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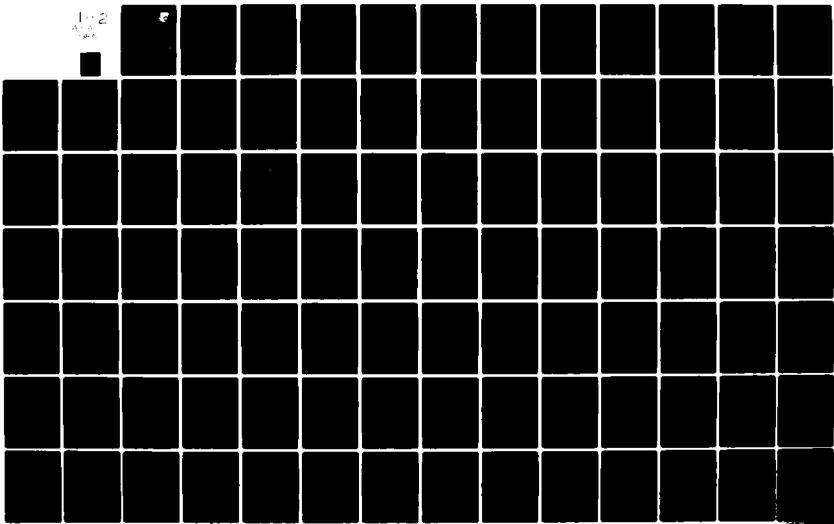
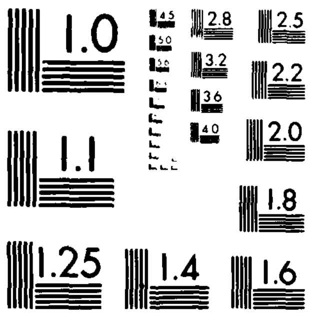
UNCLASSIFIED AFWAL-TR-80-4103 NL





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ENGINEERING DATA FOR NEW AEROSPACE MATERIALS

BATTELLE
COLUMBUS LABORATORIES
505 King Avenue
Columbus, Ohio 43201

July 1980

FINAL REPORT June 1978 to May 1980

Approved for public release; distribution unlimited.

MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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REPORT DOCUMENTATION PAGE

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19

1. REPORT NUMBER: AFWAL-TR-80-4103 (18)
2. GOVT ACCESSION NO.: AD-A098520
3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): ENGINEERING DATA FOR NEW AEROSPACE MATERIALS (6)
5. TYPE OF REPORT & PERIOD COVERED: Final Summary Report June 1978 – May 1980 (9)
6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): Omar Deel (10)
8. CONTRACT OR GRANT NUMBER(s): F33615-78-C-5040 (15)

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Battelle's Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
Program Element: 78011F
Project 130-1

11. CONTROLLING OFFICE NAME AND ADDRESS:
Materials Laboratory (AFWAL/MLS)
AF Wright Aeronautical Laboratories
Wright-Patterson Air Force Base, OH 45433

12. REPORT DATE: July 1980 (11)
13. NUMBER OF PAGES: 153

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (12) 154

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Mechanical Properties
Fatigue Properties
Fracture Toughness
Crack Propagation
Aluminum Alloys
Titanium Alloys
Heat Resistant Alloys

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The major objective of this program was to evaluate newly developed materials or materials produced by different processes of interest to the Air Force, and to provide "data sheet" type presentations of engineering data for these materials. This report presents the results of evaluations of five materials.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

407080

FOREWORD

This report was prepared by Battelle's Columbus Laboratories, Columbus, Ohio, under Contract F33615-78-C-5040. This contract was performed under Manufacturing Technologies Project No. 130-1, "Effect of Manufacturing Processes on Structural Allowables". The program was administered under the direction of the Materials Laboratory (AFWAL), Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Neal Ontko, Engineering and Design Data.

This final report covers work conducted from June 1978 to May 1980. This report was submitted by the authors on June 17, 1980.

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SECTION I

INTRODUCTION

Materials for United States Air Force advanced weapons systems must meet new combinations of design load and damage tolerance requirements as well as tightened economic and environmental constraints. New alloys and modifications in manufacturing processing or product forms of existing alloys are continually being developed to meet these increased demands. However, many potentially attractive materials or processes are either in the final development stage or have just become commercially available and, as such, engineering data adequate for comparison purposes are not available.

The Air Force, in recognition of this fact, has sponsored several programs at Battelle's Columbus Laboratories to provide comparative engineering data for these materials and processes. The results of these programs have been published in numerous technical reports, AFML-TR-67-418, AFML-TR-68-211, AFML-TR-70-252, AFML-TR-71-249, AFML-TR-72-196; Volumes I and II, AFML-TR-73-114, AFML-TR-75-97, AFML-TR-77-198, and AFML-TR-78-179. AFML-TR-78-179 is a compilation of all the "data sheets" previously published.

This report presents the results of evaluations of five materials. These are as follows:

(1) ALCAN 7010-T73651 aluminum alloy plate
(2) Corona 5 titanium alloy plate
(3) IN-792 forged disk
(4) CT-91-T7E70 aluminum alloy bar (PM)
(5) A357-T6 aluminum alloy casting.

Detailed information concerning the properties of interest, test techniques, and standard specimen drawings have been published in the reports listed above and are not discussed herein. The data sheets issued on this program are reproduced in the Appendix.

Alcan 7010-T73651 Aluminum Alloy

Material Description

Alloy 7010 has been developed over a number of years by Alcan Laboratories Banbury and Alcan Plate Limited. The development aim was for an alloy of different composition but with properties comparable to Alloy 7050 as an equivalent material for use in the Panavia Tornado program. The composition differences are:

(1) The use of high purity base aluminum to allow control of the iron and silicon impurities,
(2) The use of zirconium instead of chromium and/or manganese which makes it possible to achieve higher strength in thick section and improve exfoliation resistance, and
(3) The use of a higher copper content in order to achieve good stress-corrosion resistance in overaged tempers.

The material evaluated was 2-inch-thick plate with the following composition:

Chemical Composition	Percent
Zn	6.30
Mg	2.47
Cu	1.80
Zr	.13
Fe	.06
Si	.05
Ti	.01
Cr	<.01
Mn	<.01
Al	balance

Processing and Heat Treating

The material was evaluated in the as-received -T73651 condition. The specimen layout is shown in Figure 1.

Test Results

Tension. Tests were conducted at room temperature, 250 F (394 K), and 350 F (450 K) for both longitudinal and long transverse specimens. Test results are given in Table 1. Typical stress-strain curves at temperature are presented in Figures 2 and 3. Effect-of-temperature curves are shown in Figure 8.

Compression. Tests were conducted at room temperature, 250 F (394 K), and 350 F (450 K) for both longitudinal and long transverse specimens. Tests results are given in Table 2. Typical stress-strain and tangent-modulus curves at temperature are shown in Figures 4, 5, 6, and 7. Effect-of-temperature curves are presented in Figure 9.

Shear. Tests were conducted at room temperature, 250 F (394 K), and 350 F (450 K) for double-shear pin-type specimens in both the longitudinal and long transverse directions. Tabular data are shown in Table 3. Effect-of-temperature curves are shown in Figure 10.

Bearing. Tests were conducted at ratios of e/D = 1.5 and e/D = 2.0 at room temperature, 250 F (394 K), and 350 F (450 K) for both longitudinal and long transverse specimens. Test results are given in Table 4. Effect-of-temperature curves are shown in Figure 11.

Fracture Toughness. Compact-tension-type specimens in the longitudinal (L-T) and transverse (T-L) directions were tested at room temperature. Test results are given in Table 5.

Crack Propagation. Tests were conducted for longitudinal (L-T) specimens at room temperature. Test results are shown in Figure 12.

Fatigue. Axial load fatigue tests were conducted for both unnotched and notched transverse specimens at room temperature and 350 F (450 K). Tabular test results are given in Tables 6 and 7. S-N curves are presented in Figures 13 and 14.

Stress Corrosion. Tests were conducted using the Damage Tolerance Design Handbook bolt-loaded double cantilever beam specimen. Initial K_{ISCC} value obtained was 34.9 ksi$\sqrt{in.}$ (38.3 $MP_a \cdot m^{1/2}$) and 30.1 ksi$\sqrt{in.}$ (33.1 $MP_a \cdot m^{1/2}$) at 995 hours.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 12.7 in./in./F x 10^{-6} from 70 F to 212 F (22.9 m/(m · K)x 10^{-6} from 294 K to 373 K).

Density. The density of this alloy is 0.102 lb./in.^{3} (2.82 g/cm^3).

TABLE 1. RESULTS OF TENSILE TESTS FOR ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

Specimen Number	Ultimate Tensile Strength, ksi (MPa)	0.2 Percent Offset Yield Strength, ksi (MPa)	Elongation in 1 inch (25.4 mm), percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi (GPa)
Longitudinal at Room Temperature					
1L-1	72.0 (496.4)	63.0 (434.4)	16	49.5	10.3 (71.0)
1L-2	72.8 (502.0)	63.7 (439.2)	15	42.7	10.4 (71.7)
1L-3	72.1 (497.1)	62.9 (433.7)	14	41.8	10.4 (71.7)
Average	72.3 (498.5)	63.2 (435.8)	15	44.7	10.4 (71.5)
Transverse at Room Temperature					
1T-1	74.5 (513.7)	63.7 (439.2)	12	25.5	10.7 (73.8)
1T-2	74.1 (510.9)	63.6 (438.5)	11	29.0	10.7 (73.8)
1T-3	73.8 (508.9)	63.6 (438.5)	12	32.5	10.7 (73.8)
Average	74.1 (511.1)	63.6 (438.8)	12	29.0	10.7 (73.8)
Longitudinal at 250 F (394 K)					
1L-4	58.3 (402.0)	55.5 (382.7)	16	52.7	9.1 (62.7)
1L-5	59.9 (413.0)	56.7 (390.9)	12	34.4	9.9 (68.3)
1L-6	57.9 (399.2)	55.6 (383.4)	14	51.7	9.6 (66.2)
Average	58.7 (404.7)	55.9 (385.7)	14	46.3	9.5 (65.7)
Transverse at 250 F (394 K)					
1T-4	60.9 (419.9)	57.3 (395.1)	10	46.1	9.7 (66.9)
1T-5	60.4 (416.5)	57.4 (395.8)	11	36.7	9.8 (67.6)
1T-6	60.5 (417.1)	57.7 (397.8)	14	43.5	9.7 (66.9)
Average	60.6 (417.8)	57.5 (396.2)	12	42.1	9.7 (67.1)
Longitudinal at 350 F (450 K)					
1L-7	47.7 (328.9)	45.8 (315.8)	14	57.5	8.7 (60.0)
1L-8	47.7 (328.9)	46.0 (317.2)	14	53.0	8.8 (60.7)
1L-9	48.0 (331.0)	46.1 (317.9)	11	32.0	8.9 (61.4)
Average	47.8 (329.6)	46.0 (316.9)	13	47.5	8.8 (60.7)
Transverse at 350 F (450 K)					
1T-7	49.1 (338.5)	46.4 (319.9)	10	40.2	9.1 (62.7)
1T-8	50.5 (348.2)	48.2 (332.3)	20	42.5	9.2 (63.4)
1T-9	49.5 (341.3)	46.6 (321.3)	13	48.0	9.1 (62.7)
Average	49.7 (342.7)	47.1 (324.5)	14	43.6	9.1 (63.0)

TABLE 2. COMPRESSION TESTS RESULTS FOR ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

Specimen Number	0.2 Percent Offset Yield Strength, ksi (MPa)	Compressive Modulus, 10^3 ksi (GPa)
	Longitudinal at Room Temperature	
2L-1	63.9 (440.6)	10.1 (69.6)
2L-2	63.1 (435.1)	10.0 (69.0)
2L-3	63.2 (435.8)	9.9 (68.3)
Average	63.4 (437.2)	10.0 (69.0)
	Transverse at Room Temperature	
2T-1	68.5 (472.3)	10.3 (71.0)
2T-2	66.3 (457.1)	10.6 (73.1)
2T-3	68.4 (471.6)	10.7 (73.8)
Average	67.7 (467.0)	10.5 (72.6)
	Longitudinal at 250 F (394 K)	
2L-4	56.2 (387.5)	8.9 (61.4)
2L-5	57.1 (393.7)	8.9 (61.4)
2L-6	57.3 (395.1)	9.1 (62.7)
Average	56.0 (392.1)	9.0 (61.8)
	Transverse at 250 F (394 K)	
2T-4	59.4 (409.6)	9.0 (62.1)
2T-5	60.5 (417.1)	9.1 (62.7)
2T-6	60.2 (415.1)	9.1 (62.7)
Average	60.0 (413.9)	9.1 (62.5)
	Longitudinal at 350 F (450 K)	
2L-7	46.4 (319.9)	8.1 (55.8)
2L-8	47.2 (325.4)	8.5 (58.6)
2L-9	46.2 (318.5)	8.2 (56.5)
Average	46.6 (321.3)	8.3 (57.0)
	Transverse at 350 F (450 K)	
2T-7	49.0 (337.9)	8.4 (57.8)
2T-8	50.8 (350.3)	7.9 (54.5)
2T-9	51.1 (352.3)	8.4 (57.8)
Average	50.3 (346.8)	8.2 (56.7)

TABLE 3. RESULTS OF PIN SHEAR TESTS OF ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

Specimen Number	Ultimate Shear Strength, ksi (MPa)
Longitudinal at Room Temperature	
3L-1	43.9 (302.7)
3L-2	43.8 (302.0)
3L-3	43.1 (297.2)
Average	43.6 (300.6)
Transverse at Room Temperature	
3T-1	43.5 (299.9)
3T-2	42.7 (294.4)
3T-3	43.0 (296.5)
Average	43.1 (296.9)
Longitudinal at 250 F (394 K)	
3L-4	35.5 (244.8)
3L-5	34.7 (239.3)
3L-6	33.6 (231.7)
Average	34.6 (238.6)
Transverse at 250 F (394 K)	
3T-4	33.3 (229.6)
3T-5	34.3 (236.5)
3T-6	33.8 (233.1)
Average	33.8 (233.1)
Longitudinal at 350 F (450 K)	
3L-7	27.9 (192.4)
3L-8	29.3 (202.0)
3L-9	28.5 (196.5)
Average	28.6 (197.0)
Transverse at 350 F (450 K)	
3T-7	27.8 (191.7)
3T-8	26.1 (180.0)
3T-9	28.6 (197.2)
Average	27.5 (189.6)

TABLE 4. BEARING RESULTS OF e/D = 1.5 AND e/D = 2.0 FOR ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

Specimen Number	Bearing Ultimate Strength, ksi (MPa)		Bearing Yield Strength, ksi (MPa)	
	e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
	Longitudinal at Room Temperature			
4L-1	116.7 (804.6)	150.0 (1034.3)	93.0 (641.2)	109.2 (752.9)
4L-2	117.2 (808.1)	152.2 (1049.4)	93.0 (641.2)	109.0 (751.6)
Average	117.0 (806.4)	151.1 (1041.8)	93.0 (641.2)	109.1 (752.2)
	Transverse at Room Temperature			
4T-1	116.7 (804.6)	150.3 (1036.3)	92.5 (637.8)	115.3 (795.0)
4T-2	118.0 (813.6)	149.3 (1029.4)	92.6 (638.5)	113.0 (779.1)
Average	117.4 (809.1)	149.8 (1032.9)	92.6 (638.1)	114.2 (787.1)
	Longitudinal at 250 F (394 K)			
4L-3	91.8 (633.0)	116.6 (804.0)	77.6 (535.1)	94.9 (654.3)
4L-4	95.7 (659.9)	115.4 (795.7)	80.8 (557.1)	89.4 (616.4)
Average	93.8 (646.4)	116.0 (799.8)	79.2 (546.1)	92.2 (635.4)
	Transverse at 250 F (394 K)			
4T-3	94.7 (653.0)	118.5 (817.1)	81.5 (561.9)	94.0 (648.1)
4T-4	94.6 (652.3)	121.0 (834.3)	80.6 (555.7)	96.8 (667.5)
Average	94.7 (652.6)	119.8 (825.7)	81.1 (558.8)	95.4 (657.8)
	Longitudinal at 350 F (450 K)			
4L-5	79.3 (546.8)	95.9 (661.2)	67.2 (463.3)	79.9 (550.9)
4L-6	78.6 (541.9)	90.8 (626.1)	67.4 (464.7)	77.0 (530.9)
Average	79.0 (544.4)	93.4 (643.6)	67.3 (464.0)	78.5 (540.9)
	Transverse at 350 F (450 K)			
4T-5	74.1 (510.9)	93.2 (642.6)	65.7 (453.0)	81.2 (559.9)
4T-6	78.0 (537.8)	93.0 (641.2)	68.5 (472.3)	79.1 (545.4)
Average	76.1 (524.4)	93.1 (641.9)	67.1 (462.7)	80.2 (552.6)

TABLE 5. RESULTS OF COMPACT TENSION FRACTURE TOUGHNESS TESTS FOR ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

Specimen Number	Width, W, inches (mm)	Thickness, B, inch (mm)	Initial Crack, a, inch (mm)	P_Q, lbs (kg)	P_{max}, lbs (kg)	$f(\frac{a}{W})$	K_Q(a), ksi·in$^{1/2}$ (MPa·m$^{1/2}$)
			Longitudinal (T-L)				
6T-1	1.5 (38.1)	0.75 (19.1)	0.766 (19.5)	2,340 (1,061)	2,340 (1,061)	0.51	24.8 (27.3)
6T-2	1.5 (38.1)	0.75 (19.1)	0.786 (20.0)	2,215 (1,005)	2,335 (1,059)	0.52	24.9 (27.4)
				Average	2,338 (1,060)		24.9 (27.4)
			Transverse (L-T)				
6L-1	1.5 (38.1)	0.75 (19.1)	0.782 (19.9)	2,710 (1,229)	2,825 (1,281)	0.52	30.2 (33.2)
6L-2	1.5 (38.1)	0.75 (19.1)	0.777 (19.7)	2,620 (1,188)	2,880 (1,306)	0.52	28.9 (31.8)
				Average	2,853 (1,294)		29.6 (32.5)

(a) K_Q values are valid K_{Ic} values per ASTM E-399.

TABLE 6. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED ALCAN 7010-T73651 ALUMINUM ALLOY PLATE AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi (MPa)	Lifetime, cycles
	Room Temperature	
8-6	85 (586)	100
8-1	75 (517)	6,400
8-7	70 (483)	12,300
8-8	60 (414)	51,800
8-2	50 (345)	(a)
8-3	50 (345)	33,600
8-40	50 (345)	3,540,000(b)
8-5	45 (310)	10,000,000(b)
8-4	40 (276)	10,000,000(b)
	350 F (450 K)	
8-9	70 (483)	1
8-10	60 (414)	1
8-12	55 (379)	100
8-37	52.5 (762)	300
8-11	50 (345)	49,100
8-13	45 (310)	(c)
8-14	45 (310)	(c)
8-16	45 (310)	62,100
8-15	40 (276)	38,120(c)
8-18	40 (276)	269,700
8-38	37.5 (259)	240,500
8-17	35 (241)	76,400(c)
8-20	35 (241)	757,200(c)
8-19	35 (241)	1,124,700
8-36	30 (207)	4,084,400
8-39	25 (172)	10,000,000(b)

(a) Failed in loading.
(b) Did not fail.
(c) Failed in threads.

TABLE 7. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K_t = 3.0) ALCAN 7010-T73651 ALUMINUM ALLOY PLATE AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi (MPa)	Lifetime, cycles
	Room Temperature	
8-25	45 (310)	3,600
8-24	40 (276)	5,300
8-26	35 (241)	8,200
8-22	30 (207)	21,800
8-27	25 (172)	24,900
8-21	20 (138)	37,500
8-23	15 (103)	358,900
	350 F (450 K)	
8-32	40 (276)	3,000
8-30	30 (207)	22,100
8-28	20 (138)	41,700
8-29	15 (103)	270,400
8-33	12.5 (86)	851,400
8-34	10 (69)	1,554,200
8-34	7.5 (52)	6,772,000[a]

(a) Did not fail.

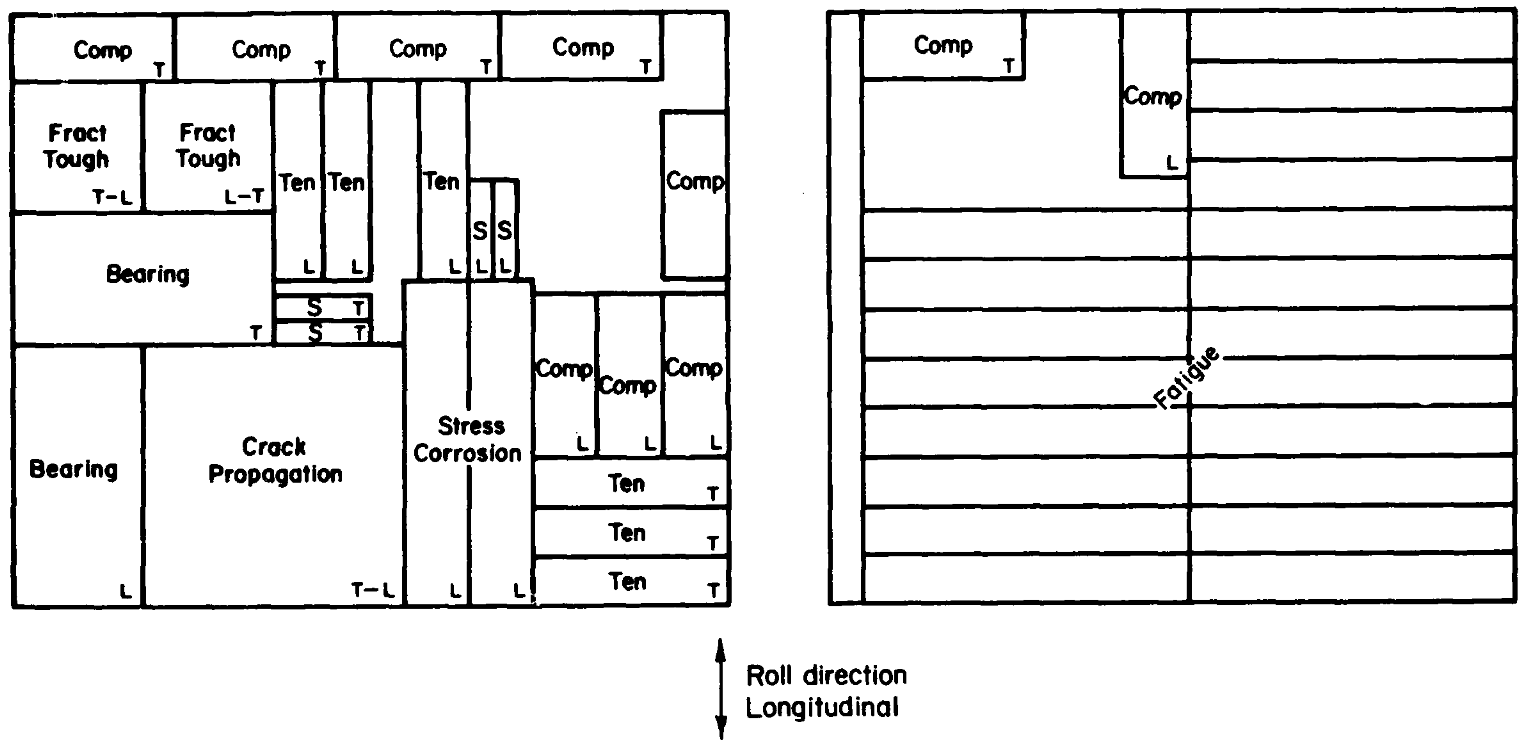

FIGURE 1. SPECIMEN LAYOUT FOR ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

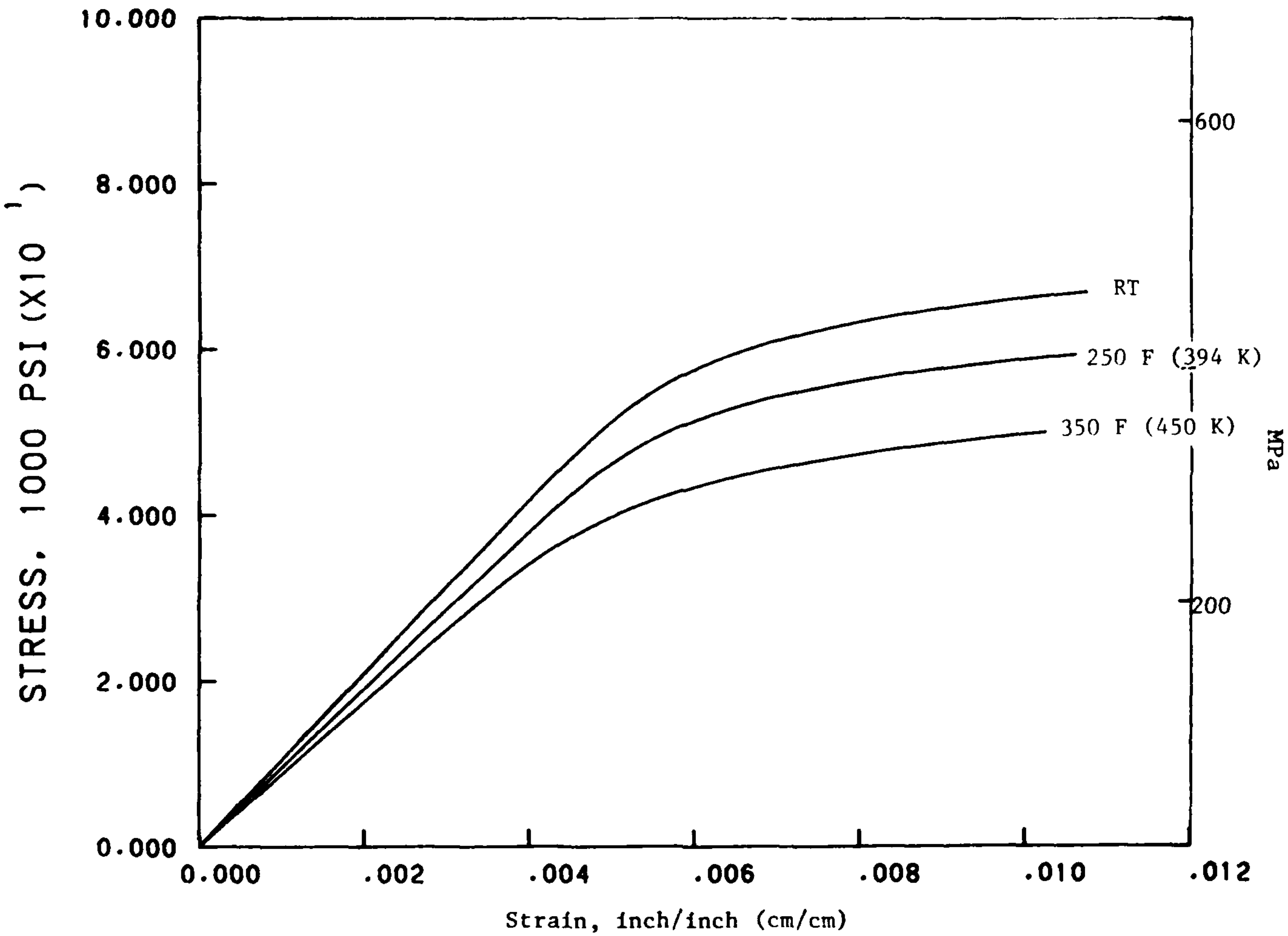

FIGURE 2. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR ALCAN 7010-T73651 ALUMINUM ALLOY PLATE (LONGITUDINAL)

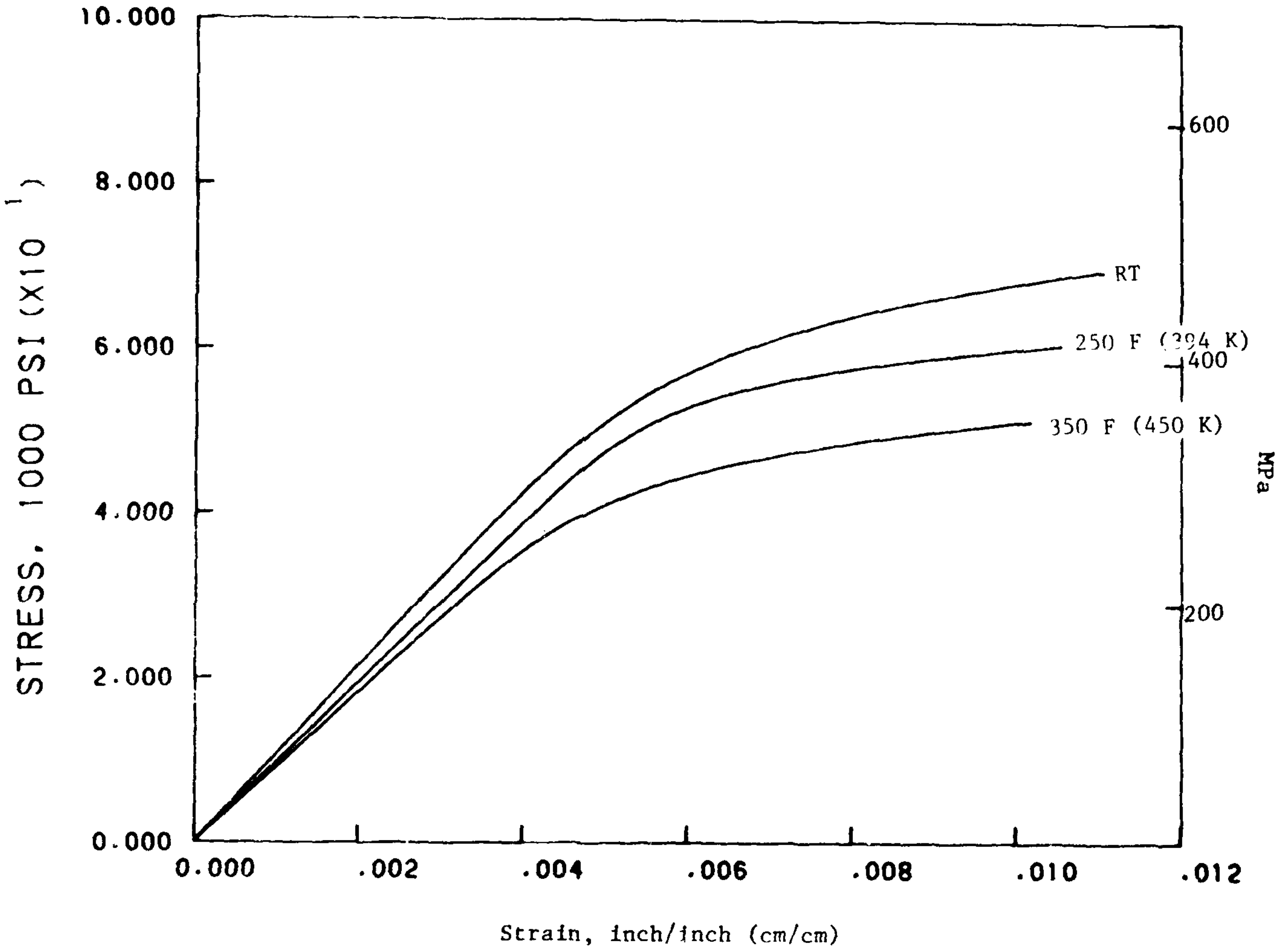

FIGURE 3. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR ALCAN 7010-T73651 ALUMINUM ALLOY PLATE (LONG-TRANSVERSE)

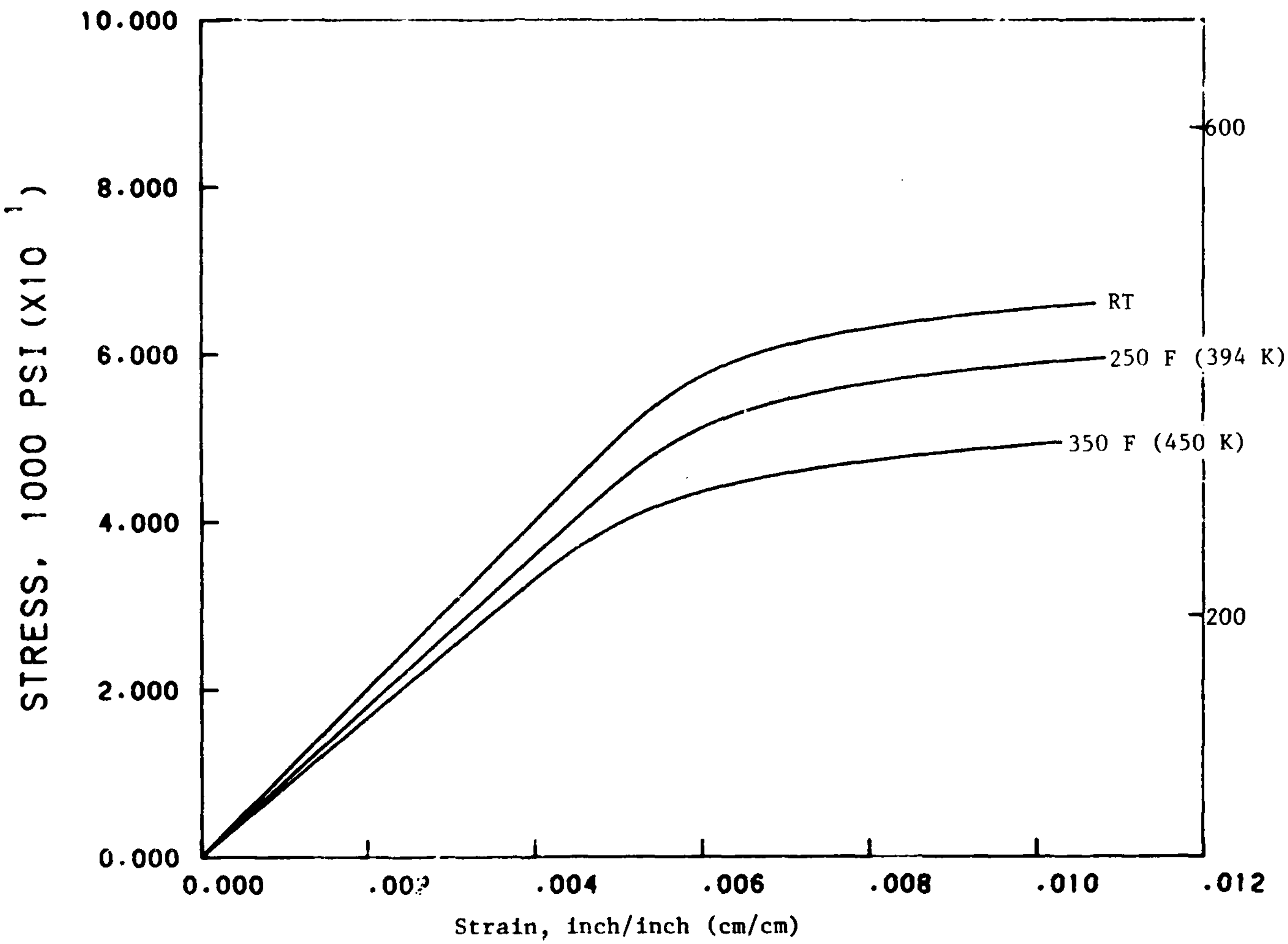

FIGURE 4. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR ALCAN 7010-T73651 ALUMINUM ALLOY PLATE (LONGITUDINAL)

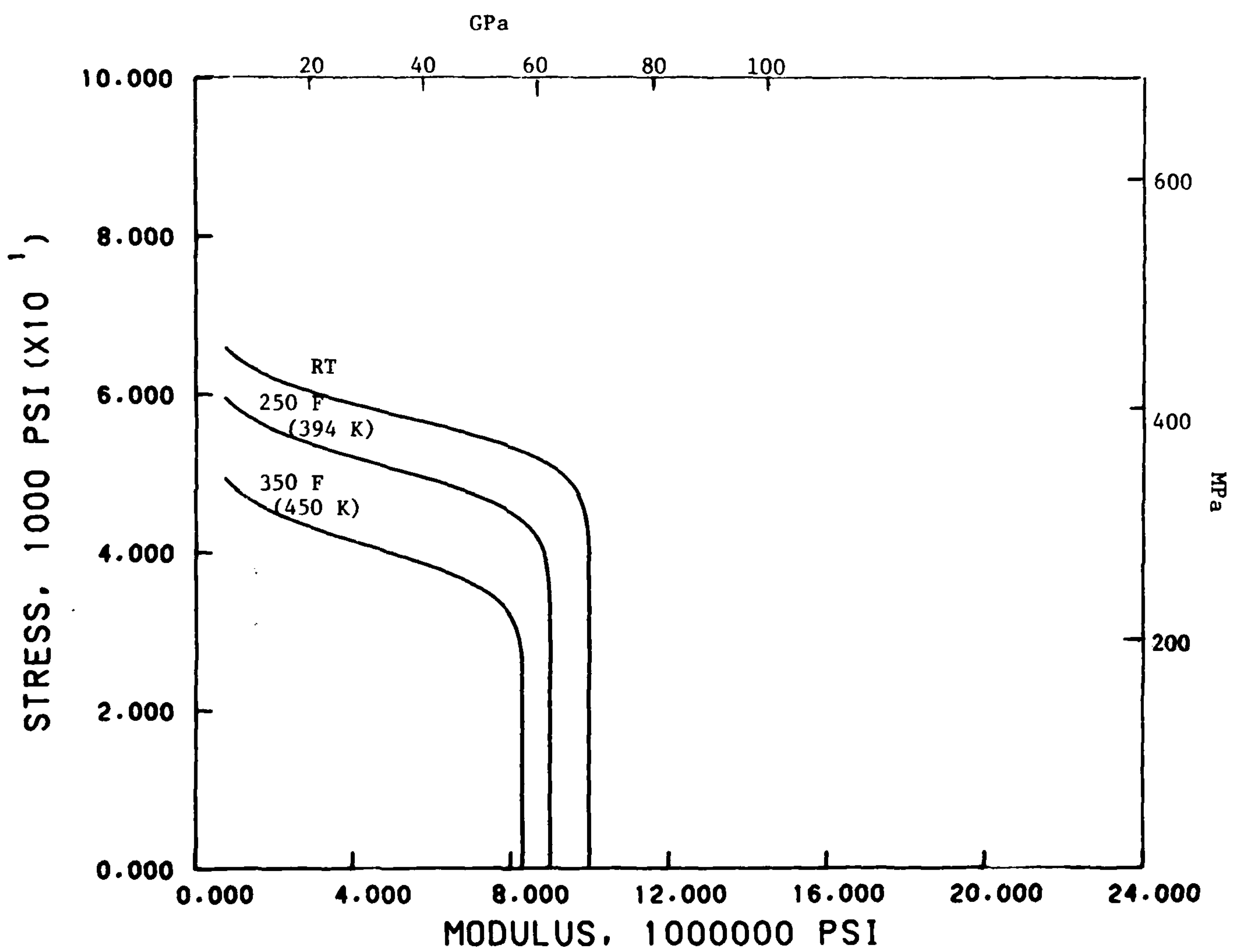

FIGURE 5. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES AT TEMPERATURE FOR ALCAN 7010-T73651 ALUMINUM ALLOY PLATE (LONGITUDINAL)

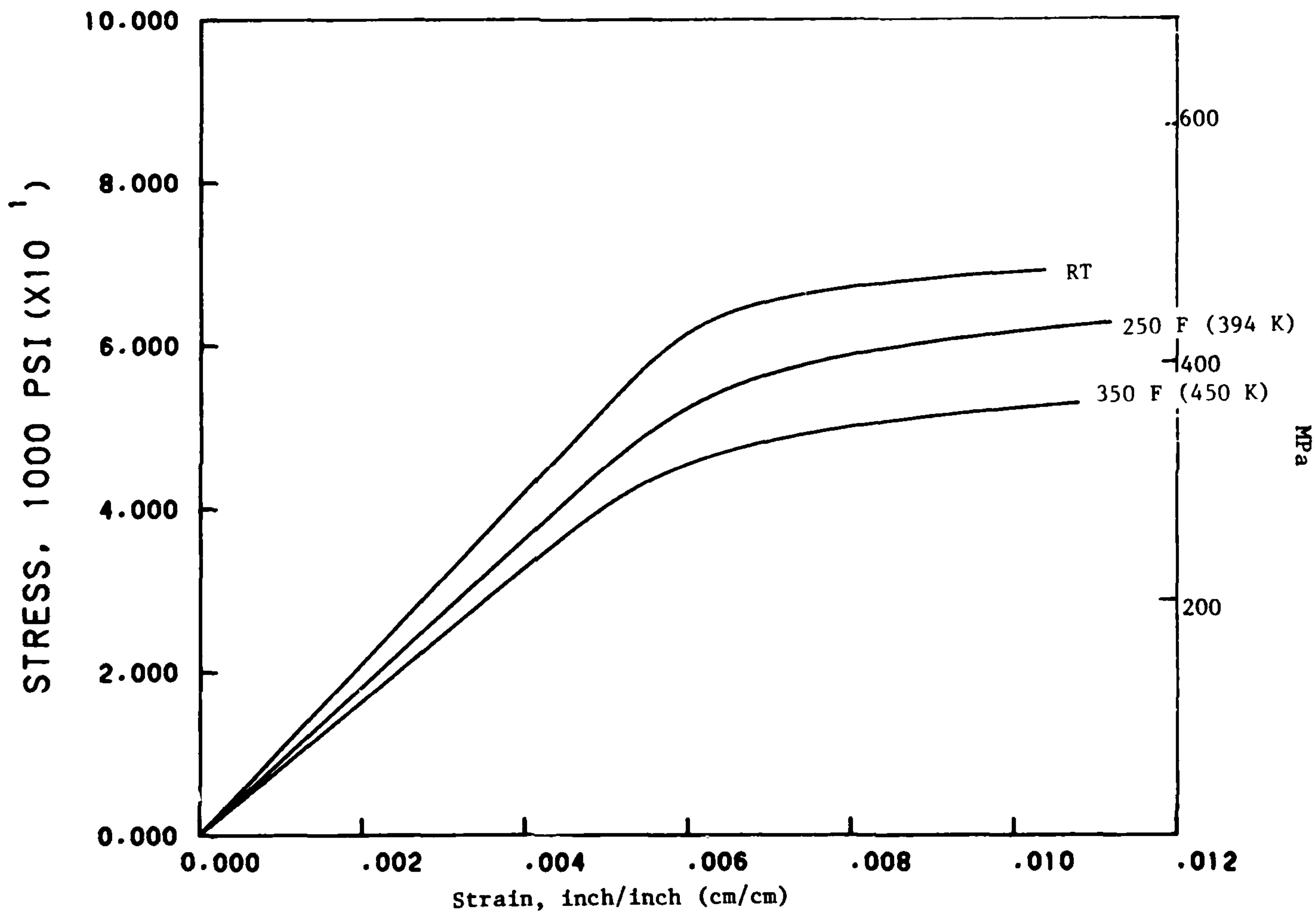

FIGURE 6. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR ALCAN 7010-T73651 ALUMINUM ALLOY PLATE (LONG-TRANSVERSE)

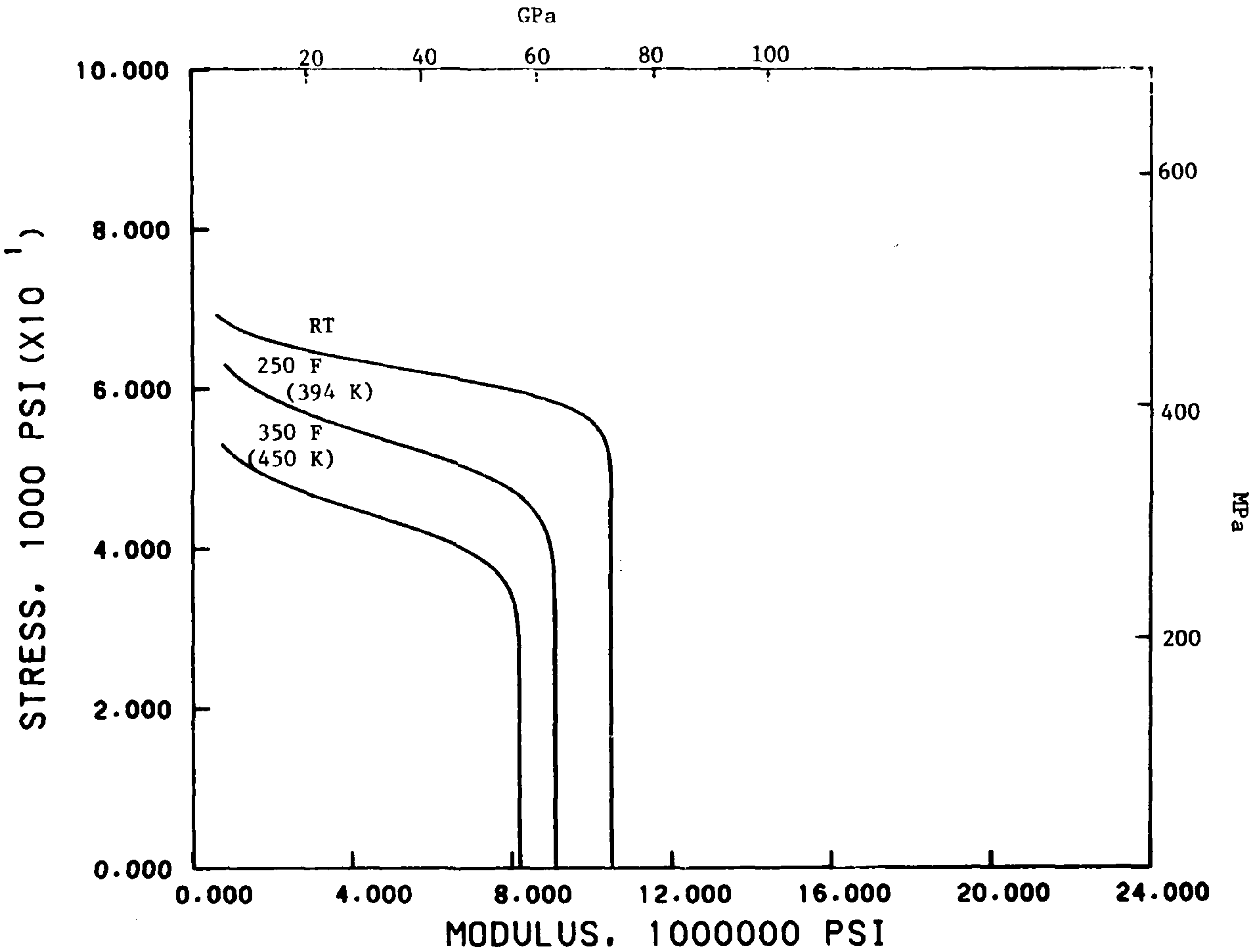

FIGURE 7. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES AT TEMPERATURE FOR ALCAN 7010-T73651 ALUMINUM ALLOY PLATE (LONG-TRANSVERSE)

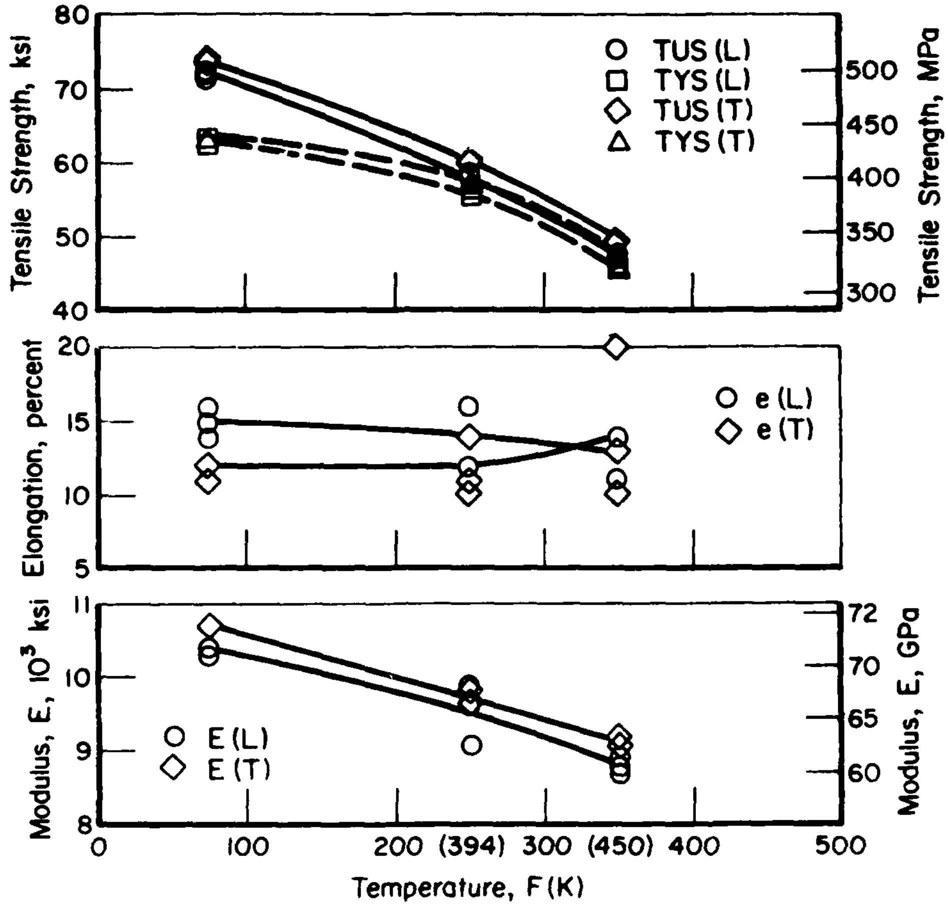

FIGURE 8. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

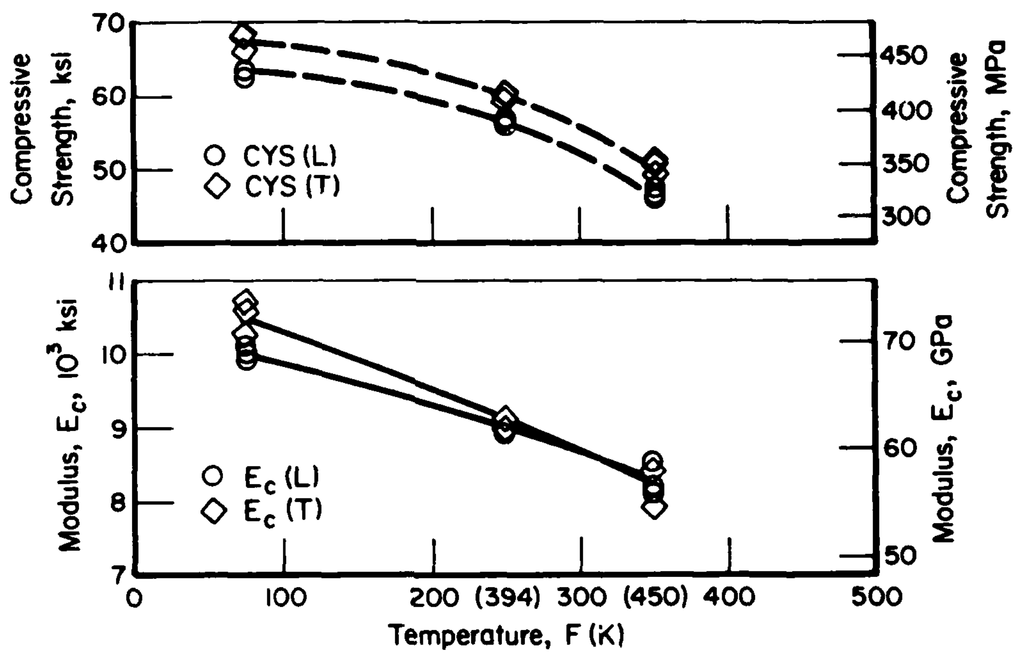

FIGURE 9. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

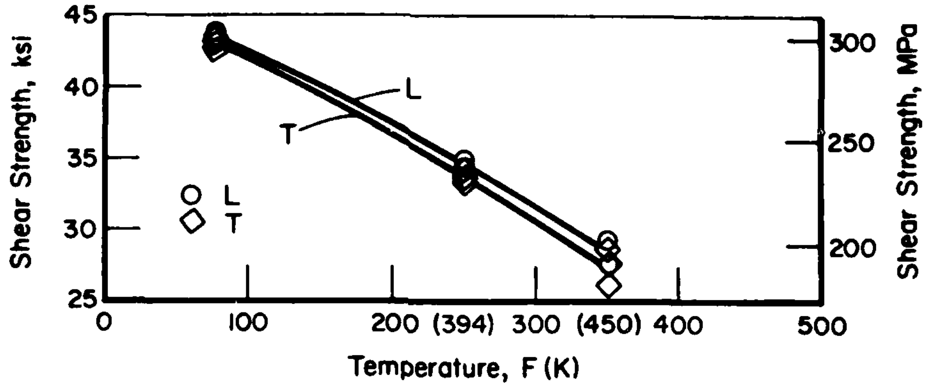

FIGURE 10. EFFECT OF TEMPERATURE ON THE SHEAR STRENGTH OF ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

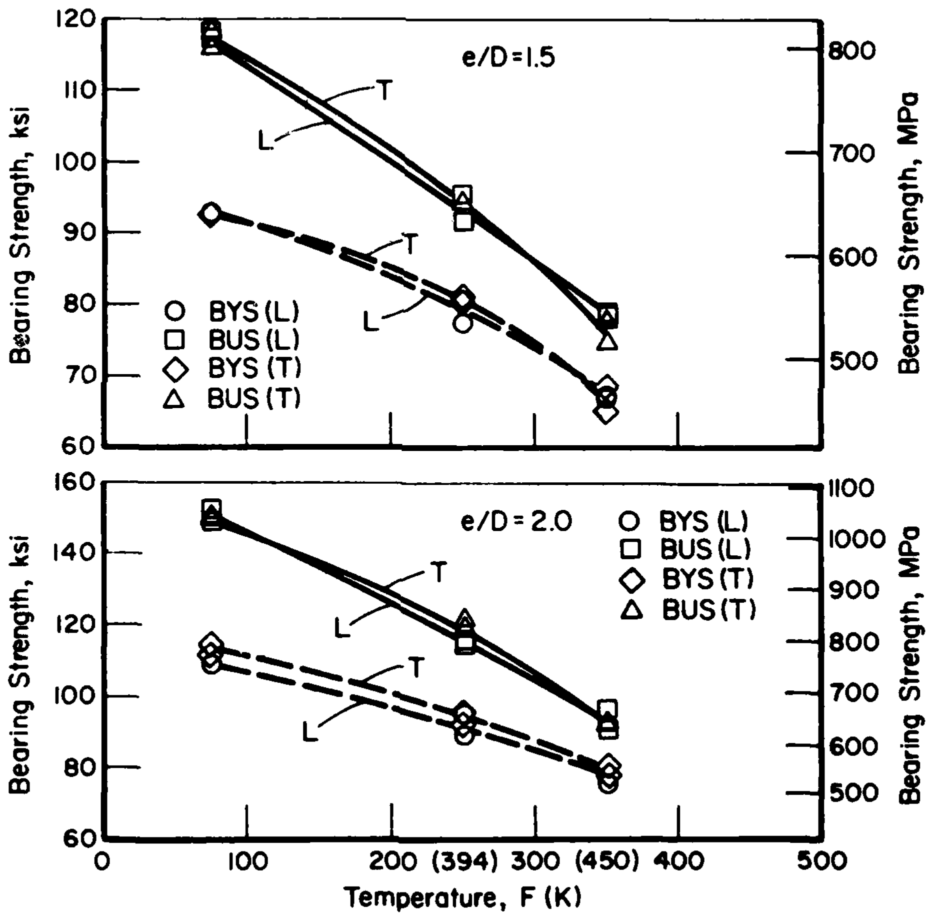

FIGURE 11. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

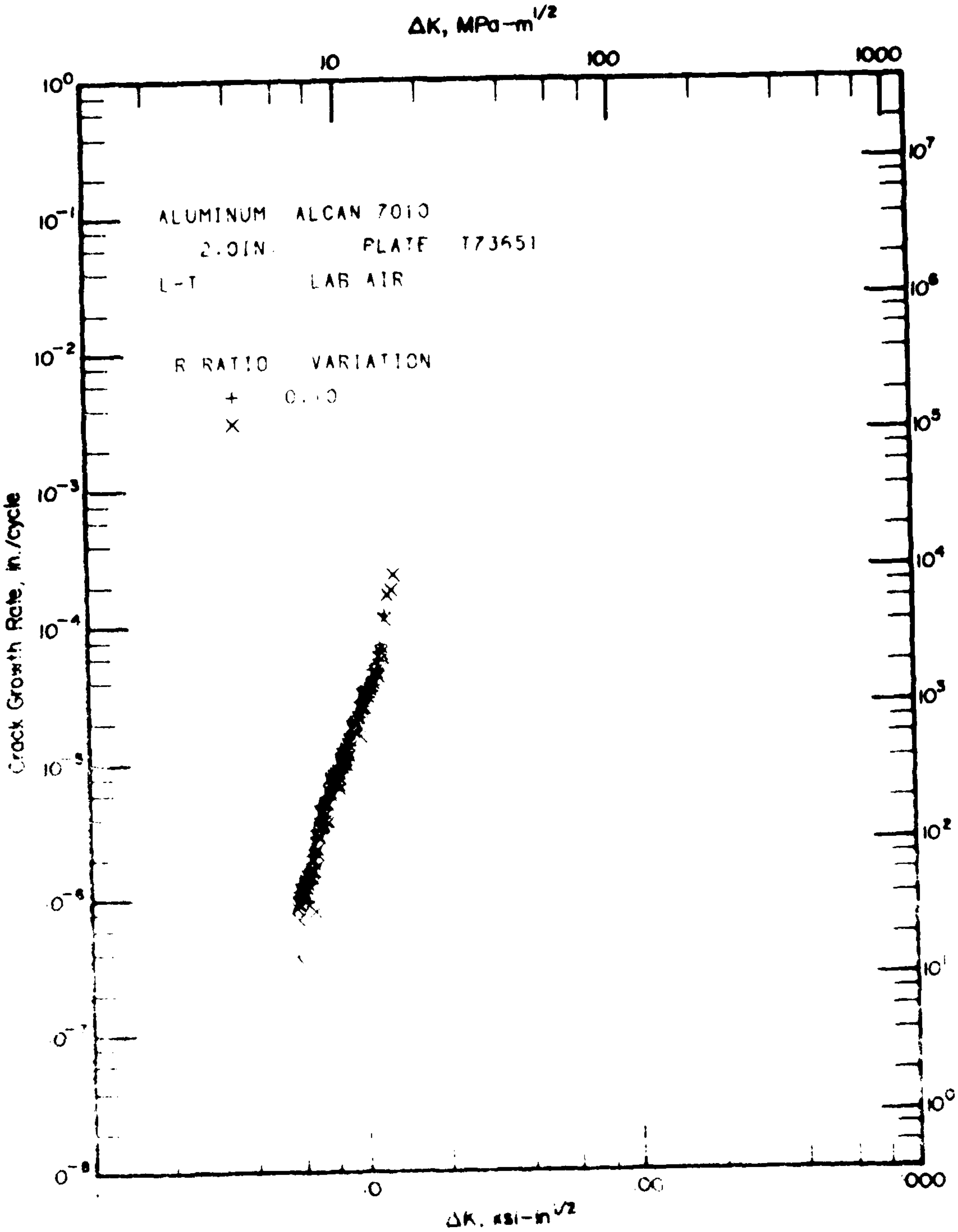

FIGURE 12 da/dN VERSUS DELTA K FOR ALCAN 7010-T73651
ALUMINUM ALLOY PLATE

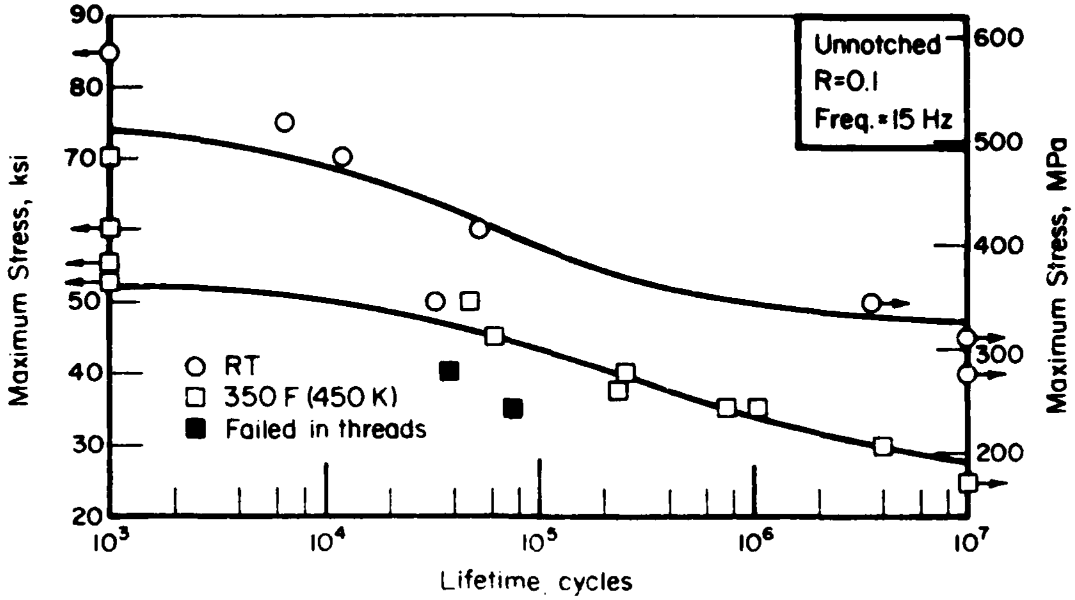

FIGURE 13. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

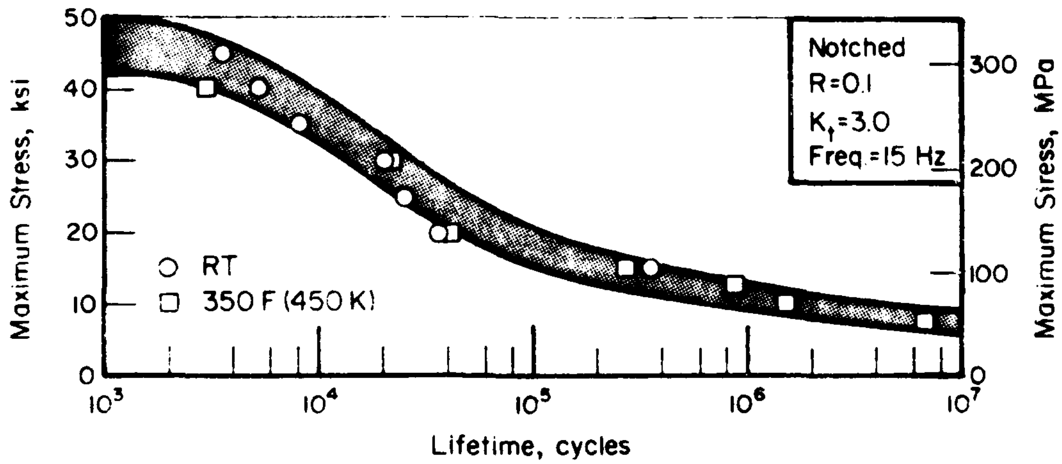

FIGURE 14. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

Corona 5 Titanium Alloy, Alpha-Beta Processed

Material Description

Corona 5 is an alpha-beta titanium alloy recently developed jointly by Rockwell International and Colt Industries under NAVAIR sponsorship. The basic alloy was developed for fracture critical applications in the aerospace industry. The alpha-beta processing was chosen to allow optimization of both fracture toughness and fatigue properties. Maximum fracture toughness alone would require beta processing, but would also result in somewhat lower tensile and fatigue values.

The material evaluated was supplied GFM as 2-inch-thick plate with the following composition:

Chemical Composition	Percent
Al	4.4
Mo	5.1
Cr	1.46
Fe	0.20
C	0.065
O_2	0.183
N_2	0.011
H_2	0.0018
Ti	Remainder

Processing and Heat Treating

The plate was alpha-beta rolled from 1650 F (1172 K). The material was then heat treated as follows: duplex alpha-beta annealed at 1685 F (1192 K) for one-half hour plus 1525 F (1103 K) for 4 hours, air cool, plus age at 1300 F (978 K) for 6 hours, air cool.

The specimen layout is shown in Figure 15.

Test Results

Tension. Results of tensile tests at room temperature, 400 F (478 K), and 800 F (700 K) are shown in Table 8 for both longitudinal and long transverse specimens. Typical stress-strain curves at temperature are presented in Figures 16 and 17. Effect-of-temperature curves are shown in Figure 22.

Compression. Compression tests were conducted for specimens in both the longitudinal and long tranverse directions at room temperature, 400 F (478 K), and 800 F (700 K). Results are presented in Table 9. Typical stress-strain and tangent-modulus curves at temperature are shown in Figures 18 through 21. Effect-of-temperature curves are shown in Figure 23.

Shear. Results of pin-shear type tests are given in Table 10 for longitudinal and long transverse specimens at room temperature, 400 F (478 K), and 800 F (700 K). Effect-of-temperature curves are presented in Figure 24.

Bearing. Tests were conducted at room temperature, 400 F (478 K), and 800 F (700 K). These tests were performed for both longitudinal and long transverse specimens at e/D = 1.5 and e/D = 2.0. Results are given in Table 11. Effect-of-temperature curves are presented in Figure 25.

Fracture Toughness. Compact-tension type specimens were tested at room temperature for longitudinal (L-T) and transverse (T-L) directions. These tests proved invalid because of "bellied" crack front. However, additional tests were performed and the valid results for L-T specimens are 60.5 ksi$\sqrt{in.}$ (66.5 $MP_a \cdot m^{1/2}$) and 59.9 ksi$\sqrt{in.}$ (65.8 $MP_a \cdot m^{1/2}$) for T-L specimens. Results are given in Table 12.

Fatigue. Results of axial-load fatigue tests on unnotched and notched transverse specimens at room temperature and 800 F (700 K) are given in Tables 13 and 14. S-N curves are shown in Figures 26 and 27.

Creep and Stress Rupture. Tests were conducted at 800 F (700 K) on transverse specimens. Results are given in Table 15. Log-stress versus log-time curves are presented in Figure 28.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 6.1 in./in./F x 10^{-6} for room temperature to 800 F (11.0 m/m · K)x 10^{-6} for room temperature to 700 K).

Density. The density for this material is 0.164 lb./in^3 (4.539 g/cm^3).

TABLE 8. TENSILE TEST RESULTS FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

Specimen Number	Ultimate Tensile Strength, ksi	(MPa)	0.2 Percent Offset Yield Strength, ksi	(MPa)	Elongation in 2 Inches (50.2 mm), percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi	(GPa)
Longitudinal at Room Temperature								
1L-1	136.7	(942.3)	135.4	(933.6)	10	7	16.5	(113.8)
1L-2	138.3	(953.6)	135.6	(935.0)	8	20	16.5	(113.8)
1L-3	141.2	(973.6)	138.4	(954.3)	4	13	16.5	(113.8)
Average	138.7	(956.6)	136.5	(940.9)	7	13	16.5	(113.8)
Transverse at Room Temperature								
1T-1	131.6	(907.4)	129.4	(892.2)	14	26	15.5	(106.9)
1T-2	130.7	(901.2)	127.1	(876.4)	14	26	15.2	(104.8)
1T-3	132.2	(911.5)	127.9	(881.9)	12	20	15.8	(108.9)
Average	131.5	(906.7)	128.1	(883.5)	13	24	15.5	(106.9)
Longitudinal at 400 F (478 K)								
1L-4	113.8	(784.7)	101.5	(699.8)	20	60.2	15.8	(108.9)
1L-5	111.1	(766.0)	98.0	(675.7)	19	55.5	14.8	(102.0)
1L-6	111.9	(771.6)	100.0	(689.5)	19	58.1	14.7	(101.4)
Average	112.3	(774.1)	99.8	(688.4)	19	57.8	15.1	(104.1)
Transverse at 400 F (478 K)								
1T-4	110.2	(759.8)	95.8	(660.5)	17	42.2	15.6	(107.6)
1T-5	107.4	(740.5)	95.4	(657.8)	20	55.6	14.4	(99.3)
1T-6	108.8	(750.2)	96.5	(665.4)	18	51.7	14.4	(99.3)
Average	108.8	(750.2)	95.9	(661.2)	18	49.8	14.8	(102.0)
Longitudinal at 800 F (700 K)								
1L-7	96.8	(667.2)	81.8	(563.8)	17	67.5	12.7	(87.6)
1L-8	98.3	(677.6)	85.4	(589.0)	17	71.9	13.0	(89.6)
1L-9	97.8	(674.4)	85.6	(590.5)	17	69.7	13.8	(95.2)
Average	97.6	(673.1)	84.3	(581.1)	17	69.7	13.2	(90.8)
Transverse at 800 F (700 K)								
1T-7	93.7	(646.1)	76.9	(530.1)	19	56.5	13.1	(90.3)
1T-8	88.5	(610.0)	73.2	(504.5)	20	66.5	13.1	(90.3)
1T-9	90.6	(624.7)	75.5	(520.4)	21	58.9	14.4	(99.3)
Average	90.9	(627.0)	75.2	(518.3)	20	60.6	13.5	(93.3)

TABLE 9. COMPRESSIVE TEST RESULTS FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

Specimen Number	0.2 Percent Offset Yield Strength, ksi	(MPa)	Compressive Modulus, 10^3 ksi	(GPa)
Longitudinal at Room Temperature				
2L-1	142.0	(979.1)	15.7	(108.3)
2L-2	142.3	(981.2)	16.7	(115.1)
2L-3	143.6	(990.1)	17.2	(118.6)
Average	142.6	(983.5)	16.5	(114.0)
Transverse at Room Temperature				
2T-1	153.8	(1060.5)	[illegible]	(120.0)
2T-2	156.1	(1076.3)	18.1	(124.8)
2T-3	154.8	(1067.3)	17.8	(122.7)
Average	154.9	(1068.0)	17.8	(122.5)
Longitudinal at 400 F (478 K)				
2L-4	102.6	(707.4)	13.9	(95.8)
2L-5	102.3	(705.4)	14.6	(100.7)
2L-6	104.1	(717.8)	15.0	(103.4)
Average	103.0	(710.2)	14.5	(100.0)
Transverse at 400 F (478 K)				
2T-4	111.7	(770.2)	15.4	(106.2)
2T-5	110.1	(759.1)	15.8	(108.9)
2T-6	108.4	(747.4)	15.2	(104.8)
Average	110.1	(758.9)	15.5	(106.6)
Longitudinal at 800 F (700 K)				
2L-7	[illegible]	(546.[illegible])	12.4	(85.5)
2L-8	[illegible]	(547.5)	12.2	(84.1)
2L-9	80.1	(552.[illegible])	13.4	(92.4)
Average	79.5	(548.5)	12.7	(87.3)
Transverse at 800 F (700 K)				
[illegible]	[illegible]	(590.[illegible])	13.4	(92.4)
[illegible]	[illegible]	(5[illegible])	12.[illegible]	(86.9)
[illegible]	[illegible]	(59[illegible])	[illegible]	(91.0)
Average	[illegible]	(59[illegible])	[illegible]	(90.[illegible])

TABLE 10. SHEAR PIN TEST RESULTS FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

Specimen Number		Ultimate Shear Strength, ksi	(MPa)
		Longitudinal at Room Temperature	
3L-1		78.2	(539.2)
3L-2		86.2	(594.3)
3L-3		84.9	(585.4)
	Average	83.1	(573.0)
		Transverse at Room Temperature	
3T-1		89.3	(615.7)
3T-2		90.1	(621.2)
3T-3		87.0	(599.9)
	Average	88.8	(612.3)
		Longitudinal at 400 F (477 K)	
3L-4		73.5	(506.8)
3L-5		72.9	(502.6)
3L-6		71.3	(491.6)
	Average	72.6	(500.3)
		Transverse at 400 F (477 K)	
3T-4		73.9	(509.5)
3T-5		74.4	(513.0)
3T-6		72.3	(498.5)
	Average	73.5	(507.0)
		Longitudinal at 800 F (700 K)	
3L-7		60.5	(417.1)
3L-8		60.3	(415.8)
3L-9		60.6	(417.8)
	Average	60.5	(417.1)
		Transverse at 800 F (700 K)	
3T-7		60.5	(417.1)
3T-8		59.6	(410.9)
3T-9		62.9	(433.7)
	Average	61.0	(420.6)

TABLE 11. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

Specimen Number	Bearing Ultimate Strength, ksi (MPa)				Bearing Yield Strength, ksi (MPa)			
	e/D = 1.5		e/D = 2.0		e/D = 1.5		e/D = 2.0	
Longitudinal at Room Temperature								
4L-1	201.6	(1390.0)	267.0	(1841.0)	195.7	(1349.4)	228.7	(1576.9)
4L-2	211.9	(1461.1)	272.6	(1879.6)	198.4	(1368.0)	243.3	(1677.6)
4L-3	212.8	(1467.3)	268.5	(1851.3)	195.1	(1345.2)	241.9	(1667.9)
Average	208.8	(1439.4)	269.4	(1857.3)	196.4	(1354.2)	238.0	(1640.8)
Transverse at Room Temperature								
4T-1	234.9	(1619.6)	302.1	(2083.0)	203.8	(1405.2)	255.7	(1763.1)
4T-2	233.9	(1612.7)	298.8	(2060.2)	211.0	(1454.8)	252.6	(1741.7)
4T-3	227.8	(1570.7)	297.1	(2048.5)	198.8	(1370.7)	246.2	(1697.5)
Average	232.2	(1601.0)	299.3	(2063.9)	204.5	(1410.3)	251.5	(1734.1)
Longitudinal at 400 F (478 K)								
4L-4	183.5	(1265.2)	221.6	(1527.9)	156.5	(1079.1)	181.2	(1249.4)
4L-5	182.2	(1256.3)	232.4	(1602.4)	154.7	(1066.7)	183.9	(1268.0)
Average	182.9	(1261.1)	227.0	(1565.2)	155.6	(1072.9)	182.5	(1258.7)
Transverse at 400 F (477 K)								
4T-4	194.1	(1338.3)	246.0	(1696.2)	161.2	(1111.5)	190.1	(1310.7)
4T-5	197.7	(1363.1)	237.7	(1638.9)	167.0	(1151.5)	188.3	(1298.3)
4T-6	U[a]	U	236.4	(1630.0)	U	U	185.3	(1277.6)
Average	195.9	(1350.7)	240.0	(1655.0)	164.1	(1131.5)	187.9	(1295.6)
Longitudinal at 800 F (700 K)								
4L-6	181.5	(1251.4)	194.9	(1343.8)	128.9	(888.8)	146.0	(1006.7)
4L-7	200.0	(1379.0)	198.6	(1369.3)	128.8	(888.1)	149.2	(1028.7)
Average	190.8	(1315.2)	196.8	(1356.6)	128.9	(888.8)	147.6	(1017.7)
Transverse at 800 F (700 K)								
4T-7	U	U	202.8	(1398.3)	133.8	(922.6)	158.7	(1094.2)
4T-8	219.8	(1515.9)	208.9	(1440.4)	132.1	(910.8)	160.8	(1108.7)
4T-9	204.5	(1410.0)	210.0	(1448.0)	133.1	(917.7)	160.0	(1103.2)
Average	212.2	(1462.9)	207.2	(1428.9)	133.0	(917.0)	159.8	(1102.1)

(a) U, unavailable.

TABLE 12. RESULTS OF COMPACT TENSION FRACTURE TOUGHNESS TESTS FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

Specimen Number	Width, W, inches	(mm)	Thickness, B, inch	(mm)	Initial Crack, a, inch	(mm)	P_Q lbs.	(kg)	P_{max}, lbs.	(kg)	$f(\frac{a}{W})$	K_Q[a], $ksi \cdot in^{\frac{1}{2}}$	$(MPa \cdot m^{\frac{1}{2}})$	R_{sc}
					Longitudinal (L-T)									
6L-1	1.5	(38.1)	0.75	(19.1)	0.619	(15.7)	10,250	(4649)	11,000	(4990)	0.41	84.0	(92.4)	0.99
6L-2	1.5	(38.1)	0.75	(19.1)	0.573	(14.6)	11,250	(5103)	12,875	(5840)	0.38	85.0	(93.5)	1.03
6L-3	1.5	(38.1)	0.75	(19.1)	0.60	(15.2)	9,700	(4400)	9,800	(4445)	0.40	76.9	(84.5)	0.84
								Average	11,225	(5092)		82.0	(90.2)	0.95
					Transverse (T-L)									
6T-1	1.5	(38.1)	0.75	(19.1)	0.573	(14.6)	10,750	(4876)	11,950	(5420)	0.38	81.3	(89.4)	1.01
6T-2	1.5	(38.1)	0.75	(19.1)	0.6046	(15.4)	10,325	(4683)	11,900	(5398)	0.40	82.5	(90.7)	1.09
6T-3	1.5	(38.1)	0.75	(19.1)	0.561	(14.2)	10,900	(4944)	13,000	(5897)	0.37	80.7	(88.8)	0.98
								Average	12,283	(5572)		81.5	(89.7)	1.05

(a) K_Q values listed are invalid per ASTM E-399. (See data sheet, page 109, for valid values)

TABLE 13. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi (MPa)	Lifetime, cycles
	Room Temperature	
8-12	110 (758)	1,000
8-1	100 (690)	7,400
8-4	95 (655)	976,840
8-3	90 (621)	1,420,400
8-2	80 (552)	4,362,220
8-5	75 (517)	2,565,500
8-6	65 (448)	2,750,450
8-7	55 (379)	10,017,650[a]
	800 F (700 K)	
8-13	90 (621)	1
8-14	85 (586)	11,600
8-8	80 (552)	9,740
8-15	75 (517)	4,581,360
8-9	70 (483)	13,690
8-11	65 (448)	3,076,730
8-10	55 (379)	10,000,000[a]

(a) Did not fail.

TABLE 14. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K_t = 3.0) ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

Specimen Number	Maximum Stress, ksi (MPa)	Lifetime, cycles
	Room Temperature	
8-4	80 (552)	4,040
8-5	60 (414)	10,250
8-1	50 (345)	20,780
8-6	40 (276)	36,880
8-2	30 (207)	104,450
8-3	20 (138)	10,938,000[a]
	800 F (700 K)	
8-10	70 (483)	3,870
8-8	60 (414)	8,670
8-7	50 (345)	35,420
8-13	45 (310)	319,090
8-9	40 (276)	4,695,890
8-11	35 (241)	40,600
8-12	30 (207)	10,000,000[a]

(a) Did not fail.

TABLE 15. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES OF CORONA 5 TITANIUM ALLOY PLATE (ALPHA-BETA PROCESSED)

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hours	Elongation in 2 Inches, percent	Reduction of Area, percent	Minimum Creep Rate, percent
			0.1	0.2	0.5	1.0	2.0					
3-11	95	800	--	0.02	0.05	0.11	0.35	2.596	2.7	20.8	56.7	2.6
3-13	90	800	0.05	0.1	0.3	0.7	2.3	1.624	19.7	20.0	58.1	0.49
3-14	75	800	0.10	1.0	5.0	15	37	0.677	501.7	26.9	63.9	0.020
3-17	70	800	1.0	3.7	10.0	20	65	0.554	1108.8	22.3	63.7	0.0075
3-12	50	800	6.5	22	100	750(b)	--	0.369	407.5(a)	1.284	--	<0.0007
3-15	30	800	18	44	500(b)	--	--	0.254	160.2(a)	0.615	--	--
3-16	15	800	165	2700(b)	--	--	--	0.196	1345.4(a)	0.369	--	0.00002

(a) Test discontinued.
(b) Estimated.

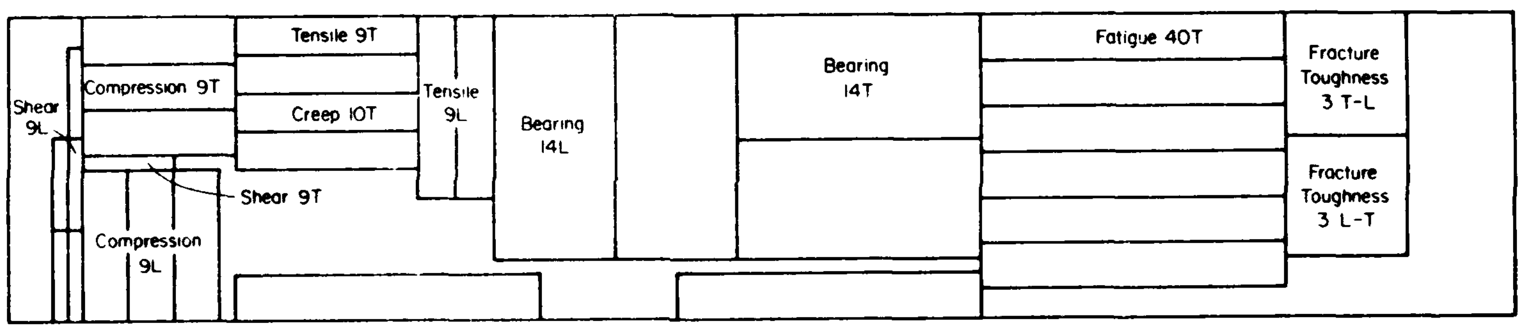

FIGURE 15. SPECIMEN LAYOUT FOR CORONA 5 ALPHA-BETA PROCESSED TITANIUM ALLOY PLATE

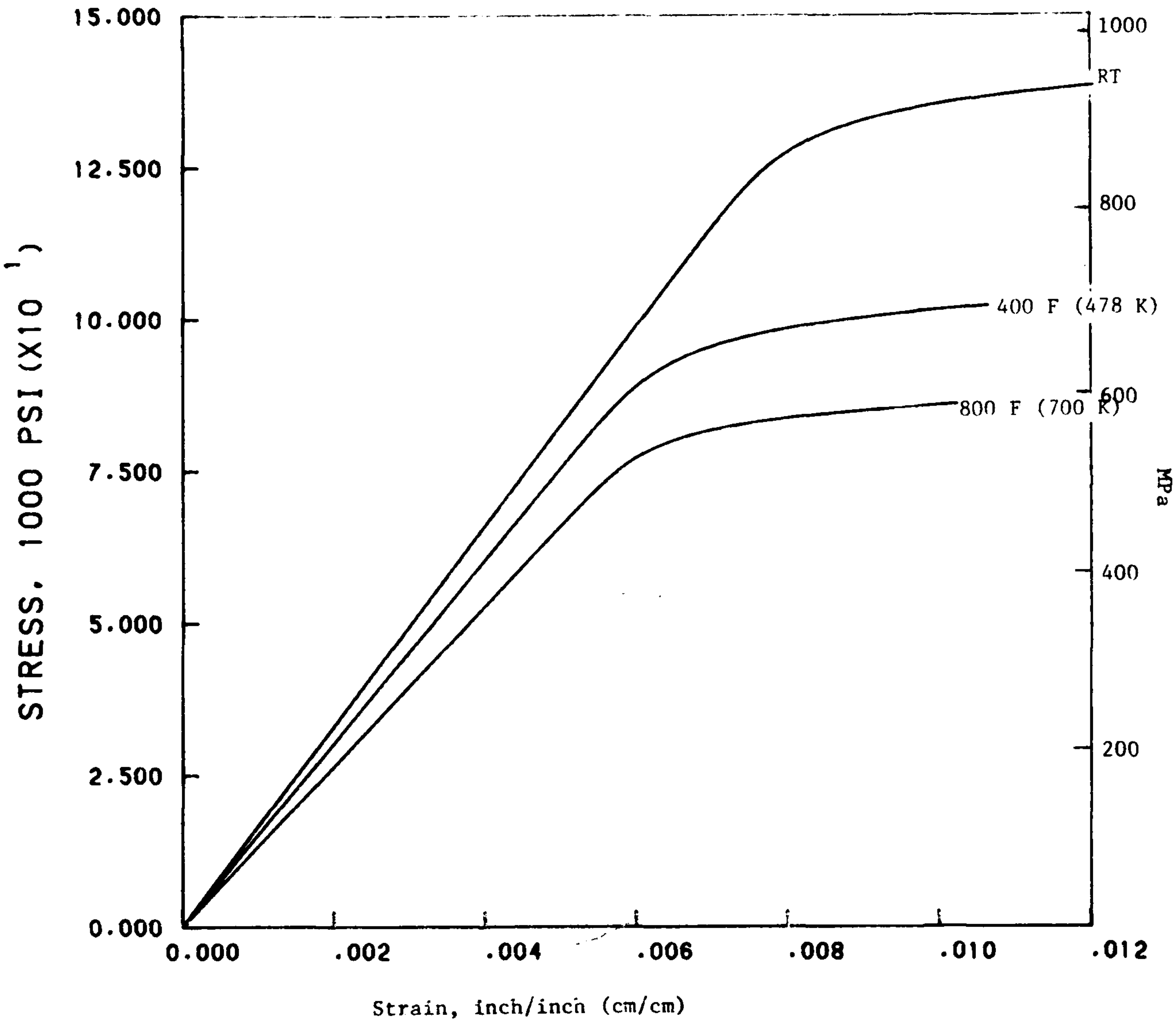

FIGURE 16. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE (LONGITUDINAL)

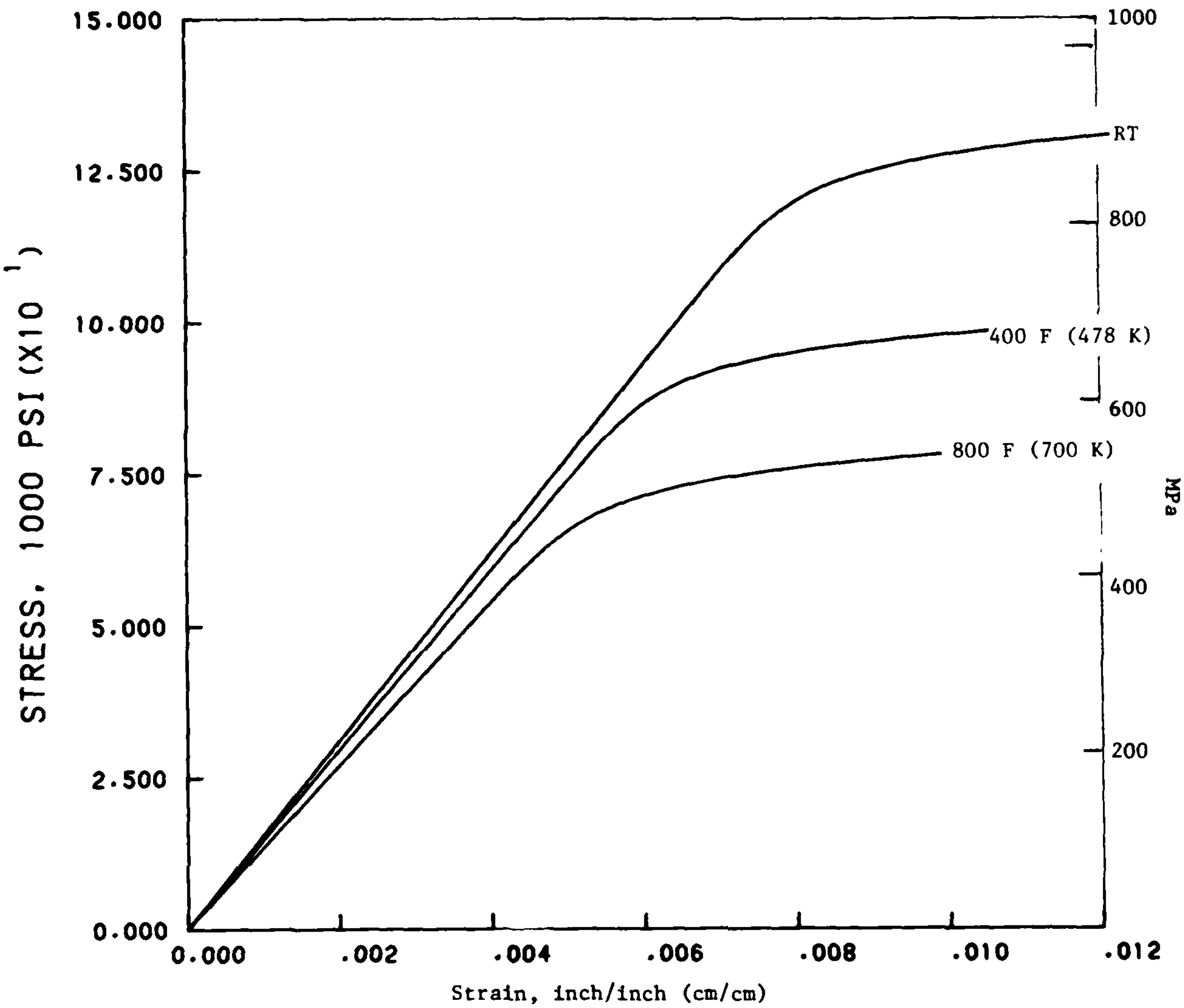

FIGURE 17. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE (LONG-TRANSVERSE)

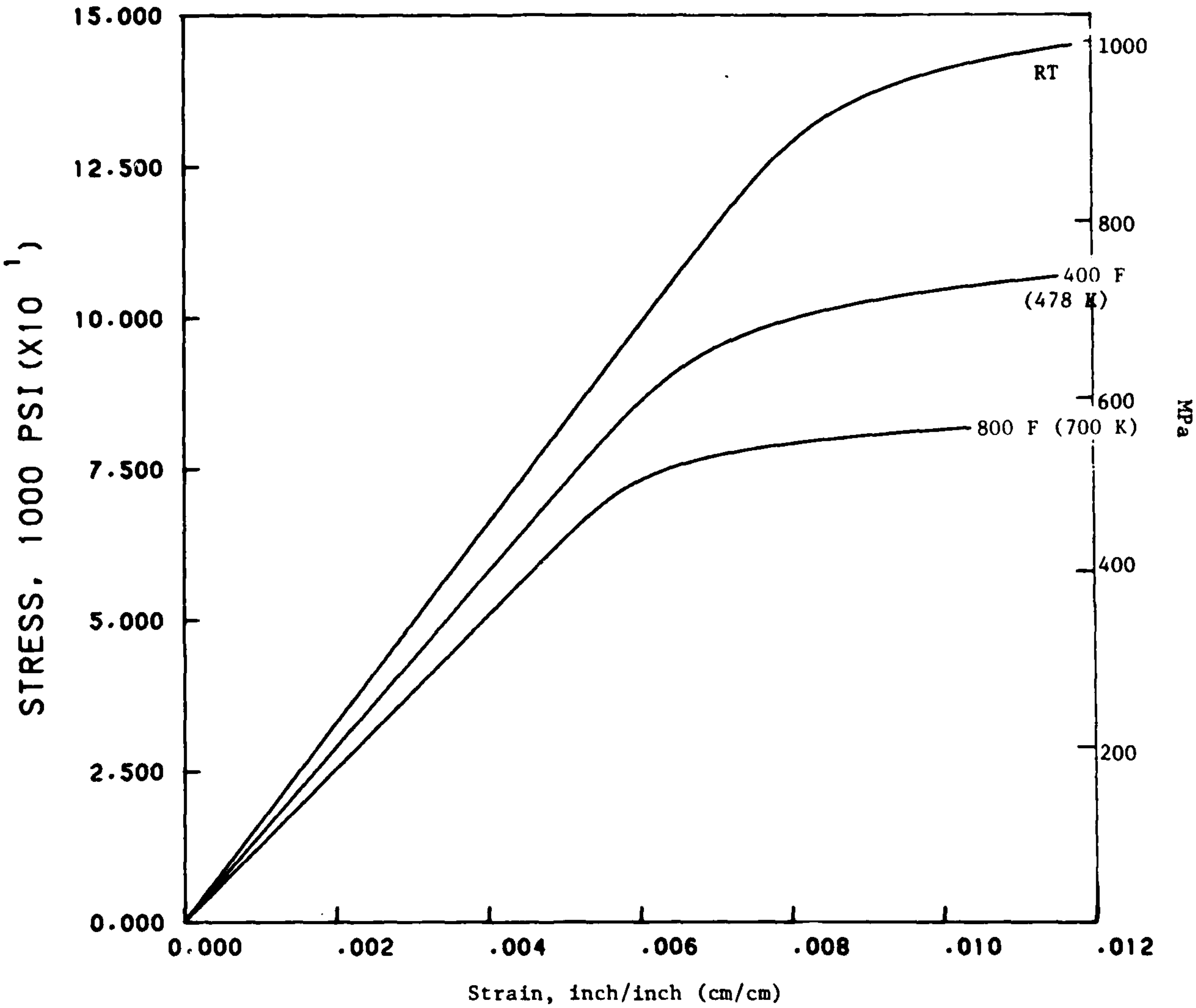

FIGURE 18. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE (LONGITUDINAL)

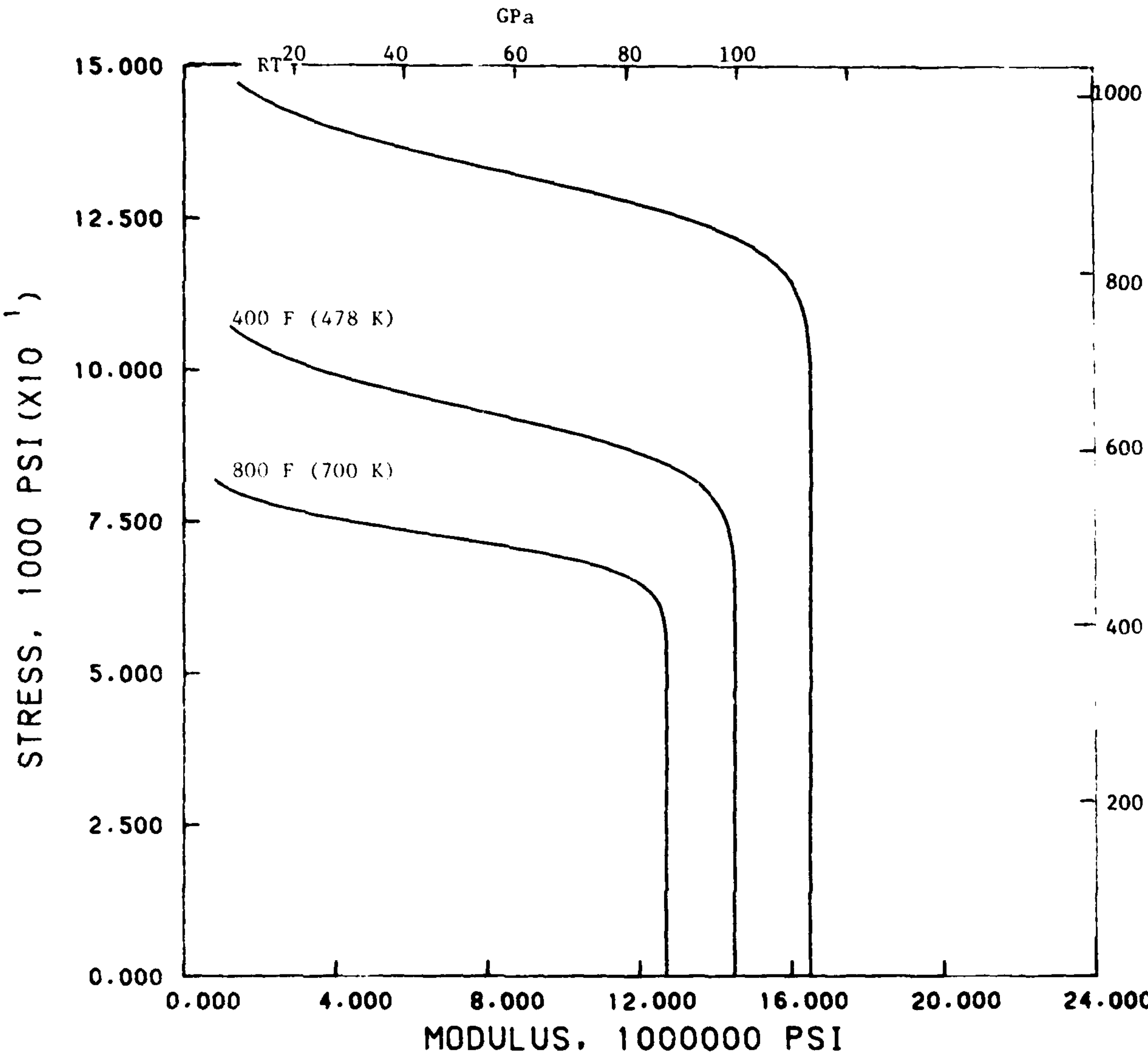

FIGURE 19. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES AT TEMPERATURE FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE (LONGITUDINAL)

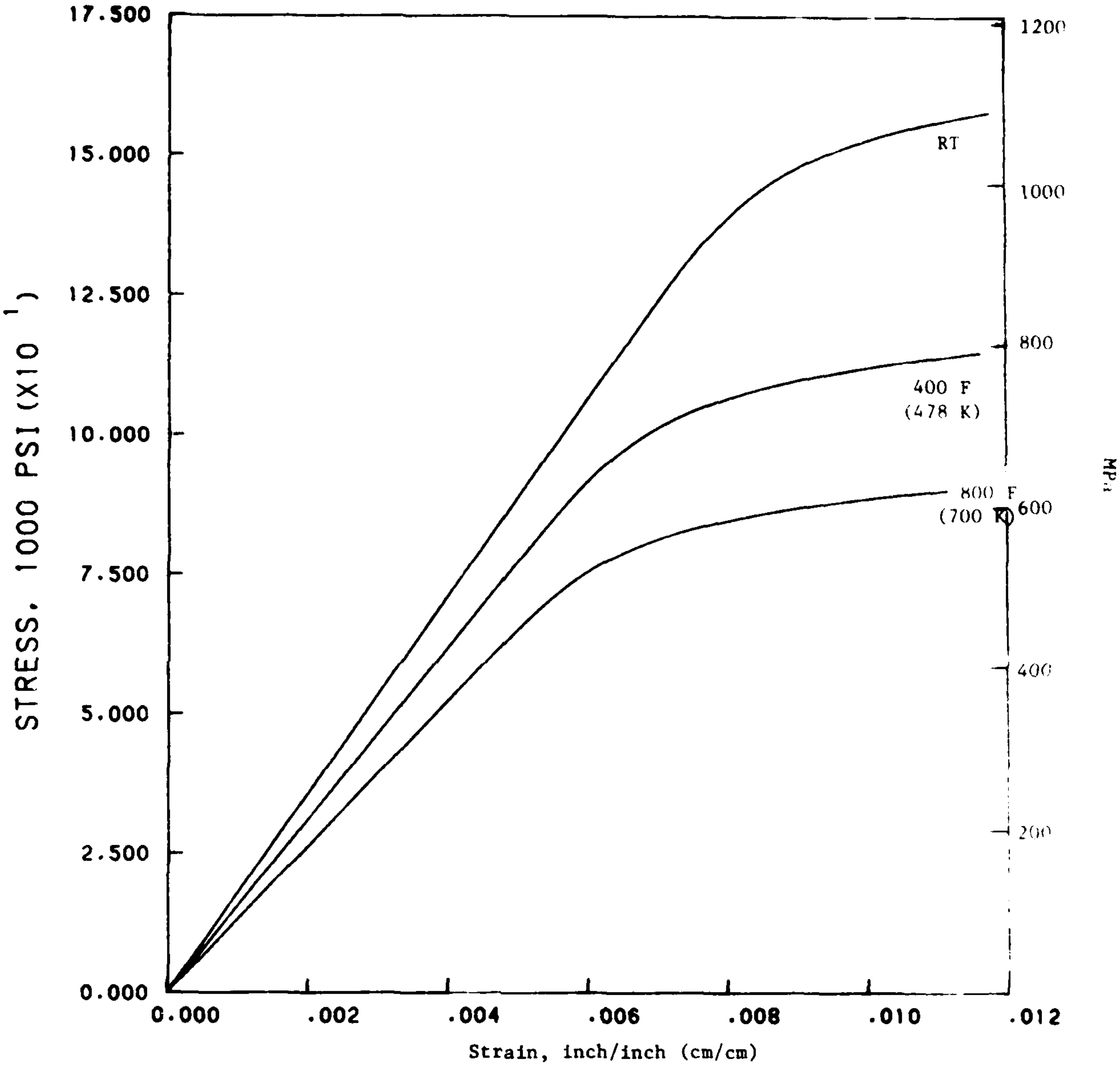

FIGURE 20. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE (TRANSVERSE)

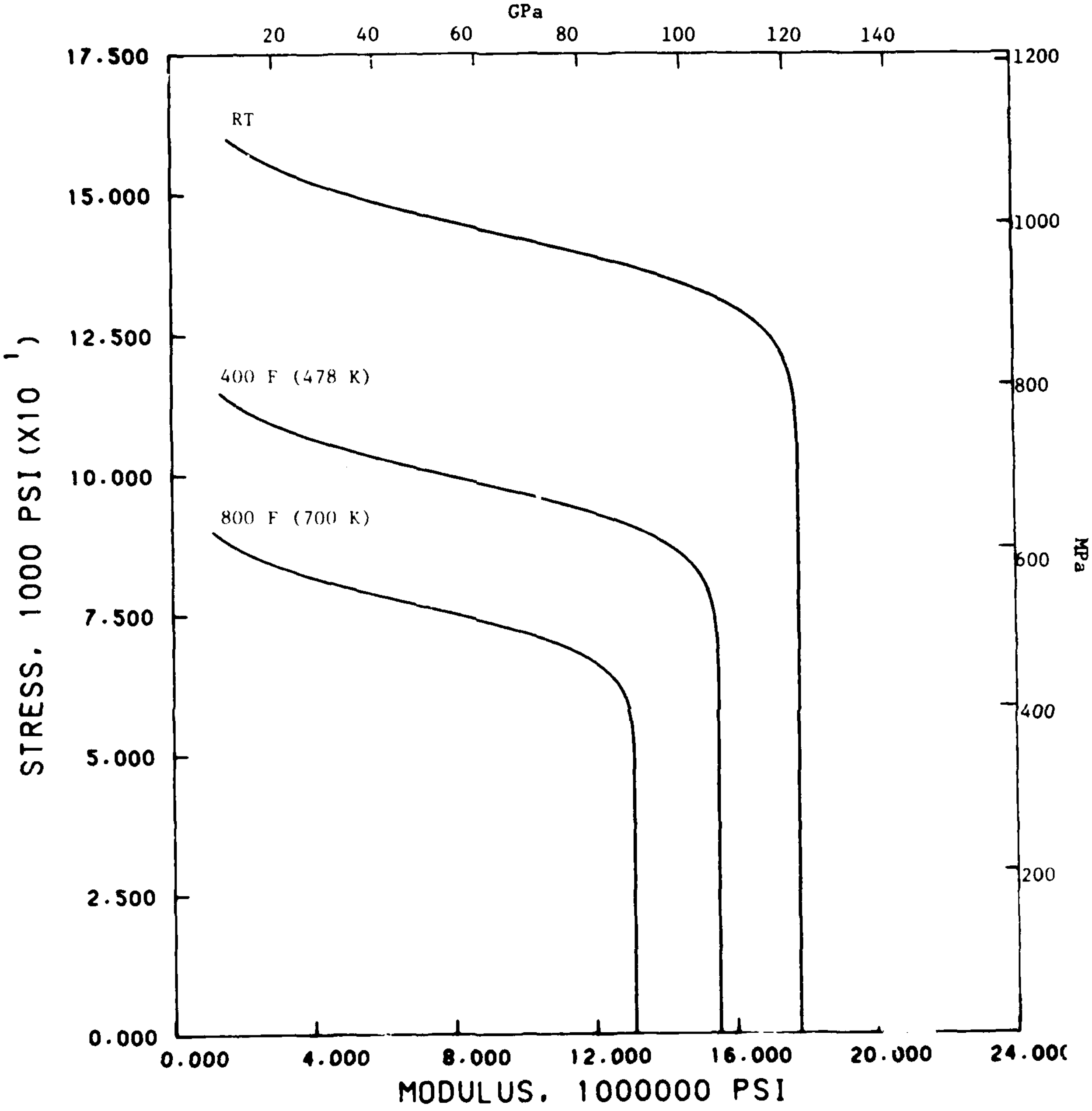

FIGURE 21. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES AT TEMPERATURE FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE (LONG-TRANVERSE)

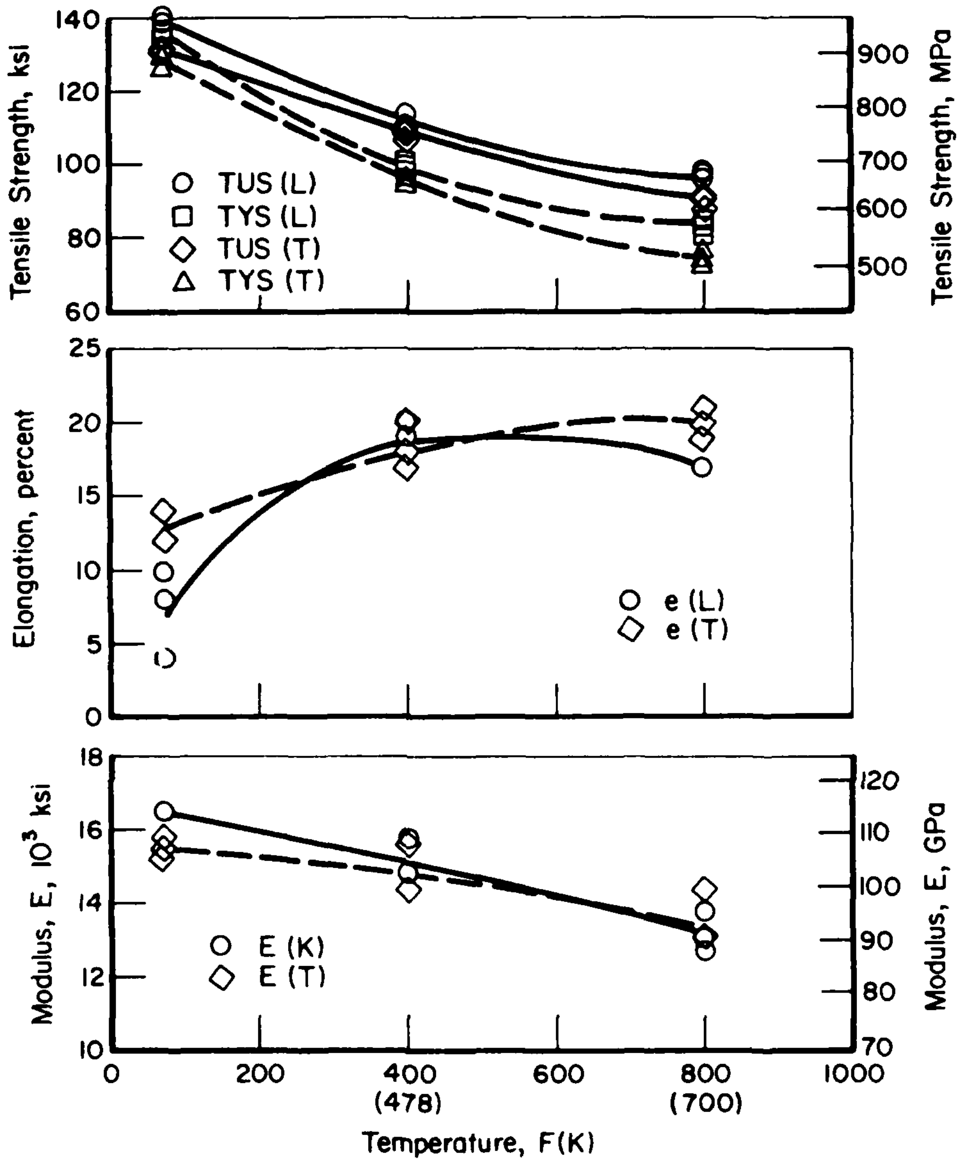

FIGURE 22. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

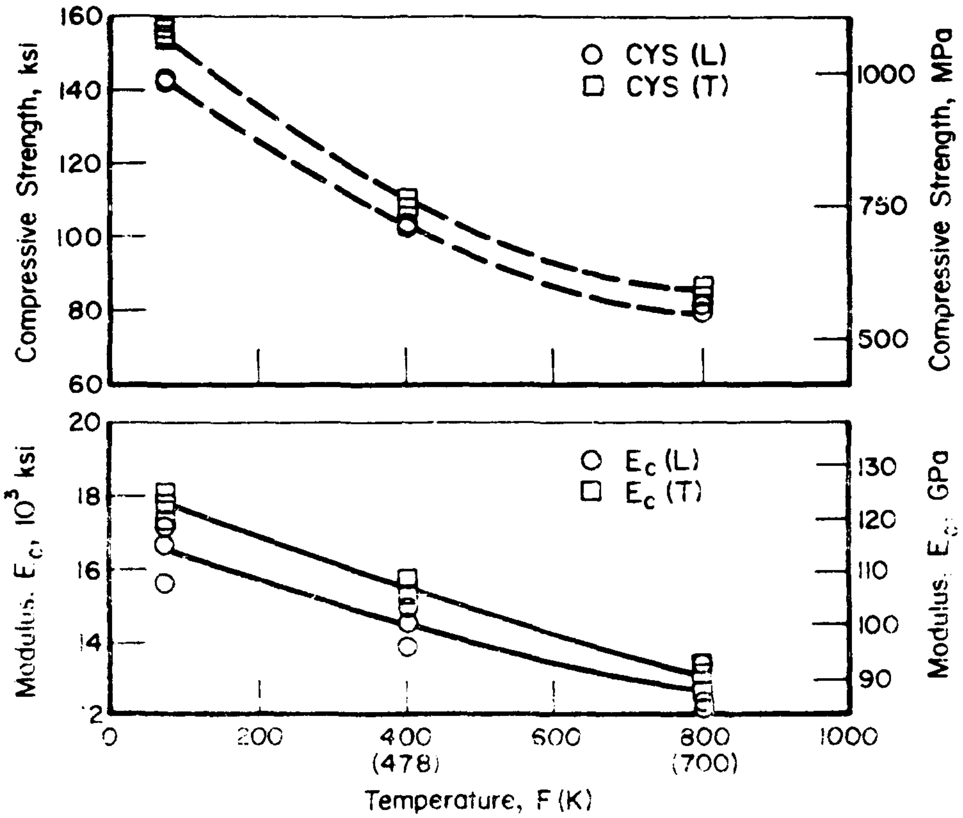

FIGURE 23. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

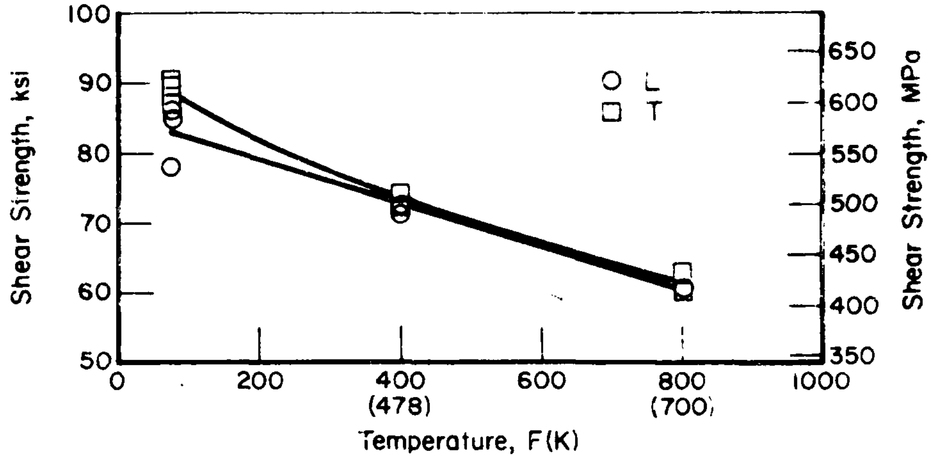

FIGURE 24. EFFECT OF TEMPERATURE ON THE SHEAR STRENGTH OF ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

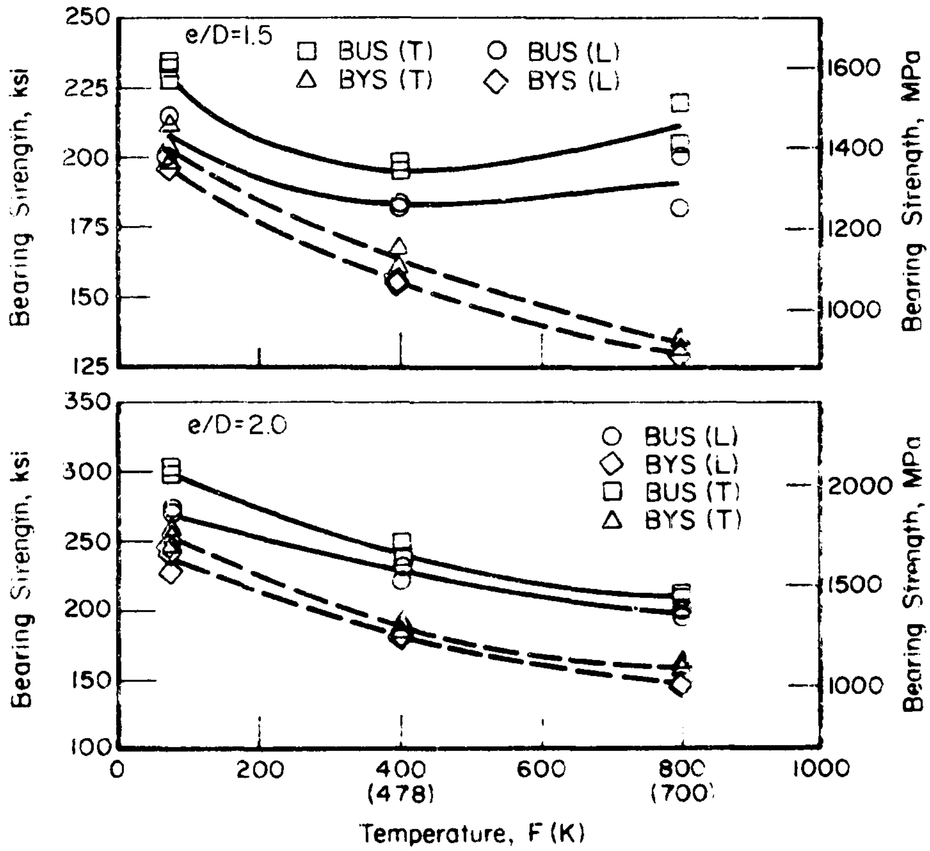

FIGURE 2[illegible]. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

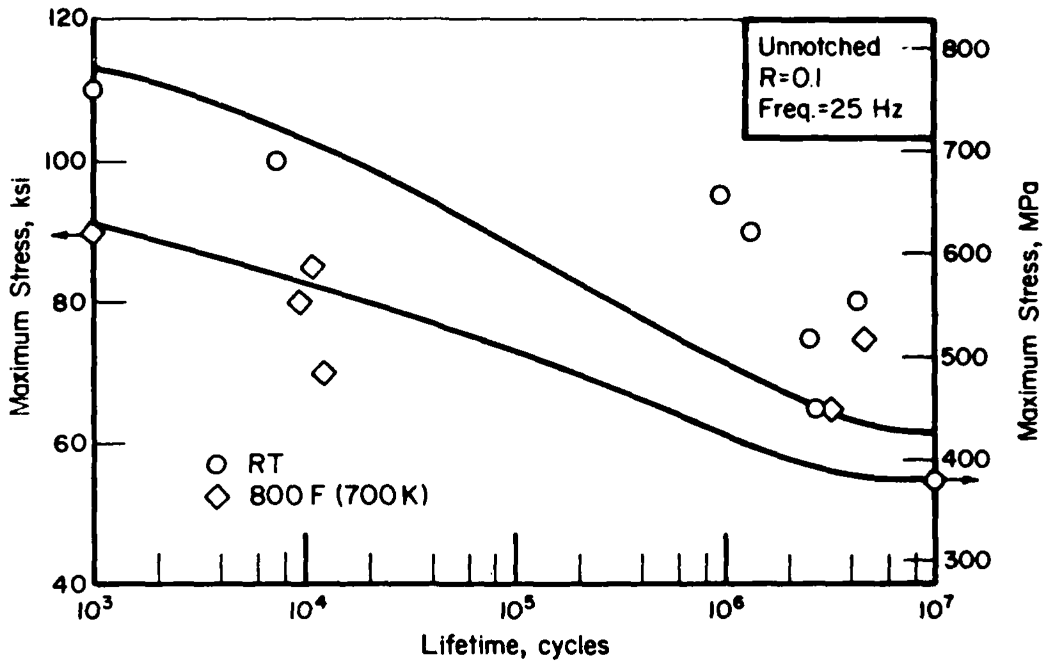

FIGURE 26. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

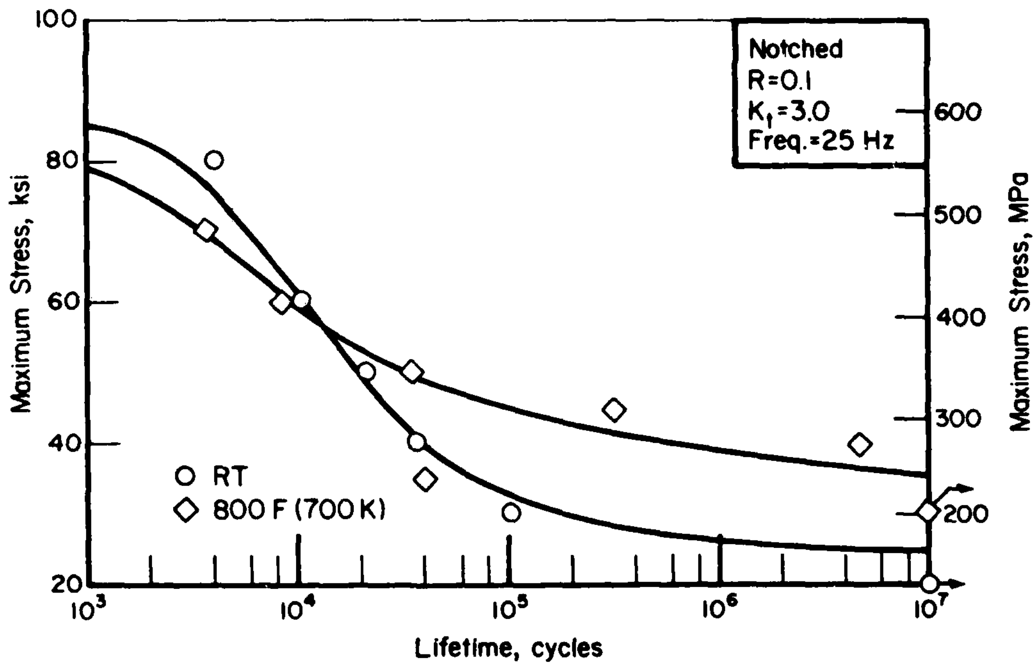

FIGURE 27. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

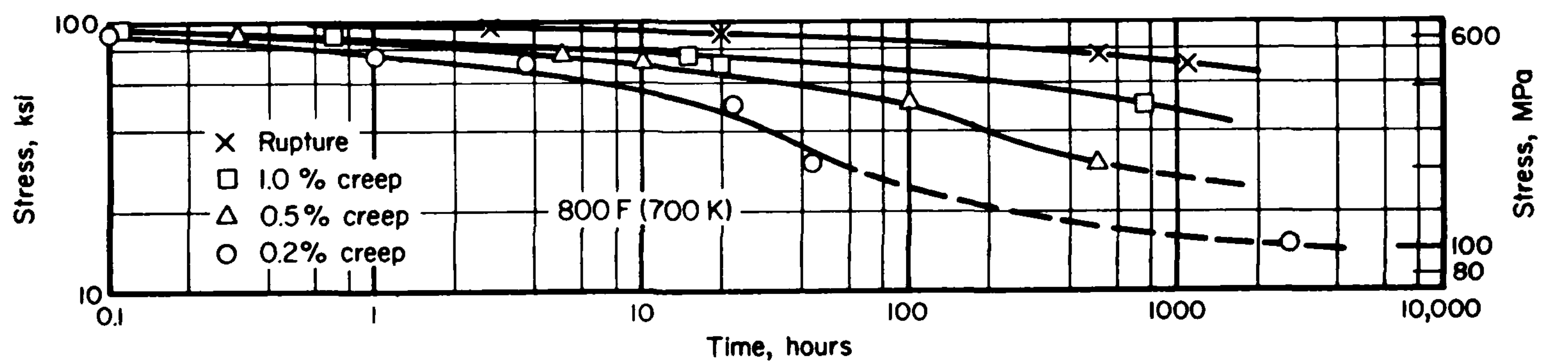

FIGURE 28. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

A357-T6 Aluminum Alloy Casting

Material Description

This aluminum alloy is one of the older, more widely used casting alloys. The particular casting used for this evaluation was obtained GFM from the Boeing Cast Aluminum Structures Technology (CAST) program (Air Force Contract F33615-76-C-3111). Several technical reports have been issued on this contract. These are AFFDL-TR-77-36, AFFDL-TR-78-62, AFFDL-TR-78-7, and AFFDL-TR-79-3029. Development history and detailed information regarding the casting is available in these documents and is not detailed in this report.

Processing and Heat Treating

Specimens were sectioned primarily from the thicker sections of the casting. Specimens were tested in the as-received-T6 temper.

Test Results

Tension. Results of tensile tests at room temperature, 250 F (394 K), and 350 F (450 K) are given in Table 16. Typical stress-strain curves at temperature are shown in Figure 29. Effect-of-temperature curves are presented in Figure 32.

Compression. Results of compression tests are shown in Table 17 for room temperature, 250 F (394 K), and 350 F (450 K). Typical stress-strain and tangent-modulus curves are presented in Figures 30 and 31. Effect-of-temperatures curves are shown in Figure [illegible].

Shear. Pin shear test results at room temperature, 250 F (394 K), 350 F (450 K) are given in Table 18. Effect-of-temperature curves are given in Figure 34.

Bearing. Results of bearing tests at e/D = [illegible] and e/D = 2.0 for room temperature, 250 F (394 K), and 350 F (450 K) are given in Table 19. Effect-of-temperature curves are shown in Figure [illegible].

Fracture Toughness. Compact tension type tests were conducted on three specimens. One specimen failed during precracking. The other two specimens (1.5 inches thick) were tested and gave an average, valid K_{Ic} value of 21.1 ksi$\sqrt{\text{in.}}$ (23.2 MPa · $m^{\frac{1}{2}}$).

Crack Propagation. Tests were conducted on three specimens at room temperature. The data obtained are presented in Figure 36.

Fatigue. Results of axial load fatigue tests for unnotched and notched specimens at room temperature and 350 F (450 K) are given in Tables 20 and 21. S-N curves are shown in Figures 37 and 38.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 12.0 in./in./F x 10^{-6} from 68 to 212 F (21.6 m/m · K)x 10^{-6} from room temperature to 373 K).

Density. The density of A357 castings is 0.097 lb./in^3 (2.68 g/cm^3).

TABLE 16. RESULTS OF TENSILE TESTS ON A357-T6 ALUMINUM ALLOY CASTING

Specimen Number		Tensile Ultimate Strength, ksi(MPa)	0.2 Percent Offset Yield Strength, ksi(MPa)	Elongation in 1 inch (25.4 mm), percent	Tensile Modulus, 10^3 ksi(GPa)
		Room Temperature			
1-1		47.1 (324.7)	43.8 (302.0)	2	10.5 (72.4)
1-2		48.0 (330.9)	42.2 (291.0)	3	10.9 (75.2)
1-3		47.7 (328.9)	40.0 (275.8)	1.5	9.8 (67.6)
	Average	47.6 (328.2)	42.0 (289.6)	2.2	10.4 (71.7)
		250 F (394 K)			
1-4		42.0 (289.6)	37.2 (256.5)	3	9.6 (66.2)
1-5		41.0 (282.7)	35.6 (245.5)	4	9.0 (62.1)
1-6		44.0 (303.4)	38.0 (262.0)	3	8.7 (60.0)
	Average	42.3 (291.9)	36.9 (254.7)	3.3	9.1 (62.7)
		350 F (450 K)			
1-7		38.6 (266.1)	33.0 (227.5)	4	7.9 (54.5)
1-8		37.1 (255.8)	33.0 (227.5)	5	8.6 (59.3)
1-9		34.2 (235.8)	31.6 (217.9)	5	8.0 (55.2)
	Average	36.6 (252.6)	32.5 (224.3)	4.7	8.2 (56.5)

TABLE 17. RESULTS OF COMPRESSION TESTS ON A357-T6 ALUMINUM ALLOY CASTING

Specimen Number		0.2 Percent Offset Yield Strength, ksi(MPa)	Compressive Modulus, ksi(GPa)
		Room Temperature	
2-1		42.6 (293.7)	10.4 (71.7)
2-2		46.0 (317.2)	10.9 (75.2)
2-3		44.7 (308.2)	11.0 (75.8)
	Average	44.4 (306.4)	10.8 (74.2)
		250 F (394 K)	
2-4		38.1 (262.7)	10.0 (68.9)
2-5		40.1 (276.5)	10.4 (71.7)
2-6		36.9 (254.4)	9.3 (64.1)
	Average	38.4 (264.5)	9.9 (68.3)
		350 F (450 K)	
2-7		34.2 (235.8)	8.2 (56.5)
2-8		36.0 (248.2)	9.0 (62.1)
2-9		32.8 (226.2)	8.2 (56.5)
	Average	34.3 (236.7)	8.5 (58.4)

TABLE 18. RESULTS OF PIN SHEAR TESTS ON A357-T6 ALUMINUM ALLOY CASTING

Specimen Number		Shear Ultimate Strength, ksi(MPa)
		Room Temperature
3-1		33.8 (233.4)
3-2		32.1 (221.1)
3-3		33.1 (228.0)
3-4		33.9 (233.8)
	Average	33.2 (229.1)
		250 F (394 K)
3-5		29.0 (199.8)
3-6		29.8 (205.7)
3-7		29.1 (200.5)
	Average	29.3 (202.0)
		350 F (450 K)
3-8		26.3 (181.2)
3-9		25.8 (178.0)
3-10		25.7 (177.3)
	Average	25.9 (178.8)

TABLE 19. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR A357-T6 ALUMINUM ALLOY CASTING

Specimen Number		Bearing Ultimate Strength, ksi(MPa)		Bearing Yield Strength, ksi(MPa)	
		Room Temperature			
		e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
4-1		82.4 (568.1)	95.8 (660.5)	66.7 (459.9)	78.5 (541.3)
4-2		80.0 (551.6)	103.8 (715.7)	65.1 (448.9)	82.4 (568.1)
4-3		76.4 (526.8)	97.9 (675.0)	65.7 (453.0)	81.4 (561.2)
	Average	79.6 (548.8)	99.2 (683.8)	65.8 (453.9)	80.8 (556.9)
		250 F (394 K)			
4-4		64.5 (443.3)	86.9 (599.2)	53.7 (370.3)	67.0 (462.0)
4-5		65.0 (448.2)	85.7 (590.9)	55.9 (385.4)	68.6 (473.0)
4-6		65.0 (448.2)	86.2 (594.3)	51.0 (351.6)	68.0 (468.9)
	Average	64.7 (445.8)	86.3 (594.8)	53.5 (369.1)	67.9 (467.9)
		350 F (450 K)			
4-[illegible]		59.3 (408.9)	71.9 (495.8)	51.3 (353.7)	[illegible] (429.6)
[illegible]		[illegible] (408.2)	70.1 (483.8)	53.6 (369.6)	[illegible] (424.0)
4-[illegible]		[illegible] (399.2)	75.0 (517.1)	50.4 (347.5)	[illegible]
	Average	[illegible]	[illegible] (498.7)	51.8 (356.[illegible])	[illegible]

TABLE 20. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED A357-T6 ALUMINUM ALLOY CASTING AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress ksi(MPa)	Cycles to Failure
	Room Temperature	
8-7	55 (379)	(a)
8-6	50 (345)	5,133
8-4	40 (276)	14,467
8-1	30 (207)	56,744
8-2	20 (138)	320,666
8-3	15 (103)	1,542,425
8-8	15 (103)	1,914,981
8-5	12.5 (86)	10,309,715[b]
	350 F (450 K)	
8-11	40 (276)	4,980
8-16	35 (241)	23,154
8-15	30 (207)	42,929
8-13	25 (172)	154,342
8-12	20 (138)	540,300
8-14	15 (103)	10,000,000[b]

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

TABLE 21. AXIAL LOAD FATIGUE RESULTS FOR NOTCHED (K_t = 3.0) A357-T6 ALUMINUM ALLOY CASTINGS AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi(MPa)	Cycles to Failure
	Room Temperature	
8-24	25 (172)	37,721
8-29	22.5 (155)	59,171
8-21	20 (138)	177,369
8-26	17.5 (121)	395,341
8-28	17.5 (121)	527,915
8-23	15 (103)	361,132
8-27	12.5 (86)	788,818
8-25	10 (69)	10,000,000[(a)]
	350 F (450 K)	
8-37	30 (207)	7,466
8-36	27.5 (190)	10,939
8-35	25 (172)	22,126
8-33	22.5 (155)	45,781
8-31	20 (138)	54,381
8-32	17.5 (121)	203,975
8-34	15 (103)	500,941
8-38	12.5 (86)	1,637,092
8-30	10 (69)	14,504,786[(a)]

(a) Did not fail.

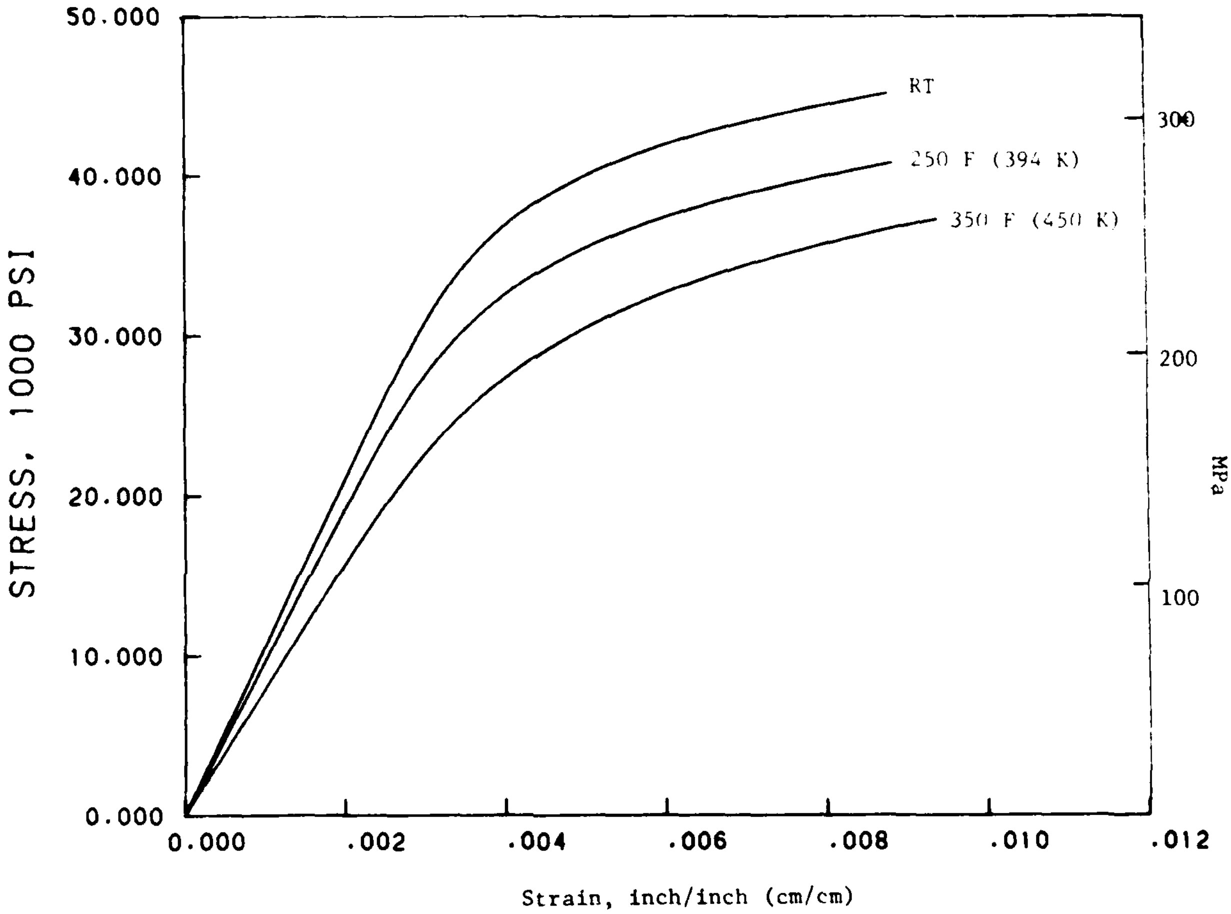

FIGURE 29. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR A357-T6 ALUMINUM ALLOY CASTING

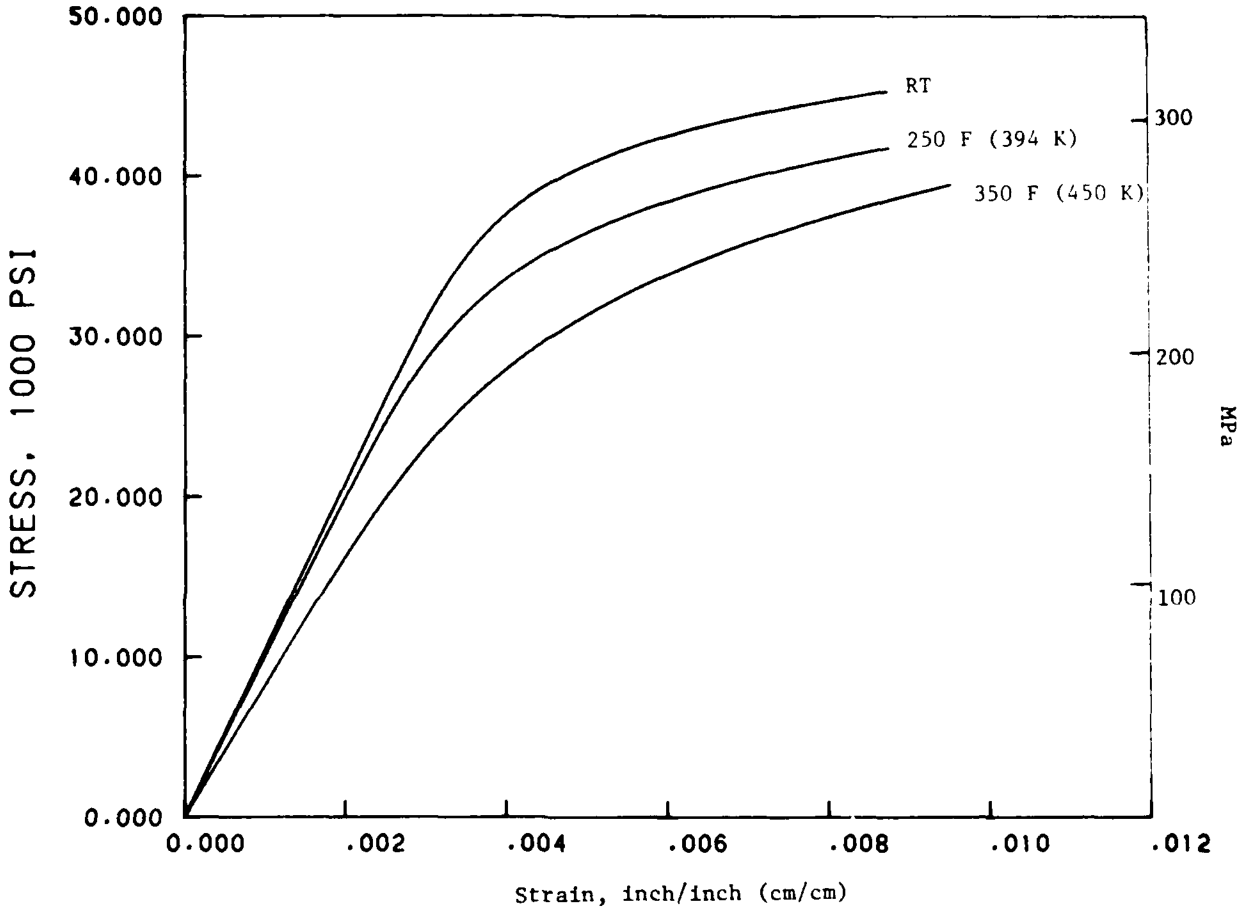

FIGURE 30. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR A357-T6 ALUMINUM ALLOY CASTING

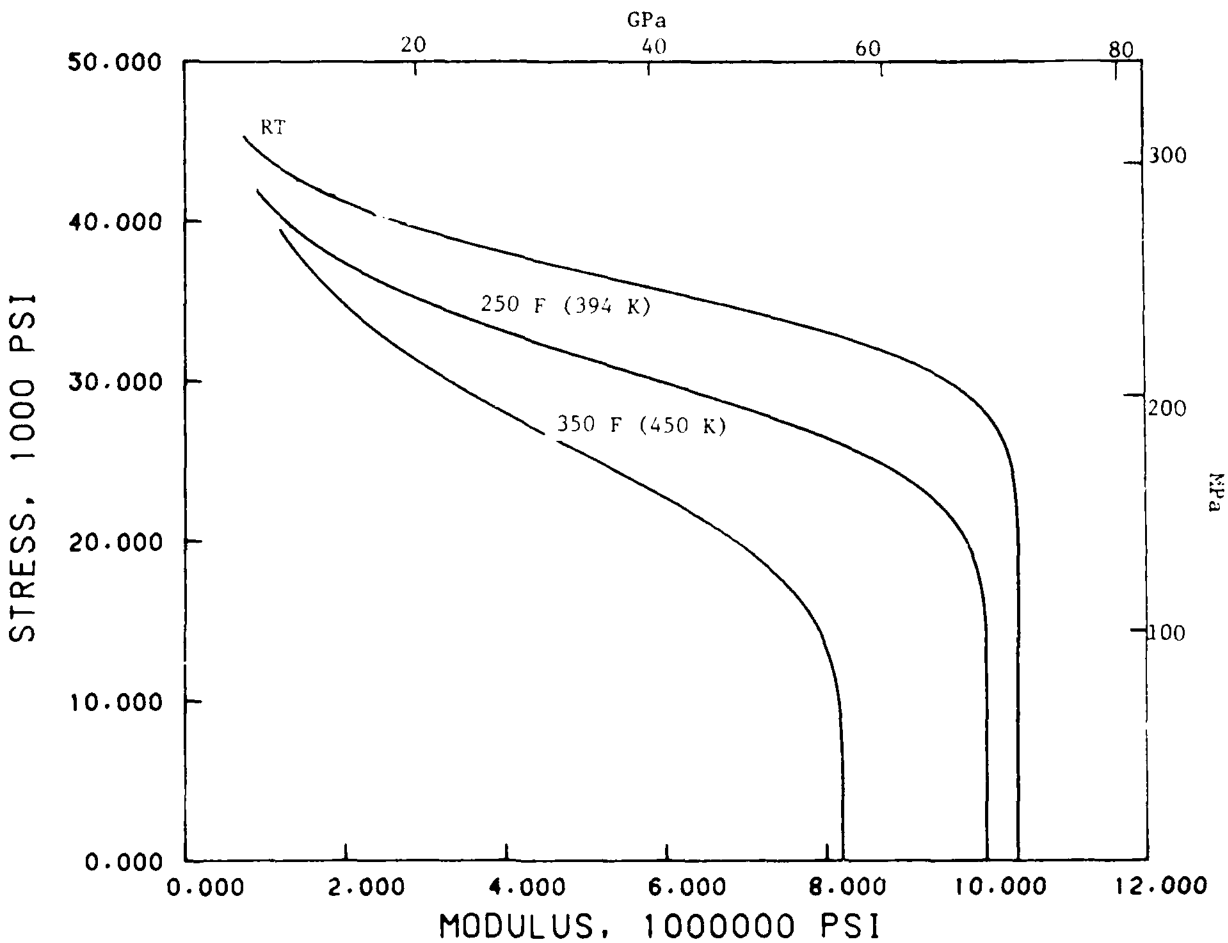

FIGURE 31. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES AT TEMPERATURE FOR A357-T6 ALUMINUM ALLOY CASTING

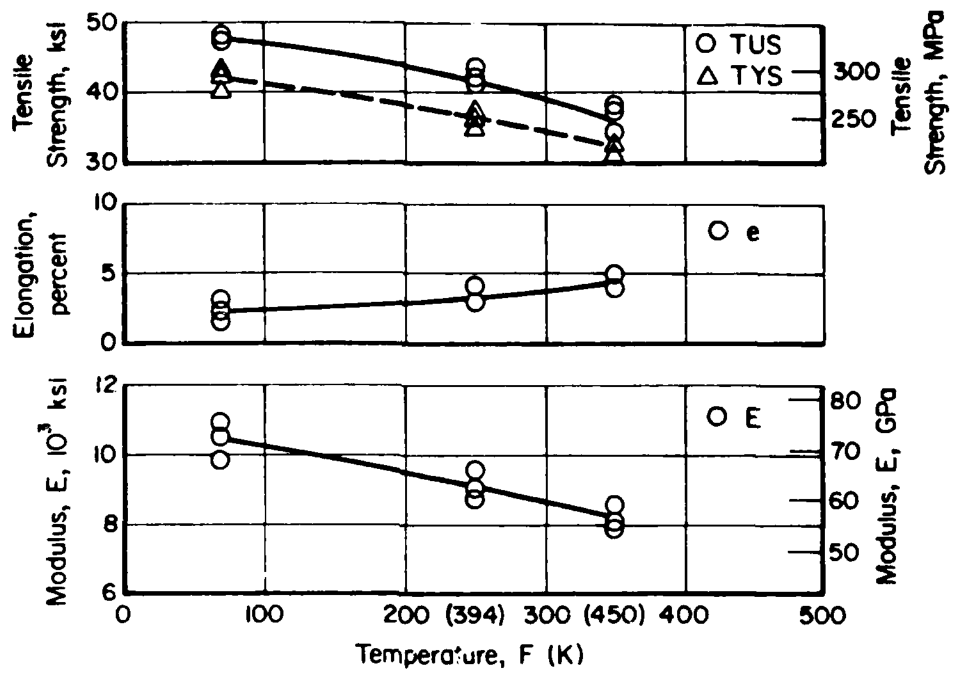

FIGURE 32. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF A357-T6 ALUMINUM ALLOY CASTING

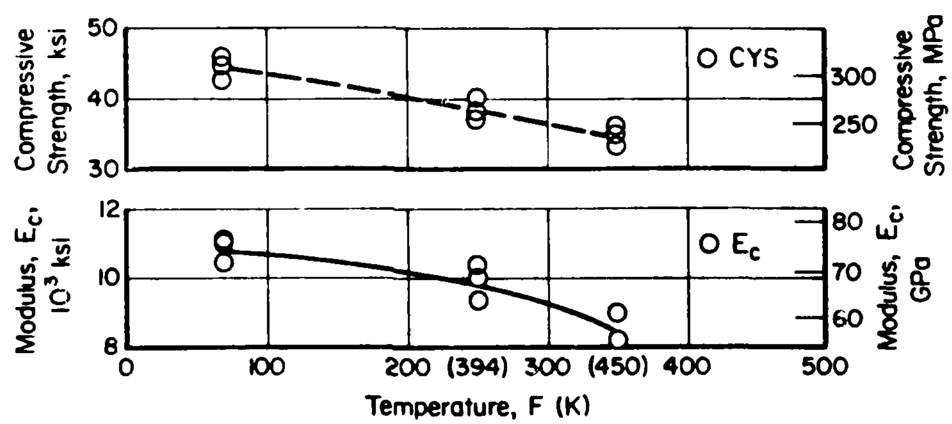

FIGURE 33. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF A357-T6 ALUMINUM ALLOY CASTING

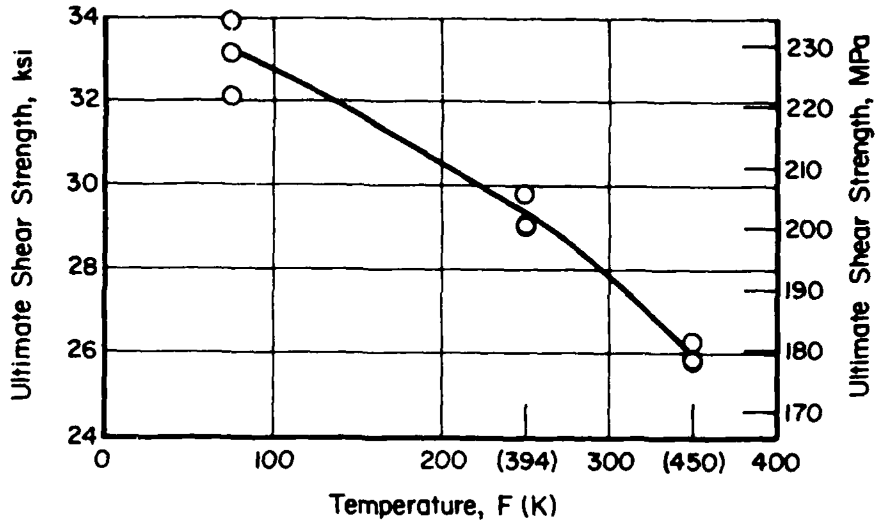

FIGURE 34. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF A357-T6 ALUMINUM ALLOY CASTINGS

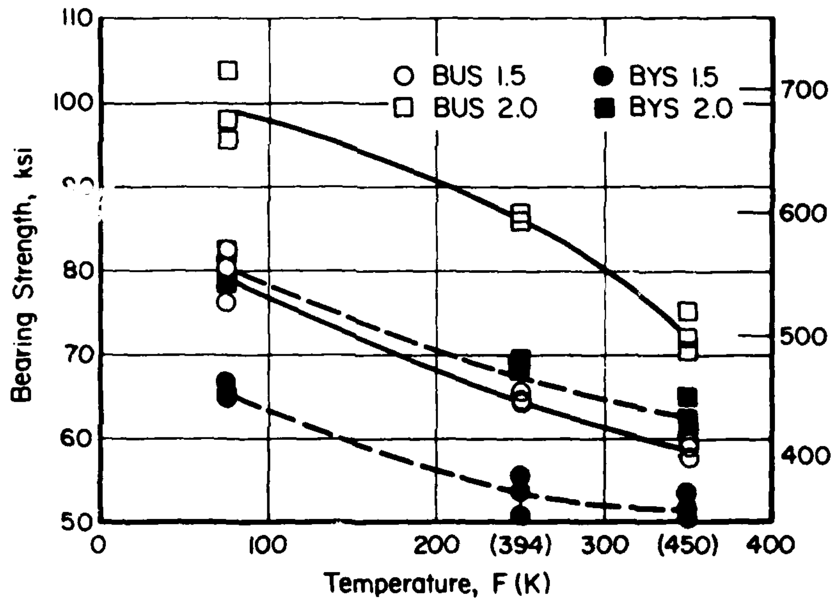

FIGURE 35. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF A357-T6 ALUMINUM ALLOY CASTINGS

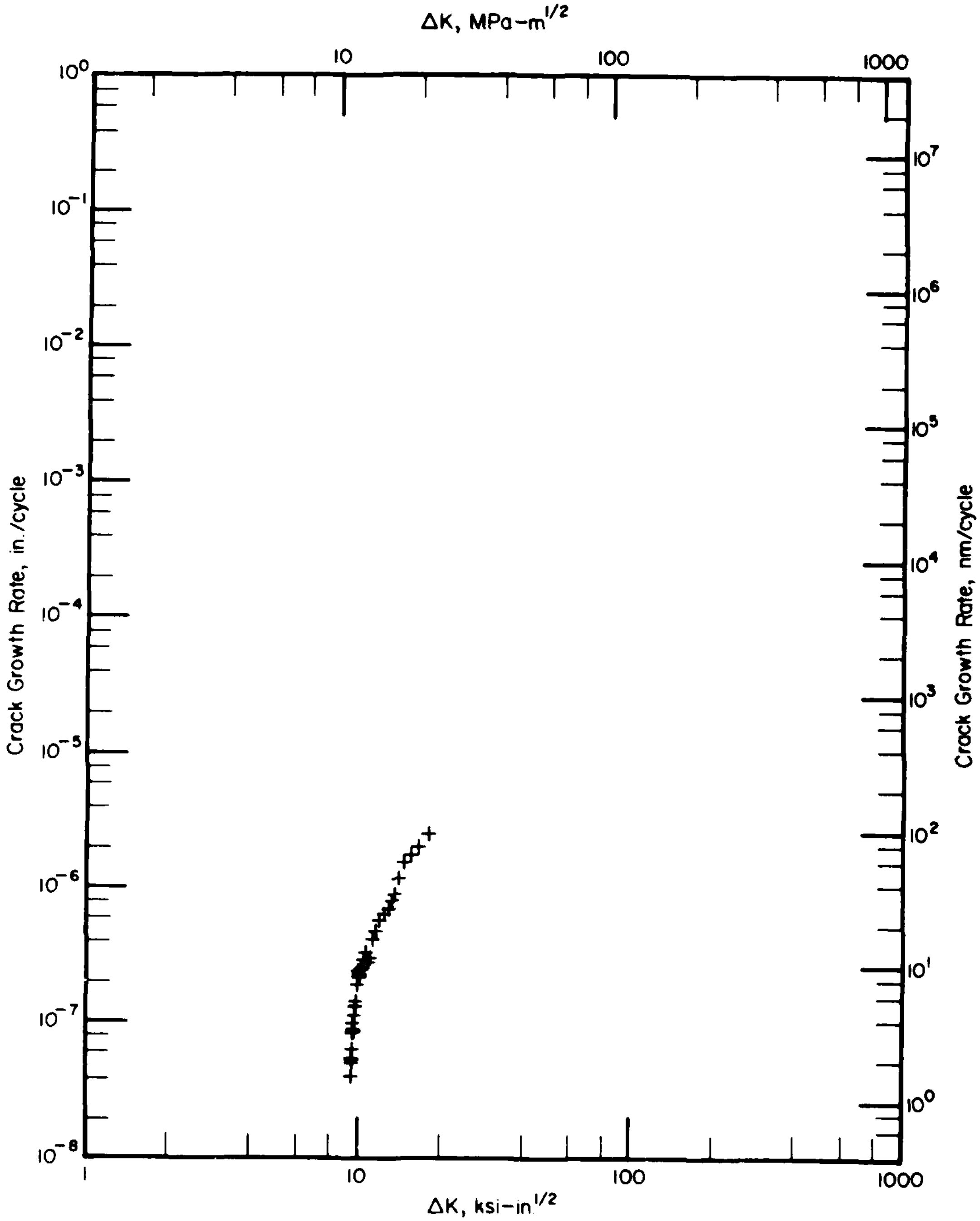

FIGURE 36. CRACK PROPAGATION TEST RESULTS FOR A357-T6 ALUMINUM ALLOY CASTING

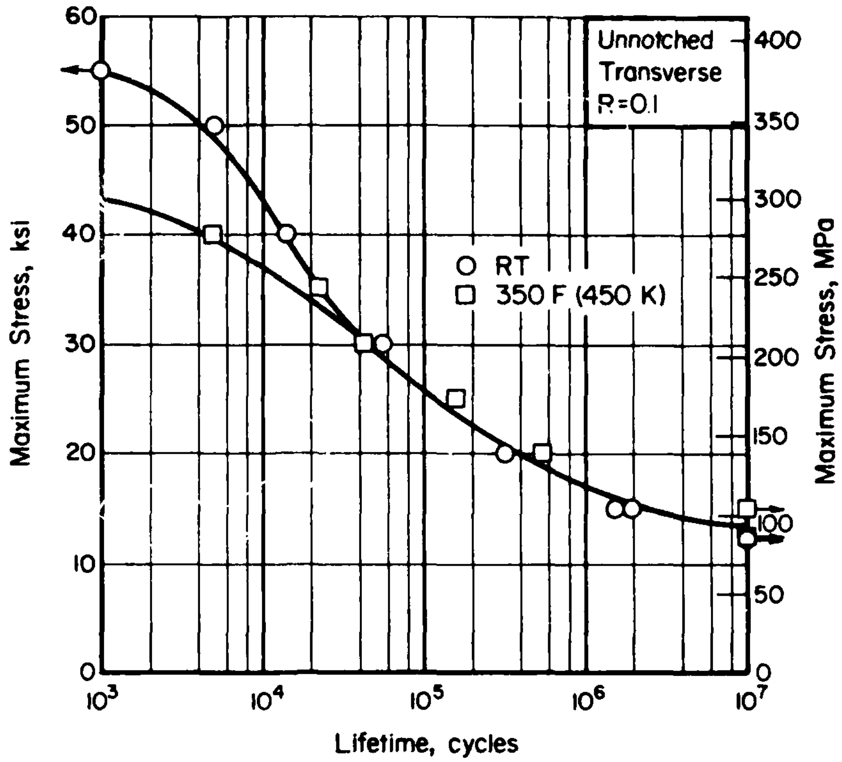

FIGURE 37. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED A357-T6 ALUMINUM ALLOY CASTING

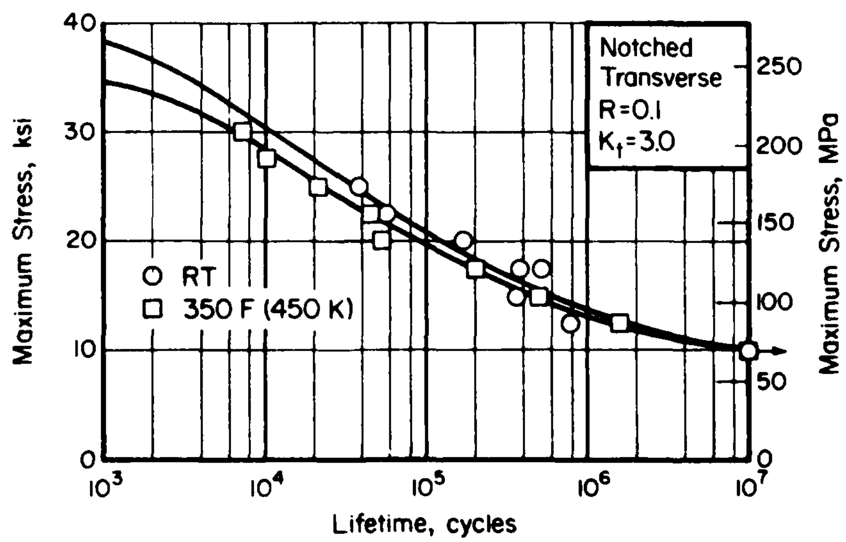

FIGURE 38. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) A357-T6 ALUMINUM ALLOY CASTING

IN-792 PM Disk (HIP)

Material Description

IN-792 is a nickel-base alloy developed by the International Nickel Company primarily for high-temperature turbine disk usage. The material evaluated on this program was supplied by the Air Force with the information that it was a powder metallurgy product that had been Hot Isostatic Pressed (HIP) at 15 ksi pressure at 2200 F for 4 hours and slow-cooled.

Processing and Heat Treating

The disks were heat treated in accordnace with the following procedure: 2150 F/2 hours, air cool, plus 1400 F/16 hours, air cool, plus 1250 F/16 hours, air cool.

A thermocouple was attached to the outside rim of two disks. The four disks were then placed in a gas-fired oven and positioned as instructed by AFML. After 2 hours at 2150 F, the disks were removed from the furnace and placed in a box. To slow cool at the desired rate (50 -100 F/min.), an insulator (exploded mica) was immediately poured into the box to cover the disks. When cooling fell below the desired rate, the insulator was removed and the disks were allowed to stand in still air until the rate fell off. A fan was then allowed to blow circulating air over the disks to maintain the desired rate.

A photograph of a disk is shown in Figure 39. Tension, compression, shear, and creep specimens were sectioned from the hub. Other specimen types were taken from the rim area.

Test Results

Tension. Tests were conducted at room temperature and 800 F (700 K). Results are given in Table 22. Typical stress-strain curves at temperature are presented in Figure 40. Effect-of-temperature curves are shown in Figure 43.

Compression. Tests were also conducted at room temperature and 800 F (700 K). Test results are given in Table 23. Typical compressive stress-strain curves at temperature are shown in Figure 41. Tangent-modulus curves are presented in Figure 42. Effect-of-temperature curves are shown in Figure 44.

Shear. Results of pin-shear type tests at room temperature and 800 F (700 K) are given in Table 24. Effect-of-temperature curves are shown in Figure 45.

Bearing. Bearing tests at e/D = 1.5 and e/D = 2.0 at room temperature and 800 F (700 K) are given in Table 25. Effect-of-temperature curves are shown in Figure 46.

Fracture Toughness. Compact tension type tests were conducted at room temperature. Test results are given in Table 26.

Crack Propagation. Crack propagation tests were conducted at room temperature. The data obtained are shown in the da/dN versus delta K plot in Figure 47.

Fatigue. Results of axial load fatigue tests for unnotched and notched (K_t = 3.0) specimens are given in Table 27. S-N curves are presented in Figures 48 and 49.

Creep and Stress Rupture. Tests were attempted at 1000 F (811 K). Very little creep occurred and the test temperature was raised to 1250 F (950 K) and eventually to 1500 F (1089 K). Test results are given in tabular form in Table 28 and as log-stress versus log-time curves in Figure 50.

Density. The density for IN-792 alloy is 0.298 lb/in^3 (8.25 g/cm^3).

TABLE 22. RESULTS OF TENSILE TESTS ON IN-792 PM DISK (HIP)

Specimen Number		Tensile Ultimate Strength, ksi(MPa)	0.2 Percent Offset Yield Strength, ksi(MPa)	Elongation in 1 inch (25.4 mm), percent	Reduction in Area, percent	Tensile Modulus, 10^3 ksi(GPa)
		Room Temperature				
1-1		198.0 (1365.2)	160.0 (1103.2)	5	5.7	31.2 (215.1)
1-2		198.7 (1370.0)	157.7 (1087.3)	4	7.8	31.6 (217.9)
1-3		198.0 (1365.2)	158.7 (1094.2)	5	8.1	31.0 (213.7)
	Average	198.2 (1366.8)	158.8 (1094.9)	4.7	7.2	31.3 (215.6)
		800 F (700 K)				
1-4		190.0 (1310.0)	152.6 (1052.2)	6	10.2	29.0 (199.9)
1-5		191.0 (1316.9)	157.0 (1082.5)	8	11.0	30.1 (207.5)
1-6		187.8 (1294.9)	149.6 (1031.5)	7	8.7	32.3 (222.7)
	Average	189.6 (1307.3)	153.1 (1055.4)	7.0	10.0	30.5 (210.1)

TABLE 23. RESULTS OF COMPRESSION TESTS ON IN-792 PM DISK (HIP)

Specimen Number		0.2 Percent Offset Yield Strength, ksi(MPa)	Compressive Modulus, 10^3 ksi(GPa)
		Room Temperature	
2-1		173.0 (1192.8)	32.0 (220.6)
2-2		170.0 (1172.1)	31.3 (215.8)
2-3		170.1 (1172.8)	33.3 (229.6)
	Average	171.0 (1179.3)	32.2 (222.0)
		800 F (700 K)	
2-4		168.1 (1159.0)	29.8 (205.5)
2-5		170.1 (1172.8)	30.0 (206.9)
2-6		164.7 (1135.6)	31.3 (215.8)
	Average	167.6 (1155.8)	30.4 (209.4)

TABLE 24. RESULTS OF PIN SHEAR TESTS ON IN-792 PM DISK (HIP)

Specimen Number		Shear Ultimate Strength, ksi(MPa)
		Room Temperature
3-1		126.6 (873.0)
3-2		127.9 (881.9)
3-3		127.2 (877.4)
	Average	127.2 (877.4)
		800 F (700 K)
3-4		130.0 (896.4)
3-5		121.7 (839.1)
3-6		122.6 (845.3)
	Average	124.8 (860.3)

TABLE 25. RESULTS OF BEARING TESTS AT e/D = 1.5 AND e/D = 2.0 FOR IN-792 PM DISK (HIP)

Specimen Number		Bearing Ultimate Strength, ksi(MPa)		Bearing Yield Strength, ksi(MPa)	
		Room Temperature			
		e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
4-1		263.7 (1818.3)	352.5 (2429.1)	236.3 (1629.3)	293.0 (2020.2)
4-2		265.6 (1831.3)	338.9 (2336.7)	231.4 (1595.5)	256.8 (1770.6)
4-3		268.8 (1853.4)	344.7 (2376.7)	237.7 (1638.9)	272.5 (1878.9)
	Average	266.0 (1834.1)	345.4 (2381.5)	235.1 (1621.0)	274.1 (1889.9)
		800 F (700 K)			
		e/D = 1.5	e/D = 2.0	e/D = 1.5	e/D = 2.0
4-4		265.5 (1830.6)	340.4 (2347.1)	237.7 (1638.9)	293.9 (2026.4)
4-5		276.4 (1905.8)	326.9 (2254.0)	228.5 (1575.5)	284.4 (1960.9)
4-6		265.6 (1831.3)	332.8 (2294.7)	228.5 (1575.5)	290.5 (2003.0)
	Average	269.2 (1855.9)	333.4 (2298.8)	231.6 (1596.7)	289.6 (1996.8)

TABLE 26. RESULTS OF COMPACT TENSION FRACTURE TOUGHNESS TESTS AT ROOM TEMPERATURE ON IN-792 PM DISK (HIP)

Specimen Number	Width, W, inches (mm)	Thickness, B, inch (mm)	Crack, a, inch (mm)	P_Q, lbs., (Kg)	P_{max}, lbs., (Kg)	K_Q, ksi$\sqrt{in.}$ (MPa · $m^{1/2}$)
6-1	1.5 (38.1)	.5806 (14.75)	.8094 (20.56)	4840 (2195)	6525 (2460)	74.7 (82.1)[a]
6-2	1.5 (38.1)	.5806 (14.75)	.753 (19.13)	6800 (3084)	8040 (3647)	92.4 (101.6)[a]
6-3	1.5 (38.1)	.5806 (14.75)	.7821 (19.86)	6240 (2830)	6680 (3030)	90.0 (99.0)

(a) Invalid (Specimen 1 and 2) due to P_{max}/P_Q ratio.

TABLE 27 . AXIAL LOAD FATIGUE TEST RESULTS FOR IN-792 PM DISK (HIP) AT A STRESS RATIO OF R = 0.1

Specimen Number	Maximum Stress, ksi(MPa)	Cycles to Failure
	Unnotched, Room Temperature	
8-12	180 (1241.1)	11,300
8-13	170 (1172.2)	22,250
8-11	160 (1103.2)	69,780
8-10	150 (1034.3)	60,120
8-14	145 (998.8)	292,750
8-15	135 (930.8)	2,961.140
8-18	130 (896.4)	2,808,420
8-19	120 (827.4)	10,000,000[a]
	Notched (K_t = 3.0), Room Temperature	
8-6	80 (551.6)	6,830
8-5	70 (482.6)	21,360
8-1	60 (413.7)	26,080
8-2	40 (275.8)	276,010
8-3	30 (206.9)	673,930
8-4	20 (137.9)	14,973,000[a]

(a) Did not fail.

TABLE 28. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR IN-792 PM DISK (HIP)

Specimen Number	Stress, ksi	Temper-ature, F	Hours to Indicated Creep Deformation, percent					Initial Strain, percent		Elongation in 2 inches, percent	Reduction of Area, percent	Minimum Creep Rate, percent
			0.1	0.2	0.5	1.0	2.0					
9-1	185	1000	0.1	0.5	10	50	--	4.200	96.2	5.4	8.3	0.010
9-2	175	1000	0.2	2.5	145	645	--	2.308	709.3	3.1	6.0	0.0010
9-1	150	1000	∿1500	--	--	--	--	0.861	551.8(a)	0.946	--	0.000020
9-2	125	1000	--	--	--	--	--	0.561	357.5(a)	0.600	--	--
9-1	100	1000	--	--	--	--	--	0.500	263.7(a)	0.508	--	--
9-5	1250	1250	0.2	1.5	6	13	--	0.770	20.0	3.1	4.2	0.069
9-4	1500	1500	0.02	0.03	0.1	0.22	0.36	0.542	0.4	3.1	3.5	4.4
9-3	1500	1500	0.1	0.2	0.5	1.1	--	0.369	1.2	2.3	3.8	0.8

(a) Time test discontinued.

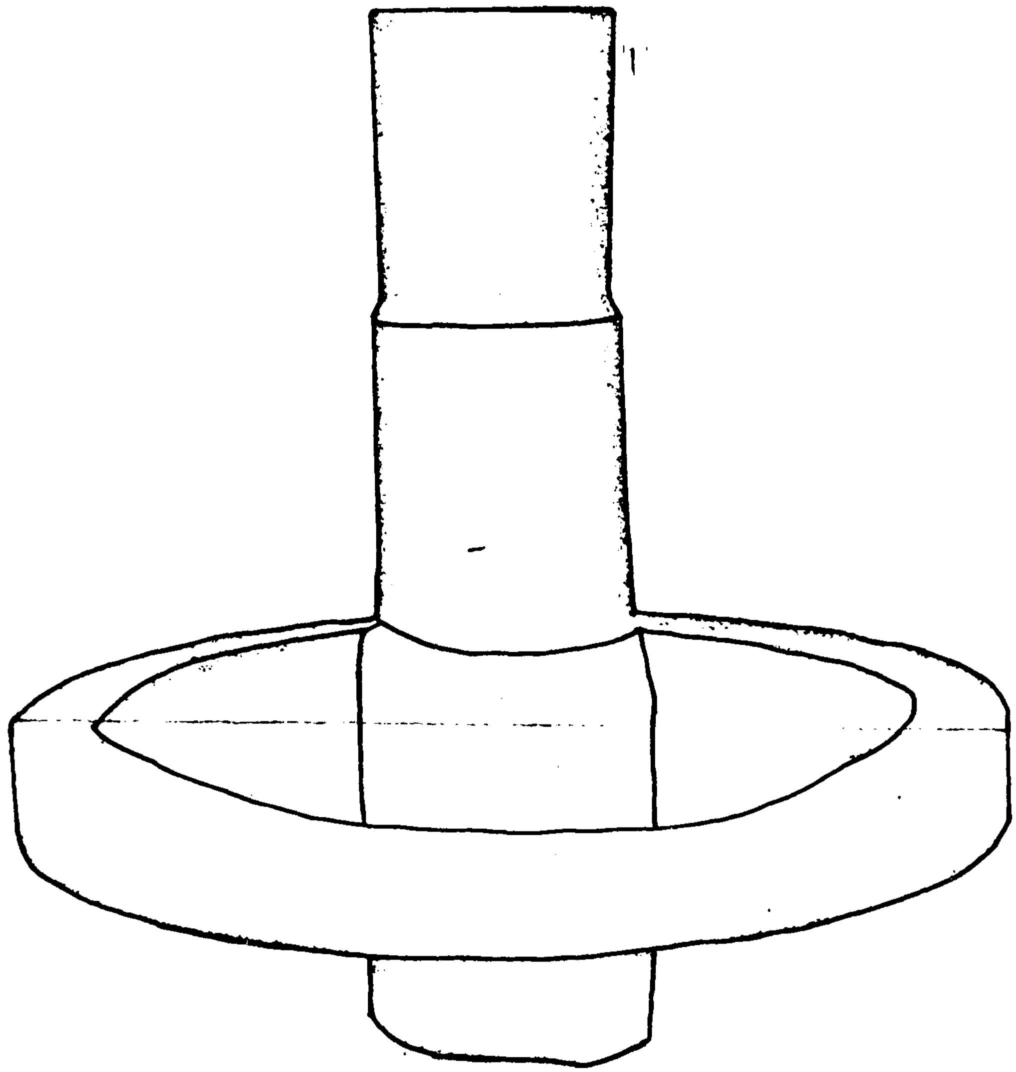

FIGURE 39. IN-792 POWDER METALLURGY DISK (HIP)

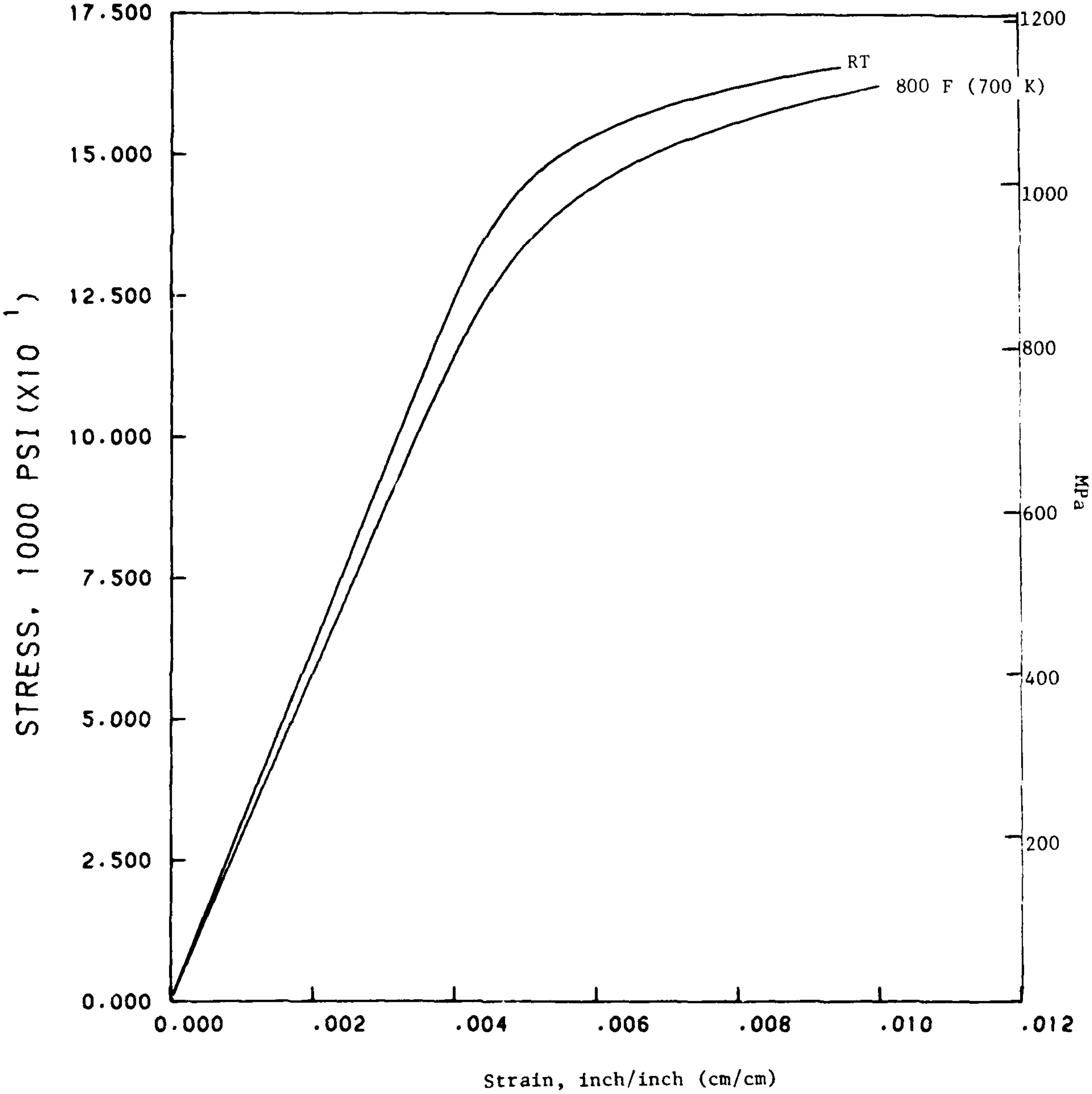

FIGURE 40. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR IN-792 PM DISK (HIP)

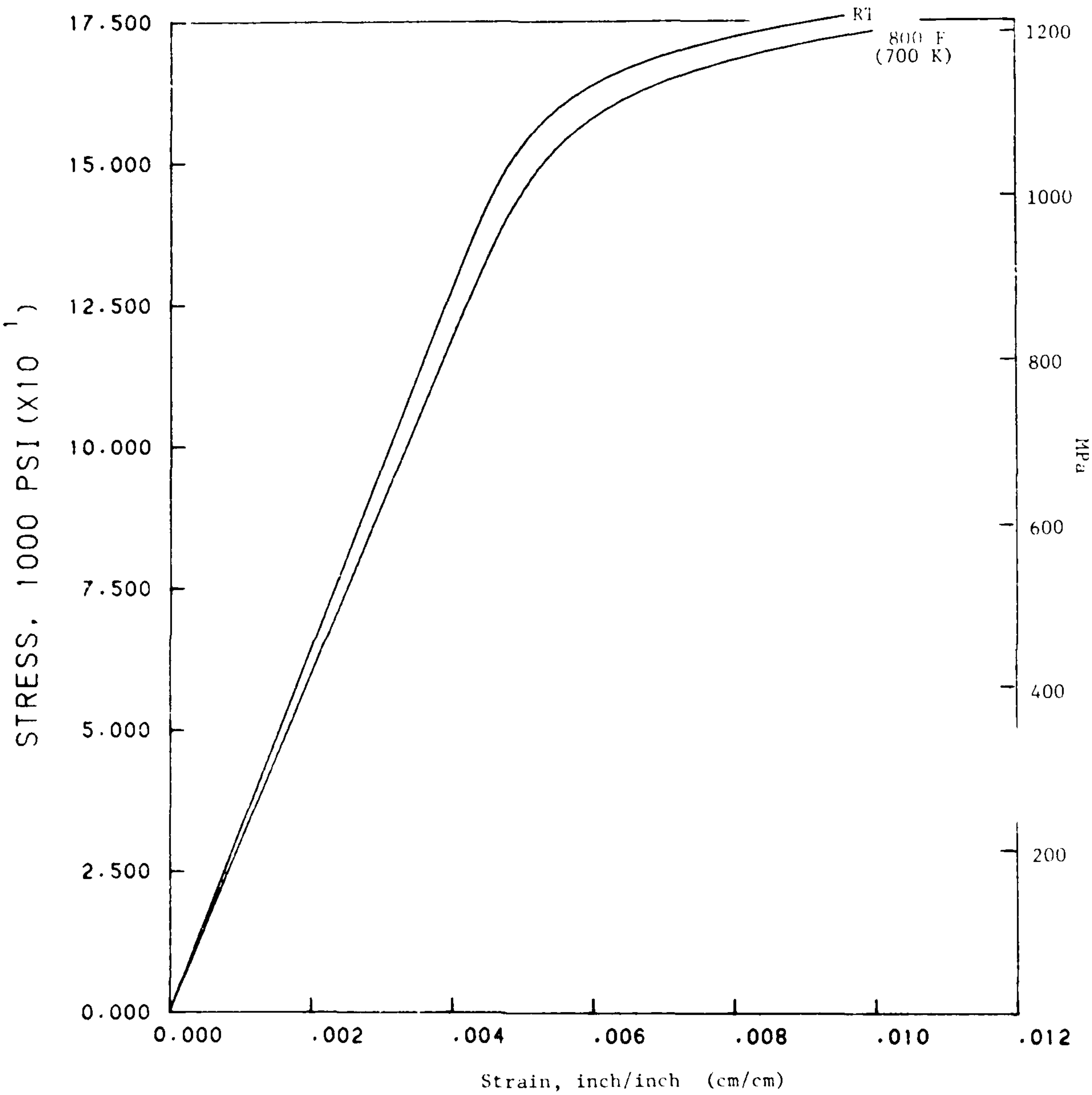

FIGURE 41. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR IN-792 PM DISK (HIP)

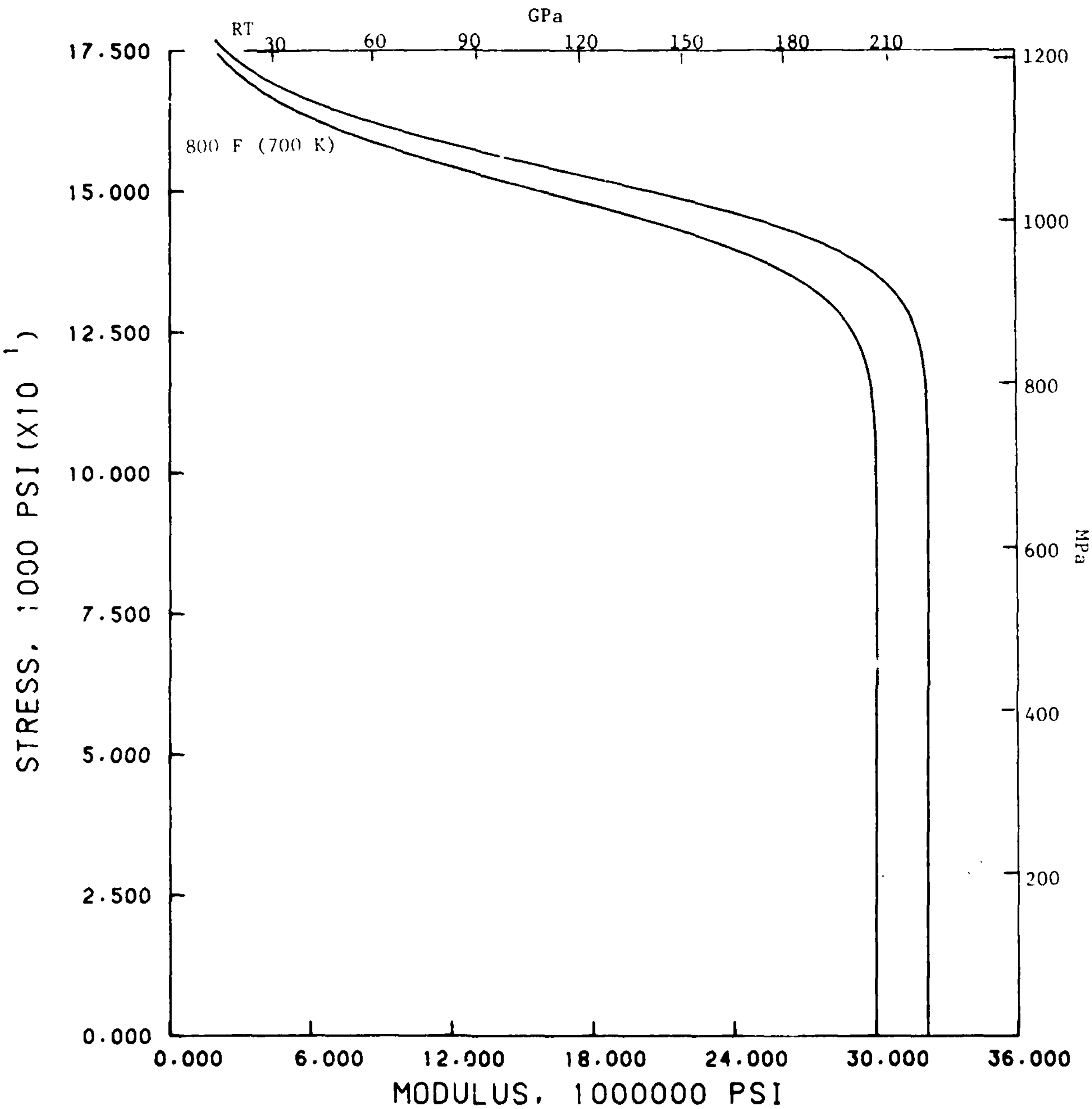

FIGURE 42. TYPICAL COMPRESSIVE TANGENT-MODULUS CURVES AT TEMPERATURE FOR IN-792 PM DISK (HIP)

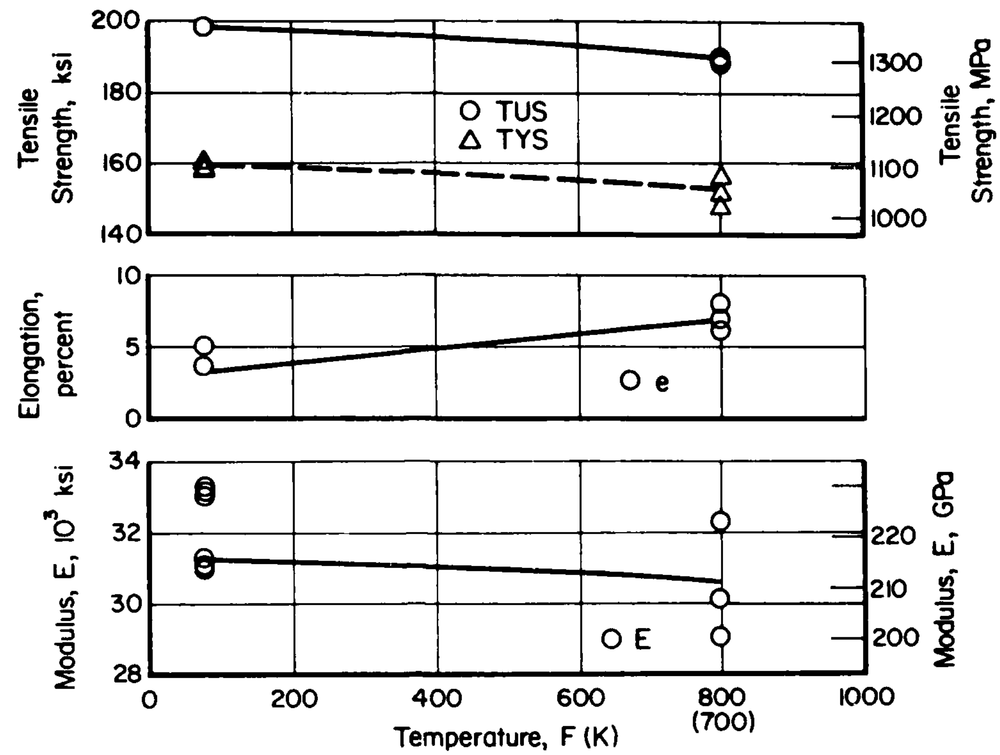

FIGURE 43. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF IN-792 PM DISK (HIP)

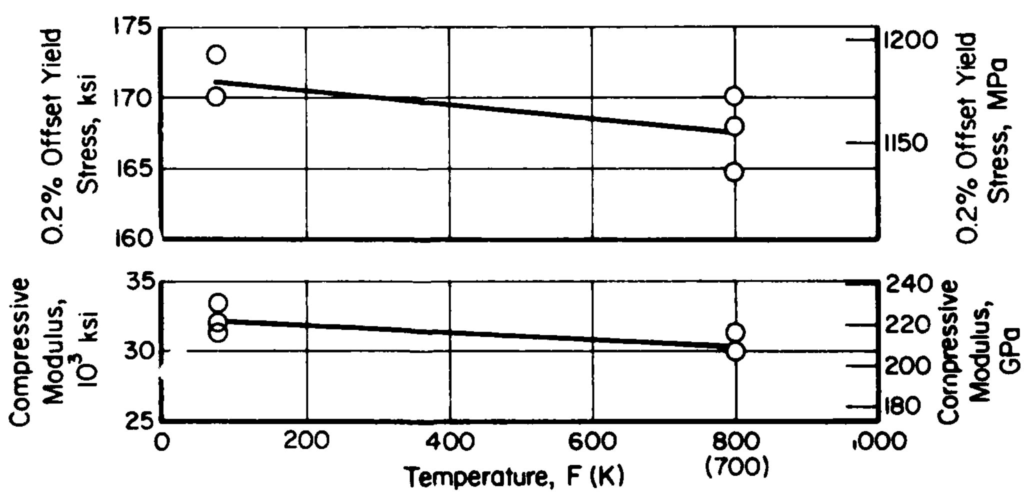

FIGURE 44. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF IN-792 PM DISK (HIP)

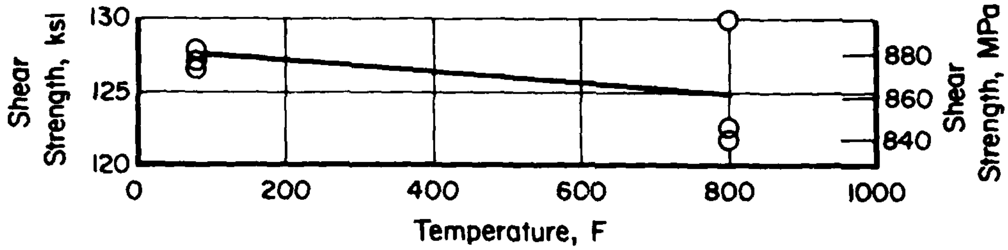

FIGURE 45. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF IN-792 PM DISK (HIP)

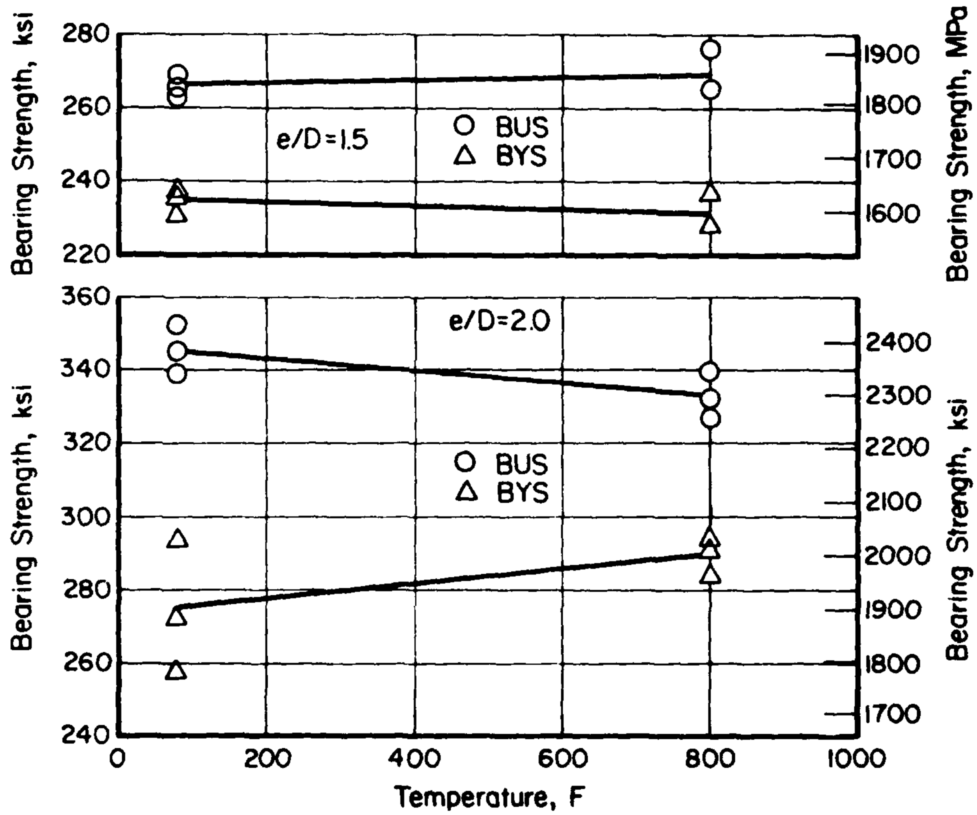

FIGURE 46. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF IN-792 PM DISK (HIP)

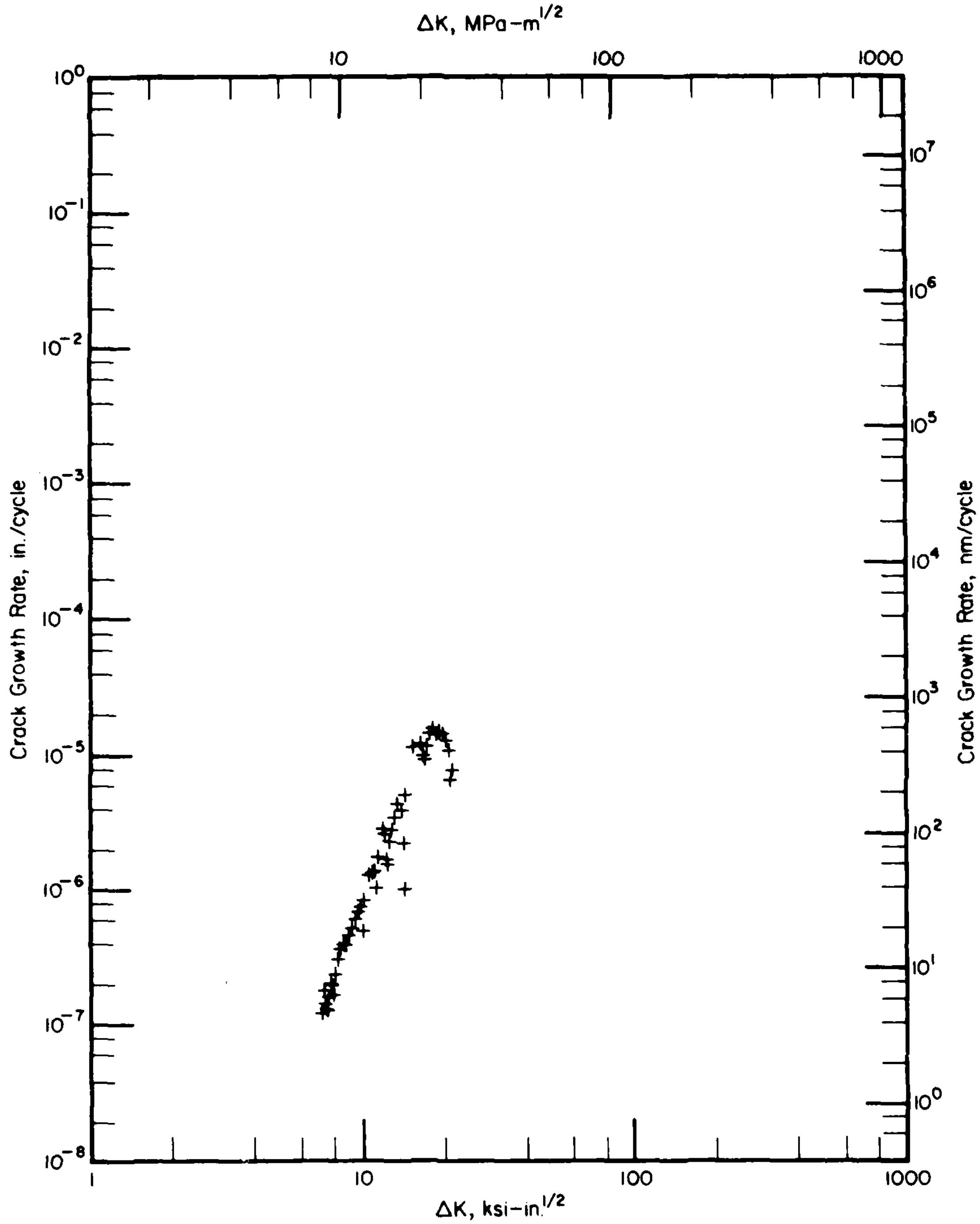

FIGURE 47. CRACK PROPAGATION TEST RESULTS FOR IN-792 PM DISK (HIP)

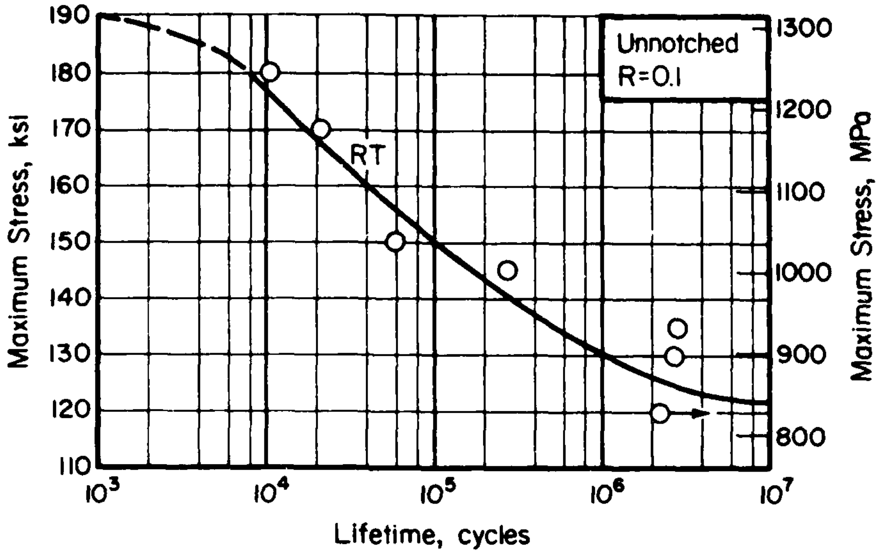

FIGURE 48. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED IN-792 PM DISK (HIP)

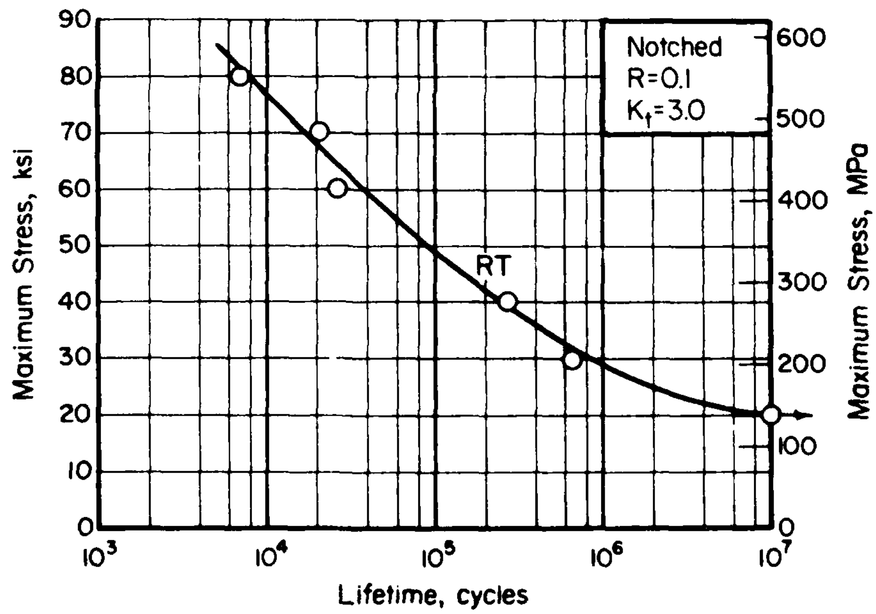

FIGURE 49. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) IN-792 PM DISK (HIP)

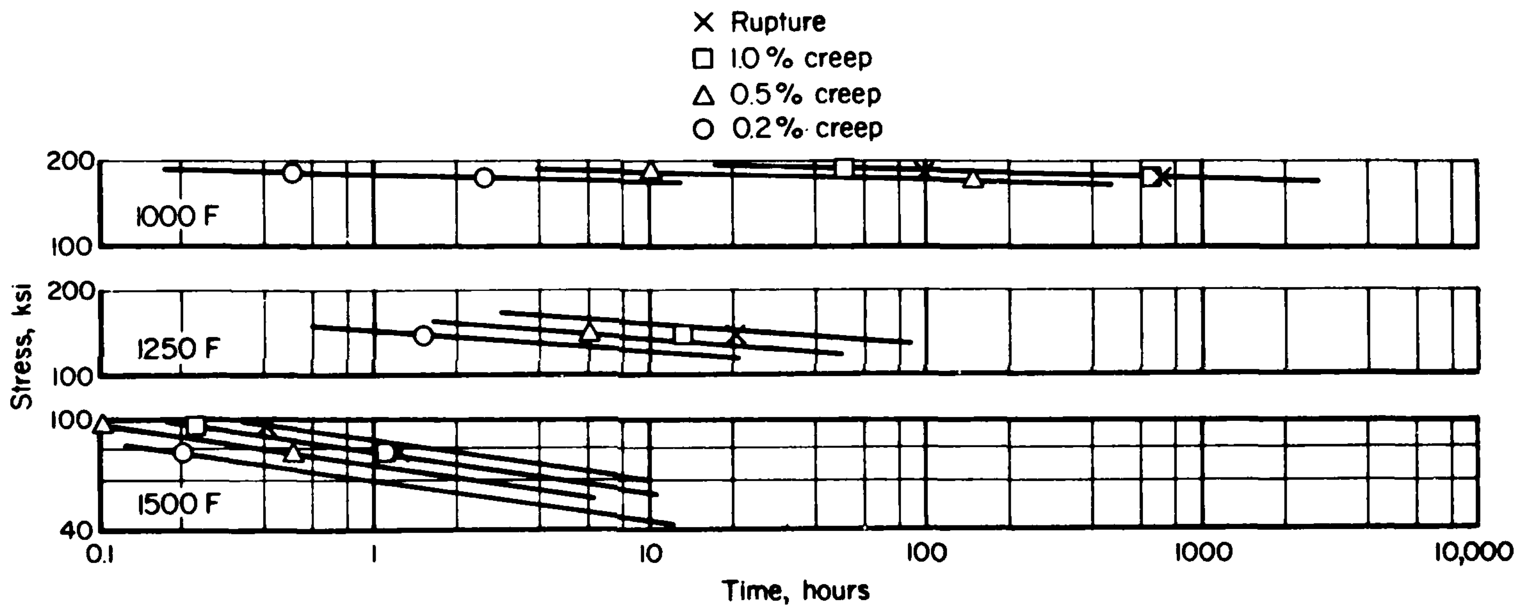

FIGURE 50. STRESS RUPTURE AND PLASTIC DEFORMATION CURVES FOR IN-792 PM DISK (HIP)

CT-91-T7E70 Aluminum Alloy PM Product

Material Description

This alloy is a recent development of the Aluminum Company of America. Formerly called MA-87, it is now finalized in composition and has been designated CT-91. It is a powder metallurgy material designed for good strength and fracture toughness. The material used in this investigation was obtained from the ALCOA Research Laboratories as 1-1/2 inch by 4-1/2 inch flat bar. The heat treatment chosen for evaluation was the -T7E70 (fracture toughness) temper.

Processing and Heat Treating

Specimens were sectioned from the bar in both longitudinal and long transverse directions. Specimens were tested in the as-received -T7E70 temper.

The specimen layout is shown in Figure 51.

Test Results

Tension. Results of tests at room temperature, 250 F (394 K) and 350 F (450 K) for specimens in the longitudinal and long transverse direction are given in Table 29. Typical tensile stress-strain curves at temperature are presented in Figures 52 and 53. Effect-of-temperature curves are shown in Figure 54.

Shear. Results of shear tests at room temperature, 250 F (394 K), and 350 F (450 K) are given in Table 30. Effect-of-temperature curves are shown in Figure 55.

Fracture Toughness. Compact tension type tests were conducted at room temperature for longitudinal (L-T) and transverse (T-L) specimens. Results are presented in Table 31.

Crack Propagation. Tests were performed at room temperature for specimens in the transverse (T-L) direction. Test results are shown in Figure 56.

Fatigue. Axial load fatigue tests were conducted at room temperature and 350 F (450 K). Test results are given in Tables 32 and 33. S-N curves are presented in Figures 57 and 58.

TABLE 29. RESULTS OF TENSILE TESTS FOR CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

Specimen Number		Tensile Ultimate Strength, ksi (MPa)	0.2 Percent Offset Yield Strength, ksi (MPa)	Elongation in 1 inch (25.4 mm), percent	Tensile Modulus, 10^3 ksi (GPa)
		Room Temperature			
1L-1		78.6 (541.9)	71.2 (490.9)	14.0	10.6 (73.1)
1L-2		78.0 (527.8)	71.2 (490.9)	15.0	11.0 (75.8)
1L-3		76.2 (525.4)	70.1 (483.3)	14.0	10.2 (70.3)
	Average	77.6 (535.1)	70.8 (488.4)	14.3	10.6 (73.1)
1T-1		72.3 (498.5)	62.8 (433.0)	10.0	10.0 (68.9)
1T-2		74.6 (514.4)	63.0 (434.4)	11.0	10.1 (69.6)
1T-3		71.0 (489.5)	64.6 (445.4)	10.0	9.9 (68.3)
	Average	72.6 (500.8)	63.5 (437.6)	10.3	10.0 (68.9)
		250 F (394 K)			
1L-4		70.6 (486.8)	63.0 (434.4)	21.0	9.8 (67.6)
1L-5		68.8 (474.4)	62.6 (431.6)	20.0	10.0 (68.9)
1L-6		67.8 (467.5)	61.0 (420.6)	21.0	10.0 (68.9)
	Average	69.1 (476.2)	62.2 (428.9)	20.7	9.9 (68.5)
1T-4		67.8 (467.5)	58.0 (399.9)	16.0	9.4 (64.8)
1T-5		65.7 (453.0)	57.7 (397.8)	17.0	8.6 (59.3)
1T-6		66.0 (455.1)	58.3 (402.0)	18.0	9.0 (62.1)
	Average	66.5 (458.5)	58.3 (402.2)	17.0	9.0 (62.1)
		350 F (450 K)			
1L-7		64.0 (441.3)	57.6 (397.2)	25.0	8.0 (55.2)
1L-8		62.1 (428.2)	54.0 (372.3)	20.0	9.1 (62.7)
1L-9		66.6 (459.2)	54.0 (372.3)	31.0	8.9 (61.4)
	Average	64.2 (442.9)	55.2 (380.6)	25.3	8.7 (59.8)
1T-7		60.2 (415.1)	54.6 (376.5)	20.1	9.2 (63.4)
1T-8		57.6 (397.2)	51.2 (353.0)	19.0	8.8 (60.6)
1T-9		58.3 (402.0)	52.1 (359.2)	24.0	8.2 (56.5)
	Average	58.7 (404.7)	52.6 (362.9)	21.0	8.7 (60.2)

TABLE 30. PIN SHEAR TEST RESULTS FOR CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

Specimen Number		Shear Ultimate Strength, ksi(MPa)
		Room Temperature
3L-1		43.7 (301.3)
3L-2		43.7 (301.3)
3L-3		42.3 (291.6)
	Average	43.2 (297.9)
3T-1		42.2 (291.0)
3T-2		42.9 (295.8)
3T-3		42.5 (293.0)
	Average	42.5 (293.0)
		250 F (394 K)
3L-4		35.7 (246.2)
3L-5		38.6 (266.1)
3L-6		36.3 (250.3)
	Average	36.9 (254.4)
3T-4		36.1 (248.9)
3T-5		37.1 (255.8)
3T-6		37.1 (255.8)
	Average	36.8 (253.7)
		350 F (450 K)
3L-7		31.7 (218.6)
3L-8		31.5 (217.2)
3L-9		31.7 (218.6)
	Average	31.6 (217.9)
3T-7		31.1 (214.4)
3T-8		30.5 (210.3)
3T-9		31.1 (214.4)
	Average	30.9 (213.1)

TABLE 31. RESULTS OF FRACTURE TOUGHNESS TESTS FOR CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

Specimen Number	Width, W, inches (mm)	Thickness, B, inch (mm)	Crack, a, inch (mm)	P_Q, lbs. (Kg)	K_Q,(a) ksi$\sqrt{in.}$ (MPa · $m^{1/2}$)
			Longitudinal (L-T)		
6L-1	3.00 (76.2)	1.495 (37.97)	1.593 (40.46)	1135 (515)	46.7 (51.4)
6L-2	3.00 (76.2)	1.499 (38.07)	1.588 (40.34)	1132 (513)	46.3 (50.9)
6L-3	3.00 (76.2)	1.498 (38.05)	1.588 (40.34)	1120 (508)	45.3 (49.8)
				Average	46.1 (50.7)
			Transverse (T-L)		
6T-1	3.00 (76.2)	1.494 (37.95)	1.570 (39.88)	1045 (474)	42.0 (46.2)
6T-2	3.00 (76.2)	1.493 (37.92)	1.536 (39.01)	1050 (476)	40.7 (44.8)
6T-3	3.00 (76.2)	1.492 (37.92)	1.580 (40.13)	1030 (467)	41.9 (46.1)
				Average	41.5 (45.7)

(a) Candidate K_Q values are valid K_{Ic} values per ASTM E399.

TABLE 32. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

Specimen Number	Maximum Stress, ksi(MPa)	Cycles to Failure
	Room Temperature	
8-26	75 (517.1)	3,600
8-25	70 (482.6)	6,200
8-23	65 (448.2)	6,000
8-27	62.5 (430.9)	12,800
8-22	60 (413.7)	21,800
8-28	57.5 (396.5)	20,800
8-29	57.5 (396.5)	36,100
8-30	55 (379.2)	30,900
8-24	55 (379.2)	10,000,000[(a)]
8-40	52.5 (362.0)	75,000
8-21	50 (344.8)	148,400
	350 F (450 K)	
8-31	60 (413.7)	100
8-37	50 (344.8)	500
8-38	47.5 (327.5)	1,200
8-36	45 (310.3)	11,000
8-32	40 (275.8)	61,600
8-35	35 (241.3)	226,100
8-33	30 (206.9)	508,600
8-39	25 (172.4)	4,242,800
8-34	20 (137.9)	10,000,000[(a)]

(a) Did not fail.

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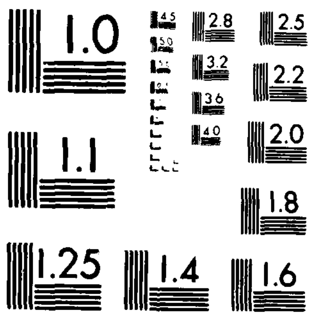
1.0
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1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

TABLE 33. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED (K_t = 3.0) CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

Specimen Number	Maximum Stress, ksi(MPa)	Cycles to Failure
	Room Temperature	
8-9	40 (275.8)	2,500
8-6	35 (241.3)	4,200
8-2	30 (206.9)	7,700
8-8	25 (172.4)	15,300
8-1	20 (137.9)	16,600
8-10	20 (137.9)	23,800
8-5	17.5 (120.7)	73,900
8-3	15 (103.4)	488,700
8-4	15 (103.4)	1,223,800
8-7	12.5 (86.2)	10,000,000[a]
	350 F (450 K)	
8-17	35 (241.3)	3,100
8-16	20 (206.9)	5,000
8-12	25 (172.4)	10,300
8-14	20 (137.9)	33,400
8-15	17.5 (120.7)	51,500
8-11	15 (103.4)	89,700
8-18	10 (68.9)	5,916,900

(a) Did not fail.

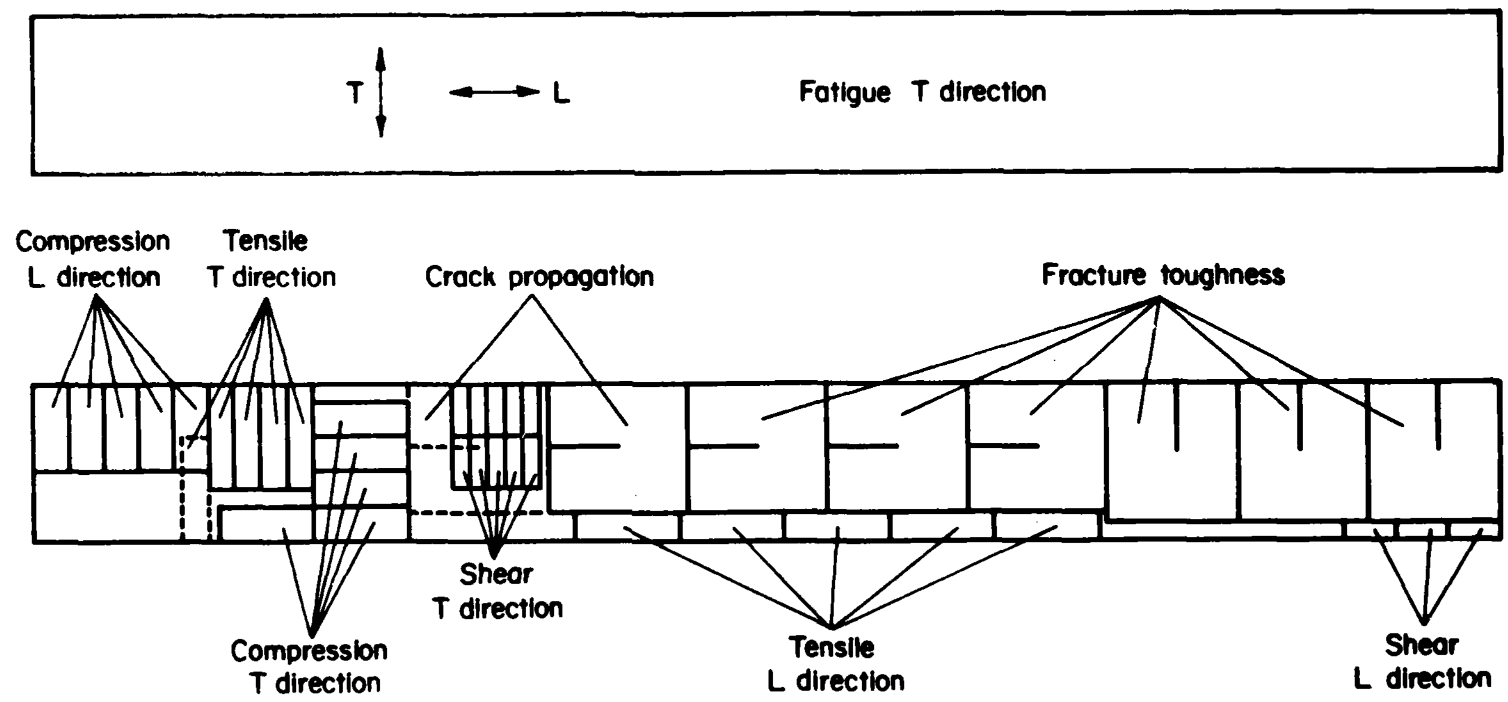
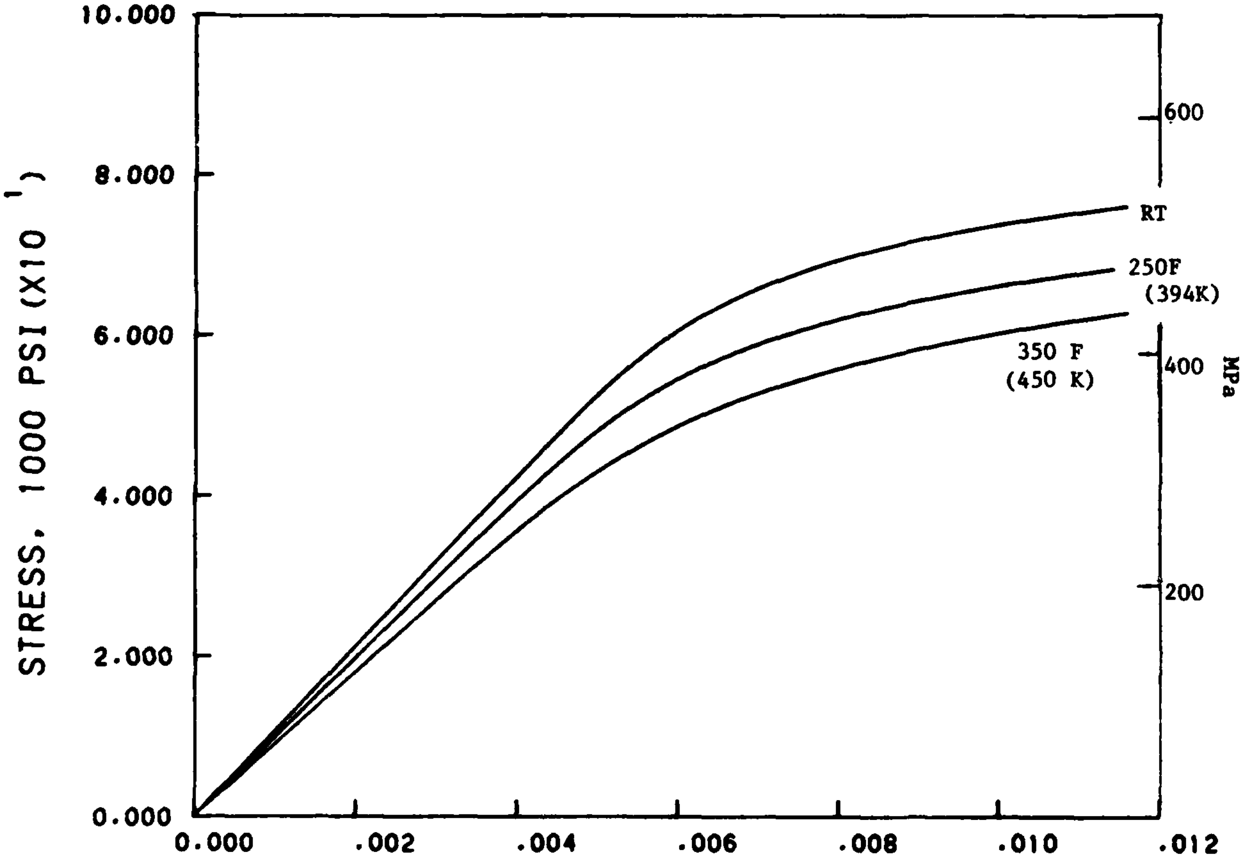


FIGURE 51. SPECIMEN LAYOUT FOR CT-91-T7E70 PM EXTRUDED FLAT BAR



Strain, inch/inch (cm/cm)

FIGURE 52. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR CT-91-T7E70 ALUMINUM PM PRODUCT (LONGITUDINAL)

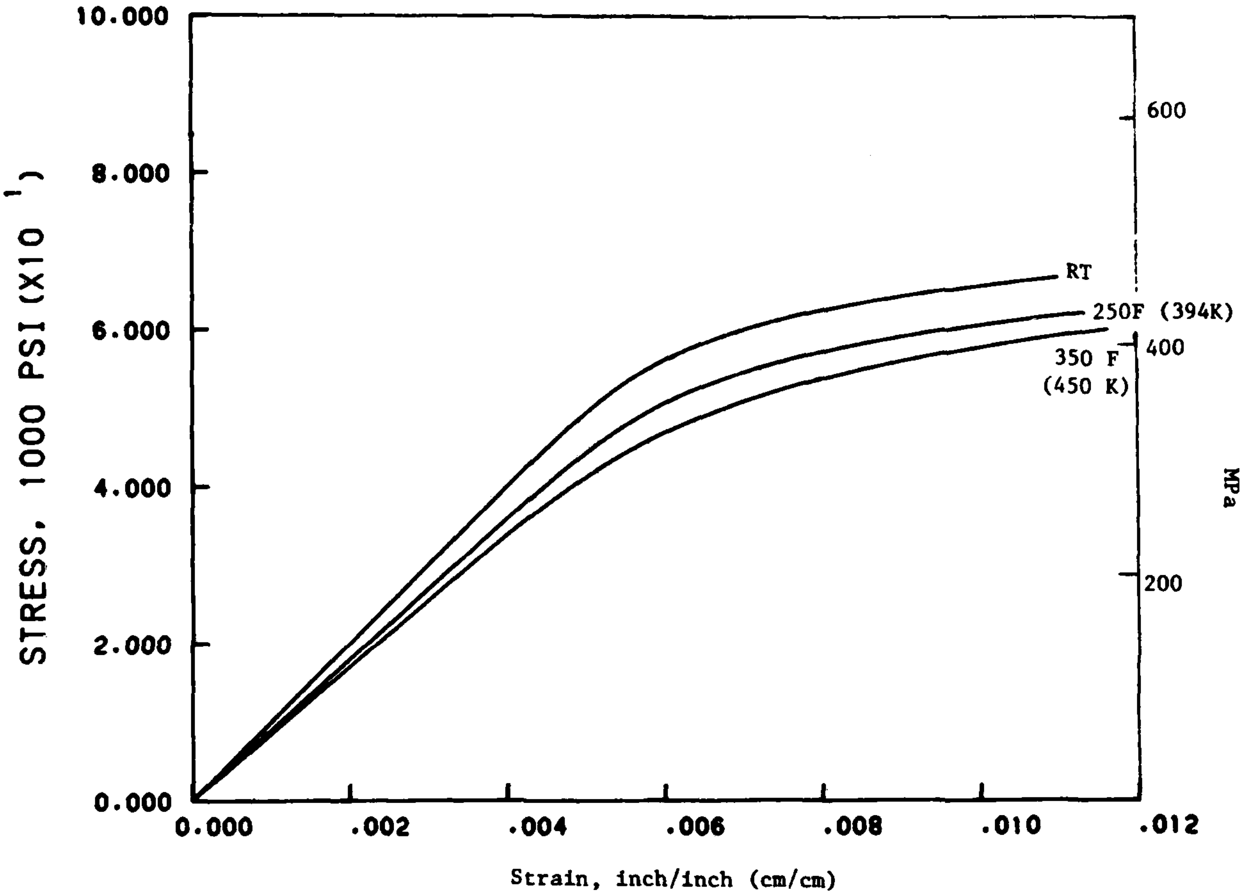


FIGURE 53. TYPICAL COMPRESSIVE STRESS-STRAIN CURVES AT TEMPERATURE FOR CT-91-T7E70 ALUMINUM PM PRODUCT (TRANSVERSE)

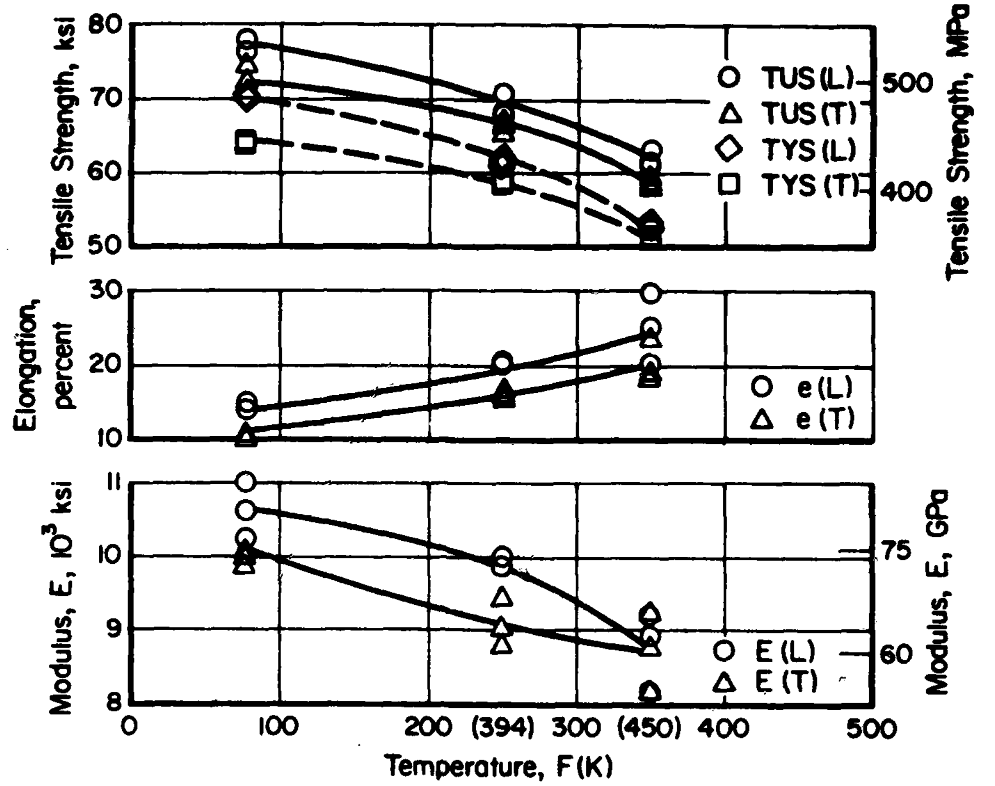


FIGURE 54. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

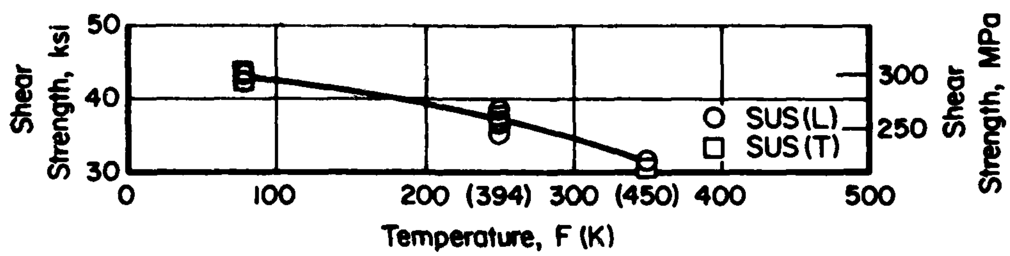


FIGURE 55. EFFECT OF TEMPERATURE ON THE SHEAR PROPERIES OF CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

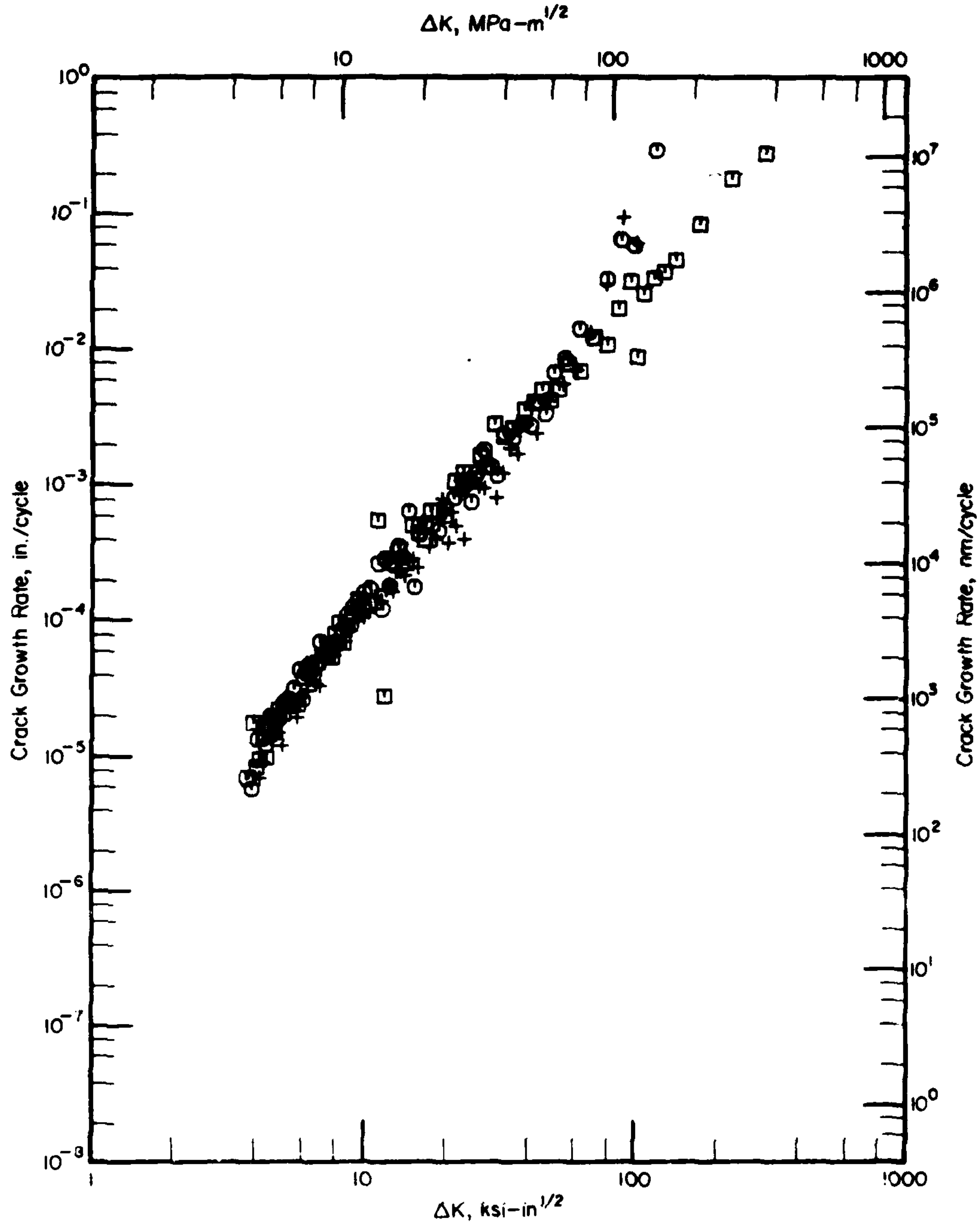


FIGURE 56. CRACK PROPAGATION TEST RESULTS FOR CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

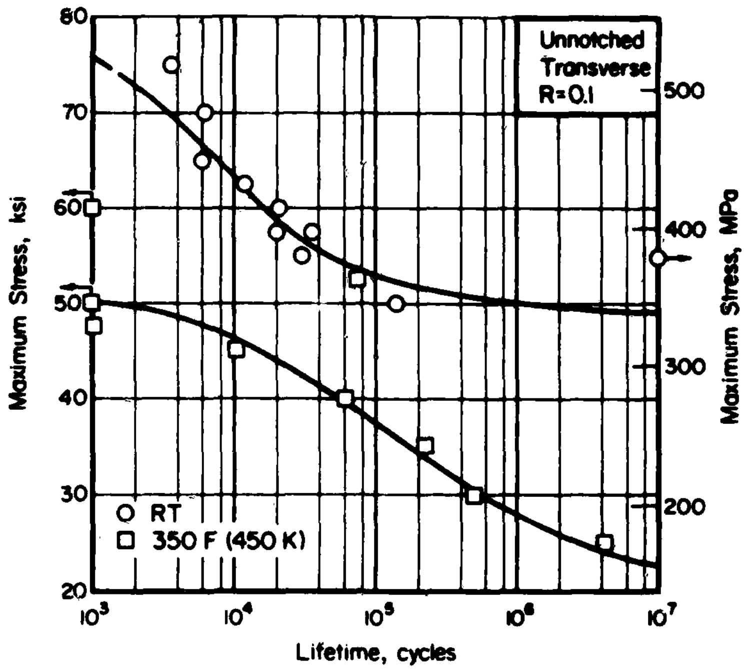


FIGURE 57. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED CT-91-T7E70 ALUMINUM PM PRODUCT

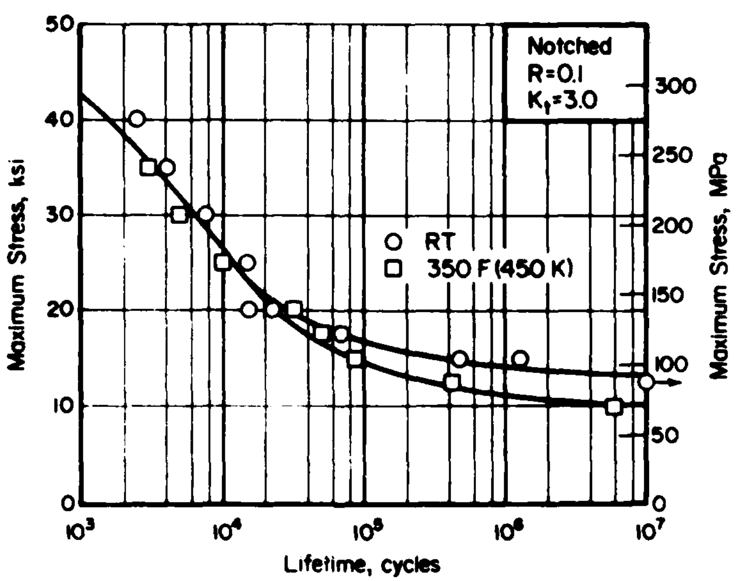


FIGURE 58. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) CT-91-T7E70 ALUMINUM PM PRODUCT

SECTION II

DISCUSSION OF PROGRAM RESULTS

As stated in past reports on other Air Force "data sheet" programs, the tendency in an evaluation program of this type is to compare the materials property information obtained with similar data on materials already in use. Whether such a comparison should be the deciding factor for interest is open to question. Many criteria such as oxidation resistance, weldability, forming characteristics, etc., can be of particular importance in a particular application 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 materials evaluated on this program are compared to each other and to similar alloys. Figures 59 and 60 are effect-of-temperature curves concerned with these properties. As can be seen from these curves, the program alloys compare well with similar materials based on these strength properties.

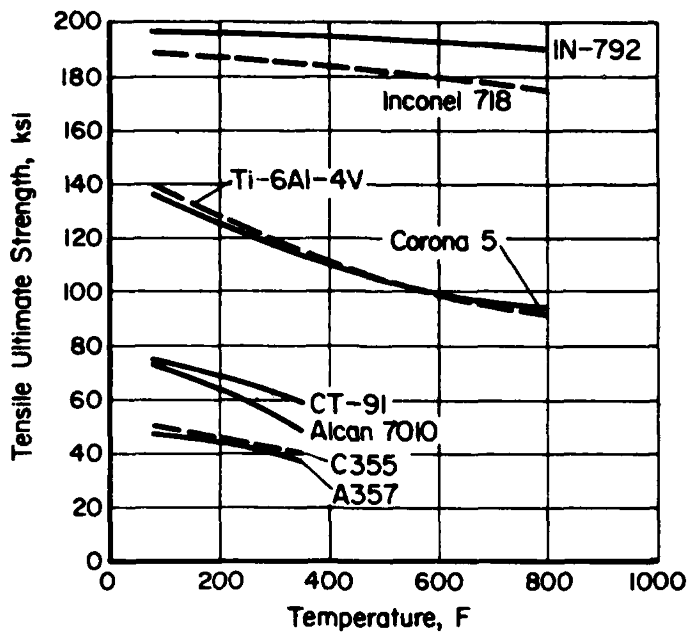


FIGURE 59. TENSILE ULTIMATE STRENGTH AS A FUNCTION OF TEMPERATURE

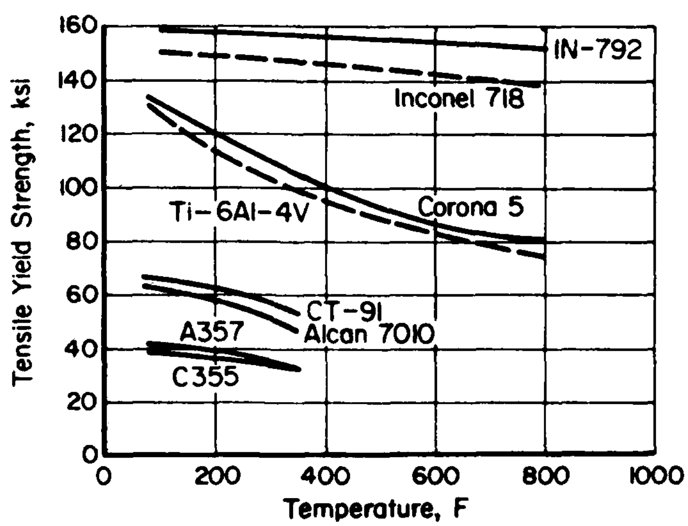


FIGURE 60. TENSILE YIELD STRENGTH AS A FUNCTION OF TEMPERATURE

SECTION III

CONCLUSIONS

The objective of this program was the generation of useful engineering data for newly developed materials and materials manufactured by different processes. During the contract term, the following materials were evaluated:

(1) ALCAN 7010-T73651 plate
(2) Corona 5 plate
(3) A357-T6 casting
(4) IN-792 PM disk
(4) Ct-91-T7E70 PM bar.

A data sheet was issued for each material. As a summary, the data sheets are reproduced in the Appendix.

APPENDIX

<u>DATA SHEETS</u>

MECHANICAL-PROPERTY DATA
ALCAN 7010 ALUMINUM ALLOY

-T73651 PLATE

Issued by

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

DECEMBER 1978

Prepared by

BATTELLE
Columbus Laboratories
Columbus, Ohio 43201

F 33615-78-C-5040

This data sheet was prepared by Battelle's Columbus Laboratories under Contract F33615-78-C-5040. The contract was initiated under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data." The major objectives of this program are to evaluate newly developed structural materials of potential interest to the Air Force weapons system and, then, to provide data-sheet-type presentations of these data. The program was assigned to the Structural Materials and Tribology Section at Battelle-Columbus under the supervision of Mr. Stephen Ford. Project Engineer was Mr. Omar Deel. The program was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Neal Ontko, Engineering and Design Data.

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Alcan 7010-T73651 Aluminum Alloy

Material Description

Alloy 7010 has been developed over a number of years by Alcan Laboratories Banbury and Alcan Plate Limited. The development aim was for an alloy of different composition but with properties comparable to Alloy 7050 as an equivalent material for use in the Panavia Tornado program. The composition differences are:

(1) The use of high purity base aluminum to allow control of the iron and silicon impurities,

(2) The use of zirconium instead of chromium and/or manganese which makes it possible to achieve higher strength in thick section and improve exfoliation resistance, and

(3) The use of a higher copper content in order to achieve good stress-corrosion resistance in overaged tempers.

The material evaluated was 2-inch-thick plate with the following composition:

Chemical Composition	Percent
Zn	6.30
Mg	2.47
Cu	1.80
Zr	.13
Fe	.06
Si	.05
Ti	.01
Cr	<.01
Mn	<.01
Al	balance

Heat Treatment

The material was evaluated in the as-received -T73651 condition.

Alcan 7010[a]

Condition: T-73651
Thickness: 2 in. (50.8 mm)

Properties	Temperature, F (K)					
	RT	(RT)	250	(394)	350	(450)
Tension						
TUS, L, ksi (MPa)	72.3	(498.5)	58.7	(404.7)	47.8	(329.6)
TUS, T, ksi (MPa)	74.1	(511.1)	60.6	(417.8)	49.7	(342.7)
TYS, L, ksi (MPa)	63.2	(435.8)	55.9	(385.7)	46.0	(316.9)
TYS, T, ksi (MPa)	63.6	(438.8)	57.5	(396.2)	47.1	(324.5)
e, L, percent in 1 in. (25.4 mm)	15	(15)	14	(14)	13	(13)
e, T, percent in 1 in. (25.4 mm)	12	(12)	12	(12)	14	(14)
RA, L, percent	44.7	(44.7)	46.3	(46.3)	47.5	(47.5)
RA, T, percent	29.0	(29.0)	42.1	(42.1)	43.6	(43.6)
E, L, 10^3 ksi (GPa)	10.4	(71.5)	9.5	(65.7)	8.8	(60.7)
E, T, 10^3 ksi (GPa)	10.7	(73.8)	9.7	(67.1)	9.1	(63.0)
Compression						
CYS, L, ksi (MPa)	63.4	(437.2)	56.9	(392.1)	46.6	(321.3)
CYS, T, ksi (MPa)	67.7	(467.0)	60.0	(413.9)	50.3	(346.8)
E_c, L, 10^3 ksi (GPa)	10.0	(69.0)	9.0	(61.8)	8.3	(57.0)
E_c, T, 10^3 ksi (GPa)	10.5	(72.6)	9.1	(62.5)	8.2	(56.7)
Shear[b]						
SUS, L, ksi (MPa)	43.6	(300.6)	34.6	(238.6)	28.6	(197.0)
SUS, T, ksi (MPa)	43.1	(296.9)	33.8	(233.1)	27.5	(189.6)
Bearing[c]						
e/D = 1.5						
BUS, L, ksi (MPa)	117.0	(806.4)	93.8	(646.4)	79.0	(544.4)
BUS, T, ksi (MPa)	117.4	(809.1)	94.7	(692.6)	76.1	(524.4)
BYS, L, ksi (MPa)	93.0	(641.2)	79.2	(546.1)	67.3	(464.0)
BYS, T, ksi (MPa)	92.6	(638.1)	81.1	(558.8)	67.1	(462.7)
e/D = 2.0						
BUS, L, ksi (MPa)	151.1	(1041.8)	116.0	(799.8)	93.4	(643.6)
BUS, T, ksi (MPa)	149.8	(1032.9)	119.8	(825.7)	93.1	(641.9)
BYS, L, ksi (MPa)	109.1	(752.2)	92.2	(635.4)	78.5	(540.9)
BYS, T, ksi (MPa)	114.2	(787.1)	95.4	(657.8)	80.2	(552.6)

Properties	Temperature, F (K) RT	(RT)	350	(450)
Fracture Toughness				
K_{Ic}, T-L, $\sqrt{in.}$ ($MPa \cdot m^{1/2}$)	24.9	(27.4)[d]	U[e]	
K_{Ic}, L-T, $\sqrt{in.}$ ($MPa \cdot m^{1/2}$)	29.6	(32.5)[d]	U	
Axial Fatigue (Transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi (MPa)	74	(510)	52	(359)
10^5 cycles, ksi (MPa)	58	(400)	43	(296)
10^7 cycles, ksi (MPa)	47	(324)	27	(186)
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi (MPa)	50	(345)	42	(290)
10^5 cycles, ksi (MPa)	18	(124)	18	(124)
10^7 cycles, ksi (MPa)	7.5	(52)	7.5	(52)
Stress Corrosion				
K_{Iscc} Values Initial, ksi$\sqrt{in.}$ ($MPa \cdot m^{1/2}$)	34.9	(38.3)[g]	U	
K_{Iscc} Values at 995 hrs., ksi$\sqrt{in.}$ ($MPa \cdot m^{1/2}$)	30.1	(33.1)	U	
Coefficient of Thermal Expansion				
12.7 in./in./F x 10^{-6} (70 to 212 F)				
22.9 m/(m·K) x 10^{-6} (294 to 373 K)				
Density				
0.102 lb./in.^{3} (2.82 g/cm^3)				

(a) VALUES 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 the results of a greater number of tests.

(b) DOUBLE-SHEAR pin-type specimen.

(c) MIL-HDBK-5 "clean pin" type tests.

(d) VALUES are valid per ASTM E399

(e) U , unavailable.

(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) Crack arrest values using Damage Tolerant Design Handbook bolt-loaded double cantilever beam specimen.

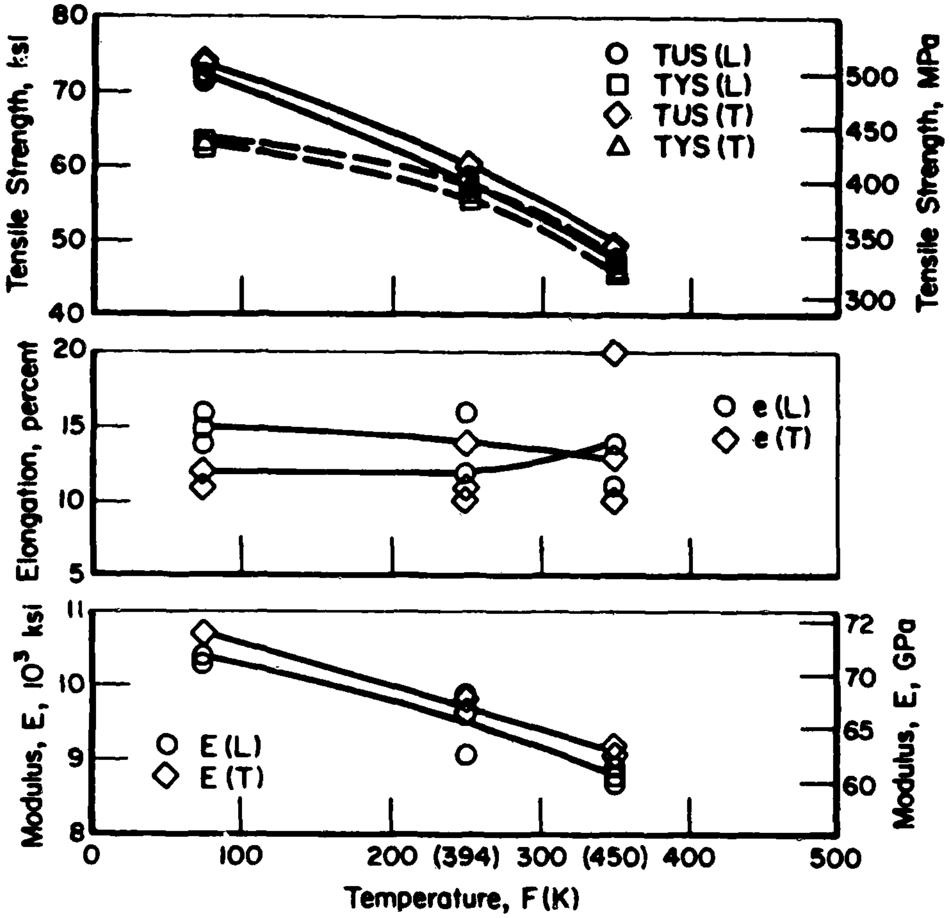

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

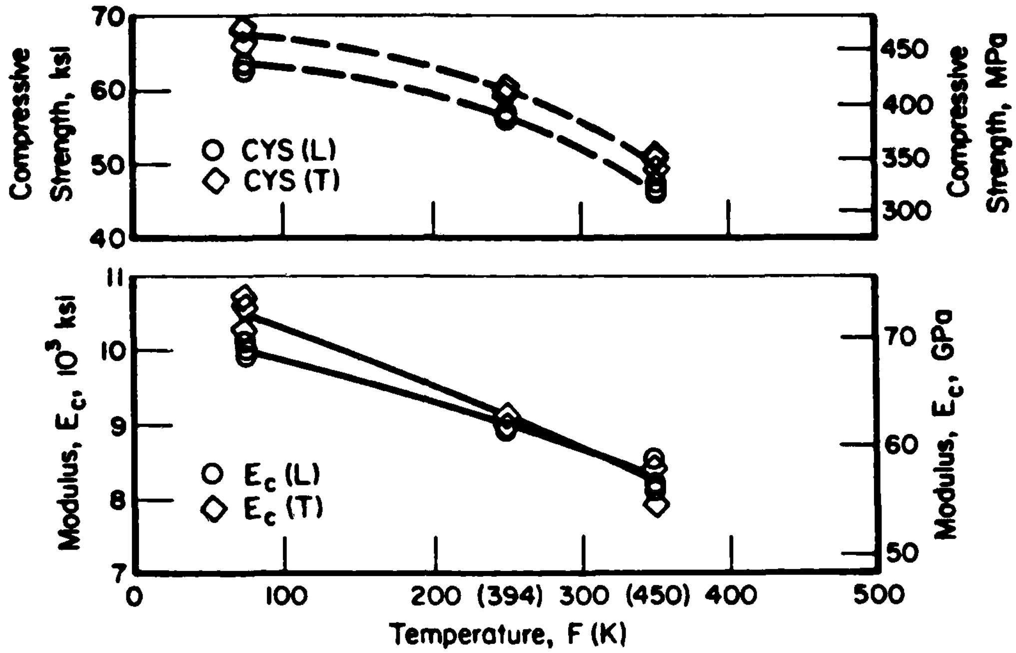

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

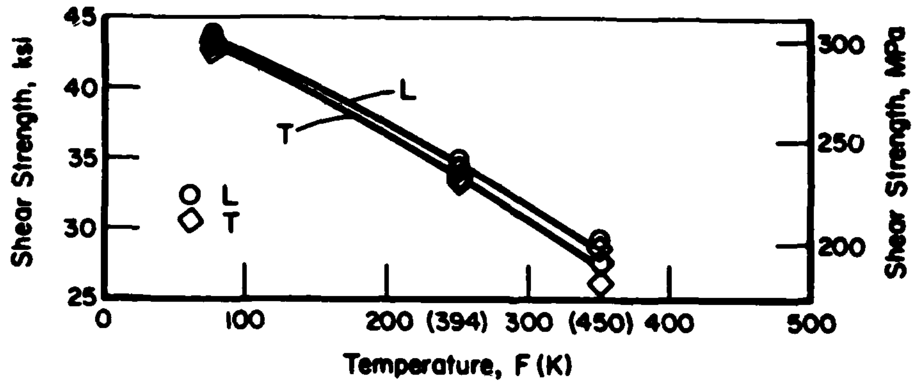

FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR STRENGTH OF ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

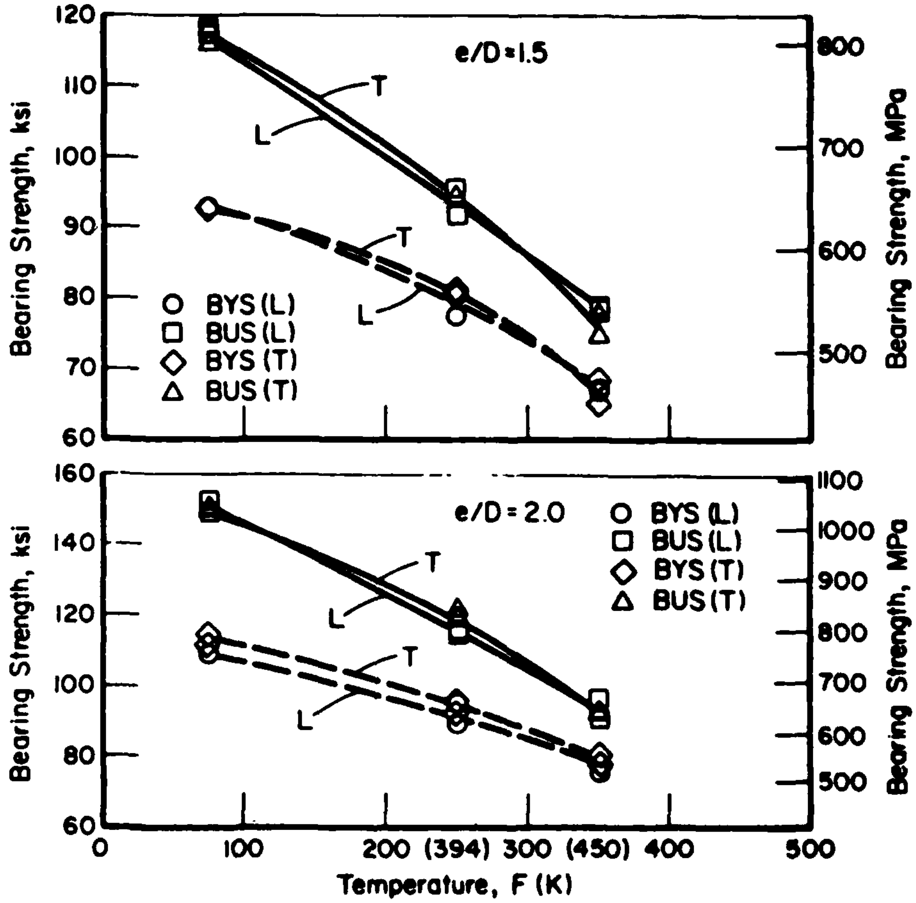

FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

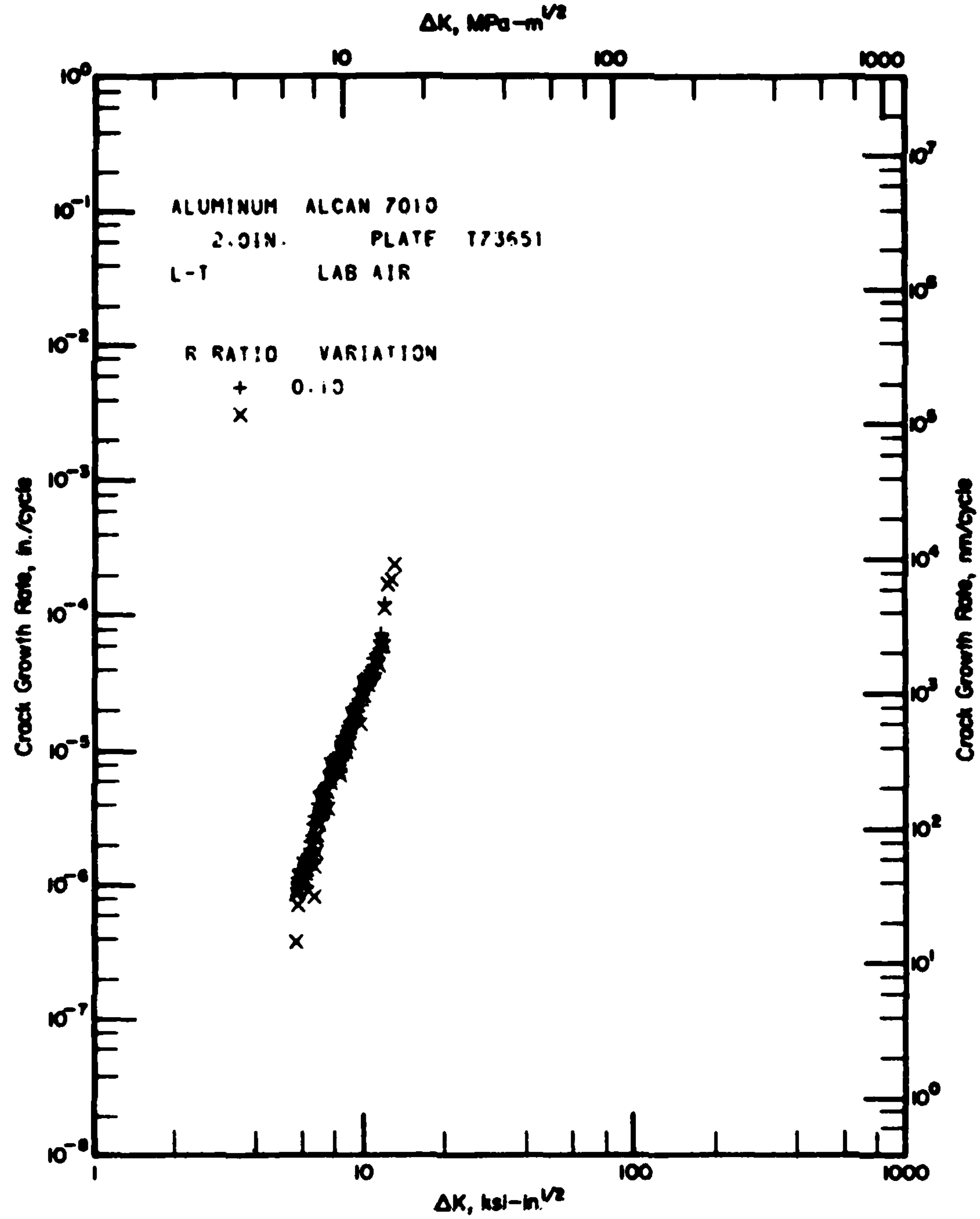

FIGURE 5. da/dN VERSUS DELTA K FOR ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

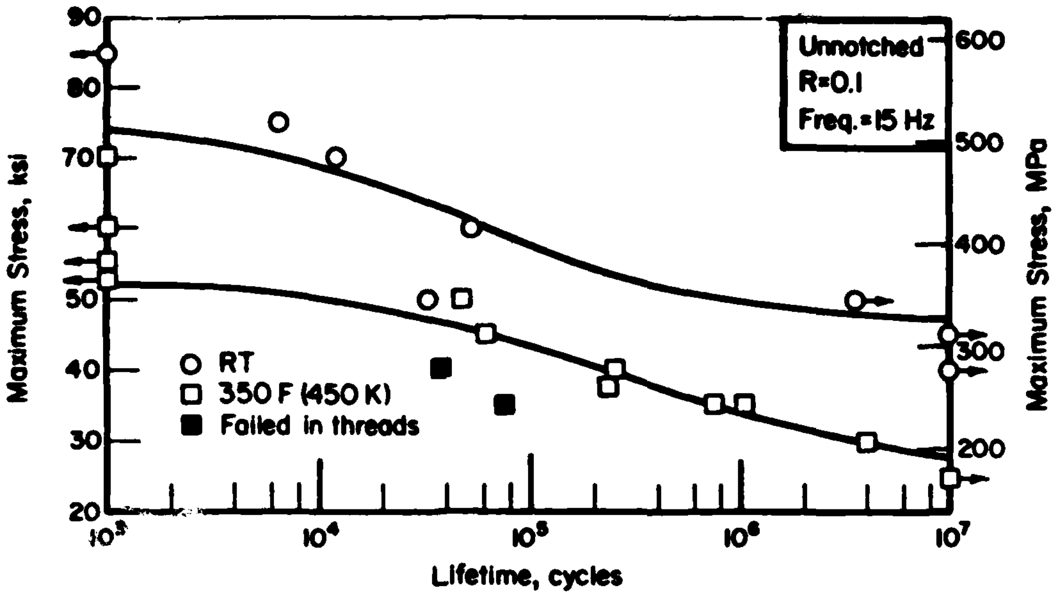

FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

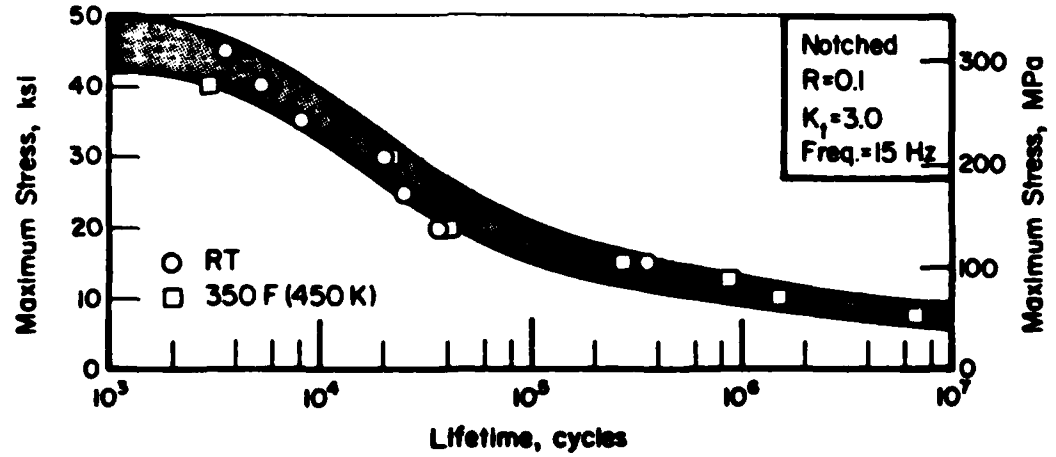

FIGURE 7. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED ALCAN 7010-T73651 ALUMINUM ALLOY PLATE

MECHANICAL-PROPERTY DATA
CORONA 5(Ti-4.5Al-5Mo-1.5Cr) ALLOY

ALPHA-BETA PROCESSED PLATE

Issued by

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

JANUARY 1980

Prepared by

BATTELLE
Columbus Laboratories
Columbus, Ohio 43201

F33615-78-C-5040

Corona 5 Titanium Alloy, Alpha-Beta Processed

Material Description

Corona 5 is an alpha-beta titanium alloy recently developed jointly by Rockwell International and Colt Industries under NAVAIR sponsorship. The basic alloy was developed for fracture critical applications in the aerospace industry. The alpha-beta processing was chosen to allow optimization of both fracture toughness and fatigue properties. Maximum fracture toughness alone would require beta processing, but would also result in somewhat lower tensile and fatigue values.

The material evaluated was supplied GFM as 2-inch-thick plate with the following composition:

Chemical Composition	Percent
Al	4.4
Mo	5.1
Cr	1.46
Fe	0.20
C	0.065
O_2	0.183
N_2	0.011
H_2	0.0018
Ti	Remainder

Processing and Heat Treating

The plate was alpha-beta rolled from 1650 F (1172 K). The material was then heat treated as follows: duplex alpha-beta annealed at 1685 F (1192 K) for one-half hour plus 1525 F (1103 K) for 4 hours, air cool, plus age at 1300 F (978 K) for 6 hours, air cool.

Corona 5 Titanium Alloy Plate[a]

Condition: Alpha-Beta Processed
Thickness: 2 inch (50.8 mm)

Properties	Temperature, F (K) RT	(RT)	400	(478)	800	(700)
Tension						
TUS, L, ksi (MPa)	138.7	(956.6)	112.3	(774.1)	97.6	(673.1)
TUS, T, ksi (MPa)	131.5	(906.7)	108.8	(750.2)	90.9	(627.0)
TYS, L, ksi (MPa)	136.5	(940.9)	99.8	(688.4)	84.3	(581.1)
TYS, T, ksi (MPa)	128.1	(883.5)	95.9	(661.2)	75.2	(518.3)
e, L, percent in 2 in. (50.8 mm)	7	(7)	19	(19)	17	(17)
e, T, percent in 2 in. (50.8 mm)	13	(13)	18	(18)	20	(20)
RA, L, percent	13	(13)	57.8	(57.8)	69.7	(69.7)
RA, T, percent	24	(24)	49.8	(49.8)	60.9	(60.9)
E, L, 10^3 ksi (GPa)	16.5	(113.8)	15.1	(104.1)	13.2	(90.8)
E, T, 10^3 ksi (GPa)	15.5	(106.9)	14.8	(102.0)	13.5	(93.3)
Compression						
CYS, L, ksi (MPa)	142.6	(983.5)	103.0	(710.2)	79.6	(548.6)
CYS, T, ksi (MPa)	154.9	(1068.0)	110.1	(758.9)	85.9	(592.3)
E_c, L, 10^3 ksi (GPa)	16.5	(114.0)	14.5	(100.0)	12.7	(87.3)
E_c, T, 10^3 ksi (GPa)	17.8	(122.5)	15.5	(106.6)	13.1	(90.1)
Shear[b]						
SUS, L, ksi (MPa)	83.1	(573.0)	72.6	(500.3)	60.5	(417.1)
SUS, T, ksi (MPa)	88.8	(612.3)	73.5	(507.0)	61.0	(420.6)
Bearing[c]						
e/D = 1.5						
BUS, L, ksi (MPa)	208.8	(1439.4)	182.9	(1261.1)	190.8	(1315.2)
BUS, T, ksi (MPa)	232.2	(1601.0)	195.9	(1350.7)	212.2	(1462.9)
BYS, L, ksi (MPa)	196.4	(1354.2)	155.6	(1072.9)	128.9	(888.8)
BYS, T, ksi (MPa)	204.5	(1410.3)	164.1	(1131.5)	133.0	(917.0)
e/D = 2.0						
BUS, L, ksi (MPa)	269.4	(1857.3)	227.0	(1565.2)	196.8	(1356.6)
BUS, T, ksi (MPa)	299.3	(2063.9)	240.0	(1655.0)	207.2	(1428.9)
BYS, L, ksi (MPa)	238.0	(1640.8)	182.6	(1258.7)	147.6	(1017.7)
BYS, T, ksi (MPa)	251.5	(1734.1)	187.9	(1295.6)	159.8	(1102.1)
Fracture Toughness*						
K_{Ic}, L-T, ksi$\sqrt{in.}$ (MPa·$m^{1/2}$)	60.5	(66.5)[d]	U[e]		U	
K_{Ic}, T-L, ksi$\sqrt{in.}$ (MPa·$m^{1/2}$)	59.8	(65.8)[d]	U		U	

*Special Note: It was necessary to obtain a second piece of Corona 5 alpha-beta processed plate of the same heat for the fracture toughness tests. Fracture toughness data generated from this piece was within the scatter band typical for this material as generated by Colt Industries. Room temperature tensile strengths for the additional material were determined to be 150 ksi (1034 MPa) ultimate tensile and 143 ksi (986 MPa) yield strength, slightly higher than previously established.

(Continued)

Properties	RT	(RT)	800	(700)
	Temperature, F (K)			
Axial Fatigue (Transverse)[f]				
Unnotched, R = 0.1				
10^3 cycles, ksi (MPa)	113	(779)	91	(627)
10^5 cycles, ksi (MPa)	88	(607)	73	(503)
10^7 cycles, ksi (MPa)	62	(427)	55	(379)
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi (MPa)	85	(586)	79	(545)
10^5 cycles, ksi (MPa)	33	(228)	45	(310)
10^7 cycles, ksi (MPa)	25	(172)	35	(241)
Creep (Transverse)				
0.2% plastic deformation, 100 hr, ksi (MPa)	NA		24	(165)
0.2% plastic deformation, 1000 hr, ksi (MPa)	NA		16	(110)
Stress Rupture (Transverse)				
Rupture, 100 hr, ksi (MPa)	NA		85	(586)
Rupture, 1000 hr, ksi (MPa)	NA		71	(490)
Coefficient of Thermal Expansion				
6.1 in./in./F x 10^{-6} (RT-800 F)				
[11.0 m/(m·K) x 10^{-6} (RT-700 K)]				
Density				
0.164 lb/in.^{3}				
(4.539 g/cm^3)				

(a) VALUES 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 the results of a greater number of tests.
(b) DOUBLE-SHEAR pin-type specimen.
(c) MIL-HDBK-5 "clean pin" type tests.
(d) VALUES are valid per ASTM E399.
(e) U; unavailable, NA; not applicable.
(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.

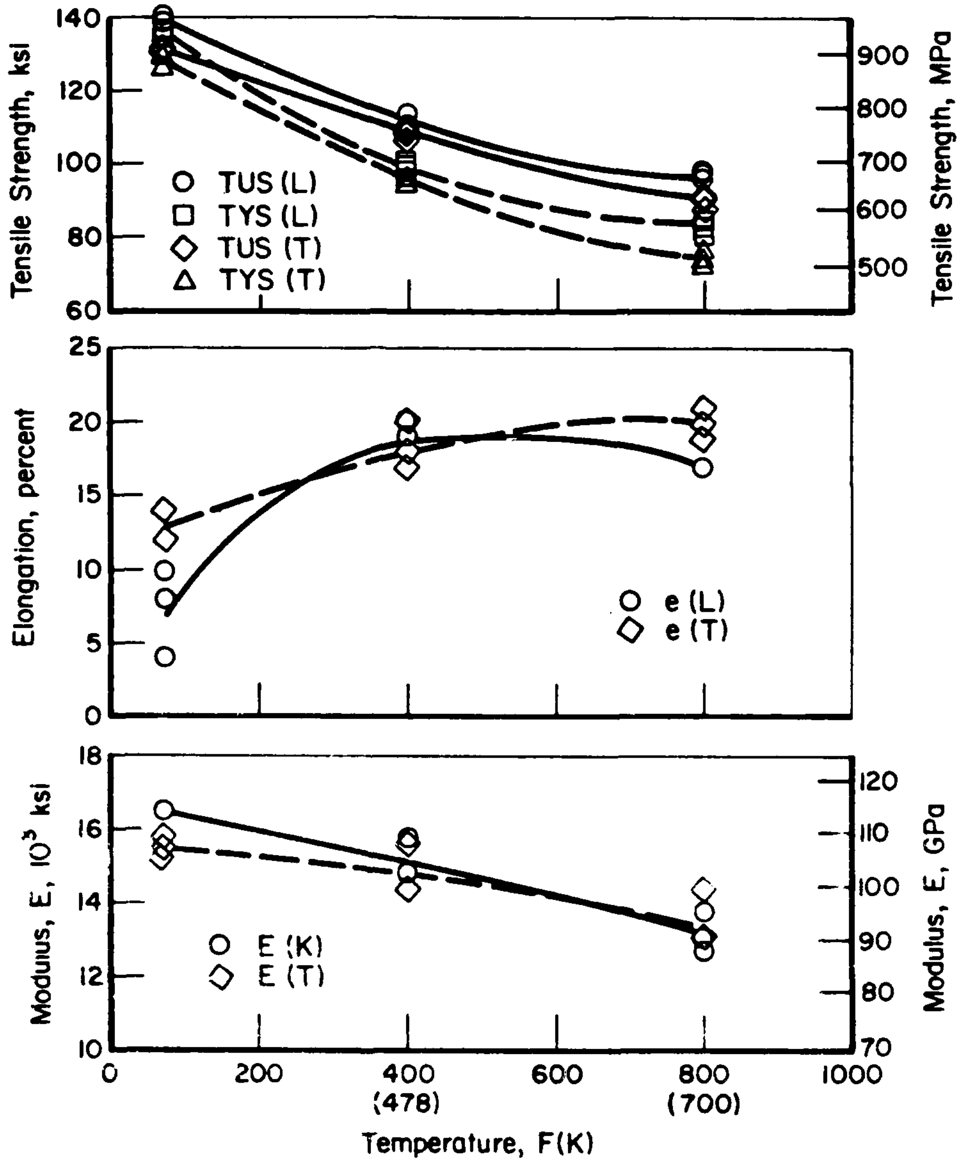

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

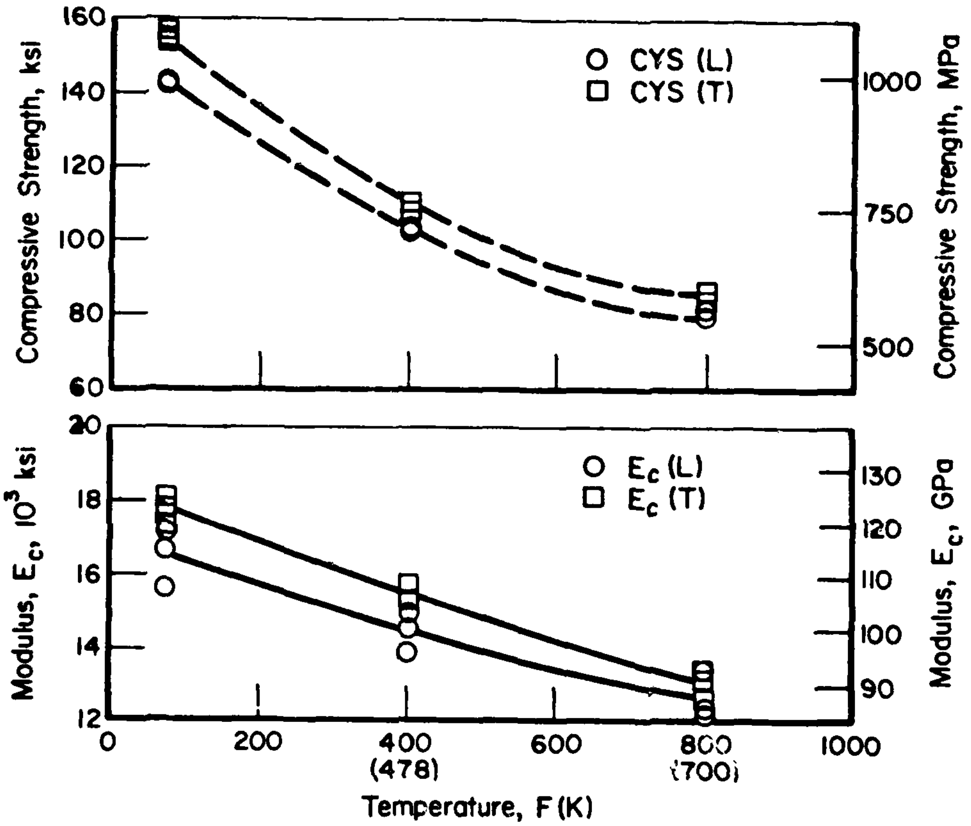

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

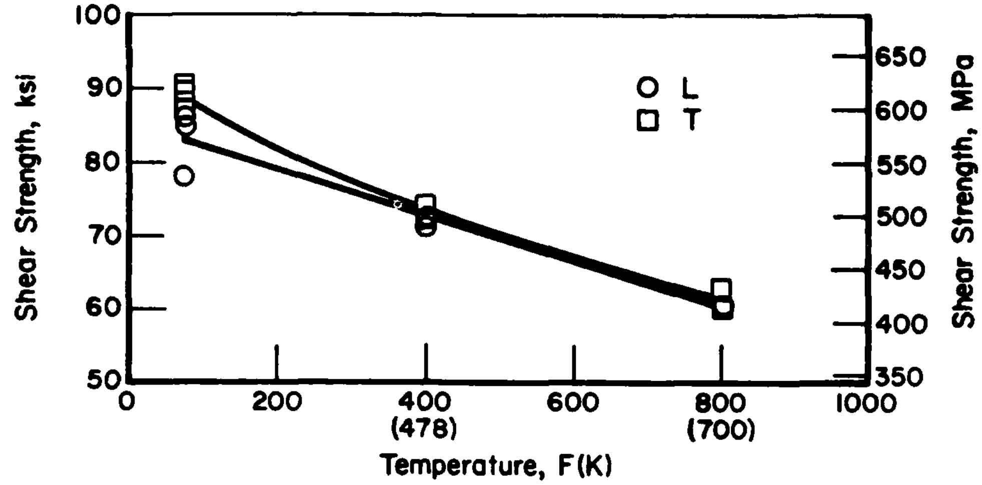

FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR STRENGTH OF ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

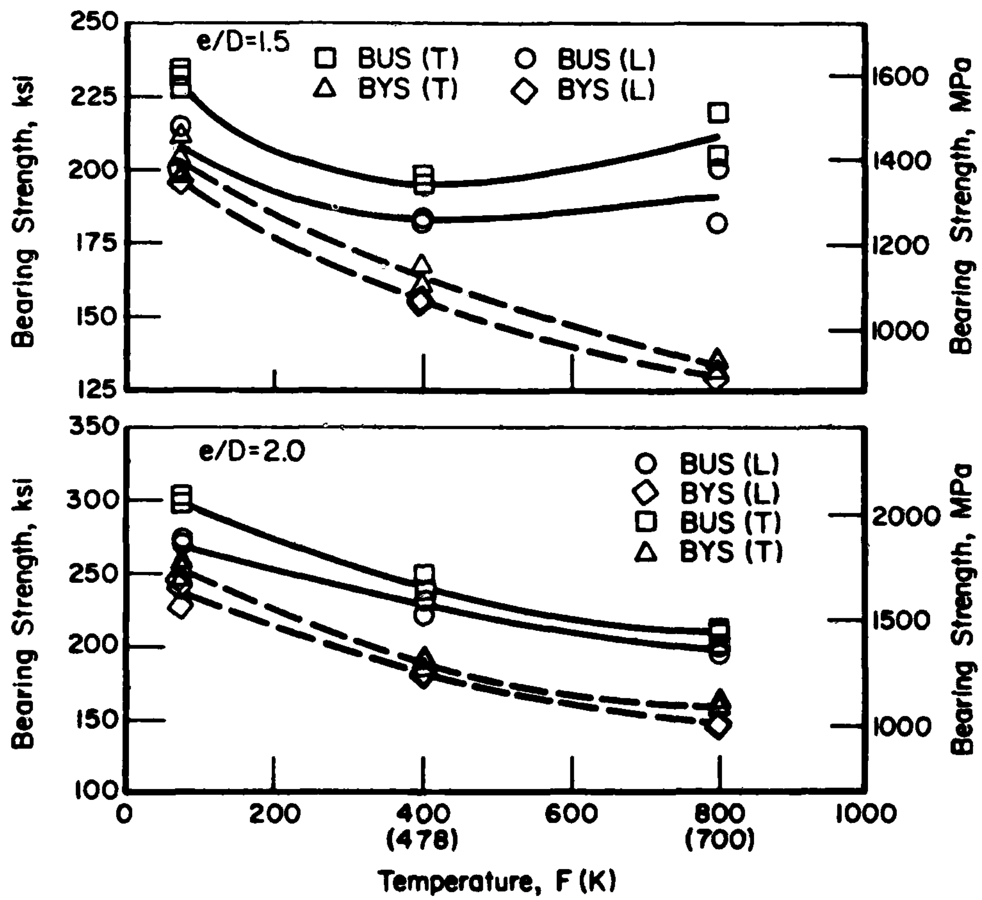

FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

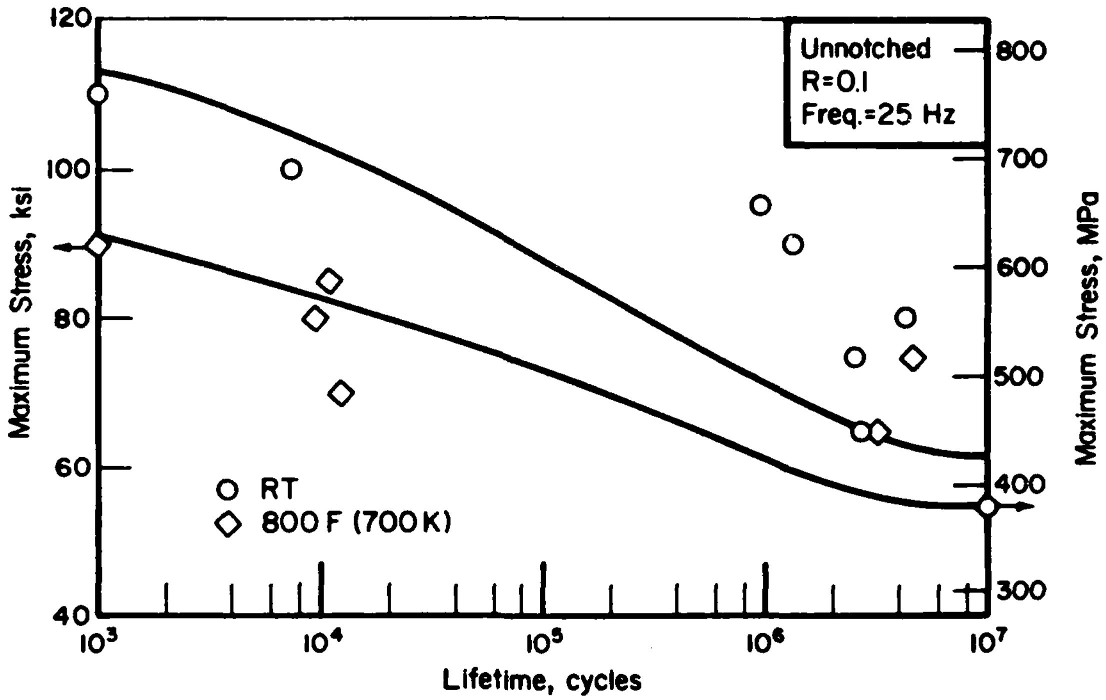

FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

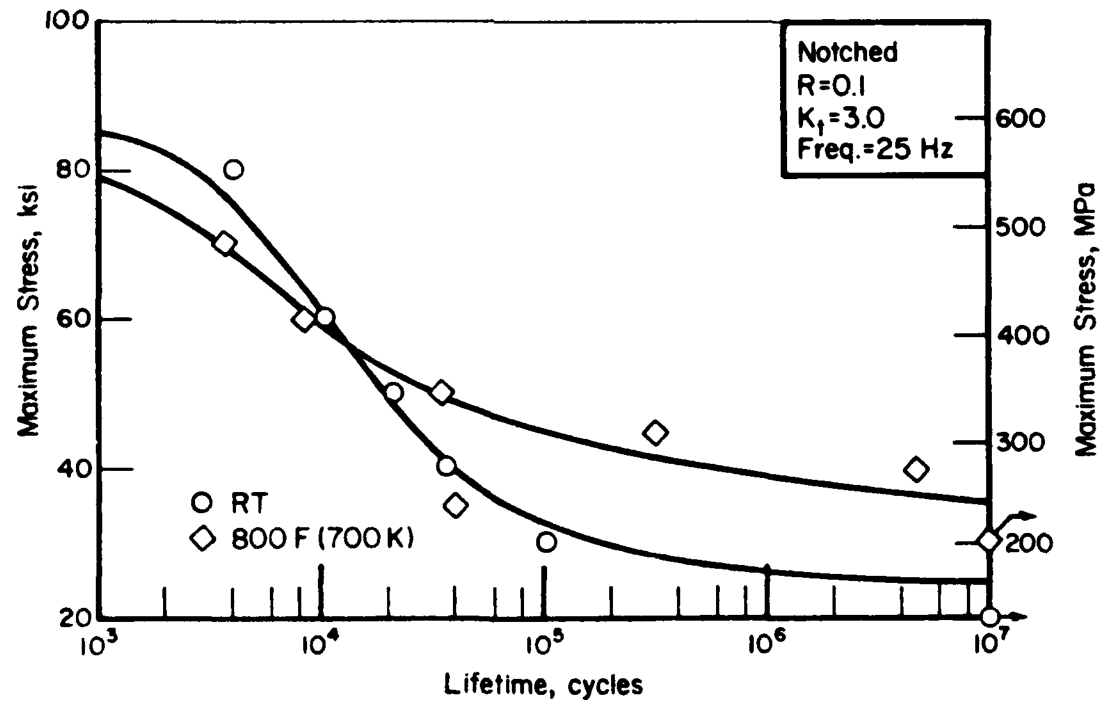

FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

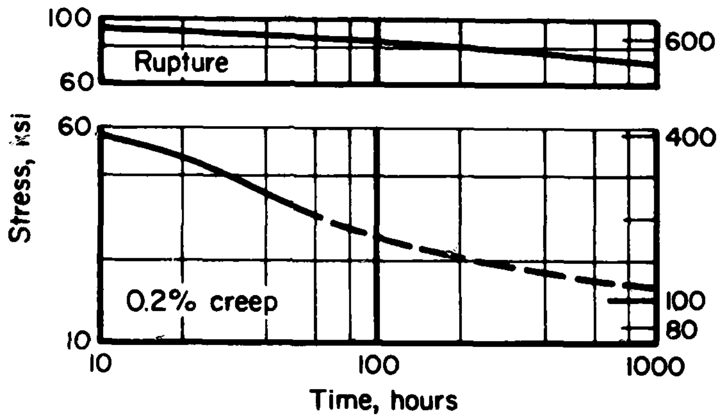

FIGURE 7. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR ALPHA-BETA PROCESSED CORONA 5 TITANIUM ALLOY PLATE

MECHANICAL-PROPERTY DATA A357 ALUMINUM ALLOY

-T6 CASTING

Issued by

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

JUNE 1980

Prepared by

BATTELLE
Columbus Laboratories
Columbus, Ohio 43201

F33615-78-C-5040

This data sheet was prepared by Battelle's Columbus Laboratories under Contract F33615-78-C-5040. The contract was initiated under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data." The major objectives of this program are to evaluate newly developed structural materials of potential interest to the Air Force weapons system and, then, to provide data-sheet-type presentations of these data. The program was assigned to the Structural Materials and Tribology Section at Battelle-Columbus under the supervision of Mr. Stephen Ford. Project Engineer was Mr. Omar Deel. The program was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Neal Ontko, Engineering and Design Data.

Notices

A357-T6 Aluminum Alloy Casting

Material Description

This aluminum alloy is one of the older, more widely used casting alloys. The particular casting used for this evaluation was obtained GFM from the Boeing Cast Aluminum Structures Technology (CAST) program (Air Force Contract F33615-76-C-3111). Several technical reports have been issued on this contract. These are AFFDL-TR-77-36, AFFDL-TR-78-62, AFFDL-TR-78-7, and AFFDL-TR-79-3029. Development history and detailed information regarding the casting is available in these documents and is not detailed in this report.

Processing and Heat Treating

Specimens were sectioned primarily from the thicker sections of the casting. Specimens were tested in the as-received -T6 temper.

A357-T6 ALUMINUM ALLOY CASTING[a]

CONDITION: -T6

THICKNESS: VARIOUS

Properties	Temperature, F (K)					
	RT	(RT)	250	(394)	350	(450)
Tension						
TUS, ksi (MPa)	47.6	(328.2)	42.3	(291.9)	36.6	(252.6)
TYS, ksi (MPa)	42.0	(289.6)	36.9	(254.7)	32.5	(224.3)
e, percent in 1 in. (25.4 mm)	2.2		3.3		4.7	
E, 10^3 ksi (GPa)	10.4	(71.7)	9.1	(62.7)	8.2	(56.5)
Compression						
CYS, ksi (MPa)	44.4	(306.4)	38.4	(264.5)	34.3	(236.7)
E_c, 10^3 ksi (GPa)	10.8	(74.2)	9.9	(68.3)	8.5	(58.4)
Shear[b]						
SUS, ksi (MPa)	33.2	(229.1)	29.3	(202.0)	25.9	(178.8)
Bearing[c]						
e/D = 1.5						
BUS, ksi (MPa)	79.6	(548.8)	64.7	(445.8)	58.8	(405.4)
BYS, ksi (MPa)	65.8	(453.9)	53.5	(369.1)	51.8	(356.9)
e/D = 2.0						
BUS, ksi (MPa)	99.2	(683.8)	86.3	(594.8)	72.3	(498.7)
BYS, ksi (MPa)	80.8	(556.9)	67.9	(467.9)	62.8	(432.8)
Fracture Toughness						
K_{Ic}, ksi$\sqrt{in.}$ (MPa $\cdot$ $m^{1/2}$)	21.1	(23.2)[d]				
Axial Fatigue[d]						
Unnotched, R = 0.1						
10^3 cycles, ksi (MPa)	55.0	(379.2)			43.3	(298.6)
10^5 cycles, ksi (MPa)	25.8	(177.9)			25.8	(177.9)
10^7 cycles, ksi (MPa)	13.5	(93.1)			13.5	(93.1)

Properties	Temperature, F (K)					
	RT	(RT)	250	(394)	350	(450)
<u>Axial Fatigue</u>[(e)]						
Notched, K_t = 3.0, R = 0.1						
10^3 cycles, ksi (MPa)	38.1	(262.7)			34.5	(237.9)
10^5 cycles, ksi (MPa)	21.0	(144.8)			19.5	(134.4)
10^7 cycles, ksi (MPa)	10.0	(68.9)			10.0	(68.9)
<u>Coefficient of Thermal Expansion</u>						
12.0 in./in./F x 10^{-6} (RT to 212 F)						
21.6 m/(m · K) x 10^{-6} (RT to 373 K)						
<u>Density</u>						
0.097 lb/in^3 (2.68 g/cm^3)						

(a) Values are average of triplicate tests conducted at Battelle unless otherwise indicated. Fatigue values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen.

(c) MIL-HDBK-5 "clean pin" type data.

(d) Values are valid per ASTM E399.

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

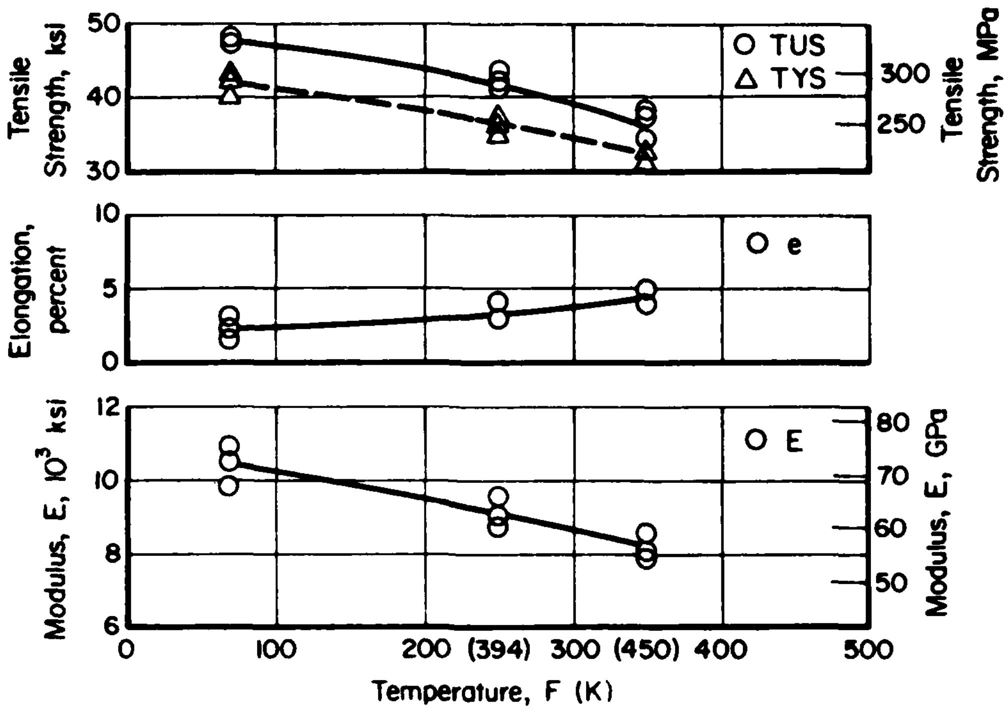

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF A357-T6 ALUMINUM ALLOY CASTING

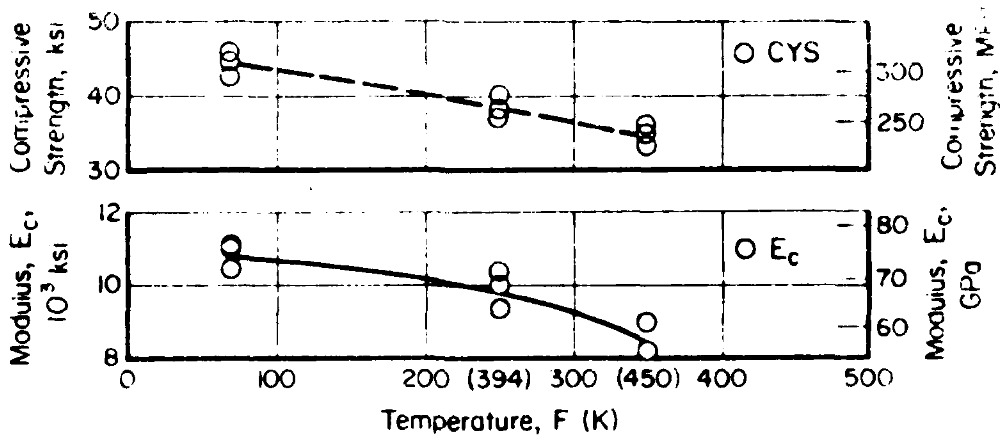

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF A357-T6 ALUMINUM ALLOY CASTING

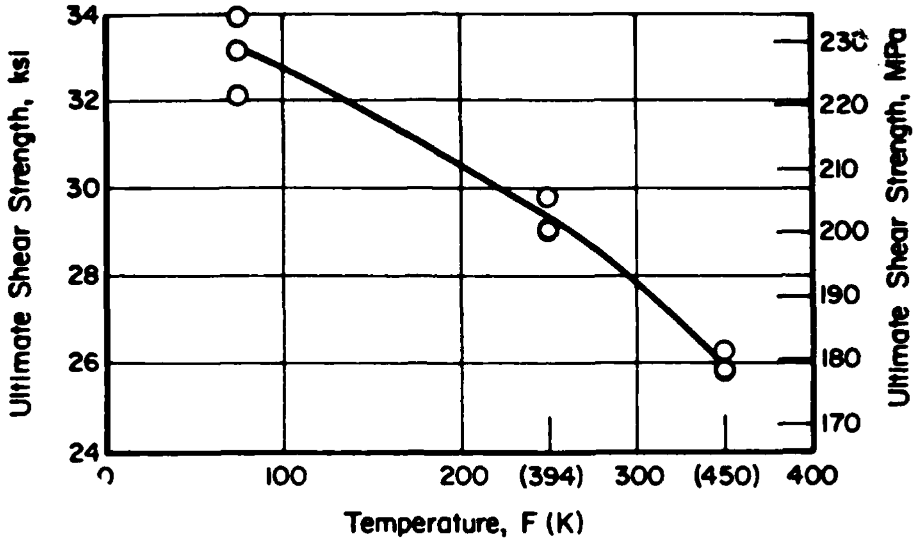

FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF A357-T6 ALUMINUM ALLOY CASTINGS

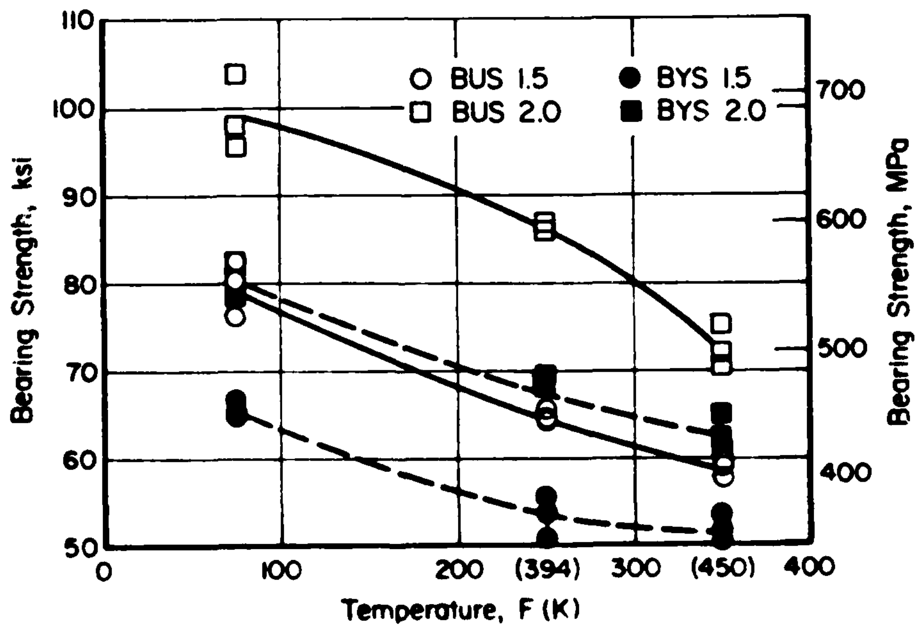

FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF A357-T6 ALUMINUM ALLOY CASTINGS

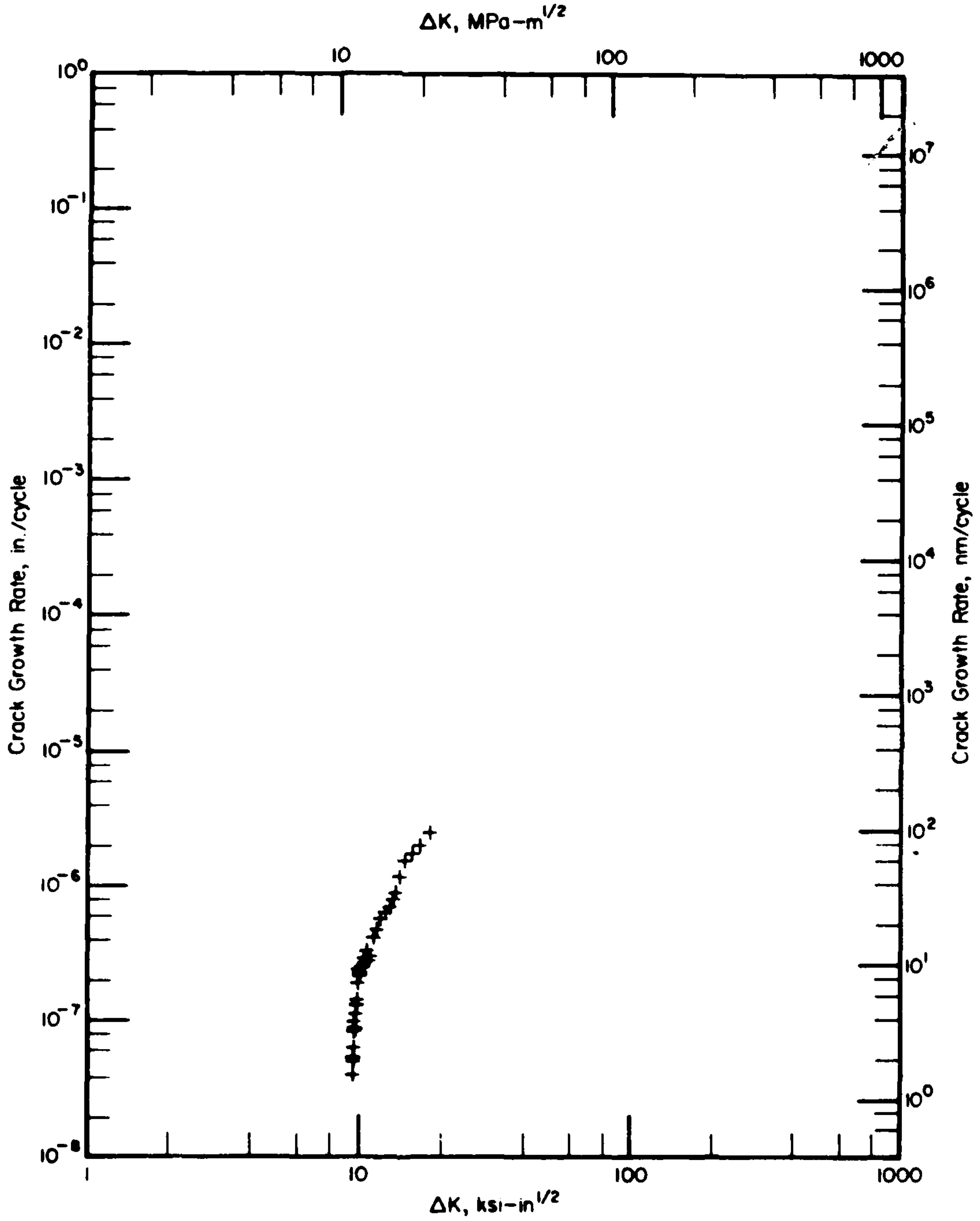

FIGURE 5. CRACK PROPAGATION TEST RESULTS FOR A357-T6 ALUMINUM ALLOY CASTING

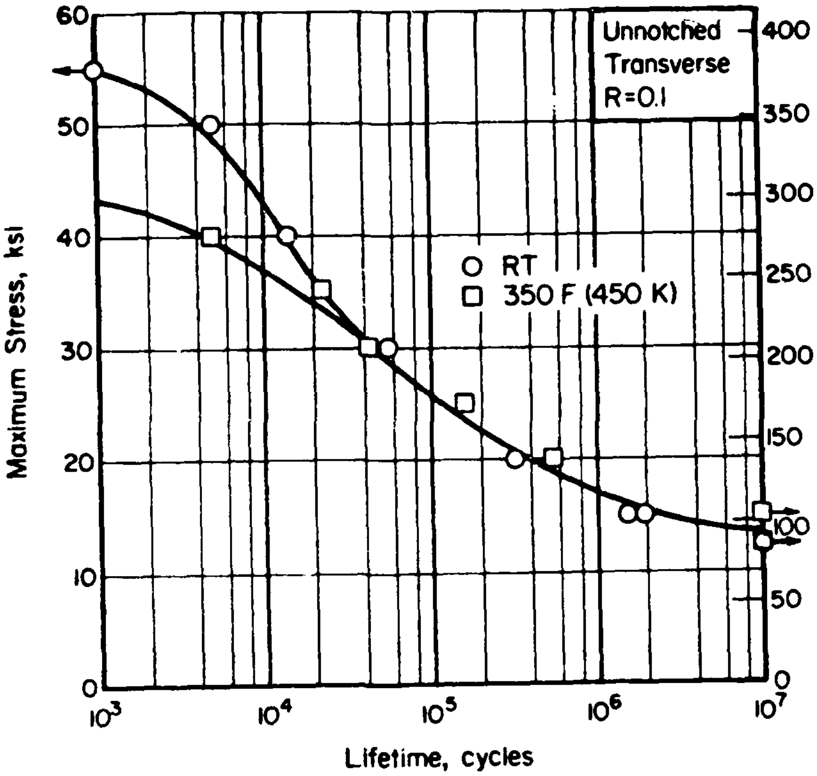

FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED A357-T6 ALUMINUM ALLOY CASTING

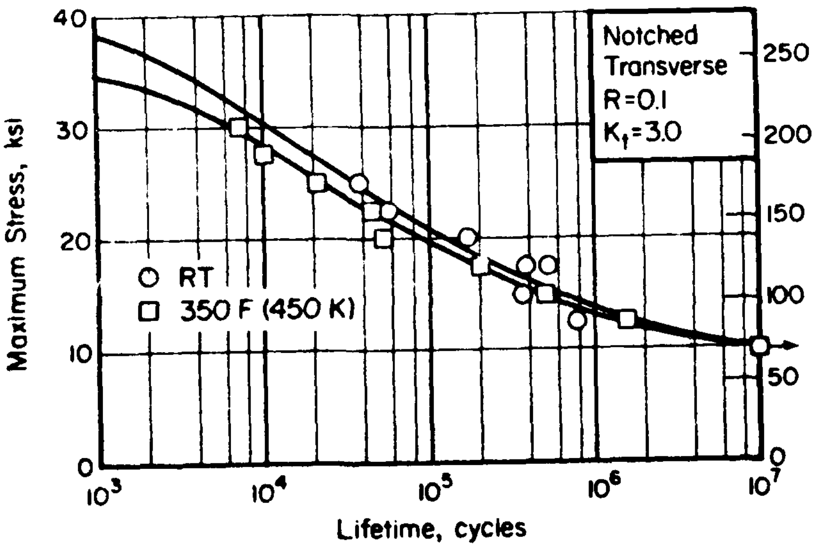

FIGURE 7. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) A357-T6 ALUMINUM ALLOY CASTING

MECHANICAL-PROPERTY DATA IN-792 NICKEL BASE ALLOY

HIP PM DISC

Issued by

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

JUNE 1980

Prepared by

BATTELLE
Columbus Laboratories
Columbus, Ohio [illegible]

F33615-78-C-[illegible]

This data sheet was prepared by Battelle's Columbus Laboratories under Contract F33615-78-C-5040. The contract was initiated under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data." The major objectives of this program are to evaluate newly developed structural materials of potential interest to the Air Force weapons system and, then, to provide data-sheet-type presentations of these data. The program was assigned to the Structural Materials and Tribology Section at Battelle-Columbus under the supervision of Mr. Stephen Ford. Project Engineer was Mr. Omar Deel. The program was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Neal Ontko, Engineering and Design Data.

Notices

IN-792 PM Disk (HIP)

Material Description

IN-792 is a nickel-base alloy developed by the International Nickel Company primarily for high-temperature turbine disk usage. The material evaluated on this program was supplied by the Air Force with the information that it was a powder metallurgy product that had been Hot Isostatic Pressed (HIP) at 15 ksi pressure at 2200 F for 4 hours and slow-cooled. Chemical analysis data for this material was not available.

Processing and Heat Treating

The disks were heat treated in accordance with the following procedure: 2150 F/2 hours, air cool, plus 1400 F/16 hours, air cool, plus 1250 F/16 hours, air cool.

A thermocouple was attached to the outside rim of two disks. The four disks were then placed in a gas-fired oven and positioned as instructed by AFWAL. After 2 hours at 2150 F, the disks were removed from the furnace and placed in a box. To slow cool at the desired rate (50 - 100 F/min.), an insulator (exploded mica) was immediately poured into the box to cover the disks. When cooling fell below the desired rate, the insulator was removed and the disks were allowed to stand in still air until the rate fell off. A fan was then allowed to blow circulating air over the disks to maintain the desired rate.

IN-792 PM DISK (HIP)[a]

Condition: Heat-treated
Thickness: Various

Properties	Temperature, F (K) RT	(RT)	800	(700)
Tension				
TUS, ksi (MPa)	198.2	(1366.8)	189.6	(1307.3)
TYS, ksi (MPa)	158.8	(1094.9)	153.1	(1055.4)
e, percent in 1 in. (25.4 mm)	4.7		7.0	
RA, percent	7.2		10.0	
E, 10^3 ksi (GPa)	31.3	(215.6)	30.5	(210.1)
Compression				
CYS, ksi (MPa)	171.0	(1179.3)	167.6	(1155.8)
E_c, 10^3 ksi (GPa)	32.2	(222.0)	30.4	(209.4)
Shear[b]				
SUS, ksi (MPa)	127.2	(877.4)	124.8	(860.3)
Bearing[c]				
e/D = 1.5				
BUS, ksi (MPa)	266.0	(1834.1)	269.2	(1855.9)
BYS, ksi (MPa)	235.1	(1621.0)	231.6	(1596.7)
e/D = 2.0				
BUS, ksi (MPa)	345.4	(2381.2)	333.4	(2298.8)
BYS, ksi (MPa)	274.1	(1889.9)	289.6	(1996.3)
Fracture Toughness				
K_{Ic}, ksi$\sqrt{in.}$ (MPa$\sqrt{m}$)	90.0	(99.0)[d]	--	--

Properties	Temperature, F (K) RT	(RT)	800	(700)
Axial Fatigue (e)				
Unnotched, R = 0.1				
10^3 cycles, ksi (MPa)	190	(1310.1)	--	--
10^5 cycles, ksi (MPa)	150	(1034.2)	--	--
10^7 cycles, ksi (MPa)	122	(841.2)	--	--
Notched, K_t = 3.0, R = 0.1				
10^3 cycles, ksi (MPa)	90	(620.5)	--	--
10^5 cycles, ksi (MPa)	49	(337.9)	--	--
10^7 cycles, ksi (MPa)	20	(137.9)	--	--

	1000 F (811)	1250 F (950)	1500 F (1089)
Creep			
0.2% plastic deformation, 10 hr., ksi (MPa)	170 (1172.2)	120 (827.4)	45 (310.3)
0.2% plastic deformation, 100 hr., ksi (MPa)	160 (1103.2)	--	--
Stress Rupture			
Rupture, 10 hr., ksi (MPa)	200 (1379.0)	150 (1034.3)	60 (413.7)
Rupture, 100 hr., ksi (MPa)	185 (1257.6)	--	--
Rupture, 1000 hr., ksi (MPa)	174 (1199.7)	--	--

(a) Values are average of triplicate tests conducted at Battelle unless otherwise indicated. Fatigue values are from curves generated using the results of a greater number of tests.

(b) Double-shear pin-type specimen.

(c) MIL-HDBK-5 "clean pin" type tests.

(d) Value is valid per ASTM E399.

(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.

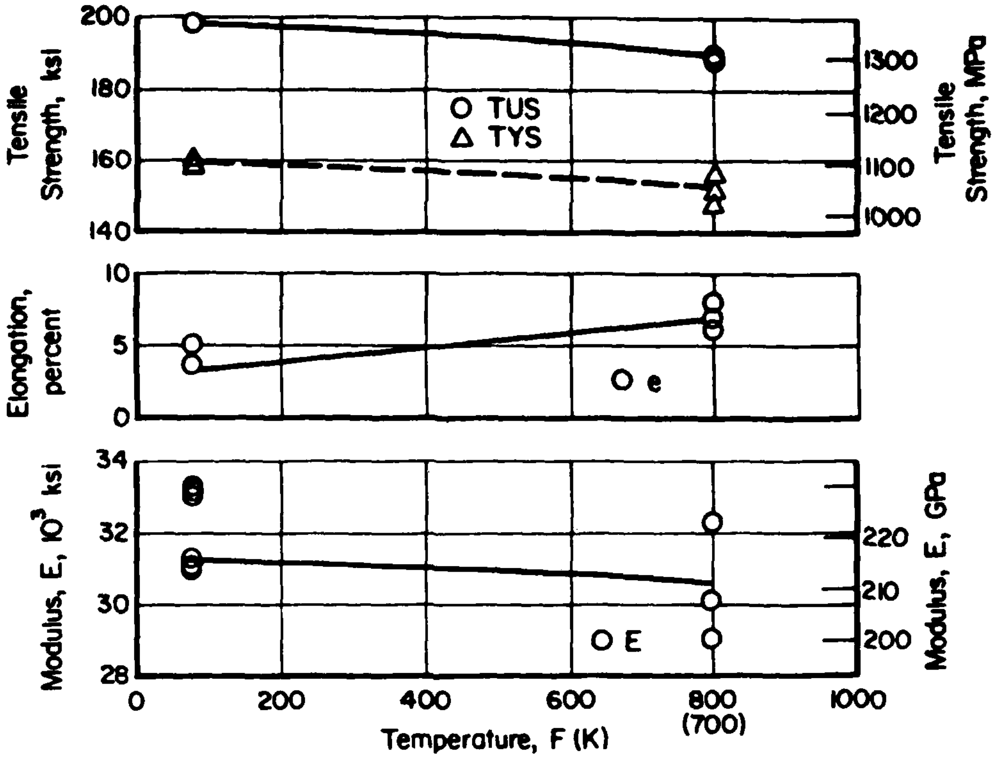

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF IN-792 PM DISK (HIP)

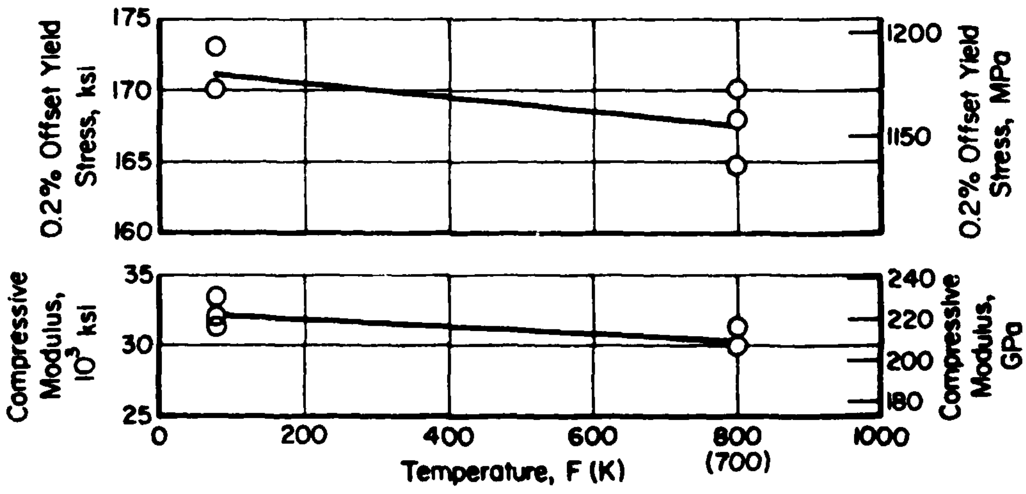

FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF IN-792 PM DISK (HIP)

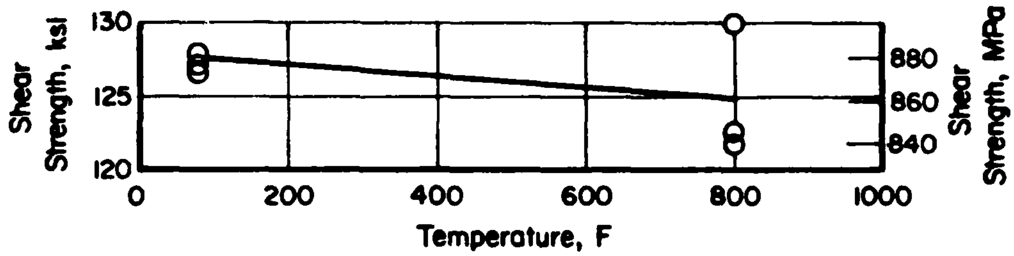

FIGURE 3. EFFECT OF TEMPERATURE ON THE SHEAR PROPERIES OF IN-792 PM DISK (HIP)

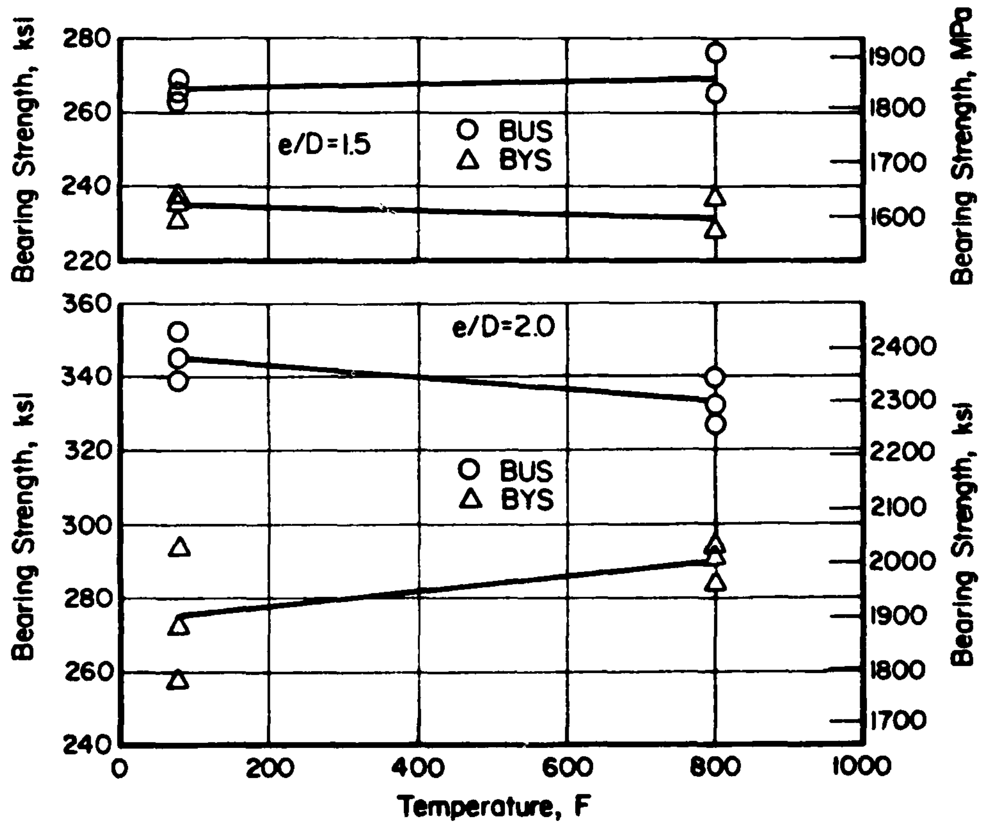

FIGURE 4. EFFECT OF TEMPERATURE ON THE BEARING PROPERTIES OF IN-792 PM DISK (HIP)

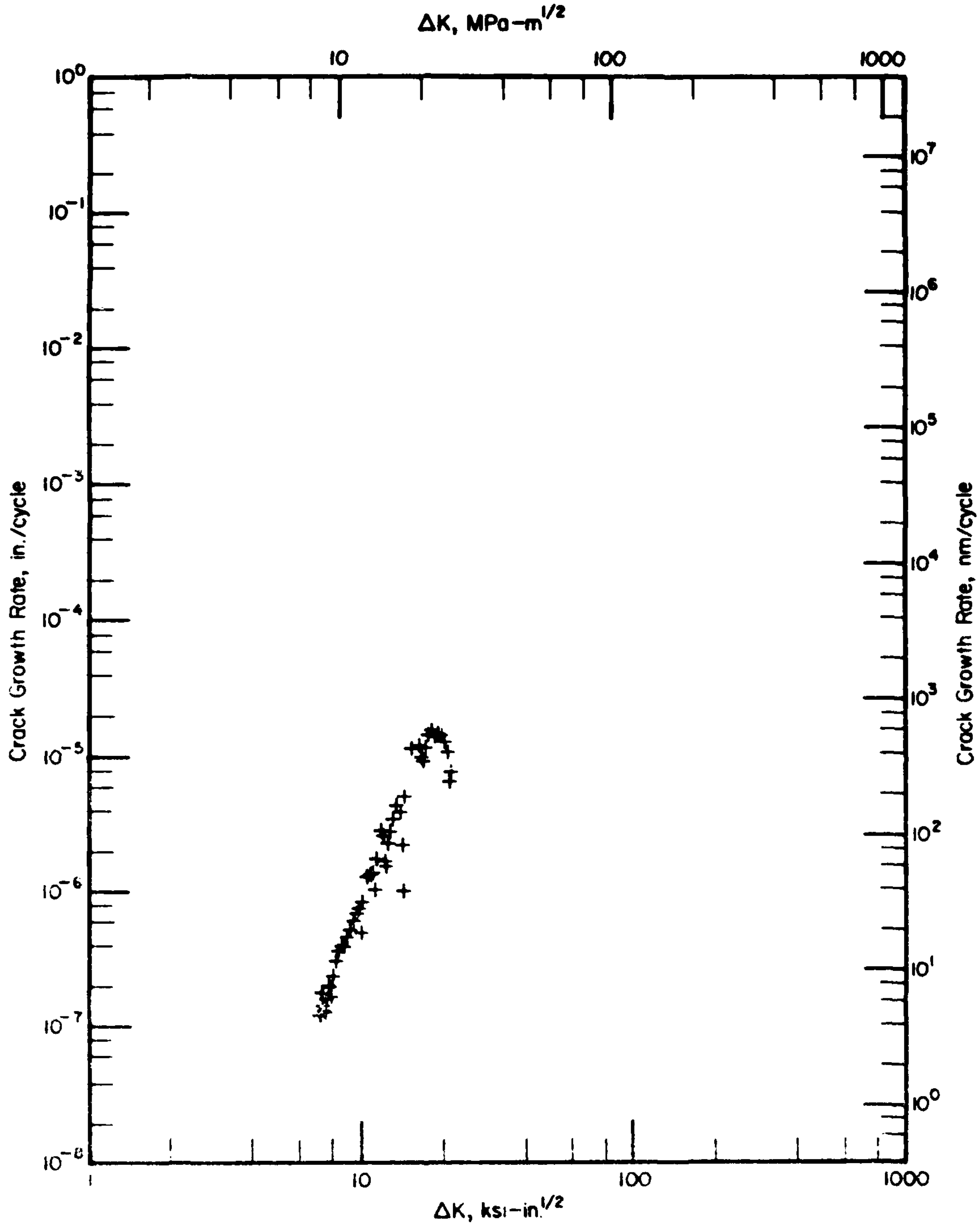

FIGURE 5. CRACK PROPAGATION TEST RESULTS FOR IN-792 PM DISK (HIP)

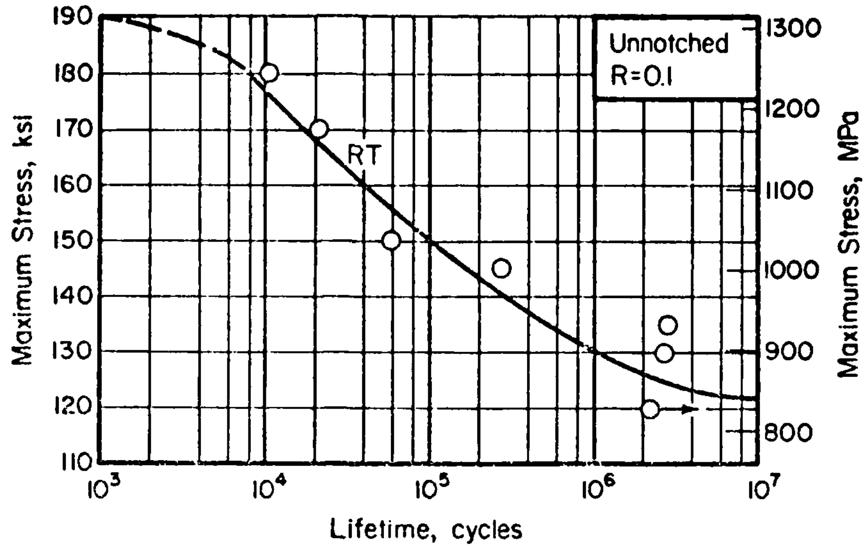

FIGURE 6. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED IN-792 PM DISK (HIP)

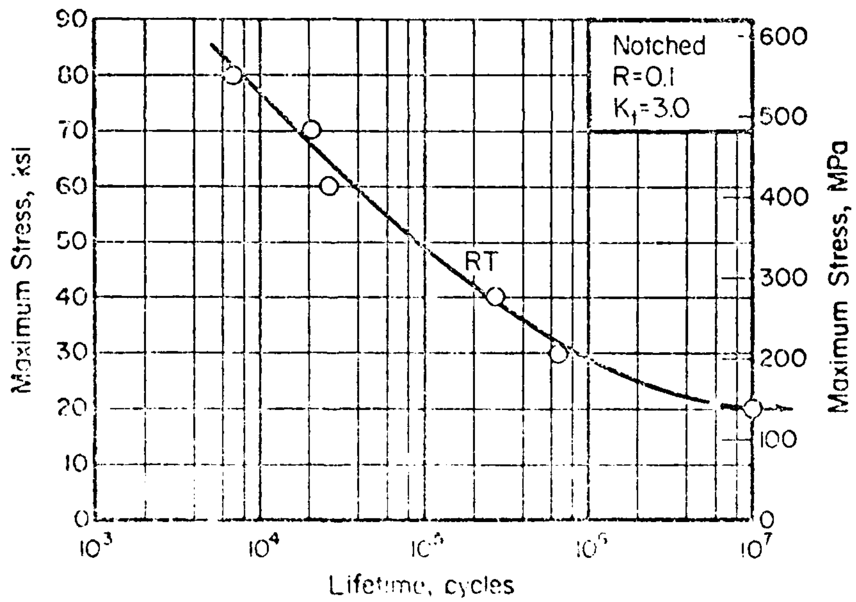

FIGURE 7. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) IN-792 PM DISK (HIP)

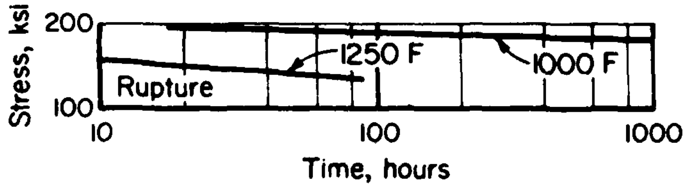

FIGURE 8. STRESS-RUPTURE PROPERTIES OF IN-792 PM DISK (HIP)

MECHANICAL-PROPERTY DATA CT-91 ALUMINUM ALLOY

-T7E70 PM PRODUCT

Issued by

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

JUNE 1980

Prepared by

BATTELLE
Columbus Laboratories
Columbus, Ohio 43201

F33615-78-C-5040

This data sheet was prepared by Battelle's Columbus Laboratories under Contract F33615-78-C-5040. The contract was initiated under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data." The major objectives of this program are to evaluate newly developed structural materials of potential interest to the Air Force weapons system and, then, to provide data-sheet-type presentations of these data. The program was assigned to the Structural Materials and Tribology Section at Battelle-Columbus under the supervision of Mr. Stephen Ford. Project Engineer was Mr. Omar Deel. The program was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Neal Ontko, Engineering and Design Data.

Notices

CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

Material Description

This alloy is a recent development of the Aluminum Company of America. Formerly called MA-87, it is now finalized in composition and has been designated CT-91. It is a powder metallurgy material designed for good strength and fracture toughness. The material used in this investigation was obtained from the ALCOA Research Laboratories as 1-1/2 inch by 4-1/2 inch extruded flat bar. Chemical analysis data was not available.

Processing and Heat Treating

Specimens were sectioned from the bar in both longitudinal and long transverse directions. The heat treatment chosen for evaluation was the -T7E70 (fracture toughness) temper.

CT-91 Aluminum PM Product[(a)]

Condition: -T7E70
Thickness: 1-1/2 inch x 4-1/2 inch bar

Properties	Temperature, F (K)					
	RT	(RT)	250	(394)	350	(450)
Tension						
TUS, L, ksi (MPa)	77.6	(535.1)	69.1	(476.2)	64.2	(442.9)
TUS, T, ksi (MPa)	72.6	(500.8)	66.5	(458.5)	58.7	(404.7)
TYS, L, ksi (MPa)	70.8	(488.4)	62.2	(428.9)	55.2	(380.6)
TYS, T, ksi (MPa)	63.5	(437.6)	58.3	(402.2)	52.6	(362.9)
e, L, percent in 1 in. (25.4 mm)	14.3		20.7		25.3	
e, T, percent in 1 in. (25.4 mm)	10.3		17.0		21.0	
E, L, 10 ksi (GPa)	10.6	(73.1)	9.9	(68.5)	8.7	(60.0)
E, T, 10 ksi (GPa)	10.0	(68.9)	9.0	(62.1)	8.7	(60.0)
Shear[(b)]						
SUS, L, ksi (MPa)	43.2	(298.2)	36.8	(254.0)	29.9	(206.3)
SUS, T, ksi (MPa)	42.5	(293.3)	36.6	(252.4)	30.9	(212.9)
Fracture Toughness[(c)]						
K_{Ic}, L-T, ksi$\sqrt{in.}$ (MPa · $m^{1/2}$)	46.1	(50.7)				
K_{Ic}, T-L, ksi$\sqrt{in.}$ (MPa · $m^{1/2}$)	41.5	(45.7)				
Axial Fatigue (Transverse)						
Unnotched, R = 0.1						
10^3 cycles, ksi (MPa)	76	(524.0)	--	--	50	(344.8)
10^5 cycles, ksi (MPa)	53	(365.4)	--	--	35	(241.3)
10^7 cycles, ksi (MPa)	49	(337.9)	--	--	23	(158.6)
Notched, K_t = 3.0, R = 0.1						
10^3 cycles, ksi (MPa)	42	(289.6)	--	--	42	(289.6)
10^5 cycles, ksi (MPa)	17	(117.2)	--	--	14	(96.5)
10^7 cycles, ksi (MPa)	13	(89.6)	--	--	10	(68.9)

(a) Values are average of triplicate tests conducted at Battelle unless otherwise indicated. Fatigue values are from curves using a greater number of tests.

(b) Double shear pin-type specimens.

(c) Values are valid per ASTM E399.

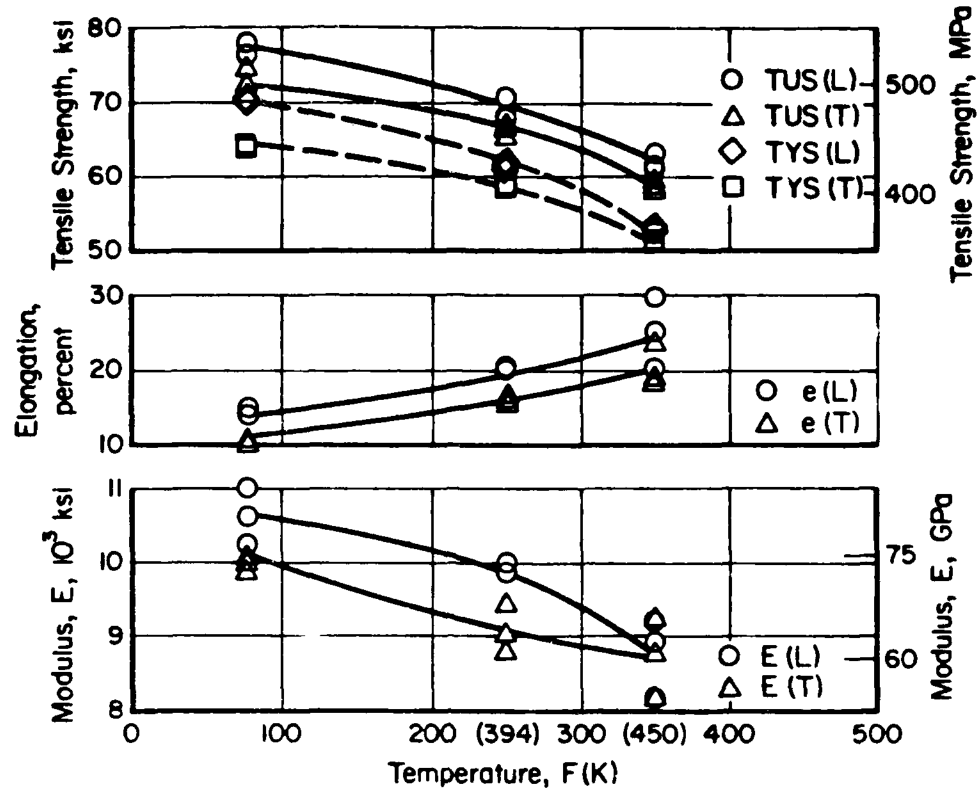

FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

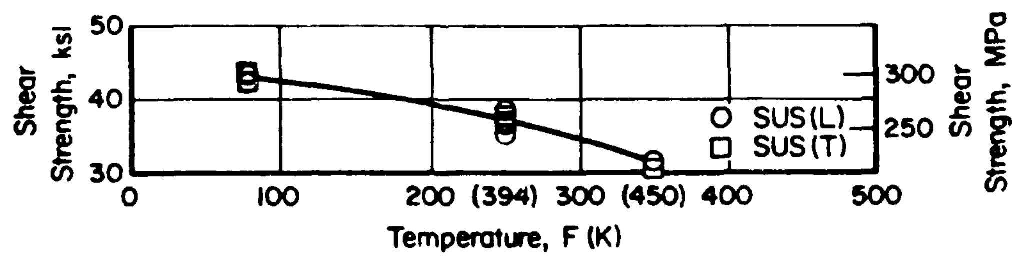

FIGURE 2. EFFECT OF TEMPERATURE ON THE SHEAR PROPERTIES OF CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

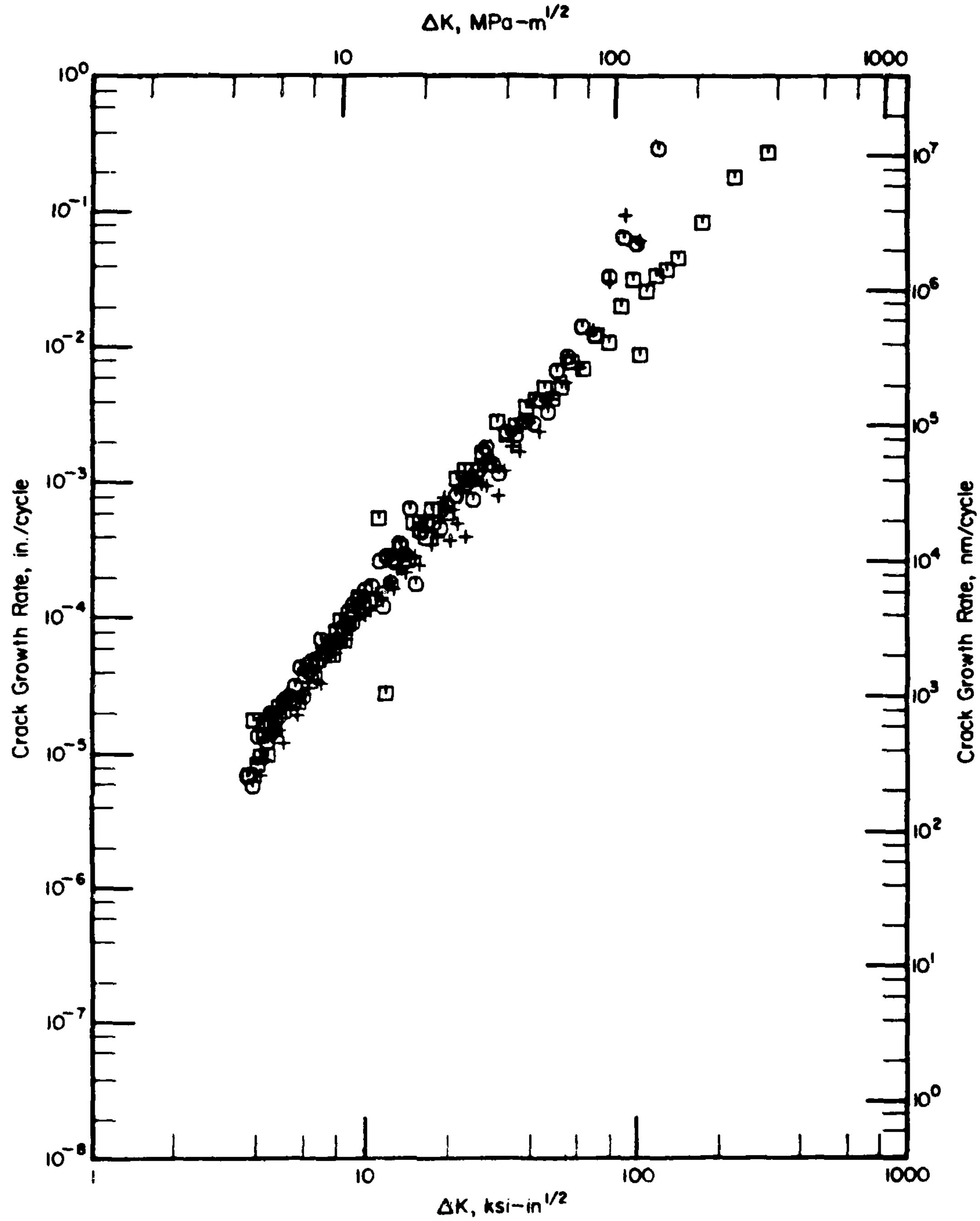

FIGURE 3. CRACK PROPAGATION TEST RESULTS FOR CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

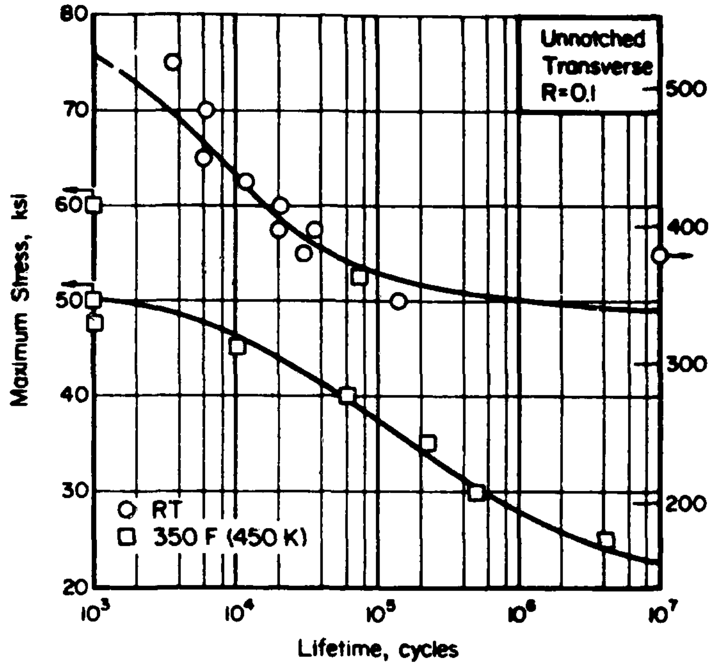

FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

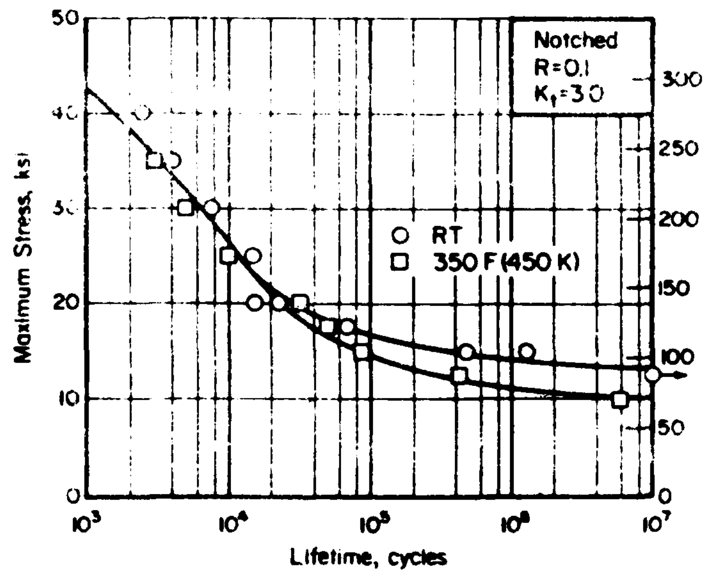

FIGURE 5. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED (K_t = 3.0) CT-91-T7E70 ALUMINUM ALLOY PM PRODUCT

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