-20AD	550				.0270	.6290	.01698	2175	128,100	101,600	11.0	36.7	12.8
AVG.									129,200	102,500	11.5	37.8	15.6
E3-18A	R.T.			10,000	.0261	.6225	.01625	2570	158,200	146,900	16.0	38.9	17.0
E3-18B	R.T.				.0260	.6255	.01626	2595	159,600	147,200	15.5	36.2	17.1
AVG.									158,900	147,000	15.7	37.5	17.0
E3-18C	550				.0265	.6277	.01663	2105	126,600	101,500	11.0	36.1	15.2
E3-18D	550				.0269	.6305	.01696	2120	125,000	99,700	12.0	40.0	14.6
E3-18E	550				.0268	.6308	.06190	2145	126,900	100,300	11.5	36.1	15.1
AVG.									126,100	100,500	11.5	37.4	15.0
E3-17A	R.T.			30,000	.0267	.5861	.01565	2415	154,300	140,600	16.0	41.2	18.3
E3-17B	R.T.				.0262	.5840	.01530	2400	156,900	145,800	16.0	34.4	18.3
AVG.									155,600	143,200	16.0	37.8	18.3
E3-17C	550				.0264	.5852	.01545	1920	124,300	99,000	13.0	36.6	14.7
E3-17D	550				.0262	.5830	.01527	1910	125,100	**	12.0	35.5	**
E3-17E	550				.0263	.5781	.01520	1945	128,000	99,000	11.5	42.7	15.9
AVG.									125,800	99,000	12.2	38.3	14.8

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY
** EXTENSOMETER MALFUNCTIONED

Table VII Ti 8Al-1Mo-1V (DUPLEX ANNEALED)
TENSILE PROPERTIES TEST DATA

(SHEET 2 of 5)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED		AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	%e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
					THICKNESS (INCHES)	WIDTH (INCHES)							
E3-7B	R.T.	UNEXPOSED CONTROLS			.0264	.5006	.01322	2040	154,300	146,700	20.0	35.0	17.8
E3-8B	R.T.				.0268	.5009	.01342	2095	156,100	145,300	17.0	35.7	17.8
E3-9B	R.T.				.0267	.5006	.01337	2105	157,400	146,200	17.0	37.3	18.0
E3-10B	R.T.				.0267	.4994	.01333	2095	157,200	146,700	15.0	38.3	17.4
E3-11B	R.T.				.0264	.4985	.01316	2100	159,600	148,200	15.0	37.2	18.1
AVG.									156,900	146,600	16.8	37.7	17.8
E2-5A	550				.0265	.6255	.01658	2090	126,100	100,700	13.5	38.1	15.6
E2-5C	550				.0272	.6242	.01698	2065	121,600	98,600	13.5	36.4	15.4
E2-6A	550				.0272	.6251	.01700	2110	124,100	99,100	13.5	37.3	15.1
E2-6B	550				.0275	.6253	.01720	2135	124,100	99,100	13.0	36.5	14.4
AVG.									124,000	99,400	13.1	37.1	15.1
E1-6A	R.T.	94,000	550	1000	.0270	.6114	.01651	2590	156,900	145,400	18.0	39.8	16.7
E1-6B	R.T.				.0255	.6148	.01568	2500	159,400	147,300	17.0	37.9	17.9
AVG.									158,200	146,400	17.5	38.9	17.3
E1-6C	550				.0268	.6152	.06149	1990	120,700	100,400	10.5	43.2	15.0
E1-6D	550				.0270	.6155	.01662	2010	120,000	98,400	11.5	39.9	15.1
E1-6E	550				.0250	.6150	.01538	1875	121,900	103,400	11.8	39.4	15.3
AVG.									121,200	100,700	11.3	40.8	15.1
E1-7A	R.T.	80,000		5000	.0269	.6112	.01644	2615	159,100	146,300	16.0	39.2	17.2
E1-7E	R.T.				.0232	.6162	.01430	2375	166,100	153,100	11.0	25.0	17.8
AVG.									162,600	149,700	13.5	32.1	17.5
E1-7B	550				.0255	.6148	.01568	1985	126,600	99,800	11.0	36.9	11.5
E1-7C	550				.0264	.6142	.01621	2000	123,400	96,200	8.5	42.2	12.7
E1-7D	550				.0268	.6170	.01654	2065	124,800	98,200	11.0	40.8	17.6
AVG.									124,900	98,100	10.2	40.0	13.9
E1-4A	R.T.	60,000		10,000	.0271	.6094	.01651	2610	158,100	143,900	17.0	39.7	18.6
E1-4B	R.T.				.0262	.6145	.01610	2560	159,000	144,700	18.0	40.2	19.0
AVG.									158,500	144,300	17.5	39.9	18.8
E1-4C	550				.0260	.6118	.01591	1980	124,500	98,400	11.0	40.5	14.3
E1-4D	550				.0265	.6141	.01627	2035	125,100	97,700	11.5	40.7	15.4
E1-4E	550				.0262	.6161	.01614	2010	124,500	99,100	11.5	40.5	15.4
AVG.									124,700	98,400	11.3	40.6	15.0
E1-3A	R.T.	40,000		30,000	.0275	.6075	.01671	2590	155,000	144,200	19.0	39.9	17.1
E1-3B	R.T.				.0268	.6135	.01644	2565	156,000	145,100	16.5	42.8	17.9
AVG.									155,500	144,700	18.3	41.4	17.5
E1-3C	550				.0263	.6126	.01611	1955	121,400	98,100	10.5	43.2	15.3
E1-3D	550				.0268	.6126	.01642	2005	122,100	96,800	12.0	40.3	15.8
E1-3E	550				.0265	.6150	.01630	2000	122,700	98,500	12.0	39.8	16.3
AVG.									122,100	97,800	11.7		15.8

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY

Table VII Ti 8A1-1Mo-1V (DUPLEX ANNEALED)
TENSILE PROPERTIES TEST DATA

(SHEET 3 of 5)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	%e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
E3-7B	R.T.	UNEXPOSED CONTROLS			.0264	.5006	.01322	2040	154,300	146,700	20.0	35.0	17.8
E3-8B	R.T.				.0268	.5009	.01342	2095	156,100	145,300	17.0	35.7	17.8
E3-9B	R.T.				.0267	.5006	.01337	2105	157,400	146,200	17.0	37.3	18.0
E3-10B	R.T.				.0267	.4994	.01333	2095	157,200	146,700	15.0	38.3	17.4
E3-11B	R.T.				.0264	.4985	.01316	2100	159,600	148,200	15.0	37.2	18.1
AVG.									156,900	146,600	16.8	37.7	17.8
E2-4A	650				.0255	.6258	.01596	1945	121,900	96,200	9.0	35.2	15.4
E2-4B	650				.0271	.6256	.01695	2050	120,900	96,500	9.0	33.0	14.5
E2-4C	650				.0268	.6245	.01674	1995	119,200	95,000	10.5	36.3	14.2
E2-5B	650				.0272	.6253	.01701	2010	118,200	-	9.0	35.3	-
E2-6C	650				.0270	.6236	.01684	2000	118,800	94,100	10.5	36.0	16.3
AVG.									119,800	95,500	9.6	35.2	15.1
E3-26A	R.T.	HEAT SOAKED ONLY	650	1000	.0270	.6278	.01695	2740	161,700	146,000	17.0	31.0	17.5
E3-26E	R.T.				.0270	.6262	.01691	2735	161,700	145,500	15.0	27.9	17.8
AVG.									161,700	145,700	16.0	29.4	17.6
E3-26B	650				.0242	.6270	.01517	1930	127,200	100,200	9.5	36.7	14.7
E3-26C	650				.0238	.6281	.01495	1860	124,400	99,300	9.0	37.8	16.2
E3-26D	650				.0260	.6276	.01632	2010	123,200	97,100	10.5	38.1	14.6
AVG.									124,900	98,900	9.7	37.5	15.2
E3-23A	R.T.			5000	.0261	.6276	.01638	2640	161,200	146,200	15.0	29.8	17.2
E3-23E	R.T.				.0256	.6260	.01603	2630	164,100	147,800	15.0	37.2	17.7
AVG.									162,700	147,000	15.0	33.5	17.4
E3-23B	650				.0259	.6258	.01621	2100	129,500	98,700	12.0	35.8	17.0
E3-23C	650				.0250	.6266	.01567	1985	126,700	99,600	9.0	36.8	15.7
E3-23D	650				.0264	.6266	.01654	2105	127,300	98,900	11.0	36.5	15.7
AVG.									127,800	99,100	10.7	36.4	16.1
E1-8A	R.T.			10,000	.0271	.6115	.01657	2665	160,800	146,600	16.5	39.4	16.9
E1-8B	R.T.				.0261	.6157	.01607	2600	161,800	146,500	16.5	37.6	16.6
AVG.									161,300	146,500	16.5	38.5	16.7
E1-8C	650				.0265	.6145	.01628	1965	120,700	93,200	10.0	39.4	14.0
E1-8D	650				.0267	.6167	.01647	1995	121,100	94,700	9.5	34.0	13.9
E1-8E	650				.0253	.6165	.01560	1960	125,600	94,900	11.5	35.7	16.0
AVG.									122,500	94,400	10.3	36.4	14.6
E3-24A	R.T.			30,000	.0268	.5841	.01565	2520	161,000	144,700	16.0	38.4	16.8
E3-24B	R.T.				.0264	.5809	.01534	2485	162,000	148,300	15.0	36.5	19.4
AVG.									161,500	146,500	15.5	37.5	18.1
E3-24C	650				.0240	.5813	.01395	1825	130,800	101,100	10.0	37.1	18.6
E3-24D	650				.0264	.5800	.01531	1925	125,700	96,700	10.5	40.6	17.3
E3-24E	650				.0265	.5799	.01537	1900	123,600	95,000	12.5	38.4	16.6
AVG.									126,700	97,600	11.0	38.7	17.5

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY

Table VII Ti-8Al-1Mo-1V (DUPLEX ANNEALED)

TENSILE PROPERTIES TEST DATA

(SHEET 4 of 5)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	%e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
E3-7B	R.T.	UNEXPOSED CONTROLS			.0264	.5006	.01322	2040	154,300	146,700	20.0	35.0	17.8
E3-8B	R.T.				.0268	.5009	.01342	2095	156,100	145,300	17.0	35.7	17.8
E3-9B	R.T.				.0267	.5006	.01337	2105	157,400	146,200	17.0	37.3	18.0
E3-10B	R.T.				.0267	.4994	.01333	2095	157,200	146,700	15.0	38.3	17.4
E3-11B	R.T.				.0264	.4985	.01316	2100	159,600	148,200	15.0	37.2	18.1
AVG.									156,900	146,600	16.8	37.7	17.8
E2-4A	650				.0255	.6258	.01596	1945	121,900	96,200	9.0	35.2	15.4
E2-4B	650				.0271	.6256	.01695	2050	120,900	96,500	9.0	33.0	14.5
E2-4C	650				.0268	.6245	.01674	1995	119,200	95,000	10.5	36.3	14.2
E2-5B	650				.0272	.6253	.01701	2010	118,200	-	9.0	35.3	-
E2-6C	650				.0270	.6236	.01684	2000	118,800	94,100	10.5	36.0	16.3
AVG.									119,800	95,500	9.6	35.2	15.1
E1-9A	R.T.	88,600	650	1,000	.0268	.6105	.01636	2600	158,900	145,500	16.5	34.6	17.1
E1-9E	R.T.				.0257	.6166	.01585	2600	164,000	148,300	14.0	35.7	17.1
AVG.									161,500	146,900	14.7	35.1	17.1
E1-9B	650				.0258	.6148	.01586	2015	127,000	103,100	12.0	35.7	15.8
E1-9C	650				.0262	.6133	.01607	2035	126,600	104,200	9.0	37.8	16.4
E1-9D	650				.0265	.6170	.01635	2140	130,900	103,700	11.0	37.0	16.8
AVG.									128,200	103,700	10.7	36.8	16.3
E1-10A	R.T.	80,000		5,000	.0271	.6103	.01654	2655	160,500	146,000	16.0	39.5	16.8
E1-10E	R.T.				.0253	.6160	.01558	2595	166,600	150,200	15.0	39.7	17.6
AVG.									163,500	148,100	15.5	39.6	17.2
E1-10B	650				.0259	.6155	.01594	1970	123,600	95,400	12.0	37.5	17.2
E1-10C	650				.0253	.6138	.01553	1985	127,800	99,500	9.5	36.3	16.1
E1-10D	650				.0263	.6169	.01622	2070	127,600	100,800	11.5	39.0	15.2
AVG.									126,300	98,600	11.0	37.6	16.2
E3-21A	R.T.	60,000		10,000	.0267	.5430	.01450	2350	162,100	148,300	16.5	38.1	16.9
E3-21B	R.T.				.0269	.5429	.01460	2390	163,700	149,300	16.0	36.6	17.1
AVG.									162,900	148,800	16.2	37.4	17.0
E3-21C	650				.0270	.5439	.01469	1850	125,900	97,300	12.0	34.9	14.7
E3-21D	650				.0271	.5440	.01474	1830	124,200	95,700	11.5	34.4	13.6
E3-21E	650				.0270	.5441	.01469	1830	124,600	96,300	10.5	32.3	13.6
AVG.									124,900	96,400	11.3	33.9	14.0
E1-5A	R.T.	40,000		30,000	.0274	.6075	.01665	2610	156,800	145,000	18.5	40.1	17.2
E1-5B	R.T.				.0269	.6133	.01650	2520	152,700	141,500	16.5	33.6	16.8
AVG.									154,700	143,300	17.5	36.9	17.0
E1-5C	650				.0265	.6105	.01618	1940	119,900	93,900	10.0	39.0	16.7
E1-5D	650				.0271	.6150	.01667	2030	121,800	93,600	12.5	36.5	16.5
E1-5E	650				.0258	.6134	.01583	1910	120,700	93,800	12.0	37.2	17.2
AVG.									120,800	93,800	11.5	37.6	16.8

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY

Table VII Ti-8Al-1Mo-1V (DUPLEX ANNEALED)
TENSILE PROPERTIES TEST DATA

(SHEET 5 of 5)

SPECIMEN NUMBER	STATIC TEST TEMPERATURE (°F)	CREEP STRESS LEVEL (PSI)	EXPOSURE TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	AREA A (SQ. IN.)	LOAD AT RUPTURE (LBS)	F_{TU} (PSI)	F_{TY} (PSI)	% e	% REDUCTION IN AREA	MODULUS OF ELASTICITY PSI X 10^{-6} *
E3-7B	R.T.	UNEXPOSED CONTROLS			.0264	.5006	.01322	2040	154,300	146,700	20.0	35.0	17.8
E3-8B	R.T.				.0268	.5009	.01342	2095	156,100	145,300	17.0	35.7	17.8
E3-9B	R.T.				.0267	.5006	.01337	2105	157,400	146,200	17.0	37.3	18.0
E3-10B	R.T.				.0267	.4994	.01333	2095	157,200	146,700	15.0	38.3	17.4
E3-11B	R.T.				.0264	.4985	.01316	2100	159,600	148,200	15.0	37.2	18.1
AVG.									156,900	146,600	16.8	37.7	17.8
E2-5A	550				.0265	.6255	.01658	2090	126,100	100,700	13.5	38.1	15.6
E2-5C	550				.0272	.6242	.01698	2065	121,600	98,600	13.5	36.4	15.4
E2-6A	550				.0272	.6251	.01700	2110	124,100	99,100	13.5	37.3	15.1
E2-6B	550				.0275	.6253	.01720	2135	124,100	99,100	13.0	36.5	14.4
AVG.									124,000	99,400	13.1	37.1	15.1
E2-4A	650				.0255	.6258	.01596	1945	121,900	96,200	9.0	35.2	15.4
E2-4B	650				.0271	.6256	.01695	2050	120,900	96,500	9.0	33.0	14.5
E2-4C	650				.0268	.6245	.01674	1995	119,200	95,000	10.5	36.3	14.2
E2-5B	650				.0272	.6253	.01701	2010	118,200	-	9.0	35.3	-
E2-6C	650				.0270	.6236	.01684	2000	118,800	94,100	10.5	36.0	16.3
AVG.									119,800	95,500	9.6	35.2	15.1
E3-16A	R.T.	HEAT SOAKED ONLY	550 STEADY	30,000	.0269	.5845	.01572	2440	155,200	143,800	14.0	36.4	16.8
E3-16B	R.T.				.0267	.5813	.01552	2420	155,900	143,000	15.0	39.7	18.9
AVG.									155,500	143,400	14.5	38.0	17.9
E3-16C	550				.0266	.5817	.01547	1945	125,700	99,200	12.5	37.9	16.2
E3-16D	550				.0266	.5802	.01543	1940	125,700	99,100	12.5	36.8	15.6
E3-16E	550				.0265	.5793	.01535	1915	124,800	98,400	12.5	41.8	17.2
AVG.									125,400	98,900	12.5	38.8	16.3
E3-15A	R.T.		650 STEADY		.0268	.5843	.01566	2485	158,700	147,800	17.0	37.2	18.0
E3-15B	R.T.				.0266	.5835	.01552	2470	159,100	148,200	16.5	39.0	16.9
AVG.									158,900	148,000	16.7	38.1	17.5
E3-15C	650				.0255	.5840	.01489	1910	128,300	99,100	12.0	37.6	16.8
E3-15D	650				.0256	.5820	.01490	1890	126,800	98,300	12.0	35.7	16.5
E3-15E	650				.0257	.5811	.01493	1905	127,600	100,100	13.0	36.7	17.7
AVG.									127,600	99,200	12.3	36.7	17.0
E1-1A	R.T.	40,000 STEADY	550 STEADY		.0273	.6100	.01665	2470	148,300	143,200	**	-	17.8
E1-1B	R.T.				.0268	.6150	.01648	2540	154,100	144,100	17.5	39.4	17.8
AVG.									151,200	143,700	17.5	39.4	17.8
E1-1C	550				.0273	.6125	.01672	2040	122,000	97,200	12.5	44.4	15.5
E1-1D	550				.0260	.6095	.01585	1980	124,900	99,700	10.5	31.9	14.7
E1-1E	550				.0268	.6100	.01635	2015	123,200	98,200	12.0	42.6	16.5
AVG.									123,400	98,400	11.6	39.6	15.6
E1-2A	R.T.		650 STEADY		.0275	.6055	.01665	2585	155,300	144,400	18.0	38.6	19.0
E1-2B	R.T.				.0269	.6120	.01646	2535	154,000	142,800	19.0	35.8	16.9
AVG.									154,700	143,600	18.5	37.2	18.0
E1-2C	650				.0266	.6095	.01621	1925	118,800	93,200	13.5	40.0	16.1
E1-2D	650				.0260	.6048	.01572	1850	117,700	92,600	11.0	45.8	15.9
E1-2E	650				.0265	.6128	.01624	1985	122,200	94,500	13.0	33.1	16.7
AVG									119,600	93,400	12.5	39.6	16.3

* DETERMINED FROM SLOPE OF LOAD - STRAIN CURVE FOR INFORMATION ONLY
** FAILED AT EXTENSOMETER GRIP

Table VIII AM-350 SCT (825)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 1 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE ($2a$) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
A2-1	UNEXPOSED CONTROLS			.0245	.9942	.02435	.363	.441	2950	121,100	217,700	1.04	1.21	110,500
A2-2				.0248	.9932	.02463	.359	.430	2960	121,100	211,800	1.01	1.17	106,800
A2-3				.0249	.9944	.02476	.368	.430	2965	119,700	211,000	1.00	1.17	105,600
A2-4				.0249	.9935	.02474	.341	.419	3050	123,200	213,200	1.01	1.18	108,500
A3-1				.0248	.9935	.02464	.323	.438	3140	127,400	227,800	1.08	1.26	115,700
AVG.										122,400	215,700	1.03	1.20	109,400
A3-14B	HEAT SOAKED ONLY	550	1000	.0249	.9965	.02481	.361	.428	3090	124,500	218,200	1.03	1.21	111,200
A3-14C				.0249	.9987	.02487	.363	.425	3090	124,200	216,300	1.02	1.20	110,300
A3-14E				.0249	.9990	.02488	.356	.437	3090	124,100	220,800	1.04	1.22	112,400
AVG.										124,300	218,400	1.03	1.21	111,300
A2-15B			5000	.0250	1.0046	.02511	.323	.425	3235	128,800	223,200	1.06	1.28	114,300
A2-15C				.0250	1.0049	.02512	.313	.424	3310	131,700	227,900	1.08	1.25	116,700
A2-15D				.0249	1.0048	.02502	.346	.428	3150	125,900	219,300	1.04	1.20	112,200
AVG.										128,800	223,500	1.06	1.22	114,400
A1-11A			10,000	.0251	1.0100	.02535	.360	.439	3210	126,600	224,000	1.07	1.26	114,700
A1-11B				.0252	1.0100	.02545	.347	.432	3270	128,500	224,600	1.08	1.26	115,100
A1-11C				.0250	1.0100	.02525	.359	.447	3235	128,100	230,000	1.10	1.29	117,500
AVG.										127,700	226,200	1.08	1.27	115,700
A1-15A			30,000	.0254	.9953	.0253	.354	.447	2845	112,400	204,600	.98	1.13	103,500
A1-15B				.0253	.9945	.0252	.390	.423	3140	124,600	218,000	1.04	1.20	110,300
A1-15C				.0253	.9942	.0252	.382	.455	3155	125,200	231,900	1.11	1.28	116,700
AVG.										120,700	218,200	1.05	1.20	110,200
A4-14A		550 STEADY	30,000	.0250	.9961	.0249	.390	.440	3055	122,600	219,700	1.05	1.21	111,600
A4-14B				.0250	.9952	.0249	.370	.448	3075	123,400	224,400	1.08	1.23	113,800
A4-14C				.0250	.9955	.0249	.366	.434	3030	121,900	216,400	1.04	1.19	109,900
AVG.										122,600	220,200	1.05	1.21	111,800

Table VIII AM-350 SCT (825)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 2 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
A2-1	UNEXPOSED CONTROLS			.0245	.9942	.02435	.363	.441	2950	121,100	217,700	1.04	1.21	110,500
A2-2				.0248	.9932	.02463	.359	.430	2960	121,100	211,800	1.01	1.17	106,800
A2-3				.0249	.9944	.02476	.368	.430	2965	119,700	211,000	1.00	1.17	105,600
A2-4				.0249	.9935	.02474	.341	.419	3050	123,200	213,200	1.01	1.18	108,500
A3-1				.0248	.9935	.02464	.323	.438	3140	127,400	227,800	1.08	1.26	115,700
AVG.										122,400	215,700	1.03	1.20	109,400
A3-15B	120	550	1000	.0250	1.0019	.02505	.373	.400	3155	125,900	209,600	.97	1.06	107,300
A3-15C				.0251	1.0014	.02514	.345	.392	3300	131,200	216,200	1.00	1.10	110,400
A3-15E				.0250	1.0028	.02507	.346	.420	3220	128,400	221,000	1.02	1.12	113,000
AVG.										128,500	215,600	1.00	1.10	110,200
A4-12A	105	550	5000	.0250	1.0018	.02505	.365	.395	3060	122,100	201,700	.95	1.08	103,200
A4-12B				.0251	1.0022	.02515	.292	.393	3440	136,700	224,900	1.06	1.21	115,200
A4-12C				.0247	1.0015	.02478	.351	.395	3085	124,500	205,900	.97	1.11	105,200
AVG.										127,800	210,800	.99	1.13	107,900
A3-12A	85	550	10,000	.0249	1.0025	.02496	.430	.495	2765	110,800	218,700	1.03	1.19	109,800
A3-12B				.0247	1.0015	.02473	.391	.465	2965	119,900	223,800	1.05	1.22	113,400
A3-12C				.0246	1.0015	.02464	.406	.465	2910	118,100	220,500	1.04	1.20	111,700
AVG.										116,300	221,000	1.04	1.20	111,600
A2-12A	67	550	30,000	.0249	1.0024	.0250	.366	.443	2985	119,400	214,700	1.02	1.19	109,000
A2-12B				.0249	1.0018	.0249	.362	.433	3180	127,700	223,900	1.07	1.24	114,700
A2-12C				.0250	1.0015	.0250	.362	.437	3055	122,200	216,600	1.03	1.20	110,500
AVG.										123,100	218,400	1.04	1.21	111,400
A1-12A	67 STEADY	550 STEADY	30,000	.0253	1.0018	.0253	.374	.453	3040	120,100	218,700	1.04	1.21	111,600
A1-12B				.0253	1.0015	.0253	.374	.447	3080	121,700	220,000	1.05	1.22	111,900
A1-12C				.0253	1.0005	.0253	.354	.435	3160	124,900	220,900	1.05	1.22	112,600
AVG.										122,200	219,800	1.05	1.21	112,000

Table VIII AM-350 SCT (825)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 3 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED		GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
				THICKNESS (INCHES)	WIDTH (INCHES)									
A2-1	UNEXPOSED CONTROLS			.0245	.9942	.02435	.363	.441	2950	121,100	217,700	1.04	1.21	110,500
A2-2				.0248	.9932	.02463	.359	.430	2960	121,100	211,800	1.01	1.17	106,800
A2-3				.0249	.9944	.02476	.368	.430	2965	119,700	211,000	1.00	1.17	105,600
A2-4				.0249	.9935	.02474	.341	.419	3050	123,200	213,200	1.01	1.18	108,500
A3-1				.0248	.9935	.02464	.323	.438	3140	127,400	227,800	1.08	1.26	115,700
AVG.										122,400	215,700	1.03	1.20	109,400
A2-13B	HEAT SOAKED ONLY	650	1000	.0249	.9996	.02489	.346	.425	3125	125,500	218,600	1.02	1.23	111,500
A2-13C				.0249	.9992	.02488	.354	.437	3110	125,000	222,300	1.04	1.25	113,100
A2-13D				.0250	.9978	.02495	.357	.424	3135	125,600	218,400	1.02	1.22	111,400
AVG.										125,400	219,800	1.03	1.23	112,000
A2-11A			5000	.0248	1.0048	.02492	.362	.425	3010	120,700	209,300	1.04	1.12	107,100
A2-11B				.0247	1.0058	.02484	.324	.405	3200	128,800	215,600	1.07	1.15	110,600
A2-11C				.0249	1.0052	.02503	.343	.411	3145	125,600	212,500	1.06	1.14	108,900
AVG.										125,000	212,400	1.06	1.14	108,900
A1-13A			10,000	.0252	1.0100	.02545	.354	.443	3210	126,100	224,600	1.03	1.19	115,000
A1-13B				.0251	1.0100	.02535	.389	.447	3090	121,900	218,700	1.00	1.16	111,800
A1-13C				.0251	1.0115	.02539	.376	.477	3170	124,800	236,200	1.08	1.25	113,800
AVG.										124,300	226,500	1.04	1.20	113,500
A4-12A			30,000	.0253	.9940	.0251	.370	.458	3020	120,300	222,000	.98	1.12	112,700
A4-12B				.0253	.9940	.0251	.370	.469	3080	122,700	231,500	1.02	1.17	117,000
A4-12C				.0252	.9935	.0250	.378	.469	3035	121,400	229,900	1.02	1.16	115,800
AVG.										121,400	227,800	1.01	1.15	115,200
A4-15A		650 STEADY	30,000	.0249	.9957	.0248	.390	.459	3045	122,700	227,200	1.01	1.14	115,200
A4-15B				.0249	.9948	.0248	.354	.456	3120	125,800	232,800	1.03	1.17	117,500
A4-15C				.0249	.9945	.0248	.350	.461	2940	118,500	221,000	.98	1.11	111,600
AVG.										122,300	227,000	1.00	1.14	114,700

Table VIII AM-350 SCT (825)
FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 4 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI $\sqrt{IN.}$)
A2-1	UNEXPOSED CONTROLS			.0245	.9942	.02435	.363	.441	2950	121,100	217,700	1.04	1.21	110,500
A2-2				.0248	.9932	.02463	.359	.430	2960	121,100	211,800	1.01	1.17	106,800
A2-3				.0249	.9944	.02476	.368	.430	2965	119,700	211,000	1.00	1.17	105,600
A2-4				.0249	.9935	.02474	.341	.419	3050	123,200	213,200	1.01	1.18	108,500
A3-1				.0248	.9935	.02464	.323	.438	3140	127,400	227,800	1.08	1.26	115,700
AVG.										122,400	215,700	1.03	1.20	109,400
A4-11A	117	650	1000	.0249	1.0019	.02495	.366	.386	3055	122,400	198,800	.91	1.03	101,900
A4-11D				.0248	1.0019	.02485	.357	.372	3185	128,100	203,900	.93	1.05	104,200
A4-11E				.0248	1.0027	.02487	.348	.372	3250	130,600	207,800	.95	1.07	106,200
AVG.										127,100	203,500	.93	1.05	104,100
A4-13B	101	650	5000	.0251	1.0016	.02514	.367	.384	3125	124,300	201,600	.91	1.04	103,100
A4-13C				.0249	1.0005	.02491	.352	.394	3200	128,400	211,900	.96	1.10	108,400
A4-13D				.0252	1.0020	.02525	.339	.384	3320	131,400	213,200	.97	1.10	109,100
AVG.										128,000	208,900	.95	1.08	106,800
A3-13A	85	650	10,000	.0252	1.0100	.02504	.425	.503	2845	113,600	222,600	1.01	1.14	113,600
A3-13B				.0251	1.0100	.02486	.412	.488	2875	115,600	219,500	1.00	1.12	113,100
A3-13C				.0251	1.0115	.02487	.391	.473	3010	121,000	222,600	1.01	1.14	115,600
AVG.										116,700	221,600	1.01	1.13	114,100
A3-11A	67	650	30,000	.0249	1.0017	.0249	.358	.440	3080	123,600	220,000	1.01	1.12	112,400
A3-11B				.0248	1.0020	.0248	.366	.440	3105	125,200	223,300	1.02	1.14	113,800
A3-11C				.0249	1.0028	.0250	.327	.452	3060	120,200	223,300	1.02	1.14	111,300
AVG.										123,000	222,200	1.02	1.14	112,500
A2-14A	67 STEADY	650 STEADY	30,000	.0249	1.0025	.0250	.382	.465	2935	117,400	219,000	1.00	1.12	111,000
A2-14B				.0248	1.0015	.0248	.386	.465	2920	117,700	219,500	1.01	1.12	111,300
A2-14C				.0249	1.0013	.0249	.382	.472	2850	114,400	215,900	.99	1.10	109,400
AVG.										116,500	218,100	1.00	1.12	110,600

Table IX PH 14-8 Mo (SRH 1050)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 1 of 2)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED		GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
				THICKNESS (INCHES)	WIDTH (INCHES)									
B-2	UNEXPOSED CONTROLS			.0252	1.0032	.02528	.348	.378	3170	125,400	201,200	.92	.99	102,900
B-4				.0252	1.0030	.02527	.349	.391	3085	122,000	200,000	.91	.98	102,500
B-6				.0252	1.0031	.02528	.334	.395	3170	125,400	206,900	.94	1.02	105,900
B-7				.0252	1.0032	.02528	.351	.405	2945	116,500	195,100	.89	.96	100,000
B-12				.0249	1.0032	.02498	.353	.381	3015	120,700	194,600	.89	.96	99,600
AVG.										122,000	199,600	.91	.98	102,200
B-28C	HEAT SOAKED ONLY	550	754	.0251	1.0008	.02530	.347	.396	3320	131,200	218,700	.99	1.04	111,100
B-28D				.0249	1.0032	.02498	.366	.425	3320	132,900	230,500	1.04	1.10	117,900
B-28E				.0249	1.0042	.02500	.355	.425	3320	132,800	230,200	1.04	1.10	117,800
AVG.										132,300	226,500	1.02	1.08	115,600
B-17A			1000	.0252	1.0038	.02530	.347	.401	3420	135,100	225,100	1.01	1.07	115,300
B-17B				.0255	1.0036	.02559	.335	.390	3505	136,900	223,900	1.00	1.07	114,700
B-17C				.0242	1.0046	.02431	.338	.411	3420	140,600	237,900	1.07	1.13	121,900
AVG.										137,600	229,000	1.03	1.09	117,300
B-27A			6,000	.0252	1.0000	.02520	.374	.453	3325	131,900	241,200	1.10	1.20	122,400
B-27B				.0253	1.0015	.02534	.380	.445	3265	128,800	231,900	1.06	1.16	118,000
B-27C				.0253	1.0020	.02535	.374	.445	3270	129,000	231,800	1.10	1.16	118,100
AVG.										129,900	235,000	1.07	1.17	119,500
B-23A			25,060	.0250	0.9981	.0249	.386	.448	3180	127,700	232,100	1.04	1.10	117,500
B-23C				.0248	1.0020	.0248	.362	.441	3280	132,200	235,900	1.06	1.12	120,400
B-23D				.0246	1.0020	.0246	.358	.436	3175	129,600	228,400	1.03	1.08	117,000
AVG.										129,800	232,100	1.04	1.10	118,300
B-20A		550 STEADY	25,800	.0253	1.0025	.0254	.370	.470	3270	128,700	242,200	1.08	1.15	123,500
B-20B				.0251	1.0014	.0251	.362	.443	3270	130,200	233,500	1.04	1.11	119,000
B-20C				.0251	1.0012	.0251	.362	.447	3270	130,200	235,200	1.05	1.12	119,700
AVG.										129,700	237,000	1.06	1.13	120,700

Table IX PH 14-8 Mo (SRH 1050)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 2 of 2)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
B-2	UNEXPOSED CONTROLS			.0252	1.0032	.02528	.348	.378	3170	125,400	201,200	.92	.99	102,900
B-4				.0252	1.0030	.02527	.349	.391	3085	122,000	200,000	.91	.98	102,500
B-6				.0252	1.0031	.02528	.334	.395	3170	125,400	206,900	.94	1.02	105,900
B-7				.0252	1.0032	.02528	.351	.405	2945	116,500	195,100	.89	.96	100,000
B-12				.0249	1.0032	.02498	.353	.381	3015	120,700	194,600	.89	.96	99,600
AVG.										122,000	199,600	.91	.98	102,200
B-26C	103	550	754	.0252	1.0032	.02528	.324	.405	3580	141,600	237,500	1.08	1.22	121,600
B-26D				.0251	1.0004	.02511	.351	.418	3295	131,200	225,300	1.02	1.16	115,100
B-26E				.0255	.9999	.02550	.345	.405	3400	133,300	224,100	1.02	1.15	114,600
AVG.										135,300	229,000	1.04	1.18	117,100
B-21B	120	550	1000	.0249	1.0015	.02494	.348	.385	3400	136,300	221,400	.98	1.13	113,300
B-21C				.0249	1.0026	.02496	.351	.405	3440	137,800	231,100	1.03	1.18	118,300
B-21E				.0250	.9998	.02500	.345	.400	3370	134,800	224,800	1.00	1.15	114,900
AVG.										136,300	225,800	1.00	1.15	115,500
B-24A	85	550	6000	.0246	1.0010	.02462	.349	.453	3320	134,800	246,300	1.10	1.28	125,100
B-24B				.0245	1.0025	.02456	.342	.440	3270	133,000	237,300	1.06	1.23	120,900
B-24C				.0245	1.0030	.02457	.359	.432	3255	132,500	232,700	1.04	1.21	119,000
AVG.										133,400	238,700	1.06	1.24	121,200
B-25A	67	550	25,060	.0258	1.0024	.0259	.366	.437	3275	126,400	224,300	1.01	1.09	114,300
B-25C				.0253	1.0042	.0254	.338	.421	3500	128,500	238,000	1.07	1.16	113,200
B-25D				.0249	1.0015	.0249	.366	.466	3265	131,100	245,400	1.10	1.20	124,100
AVG.										128,700	235,900	1.06	1.15	117,200
B-18A	67 STEADY	550 STEADY	25,800	.0252	1.0010	.0252	.378	.460	3200	126,900	235,200	1.07	1.16	117,900
B-18B				.0252	1.0011	.0252	.378	.456	3285	130,300	239,700	1.09	1.18	121,600
B-18C				.0252	1.0016	.0252	.378	.456	3155	125,200	230,200	1.04	1.13	116,800
AVG.										127,500	235,100	1.07	1.15	118,700

Table X RENÉ 41 (20% C. R. + 16 HRS @ 1400°F)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 1 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE ($2a$) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO σ_{NET}/F_{TU}	σ_{NET}/F_{TY}	K_c (PSI)$\sqrt{IN.}$
D3-1C	UNEXPOSED CONTROLS			.0228	1.0021	.02285	.354	.426	2680	117,200	204,100	.83	.90	104,200
D3-2C				.0231	1.0000	.02310	.368	.428	2745	118,800	207,800	.85	.92	106,000
D3-4C				.0233	1.0016	.02233	.365	.414	2750	123,100	200,800	.82	.88	107,400
D3-5C				.0237	1.0004	.02379	.371	.430	2830	118,900	209,300	.86	.92	106,400
D3-6C				.0238	.9990	.02378	.360	.422	2870	120,600	209,000	.85	.92	106,600
AVG.										119,700	206,200	.84	.91	106,100
D2-14AB	HEAT SOAKED ONLY	550	1000	.0225	1.0054	.02262	.357	.448	2790	123,300	222,400	.88	.96	113,500
D2-14AC				.0229	1.0051	.02302	.359	.455	2940	127,700	233,300	.93	1.00	118,800
D2-14AE				.0228	1.0042	.02289	.352	.435	2840	124,000	218,800	.87	.94	111,800
AVG.										125,000	224,800	.89	.97	114,700
D3-10AA			5000	.0245	1.0100	.02474	.349	.442	3150	127,300	226,300	.91	.98	115,900
D3-10AB				.0245	1.0090	.02472	.329	.435	3225	130,400	229,400	.92	1.00	117,400
D3-10AC				.0245	1.0100	.02474	.353	.430	3185	128,700	224,100	.90	.97	114,900
AVG.										128,800	226,600	.91	.98	116,000
D3-11AA			10,000	.0240	1.0110	.02426	.349	.422	3020	124,500	213,600	.86	.92	109,800
D3-11AB				.0242	1.0120	.02449	.354	.437	3185	130,000	228,800	.92	.99	117,400
D3-11AC				.0245	1.0115	.02478	.351	.446	3030	122,300	218,800	.88	.95	112,000
AVG.										125,600	220,400	.88	.95	113,000
D3-9AA			30,000	.0244	.9968	.0243	.366	.483	2745	112,900	219,600	.90	.97	110,000
D3-9AB				.0241	.9959	.0240	.380	.496	2805	116,800	233,700	.96	1.04	116,200
D3-9AC				.0244	.9955	.0243	.358	.469	2920	120,100	228,100	.93	1.01	114,500
AVG.										116,600	227,100	.93	1.01	113,500
D2-15AA		550 STEADY	30,000	.0224	.9969	.0223	.349	.435	2675	119,900	212,300	.87	.94	108,000
D2-15AB				.0225	.9960	.0224	.380	.453	2740	122,300	224,500	.92	1.00	111,000
D2-15AC				.0227	.9956	.0226	.350	.428	2930	129,600	227,100	.93	1.01	115,700
AVG.										123,900	221,300	.90	.98	111,600

Table X RENE′41 (20% C. R. + 16 HRS @ 1400°F)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 2 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_o$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
D3-1C	UNEXPOSED CONTROLS			.0228	1.0021	.02285	.354	.426	2680	117,200	204,100	.83	.90	104,200
D3-2C				.0231	1.0000	.02310	.368	.428	2745	118,800	207,800	.85	.92	106,000
D3-4C				.0233	1.0016	.02233	.365	.414	2750	123,100	200,800	.82	.88	107,400
D3-5C				.0237	1.0004	.02379	.371	.430	2830	118,900	209,300	.86	.92	106,400
D3-6C				.0238	.9990	.02378	.360	.422	2870	120,600	209,000	.85	.92	106,600
AVG.										119,700	206,200	.84	.91	106,100
D2-9A	138.5	550	1000	.0228	1.0013	.02283	.358	.403	2750	120,400	201,600	.80	.86	103,100
D2-9C				.0234	1.0034	.02348	.368	.450	2660	113,200	205,400	.81	.87	104,600
D2-9E				.0236	1.0062	.02375	.359	.448	2880	121,200	218,600	.86	.93	111,500
AVG.										118,300	208,500	.82	.89	106,400
D2-8A	110	550	5000	.0230	1.0025	.02306	.345	.455	2905	126,000	230,700	.93	1.01	114,600
D2-8B				.0230	1.0060	.02314	.361	.468	2820	121,900	227,900	.92	1.00	115,700
D2-8C				.0230	1.0050	.02312	.349	.440	2865	123,900	220,400	.89	.97	112,500
AVG.										123,900	226,300	.91	.99	114,200
D2-12A	70	550	10,000	.0222	1.0015	.02223	.351	.440	2760	124,200	221,300	.89	.97	112,900
D2-12B				.0224	1.0055	.02252	.341	.433	2985	132,500	232,800	.94	1.02	119,000
D2-12C				.0225	1.0040	.02259	.343	.423	2945	130,400	225,300	.91	.99	114,500
AVG.										129,000	226,500	.91	.99	115,000
D2-5A	40	550	30,000	.0230	1.0049	.0231	.330	.424	2960	128,100	220,800	.93	1.01	113,400
D2-5B				.0232	1.0036	.0233	.354	.440	2945	126,300	224,800	.94	1.03	114,800
D2-5C				.0237	1.0053	.0238	.339	.464	2865	120,400	223,800	.94	1.03	113,600
AVG.										124,900	223,100	.94	1.02	113,900
D2-1A	40 STEADY	550 STEADY	30,000	.0230	1.0057	.0231	.346	.442	2815	121,800	216,500	.91	.99	111,000
D2-1B				.0235	1.0069	.0237	.394	.448	2880	121,500	219,800	.92	1.01	111,700
D2-1C				.0233	1.0095	.0235	.374	.442	2875	122,300	217,800	.91	1.00	111,400
AVG.										121,900	218,000	.91	1.00	111,400

Table X RENE' 41 (20% C. R. + 16 HRS @ 1400°F)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 3 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
D3-1C	UNEXPOSED CONTROLS			.0228	1.0021	.02285	.354	.426	2680	117,200	204,100	.83	.90	104,200
D3-2C				.0231	1.0000	.02310	.368	.428	2745	118,800	207,800	.85	.92	106,000
D3-4C				.0233	1.0016	.02233	.365	.414	2750	123,100	200,800	.82	.88	107,400
D3-5C				.0237	1.0004	.02379	.371	.430	2830	118,900	209,300	.86	.92	106,400
D3-6C				.0238	.9990	.02378	.360	.422	2870	120,600	209,000	.85	.92	106,600
AVG.										119,700	206,200	.84	.91	106,100
D2-16AA	HEAT SOAKED ONLY	650	1000	.0223	1.0002	.02234	.359	.428	2825	126,400	221,300	.89	.95	112,800
D2-16AB				.0223	1.0007	.02246	.365	.450	2790	124,200	227,200	.91	.98	114,800
D2-16AD				.0223	1.0007	.02246	.367	.454	2700	120,200	221,400	.89	.95	111,800
AVG.										123,600	223,300	.90	.96	113,100
D3-13AB	HEAT SOAKED ONLY	650	5000	.0249	1.0054	.02503	.364	--	2615	104,400	--	--	--	--
D3-13AD				.0243	1.0054	.02443	.352	.522	3015	123,400	256,600	1.03	1.12	127,500
D3-13AE				.0247	1.0051	.02483	.340	.550	3085	124,200	274,400	1.10	1.19	134,200
AVG.										117,300	265,500	1:07	1.16	130,900
D2-13AA	HEAT SOAKED ONLY	650	10,000	.0222	1.0100	.02242	.346	.456	2890	128,900	235,000	.96	1.01	120,000
D2-13AB				.0221	1.0115	.02235	.354	.433	2900	129,800	227,000	.93	.98	116,400
D2-13AC				.0223	1.0120	.02257	.351	.448	2875	127,300	228,500	.93	.98	116,900
AVG.										128,600	230,200	.94	.99	117,700
D3-14AA	HEAT SOAKED ONLY	650	30,000	.0239	.9965	.0238	.346	.459	2860	120,100	223,400	.88	.94	112,500
D3-14AB				.0238	.9957	.0237	.390	.481	2650	111,800	217,200	.85	.91	108,400
D3-14AC				.0240	.9955	.0239	.370	.479	2810	117,500	226,600	.89	.95	113,500
AVG.										116,500	222,400	.87	.94	111,400
D3-12AA	HEAT SOAKED ONLY	650 STEADY	30,000	.0243	.9969	.0242	.346	.447	2935	121,200	219,000	.90	.97	111,700
D3-12AB				.0246	.9962	.0245	.350	.467	2935	120,500	225,700	.93	1.00	114,500
D3-12AC				.0243	.9961	.0242	.374	.457	2825	116,700	215,600	.89	.96	109,100
AVG.										119,500	220,100	.90	.98	111,800

Table X RENÉ 41 (20% C. R. + 16 HRS @ 1400°F)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 4 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE ($2a$) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
D3-1C	UNEXPOSED CONTROLS			.0228	1.0021	.02285	.354	.426	2680	117,200	204,100	.83	.90	104,200
D3-2C				.0231	1.0000	.02310	.368	.428	2745	118,800	207,800	.85	.92	106,000
D3-4C				.0233	1.0016	.02233	.365	.414	2750	123,100	200,800	.82	.88	107,400
D3-5C				.0237	1.0004	.02379	.371	.430	2830	118,900	209,300	.86	.92	106,400
D3-6C				.0238	.9990	.02378	.360	.422	2870	120,600	209,000	.85	.92	106,600
AVG.										119,700	206,200	.84	.91	106,100
D2-10A	124	650	1000	.0228	1.0058	.02293	.360	.432	2855	124,500	218,200	.93	1.02	111,700
D2-10B				.0229	1.0048	.02301	.376	.432	2790	121,200	212,600	.90	.99	108,700
D2-10C				.0232	1.0027	.02326	.382	.444	2850	122,500	219,900	.93	1.03	112,100
AVG.										122,700	216,900	.92	1.01	110,800
D2-11A	100	650	5000	.0231	1.0120	.02338	.364	.396	2525	108,000	177,400	.70	.77	91,300
D2-11B				.0233	1.0075	.02347	.355	.435	2990	127,400	224,100	.89	.97	114,800
D2-11C				.0232	1.0065	.02335	.358	.425	2865	122,700	212,300	.84	.92	108,800
AVG.										119,300	204,600	.81	.89	104,900
D2-4A	70	650	10,000	.0230	1.0025	.02306	.342	.450	2900	125,800	228,200	.92	1.00	116,100
D2-4B				.0230	1.0055	.02313	.350	.443	2810	121,500	217,100	.88	.96	110,900
D2-4C				.0232	1.0050	.02332	.336	.457	3000	128,600	236,000	.95	1.04	118,600
AVG.										125,400	227,100	.92	1.00	115,200
D2-2A	40	650	30,000	.0232	1.0045	.0233	.338	.424	2960	127,000	219,200	.91	1.00	112,500
D2-2B				.0235	1.0050	.0236	.346	.410	2970	125,400	212,100	.88	.97	108,600
D2-2C				.0233	1.0068	.0235	.350	.464	2895	123,100	229,700	.96	1.05	116,400
AVG.										125,200	220,300	.92	1.00	112,500
D2-7A	40 STEADY	650 STEADY	30,000	.0238	1.0053	.0239	.362	.448	2930	122,500	220,300	.91	.98	112,700
D2-7B				.0235	1.0072	.0237	.382	.456	2775	117,000	213,400	.88	.95	109,000
D2-7C				.0232	1.0074	.0234	.386	.484	2710	115,800	223,900	.93	1.00	112,700
AVG.										118,500	219,200	.91	.98	111,500

Table XI Ti-6Al-4V (MILL ANNEALED)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 1 of 2)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED		GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_C (PSI)$\sqrt{IN.}$
				THICKNESS (INCHES)	WIDTH (INCHES)									
C3-1A	UNEXPOSED CONTROLS			.0261	1.0004	.02620	.358	.406	2320	88,500	149,500	1.09	1.16	76,200
C3-2A				.0258	1.0003	.02588	.363	.421	2255	87,100	150,800	1.10	1.17	78,000
C3-1F				.0262	1.0013	.02623	.353	.400	2345	89,400	148,800	1.09	1.16	76,200
C3-2F				.0261	1.0001	.02613	.322	.408	2415	92,400	156,300	1.14	1.21	79,800
C3-3F				.0257	1.0010	.02573	.333	.385	2320	90,100	146,500	1.07	1.14	74,900
AVG.										89,500	150,400	1.10	1.17	77,000
C1-6A	HEAT SOAKED ONLY	550	1000	.0230	1.0035	.02308	.349	.405	2030	87,900	147,400	1.03	1.13	75,500
C1-6B				.0222	1.0035	.02228	.352	.397	1935	86,800	143,800	1.01	1.10	73,600
C1-6C				.0220	1.0045	.02210	.368	.440	1890	85,600	152,200	1.07	1.17	77,300
AVG.										86,800	147,800	1.03	1.13	75,500
C2-4A			5000	.0246	1.0004	.02470	.372	.382	2015	81,500	132,400	.92	1.00	67,500
C2-4B				.0247	1.0016	.02474	.356	.375	2085	84,200	134,600	.93	1.02	68,800
C2-4E				.0249	1.0011	.02493	.362	.374	2080	83,400	133,200	.92	1.01	68,000
AVG.										83,100	133,400	.92	1.01	68,100
C2-3A			10,000	.0238	1.0080	.02399	.352	.431	2085	86,900	151,900	1.05	1.15	77,800
C2-3B				.0235	1.0080	.02369	.327	.428	2150	90,800	157,800	1.09	1.20	80,800
C2-3C				.0234	1.0085	.02360	.333	.390	2100	89,000	145,100	1.00	1.10	74,700
AVG.										88,900	151,600	1.05	1.15	77,800
C2-2A			30,000	.0230	.9937	.0228	.386	.420	1920	84,200	145,400	1.03	1.12	74,200
C2-2B				.0234	.9938	.0232	.374	.428	1895	81,600	143,500	1.02	1.11	72,900
C2-2C				.0239	.9940	.0238	.374	.440	1875	78,700	142,000	1.00	1.09	71,700
AVG.										81,500	143,600	1.02	1.11	72,900
C1-8A		550 STEADY	30,000	.0246	.9952	.0245	.366	.430	2010	82,000	144,600	1.02	1.11	73,400
C1-8B				.0232	.9945	.0231	.378	.448	1855	80,300	146,000	1.03	1.12	74,100
C1-8C				.0238	.9943	.0237	.385	.435	1965	82,900	147,700	1.05	1.13	74,700
AVG.										81,700	146,100	1.03	1.12	74,100

Table XI Ti-6Al-4V (MILL ANNEALED)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 2 of 2)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
C3-1A	UNEXPOSED CONTROLS			.0261	1.0004	.02620	.358	.406	2320	88,500	149,500	1.09	1.16	76,200
C3-2A				.0258	1.0003	.02588	.353	.421	2255	87,100	150,800	1.10	1.17	78,000
C3-1F				.0262	1.0013	.02623	.353	.400	2345	89,400	148,800	1.09	1.16	76,200
C3-2F				.0261	1.0001	.02613	.322	.408	2415	92,400	156,300	1.14	1.21	79,800
C3-3F				.0257	1.0010	.02573	.333	.385	2320	90,100	146,500	1.07	1.14	74,900
AVG.										89,500	150,400	1.10	1.17	77,000
C2-1A	85	550	1000	.0241	1.0005	.02411	.347	.412	2140	88,800	150,900	1.04	1.12	77,200
C2-1B				.0246	1.0015	.02434	.340	.368	2220	90,100	142,300	0.98	1.05	72,800
C2-1C				.0243	1.0015	.02434	.329	.390	2235	91,800	150,400	1.04	1.11	77,000
AVG.										90,200	147,900	1.02	1.10	75,700
C2-5A	71.5		5,000	.0248	.9998	.02480	.362	.405	2090	84,200	141,600	.98	1.07	72,400
C2-5B				.0258	1.0000	.02580	.360	.385	2160	83,700	136,100	.94	1.03	69,600
C2-5D				.0252	1.0210	.02573	.352	.385	2145	83,300	133,800	.93	1.01	69,100
AVG.										83,700	137,200	.95	1.04	70,300
C1-9A	60		10,000	.0259	1.0000	.02590	.336	.401	2355	90,900	151,800	1.05	1.14	77,600
C1-9B				.0241	1.0005	.02411	.344	.432	2100	87,100	153,300	1.06	1.16	78,100
C1-9C				.0235	1.0005	.02351	.354	.443	2020	85,900	154,200	1.07	1.16	78,500
AVG.										87,900	153,100	1.06	1.15	78,000
C1-7A	40		30,000	.0233	1.0010	.02332	.386	.448	1850	79,300	143,600	1.01	1.10	73,000
C1-7B				.0236	1.0020	.02364	.378	.431	1915	81,000	142,100	1.00	1.09	72,500
C1-7E				.0234	1.0027	.02346	.370	.428	1960	83,500	145,800	1.03	1.12	74,400
AVG.										81,200	143,800	1.01	1.11	73,300
C1-5A	40 STEADY	550 STEADY	30,000	.0236	1.0022	.02365	.382	.430	1960	82,800	145,100	1.03	1.13	74,100
C1-5B				.0225	1.0011	.02252	.378	.434	1805	80,100	141,500	1.00	1.10	72,100
C1-5C				.0228	1.0005	.02281	.378	.437	1845	80,800	143,600	1.02	1.11	72,900
AVG.										81,300	143,400	1.02	1.11	73,000

Table XII Ti-8Al-1Mo-1V (DUPLEX ANNEALED)
FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 1 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
E3-1C	UNEXPOSED CONTROLS			.0280	1.0038	.02811	.366	.435	2505	89,100	157,200	1.00	1.07	80,200
E3-2C				.0274	1.0040	.02751	.366	.438	2440	88,500	157,300	1.00	1.07	80,350
E3-3B				.0268	1.0038	.02691	.356	.451	2420	89,900	163,200	1.04	1.11	83,000
E3-5B				.0270	1.0038	.02709	.358	.445	2415	89,100	160,000	1.02	1.09	81,500
E3-5C				.0269	1.0048	.02703	.365	.438	2445	90,400	160,300	1.02	1.09	81,900
AVG.										89,000	159,600	1.01	1.09	81,400
E3-7AA	HEAT SOAKED ONLY	550	1000	.0258	1.0035	.02589	.354	.443	2365	91,300	163,500	1.03	1.12	83,400
E3-7AB				.0260	1.0035	.02606	.352	.425	2415	92,700	160,500	1.01	1.10	82,200
E3-7AC				.0266	1.0035	.02669	.350	.440	2450	91,800	163,400	1.03	1.12	83,400
AVG.										91,900	162,400	1.02	1.11	83,000
E3-6AA			5,000	.0262	1.0014	.02624	.400	.423	2220	84,600	146,500	.90	.99	74,700
E3-6AD				.0271	1.0024	.02716	.351	.423	2450	90,200	156,000	.96	1.05	79,600
E3-6AE				.0268	1.0032	.02688	.366	.427	2370	88,100	153,500	.95	1.04	78,300
AVG.										87,600	152,000	.94	1.03	77,600
E3-8AA			10,000	.0255	1.0065	.02567	.383	.455	2270	88,400	161,400	1.01	1.09	82,200
E3-8AB				.0267	1.0055	.02685	.353	.440	2220	82,700	148,000	0.93	1.00	75,100
E3-8AC				.0268	1.0065	.02697	.346	.447	2520	93,400	168,100	1.05	1.14	85,700
AVG.										88,200	159,200	1.00	1.08	81,000
E3-9AA			30,000	.0270	.9960	.02689	.382	.453	2175	80,800	148,300	.95	1.03	75,100
E3-9AB				.0265	.9956	.02638	.376	.463	2235	84,700	158,300	1.01	1.10	80,000
E3-9AC				.0264	.9950	.02626	.346	.427	2230	84,900	148,700	.95	1.03	75,700
AVG.										83,500	151,800	.97	1.06	76,900
E3-11AA		550 STEADY	30,000	.0272	.9953	.02707	.343	.469	2245	82,900	156,800	1.00	1.09	78,700
E3-11AB				.0265	.9942	.02634	.370	.479	2260	85,800	165,200	1.06	1.15	85,300
E3-11AC				.0268	.9943	.02665	.380	.463	2260	84,800	158,800	1.02	1.10	80,000
AVG.										84,500	160,200	1.03	1.11	81,300

Table XII Ti-8Al-1Mo-1V (DUPLEX ANNEALED)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 2 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
E3-1C	UNEXPOSED CONTROLS			.0280	1.0038	.02811	.366	.435	2505	89,100	157,200	1.00	1.07	80,200
E3-2C				.0274	1.0040	.02751	.366	.438	2440	88,600	157,300	1.00	1.07	80,300
E3-3B				.0268	1.0038	.02691	.356	.451	2420	89,900	163,200	1.04	1.11	83,000
E3-5B				.0270	1.0038	.02709	.358	.445	2415	89,100	160,000	1.02	1.09	81,500
E3-5C				.0269	1.0048	.02703	.365	.438	2445	90,400	160,300	1.02	1.09	81,900
AVG.										89,000	159,600	1.01	1.09	81,400
E3-15A	94	550	1000	.0265	1.0025	.02657	.359	.439	2435	91,600	163,100	1.02	1.11	83,100
E3-15B				.0260	1.0030	.02608	.355	.440	2400	92,000	163,900	1.03	1.12	83,600
E3-15C				.0260	1.0025	.02607	.354	.427	2385	91,500	159,400	1.00	1.08	81,500
AVG.										91,700	162,100	1.02	1.10	82,700
E1-16C	80		5000	.0268	1.0024	.02686	.366	.434	2385	88,700	156,600	.96	1.04	79,900
E1-16D				.0269	1.0018	.02694	.356	.445	2435	90,300	162,500	1.00	1.08	82,700
E1-16E				.0268	1.0014	.02684	.362	.435	2415	89,900	159,100	.97	1.06	81,000
AVG.										89,700	159,400	.98	1.06	81,200
E3-14A	60		10,000	.0265	1.0025	.02657	.349	.439	2415	90,900	161,800	1.02	1.12	82,500
E3-14B				.0265	1.0030	.02658	.341	.454	2350	88,400	161,500	1.01	1.11	82,100
E3-14C				.0262	1.0030	.02628	.372	.458	2325	88,500	162,900	1.02	1.12	82,800
AVG.										89,300	162,000	1.02	1.12	82,500
E3-13A	40		30,000	.0270	1.0032	.02708	.380	.465	2275	84,000	156,500	1.00	1.08	79,400
E3-13B				.0268	1.0020	.02685	.380	.461	2240	83,400	154,500	.99	1.06	78,400
E3-13C				.0269	1.0010	.02692	.390	.468	2190	81,300	152,800	.98	1.05	77,300
AVG.										82,900	154,600	.99	1.06	78,300
E3-12A	40 STEADY	550 STEADY	30,000	.0270	1.0031	.02708	.380	.481	2310	85,300	163,900	1.08	1.14	82,700
E3-12B				.0266	1.0018	.02664	.362	.441	2320	87,000	155,600	1.02	1.08	79,200
E3-12C				.0265	1.0008	.02652	.350	.433	2350	88,600	156,200	1.03	1.08	79,600
AVG.										86,900	158,500	1.04	1.10	80,500

Table XII Ti-8Al-1Mo-1V (DUPLEX ANNEALED)
FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 3 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
E3-1C	UNEXPOSED CONTROLS			.0280	1.0038	.02811	.366	.435	2505	89,100	157,200	1.00	1.07	80,200
E3-2C				.0274	1.0040	.02751	.366	.438	2440	88,600	157,300	1.00	1.07	80,300
E3-3B				.0268	1.0038	.02691	.356	.451	2420	89,900	163,200	1.04	1.11	83,000
E3-5B				.0270	1.0038	.02709	.358	.445	2415	89,100	160,000	1.02	1.09	81,500
E3-5C				.0269	1.0048	.02703	.365	.438	2445	90,400	160,300	1.02	1.09	81,900
AVG.										89,000	159,600	1.01	1.09	81,400
E3-2AB	HEAT SOAKED ONLY	650	1000	.0270	1.0042	.02711	.358	.430	2440	90,000	157,400	.97	1.08	80,500
E3-2AD				.0265	1.0046	.02662	.360	.430	2340	87,900	153,600	.95	1.05	78,600
E3-2AE				.0269	1.0038	.02699	.369	.430	2350	87,000	152,300	.94	1.04	77,800
AVG.										88,300	154,400	.95	1.06	79,000
E3-5AC	(HEAT SOAKED ONLY)	(650)	5000	.0269	1.0004	.02699	.340	.405	2420	89,600	151,000	.92	1.02	76,900
E3-5AD				.0270	1.0009	.02724	.350	.405	2365	86,800	146,900	.90	1.00	74,400
E3-5AE				.0268	1.0006	.02696	.340	.429	2420	89,700	157,900	.97	1.07	80,100
AVG.										88,700	152,000	.93	1.03	77,100
E3-4AC	(HEAT SOAKED ONLY)	(650)	10,000	.0265	1.0032	.02658	.358	.460	2350	88,400	163,300	1.01	1.11	82,900
E3-4AD				.0265	1.0025	.02656	.356	.452	2320	87,300	159,100	0.98	1.08	80,900
E3-4AE				.0265	1.0025	.02656	.345	.475	2330	87,700	166,600	1.03	1.13	84,300
AVG.										87,800	163,000	1.01	1.11	82,700
E3-1AA	(HEAT SOAKED ONLY)	(650)	30,000	.0275	.9962	.02739	.374	.467	2280	83,200	156,700	.97	1.06	79,800
E3-1AB				.0270	.9952	.02687	.370	.485	2230	82,900	161,900	1.00	1.10	81,100
E3-1AC				.0268	.9952	.02667	.382	.471	2190	82,100	155,900	.96	1.06	78,500
AVG.										82,700	158,200	.97	1.08	79,800
E3-10AA	(HEAT SOAKED ONLY)	650 STEADY	30,000	.0268	.9958	.02668	.382	.480	2175	81,500	157,300	.99	1.06	79,000
E3-10AB				.0264	.9951	.02627	.386	.487	2140	81,400	159,500	1.00	1.07	79,800
E3-10AC				.0266	.9951	.02646	.398	.504	2075	78,400	158,800	1.00	1.07	78,900
AVG.										80,400	158,600	.99	1.07	79,300

Table XII Ti-8Al-1Mo-1V (DUPLEX ANNEALED)
FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT ROOM TEMPERATURE)

(SHEET 4 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_C (PSI)$\sqrt{IN.}$
E3-1C	UNEXPOSED CONTROLS			.0280	1.0038	.02811	.366	.435	2505	89,100	157,200	1.00	1.07	80,200
E3-2C				.0274	1.0040	.02751	.366	.438	2440	88,600	157,300	1.00	1.07	80,300
E3-3B				.0268	1.0038	.02691	.356	.451	2420	89,900	163,200	1.04	1.11	83,000
E3-5B				.0270	1.0038	.02709	.358	.445	2415	89,100	160,000	1.02	1.09	81,500
E3-5C				.0269	1.0048	.02703	.365	.438	2445	90,400	160,300	1.02	1.09	81,900
AVG.										89,000	159,600	1.01	1.09	81,400
E1-19A	88.6	650	1000	.0270	1.0037	.02710	.364	.414	2400	88,500	150,700	.93	1.02	77,200
E1-19B				.0264	1.0034	.02649	.369	.456	2360	89,000	163,300	1.01	1.11	83,000
E1-19D				.0269	1.0028	.02698	.355	.427	2430	90,000	156,800	.97	1.06	80,000
AVG.										89,200	156,900	.97	1.06	80,100
E1-24A	80	650	5000	.0271	1.0028	.02718	.372	.405	2310	84,900	142,500	.87	.96	72,900
E1-24C				.0261	1.0029	.02618	.364	.401	2260	86,300	143,800	.88	.97	73,500
E1-24E				.0265	1.0005	.02651	.356	.419	2445	92,200	158,600	.97	1.07	80,900
AVG.										87,800	148,300	.90	1.00	75,800
E1-17D	60	650	10,000	.0269	1.0015	.02694	.349	.450	2480	92,000	167,100	1.02	1.12	85,000
E1-17E				.0270	1.0015	.02704	.354	.468	2410	89,100	167,300	1.02	1.12	84,700
E1-17F				.0255	1.0015	.02554	.356	.462	2350	92,000	170,700	1.04	1.14	86,600
AVG.										91,000	168,400	1.03	1.13	85,400
E1-22A	40	650	30,000	.0266	1.0042	.02671	.354	.433	2220	83,100	146,100	.94	1.01	74,600
E1-22B				.0274	1.0038	.02750	.382	.459	2200	80,000	147,400	.95	1.02	73,100
E1-22C				.0270	1.0020	.02705	.242	.459	2335	86,300	159,200	1.02	1.11	80,900
AVG.										83,100	150,900	.97	1.05	76,200
E1-20A	40 STEADY	650 STEADY	30,000	.0271	1.0028	.02717	.354	.459	2320	85,300	157,500	1.01	1.09	79,900
E1-20B				.0267	1.0021	.02675	.386	.487	2235	83,500	162,500	1.05	1.13	81,700
E1-20C				.0254	1.0012	.02543	.386	.465	2095	82,300	153,900	.99	1.07	77,900
AVG.										83,700	157,900	1.02	1.10	79,900

Table XIII AM-350 SCT (825)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65°F)

(SHEET 1 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
A 3-2	UNEXPOSED CONTROLS			.0249	.9930	.02473	.322	.463	3295	133,200	249,600	1.09	1.26	125,800
A 3-3				.0249	.9932	.02473	.365	.457	3050	123,300	226,900	0.99	1.15	115,300
Avg.										128,200	238,300	1.04	1.20	120,600
A3-14A	HEAT SOAKED ONLY	550	1000	.0248	.9976	.02474	.356	.444	3255	131,600	237,000	1.02	1.20	120,500
A3-14D			1000	.0248	.9982	.02476	.365	.462	3250	131,300	244,300	1.05	1.24	123,700
Avg.										131,500	240,700	1.03	1.22	122,100
A2-15A			5000	.0251	1.0049	.02522	.352	.480	3215	127,500	244,100	1.06	1.22	123,400
A2-15E			5000	.0249	1.0043	.02500	.344	.445	3215	128,600	230,800	1.00	1.15	117,700
Avg.										128,000	237,400	1.03	1.18	120,500
A1-11D			10,000	.0250	1.0115	.02529	.345	.452	3355	132,700	240,000	1.05	1.24	122,600
A1-11E			10,000	.0250	1.0080	.02520	.299	.458	3265	129,600	237,400	1.04	1.23	121,000
Avg.										131,100	238,700	1.04	1.23	121,800
A1-15D			30,000	.0253	.9943	.02515	.362	.430	3230	128,400	226,300	1.01	1.13	115,000
A1-15E			30,000	.0253	.9940	.02514	.362	.432	3220	128,000	226,600	.99	1.13	115,100
Avg.										128,200	226,400	.99	1.13	115,100
A4-14D		550 STEADY	30,000	.0249	.9955	.02478	.386	.435	3100	125,100	222,000	.97	1.11	112,900
A4-14E			30,000	.0248	.9948	.02467	.374	.455	3145	127,400	235,000	1.03	1.17	118,900
Avg										126,200	228,500	1.00	1.14	115,900

Table XIII AM-350 SCT (825)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65°F)

(SHEET 2 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI$\sqrt{\text{IN.}}$)
A3-2	UNEXPOSED CONTROLS			.0249	.9930	.02473	.322	.463	3295	133,200	249,600	1.09	1.26	125,800
A3-3				.0249	.9932	.02473	.365	.457	3050	123,300	226,900	0.99	1.15	115,300
AVG.										128,200	238,300	1.04	1.20	120,600
A3-15A	120	550	1000	.0249	1.0019	.02495	.360	.461	3370	135,000	250,100	1.06	1.22	126,900
A3-15D	120	550	1000	.0248	1.0020	.02485	.449	.448	2800	112,700	203,700	0.86	0.99	103,700
AVG.										123,800	226,900	0.96	1.11	115,300
A4-12D	103	550	5000	.0249	1.0021	.02495	.417	.477	2890	115,800	221,100	0.95	1.08	111,600
A4-12E	103	550	5000	.0247	1.0034	.02478	.361	.458	3265	131,700	242,[illegible]00	1.04	1.19	123,100
AVG.										123,700	231,700	0.99	1.13	117,400
A3-12D	85	550	10,000	.0248	1.0015	.02484	.416	.485	3030	122,000	236,500	1.02	1.17	119,000
A3-12E	85	550	10,000	.0248	1.0025	.02486	.387	.408	3200	128,700	217,100	0.93	1.08	111,000
AVG.										125,300	226,800	0.97	1.12	115,000
A2-12D	67	550	30,000	.0249	1.0012	.02493	.378	.447	3050	122,300	221,000	.96	1.11	122,400
A2-12E	67	550	30,000	.0249	1.0012	.02493	.354	.447	3230	129,500	234,000	1.02	1.18	119,000
AVG.										125,900	227,500	.99	1.15	120,700
A1-12D	67 STEADY	550 STEADY	30,000	.0255	1.0012	.02553	.380	.460	3000	117,500	217,300	.94	1.09	110,300
A1-12E	67		30,000	.0254	1.0015	.02544	.366	.448	3055	120,000	217,200	.94	1.09	110,500
AVG.										118,800	217,300	.94	1.09	110,400

Table XIII AM-350 SCT (825)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT $-65^{0}F$)

(SHEET 3 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (^{0}F)	EXPOSURE TIME (HOURS)	MEASURED		GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
				THICKNESS (INCHES)	WIDTH (INCHES)									
A3-2	UNEXPOSED CONTROLS			.0249	.9930	.02473	.322	.463	3295	133,200	249,600	1.09	1.26	125,800
A3-3				.0249	.9932	.02473	.365	.457	3050	123,300	226,900	0.99	1.15	115,300
AVG.										128,200	238,300	1.04	1.20	120,600
A2-13A	HEAT SOAKED ONLY	650	1000	.0248	.9992	.02478	.349	.465	3265	131,700	246,400	1.05	1.25	124,600
A2-13E			1000	.0254	.9994	.02538	.326	.418	3470	136,700	235,000	1.00	1.20	120,000
AVG.										134,200	240,700	1.02	1.22	122,300
A2-11D			5000	.0248	1.0048	.02492	.369	.472	2910	116,800	220,200	0.94	1.12	111,600
A2-11E			5000	.0249	1.0046	.02501	.366	.462	3130	125,100	231,600	0.99	1.18	117,600
AVG.										120,900	225,900	0.96	1.15	114,600
A1-13D			10,000	.0250	1.0100	.02525	.357	.483	3100	122,800	235,300	0.98	1.13	119,200
A1-13E			10,000	.0250	1.0085	.02521	.370	.512	2990	118,600	240,900	1.01	1.16	120,400
AVG.										120,700	238,160	0.99	1.14	119,300
A4-12D			30,000	.0253	.9940	.02515	.370	.370	1535	61,000	97,200	.39	.45	49,400
A4-12E			30,000	.0253	.9934	.02513	.378	.378	2310	91,900	148,300	.60	.68	75,600
AVG.										76,400	122,800	.49	.56	62,500
A4-15D		650 STEADY	30,000	.0249	.9945	.02476	.380	.380	1355	54,700	88,500	.36	.41	45,100
A4-15E			30,000	.0249	.9944	.02476	.378	.378	1610	65,000	104,700	.42	.48	53,400
AVG.										59,800	96,600	.39	.44	49,300

Table XIII AM-350 SCT (825)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT $-65^{o}F$)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (^{o}F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
A3-2	UNEXPOSED CONTROLS			.0249	.9930	.02473	.322	.463	3295	133,200	249,600	1.09	1.26	125,800
A3-3				.0249	.9932	.02473	.365	.457	3050	123,300	226,900	0.99	1.15	115,300
AVG.										128,200	238,300	1.04	1.20	120,600
A4-11B	117	650	1000	.0249	1.0014	.02493	.356	.486	3260	130,800	254,000	1.06	1.20	127,800
A4-11C	117	650	1000	.0248	1.0018	.02484	.362	.424	3270	131,600	228,300	0.95	1.08	116,500
AVG.										131,200	241,200	1.00	1.14	122,200
A4-13A	101	650	5000	.0250	1.0019	.02505	.359	.458	3315	132,300	243,700	1.01	1.16	123,700
A4-13E	101	650	5000	.0251	1.0029	.02517	.362	.485	3335	132,500	256,500	1.06	1.21	129,900
AVG.										132,400	250,100	1.03	1.18	126,800
A3-13D	85	650	10,000	.0250	1.0025	.02506	.376	.451	1595	63,600	115,600	0.48	0.54	58,800
A3-13E	85	650	10,000	.0250	1.0015	.02504	.386	.473	1830	73,000	139,400	0.58	0.65	69,900
AVG.										68,300	127,500	0.53	0.59	64,300
A3-11D	67	650	30,000	.0248	1.0028	.02487	.370	.370	1105	44,400	70,400	.29	.34	36,000
A3-11E	67	650	30,000	.0248	1.0018	.02484	.362	.362	870	35,000	54,800	.23	.27	27,900
AVG.										39,700	62,600	.26	.31	31,900
A2-14D	67 STEADY	650 STEADY	30,000	.0249	1.0013	.02493	.374	.374	990	39,700	63,300	.26	.31	32,400
A2-14E			30,000	.0249	1.0016	.02494	.362	.362	1080	43,300	67,700	.28	.33	34,600
AVG.										41,500	65,500	.27	.32	33,500

Table XIV PH 14-8 Mo (SRH 1050)
FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65°F)

(SHEET 1 of 2)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE ($2a$) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
B-4	UNEXPOSED CONTROLS			.0252	1.0030	.02527	.362	.481	3180	125,800	241,800	1.07	1.13	122,000
B-8				.0245	1.0032	.02458	.353	.478	3165	128,800	245,900	1.09	1.15	124,300
AVG.										127,300	243,800	1.08	1.14	123,100
B-28A	HEAT SOAKED ONLY	550	754	.0250	.9966	.02491	.367	.432	3600	144,500	255,100	1.11	1.14	129,800
B-28B			754	.0252	.9964	.02510	.347	.430	3645	145,200	255,400	1.11	1.14	130,200
AVG.										144,800	255,200	1.11	1.14	130,000
B-17D			1000	.0254	1.0044	.02551	.345	.422	3645	142,900	246,400	1.07	1.10	126,100
B-17E			1000	.0254	1.0034	.02549	.385	.471	3425	134,400	253,300	1.10	1.13	128,300
AVG.										138,600	249,800	1.08	1.11	127,200
B-27D			6000	.0250	1.0020	.02505	.327	.413	3735	149,100	253,700	1.12	1.19	130,000
B-27E			6000	.0250	1.0010	.02503	.379	.451	3465	138,400	252,000	1.11	1.18	128,000
AVG.										143,700	252,800	1.12	1.18	129,000
B-23B			25060	.0248	0.9999	.02479	.374	.445	3410	137,500	247,800	1.06	1.12	126,000
B-23E			25060	.0252	1.0011	.02522	.386	.445	3390	134,400	241,400	1.04	1.09	123,100
AVG.										135,900	244,200	1.05	1.10	124,000
B-20D		550 STEADY	25800	.0249	1.0018	.02494	.366	.449	3525	141,300	256,100	1.10	1.16	130,300
B-20E			25800	.0251	1.0003	.02511	.362	.444	3455	137,500	247,400	1.07	1.12	126,200
AVG.										139,400	251,800	1.08	1.14	128,200

Table XIV PH 14-8 Mo (SRH 1050)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65°F)

(SHEET 2 of 2)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE ($2a$) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
B-4	UNEXPOSED CONTROLS			.0252	1.0030	.02527	.362	.481	3180	125,800	241,800	1.07	1.13	122,000
B-8				.0254	1.0032	.02458	.357	.478	3165	128,800	245,900	1.09	1.15	124,300
AVG.										127,300	243,800	1.08	1.14	123,100
B-26A	103	550	754	.0251	1.0008	.02512	.346	.405	3715	147,900	248,500	1.09	1.20	127,100
B-26B	103	550	754	.0251	1.0009	.02512	.289	.385	3965	157,800	257,400	1.13	1.24	131,100
AVG.										152,800	252,900	1.11	1.22	129,100
B-21A	120	550	1000	.0249	1.0001	.02490	.353	.422	3635	146,000	252,600	1.09	1.21	128,900
B-21D	120	550	1000	.0249	1.0002	.02490	.350	.428	3595	144,400	252,200	1.09	1.21	128,700
AVG.										145,200	252,400	1.09	1.21	128,800
B-24D	85	550	6000	.0250	1.0010	.02503	.346	.420	3610	144,200	248,400	1.07	1.20	126,900
B-24E	85	550	6000	.0250	1.0005	.02501	.363	.441	3555	142,100	254,100	1.09	1.24	129,400
AVG.										143,100	251,200	1.08	1.23	128,100
B-25B	67	550	25060	.0255	1.0026	.02556	.354	.441	3630	142,000	253,400	1.09	1.17	129,900
B-25E	67	550	25060	.0251	1.0021	.02515	.362	.448	3445	136,900	247,800	1.07	1.14	126,100
AVG.										139,400	250,600	1.08	1.15	128,000
B-18B	67 STEADY	550 STEADY	25800	.0248	1.0018	.02484	.370	.455	3590	144,500	264,700	1.14	1.22	132,400
B-18E			25800	.0249	1.0022	.02495	.374	.448	3380	135,400	244,900	1.06	1.23	124,700
AVG.										139,900	254,800	1.10	1.17	128,500

Table XV RENÉ 41 (20% C. R. + 16 HRS @ 1400°F)
FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65°F)

(SHEET 1 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
D2-13C	UNEXPOSED CONTROLS			.0230	1.0010	.02302	.360	.452	2895	125,800	229,200	.88	.96	116,500
D2-14C				.0229	1.0000	.02290	.360	.468	2850	124,500	233,900	.90	.98	118,300
AVG.										125,100	231,600	.89	.97	117,400
D2-14AA	HEAT SOAKED ONLY	550	1000	.0223	1.0061	.02244	.350	.423	2970	132,300	228,400	.85	.94	116,900
D2-14AD			1000	.0230	1.0049	.02311	.342	.421	3080	133,300	229,300	.86	.94	117,400
AVG.										132,800	228,900	.85	.94	117,200
D3-10AE			5000	.0243	1.0075	.02448	.354	.440	3200	130,700	232,000	.88	.97	118,600
			(Note: Only one specimen available)											
D3-11AD			10,000	.0245	1.0125	.02481	.348	.429	3400	137,000	237,700	.90	.99	122,000
D3-11AE			10,000	.0245	1.0115	.02428	.349	.416	3210	132,200	220,000	.83	.91	115,400
AVG.										134,600	228,800	.86	.95	118,700
D3-9AD			30,000	.0247	.9958	.02459	.350	.440	3105	126,200	226,100	.87	.95	114,900
D3-9AE			30,000	.0249	.9954	.02478	.366	.459	3080	124,200	230,500	.89	.97	116,600
AVG.										125,200	228,300	.88	.96	115,800
D2-15AD		550 STEADY	30,000	.0223	.9958	.02220	.366	.404	2820	127,000	213,600	.82	.90	109,000
D2-15AE			30,000	.0223	.9952	.02219	.362	.428	2810	126,600	222,000	.85	.94	113,000
AVG.										126,800	217,000	.84	.92	111,000

Table XV RENÉ 41 (20% C. R. + 16 HRS. @ 1400°F) FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65°F)

(SHEET 2 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA SQ.IN.	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE ($2a$) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
D2-13C	(UNEXPOSED CONTROLS)			.0230	1.0010	.02302	.360	.452	2895	125,800	229,200	.88	.96	116,500
D2-14C				.0229	1.0000	.02290	.360	.468	2850	124,500	233,900	.90	.98	118,300
AVG.										125,100	231,600	.89	.97	117,400
D2-9B	138.5	550	1000	.0228	1.0028	.02286	.367	.456	2970	129,900	238,100	.88	.99	121,100
D2-9D	138.5	550	1000	.0233	1.0040	.02339	.390	.477	2860	122,300	232,900	.86	.95	117,800
AVG.										126,100	235,500	.87	.96	119,400
D2-8D	110	550	5000	.0235	1.0050	.02362	.348	.455	3090	130,800	238,900	.90	1.00	121,700
D2-8E	110	550	5000	.0235	1.0085	.02370	.346	.462	3130	132,000	243,700	.92	1.02	124,000
AVG.										131,400	241,300	.91	1.01	122,800
D2-12D	70	550	10,000	.0230	1.0050	.02312	.287	.413	3160	136,600	232,000	.88	.97	118,800
D2-12E	70	550	10,000	.0230	1.0075	.02317	.348	.455	3065	132,300	241,100	.91	1.01	123,000
AVG.										134,400	236,500	.89	.99	120,900
D2-5D	40	550	30,000	.0237	1.0069	.02386	.362	.459	2930	122,700	225,700	.88	.98	114,900
D2-5E	40	550	30,000	.0235	1.0080	.02368	.354	.408	3015	127,300	213,800	.84	.93	109,800
AVG.										125,000	219,700	.86	.95	112,300
D2-1D	40 STEADY	550 STEADY	30,000	.0229	1.0075	.02307	.358	.410	2855	123,700	208,600	.82	.91	107,100
D2-1E	40 STEADY	550 STEADY	30,000	.0230	1.0070	.02316	.350	.440	2950	127,300	226,200	.89	.98	115,700
AVG.										125,500	217,400	.85	.94	111,400

Table XV RENE' 41 (20% C. R. + 16 HRS. @ 1400^{0}F)
FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65^{0}F)

(SHEET 3 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (^{0}F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
D2-13C	UNEXPOSED CONTROLS			.0230	1.0010	.02302	.360	.452	2895	125,800	229,200	.88	.96	116,500
D2-14C				.0229	1.0000	.02290	.360	.468	2850	124,500	233,900	.90	.98	118,300
AVG.										125,100	231,600	.89	.97	117,400
D2-16AC	HEAT SOAKED ONLY	650	1000	.0229	0.9994	.02289	.353	.427	2930	128,000	223,600	.84	.92	114,000
D2-16AE			1000	.0221	0.9998	.02209	.351	.447	2880	130,400	235,600	.89	.97	119,900
AVG.										129,200	229,600	.86	.95	116,900
D3-13AA	HEAT SOAKED ONLY	650	5000	.0244	1.0050	.02452	.350	.458	3145	128,200	235,500	.89	.98	119,800
D3-13AC			5000	.0244	1.0055	.02453	.322	.425	3360	137,000	237,200	.90	.99	121,400
AVG.										132,600	236,400	.89	.99	120,600
D2-13AD	HEAT SOAKED ONLY	650	10,000	.0225	1.0120	.02277	.355	.426	3020	132,600	228,900	.86	.95	117,600
D2-13AE			10,000	.0228	1.0115	.02306	.346	.410	3070	133,100	223,900	.84	.93	115,000
AVG.										132,800	226,400	.85	.94	116,300
D3-14AD	HEAT SOAKED ONLY	650	30,000	.0243	.9945	.02416	.380	.460	2885	119,400	222,000	.82	.94	112,200
D3-14AE			30,000	.0245	.9951	.02438	.380	.480	2795	114,600	221,400	.82	.93	111,200
AVG.										117,000	221,700	.82	.93	111,700
D3-12AD	HEAT SOAKED ONLY	650 STEADY	30,000	.0245	.9960	.02440	.343	.388	3075	126,000	206,500	.76	.87	105,300
D3-12AE			30,000	.0246	.9963	.02451	.354	.415	3060	124,800	213,900	.79	.90	109,100
AVG.										125,400	210,200	.78	.88	107,000

Table XV RENE' 41 (20% C. R. + 16 HRS. @ 1400°F)

FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65°F)

(SHEET 4 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_o$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE ($2a$) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
D2-13C	UNEXPOSED CONTROLS			.0230	1.0010	.02302	.360	.452	2895	125,800	229,200	.88	.96	116,500
D2-14C				.0229	1.0000	.02290	.360	.468	2850	124,500	233,900	.90	.98	118,300
AVG.										125,100	231,600	.89	.97	117,400
D2-10D	124	650	1000	.0231	1.0055	.02323	.367	.452	2960	127,400	231,400	.92	1.04	117,900
D2-10E	124	650	1000	.0230	1.0072	.02317	.367	.444	2980	128,600	230,100	.92	1.03	121,000
AVG.										128,000	230,800	.92	1.04	119,400
D2-11D	100	650	5000	.0225	1.0050	.02261	.362	.428	2935	129,800	226,100	.84	.94	115,600
D2-11E	100	650	5000	.0223	1.0060	.02243	.351	.431	2985	133,000	232,800	.87	.97	119,000
AVG.										131,400	229,400	.86	.96	117,300
D2-4D	70	650	10,000	.0235	1.0050	.02362	.344	.467	3060	129,600	242,000	.92	1.02	122,900
D2-4E	70	650	10,000	.0235	1.0090	.02371	.340	.432	3195	134,800	235,600	.89	.99	120,800
AVG.										132,200	238,800	.90	1.00	121,800
D2-2D	40	650	30,000	.0231	1.0062	.02324	.374	.418	2840	122,200	209,100	.82	.91	107,100
D2-2E	40	650	30,000	.0232	1.0059	.02333	.374	.436	2880	123,400	217,800	.85	.94	111,400
AVG.										122,800	213,400	.83	.92	109,200
D2-7D	40 STEADY	650 STEADY	30,000	.0237	1.0050	.02382	.370	.472	2910	122,100	230,400	.90	.97	116,700
D2-7E	40 STEADY	650 STEADY	30,000	.0237	1.0066	.02385	.358	.390	2960	124,100	202,600	.79	.86	103,900
AVG.										123,100	216,500	.85	.92	110,300

Table XVI Ti-6Al-4V TITANIUM (MILL ANNEALED) FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65°F)

(SHEET 1 of 2)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
C3-2B	(UNEXPOSED CONTROLS)			.0259	1.0001	.02593	.365	.455	2340	90,200	171,800	1.12	1.18	84,000
C3-4A				.0250	1.0008	.02520	.356	.451	2280	90,500	165,800	1.08	1.14	83,300
AVG.										90,300	168,810	1.10	1.16	83,600
C1-6D	HEAT SOAKED ONLY	550	1000	.0223	1.0050	.02241	.368	.458	1985	88,600	162,700	1.01	1.04	82,800
C1-6E	HEAT SOAKED ONLY	550	1000	.0232	1.0020	.02325	.347	.402	2200	94,600	158,600	.99	1.01	80,800
AVG.										91,600	160,300	1.00	1.03	81,800
C2-4C	HEAT SOAKED ONLY	550	5000	.0245	1.0012	.02453	.362	.430	2205	89,900	157,600	.97	1.00	80,400
C2-4D	HEAT SOAKED ONLY	550	5000	.0253	1.0009	.02553	.356	.441	2255	88,300	159,200	.98	1.00	80,400
AVG.										89,100	158,400	.97	1.00	80,400
C2-3D	HEAT SOAKED ONLY	550	10,000	.0250	1.0080	.02520	.323	.402	2305	91,500	152,000	.93	.99	78,600
C2-3E	HEAT SOAKED ONLY	550	10,000	.0246	1.0045	.02471	.316	.393	2325	94,100	154,500	.95	.98	79,200
AVG.										92,800	153,300	.94	.98	78,600
C2-2D	HEAT SOAKED ONLY	550	30,000	.0242	.9939	.02405	.366	.449	2010	83,500	152,500	.95	1.03	77,200
C2-2E	HEAT SOAKED ONLY	550	30,000	.0241	.9935	.02394	.366	.449	1985	82,900	151,200	.94	1.03	76,600
AVG.										83,200	151,800	.95	1.03	76,900
C1-8D	HEAT SOAKED ONLY	550 STEADY	30,000	.0237	.9936	.02355	.370	.431	1975	83,800	148,100	.92	1.02	75,200
C1-8E	HEAT SOAKED ONLY	550 STEADY	30,000	.0239	.9939	.02375	.374	.419	1990	83,700	144,600	.90	1.01	73,700
AVG.										83,800	146,300	.91	1.01	74,400

Table XVI Ti-6Al-4V TITANIUM (MILL ANNEALED)
FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65°F)

(SHEET 2 of 2)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_o$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
C3-2B	UNEXPOSED CONTROLS			.0259	1.0001	.02593	.365	.455	2340	90,200	171,800	1.12	1.18	84,000
C3-4A				.0250	1.0008	.02520	.356	.451	2280	90,500	165,800	1.08	1.14	83,300
AVG.										90,300	168,800	1.10	1.16	83,600
C2-1D	85	550	1000	.0233	.9985	.02327	.338	.427	2210	95,000	165,900	1.02	1.03	84,600
C2-1E	85	550	1000	.0230	.9965	.02292	.351	.421	2160	94,200	162,900	1.00	1.02	83,100
AVG.										94,600	164,400	1.01	1.02	83,800
C2-5C	71.5	550	5000	.0250	1.0004	.02501	.364	.448	2195	87,800	158,900	0.98	1.01	80,800
C2-5E	71.5	550	5000	.0252	1.0019	.02525	.359	.440	2185	86,500	154,300	0.95	0.98	78,600
AVG.										87,100	156,600	0.96	0.99	79,700
C1-9D	60	550	10,000	.0233	1.0010	.02332	.336	.387	2190	93,900	153,000	0.94	0.97	78,300
C1-9E	60	550	10,000	.0228	1.0030	.02287	.379	.420	2000	87,400	150,500	0.92	0.95	76,900
AVG.										90,600	151,700	0.93	0.96	77,600
C1-7C	40	550	30,000	.0239	1.0022	.02395	.382	.416	1975	82,400	140,900	.88	.99	72,100
C1-7D	40	550	30,000	.0241	1.0020	.02415	.378	.444	2050	84,800	152,500	.95	1.04	77,600
AVG.										83,600	146,700	.92	1.02	74,800
C1-5D	40 STEADY	550 STEADY	30,000	.0248	.9995	.02478	.374	.404	1990	80,300	134,700	.85	.95	68,900
C1-5E			30,000	.0251	.9992	.02508	.378	.424	2060	82,100	142,600	.90	1.00	72,700
AVG.										81,200	138,600	.87	.96	70,800

Table XVII Ti-8Al-1Mo-1V-(DUPLEX ANNEALED)
FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65^oF)

(SHEET 1 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (^oF)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE ($2a$) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
E3-1B	UNEXPOSED CONTROLS			.0279	1.0045	.02802	.371	.468	2590	92,400	173,000	.99	1.07	87,900
E3-3C				.0274	1.0044	.02752	.344	.435	2625	95,400	168,200	.96	1.04	85,900
AVG.										93,900	170,600	.97	1.05	86,900
E3-7AD	HEAT SOAKED ONLY	550	1000	.0265	1.0040	.02661	.328	.415	2690	101,000	172,400	.98	1.06	87,500
E3-7AE			1000	.0266	1.0010	.02663	.346	.483	2600	97,600	188,600	1.07	1.16	95,000
AVG.										99,300	180,500	1.02	1.11	91,200
E3-6AB			5000	.0266	1.0026	.02667	.351	.445	2500	93,700	168,500	.94	1.03	85,800
E3-6AC			5000	.0269	1.0036	.02699	.311	.419	2745	101,700	174,600	.97	1.06	89,300
AVG.										97,700	171,600	.95	1.05	87,500
E3-8AD			10,000	.0265	1.0060	.02666	.349	.468	2580	96,800	180,900	1.03	1.11	91,900
E3-8AE			10,000	.0265	1.0035	.02659	.352	.448	2500	94,000	169,800	.96	1.04	86,500
AVG.										95,400	175,200	1.00	1.08	89,200
E3-9AD			30,000	.0265	.9957	.02638	.358	.459	2360	89,400	165,900	.95	1.02	83,900
E3-9AE			30,000	.0266	.9938	.02643	.354	.464	2375	89,800	168,500	.97	1.06	85,000
AVG.										89,600	167,200	.96	1.05	84,400
E3-11AD		550 STEADY	30,000	.0270	.9940	.02684	.358	.475	2385	88,800	170,200	1.00	1.07	85,500
E3-11AE			30,000	.0263	.9934	.02612	.378	.472	2265	86,700	171,900	1.01	1.08	83,100
AVG.										87,200	171,100	1.00	1.08	84,300

Table XVII Ti-8Al-1Mo-1V (DUPLEX ANNEALED)
FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65°F)

(SHEET 2 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ. IN.)	INITIAL CRACK LENGTH $2a_0$ (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE $2a$ (INCHES)	MAX. LOAD AT RUPTURE (LBS)	GROSS STRESS AT RUPTURE σ_{GROSS} (PSI)	NET STRESS AT RUPTURE σ_{NET} (PSI)	NOTCHED STRENGTH RATIO σ_{NET}/F_{tu}	σ_{NET}/F_{ty}	K_c (PSI $\sqrt{IN.}$)
E3-1B	UNEXPOSED CONTROLS			.0279	1.0045	.02802	.371	.468	2590	92,400	173,000	.99	1.07	87,900
E3-3C				.0274	1.0044	.02752	.344	.435	2625	95,400	168,200	.96	1.04	85,900
AVG.										93,900	170,600	.97	1.05	86,900
E3-15D	94	550	1000	.0265	1.0025	.02657	.341	.431	2615	98,400	172,700	.98	1.06	88,100
E3-15E	94	550	1000	.0263	1.0010	.02633	.348	.460	2580	98,000	181,300	1.03	1.11	92,000
AVG.										98,200	177,000	1.01	1.09	90,000
E1-16A	80	550	5000	.0260	1.0022	.02606	.351	.442	2455	94,200	168,500	.93	1.01	85,900
E1-16B	80	550	5000	.0260	1.0024	.02606	.371	.485	2385	91,500	177,300	.98	1.06	89,300
AVG.										92,800	172,900	.95	1.03	87,600
E3-14D	60	550	10,000	.0266	1.0025	.02667	.364	.467	2470	92,600	173,400	.98	1.09	87,800
E3-14E	60	550	10,000	.0265	1.0010	.02653	.366	.467	2440	92,000	172,400	.98	1.08	87,300
AVG.										92,300	172,900	.98	1.08	87,500
E3-13D	40	550	30,000	.0272	.9998	.02719	.380	.456	2375	87,300	160,500	.92	1.02	81,400
E3-13E	40	550	30,000	.0270	1.0000	.02700	.374	.452	2400	88,800	162,200	.93	1.03	82,400
AVG.										88,100	161,400	.93	1.03	81,900
E3-12D	40 STEADY	550 STEADY	30,000	.0271	.9998	.02709	.346	.401	2490	91,900	153,500	.88	.98	78,400
E3-12E			30,000	.0268	1.0000	.02680	.374	.404	2370	88,400	148,400	.85	.95	75,800
AVG.										90,100	150,900	.87	.96	77,100

Table XVII Ti-8Al-1Mo-1V (DUPLEX ANNEALED)
FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65°F)

(SHEET 3 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA (SQ.IN.)	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c (PSI)$\sqrt{IN.}$
E3-1B	UNEXPOSED CONTROLS			.0279	1.0045	.02802	.371	.468	2590	92,400	173,000	.99	1.07	87,900
E3-3C				.0274	1.0044	.02752	.344	.435	2625	95,400	168,200	.96	1.04	85,900
AVG.										93,900	170,600	.97	1.05	86,900
E3-2AA	HEAT SOAKED ONLY	650	1000	.0262	1.0044	.02631	.357	.499	2460	93,500	185,800	1.03	1.13	93,100
E3-2AC			1000	.0265	1.0049	.02663	.355	.529	2420	90,900	191,900	1.07	1.17	94,800
AVG.										92,200	188,800	1.05	1.15	94,000
E3-5AA			5000	.0265	1.0038	.02659	.367	.500	2325	87,400	174,600	.96	1.06	87,200
E3-5AB			5000	.0269	1.0006	.02706	.332	.498	2480	91,600	183,400	1.01	1.12	91,200
AVG.										89,500	178,800	.99	1.09	89,200
E3-4AA			10,000	.0262	1.0022	.02623	.367	.455	2360	90,000	164,600	.91	1.02	83,800
E3-4AB			10,000	.0261	1.0019	.02615	.354	.475	2350	89,900	170,900	.95	1.06	86,300
AVG.										89,900	167,800	.93	1.04	85,100
E3-1AD			30,000	.0270	.9947	.02685	.374	.444	2280	84,900	153,300	.85	.95	77,800
E3-1AE			30,000	.0269	.9945	.02675	.370	.464	2270	84,800	159,000	.88	.99	80,200
AVG.										84,800	156,200	.87	.97	79,000
E3-10AD		650 STEADY	30,000	.0266	.9945	.02645	.394	.473	2150	81,200	155,000	.87	.95	78,000
E3-10AE			30,000	.0260	.9950	.02587	.394	.485	2080	80,400	156,800	.88	.96	78,600
AVG.										80,800	155,900	.87	.96	78,300

Table XVII Ti-8Al-1Mo-1V (DUPLEX ANNEALED)
FRACTURE TOUGHNESS TEST DATA (ALL TESTS AT -65°F)

(SHEET 4 of 4)

SPECIMEN NUMBER	CREEP STRESS LEVEL (KSI)	EXPOSURE TEMP. (°F)	EXPOSURE TIME (HOURS)	MEASURED THICKNESS (INCHES)	MEASURED WIDTH (INCHES)	GROSS AREA SQ.IN.	INITIAL CRACK LENGTH ($2a_0$) (INCHES)	CRACK LENGTH AT ONSET OF FAST FRACTURE (2a) (INCHES)	MAX. LOAD AT RUPTURE (LBS.)	GROSS STRESS AT RUPTURE (σ_{GROSS}) (PSI)	NET STRESS AT RUPTURE (σ_{NET}) (PSI)	NOTCHED STRENGTH RATIO $\frac{\sigma_{NET}}{F_{TU}}$	$\frac{\sigma_{NET}}{F_{TY}}$	K_c PSI$\sqrt{IN.}$
E3-1B	UNEXPOSED CONTROLS			.0279	1.0045	.02802	.371	.468	2590	92,400	173,000	.99	1.07	87,900
E3-3C				.0274	1.0044	.02752	.344	.435	2625	95,400	168,200	.96	1.04	85,900
AVG.										93,900	170,600	.97	1.05	86,900
E1-19C	88.6	650	1000	.0269	1.0039	.02700	.348	.453	2605	96,400	175,700	.98	1.07	89,400
E1-19E	88.6	650	1000	.0264	1.0011	.02643	.353	.445	2530	95,700	172,300	.96	1.05	87,700
AVG.										96,000	174,000	.97	1.06	88,500
E1-24B	80	650	5000	.0262	1.0025	.02627	.362	.468	2340	89,000	167,100	.92	1.01	84,500
E1-24D	80	650	5000	.0271	1.0011	.02713	.363	.493	2500	92,100	181,500	1.00	1.10	91,000
AVG.										90,600	174,300	.96	1.06	87,800
E1-17B	60	650	10,000	.0260	1.0030	.02608	.353	.455	2375	91,100	166,600	.93	1.00	84,700
E1-17C	60	650	10,000	.0268	1.0030	.02608	.345	.452	2500	93,000	169,200	.94	1.02	86,100
AVG.										92,000	167,900	.93	1.01	85,400
E1-22D	40	650	30,000	.0266	1.0008	.02662	.366	.472	2360	88,600	167,700	.96	1.06	84,800
E1-22E	40	650	30,000	.0266	1.0008	.02662	.350	.448	2350	88,200	159,800	.92	1.02	81,200
AVG.										88,400	163,700	.94	1.03	83,000
E1-20D	40 STEADY	650 STEADY	30,000	.0259	1.0007	.02592	.366	.436	2275	87,700	155,600	.90	.99	79,300
E1-20E			30,000	.0263	1.0015	.02634	.380	.464	2270	86,100	160,300	.92	1.02	81,400
AVG.										86,900	157,900	.91	1.00	80,300

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13. ABSTRACT

This report covers an investigation of the creep rate and metallurgical stability of candidate materials for a supersonic transport airplane when exposed to heat alone and to creep loading at temperatures of 550° or 650°F. Specimens were exposed to intermittent heating and to creep loading for times of 1000, 5000, 10,000 and 30,000 hours and, also, to steady heating and to creep loading for 30,000 hours. The materials tested were Ti-8Al-1Mo-1V (duplex annealed) and Ti-6Al-4V (mill annealed) titanium alloys, René 41 (20% cold rolled + 16 hours at 1400°F) superalloy, and AM-350 SCT (825) and PH 14-8 Mo (SRH 1050) stainless steels. The 30,000 hour creep stress level for the two titaniums and René 41 was 40,000 psi, whereas, 67,000 psi was used for the 30,000 hour creep stress level of the two stainless steels. The creep stress levels for the 1000 hours exposures were set below the yield stress of each material at the exposure temperature and intermediate stress levels were used for the 5,000 and 10,000 hour creep loadings to give a range of creep rates. The influence of each of these conditions on the tensile, fracture toughness, and metallurgical properties of materials was determined. Plastic deformation due to creep was measured throughout the duration of the exposure. (Continued)

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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The results indicated that all five materials would be satisfactory for use at 550°F for 30,000 hours at the 30,000 hour creep test stress levels. The creep behavior of Ti-6Al-4V titanium makes it undesirable for long time use at 650°F. Also, the AM-350 SCT (825) stainless steel is embrittled by long time exposure to 650°F. The PH 14-8 Mo stainless steel was not tested at 650°F. The exposure to creep loading at 650°F did not reveal any characteristics of the René 41 superalloy of the Ti-8Al-1Mo-1V titanium that would make these alloys undesirable for use in a supersonic transport airplane