

AFML-TR-73-114

AD 762305

ENGINEERING DATA ON NEW AEROSPACE STRUCTURAL MATERIALS

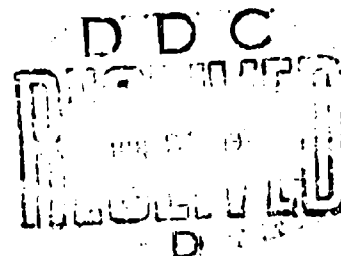
O. L. Deel, P. E. Ruff and H. Mindlin

Battelle
Columbus Laboratories

TECHNICAL REPORT AFML-TR-73-114

JUNE 1973

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. Department of Commerce
Springfield VA 22151



Approved for public release; distribution unlimited.

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

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

NTIS		✓
DDC	DDC	
UNCLASSIFIED	UNCLASSIFIED	
BY		
A		

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINAL NO. ACTIVITY (Corporate Author) Battelle Columbus Laboratories 505 King Avenue, Columbus, Ohio 43201		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP NA	
3. REPORT TITLE Engineering Data on New Aerospace Structural Materials			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Summary Report, April 1972 to April 1973			
5. AUTHOR(S) (First name, middle initial, last name) Omar L. Deel, Paul E. Ruff, and H. Mindlin			
6. REPORT DATE June 1973		7a. TOTAL NO. OF PAGES	7b. NO. OF REFS 0
8a. CONTRACT OR GRANT NO. F33615-72-C-1280		8b. ORIGINATOR'S REPORT NUMBER(S) AFML-TR-73-114	
8c. PROJECT NO. 7381			
8d. Task No. 738106		9. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Air Force Materials Laboratory Wright-Patterson Air Force Base, Ohio 45433	
13. ABSTRACT <p>The major objectives of this research program were to evaluate newly developed materials of interest to the Air Force for potential structural airframe usage, and to provide "data sheet" type presentations of engineering data for these materials. The effort covered in this report has concentrated on X2048-T851 plate, 7050-T73651 plate, 21-6-9 annealed sheet, Ti-8Mo-8V-2Fe-3Al STA sheet, Ti-6Al-2Zr-2Sn-2Mo-2Cr STA plate, and Ti-6Al-6V-2Sn STA isothermal die forgings.</p> <p>The properties investigated include tension, compression, shear, bend, impact, fracture toughness, fatigue, creep and stress-rupture, and stress corrosion at selected temperatures.</p>			

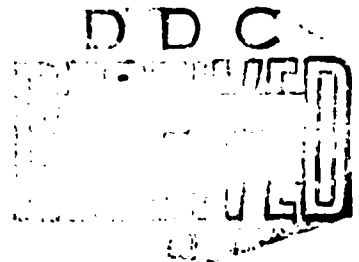
DD FORM 1473
1 NOV 65

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Mechanical Properties Fatigue Properties Creep Properties Chemical Composition Physical Properties Aluminum Alloys Stainless Steel Titanium Alloys X-2048 21-6-9 7050 Ti-8Mo-8V-2Fe-3Al Ti-6Al-2Zr-2Sn-2Mo-2Cr Ti-6Al-6V-2Sn						
ja						

ENGINEERING DATA ON NEW
AEROSPACE STRUCTURAL MATERIALS

O. L. Deel, P. E. Ruff and H. Mindlin



Approved for public release; distribution unlimited.

FOREWORD

This report was prepared by Battelle's Columbus Laboratories, Columbus, Ohio, under Contract F33615-72-C-1280. This contract was performed under Project No. 7381, "Materials Applications", Task No. 738106, "Engineering and Design Data". The work was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, by Mr. Clayton Harmsworth (AFML/MXE), technical manager.

This final report covers work conducted from April, 1972, to April, 1973. This report was submitted by the authors on April 30, 1973.

This technical report has been reviewed and is approved.

A. Olevitch

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

ABSTRACT

The major objectives of this research program were to evaluate newly developed materials of interest to the Air Force for potential structural air-frame usage, and to provide "data sheet" type presentations of engineering data for these materials. The effort covered in this report has concentrated on X2048-T851 plate, 7050-T73651 plate, 21-6-9 annealed sheet, Ti-8Mo-8V-2Fe-3Al STA sheet, Ti-6Al-2Zr-2Sn-2Mo-2Cr STA plate, and Ti-6Al-6V-2Sn STA isothermal die forgings.

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

	<u>Page</u>
INTRODUCTION	1
X2048-T351 Aluminum Alloy	2
Material Description	2
Processing and Heat Treating	2
Test Results	2
7050-T73651 Aluminum Alloy	19
Material Description	19
Processing and Heat Treating	19
Test Results	19
21-6-9 Stainless Steel Alloy	36
Material Description	36
Processing and Heat Treating	36
Test Results	36
Ti-8Mo-8V-2Fe-3Al Alloy	52
Material Description	52
Processing and Heat Treating	52
Test Results	52
Ti-6Al-2Zr-2Sn-2Mo-2Cr Alloy	68
Material Description	68
Processing and Heat Treating	68
Test Results	68
Ti-6Al-6V-2Sn Isothermal Die Forgings	85
Material Description	85
Processing and Heat Treating	85
Test Results	85
DISCUSSION OF PROGRAM RESULTS	98
CONCLUSIONS	98

APPENDIX I

EXPERIMENTAL PROCEDURE	101
Mechanical Properties	102
Specimen Identification	103
Test Description	104
Tension	104
Compression	105
Shear	105
Bend	105
Creep and Stress Rupture	105

Preceding page blank

TABLE OF CONTENTS
(Continued)

	<u>Page</u>
APPENDIX I	
(Continued)	
Stress Corrosion	106
Thermal Expansion	107
Fatigue	107
Fracture Toughness	108

APPENDIX II

SPECIMEN DRAWINGS	109
-----------------------------	-----

APPENDIX III

DATA SHEETS	113
-----------------------	-----

LIST OF TABLES

		<u>Page</u>
Table I	Tension Test Results for X2048-T851 Aluminum Plate	5
II	Compression Test Results for X2048-T851 Aluminum Plate . .	6
III	Shear Test Results for X2048-T851 Aluminum Plate at Room Temperature	7
IV	Charpy V-Notch Test Results for X2048-T851 Aluminum Plate.	7
V	Results of Slow-Bend Type Fracture Toughness Tests for X2048-T851 Aluminum Plate	8
VI	Axial Load Fatigue Test Results for X2048-T851 Aluminum Plate (Unnotched, $R = 0.1$) (Longitudinal)	9
VII	Axial Load Fatigue Results for X2048-T851 Aluminum Plate (Notched, $K_t = 3.0$, $R = 0.1$) (Longitudinal)	10
VIII	Summary Data on Creep and Rupture Properties for X2048- T851 Aluminum Plate (Longitudinal)	11
IX	Tension Test Results for 7050-T73651 Aluminum Alloy Plate.	22
X	Compression Test Results for 7050-T73651 Aluminum Alloy Plate	23
XI	Shear Test Results for 7050-T73651 Aluminum Alloy Plate at Room Temperature	24
XII	Impact Test Results for 7050-T73651 Aluminum Alloy Plate at Room Temperature	24
XIII	Results of Slow-Bend Type Fracture Toughness Tests for 7050-T73651 Aluminum Alloy Plate	25
XIV	Axial Load Fatigue Test Results for Unnotched 7050-T73651 Aluminum Plate (Transverse)	26
XV	Axial Load Fatigue Test Results for Notched ($K_t = 3.0$) 7050-T73651 Aluminum Plate (Transverse)	27
XVI	Summary Data on Creep and Rupture Properties for 7050 Aluminum Plate (Transverse)	28
XVII	Tensile Test Results for Annealed 21-6-9 Stainless Steel Sheet	39
XVIII	Compression Test Results for Annealed 21-6-9 Stainless Steel Sheet	40

LIST OF TABLES
(Continued)

	<u>Page</u>
Table XIX Shear Test Results for Annealed 21-6-9 Stainless Steel Sheet at Room Temperature	41
XX Axial Load Fatigue Test Results for Unnotched 21-6-9 Annealed Stainless Steel Sheet (Transverse)	42
XXI Axial Load Fatigue Test Results for Notched ($K_t = 3.0$) 21-6-9 Annealed Stainless Steel Sheet (Transverse)	43
XXII Summary Data on Creep and Rupture Properties for 21-6-9 Stainless Steel Sheet (Transverse)	44
XXIII Tensile Test Results for Solution-Treated and Aged Ti-8Mo-8V-2Fe-3Al Alloy Sheet	55
XXIV Compression Test Results for Solution-Treated and Aged Ti-8Mo-8V-2Fe-3Al Alloy Sheet	56
XXV Shear Test Results for Solution-Treated and Aged Ti-8Mo-8V-2Fe-3Al Alloy Sheet at Room Temperature	57
XXVI Axial Load Fatigue Test Results for Unnotched, Solution-Treated and Aged Ti-8Mo-8V-2Fe-3Al Alloy Sheet (Transverse)	58
XXVII Axial Load Fatigue Test Results for Notched ($K_t = 3.0$) Solution-Treated and Aged Ti-8Mo-8V-2Fe-3Al Alloy Sheet (Transverse)	59
XXVIII Summary Data on Creep and Rupture Properties for Ti-8Mo-8V-2Fe-3Al Alloy Sheet (Transverse)	60
XXIX Tensile Test Results for Solution-Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Alloy Plate	71
XXX Compression Test Results for Solution-Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Alloy Plate	72
XXXI Shear Test Results for Solution-Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Alloy Plate at Room Temperature	73
XXXII Impact Test Results for Solution-Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Alloy Plate at Room Temperature	73
XXXIII Results of Slow-Bend Type Fracture Toughness Tests on Solution-Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate	74
XXXIV Axial Load Fatigue Test Results for Unnotched Solution-Treated and Aged Ti-6Al-2Sn-2Mo-2Cr Alloy Plate (Transverse)	75

LIST OF TABLES
(Continued)

		<u>Page</u>
Table XXXV	Axial Load Fatigue Test Results for Notched ($K_t = 3.0$) Solution-Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Alloy Plate (Transverse)	76
XXXVI	Summary Data on Creep and Rupture Properties for Solution- Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Alloy Plate (Transverse)	7
XXXVII	Tension Test Results for Solution-Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forging (Transverse)	87
XXXVIII	Compression Test Results for Solution-Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings (Transverse)	88
XXXIX	Shear Test Results at Room Temperature for Solution- Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings	89
XL	Impact Test Results for Solution-Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings	89
XLI	Axial Load Fatigue Test Results for Unnotched Solution- Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings	90
XLII	Axial Load Fatigue Test Results for Notched ($K_t = 3.0$) Solution-Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings	91
XLIII	Summary Data on Creep and Rupture Properties for Solution- Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings (Transverse)	92

LIST OF ILLUSTRATIONS

	<u>Page</u>
Figure 1. Specimens Layout for X2048-T851 Plate	3
2 Typical Tensile Stress-Strain Curves at Temperature for X2048-T851 Plate (Longitudinal)	12
3 Typical Tensile Stress-Strain Curves at Temperature for X2048-T851 Plate (Transverse)	13
4 Typical Compressive Stress-Strain and Tangent-Modulus Curves at Temperature for X2048-T851 Plate (Longitudinal)	14
5 Typical Compressive Stress-Strain and Tangent-Modulus Curves at Temperature for X2048-T851 Plate (Transverse)	15
6 Effect of Temperature on the Tensile Properties of X2048-T851 Plate	16
7 Effect of Temperature on the Compressive Properties of X2048-T851 Plate	16
8 Axial Load Fatigue Behavior of Unnotched X2048-T851 Plate (Longitudinal)	17
9 Axial Load Fatigue Behavior of Notched ($K_t = 3.0$) X2048-T851 Plate (Longitudinal)	17
10 Stress-Rupture Curves for X2048-T851 Plate (Longitudinal)	18
11 Specimen Layout for 7050-T73651 Plate	20
12 Typical Tensile Stress-Strain Curves at Temperature for 7050-T73651 Plate (Longitudinal)	29
13 Typical Tensile Stress-Strain Curves at Temperature for 7050-T73651 Plate (Transverse)	30
14 Typical Compressive Stress-Strain and Tangent-Modulus Curves at Temperature for 7050-T73651 Plate (Longitudinal)	31
15 Typical Compressive Stress-Strain and Tangent-Modulus Curves at Temperature for 7050-T73651 Plate (Transverse)	32
16 Effect of Temperature on the Tensile Properties of 7050-T73651 Plate	33
17 Effect of Temperature on the Compressive Properties of 7050-T73651 Plate	33

LIST OF ILLUSTRATIONS
(Continued)

	<u>Page</u>
Figure 18 Axial Load Fatigue Behavior of Unnotched 7050-T73651 Plate (Transverse)	34
19 Axial Load Fatigue Behavior of Notched ($K_t = 3.0$) 7050-T73651 Plate (Transverse)	34
20 Stress-Rupture and Plastic Deformation Curves for 7050-T73651 Plate (Transverse)	35
21 Specimen Layout for 21-6-9 Annealed Sheet	37
22 Typical Tensile Stress-Strain Curves at Temperature for 21-6-9 Annealed Sheet (Longitudinal)	45
23 Typical Tensile Stress-Strain Curves at Temperature for 21-6-9 Annealed Sheet (Transverse)	46
24 Typical Compressive Stress-Strain and Tangent-Modulus Curves at Temperature for 21-6-9 Annealed Sheet (Longitudinal)	47
25 Typical Compressive Stress-Strain and Tangent-Modulus Curves at Temperature for 21-6-9 Annealed Sheet (Transverse)	48
26 Effect of Temperature on the Tensile Properties of 21-6-9 Annealed Sheet	49
27 Effect of Temperature on the Compressive Properties of 21-6-9 Annealed Sheet	49
28 Axial Load Fatigue Behavior of Unnotched 21-6-9 Annealed Sheet (Transverse)	50
29 Axial Load Fatigue Behavior of Notched ($K_t = 3.0$) 21-6-9 Annealed Sheet (Transverse)	50
30 Stress-Rupture and Plastic Deformation Curves for 21-6-9 Annealed Sheet (Transverse)	51
31 Specimen Layout for Ti-8Mo-8V-2Fe-3Al Sheet	53
32 Typical Tensile Stress-Strain Curves at Temperature for Solution-Treated and Aged Ti-8Mo-8V-2Fe-3Al Sheet (Longitudinal)	61
33 Typical Tensile Stress-Strain Curves at Temperature for Solution-Treated and Aged Ti-8Mo-8V-2Fe-3Al Sheet (Transverse)	62
34 Typical Compressive Stress-Strain and Tangent-Modulus Curves at Temperature for Solution-Treated and Aged Ti-8Mo-8V-2Fe-3Al Sheet (Longitudinal)	63

LIST OF ILLUSTRATIONS
(Continued)

	<u>Page</u>
Figure 35 Typical Compressive Stress-Strain and Tangent-Modulus Curves at Temperature for Solution-Treated and Aged Ti-8Mo-8V-2Fe-3Al Sheet (Transverse)	64
36 Effect of Temperature on the Tensile Properties of Solution Treated and Aged Ti-8Mo-8V-2Fe-3Al Sheet	65
37 Effect of Temperature on the Compressive Properties of Solution Treated and Aged Ti-8Mo-8V-2Fe-3Al Sheet	65
38 Axial Load Fatigue Behavior of Unnotched Solution-Treated and Aged Ti-8Mo-8V-2Fe-3Al Sheet (Transverse)	66
39 Axial Load Fatigue Behavior of Notched ($K_t = 3.0$) Solution Treated and Aged Ti-8Mo-8V-2Fe-3Al Sheet (Transverse)	66
40 Stress-Rupture and Plastic Deformation Curves for Solution Treated and Aged Ti-8Mo-8V-2Fe-3Al Sheet (Transverse)	67
41 Specimen Layout for Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate	69
42 Typical Tensile Stress-Strain Curves at Temperature for Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate (Longitudinal)	78
43 Typical Tensile Stress-Strain Curves at Temperatures for Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate (Transverse)	79
44 Typical Compressive Stress-Strain and Tangent-Modulus Curves for Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate (Longitudinal)	80
45 Typical Compressive Stress-Strain and Tangent-Modulus Curves for Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate (Transverse)	81
46 Effect of Temperature on the Tensile Properties of Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate	82
47 Effect of Temperature on the Compressive Properties of Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate	82
48 Axial Load Fatigue Behavior of Unnotched Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate (Transverse)	83
49 Axial Load Fatigue Behavior of Notched ($K_t = 3.0$) Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate (Transverse)	83

LIST OF ILLUSTRATIONS
(Continued)

	<u>Page</u>
Figure 50 Stress-Rupture and Plastic Deformation Curves for Solution Treated and Aged Ti-6Al-2Zr-2Sn-2Mo-2Cr Plate (Transverse) . .	84
51 Typical Tensile Stress-Strain Curves for Solution Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings	93
52 Typical Compressive Stress-Strain and Tangent Modulus Curves for Solution Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings	94
53 Effect of Temperature on the Tensile Properties of Solution Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings	95
54 Effect of Temperature on the Compressive Properties of Solution Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings	95
55 Axial Load Fatigue Behavior of Unnotched Solution-Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings (Transverse)	96
56 Axial Load Fatigue Behavior of Notched ($K_t = 3.0$) Solution Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings (Transverse)	96
57 Stress Rupture and Plastic Deformation Curves for Solution Treated and Aged Ti-6Al-6V-2Sn Isothermal Die Forgings	97
58 Tensile Ultimate Strength as a Function of Temperature	99
59 Tensile Yield Strength as a Function of Temperature	100
60 Sheet and Thin-Plate Tensile Specimen	110
61 Round Tensile Specimen	110
62 Sheet Compression Specimen	110
63 Round Compression Specimen	110
64 Sheet Creep- and Stress-Rupture Specimen	110
65 Round Creep- and Stress-Rupture Specimen	110
66 Sheet Shear Test Specimen	111
67 Pin Shear Specimen	111
68 Unnotched Sheet Fatigue Specimen	111
69 Notched Sheet Fatigue Specimen	111

LIST OF ILLUSTRATIONS
(Continued)

	<u>Page</u>
Figure 70 Unnotched Round Fatigue Specimen	111
71 Notched Round Fatigue Specimen	111
72 Sheet Fracture Toughness Specimen	112
73 Slow Bend Fracture Toughness Specimen	112
74 Stress-Corrosion Specimen	112
75 Thermal-Expansion Specimen	112
76 Sheet Bend Specimen	112
77 Notched Impact Specimen	112

INTRODUCTION

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

In recognition of this need, the Air Force has sponsored several programs at Battelle's Columbus Laboratories to provide comparative engineering data for newly developed materials. The materials included in these evaluation programs were carefully selected to insure that they were either available or could become quickly available on request and that they would represent potentially attractive alloy projections for weapons system usage. The results of these programs have been published in five technical reports, AFML-TR-67-418, AFML-TR-68-211, AFML-TR-70-252, AFML-TR-71-249, and AFML-TR-72-196, Volumes I and II.

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

The materials evaluated under this program are as follows

- (1) X2048-T851 Plate
- (2) 7050-T73651 Plate
- (3) 21-6-9 Annealed Sheet
- (4) Ti-8Mo-8V-2Fe-3Al STA Sheet
- (5) Ti-6Al-2Zr-2Sn-2Mo-2Cr STA Plate
- (6) Ti-6Al-6V-2Sn STA Isothermal Die Forgings .

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

The program approach was, as on previous contracts, to search the published literature and to contact metal producers and aerospace companies for any pertinent data. If very little pertinent information was available, a complete material evaluation was conducted. On this program a complete evaluation was conducted for each material. Upon completion of each evaluation, a "data sheet" was issued to make the information immediately available to potential users rather than defer publication to the end of the contract term and this summary technical report. These data sheets are reproduced as Appendix III of this report.

Detailed information concerning the properties of interest, test techniques, and specimen types are contained in Appendices I and II of this report.

X2048-T851 Aluminum AlloyMaterial Description

Alloy X2048-T851 is a recent development of the Reynolds Metals Company. The development aim was a thick section alloy with high toughness and stability at moderate temperatures. The goal was to achieve the strength, fatigue resistance, corrosion resistance, and thermal stability of 2024-T851 or 2124-T851 and the toughness of 2219.

The material used for this evaluation was 3-inch plate produced within the following composition limits

Copper	2.8 to 3.8
Manganese	0.20 to 0.60
Magnesium	1.2 to 1.8
Zinc	0.25 max
Titanium	0.10 max
Silicon	0.15 max
Iron	0.20 max
Others total	0.15 max
Aluminum	Balance

Processing and Heat Treating

Specimens were cut from the plate as shown in Figure 1 and were tested in the as-received -T851 temper.

Test Results

Tension. Test results for longitudinal and transverse specimens at room temperature, 250 F, 350 F, and 500 F are given in Table I. Short-transverse test results at room temperature only are also given in Table I. Stress-strain curves at temperature are shown in Figures 2 and 3. Effect-of-temperature curves are presented in Figure 6.

Compression. Results of tests in both the longitudinal and transverse directions at room temperature, 250 F, 350 F, and 500 F are given in Table II. Stress-strain and tangent-modulus curves at temperature are shown in Figures 4 and 5. Effect-of-temperature curves are presented in Figure 7.

Shear. Results of room temperature pin shear tests in both the longitudinal and transverse directions are given in Table III.

IL1	IL2	IL11	IL12	IL13	IL14	IL15	IL16	IL17	IL18	IL19	IL20	IL21	IL22	IL23	IL24	IL25	IL26	IL27	IL28	IL29	IL30	IL31	IL32	IL33	IL34	IL35	IL36	IL37	IL38	IL39	IL40	IL41	IL42	IL43	IL44	IL45	IL46	IL47	IL48	IL49	IL50	IL51	IL52	IL53	IL54	IL55	IL56	IL57	IL58	IL59	IL60	IL61	IL62	IL63	IL64	IL65	IL66	IL67	IL68	IL69	IL70	IL71	IL72	IL73	IL74	IL75	IL76	IL77	IL78	IL79	IL80	IL81	IL82	IL83	IL84	IL85	IL86	IL87	IL88	IL89	IL90	IL91	IL92	IL93	IL94	IL95	IL96	IL97	IL98	IL99	IL100	IL101	IL102	IL103	IL104	IL105	IL106	IL107	IL108	IL109	IL110	IL111	IL112	IL113	IL114	IL115	IL116	IL117	IL118	IL119	IL120	IL121	IL122	IL123	IL124	IL125	IL126	IL127	IL128	IL129	IL130	IL131	IL132	IL133	IL134	IL135	IL136	IL137	IL138	IL139	IL140	IL141	IL142	IL143	IL144	IL145	IL146	IL147	IL148	IL149	IL150	IL151	IL152	IL153	IL154	IL155	IL156	IL157	IL158	IL159	IL160	IL161	IL162	IL163	IL164	IL165	IL166	IL167	IL168	IL169	IL170	IL171	IL172	IL173	IL174	IL175	IL176	IL177	IL178	IL179	IL180	IL181	IL182	IL183	IL184	IL185	IL186	IL187	IL188	IL189	IL190	IL191	IL192	IL193	IL194	IL195	IL196	IL197	IL198	IL199	IL200	IL201	IL202	IL203	IL204	IL205	IL206	IL207	IL208	IL209	IL210	IL211	IL212	IL213	IL214	IL215	IL216	IL217	IL218	IL219	IL220	IL221	IL222	IL223	IL224	IL225	IL226	IL227	IL228	IL229	IL230	IL231	IL232	IL233	IL234	IL235	IL236	IL237	IL238	IL239	IL240	IL241	IL242	IL243	IL244	IL245	IL246	IL247	IL248	IL249	IL250	IL251	IL252	IL253	IL254	IL255	IL256	IL257	IL258	IL259	IL260	IL261	IL262	IL263	IL264	IL265	IL266	IL267	IL268	IL269	IL270	IL271	IL272	IL273	IL274	IL275	IL276	IL277	IL278	IL279	IL280	IL281	IL282	IL283	IL284	IL285	IL286	IL287	IL288	IL289	IL290	IL291	IL292	IL293	IL294	IL295	IL296	IL297	IL298	IL299	IL300	IL301	IL302	IL303	IL304	IL305	IL306	IL307	IL308	IL309	IL310	IL311	IL312	IL313	IL314	IL315	IL316	IL317	IL318	IL319	IL320	IL321	IL322	IL323	IL324	IL325	IL326	IL327	IL328	IL329	IL330	IL331	IL332	IL333	IL334	IL335	IL336	IL337	IL338	IL339	IL340	IL341	IL342	IL343	IL344	IL345	IL346	IL347	IL348	IL349	IL350	IL351	IL352	IL353	IL354	IL355	IL356	IL357	IL358	IL359	IL360	IL361	IL362	IL363	IL364	IL365	IL366	IL367	IL368	IL369	IL370	IL371	IL372	IL373	IL374	IL375	IL376	IL377	IL378	IL379	IL380	IL381	IL382	IL383	IL384	IL385	IL386	IL387	IL388	IL389	IL390	IL391	IL392	IL393	IL394	IL395	IL396	IL397	IL398	IL399	IL400	IL401	IL402	IL403	IL404	IL405	IL406	IL407	IL408	IL409	IL410	IL411	IL412	IL413	IL414	IL415	IL416	IL417	IL418	IL419	IL420	IL421	IL422	IL423	IL424	IL425	IL426	IL427	IL428	IL429	IL430	IL431	IL432	IL433	IL434	IL435	IL436	IL437	IL438	IL439	IL440	IL441	IL442	IL443	IL444	IL445	IL446	IL447	IL448	IL449	IL450	IL451	IL452	IL453	IL454	IL455	IL456	IL457	IL458	IL459	IL460	IL461	IL462	IL463	IL464	IL465	IL466	IL467	IL468	IL469	IL470	IL471	IL472	IL473	IL474	IL475	IL476	IL477	IL478	IL479	IL480	IL481	IL482	IL483	IL484	IL485	IL486	IL487	IL488	IL489	IL490	IL491	IL492	IL493	IL494	IL495	IL496	IL497	IL498	IL499	IL500	IL501	IL502	IL503	IL504	IL505	IL506	IL507	IL508	IL509	IL510	IL511	IL512	IL513	IL514	IL515	IL516	IL517	IL518	IL519	IL520	IL521	IL522	IL523	IL524	IL525	IL526	IL527	IL528	IL529	IL530	IL531	IL532	IL533	IL534	IL535	IL536	IL537	IL538	IL539	IL540	IL541	IL542	IL543	IL544	IL545	IL546	IL547	IL548	IL549	IL550	IL551	IL552	IL553	IL554	IL555	IL556	IL557	IL558	IL559	IL560	IL561	IL562	IL563	IL564	IL565	IL566	IL567	IL568	IL569	IL570	IL571	IL572	IL573	IL574	IL575	IL576	IL577	IL578	IL579	IL580	IL581	IL582	IL583	IL584	IL585	IL586	IL587	IL588	IL589	IL590	IL591	IL592	IL593	IL594	IL595	IL596	IL597	IL598	IL599	IL600	IL601	IL602	IL603	IL604	IL605	IL606	IL607	IL608	IL609	IL610	IL611	IL612	IL613	IL614	IL615	IL616	IL617	IL618	IL619	IL620	IL621	IL622	IL623	IL624	IL625	IL626	IL627	IL628	IL629	IL630	IL631	IL632	IL633	IL634	IL635	IL636	IL637	IL638	IL639	IL640	IL641	IL642	IL643	IL644	IL645	IL646	IL647	IL648	IL649	IL650	IL651	IL652	IL653	IL654	IL655	IL656	IL657	IL658	IL659	IL660	IL661	IL662	IL663	IL664	IL665	IL666	IL667	IL668	IL669	IL670	IL671	IL672	IL673	IL674	IL675	IL676	IL677	IL678	IL679	IL680	IL681	IL682	IL683	IL684	IL685	IL686	IL687	IL688	IL689	IL690	IL691	IL692	IL693	IL694	IL695	IL696	IL697	IL698	IL699	IL700	IL701	IL702	IL703	IL704	IL705	IL706	IL707	IL708	IL709	IL710	IL711	IL712	IL713	IL714	IL715	IL716	IL717	IL718	IL719	IL720	IL721	IL722	IL723	IL724	IL725	IL726	IL727	IL728	IL729	IL730	IL731	IL732	IL733	IL734	IL735	IL736	IL737	IL738	IL739	IL740	IL741	IL742	IL743	IL744	IL745	IL746	IL747	IL748	IL749	IL750	IL751	IL752	IL753	IL754	IL755	IL756	IL757	IL758	IL759	IL760	IL761	IL762	IL763	IL764	IL765	IL766	IL767	IL768	IL769	IL770	IL771	IL772	IL773	IL774	IL775	IL776	IL777	IL778	IL779	IL780	IL781	IL782	IL783	IL784	IL785	IL786	IL787	IL788	IL789	IL790	IL791	IL792	IL793	IL794	IL795	IL796	IL797	IL798	IL799	IL800	IL801	IL802	IL803	IL804	IL805	IL806	IL807	IL808	IL809	IL810	IL811	IL812	IL813	IL814	IL815	IL816	IL817	IL818	IL819	IL820	IL821	IL822	IL823	IL824	IL825	IL826	IL827	IL828	IL829	IL830	IL831	IL832	IL833	IL834	IL835	IL836	IL837	IL838	IL839	IL840	IL841	IL842	IL843	IL844	IL845	IL846	IL847	IL848	IL849	IL850	IL851	IL852	IL853	IL854	IL855	IL856	IL857	IL858	IL859	IL860	IL861	IL862	IL863	IL864	IL865	IL866	IL867	IL868	IL869	IL870	IL871	IL872	IL873	IL874	IL875	IL876	IL877	IL878	IL879	IL880	IL881	IL882	IL883	IL884	IL885	IL886	IL887	IL888	IL889	IL890	IL891	IL892	IL893	IL894	IL895	IL896	IL897	IL898	IL899	IL900	IL901	IL902	IL903	IL904	IL905	IL906	IL907	IL908	IL909	IL910	IL911	IL912	IL913	IL914	IL915	IL916	IL917	IL918	IL919	IL920	IL921	IL922	IL923	IL924	IL925	IL926	IL927	IL928	IL929	IL930	IL931	IL932	IL933	IL934	IL935	IL936	IL937	IL938	IL939	IL940	IL941	IL942	IL943	IL944	IL945	IL946	IL947	IL948	IL949	IL950	IL951	IL952	IL953	IL954	IL955	IL956	IL957	IL958	IL959	IL960	IL961	IL962	IL963	IL964	IL965	IL966	IL967	IL968	IL969	IL970	IL971	IL972	IL973	IL974	IL975	IL976	IL977	IL978	IL979	IL980	IL981	IL982	IL983	IL984	IL985	IL986	IL987	IL988	IL989	IL990	IL991	IL992	IL993	IL994	IL995	IL996	IL997	IL998	IL999	IL1000
-----	-----	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	--------

21.1	21.2	21.3	21.4	21.5	21.6	21.7	21.8	21.9	21.10	21.11	21.12	21.13	21.14	21.15	21.16	21.17	21.18	21.19	21.20	21.21	21.22	21.23	21.24	21.25	21.26	21.27	21.28	21.29	21.30	21.31	21.32	21.33	21.34	21.35	21.36	21.37	21.38	21.39	21.40	21.41	21.42	21.43	21.44	21.45	21.46	21.47	21.48	21.49	21.50	21.51	21.52	21.53	21.54	21.55	21.56	21.57	21.58	21.59	21.60	21.61	21.62	21.63	21.64	21.65	21.66	21.67	21.68	21.69	21.70	21.71	21.72	21.73	21.74	21.75	21.76	21.77	21.78	21.79	21.80	21.81	21.82	21.83	21.84	21.85	21.86	21.87	21.88	21.89	21.90	21.91	21.92	21.93	21.94	21.95	21.96	21.97	21.98	21.99	22.00	22.01	22.02	22.03	22.04	22.05	22.06	22.07	22.08	22.09	22.10	22.11	22.12	22.13	22.14	22.15	22.16	22.17	22.18	22.19	22.20	22.21	22.22	22.23	22.24	22.25	22.26	22.27	22.28	22.29	22.30	22.31	22.32	22.33	22.34	22.35	22.36	22.37	22.38	22.39	22.40	22.41	22.42	22.43	22.44	22.45	22.46	22.47	22.48	22.49	22.50	22.51	22.52	22.53	22.54	22.55	22.56	22.57	22.58	22.59	22.60	22.61	22.62	22.63	22.64	22.65	22.66	22.67	22.68	22.69	22.70	22.71	22.72	22.73	22.74	22.75	22.76	22.77	22.78	22.79	22.80	22.81	22.82	22.83	22.84	22.85	22.86	22.87	22.88	22.89	22.90	22.91	22.92	22.93	22.94	22.95	22.96	22.97	22.98	22.99	23.00	23.01	23.02	23.03	23.04	23.05	23.06	23.07	23.08	23.09	23.10	23.11	23.12	23.13	23.14	23.15	23.16	23.17	23.18	23.19	23.20	23.21	23.22	23.23	23.24	23.25	23.26	23.27	23.28	23.29	23.30	23.31	23.32	23.33	23.34	23.35	23.36	23.37	23.38	23.39	23.40	23.41	23.42	23.43	23.44	23.45	23.46	23.47	23.48	23.49	23.50	23.51	23.52	23.53	23.54	23.55	23.56	23.57	23.58	23.59	23.60	23.61	23.62	23.63	23.64	23.65	23.66	23.67	23.68	23.69	23.70	23.71	23.72	23.73	23.74	23.75	23.76	23.77	23.78	23.79	23.80	23.81	23.82	23.83	23.84	23.85	23.86	23.87	23.88	23.89	23.90	23.91	23.92	23.93	23.94	23.95	23.96	23.97	23.98	23.99	24.00	24.01	24.02	24.03	24.04	24.05	24.06	24.07	24.08	24.09	24.10	24.11	24.12	24.13	24.14	24.15	24.16	24.17	24.18	24.19	24.20	24.21	24.22	24.23	24.24	24.25	24.26	24.27	24.28	24.29	24.30	24.31	24.32	24.33	24.34	24.35	24.36	24.37	24.38	24.39	24.40	24.41	24.42	24.43	24.44	24.45	24.46	24.47	24.48	24.49	24.50	24.51	24.52	24.53	24.54	24.55	24.56	24.57	24.58	24.59	24.60	24.61	24.62	24.63	24.64	24.65	24.66	24.67	24.68	24.69	24.70	24.71	24.72	24.73	24.74	24.75	24.76	24.77	24.78	24.79	24.80	24.81	24.82	24.83	24.84	24.85	24.86	24.87	24.88	24.89	24.90	24.91	24.92	24.93	24.94	24.95	24.96	24.97	24.98	24.99	25.00	25.01	25.02	25.03	25.04	25.05	25.06	25.07	25.08	25.09	25.10	25.11	25.12	25.13	25.14	25.15	25.16	25.17	25.18	25.19	25.20	25.21	25.22	25.23	25.24	25.25	25.26	25.27	25.28	25.29	25.30	25.31	25.32	25.33	25.34	25.35	25.36	25.37	25.38	25.39	25.40	25.41	25.42	25.43	25.44	25.45	25.46	25.47	25.48	25.49	25.50	25.51	25.52	25.53	25.54	25.55	25.56	25.57	25.58	25.59	25.60	25.61	25.62	25.63	25.64	25.65	25.66	25.67	25.68	25.69	25.70	25.71	25.72	25.73	25.74	25.75	25.76	25.77	25.78	25.79	25.80	25.81	25.82	25.83	25.84	25.85	25.86	25.87	25.88	25.89	25.90	25.91	25.92	25.93	25.94	25.95	25.96	25.97	25.98	25.99	26.00	26.01	26.02	26.03	26.04	26.05	26.06	26.07	26.08	26.09	26.10	26.11	26.12	26.13	26.14	26.15	26.16	26.17	26.18	26.19	26.20	26.21	26.22	26.23	26.24	26.25	26.26	26.27	26.28	26.29	26.30	26.31	26.32	26.33	26.34	26.35	26.36	26.37	26.38	26.39	26.40	26.41	26.42	26.43	26.44	26.45	26.46	26.47	26.48	26.49	26.50	26.51	26.52	26.53	26.54	26.55	26.56	26.57	26.58	26.59	26.60	26.61	26.62	26.63	26.64	26.65	26.66	26.67	26.68	26.69	26.70	26.71	26.72	26.73	26.74	26.75	26.76	26.77	26.78	26.79	26.80	26.81	26.82	26.83	26.84	26.85	26.86	26.87	26.88	26.89	26.90	26.91	26.92	26.93	26.94	26.95	26.96	26.97	26.98	26.99	27.00	27.01	27.02	27.03	27.04	27.05	27.06	27.07	27.08	27.09	27.10	27.11	27.12	27.13	27.14	27.15	27.16	27.17	27.18	27.19	27.20	27.21	27.22	27.23	27.24	27.25	27.26	27.27	27.28	27.29	27.30	27.31	27.32	27.33	27.34	27.35	27.36	27.37	27.38	27.39	27.40	27.41	27.42	27.43	27.44	27.45	27.46	27.47	27.48	27.49	27.50	27.51	27.52	27.53	27.54	27.55	27.56	27.57	27.58	27.59	27.60	27.61	27.62	27.63	27.64	27.65	27.66	27.67	27.68	27.69	27.70	27.71	27.72	27.73	27.74	27.75	27.76	27.77	27.78	27.79	27.80	27.81	27.82	27.83	27.84	27.85	27.86	27.87	27.88	27.89	27.90	27.91	27.92	27.93	27.94	27.95	27.96	27.97	27.98	27.99	28.00	28.01	28.02	28.03	28.04	28.05	28.06	28.07	28.08	28.09	28.10	28.11	28.12	28.13	28.14	28.15	28.16	28.17	28.18	28.19	28.20	28.21	28.22	28.23	28.24	28.25	28.26	28.27	28.28	28.29	28.30	28.31	28.32	28.33	28.34	28.35	28.36	28.37	28.38	28.39	28.40	28.41	28.42	28.43	28.44	28.45	28.46	28.47	28.48	28.49	28.50	28.51	28.52	28.53	28.54	28.55	28.56	28.57	28.58	28.59	28.60	28.61	28.62	28.63	28.64	28.65	28.66	28.67	28.68	28.69	28.70	28.71	28.72	28.73	28.74	28.75	28.76	28.77	28.78	28.79	28.80	28.81	28.82	28.83	28.84	28.85	28.86	28.87	28.88	28.89	28.90	28.91	28.92	28.93	28.94	28.95	28.96	28.97	28.98	28.99	29.00	29.01	29.02	29.03	29.04	29.05	29.06	29.07	29.08	29.09	29.10	29.11	29.12	29.13	29.14	29.15	29.16	29.17	29.18	29.19	29.20	29.21	29.22	29.23	29.24	29.25	29.26	29.27	29.28	29.29	29.30	29.31	29.32	29.33	29.34	29.35	29.36	29.37	29.38	29.39	29.40	29.41	29.42	29.43	29.44	29.45	29.46	29.47	29.48	29.49	29.50	29.51	29.52	29.53	29.54	29.55	29.56	29.57	29.58	29.59	29.60	29.61	29.62	29.63	29.64	29.65	29.66	29.67	29.68	29.69	29.70	29.71	29.72	29.73	29.74	29.75	29.76	29.77	29.78	29.79	29.80	29.81	29.82	29.83	29.84	29.85	29.86	29.87	29.88	29.89	29.90	29.91	29.92	29.93	29.94	29.95	29.96	29.97	29.98	29.99	30.00	30.01	30.02	30.03	30.04	30.05	30.06	30.07	30.08	30.09	30.10	30.11	30.12	30.13	30.14	30.15	30.16	30.17	30.18	30.19	30.20	30.21	30.22	30.23	30.24	30.25	30.26	30.27	30.28	30.29	30.30	30.31	30.32	30.33	30.34	30.35	30.36	30.37	30.38	30.39	30.40	30.41	30.42	30.43	30.44	30.45	30.46	30.47	30.48	30.49	30.50	30.51	30.52	30.53	30.54	30.55	30.56	30.57	30.58	30.59	30.60	30.61	30.62	30.63	30.64	30.65	30.66	30.67	30.68	30.69	30.70	30.71	30.72	30.73	30.74	30.75	30.76	30.77	30.78	30.79	30.80	30.81	30.82	30.83	30.84	30.85	30.86	30.87	30.88	30.89	30.90	30.91	30.92	30.93	30.94	30.95	30.96	30.97	30.98	30.99	31.00	31.01	31.02	31.03	31.04	31.05	31.06	31.07	31.08	31.09	31.10	31.11	31.12	31.13	31.14	31.15	31.16	31.17	31.18	31.19	31.20	31.21	31.22	31.23	31.24	31.25	31.26	31.27	31.28	31.29	31.30	31.31	31.32	31.33	31.34	31.35	31.36	31.37	31.38	31.39	31.40	31.41	31.42	31.43	31.44	31.45	31.46	31.47	31.48	31.49	31.50	31.51	31.52	31.53	31.54	31.55	31.56	31.57	31.58	31.59	31.60	31.61	31.62	31.63	31.64	31.65	31.66	31.67	31.68	31.69	31.70	31.71	31.72	31.73	31.74	31.75	31.76	31.77	31.78	31.79	31.80	31.81	31.82	31.83	31.84	31.85	31.86	31.87	31.88	31.89	31.90	31.91	31.92	31.93	31.94	31.95	31.96	31.97	31.98	31.99	32.00	32.01	32.02	32.03	32.04	32.05	32.06	32.07	32.08	32.09	32.10	32.11	32.12	32.13	32.14	32.15	32.16	32.17	32.18	32.19	32.20	32.21	32.22	32.23	32.24	32.25	32.26	32.27	32.28	32.29	32.30	32.31	32.32	32.33	32.34	32.35	32.36	32.37	32.38	32.39	32.40	32.41	32.42	32.43	32.44	32.45	32.46	32.47	32.48	32.49	32.50	32.51	32.52	32.53	32.54	32.55	32.56	32.57	32.58	32.59	32.60	32.61	32.62	32.63	32.64	32.65	32.66	32.67	32.68	32.69	32.70	32.71	32.72	32.73	32.74	32.75	32.76	32.77	32.78	32.79	32.80	32.81	32.82	32.83	32.84	32.85	32.86	32.87	32.88	32.89	32.90	32.91	32.92	32.93	32.94	32.95	32.96	32.97	32.98	32.99	33.00	33.01	33.02	33.03	33.04	33.05	33.06	33.07	33.08	33.09	33.10	33.11	33.12	33.13	33.14	33.15	33.16	33.17	33.18	33.19	33.20	33.21	33.22	33.23	33.24	33.25	33.26	33.27	33.28	33.29	33.30	33.31	33.32	33.33	33.34	33.35	33.36	33.37	33.38	33.39
------	------	------	------	------	------	------	------	------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

FIGURE 1. SPECIMEN LAYOUT FOR X2048-T851 PLATE

Impact. Charpy V-notch test results for longitudinal and transverse specimens are given in Table IV.

Fracture Toughness. Results of slow-bend type tests in both the longitudinal (L-T) and transverse (T-L) directions are given in Table V. The specimens were 1.00-inch thick by 2.00-inches wide with a span of 8 inches. The candidate K_Q values shown in Table V are considered valid K_{Ic} values by existing ASTM criteria. (Higher K_{Ic} values may be achieved with larger specimens. Reference J. G. Kaufman, "Notes for E-24.01 Meeting", held at Battelle's Columbus Laboratories on October 4, 1972.)

Fatigue. Axial-load test results for longitudinal specimens at a ratio of $R = 0.1$ are given in Tables VI and VII. These tests were conducted for both unnotched and notched ($K_t = 3.0$) specimens at room temperature, 250 F, and 350 F. S-N curves are presented in Figures 8 and 9.

Creep and Stress-Rupture. Results of tests on longitudinal specimens at 250 F, 350 F, and 500 F are given in Table VIII. Log-stress versus log-time curves are presented in Figure 10.

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

Thermal Expansion. The coefficient of thermal expansion for this alloy was determined to be 12.9×10^{-6} in./in./F for 68 F to 350 F.

Density. The density of this material is 0.0994 lb./in.³.

TABLE I. TENSION TEST RESULTS FOR X2048-T851 ALUMINUM PLATE

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Reduction in Area, percent	Tensile Modulus, 10 ⁶ psi
<u>Longitudinal at Room Temperature</u>					
1L-1	66.2	60.5	8.0	15.7	10.2
1L-2	66.2	60.3	8.5	15.8	10.3
1L-3	<u>66.4</u>	<u>60.4</u>	<u>8.5</u>	<u>15.5</u>	<u>10.2</u>
Average	66.5	60.4	8.3	15.7	10.2
<u>Transverse at Room Temperature</u>					
1T-1	69.4	62.4	8.0	12.5	10.8
1T-2	66.4	60.0	7.0	12.2	10.5
1T-3	<u>66.3</u>	<u>60.2</u>	<u>6.5</u>	<u>10.3</u>	<u>10.3</u>
Average	67.4	60.9	7.2	11.7	10.5
<u>Short Transverse at Room Temperature</u>					
1ST-1	67.6	59.6	7.0	11.4	11.1
1ST-2	67.4	59.0	6.0	7.8	11.2
1ST-3	<u>66.4</u>	<u>58.2</u>	<u>6.0</u>	<u>9.0</u>	<u>11.1</u>
Average	67.1	58.9	6.3	9.4	11.1
<u>Longitudinal at 250 F</u>					
1L-4	59.8	56.5	13.5	33.9	9.5
1L-5	60.5	57.0	12.5	28.4	9.9
1L-6	<u>60.1</u>	<u>57.0</u>	<u>12.0</u>	<u>32.6</u>	<u>10.4</u>
Average	60.1	56.8	12.7	31.6	9.9
<u>Transverse at 250 F</u>					
1T-4	60.4	56.5	11.5	26.3	10.0
1T-5	59.7	56.0	13.5	29.3	10.0
1T-6	<u>59.8</u>	<u>56.3</u>	<u>13.0</u>	<u>27.6</u>	<u>9.4</u>
Average	60.0	56.3	12.7	27.7	9.8
<u>Longitudinal at 350 F</u>					
1L-7	51.6	49.4	13.5	38.8	9.3
1L-8	51.4	49.1	14.5	38.1	9.3
1L-9	<u>51.1</u>	<u>48.8</u>	<u>14.5</u>	<u>35.0</u>	<u>9.4</u>
Average	51.4	49.4	14.2	37.3	9.3
<u>Transverse at 350 F</u>					
1T-7	50.5	48.7	17.0	35.1	9.3
1T-8	51.1	49.4	16.5	33.5	9.4
1T-9	<u>49.3</u>	<u>48.2</u>	<u>16.0</u>	<u>33.9</u>	<u>9.1</u>
Average	50.3	48.8	16.5	34.2	9.3
<u>Longitudinal at 500 F</u>					
1L-10	34.5	32.1	10.0	27.2	8.6
1L-11	33.7	31.8	8.5	21.6	8.5
1L-12	<u>33.7</u>	<u>31.3</u>	<u>10.0</u>	<u>21.5</u>	<u>7.9</u>
Average	34.0	31.7	9.5	23.4	8.3
<u>Transverse at 500 F</u>					
1T-10	32.3	30.5	10.0	14.7	7.5
1T-11	35.0	33.2	7.5	15.1	8.0
1T-12	<u>32.8</u>	<u>31.0</u>	<u>7.0</u>	<u>15.1</u>	<u>7.6</u>
	33.4	31.6	8.2	15.0	7.7

TABLE II. COMPRESSION TEST RESULTS FOR
X2048-T851 ALUMINUM PLATE

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, 10 ³ psi
<u>Longitudinal at Room Temperature</u>		
2L-1	62.0	11.4
2L-2	59.0	11.1
2L-3	61.6	11.5
Average	60.9	11.3
<u>Transverse at Room Temperature</u>		
2T-1	60.6	10.9
2T-2	61.2	11.1
2T-3	60.0	11.4
Average	60.6	11.1
<u>Longitudinal at 250 F</u>		
2L-4	56.2	10.1
2L-5	56.8	10.3
2L-6	57.0	10.3
Average	56.7	10.2
<u>Transverse at 250 F</u>		
2T-4	56.8	10.3
2T-5	56.8	10.3
2T-6	54.4	10.2
Average	56.0	10.3
<u>Longitudinal at 350 F</u>		
2L-7	51.7	9.8
2L-8	48.8	9.4
2L-9	51.3	9.6
Average	50.6	9.6
<u>Transverse at 350 F</u>		
2T-7	52.0	9.9
2T-8	50.3	9.7
2T-9	50.9	9.6
Average	51.1	9.7
<u>Longitudinal at 500 F</u>		
2L-10	35.0	9.6
2L-11	35.3	9.0
2L-12	35.3	9.7
Average	35.2	9.4
<u>Transverse at 500 F</u>		
2T-10	33.1	9.7
2T-11	32.5	9.9
2T-12	33.1	9.7
Average	32.9	9.7

TABLE III. SHEAR TEST RESULTS FOR X2048-T851
ALUMINUM PLATE AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
<u>Longitudinal</u>	
4L-1	39.3
4L-2	39.0
4L-3	39.8
4L-4	39.3
Average	<u>39.3</u>
<u>Transverse</u>	
	39.5
4T-2	40.1
4T-3	38.8
4T-4	<u>38.5</u>
Average	<u>39.2</u>

TABLE IV. CHARPY V-NOTCH TEST RESULTS
FOR X2048-T851 ALUMINUM PLATE

Specimen Number	Energy, ft./lbs.
<u>Longitudinal</u>	
10-1L	7.0
10-2L	9.0
10-3L	7.0
10-4L	5.0
10-5L	9.0
10-6L	10.0
10-7L	<u>6.5</u>
Average	<u>8.9</u>
<u>Transverse</u>	
10-1T	4.0
10-2T	4.0
10-3T	5.0
10-4T	4.0
10-5T	5.0
10-6T	<u>5.0</u>
Average	<u>4.5</u>

TABLE V. RESULTS OF SLOW-BEND TYPE FRACTURE TOUGHNESS TESTS FOR X2048-T851 ALUMINUM PLATE

Specimen Number	W, inches	a, inches	T, inches	P, lbs	Span, inches	$f(\frac{a}{W})$	$K_Q^{(a)}$
<u>Transverse (T-L)</u>							
6-1T	2.00	0.903	1.00	4,500	8.0	2.294	29.20
6-2T	2.00	0.936	1.00	4,100	8.0	2.410	27.95
6-3T	2.00	0.946	1.00	4,350	8.0	2.448	30.12
6-4T	2.00	0.942	1.00	4,300	8.0	2.433	29.59
6-5T	2.00	0.911	1.00	4,350	8.0	2.321	28.56
6-6T	2.00	0.916	1.00	4,425	8.0	2.339	29.27
Average							29.17
<u>Longitudinal (L-T)</u>							
6-1L	2.00	0.876	1.00	4,925	8.0	2.205	30.72
6-2L	2.00	0.903	1.00	4,950	8.0	2.294	32.12
6-3L	2.00	0.918	1.00	4,900	8.0	2.346	32.52
6-4L	2.00	0.947	1.00	5,075	8.0	2.452	35.19
6-5L	2.00	0.880	1.00	4,880	8.0	2.218	30.61
6-6L	2.00	0.920	1.00	4,950	8.0	2.353	32.94
Average							32.35

(a) These candidate K_Q values do meet existing ASTM size and crack length criteria and are considered valid K_{Ic} numbers.

TABLE VI. AXIAL LOAD FATIGUE TEST RESULTS FOR X2048-T851
ALUMINUM PLATE (UNNOTCHED, R = 0.1) (LONGITUDINAL)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
<u>Room Temperature</u>		
5-2	60.0	9,500
5-3	55.0	21,300
5-1	50.0	30,200
5-4	45.0	70,600
5-8	42.5	2,581,900
5-5	40.0	50,400
5-7	37.5	53,300
5-6	35.0	3,658,400
5-9	30.0	11,340,800(a)
<u>250 F</u>		
5-10	60.0	8,400
5-11	55.0	17,400
5-12	50.0	42,200
5-13	45.0	124,100
5-15	42.5	223,900
5-14	40.0	109,300
5-16	37.5	2,384,200
5-17	35.0	204,300
5-18	30.0	238,300(b)
5-19	25.0	11,538,190(a)
<u>350 F</u>		
5-20	60.0	100
5-24	50.0	28,100
5-22	45.0	33,700
5-25	42.5	97,800
5-21	40.0	177,900
5-26	37.5	212,300
5-23	35.0	2,851,600
5-27	30.0	236,800
5-28	25.0	14,461,900

(a) Did not fail.

(b) Failed at Radius.

TABLE VII. AXIAL LOAD FATIGUE RESULTS FOR X2048-T851
ALUMINUM PLATE (NOTCHED, $K_t = 3.0$,
 $R = 0.1$) (LONGITUDINAL)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
<u>Room Temperature</u>		
5-31	40.0	7,500
5-32	30.0	21,600
5-34	25.0	44,700
5-36	22.5	107,400
5-33	20.0	247,500
5-35	17.5	2,646,500
5-37	15.0	14,621,000 ^(a)
<u>250 F</u>		
5-44	40.0	6,430
5-45	30.0	26,600
5-47	25.0	48,300
5-46	20.0	91,800
5-49	17.5	1,061,800
5-50	15.0	8,524,200
5-51	12.5	11,392,300 ^(a)
<u>350 F</u>		
5-38	40.0	6,100
5-39	30.0	15,400
5-41	25.0	43,800
5-40	20.0	128,400
5-42	17.5	243,600
5-43	15.0	509,000
5-52	12.5	4,744,700
5-53	10.0	13,384,100 ^(a)

(a) Did not fail.

TABLE VIII. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR X2048-T851 ALUMINUM PLATE (LONGITUDINAL)

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, percent				Initial Strain, percent	Rupture Time, hours	Elongation in 2 in., percent	Reduction of Area, percent	Minimum Creep Rate, percent
			0.1	0.2	0.5	1.0	2.0				
3-3	60	250	—	—	—	—	—	2.710	0.1	8.9	22.4
3-4	50	"	0.15	0.50	3.1	11	36	0.674	77.8	7.4	26.4
3-5	46	"	10	80	1150	1900 (a)	—	0.507	1363.2(b)	1.315	—
8-8	40	"	60	1375	5650 (a)	—	—	0.574	1325.4(b)	0.770	—
3-10	50	350	—	—	—	—	—	2.655	0.02	12.6	41.1
3-12	42	"	0.17	1.0	5	17	29	0.541	34.8	5.9	10.1
3-9	35	"	17	62	180	275	325	0.367	333.7	3.7	3.9
3-2	25	"	125	410	1475 (a)	3165 (a)	—	0.274	1033.1(b)	0.655	—
3-7	20	500	0.2	0.6	1.6	3.5	5.4	0.274	6.7	8.2	27.0
3-1	10	500	12	52	160	277	352	0.141	416.6	14.1	54.5
3-6	6.5	"	105	310	1200 (a)	—	—	0.118	527.3(b)	0.397	—
3-11	4.5	"	200	1000	—	—	—	0.056	984.5(b)	0.255	—

(a) Estimate.

(b) Test discontinued.

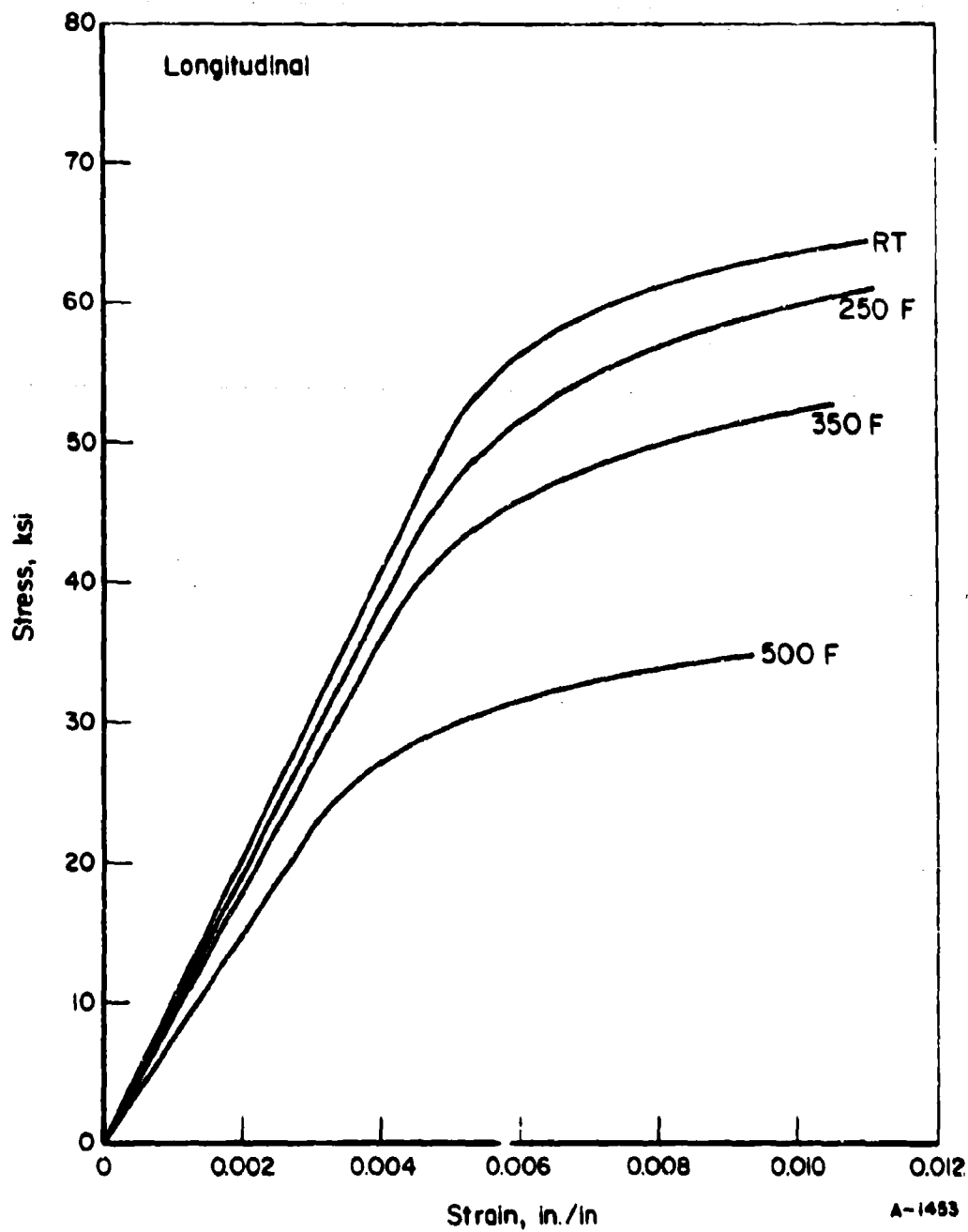


FIGURE 2. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR X2048-T851 PLATE (LONGITUDINAL.)

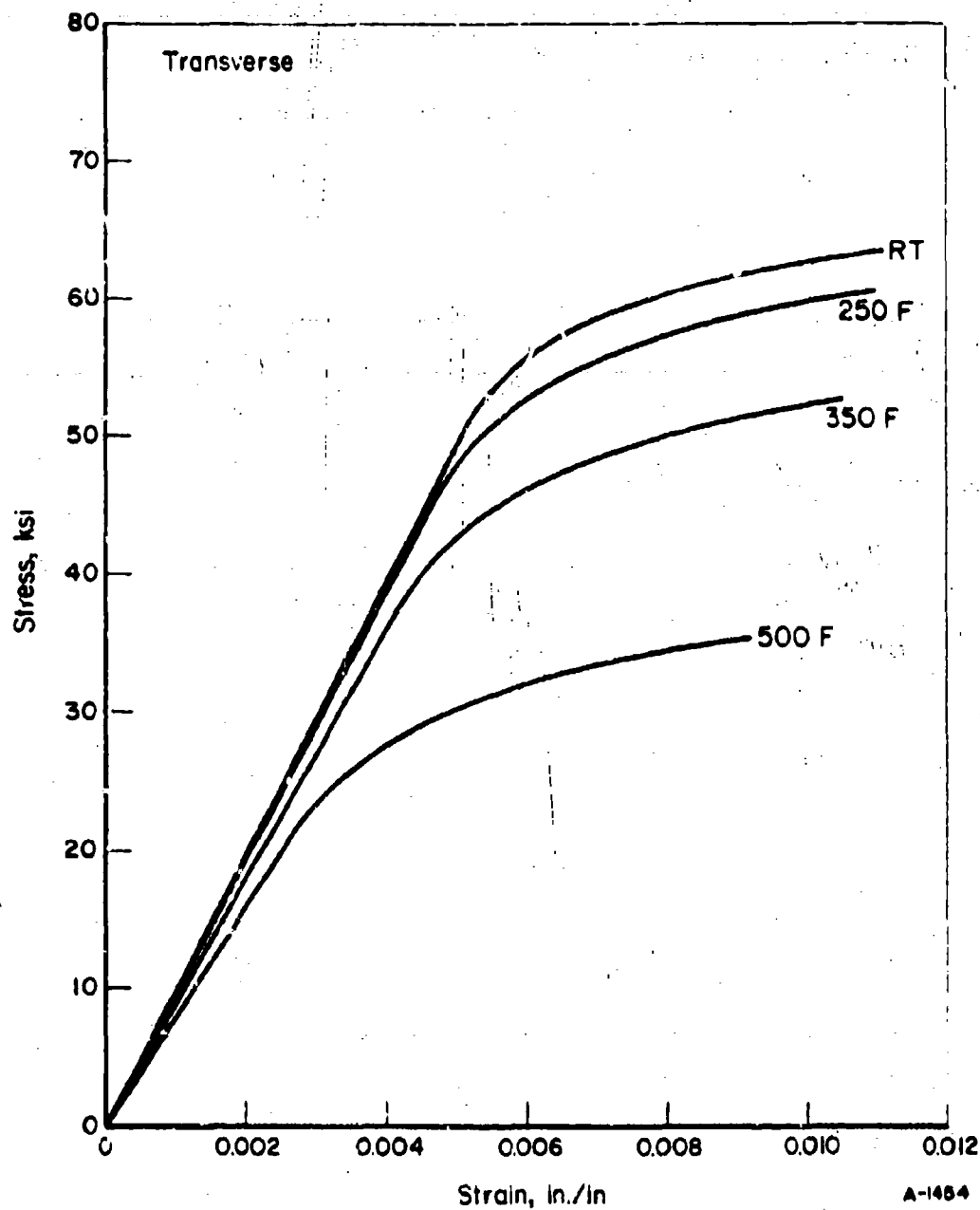


FIGURE 3. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR X2048-T851 PLATE (TRANSVERSE)

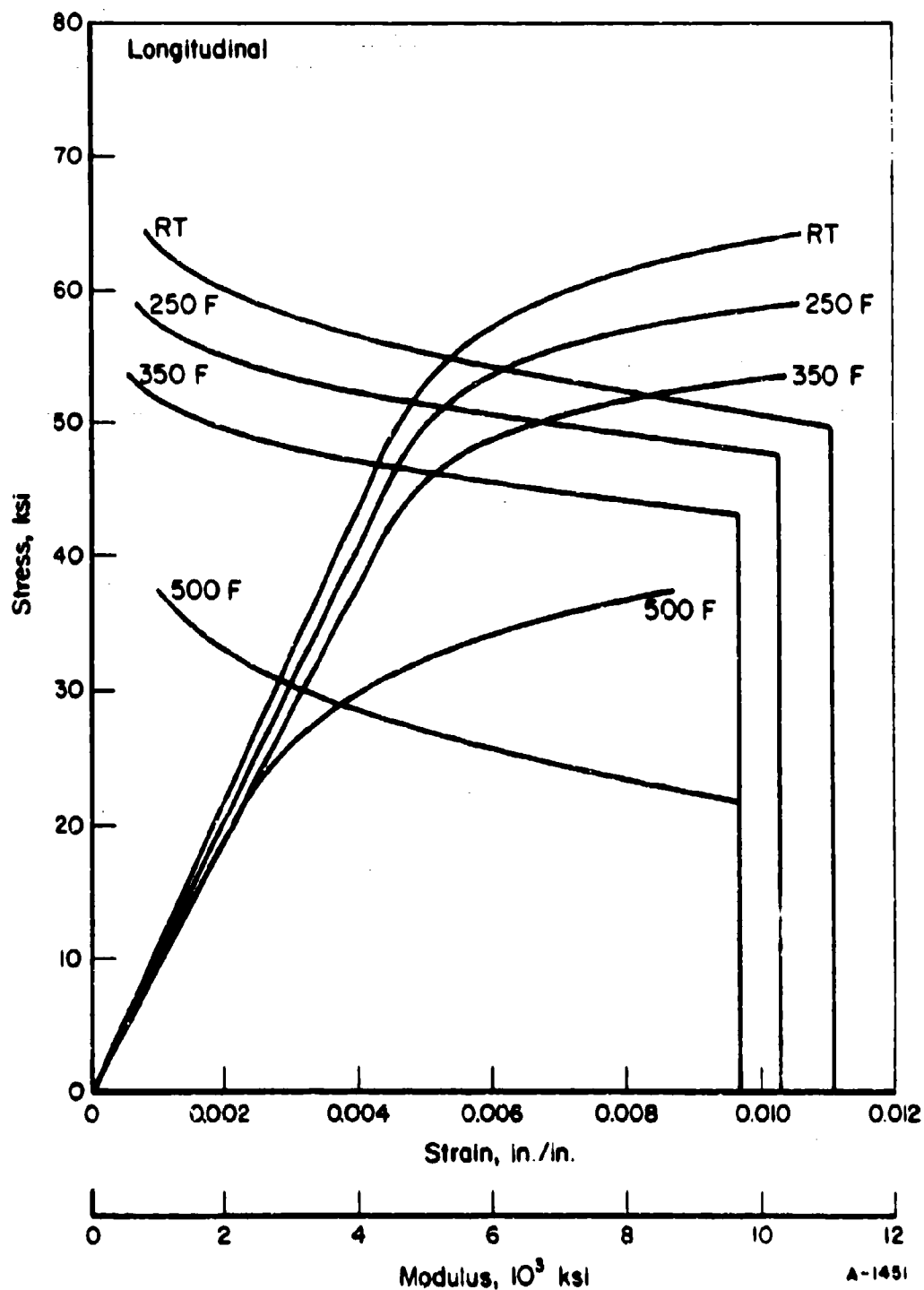


FIGURE 4. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR X2048-T851 PLATE (LONGITUDINAL)

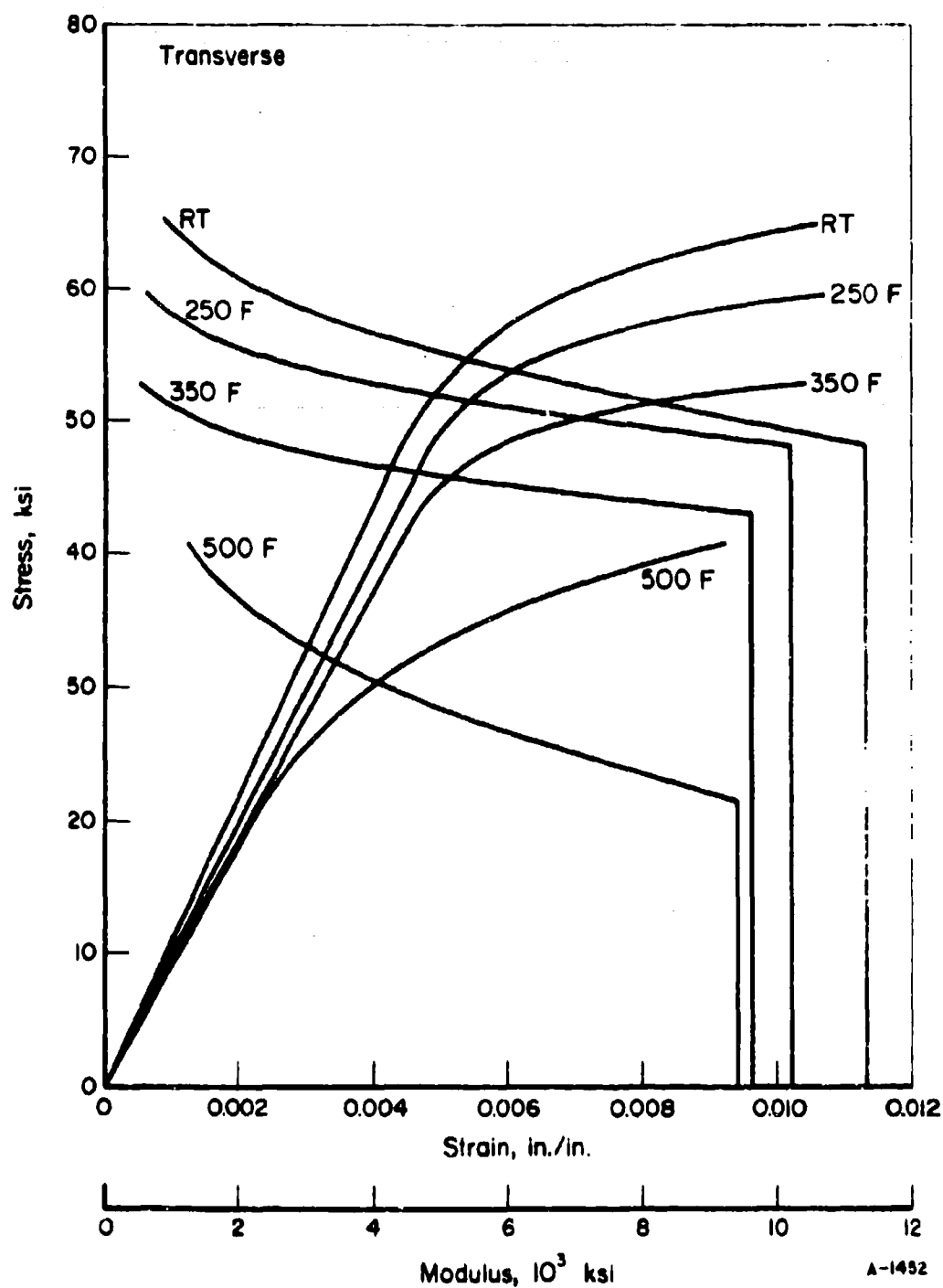


FIGURE 5. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR X2048-T851 PLATE (TRANSVERSE)

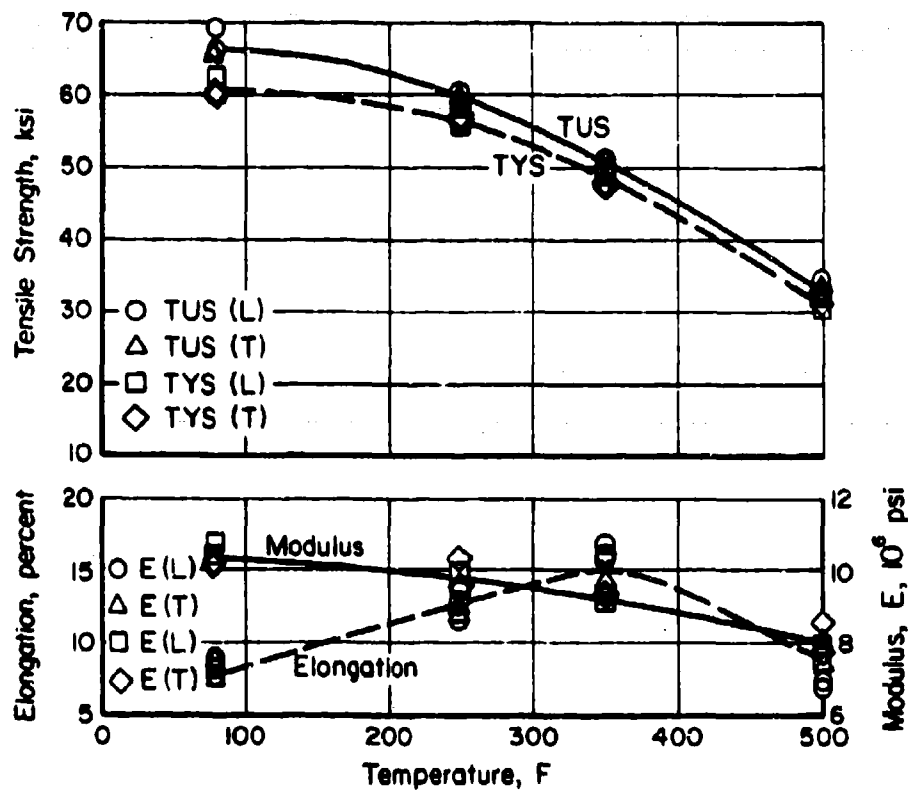


FIGURE 6. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF X2048-T851 PLATE

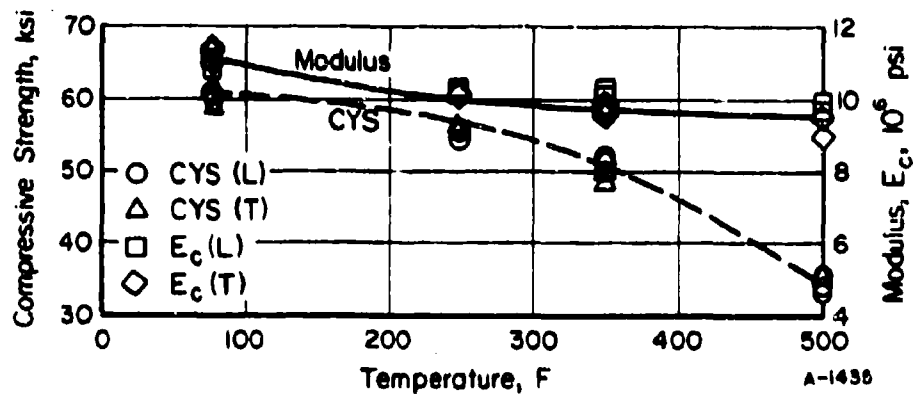


FIGURE 7. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF X2048-T851 PLATE

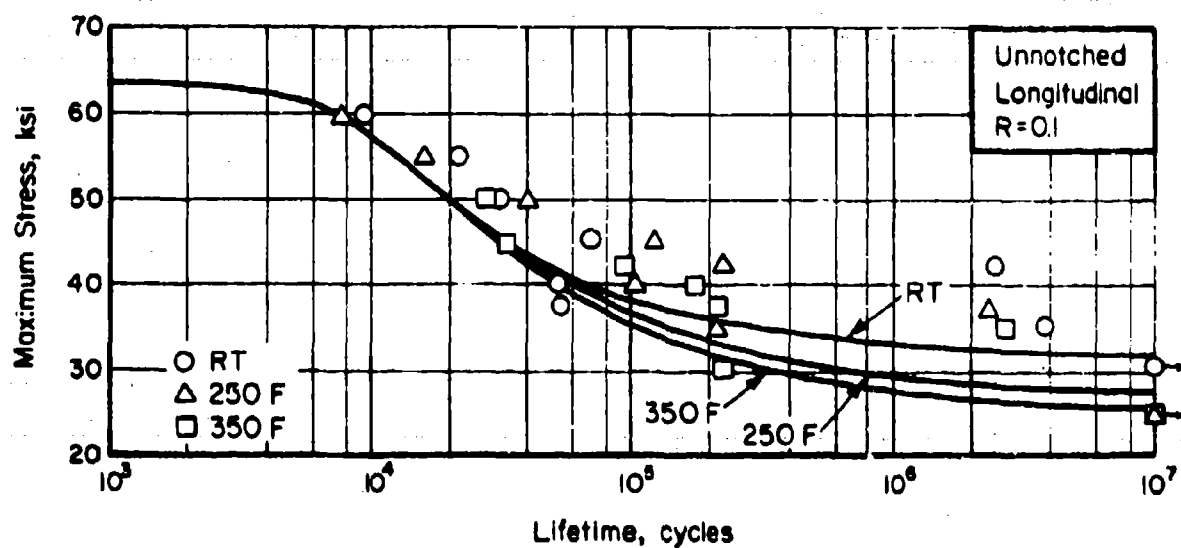


FIGURE 8. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED X2048-T851 PLATE (LONGITUDINAL)

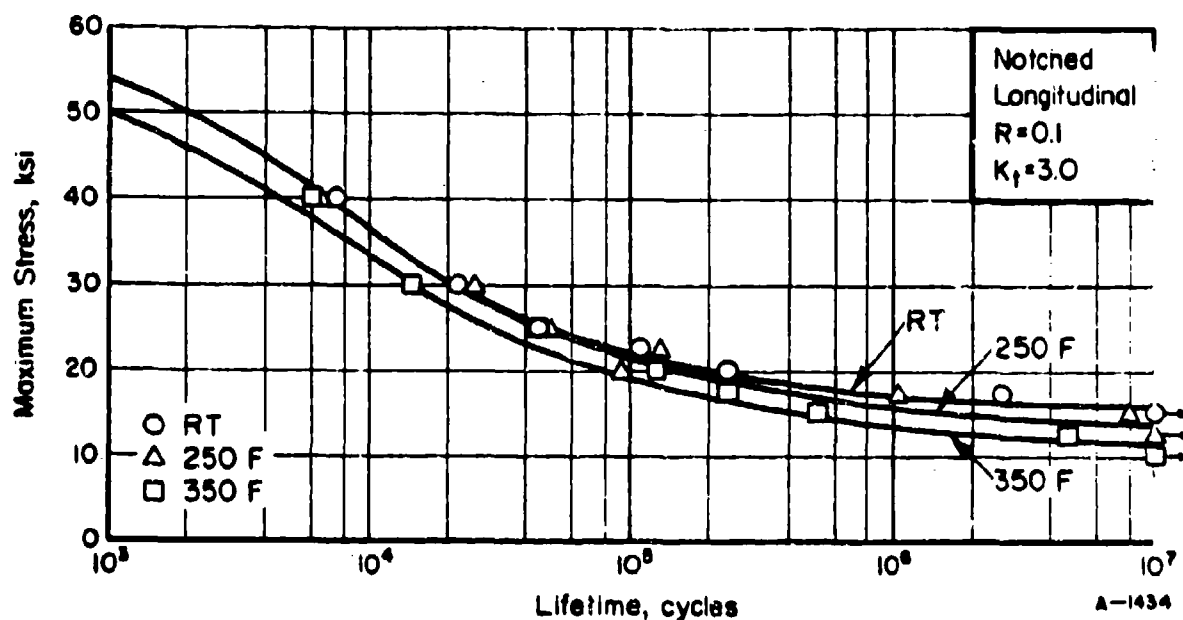


FIGURE 9. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED ($K_t = 3.0$) X2048-T851 PLATE (LONGITUDINAL)

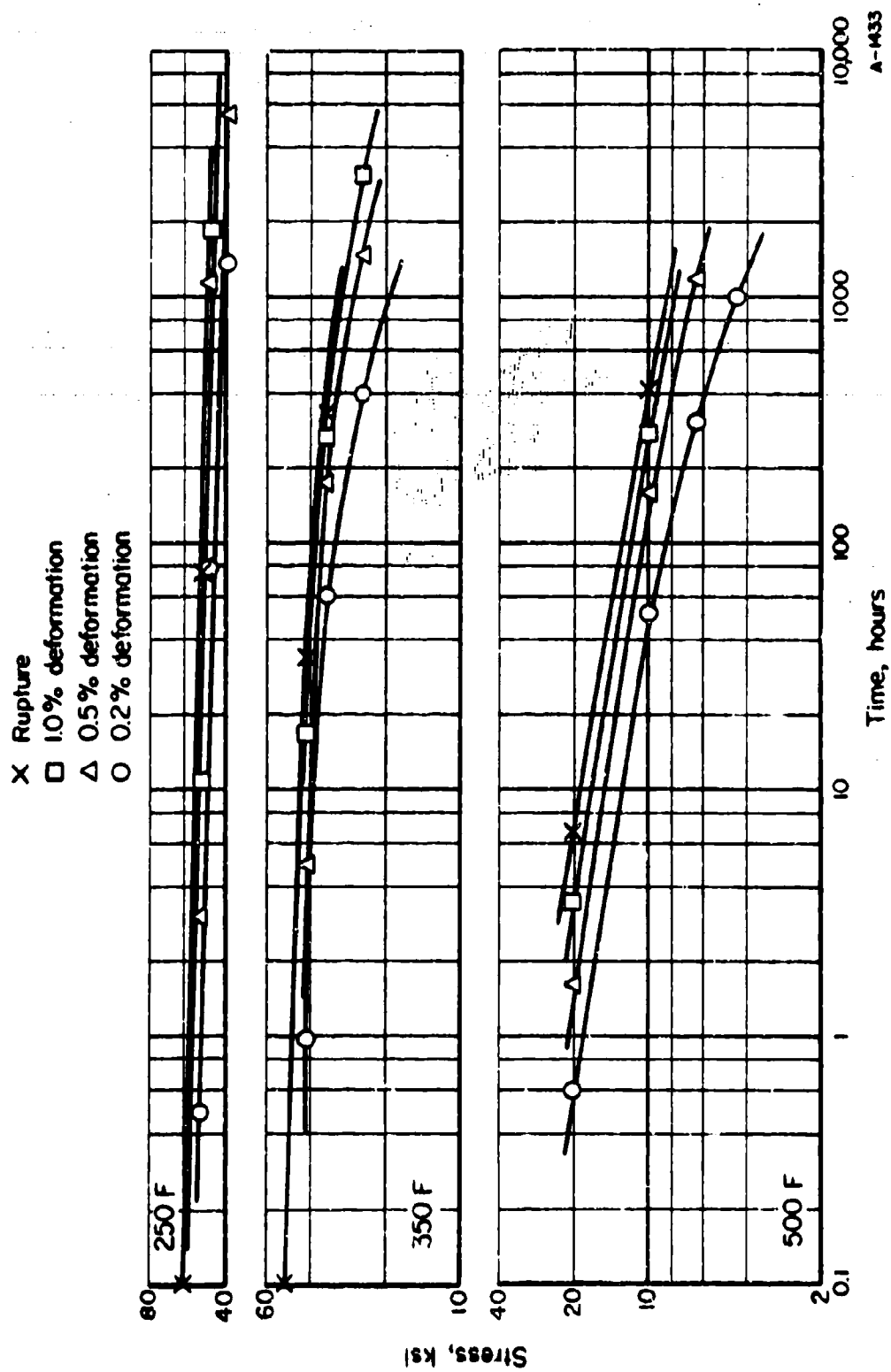


FIGURE 10. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR X2048-T851 PLATE (LONGITUDINAL)

7050-T73651 Aluminum AlloyMaterial Description

Alloy 7050 is an Al-Zn-Mg-Cu alloy developed by the Alcoa Research Laboratories supported by the Naval Air Systems Command and the Air Force Materials Laboratory. When heat treated and aged to the -T73 temper, thick 7050 plate and hand forgings exhibit strengths equal to or exceeding those of 7079-T6XX products combined with improved fracture toughness and a high resistance to exfoliation and stress-corrosion cracking. The alloy differs from conventional 7XXX series aluminum alloys in that zirconium is added and chromium and manganese are restricted in order to minimize quench sensitivity.

The material used in this evaluation was 1-inch plate from Heat S-416420 produced within the following composition limits

Copper	2.0 to 2.8
Iron	0.15 max
Silicon	0.12 max
Manganese	0.10 max
Magnesium	1.9 to 2.6
Zinc	5.7 to 6.7
Chromium	0.04 max
Titanium	0.06 max
Aluminum	Balance .

Processing and Heat Treating

The specimen layout is shown in Figure 11. Specimens were tested in the as-received -T73651 temper.

Test Results

Tension. Test results for both longitudinal and transverse specimens at room temperature, 250 F, 350 F, and 500 F are given in Table IX. Typical stress-strain curves at temperature are presented in Figures 12 and 13. Effect-of-temperature curves are shown in Figure 16.

Compression. Test results for longitudinal and transverse specimens at room temperature, 250 F, 350 F, and 500 F are given in Table X. Typical stress-strain and tangent-modulus curves at temperature are presented in Figures 14 and 15. Effect-of-temperature curves are shown in Figure 17.

FIGURE 11. SPECIMEN LAYOUT FOR 7050-T73651 PLATE.

Shear. Results of pin-type shear tests for longitudinal and transverse specimens at room temperature are given in Table XI.

Impact. Charpy V-notch test results for longitudinal and transverse specimens at room temperature are presented in Table XII.

Fracture Toughness. Results of slow-bend type tests in both the longitudinal (L-T) and transverse (T-L) directions are given in Table XIII. The candidate K_Q values shown in the Table are considered valid K_{Ic} values by existing ASTM criteria.

Fatigue. Axial load fatigue test results at a stress ratio of $R = 0.1$ are given in Tables XIV and XV for unnotched and notched transverse specimens. These tests were conducted at room temperature, 250 F, and 350 F. S-N curves are presented in Figures 18 and 19.

Creep and Stress-Rupture. Tests were conducted at 250 F, 350 F, and 500 F on transverse specimens. Tabular test results are given in Table XVI. Log-stress versus log-time curves are presented in Figure 20.

Stress Corrosion. Tests were performed as described in the experimental procedures section of this report. No failures or cracks occurred in the 1000 hour test duration.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 12.8×10^{-6} in./in./F from 68 F to 212 F.

Density. The density of this material is 0.102 lb./in.³.

TABLE IX. TENSION TEST RESULTS FOR 7050-T73651
ALUMINUM ALLOY PLATE

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Reduction in Area, percent	Tensile Modulus, 10 ⁴ psi
<u>Longitudinal at Room Temperature</u>					
1L-1	82.1	73.4	12.0	30.8	10.3
1L-2	82.9	74.0	12.0	30.0	10.4
1L-3	82.8	73.9	11.5	29.9	10.1
Average	82.6	73.8	11.8	30.2	10.3
<u>Transverse at Room Temperature</u>					
1T-1	81.4	72.4	10.0	23.3	10.6
1T-2	81.4	72.7	10.5	25.2	10.5
1T-3	81.7	72.6	11.0	24.9	10.4
Average	81.5	72.5	10.5	24.5	10.5
<u>Longitudinal at 250 F</u>					
1L-4	65.1	65.0	15.5	47.6	9.3
1L-5	64.8	64.8	15.5	48.2	9.4
1L-6	65.2	65.2	15.5	48.5	9.5
Average	65.0	64.9	15.5	48.1	9.4
<u>Transverse at 250 F</u>					
1T-4	64.4	63.8	13.5	39.1	9.3
1T-5	64.6	64.2	13.5	40.3	10.1
1T-6	64.5	64.2	13.0	36.8	9.7
Average	64.5	64.1	13.3	38.7	9.7
<u>Longitudinal at 350 F</u>					
1L-7	52.7	52.3	17.0	58.8	8.8
1L-8	54.6	54.4	16.5	57.2	8.4
1L-9	54.0	54.0	17.0	58.3	8.9
Average	53.7	53.5	16.8	58.1	8.7
<u>Transverse at 350 F</u>					
1T-7	53.0	52.8	14.5	48.8	3.9
1T-8	53.2	52.8	15.0	47.5	8.1
1T-9	54.3	54.3	14.5	47.2	9.1
Average	53.5	53.3	14.7	47.8	8.7
<u>Longitudinal at 500 F</u>					
1L-10	21.6	21.2	25.0	80.3	8.4
1L-11	22.2	21.8	22.0	79.8	8.1
1L-12	19.9	19.7	24.5	83.0	8.7
Average	21.2	20.9	23.8	81.0	8.4
<u>Transverse at 500 F</u>					
1T-10	19.9	19.7	23.0	80.8	8.5
1T-11	23.5	23.5	22.5	75.4	8.6
1T-12	19.4	19.4	25.0	83.2	8.8
Average	20.9	20.8	23.5	79.8	8.7

TABLE X. COMPRESSION TEST RESULTS FOR
7050-T73651 ALUMINUM ALLOY PLATE

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 10 ³ psi
<u>Longitudinal at Room Temperature</u>		
2L-1	73.1	10.8
2L-2	73.3	10.8
2L-3	72.7	10.8
Average	73.0	10.8
<u>Transverse at Room Temperature</u>		
2T-1	75.4	11.2
2T-2	75.2	10.9
2T-3	73.2	11.0
Average	75.3	11.0
<u>Longitudinal at 250 F</u>		
2L-4	64.4	9.5
2L-5	64.8	9.6
2L-6	63.7	9.4
Average	64.3	9.5
<u>Transverse at 250 F</u>		
2T-4	66.4	10.0
2T-5	66.1	9.9
2T-6	65.7	10.1
Average	66.1	10.0
<u>Longitudinal at 350 F</u>		
2L-7	54.2	9.0
2L-8	54.7	9.0
2L-9	52.1	9.1
Average	53.7	9.1
<u>Transverse at 350 F</u>		
2T-7	54.8	9.4
2T-8	54.8	9.6
2T-9	52.1	9.3
Average	55.1	9.4
<u>Longitudinal at 500 F</u>		
2L-10	20.1	8.5
2L-11	21.2	7.9
2L-12	21.3	7.8
Average	20.9	8.1
<u>Transverse at 500 F</u>		
2T-10	22.6	8.2
2T-11	21.0	7.9
2T-12	22.5	8.0
Average	22.0	8.0

TABLE XI. SHEAR TEST RESULTS FOR 7050-T73651 ALUMINUM ALLOY PLATE AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
<u>Longitudinal</u>	
4L-1	46.8
4L-2	46.5
4L-3	50.2
4L-4	51.3
Average	48.7
<u>Transverse</u>	
4T-1	47.5
4T-2	47.9
4T-3	48.2
4T-4	43.3
Average	47.9

TABLE XII. IMPACT TEST RESULTS FOR 7050-T73651 ALUMINUM ALLOY PLATE AT ROOM TEMPERATURE

Specimen Number	Energy, ft. lbs.
<u>Longitudinal</u>	
10L-1	26.5
10L-2	44.0
10L-3	29.0
10L-4	57.0
10L-5	22.0
10L-6	30.0
Average	34.7
<u>Transverse</u>	
10T-1	6.0
10T-2	6.0
10T-3	5.5
10T-4	6.0
10T-5	5.5
10T-6	5.0
Average	5.7

TABLE XIII. RESULTS OF SLOW-BEND TYPE FRACTURE TOUGHNESS
TESTS FOR 7050-T73651 ALUMINUM ALLOY PLATE

Specimen Number	w, inches	a, inches	T, inches	P, lbs.	Span, inches	$f(\frac{a}{w})$	$K_Q^{(a)}$
<u>Longitudinal (L-T)</u>							
6-1L	2.00	1.00	1.00	5,000	8.0	2.664	37.68
6-2L	2.00	0.990	1.00	5,100	8.0	2.622	37.83
6-3L	2.00	0.992	1.00	4,950	8.0	2.622	36.35
6-4L	2.00	1.01	1.00	5,100	8.0	2.708	39.07
6-5L	2.00	1.00	1.00	5,000	8.0	2.664	37.68
6-6L	2.00	0.964	1.00	5,190	8.0	2.508	36.90
Average							37.68
<u>(Transverse (T-L))</u>							
6-1T	2.00	0.963	1.00	5,200	8.0	2.510	36.90
6-2T	2.00	0.963	1.00	5,200	8.0	2.510	36.90
6-3T	2.00	1.00	1.00	5,000	8.0	2.663	37.70
6-4T	2.00	0.997	1.00	4,900	8.0	2.652	36.75
6-5T	2.00	0.990	1.00	4,900	8.0	2.623	36.30
6-6T	2.00	0.978	1.00	5,200	8.0	2.573	37.80
Average							36.99

(a) These candidate K_Q values do meet existing ASTM size and crack length criteria and are considered valid K_{Ic} numbers.

TABLE XIV. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED
7050-T73651 ALUMINUM PLATE (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
<u>Room Temperature</u>		
5-7	60.0	11,580
5-6	50.0	46,700
5-5	46.0	55,420
5-1	40.0	84,500
5-3	37.5	296,600
5-2	35.0	4,527,400
5-4	30.0	12,500,000 ^(a)
<u>250 F</u>		
5-16	60.0	9,390
5-14	50.0	21,680
5-13	45.0	29,390
5-9	40.0	77,100
5-10	37.5	133,200
5-11	35.0	99,900
5-25	32.5	1,086,400
5-8	30.0	363,800
5-15	25.0	443,400
5-22	20.0	10,151,300 ^(a)
<u>350 F</u>		
5-17	60.0	220
5-19	50.0	26,350
5-20	45.0	60,460
5-18	40.0	83,690
5-21	35.0	88,990
5-23	30.0	401,600
5-24	25.0	10,604,650 ^(a)

(a) Did not fail.

TABLE XV. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED
($K_t=3.0$) 7050-T73651 ALUMINUM PLATE (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
<u>Room Temperature</u>		
5-32	37.5	11,500
5-31	35.0	15,600
5-33	32.5	14,800
5-34	30.0	21,900
5-36	27.5	25,400
5-35	25.0	42,200
5-37	20.0	70,800
5-38	15.0	363,800
5-39	10.0	10,480,000 ^(a)
<u>250 F</u>		
5-40	37.5	7,200
5-41	35.0	13,000
5-42	32.5	14,400
5-43	30.0	17,100
5-44	25.0	36,900
5-46	20.0	127,300
5-45	15.0	293,600
5-47	10.0	10,000,480 ^(a)
<u>350 F</u>		
5-48	37.5	3,670
5-49	35.0	8,190
5-50	32.5	43,510
5-51	30.0	42,450
5-52	25.0	87,300
5-53	20.0	89,950
5-54	15.0	521,300
5-55	10.0	12,237,900 ^(a)

(a) Did not fail.

TABLE XVI. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR 7050 ALUMINUM PLATE (TRANSVERSE)

Specimen Number	Stress, ksi	Temper- ature, 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					
3-10	60	250	0.04	0.07	0.18	0.38	0.85	0.803	3.9	15.2	43.2	1.35
3-1	50	250	30	70	195	305 (a)	415	0.553	472.5 (b)	9.8	46.1	0.0125
3-11	45	250	15	110 (a)	605 (a)	900	--	0.504	576.1 (b)	0.993	--	0.00053
3-13	35	250	425	2700	8700	--	--	0.315	1007.3	0.432	--	0.00005
3-4	45	350	0.02	0.03	0.07	0.13	0.22	0.603	0.4	16.7	40.5	7.2
3-10	32	350	1.5	3.8	6.9	10	--	0.405	13.0	14.4	63.5	0.041
3-2	25	350	11	43	103	133	145	0.306	155.1	17.4	70.4	0.0031
3-8	20	350	35	30 (a)	305 (a)	420	490	0.315	502.7 (b)	21.2	76.9	0.0011
3-12	12	350	675	1600	4800 (a)	--	--	0.156	1028.9	0.317	--	0.000095
3-5	12	500	0.01	0.02	0.06	0.1	0.19	0.303	0.4	25.0	89.5	10.0
3-7	9	500	3	8.5	14.3	23.6	29.5	0.155	37.7	25.7	87.6	0.034
3-3	7	500	6	15	40	70	101	0.121	139.9	25.8	91.2	0.011
3-14	5	500	10	40	220	525 (a)	775	0.102	1126.9 (b)	26.5	91.0	0.0014
3-9	4	500	25	320	910	1550	--	0.045	1148.0	0.720	--	0.00001

(a) Estimated.

(b) Test discontinued.

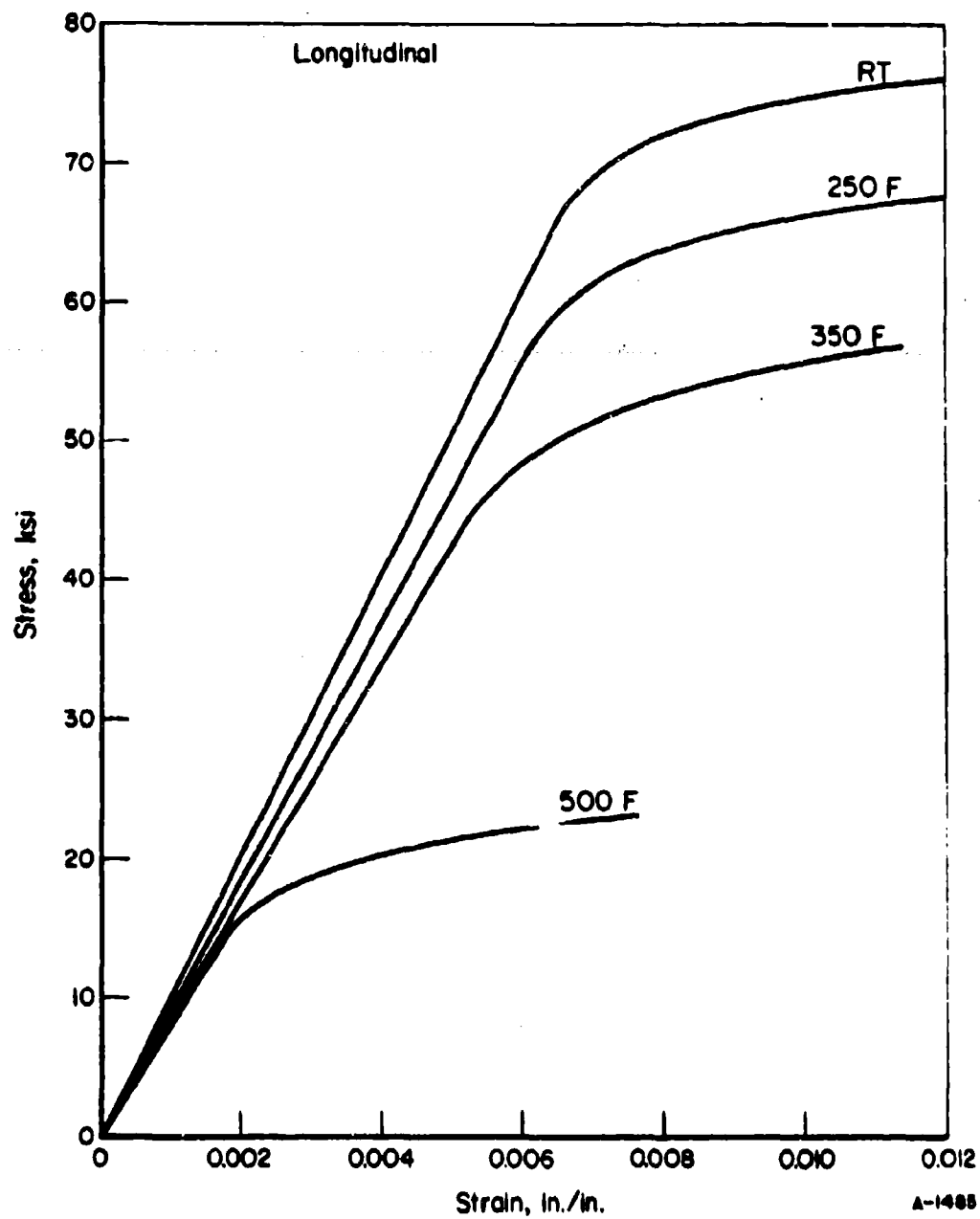


FIGURE 12. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR 7050-T73651 PLATE (LONGITUDINAL)

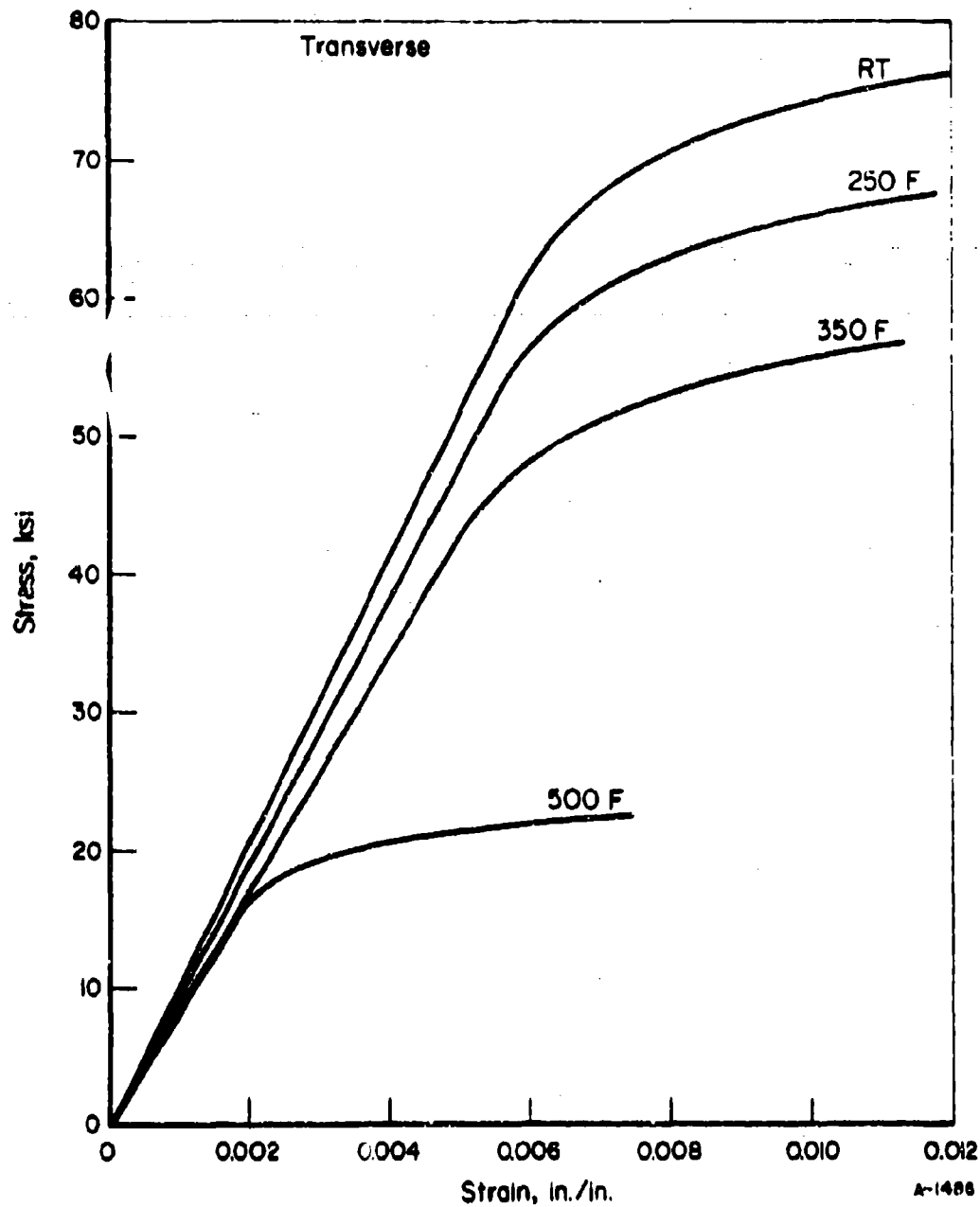


FIGURE 13. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR 7050-T73651 PLATE (TRANSVERSE)

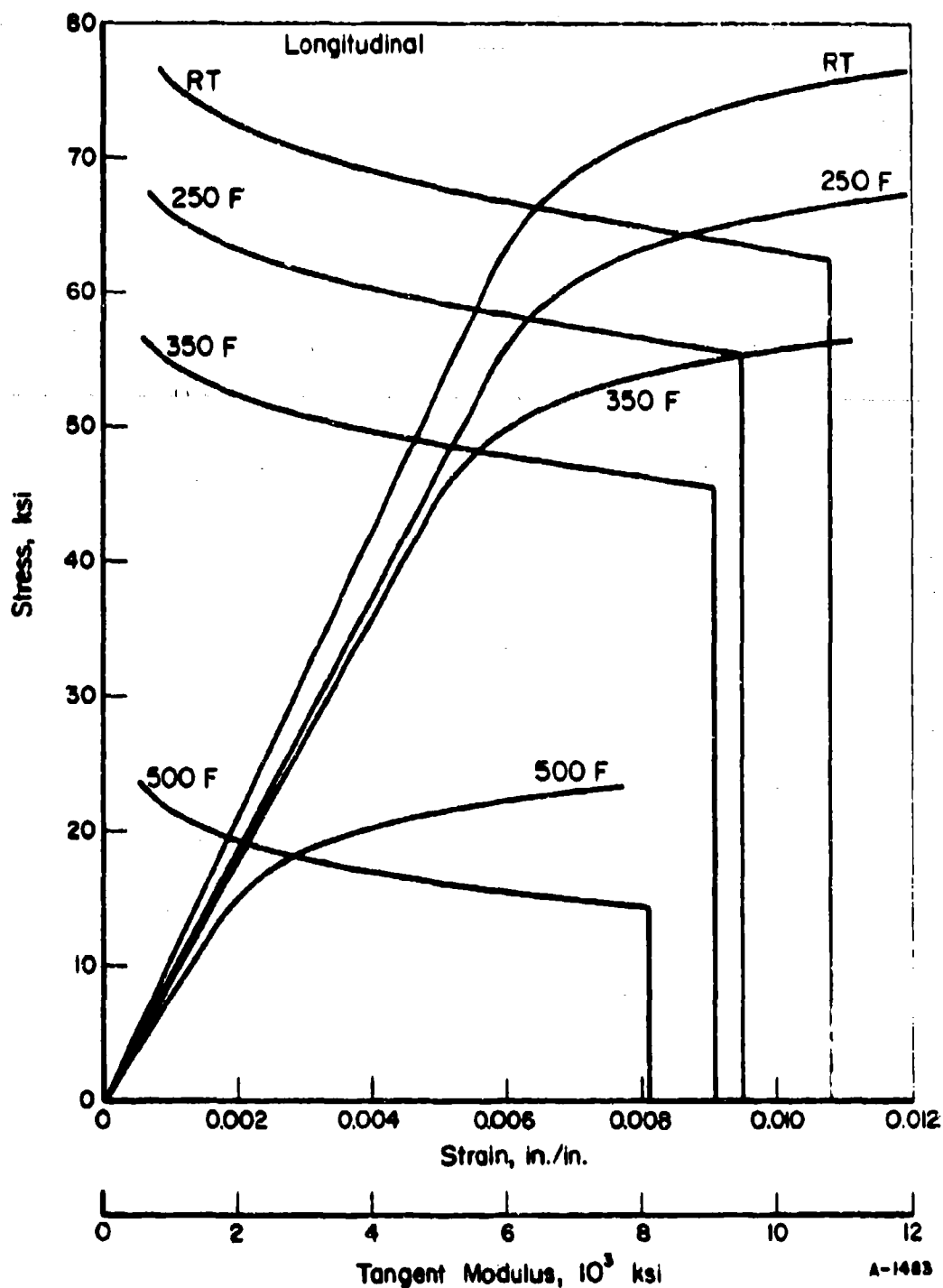


FIGURE 14. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR 7050-T73651 PLATE (LONGITUDINAL)

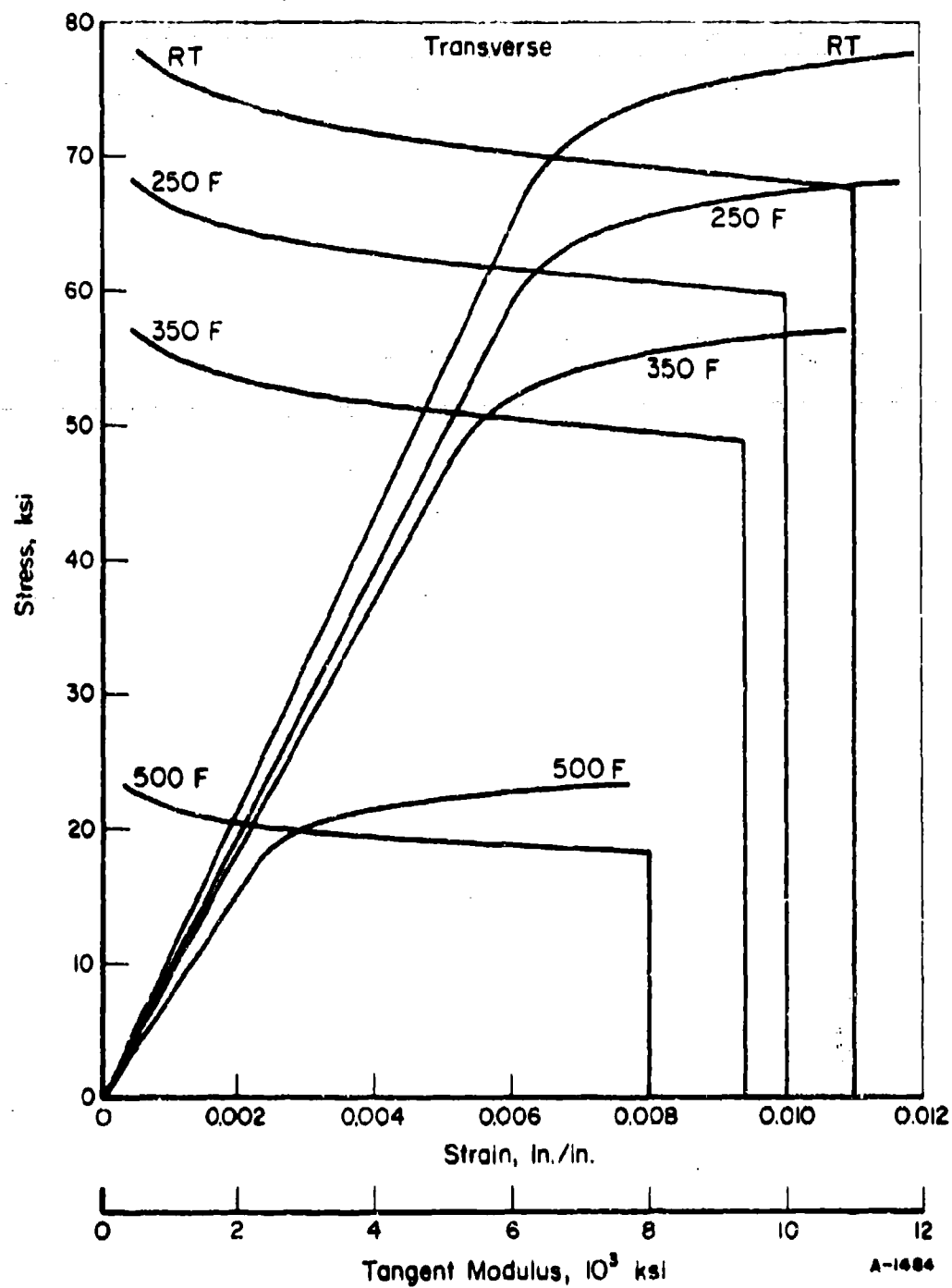


FIGURE 15. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR 7050-T73651 PLATE (TRANSVERSE)

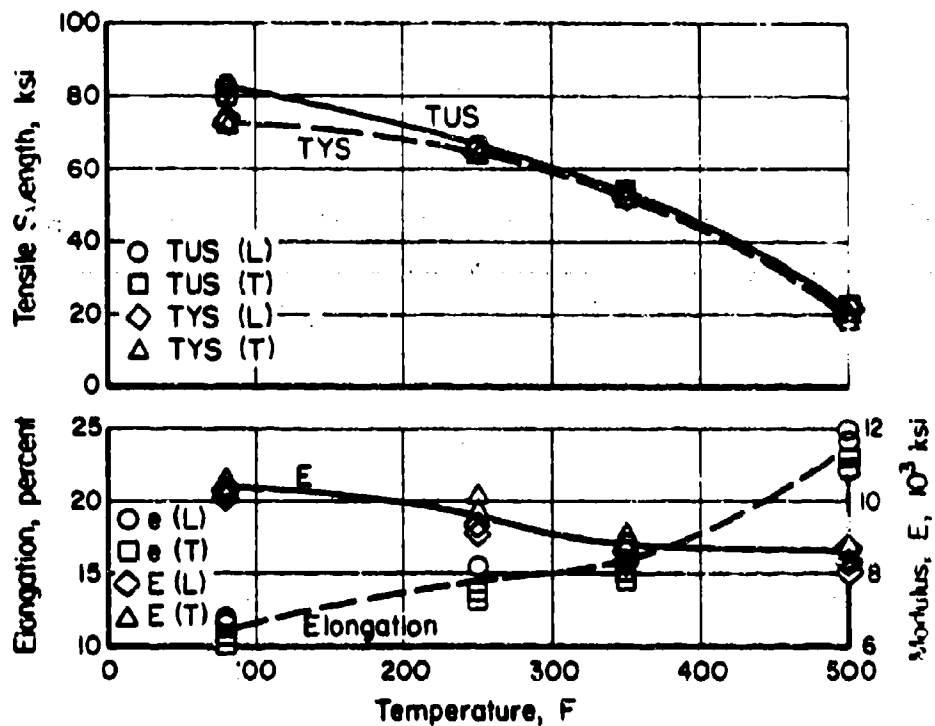


FIGURE 16. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7050-T73651 PLATE

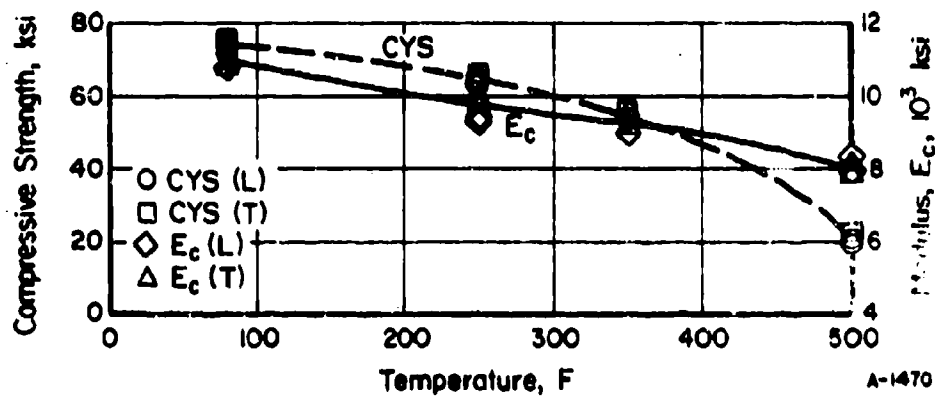


FIGURE 17. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7050-T73651 PLATE

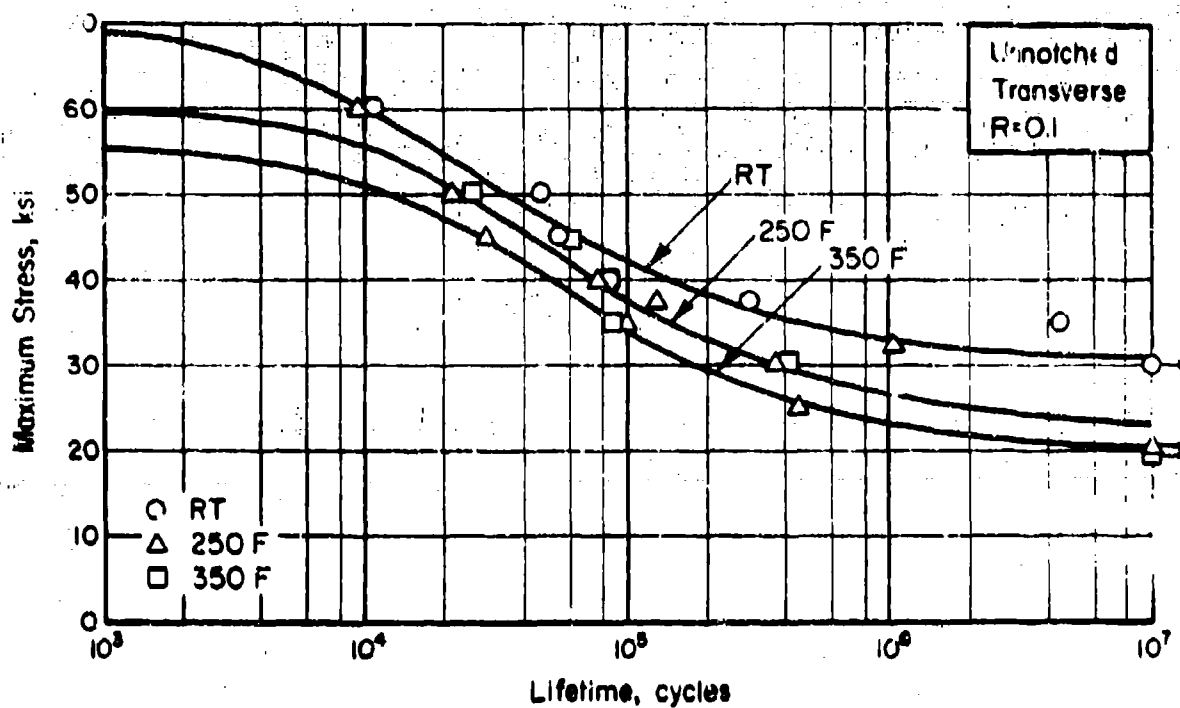


FIGURE 18. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 7050-T73651 PLATE (TRANSVERSE)

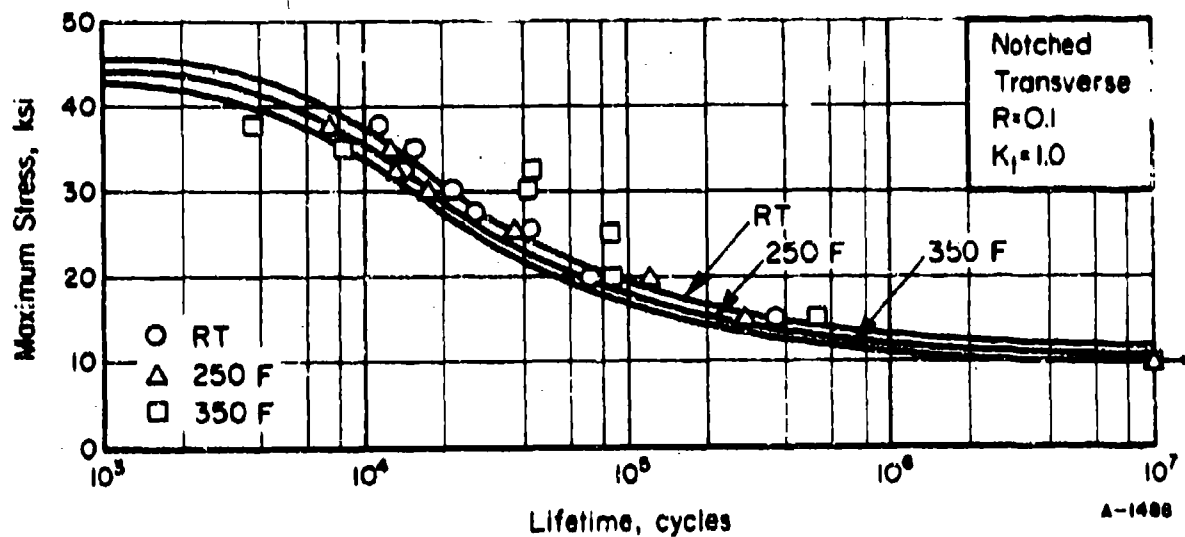


FIGURE 19. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED ($K_t = 3.0$) 7050-T73651 PLATE (TRANSVERSE)

X Rupture
 □ 1.0% creep
 △ 0.5% creep
 ○ 0.2% creep

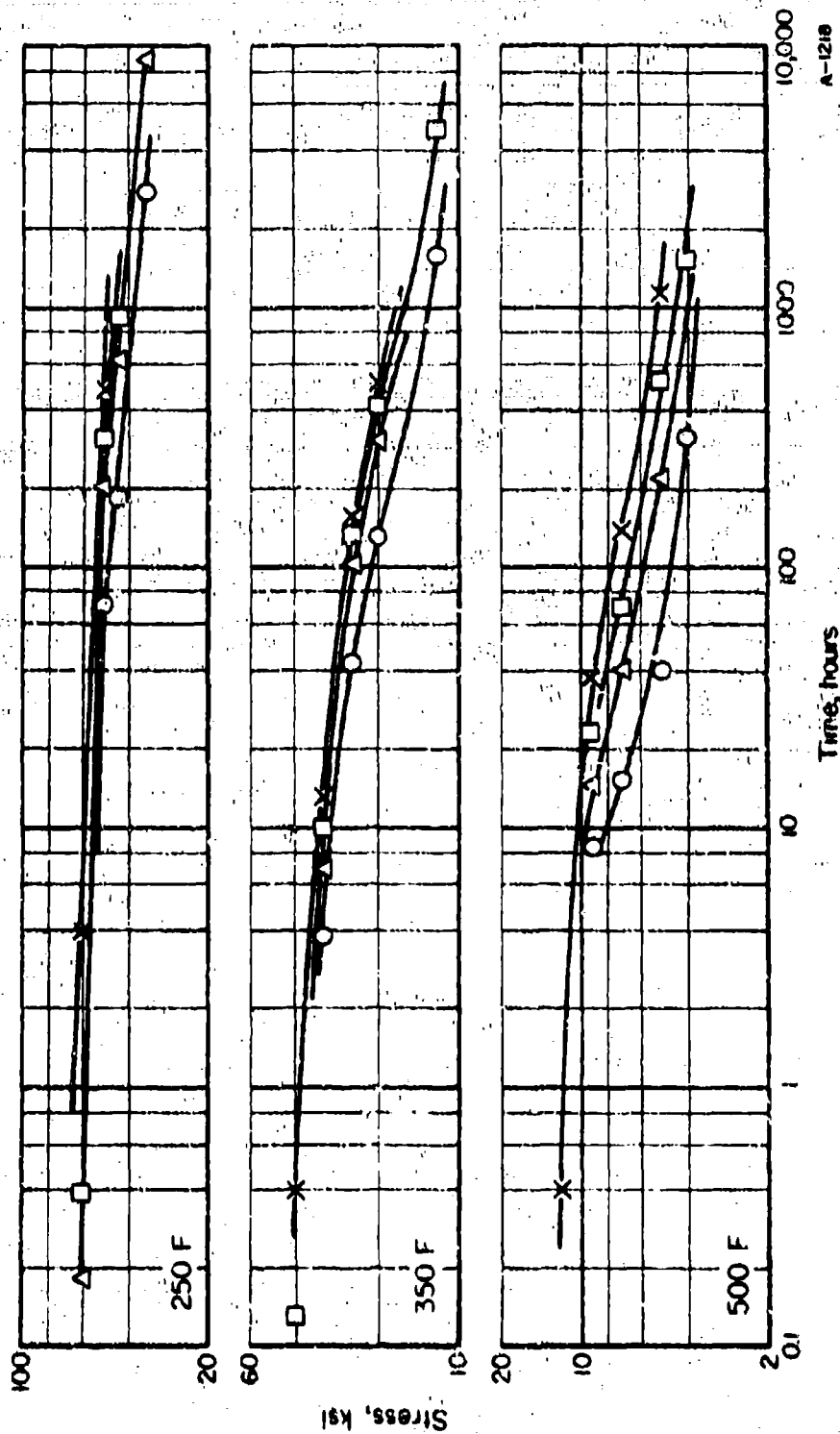


FIGURE 20. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7050-T73651 PLATE (TRANSVERSE)

21-6-9 Stainless Steel AlloyMaterial Description

Alloy 21-6-9 is a recent development of the Armco Steel Corporation. It is an austenitic stainless steel, combining high yield strength with good corrosion resistance. The room temperature yield strength of 21-6-9 is superior to Types 304, 321, and 347. It has good elevated temperature properties and retains high strength and toughness at subzero temperatures.

Armco 21-6-9 stainless steel is available in standard finishes in annealed or high tensile temper sheet and strip as well as in bar, wire, forging billets, and plate.

The materials used in this evaluation was an 0.072-inch thick sheet produced within the following composition limits

Carbon	0.08 max
Manganese	8.00 - 10.00
Phosphorus	0.060 max
Sulfur	0.030 max
Silicon	1.00 max
Chromium	19.00 - 21.50
Nickel	5.50 - 7.50
Nitrogen	0.15 - 0.40
Iron	Balance

Processing and Heat Treating

The specimen layout is shown in Figure 21. The alloy was evaluated in the as-received annealed condition.

Test Results

Tension. Results of tests on longitudinal and transverse specimens at room temperature, 400 F, 700 F, and 900 F are given in Table XVII. Typical stress-strain curves at temperature are presented in Figures 22 and 23. Effect-of-temperature curves are shown in Figure 26.

Compression. Test results for longitudinal and transverse specimens at room temperature, 400 F, 700 F, and 900 F are given in Table XVIII. Typical

549	537	525	513	51
550	538	526	514	52
551	539	527	515	53
552	540	528	516	54
553	541	529 Fatigue	517	55
554	542	530 60 T	518	56
555	543	531	519	57
556	544	532	520	58
557	545	533	521	59
558	546	534	522	610
559	547	535	523	611
560	548	536	524	612

IL1	IL2	IL3	IL4	IL5	IL6	IL7	Tensile	IL8	IL9	IL10	IL11	IL12	IT7	IT8	IT9 Tensile	IT10	IT11	IT12	IT1	IT2	IT3 12°	IT4	IT5	IT6
-----	-----	-----	-----	-----	-----	-----	---------	-----	-----	------	------	------	-----	-----	-------------	------	------	------	-----	-----	---------	-----	-----	-----

39	310	311	312	313	314	315	31	32	33	34 Creep	35	36	37	38	4T1	4T2	4T3	4T4	4L1	4L2	Shear	4L3	4L4	2T7	2T8	2T9 Comp	2T10	QT1	2T12	2T1	2T2	2T3 IPT	2T4	2T5	2T6	2L1	2L2	2L3	2L4	2L5	2L6	2L7	2L8	2L9	2L10	2L11	2L12
----	-----	-----	-----	-----	-----	-----	----	----	----	----------	----	----	----	----	-----	-----	-----	-----	-----	-----	-------	-----	-----	-----	-----	----------	------	-----	------	-----	-----	---------	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	------	------	------

FIGURE 21. SPECIMEN LAYOUT FOR 21-6-9 ANNEALED SHEET

compressive stress-strain and tangent-modulus curves at temperature are presented in Figures 24 and 25. Effect-of-temperature curves are presented in Figure 17.

Shear. Results of sheet-shear type tests for longitudinal and transverse specimens at room temperature are given in Table XIX.

Bend. The minimum bend radius for this material was 1T.

Fracture Toughness. Tests were conducted on transverse (T-L) specimens of full-sheet thickness (0.072-inch) x 18 inches x 30 inches with an EDM flaw in the center. The net section yield stress at fracture was greater than the tensile yield strength of the material; therefore, the K values obtained are considered invalid.

Fatigue. Axial-load test results for transverse specimens at a stress ratio of $R = 0.1$ are given in Tables XX and XXI. These tests were performed on both unnotched and notched specimens at room temperature, 400 F, and 700 F. S-N curves are presented in Figures 28 and 29.

Creep and Stress Rupture. Tests were conducted for transverse specimens at 400 F, 700 F, and 900 F. Tabular test results are given in Table XXII. Log-stress versus log-time curves are presented in Figure 30.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. No cracks or fractures occurred in the 1000-hour test duration.

Thermal Expansion. The coefficient of expansion for this alloy is 10.6×10^{-6} in./in./F from 80 F to 1000 F.

Density. The density of this material is 0.283 lb./in.³.

TABLE XVII. TENSILE TEST RESULTS FOR ANNEALED
21-6-9 STAINLESS STEEL SHEET

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, 10 ⁶ psi
<u>Longitudinal at Room Temperature</u>				
1L-1	113.0	64.3	54.0	26.7
1L-2	113.0	65.0	54.5	26.6
1L-3	113.0	65.1	56.5	26.4
Average	113.0	64.8	55.0	26.6
<u>Transverse at Room Temperature</u>				
1T-1	114.0	65.3	50.0	28.6
1T-2	113.0	66.3	50.0	28.2
1T-3	113.0	66.0	50.0	28.4
Average	113.3	65.7	50.0	28.4
<u>Longitudinal at 400 F</u>				
1L-4	88.4	42.3	44.0	21.2
1L-5	87.6	42.6	43.0	21.8
1L-6	98.4	42.6	43.5	20.2
Average	88.1	42.5	43.5	21.1
<u>Transverse at 400 F</u>				
1T-4	88.4	42.7	42.0	19.9
1T-5	88.4	42.5	42.0	20.5
1T-6	88.4	43.0	42.0	19.3
Average	88.4	42.7	42.0	19.9
<u>Longitudinal at 700 F</u>				
1L-7	84.2	35.9	46.0	24.8
1L-8	83.5	35.9	45.5	18.3
1L-9	83.5	35.9	45.5	22.0
Average	83.7	35.9	45.7	21.7
<u>Transverse at 700 F</u>				
1T-7	82.8	35.8	41.5	19.4
1T-8	83.4	35.9	42.0	18.4
1T-9	83.5	36.0	42.0	17.4
Average	83.2	35.9	41.8	18.4
<u>Longitudinal at 900 F</u>				
1L-10	76.0	33.0	43.0	20.4
1L-11	76.6	33.2	43.0	16.9
1L-12	75.7	32.9	43.0	20.2
Average	76.1	33.0	43.0	19.2
<u>Transverse at 900 F</u>				
1T-10	76.4	33.3	41.5	15.9
1T-11	76.6	33.3	41.0	17.6
1T-12	76.6	33.0	41.5	15.4
Average	76.5	33.2	41.3	16.3

TABLE XVIII. COMPRESSION TEST RESULTS FOR ANNEALED
21-6-9 STAINLESS STEEL SHEET

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, 10 ³ psi
<u>Longitudinal at Room Temperature</u>		
2L-1	67.2	29.3
2L-2	67.2	28.6
2L-3	67.2	27.8
Average	67.2	28.5
<u>Transverse at Room Temperature</u>		
2T-1	66.3	29.1
2T-2	66.5	29.0
2T-3	66.8	29.0
Average	66.5	29.0
<u>Longitudinal at 400 F</u>		
2L-4	44.4	26.2
2L-5	45.6	27.4
2L-6	45.4	26.6
Average	45.1	26.7
<u>Transverse at 400 F</u>		
2T-4	47.0	29.3
2T-5	46.7	29.0
2T-6	45.3	28.0
Average	46.3	28.8
<u>Longitudinal at 700 F</u>		
2L-7	40.2	25.8
2L-8	39.9	25.3
2L-9	41.4	26.4
Average	40.5	25.8
<u>Transverse at 700 F</u>		
2T-7	38.3	27.7
2T-8	37.2	25.5
2T-9	38.3	26.4
Average	37.9	26.5
<u>Longitudinal at 900 F</u>		
2L-10	35.5	25.8
2L-11	34.8	26.1
2L-12	33.8	24.1
Average	34.7	25.3
<u>Transverse at 900 F</u>		
2T-10	34.0	26.1
2T-11	34.1	25.8
2T-12	34.1	25.2
Average	34.1	25.7

TABLE XIX. SHEAR TEST RESULTS FOR ANNEALED
21-6-9 STAINLESS STEEL SHEET
AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
<u>Longitudinal</u>	
4L-1	101.0
4L-2	102.0
4L-3	103.0
4L-4	103.0
Average	<u>102.3</u>
<u>Transverse</u>	
4T-1	102.0
4T-2	102.0
4T-3	104.0
4T-4	103.0
Average	<u>102.8</u>

TABLE XX. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED 21-6-9
ANNEALED STAINLESS STEEL SHEET (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
<u>Room Temperature</u>		
5-5	105.0	3,500
5-4	100.0	43,500
5-3	95.0	83,500
5-2	90.0	153,300
5-1	85.0	294,600
5-6	80.0	344,900
5-7	75.0	206,000
5-8	65.0	10,000,000 ^(a)
<u>400 F</u>		
5-9	100.0	(b)
5-14	90.0	200
5-10	90.0	500
5-16	87.5	122,700
5-13	85.0	63,600
5-17	82.5	153,300
5-12	80.0	110,500
5-18	77.5	258,400
5-15	75.0	10,167,000 ^(a)
<u>700 F</u>		
5-19	85.0	(b)
5-21	80.0	600
5-20	75.0	3,399,200
5-24	72.5	4,821,600
5-22	70.0	140,400
5-25	70.0	4,842,000
5-23	65.0	10,029,000 ^(a)

(a) Did not fail.

(b) Failed on first cycle.

TABLE XXI. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED ($K_t=3.0$)
21-6-9 ANNEALED STAINLESS STEEL SHEET (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
<u>Room Temperature</u>		
5-11	75.0	12,240
5-4	70.0	38,380
5-5	65.0	74,510
5-3	60.0	97,190
5-14	55.0	186,620
5-6	50.0	1,757,000
5-30	40.0	10,744,400 ^(a)
<u>400 F</u>		
5-13	75.0	10,300
5-31	70.0	11,200
5-22	65.0	14,000
5-21	55.0	26,900
5-20	45.0	84,400
5-32	40.0	204,600
5-17	35.0	10,589,500 ^(a)
<u>700 F</u>		
5-29	75.0	3,300
5-28	65.0	11,400
5-24	55.0	27,200
5-19	50.0	116,300
5-26	45.0	144,200
5-18	40.0	143,700
5-24	35.0	10,519,200 ^(a)

(a) Did not fail.

TABLE XXII. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR 21-6-9 STAINLESS STEEL SHEET (TRANSVERSE)

Specimen Number	Stress, ksi	Temper- ature, F	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hours	Elongation In 2 Inches, percent	Minimum Creep Rate, percent
			0.1	0.2	0.5	1.0	2.0				
3-1	88	500	--	--	--	--	-- (a)	--	On Loading	41.3	--
3-4	83	500	0.01	0.20	0.45	19	1,500	26.68	841.4 (b)	28.4	0.0005
3-7	70	500	0.10	0.35	5.0	85	--	13.220	169.9 (b)	14.42	--
3-9	40	500	5.0	70 (a)	1,455	4,800	--	0.826	650.1 (b)	1.355	0.0001
3-12	35	500	--	3,000	--	--	--	0.229	715.1 (b)	0.251	--
3-2	86	700	--	--	--	--	--	--	On Loading	43.1	--
3-5	80	700	--	--	--	--	--	28.24	813.4 (b)	31.1	0.00007
3-8	50	700	--	0.05	0.3	7.0	--	4.920	309.7 (b)	5.990	0.00002
3-15	40	700	--	0.10	10 (a)	>1,000	--	1.452	498.6 (b)	2.050	--
3-14	35	700	0.20	0.40	5,000	--	--	0.314	120.7 (b)	1.051	--
3-11	30	700	--	10,000 (a)	--	--	--	0.180	268.5 (b)	0.218	--
3-3	76.5	900	--	--	--	--	--	--	On Loading	42.2	--
3-10	70	900	--	--	--	--	--	20.852	438.9	27.6	--
3-6	65	900	--	--	--	--	--	10.8	753.7 ()	20.9	0.0006
3-17	35	900	--	0.10	>1,000	--	--	1.260	480.0 ()	1.475	--
3-16	30	900	--	5,000 (a)	--	--	--	0.198	738.5 ()	0.222	--
3-13	25	900	--	--	--	--	--	0.162	289.4 ()	0.167	--

(a) Estimate.

(b) Test discontinued.

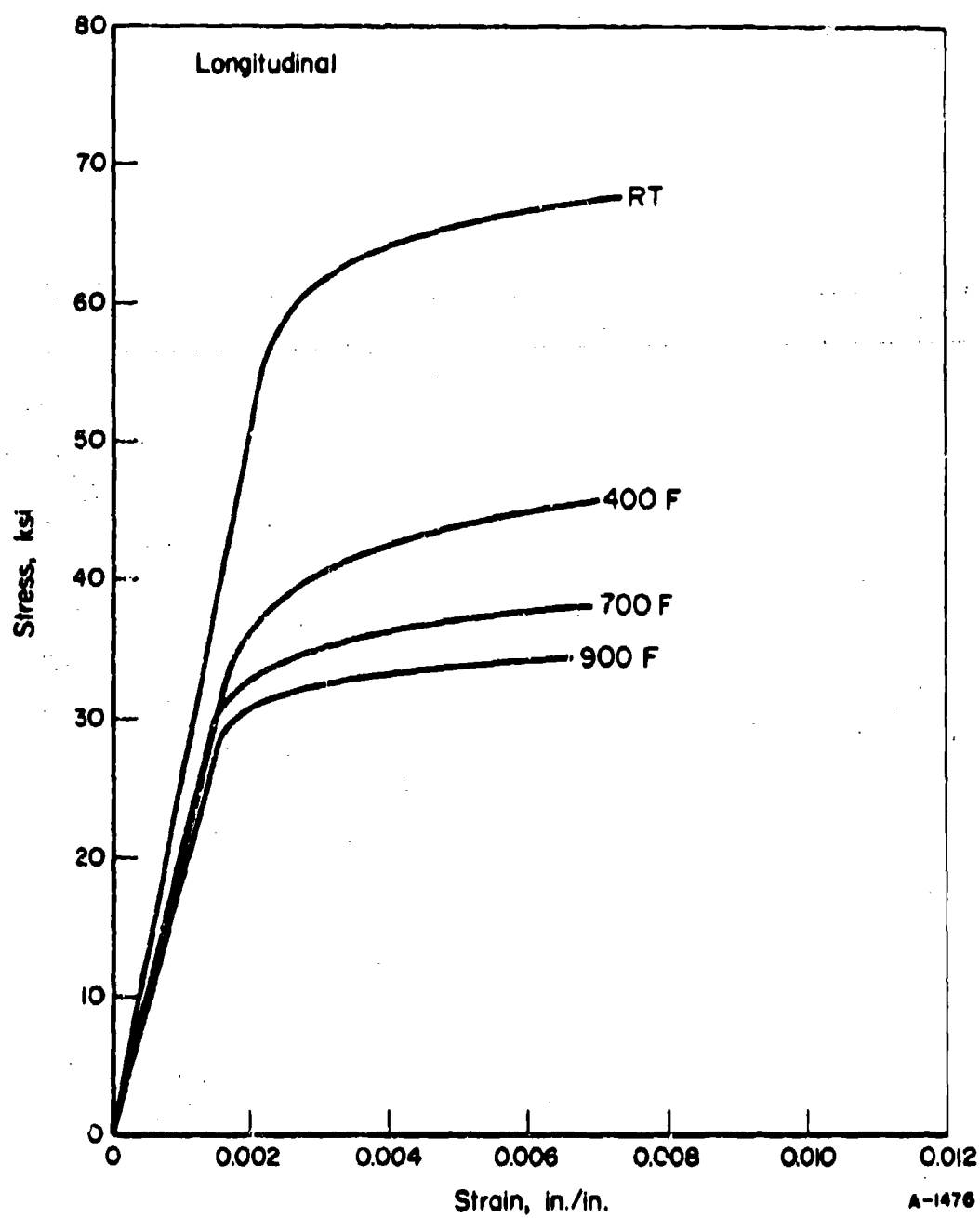


FIGURE 22. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR 21-6-9 ANNEALED SHEET (LONGITUDINAL)

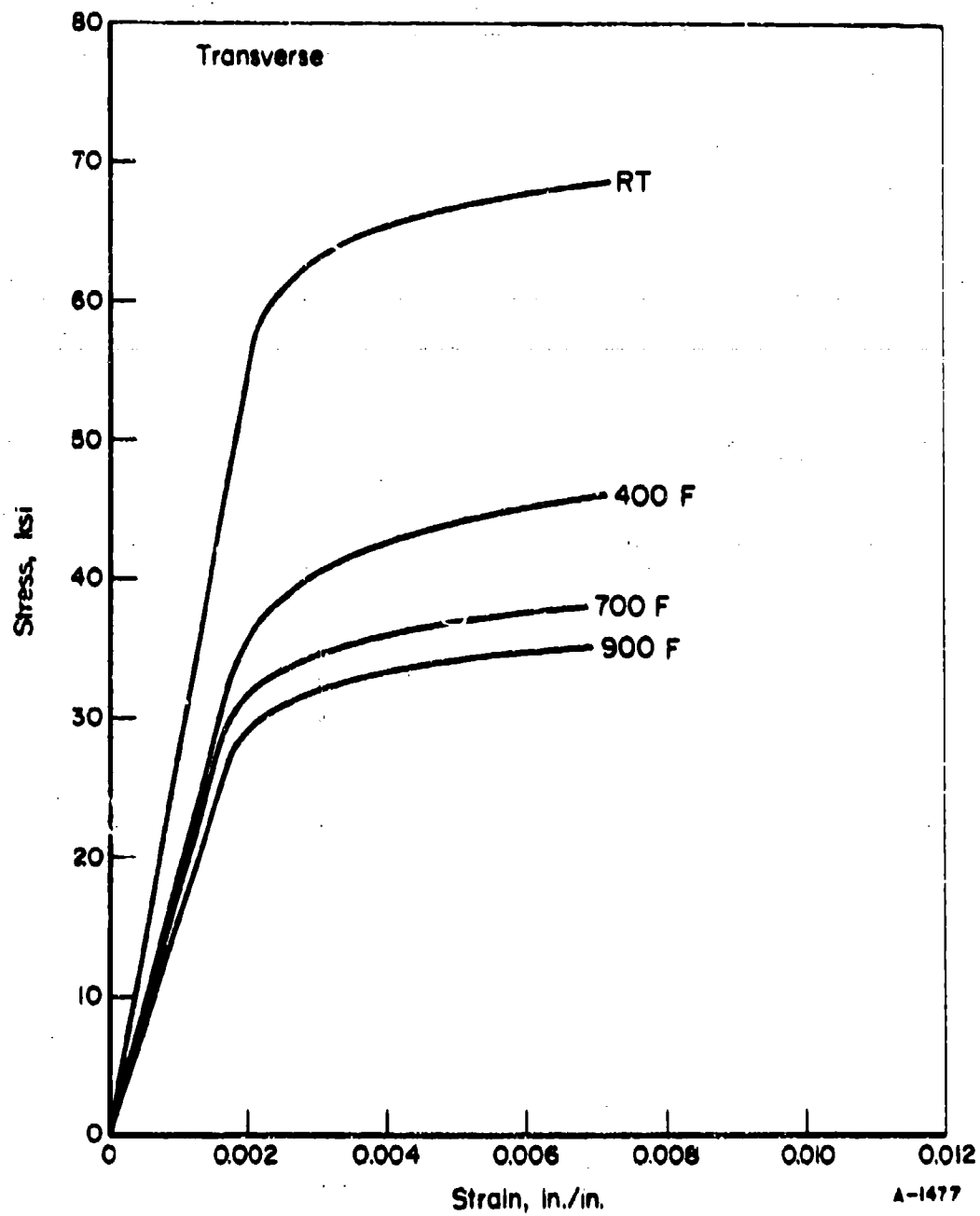


FIGURE 23. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR 21-6-9 ANNEALED SHEET (TRANSVERSE)

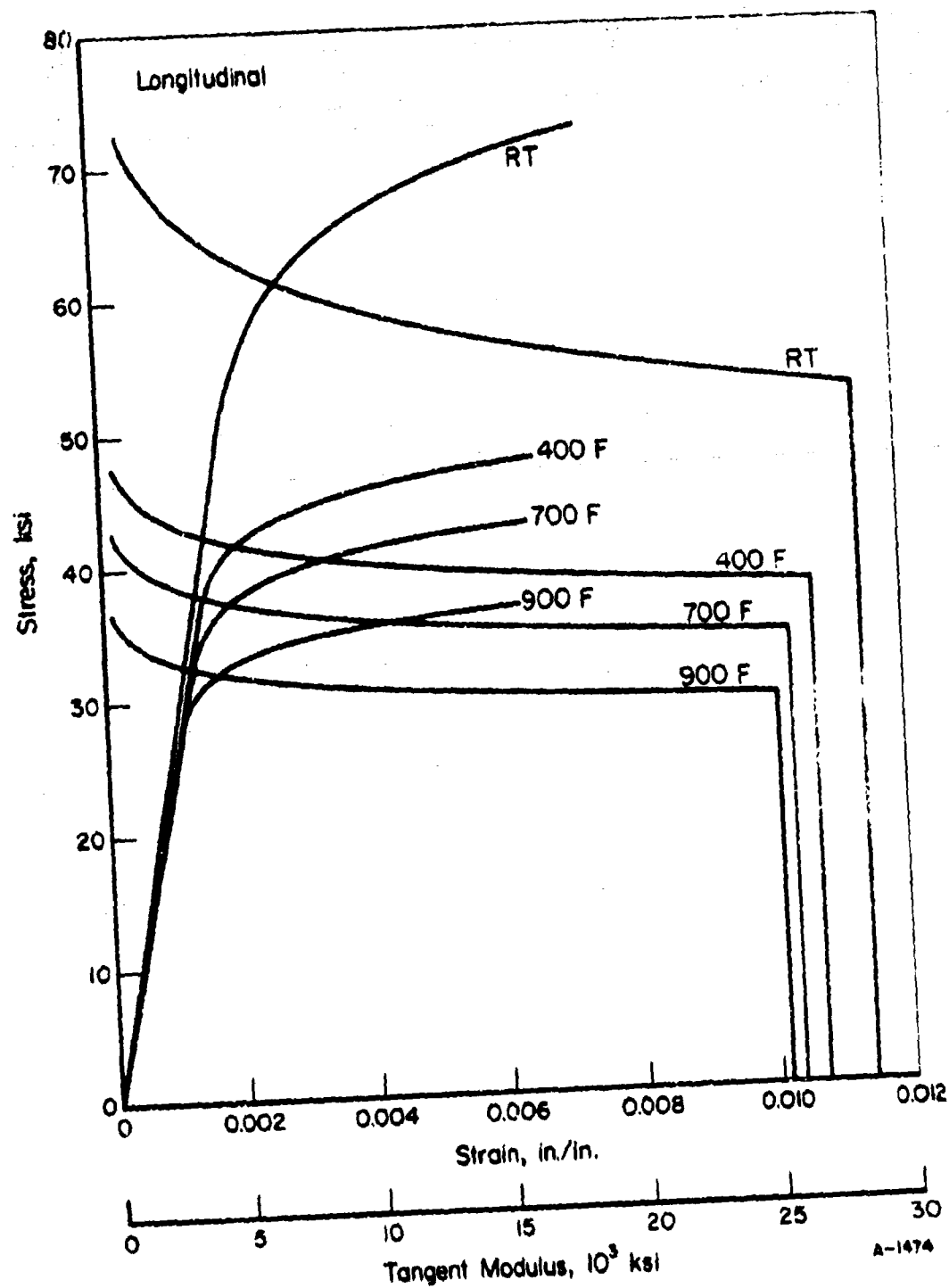


FIGURE 24. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR 21-6-9 ANNEALED SHEET (LONGITUDINAL)

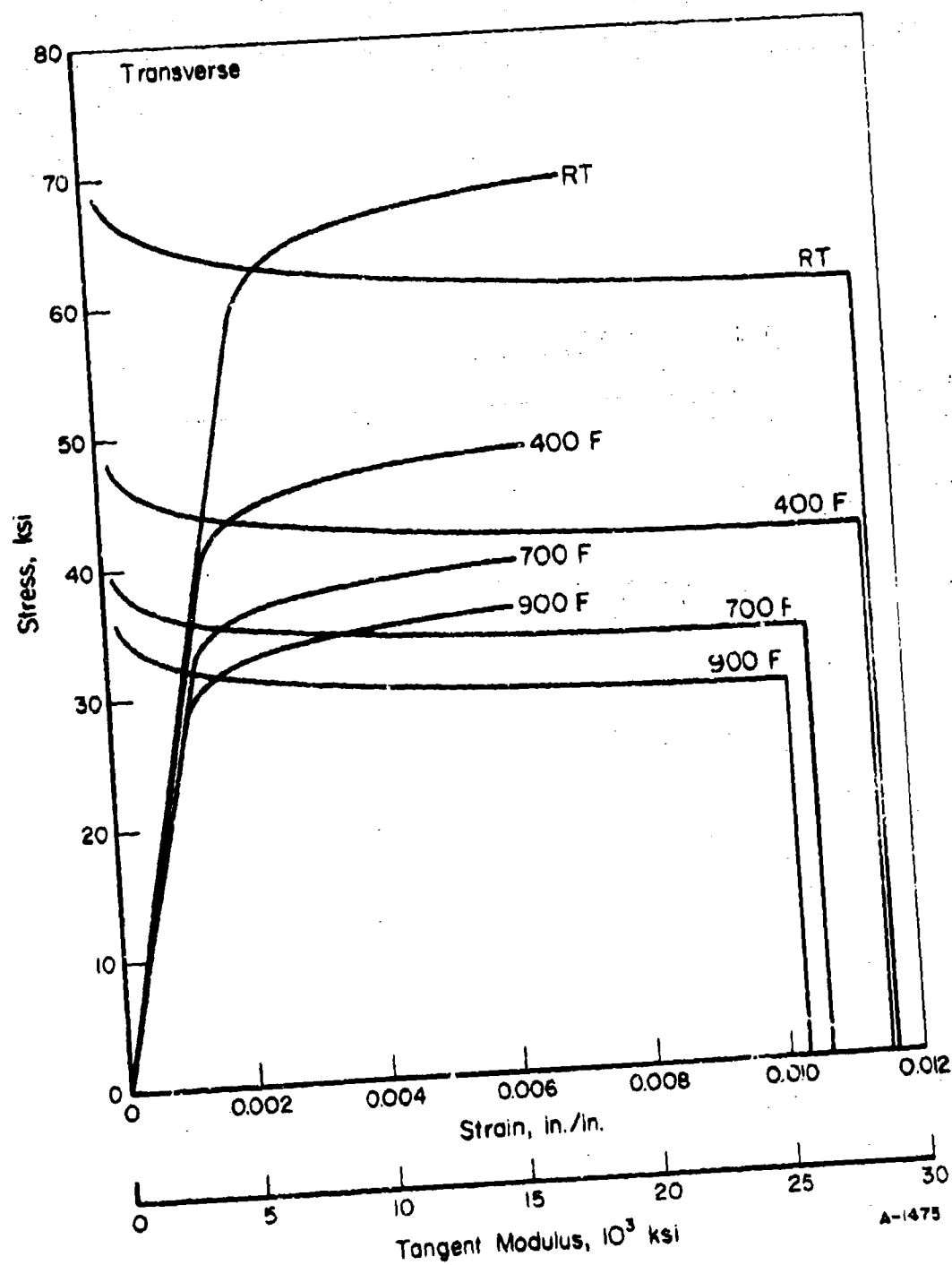


FIGURE 25. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR 21-6-9 ANNEALED SHEET (TRANSVERSE)

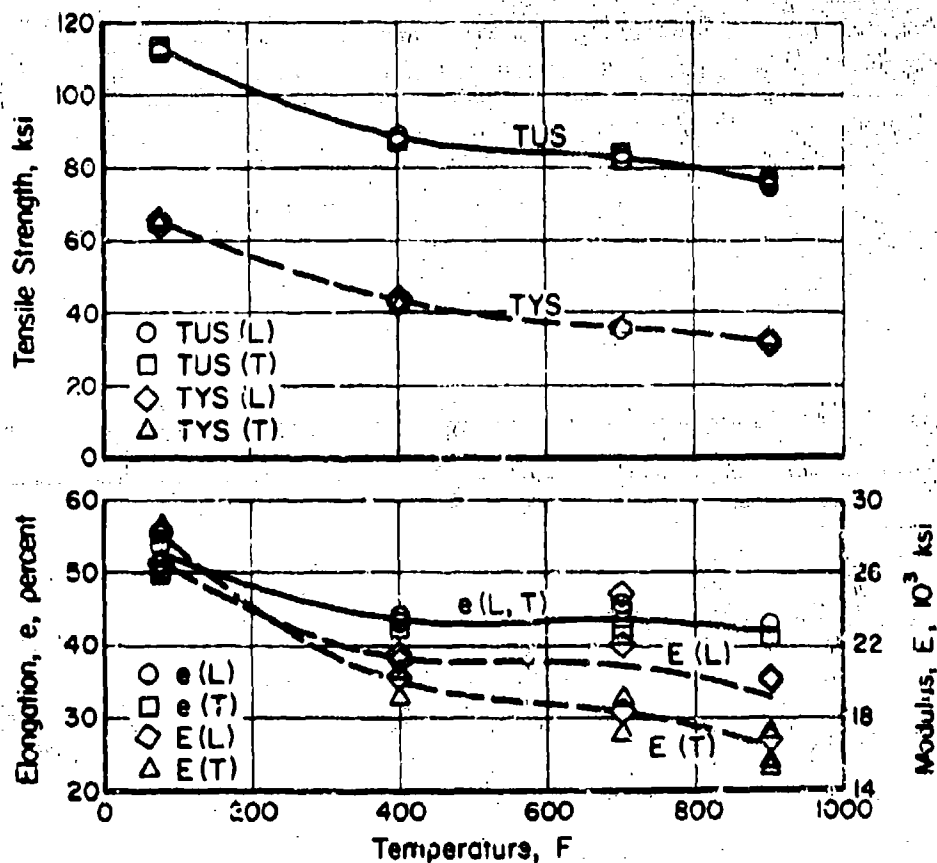


FIGURE 26. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 21-6-9 ANNEALED SHEET

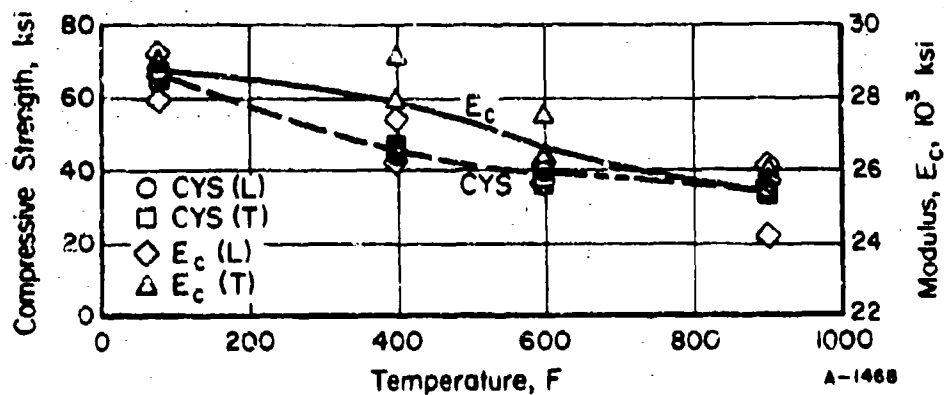


FIGURE 27. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 21-6-9 ANNEALED SHEET

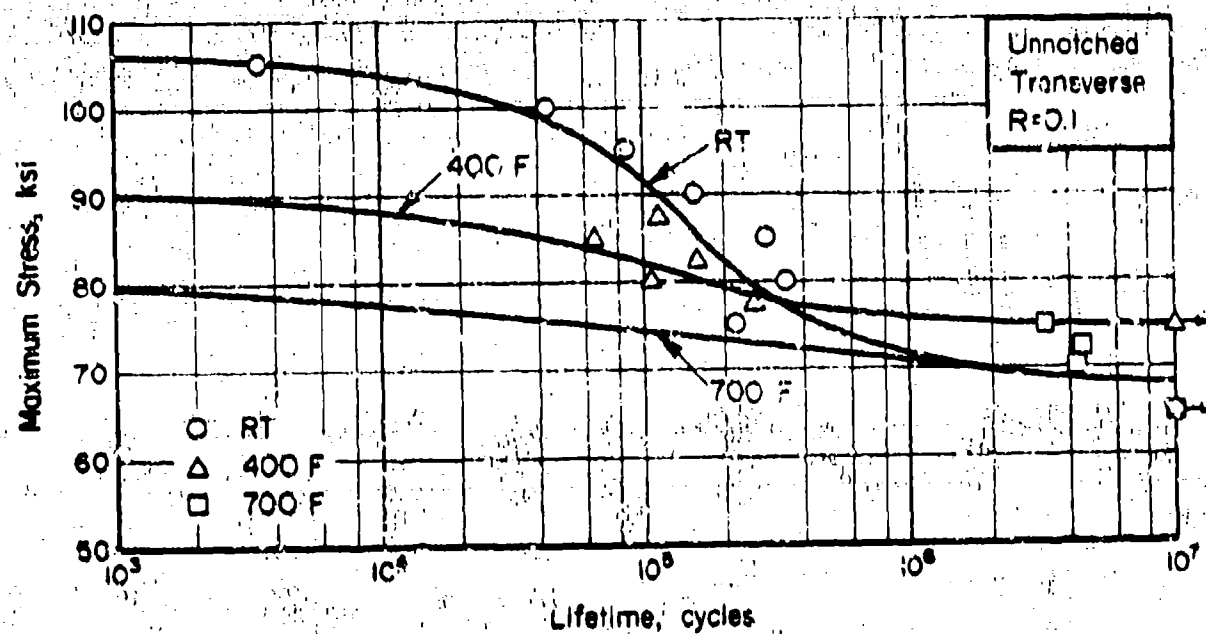


FIGURE 28. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 21-6-9 ANNEALED SHEET (TRANSVERSE)

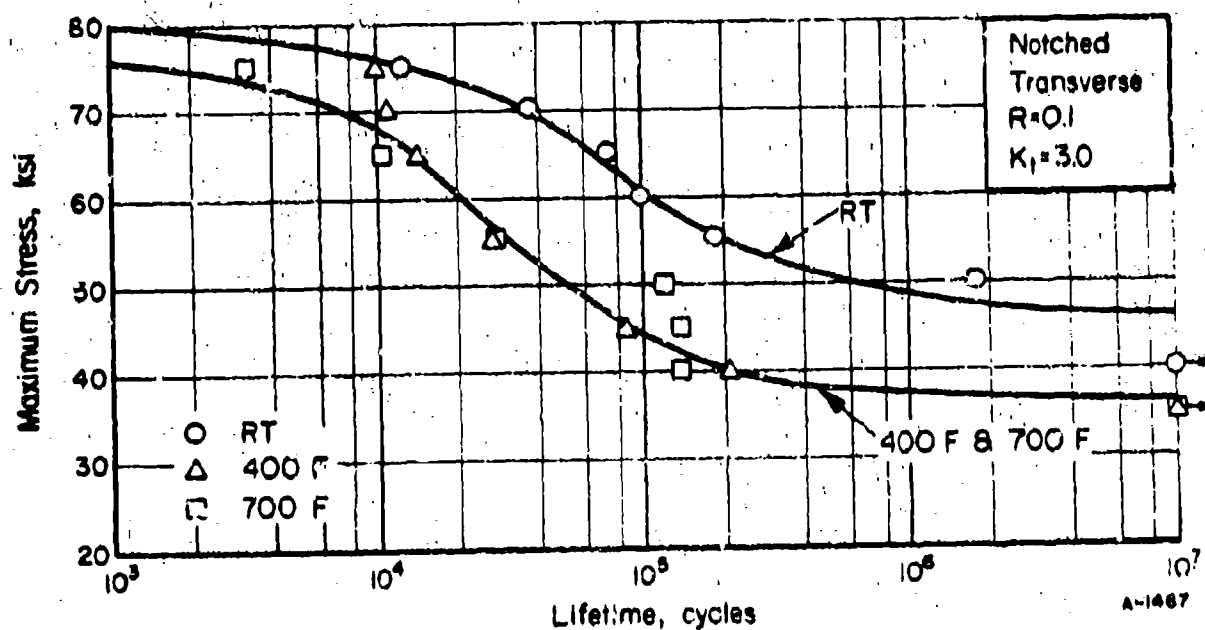


FIGURE 29. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED ($K_t = 3.0$) 21-6-9 ANNEALED SHEET (TRANSVERSE)

X Rupture
 □ 1.0% creep
 △ 0.5% creep
 ○ 0.2% creep

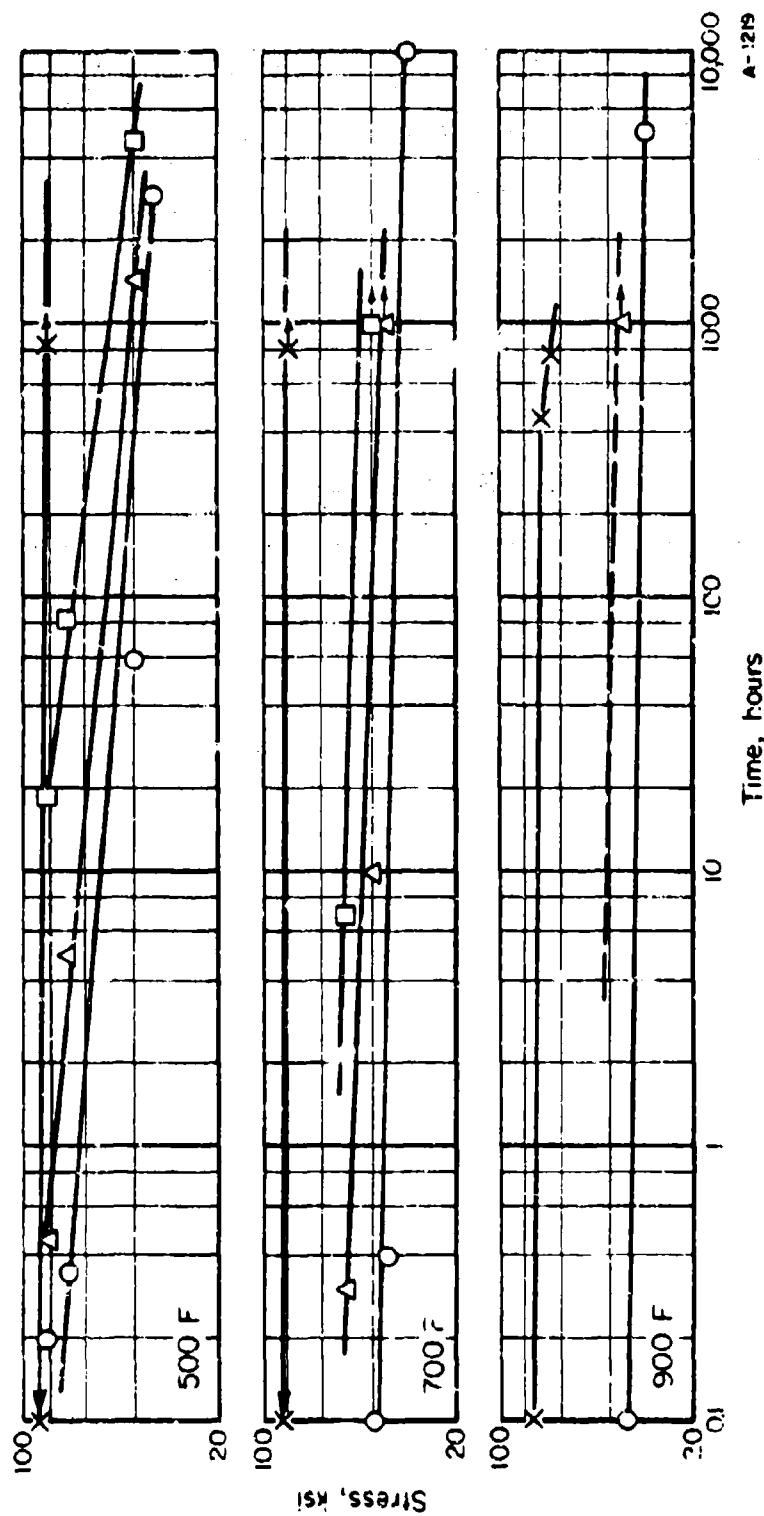


FIGURE 30. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 21-6-9 ANNEALED SHEET (TRANSVERSE)

Ti-8Mo-8V-2Fe-3Al AlloyMaterial Description

The 8Mo-8V-2Fe-3Al beta titanium alloy is a recent development of TIMET. The alloy was selected for full-scale evaluation after confirming (by TIMET) that it could be melted by the conventional consumable electrode vacuum arc process. It shows producibility and property characteristics that make it suitable for a variety of airframe applications. A variety of heat treatments are available to allow the designer to take advantage of its individual properties or its generally good overall properties.

The material used in this evaluation was an 0.040-inch-thick sheet from TIMET Heat K-5055 with the following composition

Molybdenum	8.0
Vandium	8.2
Iron	2.0
Aluminum	3.0
Oxygen	0.14
Nitrogen	0.011
Titanium	Balance

Processing and Heat Treating

The specimen layout is shown in Figure 31. The material was received in the solution-treated condition. Specimens were aged at 900 F for 6 hours. This condition is called the high strength, fully-aged condition.

Test Results

Tension. Test results for longitudinal and transverse specimens at room temperature, 400 F, 600 F, and 800 F are given in Table XXIII. Stress-strain curves at temperature are presented in Figures 32 and 33. Effect-of-temperature curves are shown in Figure 36.

Compression. Test results for longitudinal and transverse specimens at room temperature, 400 F, 600 F, and 800 F are given in Table XXIV. Typical stress-strain and tangent modulus curves at temperature are presented in Figures 34 and 35. Effect-of-temperature curves are presented in Figure 37.

549	537	525	513	51
550	538	526	514	52
551	539	527	515	53
552	540	528	516	54
553	541	529 Fatigue	517	55
554	542	530 60 T	518	56
555	543	531	519	57
556	544	532	520	58
557	545	533	521	59
558	546	534	522	510
559	547	535	523	511
560	548	536	524	512
		177	178	179
		179	180	181
		180	181	182
		181	182	183
		182	183	184
		183	184	185
		184	185	186
		185	186	187
		186	187	188
		187	188	189
		188	189	190
		189	190	191
		190	191	192
		191	192	193
		192	193	194
		193	194	195
		194	195	196
		195	196	197
		196	197	198
		197	198	199
		198	199	200
		199	200	201
		200	201	202
		201	202	203
		202	203	204
		203	204	205
		204	205	206
		205	206	207
		206	207	208
		207	208	209
		208	209	210
		209	210	211
		210	211	212
		211	212	213
		212	213	214
		213	214	215
		214	215	216
		215	216	217
		216	217	218
		217	218	219
		218	219	220
		219	220	221
		220	221	222
		221	222	223
		222	223	224
		223	224	225
		224	225	226
		225	226	227
		226	227	228
		227	228	229
		228	229	230
		229	230	231
		230	231	232
		231	232	233
		232	233	234
		233	234	235
		234	235	236
		235	236	237
		236	237	238
		237	238	239
		238	239	240
		239	240	241
		240	241	242
		241	242	243
		242	243	244
		243	244	245
		244	245	246
		245	246	247
		246	247	248
		247	248	249
		248	249	250
		249	250	251
		250	251	252
		251	252	253
		252	253	254
		253	254	255
		254	255	256
		255	256	257
		256	257	258
		257	258	259
		258	259	260
		259	260	261
		260	261	262
		261	262	263
		262	263	264
		263	264	265
		264	265	266
		265	266	267
		266	267	268
		267	268	269
		268	269	270
		269	270	271
		270	271	272
		271	272	273
		272	273	274
		273	274	275
		274	275	276
		275	276	277
		276	277	278
		277	278	279
		278	279	280
		279	280	281
		280	281	282
		281	282	283
		282	283	284
		283	284	285
		284	285	286
		285	286	287
		286	287	288
		287	288	289
		288	289	290
		289	290	291
		290	291	292
		291	292	293
		292	293	294
		293	294	295
		294	295	296
		295	296	297
		296	297	298
		297	298	299
		298	299	300
		299	300	301
		300	301	302
		301	302	303
		302	303	304
		303	304	305
		304	305	306
		305	306	307
		306	307	308
		307	308	309
		308	309	310
		309	310	311
		310	311	312
		311	312	313
		312	313	314
		313	314	315
		314	315	316
		315	316	317
		316	317	318
		317	318	319
		318	319	320
		319	320	321
		320	321	322
		321	322	323
		322	323	324
		323	324	325
		324	325	326
		325	326	327
		326	327	328
		327	328	329
		328	329	330
		329	330	331
		330	331	332
		331	332	333
		332	333	334
		333	334	335
		334	335	336
		335	336	337
		336	337	338
		337	338	339
		338	339	340
		339	340	341
		340	341	342
		341	342	343
		342	343	344
		343	344	345
		344	345	346
		345	346	347
		346	347	348
		347	348	349
		348	349	350
		349	350	351
		350	351	352
		351	352	353
		352	353	354
		353	354	355
		354	355	356
		355	356	357
		356	357	358
		357	358	359
		358	359	360
		359	360	361
		360	361	362
		361	362	363
		362	363	364
		363	364	365
		364	365	366
		365	366	367
		366	367	368
		367	368	369
		368	369	370
		369	370	371
		370	371	372
		371	372	373
		372	373	374
		373	374	375
		374	375	376
		375	376	377
		376	377	378
		377	378	379
		378	379	380
		379	380	381
		380	381	382
		381	382	383
		382	383	384
		383	384	385
		384	385	386
		385	386	387
		386	387	388
		387	388	389
		388	389	390
		389	390	391
		390	391	392
		391	392	393
		392	393	394
		393	394	395
		394	395	396
		395	396	397
		396	397	398
		397	398	399
		398	399	400
		399	400	401
		400	401	402
		401	402	403
		402	403	404
		403	404	405
		404	405	406
		405	406	407
		406	407	408
		407	408	409
		408	409	410

Shear. Test results for longitudinal and transverse specimens at room temperature are given in Table XXV.

Fracture Toughness. Specimens were full-sheet thickness (0.040-inch) by 18 inches wide by 36 inches long with an EDM flaw in the center. The average K_{IC} obtained from four transverse (T-L) specimens was 50 ksi $\sqrt{\text{in.}}$. By existing ASTM criteria, this is considered a valid K_{IC} value.

Fatigue. Axial load tests were conducted on transverse specimens, both unnotched and notched, at a stress ratio of $R = 0.1$. Test temperatures were room temperature, 400 F, and 600 F. Tabular test results are given in Tables XXVI and XXVII. S-N curves are presented in Figures 38 and 39.

Creep and Stress-Rupture. Tests were performed at 550 F, 700 F, and 900 F. Tabular test results are given in Table XXVIII. Log-stress versus log-time curves are presented in Figure 40.

Stress-Corrosion. Tests were performed as described in the experimental procedures section of this report. No failures or cracks occurred in the 1000-hour test duration.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 5.0×10^{-6} in./in./F from 68 F to 800 F.

Density. The density of this alloy is 0.175 lb./in.³.

TABLE XXIII. TENSILE TEST RESULTS FOR SOLUTION-TREATED
AND AGED Ti-8Mo-8V-2Fe-3Al ALLOY SHEET

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 2 Inches, percent	Tensile Modulus, 10 ⁶ psi
<u>Longitudinal at Room Temperature</u>				
1L-1	160.0	143.0	12.0	13.6
1L-2	162.0	147.0	12.0	13.6
1L-3	159.0	144.0	11.0	13.7
Average	160.3	144.7	11.7	13.6
<u>Transverse at Room Temperature</u>				
1T-1	176.0	160.0	9.0	15.4
1T-2	175.0	157.0	10.0	14.9
1T-3	173.0	157.0	9.5	14.5
Average	174.7	158.0	9.5	14.9
<u>Longitudinal at 400 F</u>				
1L-4	148.0	123.0	9.5	13.2
1L-5	149.0	124.0	9.0	13.5
1L-6	149.0	123.0	8.5	13.2
Average	148.7	123.3	9.0	12.9
<u>Transverse at 400 F</u>				
1T-4	153.0	135.0	7.0	14.4
1T-5	158.0	133.0	6.5	13.8
1T-6	155.0	132.0	7.0	14.1
Average	155.3	133.3	6.8	14.1
<u>Longitudinal at 600 F</u>				
1L-7	144.0	116.0	7.5	12.3
1L-8	147.0	118.0	7.5	12.4
1L-9	147.0	119.0	7.0	12.5
Average	146.3	117.7	7.3	12.4
<u>Transverse at 600 F</u>				
1T-7	152.0	123.0	6.5	13.2
1T-8	153.0	124.0	6.5	13.5
1T-9	152.0	125.0	7.0	13.0
Average	152.3	124.0	6.7	13.2
<u>Longitudinal at 800 F</u>				
1L-10	139.0	102.0	21.0	12.1
1L-11	140.0	110.0	19.0	11.8
1L-12	134.0	105.0	16.0	11.4
Average	137.7	105.7	18.7	11.8
<u>Transverse at 800 F</u>				
1T-10	139.0	112.0	16.5	12.3
1T-11	146.0	118.0	16.0	12.4
1T-12	138.0	108.0	16.0	12.2
Average	141.0	112.7	16.2	12.3

TABLE XXIV. COMPRESSION TEST RESULTS FOR SOLUTION TREATED AND AGED Ti-8Mo-8V-2Fe-3Al ALLOY SHEET

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, 10 ⁶ psi
<u>Longitudinal at Room Temperature</u>		
2L-1	177.0	15.9
2L-2	177.0	15.8
2L-3	179.0	16.0
Average	177.7	15.9
<u>Transverse at Room Temperature</u>		
2T-1	190.0	16.8
2T-2	192.0	16.8
2T-3	193.0	17.1
Average	191.7	16.9
<u>Longitudinal at 400 F</u>		
2L-4	138.0	14.4
2L-5	164.0	15.9
2L-6	142.0	14.7
Average	140.7	14.5
<u>Transverse at 400 F</u>		
2T-4	164.0	16.1
2T-5	164.0	15.9
2T-6	163.0	16.2
Average	163.7	16.1
<u>Longitudinal at 600 F</u>		
2L-7	141.0	14.5
2L-8	137.0	13.9
2L-9	138.0	14.1
Average	138.7	14.2
<u>Transverse at 600 F</u>		
2T-7	152.0	14.9
2T-8	154.0	14.9
2T-9	149.0	14.7
Average	151.7	14.8
<u>Longitudinal at 800 F</u>		
2L-10	134.0	12.7
2L-11	136.0	12.5
2L-12	134.0	12.9
Average	134.7	12.7
<u>Transverse at 800 F</u>		
2T-10	140.0	13.5
2T-11	139.0	13.7
2T-12	137.0	13.5
Average	138.7	13.6

TABLE XXV. SHEAR TEST RESULTS FOR SOLUTION-TREATED AND AGED Ti-8Mo-8V-2Fe-3Al ALLOY SHEET AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
<u>Longitudinal</u>	
4L-1	92.9
4L-2	102.0
4L-3	102.0
4L-4	<u>100.5</u>
Average	100.5
<u>Transverse</u>	
4T-1	103.0
4T-2	106.0
4T-3	109.0
4T-4	<u>109.0</u>
Average	106.8

TABLE XXVI. AXIAL LOAD FATIGUE TEST RESULTS FOR UN-NOTCHED, SOLUTION-TREATED AND AGED Ti-8Mo-9V-2Fe-3Al ALLOY SHEET (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
<u>Room Temperature</u>		
5-2	110.0	8,200
5-1	100.0	16,800
5-3	90.0	24,000
5-4	80.0	34,800
5-5	70.0	61,400 ^(a)
5-25	70.0	324,000 ^(b)
5-6	65.0	11,153,000 ^(b)
5-7	60.0	11,053,400 ^(b)
<u>400 F</u>		
5-11	110.0	12,100
5-12	100.0	13,500
5-13	90.0	22,400
5-15	85.0	40,600
5-14	80.0	33,900
5-16	75.0	36,500 ^(c)
5-9	70.0	290,000 ^(b)
5-10	70.0	10,940,500 ^(b)
5-8	60.0	10,245,100 ^(b)
<u>700 F</u>		
5-17	110.0	4,010
5-18	100.0	4,870
5-19	90.0	7,650
5-20	80.0	12,500
5-21	70.0	100,380 ^(b)
5-22	60.0	10,352,900 ^(b)

(a) Failed in grip.

(b) Did not fail.

(c) Failed at thermocouple.

TABLE XXVII. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED
(K = 3.0) SOLUTION-TREATED AND AGED Ti-8Mo-
8V-2Fe-3Al ALLOY SHEET (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
<u>Room Temperature</u>		
5-31	80.0	3,700
5-32	70.0	4,300
5-35	60.0	6,600
5-33	50.0	12,500
5-36	40.0	17,000
5-34	30.0	911,500 ^(a)
5-37	20.0	10,001,300 ^(a)
<u>400 F</u>		
5-39	80.0	4,700
5-40	70.0	5,500
5-41	60.0	6,700
5-42	50.0	11,400
5-43	40.0	21,100
5-44	30.0	10,329,900 ^(a)
5-38	20.0	10,001,700 ^(a)
<u>700 F</u>		
5-45	80.0	2,900
5-46	70.0	3,200
5-47	60.0	5,100
5-48	50.0	8,200
5-49	40.0	26,500
5-50	30.0	33,400 ^(a)
5-51	25.0	16,537,900 ^(a)

(a) Did not fail.

TABLE XXVIII. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR Ti-8Mo-8V-2Fe-3Al ALLOY SHEET (TRANSVERSE)

Specimen Number	Stress, ksi	Temperature, F	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hours	Elongation in 2 Inches, percent	Minimum Creep Rate, percent
			0.1	0.2	0.5	1.0	2.0				
3-1	156	700	--	--	--	--	--	--	On Loading	5.3	--
3-2	150	700	--	--	--	--	--	--	0.1	3.6	--
3-3	140	700	0.05	0.20	1.3	4.2	13	1.187	162.3	12.0	0.047
3-8	100	700	1.6	4	11	23	75	0.751	989.7 (b)	7.1	0.0025
3-10	60	700	4	8	27	95	500	0.491	114.6 (b)	1.578	--
3-11	30	700	20	55	450 (a)	2000 (a)	--	0.082	313.3	0.529	0.00036
3-4	75	900	--	0.1	0.3	0.65	1.7	0.545	8.1	31.1	1.2
3-5	50	900	0.05	0.15	0.6	2.0	6.7	0.264	59.4	50.2	0.22
3-7	25	900	0.50	2.5	10	40	155	0.135	1406.2 (b)	57.3	0.008
3-13	12	900	4.3	20	153	450 (a)	--	0.109	172.8	0.647	0.0018
3-6	155	550	--	--	--	--	--	--	On Loading	8.9	--
3-9	145	550	0.3	2.8	30	105 (a)	1200 (a)	2.538	1104.6 (b)	4.50	0.0003
3-12	110	550	8.0	26	98	3500	--	0.968	173.9 (b)	1.682	--
3-16	70	550	30	103	360 (a)	--	--	0.422	234.6 (b)	0.780	--

(a) Estimate.

(b) Test discontinued.

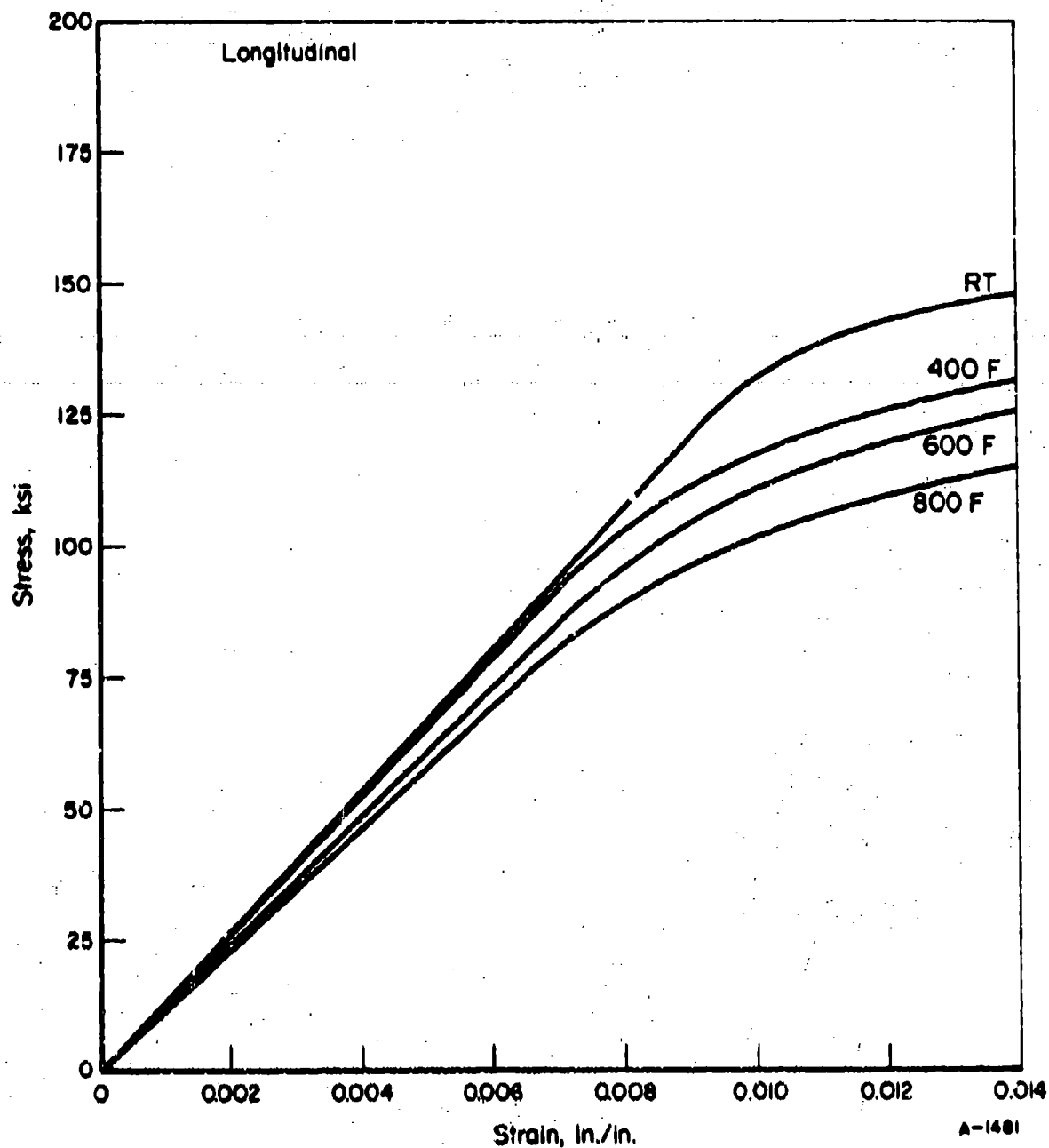


FIGURE 32. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR SOLUTION-TREATED AND AGED Ti-8Mo-8V-2Fe-3Al SHEET (LONGITUDINAL)

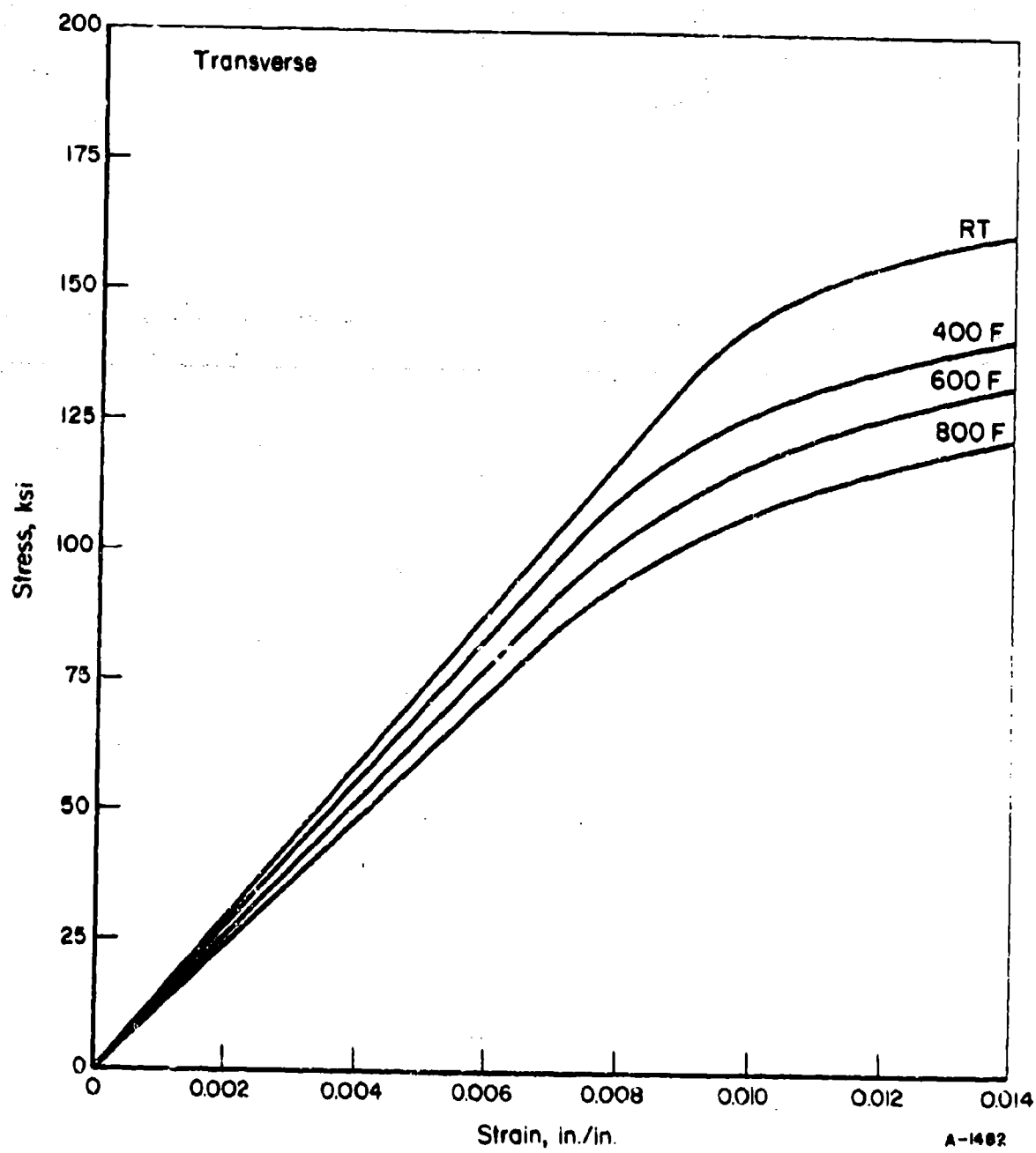


FIGURE 33. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR SOLUTION-TREATED AND AGED Ti-8Nb-8V-2Fe-3Al SHEET (TRANSVERSE)

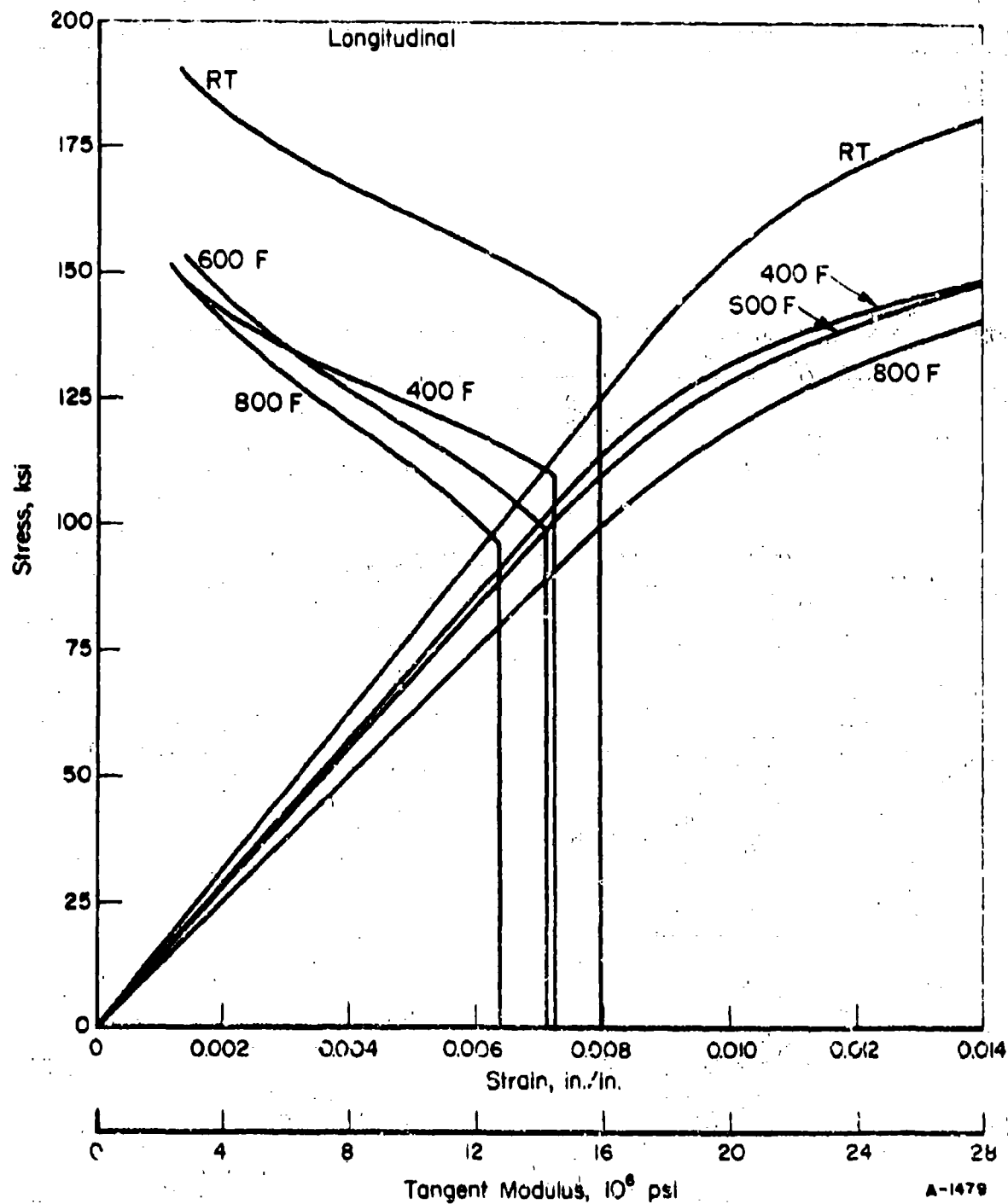


FIGURE 34. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR SOLUTION-TREATED AND AGED T1-8Mo-8V-2Fe-3Al SHEET (LONGITUDINAL)

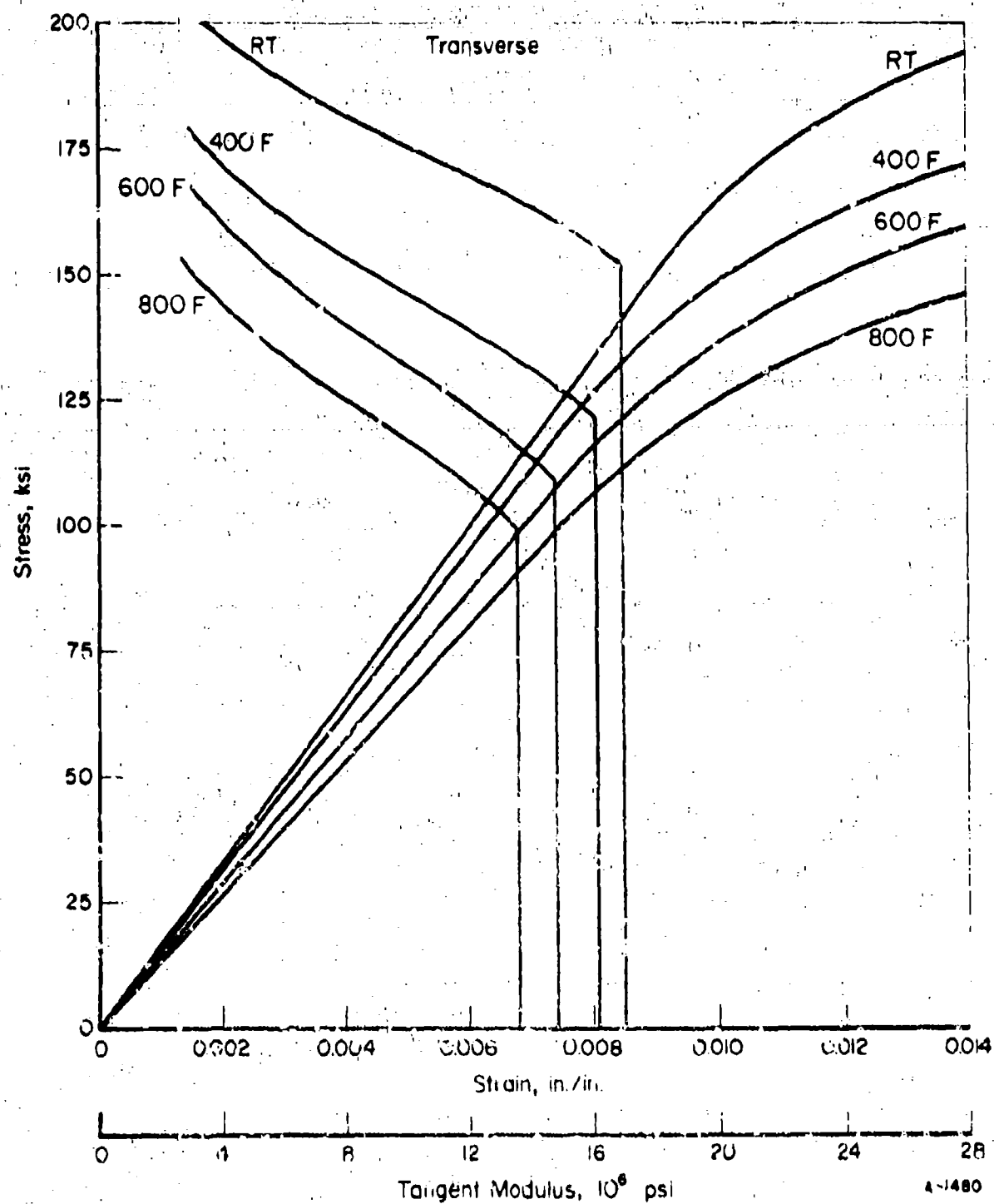


FIGURE 35. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES AT TEMPERATURE FOR SOLUTION-TREATED AND AGED TI-8Ni-8V-2Fe-0.1Al SHEET (TRANSVERSE)

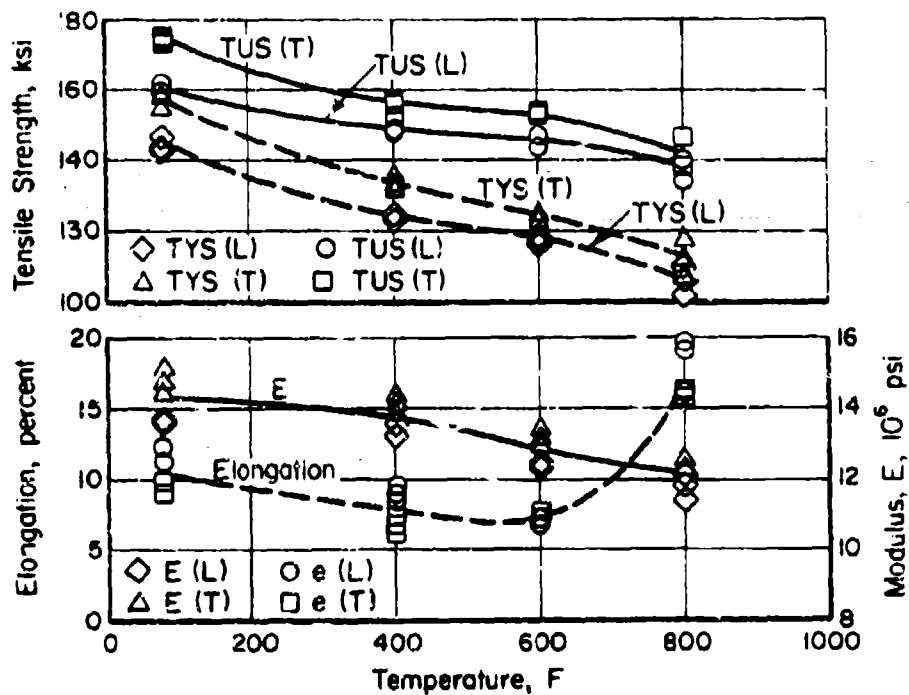


FIGURE 36. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION-TREATED AND AGED Ti-8Mo-8V-2Fe-3Al SHEET

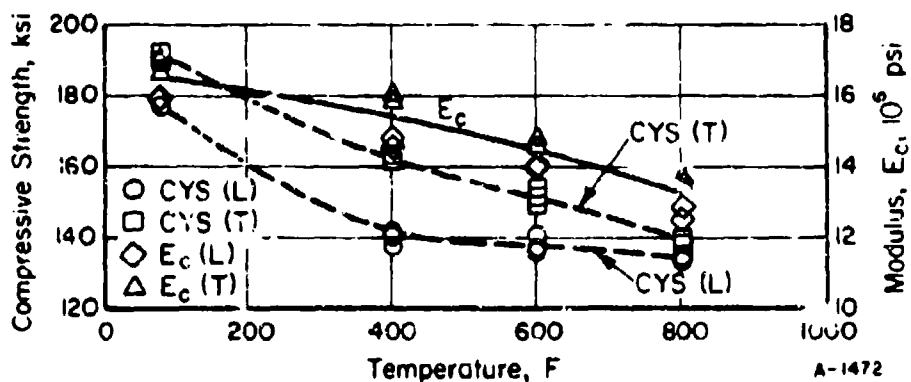


FIGURE 37. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION-TREATED AND AGED Ti-8Mo-8V-2Fe-3Al SHEET

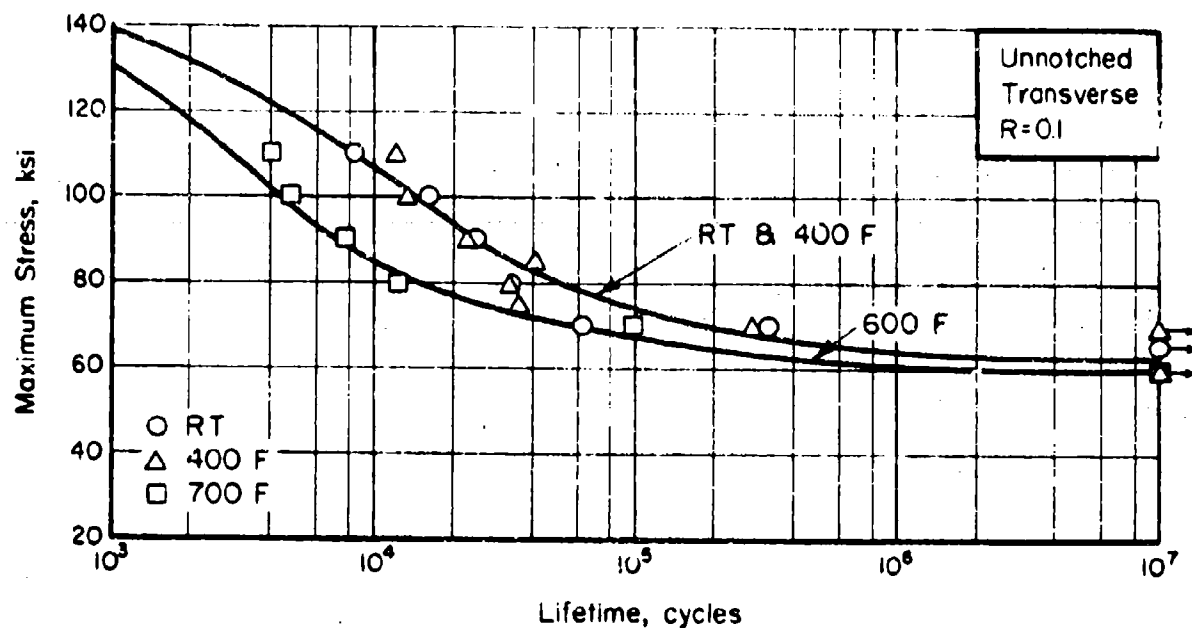


FIGURE 38. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SOLUTION-TREATED AND AGED T1-8Mo-8V-2Fe-3Al SHEET (TRANSVERSE)

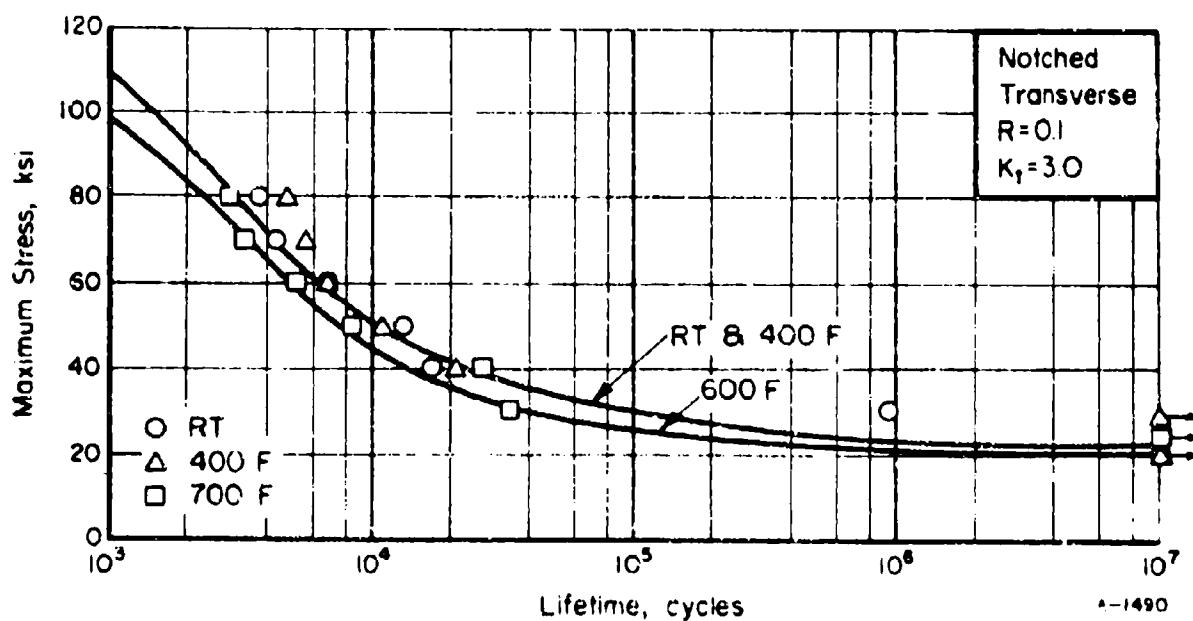
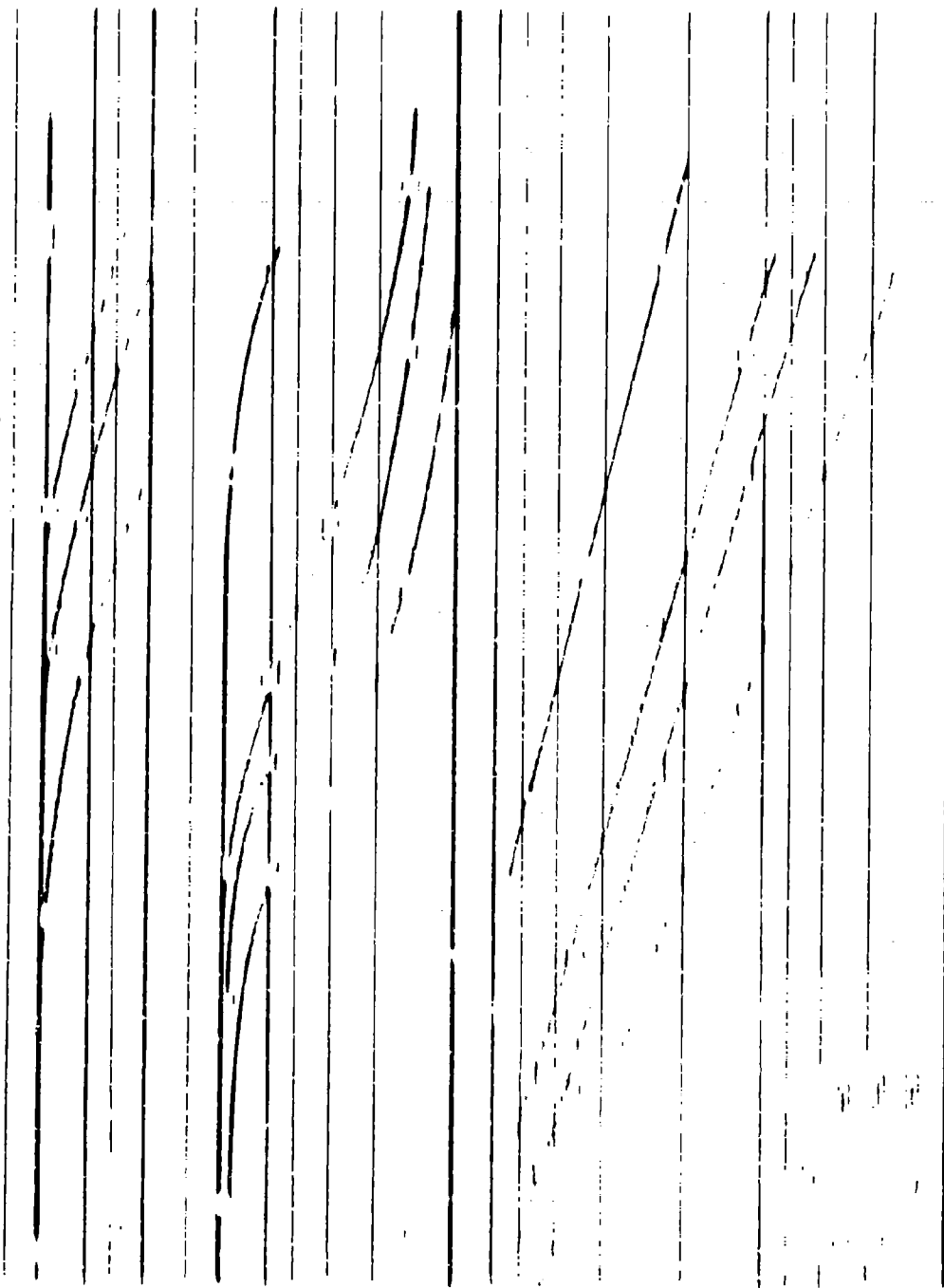


FIGURE 39. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED ($K_t = 3.0$) SOLUTION-TREATED AND AGED T1-8Mo-8V-2Fe-3Al SHEET (TRANSVERSE)



Ti-6Al-2Zr-2Sn-2Mo-2Cr Alloy

Material Description

This alloy is a recent development of RMI Company. It is an alpha-beta type alloy designed for deep hardenability. Preliminary information shows the material to have low density, high modulus, high toughness, and good producibility. Strength retention to 800 F is good.

The material used for this evaluation was a 1 1/2-inch-thick plate from RMI ingot number 890180.

Processing and Heat Treating

The specimen layout is shown in Figure 41. The material was received in the solution-treated (1740 F, 1 hour, AC) condition and specimens were aged at 1000 F for 8 hours.

Test Results

Tension. Results of tests in both the longitudinal and transverse directions at room temperature, 400 F, 600 F, and 800 F are given in Table XXIX. Typical stress-strain curves at temperature are shown in Figures 42 and 43. Effect-of-temperature curves are presented in Figure 46.

Compression. Results of tests in both the longitudinal and transverse directions at room temperature, 400 F, 600 F, and 800 F are given in Table XXX. Typical stress-strain and tangent-modulus curves at temperature are shown in Figures 44 and 45. Effect-of-temperature curves are shown in Figure 47.

Shear. Results of pin shear tests at room temperature for longitudinal and transverse specimens are given in Table XXXI.

Impact. Results of Charpy V-notch tests at room temperature in both the longitudinal and transverse directions are given in Table XXXII.

Fracture Toughness. Results of slow-bend type tests in both the longitudinal (L-T) and transverse (T-L) directions are given in Table XXXIII. Even though the candidate K_Q values do not meet the rigorous $a, T, < 2.5 \left(\frac{K_Q}{TYS} \right)^2$ criteria they are above $2.2 \left(\frac{K_Q}{TYS} \right)^2$ and should be considered good indicative K_{Ic} values.

52	54	56	58
----	----	----	----

69

Fatigue. Axial load fatigue tests were conducted at room temperature, 400 F, and 600 F for unnotched and notched transverse specimens at a stress ratio of $R = 0.1$. Results are given in tabular form in Tables XXXIV and XXXV. S-N curves are presented in Figures 48 and 49.

Creep and Stress Rupture. Tests were conducted on transverse specimens at 400 F, 600 F, and 800 F. Tabular test results are given in Table XXXVI. Log-stress versus log-time curves are presented in Figure 50.

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

Thermal Expansion. The thermal expansion coefficient for this alloy is 5.1×10^{-6} in./in./F for 70 to 800 F.

Density. The density value is 0.162 lb./in.³.

TABLE XXIX. TENSILE TEST RESULTS FOR SOLUTION-TREATED AND
AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr ALLOY PLATE

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation in 1-inch, percent	Reduction in Area, percent	Tensile Modulus, 10 ⁶ psi
<u>Longitudinal at Room Temperature</u>					
1L-1	169.0	155.0	18.0	25.0	17.9
1L-2	168.0	156.0	18.0	24.8	17.9
1L-3	<u>168.0</u>	<u>156.0</u>	<u>18.0</u>	<u>24.6</u>	<u>17.8</u>
Average	168.3	155.6	18.0	24.8	17.9
<u>Transverse at Room Temperature</u>					
1T-1	168.0	157.0	18.0	24.0	17.5
1T-2	169.0	156.0	17.5	27.3	17.7
1T-3	<u>169.0</u>	<u>157.0</u>	<u>17.5</u>	<u>27.4</u>	<u>18.3</u>
Average	168.7	156.6	17.7	26.2	17.8
<u>Longitudinal at 400 F</u>					
1L-4	144.0	111.0	17.5	29.8	15.4
1L-5	147.0	120.0	20.5	34.6	17.0
1L-6	<u>145.0</u>	<u>117.0</u>	<u>20.5</u>	<u>35.3</u>	<u>15.2</u>
Average	145.3	116.0	19.5	33.2	15.9
<u>Transverse at 400 F</u>					
1T-4	145.0	120.0	19.0	34.5	15.9
1T-5	147.0	120.0	20.0	33.5	16.1
1T-6	<u>146.0</u>	<u>119.0</u>	<u>20.0</u>	<u>33.0</u>	<u>16.7</u>
Average	146.0	119.7	19.7	33.7	16.2
<u>Longitudinal at 600 F</u>					
1L-7	138.0	107.0	18.5	34.5	14.8
1L-8	139.0	107.0	20.0	36.0	16.2
1L-9	<u>140.0</u>	<u>107.0</u>	<u>17.0</u>	<u>34.2</u>	<u>15.8</u>
Average	139.0	107.0	18.5	34.9	15.6
<u>Transverse at 600 F</u>					
1T-7	139.0	108.0	18.5	30.4	16.0
1T-8	140.0	109.0	18.0	35.0	16.0
1T-9	<u>140.0</u>	<u>109.0</u>	<u>18.0</u>	<u>34.6</u>	<u>16.0</u>
Average	139.7	108.7	18.2	33.3	16.0
<u>Longitudinal at 800 F</u>					
1L-10	131.0	99.5	22.0	41.3	13.8
1L-11	132.0	102.0	22.0	44.0	14.5
1L-12	<u>133.0</u>	<u>102.0</u>	<u>20.0</u>	<u>40.9</u>	<u>14.9</u>
Average	132.0	101.2	21.3	42.1	14.4
<u>Transverse at 800 F</u>					
1T-10	133.0	106.0	21.0	44.7	13.9
1T-11	131.0	102.0	21.0	37.4	14.4
1T-12	<u>132.0</u>	<u>104.0</u>	<u>21.0</u>	<u>42.0</u>	<u>15.5</u>
Average	132.0	104.0	21.0	41.4	14.6

TABLE XXX. COMPRESSION TEST RESULTS FOR SOLUTION-TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr ALLOY PLATE

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compressive Modulus, 10 ⁶ psi
<u>Longitudinal at Room Temperature</u>		
2L-1	168.0	17.8
2L-2	170.0	18.5
2L-3	<u>171.0</u>	<u>18.0</u>
Average	169.7	18.1
<u>Transverse at Room Temperature</u>		
2T-1	172.0	18.3
2T-2	174.0	18.5
2T-3	<u>174.0</u>	<u>18.6</u>
Average	173.3	18.5
<u>Longitudinal at 400 F</u>		
2L-4	132.0	16.5
2L-5	125.0	17.2
2L-6	<u>128.0</u>	<u>16.5</u>
Average	128.3	16.7
<u>Transverse at 400 F</u>		
2T-4	130.0	16.3
2T-5	130.0	16.5
2T-6	<u>128.0</u>	<u>16.2</u>
Average	129.3	16.3
<u>Longitudinal at 600 F</u>		
2L-7	113.0	15.7
2L-8	113.0	16.4
2L-9	<u>111.0</u>	<u>15.4</u>
Average	112.3	15.8
<u>Transverse at 600 F</u>		
2T-7	114.0	15.9
2T-8	116.0	15.6
2T-9	<u>115.0</u>	<u>15.9</u>
Average	115.0	15.8
<u>Longitudinal at 800 F</u>		
2L-10	107.0	14.4
2L-11	105.0	14.7
2L-12	<u>105.0</u>	<u>14.7</u>
Average	105.7	14.6
<u>Transverse at 800 F</u>		
2T-10	106.0	14.7
2T-11	106.0	14.7
2T-12	<u>107.0</u>	<u>14.4</u>
Average	106.3	14.6

TABLE XXXI. SHEAR TEST RESULTS FOR SOLUTION-TREATED
AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr ALLOY
PLATE AT ROOM TEMPERATURE

Specimen Number	Ultimate Shear Strength, ksi
<u>Longitudinal</u>	
4L-1	103.0
4L-2	114.0
4L-3	107.0
4L-4	<u>109.0</u>
Average	108.3
<u>Transverse</u>	
4T-1	108.0
4T-2	109.0
4T-3	109.0
4T-4	<u>106.0</u>
Average	108.0

TABLE XXXII. IMPACT TEST RESULTS FOR SOLUTION-TREATED
AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr ALLOY
PLATE AT ROOM TEMPERATURE

Specimen Number	Energy, ft./lbs.
<u>Longitudinal</u>	
10L-1	14.0
10L-2	13.0
10L-3	13.0
10L-4	15.0
10L-5	15.0
10L-6	<u>13.0</u>
Average	13.9
<u>Transverse</u>	
10T-1	16.0
10T-2	15.0
10T-3	16.5
10T-4	17.0
10T-5	16.0
10T-6	<u>17.0</u>
Average	16.3

TABLE XXXIII. RESULTS OF SLOW-BEND TYPE FRACTURE TOUGHNESS TESTS ON
SOLUTION-TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE

Specimen Number	w, inches	a, inches	T, inches	P, lbs.	Span, inches	$f(\frac{a}{w})$	$K_Q^{(a)}$
<u>Longitudinal (L-T)</u>							
6L-1	1.500	0.746	0.750	7,600	6.0	2.64	87.4
6L-2	1.500	0.783	0.750	7,200	6.0	2.86	89.8
6L-3	1.500	0.723	0.750	7,950	6.0	2.52	87.1
6L-4	1.500	0.763	0.750	7,350	6.0	2.74	87.7
<u>Transverse (T-L)</u>							
6T-1	1.500	0.770	0.750	7,650	6.0	2.78	92.7
6T-2	1.500	0.777	0.750	7,550	6.0	2.82	92.9
6T-3	1.500	0.770	0.750	8,025	6.0	2.78	97.2

(a) Candidate K_Q values are invalid as K_{Ic} values since they do not meet the rigorous standard of $a, T, < 2.5 (\frac{K_Q^{Ic}}{TYS})^2$. However, they do exceed a $2.2 (\frac{K_Q}{TYS})^2$ and as such should be considered marginally valid.

TABLE XXXIV. AXIAL LOAD FATIGUE TEST RESULTS FOR UNNOTCHED
SOLUTION-TREATED AND AGED Ti-6Al-2Sn-2Mo-2Cr
ALLOY PLATE (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
<u>Room Temperature</u>		
5-6	160.0	7,600
5-5	150.0	23,300
5-4	140.0	189,600
5-3	130.0	208,900
5-2	120.0	302,400
5-7	115.0	424,400
5-8	110.0	1,087,800
5-9	105.0	818,800
5-10	100.0	1,767,200
5-1	90.0	1,616,800
5-11	80.0	5,855,600
5-27	70.0	13,625,400 ^(a)
<u>400 F</u>		
5-12	150.0	7,100
5-13	140.0	12,000
5-14	130.0	21,400
5-15	120.0	178,500
5-16	110.0	369,000
5-17	100.0	829,500
5-18	90.0	2,142,600
5-19	80.0	3,059,600
5-24	70.0	10,144,000 ^(a)
<u>600 F</u>		
5-28	140.0	(b)
5-29	130.0	9,000
5-20	120.0	16,700
5-21	110.0	458,800
5-22	100.0	1,341,600
5-23	90.0	2,653,700
5-25	80.0	4,227,400
5-26	70.0	10,305,400 ^(a)

(a) Did not fail.

(b) Failed on loading.

TABLE XXXV. AXIAL LOAD FATIGUE TEST RESULTS FOR NOTCHED
($K_t=3.0$) SOLUTION-TREATED AND AGED Ti-6Al-
2Zr-2Sn-2Mo-2Cr ALLOY PLATE (TRANSVERSE)

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
<u>Room Temperature</u>		
5-31	120.0	1,590
5-32	100.0	5,780
5-33	90.0	7,700
5-34	80.0	11,100
5-38	75.0	24,800
5-35	70.0	133,400
5-36	60.0	400,250
5-37	50.0	813,600
5-41	45.0	1,135,800
5-40	40.0	10,624,900 ^(a)
<u>400 F</u>		
5-46	75.0	9,500
5-47	70.0	27,600
5-48	65.0	39,900
5-49	60.0	67,000
5-50	55.0	124,000
5-51	50.0	1,846,000
5-53	40.0	1,568,200
5-54	30.0	16,000,000 ^(a)
<u>600 F</u>		
5-39	80.0	2,530
5-40	70.0	9,100
5-42	60.0	25,480
5-45	55.0	361,150
5-43	50.0	366,120
5-53	40.0	1,417,600
5-55	30.0	14,718,600 ^(a)

(a) Did not fail.

TABLE XXXVI. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR SOLUTION-TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr ALLOY PLATE (TRANSVERSE)

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					
3-4	142	400	--	--	--	--	--	--	On Loading	13.6	47.7	--
3-5	137	400	0.01	0.03	0.7	--	--	3.725	353.7(b)	4.302	--	0.00005
3-6	120	400	0.10	550	--	--	--	1.180	574.5	1.400	--	0.00004
3-2	133	600	--	--	--	--	--	--	On Loading	--	--	--
3-3	128	600	0.05	10	4000(a)	--	--	2.980	643.9(b)	3.280	--	0.000055
3-10	120	600	3.5	100	--	--	--	1.940	382.3(b)	2.168	--	--
3-7	110	600	1350(a)	--	--	--	--	1.260	365.7	1.332	--	--
3-11	130	800	--	--	--	--	--	--	On Loading	13.6	48.3	--
3-9	120	800	0.1	0.3	1.5	6.2	21	2.408	504.9(b)	11.2	21.5	--
3-8	100	800	6	10	175(a)	2200(a)	--	0.992	504.4(b)	1.731	--	0.0004
3-1	50	800	320	2200(a)	7500	--	--	0.456	841.0	0.584	--	0.000056

(a) Estimate.

(b) Test discontinued.

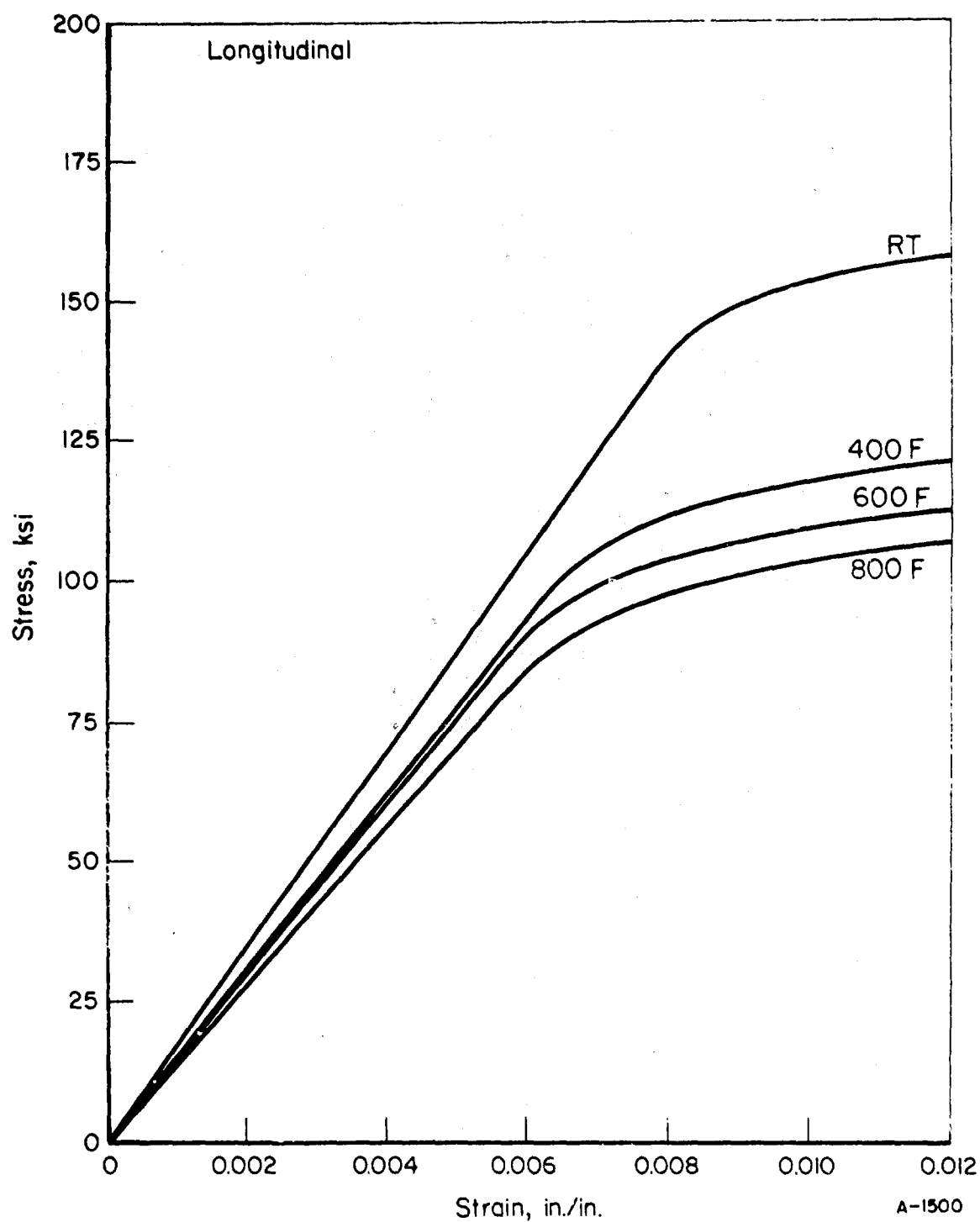


FIGURE 42. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURE FOR SOLUTION-TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE (LONGITUDINAL)

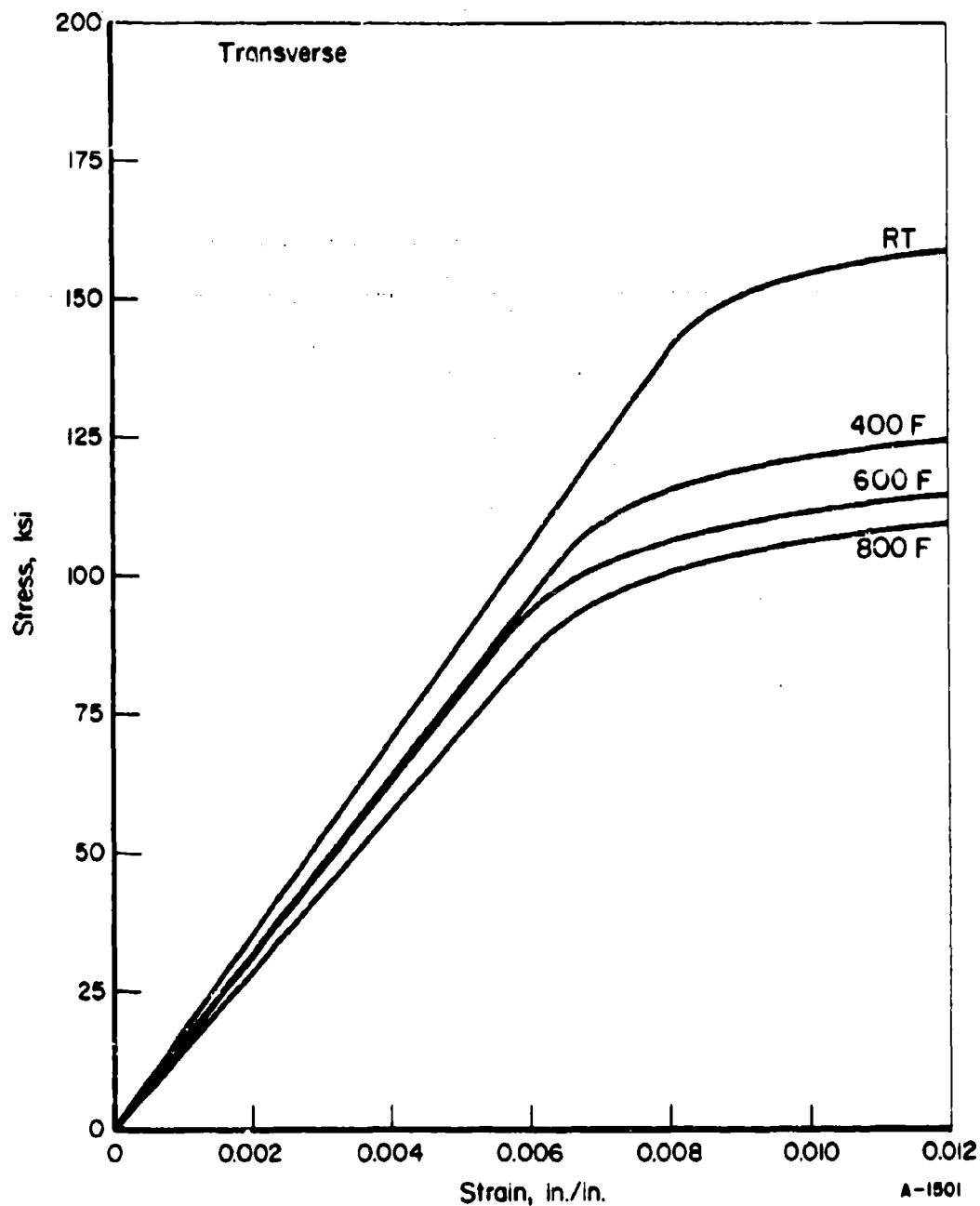


FIGURE 43. TYPICAL TENSILE STRESS-STRAIN CURVES AT TEMPERATURES FOR SOLUTION-TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE (TRANSVERSE)

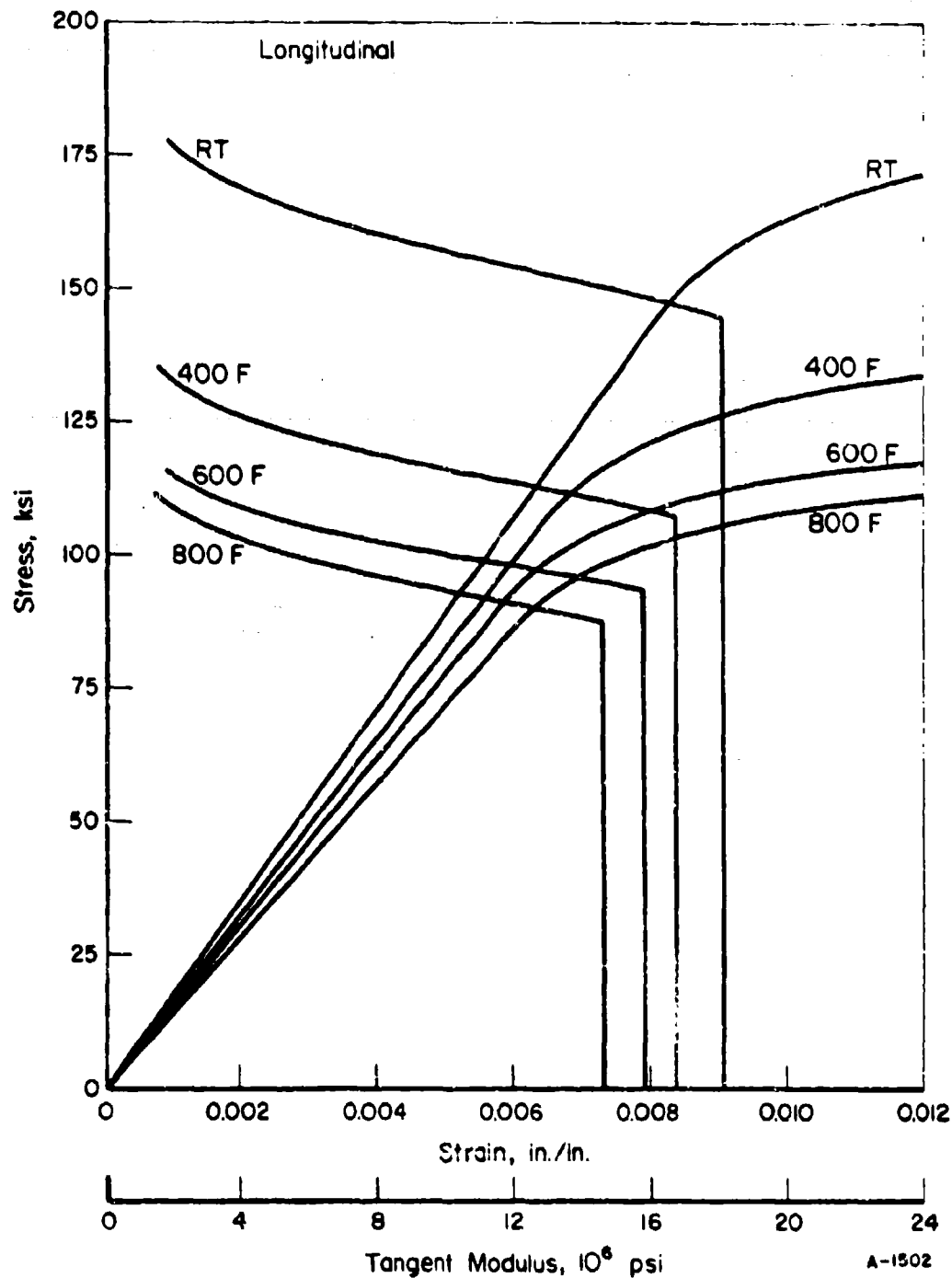


FIGURE 44. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR SOLUTION-TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE (LONGITUDINAL)

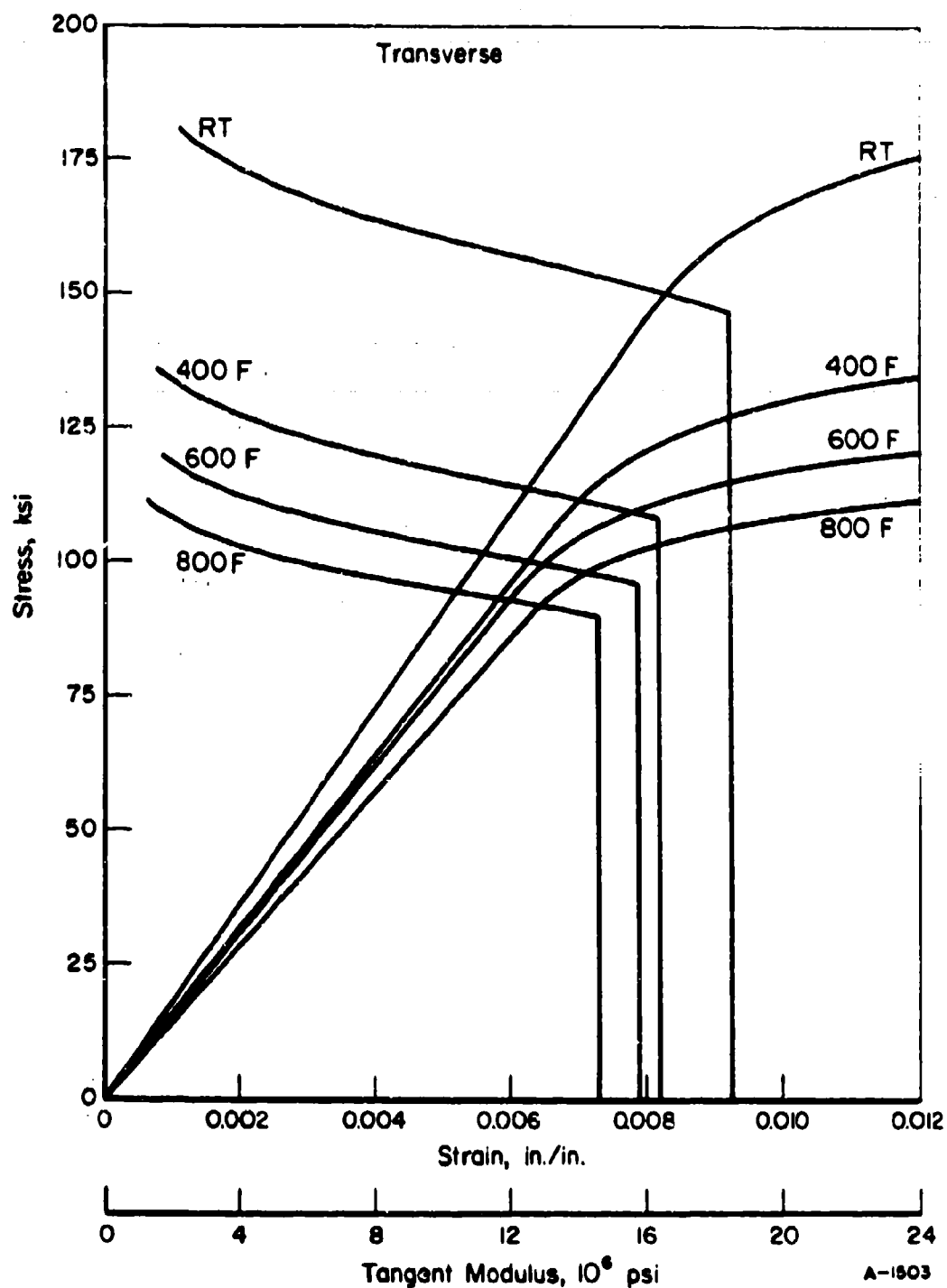


FIGURE 45. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR SOLUTION-TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE (TRANSVERSE)

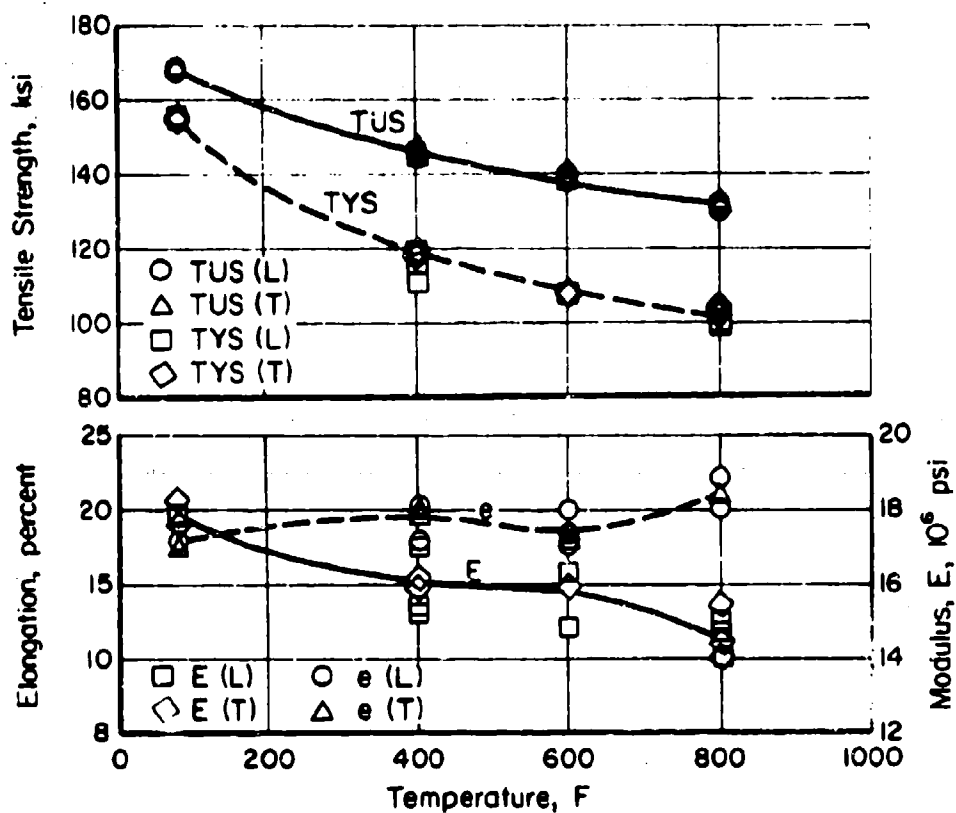


FIGURE 46. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION-TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE

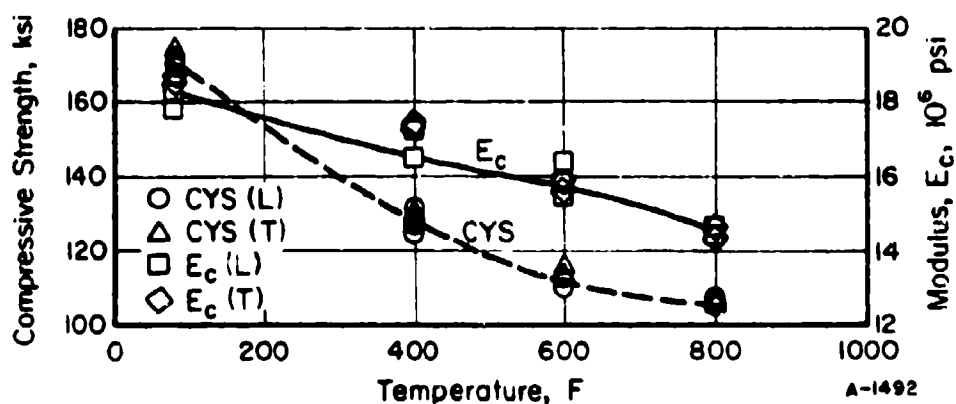


FIGURE 47. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION-TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE

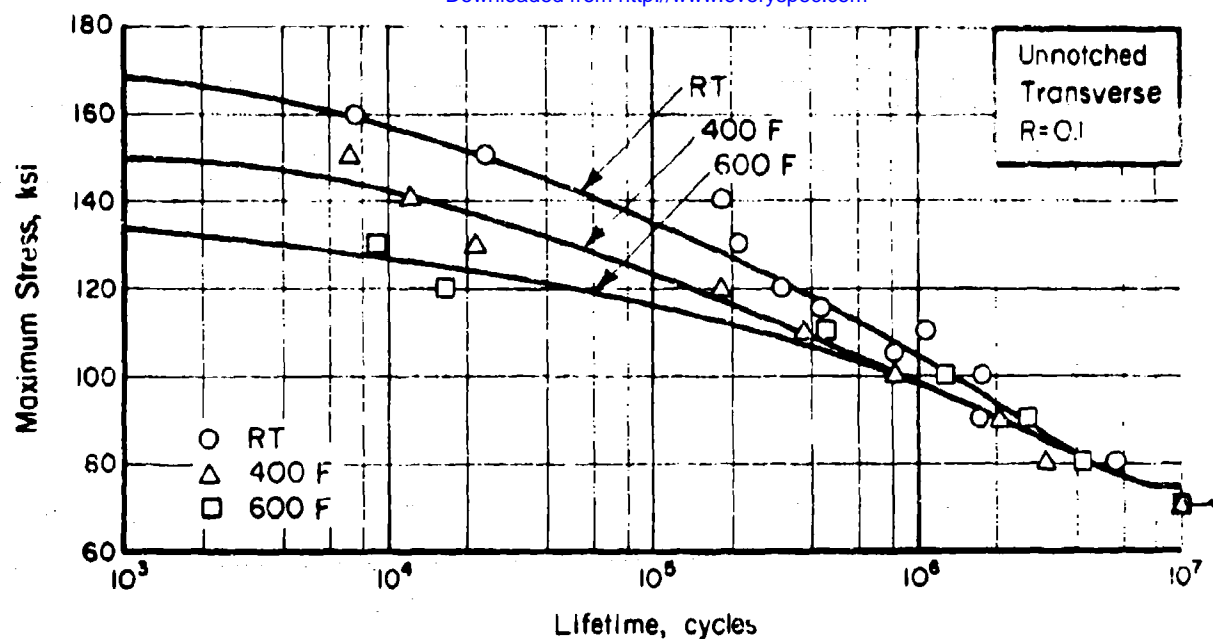


FIGURE 48. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SOLUTION-TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE (TRANSVERSE)

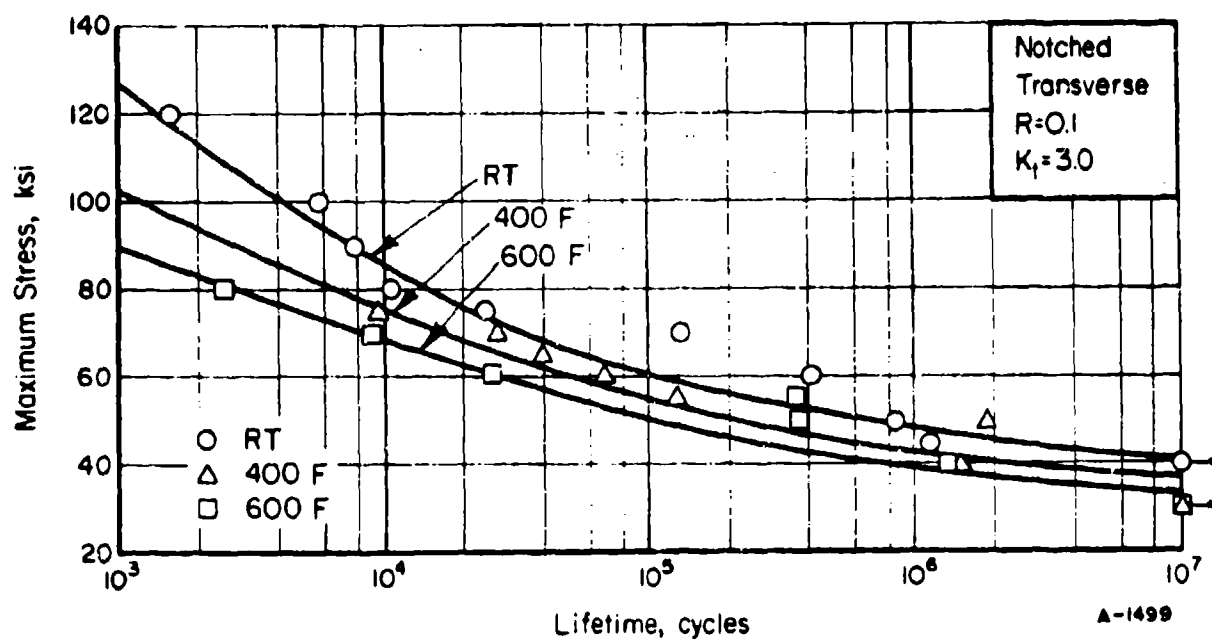


FIGURE 49. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED ($K_t = 3.0$) SOLUTION-TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE (TRANSVERSE)

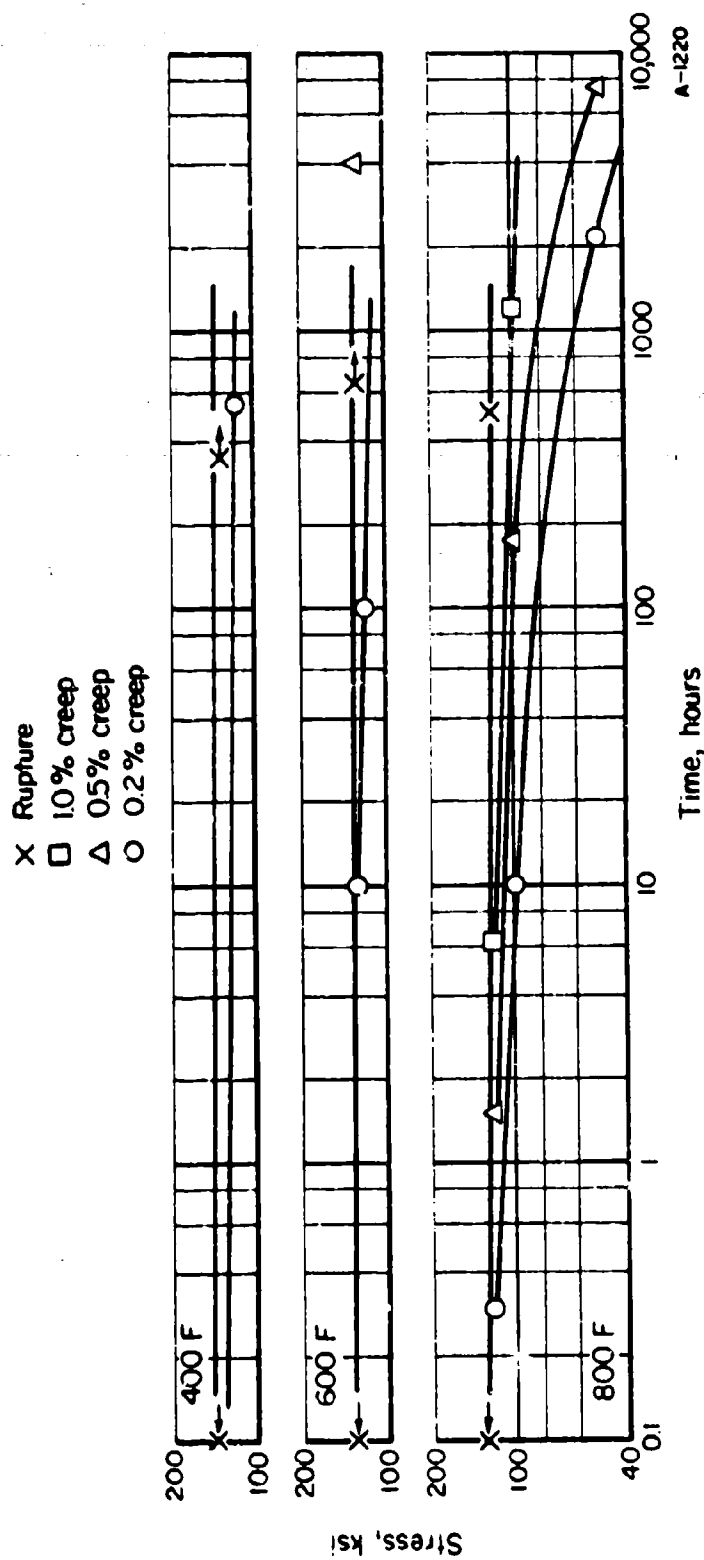


FIGURE 50. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR SOLUTION TREATED AND AGED Ti-6Al-2Zr-2Sn-2Mo-2Cr PLATE (TRANSVERSE)

Ti-6Al-6V-2Sn Isothermal Die ForgingsMaterial Description

This is a heat-treatable alpha-beta type alloy similar in many respects to Ti-6Al-4V, but containing increased content of beta-stabilizing elements which provide higher strength potential.

The material used for this evaluation was made by IIT Research Institute under Air Force Contract F33615-67-C-1722. It consisted of structural shapes and nose wheels that were isothermally creep (slow speed) forged from flat preforms machined from conventionally forged Ti-6Al-6V-2Sn alloy billets.

Processing and Heat Treating

The material was received with no heat treatment after forging. Specimens were solution treated at 1650 F for 1/2 hour, water quenched, and aged at 1050 F for 4 hours and air cooled as suggested by IIT Research Institute. Other heat treatments designed for lower UTS and higher toughness should be considered for other applications.

Since the material was of complex shapes, it was necessary to cut specimens from various positions and no specimen layout drawing is shown.

Test Results

Tension. Test results for transverse specimens at room temperature, 400 F, 700 F, and 900 F are given in Table XXXVII. Typical stress-strain curves at temperature are presented in Figure 51. Effect of temperature curves are shown in Figure 53.

Compression. Results of tests on transverse specimens at room temperature, 400 F, 700 F, and 900 F are given in Table XXXVIII. Typical stress-strain and tangent-modulus curves at temperature are shown in Figure 52. Effect of temperature curves are shown in Figure 54.

Shear. Pin shear test results at room temperature for longitudinal and transverse specimens are given in Table XXXIX.

Impact. Test results for longitudinal and transverse specimens at room temperature are given in Table XL.

Fracture Toughness. Slow-bend tests were attempted, but the material thickness was not sufficient to obtain large specimens. The candidate K_{IC} values did not meet ASTM criteria and are not reported. Results of tests on compact tension specimens at AFML are reported in the data sheet in Appendix III.

Fatigue. Axial load tests were conducted at room temperature, 400 F, and 700 F for both unnotched and notched transverse specimens at a stress ratio of $R = 0.1$. Tabular test results are given in Tables XLI and XLII. S-N curves are presented in Figures 55 and 56.

Creep and Stress Rupture. Test results for transverse specimens at 700 F and 900 F are given in Table XLIII. Tests were attempted at 400 F and 550 F, but no appreciable creep occurred. Log-stress versus log-time curves are presented in Figure 57.

Stress Corrosion. Tests were conducted as described in the experimental procedures section of this report. No failures or cracks occurred in the 1000-hour test duration.

Thermal Expansion. The coefficient of thermal expansion for this alloy is 5.3×10^{-6} in./in./F from 70 F to 900 F.

Density. The density value for this alloy is 0.164 lb./in.³.

TABLE XXXVII. TENSION TEST RESULTS FOR SOLUTION-TREATED AND AGED
Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGING (TRANSVERSE)

Specimen Number	Ultimate Tensile Strength, ksi	0.2 Percent Offset Yield Strength, ksi	Elongation, in 1 Inch, percent	Tensile Modulus, 10 ⁶ psi
<u>Room Temperature</u>				
5	203.3	194.1	3.0	14.9
6	199.6	188.6	7.0	16.0
13	204.5	196.1	4.0	17.0
Average	202.5	192.9	4.7	16.0
<u>400 F</u>				
7	171.6	154.8	7.0	15.4
8	174.0	152.0	9.0	14.1
9	165.5	152.7	7.0	14.7
Average	170.4	153.2	7.7	14.7
<u>700 F</u>				
10	154.7	134.4	12.0	13.0
11	155.7	132.8	8.0	13.3
12	164.8	128.2	5.0	13.0
Average	158.4	131.8	8.3	13.1
<u>900 F</u>				
15	137.4	82.4	23.0	11.5
16	143.6	87.5	20.0	12.4
17	119.7	70.9	23.0	12.4
Average	133.6	80.3	22.0	12.1

TABLE XXXVIII. COMPRESSION TEST RESULTS FOR SOLUTION-TREATED AND AGED
T1-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS (TRANSVERSE)

Specimen Number	0.2 Percent Offset Yield Strength, ksi	Compression Modulus, 10 ³ psi
<u>Room Temperature</u>		
2T-1	202.6	18.0
2T-2	200.1	18.5
2T-3	195.2	17.6
Average	199.3	Average 18.0
<u>400 F</u>		
2T-4	170.6	16.6
2T-5	172.2	16.0
2T-6	180.0	15.7
Average	174.3	Average 16.1
<u>700 F</u>		
2T-7	156.6	12.0
2T-8	150.0	13.6
2T-9	152.3	14.0
Average	152.9	Average 13.2
<u>900 F</u>		
2T-10	101.2	12.0
2T-11	110.0	12.2
2T-12	112.0	11.6
Average	107.7	Average 11.9

TABLE XXXIX. SHEAR TEST RESULTS AT ROOM TEMPERATURE FOR SOLUTION-TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS

Specimen Number	Ultimate Shear Strength, ksi
<u>Longitudinal</u>	
4L-1	131.0
4L-2	132.0
4L-3	131.7
4L-4	131.6
Average	131.6
<u>Transverse</u>	
4T-1	130.0
4T-2	130.0
4T-3	130.1
4T-4	130.0
Average	130.0

TABLE XL. IMPACT TEST RESULTS FOR SOLUTION-TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS

Specimen Number	Energy, ft. lbs.
<u>Longitudinal</u>	
10L-1	12.0
10L-2	11.0
10L-3	11.0
10L-4	11.7
Average	11.7
<u>Transverse</u>	
10T-1	8.5
10T-2	9.0
10T-3	8.0
10T-4	8.5
Average	8.5

TABLE XLI. AXIAL LOAD FATIGUE TEST RESULTS FOR
UNNOTCHED SOLUTION-TREATED AND AGED
Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
<u>Room Temperature</u>		
5-1	100.0	4,700
5-2	100.0	15,300
5-3	90.0	15,500
5-4	80.0	15,300
5-6	70.0	19,900
5-5	60.0	25,800
5-7	50.0	35,990
5-17	40.0	12,679,200 ^(a)
<u>400 F</u>		
5-8	80.0	15,900
5-9	70.0	19,900
5-10	60.0	100,400
5-11	50.0	30,700
5-18	40.0	100,700
5-19	30.0	10,452,600 ^(a)
<u>700 F</u>		
5-12	80.0	18,000
5-13	70.0	30,200
5-14	60.0	27,500
5-15	60.0	38,900
5-16	50.0	3,161,100 ^(b)
5-20	40.0	11,436,800 ^(a)

(a) Did not fail.

(b) Grip failure.

TABLE XLII. AXIAL LOAD FATIGUE TEST RESULTS FOR
NOTCHED ($K_t = 3.0$) SOLUTION-TREATED
AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE
FORGINGS

Specimen Number	Maximum Stress, ksi	Lifetime, cycles
<u>Room Temperature</u>		
5-35	70.0	3,900
5-31	60.0	16,200
5-32	50.0	26,300
5-33	40.0	244,000
5-34	30.0	8,134,400
5-21	25.0	10,189,800 ^(a)
<u>400 F</u>		
5-37	70.0	9,400
5-38	60.0	18,200
5-40	55.0	26,600
5-39	50.0	662,200
5-41	45.0	61,200
5-36	40.0	4,784,900
5-20	35.0	10,160,400 ^(a)
<u>700 F</u>		
5-42	65.0	6,100
5-43	60.0	7,800
5-44	55.0	19,700
5-45	50.0	56,400
5-46	45.0	120,700
5-47	40.0	86,000
5-48	35.0	1,110,500
5-49	30.0	14,219,800 ^(a)

(a) Did not fail.

TABLE XLIII. SUMMARY DATA ON CREEP AND RUPTURE PROPERTIES FOR SOLUTION-TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS (TRANSVERSE)

Specimen Number	Stress, ksi	Temperature, °F	Hours to Indicated Creep Deformation, percent					Initial Strain, percent	Rupture Time, hours	Elongation in 2 in., percent	Reduction of Area, percent	Minimum Creep Rate, percent
			0.1	0.2	0.5	1.0	2.0					
3-1	153.3	700	--	--	--	--	--	--	On Loading	8.9	24.8	--
3-4	145	700	--	--	0.07	0.25	0.70	4.133	2.6	13.8	32.6	1.5
3-5	135	700	0.08	0.2	0.8	2.5	11.0	1.680	59.8 (b)	18.5	45.3	0.13
3-6	110	700	0.3	1.0	12 (a)	47	180	0.781	1007.8 (b)	6.96	--	0.0050
3-8	50	700	17	75	1000 (a)	--	--	0.242	122.8 (b)	0.465	--	--
3-9	25	700	120	1450	7500 (a)	--	--	0.073	935.5 (b)	0.246	--	0.000030
3-2	60	900	0.07	0.15	0.7	2.0	5.2	0.446	27.6	33.9	73.2	0.31
3-7	30	900	0.30	1.0	6.0	28	77	0.350	624.3 (b)	48.5	81.0	0.020
3-10	8	900	5.5	25	--	--	--	0.138	119.8 (b)	0.469	--	--
3-11	3	900	100	125	5000 (a)	--	--	0.173	937.6 (b)	0.377	--	0.000075

(a) Estimate.

(b) Test discontinued.

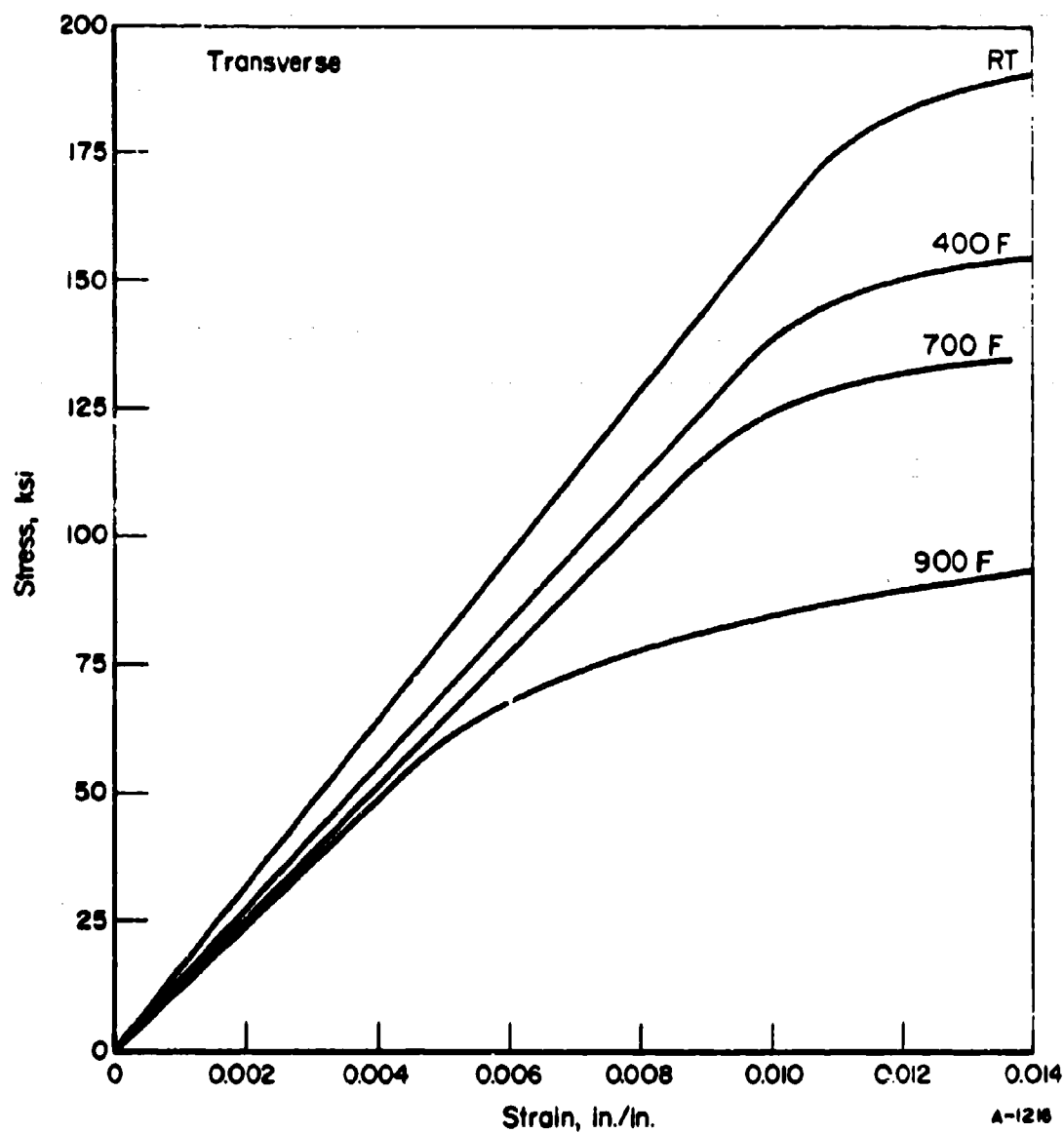


FIGURE 51. TYPICAL TENSILE STRESS-STRAIN CURVES FOR SOLUTION TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS

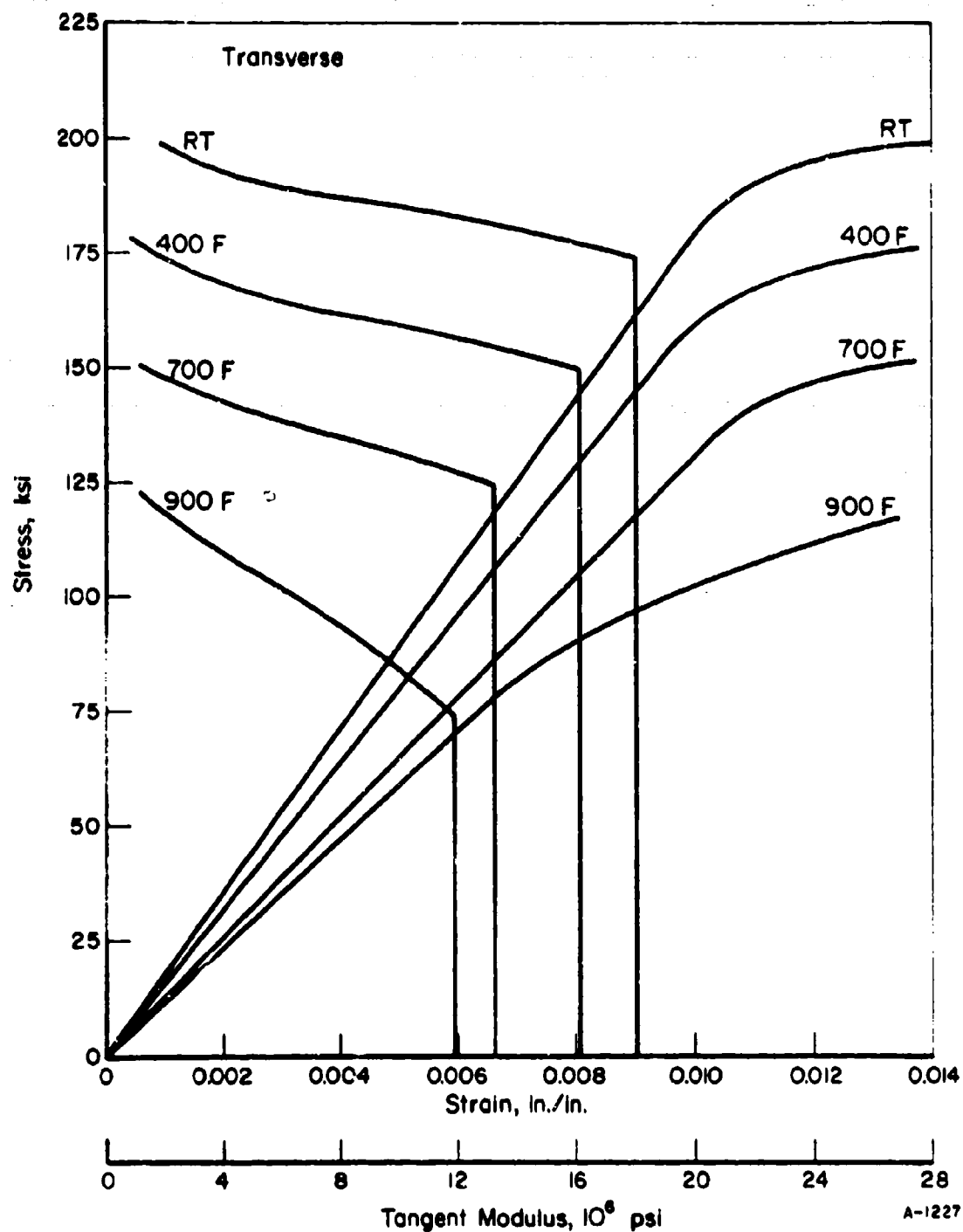


FIGURE 52. TYPICAL COMPRESSIVE STRESS-STRAIN AND TANGENT-MODULUS CURVES FOR SOLUTION TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS

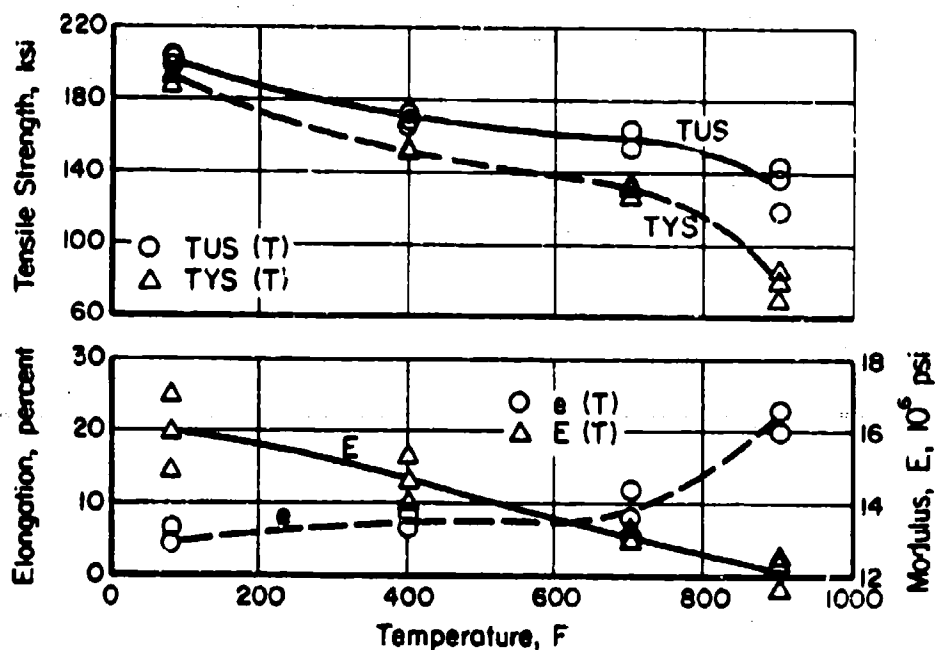


FIGURE 53. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS

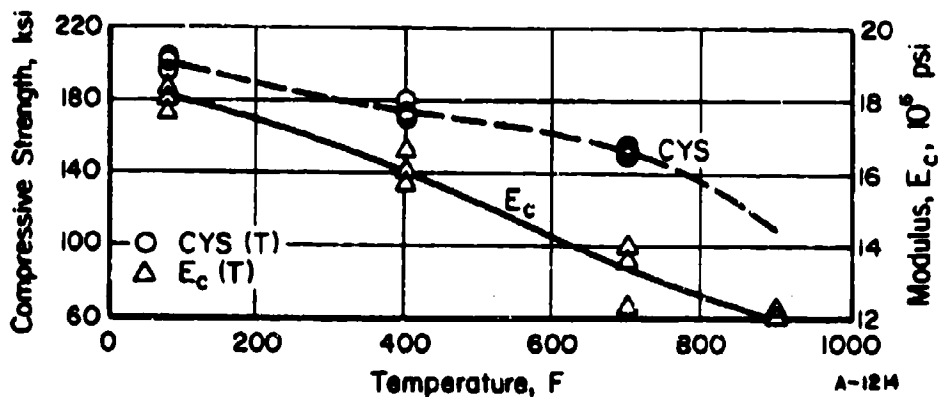


FIGURE 54. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS

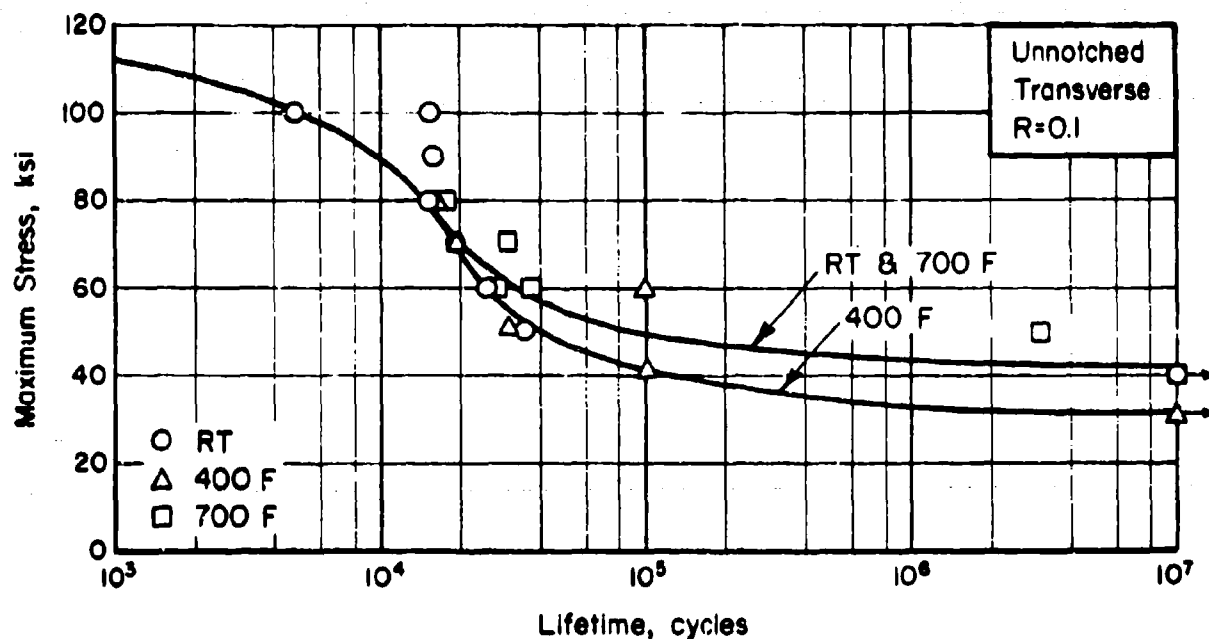


FIGURE 55. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SOLUTION-TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS (TRANSVERSE)

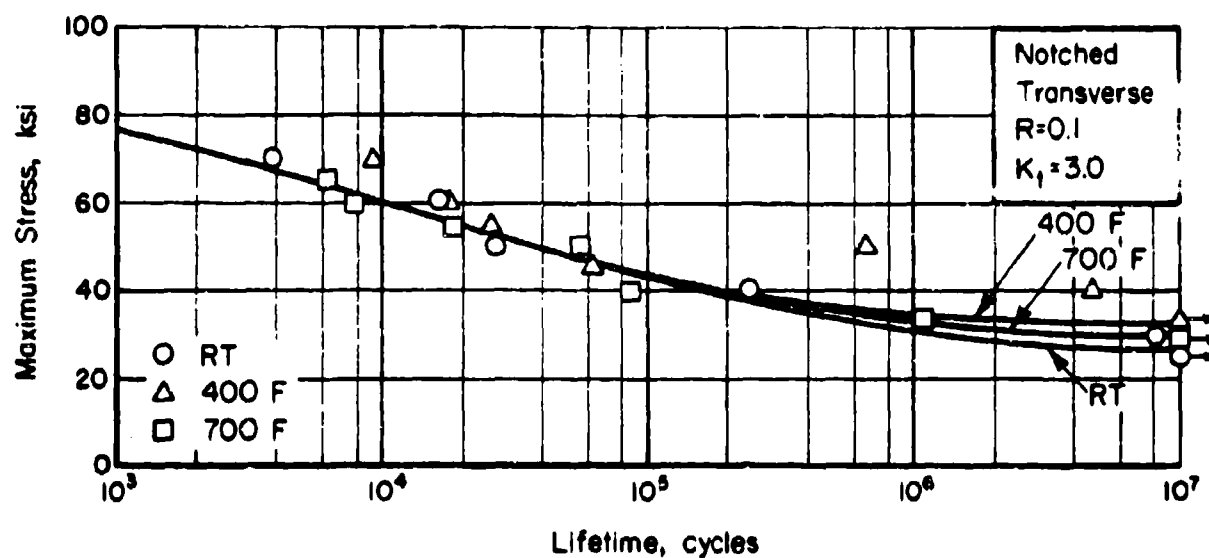


FIGURE 56. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED ($K_t = 3.0$) SOLUTION-TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS (TRANSVERSE)

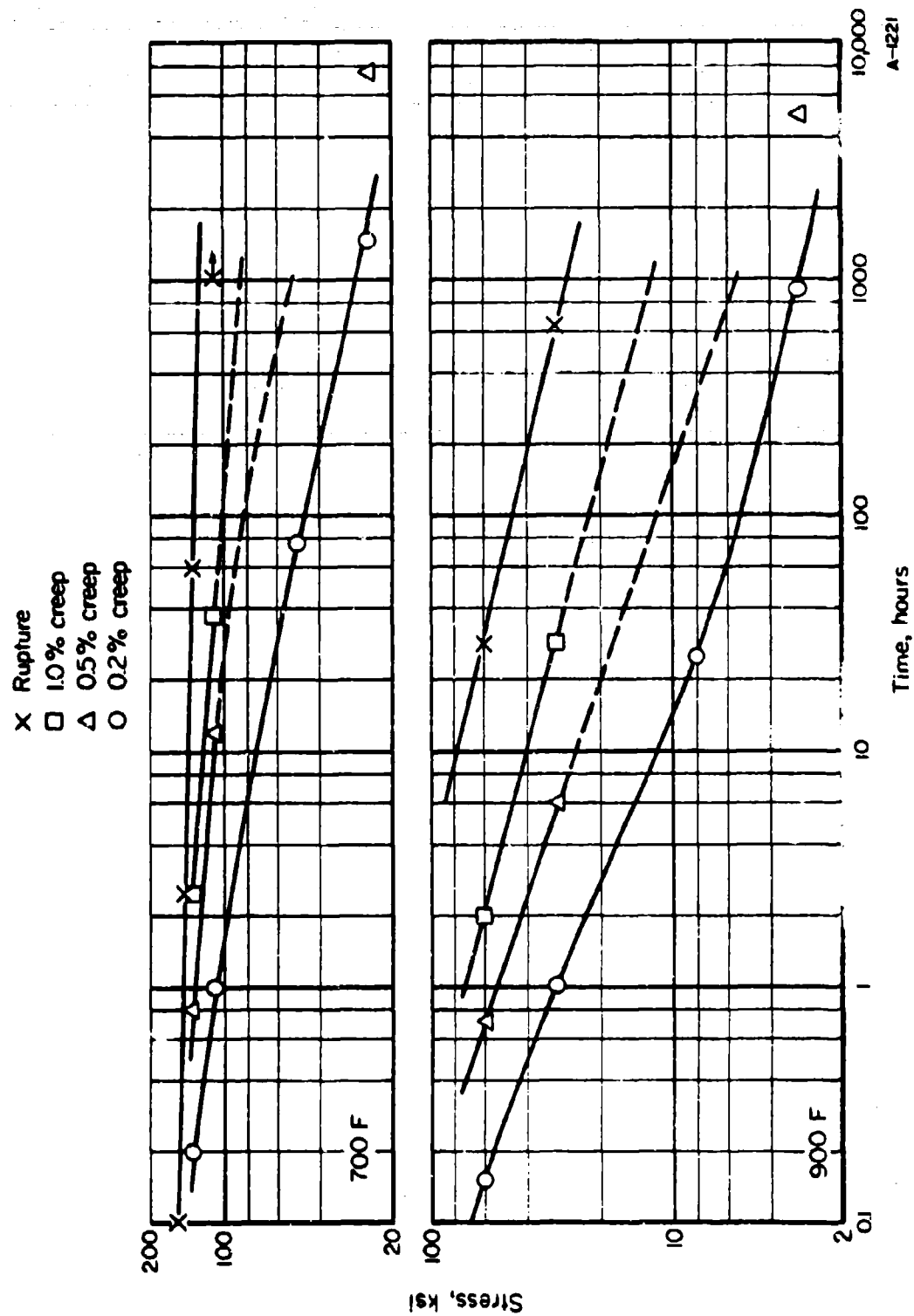


FIGURE 57. STRESS RUPTURE AND PLASTIC DEFORMATION CURVES FOR SOLUTION TREATED AND AGED Ti-6Al-6V-2Sn ISOTHERMAL DIE FORGINGS

DISCUSSION OF PROGRAM RESULTS

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 in a newer alloy is open to question. Many criteria, such as forming characteristics, weldability, oxidation resistance, etc., can be of particular importance so that strength properties may become secondary. However, since first comparisons are usually made on the basis of mechanical strength (tensile ultimate and tensile yield), the data generated on this program are compared to information for similar alloys. Figures 58 and 59 are effect-of-temperature curves concerned with these properties.

CONCLUSIONS

The objective of this program was the generation of useful engineering data for newly developed materials. During the contract term, the following materials were evaluated

- (1) X2048-T851 Plate
- (2) 7050-T73651 Plate
- (3) 21-6-9 Annealed Sheet
- (4) Ti-8Mo-8V-2Fe-3Al (STA) Sheet
- (5) Ti-6Al-2Zr-2Sn-2Mo-2Cr (STA) Plate
- (6) Ti-6Al-6V-2Sn STA Isothermal Die Forgings.

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

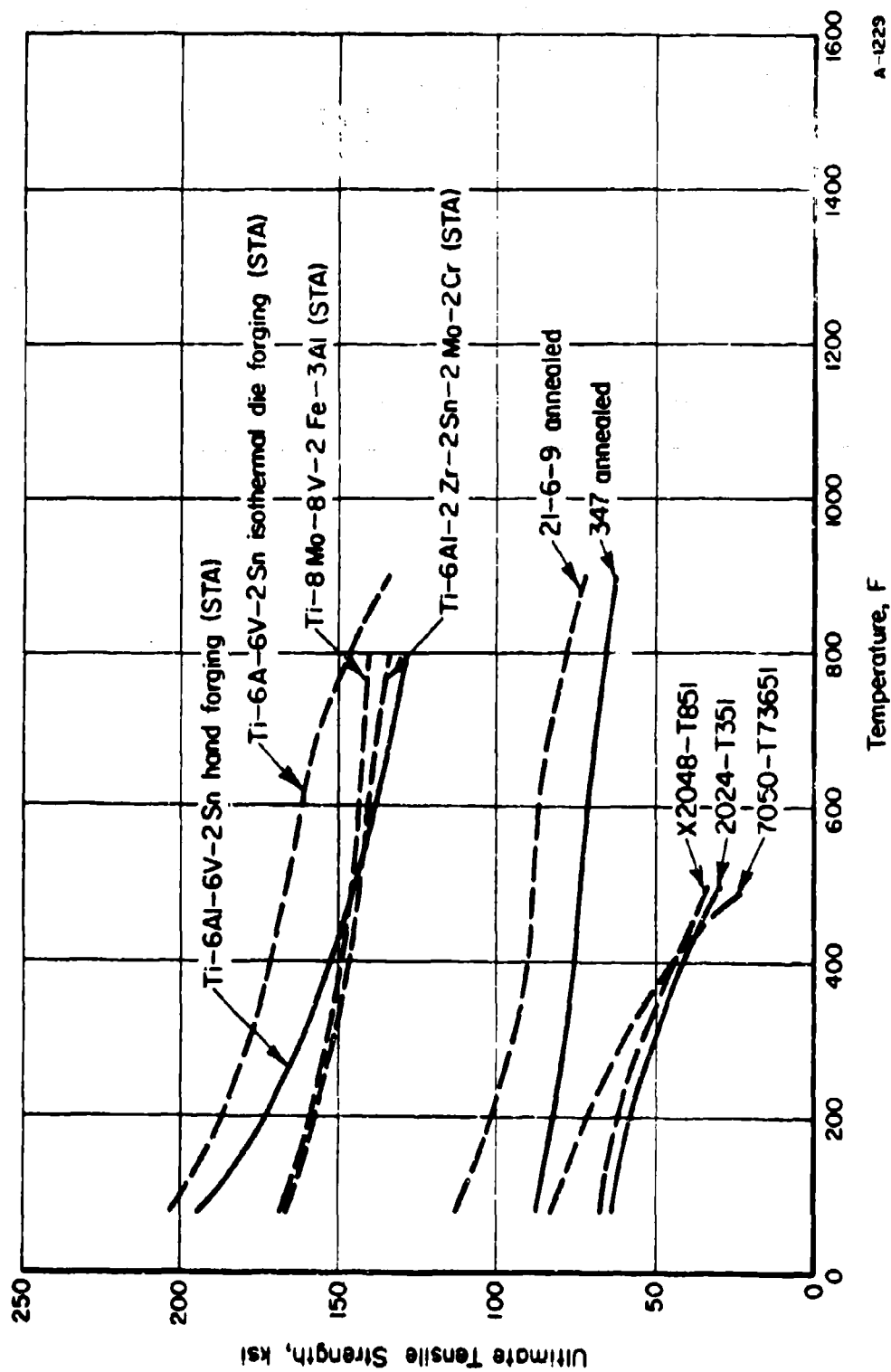
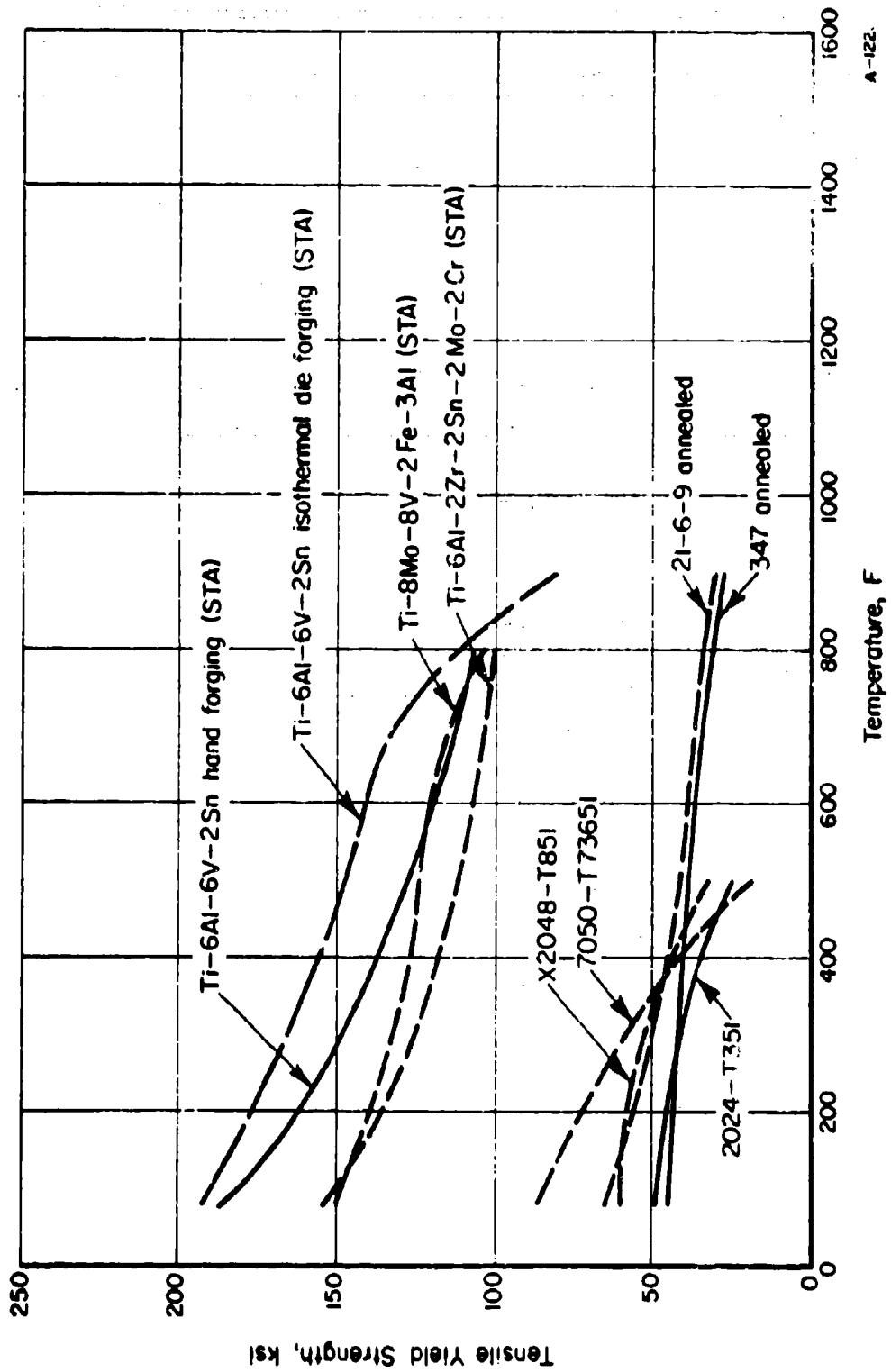


FIGURE 58. TENSILE ULTIMATE STRENGTH AS A FUNCTION OF TEMPERATURE

A-1229



A-122.

FIGURE 59. TENSILE YIELD STRENGTH AS A FUNCTION OF TEMPERATURE

APPENDIX I
EXPERIMENTAL PROCEDURE

APPENDIX I

EXPERIMENTAL PROCEDUREMechanical Properties

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

- (1) Tension
 - (a) Tensile ultimate strength, TUS
 - (b) Tensile yield strength, TYS
 - (c) Elongation, e_t
 - (d) Reduction in area, RA
 - (e) Modulus of elasticity, E_t .
- (2) Compression
 - (a) Compressive yield strength, CYS
 - (b) Modulus of elasticity, E_c .
- (3) Creep and stress-rupture
 - (a) Stress for 0.2 or 0.5 percent deformation in 100 hours and 1000 hours
 - (b) Stress for rupture in 100 hours and 1000 hours.
- (4) Shear
 - (a) Shear ultimate strength, SUS
- (5) Axial fatigue*
 - (a) Unnotched, $R = 0.1$, lifetime: 10^3 through 10^7 cycles

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

- (b) Notched ($K_t = 3.0$), $R = 0.1$, lifetime: 10^3 through 10^7 cycles.
- (6) Fracture toughness, K_{Ic} or K_c
- (7) Stress corrosion
 - (a) 80 percent TYS for 1000 hours maximum, 3-1/2 percent NaCl solution.
- (8) Thermal expansion.
- (9) Bend
 - (a) Minimum radius.
- (10) Impact
 - (a) Charpy V-notch.
- (11) Density.

Specimen Identification

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

<u>Assigned Number</u>	<u>Test Type</u>
1	Tension
2	Compression
3	Creep and stress-rupture
4	Shear
5	Fatigue
6	Fracture toughness

<u>Assigned Number</u>	<u>Test Type</u>
7	Stress corrosion
8	Thermal expansion
9	Bend
10	Impact
11	Density

As an example, a specimen numbered 2-T5 is a compression specimen, transverse orientation, cut from Location 5. Also, a specimen numbered 5-12 is a fatigue specimen cut from Location 12.

Test Description

Tension

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

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

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

An averaging-type linear differential transformer extensometer was used to measure strain. For elevated temperature testing, the extensometer was equipped with extensions to bring the transformer unit out of the furnace. The extensometer conformed to ASTM E3-64T Classification B1 having a sensitivity of 0.0001 inch/inch. The strain rate in the elastic region was maintained at 0.005 inch/inch/minute. After yielding occurred, the head speed was increased to 0.1 inch/inch/minute until fracture.

Compression

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

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

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

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

Shear

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

Bend

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

Creep and Stress Rupture

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

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

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

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

Stress Corrosion

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

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

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

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

where

y = deflection

σ = maximum fiber stress

l = distance between outer load points

a = distance between outer and inner load points

d = specimen thickness

E = modulus of specimen material.

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

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

Thermal Expansion

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

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

Fatigue

Fatigue tests were conducted using MTS electrohydraulic-servocontrolled testing machines. The frequency of cycling of these machines is variable to beyond 2,000 cpm depending on specimen rigidity. These machines operate with closed-loop deflection, strain or load control. Under load control used in this program, cyclic loads were automatically maintained (regardless of the required amount of ram travel) by means of load-cell feedback signals. The calibration and alignment of each machine are checked periodically. In each case, the dynamic load-control accuracy is better than ± 3 percent of the test load.

For elevated temperature studies, an induction heating coil controlled by a Lepel Induction Heater was used. A thermocouple placed on the center of the specimen controlled temperature to ± 5 degrees.

After machining and heat treating (when required), the edges of all sheet and plate specimens were polished according to Battelle-Columbus' standard practice prior to testing. The unnotched specimens were held against a rotating drum covered with emery paper and polished using a kerosene lubricant. Successively finer grits of emery paper were used, as required, to produce a surface

of about 10 RMS. Unnotched round specimens were polished in the Battelle-Columbus polishing apparatus. This machine utilizes a rotating belt sander driven rectilinearly along the specimen test section while the specimen is being rotated. The belt speed and specimen speed are adjusted so that polishing marks on the specimen are in the longitudinal direction. The surface finish is about the same as that on the flat specimens. The notched flat specimens were held in a fixture and polished with a slurry of oil and alundum grit applied liberally to a rotating wire. Notched round specimens are polished in the same manner, except that the specimen is rotated.

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

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

Fracture Toughness

Two types of fracture toughness tests were used. For heavy section materials, the chevron-notched, slow bend test specimen of ASTM Method E-399-72 was selected. For thinner section sheet materials, center through-cracked tension panels were used as test specimens. All specimens were precracked in fatigue and subsequently fractured in a servocontrolled electrohydraulic testing system of appropriate load capacity.

The slow-bend type specimens were precracked and tested under 3-point loading. The pop-in load for materials susceptible to brittle fracture was determined from the load-compliance curve. When pop-in was not detectable, the curves were analyzed using the 5 percent secant offset method of the ASTM procedure.

The thin sheet center through-crack tension panels were initially saw-cut and then precracked in constant amplitude fatigue loading. In order to maintain a flat fatigue crack and not plastically strain the uncracked section, the maximum stresses were adjusted to keep the applied stress-intensity factor less than one-third or one-quarter of that anticipated at fracture. This usually involved stepping down the stresses as the cracking proceeded. The crack was extended to approximately one-quarter of the panel width. Buckling guides were attached and a clip-type compliance gage was mounted in the central notch. The panels were fractured in a rising load test at a stress rate in the range

$$.002 E < \dot{S} < .005 E \text{ ksi/min} ,$$

which corresponds nominally to the gross strain rate of standard tensile testing.

APPENDIX II
SPECIMEN DRAWINGS

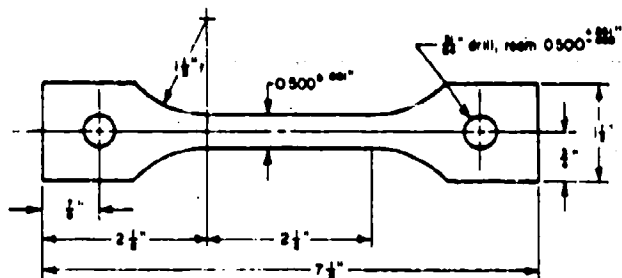


FIGURE 60. SHEET AND THIN-PLATE TENSILE SPECIMEN

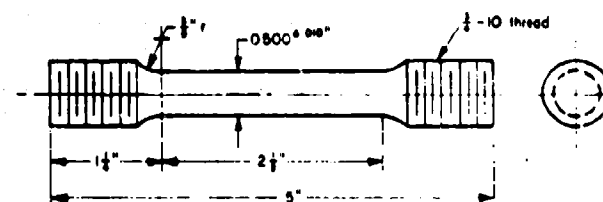
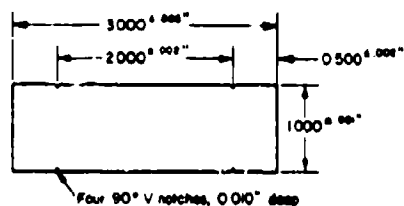
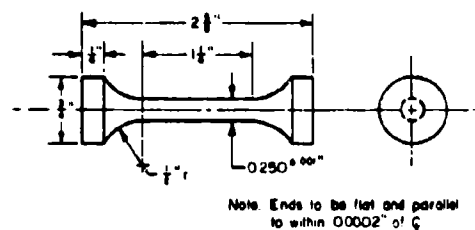


FIGURE 61. ROUND TENSILE SPECIMEN



- Notes: 1. Ends must be flat and parallel to within 0.0002 inches.
2. Surface must be free from nicks and scratches.

FIGURE 62. SHEET COMPRESSION SPECIMEN



Note: Ends to be flat and parallel to within 0.0002 inches of center.

FIGURE 63. ROUND COMPRESSION SPECIMEN

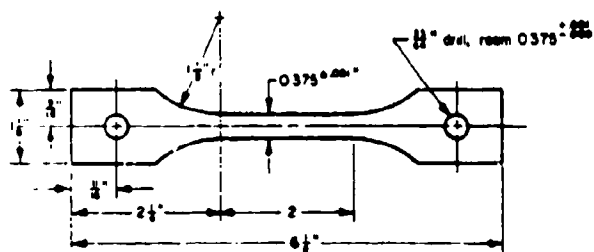
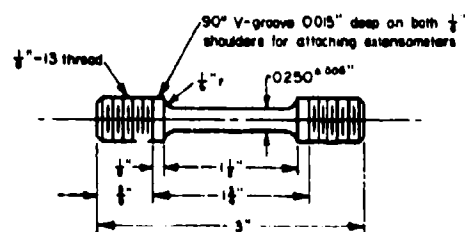


FIGURE 64. SHEET CREEP - AND STRESS-RUPTURE SPECIMEN



A-1363

FIGURE 65. ROUND CREEP - AND STRESS-RUPTURE SPECIMEN

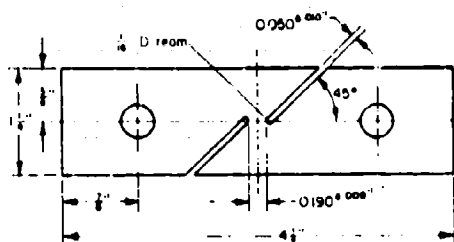


FIGURE 66. SHEET SHEAR TEST SPECIMEN

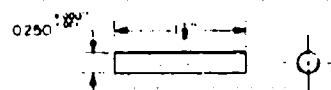


FIGURE 67. PIN SHEAR SPECIMEN

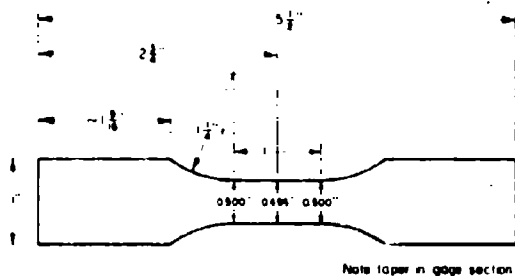


FIGURE 68. UNNOTCHED SHEET FATIGUE SPECIMEN

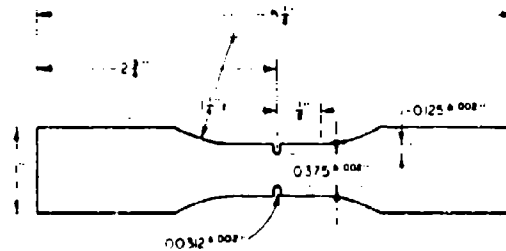


FIGURE 69. NOTCHED SHEET FATIGUE SPECIMEN

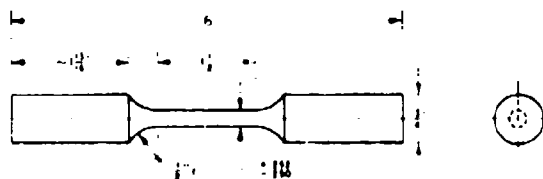


FIGURE 70. UNNOTCHED ROUND FATIGUE SPECIMEN

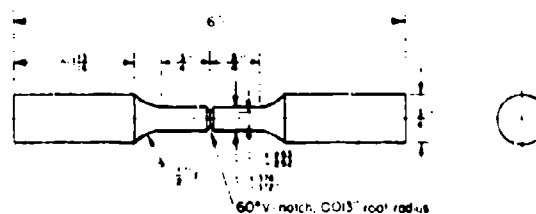


FIGURE 71. NOTCHED ROUND FATIGUE SPECIMEN

A-1226

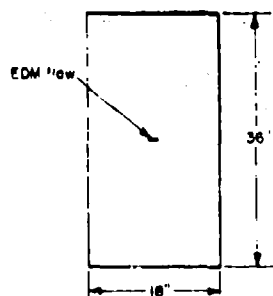


FIGURE 72. SHEET FRACTURE TOUGHNESS SPECIMEN

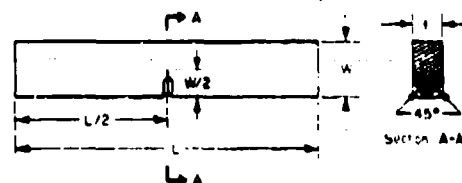


FIGURE 73. SLOW BEND FRACTURE TOUGHNESS SPECIMEN

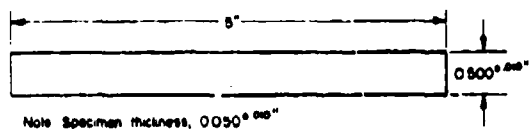


FIGURE 74. STRESS-CORROSION SPECIMEN

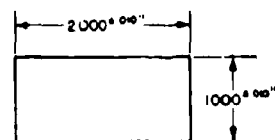


FIGURE 75. THERMAL-EXPANSION SPECIMEN

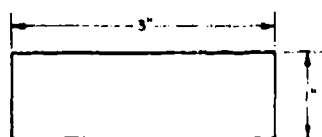


FIGURE 76. SHEET BEND SPECIMEN

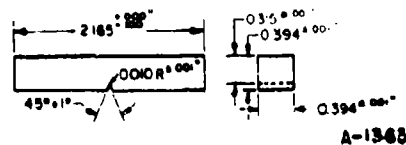


FIGURE 77. NOTCHED IMPACT SPECIMEN

APPENDIX III

DATA SHEETS

X2048-TB51 Aluminum Alloy

Material Description

Alloy X2048-TB51 is a recent development of the Reynolds Metals Company. The development aim was a thick section alloy with high toughness and stability at moderate temperatures. The goal was to achieve the strength, fatigue resistance, corrosion resistance, and thermal stability of 2024-TB51 or 2124-TB51 and the toughness of 2219.

The material used for this evaluation was 3-inch plate produced within the following composition limits:

Copper	2.8 to 3.8
Manganese	0.20 to 0.60
Magnesium	1.2 to 1.6
Zinc	0.25 max
Titanium	0.10 max
Silicon	0.15 max
Iron	0.20 max
Others total	0.15 max
Aluminum	Balance

Processing and Heat Treating

The specimens were tested in the as-received -TB51 temper.

X2048-TB51 Aluminum Alloy Data (a)

Thickness: 3-inch plate

Properties	Temperature, F		
	RT	250	500
Tension			
TTS (longitudinal), ksi	66.3	60.1	51.4
TTS (transverse), ksi	67.4	60.0	50.3
TUS (short transverse), ksi	67.1	U	U
TYS (longitudinal), ksi	60.4	56.8	49.1
TYS (transverse), ksi	60.9	56.3	48.8
ITS (short transverse), ksi	58.9	U	U
e (longitudinal), percent in 2 in.	8.3	12.7	14.2
e (transverse), percent in 2 in.	7.2	12.7	16.5
e (short transverse), percent in 2 in.	6.3	U	U
MA (longitudinal), percent	15.7	31.6	37.3
RA (transverse), percent	11.7	27.7	34.2
RA (short transverse), percent	9.4	U	U
E (longitudinal), 10 ⁶ psi	10.2	9.9	9.3
E (transverse), 10 ⁶ psi	10.5	9.8	9.3
E (short transverse), 10 ⁶ psi	11.1	U	U
Compression			
CYS (longitudinal), ksi	60.9	56.7	50.6
CYS (transverse), ksi	60.6	56.0	51.1
E _c (longitudinal), 10 ⁶ psi	11.3	10.2	9.6
E _c (transverse), 10 ⁶ psi	11.1	10.3	9.7
Shear (b)			
SUS (longitudinal), ksi	39.3	(c)	U
SUS (transverse), ksi	39.2	U	U
Impact (d)			
V-notch Charpy, ft. lb. (longitudinal)	7.6	U	U
(transverse)	4.5	U	U
Fracture Toughness (e)			
K _{IC} , crack direction II, ksi √in.	32.0	U	U
K _{IC} , crack direction I, ksi √in.	29.1	U	U

X2048-T851 Aluminum Alloy
(continued)

Properties	Temperature, F			
	RT	250	350	500
Axial Fatigue (longitudinal) (1)				
Unnotched, R = 0.1				
10 ⁷ cycles, ksi	63	63	63	U
10 ⁶ cycles, ksi	38	37	35	U
10 ⁵ cycles, ksi	32	28	25	U
Notched, K _t = 3.0, R = 0.1				
10 ⁷ cycles, ksi	54	54	50	U
10 ⁶ cycles, ksi	22	21	19	U
10 ⁵ cycles, ksi	16	14	12	U
(Creep longitudinal)				
0.2% plastic deformation, 100 hr, ksi	NA (c)	44	35	8.5
0.2% plastic deformation, 1000 hr, ksi	NA	41	19	4.5
Stress-Rupture (longitudinal)				
Rupture, 100 hr, ksi	NA	50	39	13
Rupture, 1000 hr, ksi	NA	47	32	8.5
Stress Corrosion (g)				
80% IVS, 1000 hr maximum	no cracks			
Coefficient of Thermal Expansion	U			
Density	.0994 lb/in 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; average of 4 tests in each direction.

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

(d) Values are average of 6 tests in each direction.

(e) Values are average of 6 slow-bend type tests in each direction. Specimen size was 1.000-inch thick by 2.000 inches wide with a span of 8 inches. (Higher K_{tc} values may be achieved with larger specimens. Reference J. G. Kaufman, "Notes for E-24-01 Meeting", held at Battelle's Columbus Laboratories on October 4, 1972.

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

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

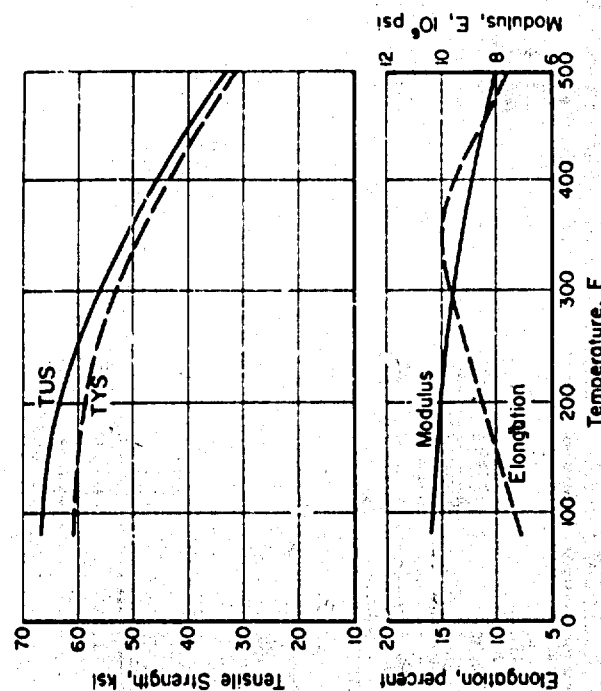


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF X2048-T851 PLATE

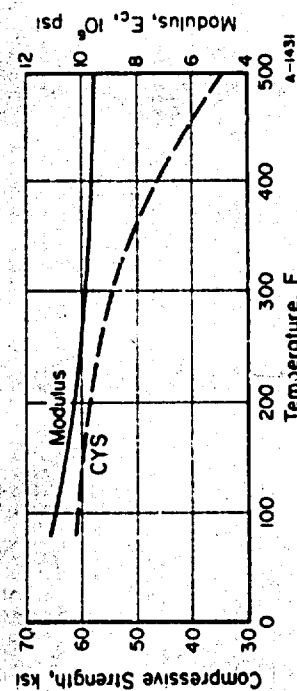


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF X2048-T851 PLATE

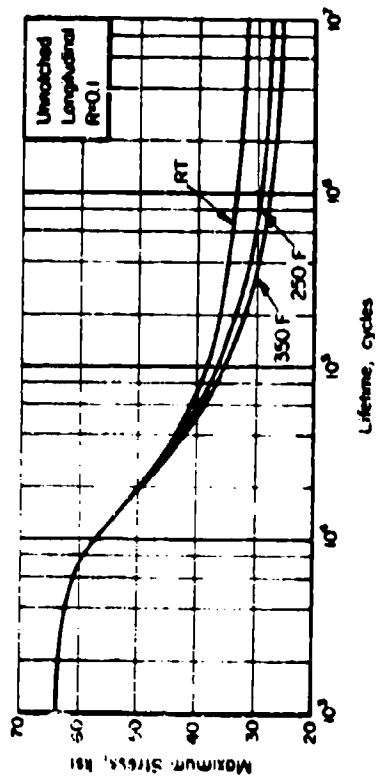


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED K2048-T851 PLATE

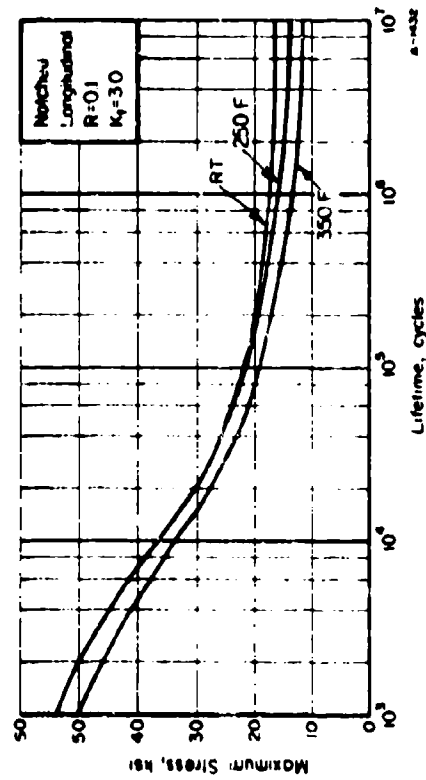


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED ($K_t = 3.0$) K2048-T851 PLATE

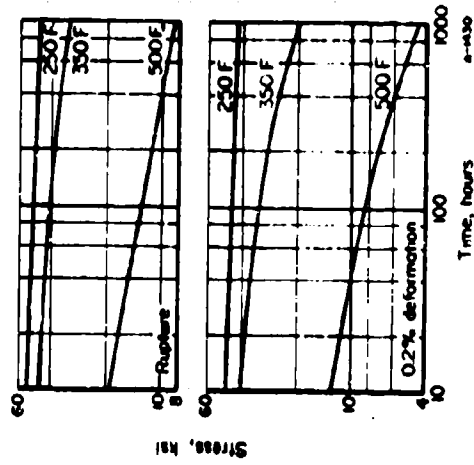


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR K2048-T851 PLATE (LONGITUDINAL)

7050-T73651 Aluminum Alloy Data (a)

7050-T73651 Aluminum Alloy

Material Description

Alloy 7050 is an Al-Zn-Mg-Cu alloy developed by the Alcoa Research Laboratories supported by the Naval Air Systems Command and the Air Force Materials Laboratory. When heat treated and aged to the T73 temper, thick 7050 plate and hand forgings exhibit strengths equal to or exceeding those of 7079-T6XN products combined with improved fracture toughness and high resistance to exfoliation and stress-corrosion cracking. The alloy differs from conventional 70XX series aluminum alloys in that zirconium is added and chromium and barium are restricted in order to minimize quench sensitivity.

The material used in this evaluation was 1-inch plate from Heat S-16420 produced within the following composition limits:

Copper	2.0 to 2.8
Iron	0.15 max
Silicon	0.12 max
Manganese	0.10 max
Magnesium	1.9 to 2.6
Zinc	5.7 to 6.7
Chromium	0.05 max
Titanium	0.06 max
Aluminum	Balance

Processing and Heat Treatment

Specimens were tested in the as-received T73651 temper.

Thickness: 1-inch plate

Properties	Temperature, F		
	RT	250	350
Tension			
T _{US} (longitudinal), ksi	82.6	65.0	53.7
T _{US} (transverse), ksi	81.5	64.5	53.5
T _{YS} (longitudinal), ksi	73.8	64.9	53.5
T _{YS} (transverse), ksi	72.5	64.1	53.3
E (longitudinal), percent in 2 in.	11.7	13.5	16.8
E (transverse), percent in 2 in.	10.5	13.3	14.7
RA (longitudinal), percent	30.2	48.1	58.1
RA (transverse), percent	34.5	48.7	47.8
F _U (longitudinal), 10 ³ psi	10.3	9.4	8.7
F _U (transverse), 10 ³ psi	11.5	9.7	8.7
Compression			
CYS (longitudinal), ksi	73.0	64.3	53.7
CYS (transverse), ksi	75.3	66.1	55.1
F _c (longitudinal), 10 ³ psi	10.8	9.5	8.1
F _c (transverse), 10 ³ psi	11.0	10.0	9.4
Shear (b)			
S _{US} (longitudinal), ksi	48.7	47.9	47.9
S _{US} (transverse), ksi	47.9	47.9	47.9
Impact (d)			
V-notch Charpy, ft.-lb. (longitudinal)	34.7	34.7	34.7
(transverse)	5.7	5.7	5.7
Fracture Toughness (e)			
K _{IC} L-T, ksi in.	27.7	27.7	27.7
K _{IC} T-L, ksi in.	30.9	30.9	30.9
Axial Fatigue (transverse) (f)			
Unnotched, R = 0.1	60	60	56
10 ⁷ cycles, ksi	42	42	42
10 ⁶ cycles, ksi	31	31	31
10 ⁵ cycles, ksi	20	20	20
Notched, K _t = 3.0, R = 0.1	43	43	43
10 ⁷ cycles, ksi	19	19	19
10 ⁶ cycles, ksi	12	12	12
10 ⁵ cycles, ksi	10	10	10

7050-T 16S1 Aluminum Alloy Data
(continued)

Properties	Temperature, F			
	RT	250	350	500
<u>Creep (transverse)</u>				
0.2% plastic deformation, 100 hr, ksi	NA (c)	49	21	5
0.2% plastic deformation, 1000 hr, ksi	NA	35	13.5	3.5
<u>Stress-Rupture (transverse)</u>				
Rupture, 100 hr, ksi	NA	53	26	7.5
Rupture, 1000 hr, ksi	NA	47	17	4.5
<u>Stress Corrosion (a)</u>				
80% TVS, 1000 hr maximum	no cracks			
<u>Coefficient of Thermal Expansion</u>				
12.6 x 10 ⁻⁶ in/in/F (68 to 212 F)				
<u>Density</u>				
0.102 lb/in 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; average of 4 tests in each direction.

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

(d) Average of 6 tests in each direction.

(e) Values are average of 6 six-head type tests in each direction. Specimen size was 1.000-inch thick by 2.000 inches wide with a span of 8 inches.

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

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

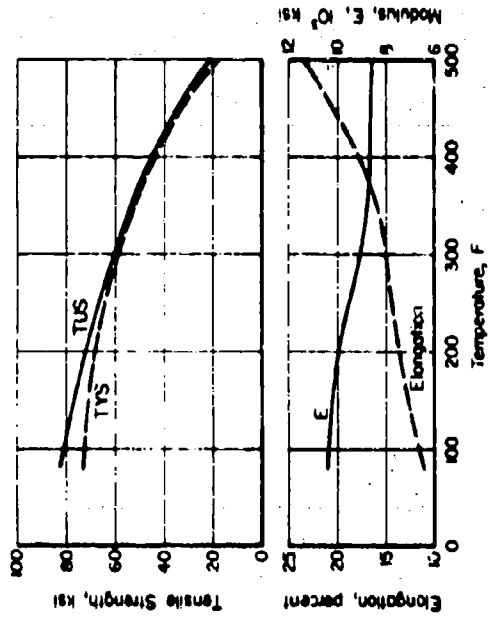


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF 7050-T16S1 ALUMINUM ALLOY PLATE

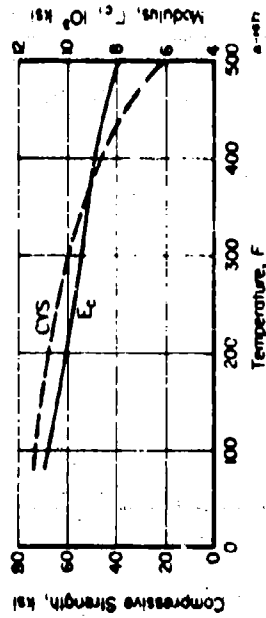


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF 7050-T16S1 ALUMINUM ALLOY PLATE

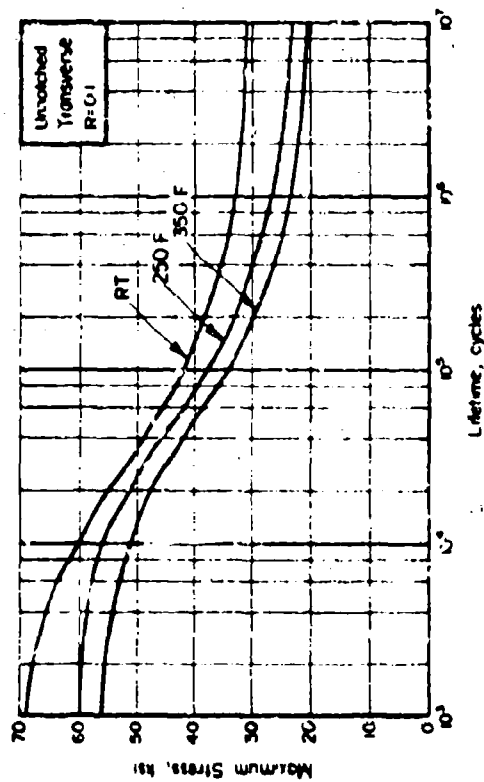


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED 7050-T73551 ALUMINUM PLATE (TRANSVERSE)

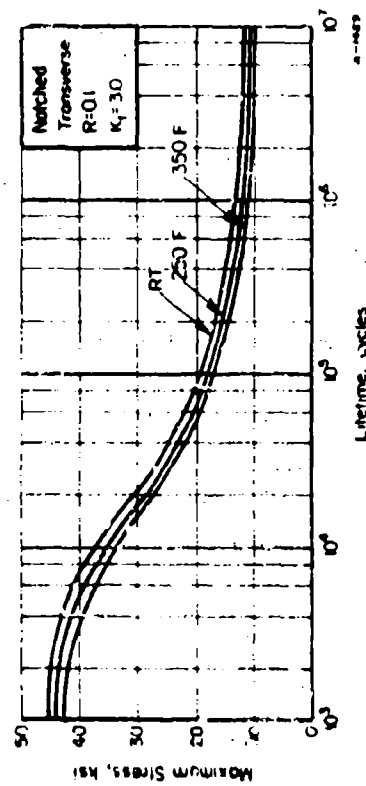


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED 7050-T73551 ALUMINUM PLATE (TRANSVERSE)

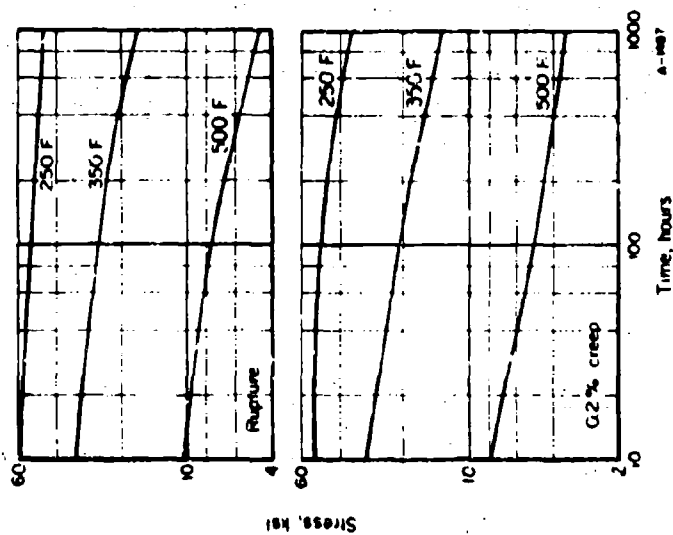


FIGURE 5. STRESS-RUPTURE AND PLASTIC DEFORMATION CURVES FOR 7050-T73551 ALUMINUM ALLOY PLATE (TRANSVERSE)

21-6-9 Stainless Steel Alloy

21-6-9 Stainless Steel Data (a)

Material Description

Alloy 21-6-9 is a recent development of the Armco Steel Corporation. It is an austenitic stainless steel, combining high yield strength with good corrosion resistance. The room temperature yield strength of 21-6-9 is superior to Types 304, 321, and 347. It has good elevated temperature properties and retains high strength and toughness at subzero temperatures.

Armco 21-6-9 stainless steel is available in standard finishes in annealed or high tensile temper sheet and strip as well as in bar, wire, forging billets, and plate.

The material used in this evaluation was an 0.072-inch thick sheet produced within the following composition limits:

Carbon	0.08 max
Manganese	9.00 - 10.00
Phosphorus	0.060 max
Sulfur	0.030 max
Silicon	1.00 max
Chromium	19.00 - 21.50
Nickel	5.50 - 7.50
Molybdenum	0.15 - 0.40
Balance	

Processing and Heat Treating

The alloy was evaluated in the as-received annealed condition.

Condition: Annealed
Thickness: 0.072-inch sheet

Properties	Temperature, F		
	RT	400	700
Tension			
TUS (longitudinal), ksi	113.0	88.1	83.7
TUS (transverse), ksi	113.3	88.4	83.2
TUS (longitudinal), ksi	94.8	72.5	69.9
TUS (transverse), ksi	65.7	52.7	50.4
E (longitudinal), percent in 2 in.	55.0	51.5	49.9
E (transverse), percent in 2 in.	50.0	47.0	45.3
E (longitudinal), 10 ⁶ psi	26.6	21.1	21.7
E (transverse), 10 ⁶ psi	28.4	19.9	18.4
Compression			
CUS (longitudinal), ksi	67.2	45.1	40.5
CUS (transverse), ksi	66.5	46.3	37.9
E _c (longitudinal), 10 ⁶ psi	28.5	26.7	25.8
E _c (transverse), 10 ⁶ psi	29.0	28.8	26.5
Shear (b)			
SUS (longitudinal), ksi	102.1	(c)	(c)
SUS (transverse), ksi	102.8	(c)	(c)
Bend (d)			
Minimum Radius	11	(c)	(c)
Fracture Toughness			
K _{IC} , T-L, ksi/in.	(e)	(c)	(c)
Axial Fatigue (transverse) (f)			
Unnotched, R = 0.1	106	90	80
10 ⁷ cycles, ksi	92	82	74
10 ⁶ cycles, ksi	86	75	68

21-6-9 Stainless Steel Data (continued)

Properties	Temperature, F			
	RT	400	700	900
<u>Asial Fatigue (transverse) (continued)</u>				
Notched, $K_t = 3.0$, $R = 0.1$				
10 ⁶ cycles, ksi	80	75	75	7
10 ⁷ cycles, ksi	61	42	42	7
10 ⁸ cycles, ksi	60	36	36	7
<u>Creep (transverse)</u>				
0.2% plastic deformation, 100 hr, ksi	NA (C)	40	33	31
0.2% plastic deformation, 1000 hr, ksi	NA	35	32	30
<u>Stress Rupture (transverse)</u>				
Rupture, 100 hr, ksi	NA	65	63	72
Rupture, 1000 hr, ksi	NA	82	82	61
<u>Stress Corrosion (C)</u>				
80 TYS, 1000 hr max/min	no cracks			
<u>Coefficient of Thermal Expansion</u>				
10.9 x 10 ⁻⁶ in/in/F (18-170 F)				

Density

7.283 lb./in.³

- 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.
- Sheet-shear type specimen; average of 4 tests in each direction.
- 1, unavailable; NA, not applicable.
- Specimens tested from RT to 900 F. No cracks.
- Transverse specimens were full sheet thickness by 15 inches wide by 36 inches long with an EPR film in the center. The net section yield strength was greater than the tensile yield strength of the material; therefore, the values obtained are considered not valid.
- σ_R represents the algebraic ratio of minimum stress to maximum stress in one cycle that is $R = \sigma_{min}/\sigma_{max}$. σ_{max} represents the Neuber-Petersen theoretical stress concentration factor.
- Rare-temperature intermediate beam test. Alternate immersion in 3-1/2% NaCl.

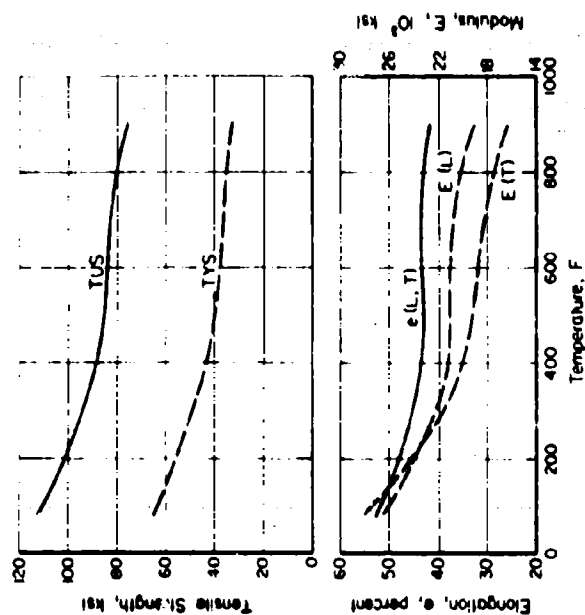


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF ANNEALED 21-6-9 STAINLESS STEEL SHEET

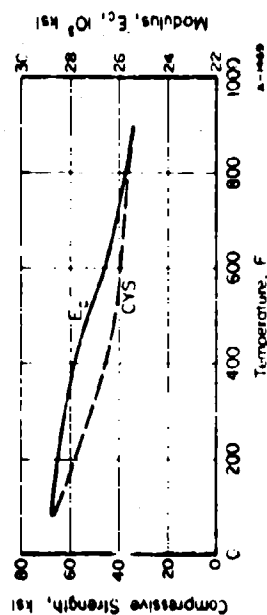


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF ANNEALED 21-6-9 STAINLESS STEEL SHEET

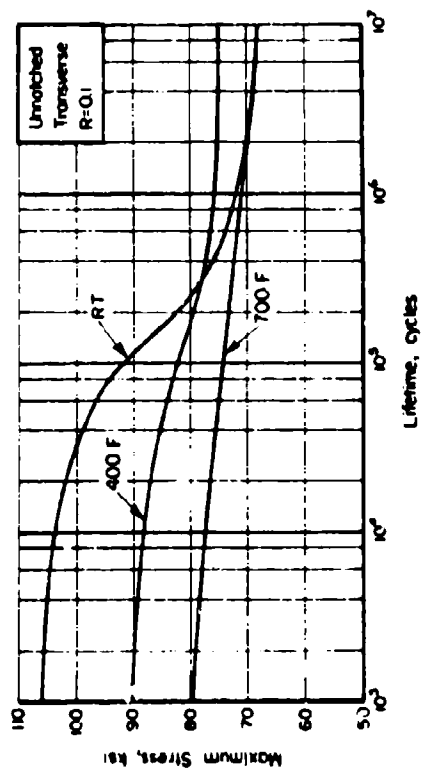


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED ANNEALED 21-6-9 STAINLESS STEEL SHEET

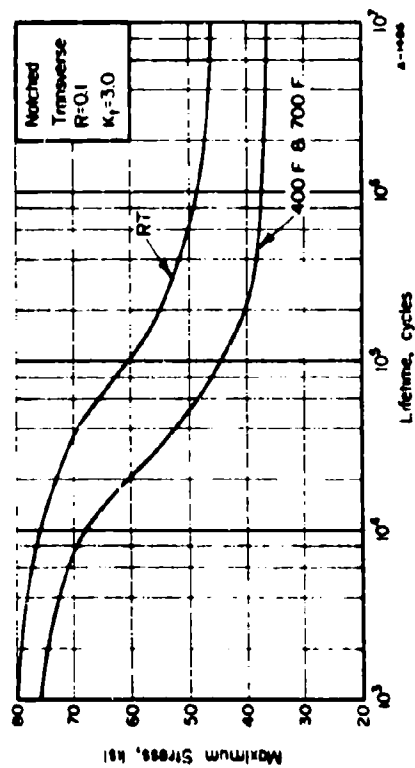


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED ($K_t = 3.0$) ANNEALED 21-6-9 STAINLESS STEEL SHEET

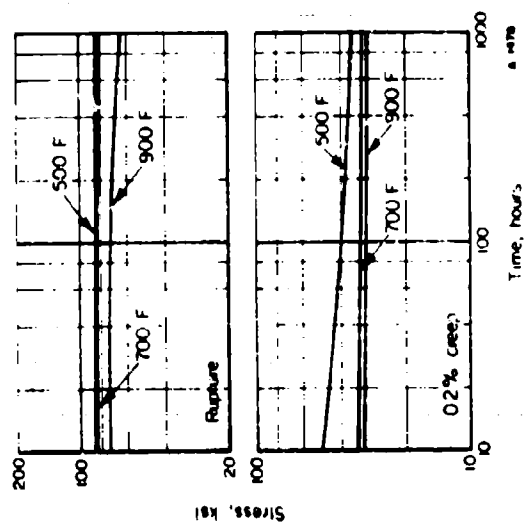


FIGURE 5. STRAIN-RATE AND PLASTIC DEFORMATION CYCLES FOR ANNEALED 21-6-9 STAINLESS STEEL SHEET

II-890-8V-2Fe-3Al Alloy

Material Description

The 890-8V-2Fe-3Al beta titanium alloy is a recent development of TIMET. The alloy was selected for full-scale evaluation after confirming (by TIMET) that it could be melted by the conventional consumable electrode vacuum arc process. It shows producibility and property characteristics that make it suitable for a variety of airframe applications. A variety of heat treatments are available to allow the designer to take advantage of its individual properties or its generally good overall properties. Its short aging times and low density make it particularly desirable for some applications.

The material used in this evaluation was from TIMET Heat K-5055 and was analyzed as follows:

Vanadium	8.0
Iron	8.2
Aluminum	2.0
Oxygen	3.0
Nitrogen	0.14
Titanium	0.011
Balance	

Processing and Heat Treating

The material was received in the solution treated condition. Specimens were aged at 900 F for 6 hours. This condition is called the high strength, fully-aged condition.

II-890-8V-2Fe-3Al Alloy Data (a)

Condition: Solution treated and aged 900 F
Thickness: 0.040-inch sheet

Properties	Test, Temperature, F		
	RY	490	800
Tension			
TUS (longitudinal), ksi	160.3	148.7	137.7
TUS (transverse), ksi	172.7	155.3	141.0
TYS (longitudinal), ksi	144.7	123.3	105.7
TYS (transverse), ksi	158.0	133.3	111.7
ϵ (longitudinal), percent in 2 in.	11.2	9.0	7.3
ϵ (transverse), percent in 2 in.	9.5	6.8	6.2
E (longitudinal), 10 ⁵ psi	13.6	13.3	11.8
E (transverse), 10 ⁵ psi	14.9	14.1	12.3
Compression			
CYS (longitudinal), ksi	177.7	140.7	138.7
CYS (transverse), ksi	191.7	163.7	138.7
E_c (longitudinal), 10 ⁵ psi	15.9	14.5	12.7
E_c (transverse), 10 ⁵ psi	16.9	15.1	13.5
Shear (b)			
SUS (longitudinal), ksi	170.5	(c)	U
SUS (transverse), ksi	174.6	U	U
Fracture Toughness (d)			
K_{Ic} , T-L, ksi/Tn.	44	U	U
Axial Fatigue (Transverse) (e)			
Unnotched, R = 0.1			
10 ⁶ cycles, ksi	118	108	100
10 ⁷ cycles, ksi	74	74	67
10 ⁸ cycles, ksi	63	63	60
Notched, R = 3.0, R = 0.1			
10 ⁶ cycles, ksi	104	109	98
10 ⁷ cycles, ksi	30	31	26
10 ⁸ cycles, ksi	22	22	20

11-870-88-2 (Fe-Al) Alloy Data
(continued)

Properties	Temperature, F			
	97	550	700	900
Creep (Transverse)				
0.2% plastic deformation, 100 hr, ksi	NA	70	27	7
0.2% plastic deformation, 1000 hr, ksi	NA	40	20	3
Stress Rupture (Transverse)				
Rupture 100 hr, ksi	NA	149	144	43
Rupture 1000 hr, ksi	NA	147	100	26
Stress Corrosion (f)				
60 TYS, 1000 hr maximum	no cracks			

Coefficient of Thermal Expansion

5.0×10^{-6} in./in./F (RT to 800 F)

Density

0.175 in/in.

- (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) Sheet-shear type specimen; average of 5 tests in each direction.
- (c) U, unavailable; NA, not applicable.
- (d) Transverse specimens were full sheet thickness by 18 inches wide by 36 inches long with an EDM flaw in the center.
- (e) "m" represents the algebraic ratio of minimum stress to maximum stress in one cycle; that is $R = S_{min}/S_{max}$. "n" represents the Neuber-Peterson theoretical stress concentration factor.
- (f) Room-temperature three-point bend test. Alternate immersion in 3-1/2% NaCl.

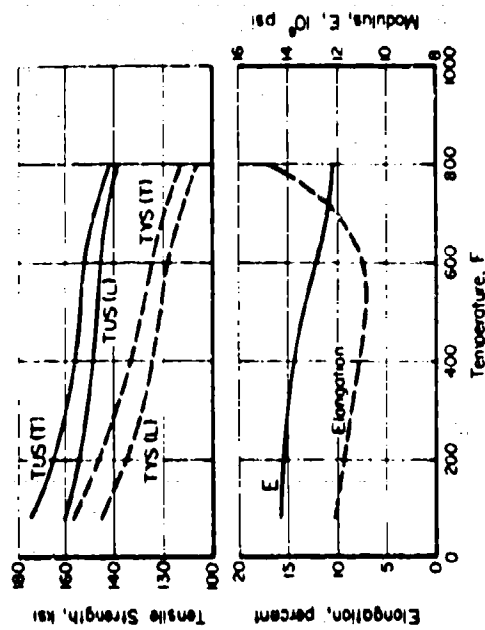


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED 11-870-88-2(Fe-Al) ALLOY SHEET

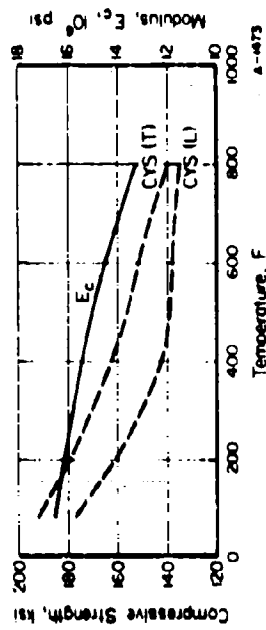


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION TREATED AND AGED 11-870-88-2(Fe-Al) ALLOY SHEET

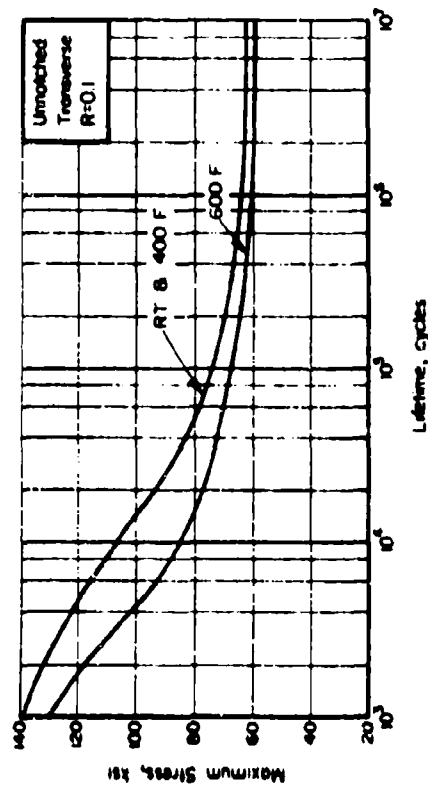


FIGURE 3. AXIAL LOAD FATIGUE BEHAVIOR OF UNNOTCHED SOLUTION TREATED AND AGED Ti-8Nb-8V-2Fe-3Al ALLOY SHEET

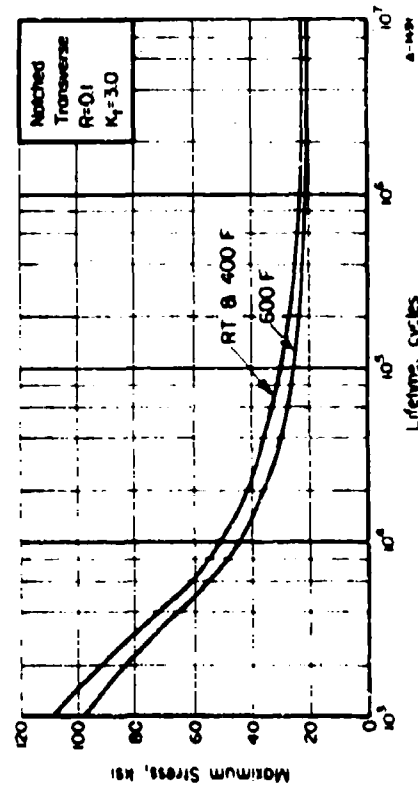


FIGURE 4. AXIAL LOAD FATIGUE BEHAVIOR OF NOTCHED SOLUTION TREATED AND AGED Ti-8Nb-8V-2Fe-3Al ALLOY SHEET

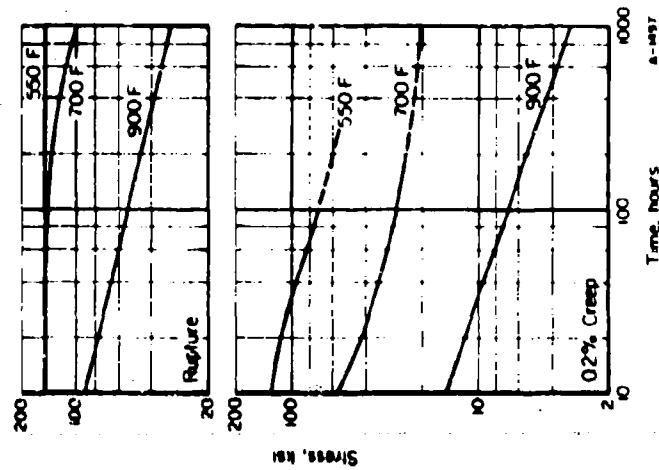


FIGURE 5. STRESS-PLASTICITY AND PLASTICITY DEFINING CURVES FOR SOLUTION TREATED AND AGED Ti-8Nb-8V-2Fe-3Al ALLOY

Ti-6Al-2Zr-2Sn-2Mo-2Cr Alloy

Ti-6Al-2Zr-2Sn-2Mo-2Cr Alloy DATA (a)

Condition: solution treated and aged
Thickness: 1 1/2 inch plate

Material Description

This alloy is a recent development of RMI Company. It is an alpha-beta type alloy designed for deep hardenability. Preliminary information shows the material to have low density, high modulus, high toughness, and good producibility. Strength retention to 800 F is good.

The material used for this evaluation was a 1 1/2-inch thick plate from RMI ingot number 890189 which had the following chemistry:

Al	5.8
Sn	2.1
Zr	1.8
Mo	2.0
Cr	1.9
Si	0.21
Fe	0.06
C	0.02
N ₂	0.010
O ₂	0.012

Additional information on this alloy is available on work performed by RMI Company under Wright Field Air Force Contract F33615-72-C-11152.

Processing and Heat Treating

The plate product evaluated was alpha beta processed to develop a refined microstructure. The plate was received in the solution-treated condition (1740 F, 1 hour, Air Cooled) condition. Specimens were then aged at 1000 F for 8 hours. It should be noted that heavier sections require oil or water quench to effectively solution treat the product.

Properties	Temperature, F	
	RT	610
Tension		
TUS (longitudinal), ksi	168.3	132.0
TUS (transverse), ksi	168.7	132.0
TYS (longitudinal), ksi	155.5	101.2
TYS (transverse), ksi	156.5	101.2
e (longitudinal), percent in 1 in.	18.0	21.3
e (transverse), percent in 1 in.	17.7	21.0
RA (longitudinal), percent	24.8	34.9
RA (transverse), percent	26.2	33.3
E (longitudinal), 10 ⁵ psi	17.9	15.6
E (transverse), 10 ⁵ psi	17.8	16.0
Compression		
CYS (longitudinal), ksi	169.7	128.1
CYS (transverse), ksi	173.3	129.3
E _c (longitudinal), 10 ⁵ psi	18.1	16.7
E _c (transverse), 10 ⁵ psi	18.5	16.3
Shear (b)		
SUS (longitudinal), ksi	108.3	(c)
SUS (transverse), ksi	106.0	(c)
Impact (d)		
V-notch Charpy, Ft. lb. (longitudinal)	13.9	(c)
(transverse)	15.3	(c)
Fracture Toughness (e)		
K _{IC} , ksi in.	85.0	(c)
K _{IC} , T-I, ksi in.	93.0	(c)
Axial Fatigue (transverse) (f)		
Unnotched, R=0.1		
10 ⁶ cycles, ksi	155	134
10 ⁷ cycles, ksi	135	115
10 ⁸ cycles, ksi	75	75
Notched, R=0.1, R=0.1		
10 ⁶ cycles, ksi	120	90
10 ⁷ cycles, ksi	60	50
10 ⁸ cycles, ksi	42	37

TI-6Al-2Zr-2Sn-2Nb-2Cr ALLOY DATA
(Continued)

Properties	Temperature, F			
	RT	400	600	800
<u>Creep (transverse)</u>				
0.2% plastic deformation, 100 hr., ksi	MA	122	120	83
0.2% plastic deformation, 1000 hr., ksi	MA	118	115	60
<u>Stress-Rupture (transverse)</u>				
Rupture, 100 hr., ksi	MA	142	132	122
Rupture, 1000 hr., ksi	MA	141	131	119
<u>Stress Corrosion (S)</u>				
80% RTS, 1500 hr. maximum	no cracks			
<u>Coefficient of Thermal Expansion</u>				
5.1×10^{-6} in./in./F (68 to 800 F)				
<u>Density</u>				
0.165 lb./in. 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; average of 4 tests in each direction.

(c) U: unavailable; MA: not applicable.

(d) Values are average of 6 tests in each direction.

(e) These values do not meet the rigorous $A_1 T_1 < 2.5 \left(\frac{R}{TS} \right)$ criteria. However, they are over $2.2 \left(\frac{R}{TS} \right)$ and should be considered good indicative K_{IC} values.

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

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

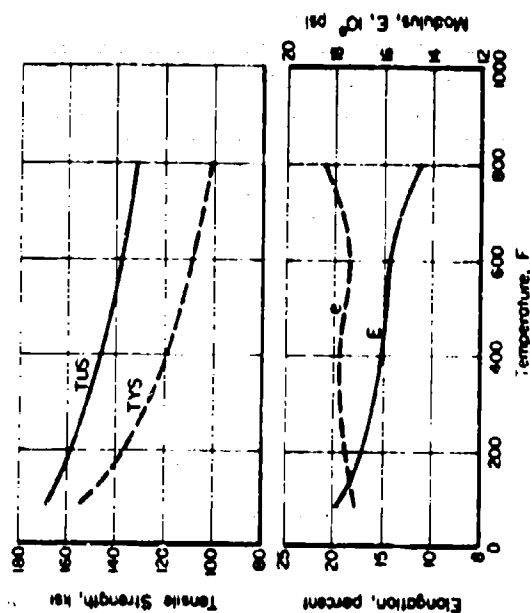


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED TI-6Al-2Zr-2Sn-2Nb-2Cr PLATE

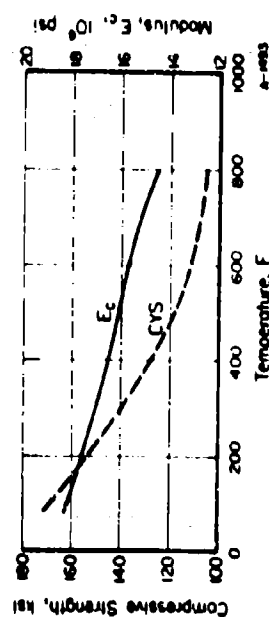


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION TREATED AND AGED TI-6Al-2Zr-2Sn-2Nb-2Cr PLATE

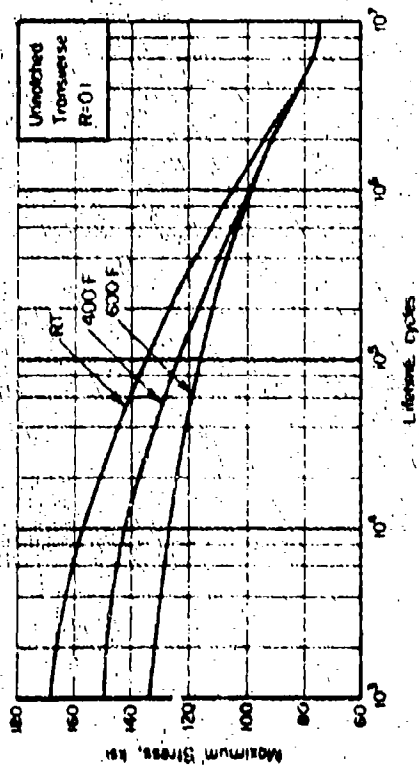


FIGURE 3. AXIAL LOW FREQUENCY BEHAVIOR OF UNTREATED SOLUTION-TREATED AND AGED Ti-5Al-2Zr-25Sn-2%Nb-Ti PLATE

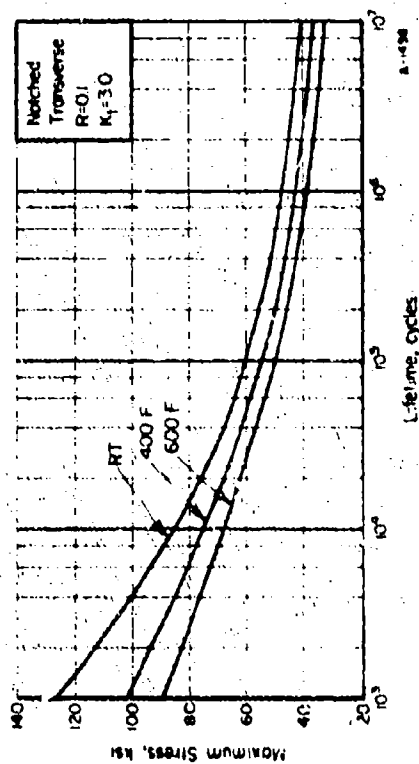


FIGURE 4. AXIAL LOW FREQUENCY BEHAVIOR OF NOTCHED ($K_t = 1.9$) SOLUTION-TREATED AND AGED Ti-5Al-2Zr-25Sn-2%Nb-Ti PLATE

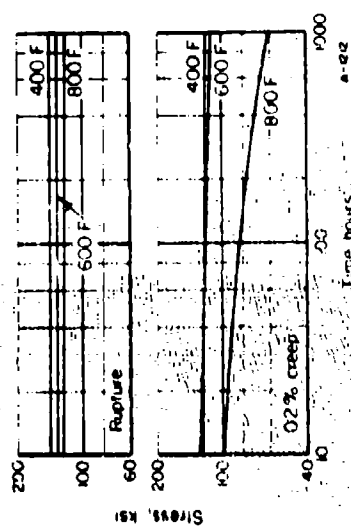


FIGURE 5. STRESS RELAXATION BEHAVIOR OF SOLUTION-TREATED AND AGED Ti-5Al-2Zr-25Sn-2%Nb-Ti PLATE

Ti-6Al-6V-2Sn Isothermal Die Forgings

Material Description

This is a heat-treatable alpha beta type alloy similar in many respects to Ti-6Al-6V, but containing increased content of beta stabilizing elements which provide higher strength potential.

The material used for this evaluation was made by IIT Research Institute under Air Force Contract F33615-67-C-1722. It consisted of structural shapes and nose wheels that were isothermally creep (slow speed) forged from flat preforms machined from conventionally forged Ti-6Al-6V-2Sn alloy billets.

Processing and Heat Treating

The material was received with no heat treatment after forging. Specimens were solution treated at 1650 F for 1 1/2 hour, water quenched, and aged at 1050 F for 4 hours and air cooled. This treatment was as suggested by IIT Research Institute.

Ti-6Al-6V-2Sn Alloy Data (a)

Condition: Solution treated and aged
Thickness: Die forging of varying thickness

Properties	Temperature, F		
	RT	200	700
Tension			
T _{TS} (transverse), ksi	202.5	170.4	158.2
T _{TS} (transverse), ksi	192.9	153.2	131.8
E (transverse), percent in 1 in.	4.7	7.7	8.3
E (transverse), 10 ⁶ psi	16.0	14.7	13.1
Compression			
CYS (transverse), ksi	199.3	175.3	152.9
F _c (transverse), 10 ³ psi	18.0	16.1	13.2
Shear			
S _{US} (longitudinal), ksi	131.6	U ^(c)	U
S _{US} (transverse), ksi	130.0	U	U
Impact (d)			
V-notch Charpy, ft. lbs.	11.7	U	U
(longitudinal)	9.5	U	U
(transverse)			
Fracture Toughness (e)			
K _{IC} , L-T, ksi/in.	25.0	U	U
K _{IC} , T-L, ksi/in.	26.7	U	U
Axial Fatigue (transverse) (f)			
Unnotched, R = 0.1	112	112	112
10 ⁶ cycles, ksi	30	30	30
10 ⁷ cycles, ksi	22	32	32
Notched, K _t = 3.0, R = 0.1	76	76	76
10 ⁶ cycles, ksi	23	23	23
10 ⁷ cycles, ksi	26	30	32
Creep (transverse)			
0.2 plastic deformation, 100 hr., ksi	NA ^(c)	NA	NA
0.2 plastic deformation, 1000 hr., ksi	NA	NA	NA

Ti-6Al-4V-2Sn Alloy Data
(Continued)

Properties	Temperature, °F		
	RT	-200	900
Stress-Rupture (transverse)			
Rupture, 100 hr., ksi	NA	NA	130
Rupture, 1000 hr., ksi	NA	NA	115
Stress Corrosion (c)			
80 TYS, 1000 hr. maximum	n cracks		
Coefficient of Thermal Expansion			
5.3x10 ⁻⁶ in./in./°F (68 °F to 900 F)			
Density			
0.164 lb./in. ³			

(a) Values are average of triplicate tests conducted at fatigue 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) Nonfatigue pin-type specimens; average of 3 tests in each direction.

(c) E, unannealed; NA, not ignitable.

(d) Average of 4 tests in each direction.

(e) Results of tests at AFML in compact tension specimens.

(f) "n" represents the alternate ratio of minor stress to maximum stress in one cycle; that is, if a 5 in. 50% "n" represents the Von-Mises theoretical stress concentration factor.

(g) Air-temperature three-point bend test. All fracture in tension in 3-1/2 NaCl.

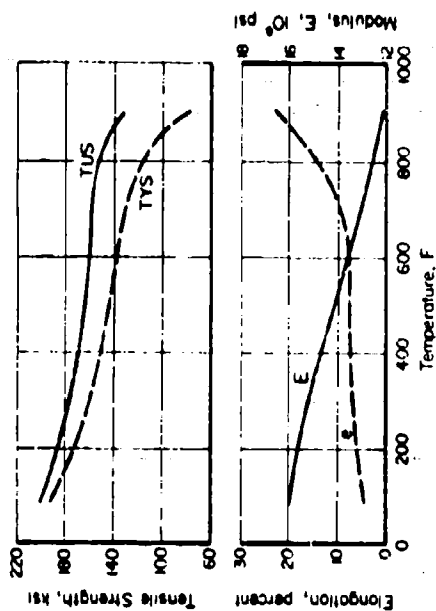


FIGURE 1. EFFECT OF TEMPERATURE ON THE TENSILE PROPERTIES OF SOLUTION TREATED AND AGED Ti-6Al-4V-2Sn IN TENSILE DIE FORMINGS

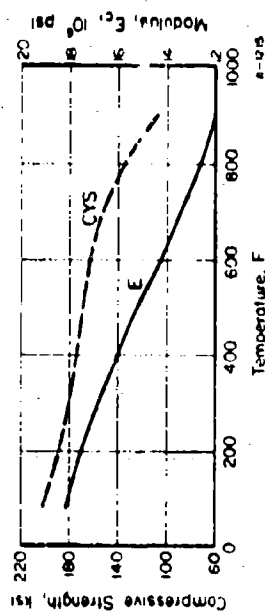


FIGURE 2. EFFECT OF TEMPERATURE ON THE COMPRESSIVE PROPERTIES OF SOLUTION TREATED AND AGED Ti-6Al-4V-2Sn IN THERMAL DIE FORMINGS

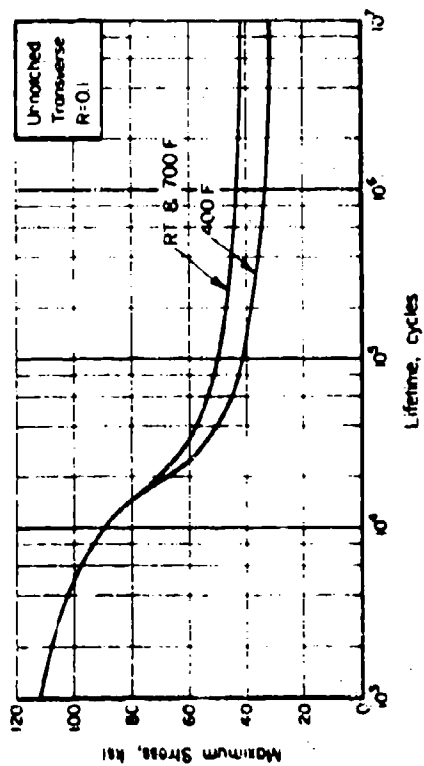
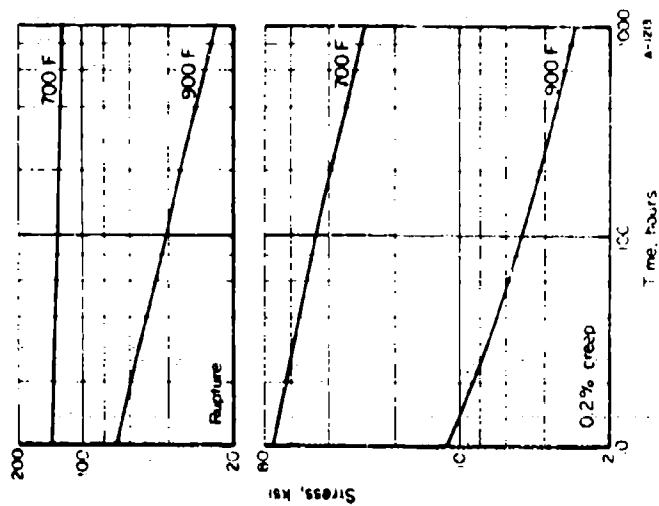
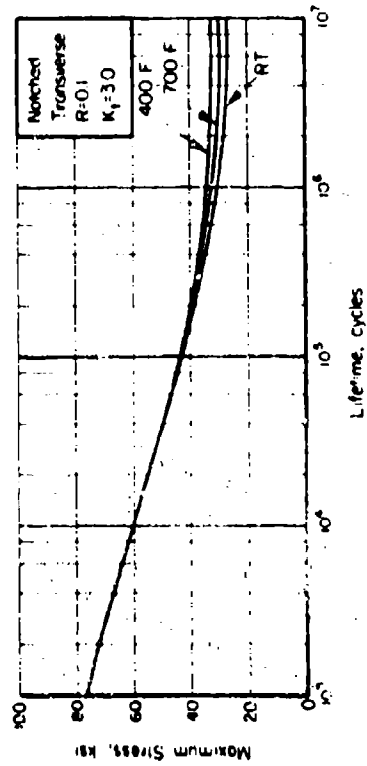


FIGURE 3. AVERAGE 10% ANTILOG OF MAXIMUM STRESS (PREDICTED) BASED ON 100,000-250 ISOTHERMAL LIFE VOLUMES



STRESS RATIO R=0.1, STRESS CONCENTRATION FACTOR K_t=3.0, BASED ON 100,000-250 ISOTHERMAL LIFE VOLUMES