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ENGINEERING DATA ON NEW AND EMERGING STRUCTURAL MATERIALS

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Battelle Memorial Institute

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AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report was prepared by Battelle Memorial Institute under Contract F33615-69-C-1115. This contract was performed under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data". The work was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Marvin Knight, project engineer.

This final report covers work conducted from November, 1968 to September, 1970. This report was released by the authors on 25 September 1970 for publication.

This technical report has been reviewed and is approved.

A. Olevitch
Chief, Materials Engineering Branch
Materials Support Division
Air Force Materials Laboratory

ABSTRACT

The major objectives of this research program were to evaluate newly developed structural materials of potential Air Force weapons system interest and then to provide "data sheet" type presentations of engineering data. The effort covered in this report has concentrated on Beta III titanium sheet, AF2-IDA heat-resistant alloy bar, 3Al-8V-6Cr-4Mo-4Zr (Beta C) titanium alloy forging, 300M high-strength steel forging, 7178-T76 aluminum alloy sheet, 7049-T73 aluminum alloy hand forging, 6Al-4V titanium alloy extrusions, 5621-S titanium alloy forging, 6Al-4V titanium alloy sheet, 7175-T736 aluminum alloy die forging, and MP35N high-strength bar.

The mechanical properties investigated include tension, compression, shear, bend, impact, fracture toughness, fatigue, creep and stress-rupture, and stress corrosion at appropriate temperatures.

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INTRODUCTION

The selection of structural materials to most effectively satisfy new environmental requirements and increased design load requirements for advanced Air Force weapons systems is of vital importance. A major difficulty that design engineers frequently encounter, especially for recently developed materials, materials processing, and product forms, is the lack of sufficient engineering data information to evaluate the relative potential of these developments for a particular application.

The Air Force, in recognition of this need, initiated a program at Battelle's Columbus Laboratories early in 1965. This program (Contract AF33(615)-2494) was to provide comparative engineering data for newly developed structural materials. Materials included in this program were carefully selected to insure that they were either available or could become quickly available upon request and that they would represent potentially attractive alloy projections for weapons-system usage. The results of this program were published in Technical Report AFML-TR-67-418, April, 1968(1)*. This concept was continued under Contract F33615-67-C-1292 and resulted in the publication of Technical Report AFML-TR-68-211, July, 1968(2).

This technical report is a result of the continuing effort to relieve the above situation and stimulate interest in the use of newly developed alloys, or new processing techniques for older alloys, for advanced structures.

The primary objective of this program was to obtain comparative engineering data for newly developed structural materials.

The materials evaluated under this contract are as follows:

(1) Be . III titanium sheet

(2) AF2-IDA Bar

(3) 38-6-44 titanium forging

(4) 300M forging

(5) 7178 aluminum sheet

(6) 7049 aluminum forging

(7) 6Al-4V titanium extrusions

(8) 6Al-4V titanium sheet

(9) 5621-S titanium forging

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*Numbers in parentheses refer to references at the end of the text.

(10) 7175 aluminum forging

(11) MP35N bar

The heat-treat or temper conditions selected for evaluation are described in each material section.

The program approach was, as on previous contracts, to search the published literature and to contact the metal producers and aerospace companies for any pertinent data. Tests were then scheduled to fill in the gaps in the existing information. Upon completion of each material evaluation, a "data sheet" was issued to make the data immediately available to potential users rather than defer publication to the end of the contract term and the summary report. These "data sheets" are reproduced in the conclusions section of this report.

Detailed information concerning the properties of interest and test techniques are described in subsequent sections of this report.

EXPERIMENTAL PROCEDURE

Mechanical Properties

The various mechanical properties of interest for each of the materials are as follows:

(1) Tension

(a) Ultimate tensile strength, F_{tu}

(b) Tensile yield strength, F_{ty}

(c) Elongation, e_t

(d) Reduction in area, RA

(e) Modulus of elasticity, E_t

(2) Compression

(a) Compressive yield strength, F_{cy}

(b) Modulus of elasticity, E_c

(3) Creep and stress rupture

(a) Stress for 0.2 or 0.5 percent deformation in 100 hours and in 1000 hours

(b) Stress for rupture in 100 hours and in 1000 hours

(4) Shear – Ultimate shear strength, F_{su}

(5) Axial fatigue*

(a) Unnotched, R = 0.1, lifetime: 10^3 through 10^7 cycles

(b) Notched (K_t = 3.0), R = 0.1, lifetime: 10^3 through 10^7 cycles

(6) Fracture toughness, K_{Ic}

(7) Stress corrosion – 80 percent F_{ty}, 1000 hours maximum, 3-1/2 percent NaCl solution

(8) Thermal expansion

(9) Bend – Minimum radius

(10) Impact – Charpy V-notch, ft-lb

(11) Density.

Specimen Identification

A simple system of numbers and letters was used for specimen identification. Coding consisted of a number indicating the type of test and also indicating a comparable area on the sheet, plate, or forging. For certain test types, the number was followed by a letter signifying specimen orientation (L for longitudinal, T for transverse). The test types where the letter did not appear were bend, fatigue, creep, and fracture toughness since, in these cases, only one specimen orientation was used. The next number in the coding specifies the location from which the specimen blank was taken from the original material configuration. Coding was as follows:

Assigned Number	Test Type
1	Tension
2	Compression
3	Creep and stress-rupture
4	Shear

* "R" represents the algebraic ratio of the minimum stress to the maximum stress in one cycle; that is, R = S_{min}/S_{max}. "K" represents the Neuber-Peterson theoretical stress concentration factor.

Assigned Number	Test Type
5	Fatigue
6	Fracture toughness
7	Stress corrosion
8	Thermal expansion
9	Bend
10	Impact

As an example, a specimen numbered 2T-5 is a compression specimen, transverse orientation, cut from Location 5. Also, a specimen numbered 5-12 is a fatigue specimen from Location 12.

Specimen designs used in this program are shown in Figures 1 through 21. These specimens conform to dimensional and tolerance specifications outlined in relevant ASTM Standards, in Federal Test method standard No. 151a, in AIA Publication ARTC-13[3], or in MAB Publication MAB 192-M[4].

Test Description

Tension

Procedures used for tension testing are those recommended in ASTM methods E8-68 and E21-66T as well as in Federal Test Method standard No. 151a (method 211.1). Six specimens (three longitudinal and three transverse) were tested at each temperature to determine ultimate tensile strength, 0.2 percent offset yield strength, elongation, and reduction in area. The modulus of elasticity was obtained from load-strain curves plotted by an autographic recorder during each test.

All tensile tests were carried out in Baldwin Universal testing machines. These machines are calibrated at frequent intervals in accordance with ASTM method E4-64 to assure loading accuracy within 0.2 percent. The machines are equipped with integral automatic strain pacers and autographic strain recorders.

Specimens tested at elevated temperatures were heated in standard wire-wound resistance-type furnaces. Each furnace was equipped with a Foxboro controller capable of maintaining the test temperature to within 5 F of the control temperature over a 2-inch gage length. Chromel-Alumel thermocouples attached to the specimen gage section were used to monitor temperatures. Each specimen was soaked at temperature at least 20 minutes before being tested.

An averaging-type linear differential transformer extensometer was used to measure strain. For elevated temperature testing, the extensometer was equipped with extensions to bring the transformer unit out of the furnace. The extensometer conformed to ASTM E3-64T Classification B1 having a sensitivity of 0.0001 inch/inch.

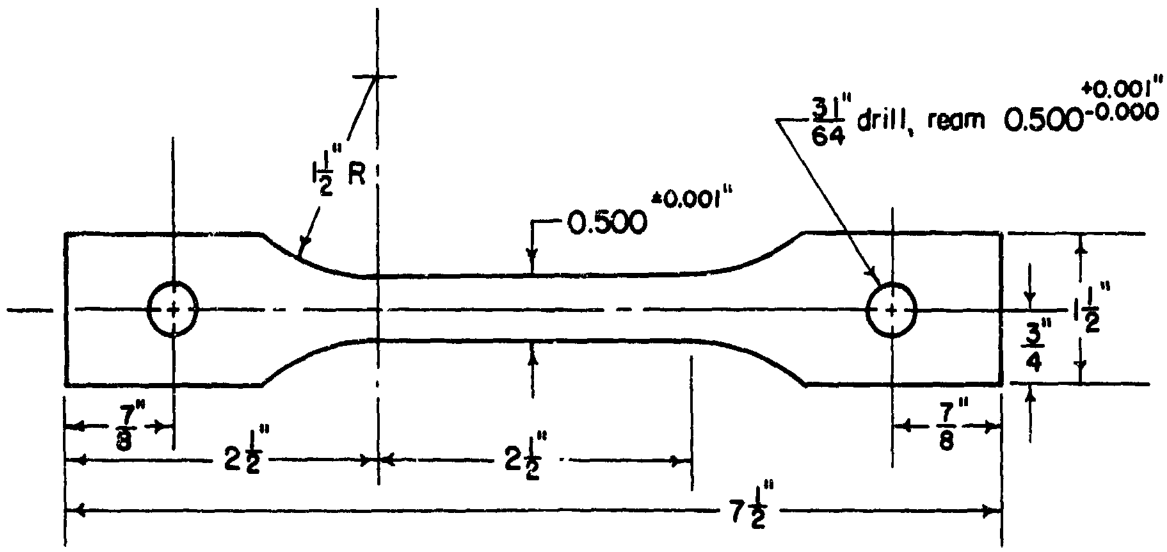


FIGURE 1. SHEET AND THIN-PLATE TENSILE SPECIMEN

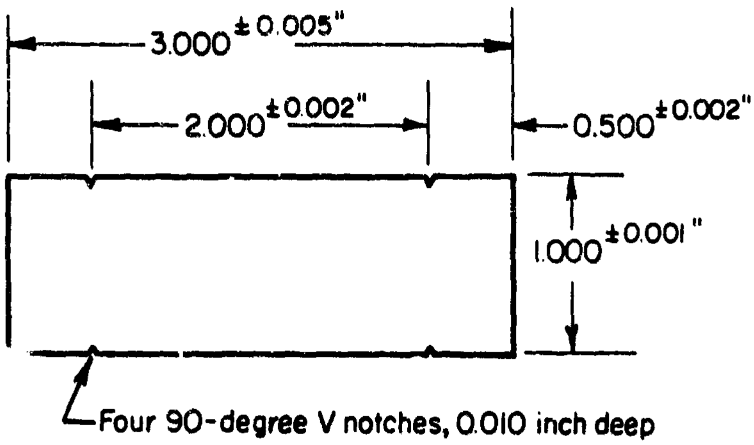


FIGURE 2. SHEET COMPRESSION SPECIMEN

Note: (1) Ends must be flat and Parallel to within 0.0002 inch
(2) Surface must be free from nicks and scratches

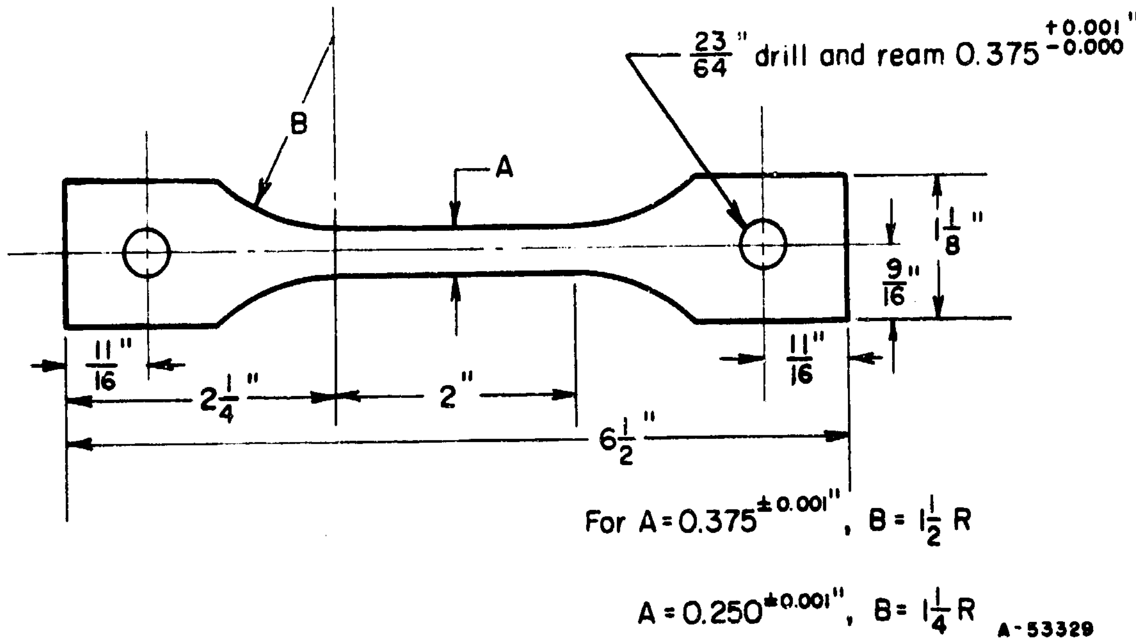


FIGURE 3. SHEET CREEP AND STRESS RUPTURE SPECIMEN

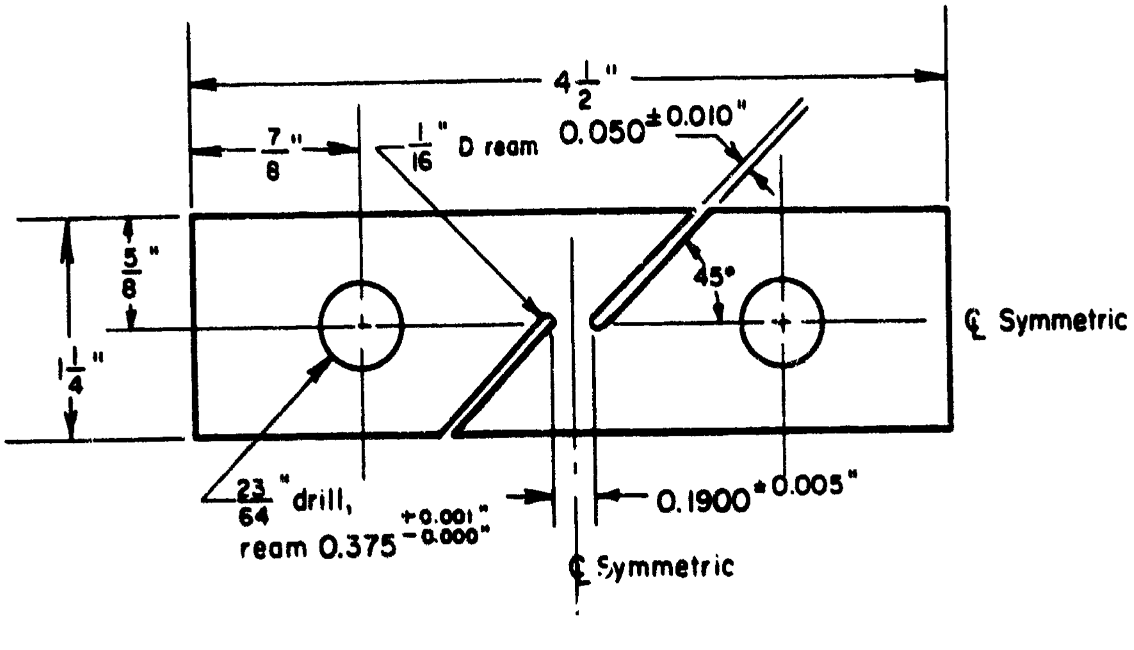
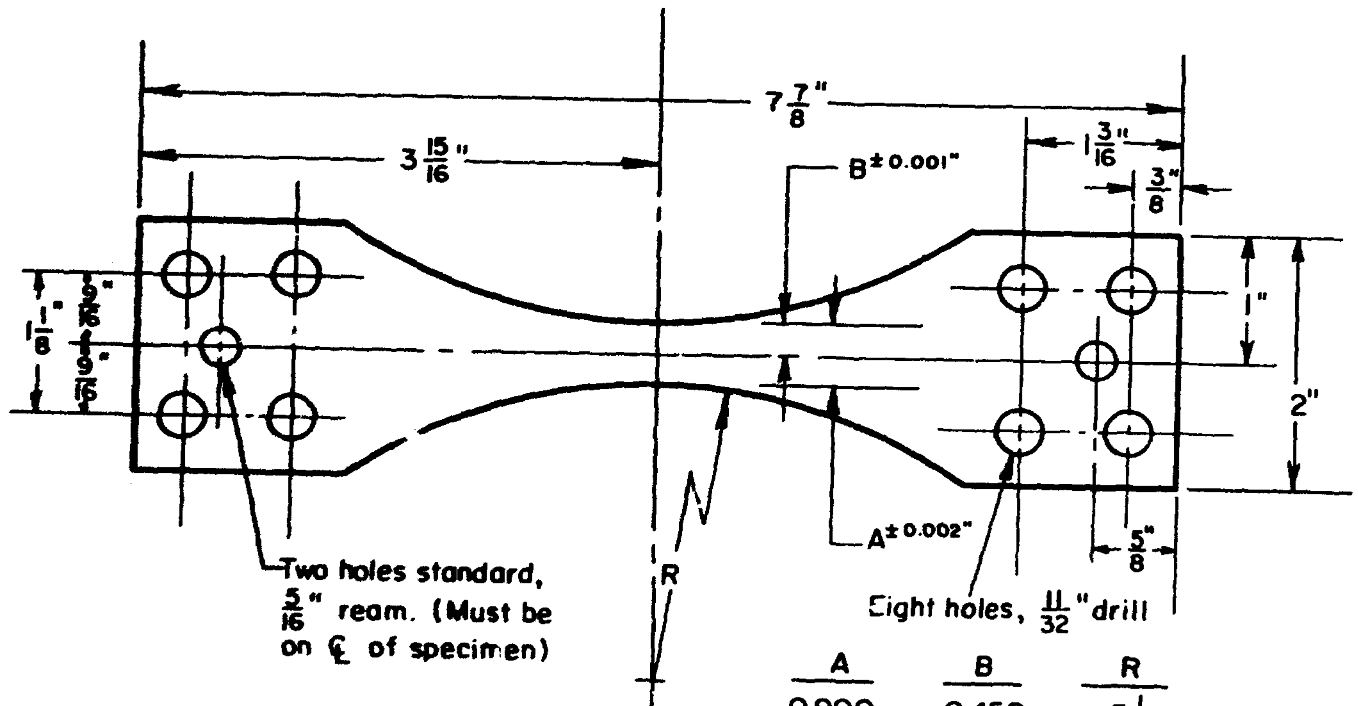


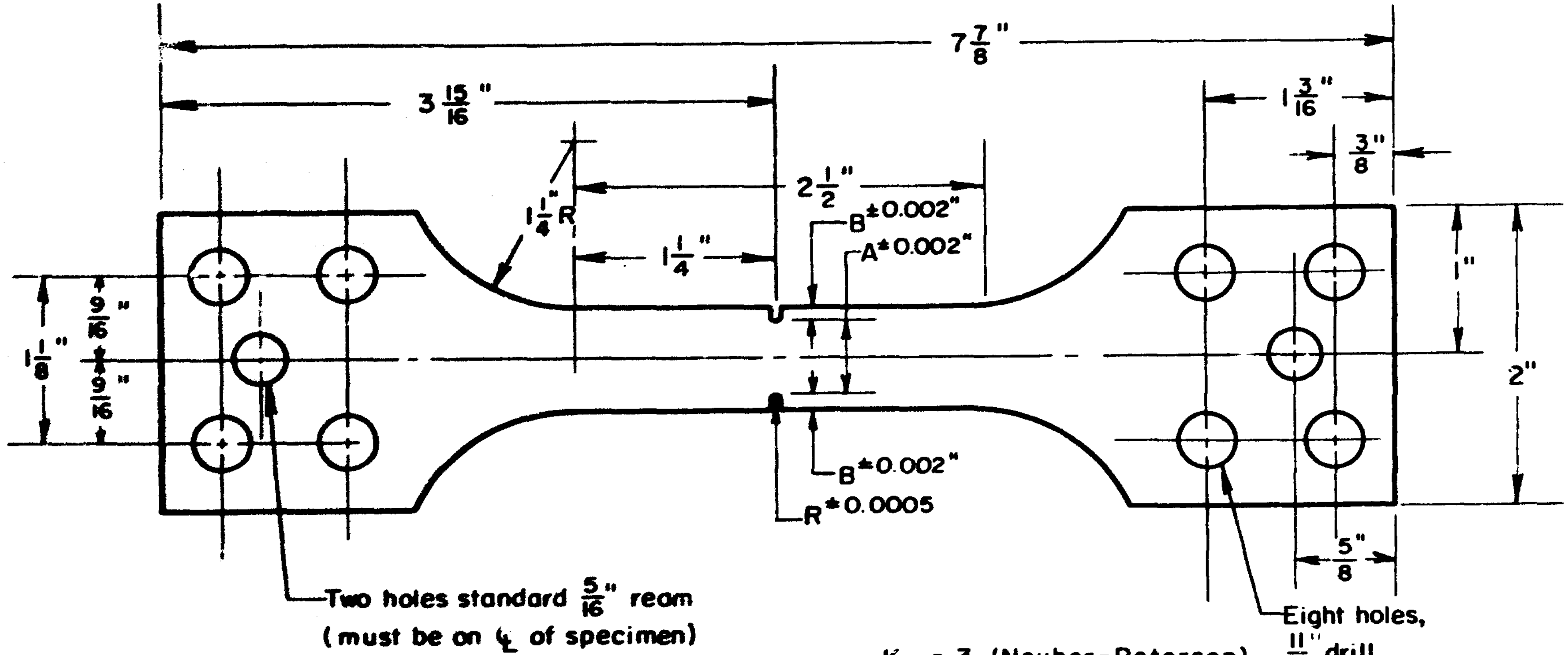
FIGURE 4. SHEET SHEAR TEST SPECIMEN



A	B	R
0.900	0.450	$5\frac{1}{2}$
0.500	0.250	4
0.250	0.125	3

A - 53330

FIGURE 5. UNNOTCHED SHEET FATIGUE SPECIMEN



K_t = 3 (Neuber-Peterson)

A	B	R
0.900	0.175	0.0625
0.375	0.125	0.0312

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FIGURE 6. NOTCHED (K_t = 3.0) SHEET FATIGUE SPECIMEN

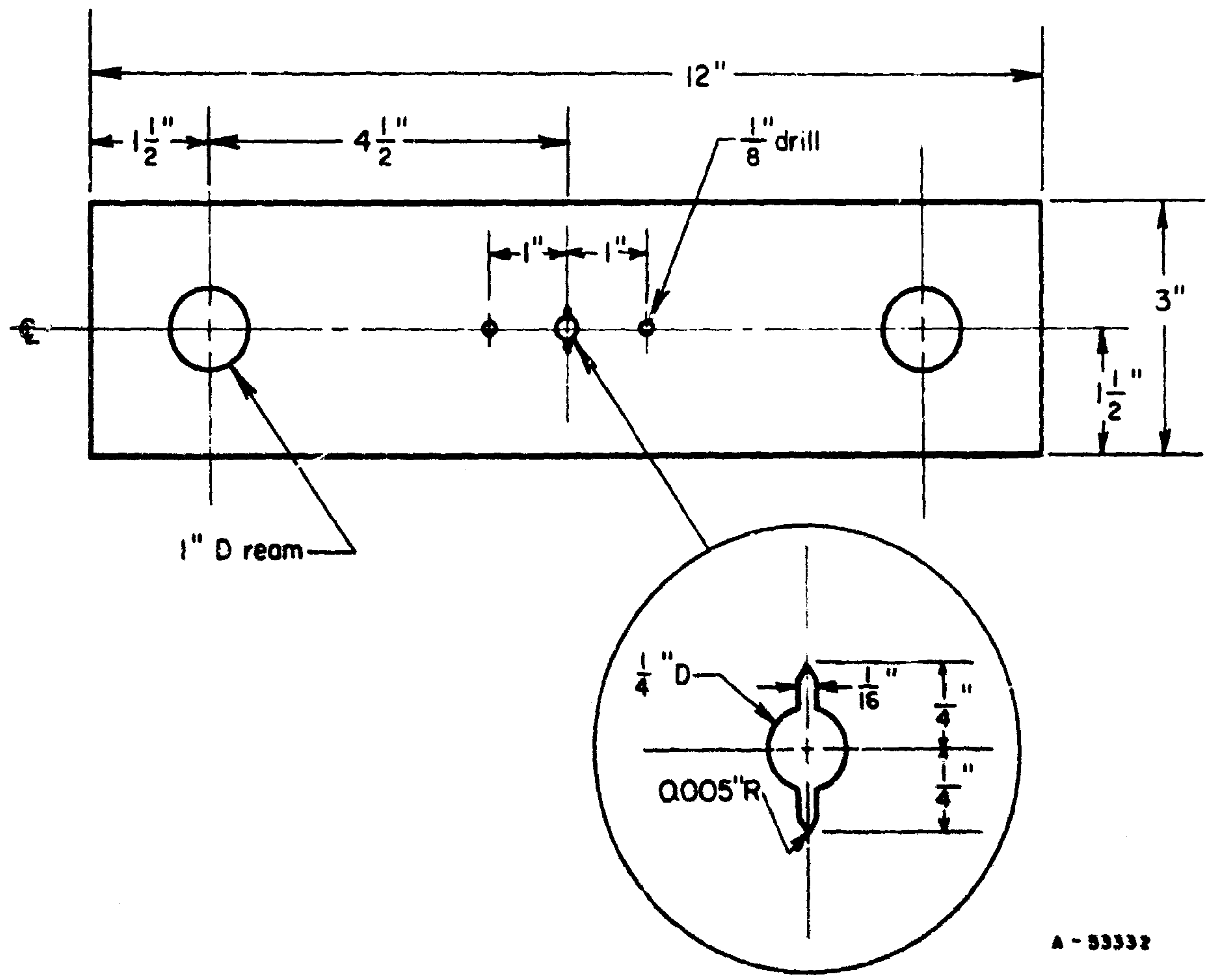

FIGURE 7. CENTER-NOTCH FRACTURE-TOUGHNESS SPECIMEN

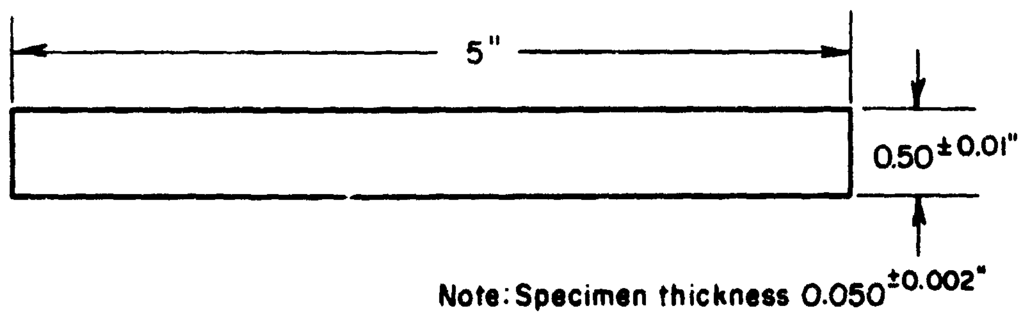

FIGURE 8. SHEET STRESS-CORROSION SPECIMEN

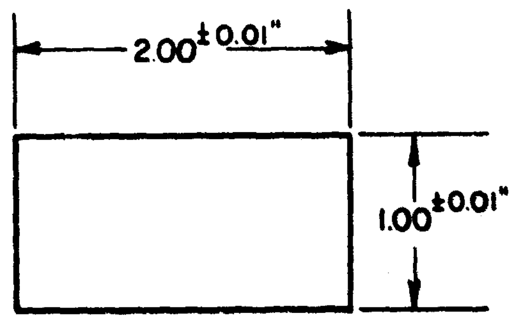

FIGURE 9. THERMAL-EXPANSION SPECIMEN

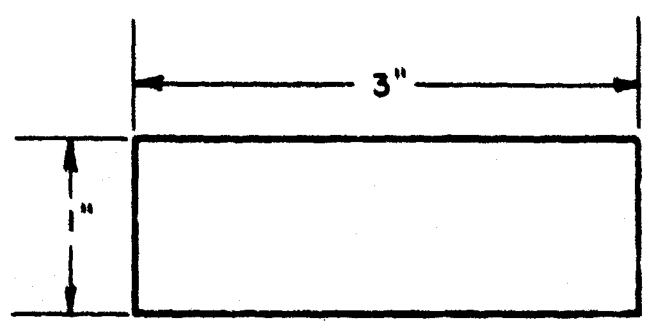

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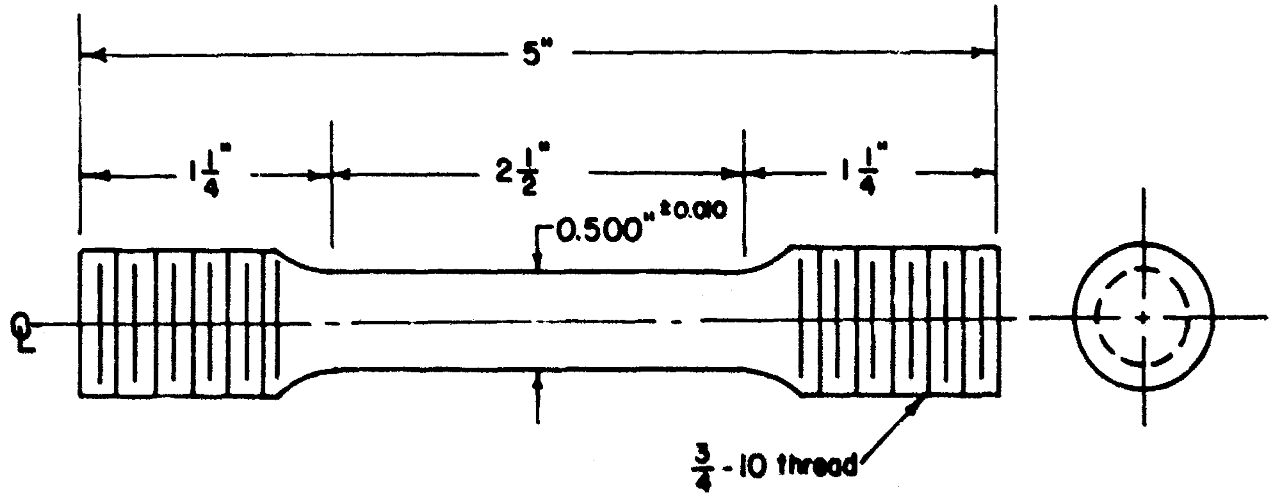
FIGURE 10. SHEET BEND SPECIMEN



All dimensions in inches

FIGURE 11. ROUND TENSILE SPECIMEN

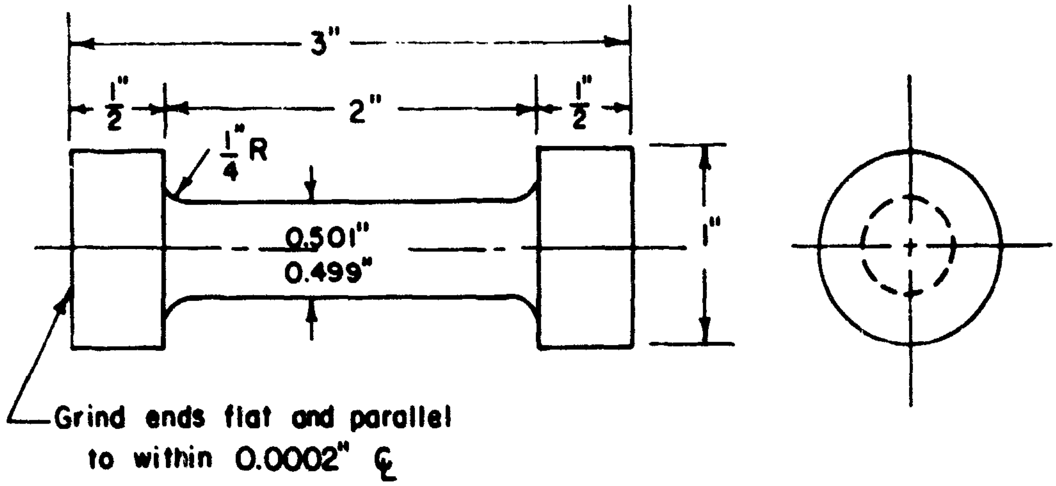


FIGURE 12. COMPRESSION SPECIMEN

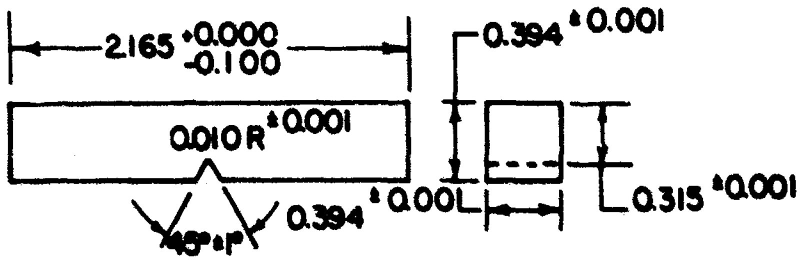


FIGURE 13. NOTCHED IMPACT SPECIMEN

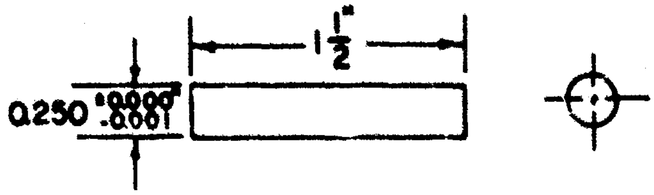


FIGURE 14. PIN SHEAR SPECIMEN

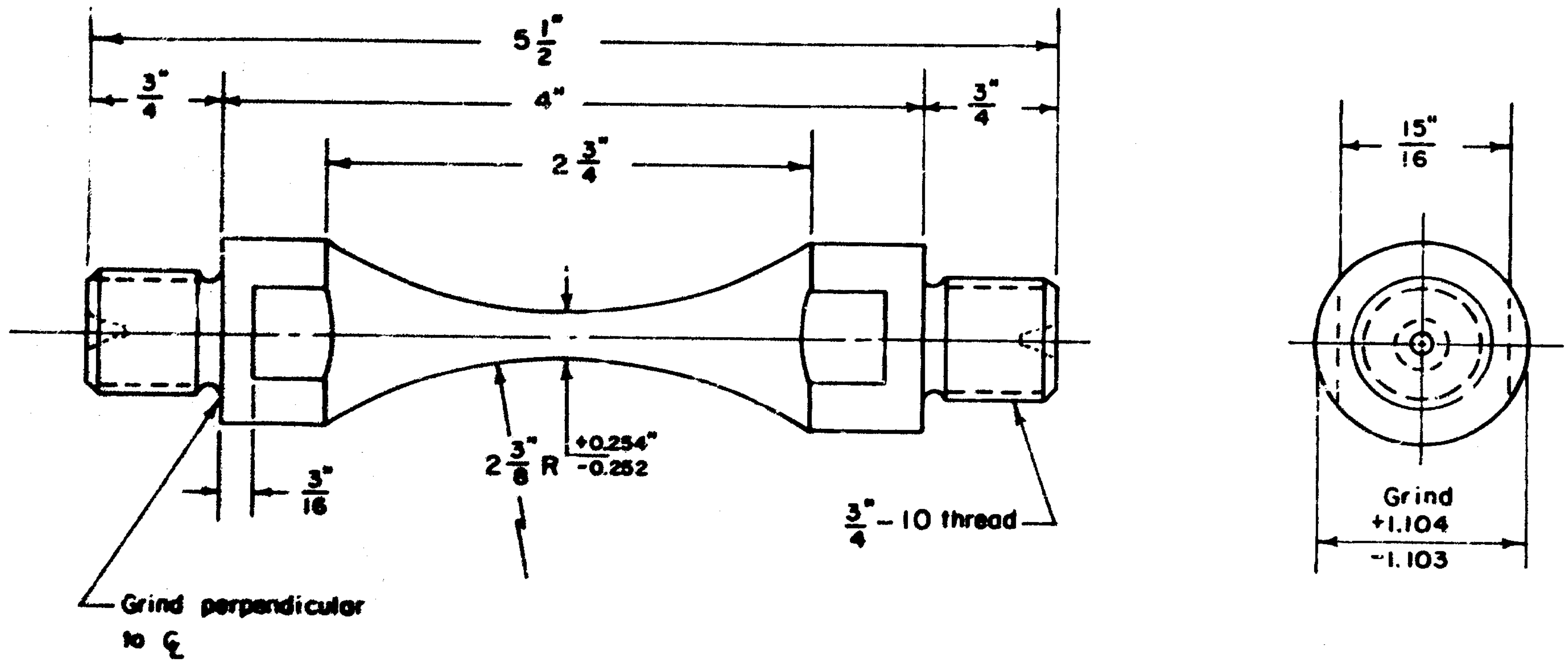


FIGURE 15. UNNOTCHED ROUND BAR FATIGUE SPECIMEN

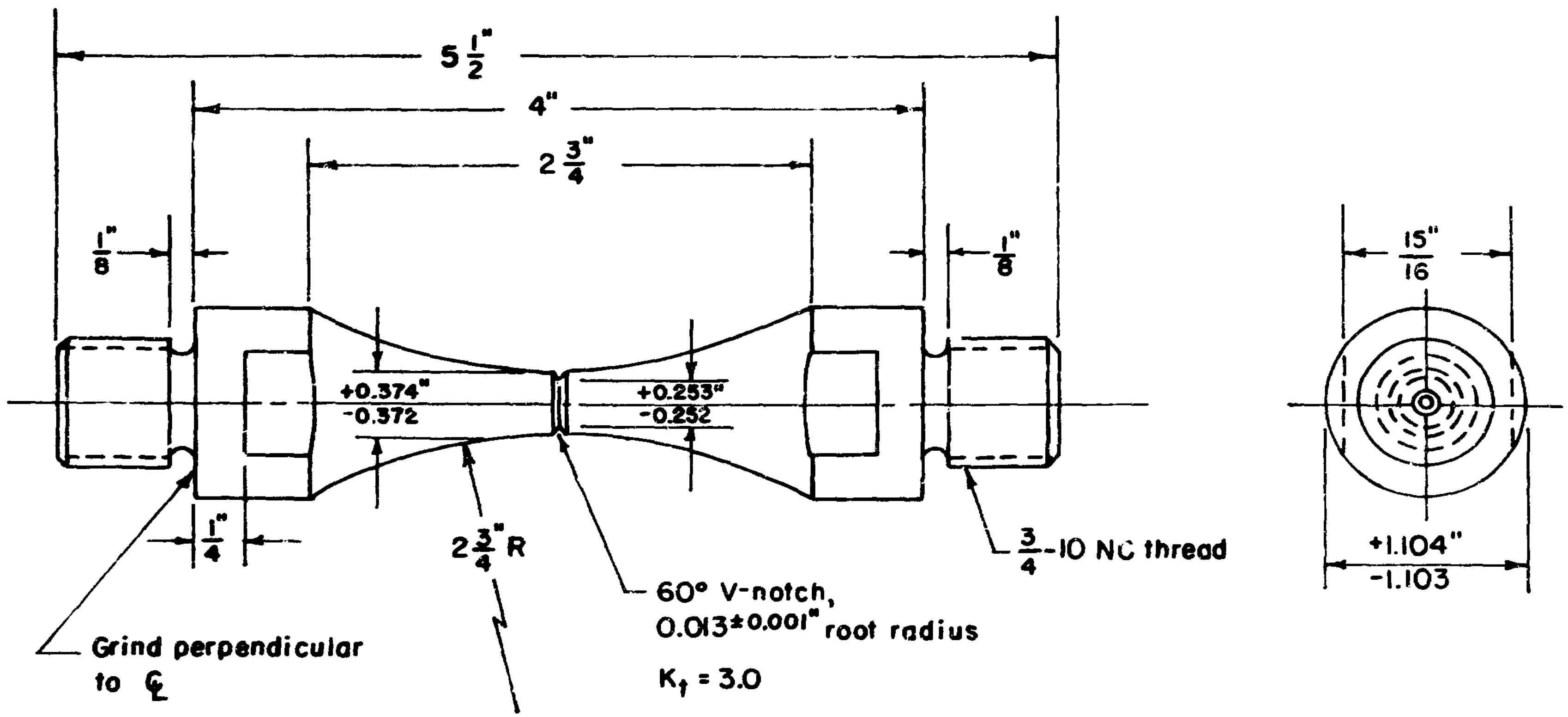


FIGURE 16. NOTCHED ROUND BAR FATIGUE SPECIMEN

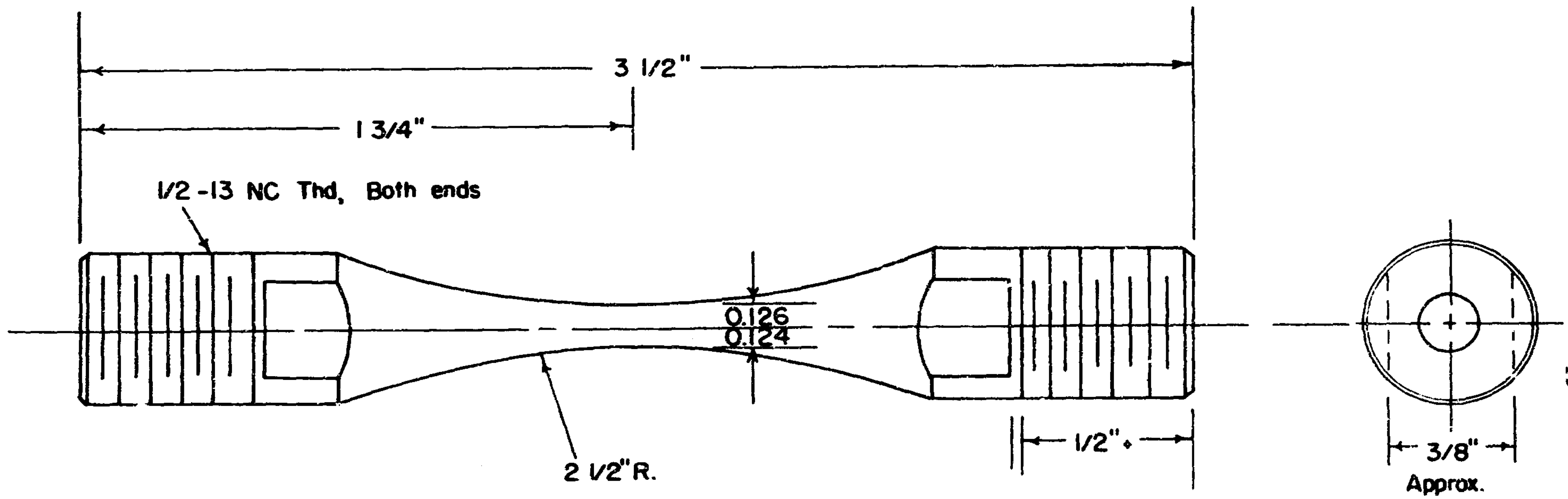
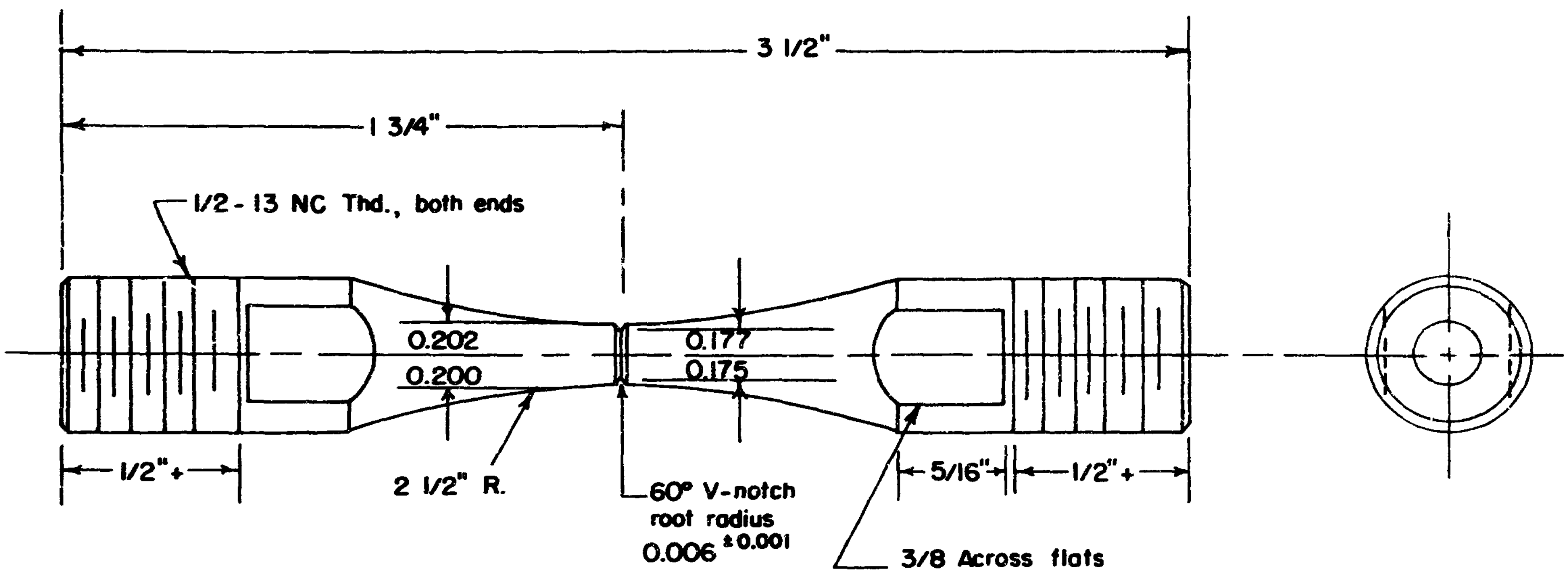


FIGURE 17. UNNOTCHED FATIGUE SPECIMEN



Note: Test section concentric with centers 0.001 T.I.R.

$K_t = 3.0$

FIGURE 18. NOTCHED FATIGUE SPECIMEN

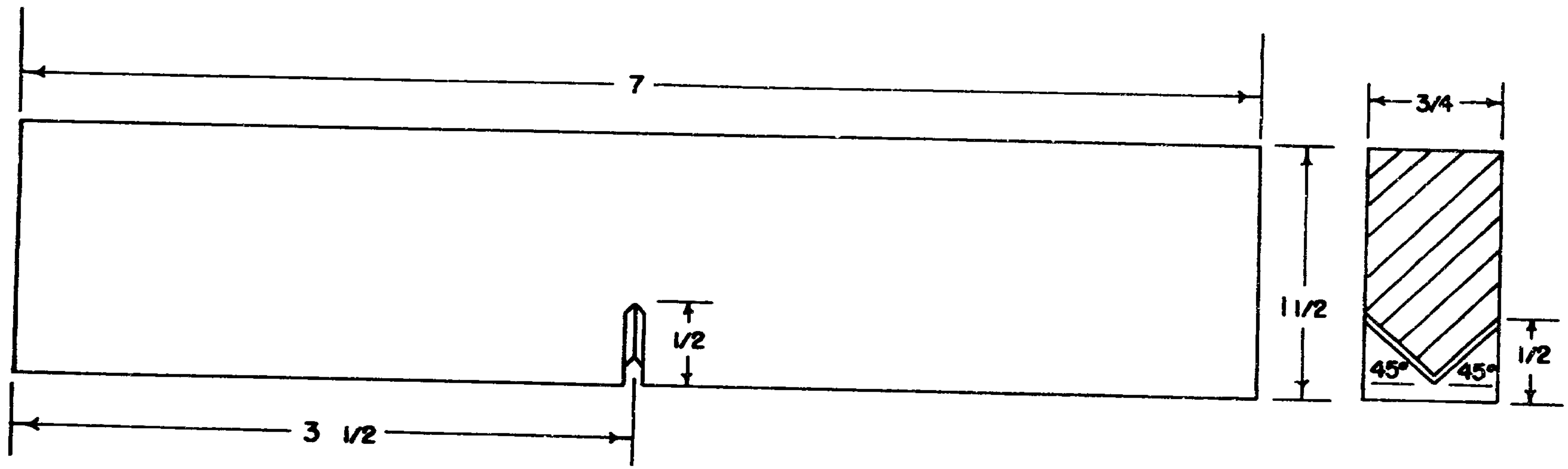


FIGURE 19. FRACTURE TOUGHNESS SPECIMEN

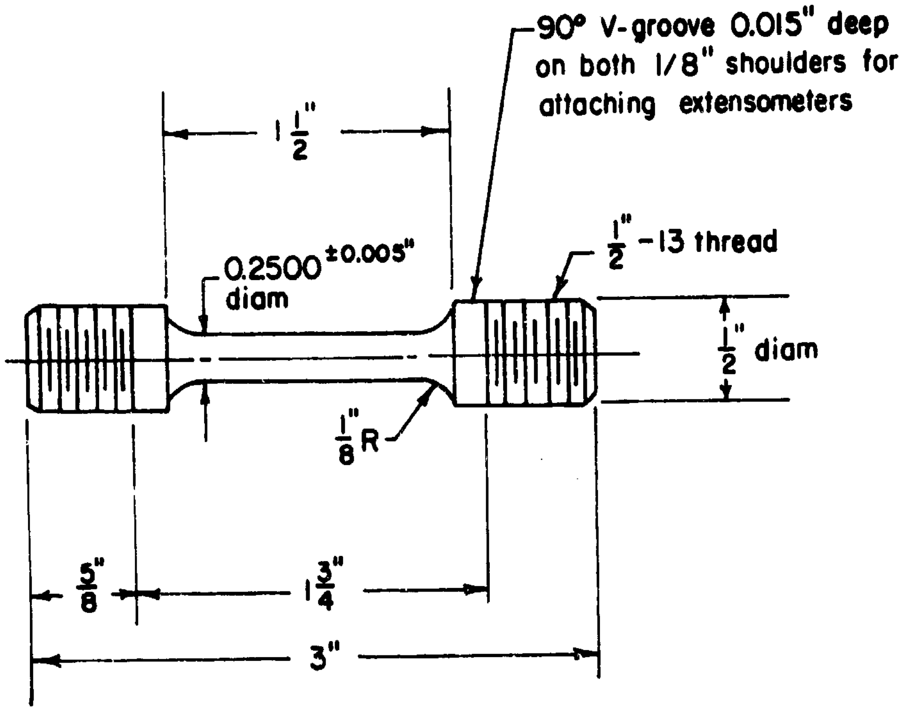


FIGURE 20. CREEP-RUPTURE SPECIMEN, 1/4-INCH DIAMETER

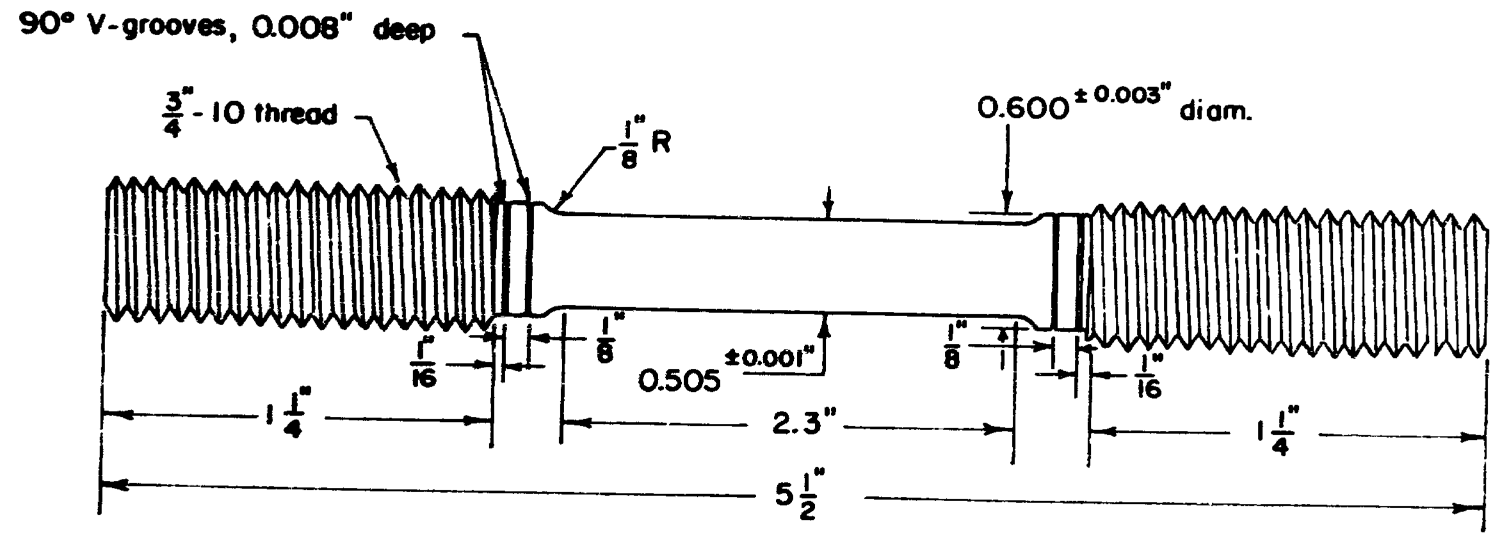


FIGURE 21. ROUND CREEP SPECIMEN 1/2 INCH DIAMETER

The strain rate in the elastic region was maintained at 0.005 inch/inch/minute. After yielding occurred, the head speed was increased to 0.1 inch/inch/minute until fracture.

Compression

Procedures for conducting compression tests are outlined in ASTM Method E9-67 along with temperature control provisions of E21-66T. All sheet and thin plate tests were carried out in Baldwin Universal testing machines using a North American type compression fixture as shown in Reference 2. Specimen heating was accomplished by a forced-air furnace for temperatures up to 1000F. Specimen temperature was maintained by means of a Wheelco pyrometer. Three Chromel-Alumel thermocouples attached to the fixture were used to monitor temperatures to within 3F of the test temperature. For higher temperatures, wire-wound furnaces were used with controls as described in the tensile test section.

The extensometer used for the compression tests was quite similar to that used in the tensile testing. The extension arms were fastened to the specimen at small notches spanning a 2-inch gage length. The output from the microformer was fed into a load-strain recorder to provide autographic load-strain curves. During testing the strain rate was adjusted to 0.005 inch/inch/minute.

For bar and forging material, cylindrical specimens similar to those described in ASTM E9-67 were used with appropriate temperature control and strain measurement as described above.

Six specimens (three longitudinal and three transverse) were tested at each temperature.

Shear

Single-shear sheet-type specimens were used for sheet and thin-plate material; for bar and forgings, a double-shear pin-type was used. Shear testing was performed at room temperature only. A minimum of six specimens (three longitudinal and three transverse) were used to determine ultimate shear strength.

Bend

The procedures for conducting bend tests are described in Report MAB-192-M. The specimens were placed in a rigid three-point loading fixture and bending tups of various sizes were used to determine the minimum bend radius at room temperature.

Fracture Toughness

Two types of specimens were used for fracture toughness tests. For sheet and thin plate a center notch tensile type specimen was used. At the time of testing, the dimensions of this specimen were in accordance with the current recommendations of the ASTM Committee on fracture toughness. For the heavier section materials, a slow-bend chevron notched type specimen was used.

All fracture toughness specimens were precracked at the root of the notch under fatigue loading. The precracking was carried out with the maximum stress limited to 60 percent of the tensile yield strength. In most cases, this stress level was found to produce a precrack of the desired length in a short time while minimizing plastic deformation at the leading edge of the crack.

All tensile tests on precracked specimens were conducted in Baldwin Universal testing machines. A flat spring-type compliance gage with extension arms was used in conjuction with an autographic recorder to provide a load-compliance curve.

Slow-bend type specimens were tested under 3-point loading as shown in Figure 22. The pop-in load for materials susceptible to brittle fracture was determined from the load compliance curve. When pop-in was not detected, the curves were analyzed using the secant offset method described in ASTM STP 410[4].

Creep and Stress Rupture

Standard dead-weight type creep testing frames were used for the creep and stress-rupture tests. These machines are calibrated to operate well within the accuracy requirements of ASTM method E139-66T.

Specimens similar to those used for tension tests were used for the creep and stress-rupture studies. A platinum strip "slide rule" extensometer is attached for measuring creep strain and three Chromel-Alumel thermocouples are attached to the gage section for temperature measurements. Extensometer measurements were made visually through windows in the furnace by means of a filar micrometer microscope in which the smallest division equals 0.00005 inch.

The furnace was of conventional Chromel A wire wound design with taps along the side to allow for correcting small temperature differences. Furnace temperature was maintained to within ± 2F by Foxboro controllers in response to signals from the centrally located thermocouple. The temperature of a specimen under test was stabilized for at least 1/2 hour prior to loading.

For each temperature condition creep and stress-rupture data were obtained to 100 and 1000 hours using as many specimens as necessary to obtain precise information. The percent creep deformation obtained was dependent on the material under test. In most instances stress-time curves were defined for 0.2 and 0.5 percent elongation.

Stress Corrosion

Seven specimens of each alloy were tested for susceptibility to stress-corrosion cracking by alternate immersion in 3-1/2 percent sodium chloride solution at room temperature.

Specimens were prepared for testing by degreasing with acetone. Where a surface film remained from heat treating, it was abraded off one side and the adjacent long edge of five of the specimens, and left intact on the other two.

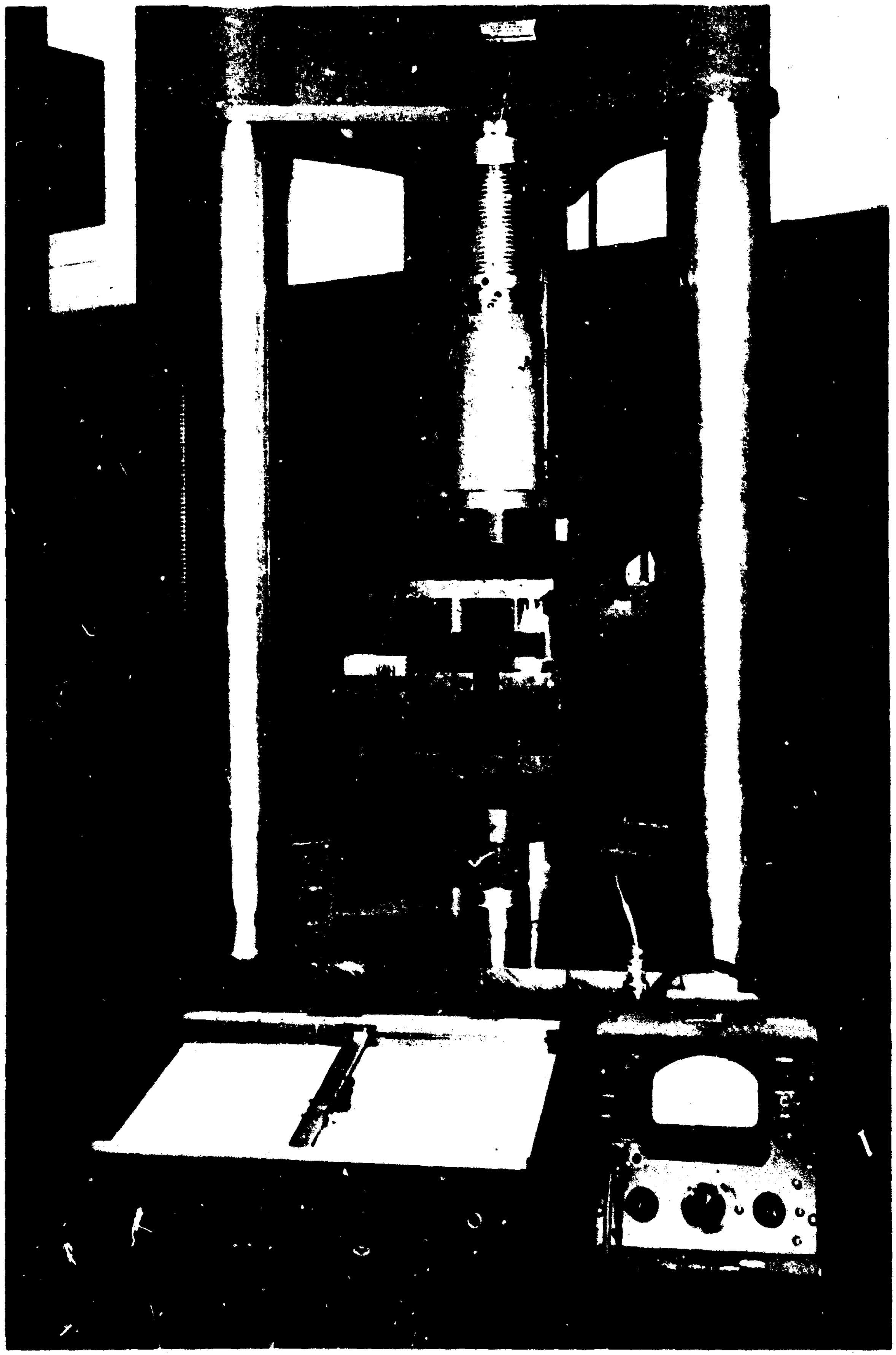


FIGURE 22. SLOW-BEND TYPE FRACTURE TOUGHNESS SPECIMEN MOUNTED IN MTS MACHINE

Each specimen was placed in a four-point loading fixture and deflected to a stress corresponding to 80 percent of the tensile yield strength of the particular material. The specimen was electrically insulated from the fixture by means of glass or sapphire rods. Deflection for a given maximum fiber stress was calculated by the following expression:

$$y = \frac{\sigma(3\ell^2 - 4a^2)}{12dE}$$

where

y = deflection

σ = maximum fiber stress

ℓ = distance between outer load points

a = distance between outer and inner load points

d = specimen thickness

E = modulus of specimen material

Each stressed specimen was suspended on an alternate immersion unit. This unit alternately immersed specimens in the 3.5 percent sodium chloride solution for ten minutes and held them above the solution to dry for 50 minutes. Tests were continued to the first sign of cracking or for 1000 hours, whichever occurred first.

Specimens were given frequent low-power microscopic examinations to detect cracks. At the first sign of cracking the specimen was removed. At the conclusion of the test, selected samples were sectioned and examined metallographically for any indication of cracking. Representatives samples in which cracks were found were also given a metallographic examination to establish the type and extent of the cracks.

Thermal Expansion

Linear-thermal-expansion measurements were performed in a recording dilatometer with specimens protected by a vacuum of about 2×10^{-5} mm of mercury. In this apparatus a sheet-type specimen is supported between two graphite structures inside a tantalum-tube heater element. On heating, the differential movement of the two structures caused by specimen expansion results in the displacement of the core of a linear-variable differential transformer. The output of the transformer is recorded continuously as a function of specimen temperature. The entire assembly is enclosed in a vacuum chamber

The furnace is controlled to heat at the desired rate, usually 5F per minute. Errors associated with measurements in this apparatus are estimated not to exceed ±2 percent. This is based on calibration with materials of known thermal-expansion characteristics.

Fatigue

Two types of fatigue equipment were used to perform the axial-load tension fatigue tests. Selection of a test machine was made on the basis of the required load level. One type was the Krouse axial-load machine, either 5,000- or 10,000-pound capacity. The specific machine was dependent upon the test load requirements dictated by the product form and heat tratement. Fatigue tests on high-strength materials were conducted on the second type machine, namely the MTS electrohydraulic servocontrolled testing machine.

The Krouse axial-load equipment is mechanically driven and provides loads on a constant-deflection basis. These machines normally operate at 1725 cpm. Hydraulic load maintainers stabilize the mean load should some creep deformation occur.

The frequency at cycling of the MTS electrohydraulic fatigue machines is variable to beyond 2000 cpm depending on specimen rigidity. These machines operate with closed-loop deflection, strain, or load control. Under load control used in this program, cyclic loads were automatically maintained (regardless of the required amount of ram travel) by means of load-cell feedback signals. The calibration and alignment of each machine are checked periodically. In each case, the dynamic load-control accuracy is better than ±3 percent of the test load.

For elevated-temperature studies, electrical resistance wire-wound furnaces of conventional design were used to heat the specimens. Three Chromel-Alumel thermocouples, placed near the center of each specimen at 1-inch intervals, were employed in furnace calibration. During a fatigue test, the center thermocouple was used in conjunction with a Foxboro controller to adjust electrical input to the furnace. The thermal gradient along the test section was continuously monitored by the other two thermocouples. During tests, the center of the specimen was held to within ±5 degrees of the control temperature.

After machining and heat treating (when required), the edges of all sheet and plate specimens were polished according to Battelle's standard practice prior to testing. The unnotched specimens were held against a rotating drum covered with emery paper and polished uising a kerosene lubricant. Successively finer grits of emery paper were used, as required, to produce a surface of about 10 rms. Unnotched round specimens were polished in the Battelle polishing apparatus. This machine utilizes a rotating belt sander driven rectilinearly along the specimen test section while the specimen is being rotated. The belt speed and specimen speed are adjusted so that polishing marks on the specimen are in the longitudinal direction. The furface finish is about the same as that on the flat specimens. The notched flat specimens were held in a fixture and polished with a slurry of oil and alundum grit applied liberally to a rotating wire. Notched round specimens are polished in the same manner, expect that the specimen is rotated.

A shadowgraph optical comparator was used for measuring the test sections of all polished specimens and for inspection of the root radius in the case of the notched specimens.

The stress ratio for all specimens was R = 0.1. Stresses for notched (K_t = 3.0) and unnotched specimens were selected so that S-N curves were defined between 10^3 and 10^7 cycles using approximately 10 specimens for each set of fatigue conditions.

MATERIALS INFORMATION AND TEST RESULTS

Beta III Titanium

Material Description

Beta III is a simple quaternary solid-solution alloy developed by the Crucible Steel Company under Air Force Contract AF33(615)-2742. It is an all beta alloy that has the ability to be cold-rolled at least as easily as commercially pure titanium. Actually, it can be cold rolled in excess of 90 percent without edge cracking. The alloy also was compounded to provide for relative ease in hot rolling.

Beta III can be heat treated over a range of tensile strengths by varying both the solution-heat-treatment temperature and the aging temperature.

Twenty-two square feet of 0.063-inch thick material were received from Crucible. This material was from a 4000- ound trial production heat (H19382) with the following composition:

Chemical Composition	Pe cent
Molybdenum	12.1
Zirconium	6.5
Tin	4.3
Iron	0.04
Carbon	0.03
Nitrogen	0.014
Hydrogen	0.0095
Oxygen	0.13
Titanium	balance

Processing and Heat Treating

The specimen layout for Beta III is shown in Figure 23. Specimens were machined in the as-received mill solution-treated condition and then aged at 950F for 8 hours. The 950F, 8 hours aged condition was recommended by Crucible as being the condition of most interest. Aged specimens were pickled in a $20HNO_3$ - 2HF solution at 1'0F to remove aging scale.

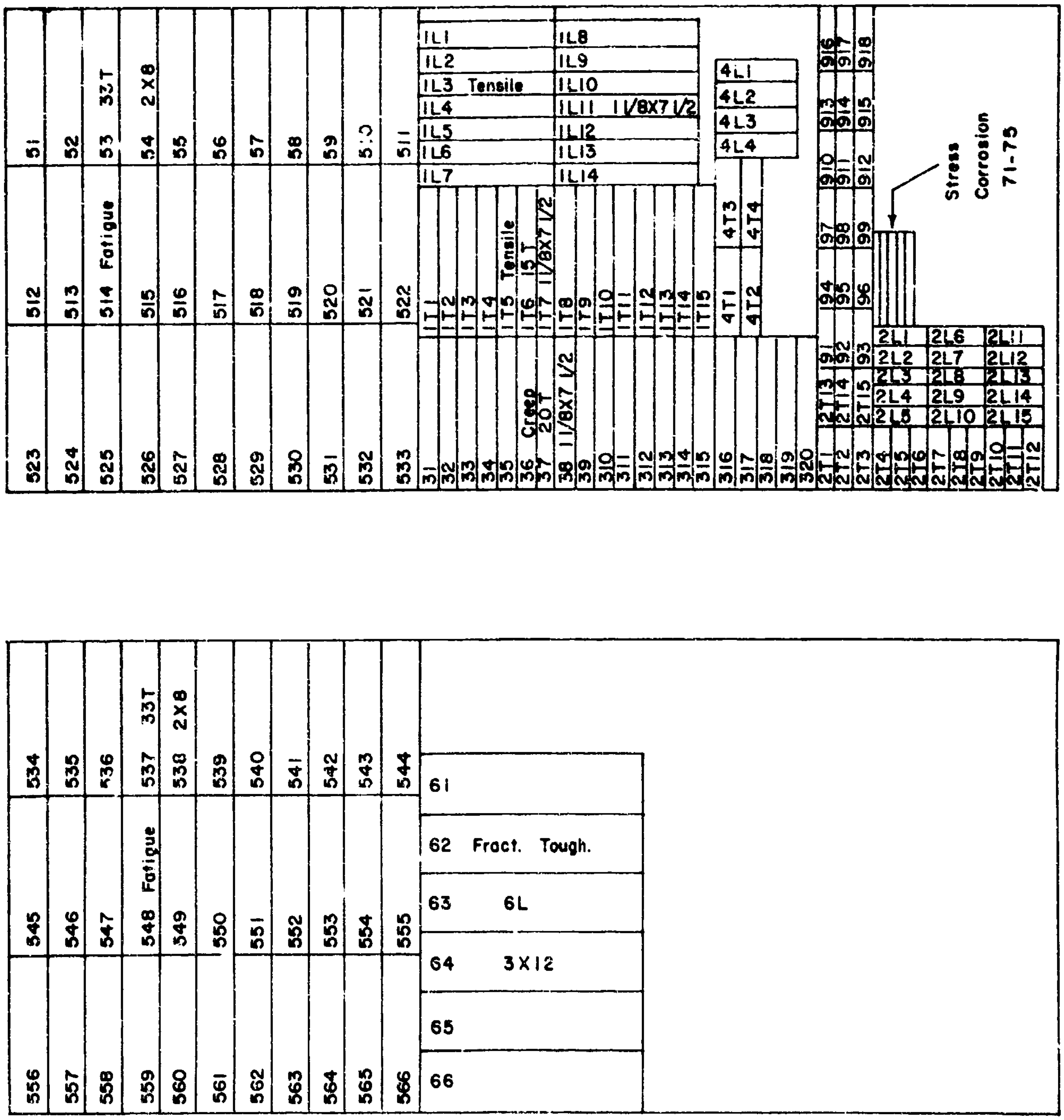


FIGURE 23. SPECIMEN LAYOUT FOR BETA III SHEET

Test Results

Tension. Results of tests in the longitudinal and transverse directions at room temperature, 400F, 600F, and 850F are given in Table 1. Stress-strain curves at temperature are shown in Figures 24 and 25. Effect-of-temperature curves are presented in Figure 28.

Compression. Results of tests in the longitudinal and transverse directions are shown in tabular form in Table 2 for room temperature, 400F, 600F, and 850F. Stress-strain and tangent modulus curves at temperature are shown in Figures 26 and 27. Effect-of-temperature curves are presented in Figure 29.

Shear. Test results at room temperature in the longitudinal and transverse directions are shown in Table 3.

Bend. The minimum bend radius for the as-received material was approximately 3.5t.

Impact. No impact tests were performed on the thin sheet.

Fracture Toughness. Center-notch fracture toughness tests were performed at room temperature. No pop-in was detected. Load-strain curves were analyzed using the secant-offset method and the tests proved to be invalid for determining K_{IC}. Average net fracture strength was 53 ksi.

Fatigue. Axial-load tests were conducted at room temperature, 400F, and 850F for transverse specimens. Test results are presented in Tables 4 and 5. S-N curves are shown in Figures 30 and 31.

Creep and Stress Rupture. Tests were conducted at 500F, 600F, and 700F. Results are presented in tabular form in Table 6 and as log stress-versus-log time curves in Figure 32.

Stress Corrosion. Specimens were tested as described in the experimental procedure section of this report. No failures or cracks occurred in the 1000-hour test duration.

Thermal Expansion and Density. Values obtained are given in the "data sheet" in the conclusions section of this report.

TABLE 1. TENSION TEST RESULTS FOR BETA III TITANIUM SHEET

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Longitudinal at Room Temperature		
1L-1	188.0	175.0	7.5	14.8
1L-2	187.0	175.0	8.0	15.1
1L-3	187.0	175.0	10.0	15.0
		Transverse at Room Temperature		
1T-1	197.0	185.0	7.0	16.0
1T-2	196.0	185.0	7.0	16.0
1T-3	196.0	(b)	6.0	16.2
		Longitudinal at 400 F		
1L-4	164.0	146.0	4.5(a)	14.0
1L-5	164.0	146.0	7.5	14.2
1L-6	164.0	146.0	7.0	13.9
		Transverse at 400 F		
1T-4	164.0(a)	157.0	1.0(a)	15.0
1T-5	169.0	157.0	7.5	14.7
1T-6	169.0	159.0	7.0	14.1
		Longitudinal at 600 F		
1L-7	159.0	140.0	7.0	13.3
1L-8	157.0	139.0	6.5	12.7
1L-9	157.0	138.0	6.5	12.9
		Transverse at 600 F		
1T-7	163.0	149.0	5.5	13.7
1T-8	163.0	149.0	6.0	14.0
1T-9	163.0	148.0	6.0	13.4
		Longitudinal at 850 F		
1L-10	145.0	127.0	11.0	11.5
1L-11	144.0	124.0	11.0	10.9
1L-12	145.0	129.0	11.0	(c)
		Transverse at 850 F		
1T-10	150.0	134.0	12.0	12.4
1T-11	150.0	136.0	10.0	12.4
1T-12	150.0	135.0	10.5	11.9

(a) Failed under knife edge.

(b) Extensometer off scale.

(c) Curve not suitable for modulus measurement.

TABLE 2. COMPRESSION TEST RESULTS FOR BETA III TITANIUM SHEET

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Longitudinal at Room Temperature	
2L-1	196.0	16.1
2L-2	194.0	15.9
2L-3	195.0	15.8
	Transverse at Room Temperature	
2T-1	211.0	17.5
2T-2	211.0	17.5
2T-3	211.0	17.6
	Longitudinal at 400 F	
2L-4	167.0	15.3
2L-5	169.0	15.6
2L-6	170.0	15.5
	Transverse at 400 F	
2T-4	182.0	16.6
2T-5	183.0	16.4
2T-6	182.0	17.0
	Longitudinal at 600 F	
2L-7	159.0	15.1
2L-8	163.0	15.1
2L-9	163.0	15.0
	Transverse at 600 F	
2T-7	176.0	16.2
2T-8	173.0	16.2
2T-9	172.0	16.1
	Longitudinal at 850 F	
2L-10	147.0	13.8
2L-11	147.0	13.4
2L-12	148.0	13.3
	Transverse at 850 F	
2T-13	160.0	14.8
2T-14	160.0	14.3
2T-15	158.0	14.3

TABLE 3. SHEAR TEST RESULTS FOR BETA III TITANIUM SHEET AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
Longitudinal	
4L-1	116.0
4L-2	117.0
4L-3	116.0
4L-4	118.0
Transverse	
4T-1	(a)
4T-2	118.0
4T-3	118.0
4T-4	117.0

(a) Specimen did not fail in shear.

TABLE 4. AXIAL-LOAD FATIGUE TEST RESULTS FOR BETA III TITANIUM SHEET, UNNOTCHED, AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-15	160.0	3,100
5-5	150.0	3,800
5-1	150.0	8,000
5-6	130.0	3,300
5-2	130.0	3,900
5-8	120.0	10,500
5-7	110.0	10,500
5-32	90.0	77,100
5-4	80.0	14,349,000[a]
	400 F	
5-14	160.0	3,300
5-12	150.0	6,300
5-19	130.0	13,000
5-17	130.0	40,400
5-13	120.0	9,300
5-10	110.0	26,800
5-9	100.0	18,900
5-16	100.0	20,800
5-11	90.0	12,299,600[a]
	850 F	
5-23	135.0	10,400
5-25	120.0	8,400
5-20	110.0	3,900
5-18	100.0	350,500
5-21	90.0	362,800
5-22	80.0	485,300

(a) Did not fail.

TABLE 5. AXIAL-LOAD FATIGUE TEST RESULTS FOR BETA III TITANIUM SHEET, NOTCHED (K_t = 3.0), AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-40	120.0	2,400
5-37	110.0	9,800
5-41	105.0	1,800
5-36	90.0	6,200
5-60	80.0	8,900
5-38	70.0	15,800
5-39	60.0	564,100
5-42	55.0	15,212,900(a)
	400 F	
5-46	100.0	3,800
5-45	80.0	7,500
5-43	70.0	12,200
5-44	65.0	15,500
5-49	57.0	280,900
5-47	50.0	2,991,800
5-48	45.0	12,457,100(a)
	800 F	
5-57	100.0	1,900
5-53	80.0	3,100
5-52	70.0	6,900
5-50	60.0	8,600
5-34	55.0	8,100
5-51	50.0	423,800
5-54	45.0	7,676,400
5-35	40.0	4,890,200
5-56	35.0	10,160,100(a)

(a) Did not fail.

TABLE 6. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES OF BETA III TITANIUM SHEET

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, Percent					Initial Strain, percent	Rupture Time, hr.	Elongation in 2 Inches, percent	Minimum Creep Rate, percent/hr.
			0.1	0.2	0.5	1.0	2.0				
34	175	500	--	--	--	--	--	--	on loading	4.5	--
35	173	500	--	--	--	--	--	--	on loading	4.1	--
36	171	500	--	--	--	--	--	--	on loading	4.5	--
310	169	500	0.5	75	7000 est.	--	--	2.754	1012.5*	3.01	0.000040
33	165	500	22	2200 est.	--	--	--	1.661	746.1*	1.809	0.000035
32	160	500	640	4000 est.	--	--	--	1.265	642.6*	1.366	0.000030
31	150	500	--	--	---	--	--	1.152	237.3*	1.211	--
312	175	600	--	--	--	--	--	--	on loading	2.4	--
37	170	600	--	0.07	0.2	27	2000 est.	3.110	1008.4*	4.77	0.00035
311	165	600	0.1	1.8	155	2200 est.	--	3.090	1031.9*	3.855	0.00020
39	160	600	0.2	16	1600 est.	--	--	1.476	813.1*	1.865	0.00015
38	155	600	2.2	240	2400 est.	--	--	1.412	503.0*	1.654	0.00010
318	165	700	--	--	--	--	--	--	on loading	3.6	--
319	163	700	0.05	0.2	2.5	16	60	2.196	184.4	5.9	0.018
317	160	700	0.1	0.4	5	26	110	1.970	438.3	7.3	0.009
316	150	700	0.5	4.7	55	254	--	1.273	769.5	2.3	0.0017
315**	145	700	1.2	14	116	--	--	1.102	121.2	--	--
320**	140	700	3.0	20	220	--	--	1.052	350.2	1.8	0.0014
314	130	700	10	55	340	1200 est.	3000 est.	1.004	860.3*	1.813	0.00055
313	110	700	40	165	1000	3000 est.	--	0.794	956.3*	1.282	0.00025

*Indicates test was discontinued at this time.

**Specimen failed prematurely due to overheating.

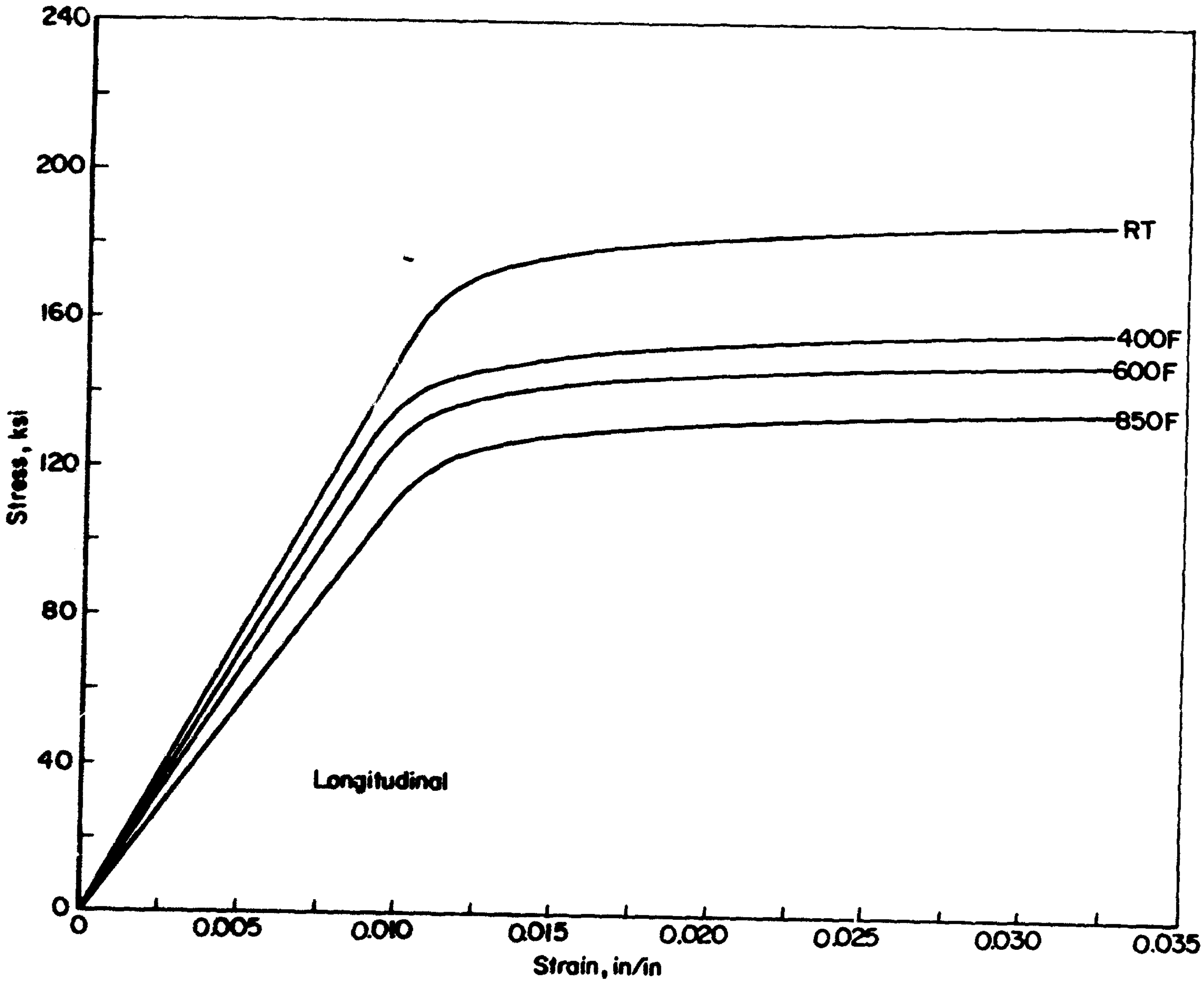


FIGURE 24. TYPICAL TENSION STRESS-STRAIN CURVE FOR BETA III SHEET AT TEMPERATURE

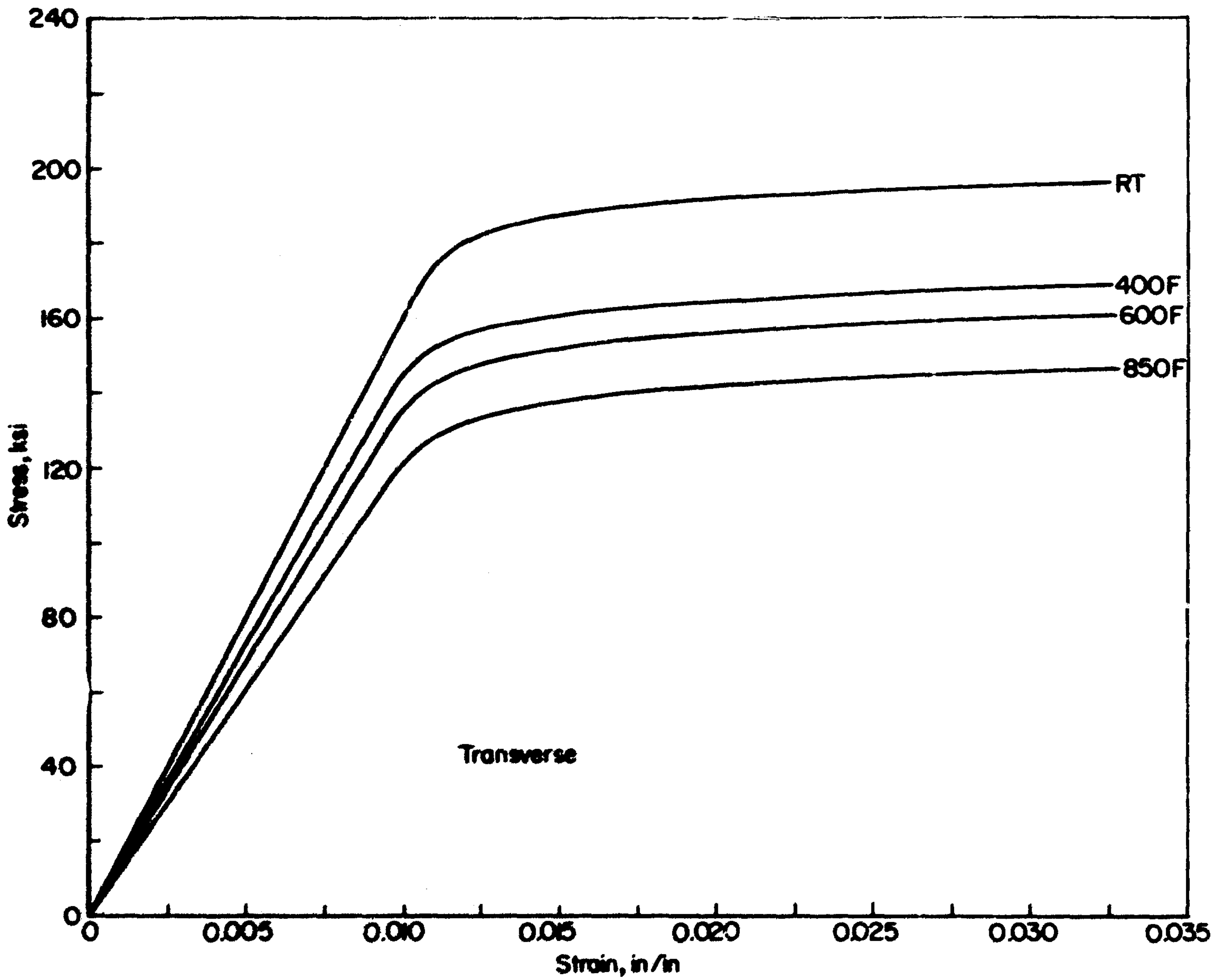


FIGURE 25. TYPICAL TENSION STRESS-STRAIN CURVE FOR BETA III SHEET AT TEMPERATURE

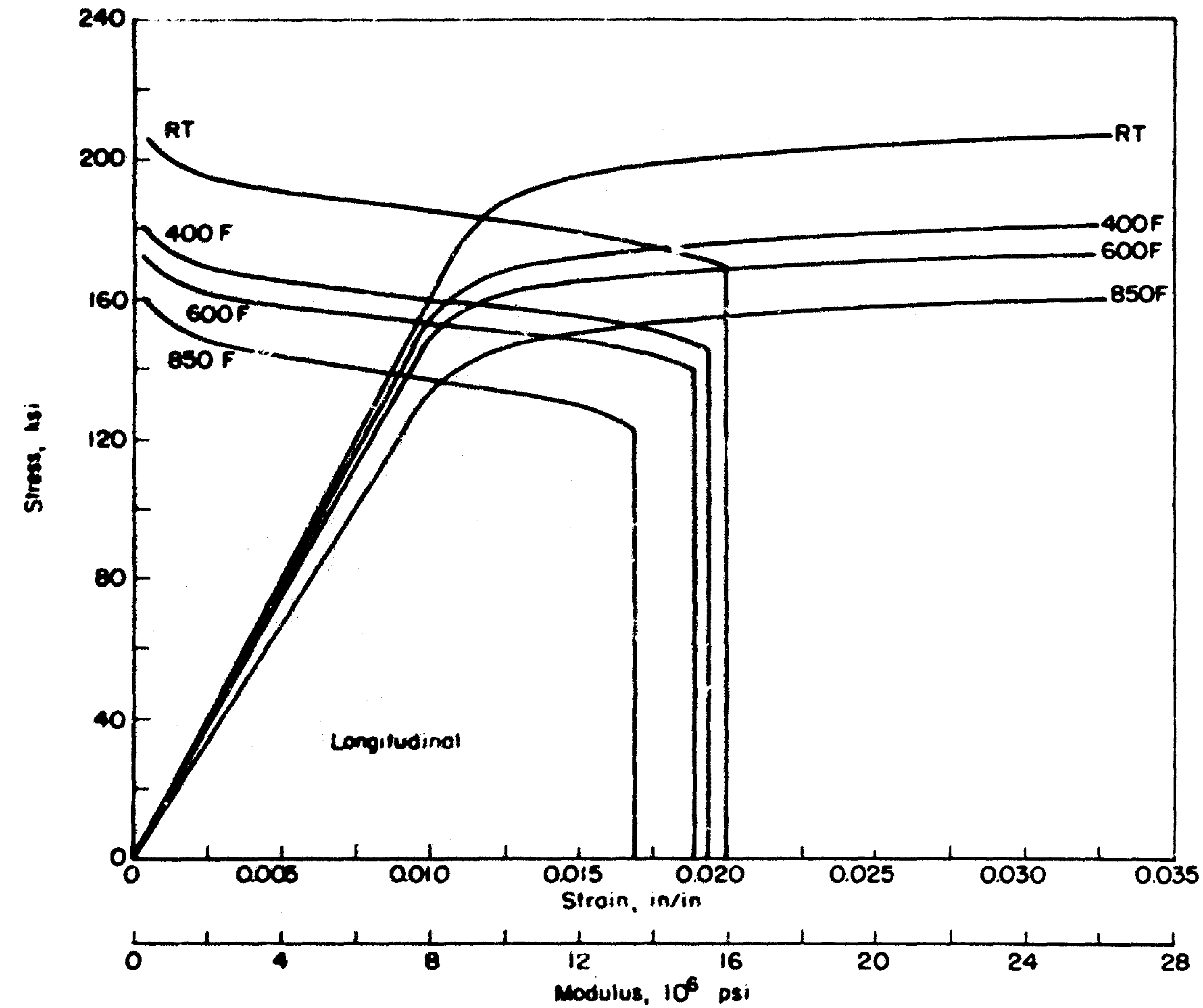


FIGURE 26 TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR BETA III SHEET AT TEMPERATURE

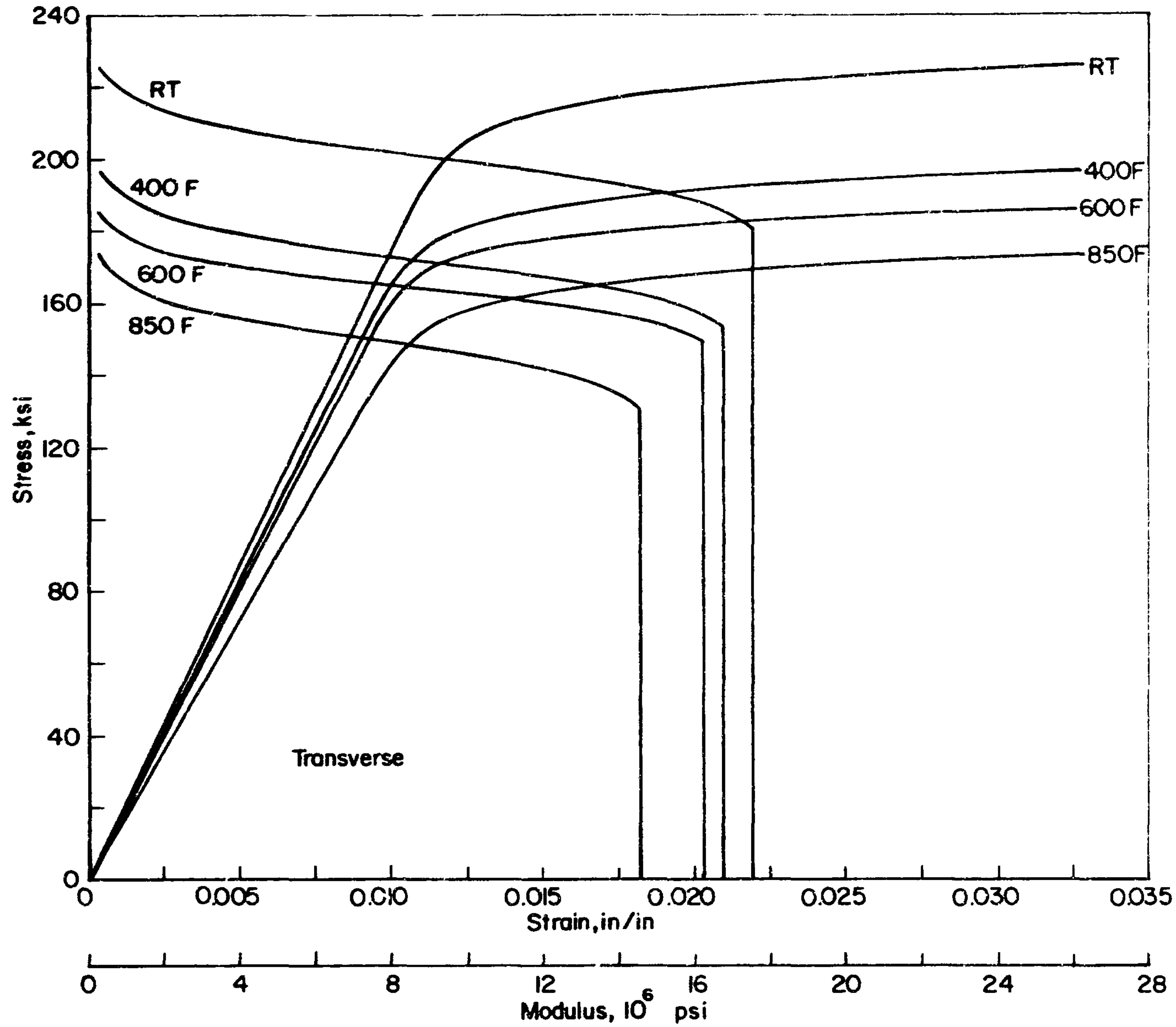


FIGURE 27. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR BETA III SHEET AT TEMPERATURE

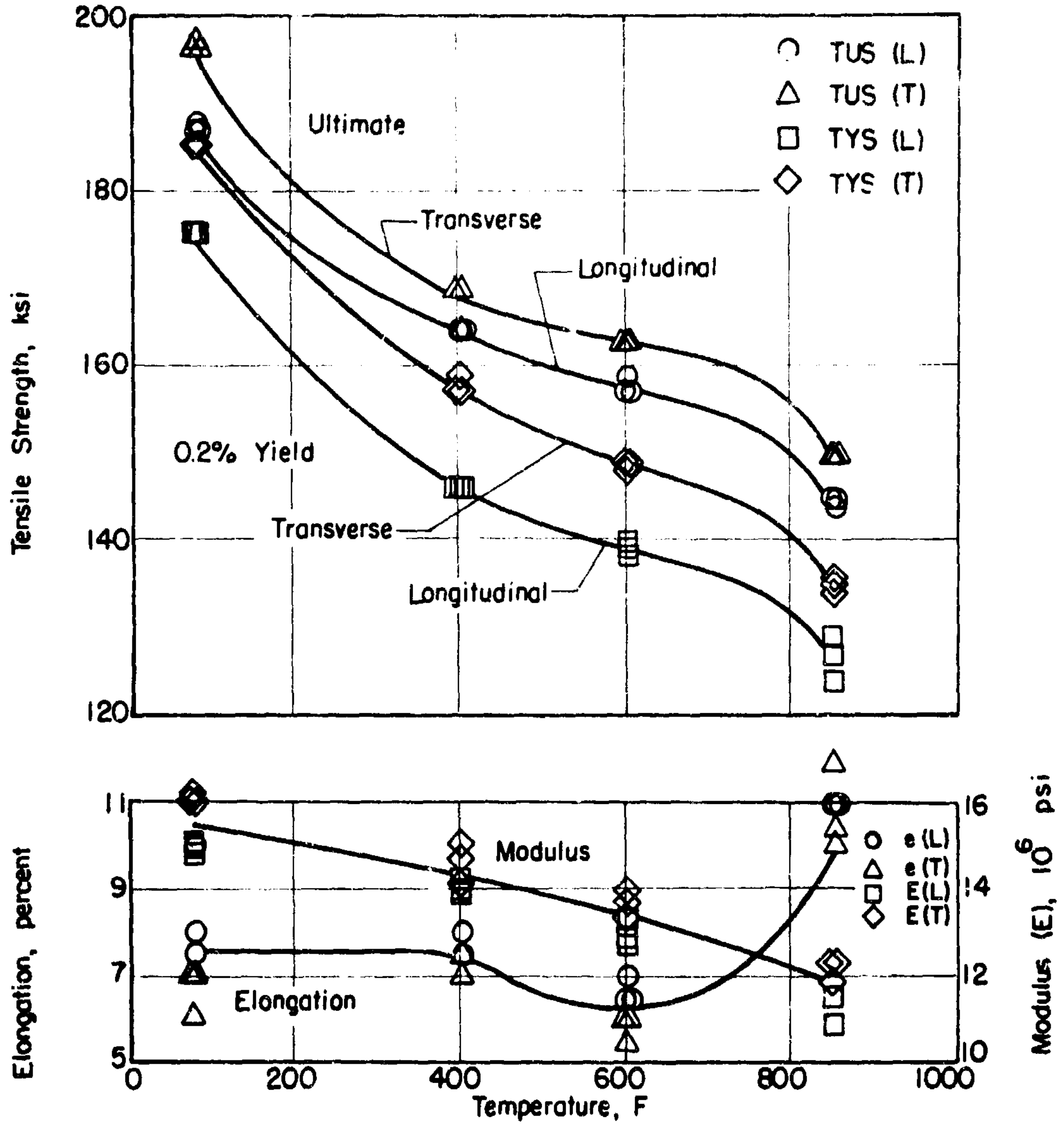


FIGURE 28. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF BETA III TITANIUM SHEET

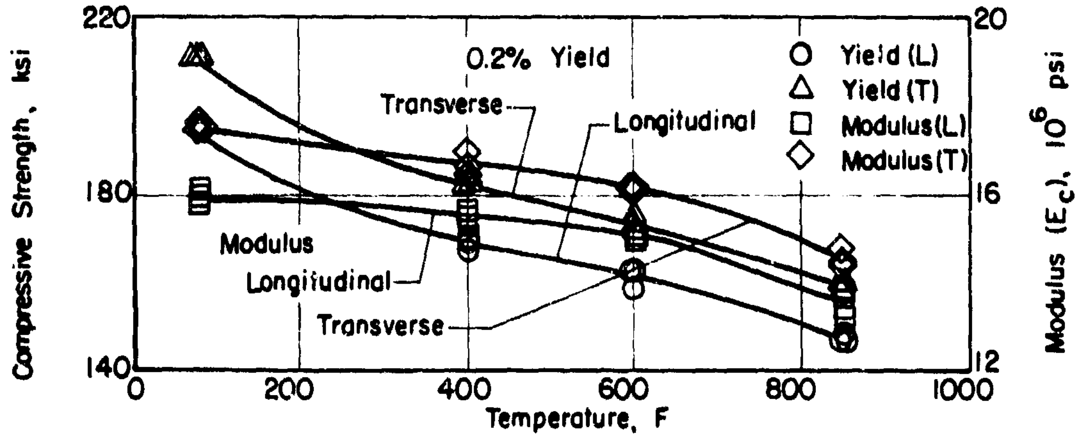


FIGURE 29. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF BETA III TITANIUM SHEET

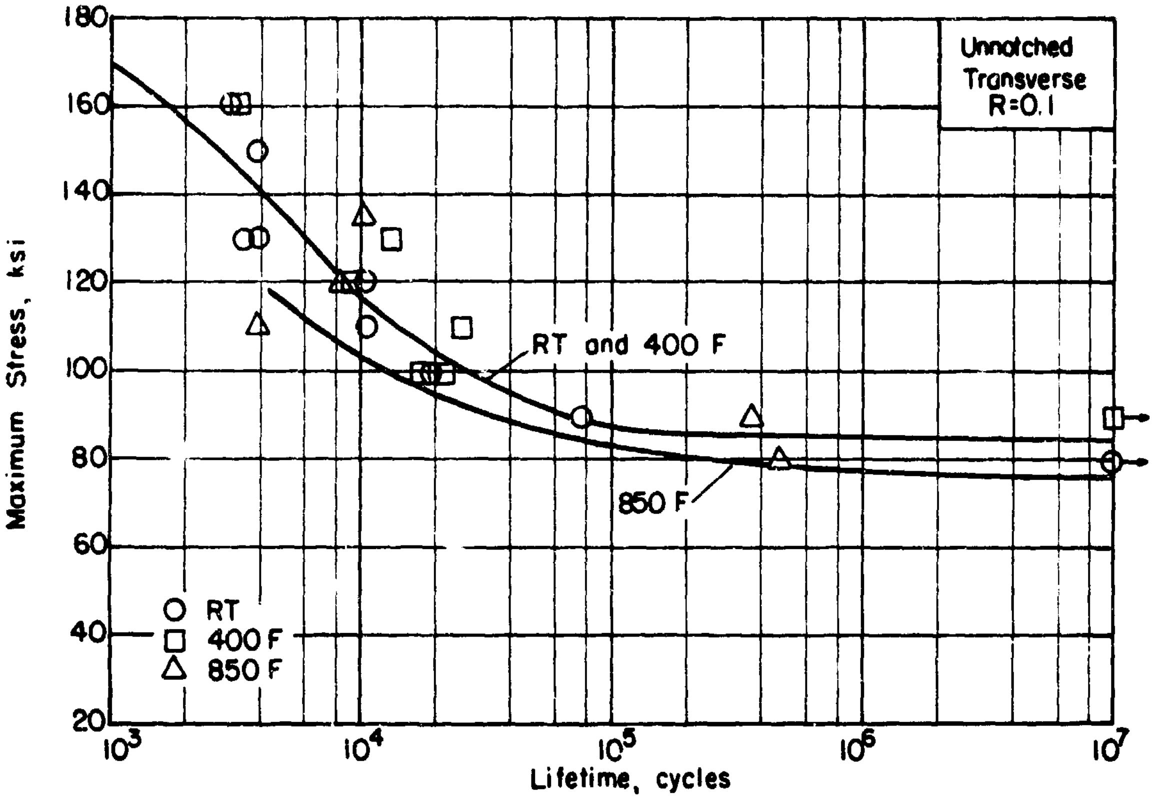


FIGURE 30. AXIAL LOAD FATIGUE RESULTS FOR BETA III TITANIUM SHEET

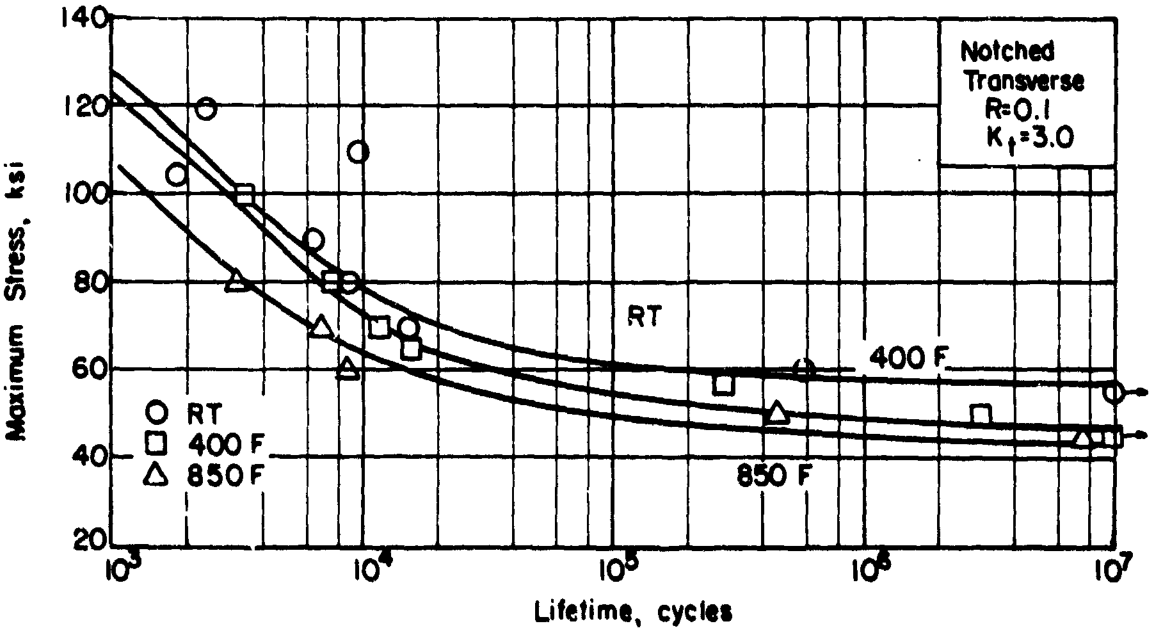


FIGURE 31. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t =3.0) BETA III TITANIUM SHEET

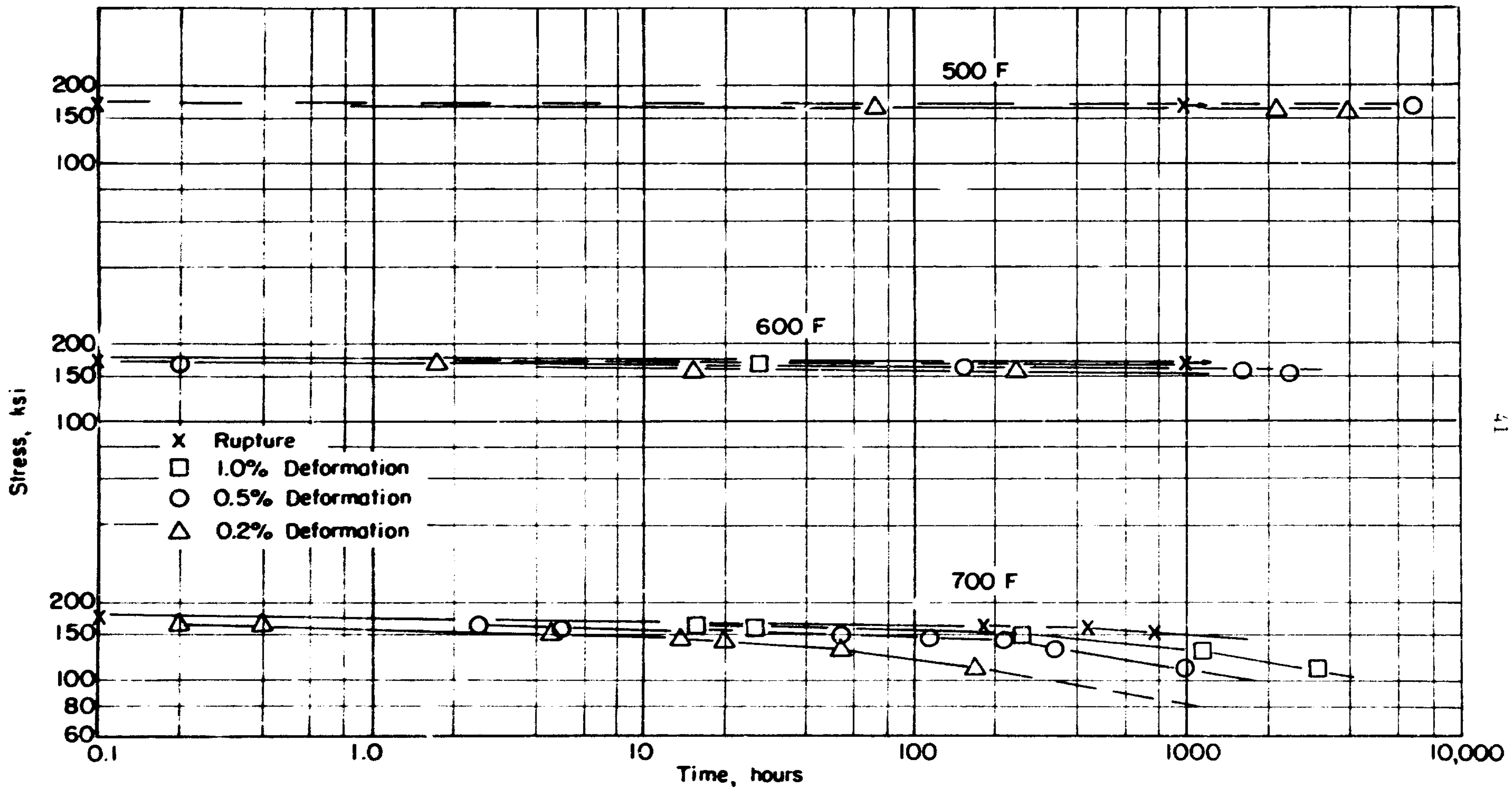


FIGURE 32. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR BETA III TITANIUM SHEET

6Al-4V Titanium Sheet

Material Description

Ti-6Al-4V is one of the oldest and most used titanium alloys. However, within the fast few years a new heat treatment, the solution treated and overaged (STOA) condition, has become of interest. This heat treatment has been an outgrowth of the SST development program. The purpose of this STOA treatment is to provide a higher resistance to stress-corrosion cracking and better fracture strength than can be obtained from the normal mill anneal or STA treatment.

A 3 x 4-feet by 0.188-inch thick sheet was supplied by the Boeing Company for this study.

Processing and Heat Treating

The specimen layout for Ti-6Al-4V is shown in Figure 33. The material was tested in the as-received STOA condition.

Test Results

Tension. Tests were conducted in both the longitudinal and transverse directions at room temperature, 300F, 500F, and 700F. Test results are presented in tabular form in Table 7. Stress-strain curves at temperature are shown in Figures 34 and 35. Effect-of-temperature curves are presented in Figure 38.

Compression. Compression tests were performed at room temperature, 300F, 500F, and 700F. Tabular test results are given in Table 8. Stress-strain and tangent modulus curves are shown in Figures 36 and 37. Effect of temperature curves are presented in Figure 39.

Shear. Room temperature test results for the longitudinal and transverse directions are given in Table 9.

Bend. The 0.188-inch thick specimens were ground to 0.100-inch thickness. Results of tests at room temperature and 32F showed the minimum bend radius to be between 3 and 4 t.

Impact. No impact tests were conducted at the sheet material.

Fracture Toughness. Center-notch tension type tests were attemped at room temperature. The results proved to be marginal by the existing criteria and are not reported.

Fatigue. Axial-load fatigue tests were performed at room temperature, 500F, and 700F. The results are tabulated in Tables 10 and 11 and presented as S-N curves in Figures 40 and 41.

Creep and Stress Rupture. Tests were conducted at 500F, 600F, and 700F. Tabular results are shown in Table 12. Log stress versus log time curves are presented in Figure 42.

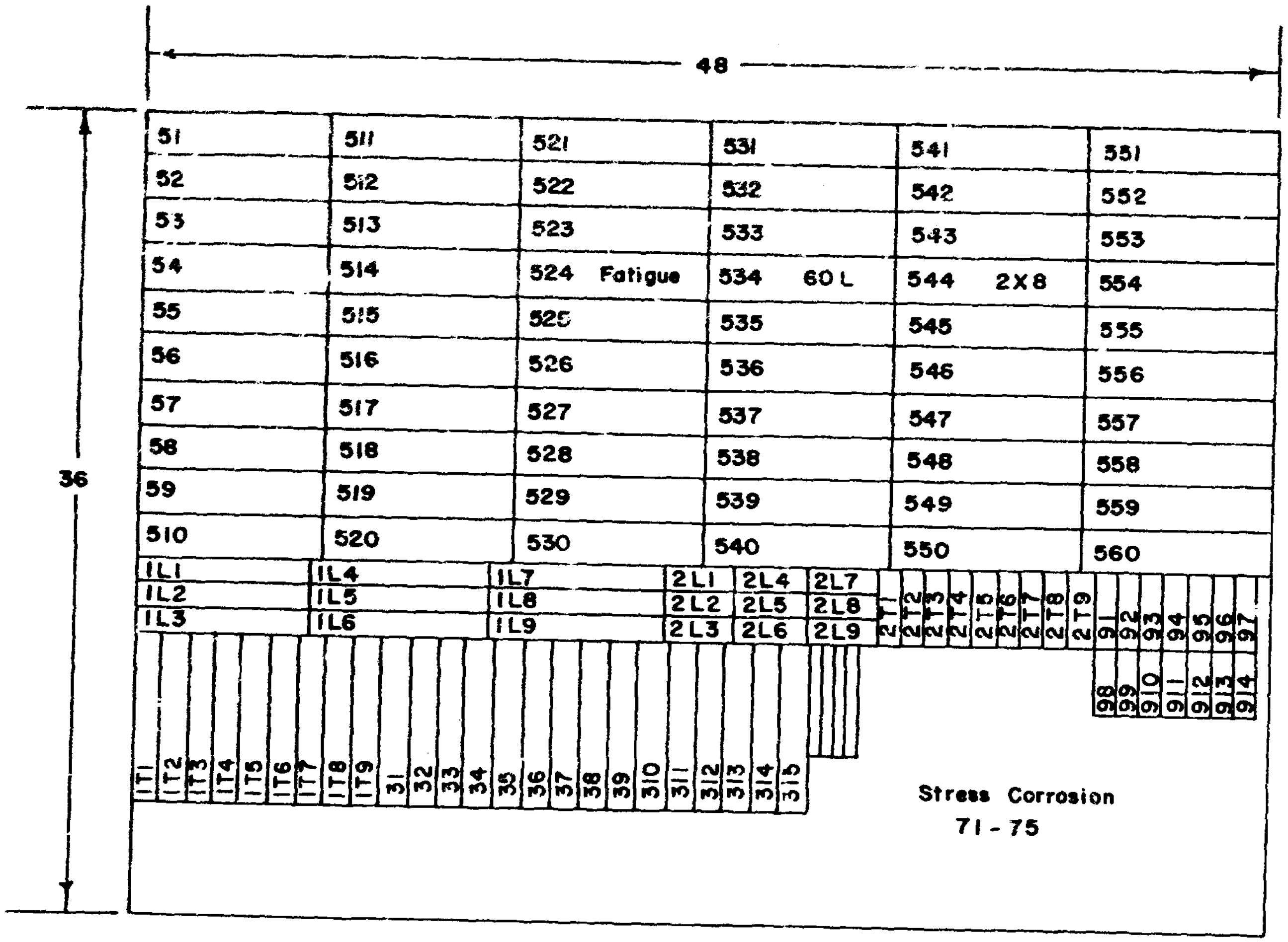


FIGURE 33. SPECIMEN LAYOUT FOR Ti-6Al-4V SHEET

Specimen Code
Prefix:

1 Tensile
2 Compression
3 Creep
5 Fatigue
7 Stress Corrosion
9 Bend

Stress Corrosion. No cracks appeared in the specimens after testing as described in the experimental procedure section.

Thermal Expansion and Density. Values for these properties are shown in the "data sheet" in the conclusions section.

TABLE 7. TENSION TEST RESULTS FOR 6Al-4V TITANIUM SHEET

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Longitudinal at Room Temperature		
1L-1	141.0	131.0	10.5	16.6
1L-2	141.5	131.5	11.0	16.6
1L-3	140.0	132.0	11.0	17.1
		Transverse at Room Temperature		
1T-1	146.5	140.0	14.0	18.3
1T-2	147.5	141.5	15.5	18.6
1T-3	146.5	140.0	14.0	18.2
		Longitudinal at 300 F		
1L-4	121.0	105.0	11.5	15.9
1L-5	121.0	105.0	13.5	16.2
		Transverse at 300 F		
1T-4	128.0	112.0	14.5	17.9
1T-5	128.0	112.0	14.5	17.4
		Longitudinal at 500 F		
1L-6	109.0	88.8	11.5	13.0
1L-7	111.0	90.0	12.5	13.5
		Transverse at 500 F		
1T-6	117.0	96.6	13.0	16.4
1T-7	117.0	96.8	13.5	17.2
		Longitudinal at 700 F		
1L-8	103.0	80.8	11.0	14.2
1L-9	104.0	81.2	9.5	13.7
		Transverse at 700 F		
1T-8	110.0	89.0	11.0	14.5
1T-9	110.0	90.4	11.0	15.1

TABLE 8. COMPRESSION TEST RESULTS FOR 6Al-4V TITANIUM SHEET

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Longitudinal at Room Temperature	
2L-1	143.0	17.4
2L-2	143.0	18.2
	Transverse at Room Temperature	
2T-1	163.0	19.1
2T-2	163.0	19.0
	Longitudinal at 300 F	
2L-3	116.0	16.9
2L-4	117.0	17.2
	Transverse at 300 F	
2T-3	[illegible]31.0	18.1
2T-4	[illegible]0.0	18.1
	Longitudinal at 500 F	
2L-5	97.0	16.1
2L-6	99.8	15.8
	Transverse at 500 F	
2T-5	111.0	17.3
2T-6	112.0	17.2
	Longitudinal at 700 F	
2L-7	88.4	14.7
2L-8	87.9	14.8
	Transverse at 700 F	
2T-7	99.4	16.2
2T-8	99.2	16.5

TABLE 9. SHEAR TEST RESULTS FOR 6Al-4V TITANIUM SHEET AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear strength, ksi
4L-1	90.2
4L-2	90.8
4L-3	89.6
4T-1	97.0
4T-2	99.1
4T-3	98.0

TABLE 10. AXIAL-LOAD FATIGUE TEST RESULTS FOR 6Al-4V TITANIUM SHEET, LONGITUDINAL, UNNOTCHED, AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-9	145.0	3,000
5-30	145.0	4,400
5-20	140.0	10,770
5-15	135.0	17,300
5-17	130.0	25,400
5-12	130.0	42,170
5-19	125.0	44,440
5-14	120.0	3,198,370
5-5	115.0	2,392,210
5-27	110.0	10,007,330[a]
5-24	100.0	7,892,500[a]
	500 F	
5-18	110.0	12,700
5-28	100.0	31,100
5-29	90.0	59,000
5-16	85.0	53,100
5-6	80.0	89,800
5-3	77.5	198,800
5-10	75.0	3,134,600
5-13	70.0	107,800
5-21	70.0	11,392,100[a]
	700 F	
5-1	100.0	23,200
5-2	100.0	25,000
5-25	95.0	13,100
5-7	90.0	31,800
5-8	87.5	62,500
5-11	85.0	907,000
5-24	80.0	2,174,700
5-22	80.0	10,017,500[a]

(a) Did not fail.

TABLE 11. AXIAL-LOAD FATIGUE TEST RESULTS FOR 6Al-4V TITANIUM SHEET, LONGITUDINAL, NOTCHED, (K_t = 3.0) AND AT STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-52	110.0	2,700
5-60	100.0	4,100
5-31	90.0	6,700
5-32	80.0	9,800
5-53	70.0	13,800
5-38	60.0	26,900
5-59	55.0	48,700
5-34	50.0	1,677,200
5-40	45.0	182,100
	500 F	
5-54	90.0	3,900
5-43	80.0	6,500
5-58	70.0	9,200
5-49	60.0	18,200
5-36	50.0	35,000
5-44	45.0	60,700
5-50	40.0	10,959,700(a)
	700 F	
5-37	80.0	4,500
5-41	70.0	8,400
5-35	60.0	13,200
5-48	50.0	23,800
5-42	45.0	29,100
5-46	40.0	272,200
5-39	40.0	1,869,200(a)
5-40	35.0	10,124,700(b)

(a) Grip failure.

(b) Did not fail.

TABLE 12. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR Ti-6Al-4V SHEET

Specimen Number	Stress ksi	Tempera-ture, F	Hours to Indicated Creep Deformation percent					Initial Strain, percent	Rupture Time, hr.	Elongation in 2 Inches, percent	Reduction of Area, percent	Minimum Creep Rate, percent/hr.
			0.1	0.2	0.5	1.0	2.0					
317	127.5	500	--	--	--	--	--	--	on loading	10.0	34.5	--
321	125	500	--	--	--	--	--	--	on loading	10.7	40.0	--
316	115	500	0.01	0.05	0.6	6000 est.	--	3.602	887.3*	4.233	--	0.000060
35	105	500	25	7500 est.	--	--	--	1.562	607.8*	1.685	--	0.000012
31	95	500	--	--	--	--	--	0.817	624.0*	0.873	--	nil
320	120	600	--	--	--	--	--	--	on loading	11.1	37.3	--
318	110	600	--	0.01	0.1	400	2500 est.	3.348	508.0*	4.408	--	0.00045
32	95	600	335	1600 est.	5400 est.	--	--	0.981	908.4*	1.125	--	0.00008
319	115	700	--	--	--	--	--	--	on loading	--	--	--
34	100	700	0.8	5	30	122	480	1.515	1602*	5.71	--	0.0020
33	80	700	20	120	1200	3500	--	0.493	1037.4*	0.958	--	0.00022

*Test discontinued.

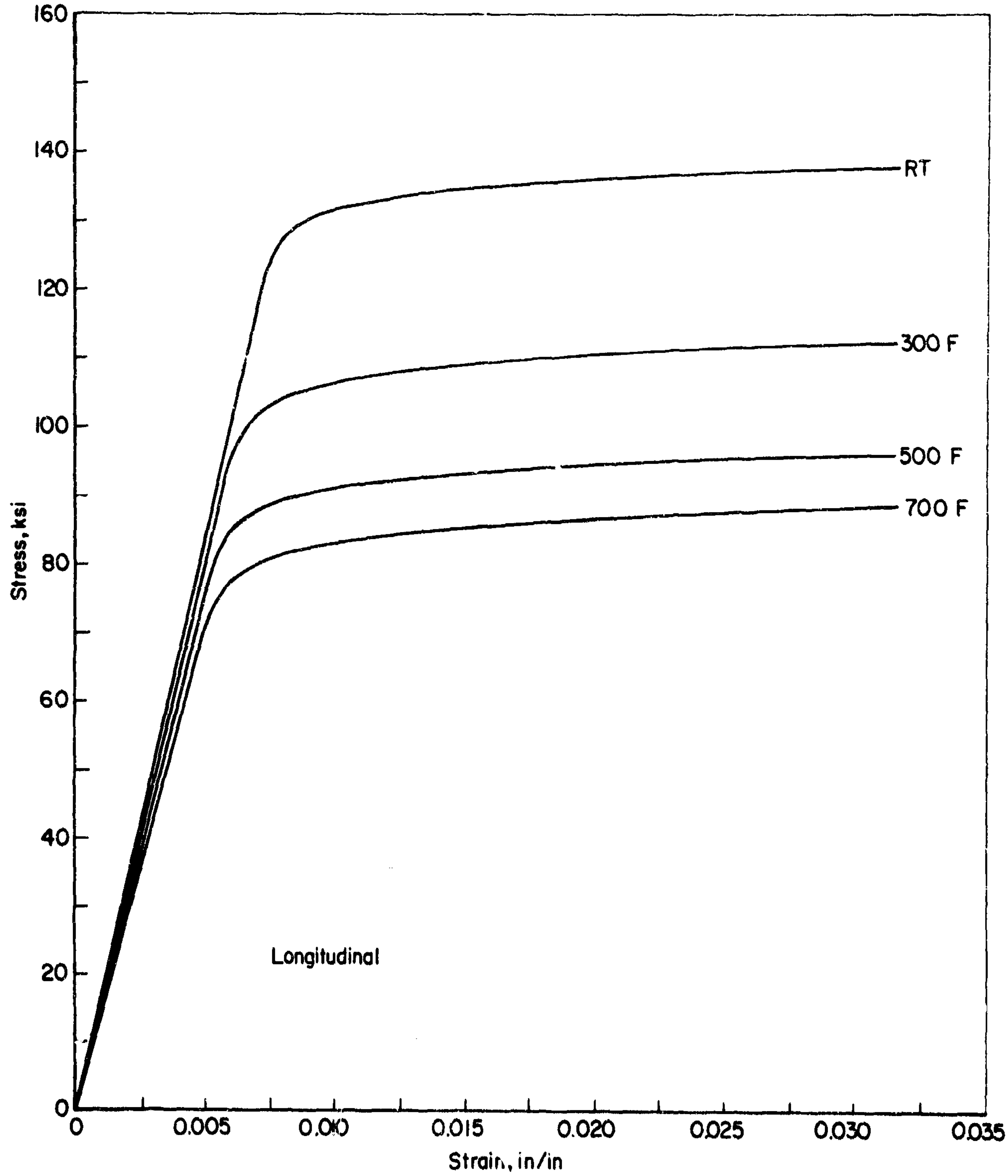


FIGURE 34. TYPICAL TENSION STRESS-STRAIN CURVES FOR TI-6AL-4V SHEET AT TEMPERATURE

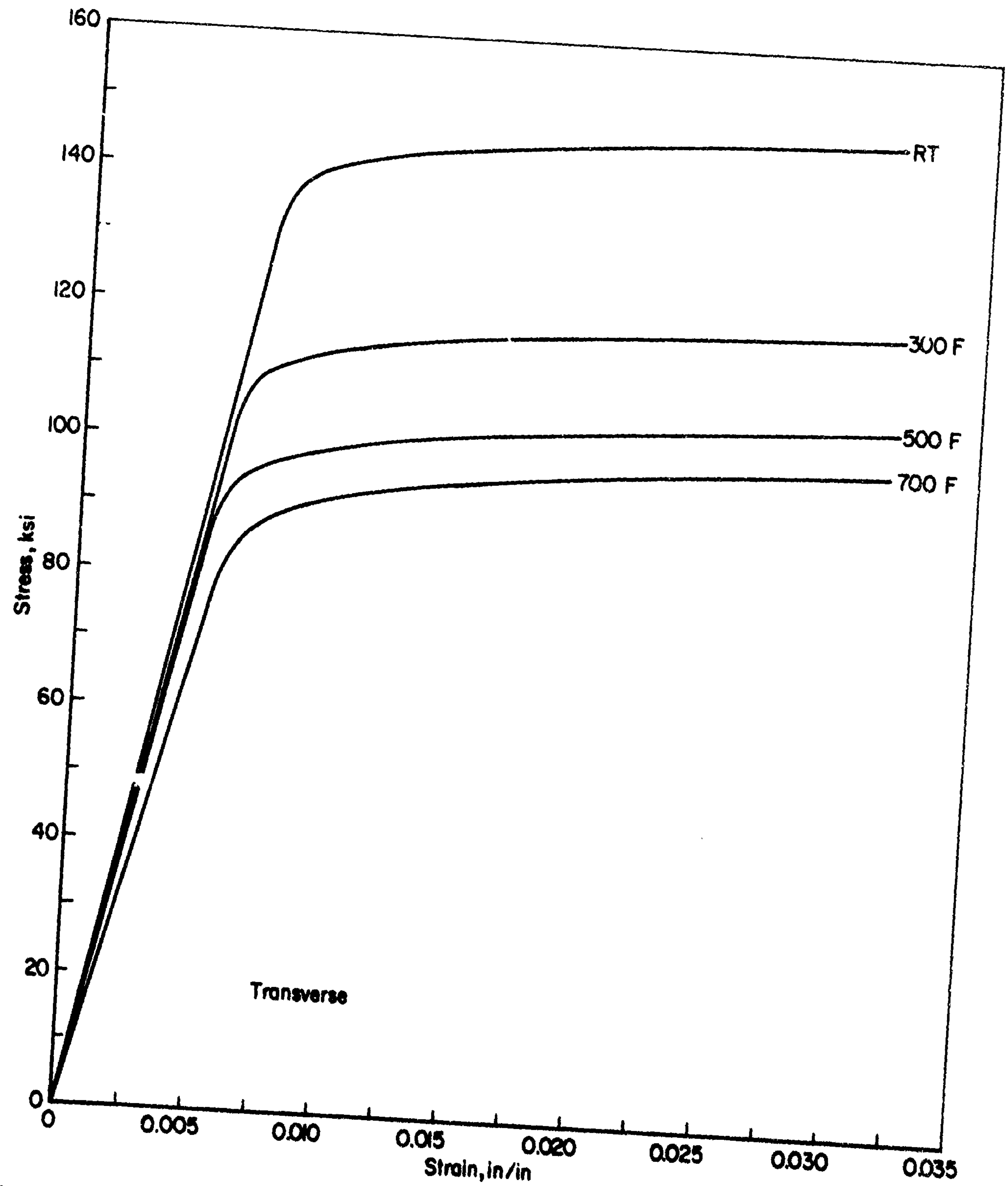


FIGURE 35. TYPICAL TENSION STRESS-STRAIN CURVES FOR TI-6AL-4V SHEET AT TEMPERATURE

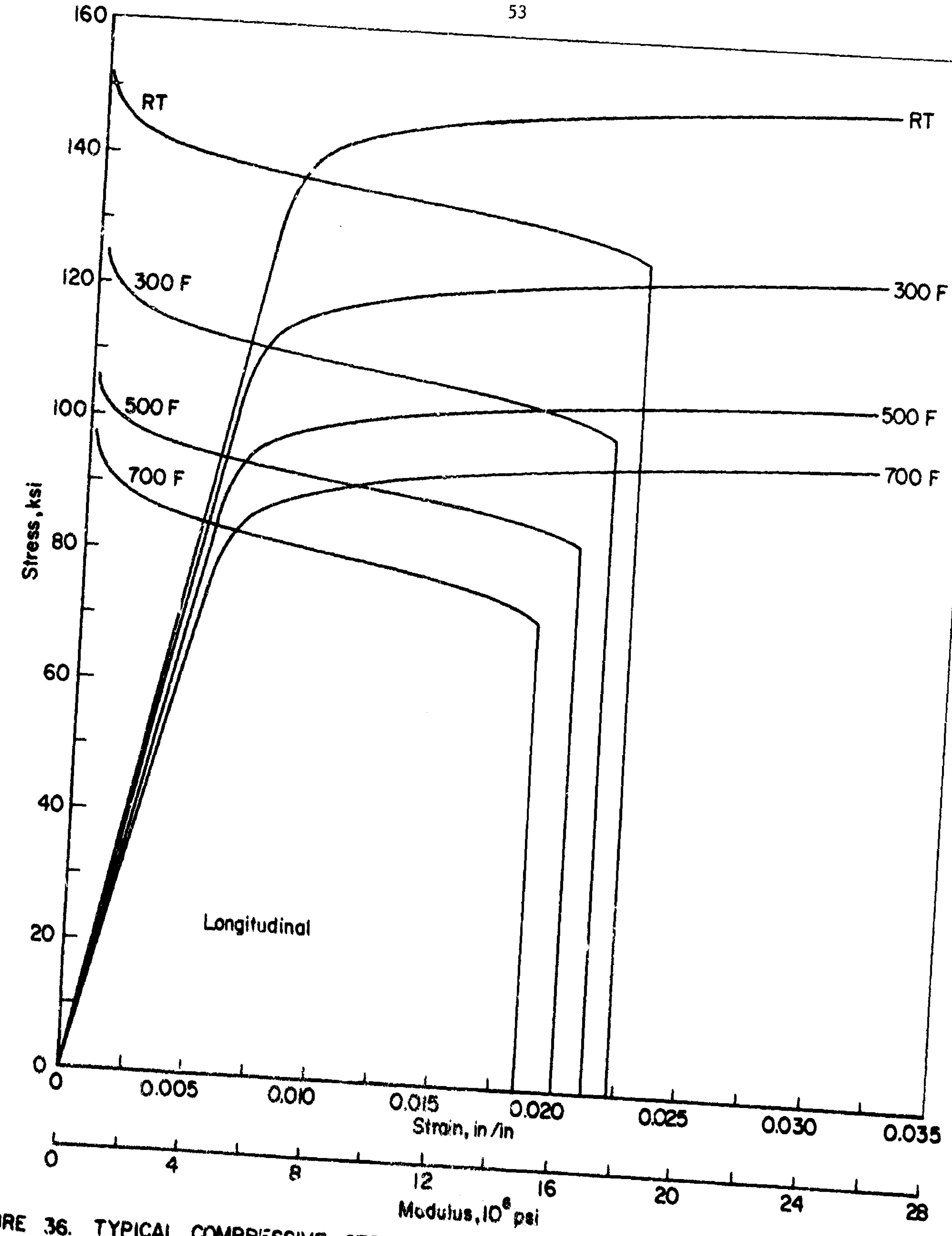


FIGURE 36. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR TI-6AL-4V SHEET AT TEMPERATURE

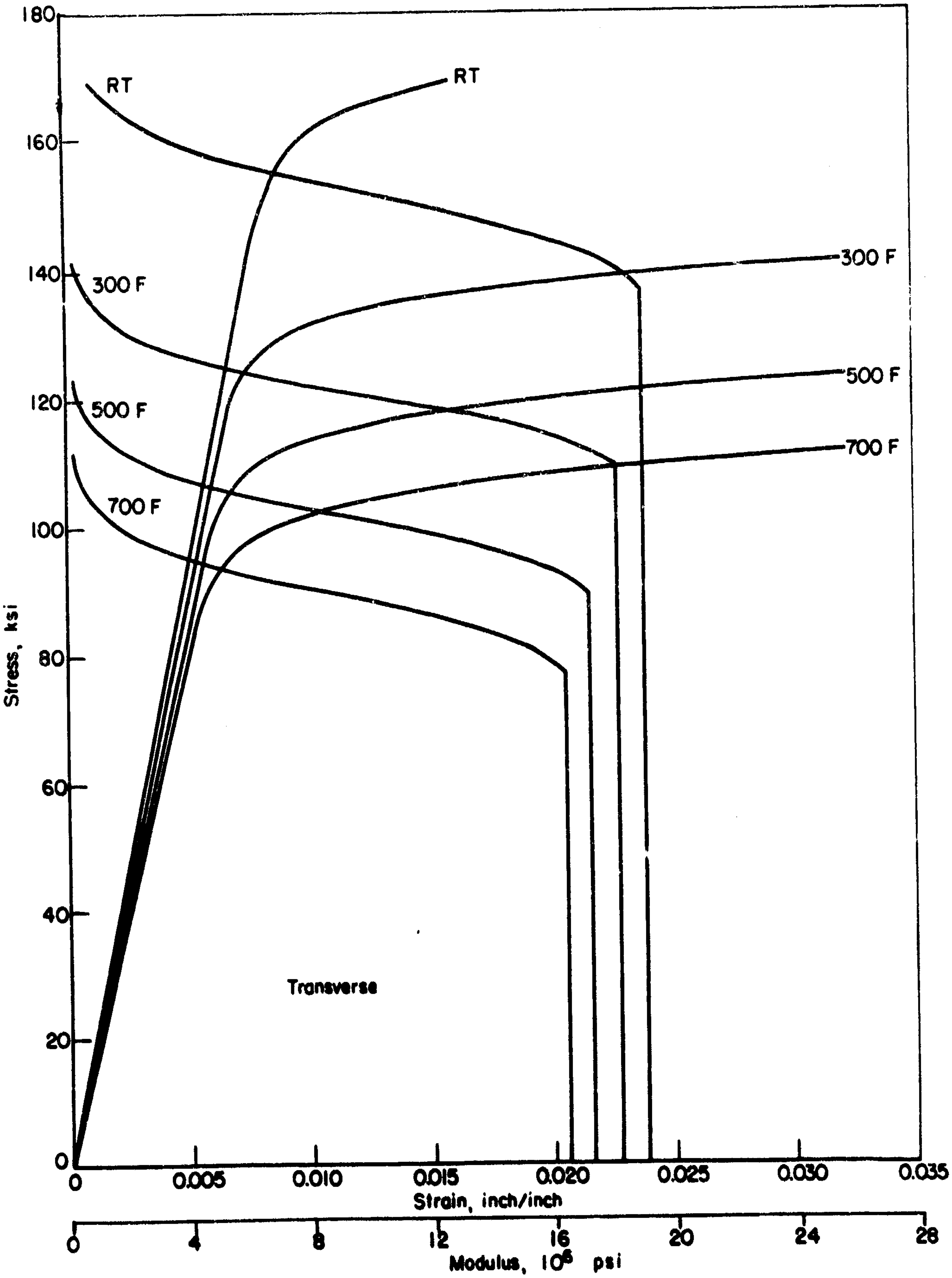


FIGURE 37. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR Ti-6Al-4V SHEET AT TEMPERATURE

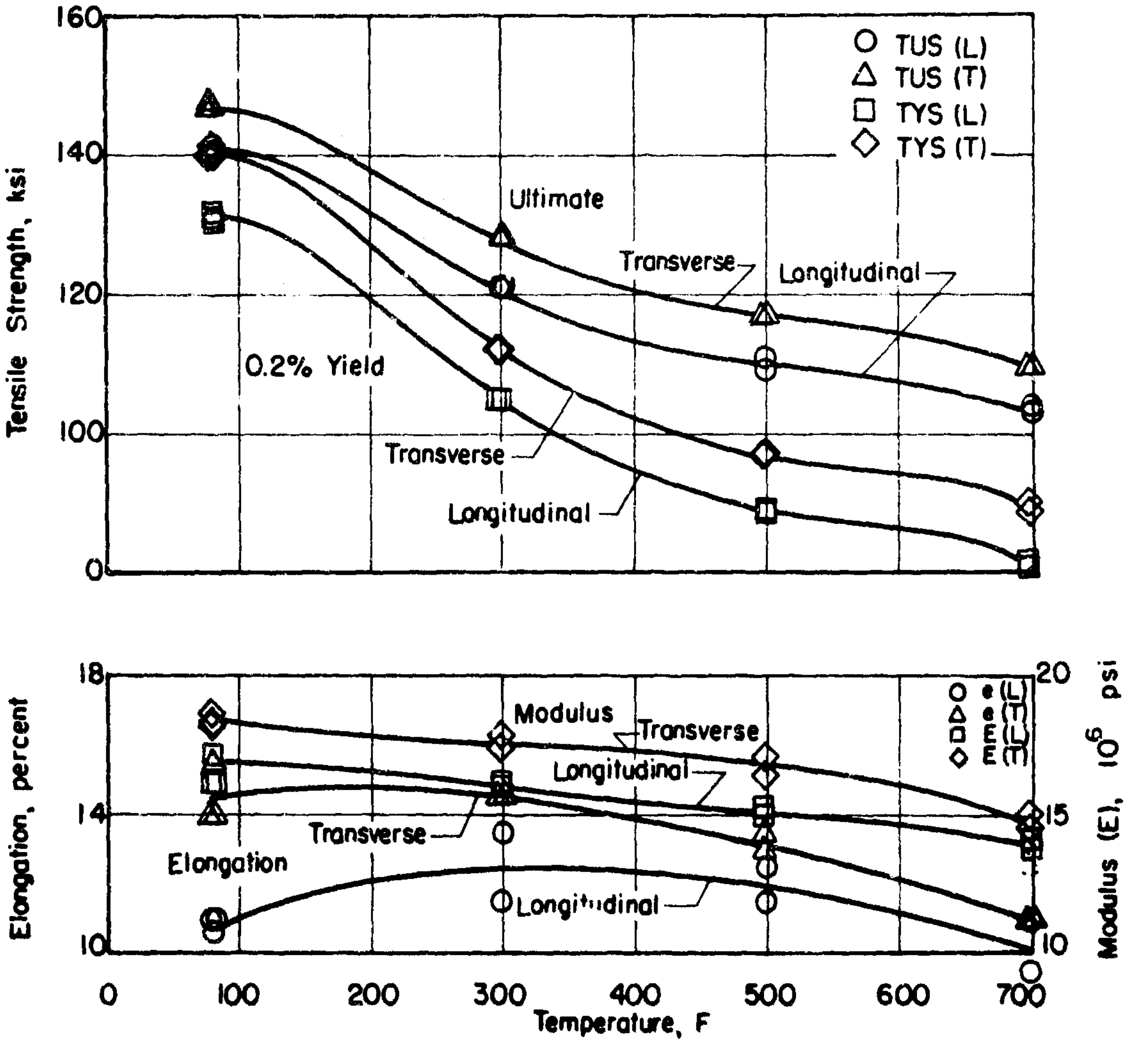


FIGURE 38. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 6Al-4V TITANIUM SHEET (STOA) AT THREE TEMPERATURES

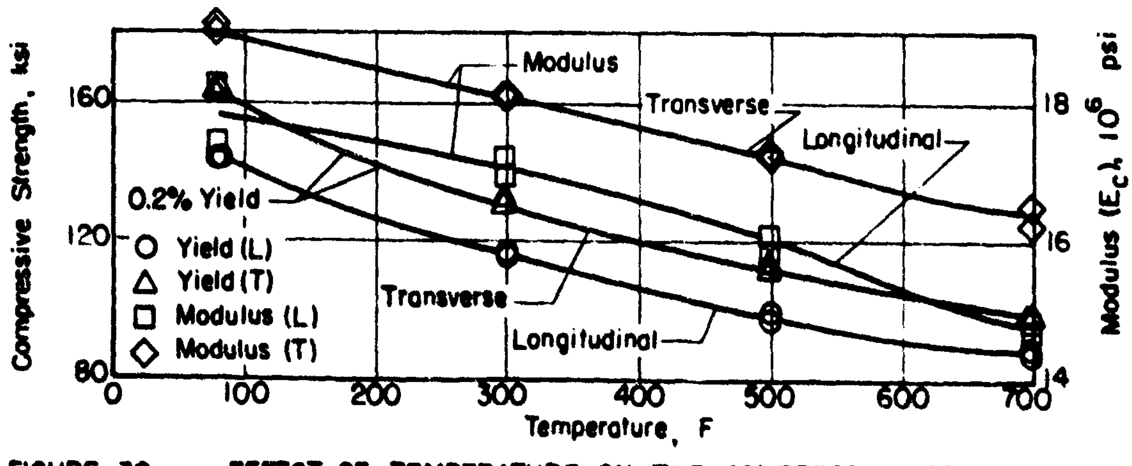


FIGURE 39. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 6Al-4V TITANIUM SHEET (STOA) AT THREE TEMPERATURES

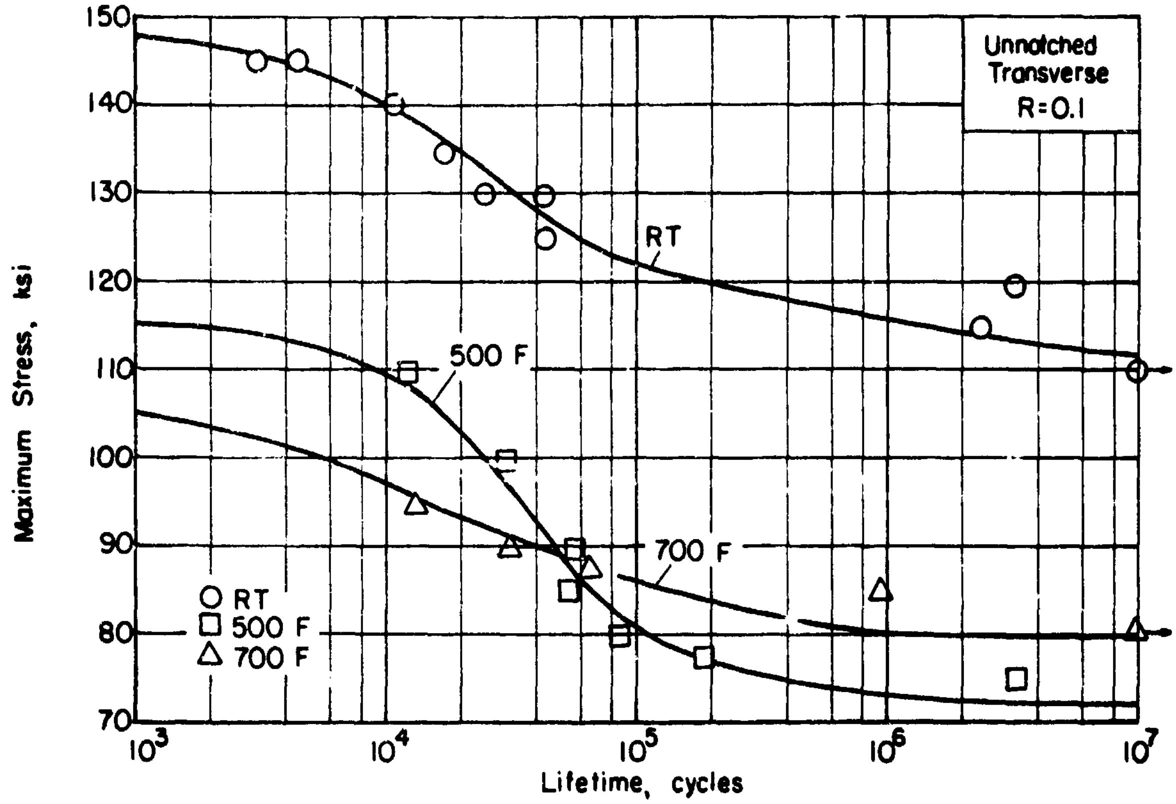


FIGURE 40. AXIAL LOAD FATIGUE RESULTS FOR 6Al-4V TITANIUM SHEET (STOA)

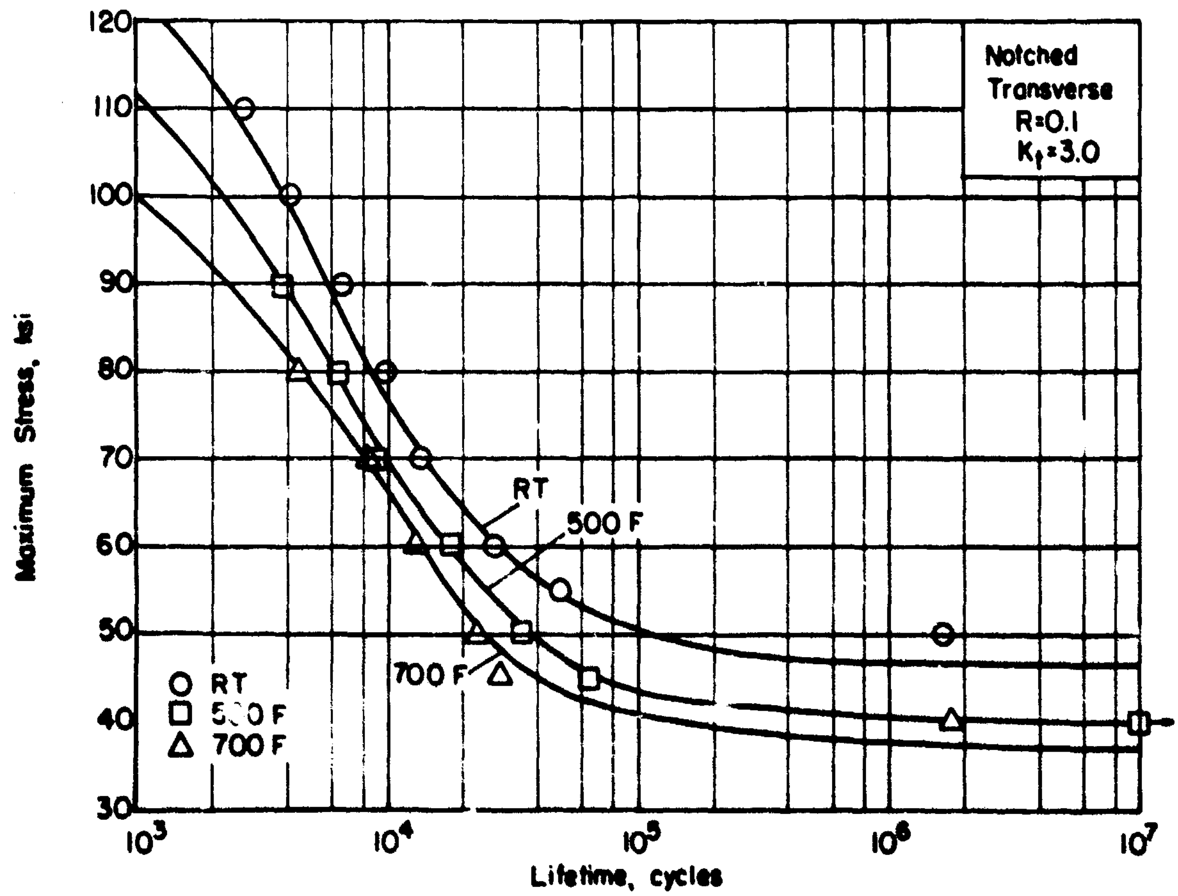


FIGURE 41. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) 6Al-4V TITANIUM SHEET (STOA)

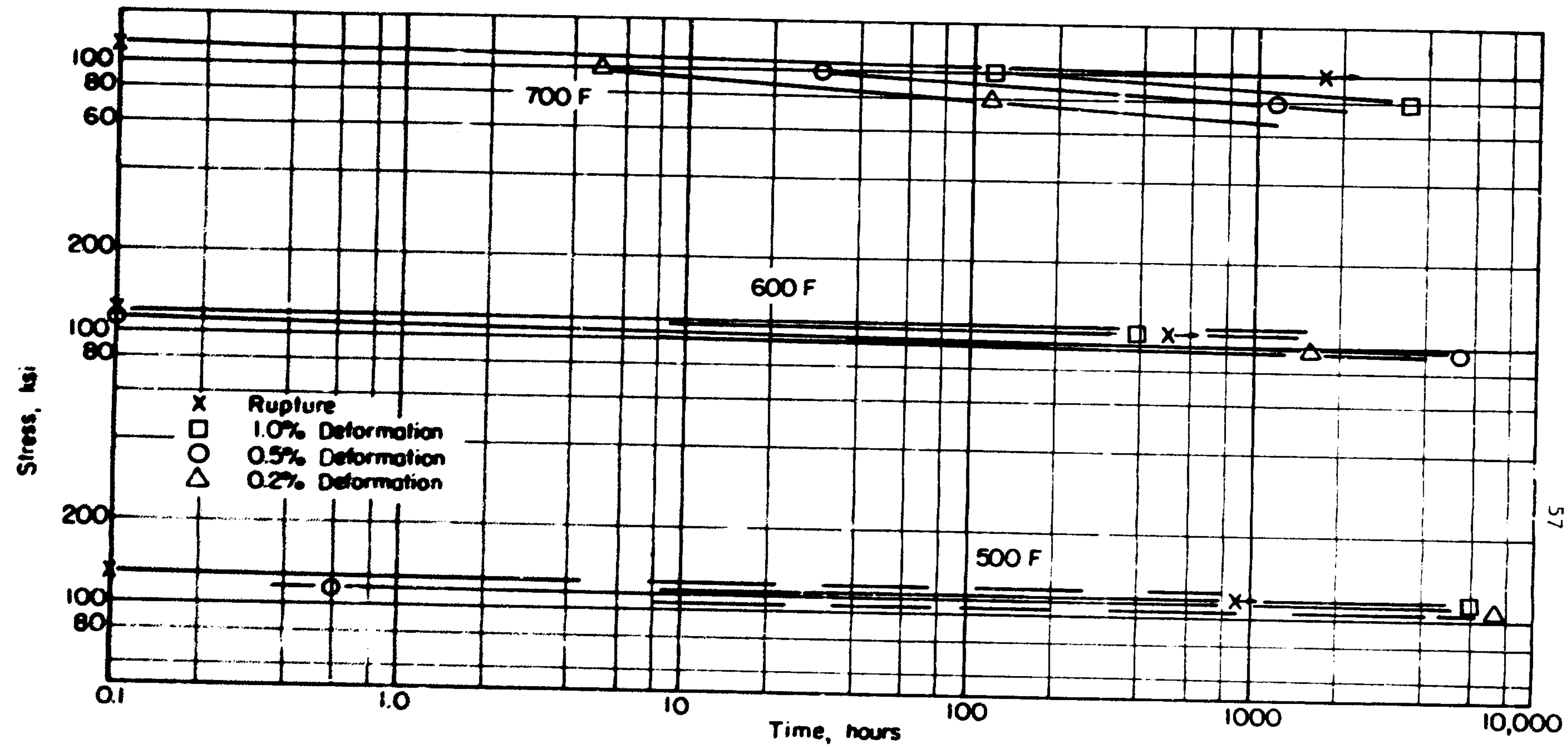


FIGURE 42. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-4V (STOA) SHEET

6Al-4V Titanium Extrusions

Material Description

As mentioned in the previous section, this alloy is one of the most widely used alloys of titanium. For this evaluation a thin "T" section extrusion was chosen to obtain properties for the material after the drawing process.

Approximately 60 feet of the thin extrusion was supplied GFM in 30-inch lengths.

Processing and Heat Treating

All of the "T" sections were extruded from billets of approximately 3.5 inches in diameter by 7 to 8 inches in length. The target thickness of 0.040 inches was attained by three draw passes plus chemical removal of 0.002 inches per side to remove contamination. After the final draw and stretch straightening operation the shapes were vacuum annealed at 1325F for 1-1/2 hours and argon cooled to room temperature.

In order to obtain enough specimen material and maintain specimen uniformity all specimens tested were in the longitudinal direction. The vertical section of the "T" was removed and the center of the "T" was the centerline of all specimens. Since the specimens were all longitudinal along the length of the "T" shape, no specimen layout is shown.

Test Results

Tension. Tensile testing was performed at room temperature, 400F, 700F, and 900F. Test results are shown in tabular form in Table 13. Stress-strain curves are shown in Figure 43. Effect-of-temperature curves are presented in Figure 45.

Compression. Tests were conducted at room temperature, 400F, 700F, and 900F. Tabular test results are presented in Table 14. Stress-strain and tangent modulus curves are shown in Figure 44. Effect-of-temperature curves are shown in Figure 46.

Shear. Test results at room temperature are shown in Table 15.

Impact. No impact tests were performed on the thin extrusions.

Fracture Toughness. The material was not of sufficient size, width or thickness, for fracture toughness testing.

Fatigue. Axial-load fatigue tests were conducted at room temperature, 400F, and 700F. Test results are presented in Tables 16 and 17. S-N curves are shown in Figures 47 and 48.

Creep and Stress Rupture. Tests were performed at 500F, 700F, and 900F. Tabular test reults are shown in Table 18. Log stress versus log time curves are presented in Figure 49.

Stress Corrosion. No cracks appeared in the seven specimens after testing as described in the experimental procedure section.

Thermal Expansion and Density. Values for these properties are given in the "data sheet" in the conclusions section.

TABLE 13. TENSION TEST RESULTS FOR Ti-6Al-4V "T" EXTRUSIONS

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Room Temperature		
1L-1	153.0	143.0	11.5	15.8
1L-2	151.0	142.0	10.0	16.0
1L-3	158.0	149.0	12.0	16.0
		400 F		
1L-4	121.0	107.0	12.0	14.5
1L-5	125.0	112.0	12.0	14.8
1L-6	124.0	109.0	12.0	14.1
		700 F		
1L-7	107.0	90.5	8.5	13.0
1L-8	106.0	87.4	9.5	12.6
1L-9	107.0	88.5	9.5	13.0
		900 F		
1L-10	95.0	81.3	14.0	11.0
1L-11	93.2	79.9	18.5	11.1
1L-12	95.1	81.5	18.5	10.9

TABLE 14. COMPRESSION TEST RESULTS FOR Ti-6Al-4V "T" EXTRUSIONS

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Room Temperature	
2L-1	144.0	17.7
2L-2	147.0	18.1
2L-3	150.0	17.9
	400 F	
2L-4	111.0	16.7
2L-5	112.0	16.6
2L-6	111.0	16.5
	700 F	
2L-7	99.1	14.7
2L-8	95.6	16.0
2L-9	96.5	15.7
	900 F	
2L-10	86.4	14.7
2L-11	87.0	14.3
2L-12	85.0	14.6

TABLE 15. SHEAR TEST RESULTS FOR Ti-6Al-4V "T" EXTRUSIONS

Specimen Number	Ultimate Shear Strength, ksi
4L-1	91.0
4L-2	92.7
4L-3	95.2

TABLE 16. AXIAL-LOAD FATIGUE TEST RESULTS FOR Ti-6Al-4V "T" EXTRUSIONS, UNNOTCHED, AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-7	140	4,830
5-5	130	7,200
5-4	120	22,330
5-3	110	36,820
5-2	100	36,470
5-1	90	65,560
5-6	80	135,500
5-8	70	277,130
5-9	60	211,820
5-29	60	15,202,800[a]
5-10	60	254,570
5-11	50	427,260
5-12	40	11,053,800[a]
	400 F	
5-17	140	800
5-16	120	20,100
5-15	110	48,700
5-14	90	48,000
5-13	80	78,500
5-18	60	1,642,800
5-19	60	12,701,700[a]
	700 F	
5-22	120	2,800
5-24	110	6,000
5-27	105	13,000
5-21	100	20,200
5-25	90	22,900
5-23	80	54,000
5-26	70	10,035,600[a]

(a) Did not fail.

TABLE 17. AXIAL-LOAD FATIGUE TEST RESULTS FOR Ti- 6Al-4V "T" EXTRUSIONS, NOTCHED (K_t = 3.0), AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-29	120	2,900
5-27	110	3,800
5-24	100	5,400
5-22	90	8,500
5-21	80	15,000
5-23	70	22,500
5-25	60	75,000
5-18	55	132,000
5-28	50	83,300
5-26	50	12,160,200[(a)]
5-11	40	10,420,560[(a)]
	400 F	
5-20	110	2,400
5-4	100	3,800
5-3	80	8,700
5-2	70	11,800
5-1	60	18,500
5-5	50	55,500
5-6	40	250,000
5-7	30	12,619,000[(a)]
	700 F	
5-19	100	2,100
5-14	90	3,500
5-9	80	6,400
5-17	70	8,900
5-8	60	12,500
5-10	50	26,000
5-12	40	86,900
5-13	30	10,277,000[(a)]

(a) Did not fail.

TABLE 18. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR Ti-6Al-4V "T" EXTRUSIONS

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, Percent					Initial Strain, percent	Rupture Time, hr.	Elongation in 2 Inches, percent	Minimum Creep Rate, percent/hr.
			0.1	0.2	0.5	1.0	2.0				
3	120	500	--	--	--	--	--	--	on loading	10.2	--
6	115	500	--	--	--	--	--	--	on loading	8.5	--
7	110	500	0.05	0.40	4000 est.	--	--	2.485	407.7*	2.772	0.00006
13	105	500	0.08	20	--	--	--	2.747	26.7*	2.952	--
14	100	500	0.15	350	--	--	--	1.076	739.3*	1.286	0.00002
2	112	700	--	--	--	--	--	--	on loading	7.2	--
5	100	700	0.2	0.7	4.0	13	50	2.492	477.0	11.9	0.013
12	80	700	4.0	20	155	690	1850 est.	0.824	768.2*	1.896	0.00080
15	65	700	20	115	1000	3500 est.	--	0.543	840.6*	1.014	0.00020
1	95	900	--	--	--	--	--	--	0.1	11.9	--
4	80	900	--	0.01	0.05	0.15	0.35	1.353	2.3	19.1	5.1
8	60	900	0.07	0.2	0.8	2.5	5.7	0.676	60.8	35.7	0.27
11	50	900	0.15	0.4	2.7	7.0	20	0.402	194.6	45.5	0.085
9	35	900	0.50	1.7	7.0	20	50	0.266	71.7	2.780	0.03
10	15	900	10	35	210	760	1900	0.083	863.1	0.953	0.0009

*Test discontinued.

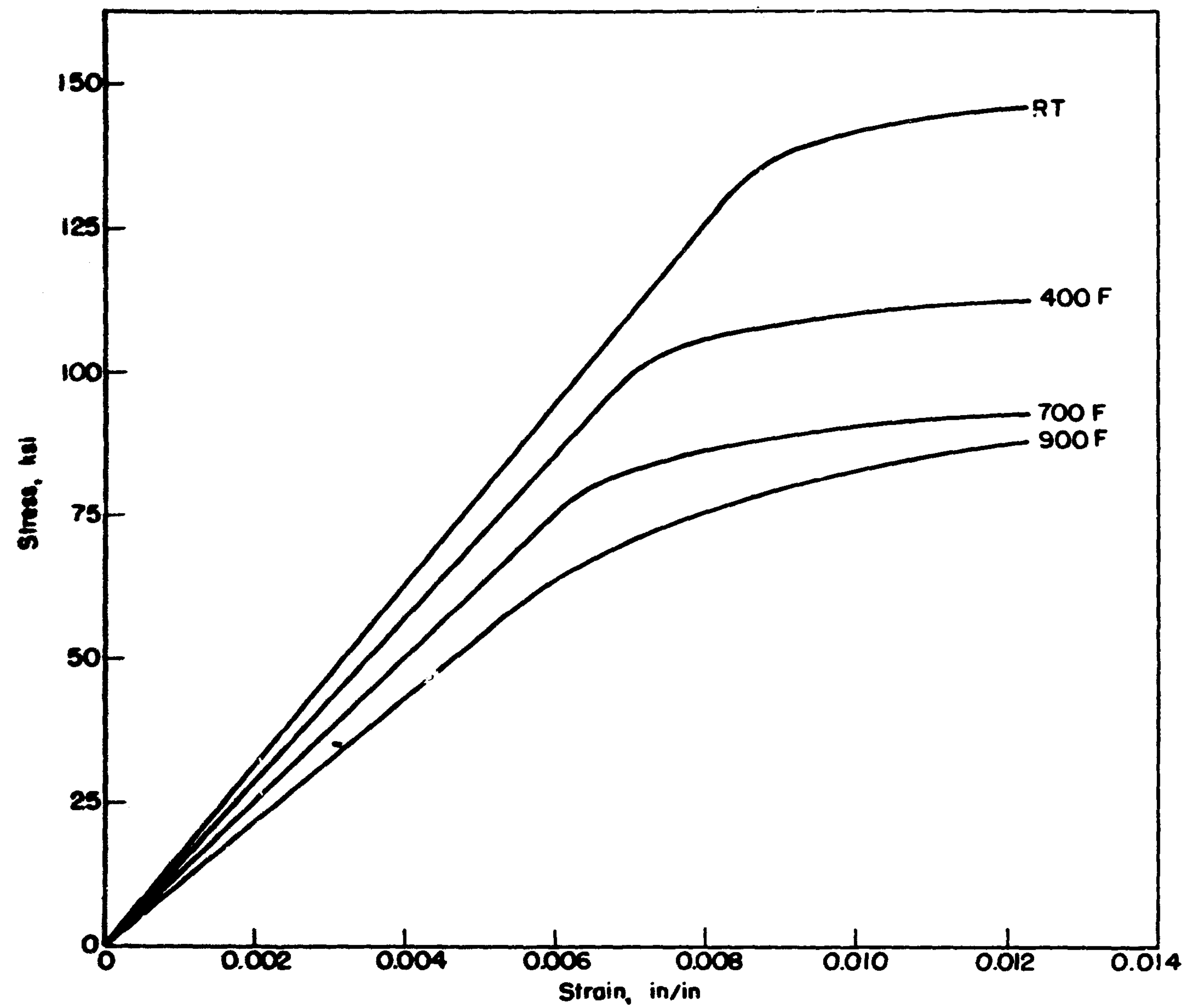


FIGURE 43. TYPICAL TENSION STRESS - STRAIN CURVES FOR Ti-6Al-4V EXTRUSIONS AT TEMPERATURE

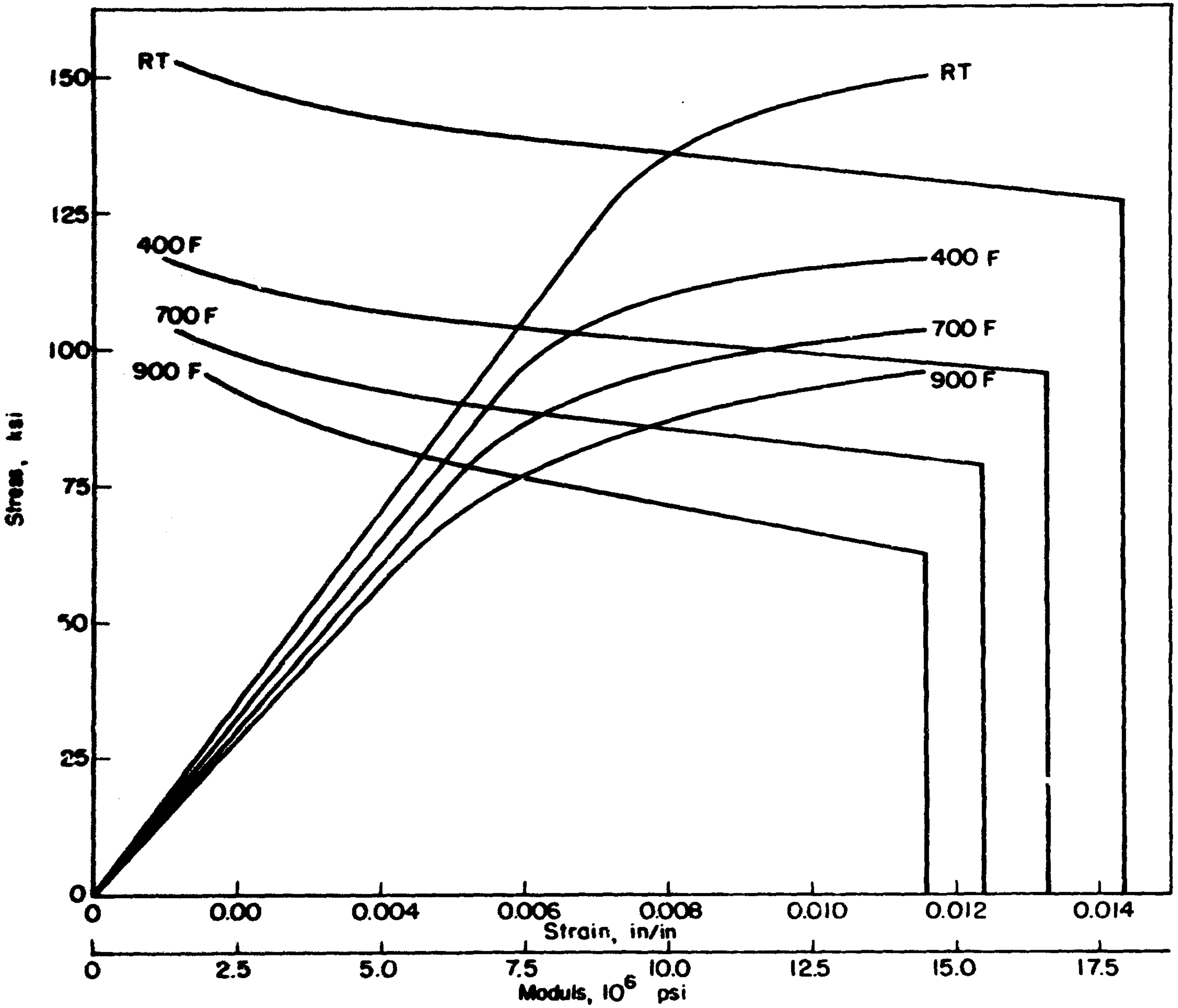


FIGURE 44. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR Ti-6Al-4V EXTRUSIONS AT TEMPERATURE

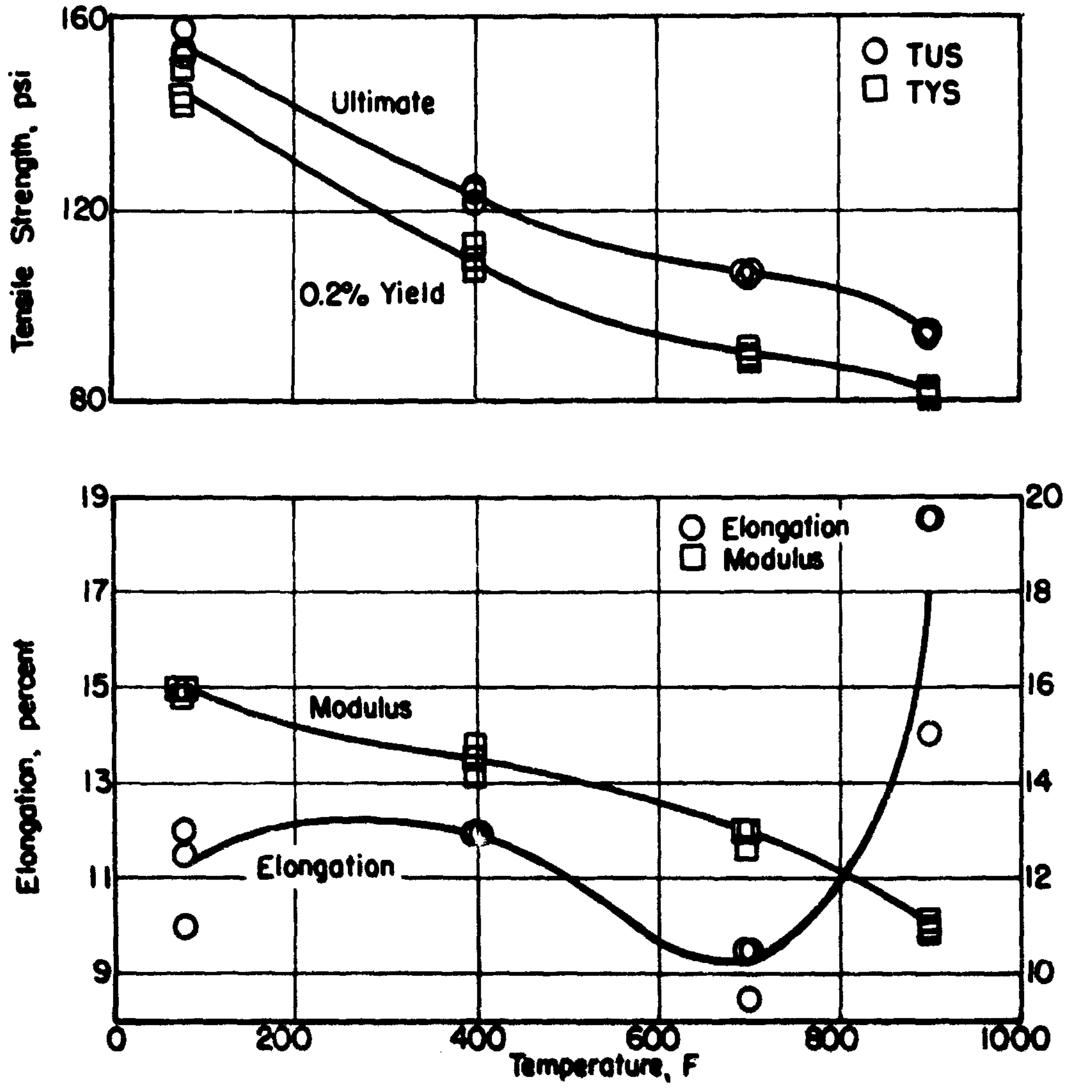


FIGURE 45. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-4V "T" EXTRUSIONS

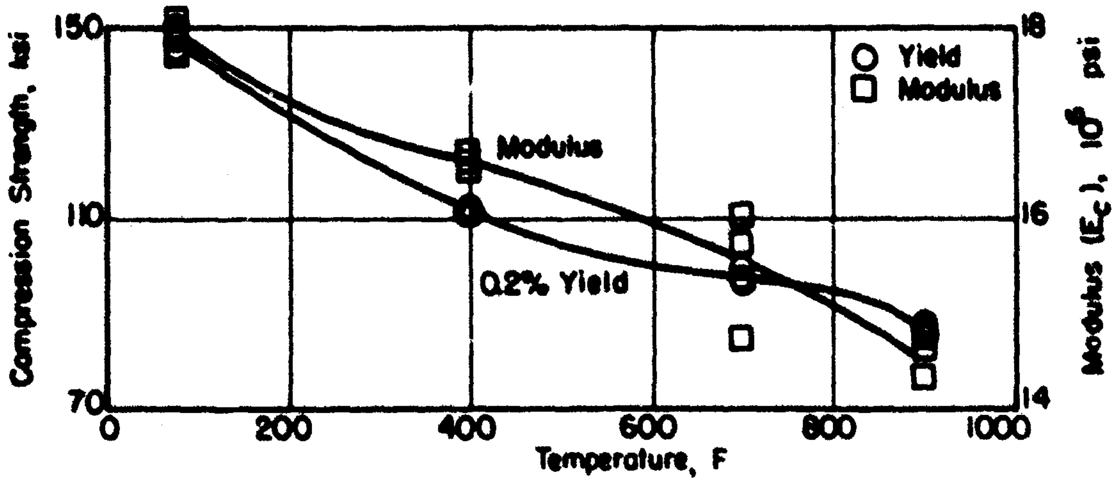


FIGURE 46. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-4V "T" EXTRUSIONS

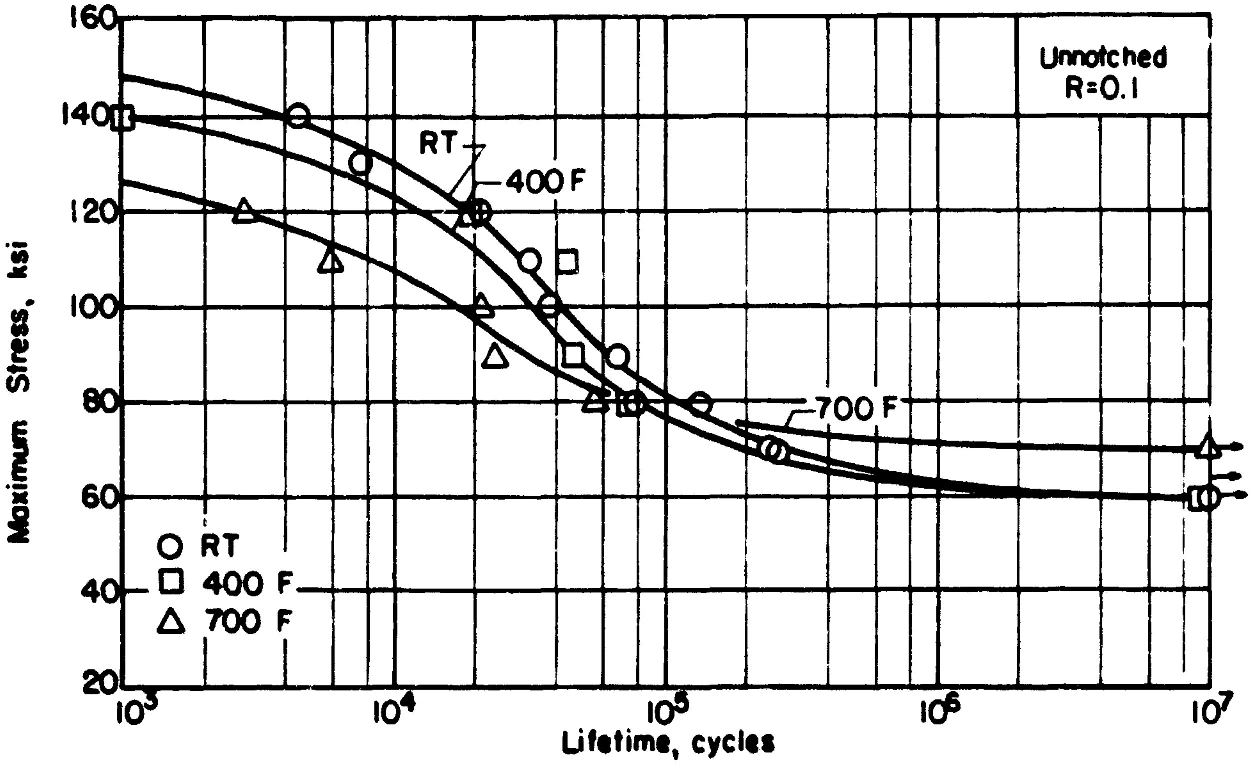


FIGURE 47. AXIAL LOAD FATIGUE RESULTS FOR Ti-6Al-4V "T" EXTRUSIONS

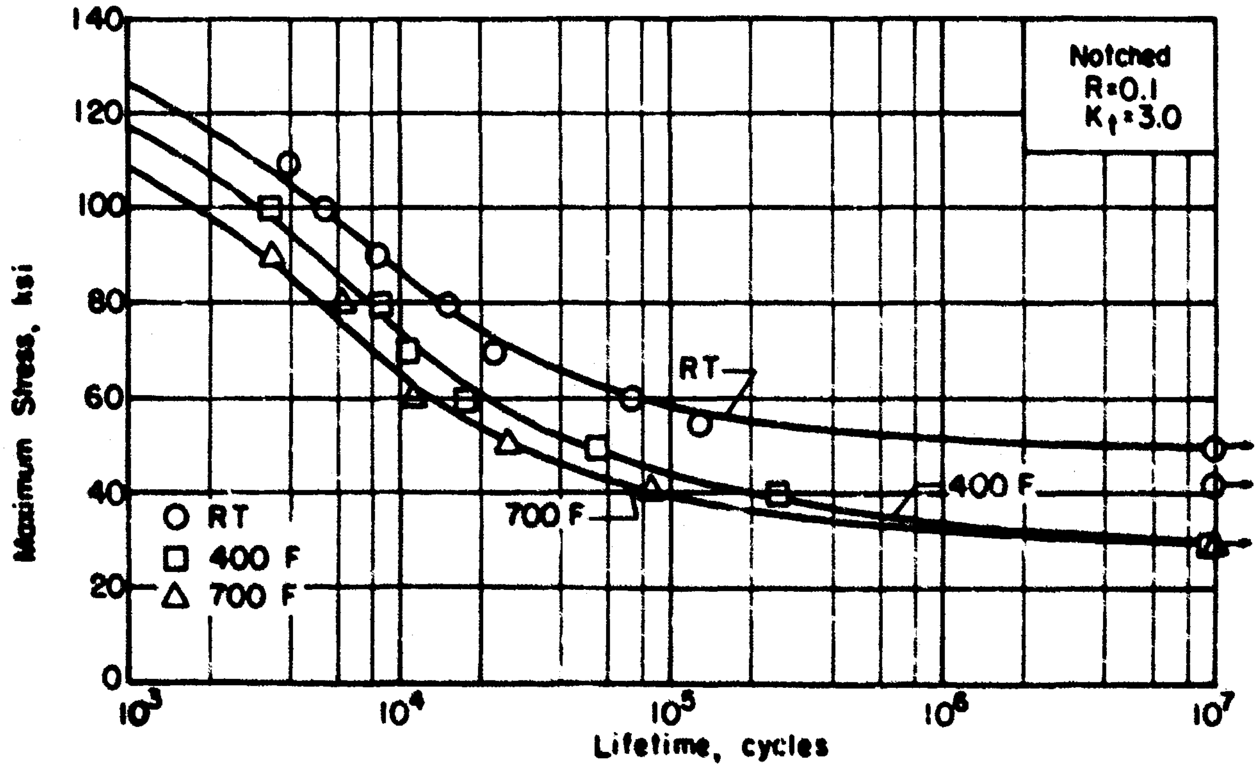


FIGURE 48. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) Ti-6Al-4V "T" EXTRUSIONS

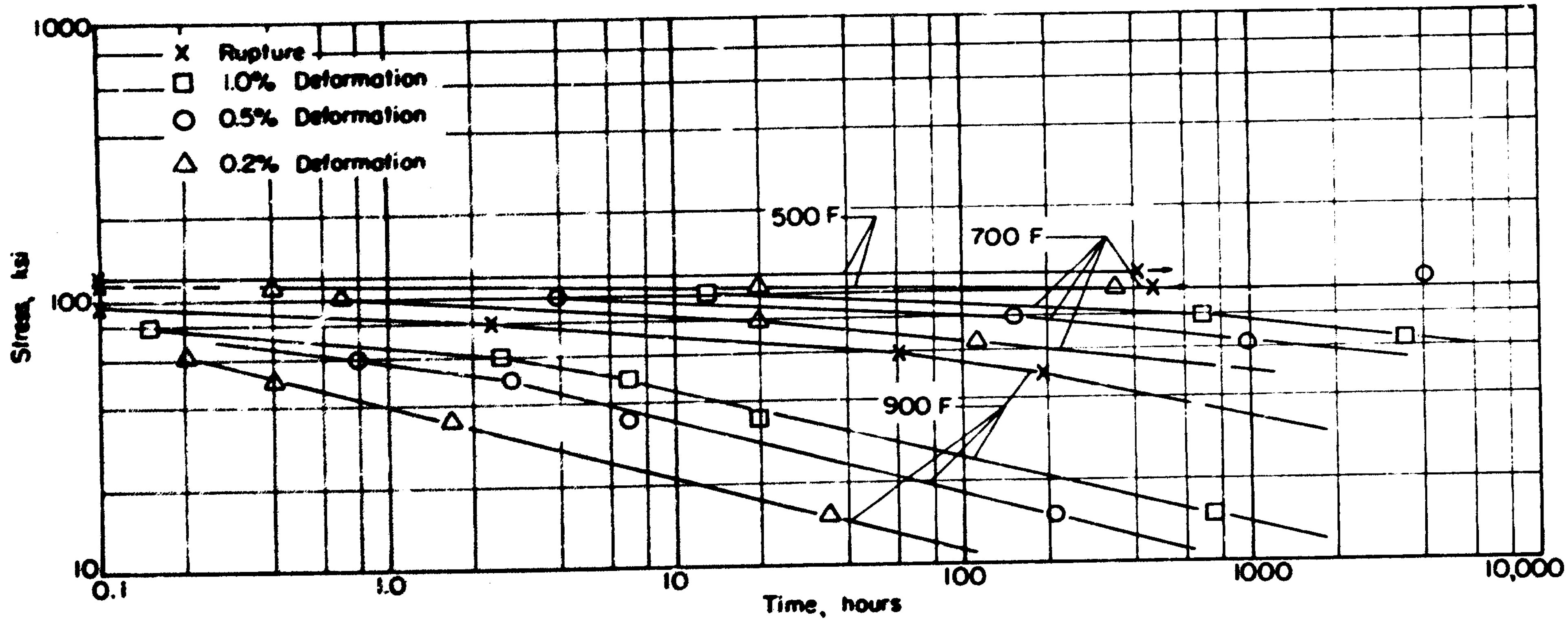


FIGURE 49. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-4V "T" EXTRUSIONS

300M Forgings

Material Description

This alloy is one of the modifications to 4340 steel that currently is being considered for use as an ultra-high strength steel. 300M combines high hardenability with relatively good impact strength and ductility.

The material used on this program was the flange section of a large I-beam forging with a cross section of approximately 20 inches by 10 inches. The flange section had a cross section of 6 inches by 10 inches. The composition of 300M is as follows:

Chemical Composition	Percent
Carbon	0.43
Silicon	1.68
Manganese	0.70
Phosphorus	0.010
Sulfur	0.010
Nickel	1.93
Chromium	0.79
Molybdenum	0.39
Aluminum	0.15
Vanadium	0.07
Iron	Balance

Processing and Heat Treating

The specimen layout for 300M is shown in Figure 50. Specimens were heat treated to the 2[illegible]0-ksi strength level as follows: 1600F, quench in warm oil, temper 2 + 2 hours at 575F.

Test Results

Tension. Tests were conducted in the longitudinal and transverse directions at room temperature, 250F, 400F, and 550F. Short transverse tests were conducted

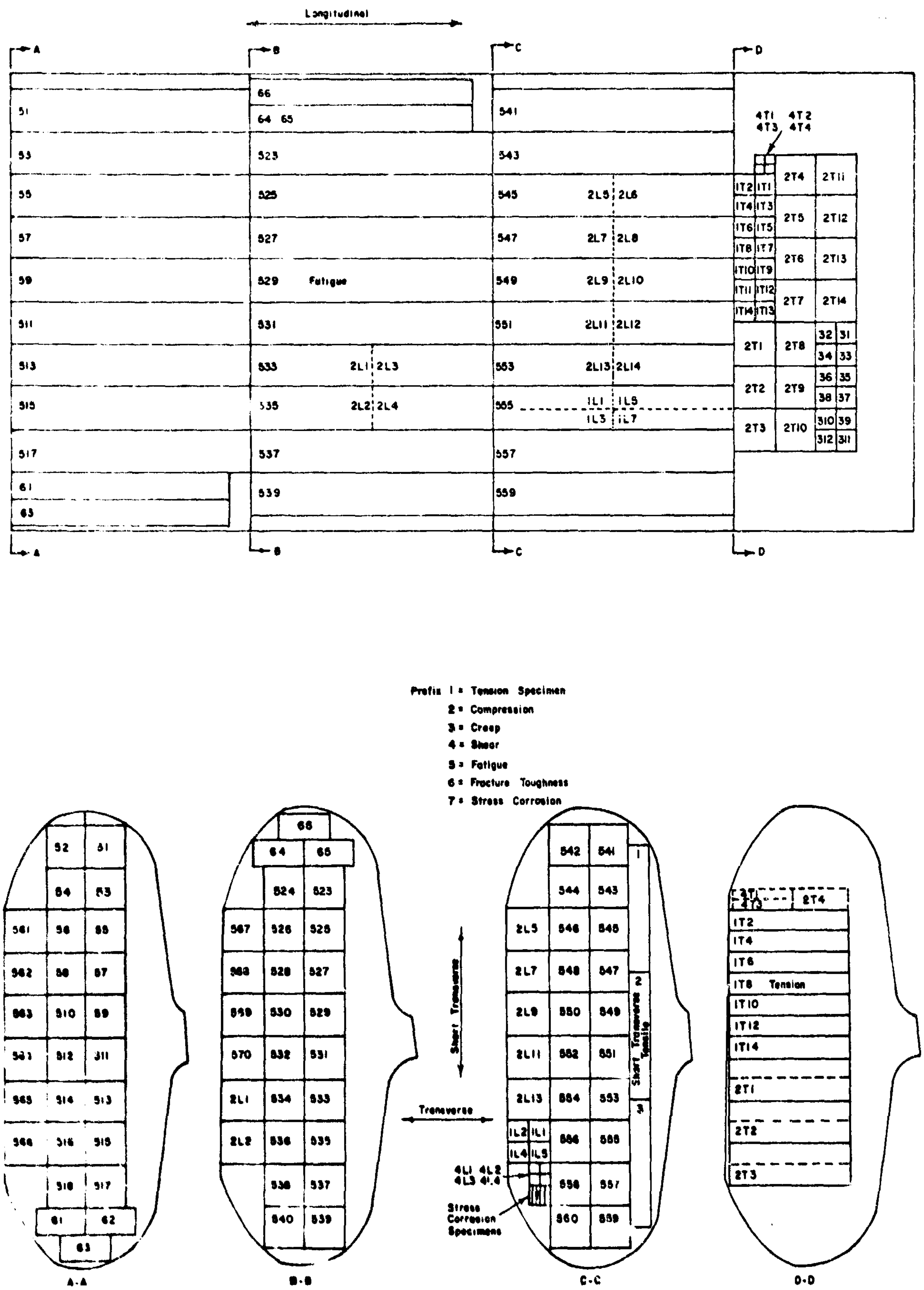


FIGURE 50. SPECIMEN LAYOUT FOR 300M FORGINGS

at room temperature only. Tabular test results are shown in Table 19. Stress-strain curves at temperature are shown in Figures 51, 52, and 53. Effect-of-temperature curves are presented in Figure 56.

Compression. Tests were performed in the longitudinal and transverse directions at room temperature, 250F, 400F, and 550F. Tabular test results are shown in Table 20. Stress-strain and tangent modulus curves are shown in Figures 54 and 55. Effect-of-temperature curves are presented in Figure 57.

Shear. Room temperature tests were conducted for longitudinal and transverse specimens. Test results are shown in Table 21.

Impact. Charpy V-notch tests were conducted at room temperature and 250 F. Average values are shown in the "data sheet" in the conclusions section.

Fatigue Toughness. Slow-bend type fracture toughness tests were conducted at room temperature. Results of these tests are presented in Table 22.

Fatigue. Axial-load fatigue tests were performed at room temperature, 300F, and 500F. Tabular test results are shown in Tables 23 and 24. S-N curves are presented in Figures 58 and 59.

Creep and Stress Rupture. Tests were conducted at 500F only. Results are presented in Table 25 and Figure 60.

Stress Corrosion. No cracks appeared in the specimens after testing as described in the experimental procedure section.

Thermal Expansion and Density. Values for these properties are given in the "data sheet" in the conclusions section.

TABLE 19. TENSION TEST RESULTS FOR 300M FORGINGS

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Longitudinal at Room Temperature		
1L-1	292.0	247.0	12.0	29.4
		Transverse at Room Temperature		
1T-1	290.0	246.0	12.0	29.0
1T-2	294.0	246.0	10.0	29.5
1T-3	294.0	248.0	11.0	29.9
		Short Transverse at Room Temperature		
1ST-1	290.0	242.0	12.0	28.8
1ST-2	289.0	242.0	10.0	28.3
1ST-3	295.0	250.0	10.0	29.9
		Longitudinal at 250 F		
1L-2	294.0	234.0	11.0	26.1
		Transverse at 250 F		
1T-4	296.0	236.0	10.0	27.0
1T-5	296.0	242.0	11.0	27.7
1T-6	296.0	234.0	11.0	28.0
		Longitudinal at 400 F		
1L-3	295.0	209.0	21.0	26.9
		Transverse at 400 F		
1T-7	296.0	210.0	18.0	27.2 (a)
1T-8	297.0	212.0	18.5	26.3
1T-9	296.0	214.0	21.0	28.3
		Longitudinal at 550 F		
1L-4	260.0	191.0	22.0	23.1 (a)
		Transverse at 550 F		
1T-10	261.0	190.0	22.0	25.5 (a)
1T-11	261.0	184.0	21.0	23.9
1T-12	264.0	186.0	22.5	27.3

(a) Slope of load/strain curve indefinite.

TABLE 20. COMPRESSION TEST RESULTS FOR 300M FORGINGS

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Longitudinal at Room Temperature	
2L-1	265.0	30.7
2L-3	264.0	29.4
	Transverse at Room Temperature	
2T-2	267.0	30.7
	Longitudinal at 250 F	
2L-4	249.0	30.0
2L-6	246.0	30.2
	Transverse at 250 F	
2T-5	251.0	29.5
	Longitudinal at 400 F	
2L-7	230.0	29.1
2L-8	229.0	29.0
	Transverse at 400 F	
2T-9	231.0	29.2
	Longitudinal at 550 F	
2L-11	206.0	27.8
2L-12	205.0	27.9
	Transverse at 550 F	
2T-10	210.0	27.7

TABLE 21. SHEAR TEST RESULTS FOR 300M FORGINGS
AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
	<u>Longitudinal</u>
4L-1	180.0
4L-2	179.0
4L-3	178.0
4L-4	179.0
	<u>Transverse</u>
4L-5	179.0
4L-6	179.0
4L-7	179.0
4L-8	180.0

TABLE 22. FRACTURE TOUGHNESS TEST RESULTS FOR 300M FORGINGS

Specimen Number	Width, Inches	Crack Length, a	Span, Inches	K_{Ic}, ksi$\sqrt{in.}$
6-1	1.228	0.6581	5.0	67.7
6-2	1.228	0.6234	5.0	53.6
6-3	1.228	0.6362	5.0	69.2
6-4	1.228	0.6306	5.0	70.6
6-5	1.228	0.6545	5.0	69.5

TABLE 23. AXIAL-LOAD FATIGUE TEST RESULTS FOR 300M FORGINGS, UNNOTCHED, AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime,Cycles
	Room Temperature	
5-55	270.0	10,300
5-26	260.0	12,900
5-69	240.0	15,100
5-57	220.0	26,100
5-37	200.0	41,900
5-35	180.0	37,500
5-25	160.0	200,400
5-16	140.0	10,017,200[a]
	300 F	
5-40	260.0	11,400
5-34	240.0	13,400
5-6	220.0	15,700
5-56	190.0	34,000
5-14	180.0	30,400
5-13	170.0	58,600
5-28	150.0	236,200
5-31	140.0	3,695,500
5-12	130.0	10,044,200[a]
	500 F	
5-48	240.0	6,400
5-63	220.0	9,000
5-30	200.0	14,500
5-54	190.0	16,800
5-61	180.0	36,400
5-42	180.0	349,500
5-15	170.0	18,900
5-27	160.0	564,600
5-44	160.0	1,586,200
5-9	150.0	22,500
5-4	150.0	1,462,600
5-2	145.0	1,610,800
5-5	140.0	3,059,200
5-64	135.0	2,869,100
5-65	130.0	6,744,600
5-20	125.0	11,666,600[a]

(a) Did not fail.

TABLE 24. AXIAL-LOAD FATIGUE TEST RESULTS FOR 300M FORGINGS, NOTCHED (K_t = 3.0), AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-66	150.0	2,900
5-7	140.0	2,700
5-70	120.0	8,100
5-67	100.0	17,100
5-36	80.0	35,100
5-10	60.0	45,700
5-62	50.0	131,800
5-51	40.0	464,600
5-47	30.0	11,357,000
	300 F	
5-24	150.0	2,000
5-41	120.0	7,200
5-49	100.0	7,900
5-39	80.0	18,000
5-11	60.0	31,200
5-53	50.0	103,900
5-17	45.0	10,685,000(a)
5-18	40.0	10,274,700(a)
	500 F	
5-8	140.0	1,400
5-38	120.0	2,800
5-19	100.0	7,500
5-1	80.0	12,600
5-52	70.0	58,800
5-33	65.0	29,800
5-43	65.0	86,600
5-23	60.0	2,360,700
5-3	55.0	11,410,300(a)

(a) Did not fail.

TABLE 25. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR 300M FORGINGS

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hr.	Elongation in 2 Inches, percent	Reduction of Area, percent	Minimum Creep Rate, percent/hr.
			0.1	0.2	0.5	1.0	2.0					
32-A	270	500	--	--	--	0.1	2.5	4.570	2.7	11.1	43.4	0.40
32	250	500	0.01	0.02	0.1	0.5	95	2.068	815.5*	4.46	--	0.00023
31	200	500	0.1	0.7	130	8500 est.	--	1.267	911.7*	1.883	--	0.00005
33	150	500	2.0	44	>10,000 est.	--	--	0.815	956.4*	1.093	--	0.00002

*Test discontinued at time indicated.

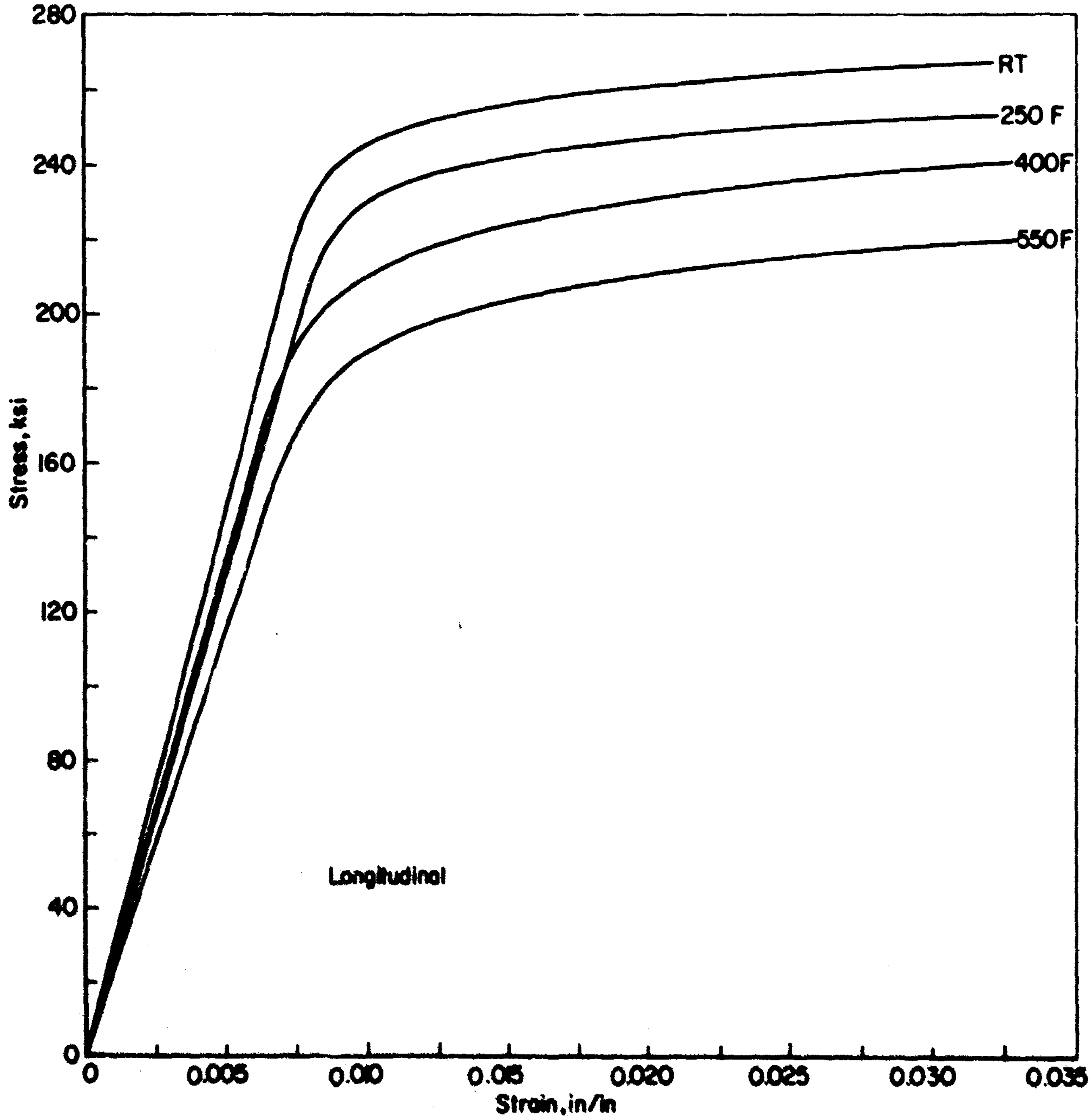


FIGURE 51. TYPICAL TENSION STRESS-STRAIN CURVES FOR 300M FORGINGS AT TEMPERATURE

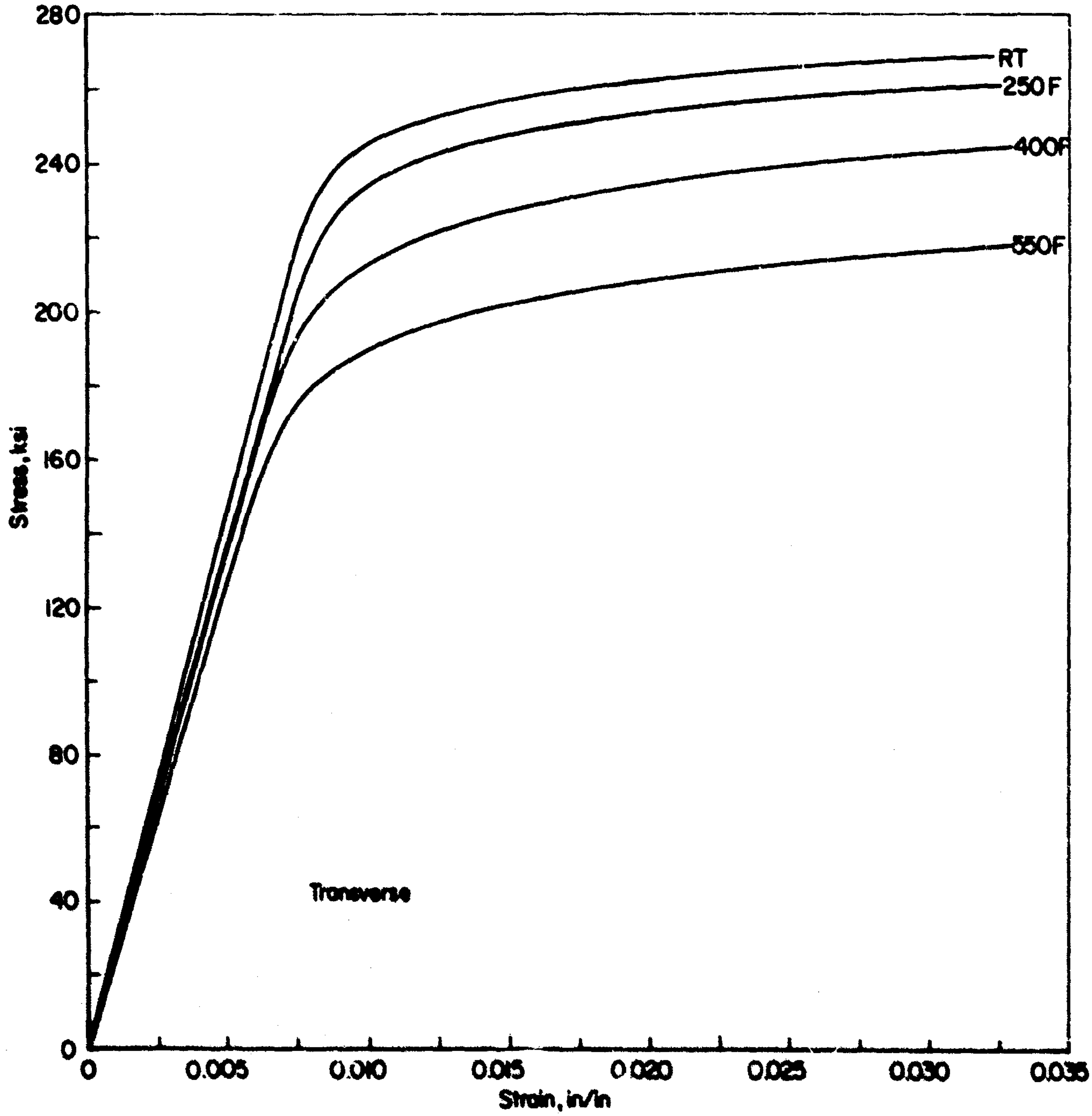


FIGURE 52. TYPICAL TENSION STRESS-STRAIN CURVES FOR 300M FORGINGS AT TEMPERATURE

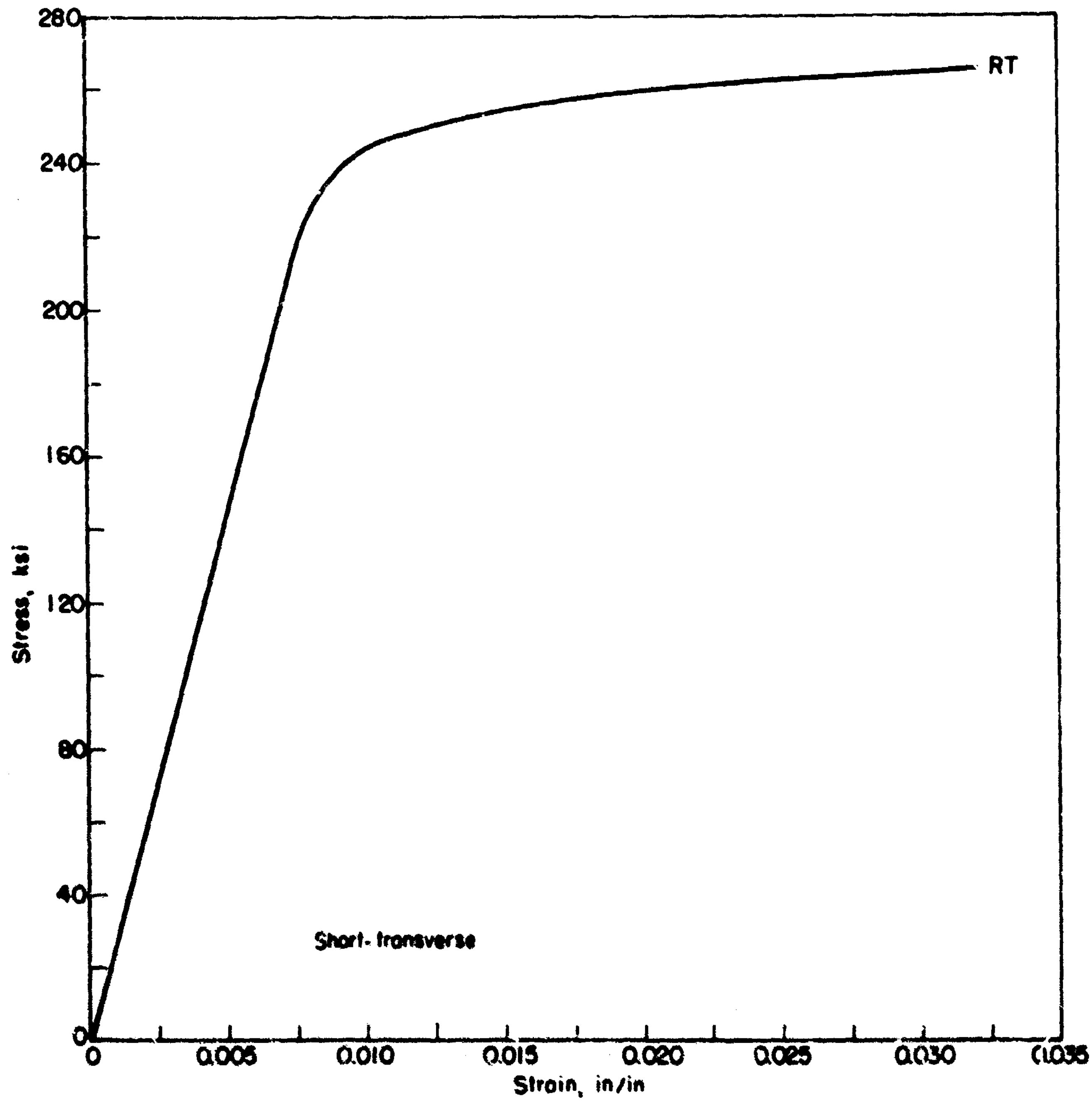


FIGURE 53. TYPICAL TENSION STRESS-STRAIN CURVE FOR 300M FORGINGS AT ROOM-TEMPERATURE

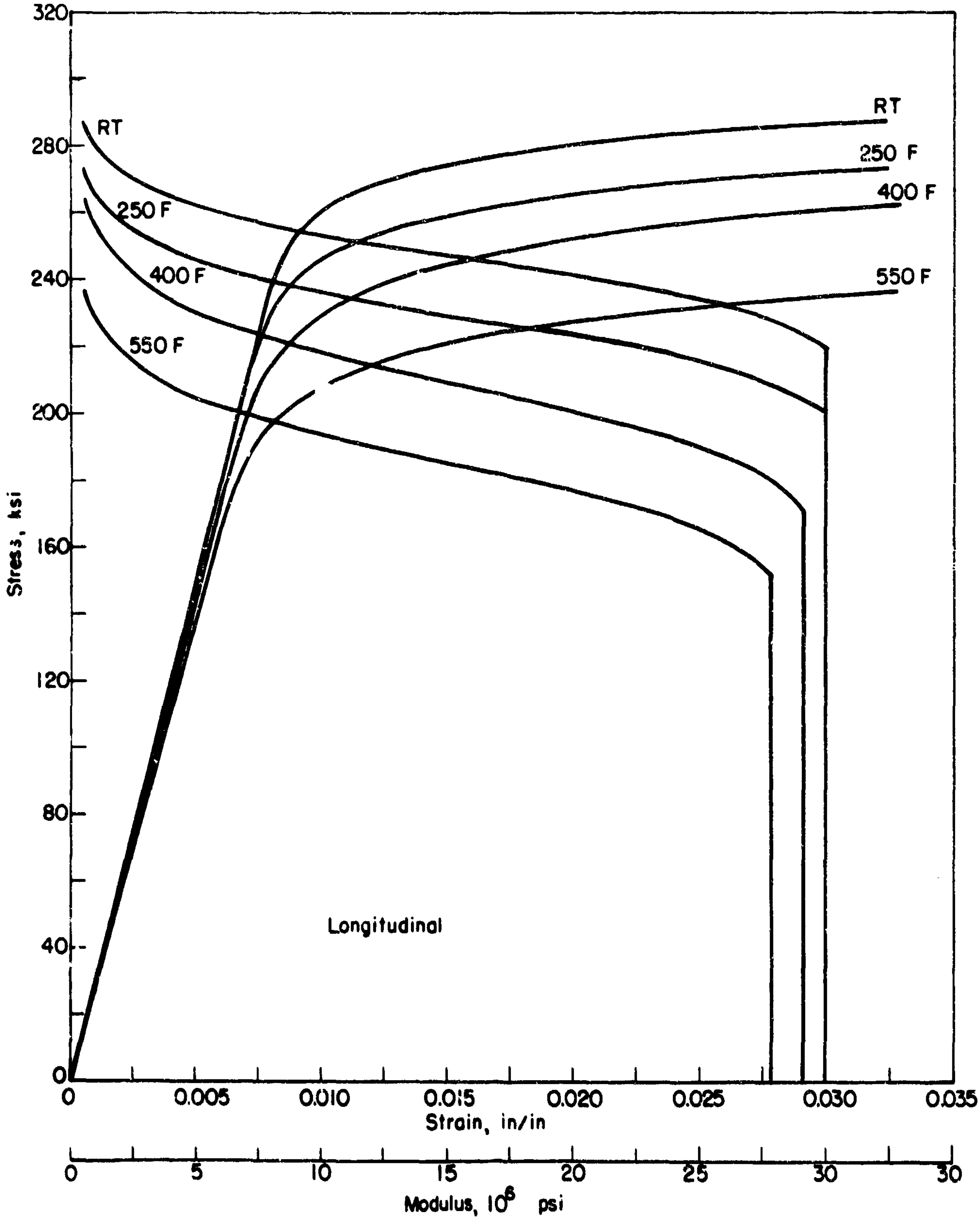


FIGURE 54. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 300M FORGINGS AT TEMPERATURE

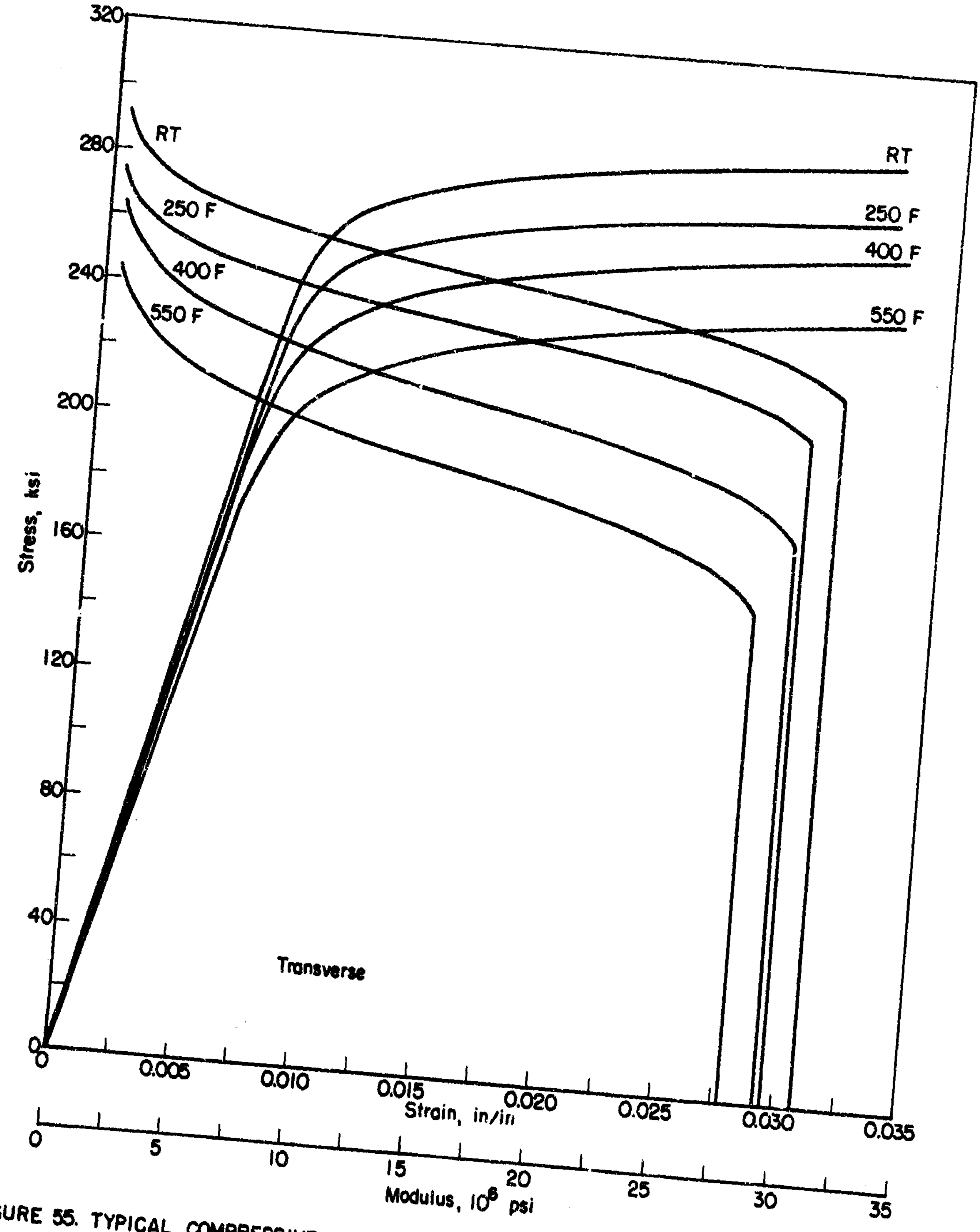


FIGURE 55. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 300M FORGING AT TEMPERATURE

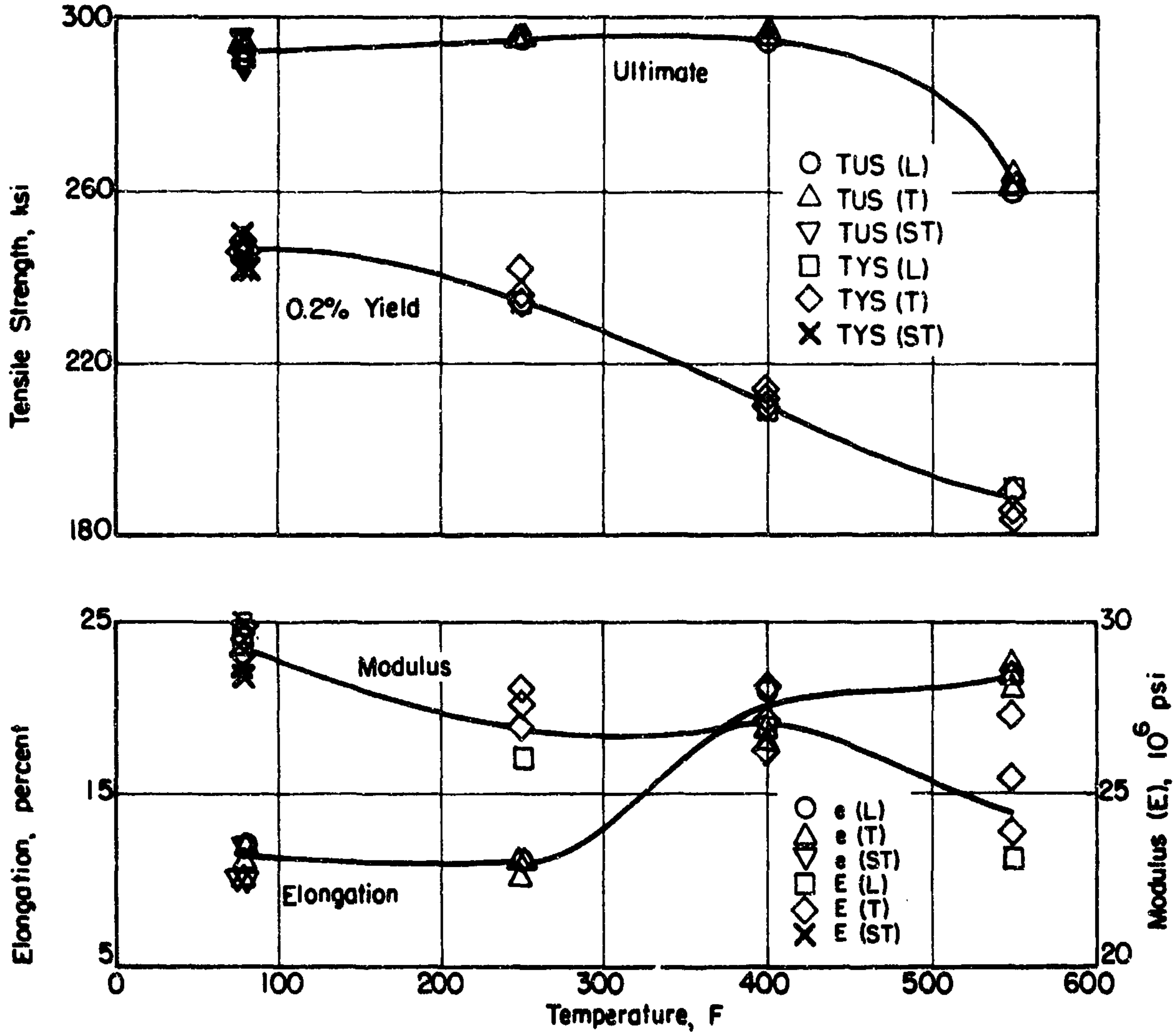


FIGURE 56 EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 300M FORGINGS

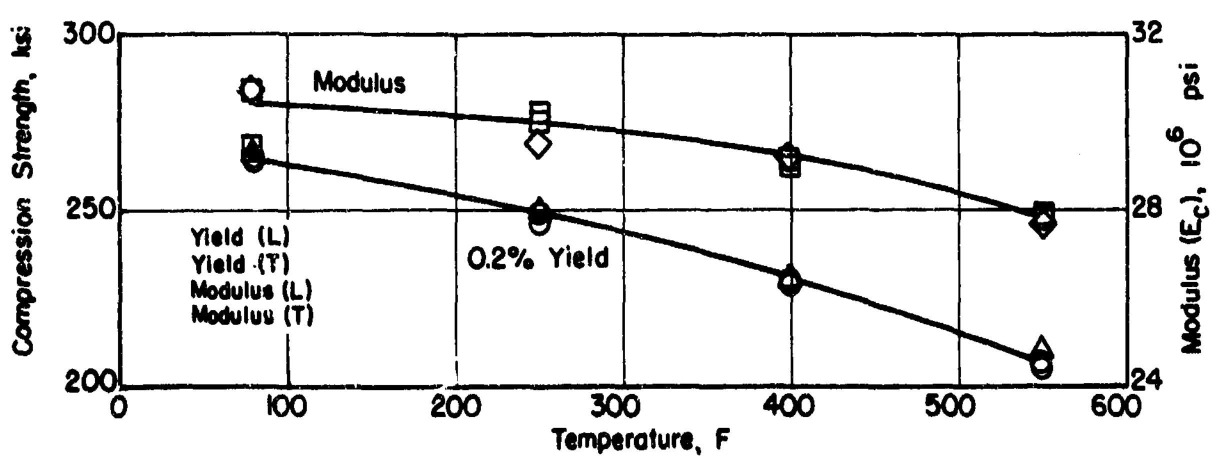


FIGURE 57. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 300M FORGINGS

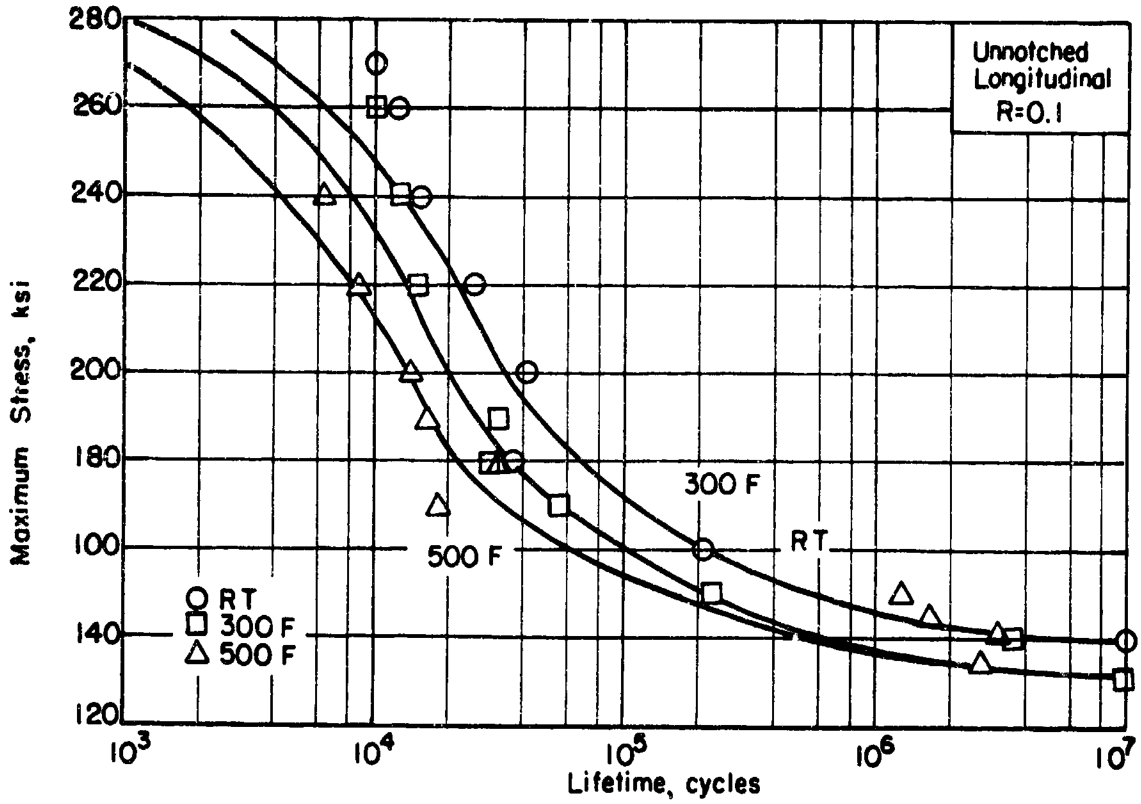


FIGURE 58. AXIAL LOAD FATIGUE RESULTS FOR 300M FORGINGS

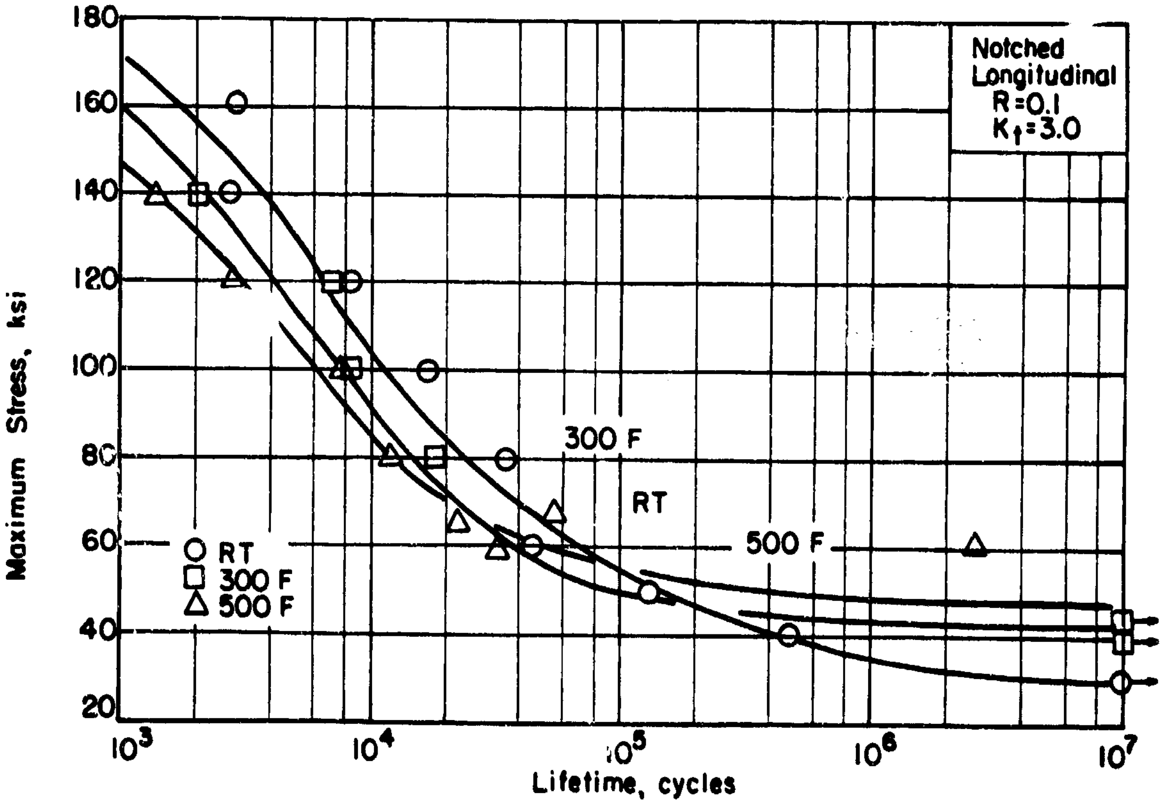


FIGURE 59. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 300M FORGINGS

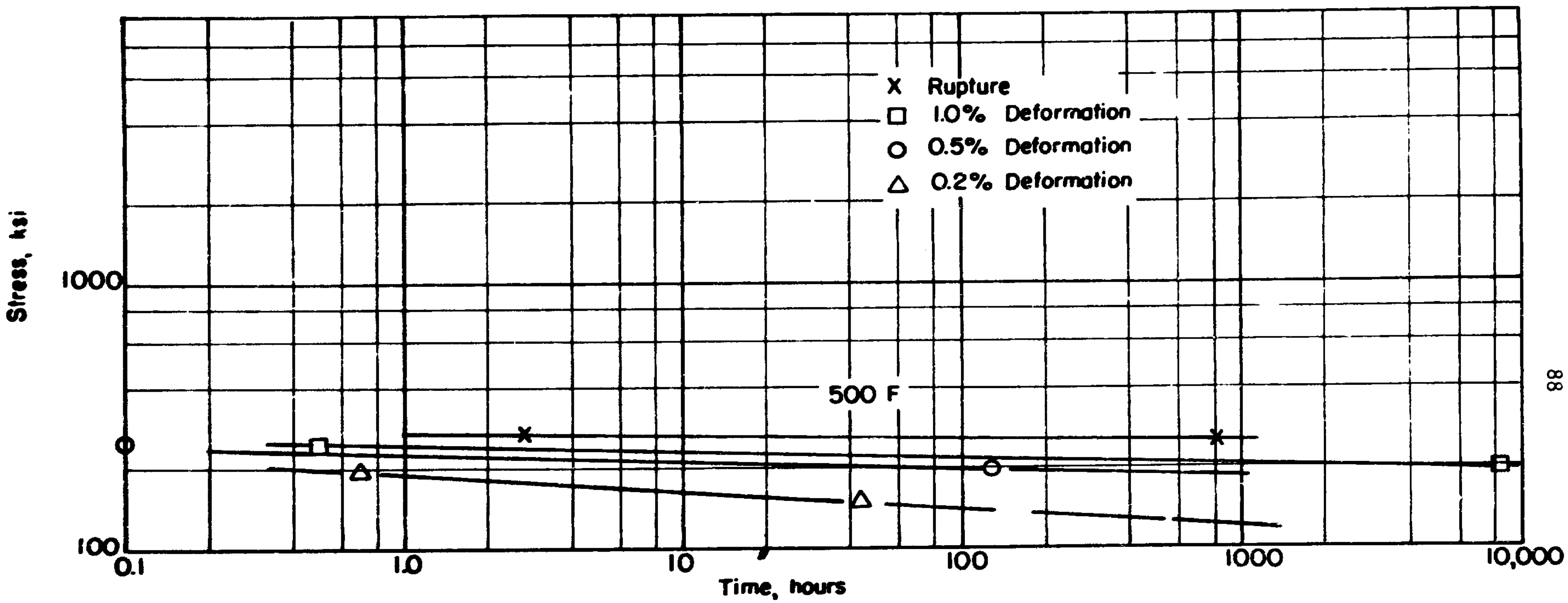


FIGURE 60. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 300M FORGINGS

7049 Aluminum Forging

Material Description

7049 alloy is a recent development of Kaiser Aluminum and Chemical Corporation. It is designed to have a strength level in the range of 7075-T6 and 7079-T6, coupled with a high resistance to stress corrosion cracking. The temper designation -T73 has been assigned to cover the alloy with these characteristics. The initial development and production has been in the form of hand and die forgings.

The threshold level for stress-corrosion cracking is reported by Kaiser to be 45 ksi.

Two hand forgings, 5 inches x 18 inches x 15 inches were received from Kaiser for this evaluation. The composition of these forgings was as follows:

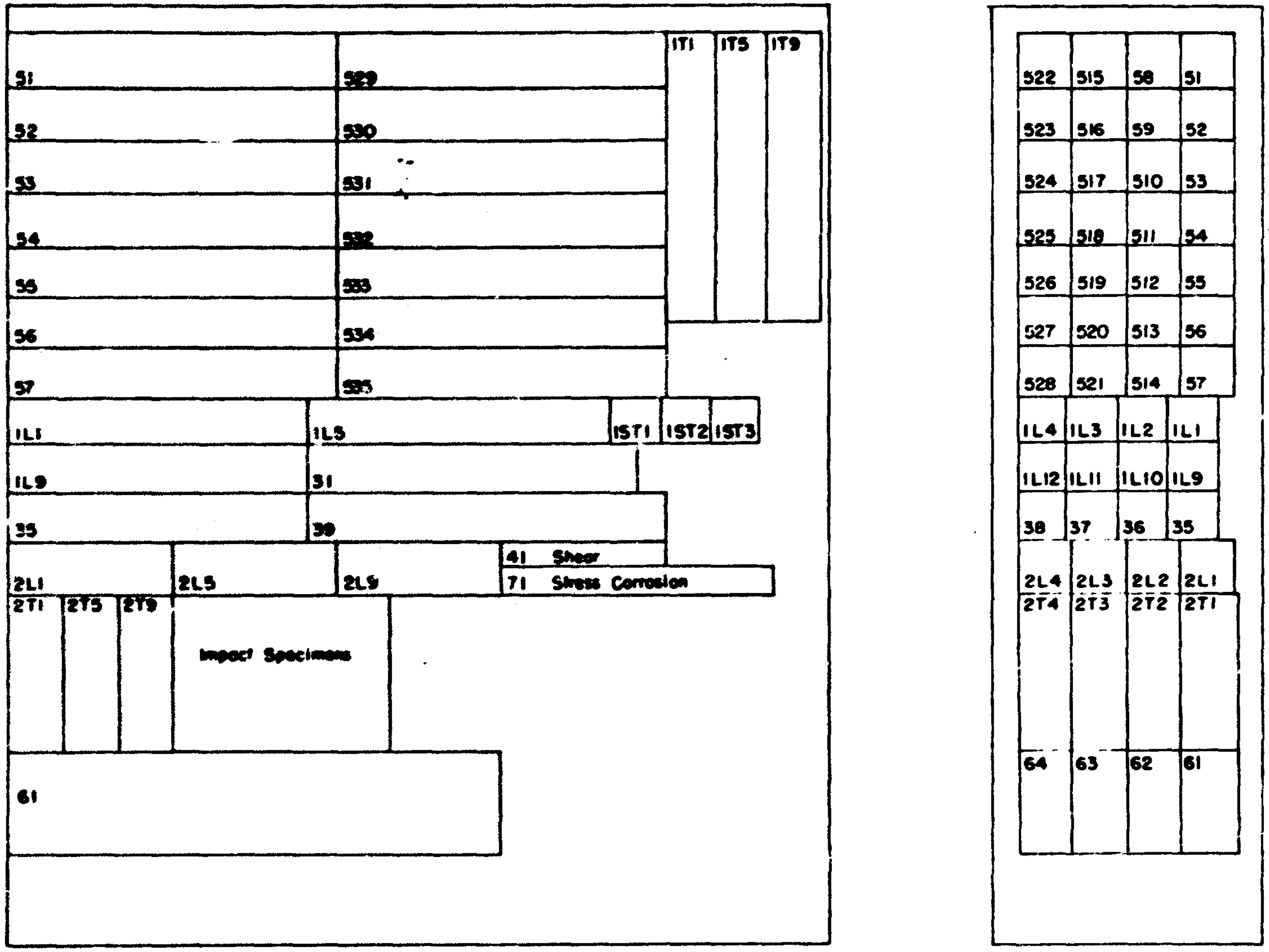
Chemical Composition	Percent
Silicon	0.07
Iron	0.13
Manganese	0.01
Copper	1.48
Magnesium	2.45
Chromium	0.16
Zinc	7.50
Aluminum	Balance

Processing and Heat Treating

The specimen layout for 7049 is shown in Figure 61. The material was tested in the -T73 temper.

Test Results

Tension. Longitudinal and transverse test results at room temperature, 250F, 350F, and 500F are given in Table 25-A. Short transverse test results at room temperature only are also shown in Table 25-A. Stress-strain curves at temperature are presented in Figures 62, 63, and 64. Effect-of-temperature curves are shown in Figure 67.



Specimen Code

Prefix
1 Tension
2 Compression
3 Creep
4 Shear
5 Fatigue
6 Fracture Toughness
7 Stress Corrosion
8 Impact

FIGURE 61 SPECIMEN LAYOUT FOR 7049 FORGING

Compression. Tests were performed at room temperature, 250F, 350F, and 500F for both longitudinal and transverse specimens. Results are given in Table 26. Stress-strain and tangent modulus curves are shown in Figures 65 and 66. Effect-of-temperature curves are presented in Figure 68.

Shear. Test results at room temperature for longitudinal and transverse specimens are shown in Table 27.

Impact. Charpy V-notch test results at room temperature, -100F, and -320F are shown in Table 28.

Fracture Toughness. Results of slow-bend type tests are given in Table 29.

Fatigue. Axial-load fatigue tests were conducted at room temperature, 250F, and 350F. Tabular test results are given in Tables 30 and 31. S-N curves are presented in Figures 69 and 70.

Creep and Stress Rupture. Tests were performed at 250F, 350F, and 500F. Results are presented in Table 32 and Figure 71.

Stress Corrosion. No cracks were evident in the specimens after testing as described in the experimental procedure section.

Thermal Expansion and Density. Thermal expansion measurements are given in Table 33. The value of density was determined to be 0.102 lb/in^3.

TABLE 25-A. TENSION TEST RESULTS FOR 7049-T73 ALUMINUM FORGINGS

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Longitudinal at Room Temperature		
1L-1	77.9	71.9	5.0	10.4
1L-2	70.5	60.5	11.0	9.7
1L-3	70.2	60.3	10.5	10.4
		Transverse at Room Temperature		
1T-1	77.3	69.1	13.0	10.6
1T-2	73.4	64.8	10.0	10.5
1T-3	74.1	65.5	10.0	10.6
		Short Transverse at Room Temperature		
1ST-1	70.4	60.0	6.0	9.9
1ST-2	70.7	62.6	6.0	10.3
1ST-3	71.6	63.0	6.0	9.5
		Longitudinal at 250 F		
1L-4	64.9	62.4	11.0	9.4
1L-5	64.5	63.2	12.0	10.2
1L-6	57.1	53.6	21.5	10.1
		Transverse at 250 F		
1T-4	63.5	61.5	14.5	9.6
1T-5	62.2	59.7	16.5	10.4
1T-6	61.3	59.0	16.0	10.7
		Longitudinal at 350 F		
1L-7	45.4	44.6	25.0	9.1
1L-8	52.1	51.7	16.0	8.4
1L-9	51.5	50.6	19.0	9.0
		Transverse at 350 F		
1T-7	49.3	48.6	20.0	8.6
1T-8	50.3	49.6	18.0	8.1
1T-9	51.4	50.2	16.0	8.0
		Longitudinal at 500 F		
1L-10	15.6	15.5	28.0	7.7
1L-11	16.2	16.1	27.0	5.8
1L-12	18.3	18.2	33.0	7.7
		Transverse at 500 F		
1T-10	18.1	18.0	32.0	6.9
1T-11	17.3	17.2	29.0	7.5
1T-12	19.0	18.8	30.0	6.2

TABLE 26. COMPRESSION TEST RESULTS FOR 7049-T73 ALUMINUM FORGINGS

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Longitudinal at Room Temperature	
2L-1	74.0	10.6
2L-2	63.4	10.4
2L-3	63.0	10.7
	Transverse at Room Temperature	
2T-1	73.5	10.5
2T-2	64.4	10.7
2T-3	65.0	10.6
	Longitudinal at 250 F	
2L-4	66.8	9.0
2L-5	67.3	10.3
2L-6	58.0	8.9
	Transverse at 250 F	
2T-4	66.0	9.6
2T-5	65.9	10.1
2T-6	58.1	9.1
	Longitudinal at 350 F	
2L-7	47.7	8.2
2L-8	55.8	8.0
2L-9	56.5	8.9
	Transverse at 350 F	
2T-7	49.8	8.8
2T-8	54.8	8.9
2T-9	51.0	8.2
	Longitudinal at 500 F	
2L-10	18.0	--
2L-11	19.4	8.3
2L-12	23.9	8.1
	Transverse at 500 F	
2T-10	17.7	7.8
2T-11	20.1	7.7
2T-12	20.3	8.1

TABLE 27. SHEAR TEST RESULTS FOR 7049-T73 ALUMINUM FORGINGS AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
	Longitudinal
4L-1	48.0
4L-2	48.0
4L-3	47.5
	Transverse
4T-1	47.7
4T-2	47.7
4T-3	47.8

TABLE 28. 2/3-SIZE CHARPY V-NOTCH IMPACT TEST RESULTS FOR 7049-T73 ALUMINUM FORGINGS

Specimen Number	Test Temperature, F	Impact Energy, ft/lb
1	RT	3.0
2	RT	5.5
3	RT	4.0
4	-100	2.0
5	-100	4.5
6	-100	4.0
7	-320	3.5
8	-320	3.0
9	-320	3.0

TABLE 29. FRACTURE TOUGHNESS TEST RESULTS FOR 7049-T73 ALUMINUM FORGINGS

Specimen Number	Width, Inches	Crack Length, Inches	Span, Inches	K_{Ic}, ksi$\sqrt{in.}$
6-1	2.002	1.003	8.0	35.4*
6-2	2.002	1.003	8.0	29.7
6-3	2.002	1.003	8.0	28.6
6-4	2.001	1.003	8.0	33.1

*Marginal value.

TABLE 30. AXIAL-LOAD FATIGUE TEST RESULTS FOR 7049-T73 ALUMINUM FORGINGS, LONGITUDINAL, UNNOTCHED AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-28	80.0	320
5-19	70.0	4,510
5-10	65.0	18,040
5-23	60.0	66,690
5-13	55.0	142,060
5-26	50.0	347,430
5-6	45.0	11,164,730[a]
	250 F	
5-18	75.0	1
5-5	70.0	7,700
5-24	60.0	15,500
5-9	50.0	125,760
5-17	50.0	132,600
5-16	45.0	12,849,400[a]
5-15	40.0	17,000,000[a]
	350 F	
5-7	70.0	5,693
5-4	65.0	21,040
5-29	60.0	22,610
5-2	55.0	121,110
5-3	50.0	105,090
5-27	45.0	95,630
5-1	40.0	7,291,370

(a) Did not fail.

TABLE 31. AXIAL-LOAD FATIGUE TEST RESULTS FOR 7049-T73 ALUMINUM FORGINGS, LONGITUDINAL, NOTCHED (K_t = 3.0), AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-49	45.0	2,910
5-40	40.0	6,460
5-47	35.0	10,960
5-46	30.0	18,930
5-31	25.0	43,080
5-30	20.0	90,060
5-45	17.5	5,231,450
5-38	15.0	10,101,000(a)
	250 F	
5-43	45.0	5,240
5-50	40.0	6,530
5-39	35.0	12,910
5-52	30.0	32,810
5-29	25.0	61,700
5-34	20.0	112,500
5-44	15.0	3,000,000
5-56	12.5	11,400,000(a)
	350 F	
5-48	60.0	1,360
5-36	50.0	2,300
5-55	40.0	7,950
5-53	30.0	19,850
5-37	25.0	37,610
5-51	20.0	95,420
5-32	15.0	305,500
5-35	10.0	3,735,920 (?)

(a) Did not fail.

TABLE 32. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR 7049-T73 ALUMINUM FORGINGS

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hr	Elongation in 2 Inches, percent	Reduction of Area, percent	Minimum Creep Rate, percent/hr.
			0.1	0.2	0.5	1.0	2.0					
39	50	250										
		250						Scheduled				
31	40	250	49	280	680	925	1115	"				
35	35	350	1.8	3.4	5.6	8.4	10.5	0.474	1209.3			0.0004
36	25	350	4.0	7.6	15.7	23.5	28.1	0.492	11.4	16.6	53.7	0.10
40	10	350	4.1					0.364	32.3	14.9	71.0	0.020
32	15	500	--	--	--	--	--	0.221	335			
33	10	500	--	--	0.02	0.05	0.15	--	On load	48.0	91.0	--
37	7	500	0.6	1.5	4.0	5.6	10.5	1.64	0.3	49.0	94.4	--
34	5	500	16	35	80	125	175	0.106	15.4	25.5	90.5	0.010
38	35	500	100					0.062	308.4	27.7	91.0	0.005
								0.053	167(a)	0.198		

TABLE 33. MEAN LINEAR THERMAL EXPANSION COEFFICIENTS OF 7049-T73 ALUMINUM FORGINGS

Temperature Range, F	Coefficient, α, 10^{-6} in/in/F
68-100	11.25
68-150	11.71
68-200	12.12
68-250	12.55
68-300	12.97
68-350	13.30

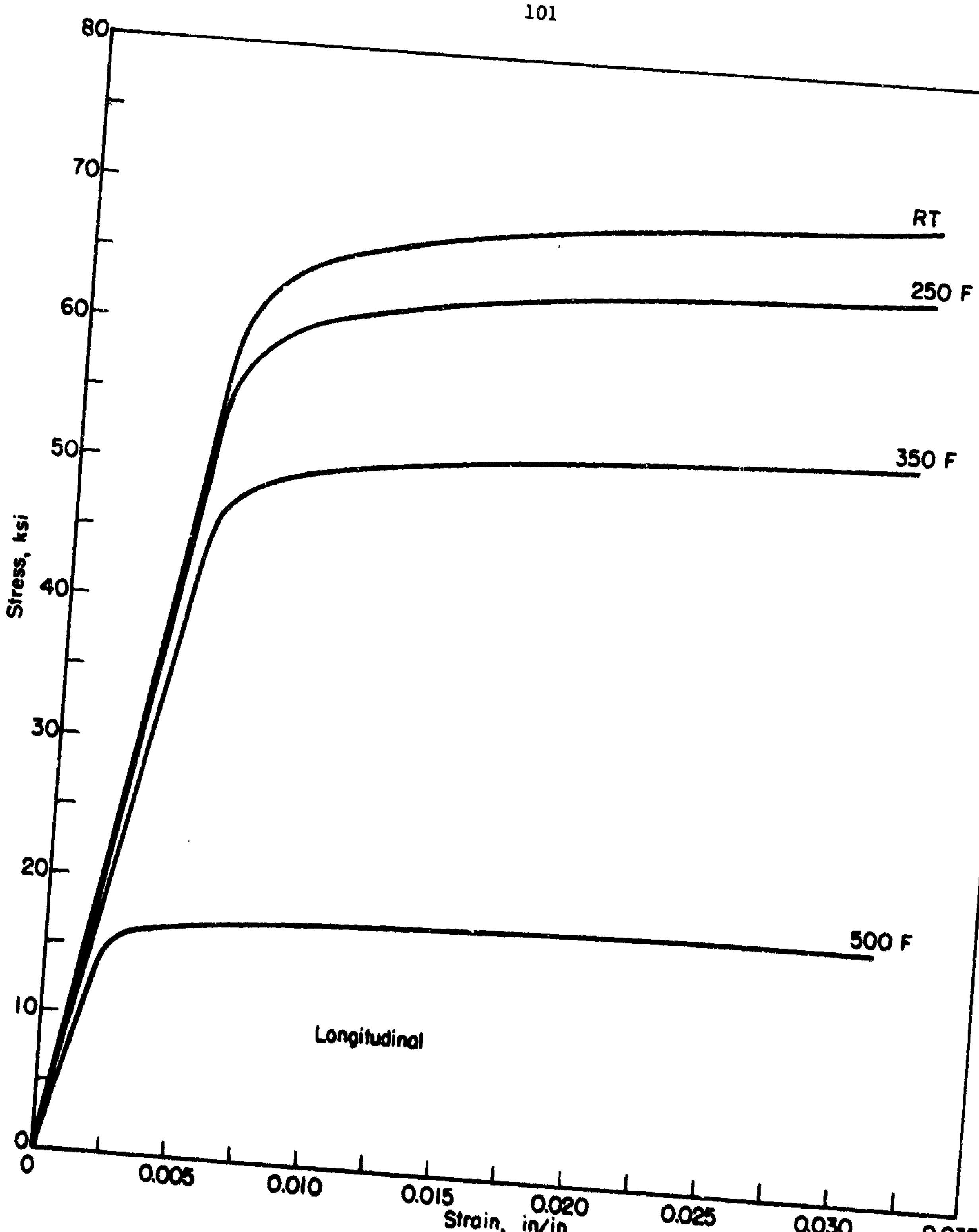


FIGURE 62. TYPICAL TENSION STRESS-STRAIN CURVES FOR 7049-T73 FORGINGS AT TEMPERATURE

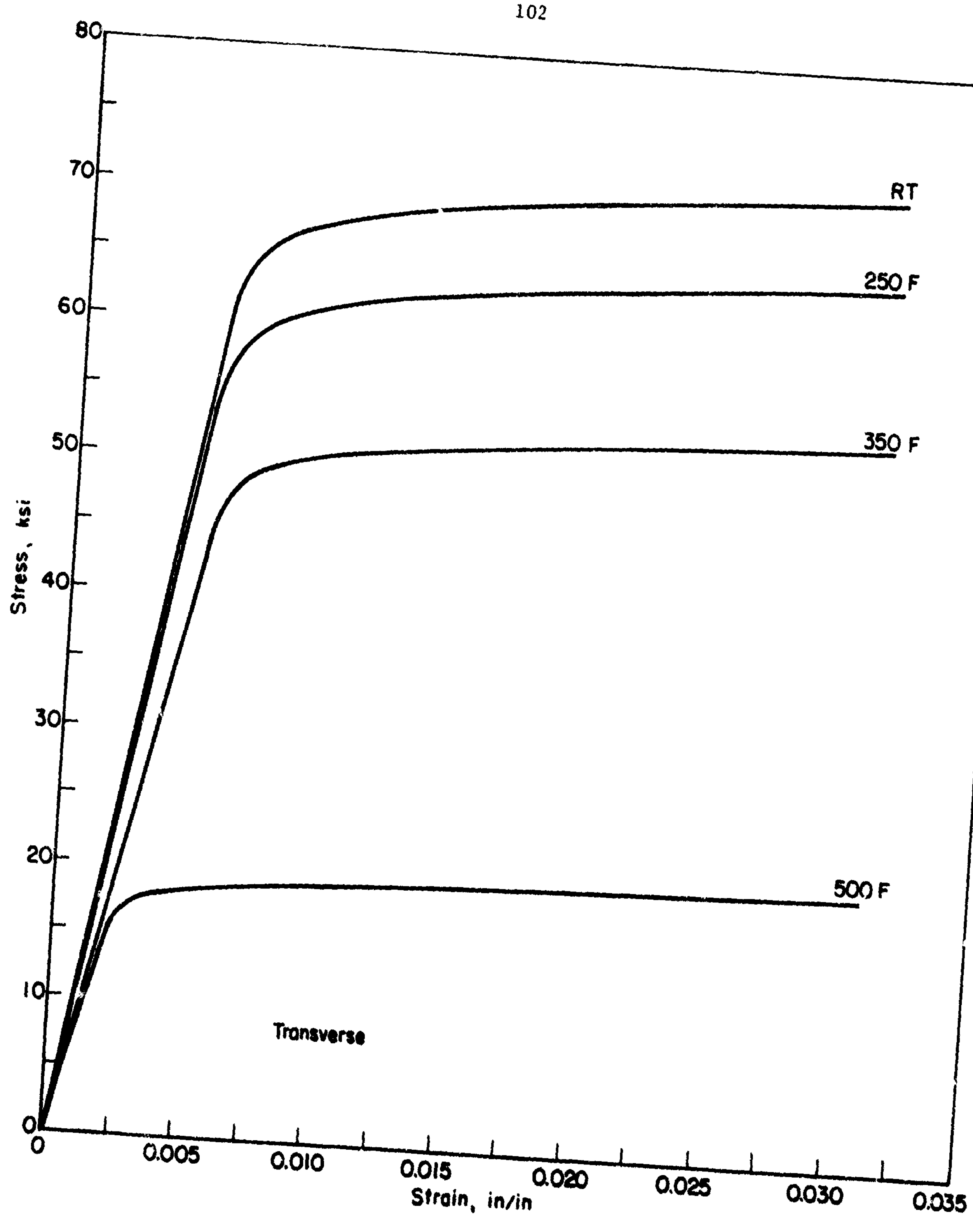


FIGURE 63. TYPICAL TENSION STRESS-STRAIN CURVES FOR 7049-T73 FORGINGS AT TEMPERATURE

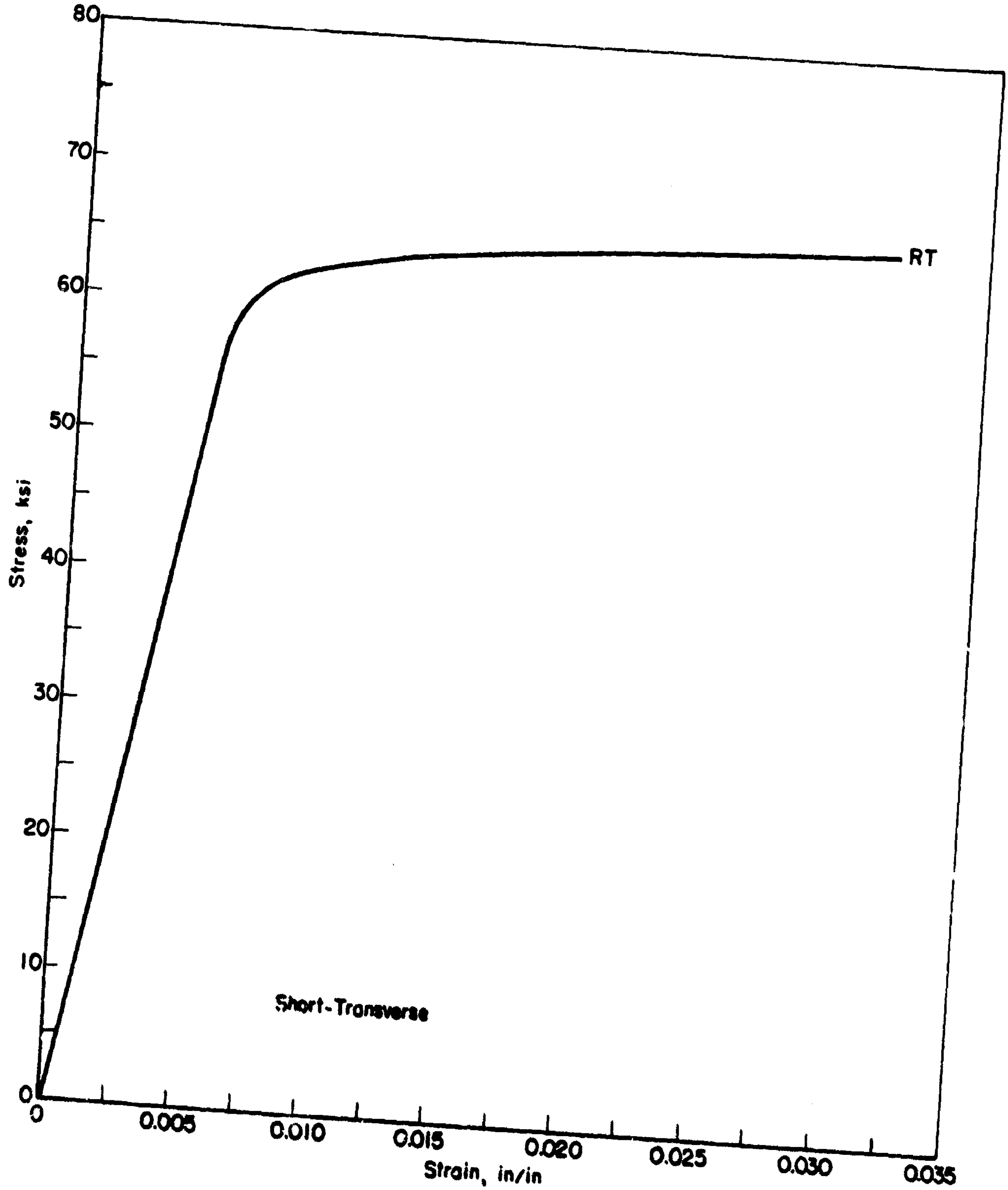


FIGURE 64. TYPICAL TENSION STRESS-STRAIN CURVE FOR 7049-T73 FORGINGS AT ROOM TEMPERATURE

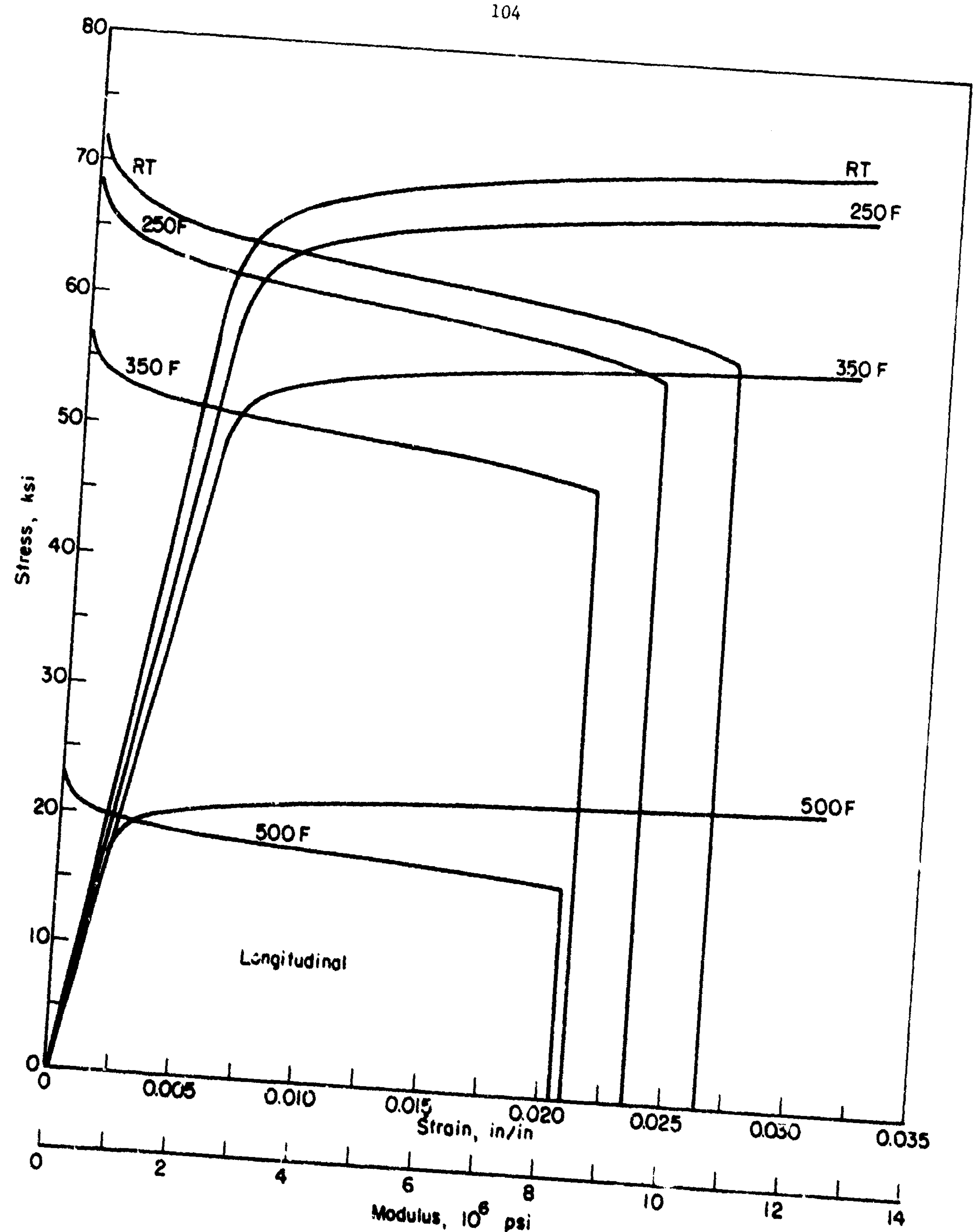


FIGURE 65. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 7049-T73 FORGINGS AT TEMPERATURE

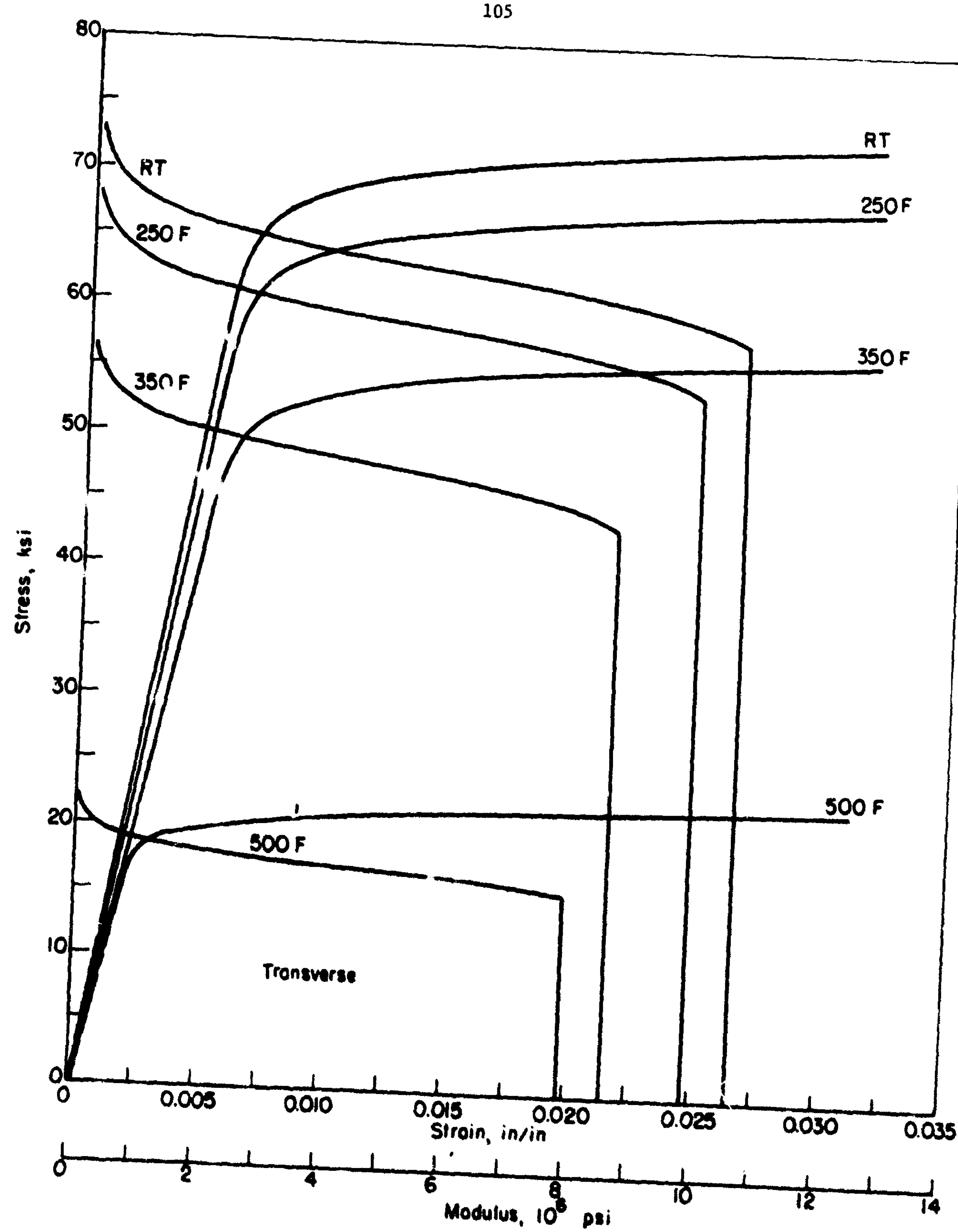


FIGURE 66. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 7049-T73 FORGINGS AT TEMPERATURE

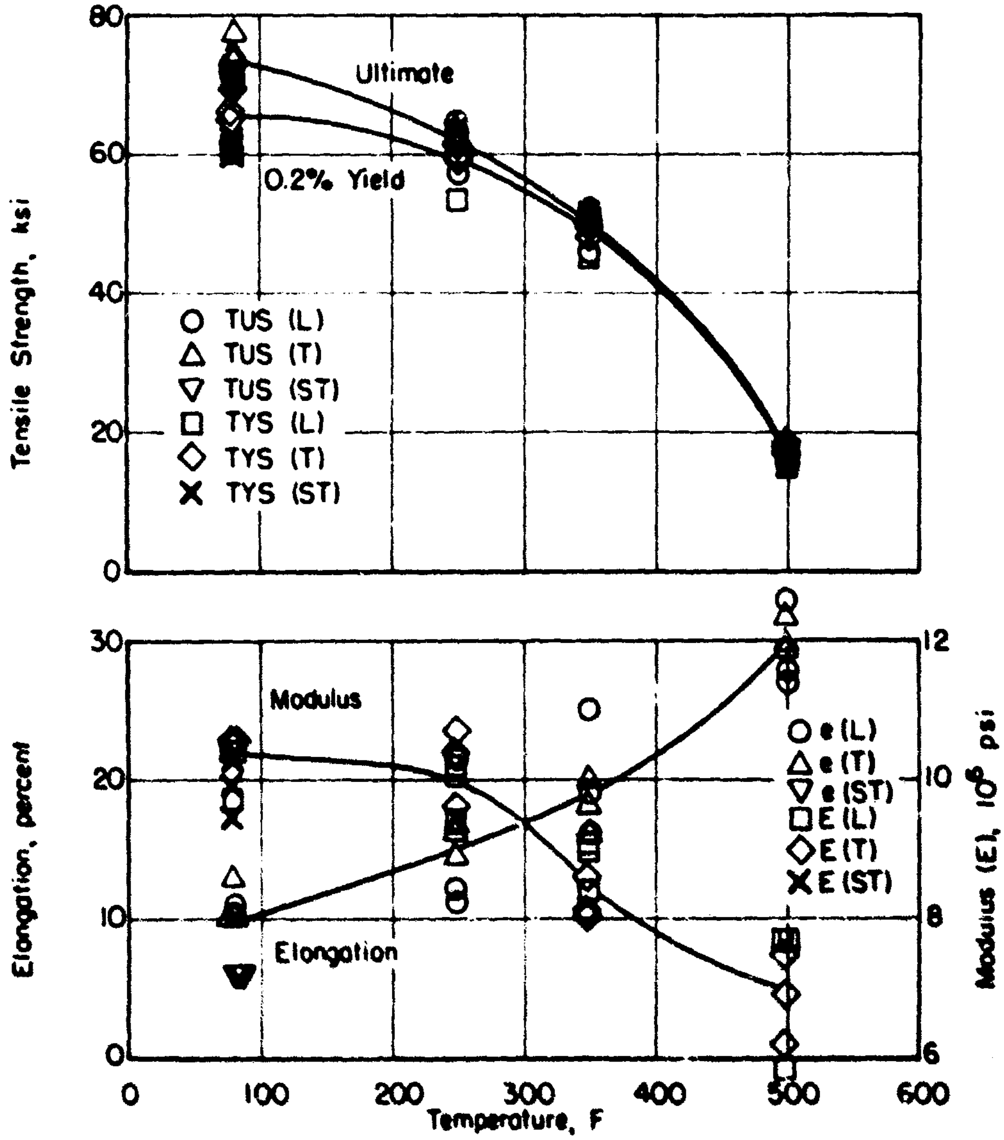


FIGURE 67. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7049-T73 ALUMINUM FORGINGS

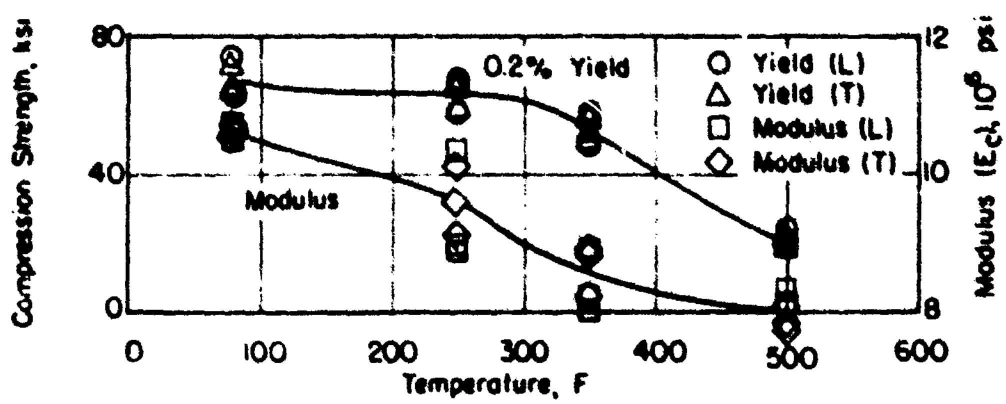


FIGURE 68. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF 7049-T73 ALUMINUM FORGINGS

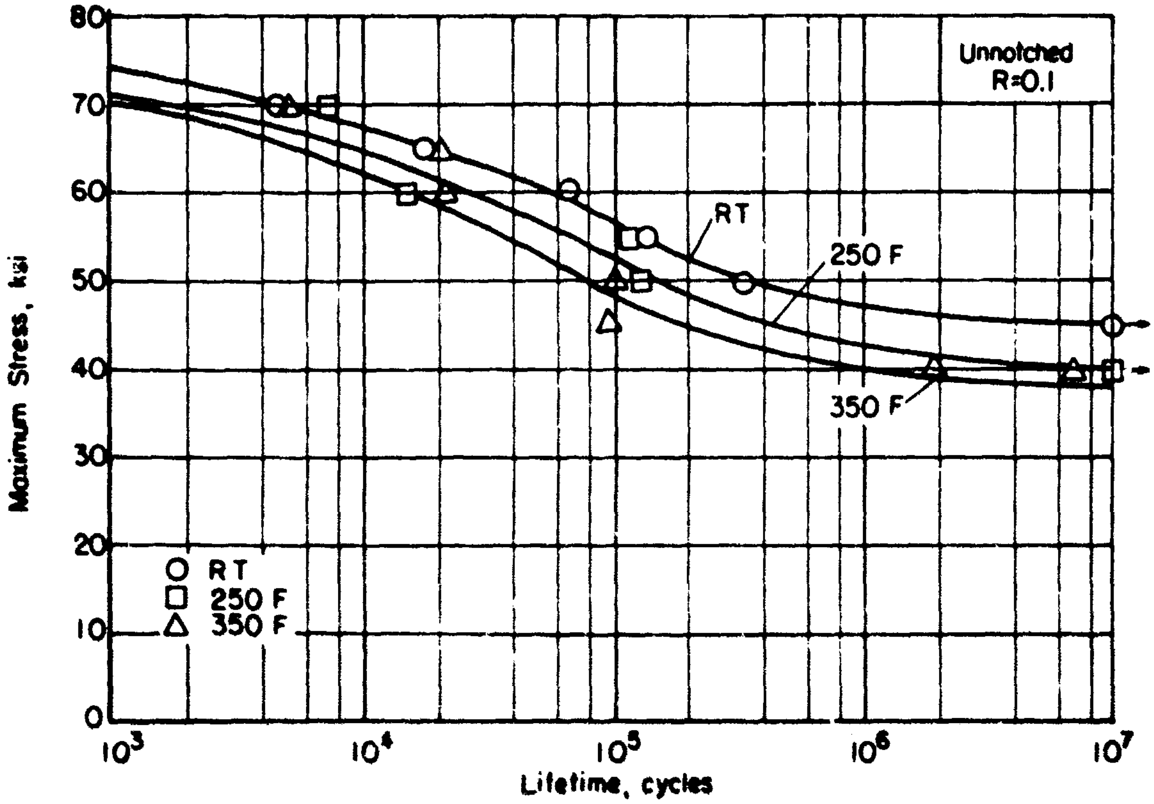


FIGURE 69. AXIAL LOAD FATIGUE RESULTS FOR 7049-T73 ALUMINUM FORGINGS

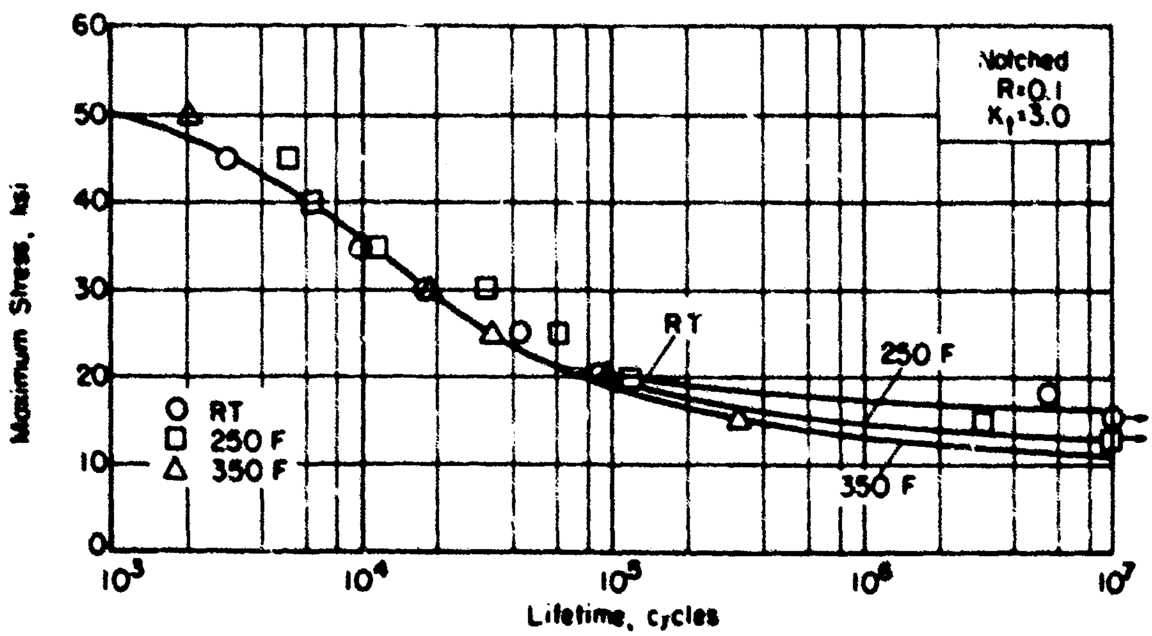


FIGURE 70. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 7049-T73 ALUMINUM FORGINGS

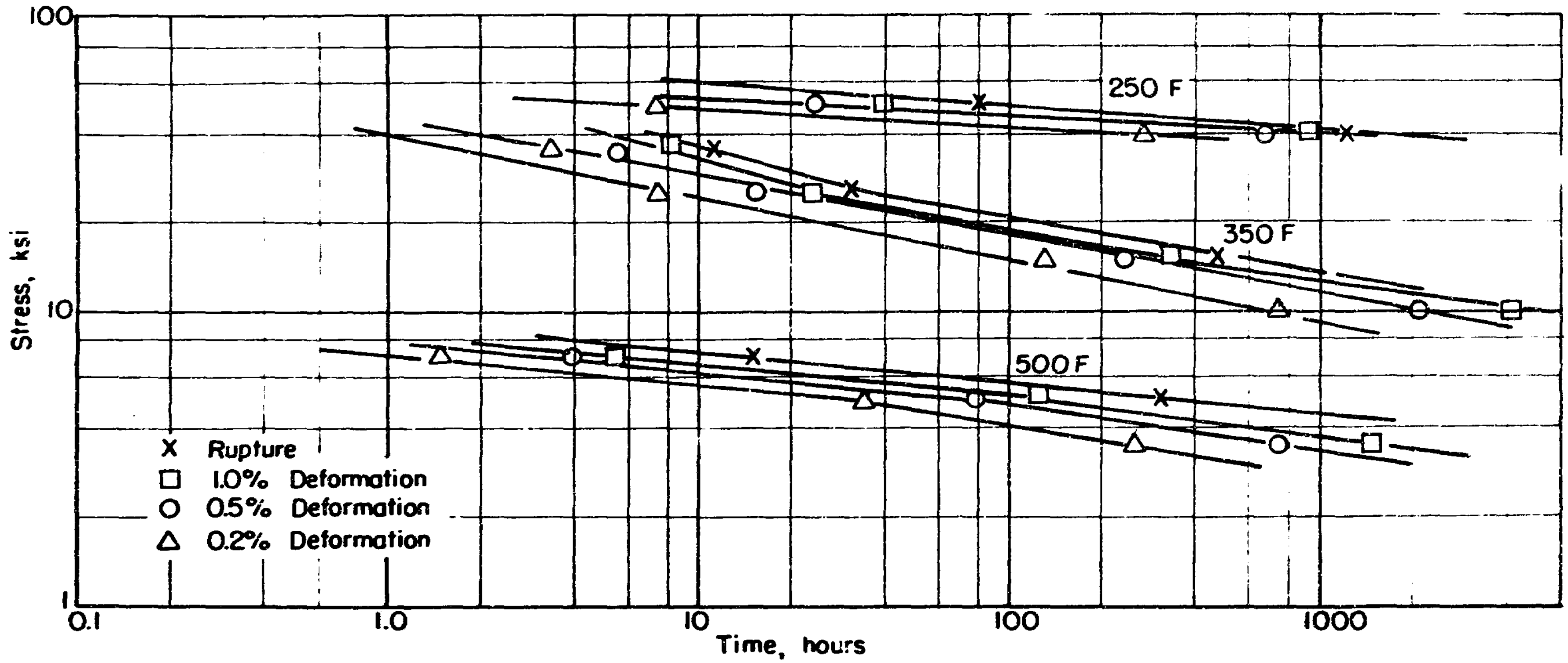


FIGURE 71. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7049-T73 ALUMINUM FORGINGS

7178 Aluminum Sheet

Material Description

Alloy 7178 is a heat-treatable aluminum alloy containing zinc, copper, and magnesium as hardeners. At present it is one of the strongest wrought aluminum alloys produced. Its general properties are similar to these of 7075, but its use is limited to a rather narrow range of thickness due to its limited hardenability.

The -T76 temper evaluated under this program was developed as a compromise between the exfoliation resistance of 7075-T73 and the structural capability of 7075-T6. It was to achieve an increase in resistance to exfoliation over that of 7075-T6 while maintaining a high level of strength and fracture toughness characteristics.

The nominal composition of 7178 alloy is as follows:

Chemical Composition	Percent
Silicon	0.50
Iron	0.70
Copper	1.6-2.4
Manganese	0.30
Magnesium	2.4-3.1
Chromium	0.18-0.40
Zinc	6.3-7.3
Titanium	0.20
Aluminum	Balance

Processing and Heat Treating

The specimen layout for 7178 is shown in Figure 72. The material was evaluated in the -T76 temper.

Test Results

Tension. Tests were performed at room temperature 250F, 350F, and 500F in both the longitudinal and transverse directions. Tabular test results are presented in Table 34. Stress-strain curves at temperature are shown in Figures 73 and 74. Effect-of-temperature curves are presented in Figure 77.

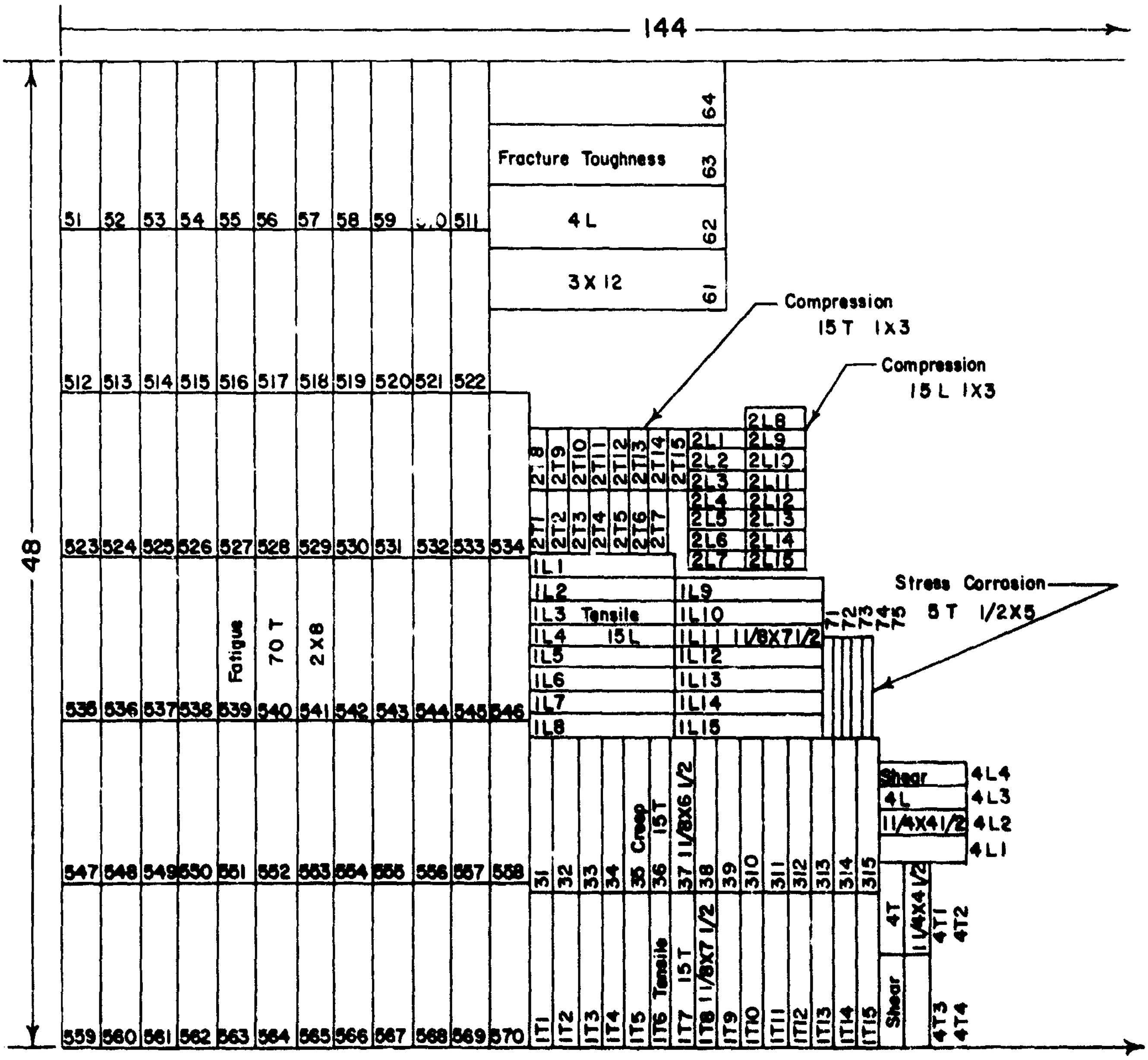


FIGURE 72. SPECIMEN LAYOUT FOR 7178 ALUMINUM

Compression. Tests were performed at room temperature, 250F, 350F, and 500F in both the longitudinal and transverse directions. Test results are given in tabular form in Table 35. Stress-strain and tangent modulus curves are shown in Figures 75 and 76. Effect-of-temperature curves are presented in Figure 78.

Shear. Test results at room temperature for the longitudinal and transverse direction are given in Table 36.

Fracture Toughness. Fracture toughness tests were conducted at room temperature and 250F on center-notched tensile type specimens. Results for room temperature tests are given in Table 37. Tests at 250F proved to be invalid by the existing criteria.

Fatigue. Axial-load fatigue tests were performed at room temperature, 250F, and 350F. Test results are given in Tables 38 and 39 and S-N curves are presented in Figures 79 and 80.

Creep and Stress Rupture. Tests were conducted at 350F, 450F, and 600F. Tabular results are presented in Table 40. Log stress versus log time curves are presented in Figure 81.

Stress Corrosion. No cracks were experienced in the specimens after testing as described in the experimental procedure section.

Thermal Expansion and Density. Values for these properties are given in the "data sheet" in the conclusions section.

TABLE 34. TENSION TEST RESULTS FOR 7178-T76 ALUMINUM SHEET

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Longitudinal at Room Temperature		
1L-1	80.2	71.7	11.5	10.0
1L-2	80.1	71.8	10.0	10.0
1L-3	80.2	71.6	10.5	10.1
		Transverse at Room Temperature		
1T-1	84.0	71.0	9.0	10.2
1T-2	83.6	70.3	9.0	10.0
1T-3	85.0	71.8	10.5	10.2
		Longitudinal at 250 F		
1L-4	64.0	63.6	13.5	9.5
1L-5	63.9	63.3	17.0	9.7
1L-6	63.6	63.1	14.0	9.6
		Transverse at 250 F		
1T-4	64.6	61.5	16.5	10.4
1T-5	66.7	63.8	18.5	10.0
1T-6	65.0	62.0	14.5	9.9
		Longitudinal at 350 F		
1L-7	50.3	49.9	17.0	8.6
1L-8	50.5	50.2	16.0	8.5
1L-9	51.9	50.4	16.0	8.6
		Transverse at 350 F		
1T-7	52.3	50.1	17.0	9.8
1T-8	52.4	50.7	17.0	9.3
1T-9	50.3	48.6	19.0	9.1
		Longitudinal at 500 F		
1L-10	20.9	20.2	23.5	6.7
1L-11	18.4	17.9	27.5	--
1L-12	16.9	16.6	23.5	6.0
		Transverse at 500 F		
1T-10	17.7	17.3	24.0	7.7
1T-11	17.3	17.0	22.5	6.7
1T-12	17.2	16.8	23.0	7.4

TABLE 35. COMPRESSION TEST RESULTS FOR 7178-T76 ALUMINUM SHEET

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Longitudinal at Room Temperature	
2L-1	76.2	10.5
2L-2	76.3	10.5
2L-3	76.1	10.5
	Transverse at Room Temperature	
2T-1	80.4	11.0
2T-2	80.4	10.9
2T-3	80.2	10.9
	Longitudinal at 250 F	
2L-4	69.1	10.2
2L-5	69.6	10.3
2L-6	70.1	10.1
	Transverse at 250 F	
2T-4	73.4	10.2
2T-5	73.4	10.2
2T-6	73.8	10.3
	Longitudinal at 350 F	
2L-7	57.0	9.2
2L-8	57.4	9.1
2L-9	57.9	9.1
	Transverse at 350 F	
2T-7	60.3	10.1
2T-8	60.8	10.1
2T-9	60.8	10.1
	Longitudinal at 500 F	
2L-10	20.9	8.5
2L-11	20.3	8.6
2L-12	19.3	8.8
	Transverse at 500 F	
2T-10	19.7	8.9
2T-11	19.3	9.2
2T-12	19.7	8.8

TABLE 36. SHEAR TEST RESULTS FOR 7178-T76 ALUMINUM SHEET AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
	Longitudinal
4L-1	54.0
4L-2	53.5
4L-3	53.1
4L-4	52.8
	Transverse
4T-1	53.2
4T-2	52.9
4T-3	54.0
4T-4	55.8

TABLE 37. FRACTURE TOUGHNESS TEST RESULTS FOR 7178-T76 ALUMINUM SHEET

Specimen Number	Thickness, Inches	Width, Inches	Crack Length, Inches	K_{Ic}, ksi$\sqrt{in.}$
6-1	0.207	2.998	1.50	30.3
6-2	0.206	2.998	1.43	27.7
6-3	0.206	2.997	1.53	26.3
6-4	0.205	2.996	1.55	26.5

TABLE 38. AXIAL-LOAD FATIGUE TEST RESULTS FOR 7178-T76 ALUMINUM SHEET, TRANSVERSE, UNNOTCHED, AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-24	85.0	3,400
5-8	80.0	5,800
5-9	75.0	9,300
5-10	65.0	17,500
5-11	55.0	34,700
5-2	50.0	48,300
5-12	45.0	36,600
5-13	40.0	83,100
5-26	35.0	120,700
5-3	30.0	12,442,900[a]
	250 F	
5-14	75.0	3,200
5-6	70.0	8,400
5-22	60.0	15,300
5-31	50.0	36,100
5-32	40.0	68,100
5-17	35.0	127,900
5-5	30.0	401,700
5-21	25.0	604,900
	350 F	
5-15	65.0	(b)
5-4	60.0	10,500
5-33	55.0	16,700
5-29	50.0	22,500
5-35	45.0	49,700
5-27	40.0	66,600
5-28	35.0	109,600
5-34	30.0	163,500
5-26	25.0	2,795,000
5-19	20.0	11,752,000[a]

(a) Did not fail.

(b) Failed on loading.

TABLE 39. AXIAL-LOAD FATIGUE TEST RESULTS FOR 7178-T76 ALUMINUM SHEET, TRANSVERSE, NOTCHED (K_t = 3.0), AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-47	50.0	2,000
5-43	40.0	4,100
5-50	35.0	7,200
5-51	25.0	34,500
5-69	20.0	198,000
5-67	17.5	12,423,400[a]
5-45	15.0	10,079,000[a]
	250 F	
5-70	40.0	2,900
5-41	30.0	10,100
5-66	25.0	21,500
5-56	20.0	32,300
5-68	15.0	655,100
5-52	12.5	10,126,500[a]
	350 F	
5-54	40.0	2,600
5-38	35.0	5,300
5-61	30.0	14,000
5-40	25.0	20,000
5-55	20.0	22,500
5-42	17.5	99,600
5-37	15.0	178,600
5-64	12.5	12,305,200[a]

(a) Did not fail.

TABLE 40. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR 7178-T76 ALUMINUM SHEET

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, percent 0.1	0.2	0.5	1.0	2.0	Initial Strain, percent	Rupture Time, hr.	Elongation in 2 Inches, percent	Reduction of Area, percent	Minimum Creep Rate, percent/hr.
43	35	350	0.15	0.30	0.70	1.5	2.0	0.421	2.6	14.0	63.5	0.70
44	25	350	3	7.5	20.5	30	34	0.304	36.8	12.8	65.7	0.021
34	16.5	350	35	115	300	420	500	0.332	553.7	16.2	81.5	0.0018
38	12	350	190	600	1780 est.	4000 est.	--	0.213	931.8*	0.500	--	0.00025
33	15	450	--	--	0.02	0.07	0.12	0.436	0.2	38.3	88.9	16.0
32	10	450	2.5	7	23	34	43	0.138	58.0	31.9	60.2	0.018
36	7	450	15	62	255	490	730	0.079	969.3	14.9	89.0	0.0015
37	4.5	450	200	1150	3150 est.	--	--	0.094	958.8*	0.277	--	0.00010
42	6	600	0.2	0.5	1.5	2.7	4.0	0.128	6.0	24.3	90.9	0.30
31	3.5	600	4	12	46	105	205	0.064	636.9	17.4	41.4	0.0082
45	1.7	600	325	1380	4700	--	--	0.021	1005.0*	0.180	--	0.00009

*Test discontinued.

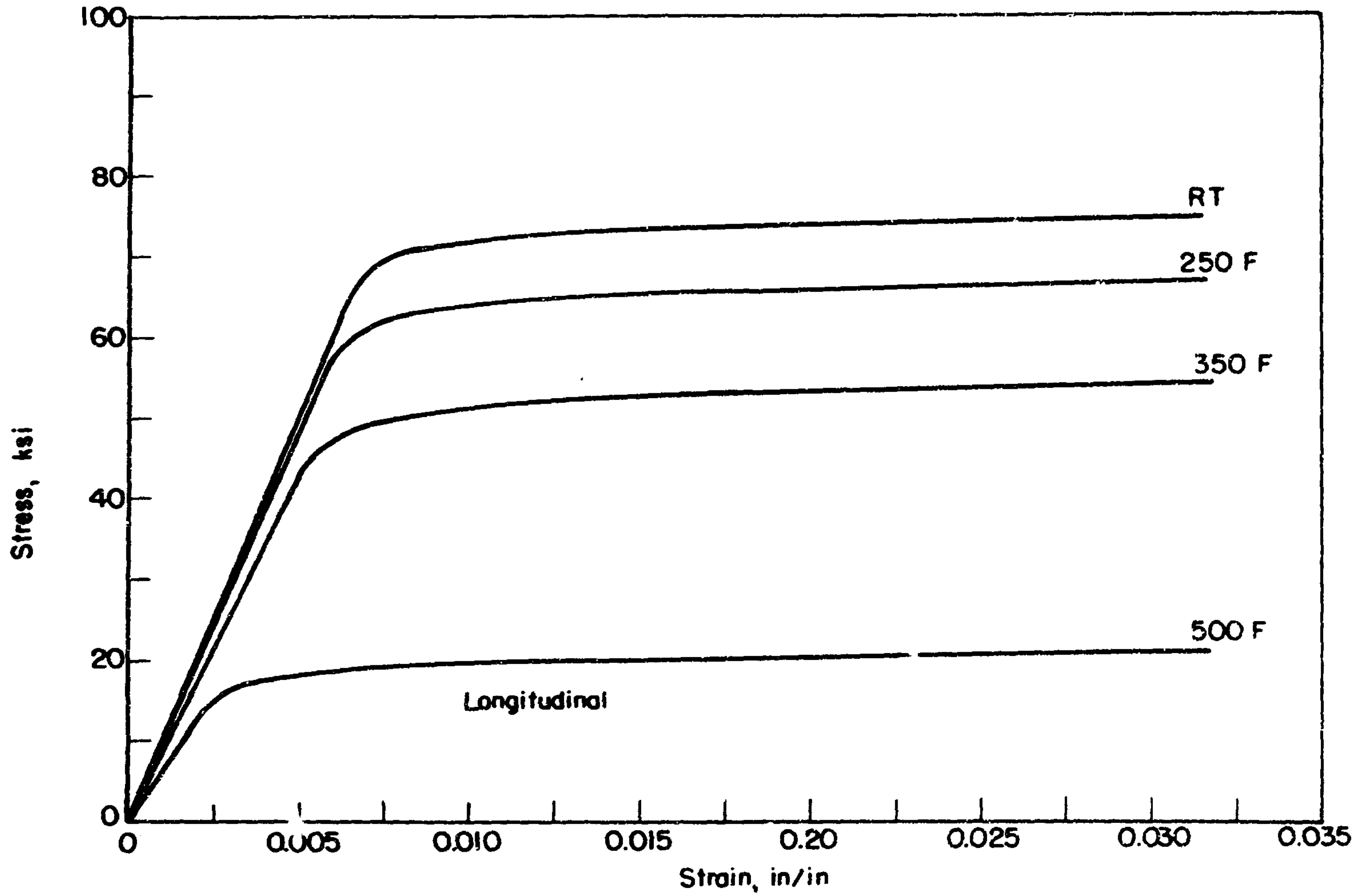


FIGURE 73. TYPICAL TENSION STRESS-STRAIN CURVES FOR 7178-T76 SHEET AT TEMPERATURE

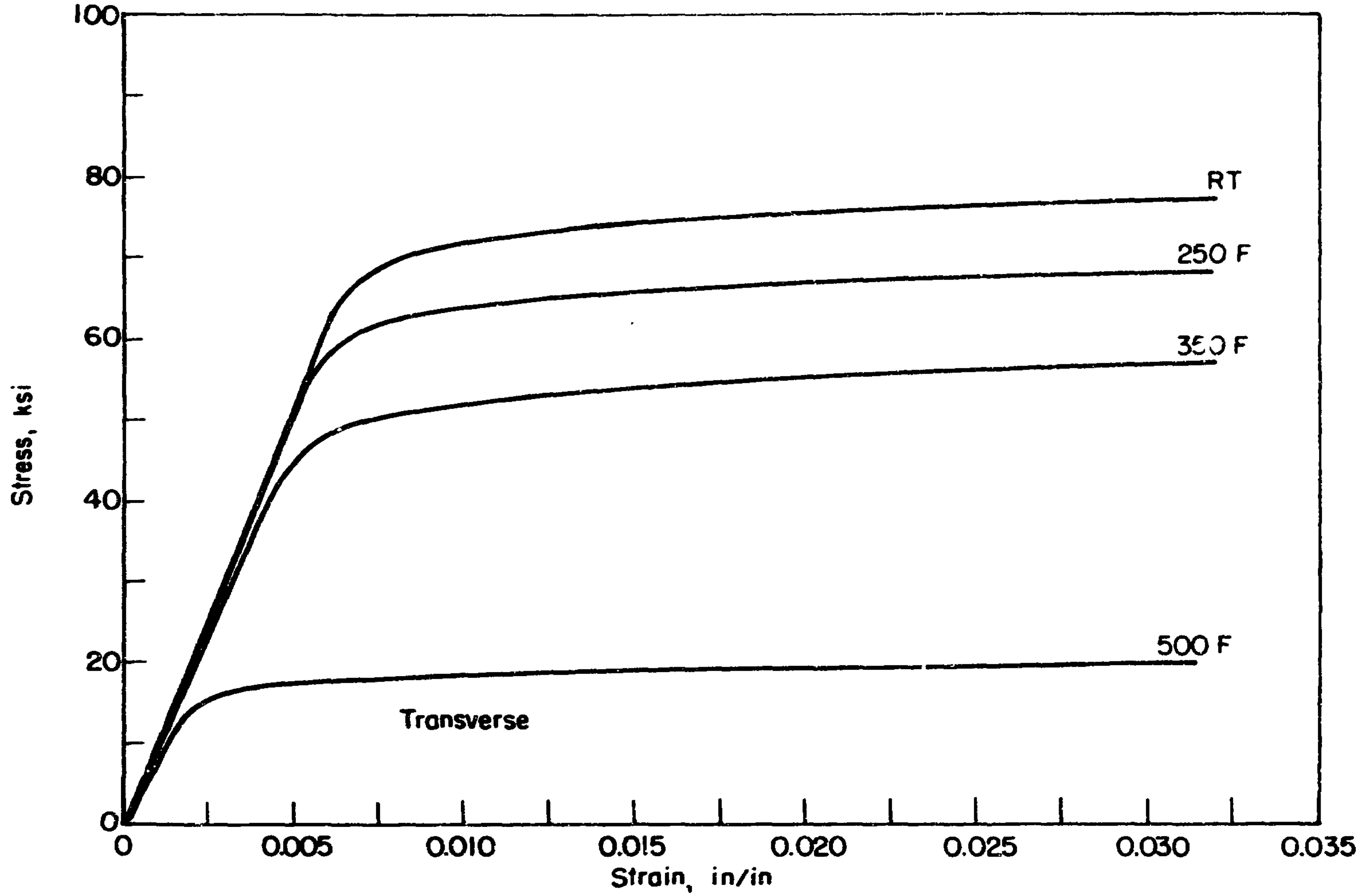


FIGURE 74. TYPICAL TENSION STRESS-STRAIN CURVES FOR 7178-T76 SHEET AT TEMPERATURE

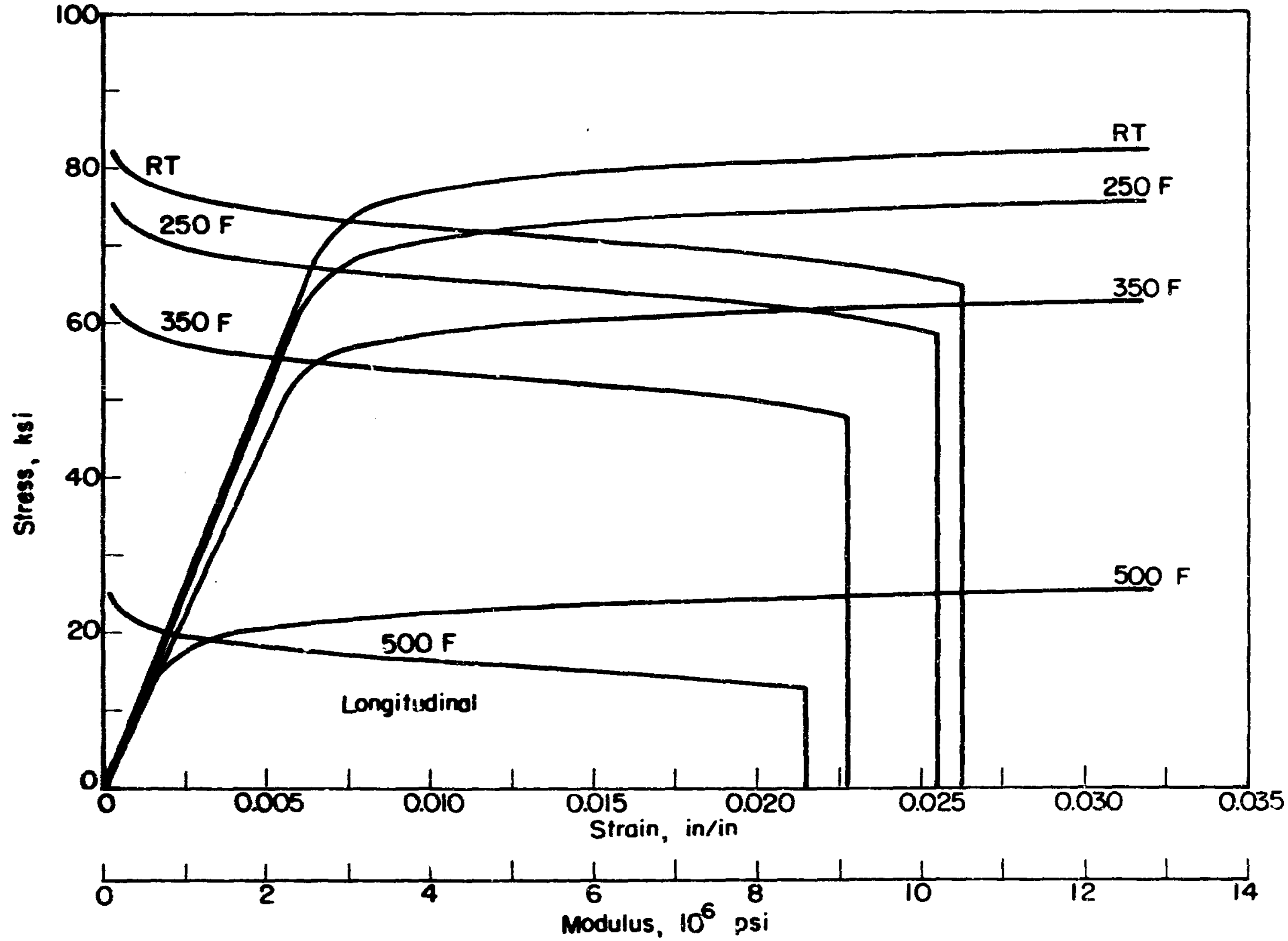


FIGURE 75. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 7178-T76 SHEET AT TEMPERATURE

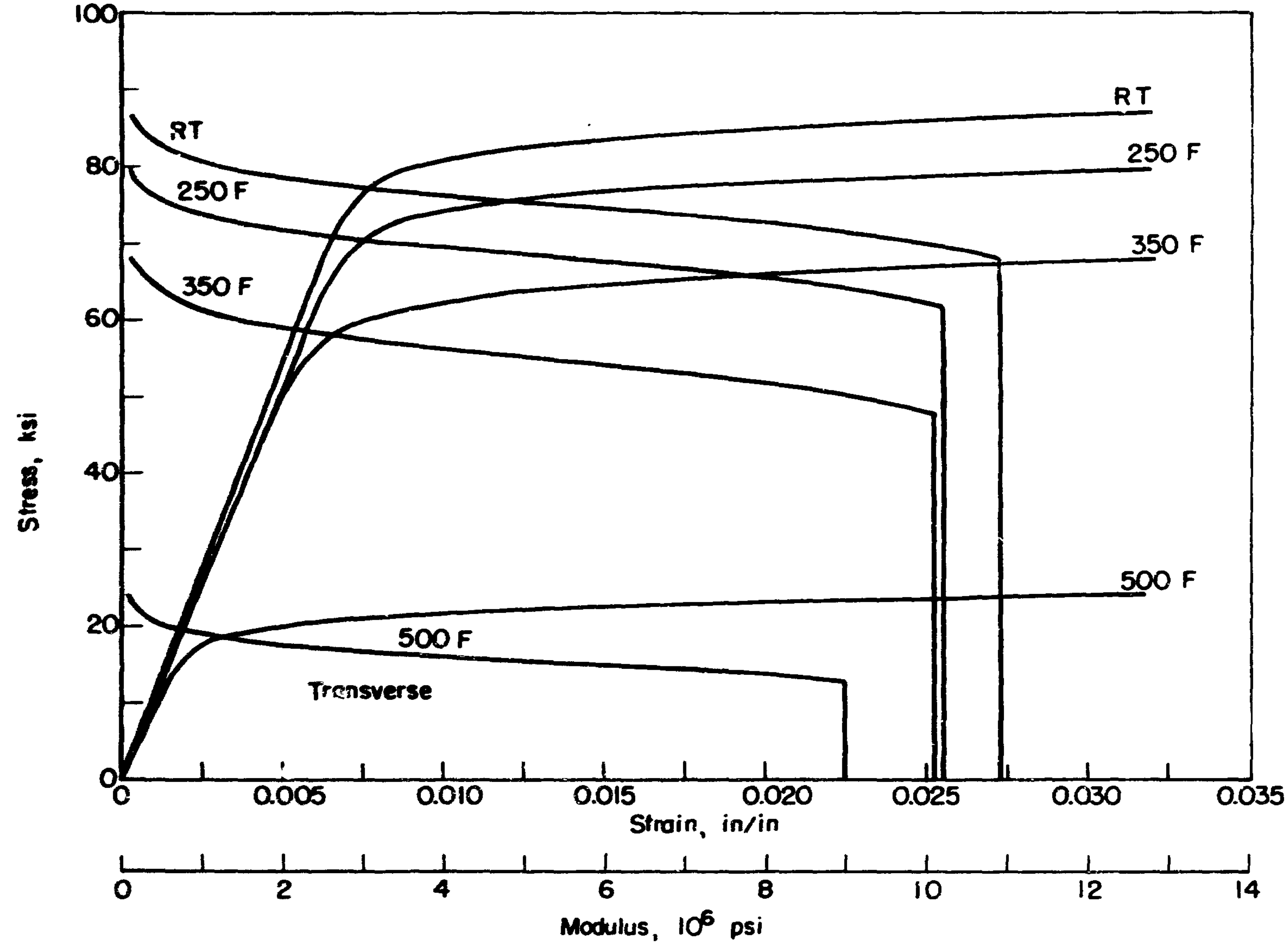


FIGURE 76. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 7178-T76 SHEET AT TEMPERATURE

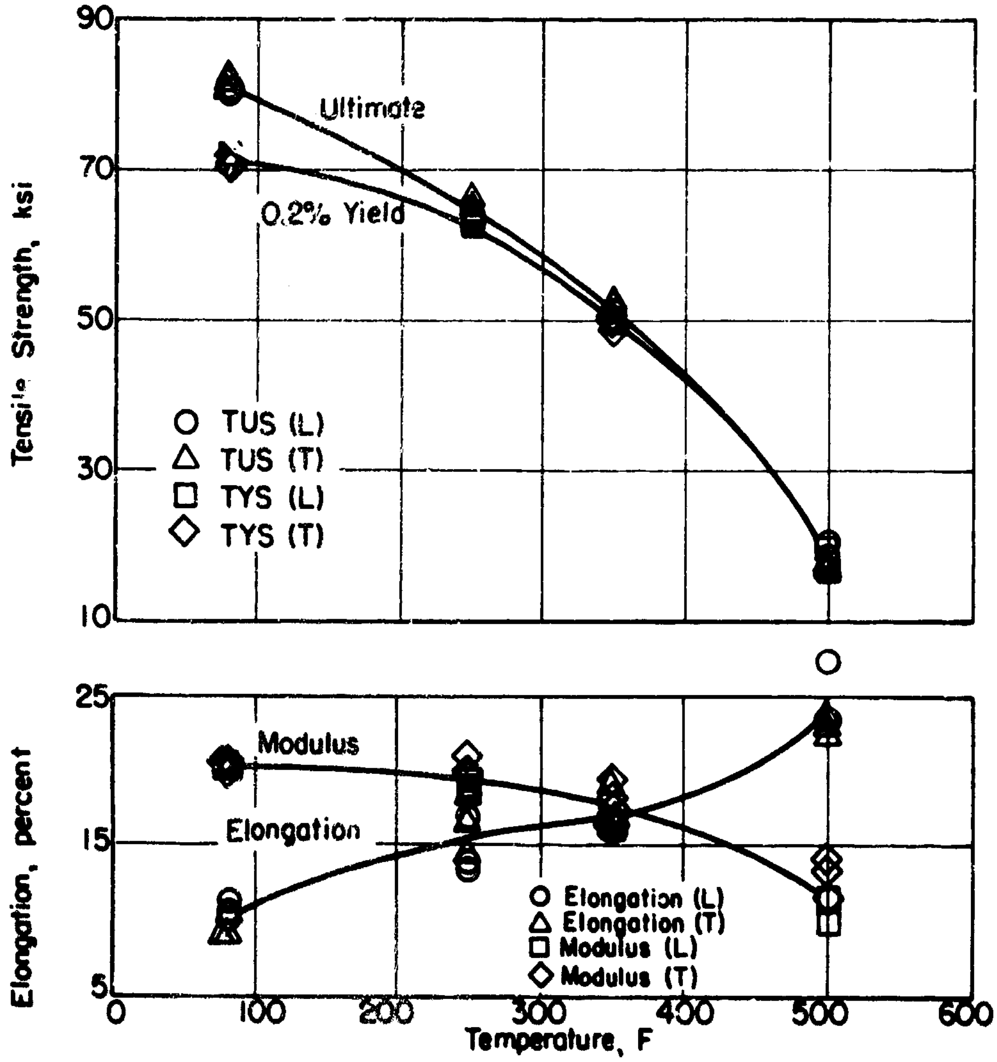


FIGURE 77. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7178-T76 ALUMINUM SHEET

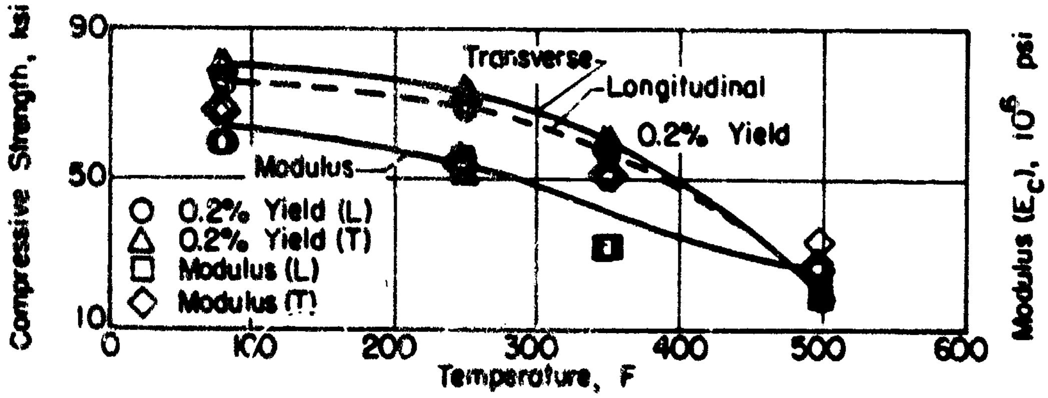


FIGURE 78. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7178-T76 ALUMINUM SHEET

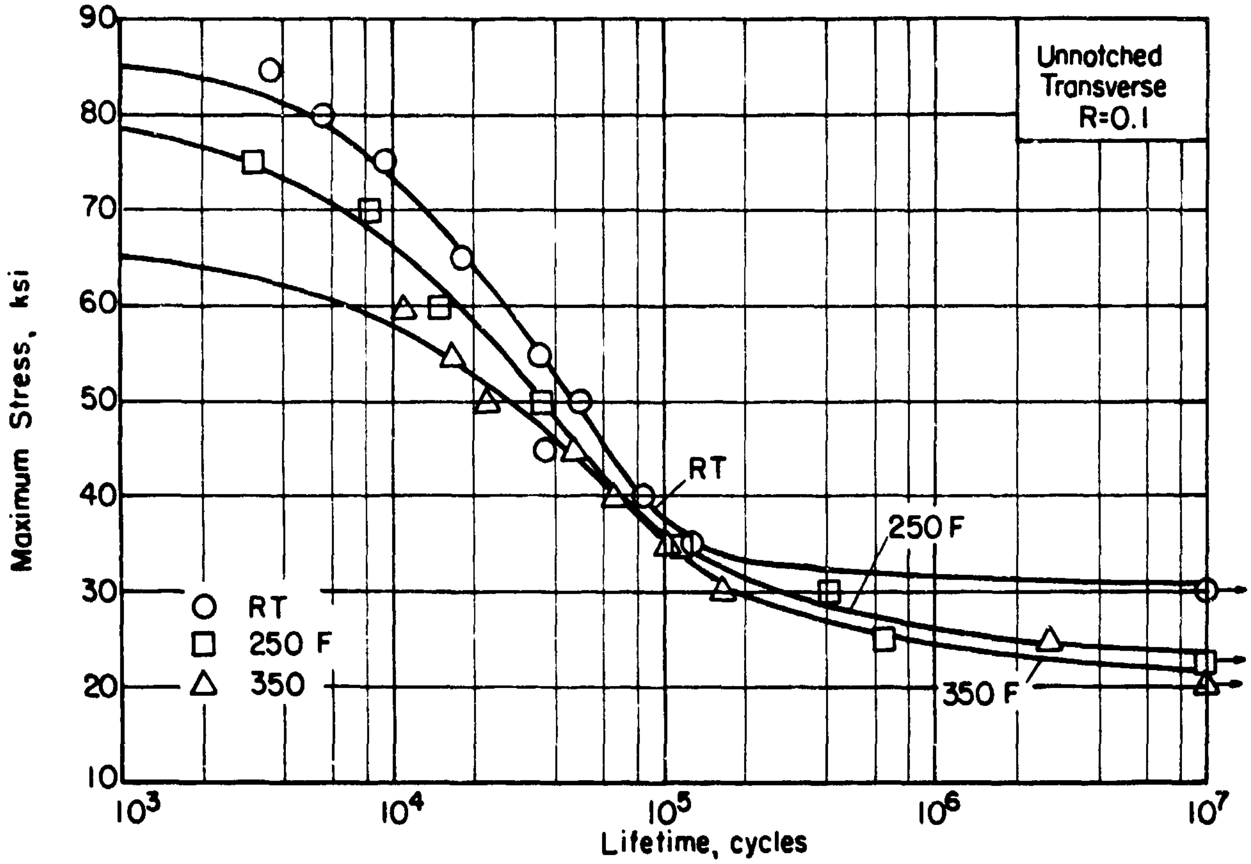


FIGURE 79. AXIAL LOAD FATIGUE RESULTS FOR 7178-T76 ALUMINUM SHEET

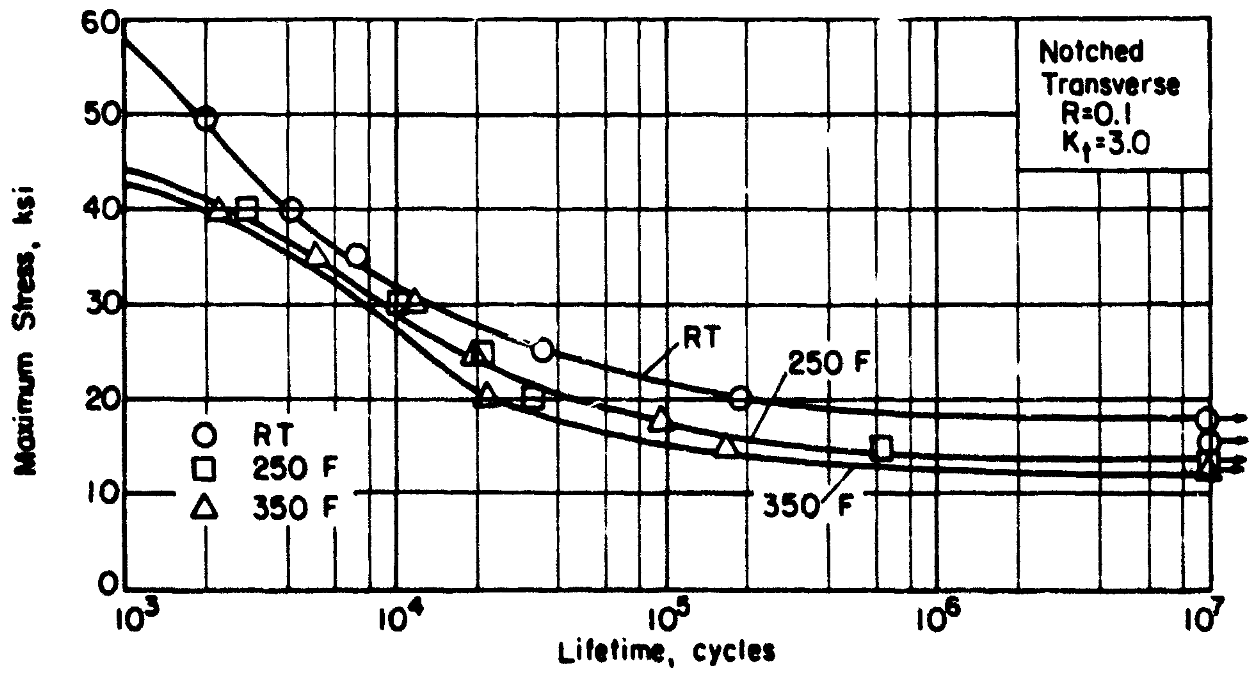


FIGURE 80. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 7178-T76 ALUMINUM SHEET

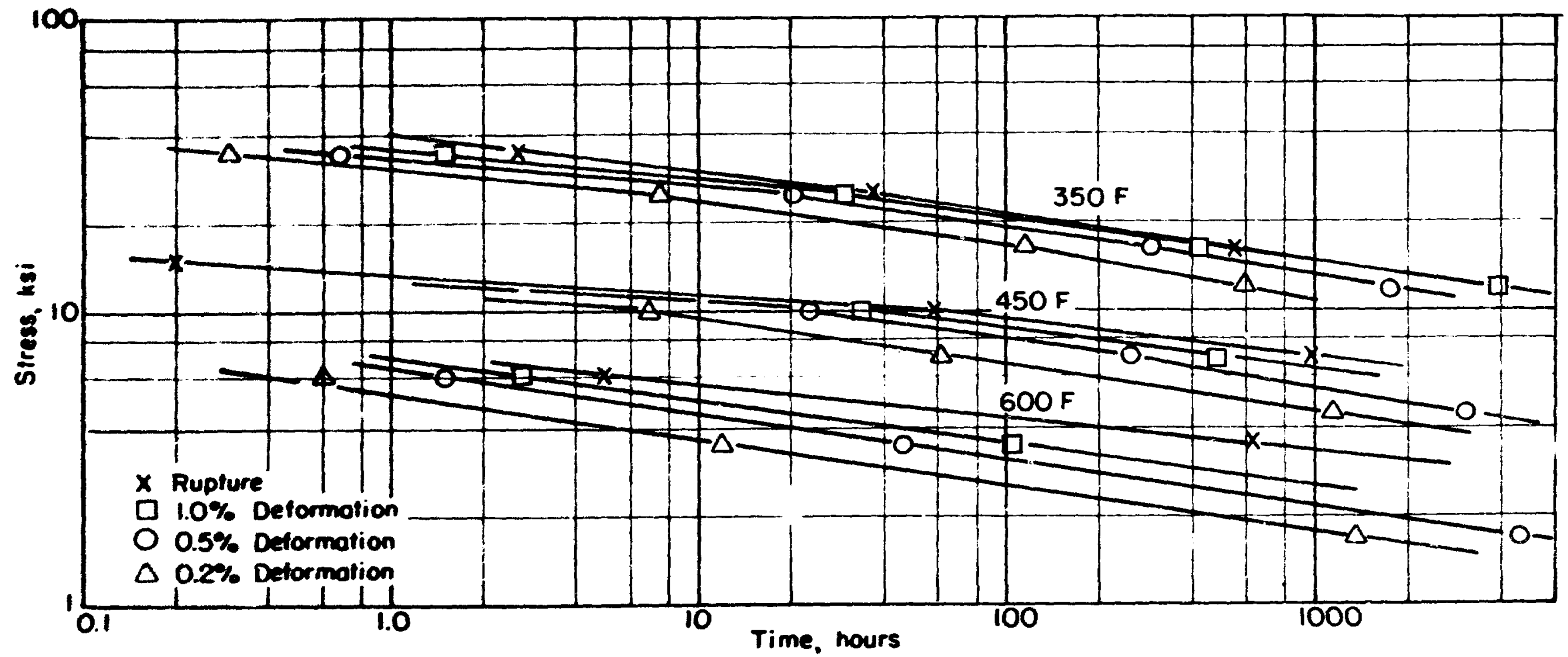


FIGURE 81. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7178-T76 ALUMINUM SHEET

AF2-IDA Alloy

Material Description

AF2-IDA is a new high-temperature nickel-base alloy developed by the Universal Cyclops Steel Division under Air Force Contract AF33(615)-1729. Further development and scale-up is being carried out under Contract F33615-67-C-1056. The intended usage of this material is for turbine wheel/bucket applications.

Thirteen extruded bars, approximately 1-1/8 inch in diameter, were received for this property survey. The identification, extrusion parameters, and composition of the bars are shown in Table 41.

Processing and Heat Treating

Since the material was in round bar form and only one direction (longitudinal) could be evaluated, no specimen layout is shown.

Specimens were heat treated as recommended by Universal Cyclops. The treatment was as follows: 2225F/2 hours/rapid air cool; 1950F/2 hours/rapid air cool; 1400F/16 hours/air cool.

Test Results

Tension. Tension tests were conducted at room temperature, 1000F, 1400F, and 1800F. Tabular test results are given in Table 42. Stress-strain curves at temperature are shown in Figure 82. Effect-of-temperature curves are presented in Figure 84.

Compression. Tests were performed at room temperature, 1000F, 1400F, and 1800F. Results are given in Table 43. Stress-strain and tangent modulus curves at temperature are shown in Figure 83. Effect-of-temperature curves are presented in Figure 85.

Shear. Test results at room temperature are given in Table 44.

Impact. Material quantity was not sufficient for impact tests.

Fracture Toughness. Material quantity was not sufficient for fracture toughness tests.

Fatigue. Material quantity was sufficient for only 13 specimens. Results of axial-load tests on these specimens are presented in Tables 45 and 46.

Creep and Stress Rupture. Tests were conducted at 1400F, 1600F, and 1800F. Results are given in Table 47 and Figure 86.

Stress Corrosion. No cracks appeared in the specimens after testing as described in the experimental procedure section.

Thermal Expansion and Density. Values are given in the "data sheet" in the conclusions section.

TABLE 41. IDENTIFICATION AND CHEMICAL COMPOSITION OF AF2-1DA EXTRUDED BAR

Extrusion Number	Heat Number	Extrusion Ratio	Extrusion Temperature, F	Chemical Composition (weight percent) for:											
				C	Cr	Co	Mo	W	Ta	Al	Ti	B	Zr	Ni	N
2622	KC1594B	5.3:1	2025	0.35	12.02	9.94	2.99	6.04	1.65	4.52	2.89	0.015	0.13	Bal.	2.37
2623	KC1595T	5.3:1	2025	0.34	11.94	9.92	3.05	5.93	1.66	4.69	3.04	0.012	0.14	Bal.	2.46
2624	KC1595B	5.3:1	2025	0.34	11.94	9.92	3.05	5.93	1.66	4.69	3.04	0.012	0.14	Bal.	2.46
2625	KC1596T	5.2:1	2025	0.34	11.98	9.91	3.01	6.01	1.73	4.68	3.03	0.015	0.13	Bal.	2.47
2626	KC1596B	5.4:1	2025	0.34	11.98	9.91	3.01	6.01	1.73	4.68	3.03	0.015	0.13	Bal.	2.47
2629	KC1598T	4.8:1	2025	0.36	12.04	9.97	2.98	6.06	1.64	4.58	3.08	0.016	0.14	Bal.	2.43
2630	KC1598B	5.4:1	2025	0.36	12.04	9.97	2.98	6.06	1.64	4.58	3.08	0.016	0.14	Bal.	2.43
2635	KC1601T	7:1	2025	0.33	11.92	9.93	2.97	5.94	1.64	4.53	3.12	0.015	0.14	Bal.	2.41
2637	KC1602T	5.3:1	2025	0.34	12.08	9.99	3.01	5.92	1.54	4.64	2.95	0.015	0.14	Bal.	2.41
2638	KC1602B	5.3:1	2025	0.34	12.08	9.99	3.01	5.92	1.54	4.64	2.95	0.015	0.14	Bal.	2.43
2639	KC1603T	5.3:1	2025	0.35	12.10	9.99	3.00	6.00	1.59	4.62	2.98	0.015	0.14	Bal.	2.43
2640	KC1603B	7:1	2025	0.35	12.10	9.99	3.00	6.00	1.59	4.62	2.98	0.015	0.14	Bal.	2.43

TABLE 42. TENSILE TEST RESULTS FOR AF2-1DA EXTRUDED ROUND BARS

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 1 inch, percent	Tensile Modulus, psi x 10^6
		Room Temperature		
1L-1	195.5	146.9	11.5	31.5
1L-2	197.4	151.5	11.0	31.9
1L-3	196.2	148.6	11.0	31.0
		1000 F		
1L-4	176.3	146.4	6.0	28.1
1L-5	175.3	148.0	5.0	27.7
1L-6	176.0	148.2	6.0	27.9
		1400 F		
1L-7	160.0	145.1	3.0	26.6
1L-8	155.6	142.7	2.5	24.5
1L-9	157.8	144.0	2.5	25.0
		1800 F		
1L-10	63.7	47.8	10.0	19.1
1L-11	66.7	48.5	8.0	19.2
1L-12	60.9	48.0	8.5	19.0

TABLE 43. COMPRESSION TEST RESULTS FOR AF2-1DA EXTRUDED ROUND BARS

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Room Temperature	
2L-1	156.0	32.2
2L-2	157.0	32.4
2L-3	153.0	33.3
	1000 F	
2L-4	158.6	29.4
2L-5	161.7	31.8
2L-6	161.0	31.6
	1400 F	
2L-7	153.0	28.9
2L-8	(a)	28.5
2L-9	144.0	30.4
	1800 F	
2L-10	53.4	26.0
2L-11	50.8	24.1
2L-12	52.8	23.9

(a) Jig failed during test.

TABLE 44. SHEAR TEST RESULTS FOR AF2-1DA EXTRUDED ROUND BARS AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
4L-1	134.0
4L-2	135.0
4L-3	135.0

TABLE 45. AXIAL-LOAD FATIGUE TEST RESULTS FOR AF2-1DA, EXTRUDED BAR, UNNOTCHED, AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-6	160.0	42,400
5-5	150.0	119,600
5-2	150.0	480,400
5-4	140.0	67,600
5-3	140.0	248,200
5-1	130.0	227,200
5-7	120.0	318,100

TABLE 46. AXIAL-LOAD FATIGUE TEST RESULTS FOR AF2-1DA EXTRUDED BAR, NOTCHED (K_t = 3.0), AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-10	140.0	(a)
5-11	120.0	(a)
5-12	100.0	22,100
5-13	80.0	54,300
5-14	60.0	234,300
5-15	50.0	542,300

(a) Broke while loading.

TABLE 47. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES OF AF2-1DA ROUND BAR MATERIAL

Specimen Number	Stress, ksi	Tempera-ture, F	Hours to Indicated Creep Deformation, percent: 0.1	0.2	0.5	1.0	2.0	Initial Strain, percent	Rupture Time, hr	Elongation in 2 Inches, percent	Minimum Creep Rate, percent/hr.
2622	100	1400	--	--	--	--	--	0.320	0.2	0	--
2623	95	1400	--	--	--	--	--	0.367	0.2	1.6	--
2625	85	1400	--	--	--	--	--	0.425	0.7	2.3	--
2629	77	1400	4.8	15	--	--	--	0.340	17.4	0	0.01
26	70	1400	4.5	33	101	198	330	0.184	511.2	5.5	0.0031
2630	60	1400	60	164	446	780	1410 (est.)	0.312	841.2[a]	1.414	0.0010
2639	50	1400	250	665	1725 (est.)	3600 (est.)	--	0.281	1006.2[a]	0.574	0.00027
35	60	1600	0.2	0.4	1.6	3.0	5.6	0.360	12.2	10.2	0.23
24	50	1600	1.4	2.5	7.1	14.4	24	0.316	53.8	10.2	0.07
37	35	1600	8	30	95	180	281	0.230	467.0	13.3	0.0045
2638	20	1600	200	420	992	1930 (est.)	--	0.090	958.4[a]	0.574	0.0005
25-2	27	1800	0.3	0.7	2.0	3.3	5.6	0.141	11.4	11.7	0.23
25-1	20	1800	1.1	2.2	4.7	11.5	22	0.336	33.3	7.8	0.085
25-3	10	1800	8	26	81	153	281	0.113	820.4	21.9	0.0055
25-4	6	1800	64	136	288	460	765	0.035	760.9[a]	2.03	0.0013
25-5	4	1800	103	250	645	1300 (est.)	--	0.031	1055.5[a]	1.008	0.0004

(a) Indicates test was discontinued at this time.

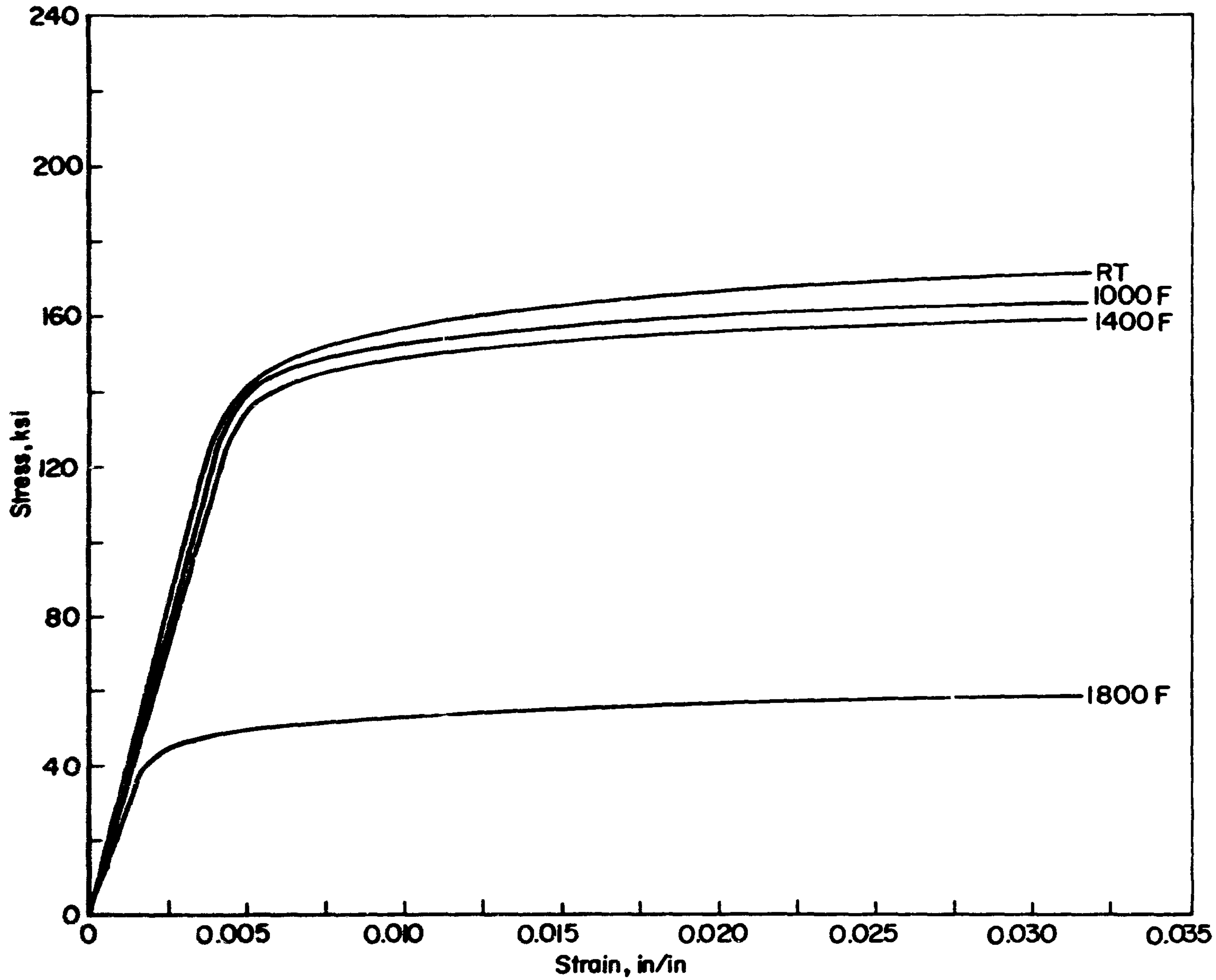


FIGURE 82. TYPICAL TENSION STRESS-STRAIN CURVE FOR AF2-1DA ROUND BAR AT TEMPERATURE

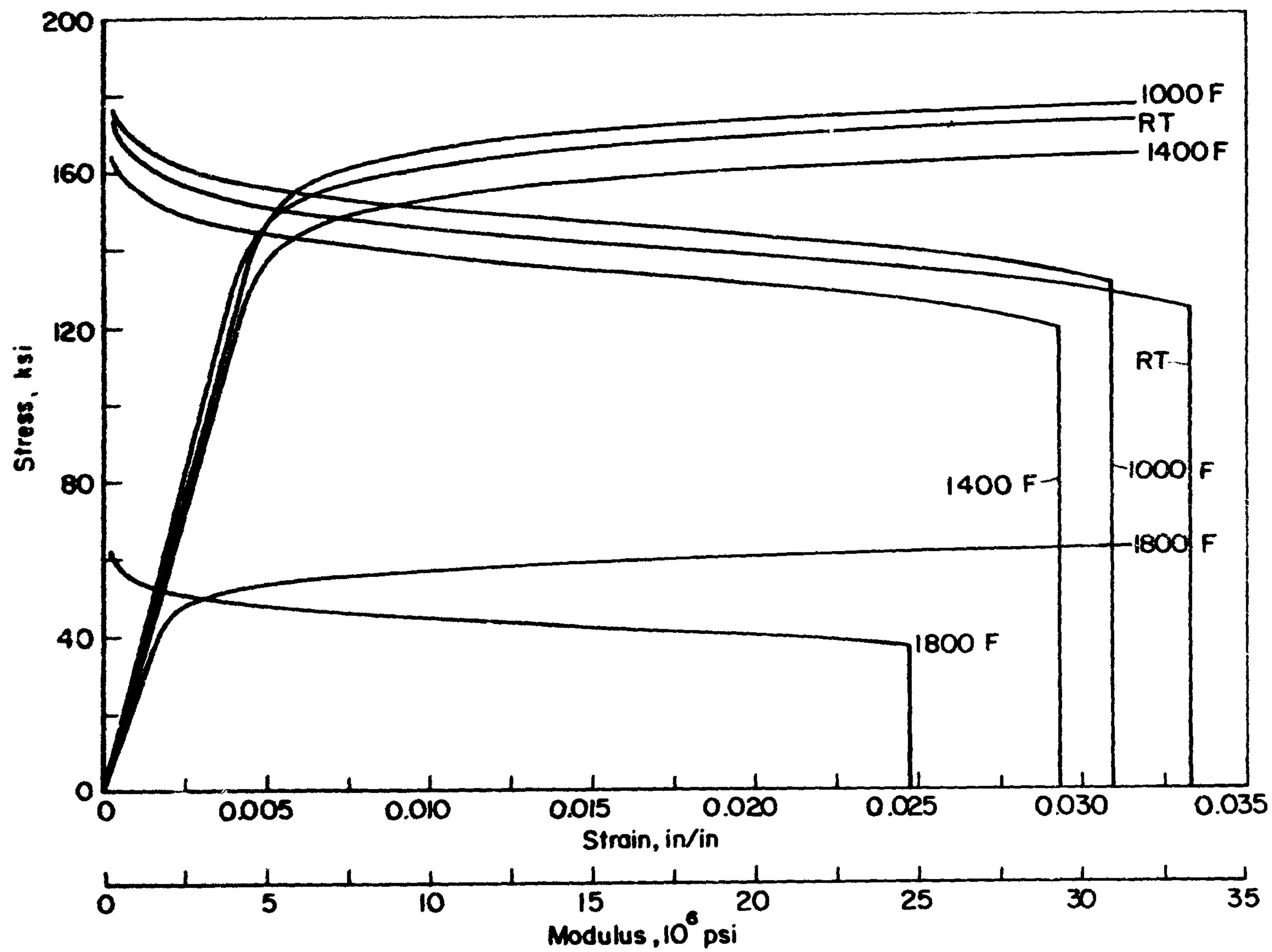


FIGURE 83. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR AF2-1DA ROUND BAR AT TEMPERATURE

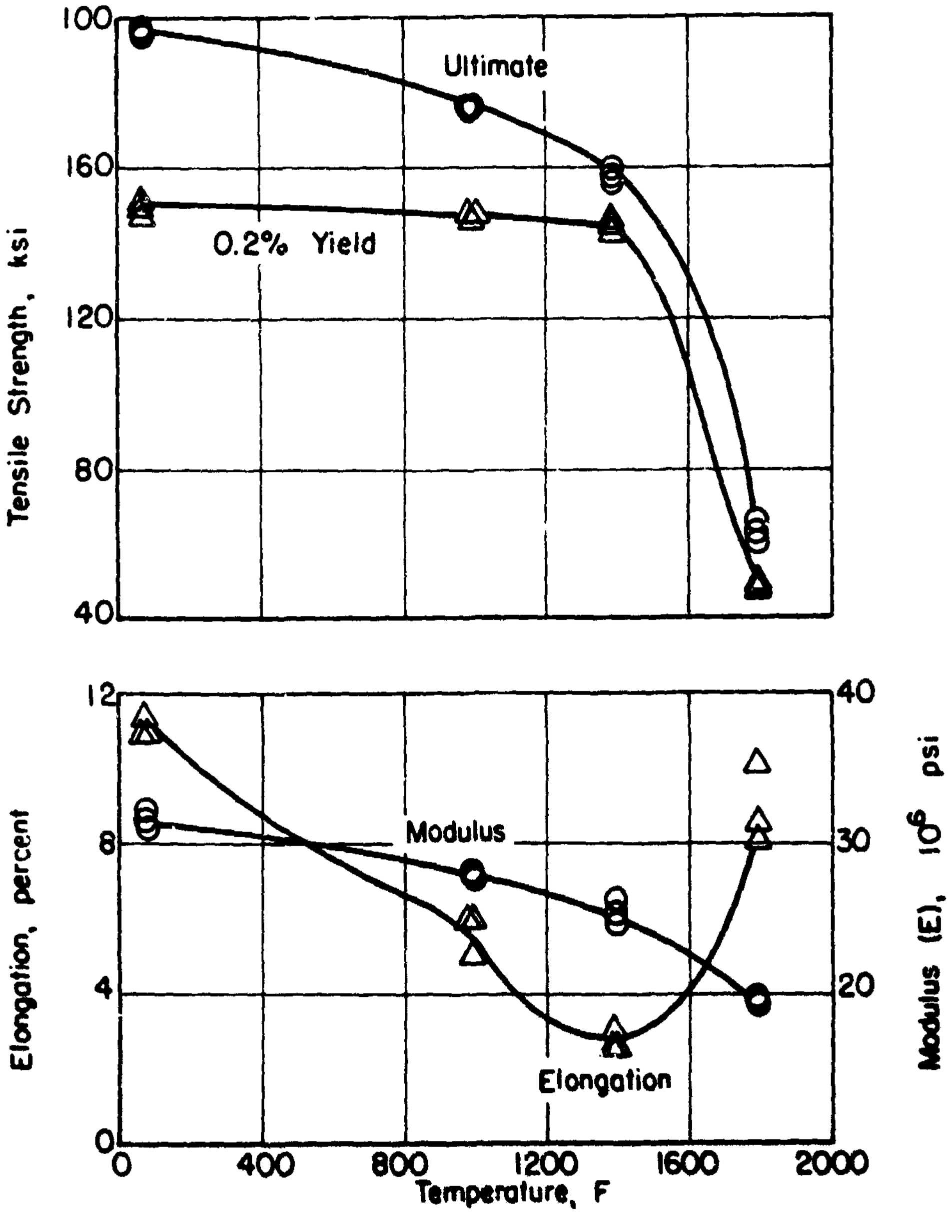


FIGURE 84. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF AF2-IDA EXTRUDED ROUND BAR

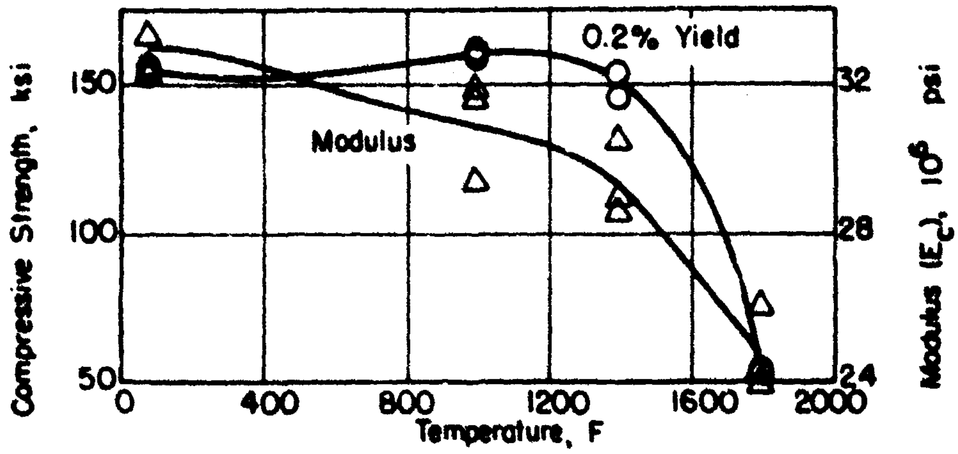


FIGURE 85. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF AF2-DA EXTRUDED ROUND BAR

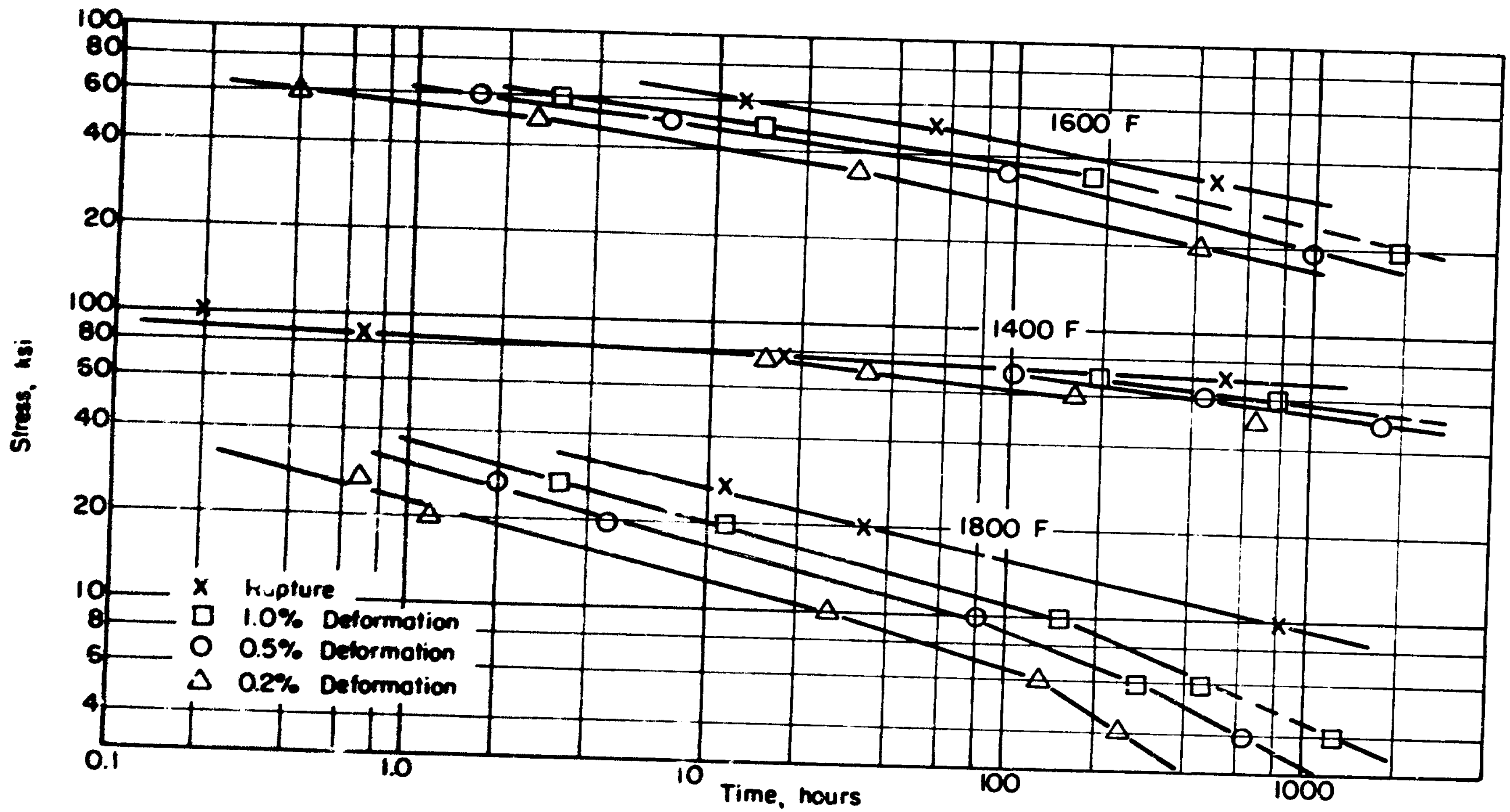


FIGURE 86. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR AF2-IDA EXTRUDED ROUND BAR

MP35N Alloy

Material Description

MP35N is a new nickel-cobalt-chromium-molybdenum alloy developed by the E. I. duPont deNemours and Company, Incorporated. The rights to this alloy, MP35N, and the family of composition from which it was derived, MULTIPHASE(T) Alloys, were acquired by Standard Pressed Steel Company in 1967 and Latrobe Steel Company was subsequently licensed to manufacture the MULTIPHASE Alloys.

MP35N is hardened by work strengthening and aging to strength levels of 260 - 300 ksi. In addition to high strength and good ductility, the alloy is reported to have excellent resistance to corrosion and stress corrosion in salt water and other chloride solutions. Potential usage of this material is for fasteners, springs, marine drive shafts, cables, etc.

MP35N is available as ingot, billet, bar stock, wire, and tubing. A fabricator of flat-rolled products will be licensed soon so that all product forms will be available.

The composition of the 1-inch round bar stock used for this evaluation was as follows:

Chemical Composition	Percent
Nickel	35.24
Cobalt	35.11
Chromium	19.48
Molybdenum	9.61
Carbon	0.015

Processing and Heat Treating

A specimen layout is not shown since round bar stock was used for this evaluation. The as received work strengthened bar was aged at 1050F for 4 hours to attain a nominal strength level of 260 ksi. Because of a serious drop in ductility at about 900 - 1000F, Latrobe has recommended that material heat-treated to this strength level not be used above 750F.

Test Results

Tension. Tests were performed at room temperature, 400F, 700F, and 1200F. Results are given in Table 48. Stress-strain curves are presented in Figure 87. Effect-of-temperature curves are shown in Figure 89.

Compression. These tests were also conducted at room temperature, 400F, 700F, and 1200F. Test results are given in Table 49. Stress-strain and tangent

(T) Trademark of the Standard Pressed Steel Company modulus curves at temperature are shown in Figure 88. Effect-of-temperature curves are presented in Figure 90.

Shear. Results of tests at room temperature are given in Table 50.

Impact. Tests were conducted at room temperature, -40F, and -100F. Test results are given in Table 51.

Fracture Toughness. Slow-bend type tests were conducted at room temperature for work strengthened only and work strengthened and aged material. Results are given in Table 52.

Fatigue. Axial-load tests were performed at room temperature, 400F, and 700F. Tabular data are given in Tables 53 and 54. S-N curves are presented in Figures 91 and 92.

Creep and Stress Rupture. Tests were performed at 700F, 900F, and 1200F. Test results are given in Table 55 and Figure 93.

Stress Corrosion. No cracks were evident after testing as described in the experimental procedure section.

Thermal Expansion and Density. Values are given in the "data sheet" in the conclusions section.

TABLE 48. TENSION TEST RESULTS FOR MP35N MULTIPHASE ALLOY BAR

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Room Temperature		
1	273.0	262.0	12.0	34.9
2	273.0	263.0	11.0	34.7
3	273.0	264.0	11.0	36.2
		400 F		
4	244.0	238.0	11.0	31.6
5	244.0	239.0	10.0	32.3
6	246.0	238.0	11.0	34.3
		700 F		
7	227.0	220.0	9.0	32.4
8	229.0	223.0	8.0	34.4
9	227.0	220.0	8.0	31.4
		1200 F		
10	190.0	154.0	19.0	23.1
11	189.0	157.0	21.0	23.6
12	189.0	56.0	19.0	24.0

TABLE 49. COMPRESSION TEST RESULTS FOR MP35N MULTIPHASE ALLOY BAR

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Room Temperature	
1	255.0	33.9
2	252.0	34.3
3	251.0	33.6
	400 F	
4	211.0	32.7
5	211.0	32.5
6	211.0	32.2
	700 F	
7	194.0	29.0
8	200.0	29.7
9	196.0	29.3
	1200 F	
10	148.0	24.1
11	150.0	23.6
12	153.0	(a)

(a) Load/strain curve not good for modulus.

TABLE 50. SHEAR TEST RESULTS FOR MP35N MULTIPHASE ALLOY BAR AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
1	144.0
2	145.0
3	145.0

TABLE 51. 2/3-SIZE CHARPY V-NOTCH IMPACT TEST RESULTS FOR MP35N MULTIPHASE ALLOY BAR

Specimen Number	Test Temperature, F	Impact Energy, ft/lb
1	RT	22.0
2	RT	23.5
3	RT	19.0
4	-40	16.0
5	-40	16.5
6	-40	19.0
7	-100	14.0
8	-100	13.0
9	-100	15.0

TABLE 52. FRACTURE TOUGHNESS TEST RESULTS FOR MP35N MULTIPHASE ALLOY BAR

Specimen Number	Thickness, inch	Width, inch	Crack Length, inch	Span, inch	K_{Ic} ksi$\sqrt{in}$
6-1	0.401	0.80	0.41	3.2	42.7[(a)]
6-2	0.401	0.80	0.40	3.2	46.4[(a)]
6-3	0.401	0.80	0.41	3.2	49.5[(a)]
6-4	0.401	0.80	0.42	3.2	77.1[(b)]
6-5	0.401	0.80	0.40	3.2	74.9[(b)]
6-6	0.400	0.80	0.40	3.2	82.5[(b)]

(a) Material work-strengthened only

(b) Material work-strengthened and aged

TABLE 53. AXIAL-LOAD FATIGUE TEST RESULTS FOR MP35N MULTIPHASE ALLOY BAR, UNNOTCHED, AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
9	270.0	27,600
4	250.0	39,000
2	230.0	75,800
5	210.0	73,200
6	190.0	82,800
8	170.0	709,400
11	160.0	6,401,400
	400 F	
16	250.0	8,800
15	230.0	18,600
12	210.0	48,500
14	190.0	100,500
13	170.0	825,000
17	160.0	269,200
18	150.0	1,906,500(a)
19	145.0	3,122,600
	700 F	
21	230.0	8,100
24	210.0	78,800
20	190.0	115,300
23	170.0	149,000
25	150.0	1,920,300
26	140.0	4,512,700
27	130.0	4,595,800

(a) Failed in grip.

TABLE 54. AXIAL-LOAD FATIGUE TEST RESULTS FOR MP35N MULTIPHASE ALLOY BAR, NOTCHED (K_t = 3.0), AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
1	190.0	2,400
2	150.0	6,900
3	130.0	13,000
4	110.0	25,000
6	90.0	53,200
7	70.0	452,300
8	60.0	744,900
9	50.0	2,054,900
10	40.0	11,652,200[(a)]
	400 F	
17	160.0	3,900
15	130.0	7,600
12	110.0	50,300
16	100.0	29,200
11	90.0	65,000
14	70.0	154,000
18	50.0	10,000,000[(a)]
	700 F	
23	150.0	2,800
22	130.0	4,800
21	110.0	7,700
19	90.0	29,900
20	70.0	94,300
	60.0	

(a) Did not fail.

TABLE 55. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR MP35N MULTIPHASE ALLOY BAR

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hr.	Elongation in 2 Inches, percent	Reduction of Area percent	Minimum Creep Rate, percent/hr.
			0.1	0.2	0.5	1.0	2.0					
MP-6	225	700	--	--	--	--	--	--	on loading	7.0	42.5	--
MP-8	220	700	340	2000 est.	--	--	--	1.169	956.0*	1.304	--	0.00005
MP-7	215	700	360	2100 est.	--	--	--	1.131	771.9*	1.254	--	0.00006
MP-11	220	900	--	--	--	--	--	--	on loading	4.6	22.5	--
MP-13	210	900	0.3	1.0	7	30	110	1.080	753.7	12.3	14.3	0.011
MP-9	200	900	0.4	1.5	14	65	230	0.966	1474.2	10.8	13.8	0.0050
MP-4	175	900	0.7	4.4	50	270	1125 est.	0.677	980.0*	2.519	--	0.0011
MP-10	125	900	25	154	1200	3200 est.	--	0.396	977.0*	0.781	--	0.00025
MP-2	125	1200	0.01	0.03	0.15	0.4	1	0.723	5.9	34.6	46.4	2.0
MP-1	100	1200	0.08	0.15	0.8	2.6	8	0.604	54.0	38.5	58.7	0.18
MP-3	75	1200	0.20	1.0	7	40	180	0.458	971.2	43.1	70.4	0.007
MP-5	40	1200	2.7	30	5000 est.	--	--	0.227	959.0*	0.577	--	0.00001
MP-12	25	1200	37	7000 est.	--	--	--	0.111	977.1*	0.254	--	<0.00001

*Test was discontinued.

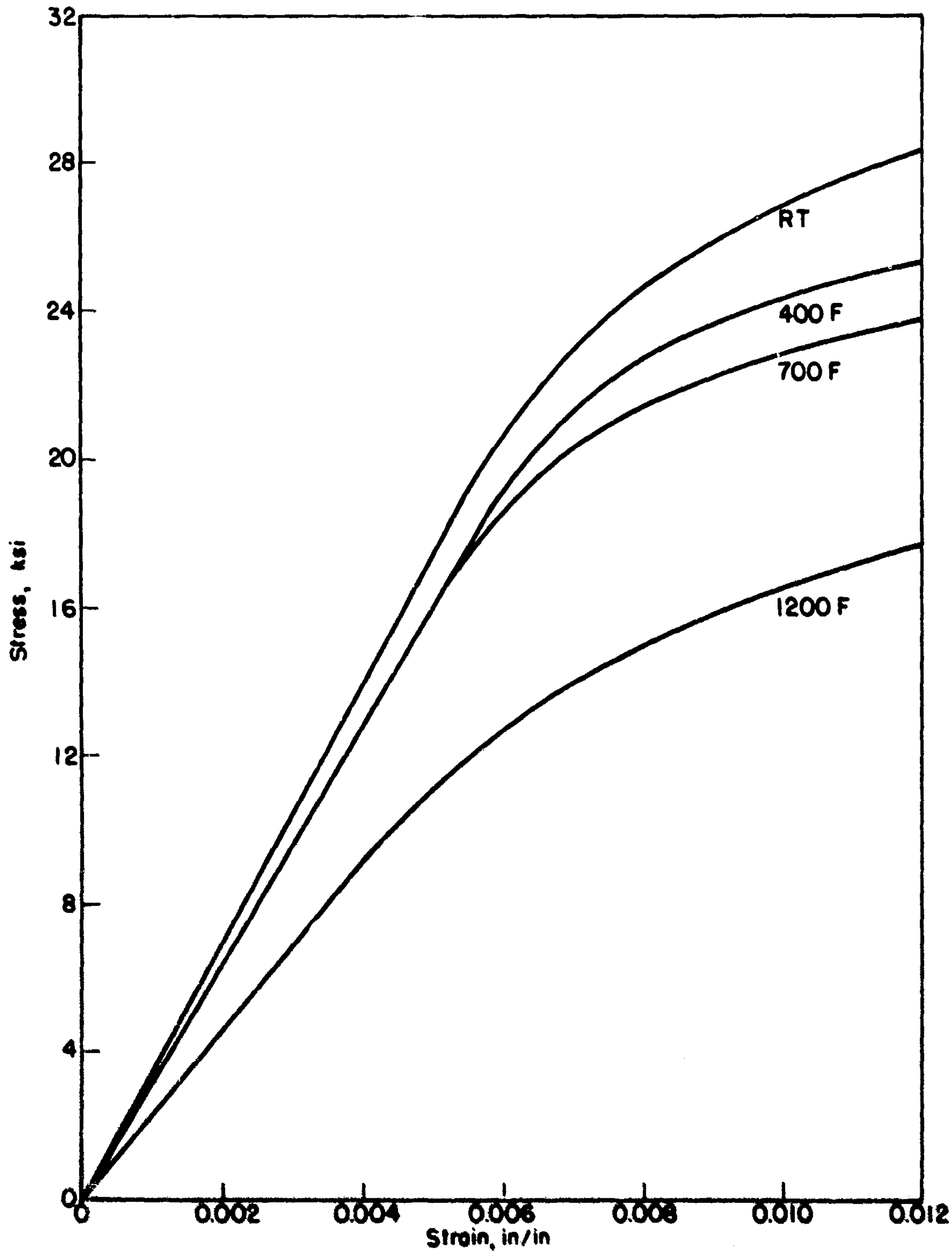


FIGURE 87 TYPICAL TENSION STRESS-STRAIN CURVES FOR MP35N MULTIPHASE BAR

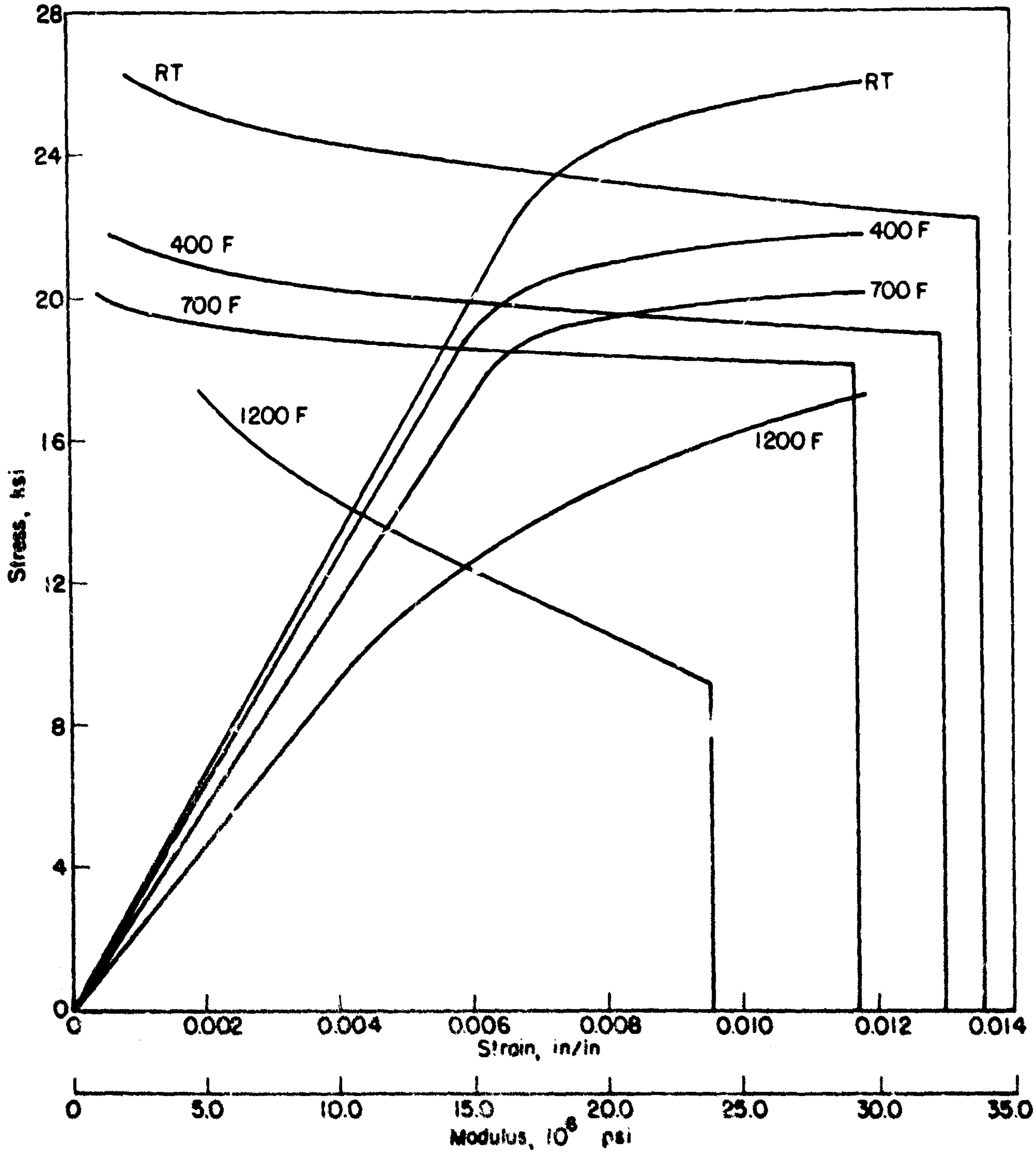


FIGURE 88. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR MP35N MULTIPHASE BAR

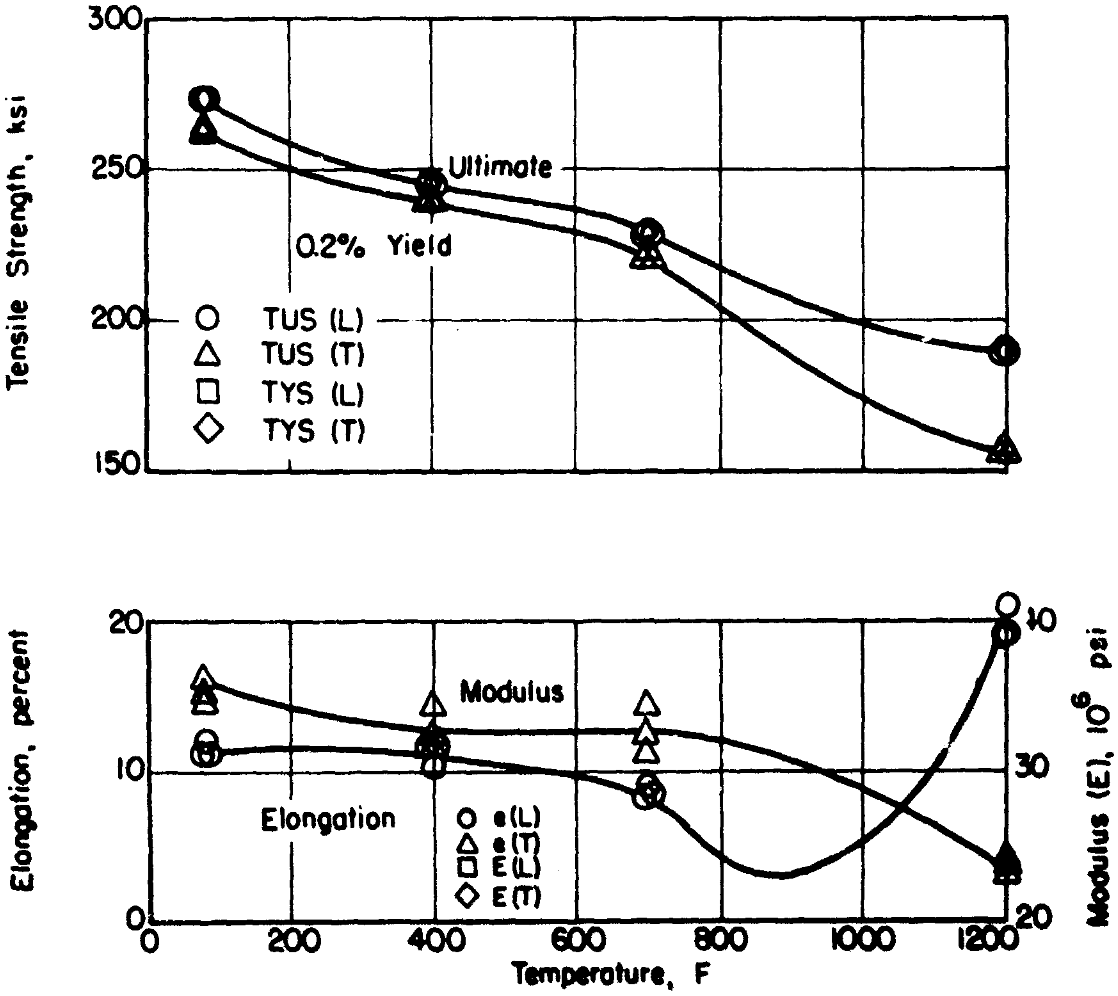


FIGURE 89. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF MP35N MULTIPHASE ALLOY BAR

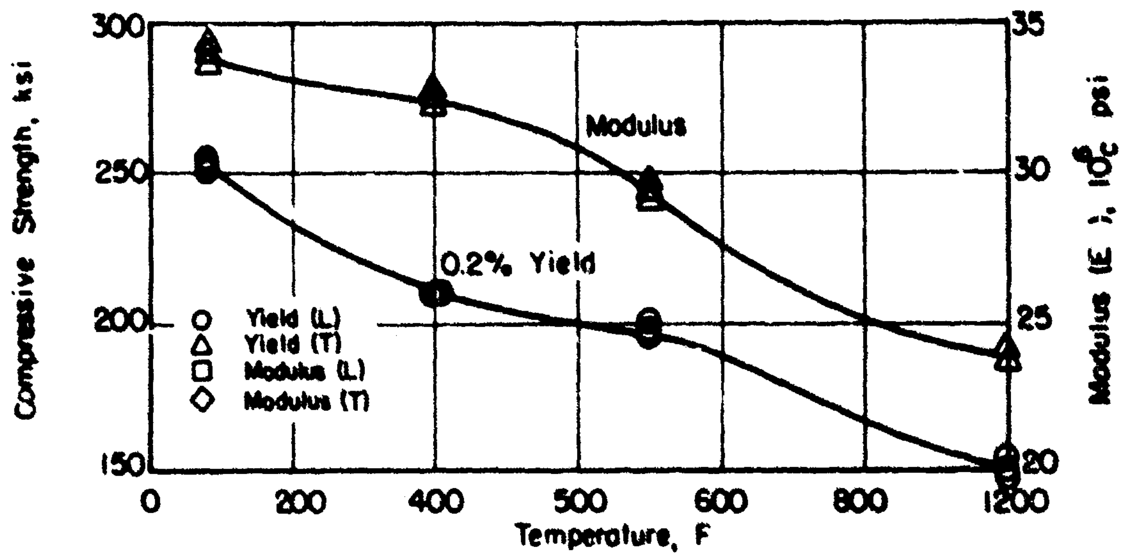


FIGURE 90. EFFECT OF TEMPERATURE ON TH~ COMPRESSION PROPERTIES OF MP35N MULTIPHASE A_LOY BAR

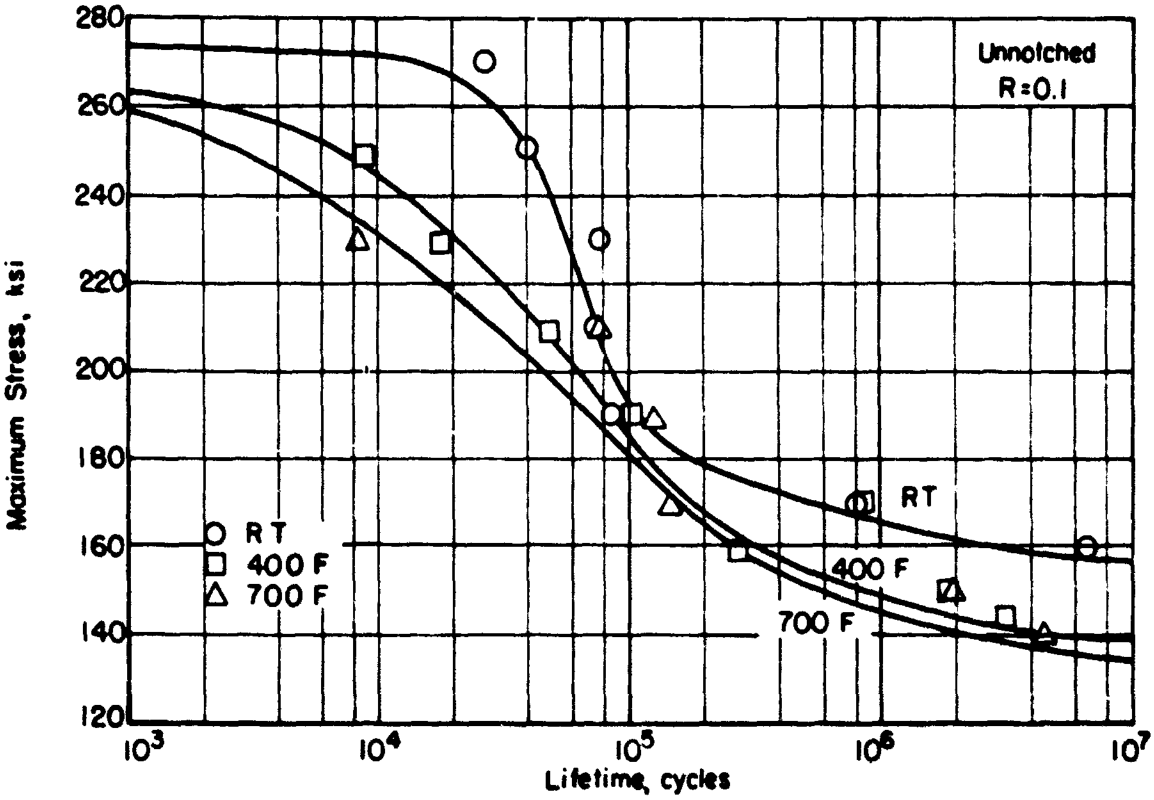


FIGURE 91. AXIAL LOAD FATIGUE RESULTS FOR MP35N MULTIPHASE ALLOY BAR

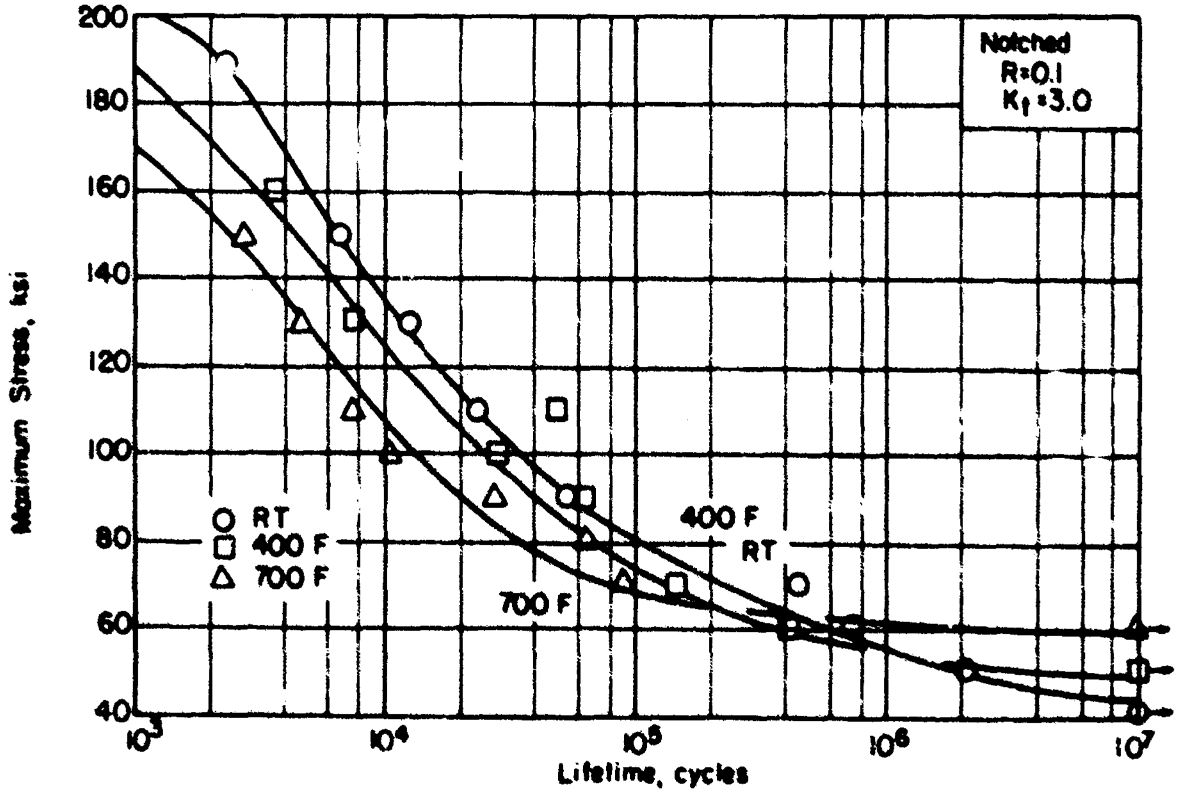


FIGURE 92. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) MP35N MULTIPHASE ALLOY BAR

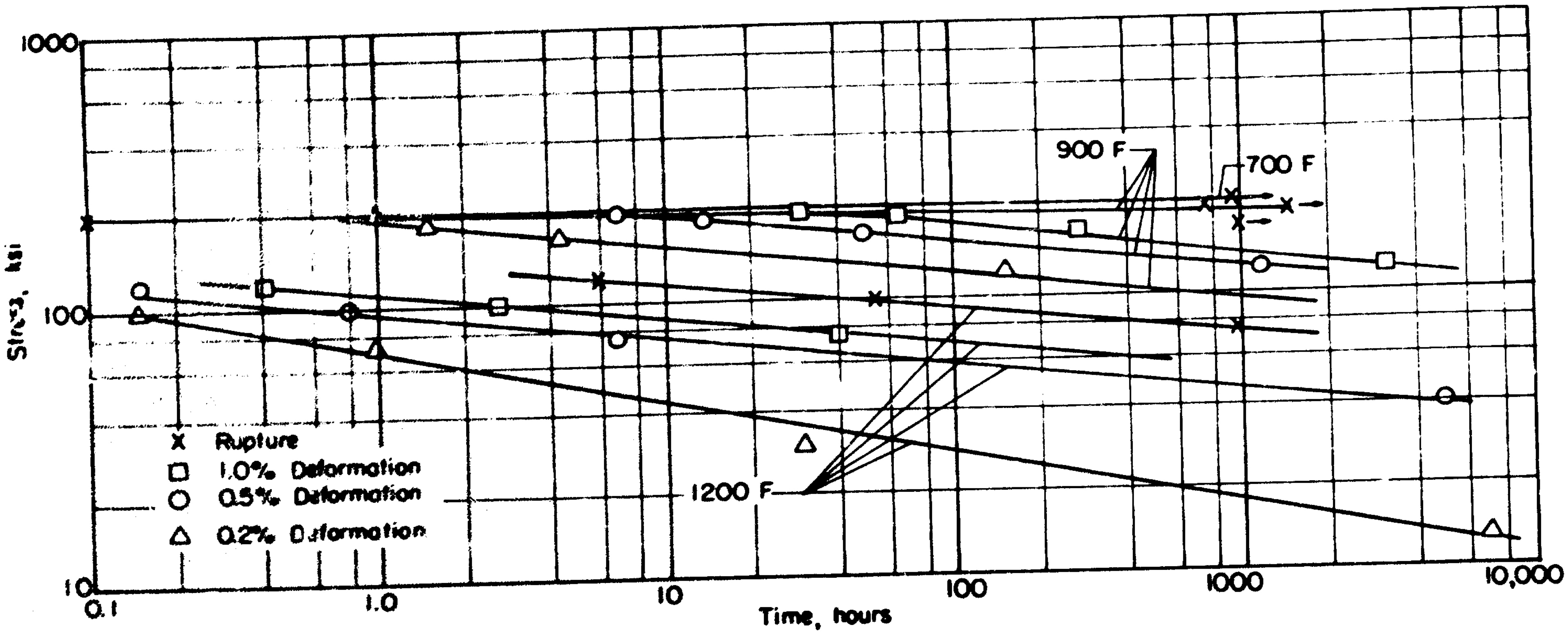


FIGURE 93. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR MP35N MULTIPHASE ALLOY BAR

38-6-44 Titanium Forgings

Material Description

38-6-44 (Ti-3Al-8V-6Cr-4Mo-4Zr) is a new deep-hardening beta composition alloy developed by Reactive Metals, Inc. The large amount of beta stabilizing elements in this composition results in sluggish transformation characteristics which gives deep hardening. The metallurgy of this alloy is similar to other beta alloys such that solution annealing retains the more ductile body-center-cubic beta phase at room temperature.

A 6 inch by 6 inch by 48 inch forged billet was used for this property evaluation.

Processing and Heat Treatment

The specimen layout for 38-6-44 alloy is presented in Figure 94. The thermal treatment was as follows: 1500F/15 minutes/air cool plus 1050F for 12 hours.

Test Results

Tension. Tests were conducted at room temperature, 400F, 700F, and 900F for the longitudinal and transverse directions. Results are given in Table 56. Stress-strain curves at temperature are presented in Figures 95 and 96. Effect-of-temperature curves are shown in Figure 99.

Compression. Tests were performed at room temperature, 400F, 700F, and 900F. Test results are given in Table 57. Stress-strain and tangent modulus curves at temperature are shown in Figures 97 and 98. Effect-of-temperature curves are presented in Figure 100.

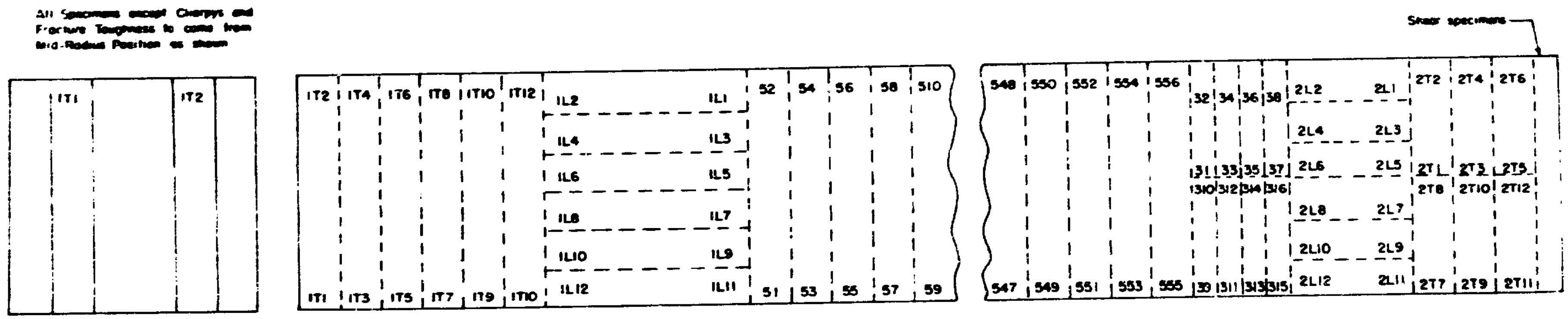
Shear. Results of tests at room temperature for both longitudinal and transverse directions are given in Table 58.

Impact. Charpy V-notch results on longitudinal and transverse specimens at room temperature and +32F are given in table 59.

Fracture Toughness. Test results for slow-bend type specimens at room temperature are given in Table 60.

Fatigue. Axial-load tests were performed at room temperature, 500F, and 700F. Tabular results are given in Tables 61 and 62. S-N curves are presented in Figures 101 and 102.

Creep and Stress Rupture. Tests were conducted at 500F, 700F, and 900F. Results are presented in Table 63 and Figure 103.



Specimen Code:

1 Tensile
2 Compression
3 Creep
5 Fatigue
6 Fracture-Toughness

FIGURE 94. SPECIMEN LAYOUT FOR RMI 38-6-44 TITANIUM FORGINGS

Stress Corrosion. No cracking was experienced after testing as described in the experimental procedure section.

Thermal Expansion and Density. Results of thermal expansion tests are given in Table 64. The alloy shows a permanent shrinkage of about 0.01 percent upon thermal cycling to 900F. The density for 38-6-44 alloy is 0.174 lb/in^3.

TABLE 56. TENSION TEST RESULTS FOR 38-6-44 TITANIUM FORGINGS

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Longitudinal at Room Temperature		
1L-1	174.0	164.0	11.0	16.1
1L-2	179.0	168.0	10.5	14.6
1L-3	178.0	170.0	8.5	15.4
		Transverse at Room Temperature		
1T-1	165.0	159.0	4.0	15.1
1T-2	170.0	165.0	8.0	14.7
1T-3	168.0	162.0	7.0	15.4
		Longitudinal at 400 F		
1L-4	166.0	146.0	5.5	14.0
1L-5	165.0	143.0	5.5	13.8
1L-6	167.0	150.0	4.0	13.7
		Transverse at 400 F		
1T-4	162.0	146.0	5.5	14.4
1T-5	163.0	143.0	5.5	14.4
1T-6	168.0	150.0	4.0	15.0
		Longitudinal at 700 F		
1L-7	159.0	137.0	8.0	11.6
1L-8	159.0	142.0	10.0	12.5
1L-9	160.0	138.0	8.0	12.8
		Transverse at 700 F		
1T-7	156.0	134.0	7.5	13.4
1T-8	157.0	137.0	4.5	12.9
1T-9	152.0	133.0	6.0	12.8
		Longitudinal at 900 F		
1L-10	139.0	121.0	31.0	11.6
1L-11	141.0	123.0	40.0	11.2
1L-12	141.0	125.0	29.5	12.0
		Transverse at 900 F		
1T-10	145.0	129.0	19.0	12.0
1T-11	133.0	121.0	11.0	11.3
1T-12	141.0	126.0	22.0	12.1

TABLE 57. COMPRESSION TEST RESULTS FOR 38-6-44 TITANIUM FORGINGS

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Longitudinal at Room Temperature	
2L-1	156.0	(a)
2L-2	165.0	14.8
2L-3	161.0	14.8
	Transverse at Room Temperature	
2T-1	157.0	14.7
2T-2	159.0	14.9
2T-3	150.0	14.7
	Longitudinal at 400 F	
2L-4	142.0	13.9
2L-5	139.0	13.4
2L-6	138.0	13.1
	Transverse at 400 F	
2T-4	143.0	13.7
2T-5	130.0	(a)
2T-6	138.0	13.8
	Longitudinal at 700 F	
2L-7	133.0	12.5
2L-8	125.0	12.4
2L-9	132.0	12.4
	Transverse at 700 F	
2T-7	127.0	11.5
2T-8	137.0	12.1
2T-9	122.0	12.1
	Longitudinal at 900 F	
2L-10	116.0	11.6
2L-11	113.0	11.1
2L-12	111.0	10.9
	Transverse at 700 F	
2T-10	114.0	11.6
2T-11	115.0	11.3
2T-12	119.0	11.4

*Load/Strain curve no good for modulus.

TABLE 58. SHEAR TEST RESULTS FOR 38-6-44 TITANIUM ALLOY FORGING

Specimen Number	Ultimate Shear Strength, ksi
	Longitudinal
4L-1	117.0
4L-2	124.0
4L-3	114.0
4L-4	123.0
	Transverse
4T-1	116.0
4T-2	119.0
4T-3	122.0
4T-4	120.0

TABLE 59. RESULTS OF CHARPY IMPACT TESTS ON 38-6-44 TITANIUM FORGING

Specimen Number	Specimen Direction	Temperature, F	Energy, ft. lbs.
1	Longitudinal	RT	8.0
2	Longitudinal	RT	7.0
3	Transverse	RT	5.0
4	Transverse	RT	5.0
5	Longitudinal	+32	8.5
6	Longitudinal	+32	6.5
7	Transverse	+32	6.0
8	Transverse	+32	5.5

TABLE 60. FRACTURE TOUGHNESS TEST RESULTS FOR 38-6-44 TITANIUM FORGING

Specimen Number	Thickness, in.	Width, in.	Crack Length in.	Span, in.	K_{Ic} ksi$\sqrt{in.}$
0-1[(a)]	0.754	1.50	0.788	6.0	55.0
0-2	0.753	1.50	0.886	6.0	60.8
0-3	0.753	1.50	0.776	6.0	58.0
0-4	0.752	1.50	0.785	6.0	57.1
M-1[(b)]	0.753	1.50	0.805	6.0	64.6
M-2	0.752	1.50	0.780	6.0	58.7
M-3	0.753	1.50	0.741	6.0	64.8
M-4	0.753	1.50	0.800	6.0	52.4

(a) "O" denotes specimen from outside of forging.

(b) "M" denotes specimen from middle of forging.

TABLE 61. FATIGUE TEST RESULTS FOR 38-6-44 TITANIUM FORGINGS, TRANSVERSE, UNNOTCHED, AND AT A STRESS RATIO OF R = 0.1

Specimen No.	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-29	170	10+
5-44	150	25,710
5-37	140	66,670
5-21	130	15,600
5-15	130	33,060
5-47	120	435,170
5-48	110	112,790 [a]
5-18	110	268,880
5-33	100	2,264,770
5-32	90	7,844,600
	500 F	
5-25	150	5,250
5-35	140	7,700
5-46	130	85,880
5-9	120	143,680
5-2	110	114,750
5-17	110	55,660
5-31	100	68,190
5-59	90	2,621,000
5-51	70	10,264,130 [a]
	700 F	
5-24	140	8,477
5-6	120	83,250
5-40	105	21,360
5-19	100	58,880
5-38	90	594,480
5-50	70	1,251,350

(a) Failed in grip.
(b) Did not fail.

TABLE 62. FATIGUE TEST RESULTS FOR 38-6-44 TITANIUM FORGINGS, TRANSVERSE, NOTCHED (K_t = 3.0), AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
5-39	120	1,150
5-43	100	2,810
5-23	80	11,300
5-3	60	30,040
5-12	50	35,140
5-30	45	44,830
5-13	40	14,519,780
	500 F	
5-7	120	572
5-27	100	1,560
5-10	80	3,910
5-1	60	83,390
5-14	40	33,500
5-36	30	16,847,960*
5-11	20	11,242,260*
	700 F	
5-8	80	2,322
5-4	70	5,470
5-9	60	6,780
5-42	50	12,920
5-5	45	56,700
5-41	40	2,177,710
5-49	35	10,086,000*

* Did not fail.

TABLE 63. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES OF RMI 38-6-44 TITANIUM FORGINGS

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hr.	Elongation in 2 Inches, percent	Reduction of Area, percent	Minimum Creep Rate, percent/hr.
			0.1	0.2	0.5	1.0	2.0					
B-31	146,000	500	--	--	--	--	--	--	on loading	3.7	7.6	--
B-36	140,000	500	15.0	1000	--	--	--	1.633	575.7*	1.800	--	0.00006
B-32	145	700	--	--	--	--	--	--	on loading	3.7	13.7	--
B-34	135	700	0.1	0.5	9.4	30	85	1.856	412.5	5.9	6.8	0.0056
B-39	100	700	10	30	80	160	320 est.	0.911	166.4*	1.931	--	--
B-312	70	700	34	80	217	605	--	0.704	643.9*	1.738	--	0.0009
B-313	40	700	100	184	--	--	--	0.389	--	--	--	--
B-33	130	900	--	--	--	--	--	--	on loading	6.7	18.6	--
B-35	110	900	--	0.02	0.07	0.12	0.21	1.180	0.6	11.8	44.6	8.0
B-37	60	900	0.15	0.35	0.80	2.0	4.5	0.456	40.5	32.6	72.9	0.36
B-38	40	900	0.2	0.50	1.5	4.0	13.0	0.408	330.7	47.4	81.3	0.040
B-310	20	900	0.8	3.0	13.0	58	--	0.193	137.8*	1.462*	--	--
B-311	7	900	8.0	28.0	610	--	--	0.107	257.3*	0.467	--	0.00010
B-314	4	900	43	--	--	--	--	0.030	--	--	--	--

*Test discontinued.

TABLE 64. MEAN LINEAR EXPANSION COEFFICIENTS FOR 38-6-44 TITANIUM FORGINGS

Temperature Range, F	Coefficient, α, 10^{-6} in./in./F Heating	Cooling
68-100	4.69	4.69
68-150	4.76	5.06
68-200	4.81	5.11
68-250	4.89	5.14
68-300	4.94	5.17
68-350	4.98	5.21
68-400	5.03	5.24
68-450	5.09	5.27
68-500	5.14	5.30
68-550	5.19	5.33
68.600	5.23	5.36
68-650	5.27	5.39
68-700	5.30	5.41
68-750	5.32	5.44
68-800	5.34	5.46
68-850	5.36	5.49
68-900	5.38	5.51

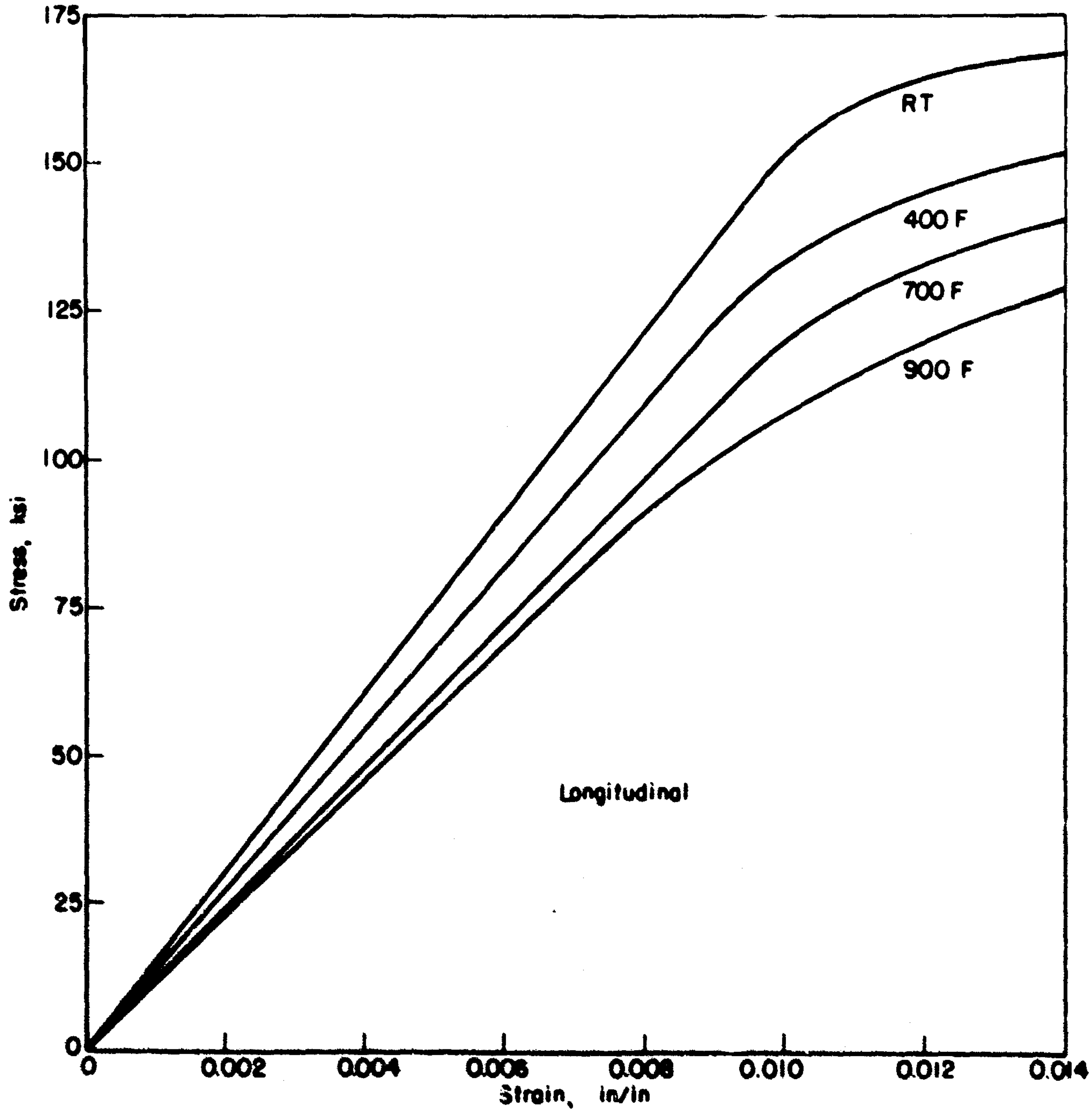


FIGURE 95. TYPICAL TENSION STRESS-STRAIN CURVES FOR RMI 38-6-44 FORGINGS AT TEMPERATURE

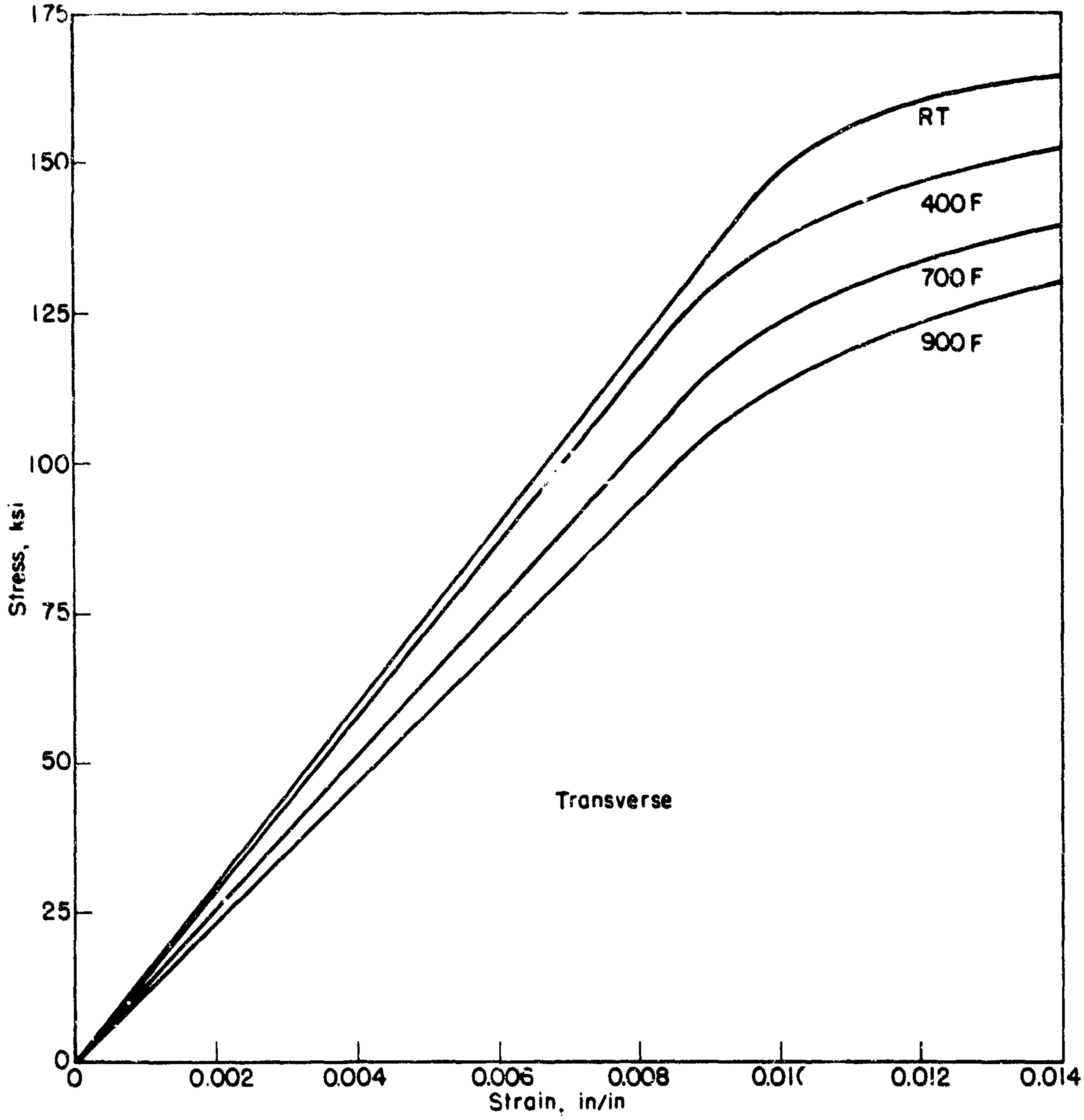


FIGURE 96. TYPICAL TENSION STRESS-STRAIN CURVES FOR RMI-38-6-44 FORGINGS AT TEMPERATURE

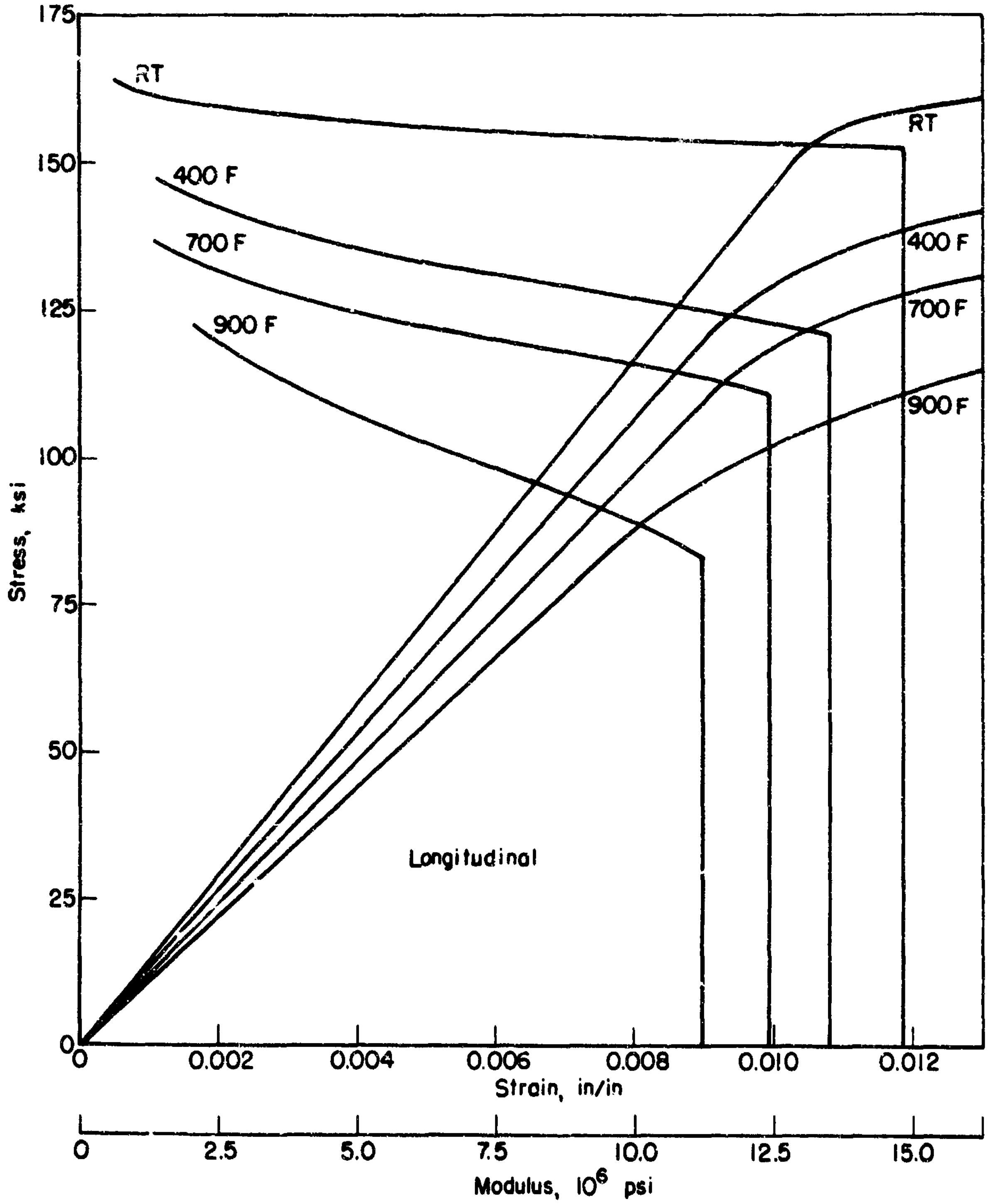


FIGURE 97. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR RMI-38-6-44 FORGINGS AT TEMPERATURE

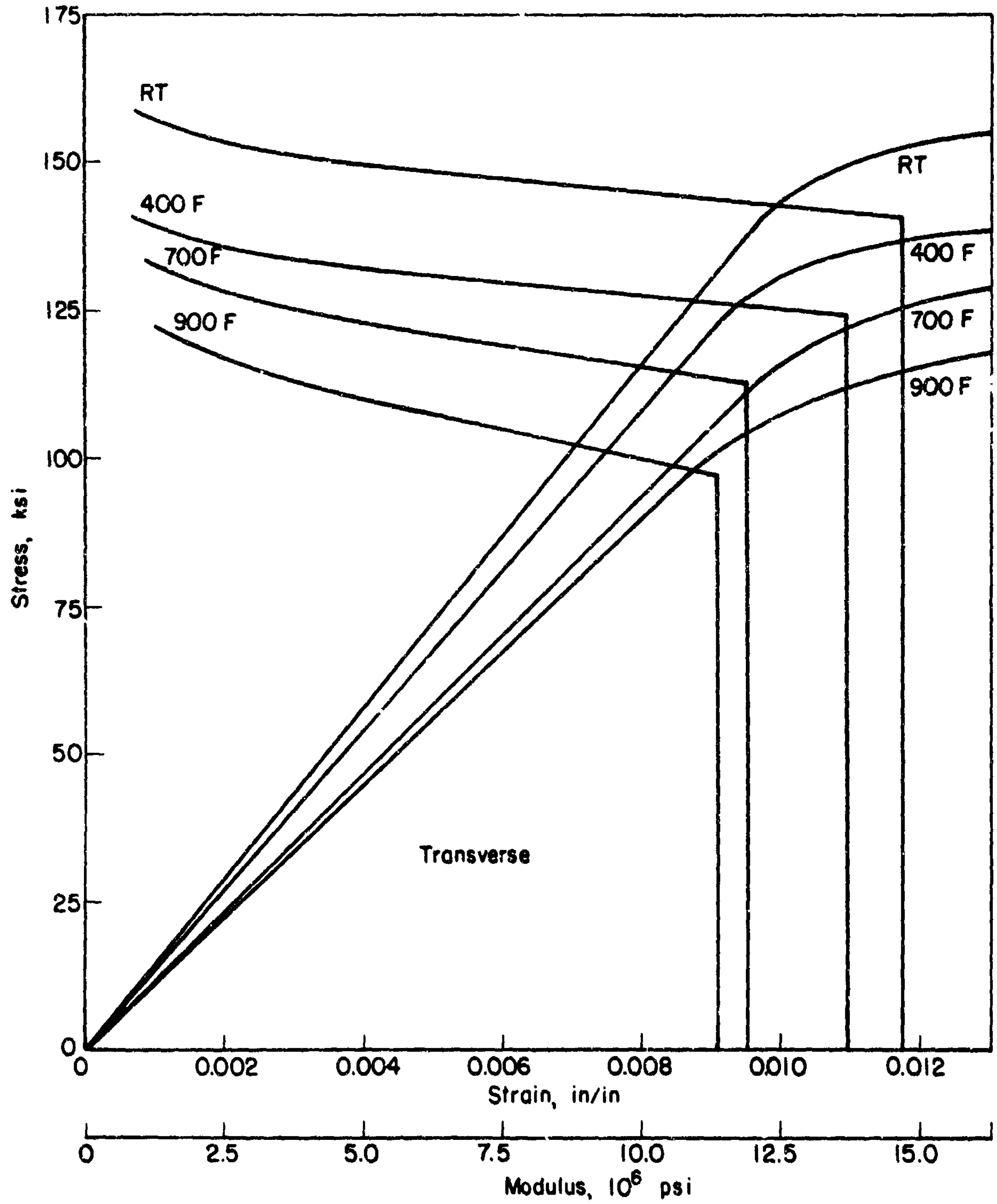


FIGURE 98. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR RMI-38-6-44 FORGINGS AT TEMPERATURE

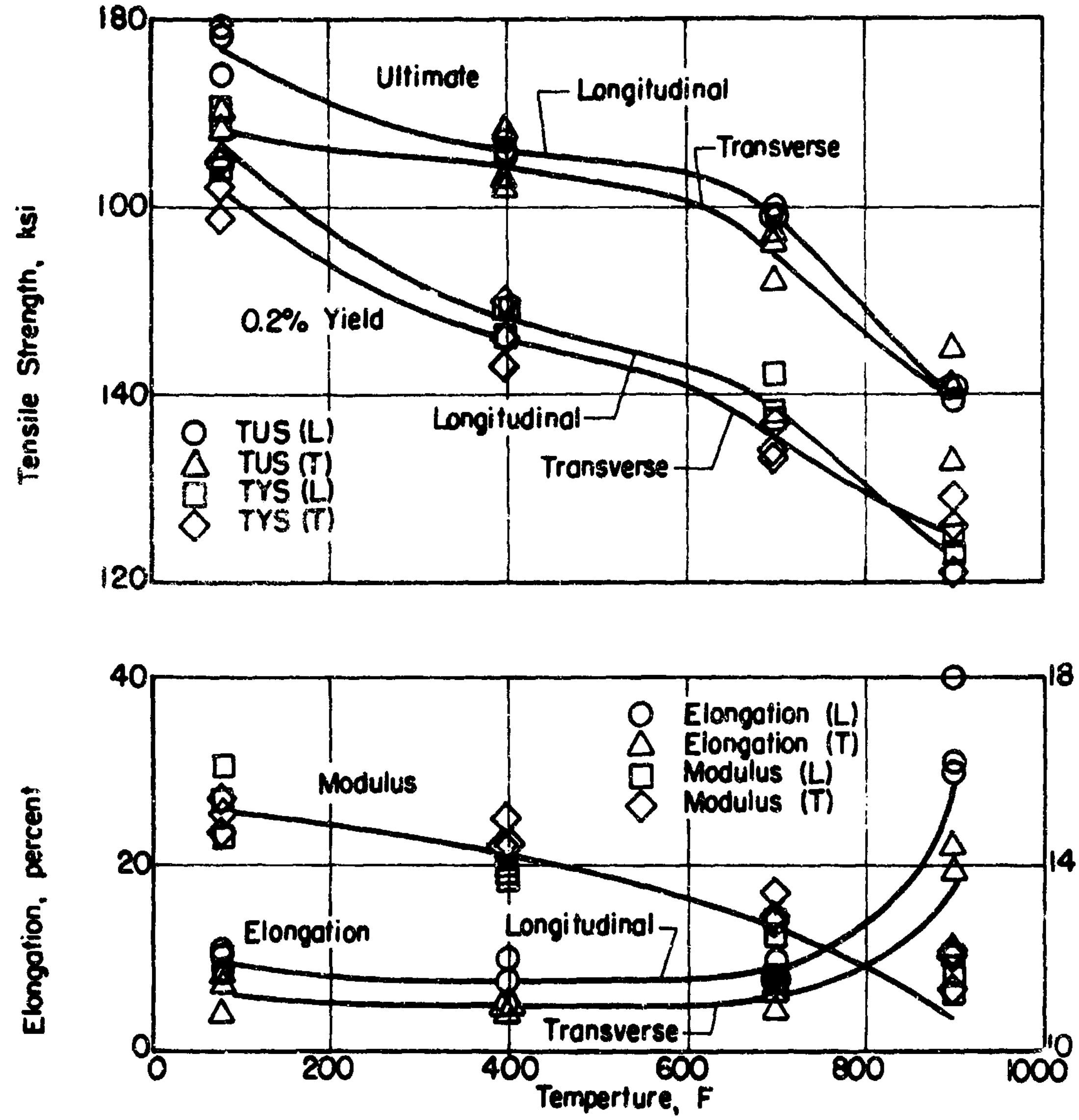


FIGURE 99. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 38-6-44 TITANIUM FORGINGS

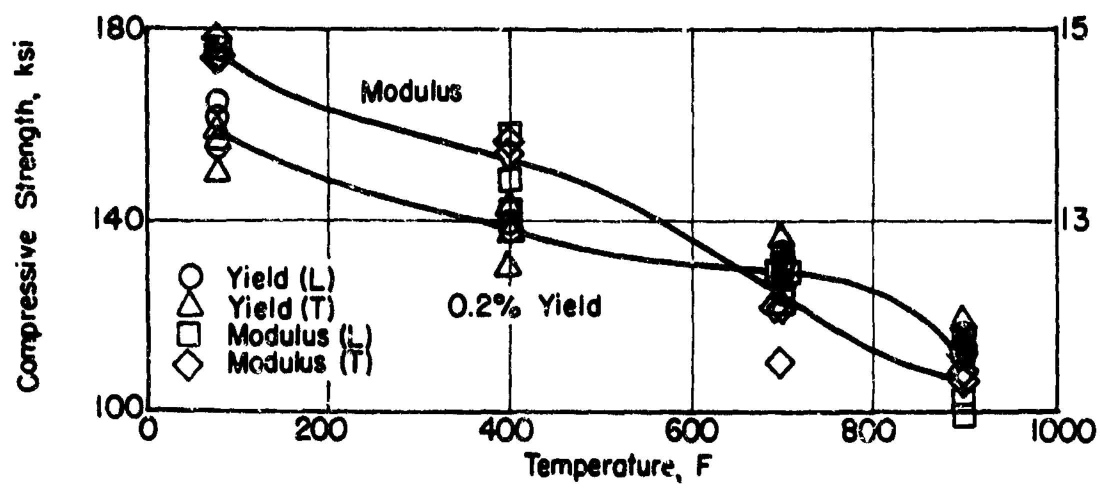


FIGURE 100. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 38-6-44 TITANIUM FORGINGS

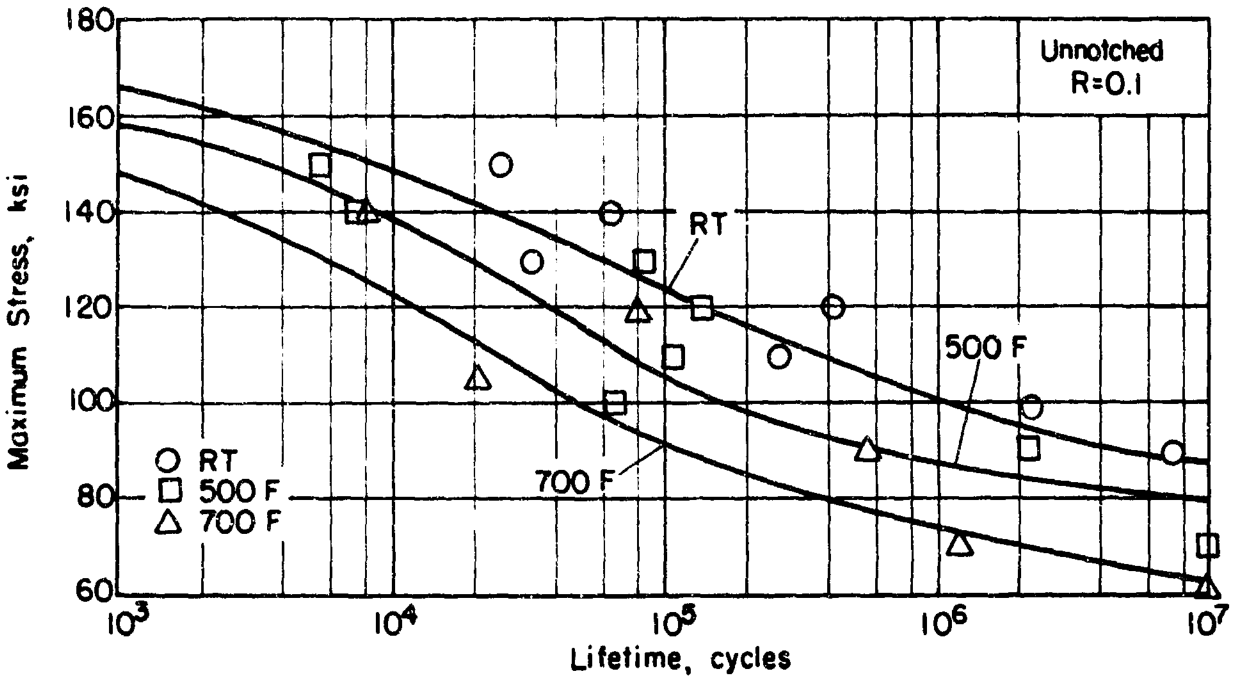


FIGURE 101. AXIAL LOAD FATIGUE RESULTS FOR 38-6-44 TITANIUM FORGINGS

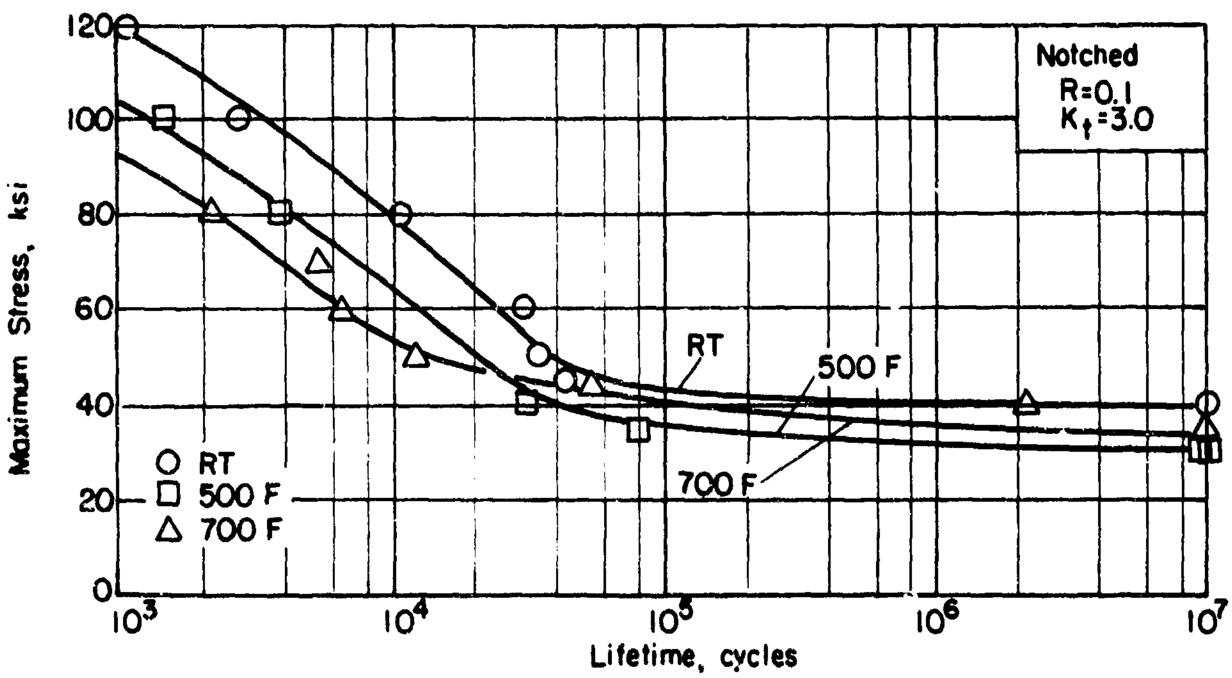


FIGURE 102. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 38-6-44 TITANIUM FORGINGS

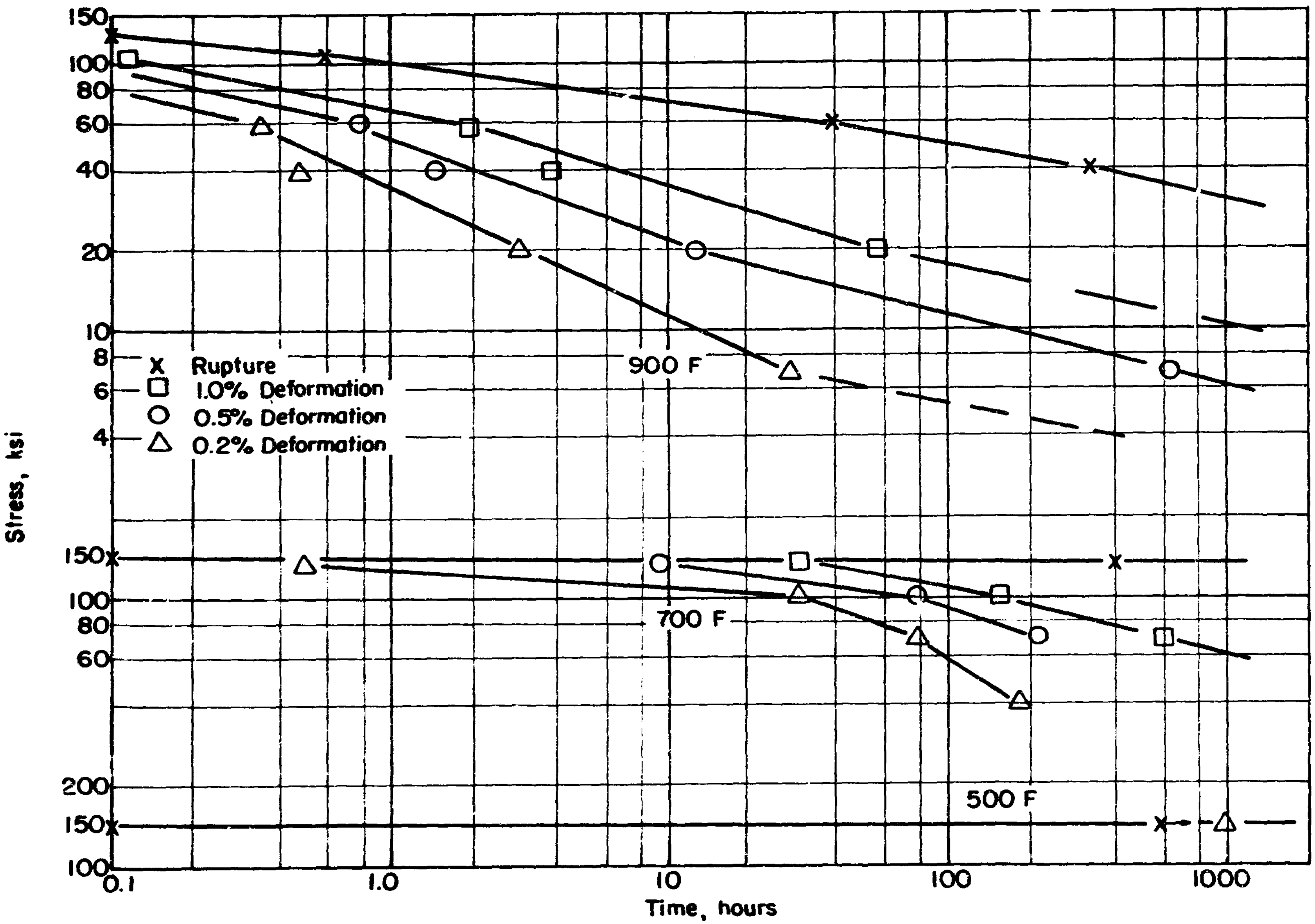


FIGURE 103. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 38-6-44 TITANIUM FORGINGS

7175 Aluminum Forging

Material Description

7175 is a new premium strength die forging developed by Alcoa. This development is intended to provide relatively high strength/weight ratios for aerospace applications. The guaranteed minimum longitudinal yield strength is approximately 17 percent above the current minimum requirements of specifications covering 7075 alloy die forging in the -T73 temper. Although the development emphasis was placed on high longitudinal strength, the transverse ductility is also well above that of most conventional 7075 die forgings.

Tests on a limited number of forgings (by Alcoa) in the -T736 temper indicate that the stress corrosion cracking threshold in the short transverse direction should be at least 35 ksi.

Current production is limited to closed die airframe type forgings. Two such forgings were supplied by Alcoa for this evaluation.

Processing and Heat Treatment

Because of the complex shape of the die forging and the fact that it was an actual structural forging, no specimen layout is shown. The alloy was evaluated in the -T736 temper.

Test Results

Tension. Tension tests were conducted in the longitudinal and transverse directions at room temperature, 250F, 350F, and 500F. Results are shown in tabular form in Table 65. Stress-strain curves at temperature are presented in Figures 104 and 105. Effect-of-temperature curves are shown in Figure 108.

Compression. Tests were performed at room temperature, 250F, 350F, and 500F in the longitudinal and transverse directions. Results are shown in Table 66. Stress-strain and tangent modulus curves at temperature are presented in Figures 106 and 107. Effect-of-temperature curves are presented in Figure 109.

Shear. Room temperature test results for both the longitudinal and transverse directions are given in Table 67.

Impact. Charpy V-notch test results for both the longitudinal and transverse directions are given in Table 68 for room temperature, -95F, and -320F.

Fracture Toughness. Slow-bend type test results are given in Table 69. Even though the tests proved to be marginal by the existing criteria, the results were quite consistent and are reported.

Fatigue. Axial-load tests were conducted at room temperature, 250F, and 350F. Tabular results are given in Tables 70 and 71. S-N curves are presented in Figures 110 and 111.

Creep and Stress Rupture. Tests were performed at 250F, 350F, and 500F. Results are given in tabular form in Table 72 and presented as log stress versus log time curves in Figure 112.

Stress Corrosion. No cracks appeared in the seven specimens after testing as described in the experimental procedure section.

Thermal Expansion and Density. Values for these properties are given in the "data sheet" in the conclusions section.

TABLE 65. TENSION TEST RESULTS FOR 7175-T736 DIE FORGINGS

Specimen No.	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, psi x 10^6
		Longitudinal at Room Temperature		
1L1	81.9	75.2	15.0	10.7
1L2	81.5	74.6	15.0	10.0
1L3	82.7	76.4	13.0	10.1
		Transverse at Room Temperature		
1T1	79.1	72.6	12.0	9.7
1T2	79.2	72.1	13.0	10.0
1T3	79.2	72.1	12.0	10.2
		Longitudinal at 250 F		
1L4	67.0	67.0	19.0	9.4
1L5	66.1	65.9	21.0	10.1
1L6	65.7	65.3	22.0	9.6
		Transverse at 250 F		
1T4	63.8	63.5	18.0	9.6
1T5	64.6	64.6	15.0	9.3
1T6	64.1	63.9	15.0	9.7
		Longitudinal at 350 F		
1L7	53.0	52.6	27.0	8.3
1L8	52.5	52.5	20.0	8.7
1L9	53.0	52.6	23.0	8.9
		Transverse at 350 F		
1T7	51.0	50.4	20.0	8.5
1T8	50.9	50.7	22.0	8.7
1T9	50.2	50.2	20.0	8.3
		Longitudinal at 500 F		
1L10	18.7	18.7	32.0	8.1
1L11	19.7	19.7	28.0	8.2
1L12	20.6	20.6	27.0	8.3
		Transverse at 500 F		
1T10	19.1	19.1	27.0	8.4
1T11	19.1	19.1	27.0	8.6
1T12	19.5	19.5	25.0	7.9

TABLE 66. COMPRESSION TEST RESULTS FOR 7175-T736 DIE FORGINGS

Specimen No.	0.2 Percent Offset Yield Strength, psi	Compression Modulus, psi x 10^6
Longitudinal at Room Temperature		
2L1	(a)	(a)
2L2	78.2	10.8
2L3	79.3	11.2
Transverse at Room Temperature		
2T1	74.0	10.8
2T2	73.8	10.7
2T3	74.3	10.6
Longitudinal at 250 F		
2L4	70.1	9.8
2L5	70.3	9.9
2L6	69.0	10.5
Transverse at 250 F		
2T4	65.5	9.8
2T5	65.4	9.9
2T6	65.6	9.9
Longitudinal at 350 F		
2L7	57.2	9.2
2L8	56.6	8.7
2L9	57.5	8.8
Transverse at 350 F		
2T7	54.6	9.3
2T8	54.6	9.2
2T9	55.2	9.3
Longitudinal at 500 F		
2L10	22.0	8.0
2L11	21.1	7.8
2L12	23.4	8.1
Transverse at 500 F		
2T10	21.1	7.7
2T11	21.7	7.4
2T12	22.5	7.6

(a) Specimen buckled.

TABLE 67. SHEAR TEST RESULTS FOR 7175-T736 DIE FORGINGS AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
Longitudinal	
4L-1	46.2
4L-2	49.4
4L-3	47.6
4L-4	46.8
Transverse	
4T-1	51.0
4T-2	50.6
4T-3	46.4
4T-4	49.0

TABLE 68. CHARPY V-NOTCH TEST RESULTS FOR 7175-T736 DIE FORGINGS

Specimen Number	Specimen Direction	Temperature, F	Energy, ft-lb
9	Longitudinal	RT	6.5
10	Longitudinal	RT	6.0
5	Transverse	RT	5.5
6	Transverse	RT	5.0
8	Longitudinal	-95	4.5
7	Longitudinal	-95	4.5
4	Transverse	-95	4.0
3	Transverse	-95	4.0
11	Longitudinal	-320	5.0
12	Longitudinal	-320	4.5
1	Transverse	-320	3.5
2	Transverse	-320	3.5

TABLE 69. FRACTURE TOUGHNESS TEST RESULTS FOR 7175-T736 DIE FORGINGS (LONGITUDINAL)

Specimen Number	Thickness, inch	Width, inches	Crack Length, inches	Span, inches	K_{Ic} ksi$\sqrt{in}$
6-1	0.603	1.203	0.69	5.0	46.9
6-2	0.604	1.204	0.65	5.0	55.3
6-3	0.602	1.204	0.60	5.0	42.3
6-4	0.604	1.204	0.59	5.0	44.6
6-5	0.611	1.203	0.65	5.0	54.6
6-6	0.604	1.203	0.62	5.0	47.3

TABLE 70. FATIGUE TEST RESULTS FOR 7175-T736 DIE FORGINGS, UNNOTCHED, AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
	Room Temperature	
515	85	22,000
527	75	39,400
54	70	105,400
58	65	53,000
520	60	98,300
52	50	230,500
525	45	408,900
519	40	3,303,500
510	35	6,996,900
	250 F	
513	80	1,900
55	70	14,600
517	65	72,100
516	60	79,700
514	50	77,600
53	45	395,900
526	40	8,218,700
	350 F	
56	60	25,200
52	50	74,200
528	45	1,169,400
512	40	273,300
51	37.5	5,917,400
522	35	1,789,600
511	30	4,385,500
518	25	10,000,000*

* Did not fail.

TABLE 71. FATIGUE TEST RESULTS FOR 7175-T736 DIE FORGINGS, NOTCHED (K_t=3.0), AND AT A STRESS RATIO OF R=0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temp.	
5-8	55	3,100
5-20	55	3,700
5-19	50	6,300
5-22	45	11,000
5-24	35	20,300
5-21	30	87,100
5-1	20	463,000
5-15	15	10,028,000[a]
	250 F	
5-8	55	3,100
5-16	45	6,700
5-21	35	11,000
5-23	35	7,500
5-10	30	33,500
5-4	25	106,700
5-11	20	323,500
5-6	15	8,220,000
5-25	12.5	10,000,000[a]
	350 F	
5-17	50	2,500
5-26	45	6,500
5-13	40	7,800
5-9	35	10,800
5-12	30	24,100
5-3	25	43,000
5-5	20	400,800
5-18	17.5	467,600
5-7	12.5	8,758,800

(a) Did not fail

TABLE 72. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR 7175 T736 DIE FORGINGS

Specimen Number	Stress, ksi	Temperature F	Hours to Indicated Creep Deformation, percent 0.1	0.2	0.5	1.0	2.0	Initial Strain, percent	Rupture Time, hr.	Elongation in 2 Inches, percent	Reduction of Area percent	Minimum Creep Rate, percent/hr.
L-1	55	250	0.6	1.4	3.7	6.5	11	0.765	20.4	15.4	54.6	0.13
L-5	50	250	10	30	60	85	145	0.523	182.4	13.1	57.7	0.005
L-9	48	250	15	35	80	135	200	0.708	240.3	13.8	56.5	0.0045
L-10	45	250	50	110	283	412	--	0.612	580.8	13.1	57.9	0.0013
L-2	30	350	3.7	7.5	13.5	15.7	19	0.496	20.8	15.4	80.4	0.03
L-6	20	350	46	75	120	175	210	0.308	227.2	18.5	82.3	0.0025
L-8	14	350	250	450	865	1200 est.	--	0.258	1031.9*	0.953	--	0.0002
L-4	10	500	0.8	2.5	4.5	6.0	7.5	0.200	8.6	42.3	92.6	0.075
L-3	7	500	2.2	5.8	12	21	30	0.100	57.1	40.0	95.7	0.030
L-7	4.5	500	55	135	293	475	700	0.046	1295.3	30.8	96.0	0.0014

*Test discontinued

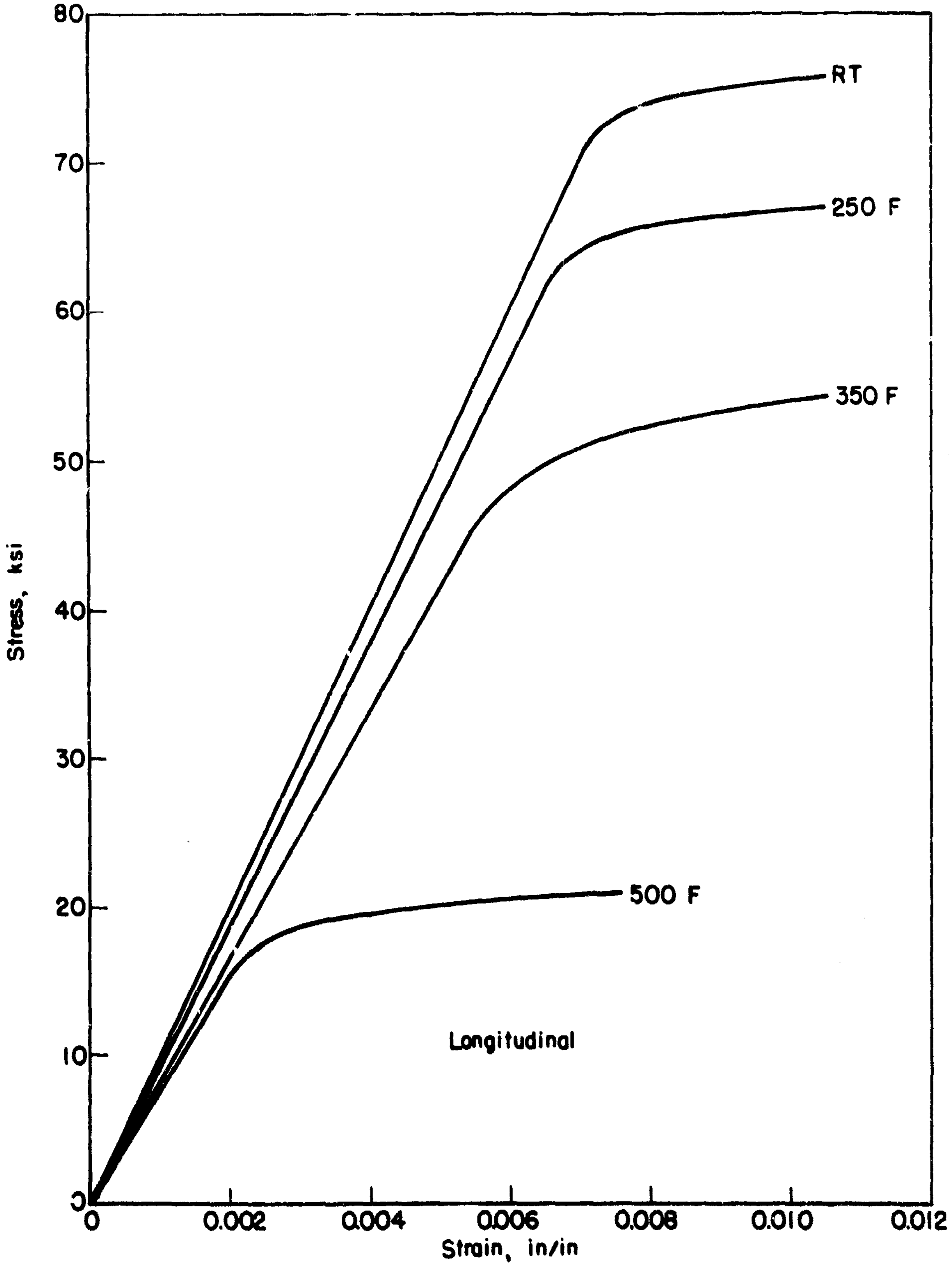


FIGURE 104. TYPICAL TENSION STRESS-STRAIN CURVES FOR 7175-T736 DIE FORGINGS AT TEMPERATURE

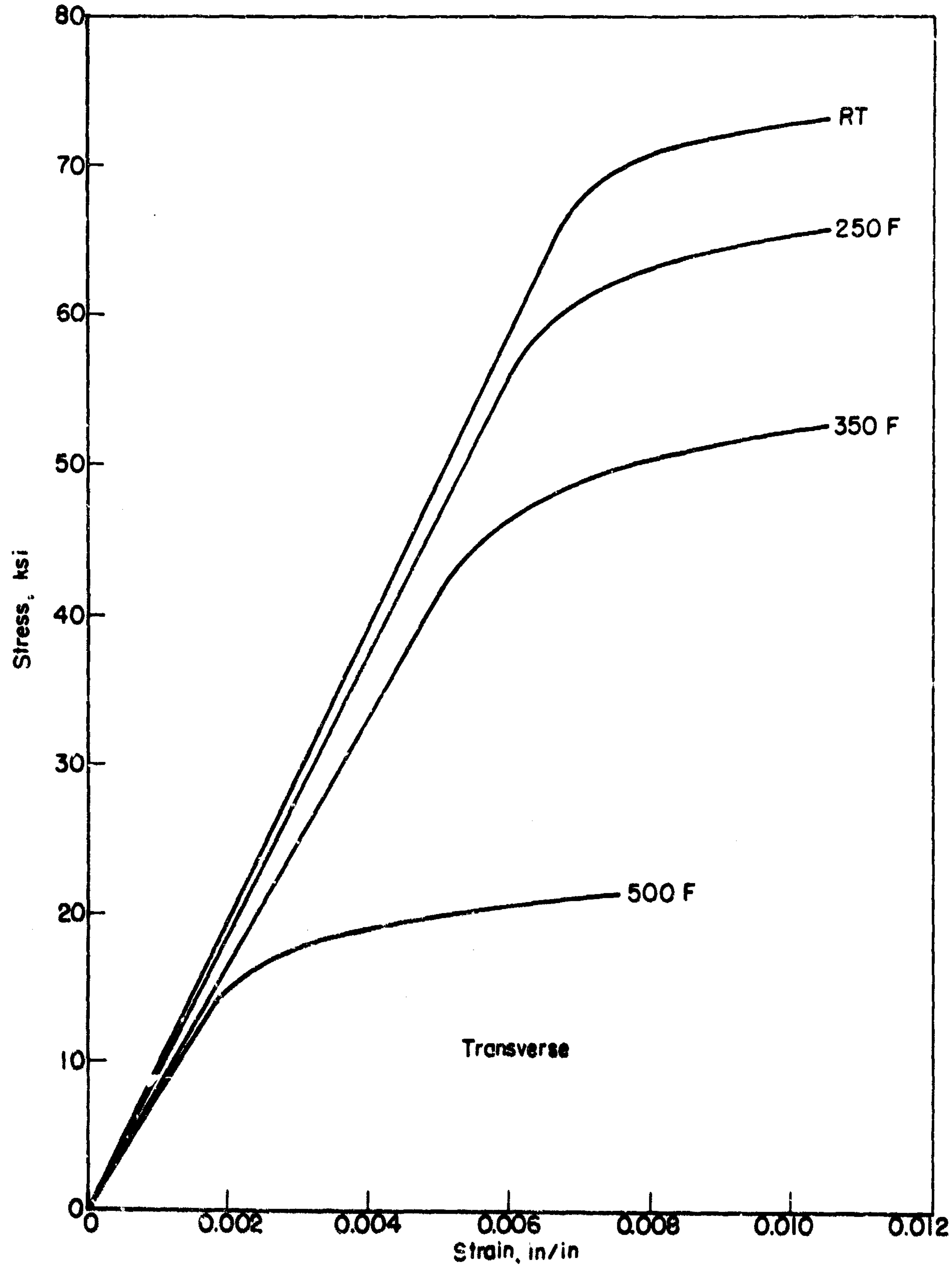


FIGURE 105. TYPICAL TENSION STRESS-STRAIN CURVES FOR 7175-T736 DIE FORGINGS AT TEMPERATURE

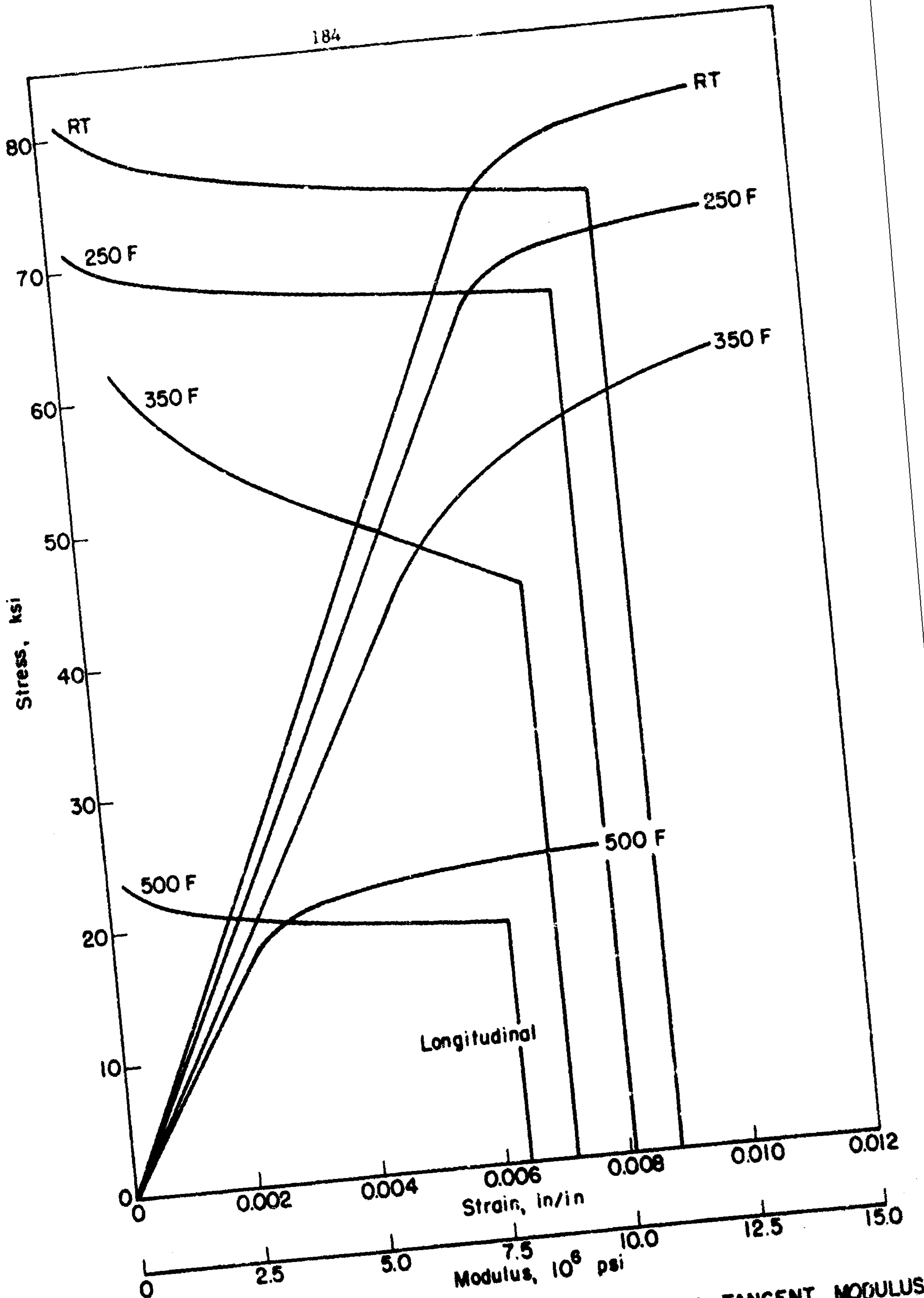


FIGURE 106. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 7175-T736 DIE FORGINGS AT TEMPERATURE

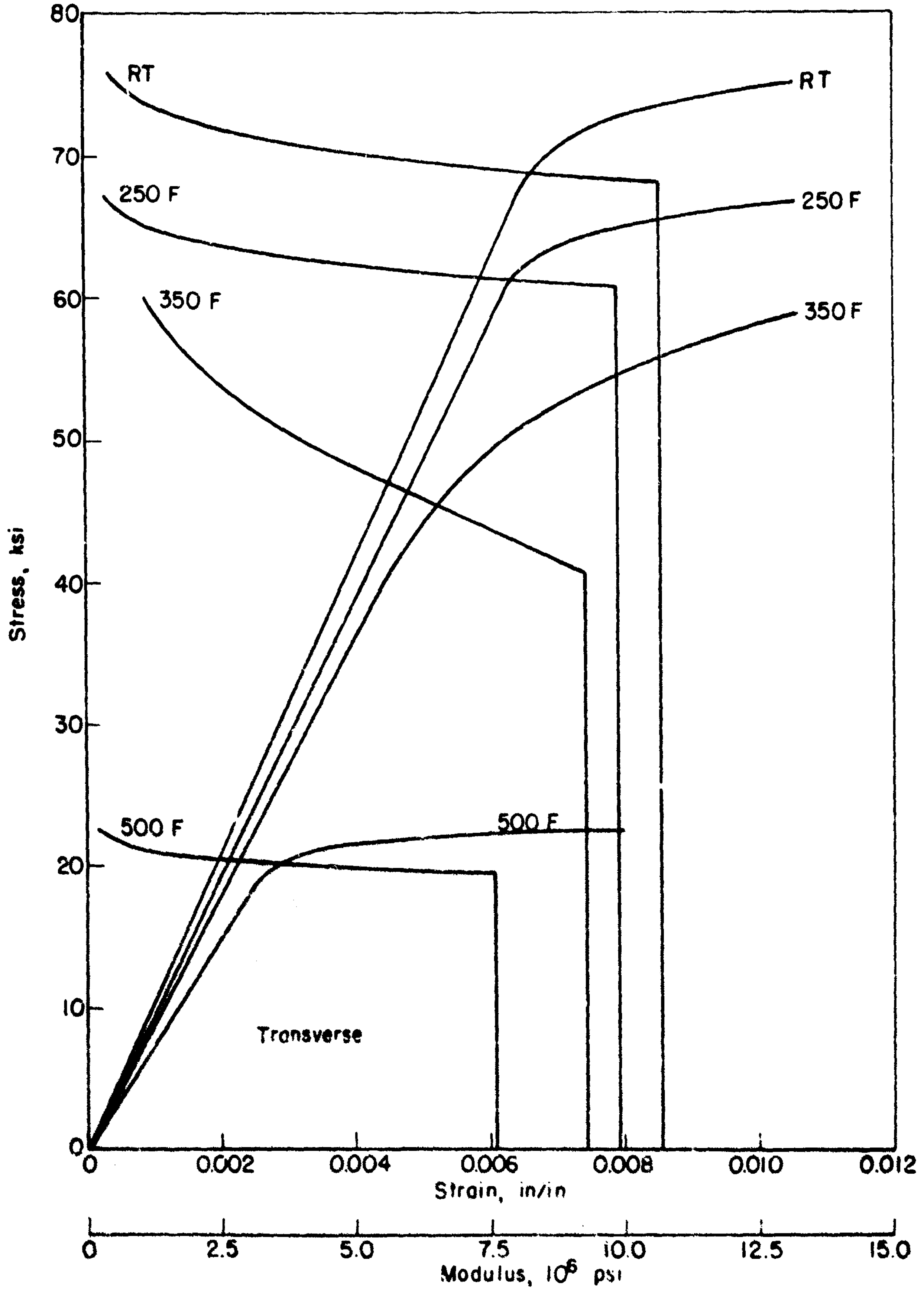


FIGURE 107. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 7175-T736 DIE FORGINGS AT TEMPERATURE

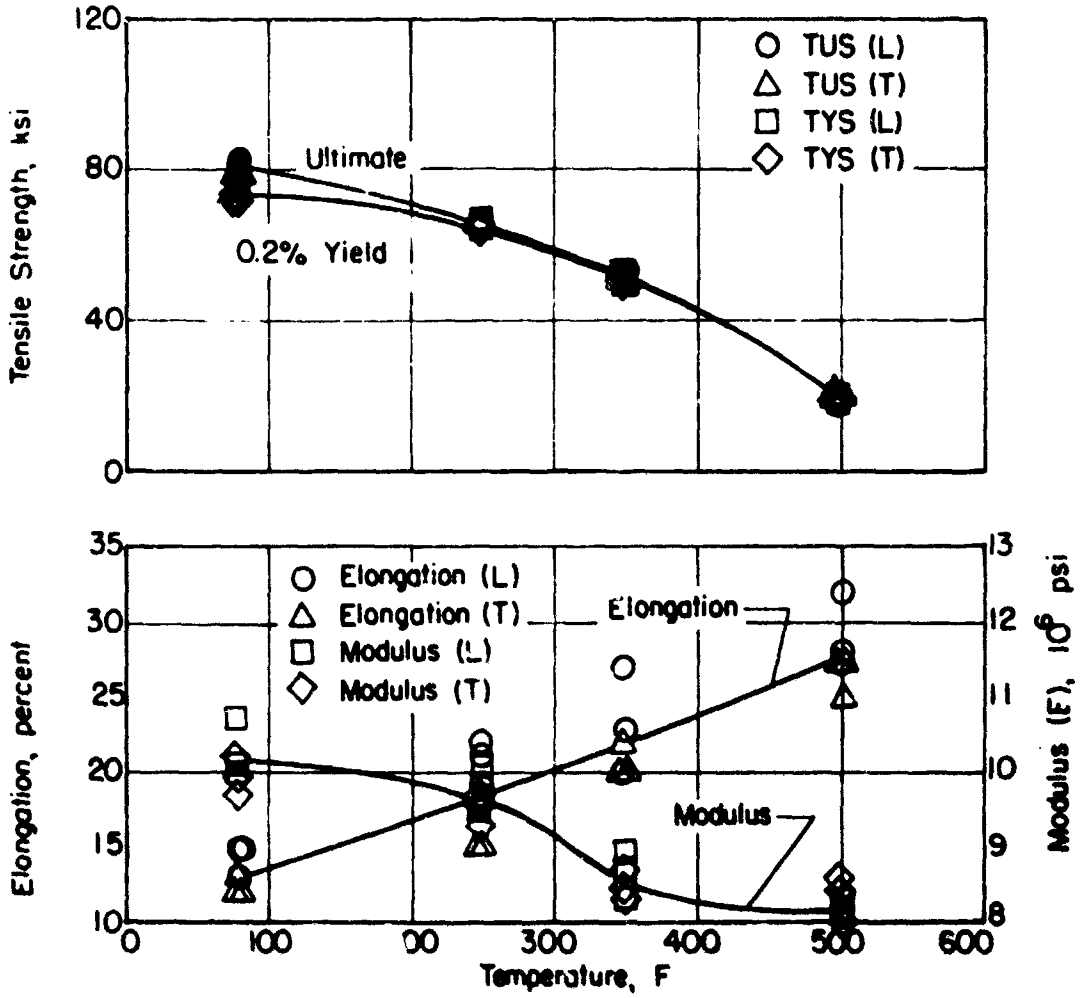


FIGURE 108. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7175-T736 DIE FORGING

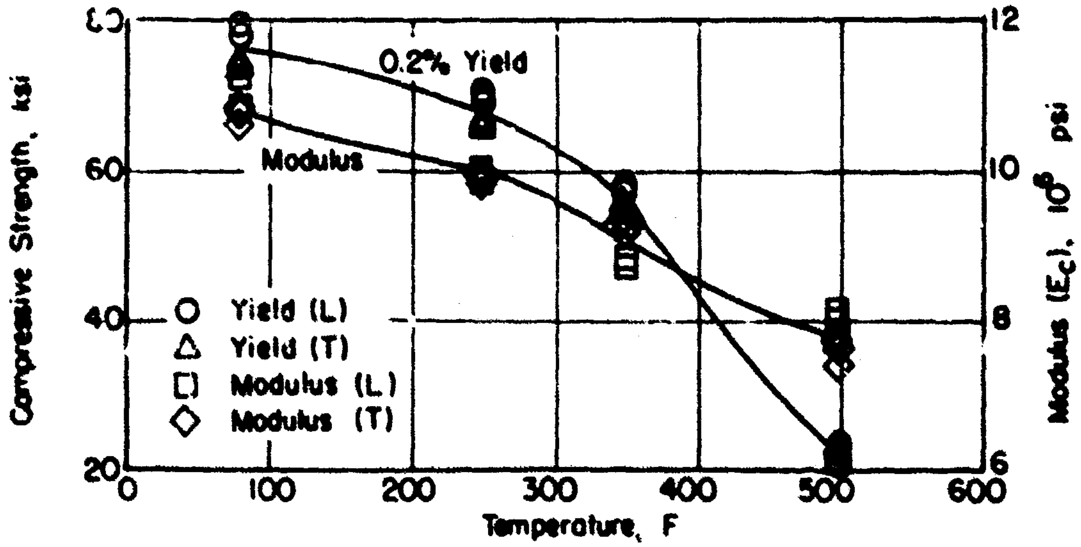


FIGURE 109. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF 7175-T736 DIE FORGING

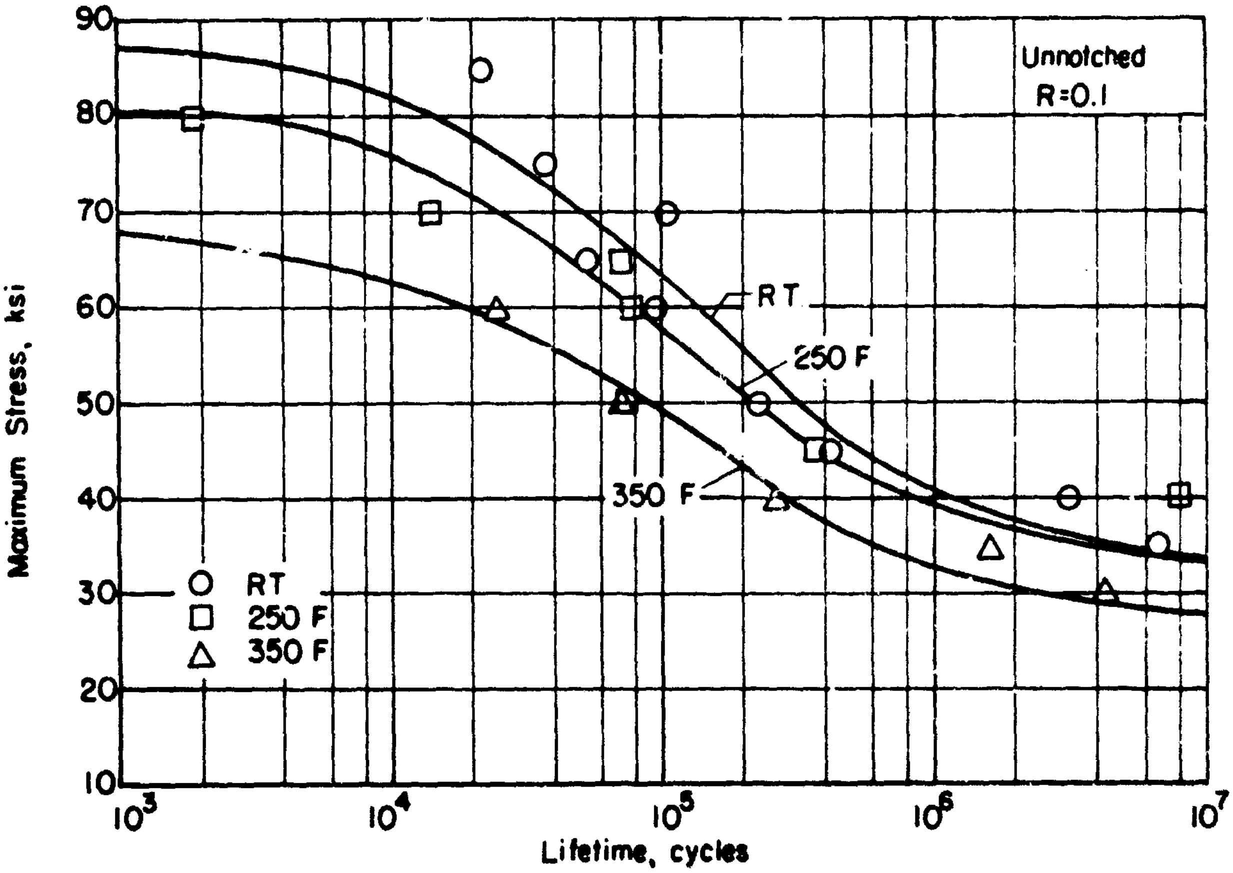


FIGURE 110. AXIAL LOAD FATIGUE RESULTS FOR 7175-T736 DIE FORGINGS

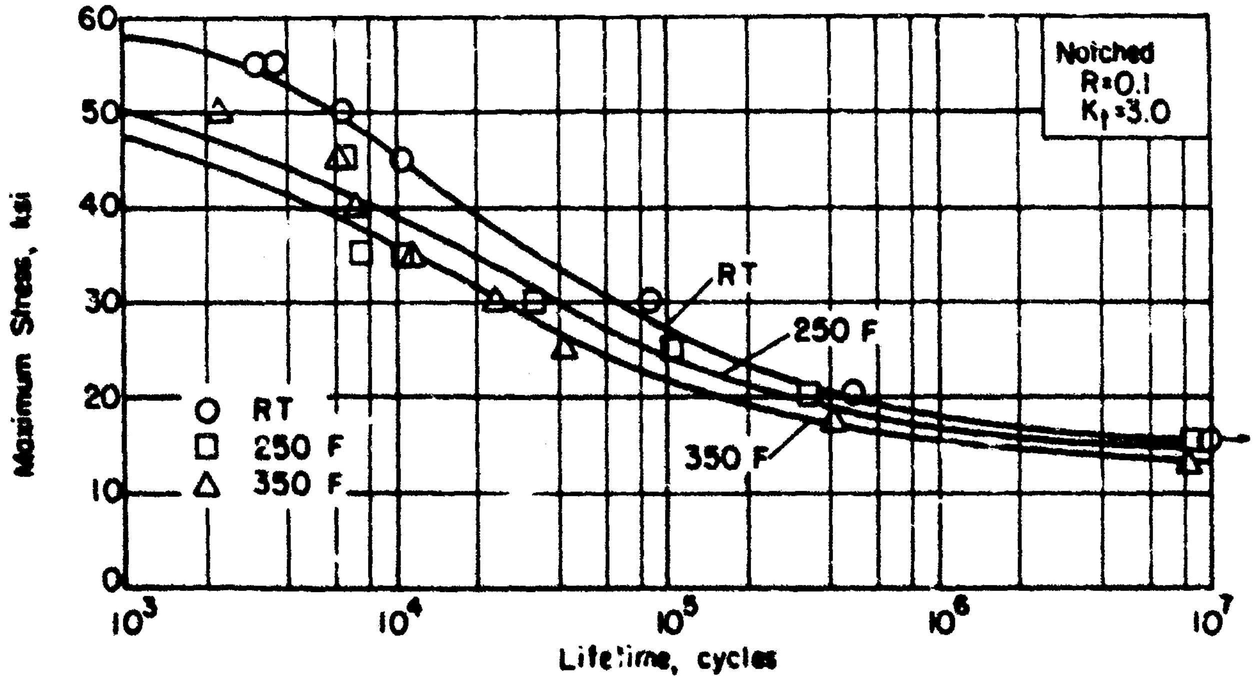


FIGURE 111. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 7175-T736 DIE FORGINGS

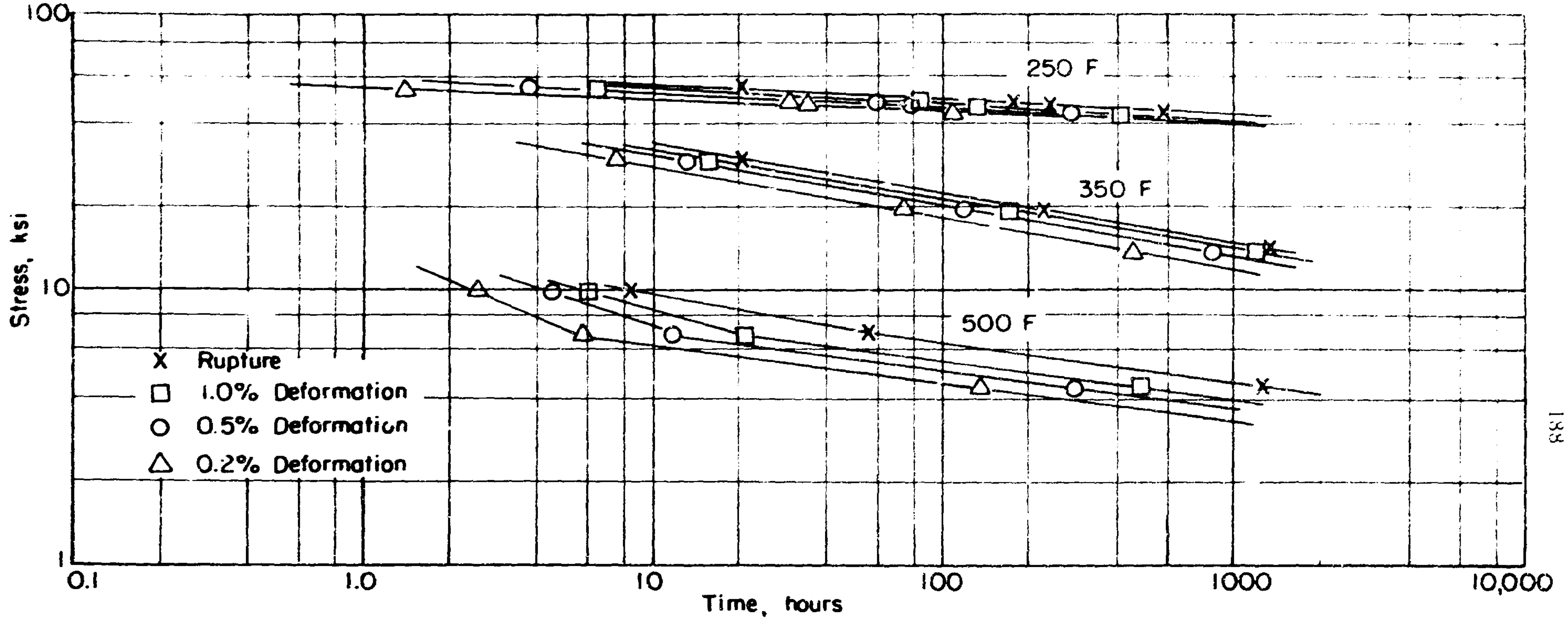


FIGURE 112. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7175-T736 DIE FORGINGS

5621-S Titanium Forging

Material Description

5Al-6Sn-2Zr-1Mo-0.25S titanium alloy is a new high temperature alloy developed by Reactive Metals, Incorporated. The alloy was developed to meet the need for a titanium alloy capable of withstanding temperatures for long time service at 850 - 900F and short time service at 950 - 1000F. This alloy contains silicon which enhances high temperature creep strength. This alpha matrix alloy is reported to have moderate room temperature tensile strength, excellent notch toughness, fatigue and creep strength, hot salt stress corrosion resistance, and thermal stability.

Currently all mill product forms have been manufactured, and bar and billet are available. Sheet and plate are undergoing investigation and are expected to soon be commercially available.

A 1-1/2 inch thick by approximately 25 inch diameter pancake forging was used for this property evaluation.

Processing and Heat Treating

The specimen layout is shown in Figure 113. The material was forged from temperatures over the beta transus and subsequently solution annealed at 1800F for 1 hour, air cool, followed by 1100F for 2 hours and air cool.

Test Results

Tension. Results of tests at room temperature, 400F, 700F, and 900F in both the radial and tangential directions are given in Table 73. Stress-strain curves are shown in Figures 114 and 115. Effect-of-temperature curves are presented in Figure 118.

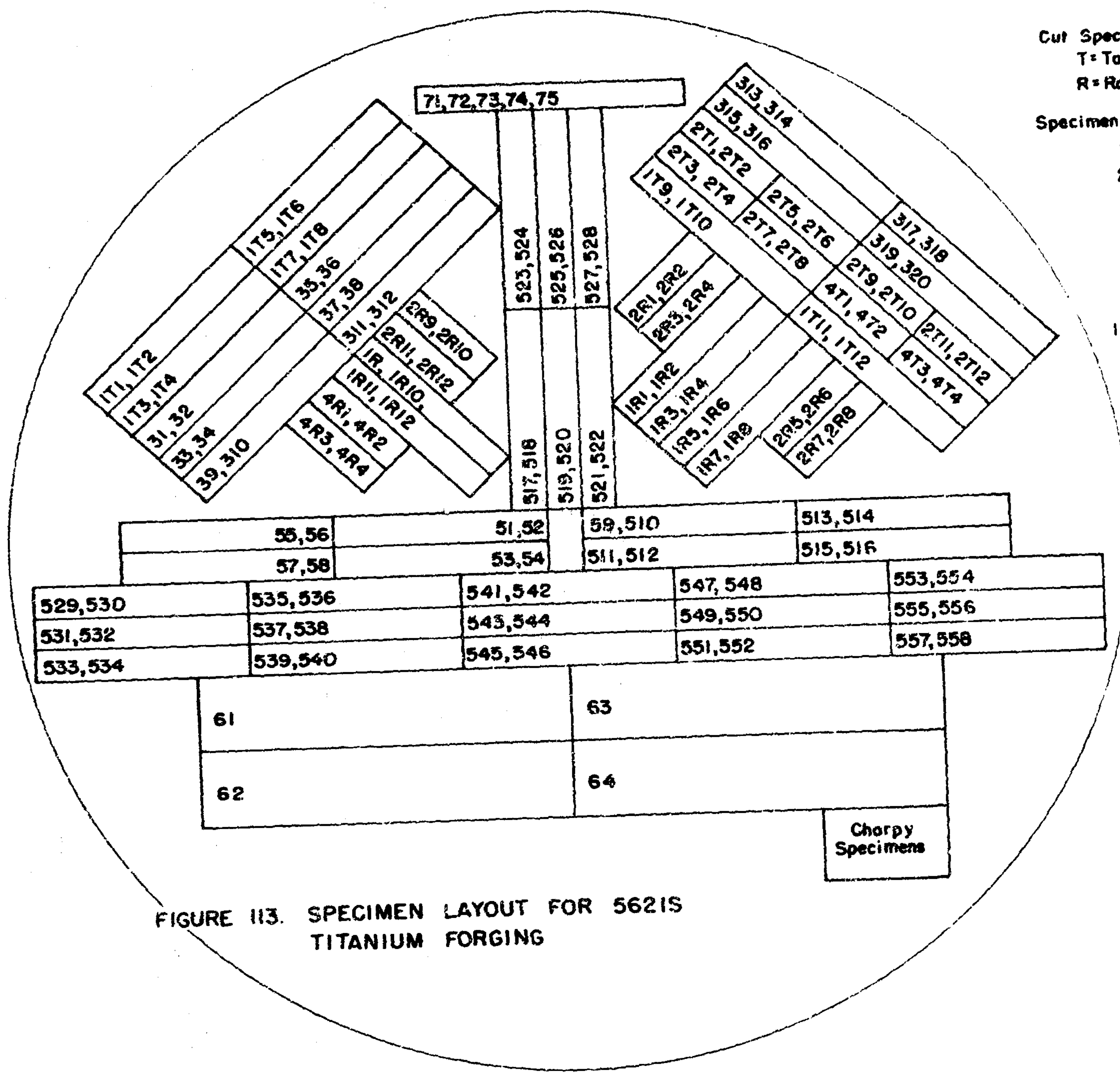
Compression. Results of tests at room temperature, 400F, 700F, and 900F in both the radial and tangential directions are given in Table 74. Stress-strain and tangent modulus curves at temperature are shown in Figures 116 and 117. Effect-of-temperature curves are shown in Figure 119.

Shear. Test results are given in Table 75 for room temperature tests in both directions.

Impact. Test results for room temprature, 40F, and -100F are given in table 76.

Fracture Toughness. Slow-bend type specimens were tested at room temperature only. Results are given in Table 77.

Fatigue. Tests were performed at room temperature, 400F, and 700F. Results are given in Tables 78 and 79 and Figures 120 and 121.



Cut Specimens 2 deep
T = Tangential
R = Radial

Specimen Code:
1 Tension
2 Compression
3 Creep
4 Shear
5 Fatigue
6 Fracture Toughness
7 Stress Corrosion
10 Impact

FIGURE 113. SPECIMEN LAYOUT FOR 5621S TITANIUM FORGING

Creep and Stress Rupture. Results of tests at 600F, 800F, and 950F are given in Table 80. Log stress versus log time curves are presented in Figure 122.

Stress Corrosion. No crack were evident in the seven specimens after testing as described in the experimental procedure section.

Thermal Expansion and Density. Results of thermal expansion tests are given in Table 81. The density of 5621-S is 0.166 lbs/in^3.

TABLE 73. TENSION TEST RESULTS FOR 5621-S TITANIUM FORGINGS

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 inches, percent	Tensile Modulus, psi X10^6
		Radial At Room Temperature		
1R1	140.0	119.0	15.0	16.8
1R2	142.0	121.0	13.0	17.6
1R3	137.0	117.0	13.0	17.3
		Tangential At Room Temperature		
1T1	135.0	115.0	11.0	17.7
1T2	135.0	116.0	11.0	16.9
1T3	139.0	121.0	12.0	16.8
		Radial At 400 F		
1R4	116.0	88.6	17.0	17.6
1R5	116.0	88.3	16.0	15.8
1R6	116.0	88.6	17.0	17.4
		Tangential At 400 F		
1T4	117.0	89.0	15.0	16.8
1T5	113.0	88.0	13.0	17.4
1T6	113.0	88.1	17.0	15.6
		Radial At 700 F		
1R7	103.0	73.2	17.5	15.6
1R8	103.0	74.4	17.0	13.8
1R9	104.0	75.4	20.0	15.8
		Tangential At 700 F		
1T7	105.0	77.2	15.0	14.3
1T8	106.0	79.0	15.0	15.0
1T9	104.0	75.5	15.0	15.1
		Radial At 900 F		
1R10	98.9	71.4	18.0	14.9
1R11	97.5	71.4	20.0	12.7
1R12	97.8	70.8	20.0	15.4
		Tangential At 900 F		
1T10	101.0	73.6	15.5	13.9
1T11	95.4	69.1	17.0	14.6
1T12	97.4	71.8	16.0	14.2

TABLE 74 COMPRESSION TEST RESULTS FOR 5621-S TITANIUM FORGINGS

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, psi x 10^6
	Radial at Room Temperature	
2R1	133.0	17.5
2R2	134.0	18.1
2R3	132.0	17.0
	Tangential at Room Temperature	
2T1	136.0	18.0
2T2	141.0	17.5
2T3	129.0	16.9
	Radial at 400 F	
2R4	96.9	16.9
2R5	94.2	16.0
2R6	95.1	16.3
	Tangential at 400 F	
2T4	94.0	15.7
2T5	96.1	15.8
2T6	98.6	16.2
	Radial at 700 F	
2R7	78.4	15.3
2R8	78.3	14.9
2R9	75.8	14.3
	Tangential at 700 F	
2T7	78.1	14.7
2T8	78.7	15.2
2T9	77.1	14.8
	Radial at 900 F	
2R10	77.3	14.7
2R11	74.5	14.1
2R12	74.6	13.5
	Tangential at 900 F	
2T10	75.4	15.3
2T11	75.6	14.5
2T12	79.6	13.0

TABLE 75. SHEAR TEST RESULTS FOR 5621-S TITANIUM FORGINGS

Specimen Number	Ultimate Shear Strength, ksi
Radial	
4R-1	99.5
4R-2	100.0
4R-3	98.3
4R-4	99.6
Tangential	
4T-1	91.7
4T-2	92.2
4T-3	98.5
4T-4	97.3

TABLE 76. CHARPY V-NOTCH TEST RESULTS FOR 5621-S TITANIUM FORGINGS

Specimen Number	Temperature, F	Energy, ft lbs
1	RT	22.0
2	RT	23.5
3	RT	19.0
4	-40	16.0
5	-40	16.5
6	-40	19.0
7	-100	14.0
8	-100	13.0
9	-100	15.0

TABLE 77. FRACTURE TOUGHNESS TEST RESULTS
FOR 5621-S TITANIUM FORGINGS

Specimen Number	Thickness, inch	Width, inch	Crack Length, inch	Span, inch	K_{Ic}, ksi $\sqrt{in}$
6 - 1	0.757	1.505	0.780	6.0	73.4
6 - 2	0.757	1.505	923	6.0	76.3
6 - 3	0.758	1.505	0.821	6.0	78.5
6 - 4	0.758	1.507	0.833	6.0	77.7

TABLE 78. AXIAL-LOAD FATIGUE TEST RESULTS FOR Ti-5621-S FORGINGS, UNNOTCHED, AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-48	150.0	12,100
5-34	140.0	16,100
5-30	120.0	22,600
5-45	110.0	249,800
5-51	100.0	500,000
5-57	90.0	3,349,300
5-50	80.0	10,041,500(a)
	400 F	
5-43	140.0	1,100
5-44	130.0	6,300
5-49	120.0	29,700
5-54	110.0	100,900
5-47	100.0	318,600
5-41	90.0	1,152,100
5-36	80.0	16,738,100(a)
	700 F	
5-55	120.0	2,000
5-46	115.0	32,200
5-40	110.0	24,600
5-37	105.0	94,000
5-58	100.0	95,000
5-42	90.0	1,529,700
5-38	80.0	9,772,500

(a) Did not fail.

TABLE 79. AXIAL-LOAD FATIGUE TEST RESULTS FOR Ti-5621-S FORGINGS, NOTCHED (K_t = 3.0) AND AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi	Lifetime, Cycles
	Room Temperature	
5-20	110.0	4,600
5-25	110.0	3,800
5-23	90.0	6,700
5-3	80.0	11,300
5-6	70.0	31,500
5-22	60.0	86,200
5-24	50.0	127,700
5-17	45.0	2,769,500
5-9	40.0	7,316,700
	400 F	
5-2	110.0	3,00
5-26	100.0	4,500
5-29	90.0	5,600
5-15	80.0	12,000
5-18	70.0	11,200
5-16	60.0	41,200
5-8	50.0	82,100
5-12	45.0	14,516,700[a]
5-21	40.0	14,653,200[a]
	700 F	
5-13	100.0	2,800
5-11	90.0	3,400
5-19	80.0	6,500
5-14	70.0	8,300
5-27	60.0	16,300
5-10	50.0	65,800
5-5	45.0	1,964,100
5-7	40.0	16,990,500[a]

(a) Did not fail.

TABLE 80. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR Ti-5621-S FORGINGS

Specimen Number	Stress ksi	Temperature F	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hr.	Elongation in 2 Inches, percent	Reducation of Area percent	Minimum Creep Rate, percent/hr.
			0.1	0.2	0.5	1.0	2.0					
34	111	600	--	--	--	--	--	--	on loading	13.1	33.4	--
37	105	600	--	--	--	--	--	7.819	814.7*	7.892	--	0.00001
31	95	600	--	--	--	--	--	2.608	329.7*	2.630	--	nil
35	92.5	800	--	--	--	--	--	--	on loading	11.5	27.2	--
38	90	800	140	1700 est.	6700 est.	--	--	1.912	984.0*	2.072	--	0.00006
32	85	800	285	3000 est.	--	--	--	1.477	619.4*	1.592	--	0.00004
36	87.5	950	--	--	--	--	--	--	on loading	11.5	26.5	--
39	85	950	1.3	7.5	45	120	230	3.188	287.40	7.7	16.7	0.0062
33	80	950	2	14	117	335	500	1.285	657.7	6.9	10.9	0.0025
310	70	950	10	135	575	1200 est.	--	0.793	792.8*	1.384	--	0.00052
311	60	950	150	860	3300 est.	--	--	0.554	791 8*	0.746	--	0.00012

*Test discontinued at this time.

TABLE 81. MEAN LINEAR THERMAL EXPANSION COEFFICIENTS FOR 5621-S FORGINGS

Temperature Range, F	Coefficient, α, 10^{-6} in/in/F
68-100	4.38
68-150	4.63
68-200	4.70
68-250	4.78
68-300	4.87
68-350	4.93
68-400	5.00
68-450	5.07
68-500	5.13
68-550	5.20
68-600	5.25
68-650	5.31
68-700	5.36
68-750	5.41
68-800	5.45
68-850	5.49
68-900	5.52

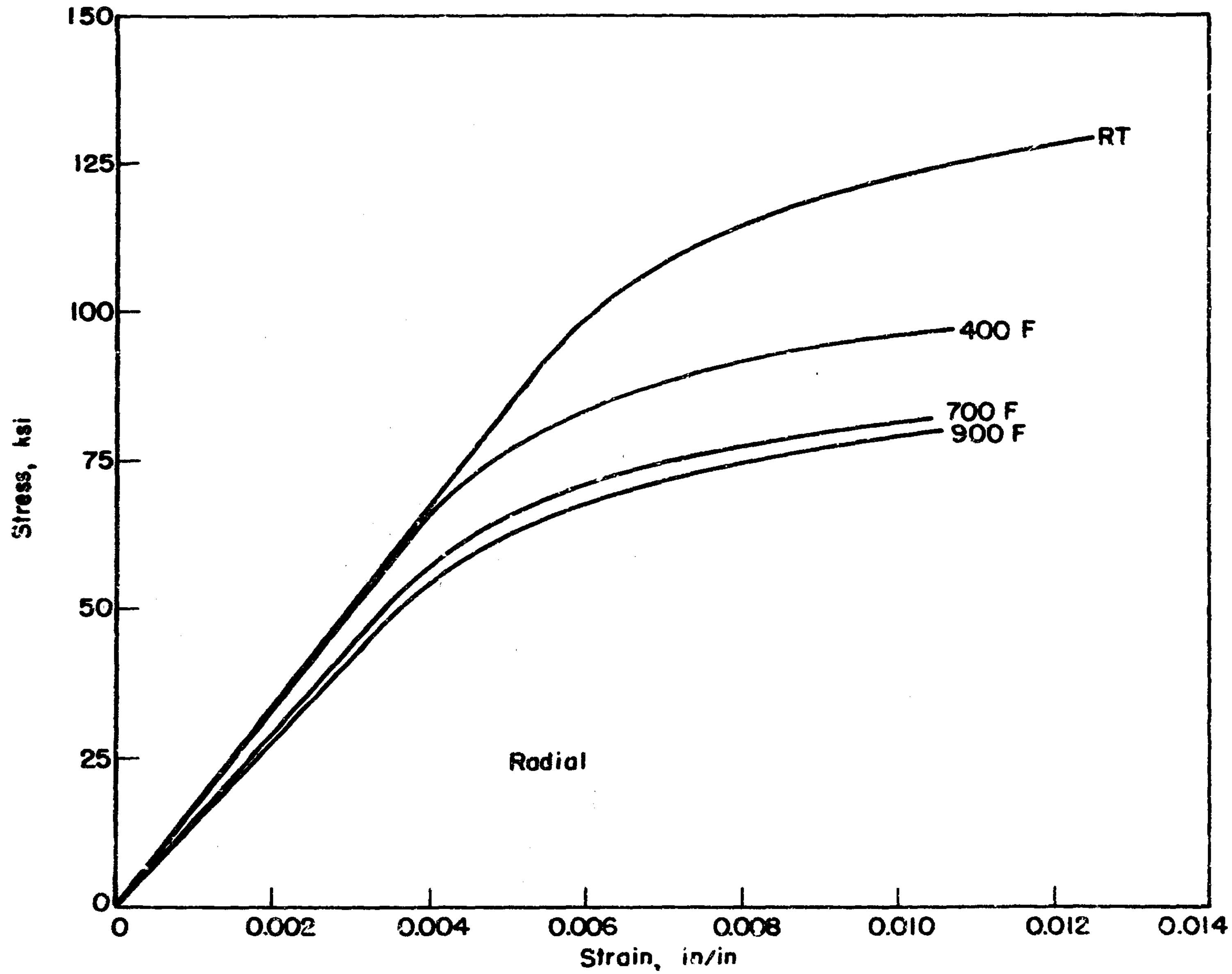


FIGURE 114. TYPICAL TENSION STRESS-STRAIN CURVES FOR 5621S FORGINGS AT TEMPERATURE

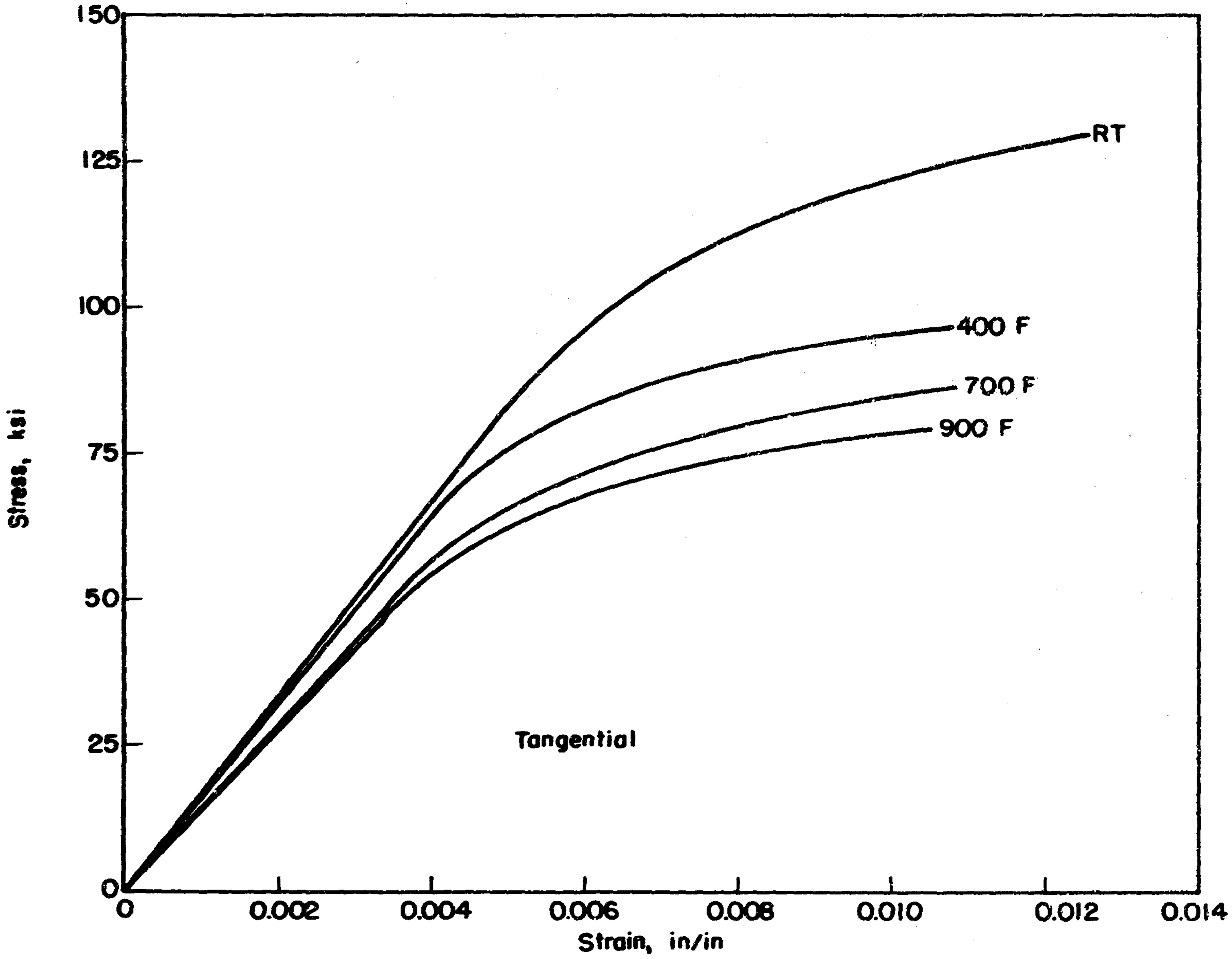


FIGURE 115. TYPICAL TENSION STRESS-STRAIN CURVES FOR 5621S FORGINGS AT TEMPERATURE

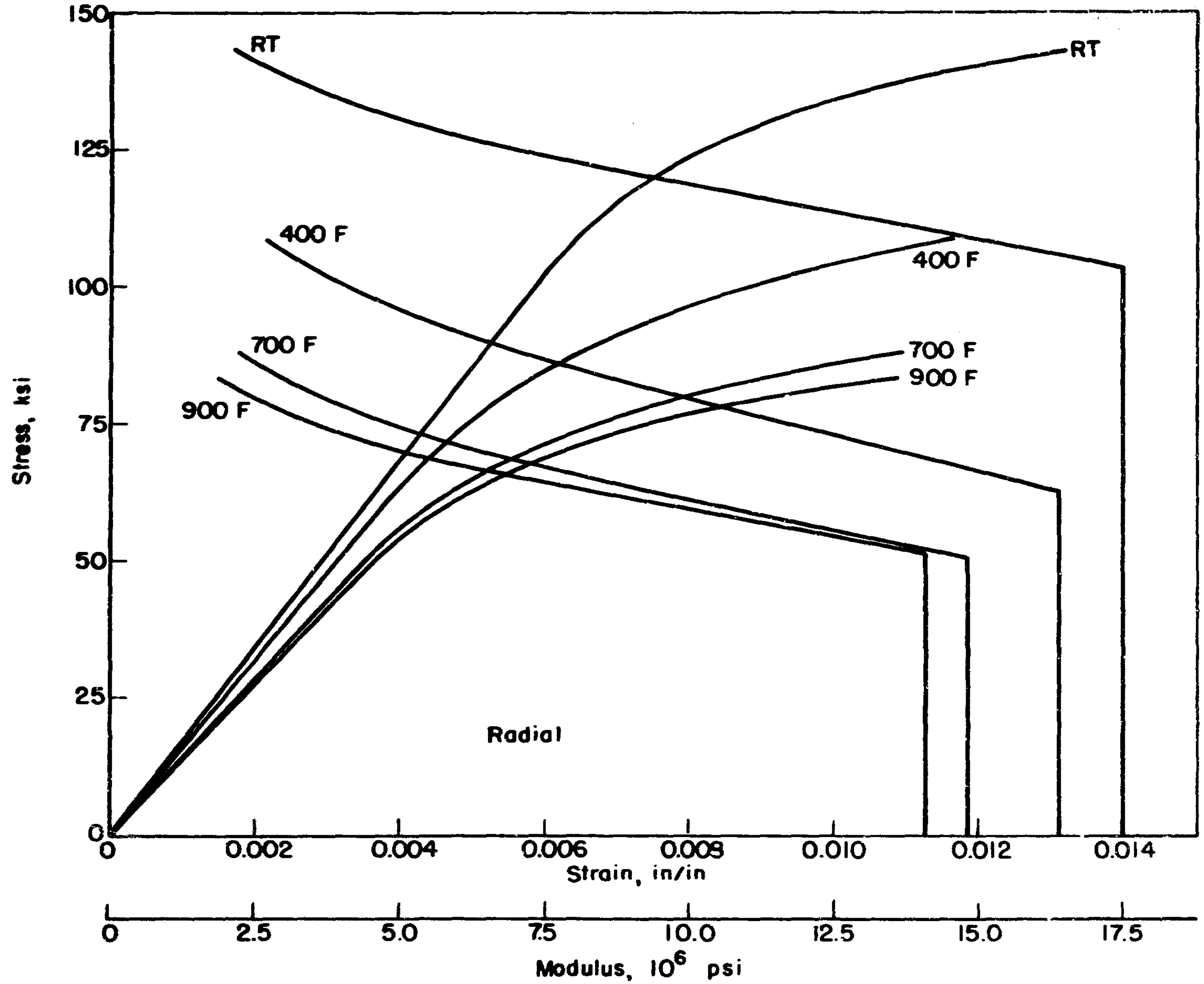


FIGURE 116. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 5621S FORGINGS AT TEMPERATURE

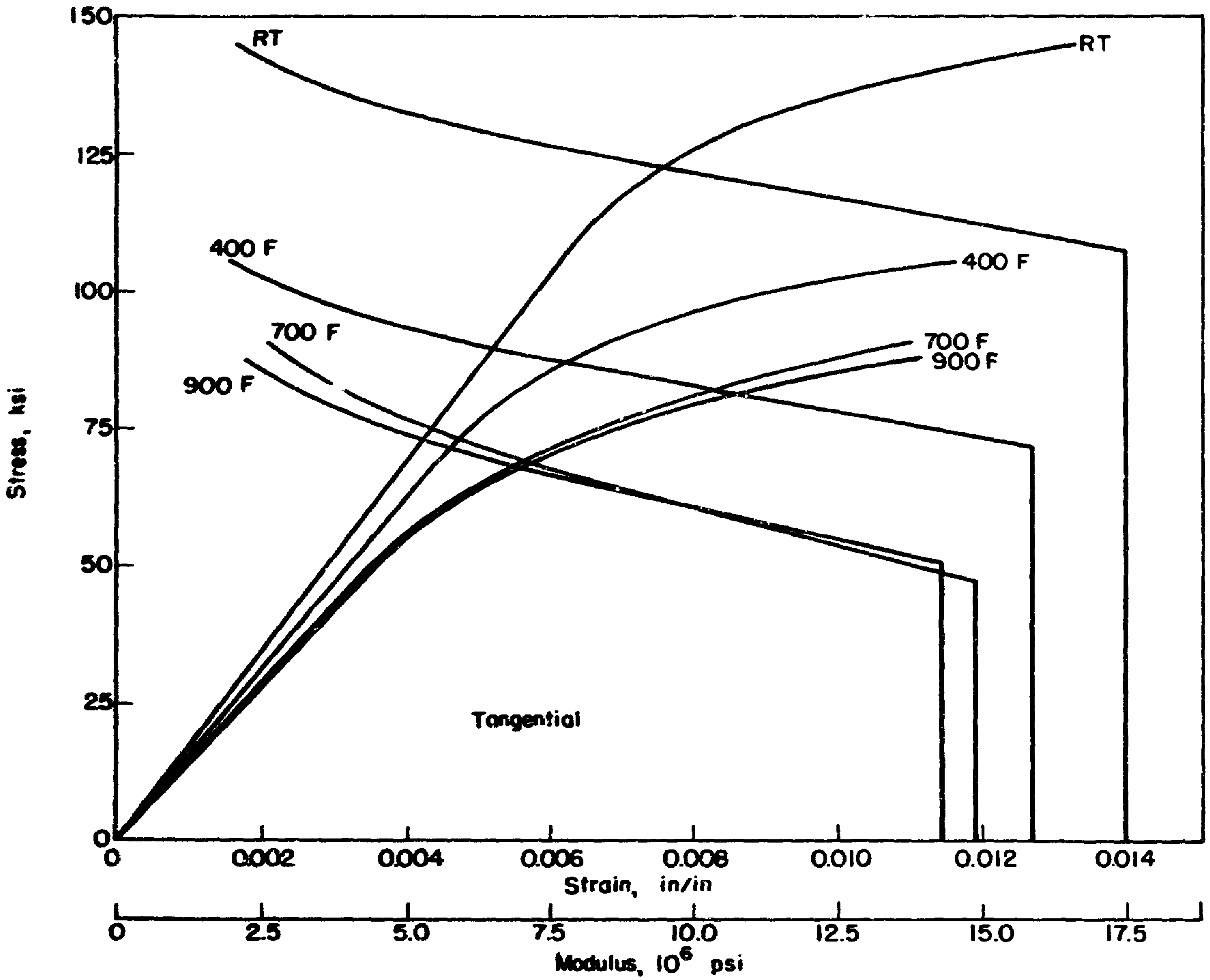


FIGURE 117. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT MODULUS CURVES FOR 5621S FORGINGS AT TEMPERATURE

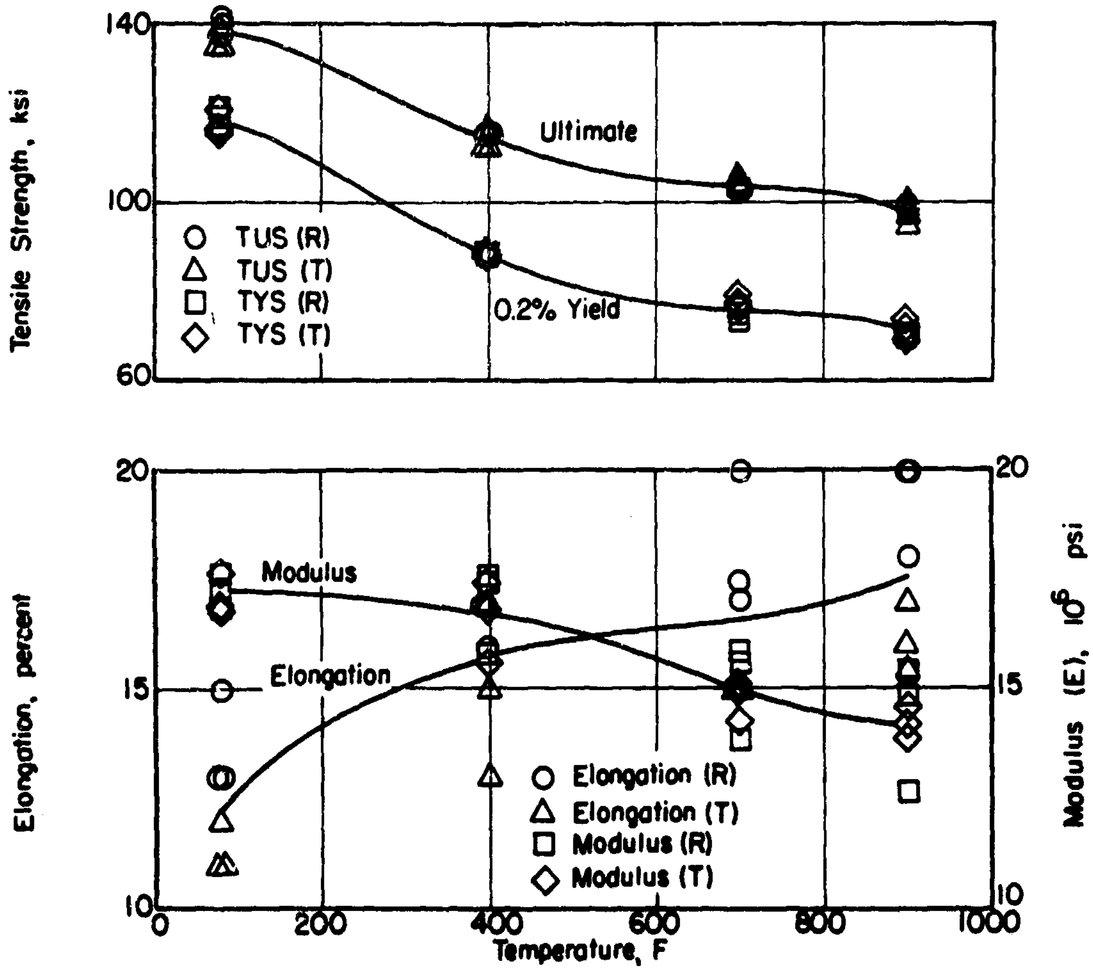


FIGURE 118. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-5621S PANCAKE FORGING

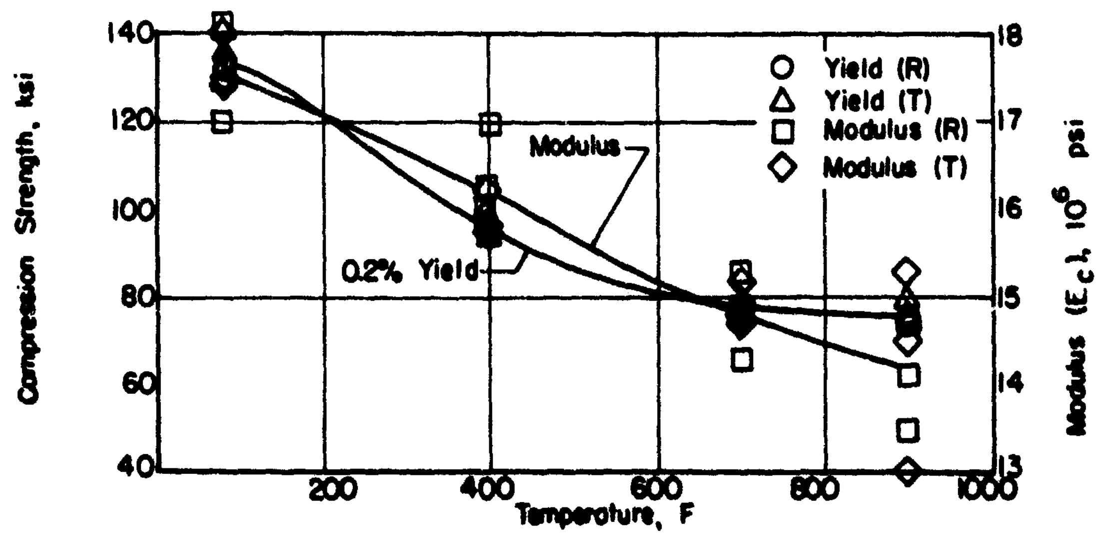


FIGURE 119. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF Ti-5621S PANCAKE FORGING

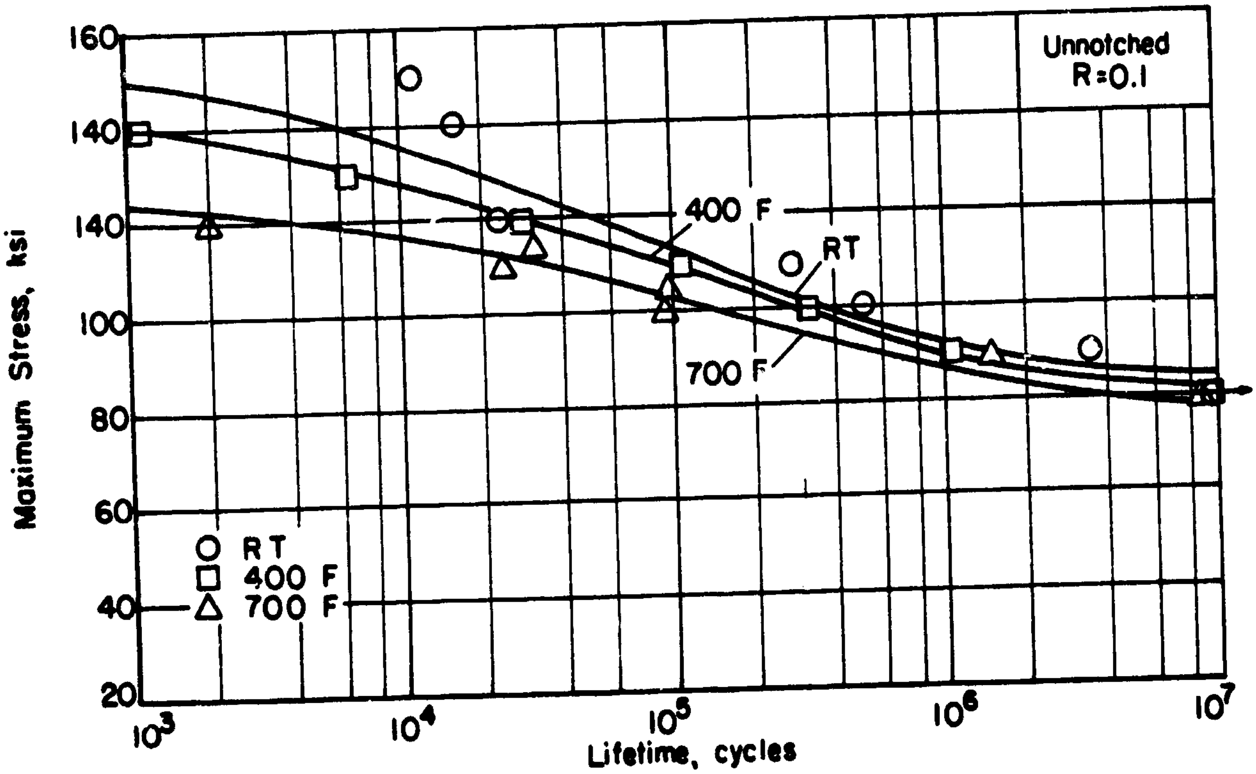


FIGURE 120. AXIAL LOAD FATIGUE RESULTS FOR Ti-5621S PANCAKE FORGING

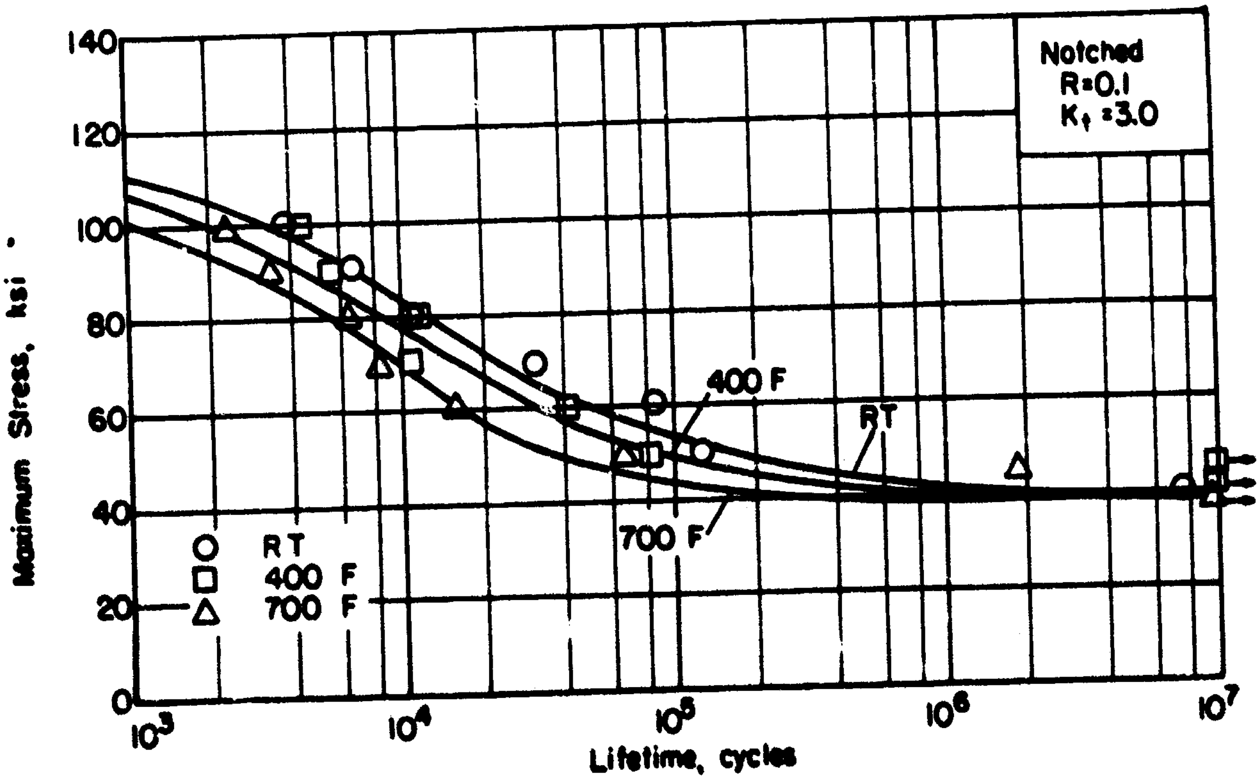


FIGURE 121. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) Ti-5621S PANCAKE FORGING

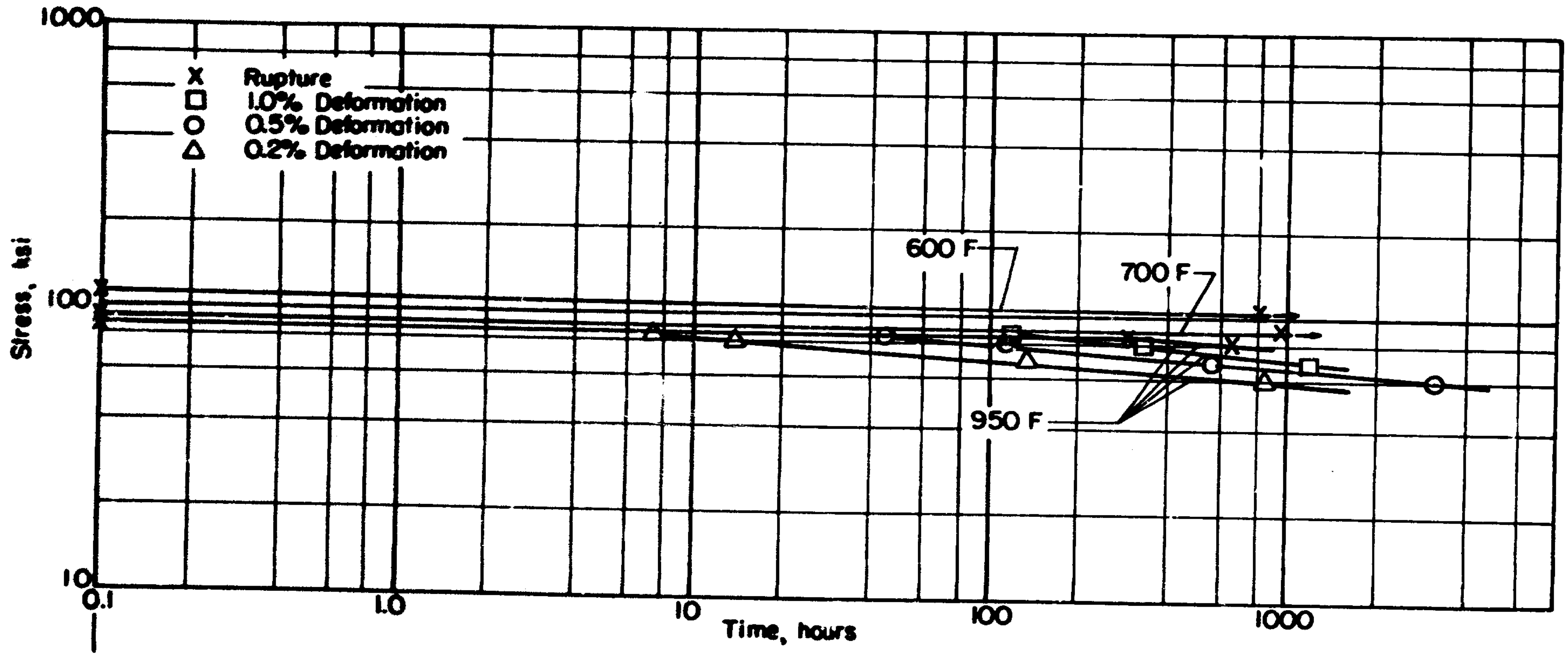


FIGURE 122. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-5621S PANCAKE FORGINGS

Discussion of Program Results

As has been stated in previous reports on the Air Force "data sheet" program (AFML TR 67-418 and AFML TR 68-211), in a program of this type the tendency will be to compare the materials property information obtained with similar data on materials in use in systems structures and components. Whether such a comparison should be the deciding factor for interest in a newer alloy is open to question. Many criteria, such as forming characteristics, weldability, oxidation resistance, etc., can be of particular importance so that strength properties may become secondary. However, since first comparisons are usually made on the basis of mechanical strength (tensile ultimate and tensile yield), the data generated on this program are compared to information obtained from MIL-HDBK-5A for similar alloys. Figures 123 and 124 are concerned with these properties.

In the following discussions each alloy evaluated on this program will be treated separately.

Beta III Titanium Alloy

Figures 123 and 124 show this alloy to be the highest strength titanium alloy evaluated on this program with properties higher than the beta alloy Ti-13V-11Cr-3Al. The data tables in the Beta III materials section show all transverse properties, except elongation, to be higher than the longitudinal properties.

From the S-N fatigue curves fatigue strength reduction factors, K_t, have been computed at the 10^7 lifetime line. These are (1) 1.5 at room temperature, (2) 1.8 at 400F, and (3) 1.8 at 850F.

Creep and stress rupture tests were performed at 500, 600, and 700F. Times to reach plastic deformation of 0.1, 0.2, 0.5, 1.0, and 2.0 percent are given in Table 6. At 500 and 600F, the rupture and creep stress versus time curves are quite flat. In fact rupture did not occur in the 1000 hour test period. Figure 32 also shows creep strength at 700F to be good.

Stress corrosion behavior of this alloy is considered good when tested as discussed in the test procedure section of this report.

Ti-6Al-4V(STOA) Sheet

Tables 7 and 8 show the transverse properties of this alloy to be appreciably higher than longitudinal properties, particularly the compressive properties. Strength properties, in general, appear to be slightly lower than the Ti-6Al-4V with a normal STA treatment (Figures 123 and 124).

Fatigue strength reduction factors, K_f, for this alloy at 10^7 cycles are as follows: 2.4 at room temperature, 1.8 at 500F, and 2.2 at 700F. These values are approximately the same as for 6Al-4V (STA).

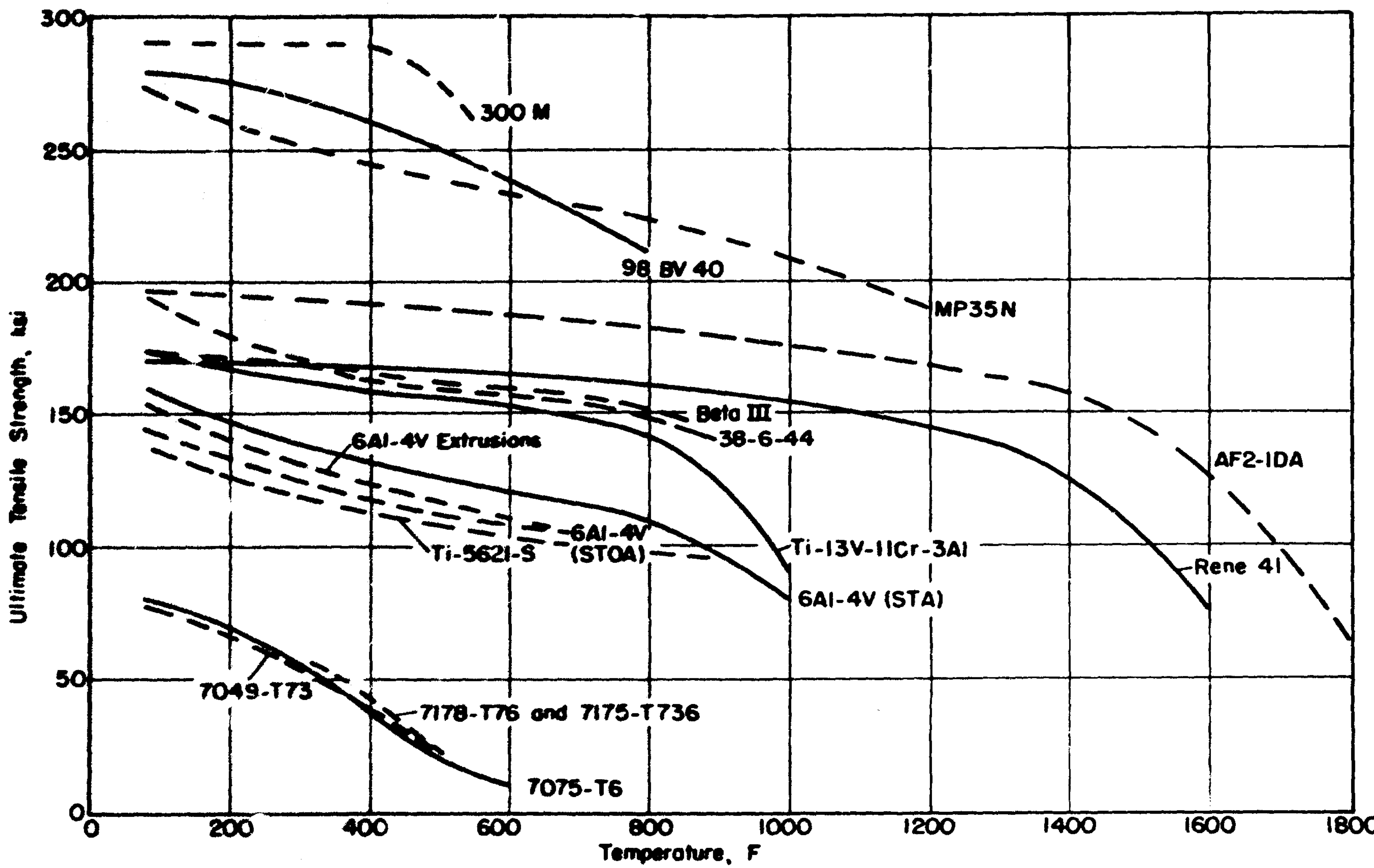


FIGURE 123. ULTIMATE TENSILE STRENGTH AS A FUNCTION OF TEMPERATURE

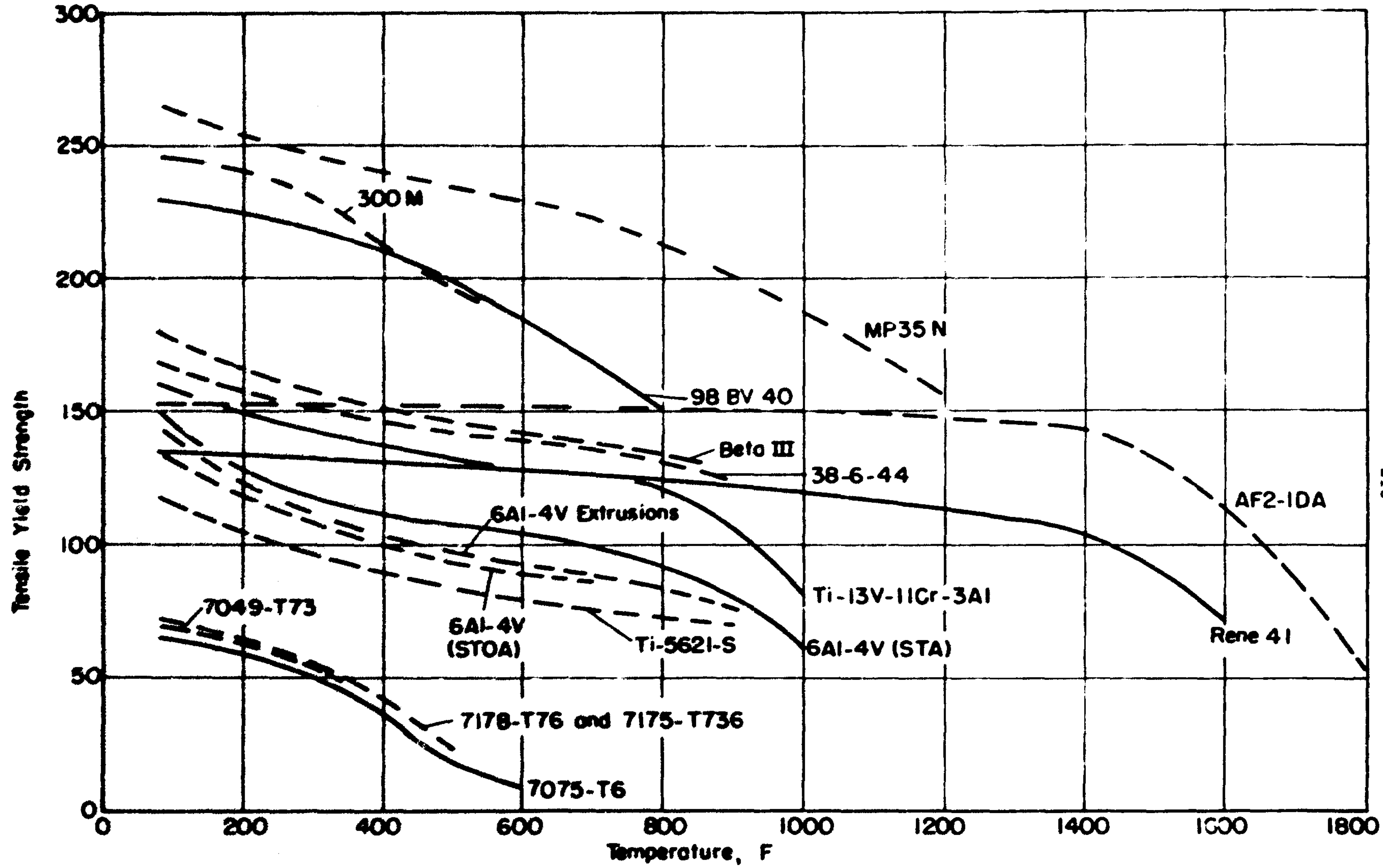


FIGURE 124. TENSILE YIELD STRENGTH AS A FUNCTION OF TEMPERATURE

Creep and stress-rupture tests were performed at 500, 600, and 700F. Times to reach plastic deformation of 0.1, 0.2, 0.5, 1.0, and 2.0 percent are given in Table 12. Figure 42 shows no appreciable creep effect except for longer times at 700F.

Ti-6Al-4V Extrusions

The drawing and annealing process has evidently strengthened this alloy as can be seen in Figures 123 and 124. Tensile properties are slightly higher than STA properties given in MIL-HDBK-5A.

Unnotched fatigue properties have also been affected in that the longer lifetimes at elevated temperature show a considerable drop in fatigue strength. Notch fatigue properties are generally the same as for the Ti-6Al-4V(STOA). Fatigue strength reduction factors for Ti-6Al-4V processed in this manner are: 1.2 at room temperature, 2.0 at 400F, and 2.3 at 700F.

Creep and rupture properties at 500 and 700F are about the same as for the STOA material. Tests were also conducted at 900F. Figure 49 shows the alloy to have low creep strength as is normal at this temperature.

300M Forgings

The strength properties of 300M show no appreciable effect of test direction although the modulus values tend to be slightly higher in the transverse direction. Fracture toughness tests at room temperature (Table 22) are quite consistent with the exception of one marginal value for specimen 6-2.

Fatigue strength reduction factors, K_f, for 300M at 10^7 cycles are as follows: 4.6 at room temperature, 3.1 at 300F, and 2.7 at 500F. This alloy is quite notch sensitive at room temperature.

Tests were conducted at 500F only for creep and stress rupture. As shown in Table 25, the alloy does not rupture in 1000 hours when stressed at the tensile yield strength.

7049 Aluminum

Table 25 and 26 show this alloy to be only slightly affected by test direction. Impact and fracture toughness values are good.

Fatigue strength reduction factors at 10^7 cycles are as follows: 2.8 at room temperature, 3.0 at 250F, and 3.4 at 350F. The alloy is notch sensitive but has good unnotched fatigue strength.

Times to reach creep deformation of 0.1, 0.2, 0.5, 1.0, and 2.0 percent are shown in Table 32 with results being generally as expected for a 7000 series aluminum.

7178 Aluminum

Tables 34 and 35 show this alloy to be somewhat sensitive to test direction. Transverse properties are slightly higher than longitudinal properties. The material seems to retain its strength well at the lower elevated temperatures. Fracture toughness values shown in Table 37 are very consistent.

Fatigue strength reduction factors, K_f, at 10^7 cycles are: 1.7 at room temperature, 1.7 at 250F, and 1.75 at 350F. The material is not particularly notch sensitive.

Creep and stress rupture tests were conducted at 350, 450, and 600F. Figure 81 shows the alloy to have creep strength in the same range as the 7049 material.

AF2-IDA Alloy

As shown in Tables 42 and 43 and Figures 84 and 85, this material maintains its strength well up to 1400F. Above 1400F, a fairly sharp drop occurs. This is also shown for creep properties in Figure 86. Because of the limited amount of usable material received, a full fatigue evaluation was not possible. Same data are presented in Tables 45 and 46.

MP35N Multiphase Alloy

Latrobe Steel Company has advised that this alloy treated to the 260 ksi strength level not be used above 750F due to a serious drop in ductility at about 900 - 1000F. The test results in Table 48 do not show this drop since no testing was performed in this temperature range. However, the effect-of-temperature curve in Figure 89 has been drawn to reflect this loss in ductility.

Fracture toughness tests were conducted and are presented in Table 52. Toughness of this material appears to be quite good.

Fatigue strength reduction factors for MP35N are: 3.5 at room temperature, 2.8 at 400F, and 2.2 at 700F. The material is somewhat notch sensitive at room temperature.

Creep deformation and stress-rupture results are shown in Table 55 and Figure 93. The material shows good creep strength under 900F.

38-6-44 Titanium Forging

This material compares with the other Beta titanium evaluated, Beta III, as shown in Figures 123 and 124. The alloy shows same scatter in test results (Table 56) with longitudinal properties being higher than transverse properties in general. As with Beta III this alloy maintains its strength well at elevated temperatures. Charpy values and fracture values were quite consistent showing no great difference between specimens taken from the outside of the forging and the middle of the forging.

Fatigue strength reduction factors, 2.2 at room temperature, 2.6 at 400F, and 1.9 at 500F show the notch sensitivity to be equal to other titanium alloys.

Creep strength appears to be generally the same as the other titanium alloys evaluated.

7175 Aluminum

Tables 65 and 66 show this material to be somewhat sensitive to test direction with longitudinal properties higher than transverse properties. The alloy, as was the development aim, does have a good yield strength value.

Fracture toughness tests are very consistent although considered marginal by the existing criteria.

Fatigue test reduction factors, K_f, are 2.3 at room temperature, 2.35 at 250F, and 2.2 at 350F.

Creep strength of this alloy is very similar to the other 7000 series alloy evaluated.

5621-S Titanium Forging

Tables 73 and 74 show this material not particularly sensitive to testing direction although the radial test direction properties tend to be somewhat higher at room temperature. Fracture toughness test results are very consistent (Table 77).

Fatigue strength reduction facotrs, 2.25 at room temperature, 2.2 at 400F, 2.1 at 700F are in line with other titanium alloys.

The creep strength of this alloy does seem to be excellent. Only a slight affect is noticed at 950F in Figure 122.

CONCLUSIONS

The objective of this program was the generation of useful engineering data for newly developed or differently processed structural materials. During the contract term the following materials were evaluated:

(1) Beta III Titanium Sheet

(2) Ti-6Al-4V(STOA) Sheet

(3) Ti-6Al-4V Thin Extrusions

(4) 300M Forgings

(5) 7049 Hand Forging

(6) 7178 Sheet

(7) AF2-IDA Extruded Bar

(8) MP35N Multiphase Bar

(9) 8-6-44 Titanium Forging

(10) 7175 Die Forging

(11) 5621-S Titanium Forging

A data sheet was issued for each material. As a summary to this report, each of the data sheets is reproduced in this section of this final report.

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2. Deel, O. L., and Hyler, W. S., "Engineering Data on Newly Developed Structural Materials", AFML-TR-68-211 (July 1968).

3. "Standard Elevated Temperature Testing Procedures for Metallic Materials", ARTC-13, prepared by the Aerospace Research and Testing Committee (July 1957, revised March, 1958, and June 1959).

4. "Evaluation of Test Methods for Refractory Metal Sheet Material", MAB 192-M (April 1963).

5. Brown, W. F., Jr., and Srawley, J. E., "Plane Strain Crack Toughness Testing of High Strength Metallic Materials", ASTM Special Technical Publication 410 (1967).

6. Peterson, V. C., Guernsey, J. B., and Buehl, R. C., "Manufacturing Procedures for a new High Strength Beta Titanium Alloy Having Superior Formability", AFML-TR-69-171, Crucible Steel Company (June 1969).

7. Pendleberry, S. L., Simenz, R. F., and Walker, E. K., "Fracture Toughness and Crack Propagation of 300M Steel", TD-DS-68-18, Lockheed California Co. (August 1968).

8. Alcoa Green Letter for 7178 Alloy.

9. Hagan, F., "Physical Property Data on Multiphase Alloy Bolts", Report No. 1740, Standard Pressed Steel Company (July 1968).

10. "Preliminary Report on RMI 5Al-6Sn-2Zr-1Mo-0.25 Si", Reactive Metals, Inc. (October 1968).

11. Allen, M. M., "Advanced Titanium Alloy Disk Production and Evaluation", Interim Progress Reports IR-120-8, 1 through 4, Pratt and Whitney Aircraft Co.

Beta III

Beta III is a simple quaternary solid-solution titanium alloy developed by the Crucible Steel Company under Air Force Contract AF 33(615)-2742. It is an all-beta alloy that has the ability to be cold rolled at least as easily as commercially pure titanium. Actually, tests show it can be cold rolled in excess of 90 percent without edge cracking. The alloy also was compounded to provide for relative ease in hot rolling.

The alloy can be heat treated over a range of tensile strengths by varying both solution-heat-treatment temperature and aging temperature. The treatment selected for this evaluation was the 950 F, 8 hours aged condition.

The composition of this material is as follows: 12.1 Mo, 6.5 Zr, 4.35 Sn, 0.04 Fe, 0.03 C, 0.014 F, 0.0095 H, 0.13 O, balance titanium.

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BETA III TITANIUM DATA[a]

Condition: STA
Thickness: 0.062 Inch

Properties	Temperature, F			
	RT	400	600	850
Tension				
F_{tu} (longitudinal), ksi	187.3	164.0	157.7	144.7
F_{tu} (transverse), ksi	196.3	167.3	163.0	150.0
F_{ty} (longitudinal), ksi	175.0	146.0	139.0	126.7
F_{ty} (transverse), ksi	185.0	157.7	148.7	135.0
e_t (longitudinal), percent in 2 in.	8.5	6.7	6.7	11.0
e_t (transverse), percent in 2 in.	6.7	5.2	5.8	10.8
E_t (longitudinal), 10^6 psi	15.0	14.0	13.0	11.2
E_t (transverse), 10^6 psi	16.0	14.6	13.7	12.6
Compression				
F_{cy} (longitudinal), ksi	194.5	168.7	161.7	147.3
F_{cy} (transverse), ksi	211.0	182.3	173.7	159.3
E_c (longitudinal), 10^6 psi	15.9	15.5	15.1	13.5
E_c (transverse), 10^6 psi	17.5	16.7	16.2	14.5
Shear[b]				
F_{su} (longitudinal), ksi	117.0	U	U	U
F_{su} (transverse), ksi	118.0	U	U	U
Impact (V-notch Charpy), ft-lb	U[c]	U	U	U
Fracture Toughness, K_{Ic}, ksi$\sqrt{in.}$	(d)	U	U	U
Axial Fatigue (Transverse)[e]				
Unnotched, R = 0.1				
10^3 cycles, ksi	170	123	U	140
10^5 cycles, ksi	88	88	U	84
10^7 cycles, ksi	86	86	U	77
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	128	123	U	108
10^5 cycles, ksi	62	55	U	50
10^7 cycles, ksi	57	48	U	43

Properties	Temperature, F 500	600	700
Creep (Transverse)			
0.2% plastic deformation, 100 hr, ksi	165.0	158.0	120.0
0.2% plastic deformation, 1000 hr, ksi	163.0	151.0	80.0
Stress Rupture (Transverse)			
Rupture 100 hr, ksi	170	170	163.0
Rupture 1000 hr, ksi	169	169	150.0
Stress Corrosion			
80% F_{ty}, 1000 hr max	No cracks(f)	U	U

Coefficient of Thermal Expansion

4.8 x 10^{-6} in./in./F (RT to 900 F)

Density(g) 0.183 lb/in.^{3}

(a) [illegible]
(b) [illegible]
(c) [illegible]
(d) [illegible]
(e) [illegible]
(f) [illegible]
(g) [illegible]

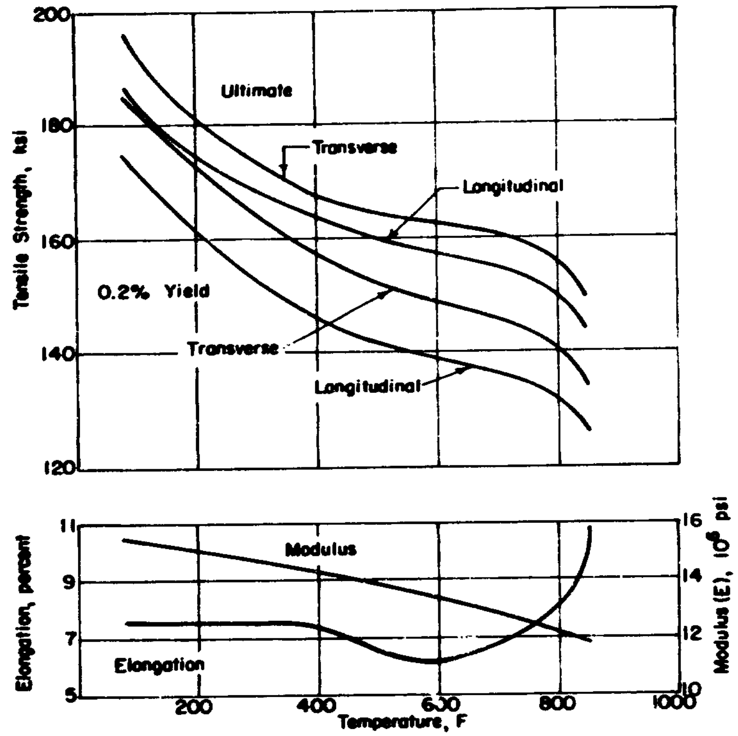

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF BETA III TITANIUM SHEET

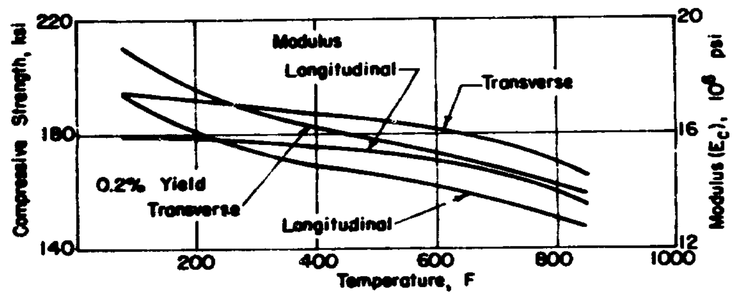

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF BETA III TITANIUM SHEET

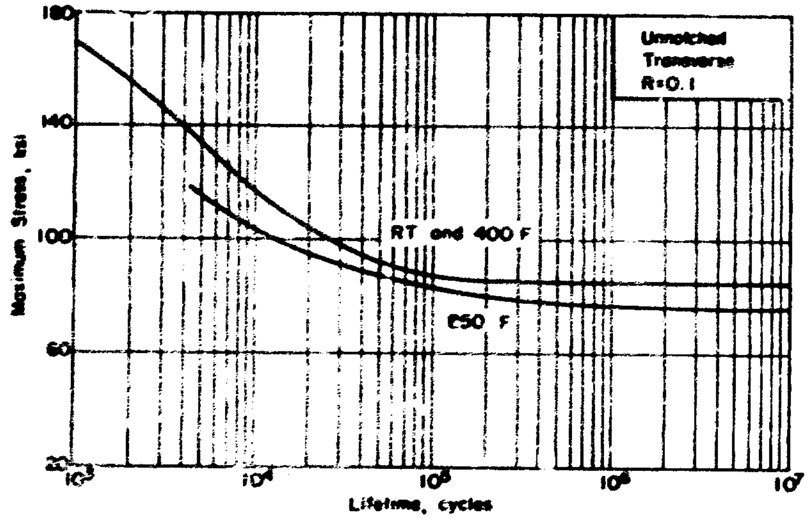

FIGURE 3 AXIAL-LOAD FATIGUE BEHAVIOR OF UNNOTCHED BETA III TITANIUM SHEET AT THREE TEMPERATURES

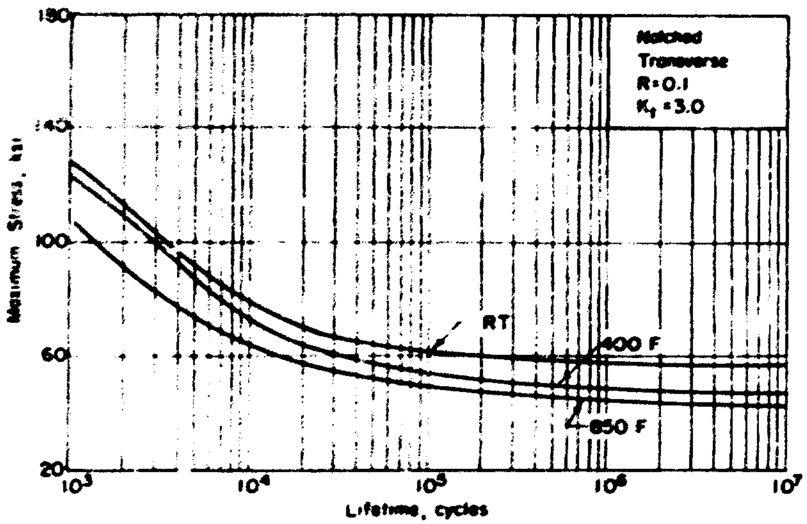

FIGURE 4 AXIAL-LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) BETA III TITANIUM SHEET AT THREE TEMPERATURES

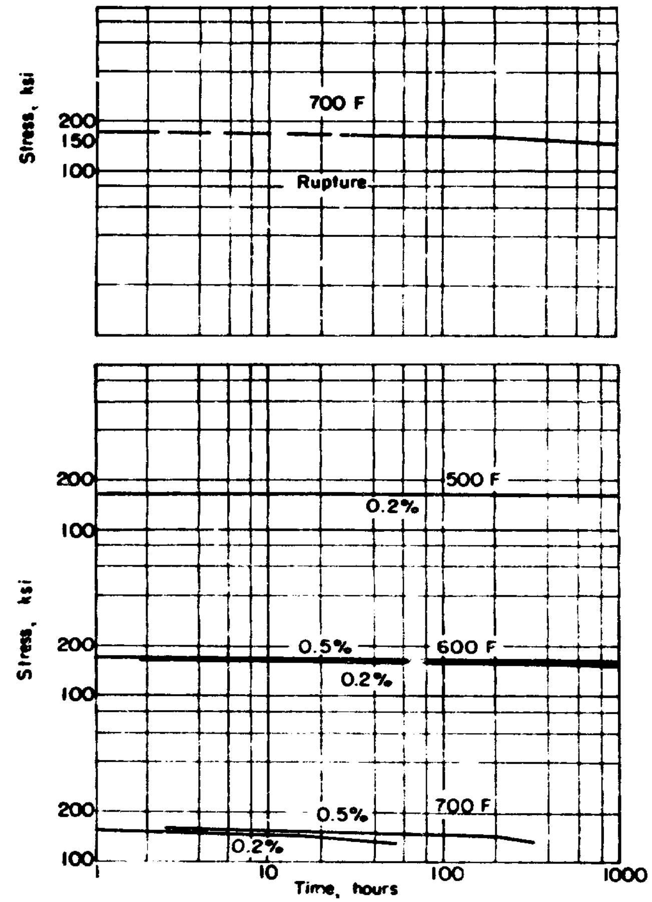

FIGURE 5. STRESS-RUPTURE AND PLASTIC-DEFORMATION CURVES FOR BETA III TITANIUM SHEET

Ti-6Al-4V

Although Ti-6Al-4V sheet has been used for years, only within the past 2 years ... so has the solution-treated- and overaged (STOA) heat treatment become of interest. This heat treatment has been an outgrowth of the SST development program. The problem was one of finding a new heat treatment that would provide higher resistance to stress-corrosion cracking and fracture strength that can be obtained with the normal mill anneal or STA treatment. The Boeing Company, together with the two major titanium producers, agreed upon the STOA condition to satisfy this desire. The heat treatment used for this testing program follows: solution treat ... 1750 F for 10 minutes, water quench, age at 1250 F for 4 hours, air cool.

Recent discussions with TIMET personnel indicate that the producers will guarantee F_{tu} of 130 ksi for this condition.

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6Al-4V TITANIUM SHEET DATA[a]

Condition: STOA
Thickness: 0.188 Inch

Properties	Temperature, F: -65	RT	300	500	700
Tensile					
F_{tu} (longitudinal), ksi	165.0	140.9	121.0	110.0	103.5
F_{tu} (transverse), ksi	171.8	146.8	128.0	117.0	110.0
F_{ty} (longitudinal), ksi	153.0	131.5	105.0	89.4	81.0
F_{ty} (transverse), ksi	162.0	140.5	112.0	97.8	89.7
e_t (longitudinal), percent in 2 in.	9.0	10.8	12.5	12.0	10.2
e_t (transverse), percent in 2 in.	14.0	14.5	14.5	13.2	11.0
E_t (longitudinal), 10^6 psi	17.3	16.8	16.1	15.2	14.0
E_t (transverse), 10^6 psi	18.8	18.4	17.6	17.1	14.8
Compression					
F_{cy} (longitudinal), ksi		143.0	116.5	98.4	88.1
F_{cy} (transverse), ksi		163.0	130.5	111.5	99.3
E_c (longitudinal), 10^6 psi		17.8	17.0	16.0	14.8
E_c (transverse), 10^6 psi		19.0	18.1	17.2	16.4
Shear[b]					
F_{su}, (longitudinal), ksi		90.2	U	U	U
F_{su}, (transverse), ksi		98.0	U	U	U
Fracture Toughness[d], K_{Ic}, ksi$\sqrt{in}$		U[c]	U	U	U
Axial Fatigue (Transverse)[e]					
Unnotched, R = 0.1					
10^3 (K_t = 1) (R = 0.1), ksi		145	115		105
10^5 (K_t = 1) (R = 0.1), ksi		122	81		86
10^7 (K_t = 1) (R = 0.1), ksi		111	72		80
Notched (K_t = 3.0), R = 0.1					
10^3 (K_t = 3) (R = 0.1), ksi		123	111		100
10^5 (K_t = 3) (R = 0.1), ksi		51	43		40
10^7 (K_t = 3) (R = 0.1), ksi		46	40		37

Properties	Temperature, F RT	500	600	700
Creep				
0.2% elongation 100 hr, ksi	NA	110	100	81
0.2% elongation 1000 hr, ksi	NA	108	[illegible]	68
Stress Rupture				
Rupture 100 hr, ksi	NA	120	114	106
Rupture 1000 hr, ksi	NA	118	112	102
Stress Corrosion				
80% F_{ty}, 1000 hr max	No cracks[f]			
Coefficient of Thermal Expansion				
[illegible] x 10⁻⁶ in./in./F (RT to 1000 F)				
Density, [illegible] 160 lb/in.³				

[illegible]

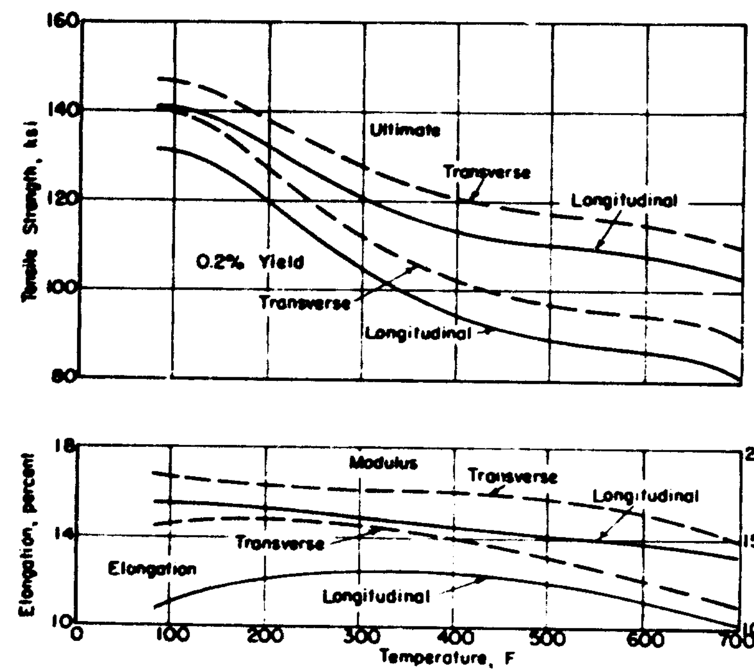

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 6Al-4V TITANIUM SHEET (STOA) AT THREE TEMPERATURES

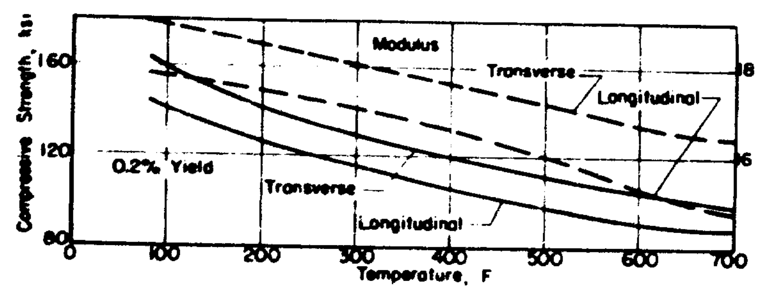

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 6Al-4V TITANIUM SHEET (STOA) AT THREE TEMPERATURES

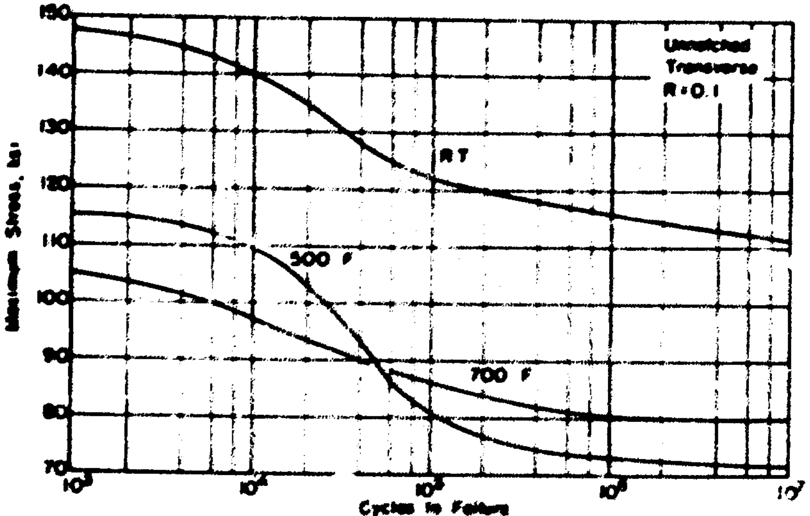

FIGURE 3. AXIAL-LOAD FATIGUE RESULTS FOR UNNOTCHED 6Al-4V TITANIUM SHEET (STOA) AT THREE TEMPERATURES

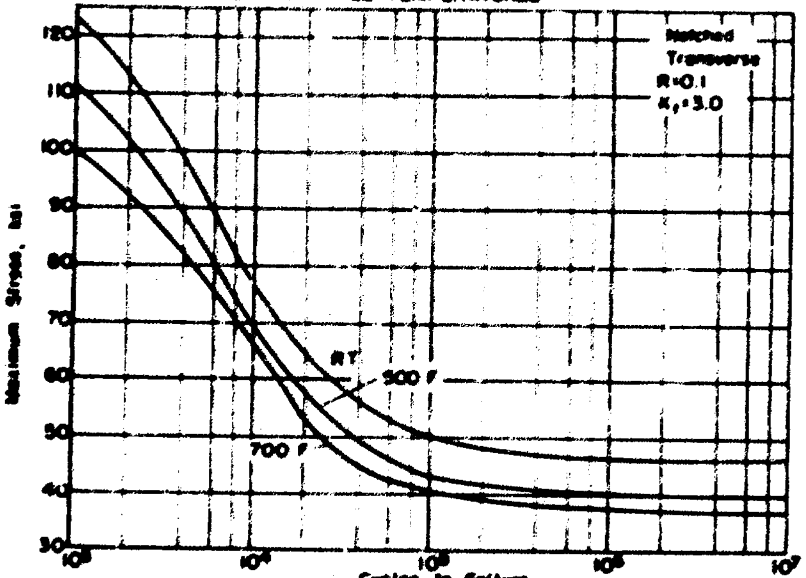

FIGURE 4. AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 6Al-4V TITANIUM SHEET (STOA) AT THREE TEMPERATURES

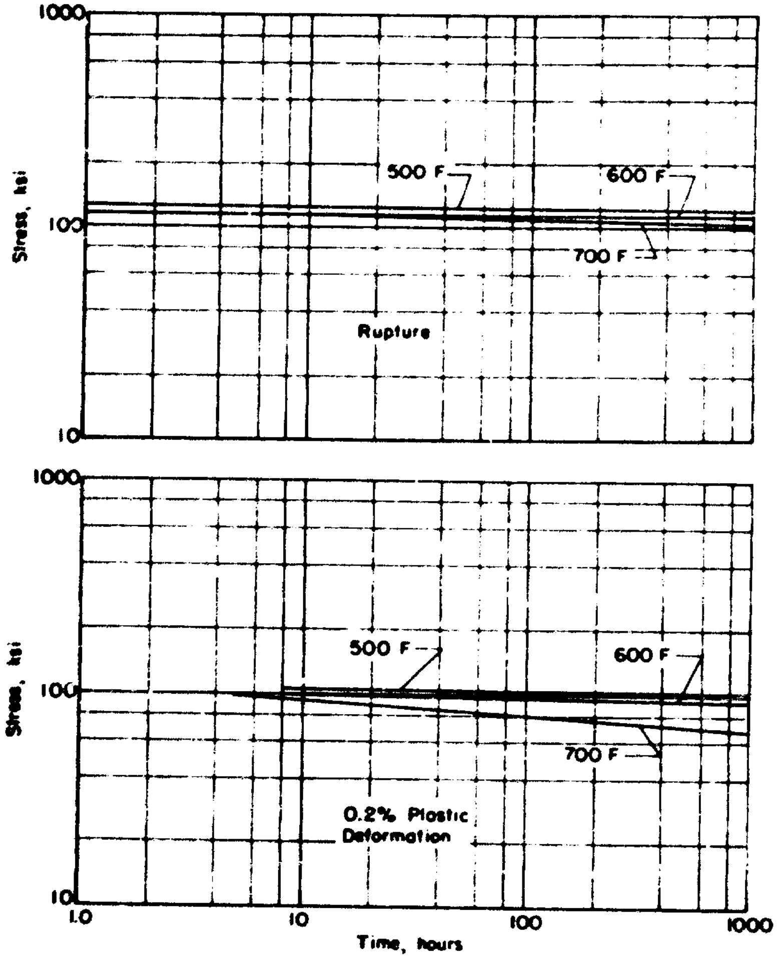

FIGURE 5. STRESS-RUPTURE AND PLASTIC-DEFORMATION CURVES FOR Ti-6Al-4V ALLOY SHEET

6Al-4V Titanium Extrusions

This alloy is one of the most widely used alloys of titanium. For this evaluation a thin "T" section extrusion was chosen to obtain properties for the material after the drawing process.

Approximately 60 feet of the thin extrusion was supplied CPH in 30-inch lengths.

All of the "T" sections were extruded from billets of approximately 3.5 inches in diameter by [illegible] inches in length. The target thickness of 0.040 inches was attained by three draw passes plus chemical removal of 0.002 inches per side to remove contamination. After the final draw and stretch straightening operation the shapes were vacuum annealed at 1325 F for 1-1/2 hours and argon cooled to room temperature.

In order to obtain enough specimen material and maintain specimen uniformity all specimens tested were in the longitudinal direction. The vertical section of the "T" was removed and the center of the "T" was the centerline of all specimens.

Ti-6A-4V "T" Extrusion Data(a)
Condition: Drawn and Annealed
Thickness: 0.04-inch nominal

Properties	Temperature, F RT	400	700	900
Tension (longitudinal)				
F_{tu}, ksi	154.0	123.3	106.7	94.4
F_{ty}, ksi	144.7	109.3	88.8	80.9
e, percent in 2-in	11.2	12.0	9.2	17.0
E, 10^6 psi	16.0	14.5	12.9	11.0
Compression (longitudinal)				
F_{cy}, ksi	147.0	111.3	97.2	86.1
E_c, 10^6 psi	17.9	16.6	15.5	14.5
Impact(b)	U(e)	U	U	U
Fracture Toughness(c)	U	U	U	U
Shear (longitudinal)(d)				
F_{su}, ksi	93.0	U	U	U
Axial Fatigue (longitudinal)(f)				
Unnotched, R = 0.1				
10^3 cycles, ksi	148	140	126	U
10^5 cycles, ksi	82	78	78	U
10^7 cycles, ksi	60	60	70	U
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	125	118	109	U
10^5 cycles, ksi	59	45	40	U
10^7 cycles, ksi	50	30	30	U
Creep (longitudinal)				
0.2% plastic deformation, 100 hr	NA	102(g)	66	11
0.2% plastic deformation, 1000 hr	NA	98(g)	54	6

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Ti-6Al-4V "T" Extrusion Data (continued)

Properties	Temperature, F RT	400	700	900
Stress Rupture (longitudinal)				
Rupture, 100 hr	NA	112(g)	102	56
Rupture, 100 hr	NA	111(g)	98	35
Stress Corrosion				
80% F_{ty}, 100 hr max	No Cracks(h)			
Coefficient of Thermal Expansion				
5.8×10^{-6} in./in./F(RT to 1000 F)				
Density				
0.160 lb/in.^{3}				

(a) Each value given is the average of at least three tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Material not of sufficient thickness for Charpy tests.

(c) Material not of sufficient size for K_{IC} tests.

(d) Single-shear sheet-type specimen.

(e) U, unavailable; NA, not applicable.

(f) "R" represents the algebraic ration of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(g) Data for 500 F.

(h) Room-temperature three point bend test. Alternate immersion in 3-1/2 percent NaCl.

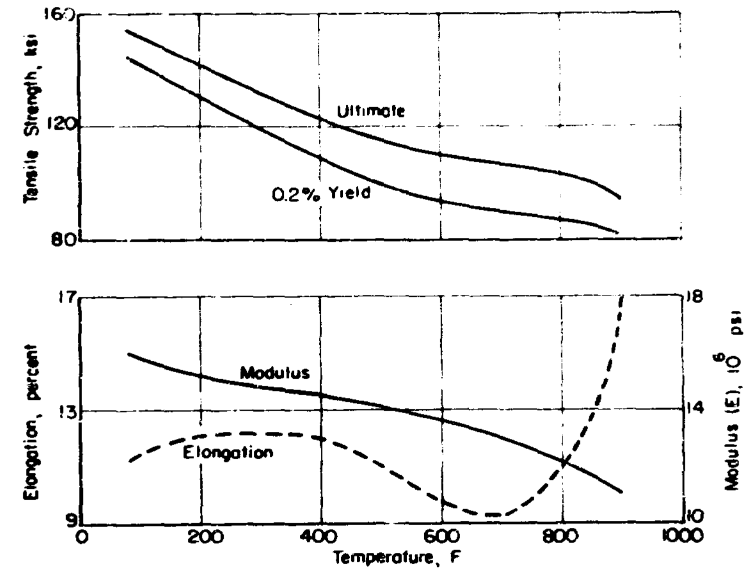

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-6Al-4V "T" EXTRUSIONS

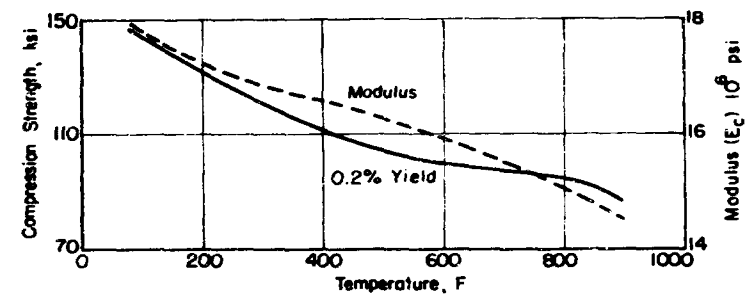

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF Ti-6Al-4V "T" EXTRUSIONS

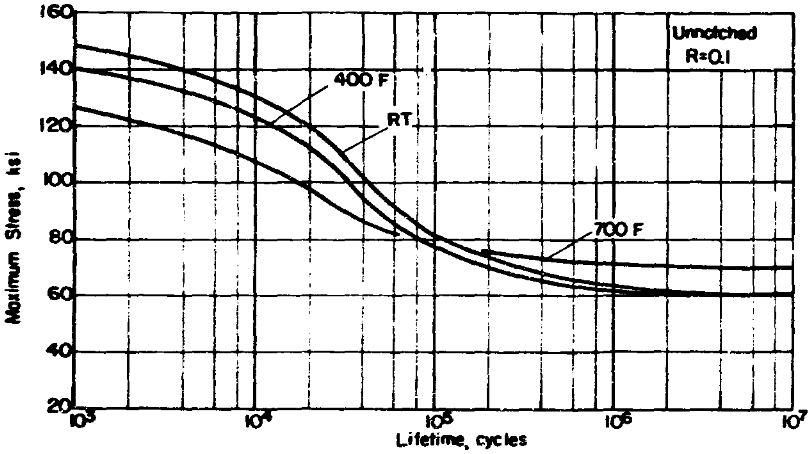

FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR Ti-6Al-4V "T" EXTRUSIONS AT THREE TEMPERATURES

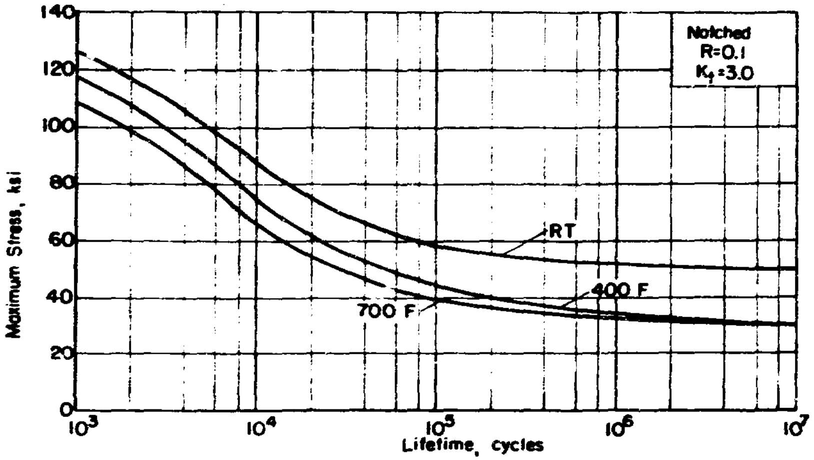

FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) Ti-6Al-4V "T" EXTRUSIONS AT THREE TEMPERATURES

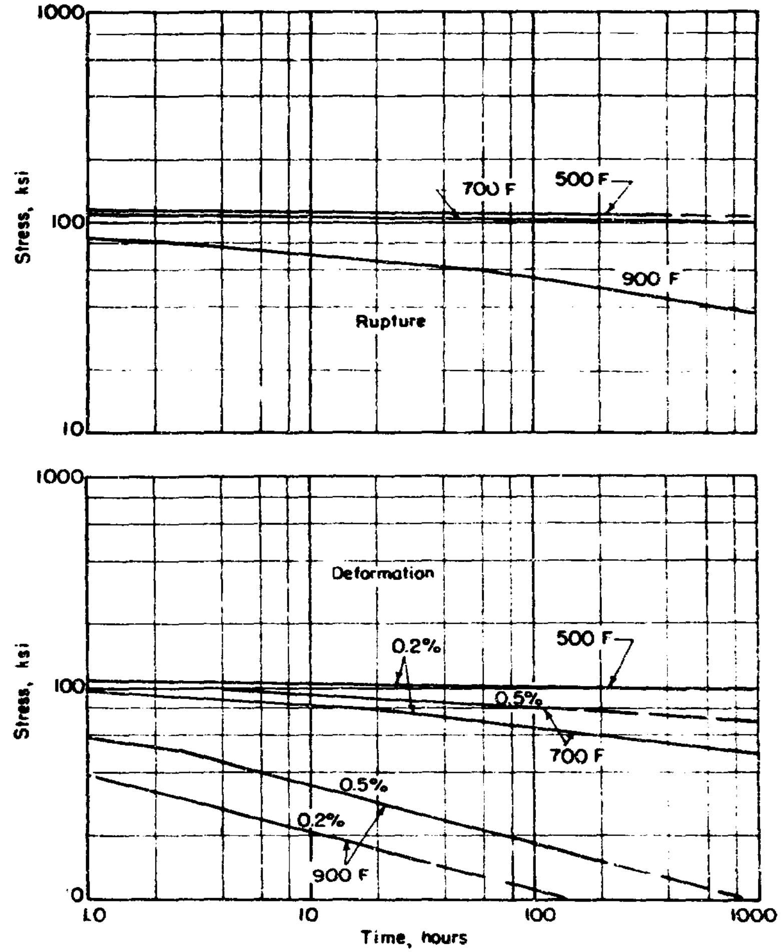

FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR Ti-6Al-4V "T" EXTRUSIONS

300M

300M is one of the modifications to 4340 steel that currently is being considered for use as an ultrahigh-strength steel. The low-alloy steel combines high hardenability with relatively good impact strength and ductility. Formerly called "Tricent" and used in the 200 to 220-ksi strength range, 300M is now considered useful at the 280-ksi strength level.

The composition of this material is as follows:

Carbon	0.43
Silicon	1.68
Manganese	0.70
Phosphorus	0.010
Sulfur	0.010
Nickel	1.93
Chromium	0.79
Molybdenum	0.39
Aluminum	0.15
Vanadium	0.07
Iron	Balance

All of the specimens used in this test program were obtained from the flange section of a large I-beam forging with a cross section of approximately 20 inches by 10 inches. The flange section had a cross section of approximately 6 inches by 10 inches. Specimens were heat treated to the 280-ksi strength level as follows: 1600 F, quench in warm oil, temper 2 + 2 hours at 575 F.

300M STEEL DATA[a]

Condition: Quenched and Tempered

Properties	Temperature, F			
	RT	250	400	550
Tension				
F_{tu} (longitudinal), ksi	292.0	294.0	295.0	260.0
F_{tu} (transverse), ksi	293.0	296.0	296.0	263.0
F_{tu} (short transverse), ksi	291.0	--	--	--
F_{ty} (longitudinal), ksi	247.0	234.0	209.0	191.0
F_{ty} (transverse), ksi	247.0	237.0	212.0	187.0
F_{ty} (short transverse), ksi	245.0	--	--	--
e_t (longitudinal), percent in 1 in.	12.0	11.0	21.0	22.0
e_t (transverse), percent in 1 in.	11.0	11.0	19.2	21.8
e_t (short transverse), percent in 1 in.	11.0	--	--	--
RA (longitudinal), percent	43.6	36.8	49.5	56.5
RA (transverse), percent	37.7	34.3	42.8	55.0
RA (short transverse), percent	40.1	--	--	--
E_t (longitudinal), 10^6 psi	29.4	26.1	26.9	23.1
E_t (transverse), 10^6 psi	29.5	27.6	27.3	25.6
E_t (short transverse), 10^6 psi	29.0	--	--	--
Compression				
F_{cy} (longitudinal), ksi	264.5	247.5	229.5	205.5
F_{cy} (transverse), ksi	267.0	251.0	231.0	210.0
E_c (longitudinal), 10^6 psi	30.1	29.5	29.1	27.7
E_c (transverse), 10^6 psi	30.7	30.1	29.2	27.8
Shear[b]				
F_{su} (longitudinal), ksi	179.0	U[c]	U	U
F_{su} (transverse), ksi	179.2	U	U	U
Impact (V-notch Charpy), ft-lb	15.5	16.5	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in.}$	69.2[d]	U	U	U

Properties	Temperature, F		
	RT	300	500
Axial Fatigue (Longitudinal)(e)			
Unnotched, R = 0.1			
10^3 cycles, ksi	285	280	270
10^5 cycles, ksi	172	160	154
10^7 cycles, ksi	140	132	132
Notched (K_t = 3.0), R = 0.1			
10^3 cycles, ksi	170	160	146
10^5 cycles, ksi	56	50	56
10^7 cycles, ksi	30	42	48
Creep and Stress Rupture(f)	NA	NA	U
Stress Corrosion			
80% F_{ty}, 1000 hr max	No cracks(g)	U	U
Coefficient of Thermal Expansion(h)			
8.1×10^{-6} in./in./F (0 to 1200 F)			
Density(h) 0.283 lb/in.^{3}			

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen, 1/4-inch diameter.

(c) U, unavailable; NA, not applicable.

(d) Average of 5 chevron-notched slow-bend tests.

(e) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(f) Specimens did not go to 0.2 percent elongation or to rupture at 500 F when stressed to the tensile yield strength. Specimen stressed at 250 ksi reached 0.2 percent deformation in 1 hour, but did not rupture in 1000 hours.

(g) Three-point bend test. Alternate immersion in 3-1/2 percent NaCl.

(h) Value from Reference (2).

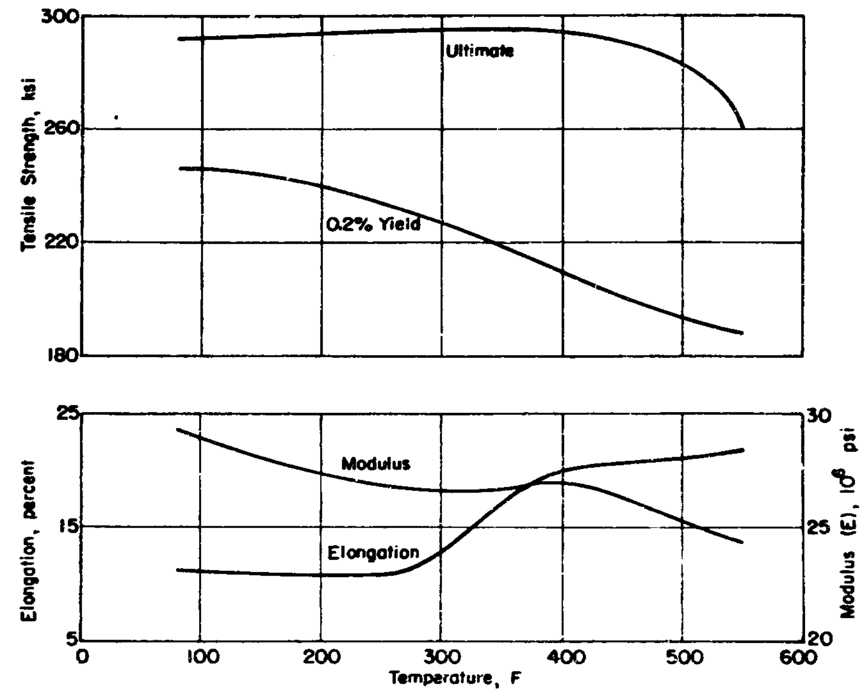

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 300M FORGINGS

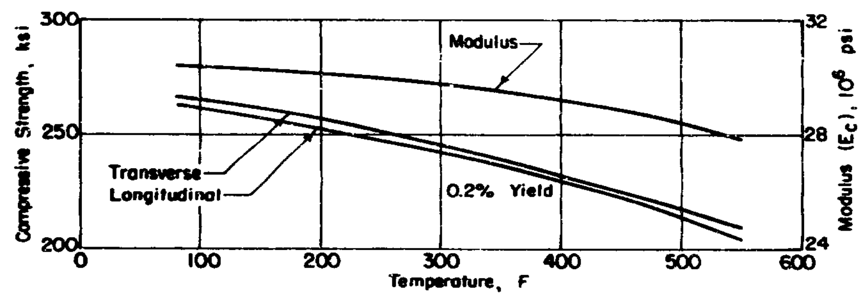

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 300M FORGINGS

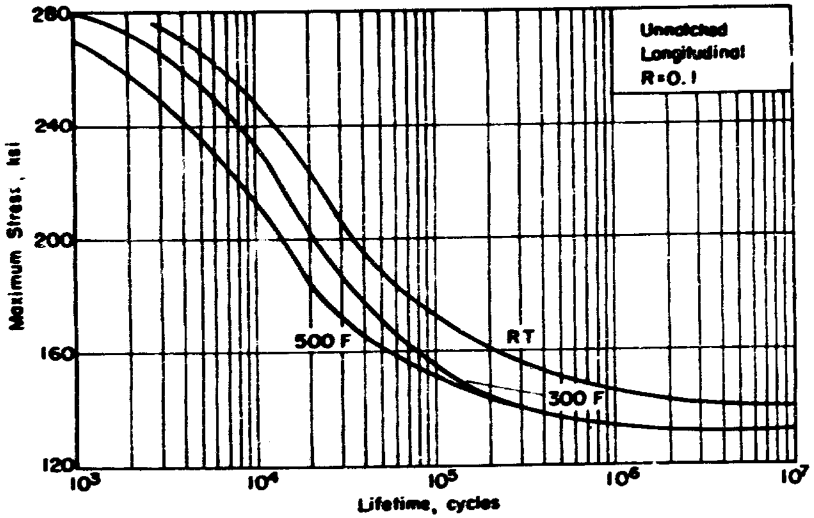

FIGURE 3. AXIAL-LOAD FATIGUE BEHAVIOR OF UNNOTCHED 300M FORGING AT THREE TEMPERATURES

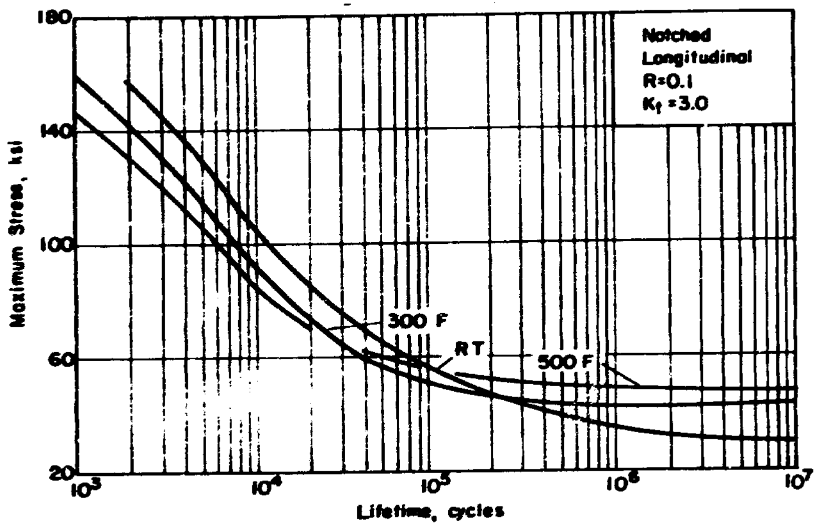

FIGURE 4. AXIAL-LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t=3.0) 300M FORGING AT THREE TEMPERATURES

7049-T73

Alloy X7049 is a new development by Kaiser Aluminum and Chemical Corporation. It was designed to have a strength level in the range of 7075-T6 and 7079-T6, coupled with a high resistance to stress-corrosion cracking. The temper designation -T73 has been assigned to cover the alloy with these characteristics. The initial development and production has been in the form of die forgings and hand forgings.

The threshold level for stress-corrosion cracking is reported by Kaiser to be 45 ksi.

All specimens used for this test program were from a 5-inch-thick forging. The composition of this forging is as follows:

Si	0.07
Fe	0.13
Mn	0.01
Cu	1.48
Mg	2.45
Cr	0.16
Zn	7.50
Al	Balance

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7049 DATA[a]

Condition: T73
Thickness: 5-Inch Forging

Properties	Temperature, F RT	250	350	500
Tension				
F_{tu} (longitudinal), ksi	72.9	62.2	49.7	16.7
F_{tu} (transverse), ksi	74.9	62.3	50.3	18.1
F_{tu} (short transverse), ksi	70.9	--	--	--
F_{ty} (longitudinal), ksi	64.2	59.7	49.0	16.6
F_{ty} (transverse), ksi	66.5	60.1	49.5	18.0
F_{ty} (short transverse), ksi	61.9	--	--	--
e_t (longitudinal), percent in 2 in.	8.8	14.8	20.0	29.3
e_t (transverse), percent in 2 in.	11.0	15.7	18.0	30.0
e_t (short transverse), percent in 2 in.	6.0	--	--	--
E_t (longitudinal), 10^6 psi	10.2	9.9	8.8	7.1
E_t (transverse), 10^6 psi	10.6	10.2	8.2	6.9
E_t (short transverse), 10^6 psi	9.9	--	--	--
Compression				
F_{cy} (longitudinal), ksi	66.8	64.0	53.3	20.4
F_{cy} (transverse), ksi	67.6	63.0	51.9	19.7
E_c (longitudinal), 10^6 psi	10.6	9.4	8.4	8.2
E_c (transverse), 10^6 psi	10.6	9.9	8.6	7.9
Shear[b]				
F_{su}, (longitudinal), ksi	47.8	U	U	U
F_{su}, (transverse), ksi	47.7	U	U	U
Impact (V-notch charpy), ft-lb	4.1[c]	U	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in.}$	31.7	(d)	U	U

Properties	Temperature, F RT	250	350	500
Axial Fatigue (Transverse)(e)				
Unnotched, R = 0.1				
10^3 cycles, ksi	73	71	70	--
10^5 cycles, ksi	57	53	48	--
10^7 cycles, ksi	46	40	38	--
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	50	50	50	--
10^5 cycles, ksi	21	20	19	--
10^7 cycles, ksi	16	13	11	--
Creep (Transverse)				
0.2% plastic deformation 100 hr, ksi	NA	42	15	4
0.2% plastic deformation 1000 hr, ksi	NA	36	9	2.7
Stress Rupture (Transverse)				
Rupture 100 hr, ksi	NA	50	21	5.6
Rupture 1000 hr, ksi	NA	40	13.5	4.3
Stress Corrosion				
80% F_{ty}, 1000 hr max	No cracks(f)			
Coefficient of Thermal Expansion				
13.0×10^{-6} in./in./F (RT to 212 F)				
Density 0.099 lb/in.^{3}				

(a) Data are average of triplicate tests conducted at Battelle unless otherwise indicated. Fatigue, creep, and stress-rupture values are from data curves generated using a greater number of tests.

(b) Double-shear [illegible] specimen, 1/2-inch diameter.

(c) 4.1 at RT, 3.5 at -100 F, 3.2 at -320 F.

(d) Average of [illegible] chevron-notched slow-bend tests. Tests at 250 F proved to be invalid.

(e) "R" represents the algebraic ratio of minimum to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(f) Three-point bend test. Alternate immersion in 3-1.2 percent NaCl.

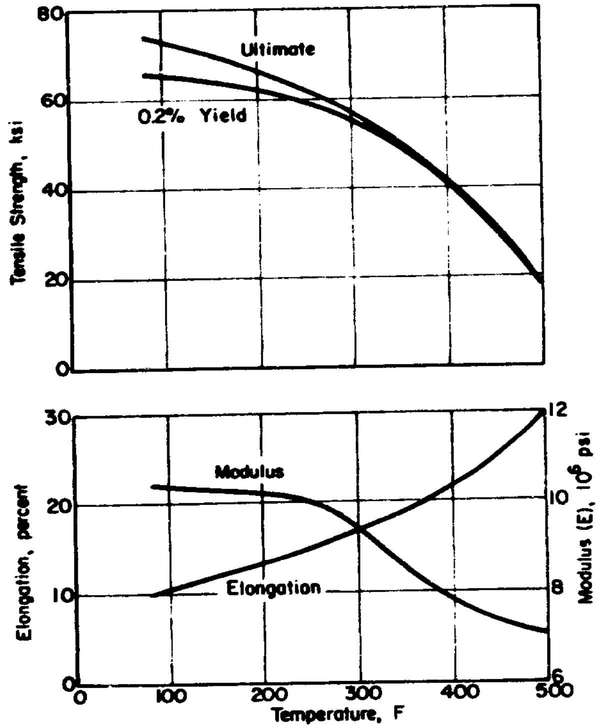

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7049-T73 ALUMINUM FORGINGS

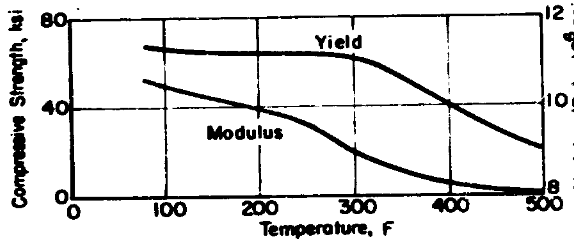

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF 7049-T73 ALUMINUM FORGINGS

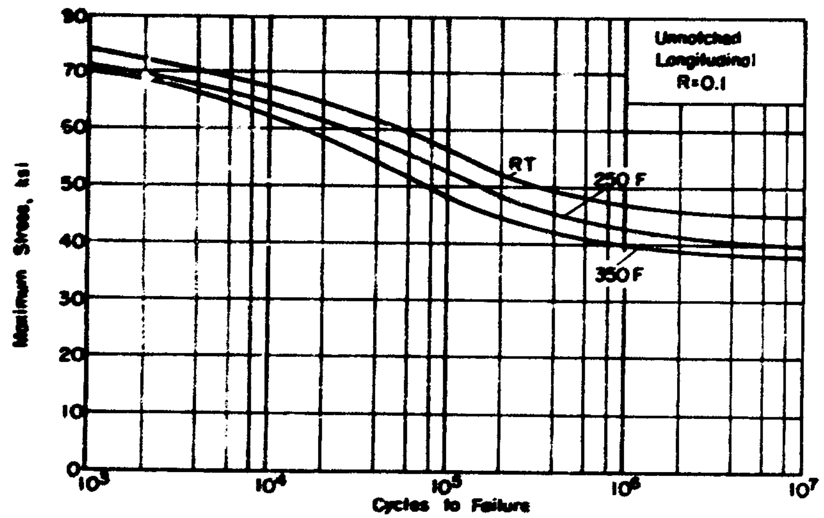

FIGURE 3. AXIAL-LOAD FATIGUE RESULTS FOR UNNOTCHED 7049-T73 ALUMINUM FORGING AT THREE TEMPERATURES

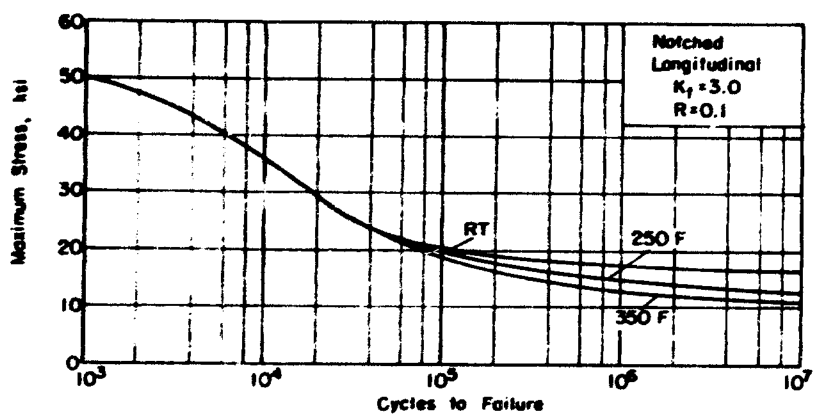

FIGURE 4. AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 7049-T73 ALUMINUM FORGING AT THREE TEMPERATURES

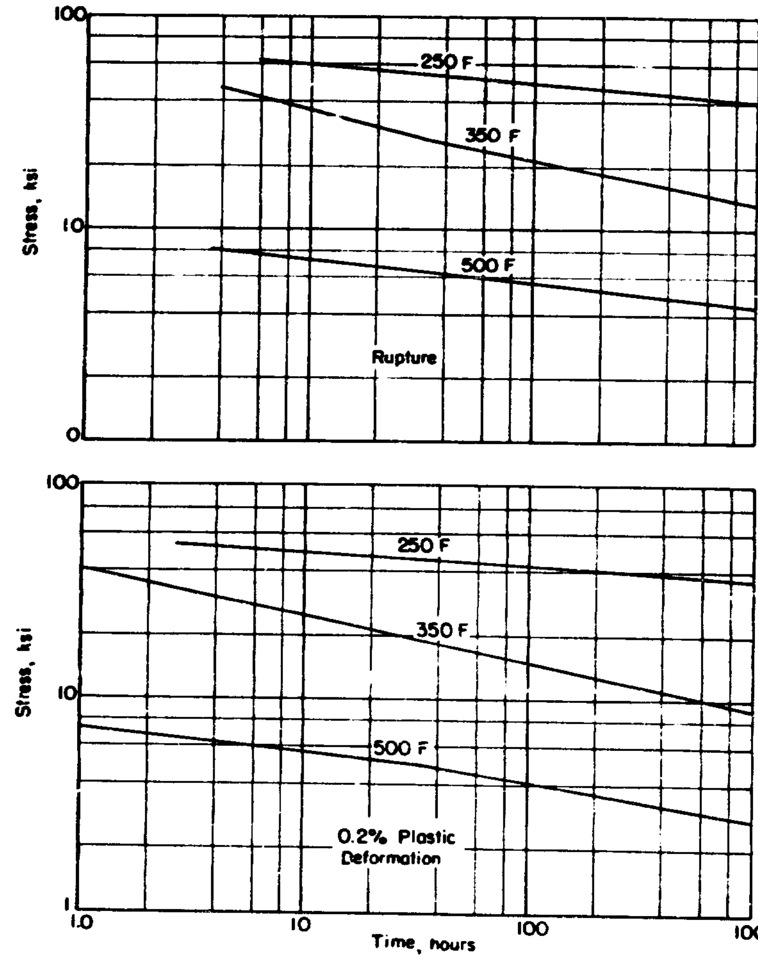

FIGURE 5. STRESS-RUPTURE AND PLASTIC-DEFORMATION CURVES FOR 7049-T73 ALUMINUM FORGINGS

7178-T76

Alloy 7178 is a heat-treatable aluminum alloy containing zinc, copper, and magnesium as hardeners. At present it is one of the strongest wrought aluminum alloys produced. Its general properties are similar to those of alloy 7075, but its use is limited to a rather narrow range of thickness owing to its limited hardenability.

The -T76 temper for 7178 was developed as compromise between the exfoliation resistance of 7075-T73 and the structural capability of 7075-T6. It was to achieve an increase in resistance to exfoliation over that of 7075-T6 while maintaining a high level of strength and fracture toughness characteristics.

The nominal composition of 7178 is as follows:

Silicon	0.50
Iron	0.70
Copper	1.6-2.4
Manganese	0.30
Chromium	0.18-0.40
Zinc	6.3-7.3
Titanium	0.20
Aluminum	Balance
Magnesium	2.4-3.1

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7178 Data[a]

Condition: -T76
Thickness: 0.215-Inch Sheet

Properties	Temperature, F RT	250	350	500
Tension				
F_{tu} (longitudinal), ksi	80.2	63.8	50.9	18.7
F_{tu} (transverse), ksi	81.6	65.4	51.7	17.4
F_{ty} (longitudinal), ksi	71.7	63.3	50.2	18.2
F_{ty} (transverse), ksi	71.0	62.4	49.8	17.0
e_t (longitudinal), percent in 2 in.	10.7	14.8	16.3	24.8
e_t (transverse), percent in 2 in.	9.5	16.5	17.7	23.2
E_t (longitudinal), 10^6 psi	10.0	9.6	8.6	6.4
E_t (transverse), 10^6 psi	10.2	10.1	9.4	7.3
Compression				
F_{cy} (longitudinal), ksi	76.2	69.6	57.4	20.2
F_{cy} (transverse), ksi	80.3	73.5	60.6	19.6
E_c (longitudinal), 10^6 psi	10.5	10.2	9.1	8.6
E_c (transverse), 10^6 psi	10.9	10.2	10.1	9.0
Shear[b]				
F_{su} (longitudinal), ksi	53.4	U[c]	U	U
F_{su} (transverse), ksi	54.0	U	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in.}$[d]	27.7	U	U	U

Properties	Temperature F, RT	250	350	500
Axial Fatigue (transverse)(e)				
Unnotched, R = 0.1				
10^5 cycles, ksi	45	78	65	--
10^6 cycles, ksi	38	36	35	--
10^7 cycles, ksi	31	24	21	--
Notched (K_t = 3.0), R = 0.1				
10^5 cycles, ksi	56	45	43	--
10^6 cycles, ksi	22	18	16	--
10^7 cycles, ksi	18	14	12	--
Creep (transverse)	RT	350	450	600
0.2% plastic deformation 100 hr, ksi	NA	17	6.6	2.5
0.2% plastic deformation 1000 hr, ksi	NA	11	4.4	1.8
Stress Rupture (transverse)				
Rupture 100 hr, ksi	NA	22	9.5	4.3
Rupture 1000 hr, ksi	NA	15	7.0	3.3

Stress Corrosion

40% F_{ty}, 1000 hr max No cracks(f)

Coefficient of Thermal Expansion(g)

13.0 x 10^{-6} in./in./F (70 to 212 F)

Density(h)

0.102 lb/in.^{3}

[illegible]

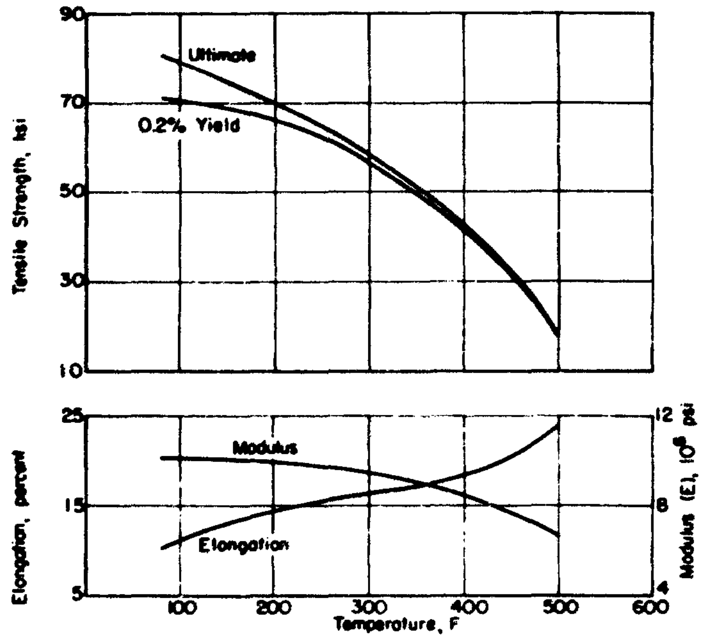

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7178-T76 ALUMINUM-ALLOY SHEET

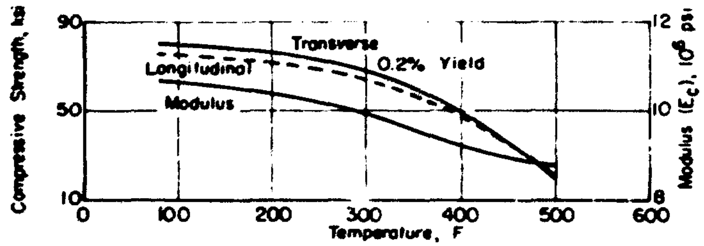

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7178-T76 ALUMINUM-ALLOY SHEET

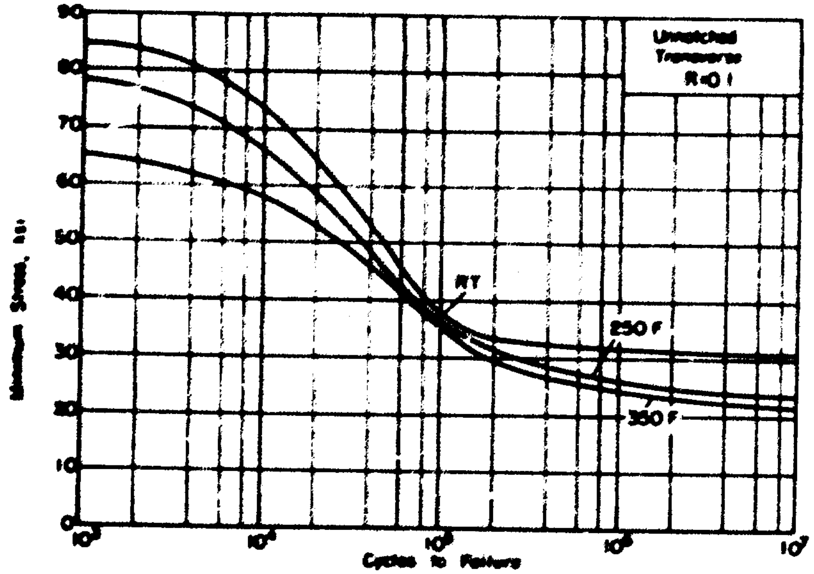

FIGURE 3 AXIAL-LOAD FATIGUE RESULTS FOR UNNOTCHED 7178-T76 ALUMINUM SHEET AT THREE TEMPERATURES

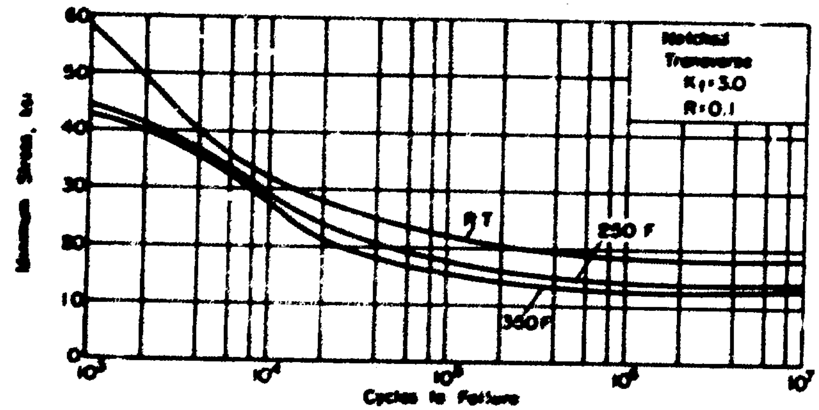

FIGURE 4. AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 7178-T76 ALUMINUM SHEET AT THREE TEMPERATURES

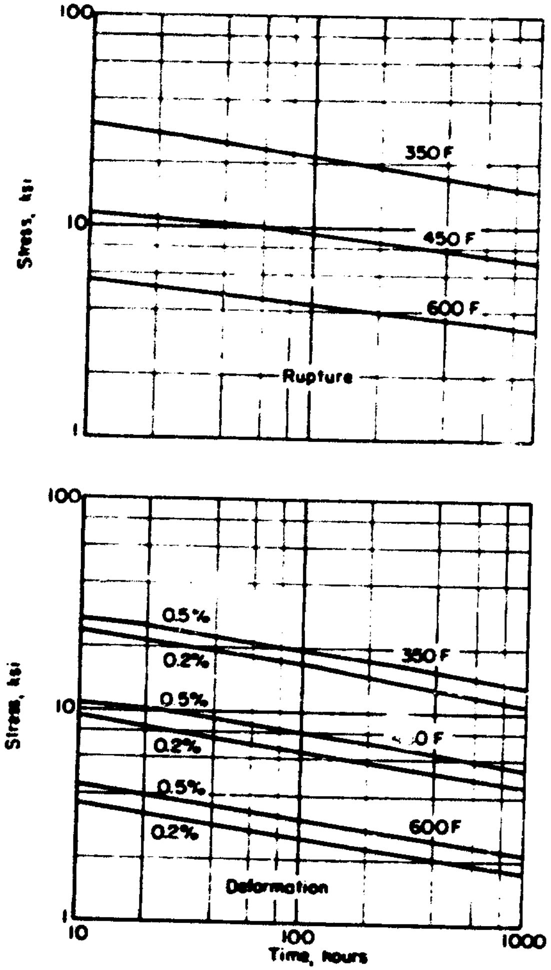

FIGURE 5. STRESS-RUPTURE AND PLASTIC-DEFORMATION CURVES FOR 7178-T76 ALUMINUM-ALLOY SHEET

AF2-1DA

AF2-1DA is a newly developed high-temperature nickel-base alloy. It was developed by the Universal-Cyclops Specialty Steel Division under Air Force Contract AF 33(615)-1729. Further development and scale-up is being carried out under Contract F33615-67-C-1056. The intended usage of this material is for turbine wheel/bucket applications.

Nominal composition for AF2-1DA is 0.34 Cr, 12.0 Cr, 10.0 Co, 3.0 Mo, 6.0 W, 1.85 Ta, 4.50 Al, 3.0 Ti, 0.015 B, 0.14 Zr, balance nickel.

No fatigue data are presented in the data sheet. The quantity of usable material was limited and although fatigue tests were attempted, it is believed that the data obtained are not representative of the material's capabilities. If additional bar becomes available during the contract year the fatigue data will be added to this data sheet.

AF2-1DA DATA[a]

Condition: Aged
Thickness: 1-1/4 Inch Extruded Round Bar

Properties	Temperature, F			
	RT	1000	1400	1800
Tension				
F_{tu}, ksi	196.4	175.9	157.8	63.8
F_{ty}, ksi	149.0	147.5	143.9	48.1
e_t, percent in 2 in.	11.2	5.7	2.7	25.4
E_t, 10^6 psi	31.5	27.9	25.4	19.1
Compression				
F_{cy}, ksi	155.3	160.4	148.0	52.3
E_c, 10^6 psi	33.3	30.9	29.3	24.9
Shear				
F_{su}, ksi	135.0(b)	U(c)	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in}$	U	U	U	U
Axial Fatigue				
Unnotched, R = 0.1				
10^3 cycles, ksi	U	--	U	U
10^5 cycles, ksi	U	--	U	U
10^7 cycles, ksi	U	--	U	U
Notched (K_t = 4.0), R = 0.1				
10^3 cycles, ksi	U	--	U	U
10^5 cycles, ksi	U	--	U	U
10^7 cycles, ksi	U	--	U	U

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Properties	Temperature, F 1400	1600	1800
Creep			
0.2% plastic deformation 100 hr, ksi	64.0	27.0	6.6
0.2% plastic deformation 1000 hr, ksi	54.0	16.5	3.3
Stress Rupture			
Rupture 100 hr, ksi	73.0	44.0	16.0
Rupture 1000 hr, ksi	68.0	30.0	9.5
Stress Corrosion			
80% F_{ty}, 1000 hr max	No cracks[d]		
Coefficient of Thermal Expansion			
6.5 x 10^{-6} in./in./F (RT to 1200 F)			
Density 0.292 lb/in.^{3}			

(a) Data are average of triplicate tests conducted at Battelle under the subject contract unless otherwise indicated. Creep and stress-rupture values are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen.

(c) U = unavailable.

(d) Room-temperature three-point bend test. No cracks appeared after alternate immersion in 3-1/2 percent NaCl for 1000 hours.

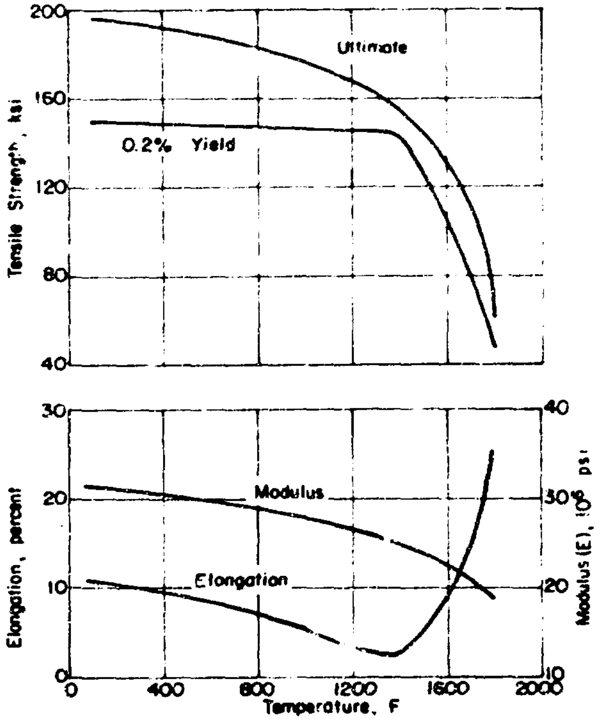

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF AF2-1DA EXTRUDED ROUND BAR

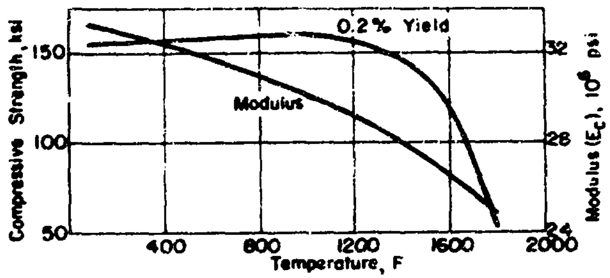

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF AF2-1DA EXTRUDED ROUND BAR

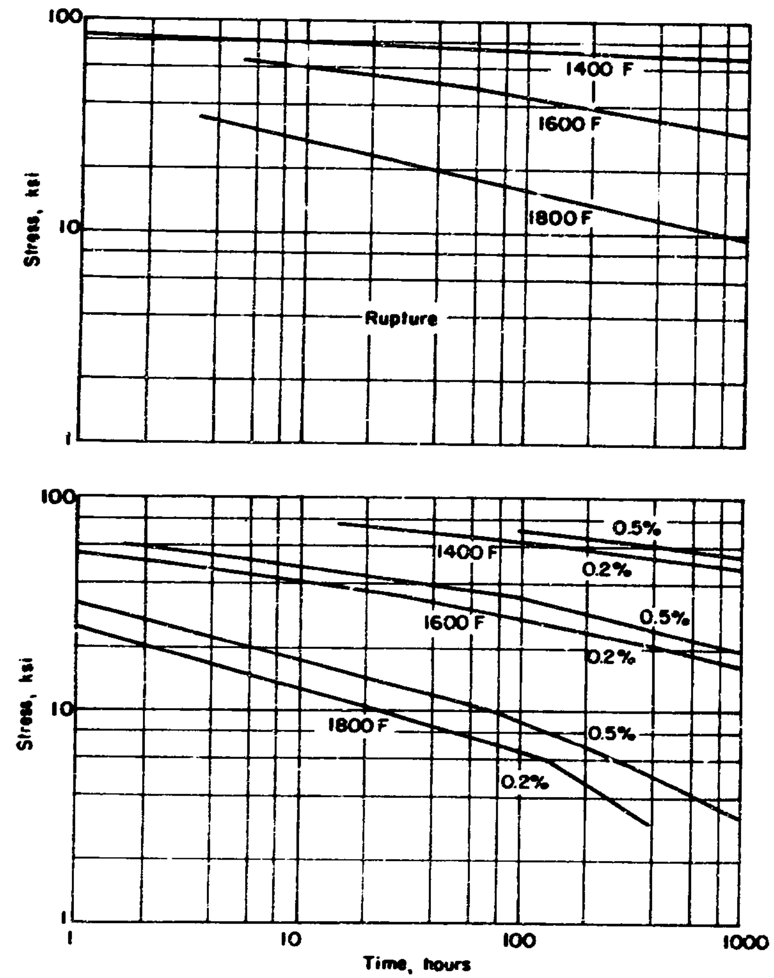

FIGURE 5. STRESS-RUPTURE AND PLASTIC-DEFORMATION CURVES FOR AF2-1DA EXTRUDED ROUND BAR

MP35N Multiphase Alloy

MP35N is a new nickel-cobalt-chromium-molybdenum alloy developed by the E. I. duPont deNemours and Company, Incorporated. The rights to this alloy, MP35N, and the family of composition from which it was derived, MULTIPHASE[(T)] Alloys, were acquired by Standard Pressed Steel Company in 1967 and Latrobe Steel Company was subsequently licensed to manufacture the MULTIPHASE Alloys.

MP35N is hardened by work strengthening and aging to strength levels of 260 – 300 ksi. In addition to high strength and good ductility, the alloy is reported to have execellent resistance to corrosion and stress corrosion in salt water and other chloride solutions. Potential usage of this material is for fasteners, springs, marine drive shafts, cables, etc.

MP35N is available as ingot, billet, bar stock, wire, and tubing. A fabricator of flat-rolled products will be licensed soon so that all product forms will be available.

The composition of the 1-inch round bar stock used for this evaluation was as follows:

Ni – 35.24
Co – 35.11
Cr – 19.48
Mo – 9.61
C – 0.015

The material was work strengthened and aged at 1050 F for 4 hours and air cooled to attain a nominal strength level of 260 ksi.

(T) Trademark of the Standard Pressed Steel Company.

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MP35N ALLOY DATA[(a)]

CONDITION: WORK-STRENGTHENED AND AGED
THICKNESS: 1-INCH DIAMETER ROUND BAR

Properties	Temperature, F: RT	400	700	1200
Tension				
F_{tu}, ksi	273.0	245.0	228.0	[illegible]
F_{tu}, Notched (K_t = 6.3), ksi	304.1	--	--	--
F_{tu}, Notched (K_t = 9.0), ksi	284.1	--	--	--
F_{ty}, ksi	263.0	238.3	221.0	[illegible]
e_t, percent in 2-in.	11.3	11.0	8.3	[illegible]
RA, percent	53.5	51.2	42.5	23.2
E_t, 10^6 psi	35.9	32.7	32.7	[illegible]
Compression				
F_{cy}, ksi	253.0	211.0	197.0	150.0
E_c, 10^6 psi	33.9	32.5	29.3	23.8
Shear				
F_{su}, ksi	144.7[(b)]	U[(c)]	U	U
Impact (v-notch charpy), ft-lb	24.0	20.5	14.6	U
Fracture Toughness, K_{Ic}[(d)]	78.7	U	U	U
Axial Fatigue[(e)]				
Unnotched, R = 0.1				
10^3 cycles, ksi	273	264	258	U
10^6 cycles, ksi	194	184	130	U
10^7 cycles, ksi	157	140	134	U
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	204	188	170	U
10^6 cycles, ksi	80	74	68	U
10^7 cycles, ksi	45	50	60	U

Properties	Temperature, F			
	RT	700	900	1200
Creep				
	NA	222	130	35
	NA	221	103	25
Stress Rupture				
	NA	223	212	97
	NA	222	209	75
Stress Corrosion				
80% F_{ty}, 1000 hrs. Max.	No Cracks[(f)]			
Coefficient of Thermal Expansion				
10^{-6} in/in/F	7.1 (70-200 F)			
	8.2 (70-600 F)			
	8.7 (70-1000 F)			
Density				
0.304 lb/in^3				

(a) Data are average of at least three tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen, 0.250-inch diameter.

(c) U, unavailable; NA, not applicable.

(d) Average of 4 slow-bend tests.

(e) "R" represents the algebraic ratio of minimum to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress concentration factor.

(f) 3-point bend test. Alternate immersion 3-1/2 percent NaCl.

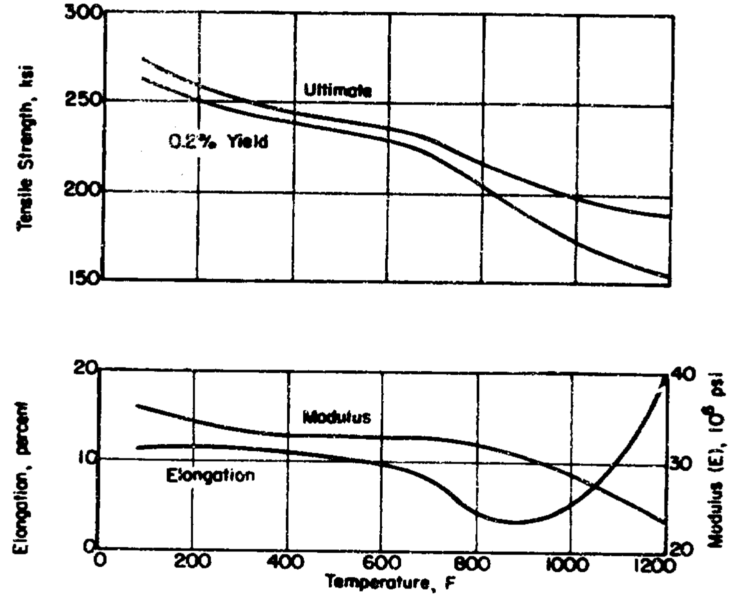

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF MP35N MULTIPHASE ALLOY BAR

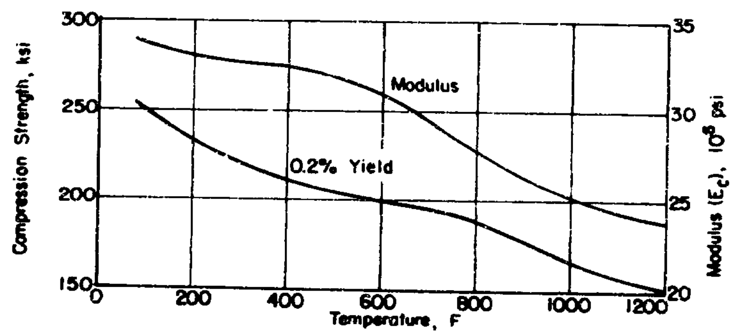

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF MP35N MULTIPHASE ALLOY BAR

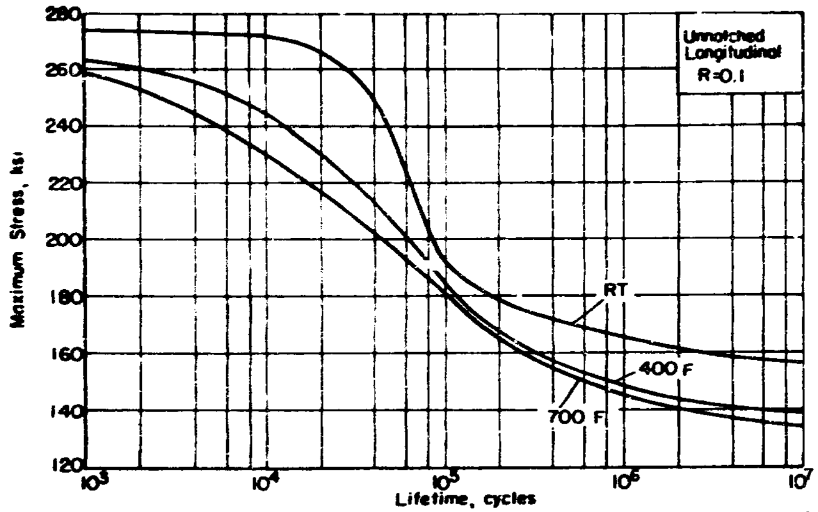

FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR MP35N MULTIPHASE ALLOY BAR AT THREE TEMPERATURES

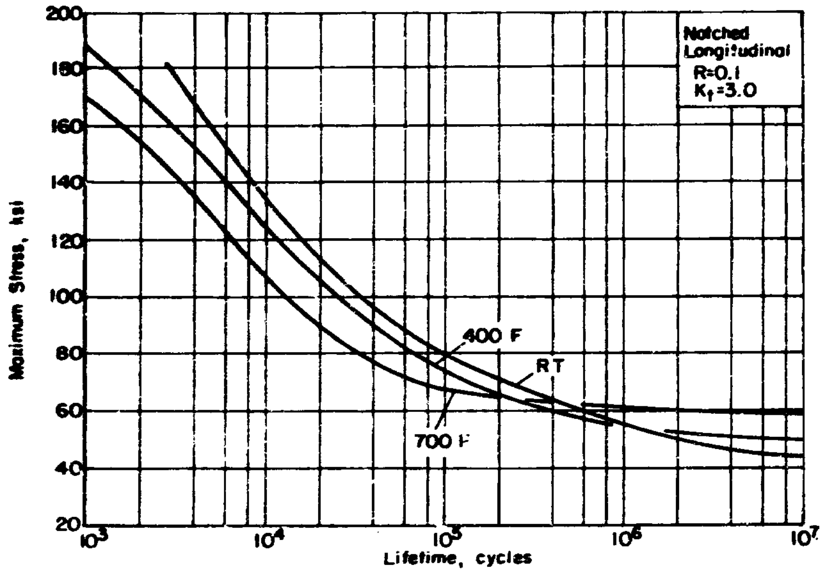

FIGURE 4. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) MP35N MULTIPHASE ALLOY BAR AT THREE TEMPERATURES

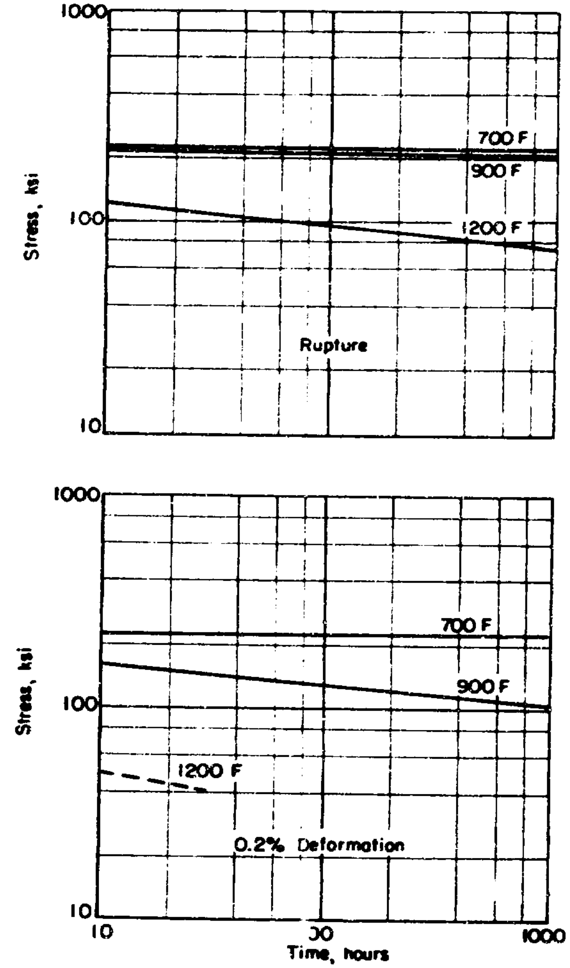

FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR MP35N MULTIPHASE ALLOY BAR

RMI 38-6-44 TITANIUM ALLOY

38-6-44 alloy (3Al-8V-6Cr-4Mo-4Zr) is a new deep-hardening beta composition alloy developed by Reactive Metal, Incorporated. The large amount of beta stabilizing elements in this composition results in sluggish transformation characteristics which give deep hardening. The metallurgy of 38-6-44 alloy is similar to other beta alloys such that solution annealing retains the more ductile body-center-cubic beta phase at room temperature.

The 6-inch by 6-inch billet used in this property survey was solution annealed at 1500 F for 15 minutes and air cooled, plus aging at 1050 F for four hours.

RMI 38-6-44 TITANIUM ALLOY[a]

Condition: STA
Thickness: 6 x 6 Forging

Properties	Temperature, F			
	RT	400	700	900
Tension				
F_{tu} (longitudinal), ksi	177.0	166.0	159.0	140.0
F_{tu} (transverse), ksi	168.0	164.0	155.0	140.0
F_{ty} (longitudinal), ksi	167.0	148.0	139.0	123.0
F_{ty} (transverse), ksi	167.0	146.3	135.0	125.0
e (longitudinal), percent in 2 in.	10.0	7.7	8.7	33.5
e (transverse), percent in 2 in.	6.0	5.0	6.0	17.3
RA (longitudinal), percent	18.2	13.5	15.6	76.0
RA (transverse), percent	10.9	8.9	11.9	42.5
E (longitudinal), 10^6 psi	15.4	13.8	12.3	11.6
E (transverse), 10^6 psi	15.1	14.6	13.0	11.8
Compression				
F_{cy} (longitudinal), ksi	161.0	140.0	130.0	113.3
F_{cy} (transverse), ksi	155.0	137.0	129.0	116.0
E_c (longitudinal), 10^6 psi	14.8	13.5	12.4	11.2
E_c (transverse), 10^6 psi	14.7	13.7	11.9	11.4
Shear[b]				
F_{su} (longitudinal), ksi	119.5	U[c]	U	U
F_{su} (transverse), ksi	119.0	U	U	U
Impact (V-notch charpy)[d]				
Energy (longitudinal), ft-lb	7.5	U	U	U
Energy (transverse), ft-lb	5.0	U	U	U
Fracture Toughness, K_{IC}, ksi $\sqrt{in.}$				
Near outside of forging	57.7	U	U	U
Near center of forging	60.1	U	U	U
Fatigue (Transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi	166.0	158.0	148.0	U
10^5 cycles, ksi	124.0	106.0	92.0	U
10^7 cycles, ksi	87.0	80.0	64.0	U
Notched (K_t = 3.0), R = 0.1				
10^3 cycles, ksi	120.0	104.0	92.0	U
10^5 cycles, ksi	44.0	36.0	40.0	U
10^7 cycles, ksi	40.0	30.0	34.0	U

Properties	RT	400	700	900
	Temperature, F			
Creep (Transverse)				
0.2% plastic deformation, 100 hr	NA	141.0	58.0	5.4
0.2% plastic deformation, 1000 hr	NA	140.0	25.0	2.5
Stress Rupture (Transverse)				
Rupture, 100 hr	NA	143.0	137.0	50.0
Rupture, 1000 hr	NA	142.0	133.0	31.0
Stress Corrosion				
80% F_{ty}, 1000 hr max	No cracks[g]			
Coefficient of Thermal Expansion				
5.38×10^{-6} in./in./F (68-900 F)				
Density				
0.174 lb/in.^{3}				

(a) Each value given is the average of at least three tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen, 0.250-inch diameter.

(c) U, unavailable; NA, not applicable.

(d) Longitudinal 7.5 at +32 F
Transverse 5.7 at +32 F

(e) Each value is average of 4 slow-bend tests.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, R = S_{min}/S_{max}. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(g) Room temperature three-point bend test. Alternate immersion in 3-1/2 percent NaCl.

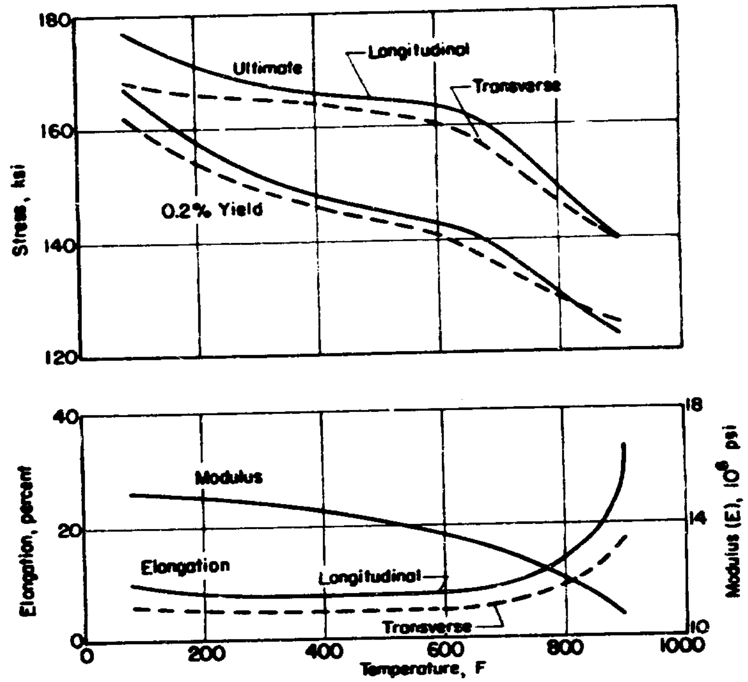

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 38-6-44 TITANIUM FORGINGS

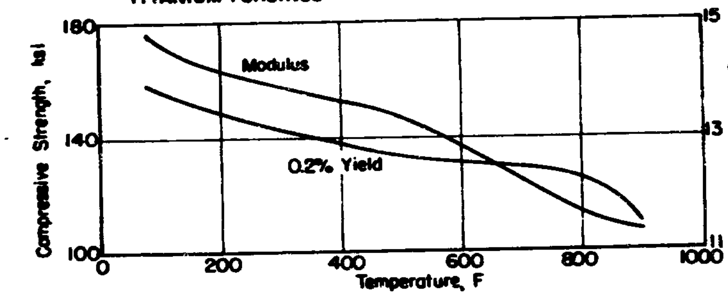

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 38-6-44 TITANIUM FORGINGS

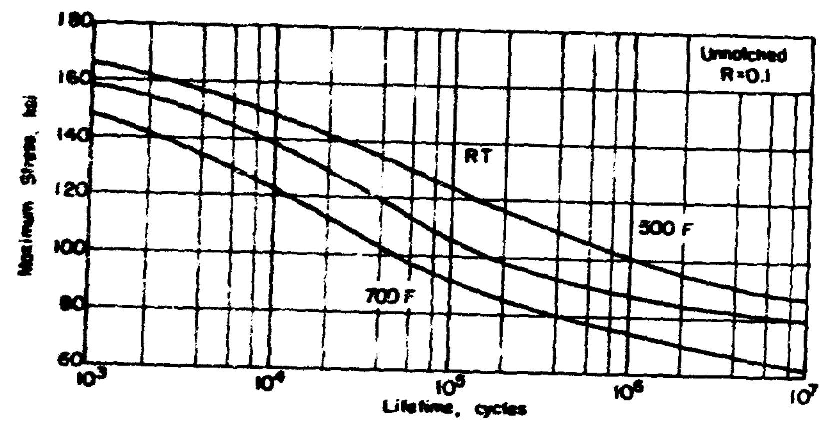

FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR 38-6-44 TITANIUM FORGINGS

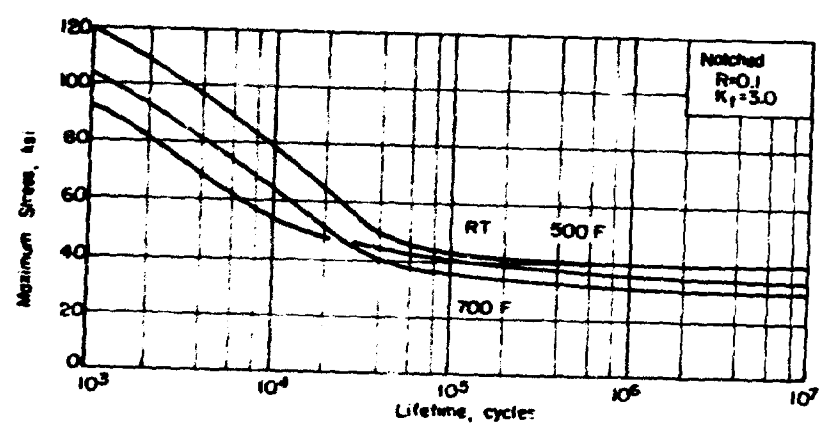

FIGURE 4 AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 38-6-44 TITANIUM FORGINGS

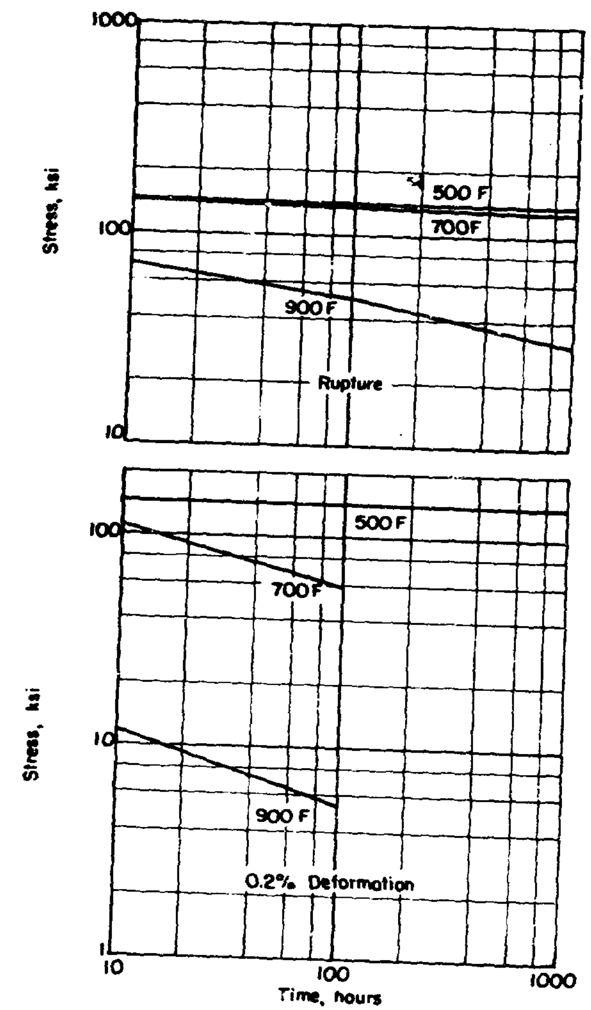

FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 38-6-44 TITANIUM FORGINGS

7175 Aluminum Alloy

7175 is a new Premium Strength Die Forging developed by Alcoa. This development is intended to provide relatively high strength/weight ratios for aerospace applications. The guaranteed minimum longitudinal yield strength for the -T736 temper is approximately 17 percent above the current minimum requirements of specifications covering 7075 alloy die forgings in the -T73 temper. Although the development emphasis was placed on high longitudinal strength, the transverse ductility is also well above that of most conventional 7075 die forgings.

Tests on a limited number of forgings (by Alcoa) in the -T736 temper indicate that the stress-corrosion cracking threshold in the short transverse direction should be at least 35 ksi.

Currently, the product is limited to closed die airframe-type forgings.

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7175 Aluminum[(a)]
Condition: -T736
Thickness: Various (Die Forging)

Properties	Temperature, F RT	250	350	500
Tension				
F_{tu} (longitudinal), ksi	82.0	66.3	52.8	19.7
F_{tu} (transverse), ksi	79.2	64.2	50.7	19.2
F_{ty} (longitudinal), ksi	75.4	66.2	52.6	19.7
F_{ty} (transverse), ksi	72.3	64.0	50.4	19.2
e_t (longitudinal), percent in 2 in.	14.3	21.0	23.3	29.0
e_t (transverse), percent in 2 in.	12.3	16.0	21.0	26.3
RA (longitudinal), percent	36.8	52.8	67.0	91.5
RA (transverse), percent	35.8	47.2	62.9	91.0
E_t (longitudinal), 10^6 psi	10.3	9.7	8.6	8.2
E_t (transverse), 10^6 psi	10.0	9.5	8.5	8.3
Compression				
F_{cy} (longitudinal), ksi	78.8	69.8	57.1	22.2
F_{cy} (transverse), ksi	74.0	65.5	54.8	21.8
E_c (longitudinal), 10^6 psi	11.0	10.1	8.9	8.0
E_c (transverse), 10^6 psi	10.7	9.9	9.3	7.6
Shear[(b)]				
F_{su} (longitudinal), ksi	47.5	U[(c)]	U	U
F_{su} (transverse), ksi	49.7	U	U	U
Impact (V-Notch Charpy)				
Energy (longitudinal), ft-lb	6.2[(d)]	U	U	U
Energy (transverse), ft-lb	5.3	U	U	U
Fracture Toughness, K_{Ic}, ksi$\sqrt{in}$	48.5[(e)]	U	U	U

Property	Temperature, F			
	RT	[illegible]	350	550
Fatigue (longitudinal)[f]				
Unnotched, R = [illegible]				
10[illegible] cycles, ksi	62	56	68	U
10[illegible] cycles, ksi	63	[illegible]	50	U
10[illegible] cycles, ksi	[illegible]	33	28	U
Notched K_t = [illegible]				
10[illegible] cycles, ksi	58	5[illegible]	47	U
10[illegible] cycles, ksi	22	2[illegible]	22	U
10[illegible] cycles, ksi	15	1[illegible]	13	U
Creep (longitudinal)				
0.2% plastic deformation, 100 hr	NA	45	18	4.5
0.2% plastic deformation, 1000 hr	NA	40	12	3.0
Stress Rupture				
Rupture 100 hr	NA	51	23	6.5
Rupture 1000 hr	NA	44	15.5	4.7
Stress Corrosion				
80% F_{ty}, 1000 hr max	No cracks[g]			
Coefficient of Thermal Expansion				
12.5 x 10[illegible] in/in/F (RT - 230 F)				
Density 0.101 lb/in[illegible]				

(a) Each value given is the average of at least three tests [illegible] at Battelle under the subject contract unless otherwise indicated. [illegible] fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.

(b) Double-shear pin-type specimen, [illegible] diameter.

(c) U, unavailable; NA, not applicable

(d) Longitudinal at -100 F = 4.[illegible]

Transverse at -100 F = [illegible]

Longitudinal at -320 F = [illegible]

Transverse at -320 F = 3.5

Each value is average of three tests at temperature indicated.

(e) Average of six slow bend tests.

(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is, $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.

(g) Room temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

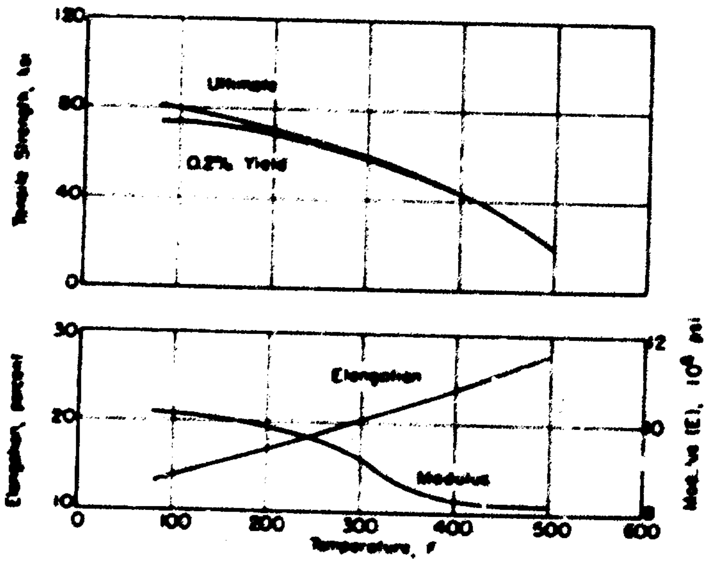

FIGURE 1 EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7175-T736 DIE FORGING

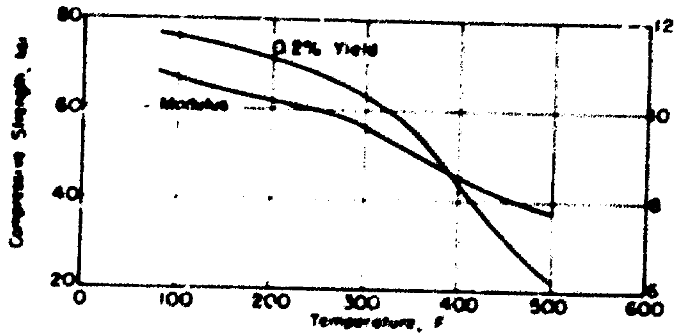

FIGURE 2 EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7175-T736 DIE FORGING

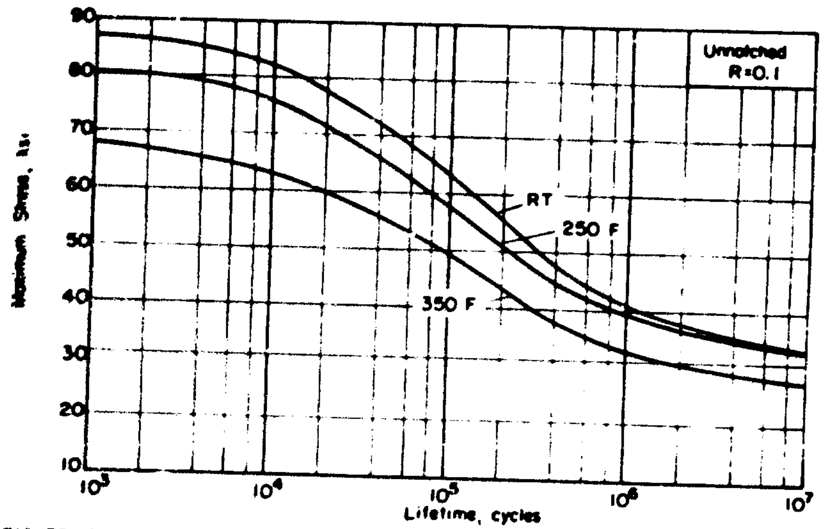

FIGURE 3. AXIAL LOAD FATIGUE RESULTS FOR 7175-T736 DIE FORGINGS AT THREE TEMPERATURES

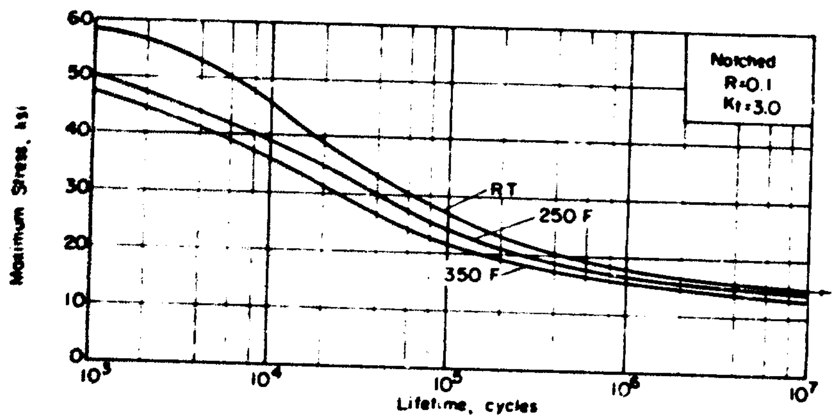

FIGURE 4. AXIAL LOAD LOAD FATIGUE RESULTS FOR NOTCHED (K_t=3.0) 7175-T736 DIE FORGINGS AT THREE TEMPERATURES

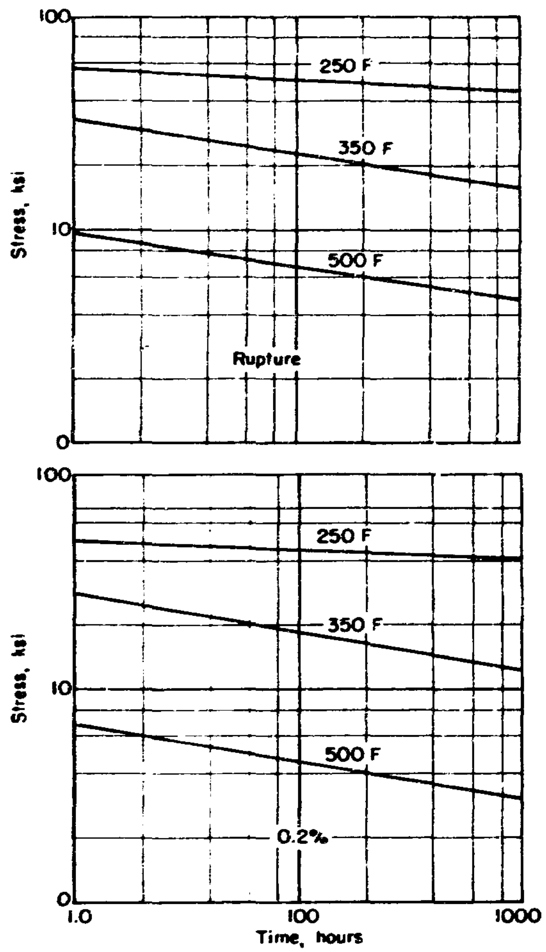

FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7175-T736 DIE FORGINGS

5621-S Titanium Alloy

5621-S alloy is a new high-temperature titanium alloy developed by Reactive Metals, Incorporated. The alloy was developed to meet the need for a titanium alloy capable of withstanding temperatures as high as 1000 F for long periods. 5621-S contains silicon which enhances high temperature creep strength. This alpha-matrix alloy is reported to have moderate room temperature tensile strength, excellent notch toughness, fatigue and creep strength, hot salt stress corrosion resistance, and thermal stability. It is reported to have greater creep strength than any other commercially available titanium alloy.

Currently all mill product forms have been manufactured, and bar and billet are available from RMI. Sheet and plate are undergoing investigation and are expected to be commercially available in the near future.

The nominal chemical composition of 5621-S is as follows:

Al	4.50-5.50
Sn	5.00-7.00
Zr	1.50-2.50
Mo	0.50-1.00
Si	0.15-0.35
Fe	0.30 Maximum
C	0.05 Maximum
O	0.15 Maximum
N	0.03 Maximum
H	0.0125
Others	0.40 Total
Balance Titanium	

Ti-5621-S[a]
Condition: STA
Thickness: 1-1/2-inch Pancake Forging

Properties	Temperature, F RT	400	700	900
Tension				
F_{tu} (Radial), ksi	139.6	116.0	103.3	98.1
F_{tu} (Tangential), ksi	136.3	114.3	105.0	97.9
F_{ty} (Radial), ksi	119.0	88.5	74.3	71.2
F_{ty} (Tangential), ksi	117.3	88.3	77.2	71.5
e_t (Radial), percent in 2 in.	13.6	16.7	18.2	19.0
e_t (Tangential), percent in 2 in.	11.3	15.0	15.0	16.2
RA (Radial), percent	20.4	27.2	30.4	37.0
RA (Tangential), percent	19.2	29.1	31.6	32.3
E_t (Radial), 10^6 psi	17.2	16.9	15.1	14.3
E_t (Tangential), 10^6 psi	17.1	16.6	14.8	14.2
Compression				
F_{cy} (Radial), ksi	133.0	95.4	77.5	74.3
F_{cy} (Tangential), ksi	135.3	96.2	[illegible]	76.9
E_c (Radial), 10^6 psi	17.5	16.4	14.8	14.1
E_c (Tangential), 10^6 psi	17.5	15.9	14.9	14.3
Shear[b]				
F_{su} (Radial), ksi	99.3	U[d]	U	U
F_{su} (Tangential), ksi	94.9	U	U	U
Impact (V-Notch Charpy), ft-lb	21.3[c]	U	U	U
Fracture Toughness, K_{Ic}, ksi $\sqrt{in.}$	76.5[e]	U	U	U

Properties	Temperature, F RT	400	700	900
Fatigue (Radial)(f)				
Unnotched, R = 0.1				
10^5 cycles, ksi	150	140	124	U
10^6 cycles, ksi	114	110	103	U
10^7 cycles, ksi	85	82	78	U
Notched (K_t = 3.0) R = 0.1				
10^5 cycles, ksi	110	106	100	U
10^6 cycles, ksi	54	49	44	U
10^7 cycles, ksi	38	38	38	U
Creep (Radial)	RT	600	800	950
0.2% plastic deformation, 100 hr	NA	107	91	71
0.2% plastic deformation, 1000 hr	NA	106	90	60
Stress Rupture (Radial)				
Rupture 100 hr	NA	108	91.5	86
Rupture 1000 hr	NA	107	91	79
Stress Corrosion				
80% F_{ty}, 1000 hr max	No Cracks(g)			
Coefficient of Thermal Expansion				
5.36×10^{-6} in./in./F(68 – 700 F)				
Density 0.163 lb/in.^{3}				

(a) Each value given is the average of at least three tests conducted at Battelle under the subject contract unless otherwise indicated. Fatigue, creep, and stress-rupture values are from curves generated using a greater number of tests.
(b) Double-shear pin-type test, 0.250-inch specimen.
(c) 21.3 at RT, 17.2 at -40 F, 14.0 at -100 F.
(d) U, unavailable. NA, not applicable.
(e) Average of five slow-bend tests, tests at 400 F were marginal by the established criteria and are not reported.
(f) "R" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is $R = S_{min}/S_{max}$. "K_t" represents the Neuber-Peterson theoretical stress-concentration factor.
(g) Room-temperature three-point bend test. Alternate immersion in 3-1/2 percent NaCl.

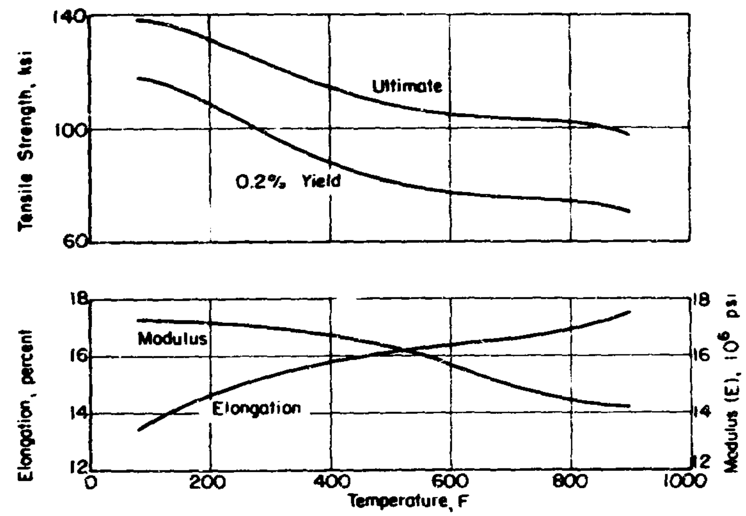

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF Ti-5621S PANCAKE FORGING

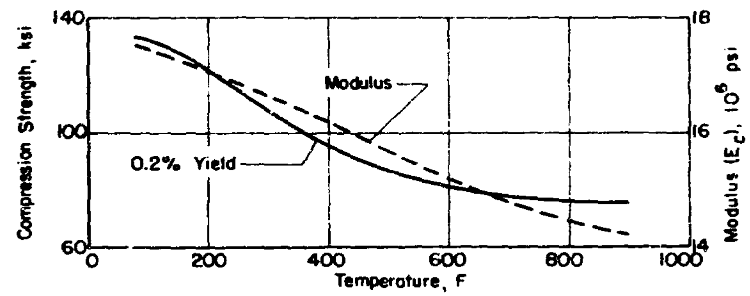

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSION PROPERTIES OF Ti-5621S PANCAKE FORGINGS

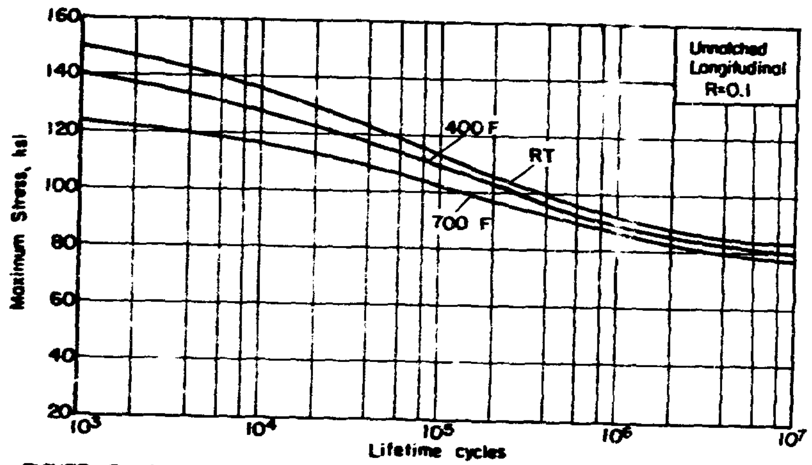

FIGURE 3. AXIAL-LOAD FATIGUE RESULTS FOR Ti-5621S PANCAKE FORGING AT THREE TEMPERATURES

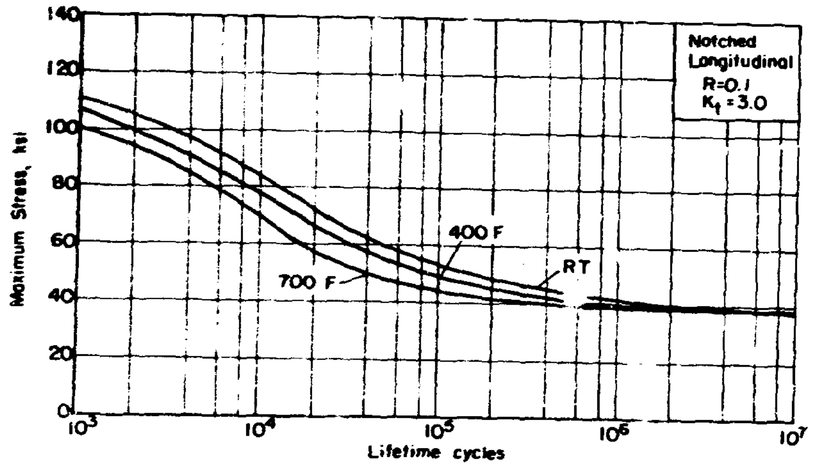

FIGURE 4. AXIAL-LOAD FATIGUE RESULTS FOR NOTCHED (K_t =3.0) Ti-5621S PANCAKE FORGING AT THREE TEMPERATURES

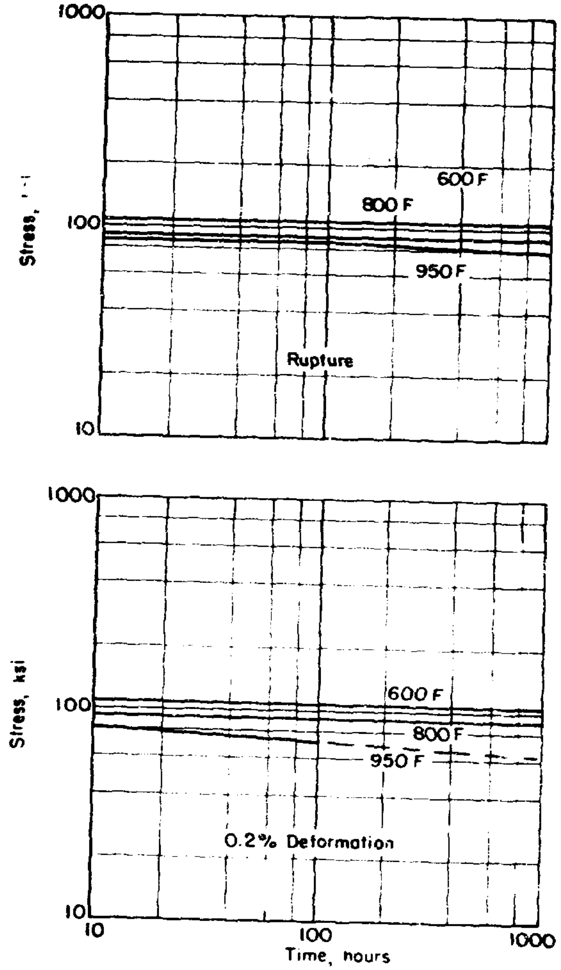

FIGURE 5. STRESS-RUPTURE AND PLASTIC-DEFORMATION CURVES FOR Ti-5621S PANCAKE FORGING

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13. ABSTRACT

The major objectives of this research program were to evaluate newly developed structural materials of potential Air Force weapons system interest and then to provide "data sheet" type presentations of engineering data. The effort covered in this report has concentrated on Beta III titanium sheet, AF2-IDA heat-resistant alloy bar, 3Al-8V-6Cr-4Mo-4Zr (Beta C) titanium alloy forging, 300M high-strength steel forging, 7178-T76 aluminum alloy sheet, 7049-T73 aluminum alloy hand forging, 6Al-4V titanium alloy extursions, 5621-S titanium alloy forging, 6Al-4V titanium alloy sheet, 7175-T736 aluminum alloy die forging, and MP35N high-strength bar.

The mechanical properties investigated include tension, compression, sheer, bend, impact, fracture toughness, fatigue, creep and stress-rupture, and stress corrosion at appropriate temperatures.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Mechanical properties						
Chemical composition						
Corrosion resistance						
Physical properties						
Stainless Steel						
Aluminum alloy						
Titanium alloy						
Nickel alloy						
Beta III						
AF2-IDA						
3Al-8V-6Cr-4Mo-4Zr						
300M						
7178						
7049						
6Al-4V						
5621-S						
7175						
Mp35N						