NASA CR-115388
BOEING D180-14480-1

(NASA-CR-115388) DETERMINATION OF DESIGN ALLOWABLE PROPERTIES. FRACTURE OF 2219-T87 ALUMINUM ALLOY W.L. Engstrom (Boeing Co., Seattle, Wash.) Mar. 1972 253 p CSCL 11F

N72-33531

G3/17 Unclas 41489

DETERMINATION OF DESIGN ALLOWABLE PROPERTIES

FRACTURE OF 2219-T87 ALUMINUM ALLOY

By

Failure Mechanisms Research Organization

W. L. Engstrom, Principal Investigator

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

Contract NAS 9-10364, Task 24

THE BOEING COMPANY

Requests for copies of this report should be referred to

National Aeronautics and Space Administration
Office of Scientific and Technical Information
Attention: AFSS-A
Washington, D.C. 20546

NASA CR 115388
Boeing D180-14480-1

DETERMINATION OF DESIGN ALLOWABLE PROPERTIES - FRACTURE OF 2219-T87 ALUMINUM ALLOY

By

THE BOEING COMPANY

Failure Mechanisms Research Organization

W. L. Engstrom, Principal Investigator

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

March 1972

Contract NAS 9-10364, Task 24

Technical Management

NASA Manned Spacecraft Center
Houston, Texas

R. G. Forman

Aerospace Group
Research and Engineering Division

THE BOEING COMPANY
Seattle, Washington

PRECEDING PAGE BLANK NOT FILME:

FOREWORD

Aluminum alloy 2219-T87 has been determined to be one of the op·imum materials available for fabrication of manned spacecraft tankage. In order to provide a comprehensive report of available data on fracture toughness, fatigue crack propagation and sustained load crack behavior, NASA requested the Aerospace Group of The Boeing Company to perform a literature search of 2219-T87 test data. This program was performed under NASA Contract NAS 9-10364, Task 24 from August 9, 1971 to February 15, 1972 and the results are reported herein. The work was administered under the direction of R. G. Form_n at NASA/MSC.

Boeing personnel who participated in this investigation include J. N. Masters, Program Leader, and W. D. Bixler, W. L. Engstrom, R. W. Finger and R. C. Shah, Research Engineers, and C. Bilbao, Engineering Aide. Don Good prepared the art work.

Th information contained in this report is also released as Boeing Document D180-14480-1.

DETERMINATION OF DESIGN ALLOWABLE PROPERTIES - FRACTURE OF 2219-T87 ALUMINUM ALLOY

By

W. L. Engstrom

ABSTRACT

A literature survey was conducted to provide a comprehensive report of available valid data on tensile properties, fracture toughness, fatigue crack propagation and sustained load behavior of 2219-T87 aluminum alloy base metal and weldments as applicable to manned spacecraft tankage. Most of the data found were from tests conducted at room temperature, -320°F and -423°F. Data are presented in graphical and tabular form and areas in which data are lacking are established.

KEY WORDS

2219-T87 Aluminum Alloy
Manned Spacecraft
Weldments
Fracture Characteristics
Threshold Stress Intensity
Cyclic crack growth

TABLE OF CONTENTS

			PAGE
ABSTRACT			vi
SYMBOLS			vii
SUMMARY			1
1.0	INTRODUCTION		3
2.0	PROCEDURES		5
	2.1 Screening of the Data		5
		2.1.1 Tensile Data	5
		2.1.2 Fracture Toughness Data from Surface Flawed Specimens, K_{IE}	5
		2.1.3 Fatigue Crack Growth and Sustained Load Data Obtained from Surface Flawed Specimens	6
	2.2 Surface Flawed Specimen Stress Intensity Solution		6
3.0	DISCUSSION		7
	3.1 Tensile Data		7
		3.1.1 Base Metal Tensile Data	7
		3.1.2 Gas Tungsten Arc Weldment Tensile Data	7
		3.1.3 Gas Metal Arc Weldment Tensile Data	8
	3.2 Fracture Data		9
		3.2.1 Base Metal Surface Flawed Fracture Toughness Data	9
		3.2.2 Weldment Surface Flawed Fracture Toughness Data	10
	3.3 Sustained Load Data		10
		3.3.1 Base Metal Surface Flawed Sustained Load Data	11
		3.3.2 Weldment Surface Flawed Sustained Load Data	12
	3.4 Fatigue Data		13
		3.4.1 Base Metal Fatigue Crack Growth Data	13
		3.4.2 Weldment Fatigue Crack Growth Data	15
4.0	RECOMMENDATIONS		17
APPENDIX A - OTHER DATA			19
A1.0	INTRODUCTION		19
A2.0	PROCEDURES		20
	A2.1 Screening of the Data		20
		A2.1.1 Plane Strain Fracture Toughness, K_{Ic}, Data from Through-the-Thickness and Round Notched Bar Specimens	20

TABLE OF CONTENTS (Continued)

PAGE

A2.1.2 Plane Stress Fracture Toughness, K_c, Data from Through-the-Thickness Center Notched Panels 21

A2.1.3 Plane Strain Fatigue Crack Growth and Sustained Load Data from Through-the-Thickness Specimens 21

A2.1.4 Plane Stress Fatigue Crack Growth and Sustained Load Data from Through-the-Thickness Center Notched Panels 21

A2.2 Stress Intensity Solutions 21

A2.2.1 Compact Tension Specimens 21

A2.2.2 Three Point Loaded Single Edge Notch Bend Specimens 22

A2.2.3 Single Edge Notched Tension Specimens 22

A2.2.4 Tapered Double Cantilever Beam Specimens 22

A2.2.5 Plane Stress Through-the-Thickness Center Notched Specimens 23

A3.0 DISCUSSION 24

A3.1 Fracture Data 24

A3.1.1 Through-the-Thickness Plane Strain Fracture Toughness, K_{Ic}, Data 24

A3.1.2 Through-the-Thickness Plane Stress Fracture Toughness, K_c, Data 24

A3.2 Sustained Load and Fatigue Data 25

A3.2.1 Through-the-Thickness Plane Strain Sustained Load and Fatigue Crack Growth Data 25

A3.2.2 Through-the-Thickness Plane Stress Sustained Load and Fatigue Crack Growth Data 25

APPENDIX B - REPORTS CONTAINING INVALID OR OTHERWISE UNUSABLE DATA 27

APPENDIX C - CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS 29

REFERENCES 31

SYMBOLS

a	Flaw depth
c	Half flaw length
C	Constant from Forman's equation for fatigue crack growth rates; also, used to denote compliance in stress intensity solutions for single edge notched specimens and tapered double cantilever beam specimens.
d_{NOTCH}	Diameter at the notch on a round notched bar fracture specimen
D_{BAR}	Diameter of the bar for a round notched bar fracture specimen
E	Young's Modulus
F_{tu}	Tensile ultimate strength
F_{ty}	Tensile yield strength
G	Constant relating flaw opening displacement to flaw size and stress level
h	Height of a compact tension specimen or the short height of a tapered double cantilever beam specimen.
h_1	Height of the highest end of a tapered double cantilever beam specimen.
K	Plane-stress stress intensity factor
K_I (IRWIN)	Irwin stress intensity factor for a surface flaw.
K_I	Irwin stress intensity for a surface flaw with deep flaw magnification, M_K, included; also, plane-strain stress intensity factor for values reported in Appendix A.
K_{IE}	Critical stress intensity or plane strain fracture toughness for surface flaws, with M_K included.
K_{TH}	Threshold stress intensity for surface flaw specimens.
L	Length of a specimen, length of test section.
M_K	Deep flaw magnification factor for 2219-T87 aluminum alloy base metal.

N	Number of load cycles for fatigue test.
n	Exponent from Forman's equation for fatigue crack growth rates.
NA	Not available.
P	Applied load
Q	Flaw shape parameter $= \Phi^2 - 0.212\ (\sigma/\sigma_y)^2$
R	Stress ratio, $(\sigma_{min}/\sigma_{max})$ for a cyclic fatigue crack growth test.
t	Specimen thickness
t_g	Specimen thickness at the side groove on side grooved specimens.
w	Specimen width
α	Polar angle measured from the minor axis of a surface flaw
δ	Flaw opening displacement
μ	Poisson's ratio
σ	Applied stress
σ_N, σ_{NET}	Net section stress
σ_y, σ_{YIELD}	Yield stress
Φ	Complete elliptical integral of the second kind having modulus k defined as $k = (1 - a^2/c^2)^{1/2}$
$>$	Greater than
$<$	Less than

SUBSCRIPTS

i	Initial condition
f	Final condition
c	Critical condition
max.	Maximum condition
min.	Minimum condition

LIST OF FIGURES

NO.	TITLE	PAGE
1	Surface Flaw Specimen Configuration	35
2	Propagation Direction Code for Surface Flaw Specimens	35
3	Deep Flaw Magnification Curves (Reference 3)	36
4	Shape Parameter Curves for Surface and Internal Flaws	37
5	Ultimate and Yield Strength Vs. Temperature, 2219-T87 Aluminum Alloy, Longitudinal Grain Direction	38
6	Ultimate and Yield Strength Vs. Temperature, 2219-T87 Aluminum Alloy, Long Transverse Direction	39
7	Ultimate and Yield Strength Vs. Temperature, GTA Welded 2219-T87 Aluminum Alloy, No Post Weld Heat Treatment	40
8	Ultimate Strength Vs. Temperature, GMA Welded 2219-T87 Aluminum Alloy, No Post Weld Heat Treatment	41
9	Fracture Toughness Vs. Temperature, 2219-T87 Aluminum Alloy, RT and WT Propagation Direction (From Surface Flawed Specimen Tests)	42
10	Growth-On-Loading in 2219-T87 Aluminum Base Metal in Liquid Nitrogen at -320°F (surface flawed specimens)	43
11	Growth-On-Loading in 2219-T87 Aluminum GTA Weldment in Air at Room Temperature, No Post Weld Heat Treatment (Surface Flawed Specimens)	44
12	Stress Intensity Vs. Test Duration, 2219-T87 Aluminum Alloy, WT Propagation Direction, Room Temperature Air, t = 0.65 inches (Reference 14)	45
13	Cyclic Loading Profile	46
14	Initial Stress Intensity Vs. Cycles to Failure, 2219-T87 Aluminum Alloy Tested at Room Temperature in Air	47
15	Initial Stress Intensity Vs. Cycles to Failure, 2219-T87 Aluminum Alloy Tested at -320°F in Liquid Nitrogen	48
16	Initial Stress Intensity Vs. Cycles to Failure, 2219-T87 Aluminum Alloy Tested at -423°F in Liquid Hydrogen	49
17	Cyclic Flaw Growth Rates for 2219-T87 Aluminum Base Metal at Room Temperature for the WT Propagation Direction, $R \leq 0.1$	50
18	Cyclic Flaw Growth Rates for 2219-T87 Aluminum Base Metal at Room Temperature for the RT Propagation Direction, $R \leq 0.1$	51
19	Cyclic Flaw Growth Rates for 2219-T87 Aluminum Base Metal at Room Temperature in a 3½% NaCl Environment for the WT Propagation Direction, $R \leq 0.1$	52

FIGURE NO.	TITLE	PAGE
20	Cyclic Flaw Growth Rates for 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction, R ≤ 0.1	53
21	Cyclic Flaw Growth Rates for 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction, R ≤ 0.1	54
22	Cyclic Flaw Growth Rates for 2219-T87 Aluminum Base Metal at -320°F for the RT Propagation Direction, R ≤ 0.1	55
23	Cyclic Flaw Growth Rates for 2219-T87 Aluminum Base Metal at -423°F for the WT Propagation Direction, R ≤ 0.1	56
24	Cyclic Flaw Growth Rates for 2219-T87 Aluminum Base at Elevated Temperatures for the WT and RT Propagation Direction, R≤0.1	57
25	Cyclic Flaw Growth Rates for 2219-T87 Aluminum Base Metal at Room Temperature, -320°F and -423°F for the WT Propagation Direction, R = 0.5	58
26	Cyclic Flaw Growth Rates for 2219 Aluminum Alloy Weldments at 72°F, R ≤ 0.1	59
27	Cyclic Flaw Growth Rates for 2219 Aluminum Weldments at -320°F, R ≤ 0.1	60
28	Cyclic Flaw Growth Rates for 2219 Aluminum Weldments at -423°F, R ≤ 0.1	61
29	Room Temperature (70°F - 75°F) Yield Strength and Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy, Longitudinal Grain	62
30	Room Temperature (70°F - 75°F) Yield Strength and Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy Long Transverse Grain	63
31	Liquid Nitrogen Temperature (-320°F) Yield Strength and Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy Longitudinal Grain	64
32	Liquid Nitrogen Temperature (-320°F) Yield Strength and Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy Long Transverse Grain	65
33	Liquid Hydrogen Temperature (-423°F) Yield Strength Vs. Thickness for 2219-T87 Aluminum Alloy Longitudinal Grain	66
34	Liquid Hydrogen Temperature (-423°F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy Longitudinal Grain	67
35	Liquid Hydrogen Temperature (-423°F) Yield Strength Vs. Thickness for 2219-T87 Aluminum Alloy Long Transverse Grain	68
36	Liquid Hydrogen Temperature (-423°F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy Long Transverse Grain	69
37	Room Temperature (70°F - 75°F) Yield Stress Vs Thickness for 2219-T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment	70

FIGURE NO.	TITLE	PAGE
38	Room Temperature (70°F - 75°F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment	71
39	Liquid Nitrogen Temperature (-320°F) Yield Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA weldments, No Post Weld Heat Treatment	72
40	Liquid Nitrogen Temperature (-320°F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment	73
41	Liquid Hydrogen Temperature (-423°F) Yield Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment	74
42	Liquid Hydrogen Temperature (-423°F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment	75
43	Room Temperature (70°F - 75°F) Ultimate and Yield Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, Weldments Subjected to STA Thermal Cycle After Welding	76
44	Room Temperature (70°F - 75°F) Ultimate and Yield Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, Weldments Aged After Welding	77
45	Room Temperature (70°F - 75°F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy GMA Weldments, No Post Weld Heat Treatment	78
46	Liquid Nitrogen Temperature (-320°F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy GMA Weldments, No Post Weld Heat Treatment	79
47	Liquid Hydrogen Temperature (-423°F) Ultimate Strength Vs. Temperature for 2219-T87 Aluminum Alloy GMA Weldments, No Post Weld Heat Treatment	80
48	Room Temperature (70°F - 75°F) Critical Stress Intensity Vs. Tested Thickness, 2219-T87 Aluminum Alloy, RT Propagation Direction	81
49	Room Temperature (70°F - 75°F) Critical Stress Intensity Vs. Tested Thickness, 2219-T87 Aluminum Alloy, WT Propagation Direction	82
50	Liquid Nitrogen Temperature (-320°F) Critical Stress Intensity Vs. Tested Thickness, 2219-T87 Aluminum Alloy, RT Propagation Direction	83
51	Liquid Nitrogen Temperature (-320°F) Critical Stress Intensity Vs. Tested Thickness, 2219-T87 Aluminum Alloy, WT Propagation Direction	84
52	Liquid Hydrogen Temperature (-423°F) Critical Stress Intensity Vs. Tested Thickness, 2219-T87 Aluminum Alloy, RT Propagation Direction	85

FIGURE NO.	TITLE	PAGE
53	Liquid Hydrogen Temperature (-423°F) Critical Stress Intensity Vs. Tested Thickness, 2219-T87 Aluminum Alloy, WT Propagation Direction	86
54	Liquid Nitrogen Temperature (-320°F) and Liquid Hydrogen Temperature (-423°F) Irwin Critical Stress Intensity Vs. Tested Thickness 2219-T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment	87
55	Cyclic Flaw Growth Rates for 0.40 and 0.80-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)	88
56	Cyclic Flaw Growth Rates for 0.40-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)	88
57	Cyclic Flaw Growth Rates for 0.60 and 1.25-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 13)	88
58	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 26)	89
59	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 26)	89
60	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 6)	90
61	Cyclic Flaw Growth Rates for 0.250-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 26)	90
62	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the RT Propagation Direction (Reference 26)	91
63	Cyclic Flaw Growth Rates for 0.250-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the RT Propagation Direction (Reference 26)	91
64	Cyclic Flaw Growth Rates for 0.40-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)	92
65	Cyclic Flaw Growth Rates for 0.400-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)	92
66	Cyclic Flaw Growth Rates for 0.40 and 0.80-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)	92
67	Cyclic Flaw Growth Rates for 0.150-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	93
68	Cyclic Flaw Growth Rates for 0.150-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	93
69	Cyclic Flaw Growth Rates for 0.150-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	94

FIGURE NO.	TITLE	PAGE
70	Cyclic Flaw Growth Rates for 0.150-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	94
71	Cyclic Flaw Growth Rates for 0.200-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	95
72	Cyclic Flaw Growth Rates for 0.200-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	95
73	Cyclic Flaw Growth Rates for 0.400-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 5)	96
74	Cyclic Flaw Growth Rates for 0.400-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 5)	96
75	Cyclic Flaw Growth Rates for 0.40 and 0.80-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 5)	96
76	Cyclic Flaw Growth Rates for 0.65-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 14)	97
77	Cyclic Flaw Growth Rates for 0.60 and 1.25-inch-Thick 2219 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 13)	97
78	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 6)	97
79	Cyclic Flaw Growth Rates for 0.500-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	98
80	Cyclic Flaw Growth Rates for 0.500-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	98
81	Cyclic Flaw Growth Rates for 0.500-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	99
82	Cyclic Flaw Growth Rates for 0.500-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	99
83	Cyclic Flaw Growth Rates for 0.625-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the RT Propagation Direction (Reference 3)	100
84	Cyclic Flaw Growth Rates for 0.250-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the RT Propagation Direction (Reference 26)	100
85	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the RT Propagation Direction (Reference 6)	101
86	Cyclic Flaw Growth Rates for 0.500-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the RT Propagation Direction (Reference 23)	101
87	Cyclic Flaw Growth Rates for 0.400-inch-Thick 2219-T87 Aluminum Base Metal at -423°F for the WT Propagation Direction (Reference 5)	102
88	Cyclic Flaw Growth Rates for 0.400-inch-Thick 2219-T87 Aluminum Base Metal at -423°F for the WT Propagation Direction (Reference 5)	102

FIGURE NO.	TITLE	PAGE
89	Cyclic Flaw Growth Rates for 0.60 and 1.25-inch-Thick 2219-T87 Aluminum Base Metal at -423°F forthe WT Propagation Direction (Reference 13)	103
90	Cyclic Flaw Growth Rates for 0.40 and 0.80-inch-Thick 2219-T87 Aluminum Base Metal at -423°F for the WT Propagation Direction (Reference 5)	103
91	Cyclic Flaw Growth Rates for 0.250-inch-Thick 2219-T87 Aluminum Base Metal at 350°F for the RT Propagation Direction (Reference 26)	104
92	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219-T87 Aluminum Base Metal at 350°F for the WT Propagation Direction (Reference 26)	104
93	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219-T87 Aluminum Base Metal at 300°F for the WT Propagation Direction (Reference 26)	104
94	Cyclic Flaw Growth Rates for 0.250-inch-Thick 2219-T87 Aluminum Base Metal at 400°F for the RT Propagation Direction (Reference 26)	105
95	Cyclic Flaw Growth Rates for 0.250-inch-Thick 2219-T87 Aluminum Base Metal at 350°F for the RT Propagation Direction (Reference 26)	105
96	Cyclic Flaw Growth Rates for 0.60 and 1.25-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for WT Propagation Direction, R = 0.5 (Reference 13)	106
97	Cyclic Flaw Growth Rates for 0.60 and 1.25-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction, R = 0.5 (Reference 13)	106
98	Cyclic Flaw Growth Rates for 0.60 and 1.25-inch-Thick 2219-T87 Aluminum Base Metal at -423°F for the WT Propagation Direction, R = 0.5 (Reference 13)	106
99	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219 Aluminum Weldments at 72°F (Reference 3)	107
100	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219 Aluminum Weldments at 72°F (Reference 3)	107
101	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219 Aluminum Weldments at -320°F (Reference 3)	108
102	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219 Aluminum Weldments at -320°F (Reference 3)	108
103	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219 Aluminum Weldments at -320°F (Reference 23)	108
104	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219 Aluminum Weldments at -423°F (Reference 3)	109
105	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219 Aluminum Weldments at -423°F (Reference 3)	109
106	Cyclic Flaw Growth Rates for 0.40 and 0.80-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)	110

FIGURE NO.	TITLE	PAGE
107	Cyclic Flaw Growth Rates for 0.40-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)	110
108	Cyclic Flaw Growth Rates for 0.60 and 1.25-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 13)	110
109	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 26)	111
110	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 26)	111
111	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 6)	112
112	Cyclic Flaw Growth Rates for 0.250-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 26)	112
113	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the RT Propagation (Reference 26)	113
114	Cyclic Flaw Growth Rates for 0.250-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the RT Propagation (Reference 26)	113
115	Cyclic Flaw Growth Rates for 0.40-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)	114
116	Cyclic Flaw Growth Rates for 0.40-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)	114
117	Cyclic Flaw Growth Rates for 0.40 and 0.80-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)	114
118	Cyclic Flaw Growth Rates for 0.150-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	115
119	Cyclic Flaw Growth Rates for 0.150-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	115
120	Cyclic Flaw Growth Rates for 0.150-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	116
121	Cyclic Flaw Growth Rates for 0.150-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	116
122	Cyclic Flaw Growth Rates for 0.200-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	117
123	Cyclic Flaw Growth Rates for 0.200-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	117
124	Cyclic Flaw Growth Rates for 0.400-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 5)	118
125	Cyclic Flaw Growth Rates for 0.40-inch Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 5)	118

FIGURE NO.	TITLE	PAGE
126	Cyclic Flaw Growth Rates for 0.40 and 0.80-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 5)	118
127	Cyclic Flaw Growth Rates for 0.65-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 14)	119
128	Cyclic Flaw Growth Rates for 0.60 and 1.25-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 13)	119
129	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 6)	119
130	Cyclic Flaw Growth Rates for 0.500-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	120
131	Cyclic Flaw Growth Rates for 0.500-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	120
132	Cyclic Flaw Growth Rates for 0.500-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	121
133	Cyclic Flaw Growth Rates for 0.500-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction (Reference 2)	121
134	Cyclic Flaw Growth Rates for 0.625-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the RT Propagation Direction (Reference 3)	122
135	Cyclic Flaw Growth Rates for 0.250-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the RT Propagation Direction (Reference 26)	122
136	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the RT Propagation Direction (Reference 6)	123
137	Cyclic Flaw Growth Rates for 0.500-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the RT Propagation Direction (Reference 23)	123
138	Cyclic Flaw Growth Rates for 0.400-inch-Thick 2219-T87 Aluminum Base Metal at -423°F for the WT Propagation Direction (Reference 5)	124
139	Cyclic Flaw Growth Rates for 0.400-inch-Thick 2219-T87 Aluminum Base Metal at -423°F for the WT Propagation Direction (Reference 5)	124
140	Cyclic Flaw Growth Rates for 0.60 and 0.125-inch-Thick 2219-T87 Aluminum Base Metal at -423°F for the WT Propagation Direction (Reference 13)	125
141	Cyclic Flaw Growth Rates for 0.400 and 0.800-inch-Thick 2219-T87 Aluminum Base Metal at -423°F for the WT Propagation Direction (Reference 5)	125
142	Cyclic Flaw Growth Rates for 0.250-inch-Thick 2219-T87 Aluminum Base Metal at 300°F for the RT Propagation Direction (Reference 26)	126
143	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219-T87 Aluminum Base Metal at 350°F for the WT Propagation Direction (Reference 26)	126

FIGURE NO.	TITLE	PAGE
144	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219-T87 Aluminum Base Metal at 300°F for the WT Propagation Direction (Reference 26)	126
145	Cyclic Flaw Growth Rates for 0.250-inch-Thick 2219-T87 Aluminum Base Metal at 400°F for the RT Propagation Direction (Reference 26)	127
146	Cyclic Flaw Growth Rates for 0.250-inch-Thick 2219-T87 Aluminum Base Metal at 350°F for the RT Propagation Direction (Reference 26)	127
147	Cyclic Flaw Growth Rates for 0.60 and 1.25-inch-Thick 2219-T87 Aluminum Base Metal at 72°F for the WT Propagation Direction, R = 0.5, (Reference 13)	128
148	Cyclic Flaw Growth Rates for 0.60 and 1.25-inch-Thick 2219-T87 Aluminum Base Metal at -320°F for the WT Propagation Direction, R = 0.5, (Reference 13)	128
149	Cyclic Flaw Growth Rates for 0.60 and 1.25-inch-Thick 2219-T87 Aluminum Base Metal at -423°F for the WT Propagation Direction, R = 0.5, (Reference 13)	128
150	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219 Aluminum Weldments at 72°F (Reference 3)	129
151	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219 Aluminum Weldments at 72°F (Reference 3)	129
152	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219 Aluminum Weldments at -320°F (Reference 3)	130
153	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219 Aluminum Weldments at -320°F (Reference 3)	130
154	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219 Aluminum Weldments at -320°F (Reference 23)	130
155	Cyclic Flaw Growth Rates for 0.125-inch-Thick 2219 Aluminum Weldments at -423°F (Reference 3)	131
156	Cyclic Flaw Growth Rates for 1.00-inch-Thick 2219 Aluminum Weldments at -423°F (Reference 3)	131
A-1	Fracture Specimen Configurations	132
A-2	Propagation Direction Code	133
A-3	Stress Intensity Expressions for CT and SENB Specimens	134
A-4	Plane Stress Critical Stress Intensity Vs. Thickness, 2219-T87 Aluminum Alloy Tested in Room Temperature Air	135
A-5	Plane Stress Critical Stress Intensity Vs. Thickness, 2219-T87 Aluminum Alloy Tested in -320°F Liquid Nitrogen	136
A-6	Plane Stress Critical Stress Intensity Vs. Thickness, 2219-T87 Aluminum Alloy Tested in -423°F Liquid Hydrogen	137

FIGURE NO.	TITLE	PAGE
A-7	Average Stress Intensity, K_I, Vs. Crack Growth Rate, da/dN, 1.0 inch Thick 2219-T87 Aluminum Alloy Tapered DCB Specimens Tested at Room Temperature in 3-1/2% NaCl Solution. WR Propagation Direction (Reference 5)	138
A-8	Average Plane Stress Stress Intensity Vs. Average Growth Rate, 2219-T87 Aluminum Alloy, 0.063 inch Sheet, WR Propagation Direction (All points from Reference 8)	139

LIST OF TABLES

NO.	TITLE	PAGE
1	Ultimate and Yield Strength Summary 2219-T87 Aluminum Alloy Longitudinal Grain	140
2	Ultimate and Yield Strength Summary 2219-T87 Aluminum Alloy Long Transverse Grain	140
3	Ultimate and Yield Strength Summary, GTA Welded 2219-T87 Aluminum Alloy, No Post Weld Heat Treatment	141
4	Ultimate Strength Summary, GMA Welded 2219-T87 Aluminum Alloy, No Post Weld Heat Treatment	141
5	Mean Values of Fracture Toughness, K_{IE}, 2219-T87 Aluminum Alloy (From Surface Flawed Specimen Tests)	142
6	Mean Values of Fracture Toughness, K_{IE}, GTA Welded 2219-T87 Aluminum Alloy (From Surface Flawed Specimen Tests)	142
7	Threshold Values for 2219-T87 Aluminum Alloy Base Metal	143
8	Threshold Values for GTA Welded 2219-T87 Aluminum Alloy	145
9	Room Temperature (70°F - 75°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Longitudinal Grain Direction	146
10	Room Temperature (70°F - 75°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Long Transverse Grain Direction	150
11	Room Temperature (70°F - 75°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Short Transverse Grain Direction	154
12	Dry Ice and Acetone (-110°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal	154
13	Liquid Nitrogen (-320°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Longitudinal Grain Direction	155
14	Liquid Nitrogen (-320°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Long Transverse Grain Direction	157
15	Liquid Hydrogen (-423°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Longitudinal Grain Direction	159
16	Liquid Hydrogen (-423°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Long Transverse Grain Direction	161
17	Room Temperature (70°F-75°F) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation, 2319 Wire Used. No Post Weld Heat Treatment.	164
18	Liquid Nitrogen Temperature (-320°F) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment.	167
19.	Liquid Hydrogen Temperature (-423°F) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment.	170

TABLE NO.	TITLE	PAGE
20	Room Temperature (70°F-75°F) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy Square Butt Weld Edge Preparation. 2319 Filler Wire Used. Aged after welding.	173
21	Room Temperature (70°F-75°F) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy Square Butt Weld Edge Preparation. 2319 Filler Wire Used. Solution Treated and Artificially Aged After Welding.	173
22	Room Temperature (70°F-75°F) Tensile Properties of GMA Welded 2219-T87 Aluminum Alloy. Double 70° "V" Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment.	174
23	Liquid Nitrogen Temperature (-320°F) Tensile Properties of GMA Welded 2219-T87 Aluminum Alloy. Double 70° "V" Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment.	176
24	Liquid Hydrogen Temperature (-423°F) Tensile Properties of GMA Welded 2219-T87 Aluminum Alloy. Double 70° "V" Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment.	178
25	Room Temperature (70°-75°F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. RT Propagation Direction	180
26	Room Temperature (70°F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction	181
27	Liquid Nitrogen Temperature (-320°F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. RT Propagation Direction	185
28	Liquid Nitrogen Temperature (-320°F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction	186
29	Liquid Hydrogen Temperature (-423°F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. RT Propagation Direction	189
30	Liquid Hydrogen Temperature (-423°F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction	190
31	Liquid Nitrogen Temperature (-320°F) Surface Flawed Fracture Tests of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. No Filler Wire. No Post Weld Heat Treatment.	191
32	Liquid Hydrogen Temperature (-423°F) Surface Flawed Fracture Tests of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. No Filler Wire. No Post Weld Heat Treatment.	191
33	Room Temperature (70°F-75°F) Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy	192
34	-230°F Temperature Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy	196
35	Liquid Nitrogen Temperature (-320°F) Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy	197
36	-413°F Temperature Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy	199

TABLE NO.	TITLE	PAGE
37	Liquid Hydrogen Temperature (-423°F) Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy	200
38	Room Temperature (70°F-75°F) Surface Flawed Sustained Load Tests of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment.	201
39	Liquid Nitrogen Temperature (-320°F) Surface Flawed Sustained Load Tests of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment	203
40	-413°F Temperature Surface Flawed Sustained Load Tests of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment	205
41	Liquid Hydrogen Temperature (-423°F) Surface Flawed Sustained Load Tests of GTA Welded 2219-T87 Aluminum Alloy Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment	205
42	Room Temperature Air Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction	206
43	Room Temperature Air Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, RT Propagation Direction	209
44	Room Temperature Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy in Salt Water, WT Propagation Direction	211
45	-320°F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction (Thickness < 0.25 inch)	212
46	-320°F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction (Thickness > 0.25 inch)	214
47	-320°F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, RT Propagation Direction	217
48	-423°F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction	219
49	-423°F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, RT Propagation Direction	220
50	Elevated Temperature Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, WT and RT Propagation Direction	221
51	Room Temperature Surface Flawed Cyclic Flaw Growth Tests of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment.	222
52	-320°F Surface Flawed Cyclic Flaw Growth Tests of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment.	223

TABLE NO.	TITLE	PAGE
53	$-423^{\circ}F$ Surface Flawed Cyclic Flaw Growth Tests of GTA Welded 2219-T87 Aluminum Alloy Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment.	224
A-1	Room Temperature, Liquid Nitrogen Temperature and Liquid Hydrogen Temperature Compact Tension Fracture Toughness Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction	225
A-2	Room Temperature, Liquid Nitrogen Temperature and Liquid Hydrogen Temperature Three Point Bend Fracture Toughness Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction	225
A-3	Room Temperature Single Edge Notch Tension Fracture Toughness Tests of 2219-T87 Aluminum Alloy	226
A-4	Room Temperature (70° - $75^{\circ}F$) Through-The-Thickness Center Notched Fracture Tests of 2219-T87 Aluminum Alloy	227
A-5	Liquid Nitrogen Temperature ($-320^{\circ}F$) Through-The-Thickness Center Notched Fracture Tests of 2219-T87 Aluminum Alloy	228
A-6	Liquid Hydrogen Temperature ($-423^{\circ}F$) Through-The-Thickness Center Notched Fracture Tests of 2219-T87 Aluminum Alloy	228
A-7	Room Temperature (70° - $75^{\circ}F$) Through-The-Thickness Center Notched Panel Cycle to Failure Tests of 0.060" Thick 2219-T87 Aluminum Alloy Sheet, WR Propagation Direction	229
A-8	Liquid Nitrogen Temperature ($-320^{\circ}F$) Through-The-Thickness Center Notched Panel Cycle to Failure Tests of 0.060" Thick 2219-T87 Aluminum Alloy Sheet, WR Propagation Direction	229
A-9	Liquid Hydrogen ($-423^{\circ}F$) Through-The-Thickness Center Notched Panel Cycle to Failure Tests of 0.060" Thick 2219-T87 Aluminum Alloy Sheet, WR Propagation Direction	230
A-10	Tapered Double Cantilever Beam Specimen Cyclic Tests of 1.0 Inch 2219-T87 Aluminum Alloy in Room Temperature 3½% Salt Water Solution, WR Propagation Direction	231

SUMMARY

The study described herein was undertaken to locate and report all available valid data on tensile properties, fracture toughness, fatigue crack propagation and sustained load crack behavior of 2219-T87 aluminum alloy base metal and weldments. The objective was to provide a comprehensive report which could be used in design of manned spacecraft tankage.

Most of the data found and reported were tested in room temperature air, liquid nitrogen at -320°F and liquid hydrogen at -423°F. In addition, tensile data were located for tests conducted in dry ice and acetone at -110°F and in gaseous helium at -423°F. Fatigue crack growth data were also found for tests conducted in salt water and helium at room temperature. Furthermore, sustained load data were also found for temperatures of -230°F and -413°F and environments of gaseous hydrogen, gaseous and liquid oxygen, oxygen difluoride (OF_2), FLOX (80% fluorine, 20% oxygen), 3½% salt water solution, distilled water, 172 decibel noise level, dye penetrant, argon, and trichloroethylene. The data are reported in graphical and tabular form.

During the course of this study, shortages of data were discovered in several areas. There were shortages of valid fracture toughness, sustained load and cyclic data of weldments, fracture properties of base metal in the RT propagation direction, and fracture toughness data in the WT direction at -423°F. Properties were also found to be lacking at elevated temperatures and combined thermal and applied stress spectrum loadings. Furthermore, there were not enough data to firmly establish thickness effects for the properties investigated.

1.0 INTRODUCTION

The objective of this investigation was to provide a comprehensive report of available data on fracture toughness, fatigue crack propagation and sustained load crack behavior of 2219-T87 aluminum alloy and weldments as applicable to manned spacecraft tankage. The majority of the useful fracture data obtained were from surface flawed specimens and they are covered in the main body of this report. Fracture data from other types of specimens were scarce and they are reported in Appendix A. A review of reports containing invalid or otherwise unusable data is contained in Appendix B. A summary of the quantities of tensile and surface flaw data in the main body of this report is shown below.

QUANTITIES OF TENSILE TESTS

TEMPERATURE	RT		-110°F		-320°F		-423°F	
ENV \ MAT'L	BM	WM	BM	WM	BM	WM	BM	WM
AIR	168	109						
DRY ICE +ACETONE			4					
LN_2					69	93		
LH_2							80	91
GHe							4	

QUANTITIES OF SURFACE FLAW FRACTURE TESTS

TEMPERATURE	RT		-320°F		-423°F	
ENV \ MAT'L	BM	WM	BM	WM	BM	WM
AIR	82					
LN_2			72	2		
LH_2					17	8

QUANTITIES OF SURFACE FLAW FATIGUE CRACK GROWTH TESTS

TEMPERATURE	+400°F		+350°F		+300°F		RT		-320°F		-423°F	
ENV \ MAT'L	BM	WM	BM	WM	BM	WM	BM	WM	BM	WM	BM	WM
AIR	2		6		2		88	10				
GHe							3					
3.5% NaCl							11					
LN_2									131	15		
LH_2											34	10

QUANTITIES OF SURFACE FLAW SUSTAINED LOAD TESTS

TEMPERATURE	RT		-230°F		-320°F		-413°F		-423°F	
ENV. \ MAT'L	BM	WM	BM	WM	BM	WM	BM	WM	BM	WM
AIR	54	8								
LN_2					34	11				
LH_2									15	2
GH_2	2	2			2	2	3	5		
LO_2					2	2				
GO_2	2	2								
OF_2	2	3			2	2				
FLOX	3	2			2	2				
3.5% NaCl	6	2								
DISTILLED WATER	2	2								
172 db NOISE LEVEL	2		3							
DYE PENETRANT	2	2								
ARGON	2									
TRICHLORO-ETHYLENE	2	2								

2.0 PROCEDURES

2.1 SCREENING OF THE DATA

In order to ensure that only valid data would be reported, screening procedures were established. In some cases the screening eliminated much of the available data; however, this ensured the quality of the data presented herein. If a report did not appear to be accurate (e.g., improper use of stress intensity equation) all data from that report were eliminated. Data coming from remaining reports were then further screened to ensure that validity requirements were met for individual data points. Individual data points which did not meet validity requirements were eliminated, all data points which met validity criteria were included. Screening procedures are presented below for each type of test.

2.1.1 Tensile Data

Tensile data were inspected and an attempt was made to include only data which had been tested according to ASTM procedures (Ref. 1). Wherever tensile values did not appear reasonable, or specimen dimensions did not strictly match ASTM requirements, the text of the reference was carefully inspected to ensure that the data were indeed accurate. All accurate data were included in this report.

2.1.2 Fracture Toughness Data from Surface Flawed Specimens, K_{IE}

Most of the valid fracture data found in the literature were obtained from surface flawed fracture specimens. Fig. 1 shows a sketch of a typical surface flaw specimen and Fig. 2 shows the crack propagation orientation code. This specimen configuration has been especially popular in investigations of tankage materials because it can best approximate the actual defects commonly found. The main criteria for validity are as follows:

1. $\sigma_N / \sigma_y \leqslant 0.9$
2. $w/2c > 4$
3. $(t-a) \geqslant 0.1\ (K_{IE}/\sigma_y)^2$

Criterion 1. ensures that the failure is not dominated by net section yielding of the test specimen. Criterion 2. ensures that bending effects are at a minimum and it also aids in screening out net section effects and edge effects. Criterion 3. appears to be a limiting case for break before leak requirement. In the past, this criterion has been assumed to be $(t-a) \geqslant \pi/16 \times (K_{IE}/\sigma_y)^2$; however, recent analysis of data generated under NASA Contract NAS 3-14341 (Ref. 2) indicates that the coefficient, $\pi/16$ ($\approx$ 0.196), can be reduced to 0.1 for 2219-T87 aluminum alloy.

2.1.3 Fatigue Crack Growth and Sustained Load Data Obtained from Surface Flawed Specimens

Fatigue and sustained load data were not subjected to the strict criteria required of fracture toughness data. Most of the data obtained were tested at relatively high stresses. If the fracture toughness criteria were strictly enforced for sustained load and cyclic data, a great deal of data would have been eliminated. In general, most sustained load and fatigue data were used unless they obviously appeared to be in error. Test data were reported for w/2c ratios as low as 3.

2.2 SURFACE FLAWED SPECIMEN STRESS INTENSITY SOLUTION

The base metal fracture, fatigue, and sustained load data were adjusted for deep flaw effects using the empirical deep flaw magnification factor reported in Ref. 3 and shown in Fig. 3. The magnification factor was used to modify the Irwin stress intensity (Ref. 4) so that the resulting stress intensities were calculated as follows:

$$K_I = \underbrace{1.1\ \sigma\,(\pi a/Q)^{1/2}}_{\text{Irwin Stress intensity}}\ M_K$$

where K_I = Stress Intensity

σ = Gross stress

a = Flaw depth

Q = Flaw shape parameter (see Fig. 4)

M_K = Deep flaw magnification factor from Ref. 3 (see Fig. 3).

Ref. 3 has demonstrated that a deep flaw magnification may not be inherent in weldment fracture tests. Therefore, K_I values for weldment tests were calculated without M_K.

3.0 DISCUSSION

3.1 TENSILE DATA

3.1.1 Base Metal Tensile Data

Most of the base metal data were generated in room temperature air, -320°F liquid nitrogen, or -423°F liquid hydrogen. Original thicknesses tested varied from 0.03 to 4.0 inches. Useful data were obtained from Refs. 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 and 17. A normal distribution was assumed for the statistical analysis; however, no tests for goodness of fit were performed to verify this hypothesis. Ref. 18 was used as a guideline in the statistical analysis.

Ultimate strength, F_{tu}, and yield strength, F_{ty}, values for longitudinal and long transverse grain base metal are summarized as a function of temperature in Figs. 5 and 6. Both mean and 99% probability, 95% confidence levels are shown. The "A" values from the Boeing Design Manual (Ref. 19) are also shown for reference. These "A" values correspond to the 99% probability, 95% confidence level. A summary of the base metal tensile values is tabulated in Tables 1 and 2.

Individual ultimate and yield strength data points are plotted as a function of thickness in Figs. 29 through 36, and the raw data points are tabulated in Tables 9 through 16. Figs. 29 and 30 indicate that for room temperature tests, there may be an increase in F_{tu} and F_{ty} properties in very thin gages (0.03 to 0.06 inches). The available data are not extensive enough to fully determine thickness effects in thin gages, therefore, data for all thicknesses were combined in this analysis.

Data available from the short transverse direction were limited to the points shown in Table 11. The scarce amount of data tested at -110°F in dry ice and acetone are shown in Table 12. Four tests at -423°F in a gaseous helium environment were included with the specimens tested in liquid hydrogen.

3.1.2 Gas Tungsten Arc Weldment Tensile Data

Most of the gas tungsten arc (GTA) weldment data was generated in room temperature air, -320°F liquid nitrogen, or -423°F liquid hydrogen. Original thicknesses tested ranged from 0.10 to 1.00 inches. Wherever filler wire was used, the filler material was 2319 aluminum alloy. The majority of the data were not heat treated after welding although some limited data were found for specimens aged after welding and also for some specimens which were solution treated and aged (STA) after welding. Useful data were obtained from Refs. 3, 6, 12, 15, 16, 17 and 20. The statistical analysis was the same as that described in Section 3.1.1.

The GTA welded tests without a post weld heat treatment are summarized as a function of temperature in Fig. 7. Most of the available data consisted of ultimate strength values only. Because of a shortage of yield strength values, only "apparent" mean yield strengths can be reported, and no 99% probability, 95% confidence level values of yield strength could be calculated. The available data were sufficient to show mean and 99% probability, 95% confidence levels for ultimate strength. "A" values from Ref. 19 for ultimate and yield strength values are also shown in Fig. 7. A summary of F_{tu} and F_{ty} values for GTA welded material without post weld heat treatment is also shown tabulated in Table 3.

Individual ultimate and yield strength data points for GTA weldments without post weld heat treatment are shown plotted as a function of thickness in Figs. 37 through 42, and the raw data points are tabulated in Tables 17 through 19. Not enough data were available to fully determine thickness effects on material properties, therefore, all thicknesses were combined for this analysis.

Those GTA weldment data points subjected to a post weld age and a post weld solution treat and age are shown plotted versus thickness in Figs. 43 and 44 respectively. Individual values are listed in Tables 20 and 21. There were not enough data points available to firmly establish mean or 99% probability, 95% confidence levels.

3.1.3 Gas Metal Arc Weldment Tensile Data

All of the gas metal arc (GMA) weldment data come from Ref. 17. Plate material data in original thicknesses of 0.5, 1.0 and 1.5 inches were available for tests conducted in room temperature air, $-320^{\circ}F$ liquid nitrogen and $-423^{\circ}F$ liquid hydrogen. The filler wire used was 2319 aluminum alloy. Only ultimate strength values were reported. A summary of the ultimate strength values is shown in Fig. 8 and tabulated in Table 4. As in the previously reported data, "A" values from Ref. 19 are shown for comparison. The statistical analysis if described in Section 3.1.1.

Individual ultimate strength data are plotted as a function of thickness in Figs. 45, 46 and 47 and the raw data points are listed in Tables 22, 23 and 24. Not enough data are available to firmly establish thickness effects; however, examination of Figs. 45, 46 and 47 indicates that as the temperature decreases, the 0.5 thick weldments exhibit a greater average strength increase than do the 1.0 and 1.5 inch thick weldments.

3.2 FRACTURE DATA

3.2.1 Base Metal Surface Flawed Fracture Toughness Data

Surface flawed fracture toughness data were avilable from tests in room temperature air, -320°F liquid nitrogen and -423°F liquid hydrogen. Usable data were obtained from Refs. 2, 3, 6, 13, 14, 15, 21, 22, 23 and 24. The thicknesses of valid data points ranged from 0.25 to 1.25 inches, with the majority of the data lying in the range of 0.5 to 0.65 inch. Tests conducted on gages thinner than 0.25 inch were generally disqualified because the remaining ligament size, t-a was less than $0.1\ (K_{IE}/\sigma_y)^2$.

Data obtained for RT and WT propagation directions are summarized as a function of temperature in Fig. 9 and Table 5. Because of the scarcity of data in the RT direction at -423°F and room temperature, and in the WT direction at -423°F, only "apparent" mean values are reported for these conditions. The data indicate that fracture toughness values for the WT propagation direction are lower than those for the RT propagation direction.

Individual fracture toughness values are plotted as a function of thickness in Figs. 48 through 53, and raw data points are listed in Tables 25 through 30. Mean or "apparent" mean values are shown and where possible, 99% probability, 95% confidence levels are also shown. The statistical analysis is described in Section 3.1.1.

3.2.2 Weldment Surface Flawed Fracture Toughness Data

Valid surface flawed fracture toughness values for weldments were almost nonexistent. Those values which fulfilled the validity requirements all came from Ref. 3 . No data were available for room temperature, two data points were available for -320°F and eight data points were available for -423°F. All ten of these data points were obtained from GTA weldments of 1.0 inch plate material. The data are summarized in Table 6 and individual data points are plotted as a function of thickness in Fig. 54 , and are listed in Tables 31 and 32.

The low yield strength of weldment material requires testing of large panels in order to meet the validity requirements for net yield strength ($\sigma_N \leqslant 0.9\ \sigma_y$), and ligament size $(t-a) \geqslant 0.1\ (K_{IE}/\sigma_y)^2$. The panels tested in Ref. 3 ranged in size up to 30 inches wide. The testing of such panels requires extremely high load capabilities of testing facilities. The major reason for the shortage of "valid" weldment fracture toughness data stems from the apparent high toughness/low yield strength combination.

3.3 SUSTAINED LOAD DATA

All sustained load data found in the literature were for tests which were on the order of 100 hours or less in duration. Hyatt and Speidel have shown that proper determination of a threshold can be dependent on the length of the test (Ref. 25). Therefore, the threshold values reported herein have been qualified by noting the duration of the tests.

Another factor which must be taken into consideration is growth-on-loading. This phenomenon is non-environmentally induced growth which occurs on initial loading of a specimen. In order to determine sustained load growth, it is necessary to subtract growth-on-loading from total growth incurred during a test. Growth-on-loading as a function of initial stress intensity is shown for base metal in Fig. 10 and for weldments in Fig. 11 . These curves were taken from data generated in Refs. 2 and 22 respectively. As shown by these two figures, precise separation of growth-on-loading from total growth to determine environmental growth can be difficult. This further emphasizes the need to report test times along with threshold values.

Average crack growth rates as a function of time, da/dt, could not be obtained because of the problem in separating environmentally induced growth from growth-on-loading. Likewise, good instrumented test results producing instantaneous growth rates were not available either. Therefore, no K versus aa/dt data are reported herein.

3.3.1 Base Metal Surface Flawed Sustained Load Data

Surface flawed sustained load data were found for base metal tests at room temperature, -230°F, -320°F, -413°F and -423°F in environments of air, 3½% salt water solution, distilled water, dye penetrant, FLOX (80% F_2, 20% O_2), oxygen difluoride (OF_2), Argon, Trichloroethylene, 172 decibel noise level, liquid nitrogen, gaseous and liquid oxygen, and gaseous and liquid hydrogen. Thicknesses varied from 0.125 to 1.00 inch. Useful base metal sustained load data were obtained from Refs. 5, 6, 14, 22 and 24 . In addition, some data were obtained from Refs. 23 and 26; however, these data were not complete enough for use in establishing thresholds.

Threshold values are summarized in Table 7 . Where a value is reported qualified with a less than, $<$, or greater than, $>$, symbol, not enough data were available for a precise determination of the threshold; however, enough data were available to provide an approximation of the threshold. In order to report the threshold as a percentage of critical stress intensity, K_{TH}/K_{IE} value, it was necessary to choose a K_{IE} value. Wherever possible, the endpoint critical stress intensity, K_{IE}, value for each particular threshold specimen was used. If the endpoint for a particular specimen was not available, then the average K_{IE} value for all the K_{IE} tests in the same reference was chosen. Finally, if neither of the above K_{IE} values was available, then K_{IE} was chosen from the overall mean of data points from the particular propagation direction and temperature in question. The source of the K_{IE} value is reported with each threshold value. Individual test datum points are listed in Tables 33 through 37.

In most cases, only a few data points were available and the threshold was chosen by determining the highest K level at which all growth appeared to be growth-on-loading only. For some of the threshold determinations, many data were available and so the data could be plotted to determine threshold. An example of such a plot is shown in Fig. 12 .

In general, for most environments, a threshold level on the order of 85% can be assumed for approximately 24 hours. With the exception of tests from Ref. 5, in liquid hydrogen at -423°F, all thresholds were at least 82% of the critical stress intensity value. The threshold level of the LH_2 data from Ref. 5 was found to be in the range of 35.6 to 38.4 ksi $\sqrt{in.}$ Combining these figures with the overall apparent mean K_{IE} value of 47.0 ksi $\sqrt{in}$ produces threshold/critical stress intensity ratios of 0.75 to 0.82. The low threshold ratios determined here could be accounted for by the selection of a critical stress intensity that was too high. If actual end-point K_{IE} values were available, the threshold ratio reported could be higher.

3.3.2 Weldment Surface Flawed Sustained Load Data

Surface flawed sustained load data were found for weldment tests at room temperature, -320°F, -413°F and -423°F in environments of air, 3½% salt water solution, distilled water, dye penetrant, FLOX (80% F_2, 20% O_2), oxygen difluoride (OF_2), trichloroethylene, liquid nitrogen, gaseous and liquid oxygen, and gaseous and liquid hydrogen. Data were reported in thickness of 0.90, 0.95 and 1.00 inch. Useful weldment sustained load data were obtained from Refs. 22 and 23 . In addition, some data were obtained from Ref. 24 . However, most of the data from Ref. 24 were tested at very high stress levels so that threshold levels could not be determined from them.

Threshold values are summarized in Table 8 . Because of the scarcity of weldment fracture toughness data, no attempt was made to report thresholds in terms of a percentage of critical stress intensity. The analysis of weldment data was similar to that employed for base metal data.

The available data indicate thresholds on the order of 23-30 ksi $\sqrt{in}$ for all environments with the exception of 3½% salt water solution. The data show that the threshold for this environment lies somewhere below 23.8 ksi $\sqrt{in.}$

Individual datum points are listed in Tables 38 through 41.

3.4 FATIGUE DATA

3.4.1 Base Metal Fatigue Crack Growth Data

Base metal fatigue crack growth data were generated in air, gaseous helium, 3½% salt water solution, liquid nitrogen and liquid hydrogen. Test temperatures were room temperature, -320°F, -423°F, +300°F, +350°F and +400°F. Data were obtained from References 2, 3, 5, 6, 13, 14, 23 and 26.

Thicknesses of test specimens ranged from 0.125 to 1.25 inches. Cyclic stresses ranged from 7 ksi to 65 ksi and stress ratios, R, ranged from 0.0 to 0.5 with the majority of the data tested at R = 0.0 to 0.1. Test frequencies ranged from 0.008 to 120 cpm. Typical cyclic loading profiles are shown in Fig. 13 and individual data points are summarized in Tables 42 through 50 .

Data were found to be lacking in the RT propagation direction at room temperature, -320°F and -423°F. One of the reasons for a shortage of data in the RT direction is that delamination commonly occurs in specimens which are tested in this direction, especially at room temperature. While this makes testing difficult in the RT direction, it is beneficial in hardware because the delamination also causes a retardation in crack growth.

Figures 14 to 16 show the relationship between stress intensity ratio, K_{II}/K_{IE}, to cycles to failure, N, for the environments of ambient air, liquid nitrogen and liquid hydrogen. Examination of these plots indicates that the polynomial function of $\log_{10} N$, shown below, would best represent the data:

$$K_{II}/K_{IE} = A + B \log_{10} N + C(\log_{10} N)^2 + D(\log_{10} N)^3 + E(\log_{10} N)^4$$

Since the ratio of stress intensities K_{II}/K_{IE} contain errors due to measurement of flaw sizes, computations of stress intensities from stress intensity equations, etc., K_{II}/K_{IE} is taken as a dependent variable and N as an independent variable. The polynomial function was limited to the fourth order of $\log_{10}N$ to avoid oscillations between fitted points.

Data for each of the plots of Figures 14 to 16 were successively least square fitted with the second, third and fourth degree polynomials of $\log_{10}N$. Out of these curves, the one which best describes the data was selected and the best fit least square cruve with the equation is shown in each figure.

Crack growth rates da/dN and d(a/Q)/dN were computed from either average or instantaneous crack growth measurements. Measured average growth rates were determined by taking the difference between the final and initial flaw sizes and dividing this quantity by the number of cycles. The corresponding stress intensity value was taken as the average maximum stress intensity during the test.

Instantaneous growth rate data were available from Refs. 2 and 5. Instantaneous growth rate data were determined by instrumenting specimens with ASTM type crack opening displacement, δ, clip gages.

The clip gage was spring loaded against knife edges spot welded to the specimen. An expression for the opening displacements of a completely embedded flaw was provided by Green and Sneddon (Ref. 27). The flaw embedded in an elastic solid was subjected to a uniform load normal to the crack surface at infinity. The maximum opening displacement occurs at the diametrical center of the crack and is expressed by the equation:

$$\delta = \frac{4(1 - \mu^2)}{E} \quad \frac{\sigma a}{\Phi}$$

Although a rigorous solution is not available for flaw opening displacements for a semi-elliptical surface flaw, such displacements should also be proportional to σ and a/Φ for elastic materials. By following Irwin's procedure (Ref. 4) to account for the effect of plastic yielding, the flaw opening displacement, δ, for a surface flaw can be approximated by

$$\delta = G \frac{\sigma \ a}{\sqrt{Q}}$$

where G is a constant. The value of G can be determined by knowledge of initial and final flaw sizes and the change in flaw opening displacement as indicated below:

$$G = \frac{\delta_f - \delta_i}{(a/\sqrt{Q})_f - (a/\sqrt{Q})_i}$$

Knowing the above constant, the instantaneous flaw size can be estimated and, therefore, the instantaneous flaw growth rates can be calculated.

Crack growth rates da/dN and d(a/Q)/dN were plotted as a function of stress intensity and summary curves of the results are shown in Figs. 17 through 25. Individual da/dN data points are plotted in Figures 55 through 98 and individual d(a/Q)/dN data points are plotted in Figures 106 through 149. Data are identified as instantaneous or measured average growth rates.

Forman, Kearney and Engle (Ref. 28) have proposed a fatigue crack propagation model of the form:

$$da/dN = \frac{C\ (\Delta K_I)^n}{(1 - R)K_{cr} - \Delta K_I}$$

where: da/dN = fatigue crack growth rate

ΔK_I = cyclic stress intensity range

K_{IE} = critical stress intensity

R = stress ratio, minimum stress/maximum stress

C,n = empirically determined constants

Forman's equation can be rewritten as $\log \left\{ [(1 - R)\, K_{IE} - \Delta K_I]\ da/dN \right\}$

$$= \log C + n \log \Delta K_I = C_1 + nx$$

which is an equation of a straight line. The constants C and n were determined by fitting crack growth rate data da/dN with ΔK_I and K_{IE} with the least square method wherever possible. The resulting constant C and exponent n for each of the summary da/dN plots in Figures 17 to 23 are shown.

3.4.2 Weldment Fatigue Crack Growth Data

There was a severe shortage of weldment fatigue crack growth data. Some data were found in Refs. 3 and 23 for tests conducted in room temperature air, liquid nitrogen at -320°F and liquid hydrogen at -423°F.

Thicknesses ranged from 0.125 to 1.00 inch. Cyclic stresses ranged from 13 to 25 ksi with stress ratios of 0.0 or 0.1. Test frequencies were 1 or 20 cpm. Typical cyclic loading profiles are shown in Fig. 13 and individual data points are summarized in Tables 51, 52 and 53. Figures 26, 27 and 28 show summary plots of crack growth rates da/dN and d(a/Q)/dN.

Individual da/dN data points are plotted in Figures 99 through 105, and individual d(a/Q)/dN data points are plotted in Figures 150 through 156.

In order to obtain cyclic flaw growth rates from the weldment data presented in Ref. 3, it was necessary to assume a manner in which the crack length varied during the cyclic test. For the 0.125 inch thick specimens ($a/2c_{initial}$ = 0.05) it was assumed that the crack length remained constant throughout the tests. For the 1.00 inch thick specimen ($a/2c_{initial}$ = 0.30) it was assumed that the flaw aspect ratio remained constant. Experience has shown these assumptions to be quite reasonable.

4.0 RECOMMENDATIONS

During the course of this study, it was found that data are lacking in several areas. In general, there were very little data at elevated temperatures. Also, there were virtually no data on the interaction of changing thermal and loading conditions such as might be encountered by tankage during flight. Investigation of the effects of such spectrum loading on flaw growth is needed in order to more accurately predict life expectancies of tankage. It was also found that there are few data to fully determine thickness effects on all properties investigated.

In addition to the general areas described above, more specific areas in which data are lacking are listed below:

1. Fracture Toughness Data
   a. Base Metal - Data are lacking in the RT propagation direction at room temperature and -423°F, and in the WT direction at -423°F. The lack of data in the RT direction is caused mainly by the fact that the material has a tendency to delaminate in this direction.
   b. Weldments - Extensive valid testing of weldments is recommended. Only ten valid test points were found, two at -320°F and eight at -423°F. This shortage of valid test points is caused by the apparent high toughness, low yield strength combination found in weldments.

2. Sustained Load Data
   a. Base Metal - Data for room temperature air, liquid nitrogen at -320°F and liquid hydrogen at -423°F appear to be adequate for the WT propagation direction. While data in the RT direction are lacking, it is anticipated that the WT direction would be the worst case, because of delamination (and hence, crack growth retardation) which has been shown to occur in the RT direction. In addition, some data are available on environments other than room air, LN_2 and LH_2. It is recommended that if applications are found for environments other than those for which thresholds are reported herein, then those environments should be tested to ensure a reasonable life expectancy of the hardware.

b. Weldments - It is recommended that further testing of weldments be undertaken to confirm the results reported herein for particular applications, especially in a 3½% salt water environment.

One of the greatest problems in using weldment threshold data in design is caused by the shortage of valid weldment fracture data. Without valid toughness values, threshold ratios, K_{TH}/K_{IE}, used in design, cannot be determined.

3. Cyclic Flaw Growth Data

a. Base Metal - Additional testing is needed at room temperature, -320°F, and -423°F in the RT propagation direction. As stated above, the shortage of data in the RT direction is mainly caused by the fact that 2219-T87 alloy has a tendency to delaminate in this direction. Cyclic flaw growth data are also lacking at R ratios other than 0.0 to 0.1.

b. Weldments - There is a general shortage of weldment cyclic growth data at all temperatures of interest. It is recommended that this area be investigated extensively.

APPENDIX A - OTHER DATA

A1.0 INTRODUCTION

All available surface flaw data are contained in the main body of this report. The limited amount of data from other types of fracture specimens are reported in this Appendix. These data all consist of tests on base metal material. A summary of the number of data points found for each type of test is shown below:

QUANTITIES OF OTHER BASE METAL TESTS

TEST TYPE \ ENVIRONMENT	3.5% NaCl	AIR @ RT	LN_2 @ -320°F	LH_2 @ -423°F
SENT K_{Ic}		4		
C.T. K_{Ic}		2	2	2
SENB K_{Ic}		2	2	2
TAPERED DCB FATIGUE	6			
T-T-T CENTER NOTCH K_c		15	4	13
T-T-T CENTER NOTCH FATIGUE		8	10	8

A2.0 PROCEDURES

A2.1 SCREENING OF THE DATA

In order to ensure that only valid data would be reported, the screening procedures outlined below were established. In addition, data were not included from reports which did not appear to be accurate. The various types of fracture specimens from which data points were obtained and the crack propagation code are shown in Figures A-1 and A-2.

A2.1.1 Plane Strain Fracture Toughness, K_{Ic}, Data from Through-the-Thickness and Round Notched Bar Specimens

Through-the-thickness data found in the literature included data from the following types of specimens: compact tension (CT), single edge notched bend (SENB), single edge notched tension (SENT), and tapered double cantilever beam (TDCB). The following ASTM criteria (Ref. 29) were used to screen this data:

1. $t \geqslant 2.5\ (K_{Ic}/\sigma_y)^2$
2. $a \geqslant 2.5\ (K_{Ic}/\sigma_y)^2$ (not required for TDCB specimens)
3. Permanent crack opening displacement (COD) at 80% of $P_{critical}$ $\leqslant$ 25% of COD at $P_{critical}$ on load versus COD Trace (CT and SENB specimens)

The load traces were generally not available, therefore, it was not always possible to determine if criterion 3 was satisfied. A limited amount of valid data was found for CT, SENB, and SENT specimens.

The following criteria were used to validate round notched bar data:

1. $\sigma_N/\sigma_y \leqslant 1.0$
2. $d_{NOTCH}/D_{BAR} = 0.4$ to 0.6
3. Notch angle $= 30^\circ$ to 60°

No valid round notched bar data were obtained.

A2.1.2 Plane Stress Fracture Toughness, K_c, Data from Through-the-Thickness Center Notched Panels

Plane stress fracture toughness data were collected only from those specimens for which $\sigma_N / \sigma_y \leqslant 0.8$.

A2.1.3 Plane Strain Fatigue Crack Growth and Sustained Load Data from Through-the-Thickness Specimens

The thickness and crack length requirements employed for fracture tests were also used for fatigue crack growth and sustained tests. The only valid fatigue data obtained from specimens other than surface flawed specimens were obtained from TDCB specimens. No valid sustained load data were obtained from specimens other than surface flawed specimens.

A2.1.4 Plane Stress Fatigue Crack Growth and Sustained Load Data from Through-the-Thickness Center Notched Panels

Only a limited amount of fatigue data were available and they fell within the $\sigma_N / \sigma_y \leqslant 0.8$ guideline. No sustained load data were found.

A2.2 STRESS INTENSITY SOLUTIONS

A2.2.1 Compact Tension Specimens

The stress intensities for compact tension specimens were calculated using the relation:

$$K_I = P/tw^{1/2} F_1 (a/w)$$

where

K_I = Plane Strain Stress intensity

P = Load

t = Thickness of Specimen

w = Width of specimen

$F_1(a/w)$ = Geometry factor from Ref. 15 (see Fig. A-3).

A2.2.2 Three Point Loaded Single Edge Notch Bend Specimens

Stress intensities for 3 point loaded single edge notched bend specimens were calculated using the relation

$$K_I = PL/tw^{3/2} \quad F_2\,(a/w)$$

where

K_I = Plane Strain Stress Intensity

P = Load

L = Span between load points at each end of the specimen

t = Thickness of specimen

w = Width of specimen

$F_2(a/w)$ = Geometry factor from Ref. 15 (see Fig. A-3)

A2.2.3 Single Edge Notched Tension Specimens

Stress intensities for SENT specimens were calculated using an experimental compliance calibration described in Ref. 30. The compliance calibration is performed by loading a specimen with varying crack lengths and measuring compliance. The rate of change of compliance with respect to crack length is then incorporated into a relation proposed by Irwin (Ref. 31). The resulting equation is of the form:

$$K_I = P/\sqrt{2}\left(E/(1-\mu^2)\cdot dC/da\right)^{1/2}$$

where

K_I = Plane strain stress intensity

P = Load

E = Young's modulus

μ = Poisson's ratio

C = compliance

a = crack length

A2.2.4 Tapered Double Cantilever Beam Specimens

Stress intensities for tapered double cantilever beam (TDCB) specimens were calculated using the following equation from Ref. 5 :

$$K_I = P/\sqrt{2t_g} \left(E/(1-\mu^2) \cdot dC/da \right)^{1/2}$$

where

K_I = Plane strain stress intensity

P = Load

t_g = Thickness at the groove (specimens were side grooved)

E = Young's modulus

μ = Poisson's ratio

C = Compliance

a = Crack length

This equation is derived from Irwin's analysis (Ref. 31). For the specimens reported herein, the design of the taper was such that the quantity dC/da was a constant. Thus the stress intensity becomes a function of variation in load only.

A2.2.5 Plane Stress Through-the-Thickness Center Notched Specimens

Stress Intensity factors for through-the-thickness center notched specimens were calculated using the "secant formula" proposed by Fedderson in Ref. 32 . It is as follows:

$$K = \sigma \sqrt{\pi c} \cdot \sqrt{\sec (\pi c/w)}$$

where

K = Plane stress stress intensity

σ = gross stress

c = half crack length

w = panel width

A3.0 DISCUSSION

A3.1 FRACTURE DATA

A3.1.1 Through-the-Thickness Plane Strain Fracture Toughness, K_{Ic}, Data

The available valid through-the-thickness plane strain fracture toughness data were limited in quantity. Some data were found in Ref. 15 for compact tension (CT) and three point loaded bend (SENB) specimens. They are reported in Tables A1 and A2. These specimens were tested in room temperature air, liquid nitrogen at -320°F and liquid hydrogen at -423°F. The propagation direction was WT. The fracture toughness values of the CT specimens were somewhat below those reported for the SENB specimens. Except in the case of SENB specimens tested at -423°F, the CT and SENB specimens exhibited lower toughness than the surface flawed (SF) specimens covered in the main body of the report. These phenomena were demonstrated earlier by Hall and Finger in Ref. 15.

Single edge notch tension specimens tested at room temperature were found in Ref. 9 for the RW and WR propagation direction. They are reported in Table A-3. No other plane strain data from other specimens with these propgation directions are available for comparison. However, the values reported appear to be somewhat lower than data from SENB tests in the WT direction and surface flaw tests in the WT and RT directions.

A3.1.2 Through-the-Thickness Plane Stress Fracture Toughness, K_c, Data

Plane stress fracture data from through-the-thickness center notched panels were found in Refs. 8, 10, 33 and 34. Test temperatures were room temperature, -320°F and -423°F, and propagation directions were WR and RW. The data are reported in Tables A-4, A-5 and A-6. In addition, endpoint critical stress intensities of cyclic tests can be found in Tables A-7, A-8 and A-9. The fracture toughness data are summarized as a function of thickness in Figs. A-4, A-5 and A-6. Because of disparities in the methods of crack initiation, and the wide scattering of the data, no attempt is made at analysis. The data are presented herein only to show what is available in the literature.

A3.2 SUSTAINED LOAD AND FATIGUE DATA

A3.2.1 Through-the-Thickness Plane Strain Sustained Load and Fatigue Crack Growth Data

No plane strain sustained load data were found; however, some cyclic growth data for tapered double cantilever bend specimens were found in Ref. 5 . These specimens were cycled in room temperature 3½% salt water solution. Propagation direction was WR. The data are reported in Table A-10 and cyclic crack growth rates are shown in Fig. A-7. No other data are available for comparison.

A3.2.2 Through-the-Thickness Plane Stress Sustained Load and Fatigue Crack Growth Data

No plane stress sustained load data were found; however, some cyclic growth data for through-the-thickness center notched panels were found in Ref. 8 . These specimens were cycled in room temperature air, liquid nitrogen at -320°F and liquid hydrogen at -423°F. Test results are tabulated in Tables A-7, A-8 and A-9 . The data were not available in a form readily usable, because instantaneous growth rates were not available. However, average stress intensities and average growth rates were calculated and these values are shown graphically in Fig. A-8. The data were not suitable for a detailed analysis.

APPENDIX B - REPORTS CONTAINING INVALID OR OTHERWISE UNUSABLE DATA

During the course of this study, many reports were found containing data which could not be used in this analysis for various reasons. In order to provide a single listing for easy reference in future studies, the reports containing this data are described below.

Additional base metal tensile data were found in Refs. 35 through 50. Data from these references were not included because the data were typical or average values, or they were meant for special applications. Of these references, 41, 49 and 50 were of particular interest. Ref. 41 was a survey of tensile values for material ranging in thickness from 0.040 inch to 5.00 inches; including tensile values from various locations in thick plate. Ref. 49 provided typical values for several different alloys. Ref. 50 reported the effect of magnetic forming on tensile values.

Additional weld metal tensile data were found in Refs. 39, 51 and 52. Data from Refs. 39 and 51 were typical values, while Ref. 52 provided a study of weldment properties at different weldment locations (weld centerline, fusion line, heat affected zone).

Additional fracture data were found in Refs. 2, 11, 16, 17, 26, 34, 36, 38, 46, 52, 53 and 54. Ref. 36 contained only typical values of fracture toughness. Invalid K_{Ic} values for notched bend, single edge notched tension, and round notched bars were found in Refs. 11, 46, and 34 respectively. Ref. 17 contained data from charpy and [illegible]n tear specimens. Invalid weldment fracture tests conducted on single edge notched bend, single edge notched tension, and double cantilever beam specimens were found in Ref. 52. Ref. 26 contained a plot of fatigue crack growth rate data for compact tension specimens; however, these were unpublished data from the Space Division of North American Rockwell, and the tabular values were not available to this author. Through-the-thickness center notched tests for which $\sigma_N / \sigma_y > 0.8$ were found in Ref. 54.

Invalid surface flawed data were found in Ref. 53 . In addition, Refs. 2 and 53 both contained tests investigating the effect of proof overloading on subsequent testing. Testing in Ref. 16 was just commencing at the time of publication of this report; therefore, only tensile data were available from this reference. Testing to be conducted in Ref. 16 will include cyclic tests with and without prior proof overloading. Ref. 38 contains useful data for surface flaws emanating from holes.

Most of the references cited in the main body of this report contained some invalid fracture data in addition to the valid data that was reported.

APPENDIX C

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

Due to the complexity of the data presented in this report, only U.S. customary units are used. Conversion factors for converting U.S. customary to SI units are given in the following table:

To Convert From (U.S. Customary Unit)	Multiply by	To Obtain (SI Units)
in.	2.54×10^{-2}	meter (m)
lbf	4.448	newton (n)
kip	4.448	kilonewton (kN)
ksi	6.895	meganewton/meter^2 (MN/m^2)
ksi$\sqrt{\text{in}}$	1.099	MN/m$^{3/2}$

PRECEDING PAGE BLANK NOT FILMED

REFERENCES

1. "Tension Testing of Metallic Materials", ASTM E8-69.

2. "Fracture Characteristics of Structural Aerospace Alloys", NAS Contract NAS 3-14341 (in work, to be published as a NASA Contract Report in 1972)

3. Masters, J.N., Haese, W.P., and Finger, R.W., "Investigation of Deep Flaws in Thin Walled Tanks", NASA CR-72606, Dec. 1969.

4. Irwin, G.R., "Crack Extension Force for a Part-Through-Crack in a Plate", Journal of Applied Mechanics, Vol. 29, Trans. ASME, Vol. 84, Series E, December 1962.

5. "Subcritical Flaw Growth in Metal Tanks", NASA Contract NAS 3-12044 (in work) to be published as a NASA Contract Report in 1972.

6. Lorenz, P.M., "Fracture Toughness and Subcritical Flaw Growth Characteristics of Saturn SI-C Tankage Materials", Boeing Co. Report D2-22802, April 1964.

7. Hunter, M.S., and Fricke, W.G., "Study of Crack Initiation Phenomena Associated with Stress Corrosion of Aluminum Alloys", NASA CR 102474, October 1969.

8. Eitman, D.A., and Rawe, R.A., "Plane Stress Cyclic Flaw Growth of 2219-T87 Aluminum and 5Al-2.5Sn (ELI) Titanium Alloys at Room and Cryogenic Temperatures", NASA CR 54956, Sept. 1966.

9. Freed, C.N., Goode, R.J., and Judy, R.W., "Comparison of Fracture Toughness Test Procedures for Aluminum Alloys", NRL Report 6853, Feb. 17, 1969.

10. Ferguson, C.W., "Hypervelocity Impact Effects on Liquid Hydrogen Tanks", NASA CR 54852, March 1966.

11. Carman, C.M., Forney, J.W., and Katlin, J.M., "Plane Strain Fracture Toughness of 2219-T87 Aluminum Alloy at Room and Cryogenic Temperatures", NASA CR-54297, Aug. 1966.

12. Turley, R.V., Dash, E., and Avery, C.H., "Stress Corrosion Susceptibility of Welded Aluminum Alloys", AFML-TR-67-291, August 1967.

13. Tiffany, C.F., Lorenz, P.M., and Hall, L.R., "Investigation of Plane Strain Flaw Growth in Thick-Walled Tanks", NASA CR-54837, Feb. 1966.

14. Tiffany, C.F., Lorenz, P.M., and Shah, R.C., "Extended Loading of Cryogenic Tanks", NASA CR-72252, July 1967.

15. Hall, L.R., and Finger, R.W., "Investigation of Flaw Geometry and Loading Effects on Plane Strain Fractures in Metallic Materials", NASA CR 72659, Dec. 1971, (NAS 3-12016).

16. "Study of Deep Flaws in Weldments of Aluminum and Titanium", NASA Contract NAS 3-14386 (in work, to be published as a NASA Contract Report in 1972).

17. Hellquist, V.G., Hurlich, A., Goldberg, M.L., and Duffy J.C., "Nova Study Program - Supporting Hardware Investigations, Weld Test Program", General Dynamics/Astronautics Report No. GD/A 63-0705, August 16, 1963, (NASA Contract NAS 8-5136).

18. Natrella, M.G., Experimental Statistics, National Bureau of Standards Handbook 91, U.S. Government Printing Office, Washington, D.C., August 1, 1963.

19. D-5000, Boeing Design Manual, Book 84-A2, Section 82.

20. Kiefer, T.F., Keys, R.D., and Schwartzberg, F.R., "Determination of Low Temperature Fatigue Properties of Structural Metal Alloys", Martin Co., Denver, Colo., Report CR 64-74, October 1964 (NASA Contract NAS 8-2631).

21. Munafo, P., "Fracture Toughness Evaluation of 2219-T87 Aluminum and AISI 321 CRES.", Boeing Co. Report D5-14229, March 1970.

22. "Stress Corrosion of Metal Tank Materials", NASA Contract NAS 3-12003 (in work, to be published as a NASA Contract Report in 1972).

23. Tiffany, C.F., "Investigation of Preflawed 2219 Aluminum Tanks", Boeing Co. Report D5-13663, Aug. 1966.

24. Munafo, P.M., "Investigation of the Deep Flaw Effect in SI-C Tankage", Boeing Document D5-14232, September 1970 (NASA Contract NAS 8-5608).

25. Hyatt, M.V., and Speidel, M.O., "Stress-Corrosion Cracking of High Strength Aluminum Alloys", Boeing Document D6-24840, June 1970, (also published by Plenum Press in Advances in Corrosion Science and Technology, Volume 2, edited by M.G. Fontana and R.W. Staehle, 1971).

26. Forman, R.G., "Fatigue Flaw Growth Behavior of 2219-T87 Aluminum at Cryogenic, Room and Elevated Temperatures", NASA Manned Spacecraft Center, Materials Technology Branch, Report 71-ES5-1, Sept. 1971.

27. Green, A.E., and Sneddon, I.N., "The Distribution of Stress in the Neighborhood of a Flat Elliptical Crack in an Elastic Solid", Proc. Cambridge Phil. Soc. Vol. 46 (1950).

28. Forman, R.G., Kearney, V.E., and Engle, R.M., "Numberical Analysis of Crack Propagation in Cyclic-Loaded Structures", Journal of Basic Engineering, Vol. 89, No. 3, September 1967.

29. "Tentative Method of Test for Plane Strain Fracture Toughness of Metallic Materials", ASTM E399-70T.

30. Sullivan, A.M., "New Specimen Design for Plane-Strain Fracture Toughness Tests", Materials Research and Standards, January 1964.

31. Irwin, G.R., "Fracture Testing of High Strength Sheet Materials Under Conditions Appropriate for Stress Analysis", Report 5486, U.S. Naval Research Laboratory, July 1960.

32. Brown, W.F., and Srawley, J.E., "Plane Strain Crack Toughness Testing of High Strength Metallic Materials", Discussion, ASTM STP 410, 1966.

33. Pfluger, A.R., "Fracture Toughness of 2219-T87 Aluminum", NASA CR 60285, Oct. 10, 1964, X65-11726 (NASA Contract NAS 8-9500).

34. Eichenberger, T.W., "Fracture Resistance Data Summary", Boeing Co. Report D2-20947, June 1962.

35. Kaufman, J.G., Bogardous, K.O., and Wanderer, E.T., "Tensile Properties and Notch Toughness of Aluminum Alloys at $-452^{\circ}F$ in Liquid Helium", Alcoa Paper presented at Cryogenic Engineering Conference, Palo Alto, Calif., Aug. 21-23, 1967.

36. Freed, C.N., and Goode, R.J., "Relationship Between Fracture Toughness and Estimated Plastic Zone Size in Steel, Titanium and Aluminum Alloys", Naval Research Lab., Washington, D.C., Final Report No. 6991, Nov. 28, 1969.

37. Horst, R.L., Hollingsworth, E.H., and King, W., "A New Solution Potential Measurement for Predicting Stress Corrosion Performance of 2219 Aluminum Alloy Products", Corrosion, Vol. 25, No. 5, May 1969.

38. Hall, L.R., and Finger, R.W., "Fracture and Fatigue Growth of Partially Embedded Flaws", AFFDL TR 70-144, Sept. 1970.

39. Kaufman, J.G., Nelson, F.G., and Johnson, E.W., "The Properties of Aluminum Alloy 2219 Sheet, Plate, and Welded Joints at Low Temperature", Advances in Cryogenic Engineering - Vol. 8, Proceedings of the 1962 Cryogenic Engineering Conference, August 1962.

40. Hunsicker, H.Y., and Hess, J.H., "New Weldable High Strength Aluminum Alloys for Cryogenic Service", Advances in Cryogenic Engineering, Vol. II, 1966.

41. Denaburg, C.R., "Low Temperature Mechanical Properties of Aluminum Alloy 2219-T87, 0.04 inch Thick Sheet Through 5.00 inch Thick Plate", NASA TM-X-53332, Sept. 1965.

42. Nock, J.A., Holt, M., Sprowls, D.O., "Alcoa Aluminum Alloy 2219, A High Strength Aluminum Alloys", Metals Progress, Sept. 1961.

43. Montano, J.W., "Short Time Elevated Temperature Mechanical Properties of 2219-T87 and 2219-T6 Aluminum Alloys", Journal of Basic Engineering, Vol. 89, No. 1, March 1967.

44. "What Metal Shall I Use for High Strength Welded Structures", Metal Progress, October 1966.

45. Sessler, J., and Weiss, J., "Material Data Handbook - Aluminum Alloy 2219", NASA CR 74545, March 1966.

46. Goode, R.J., et al., "Metallurgical Characteristics of High Strength Structural Materials", NRL Report 6405, November 1965.

47. Mayer, L.W., "Alcoa Aluminum Alloy 2219", Alcoa Green Letter Sept. 1965.

48. Schwartzberg, F.R., "Cryogenic Materials Data Handbook Vol. I and II", AFML-TDR-64-280, Revision of August 1968.

49. Kaufman, J.G., and Holt, M., "Fracture Characteristics of Aluminum Alloys", Alcoa Research Laboratories, Technical Paper No. 18, 1965.

50. Jewett, R.P., "Influence of Magnetic Forming on 2219 and 2014 Aluminum Alloys", Rocketdyne Report R-6703, September 1966 (NASA Contract NAS 8-20278).

51. Robinson, I.B., Collins, F.R., and Dowd, R.D., "Welding High Strength Aluminum Alloys", Welding Journal Research Supplement, May 1962.

52. Pyle, R., Schillinger, D.E., and Carman, C.M., "Plane Strain Fracture Toughness and Mechanical Properties of 2219-T87 Aluminum and 5Al-2.5Sn ELI Titanium Alloy Weldments and One inch Thick 5Al-2.5Sn ELI Titanium Alloy Plate", NASA CR 72154, Sept. 1968.

53. "Metal Tank Fracture and Design Criteria", NASA Contract NAS 3-14346 (in work, to be published as a NASA Contract Report in 1972).

54. Orange, T.W., Sullivan, T.L., and Calfo, F.D., "Fracture of Thin Sections Containing Through and Part Through Cracks", NASA TN D-6305, April 1971.

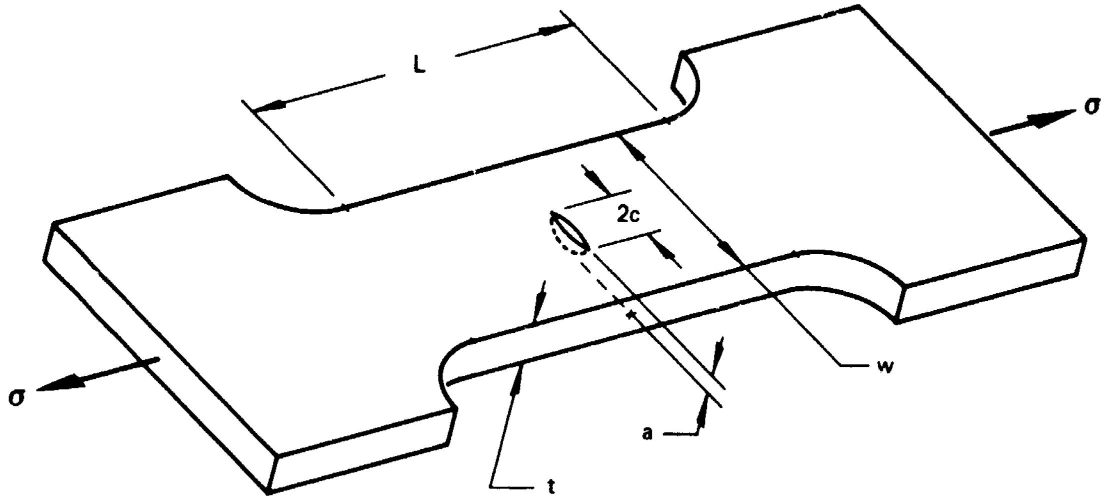


Figure 1: Surface Flaw Specimen Configuration

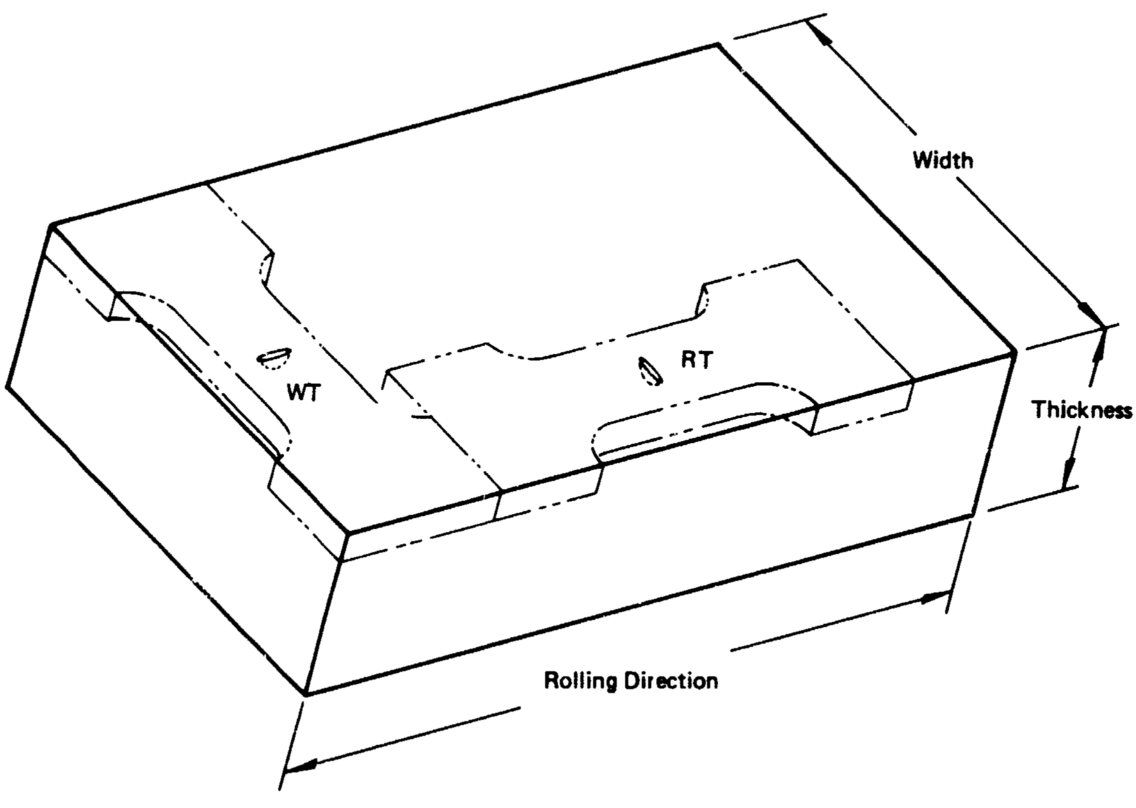


Figure 2: Propagation Direction Code For Surface Flaw Specimens

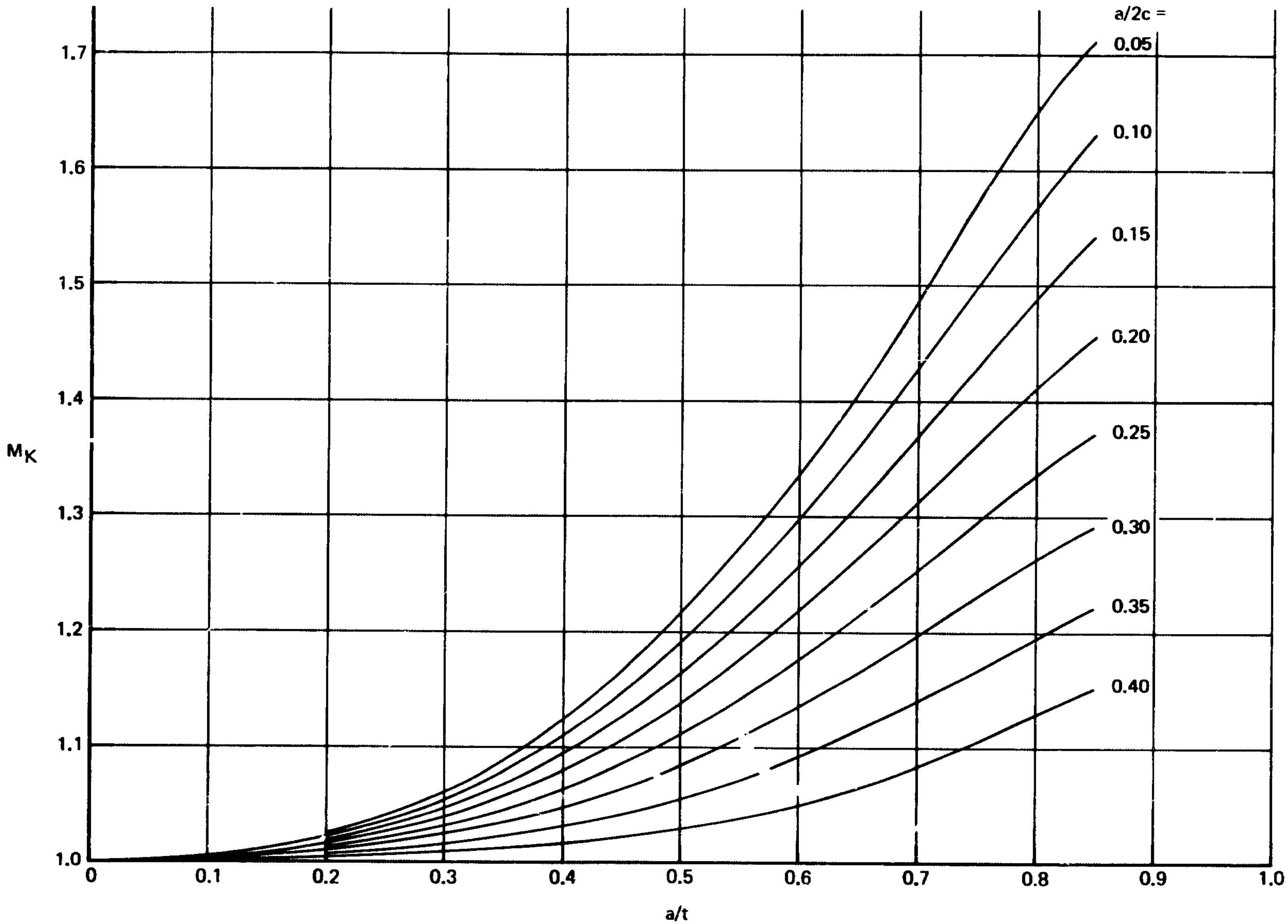


Figure 3: Deep Flaw Magnification Curves (Reference 3)

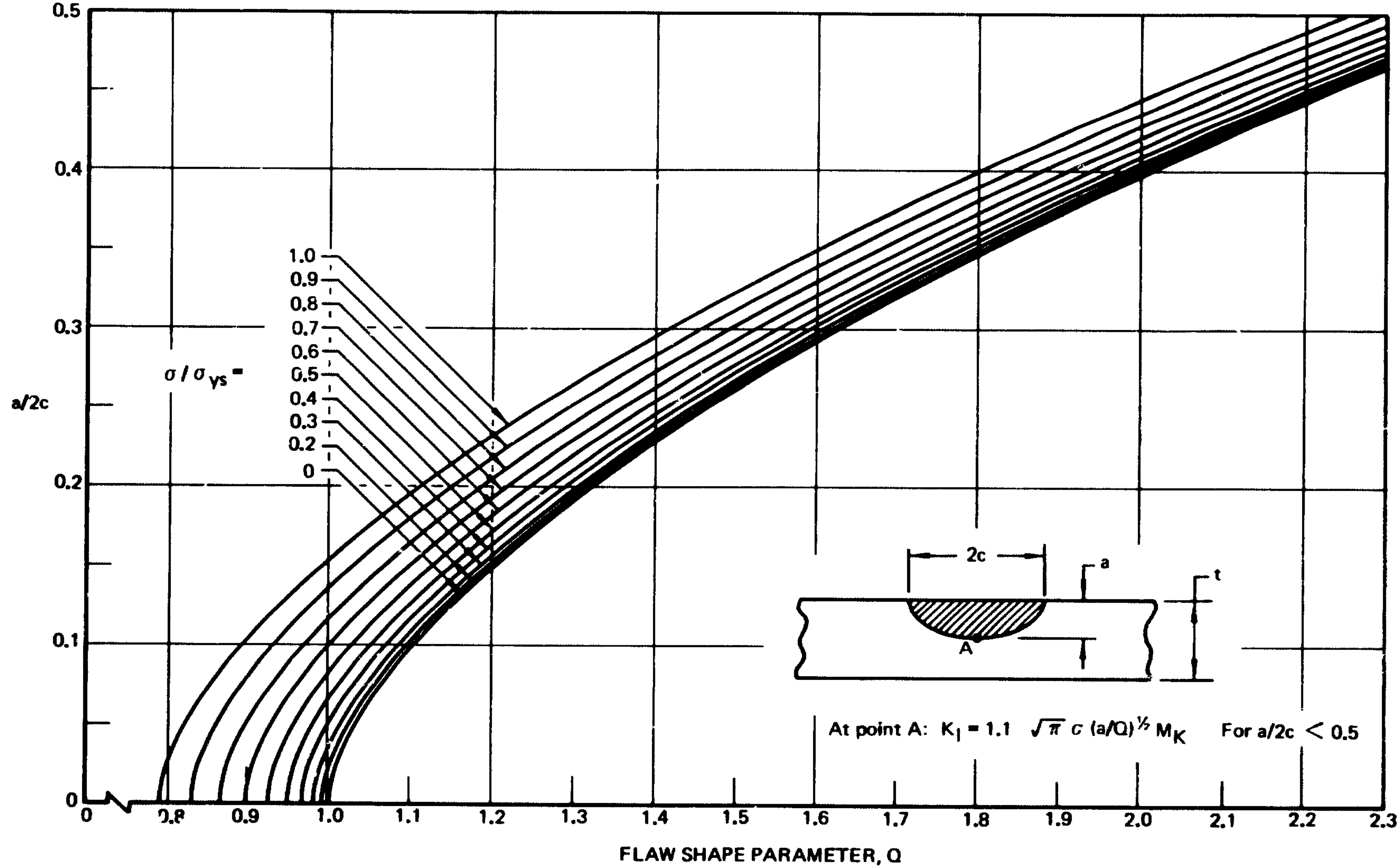


Figure 4 : Shape Parameter Curves for Surface and Internal Flaws

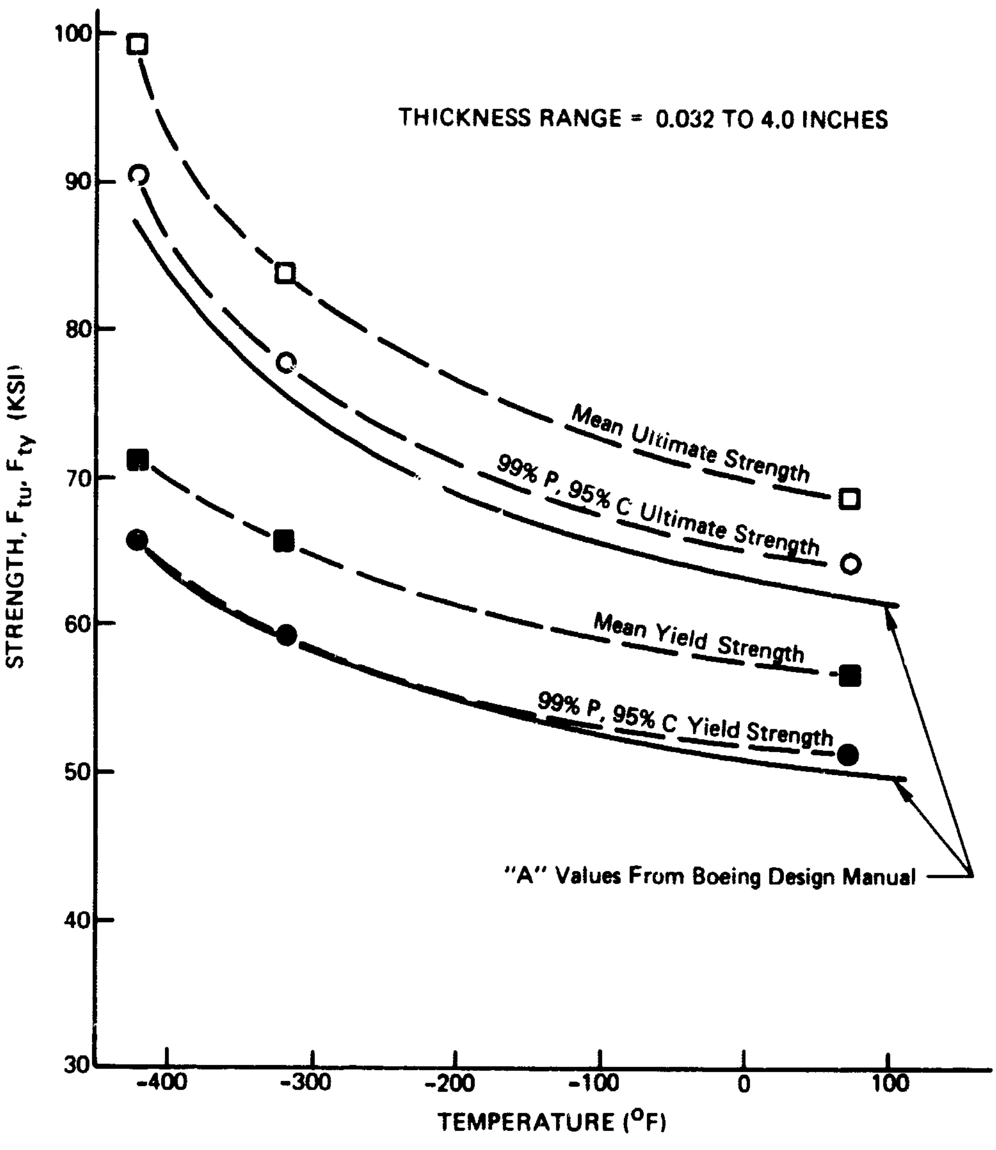


Figure 5: Ultimate and Yield Strength Vs. Temperature , 2219-T87 Aluminum Alloy, Longitudinal Grain Direction

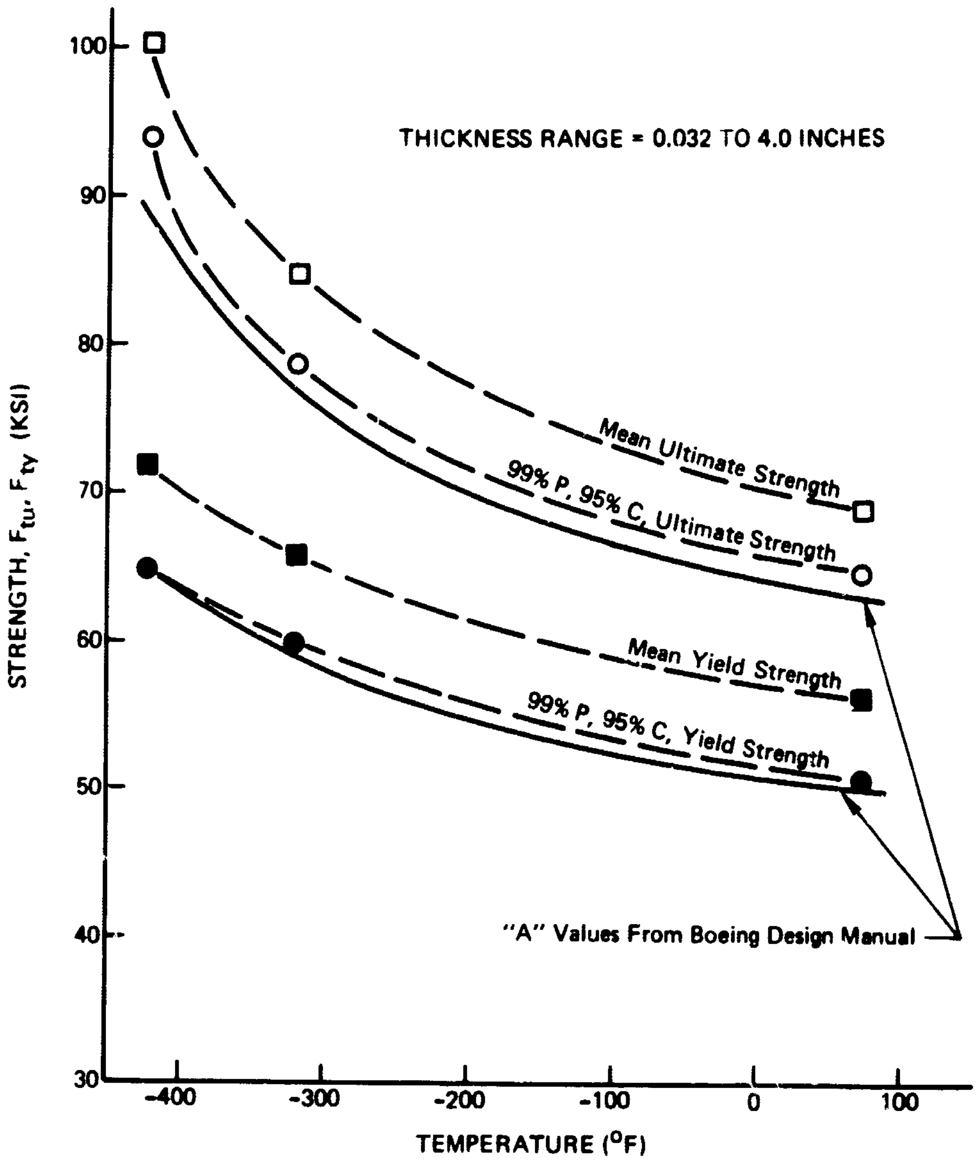


Figure 6: Ultimate and Yield Strength Vs. Temperature, 2219-T87 Aluminum Alloy, Long Transverse Direction

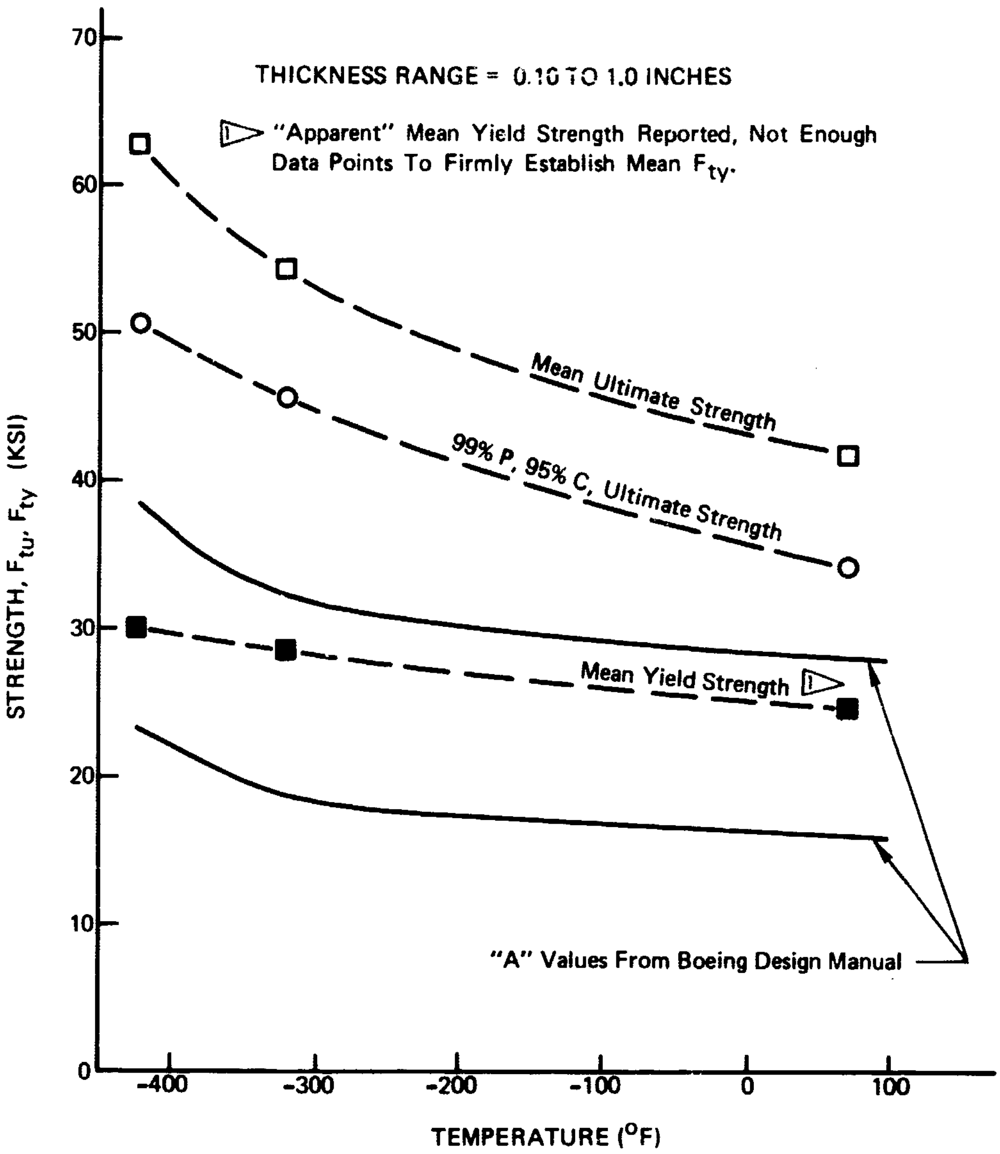


Figure 7: Ultimate and Yield Strength Vs. Temperature, GTA Welded 2219-T87 Aluminum Alloy, No Post Weld Heat Treatment

2

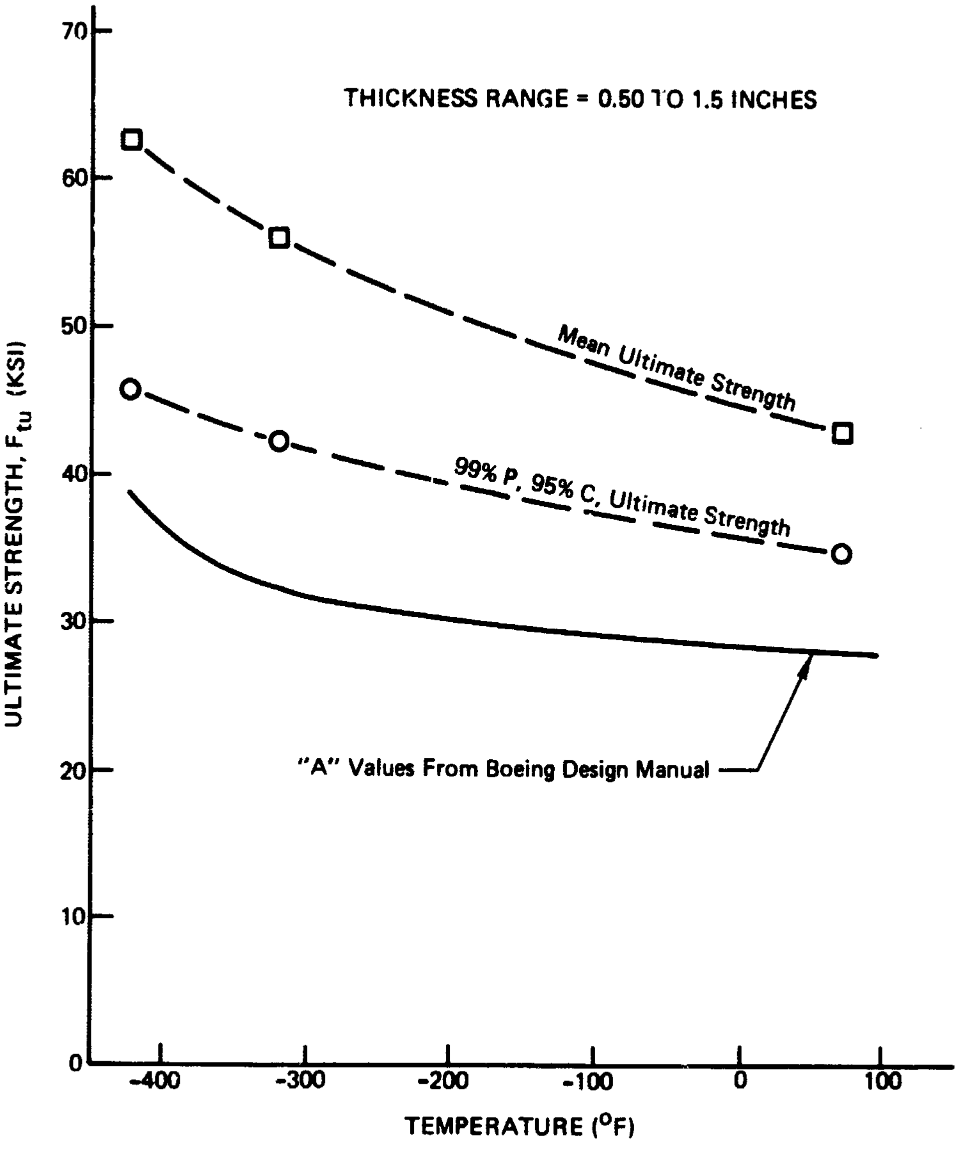


Figure 8: Ultimate Strength Vs. Temperature, GMA Welded 2219-T87 Aluminum Alloy, No Post Weld Heat Treatment

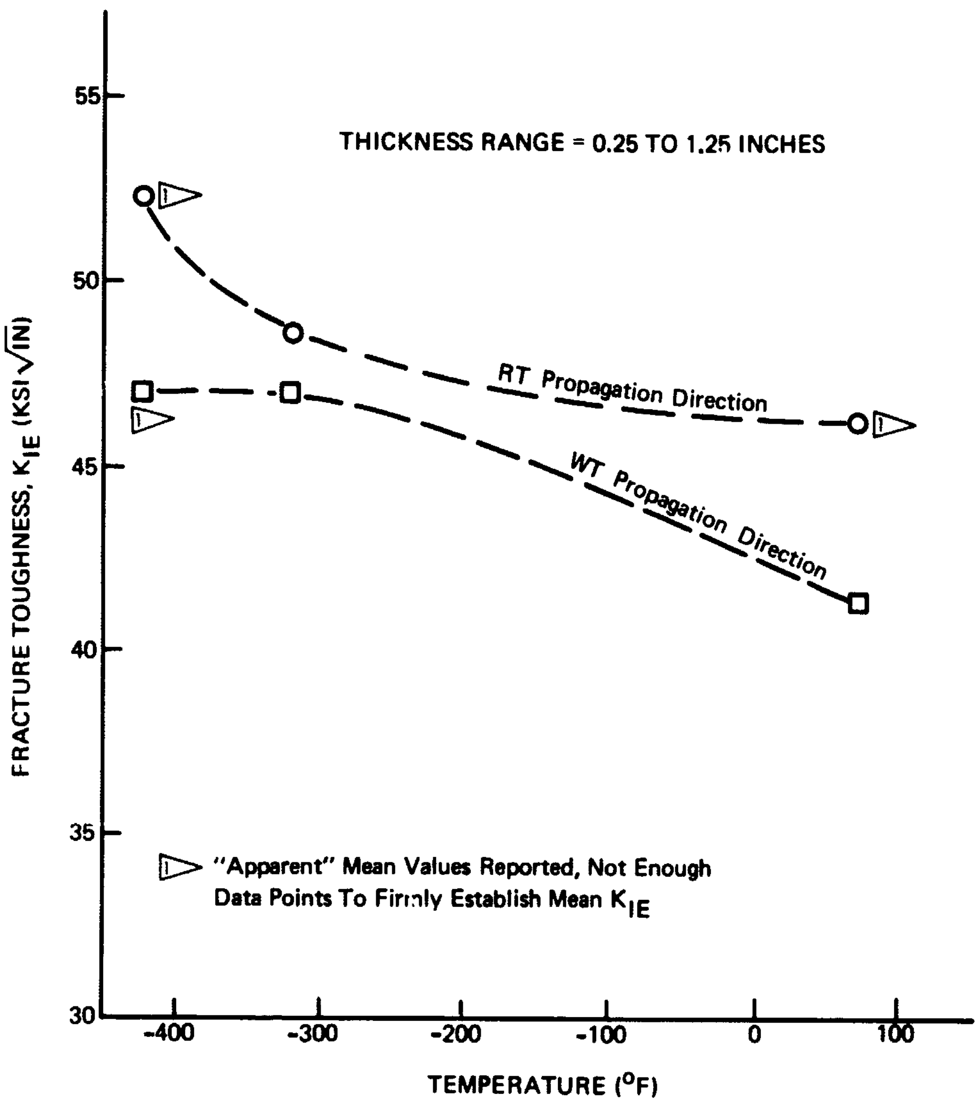


Figure 9: Fracture Toughness Vs. Temperature, 2219-T87 Aluminum Alloy, RT and WT Propagation Direction (From Surface Flawed Specimen Tests)

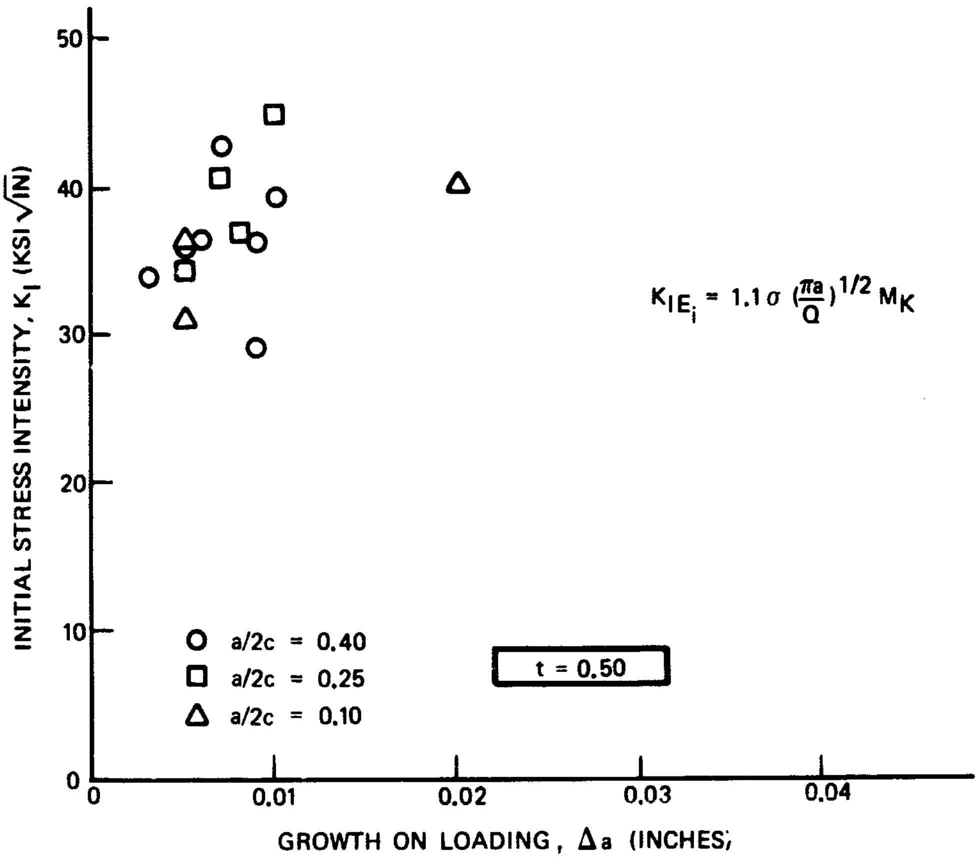


Figure 10: Growth-On-Loading in 2219-T87 Aluminum Base Metal in Liquid Nitrogen at -320°F (surface flawed specimens)

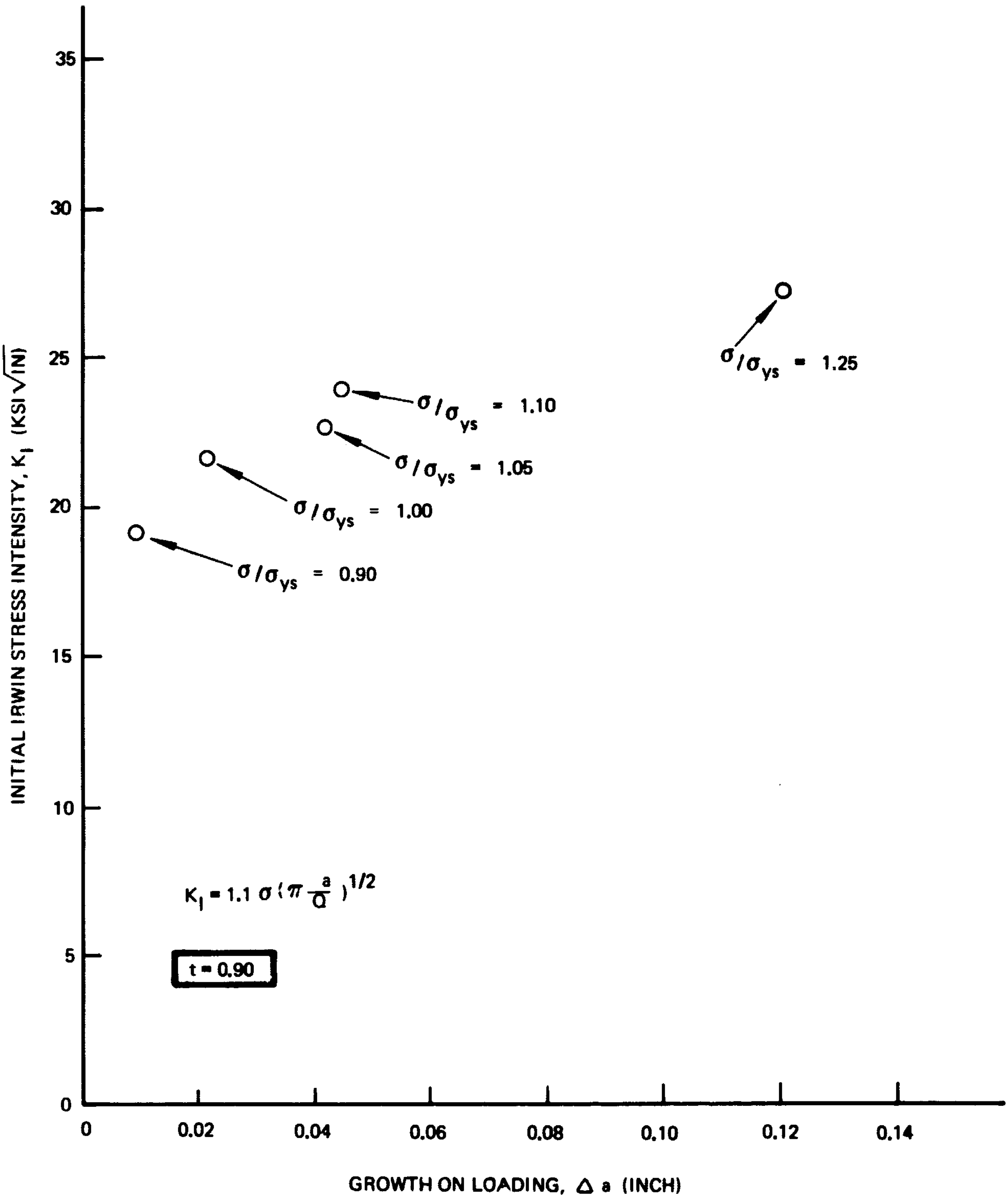


Figure 11: Growth-On-Loading In 2219-T87 Aluminum GTA Weldment In Air At Room Temperature, No Post Weld Heat Treatment (Surface Flawed Specimens)

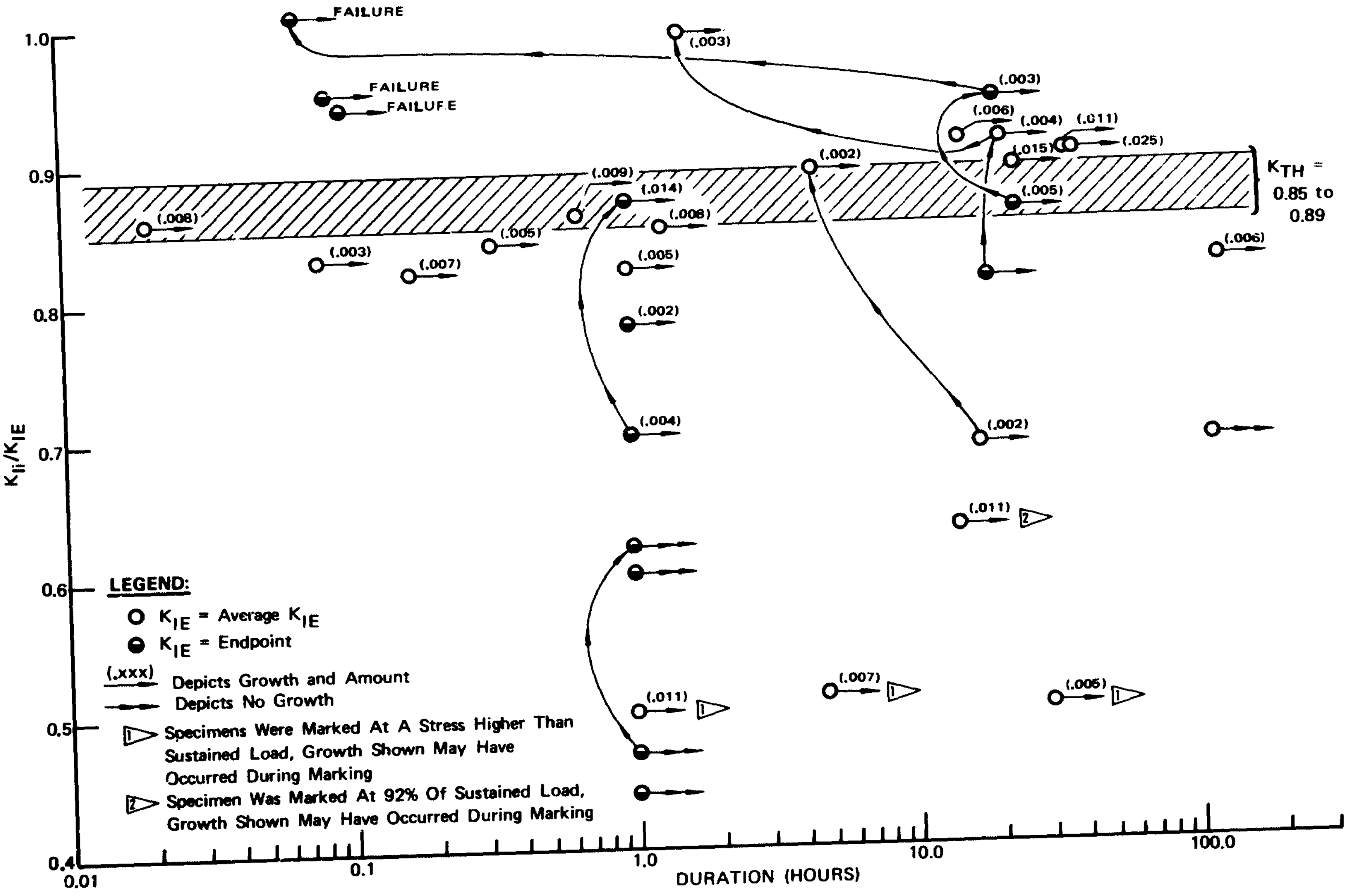


Figure 12: Stress Intensity Vs. Test Duration, 2219-T87 Aluminum Alloy, WT Propagation Direction, Room Temperature Air, t = 0.65 Inches (Reference 14)

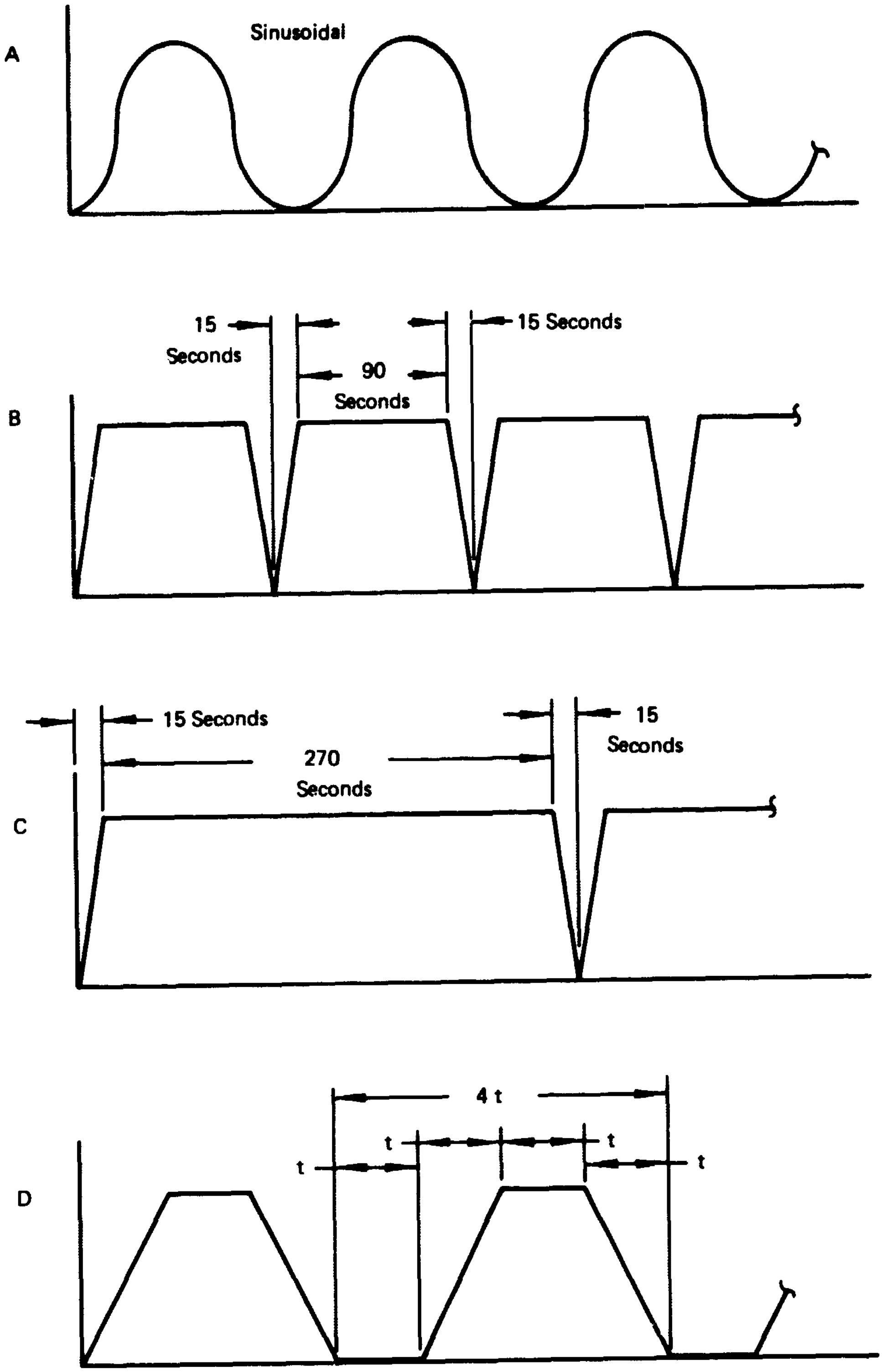


Figure 13: Cyclic Loading Profile

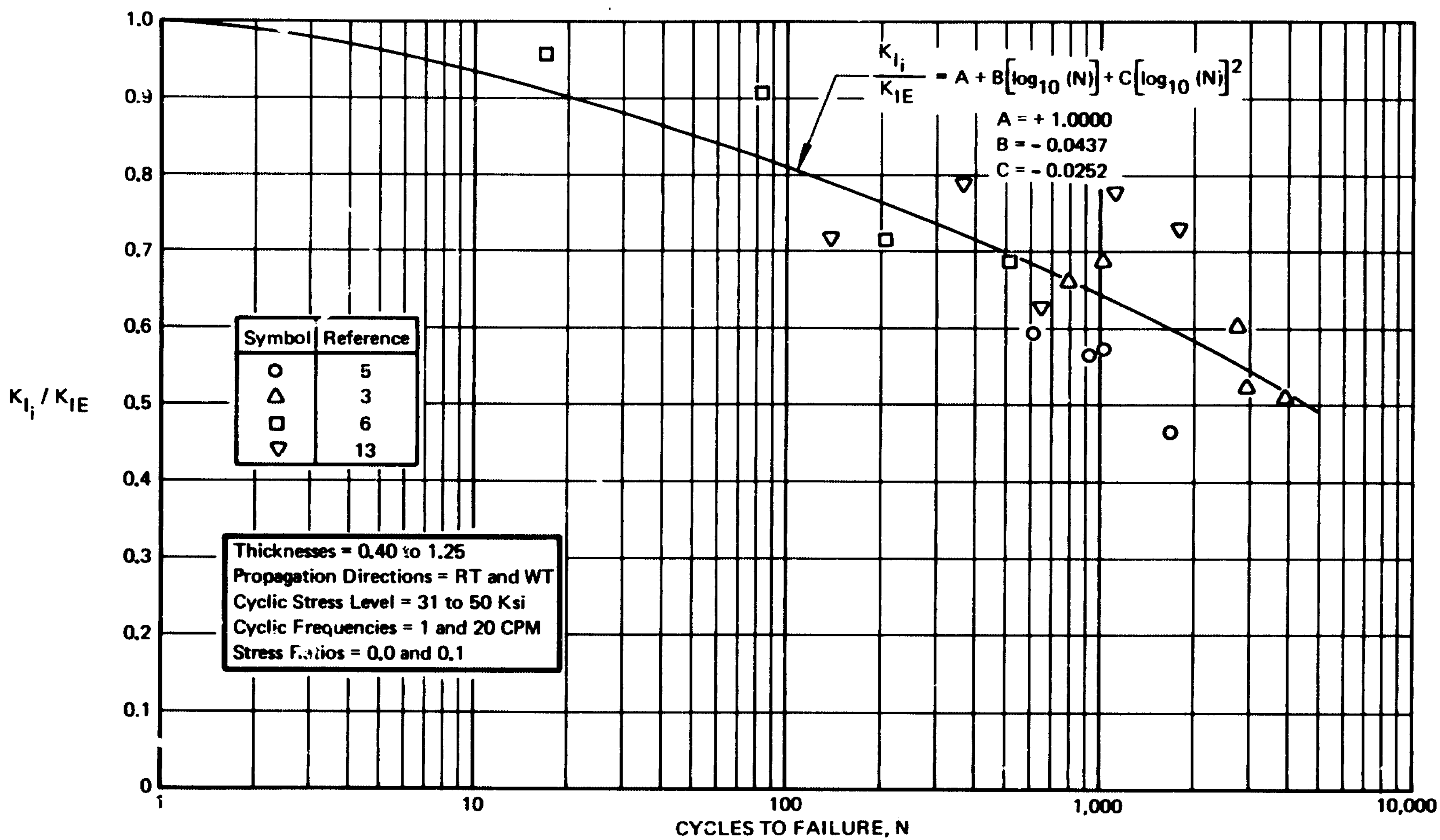


Figure 14: Initial Stress Intensity Vs. Cycles to Failure, 2219–T87 Aluminum Alloy Tested at Room Temperature in Air

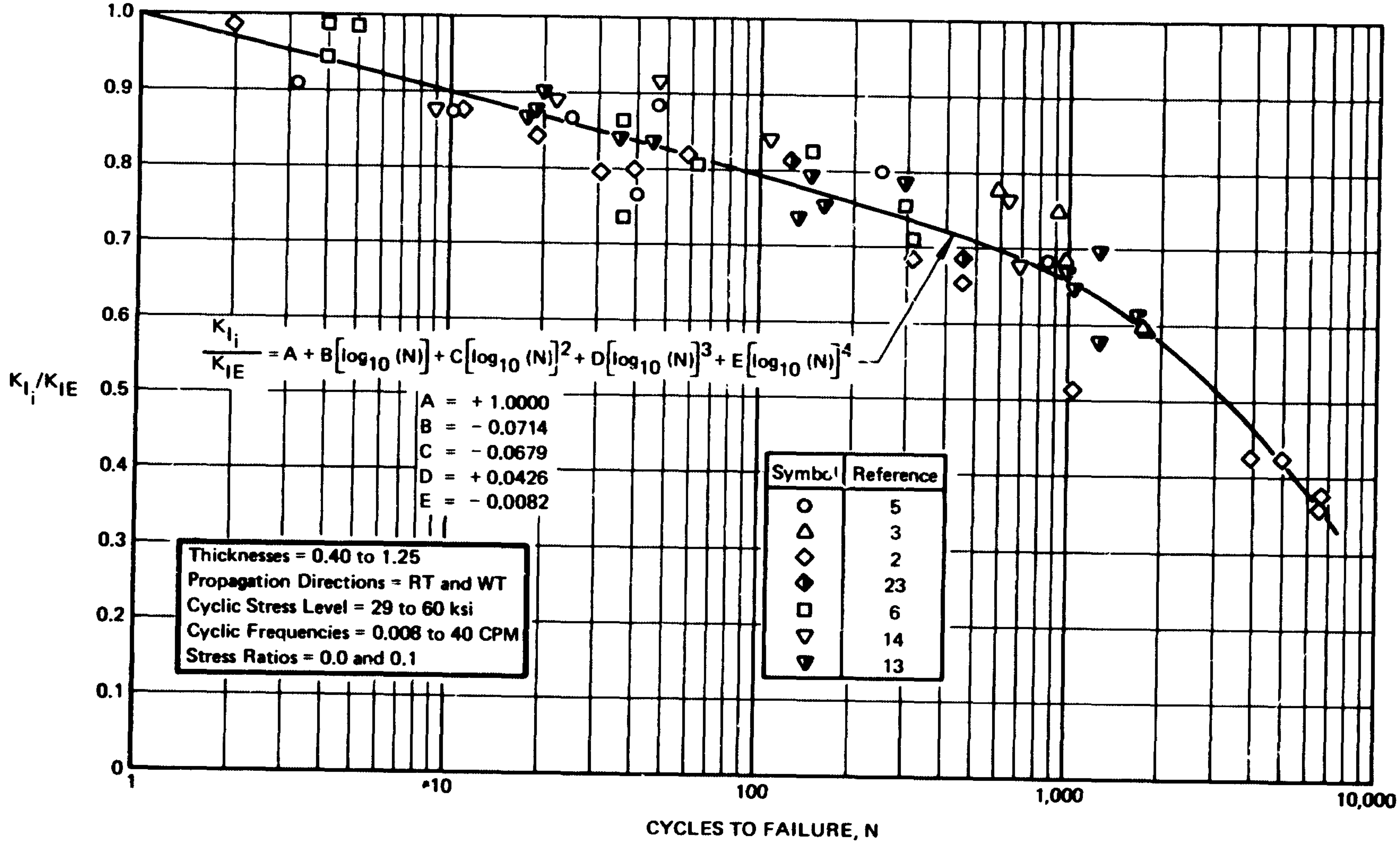


Figure 15: Initial Stress Intensity Vs. Cycles to Failure, 2219-T87 Aluminum Alloy Tested at -320° F in Liquid Nitrogen

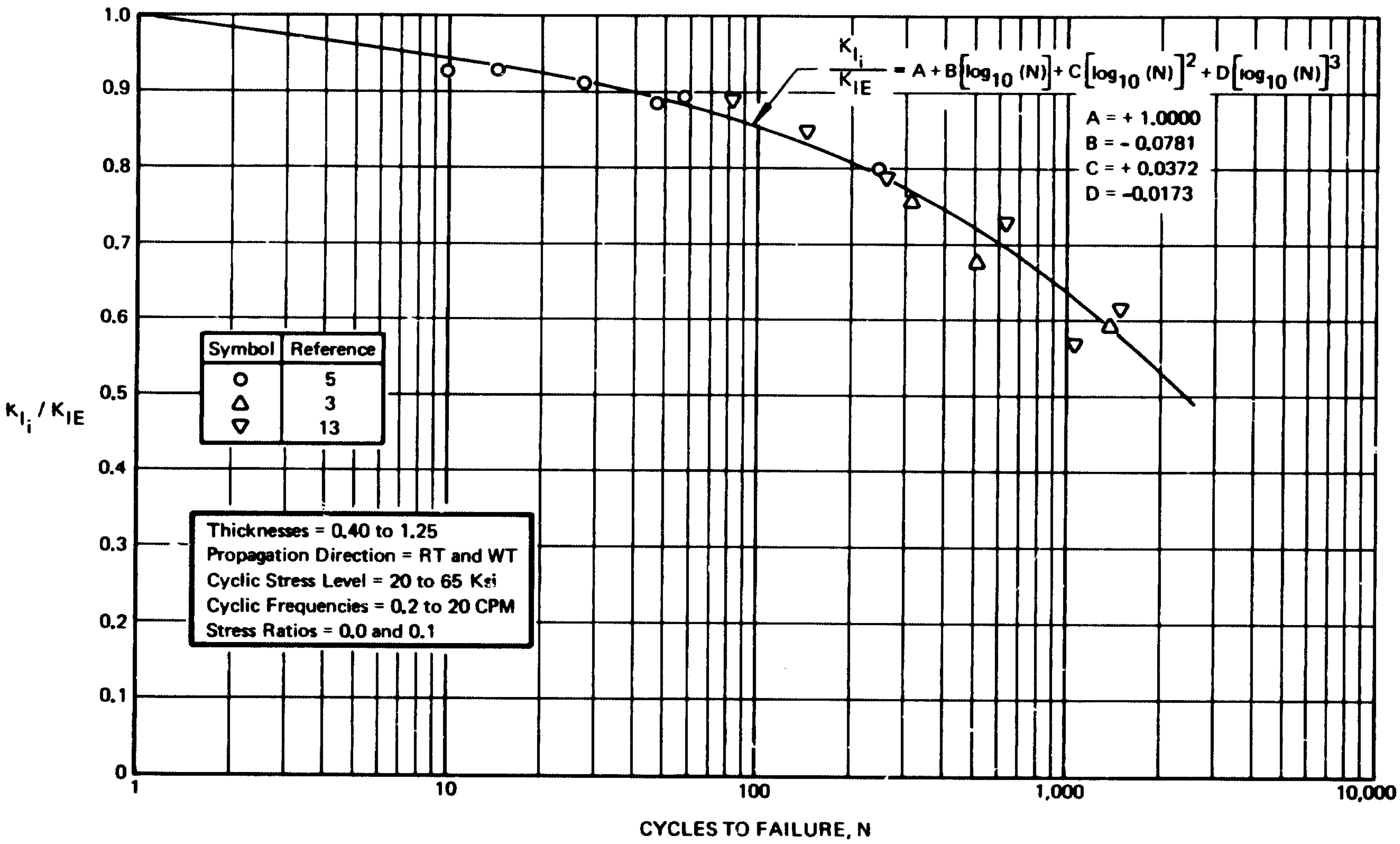


Figure 16: Initial Stress Intensity Vs. Cycles to Failure, 2219–T87 Aluminum Alloy Tested at –423°F in Liquid Hydrogen

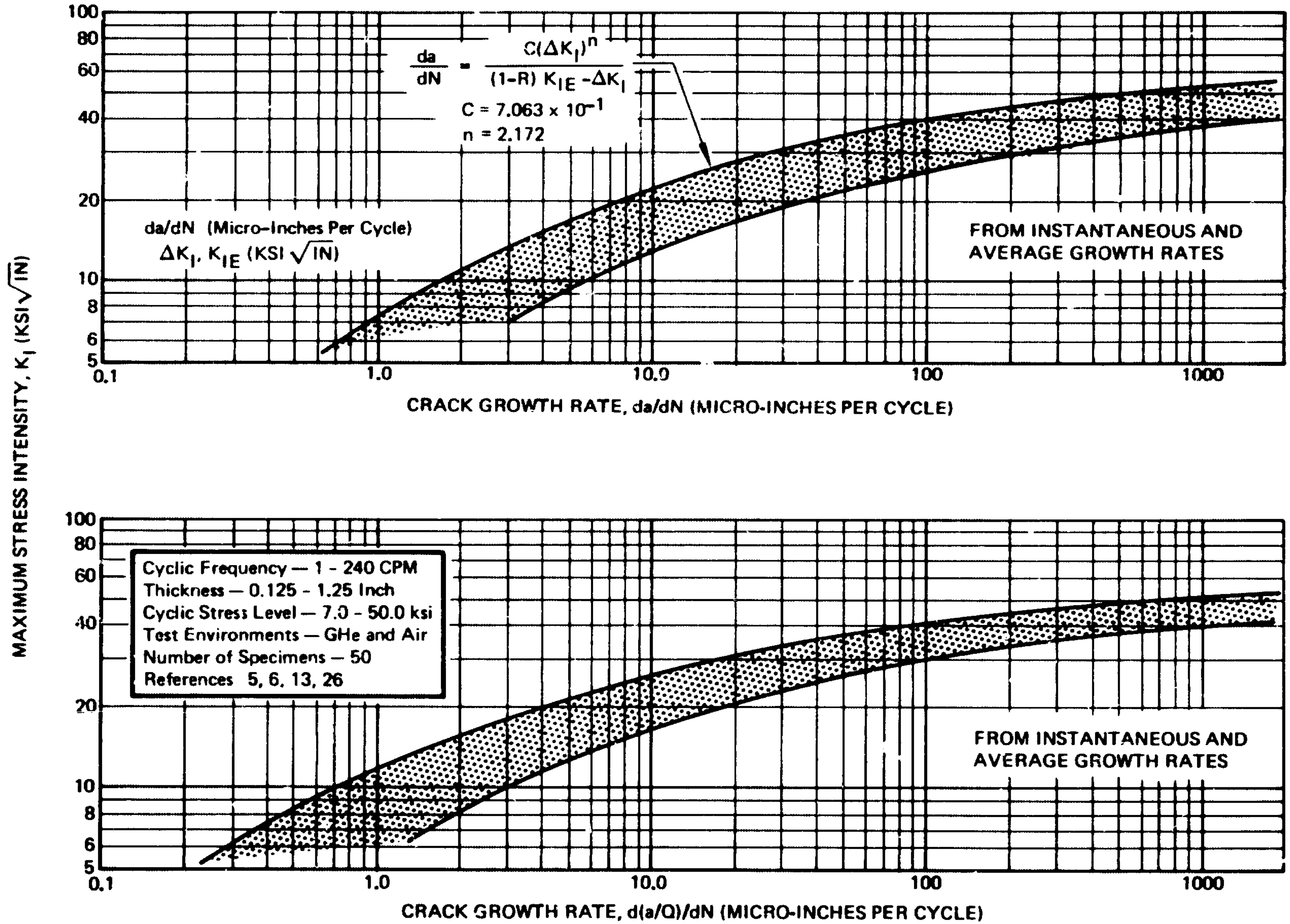


Figure 17 : Cyclic Flaw Growth Rates For 2219-T37 Aluminum Base Metal At Room Temperature For The WT Propagation Direction, $R \leq 0.1$

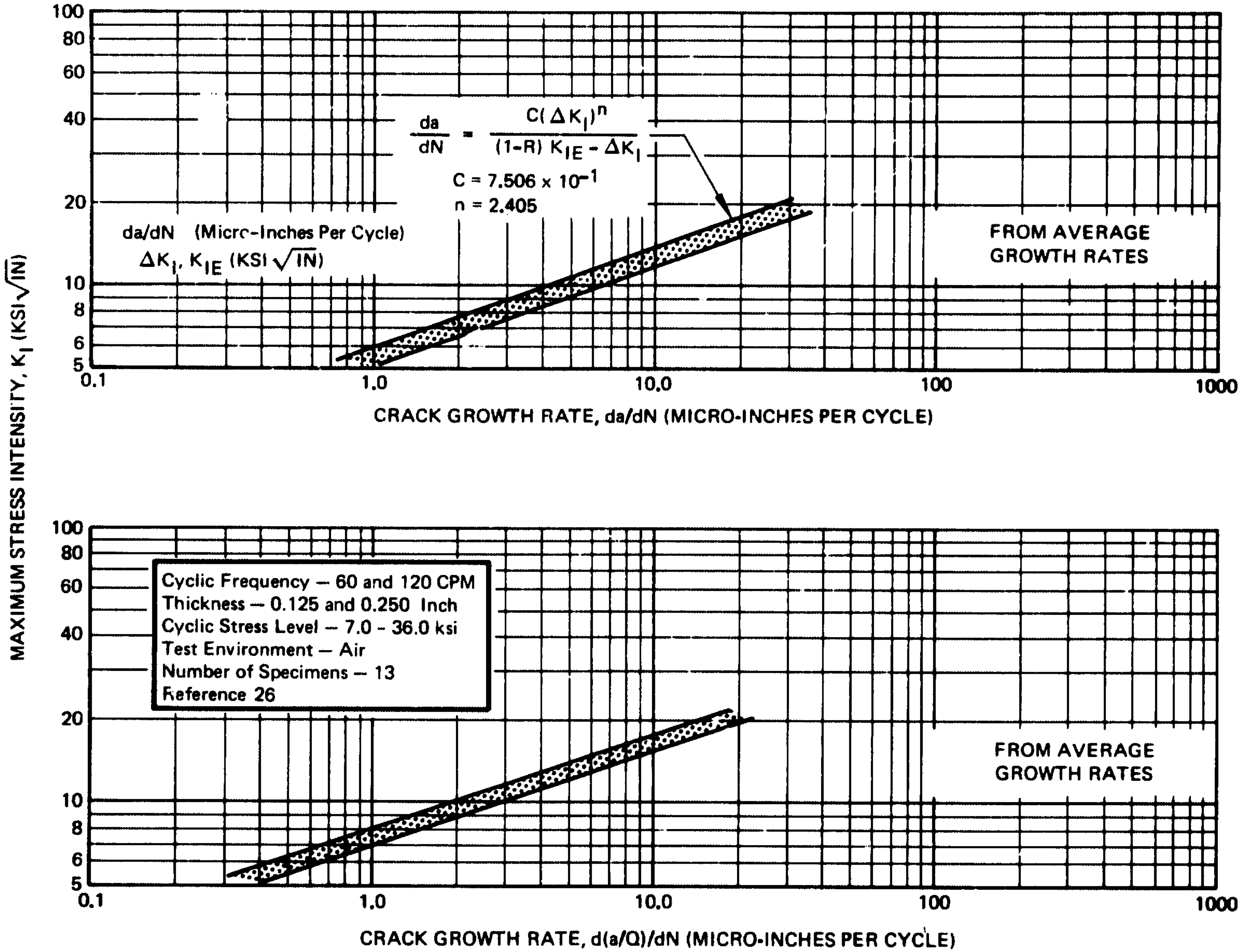


Figure 18 : Cyclic Flaw Growth Rates For 2219-T87 Aluminum Base Metal At Room Temperature For The RT Propagation Direction , $R \leq 0.1$

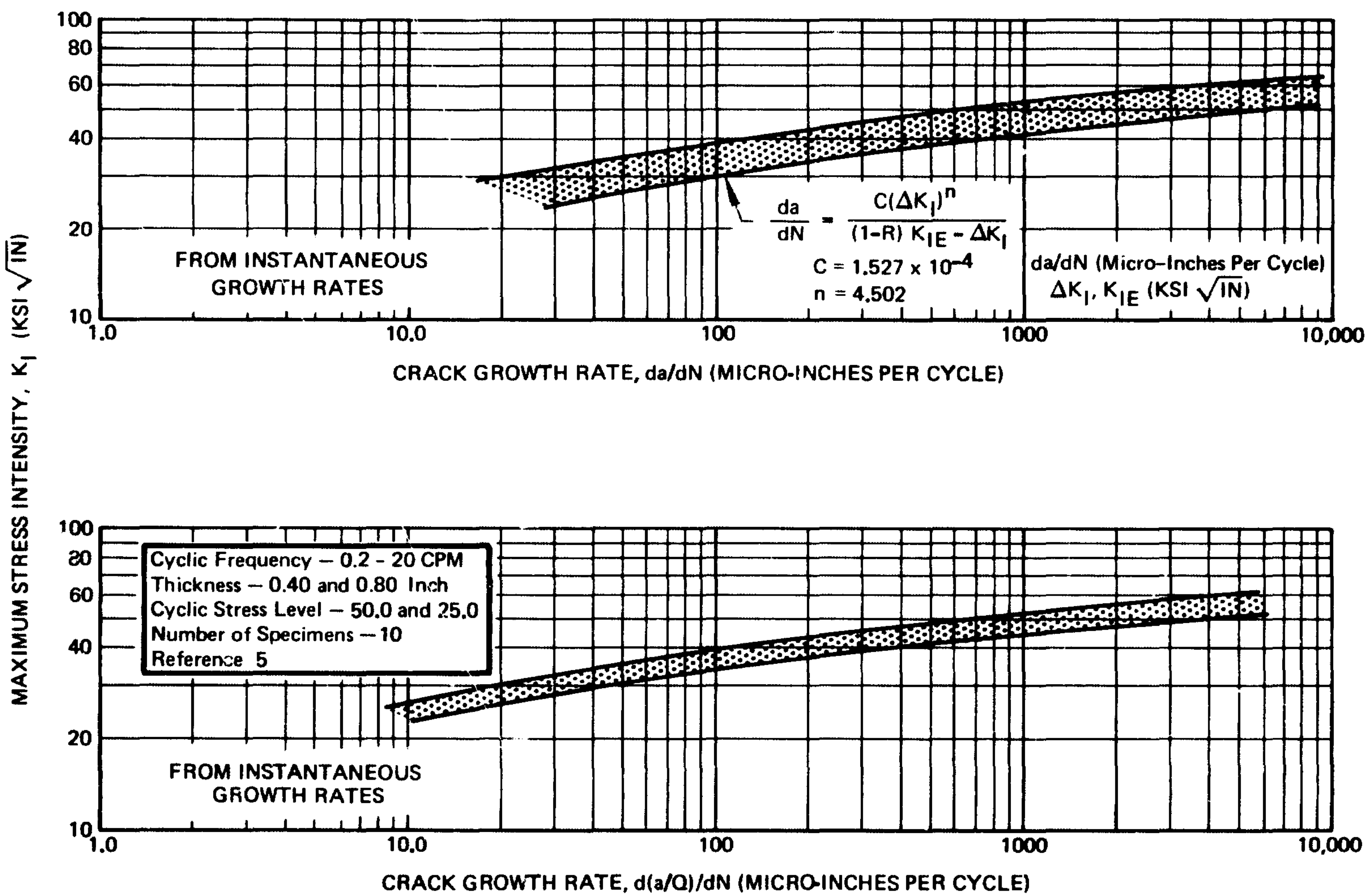


Figure 19 : Cyclic Flaw Growth Rates for 2219-T87 Aluminum Base Metal At Room Temperature in a 3½ % NaCl Environment for the WT Propagation Direction ,R ≤ 0.1

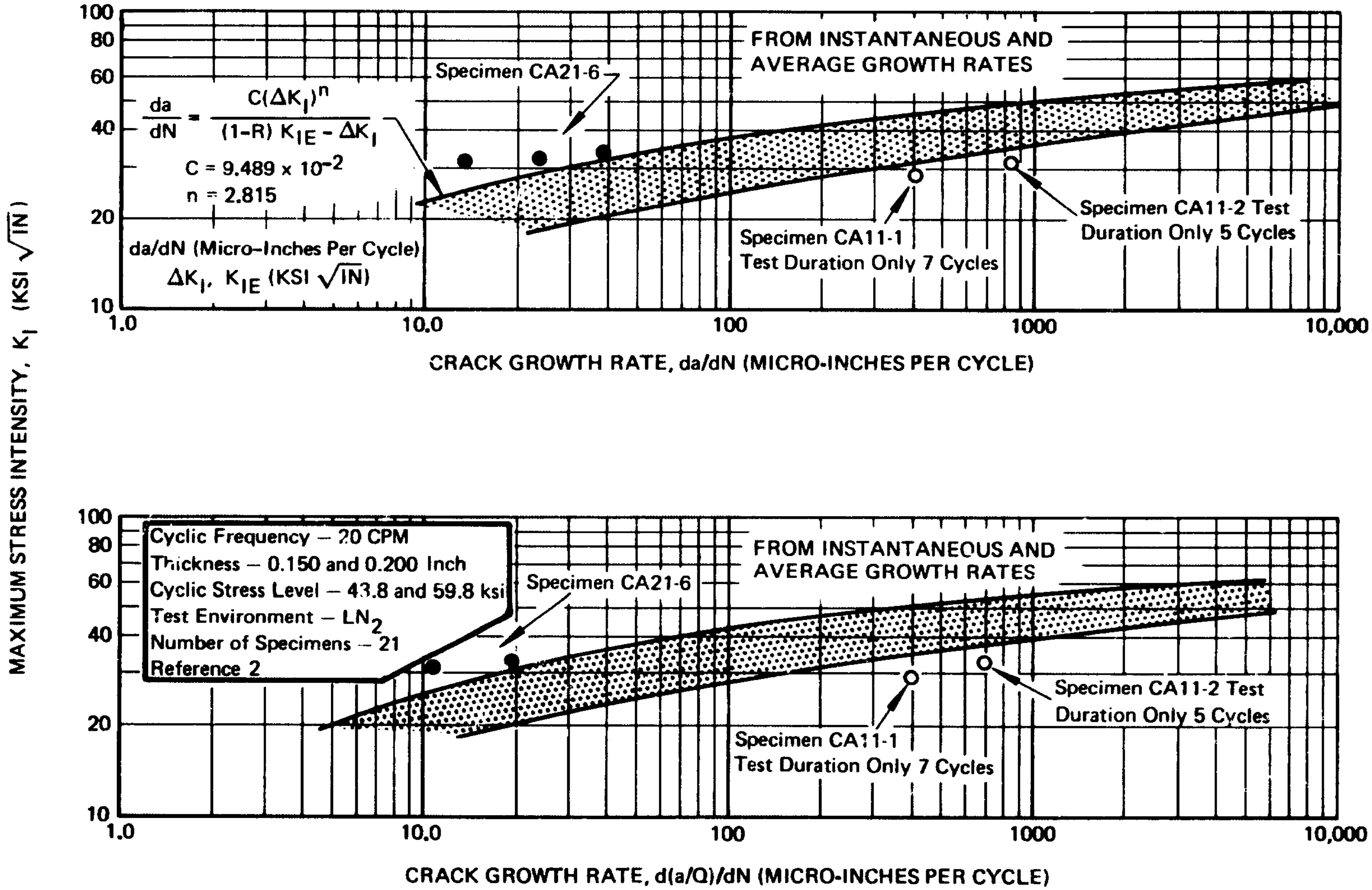


Figure 20 : Cyclic Flaw Growth Rates For 2219-T87 Aluminum Base Metal At -320 °F For The WT Propagation Direction, R ≤ 0.1

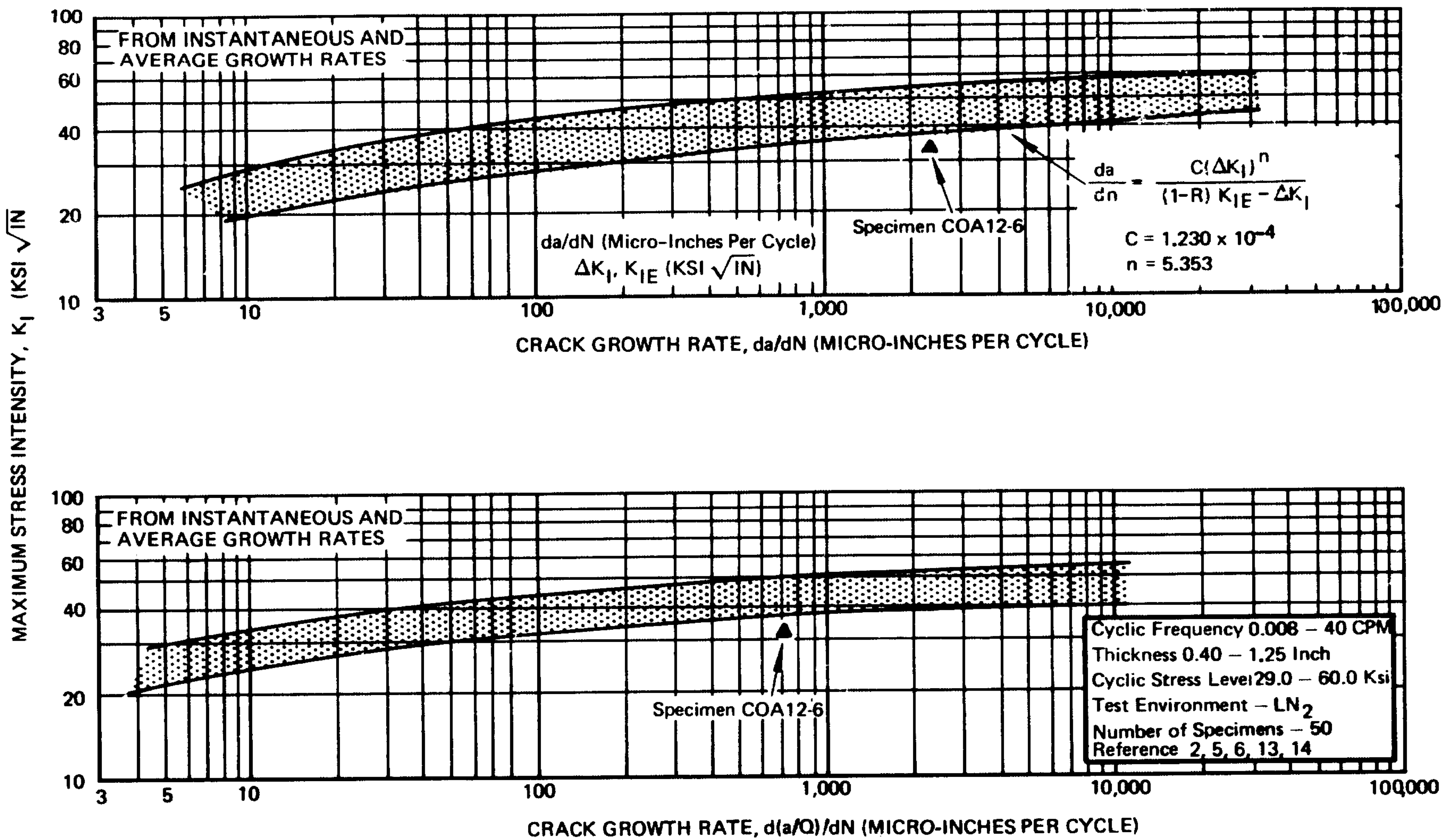


Figure 21: Cyclic Flaw Growth Rates For 2219-T87 Aluminum Base Metal At -320^0F For The WT Propagation Direction, $R \leq 0.1$

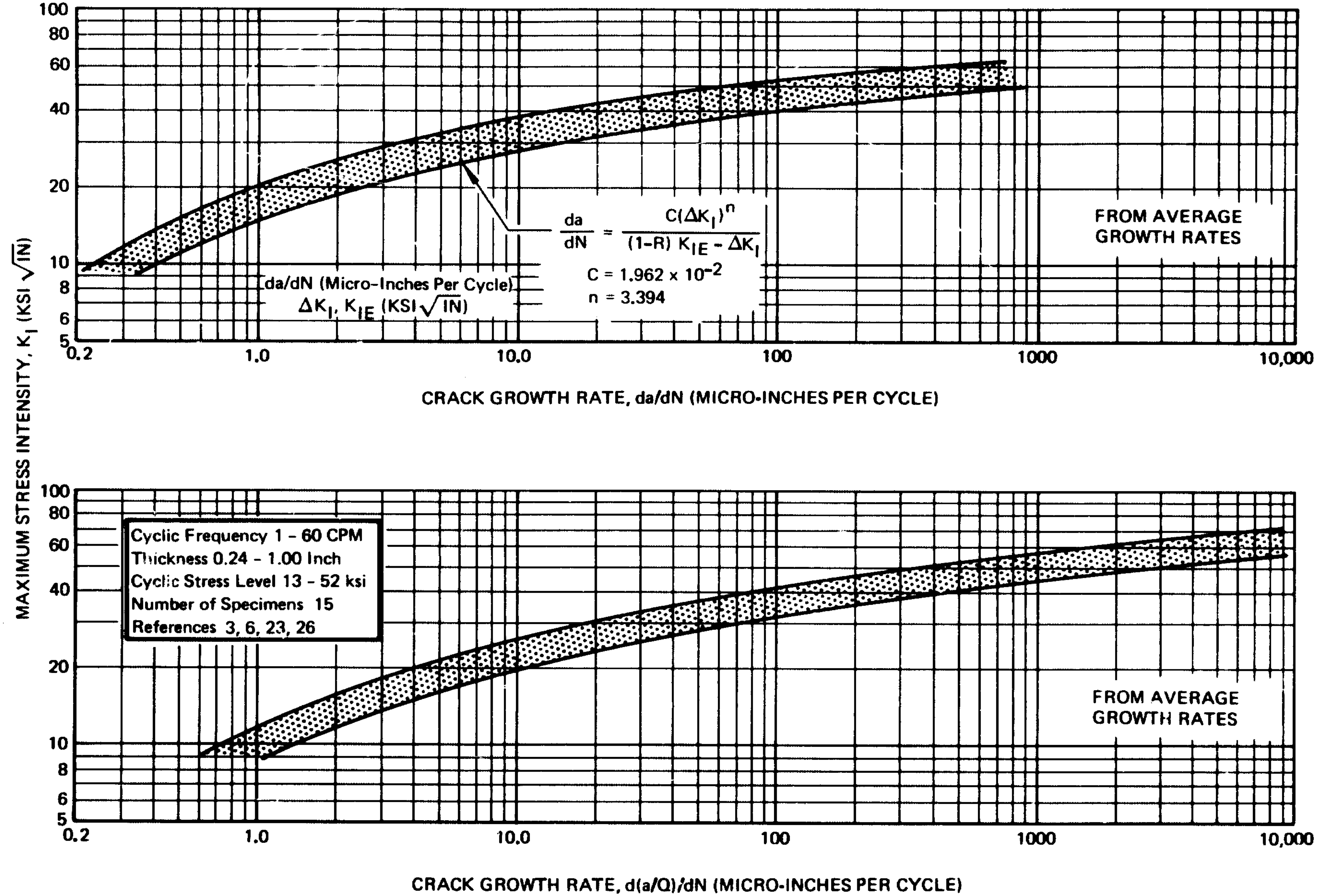


Figure 22 : Cyclic Flaw Growth Rates For 2219-T87 Aluminum Base Metal At -320 °F For The RT Propagation Direction, $R \leq 0.1$

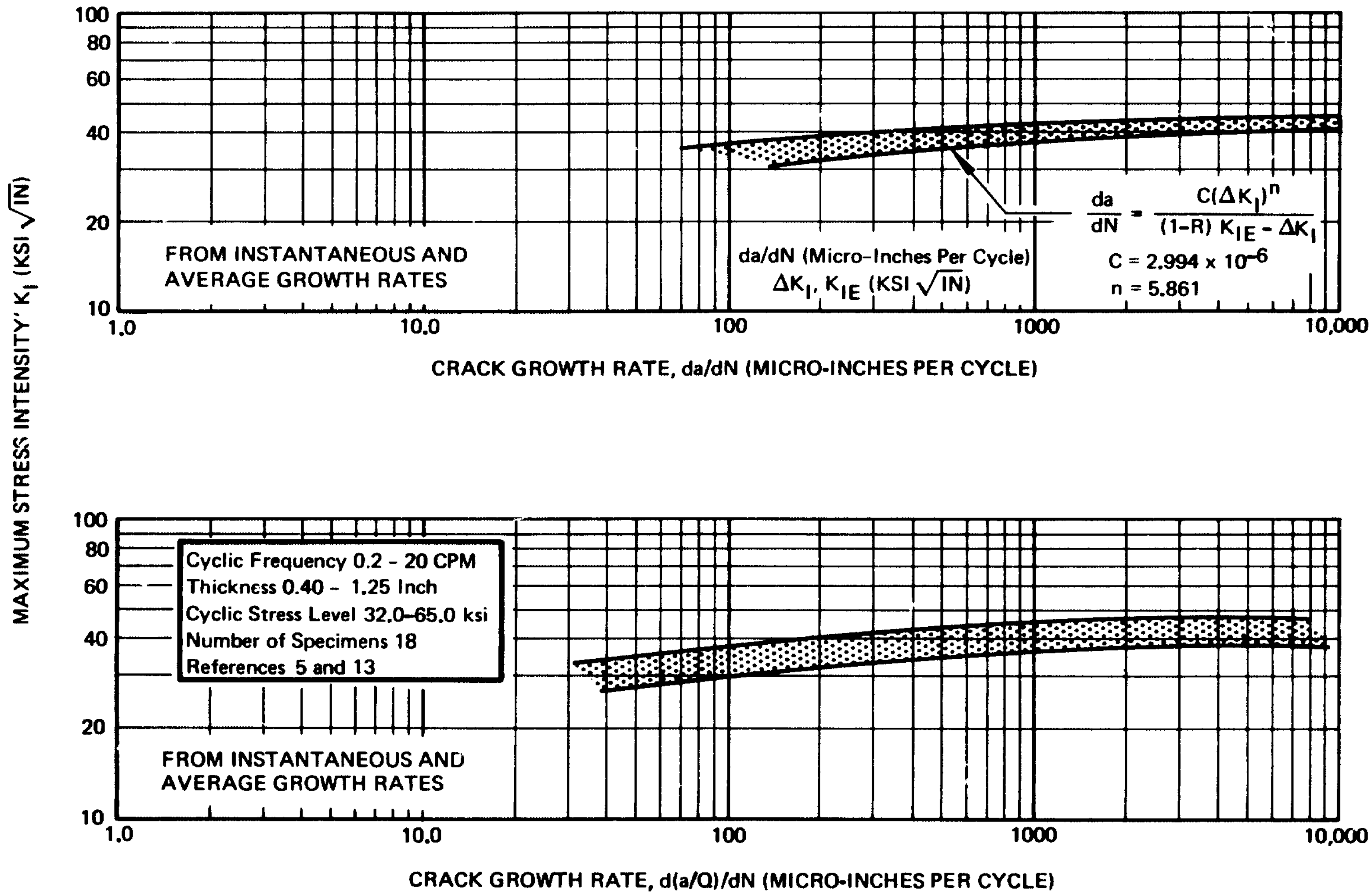


Figure 23 : Cyclic Flaw Growth Rates For 2219-T87 Aluminum Base Metal At -423° F For The WT Propagation Direction, $R \leq 0.1$

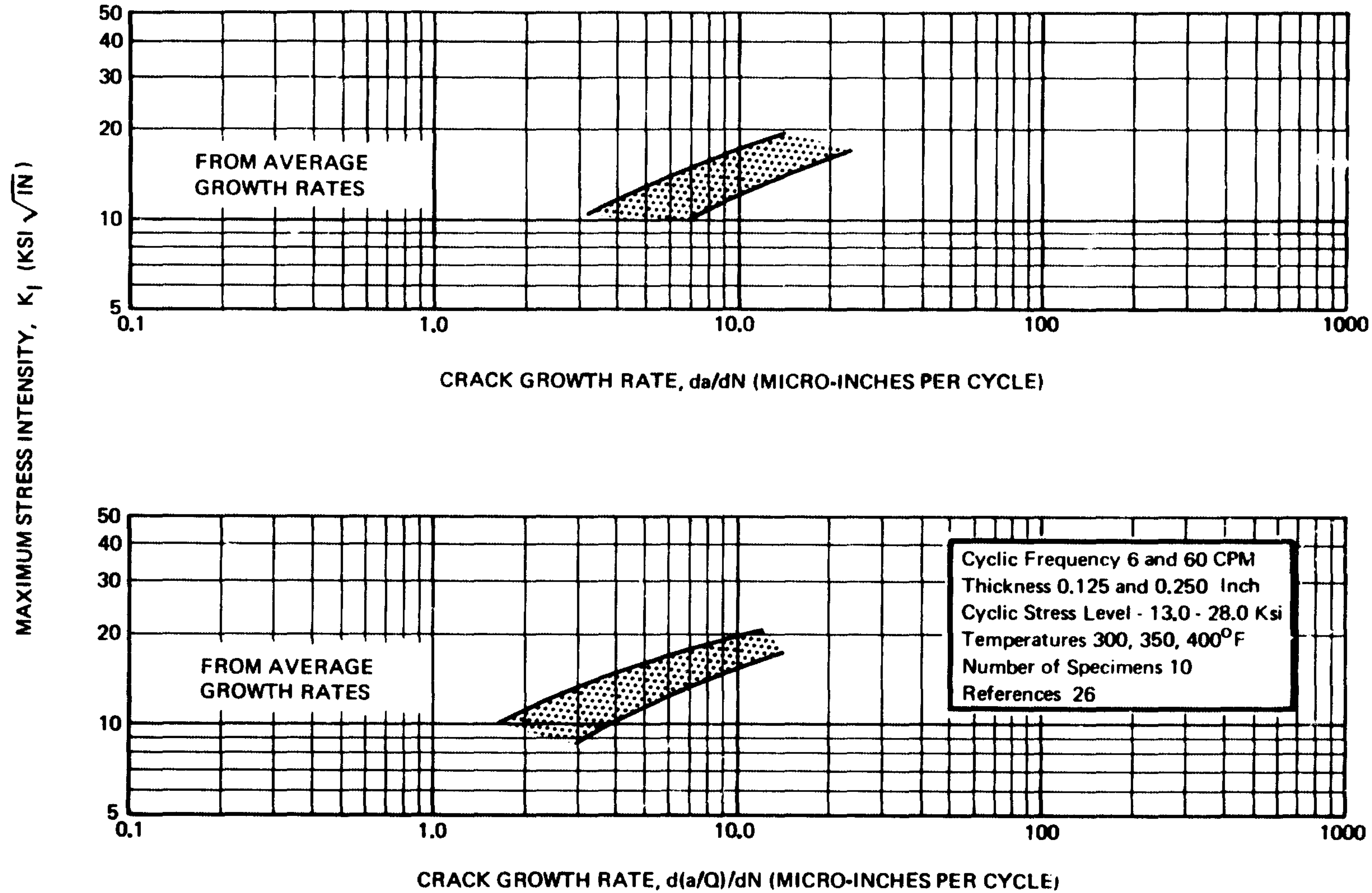


Figure 24 : Cyclic Flaw Growth Rates For 2219-T87 Aluminum Base At Elevated Temperatures For The WT And RT Propagation Direction, $R \leq 0.1$

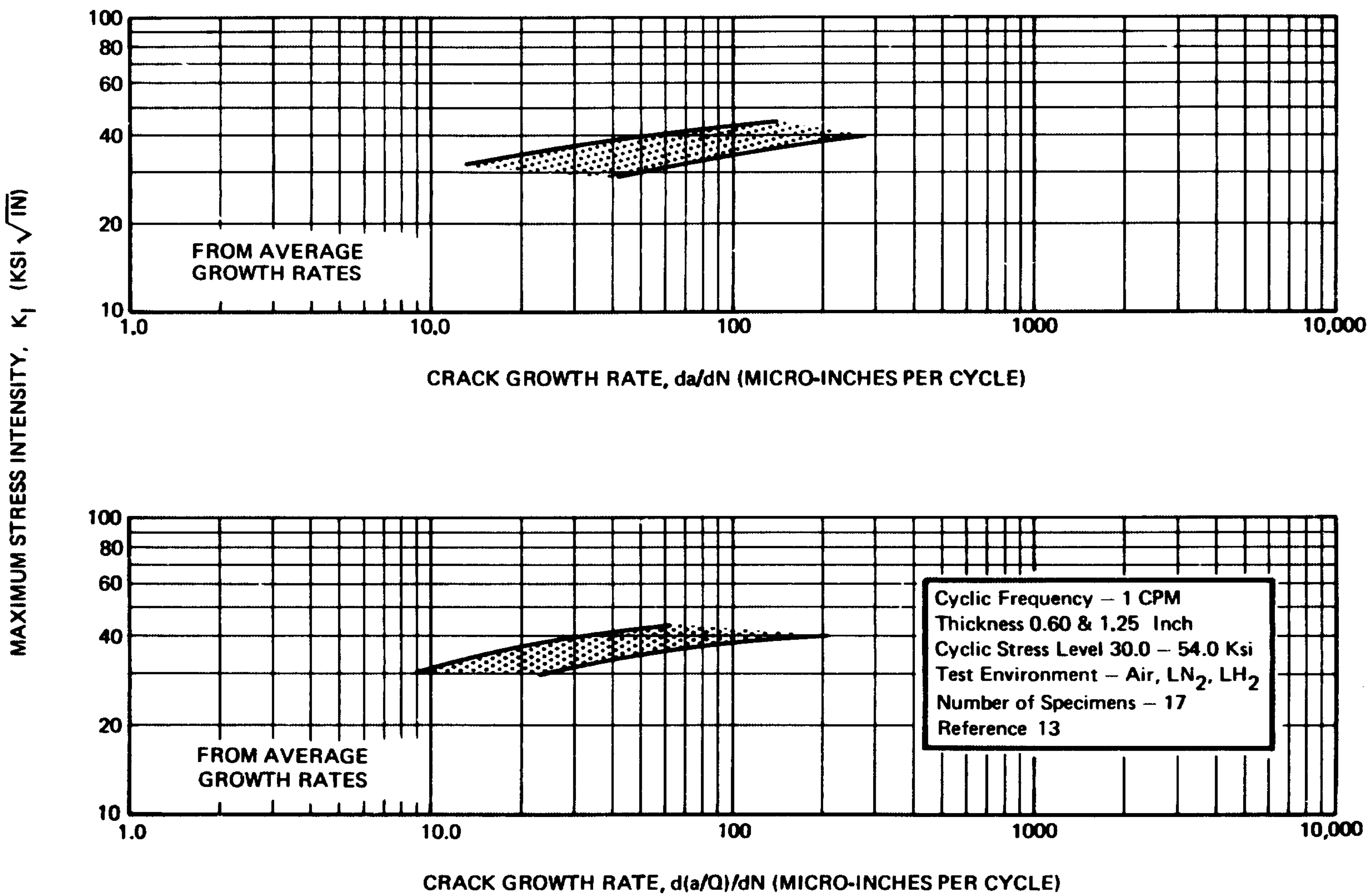


Figure 25 : Cyclic Flaw Growth Rates For 2219-T87 Aluminum Base Metal at Room Temperature, $-320^{\circ}F$ And $-423^{\circ}F$ For The WT Propagation Direction, $R = 0.5$

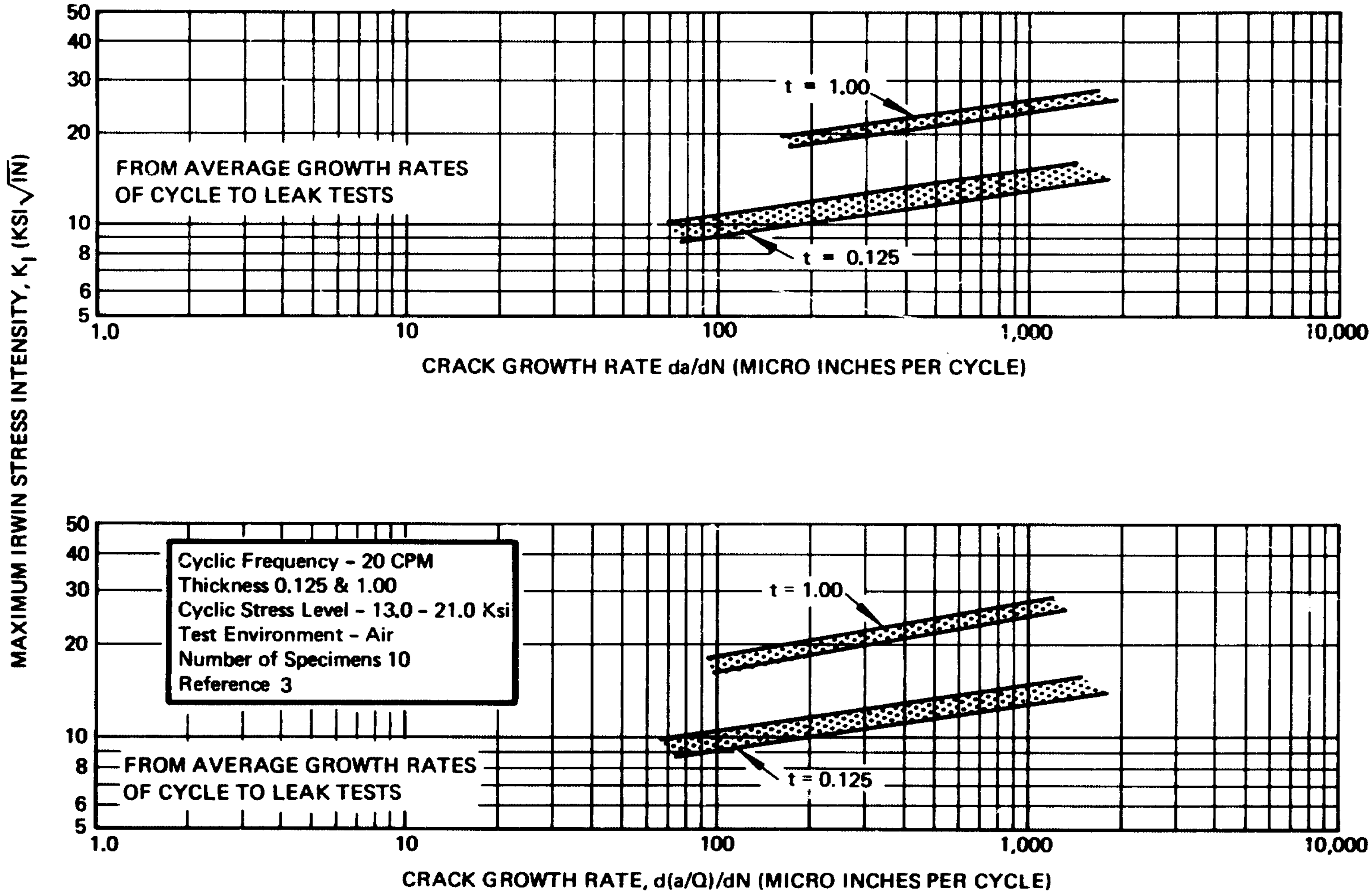


Figure 26: Cyclic Flaw Growth Rates for 2219 Aluminum Alloy Weldments at 72°F, R ≤ 0.1

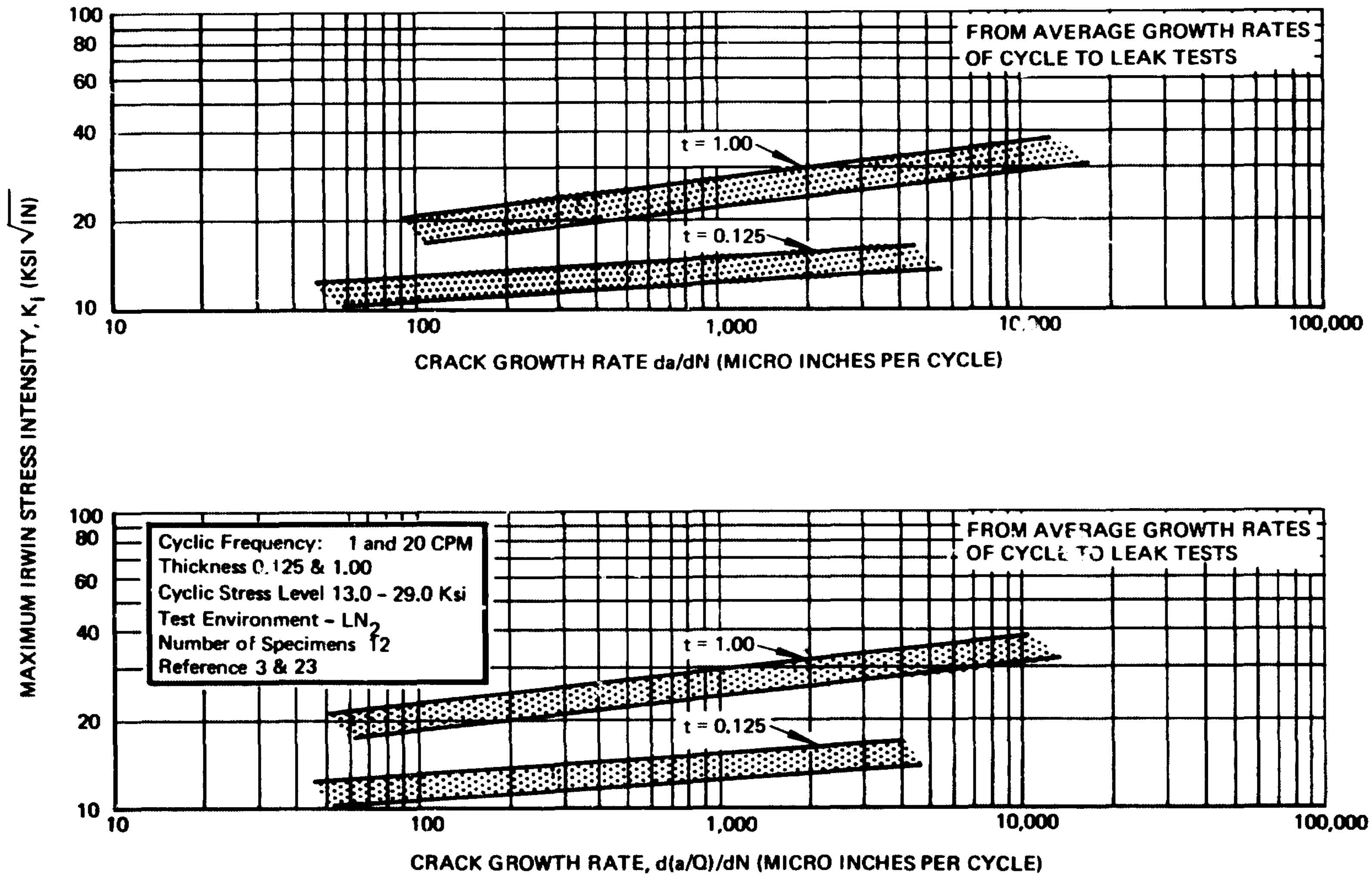


Figure 27: Cyclic Flow Growth Rates For 2219 Aluminum Weldments at -320^{o}F ,R $\leq$ 0.1

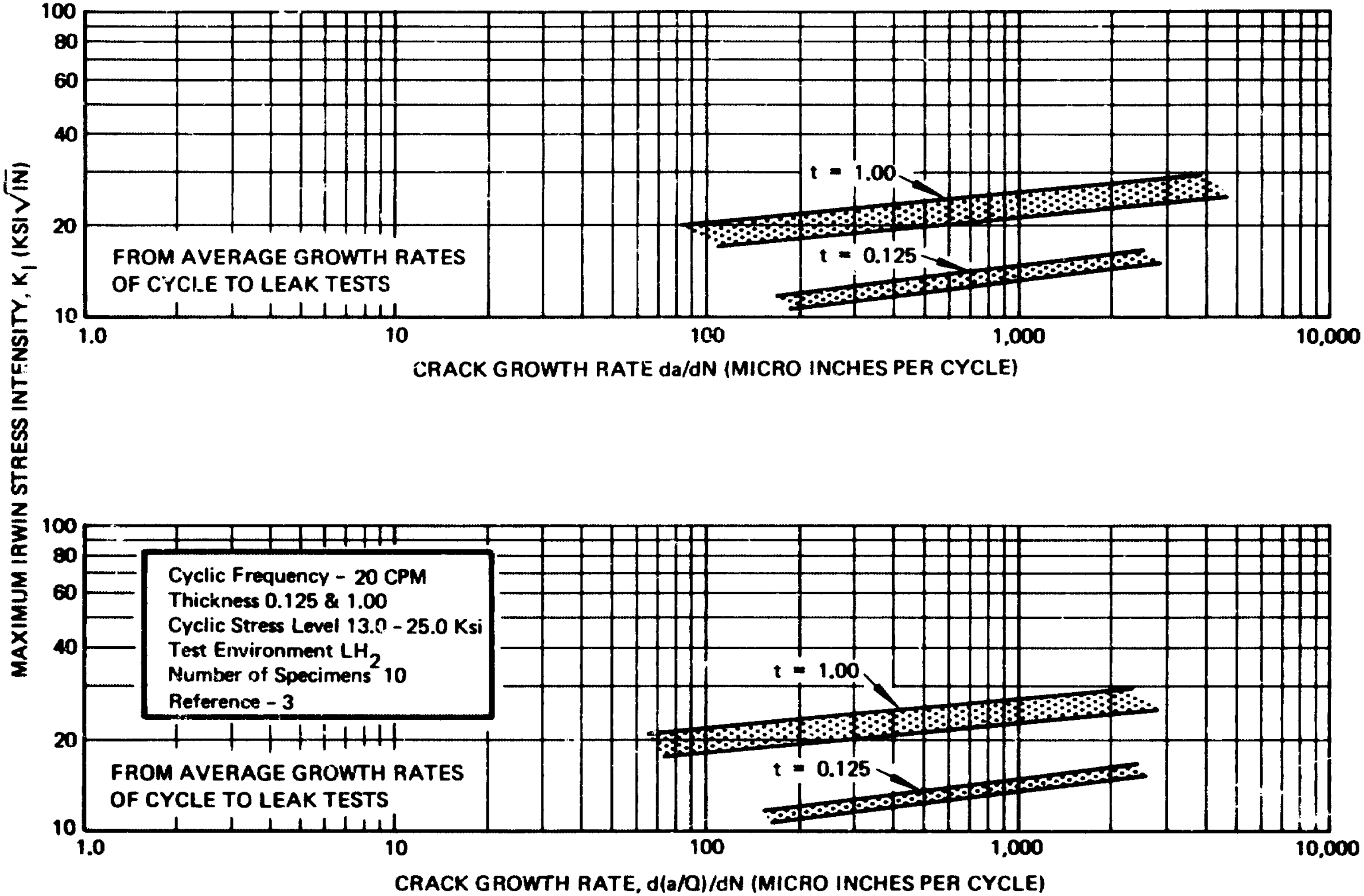


Figure 28: Cyclic Flaw Growth Rates for 2219 Aluminum Weldments at –423°F, R ≤ 0.1

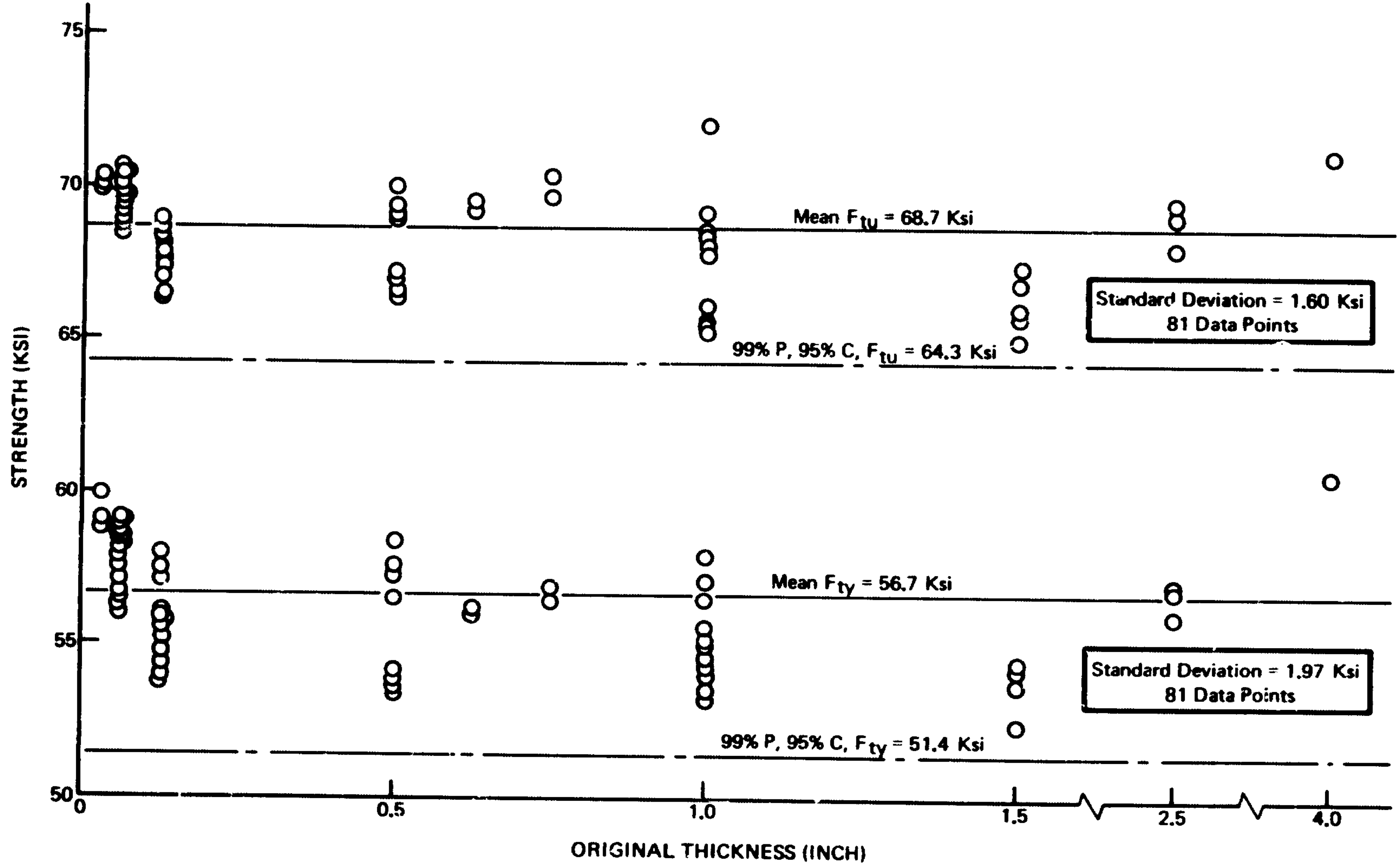


Figure 29: Room Temperature (70°F - 75°F) Yield Strength and Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy, Longitudinal Grain

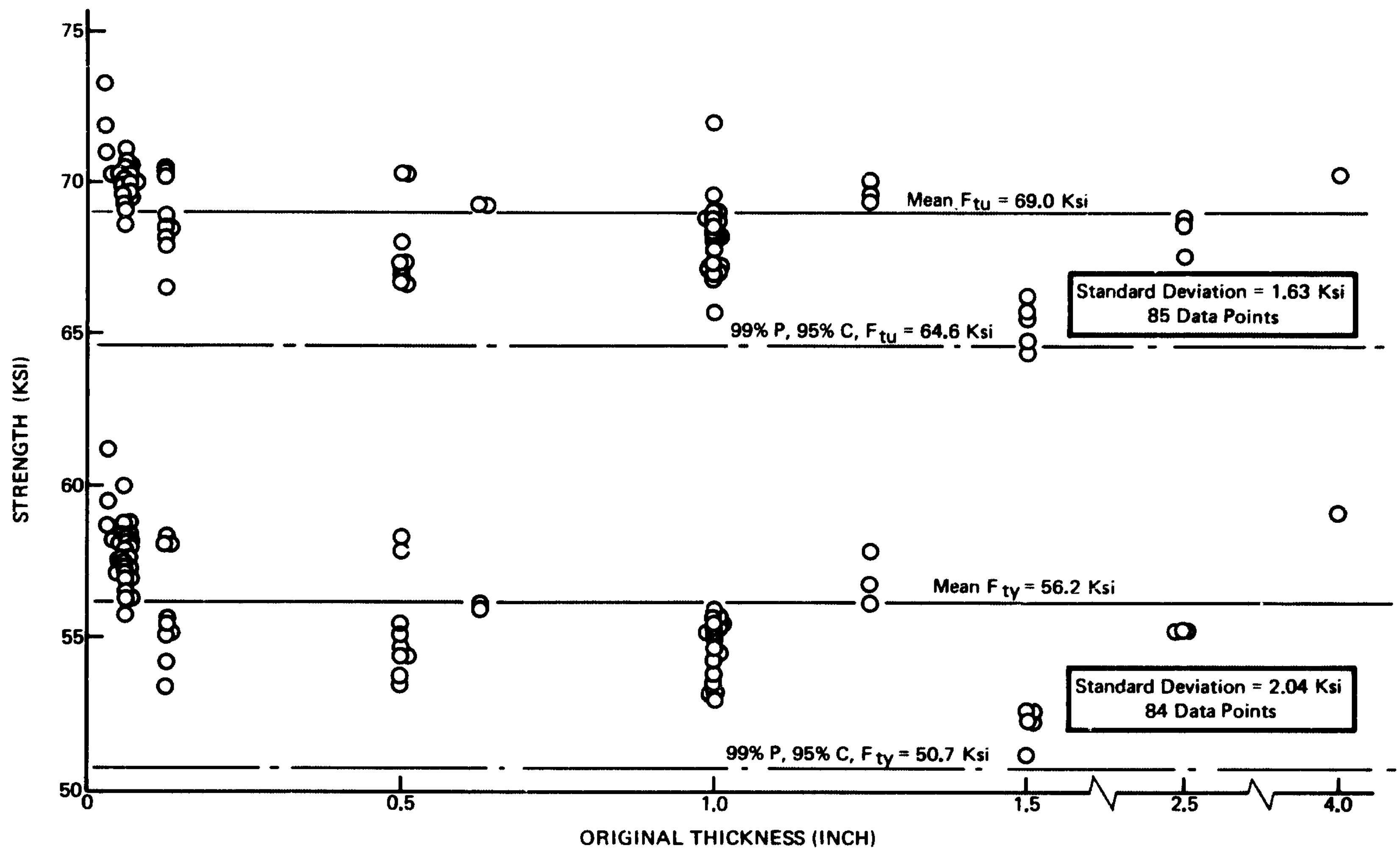


Figure 30: Room Temperature (70^0F - 75^0F) Yield Strength and Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy Long Transverse Grain

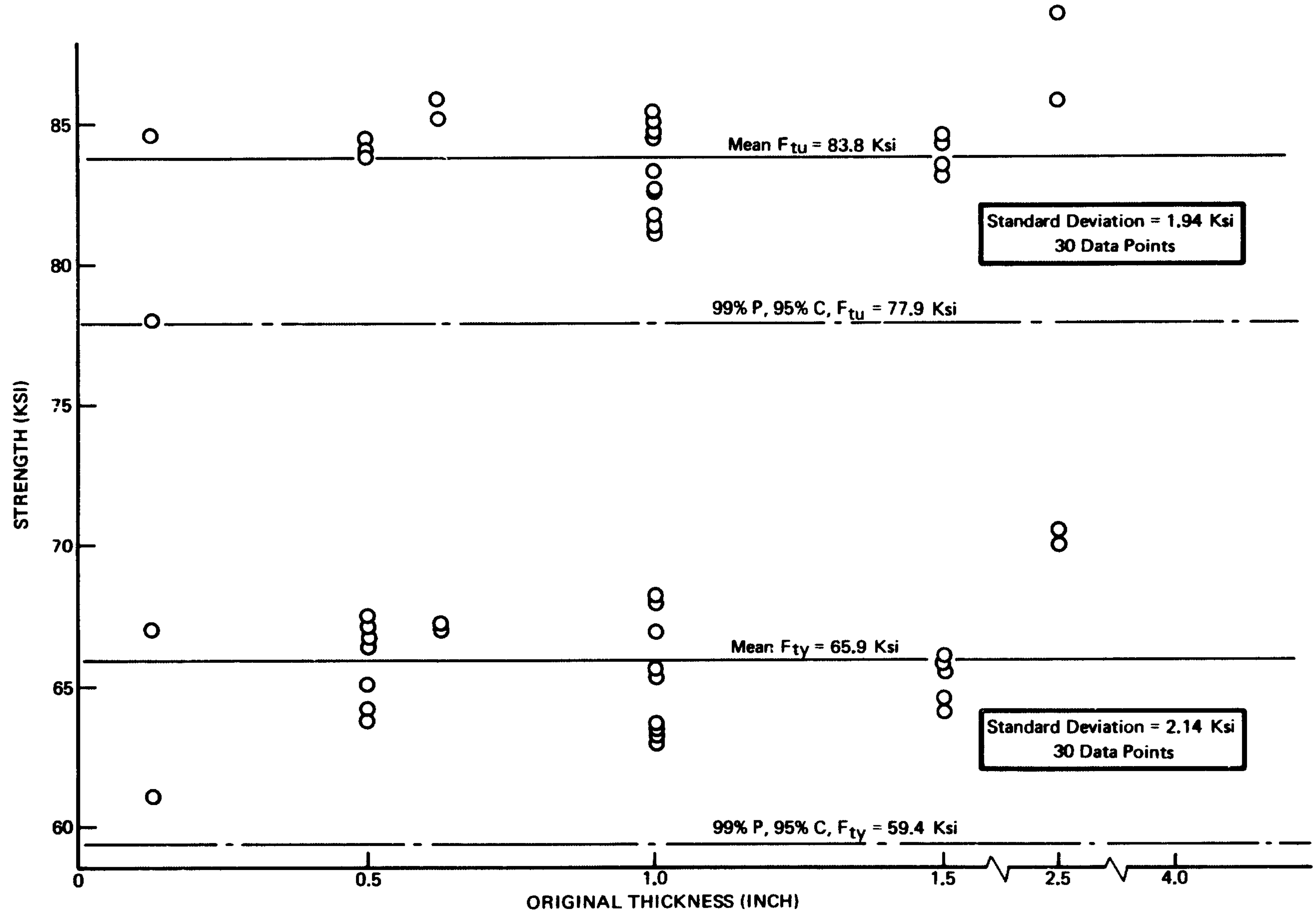


Figure 31: Liquid Nitrogen Temperature (-320^{0}F) Yield Strength and Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy Longitudinal Grain

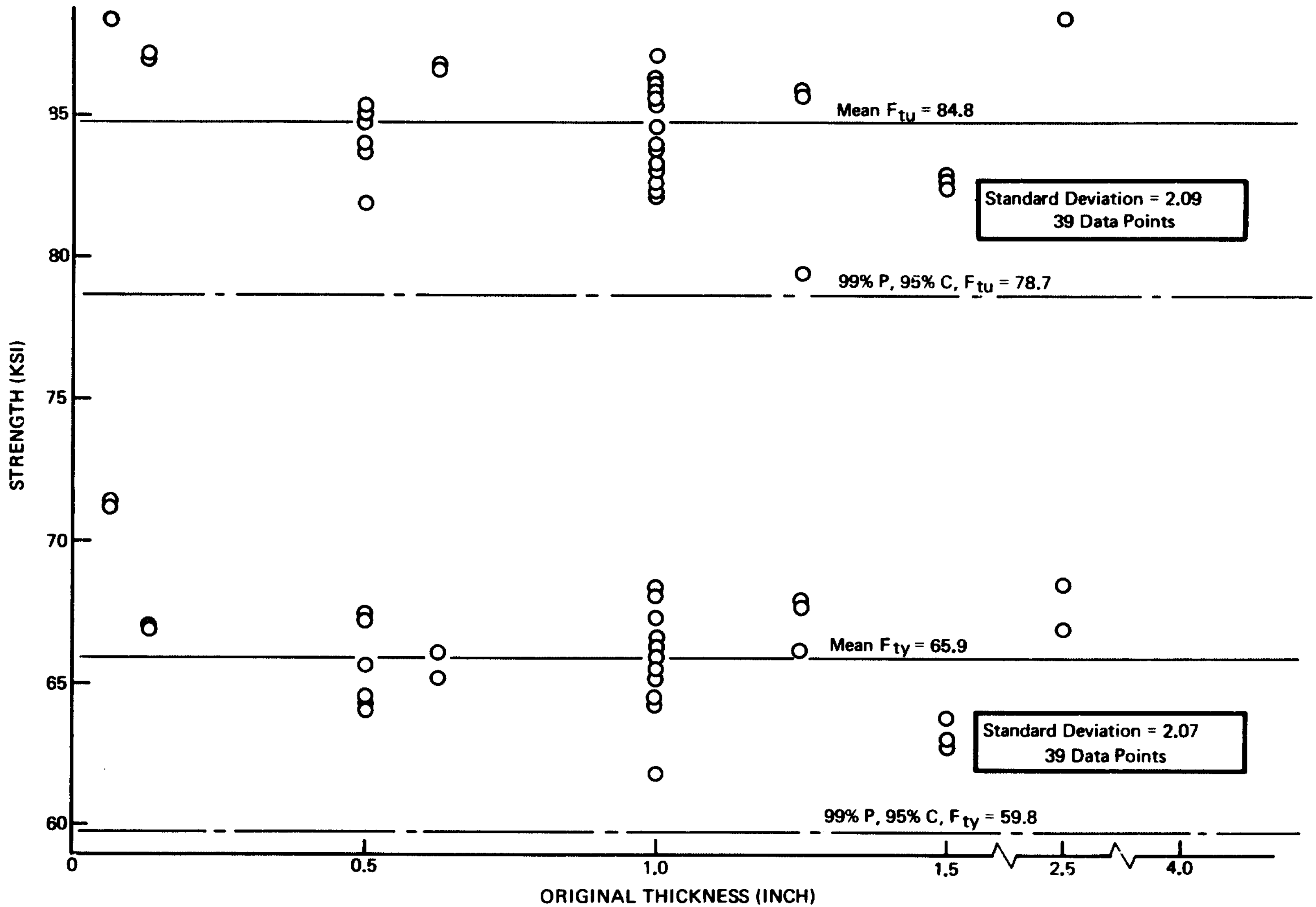


Figure 32: Liquid Nitrogen Temperature (-320^{0}F) Yield Strength and Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy Long Transverse Grain

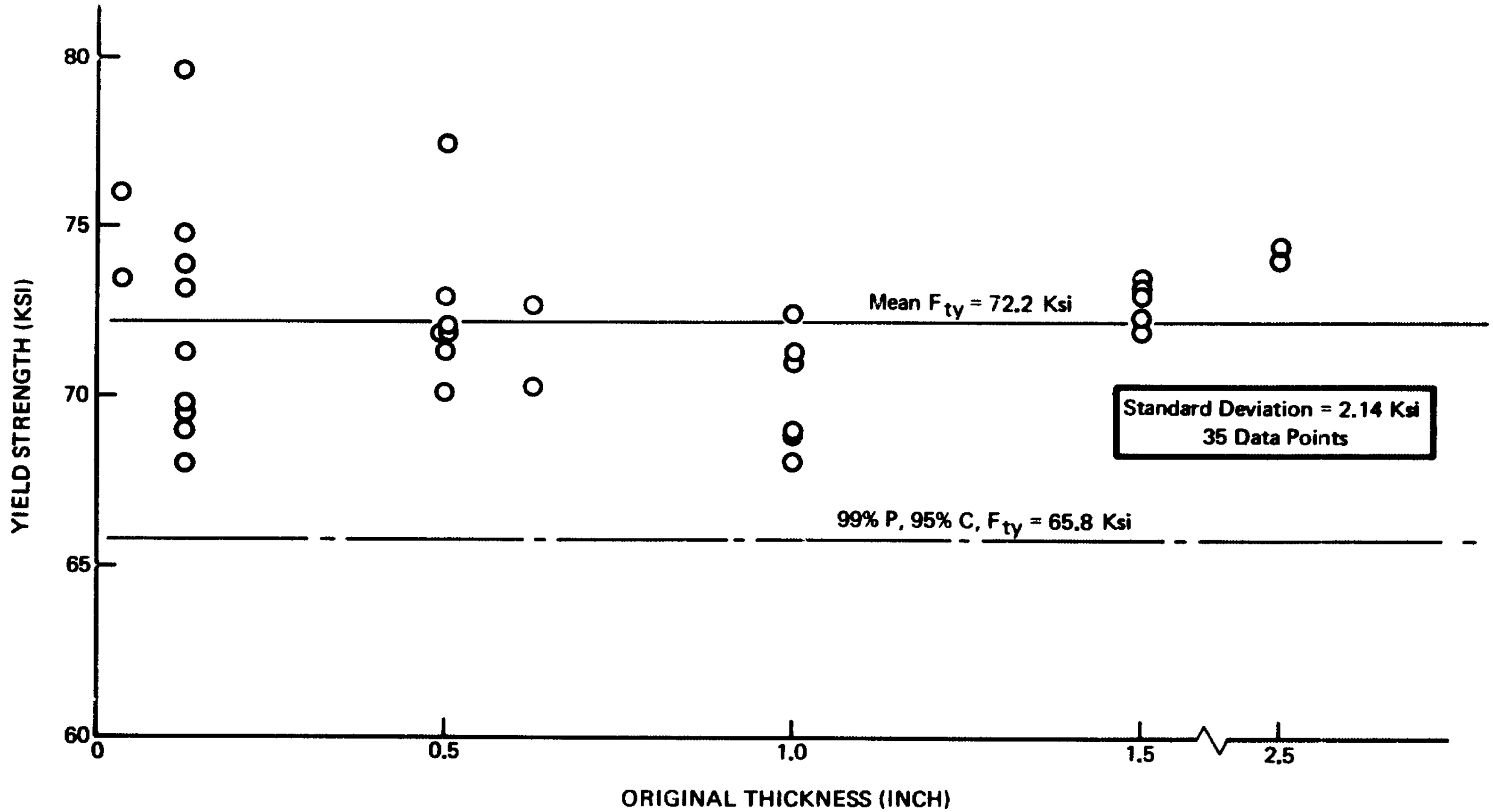


Figure 33: Liquid Hydrogen Temperature (−423°F) Yield Strength Vs. Thickness for 2219-T87 Aluminum Alloy Longitudinal Grain

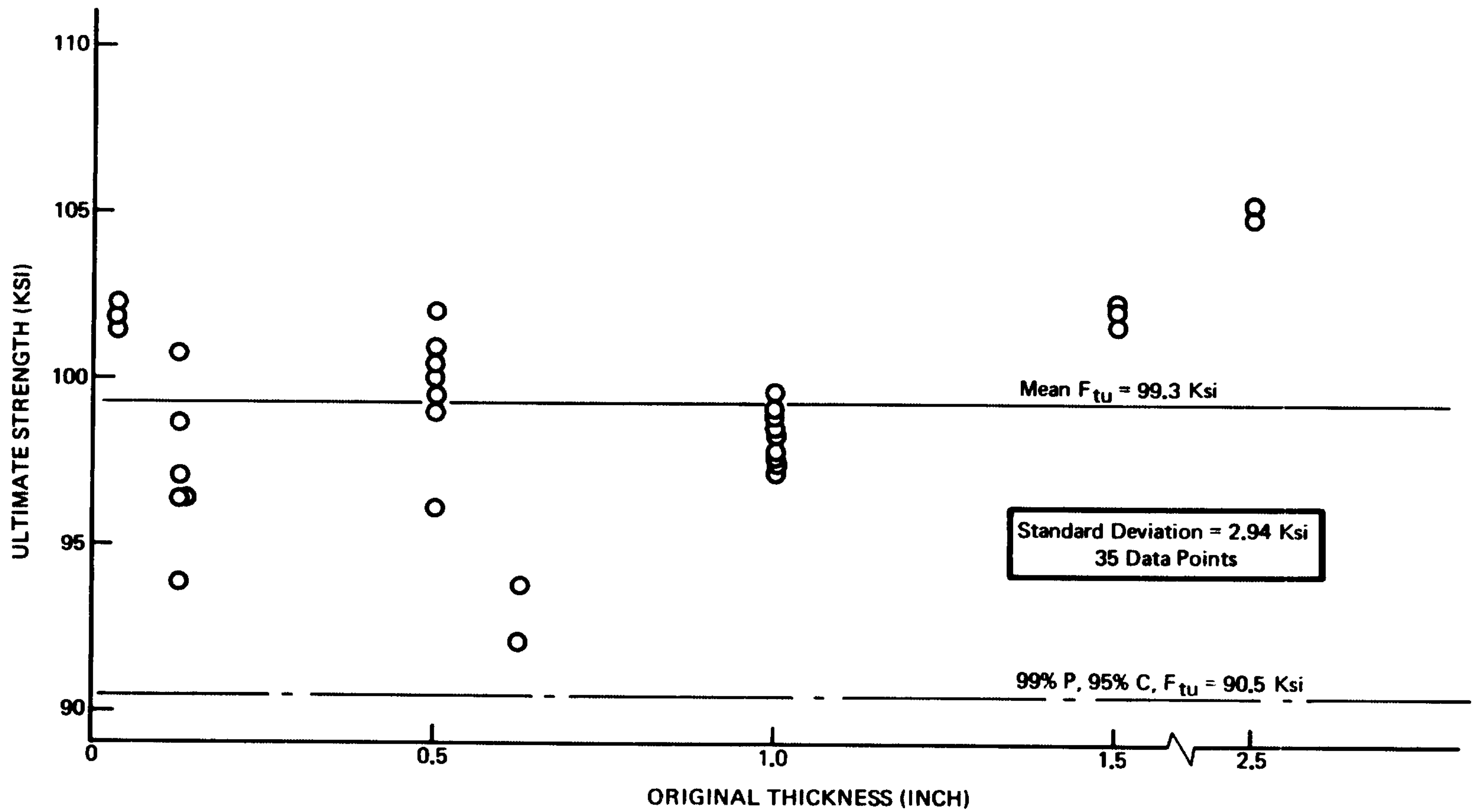


Figure 34: Liquid Hydrogen Temperature (−423°F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy Longitudinal Grain

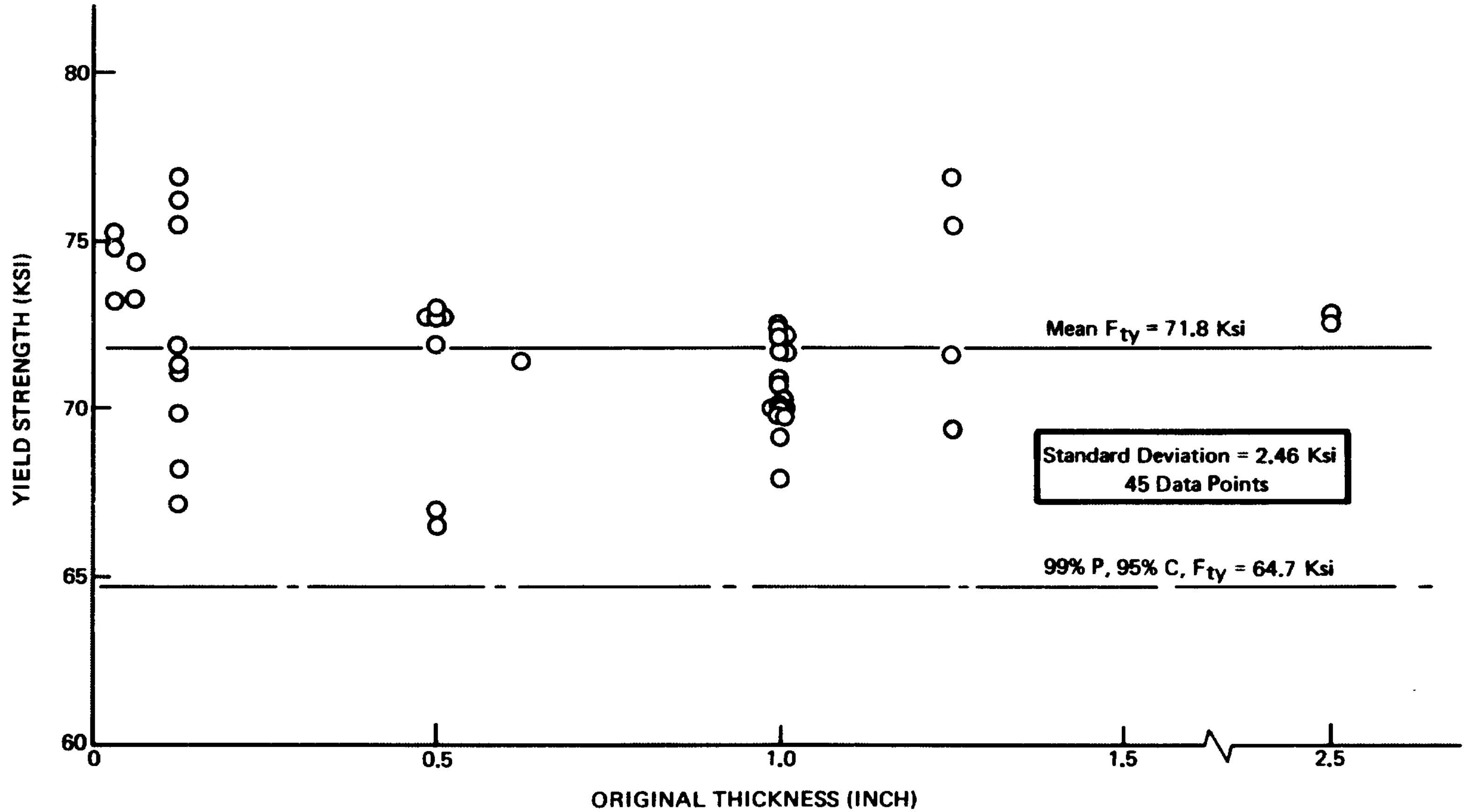


Figure 35: Liquid Hydrogen Temperature (−423°F) Yield Strength Vs. Thickness for 2219-T87 Aluminum Alloy Long Transverse Grain

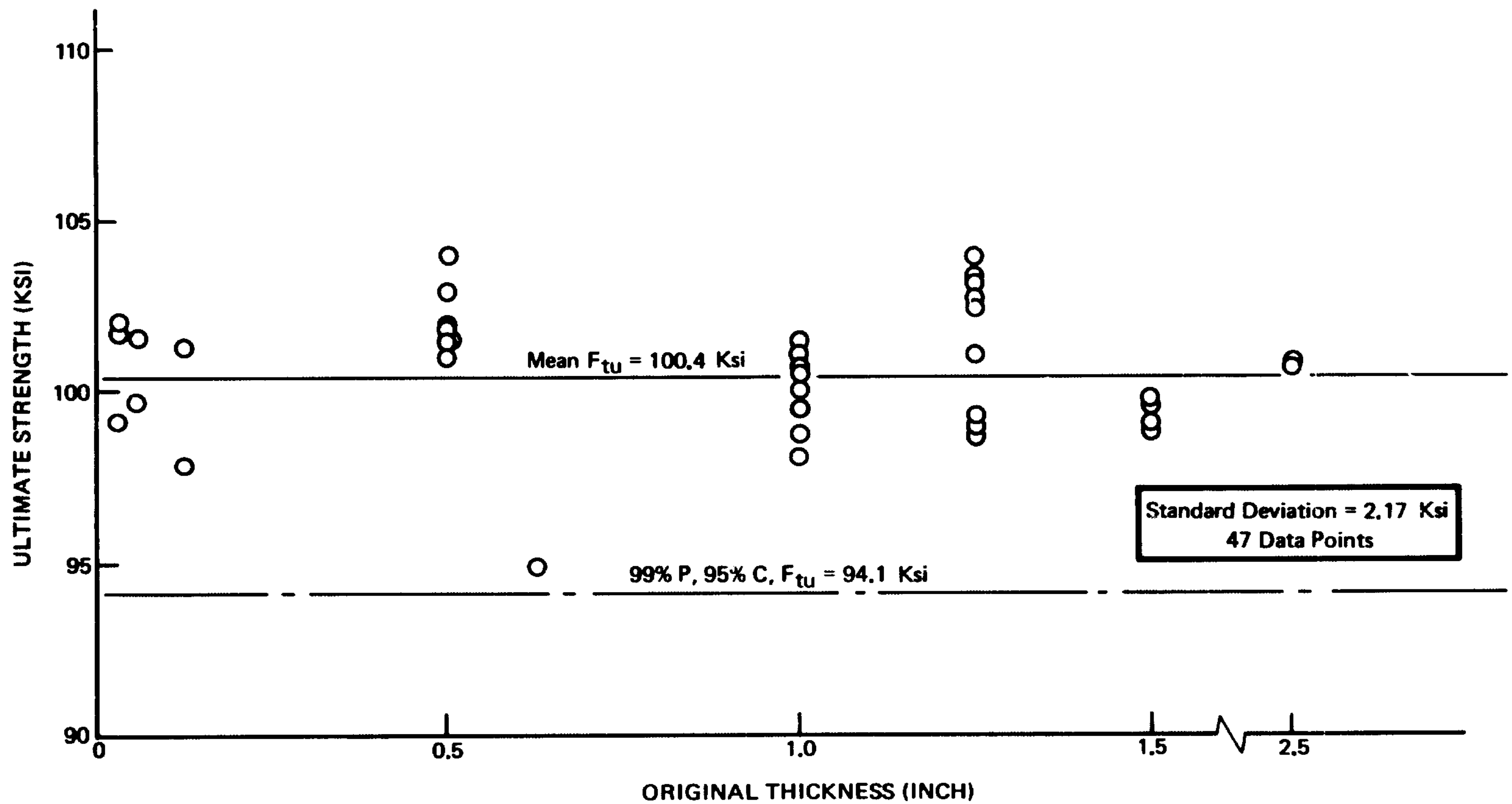


Figure 36: Liquid Hydrogen Temperature (-423°F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy Long Transverse Grain

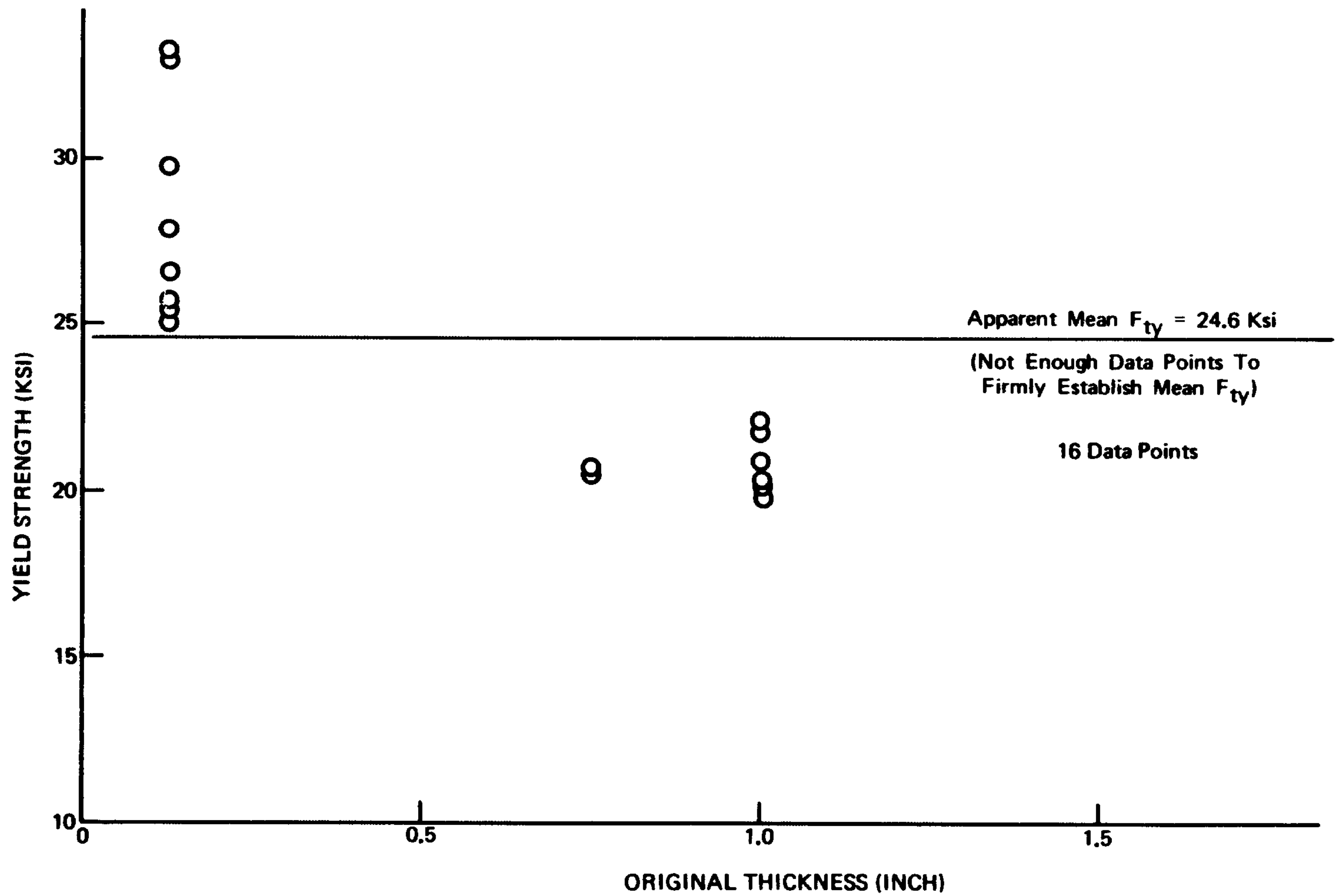


Figure 37: Room Temperature (70°F - 75°F) Yield Stress Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment

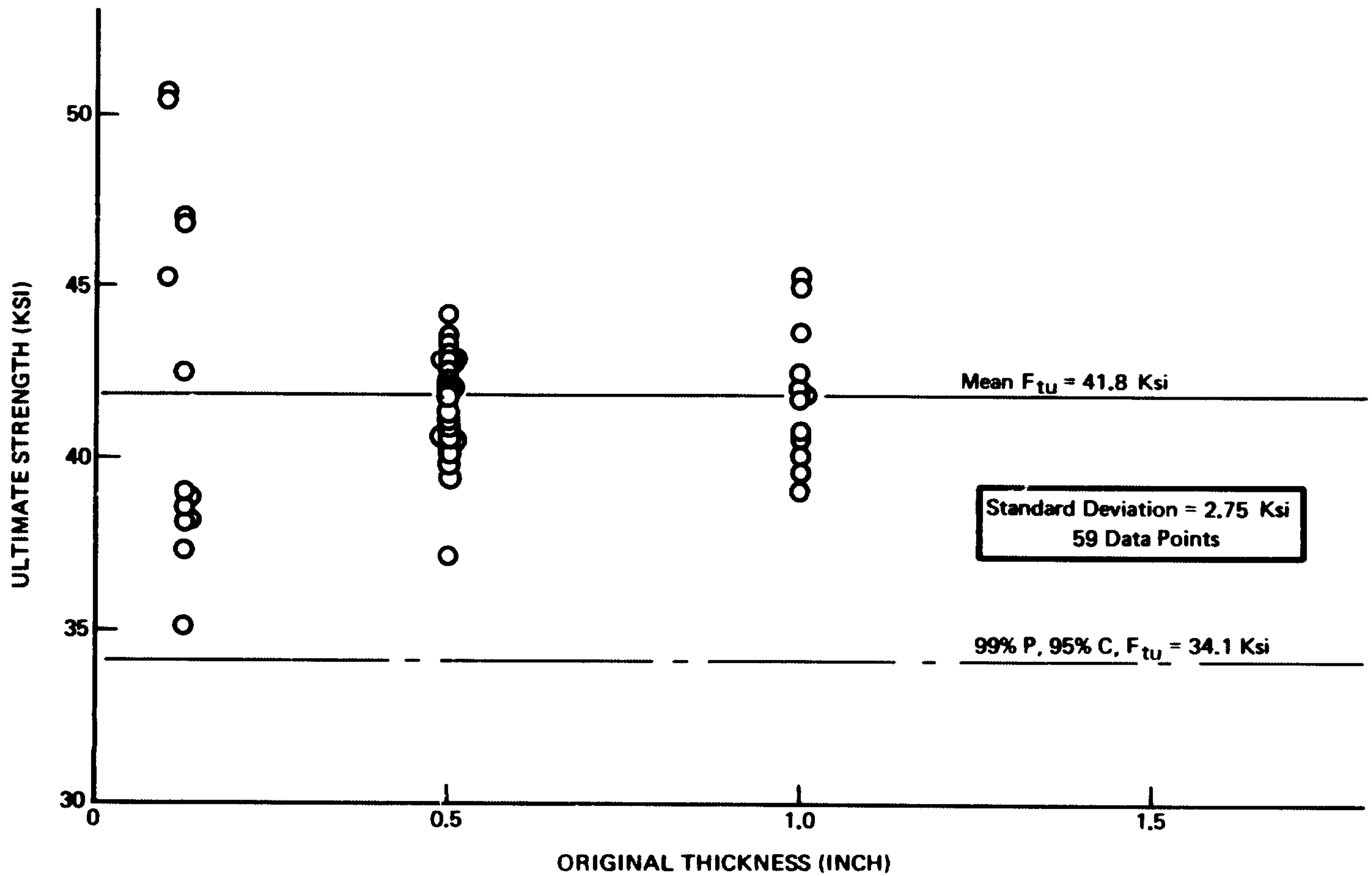


Figure 38: Room Temperature (70°F - 75°F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment

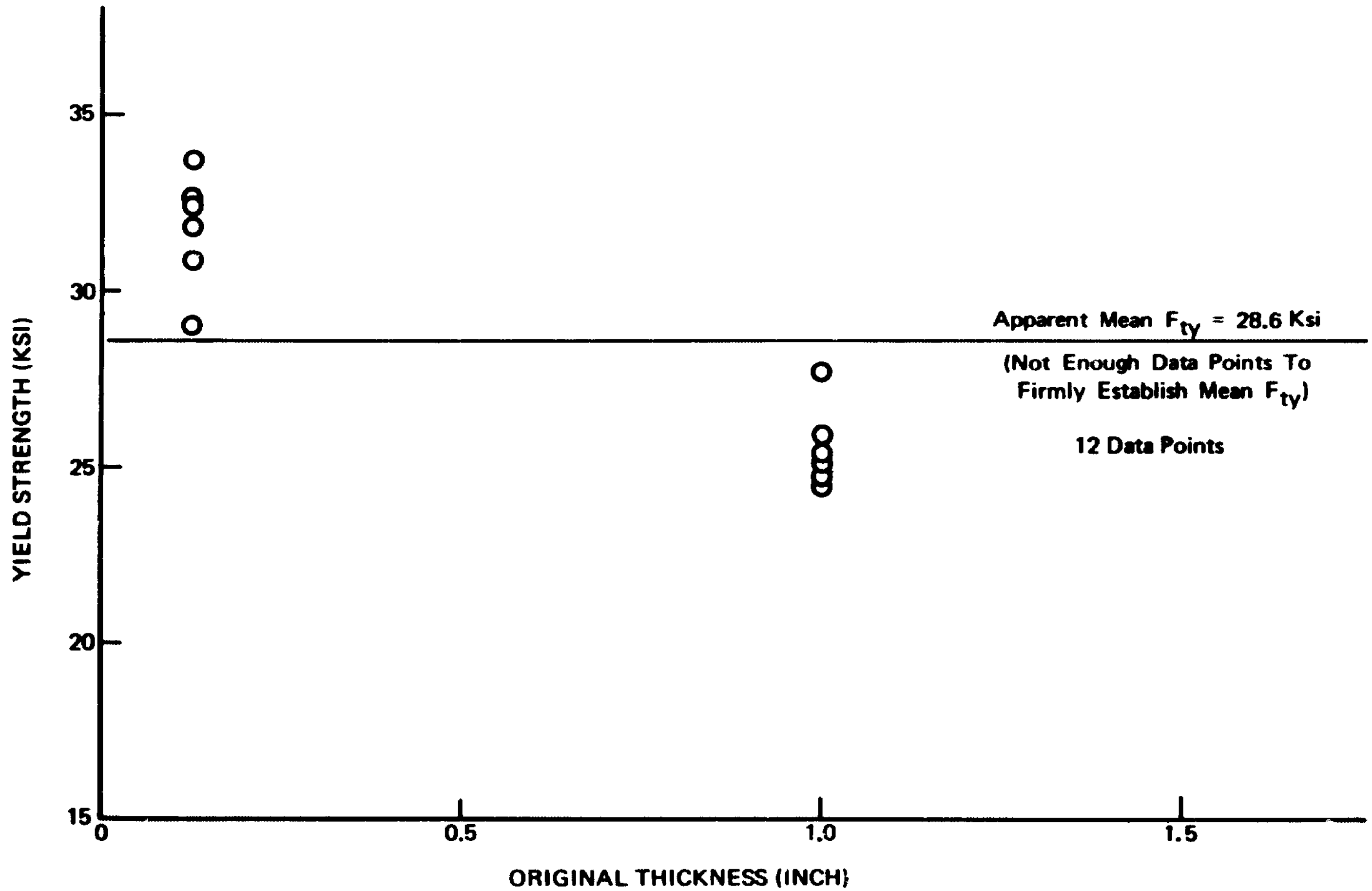


Figure 39: Liquid Nitrogen Temperature (-320°F) Yield Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment

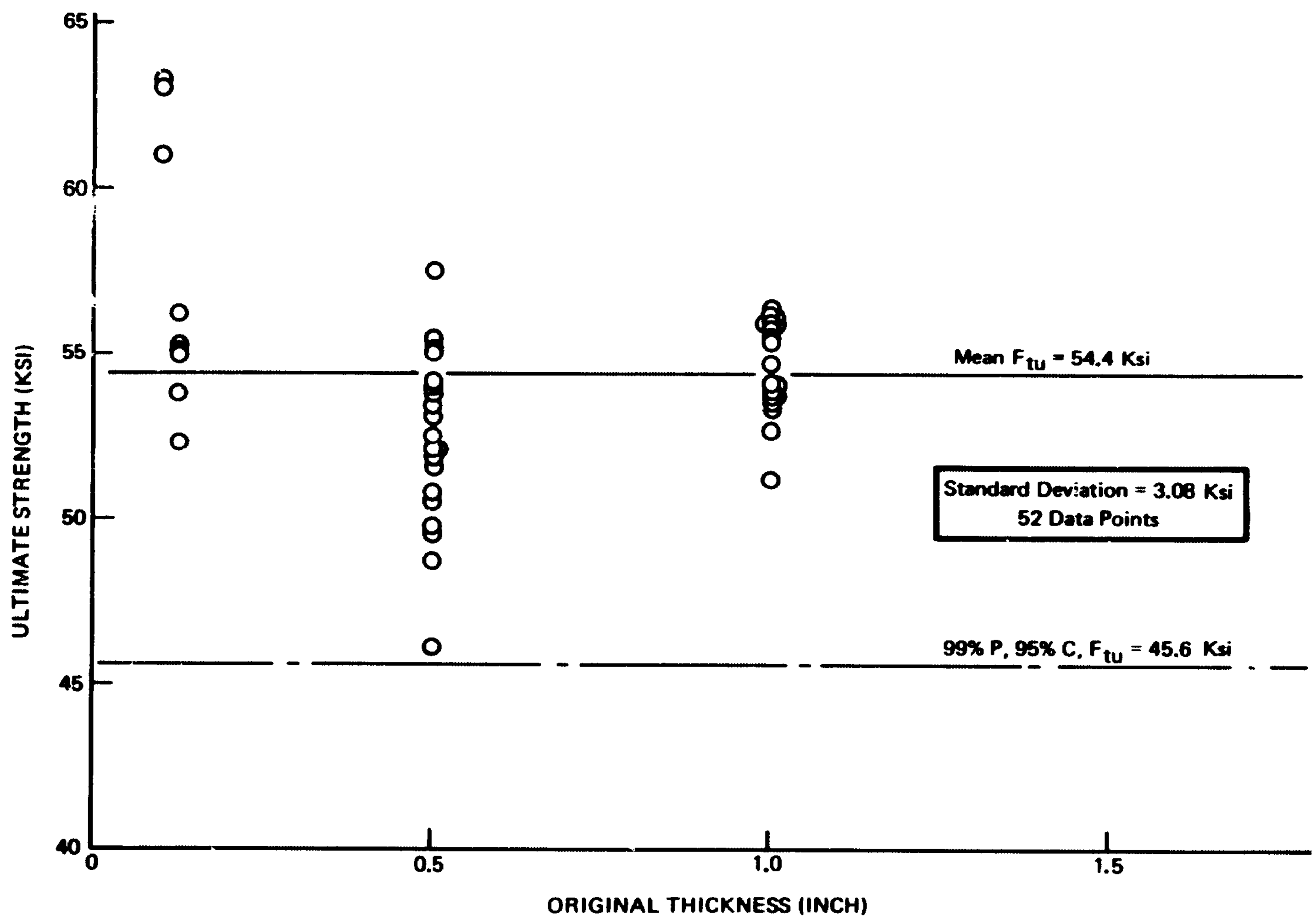


Figure 40: Liquid Nitrogen Temperature (-320°F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment

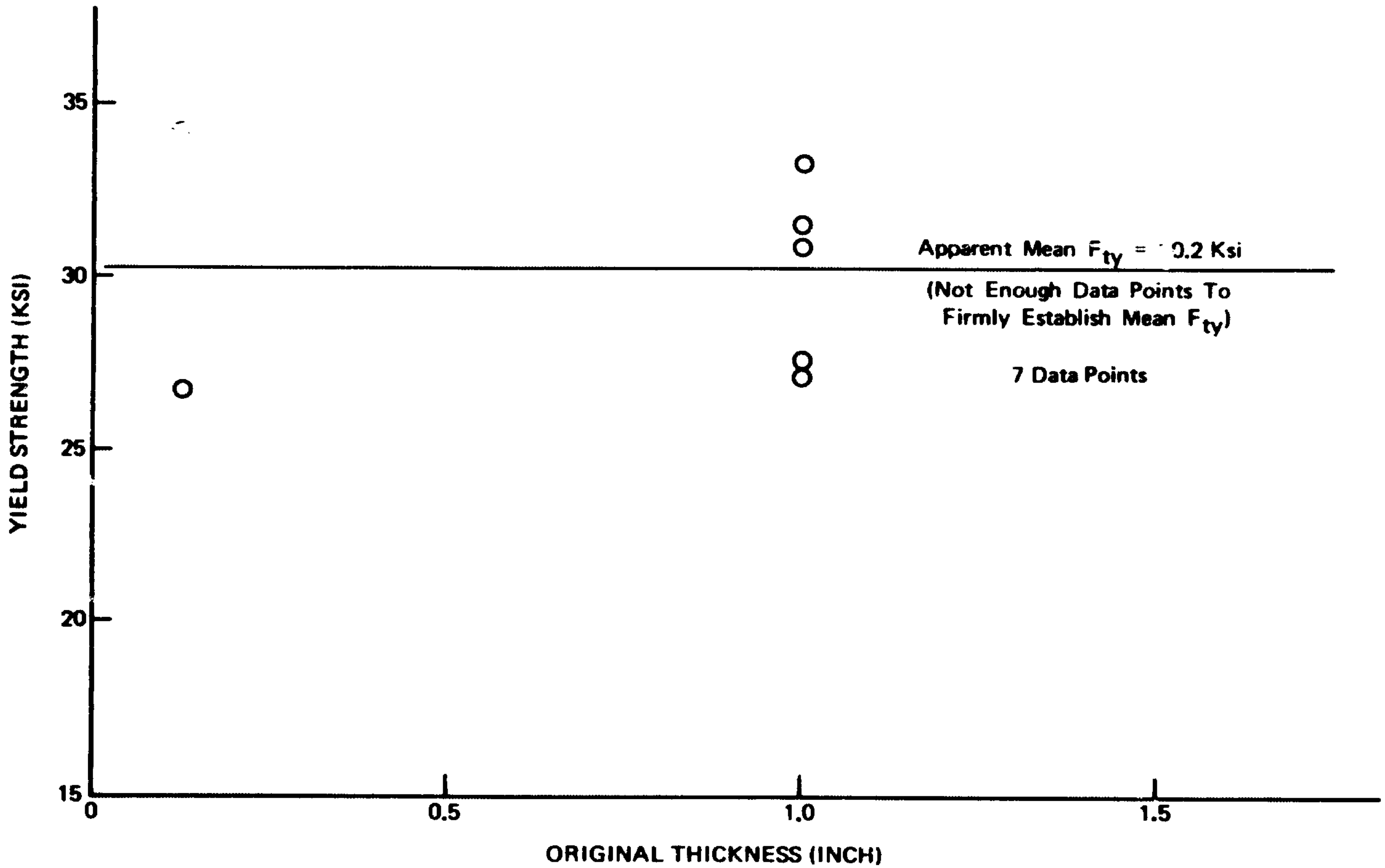


Figure 41: Liquid Hydrogen Temperature (-423^{0}F) Yield Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment

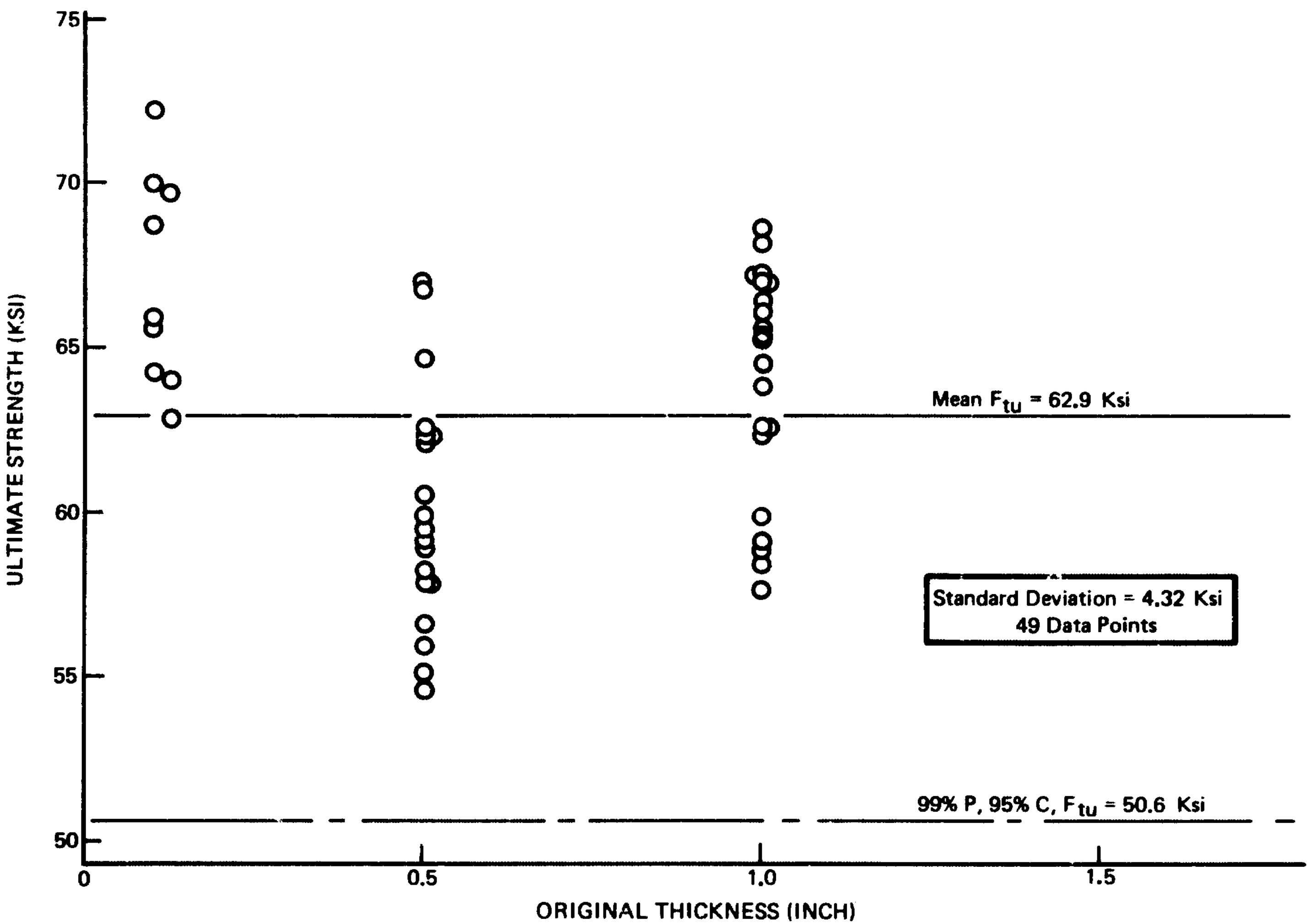


Figure 42: Liquid Hydrogen Temperature (−423^{0}F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment

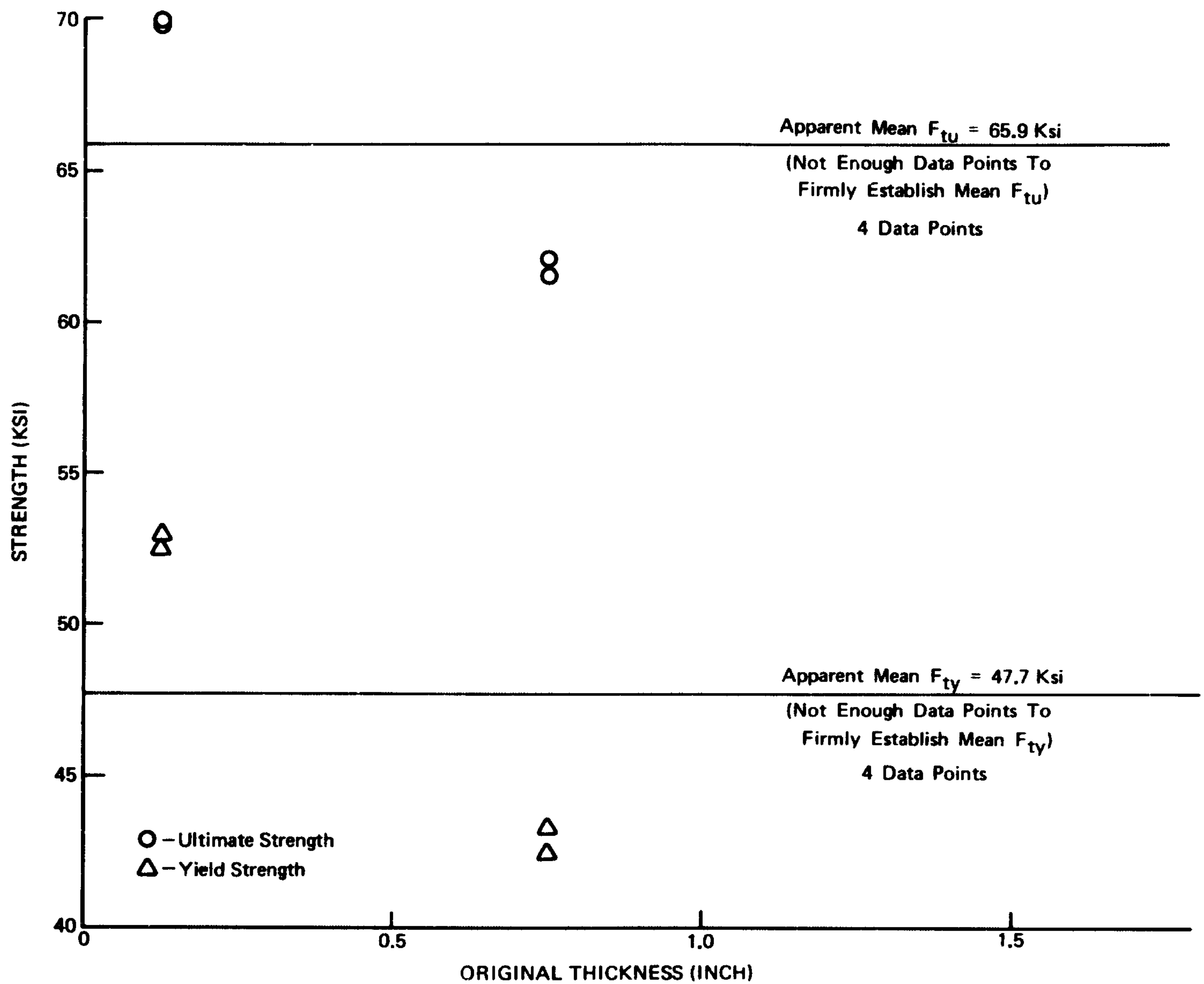


Figure 43: Room Temperature (70^{0}F - 75^{0}F) Ultimate and Yield Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, Weldments Subjected to STA Thermal Cycle After Welding

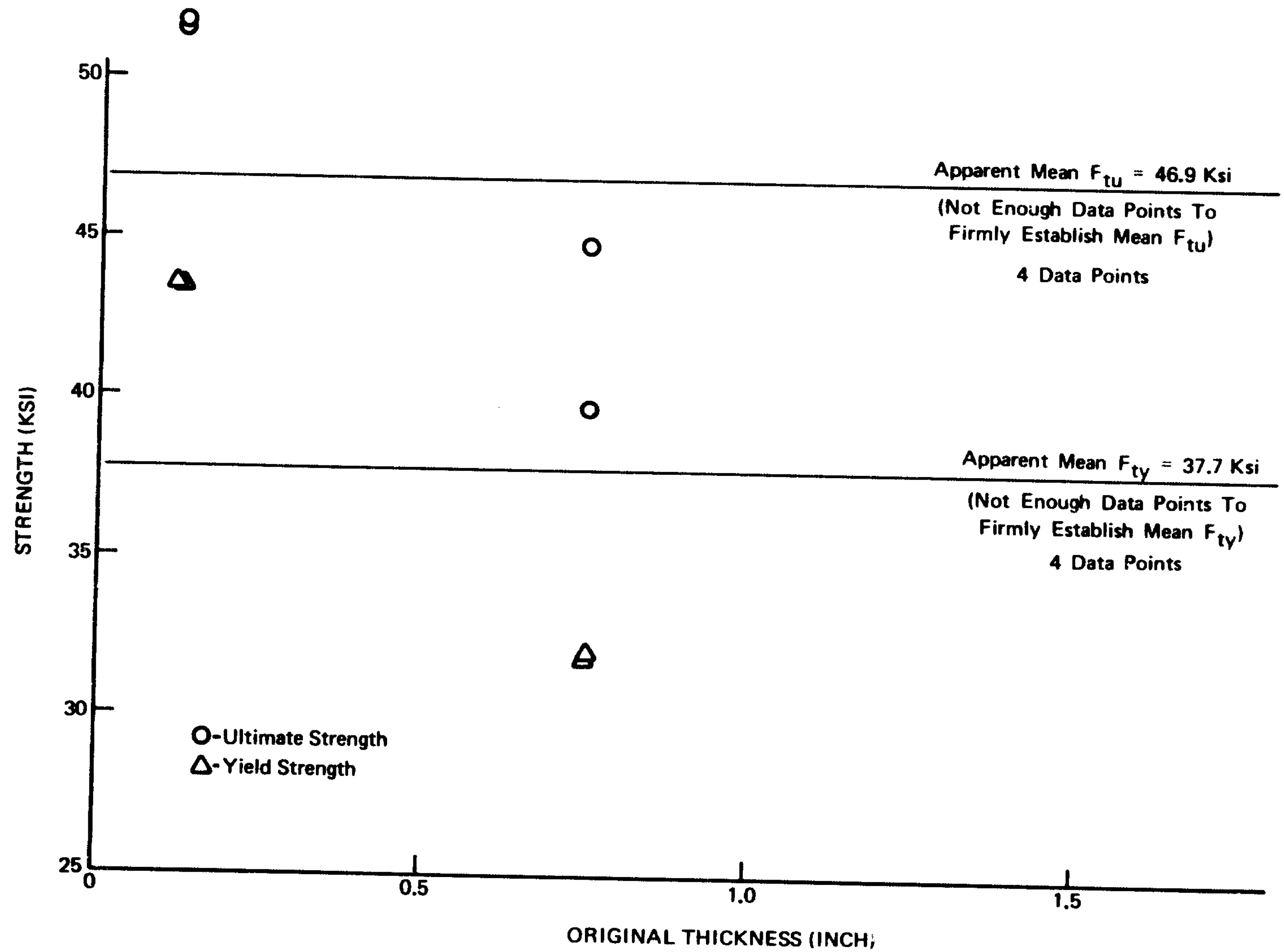


Figure 44: Room Temperature (70°F - 75°F) Ultimate and Yield Strength Vs. Thickness for 2219-T87 Aluminum Alloy GTA Weldments, Weldments Aged After Welding

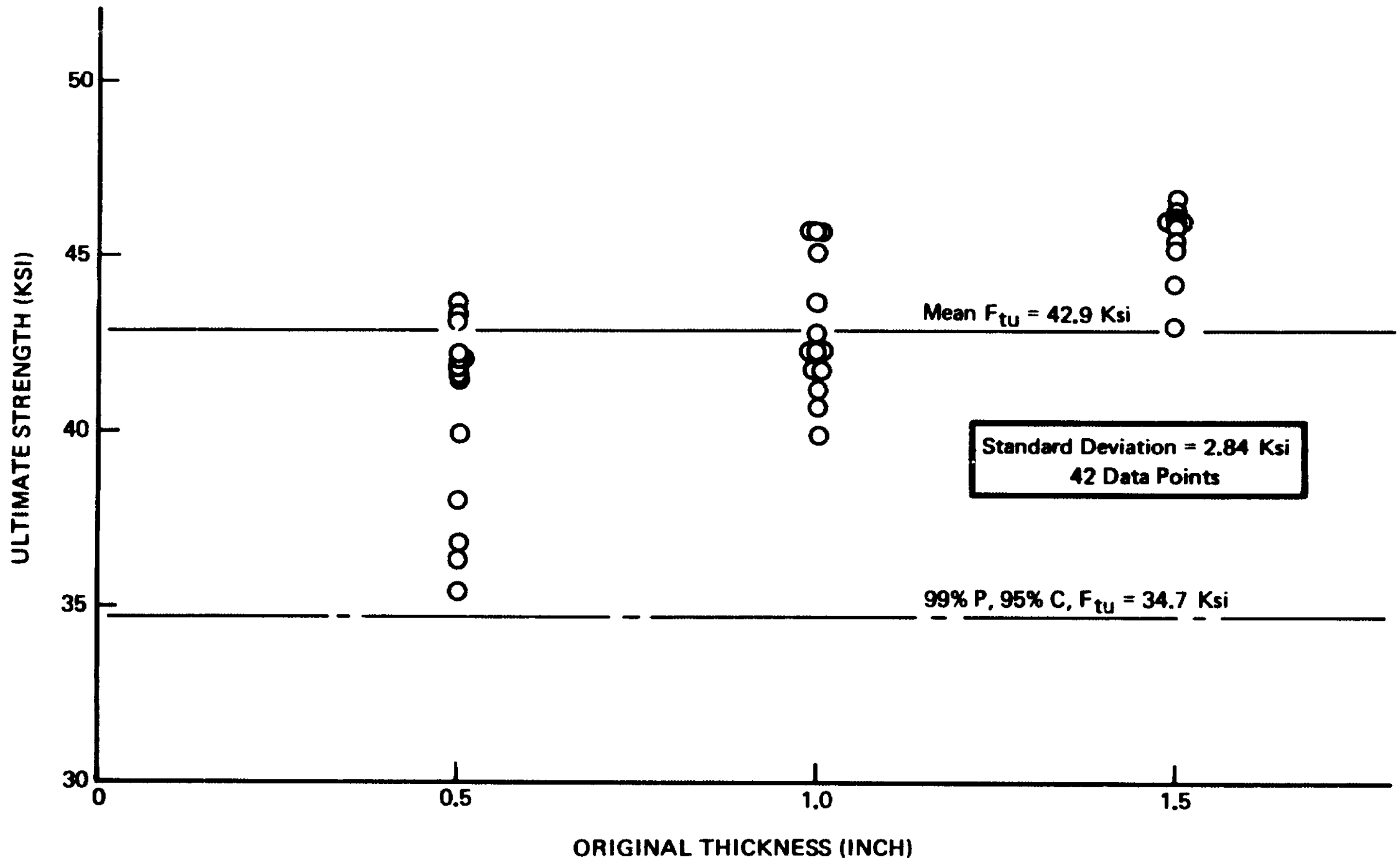


Figure 45: Room Temperature (70° F - 75° F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy GMA Weldments, No Post Weld Heat Treatment

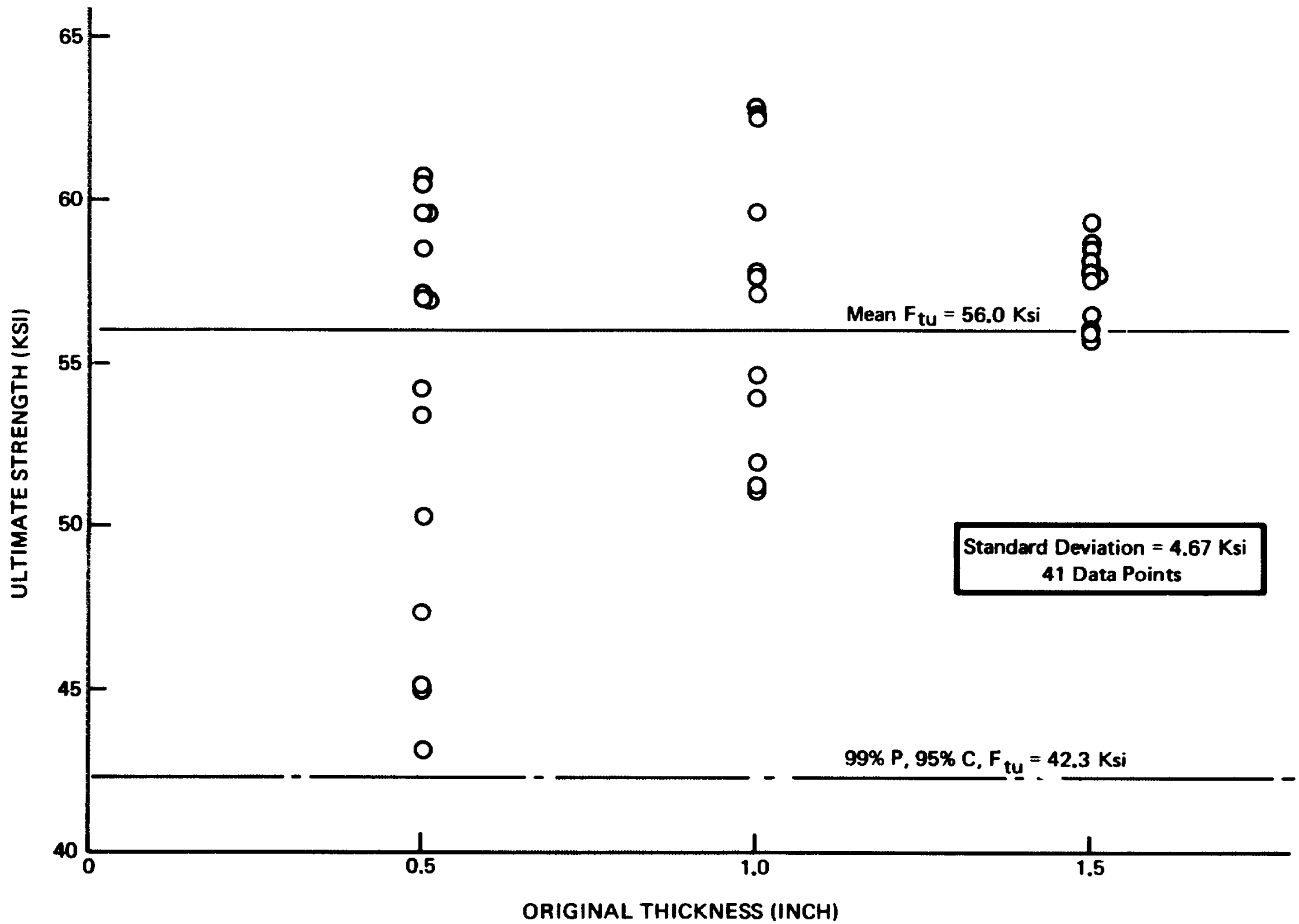


Figure 46: Liquid Nitrogen Temperature (-320°F) Ultimate Strength Vs. Thickness for 2219-T87 Aluminum Alloy GMA Weldments, No Post Weld Heat Treatment

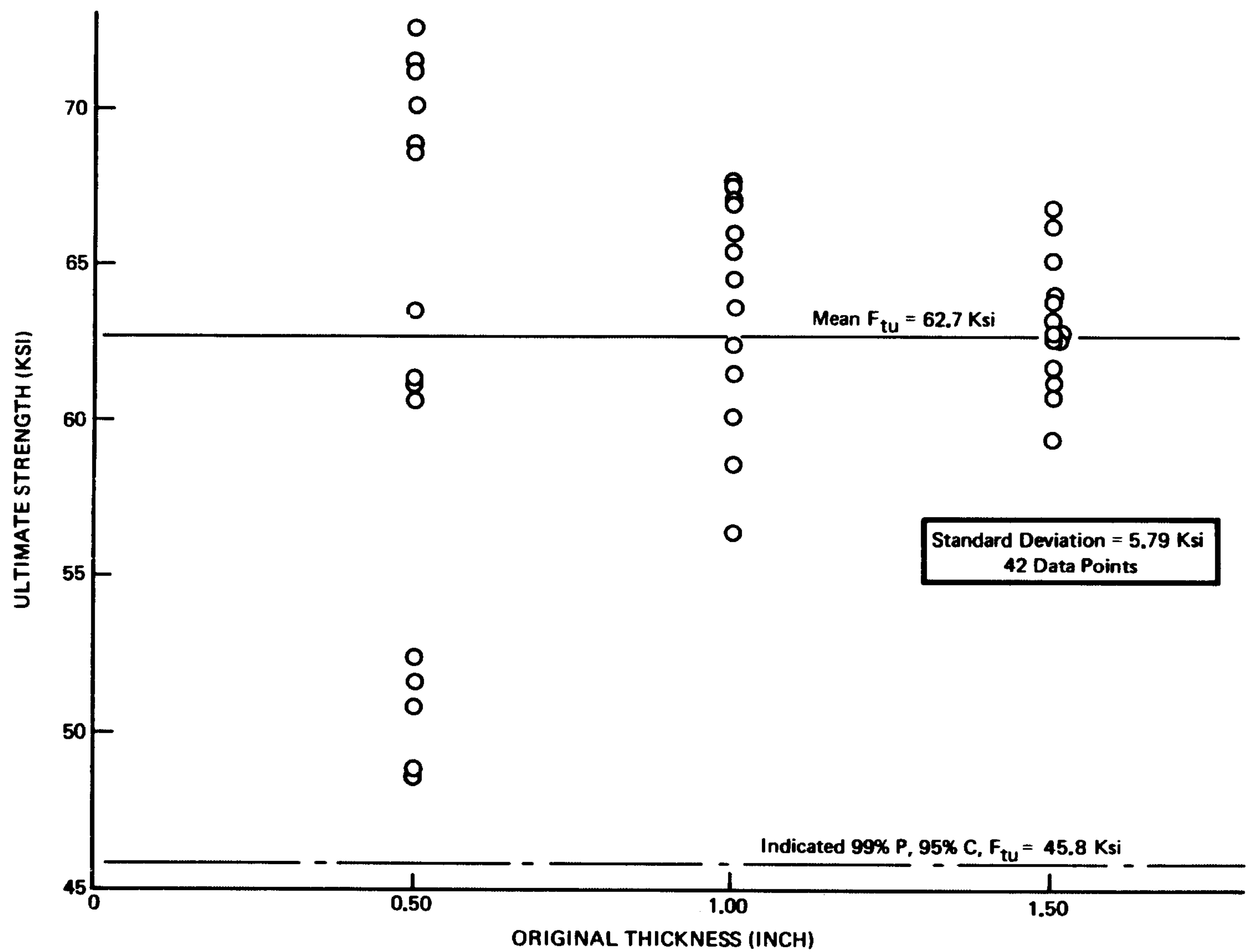


Figure 47: Liquid Hydrogen Temperature (-423^{0}F) Ultimate Strength Vs. Temperature for 2219-T87 Aluminum Alloy GMA Weldments, No Post Weld Heat Treatment

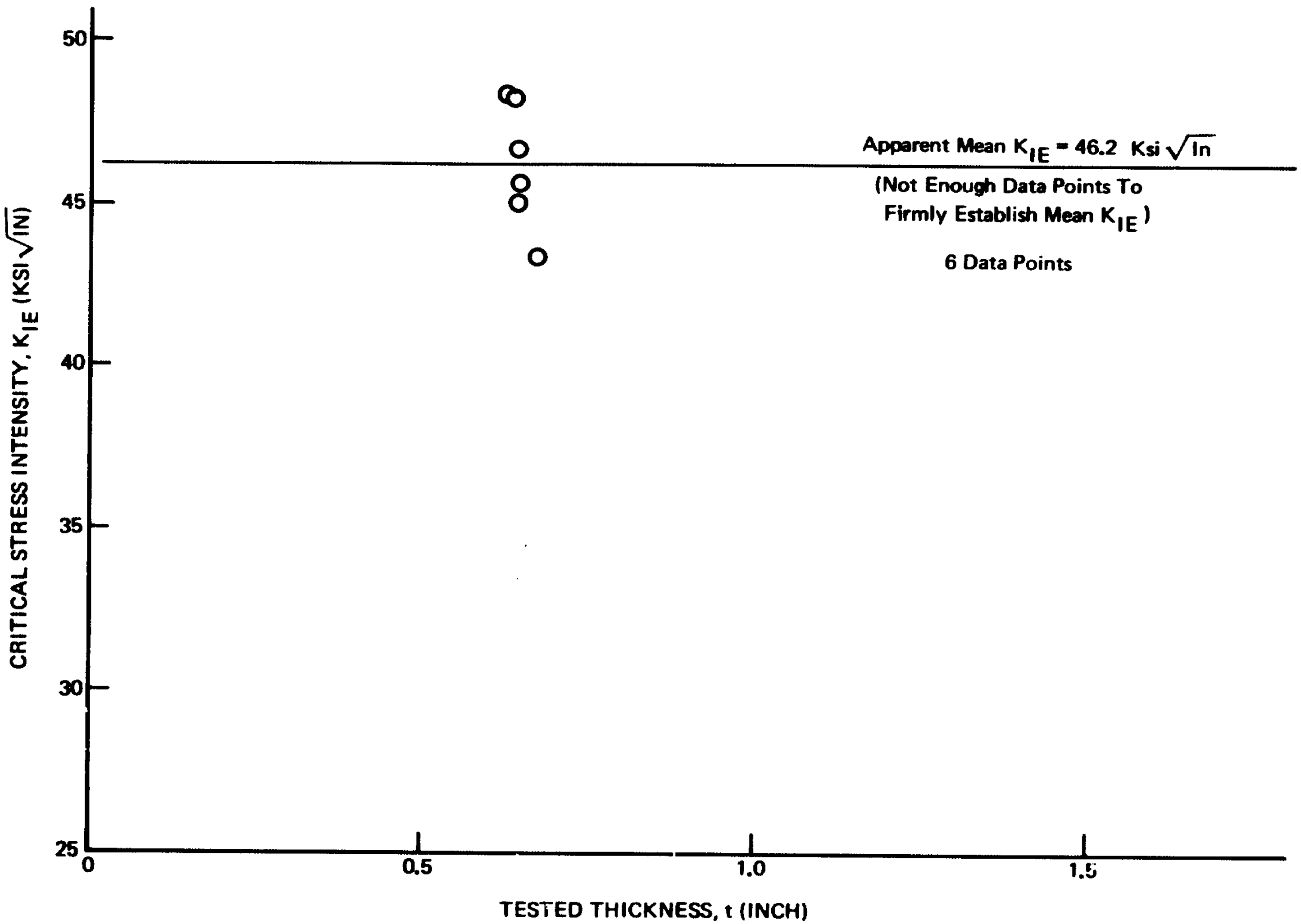


Figure 48: Room Temperature (70^0F - 75^0F) Critical Stress Intensity Vs. Tested Thickness, 2219-T87 Aluminum Alloy, RT Propagation Direction

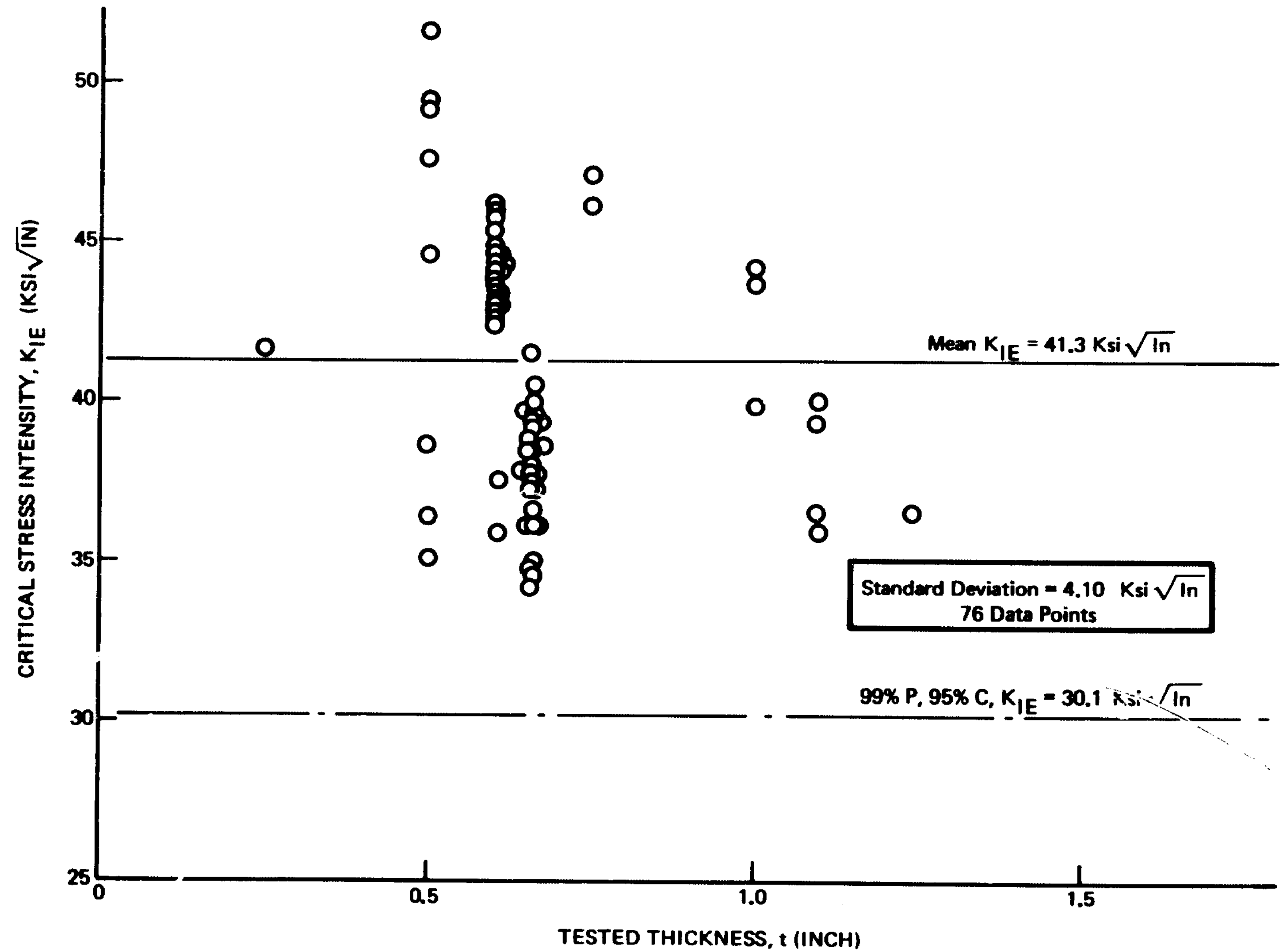


Figure 49: Room Temperature (70°F - 75°F) Critical Stress Intensity Vs. Tested Thickness, 2219-T87 Aluminum Alloy, WT Propagation Direction

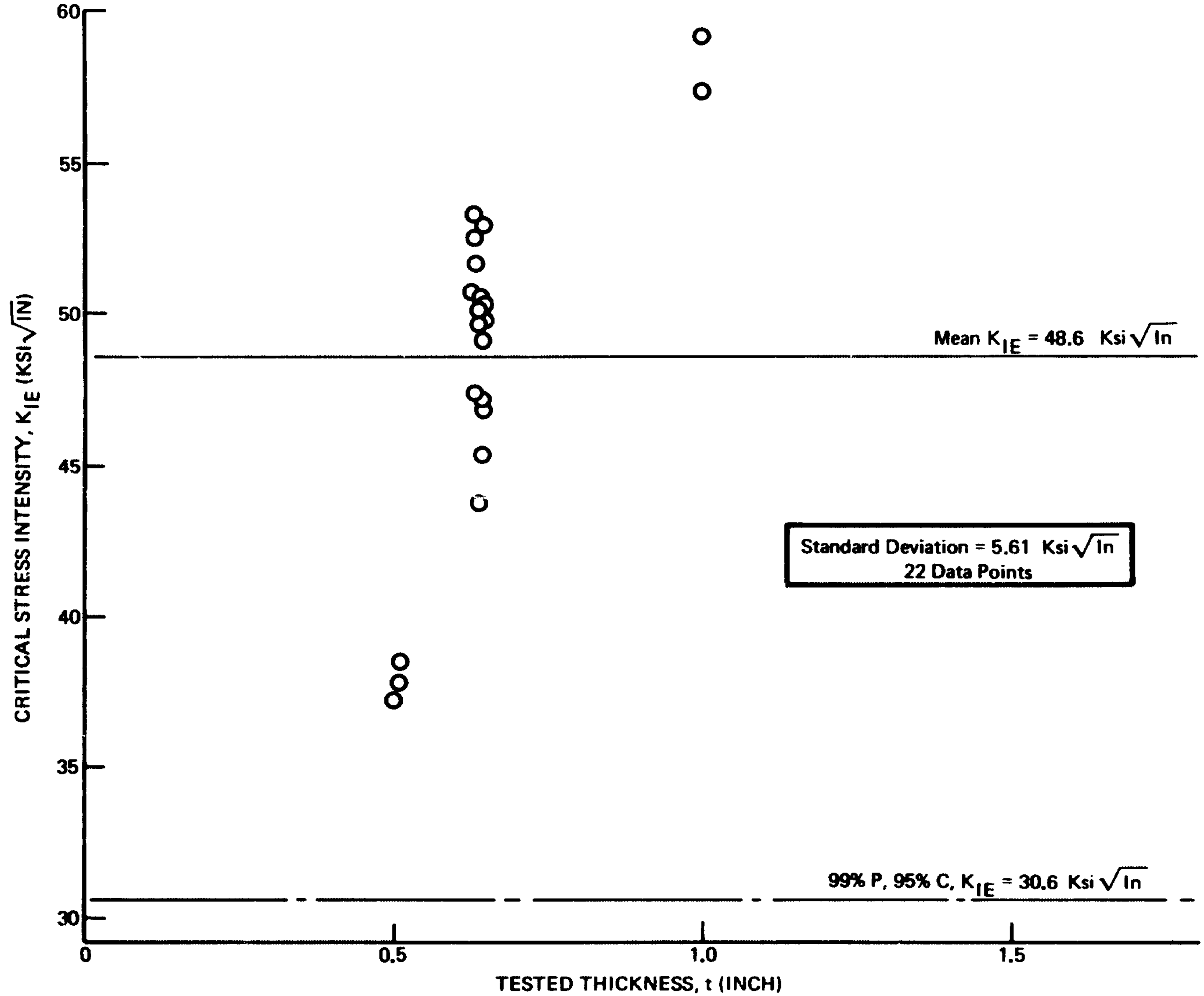


Figure 50: Liquid Nitrogen Temperature (-320^0 F) Critical Stress Intensity Vs. Tested Thickness, 2219-T87 Aluminum Alloy, RT Propagation Direction

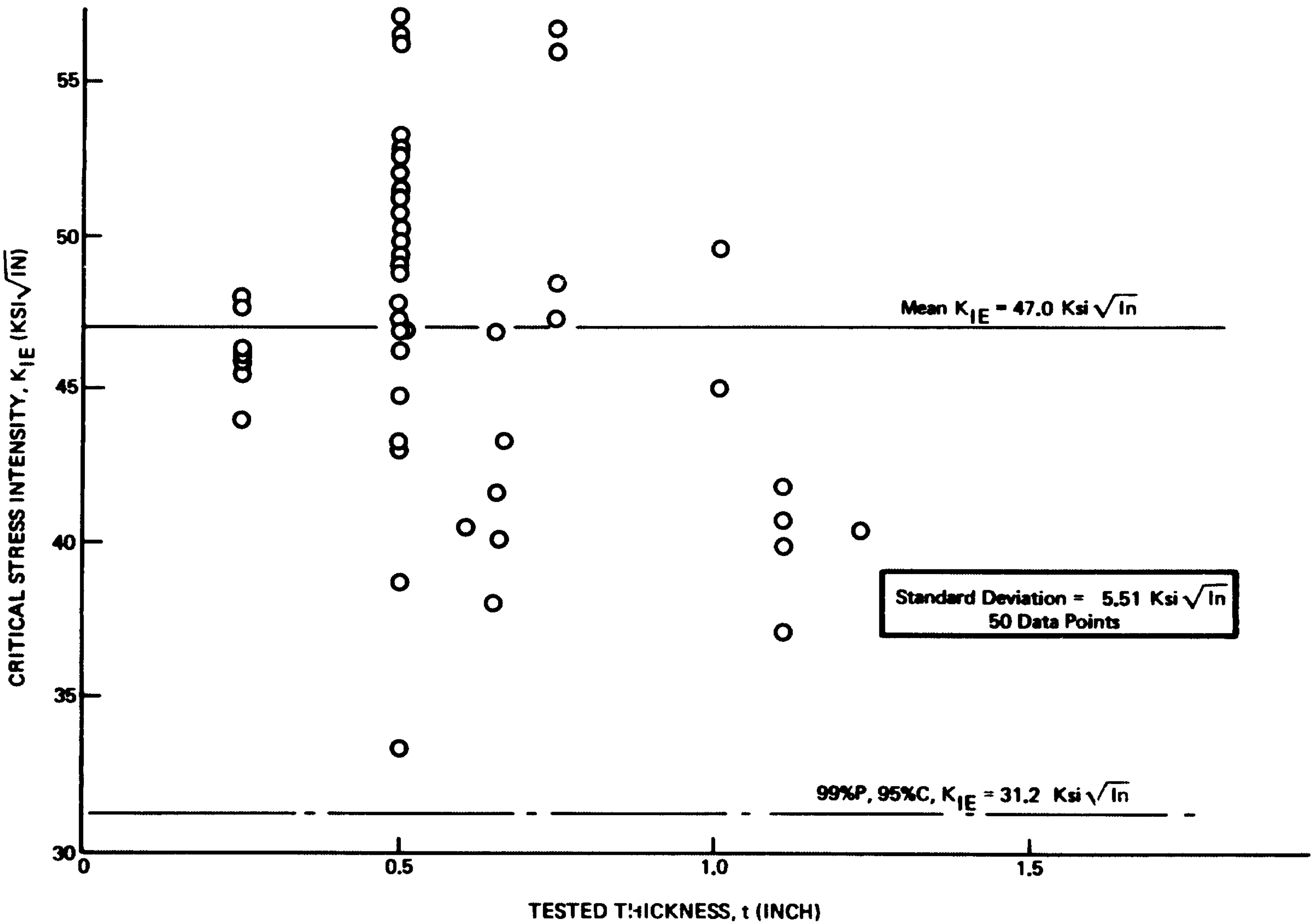


Figure 51: Liquid Nitrogen Temperature (-320°F) Critical Stress Intensity Vs. Tested Thickness, 2219-T87 Aluminum Alloy, WT Propagation Direction

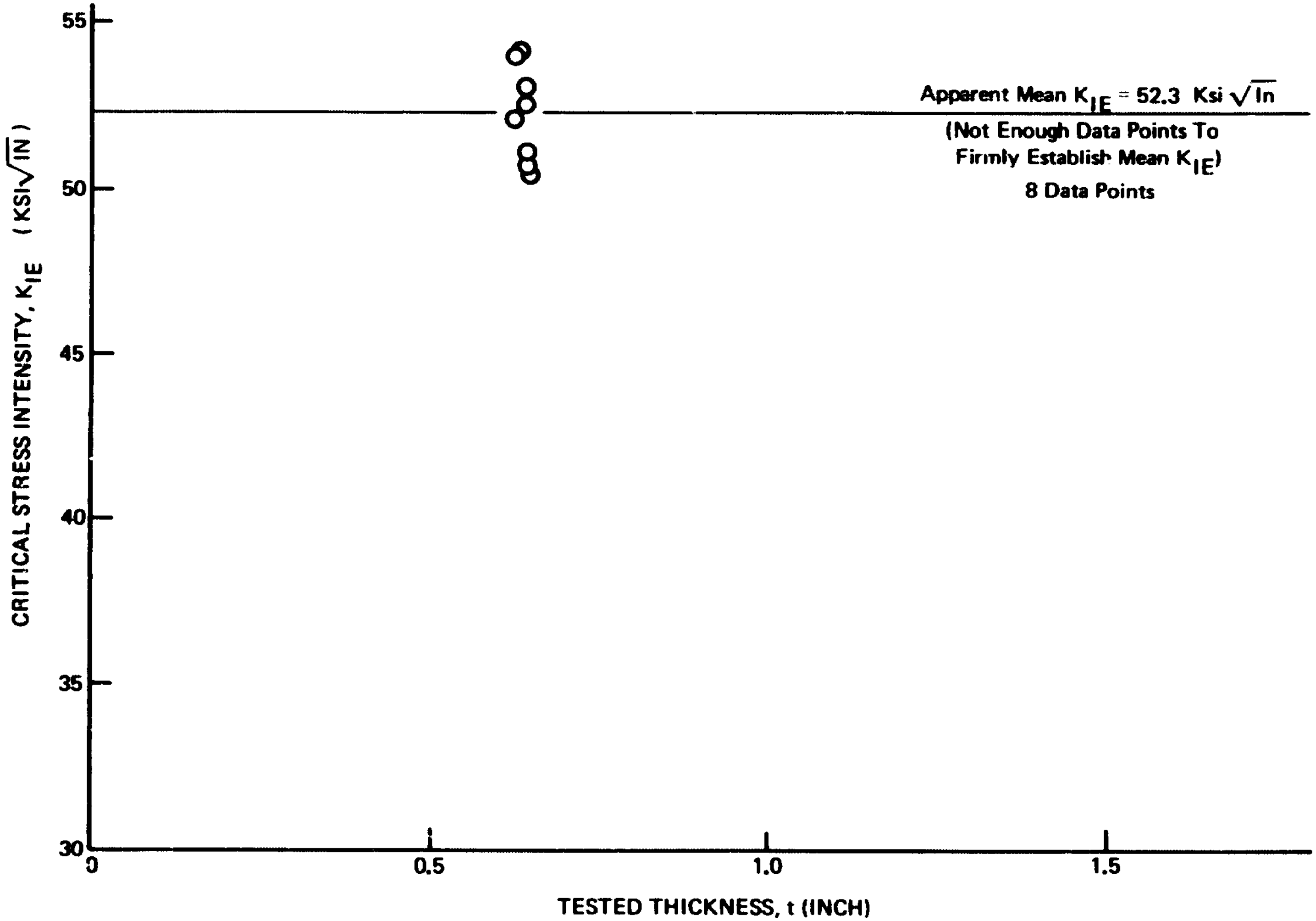


Figure 52: Liquid Hydrogen Temperature (-423°F) Critical Stress Intensity Vs. Tested Thickness, 2219-T87 Aluminum Alloy, RT Propagation Direction

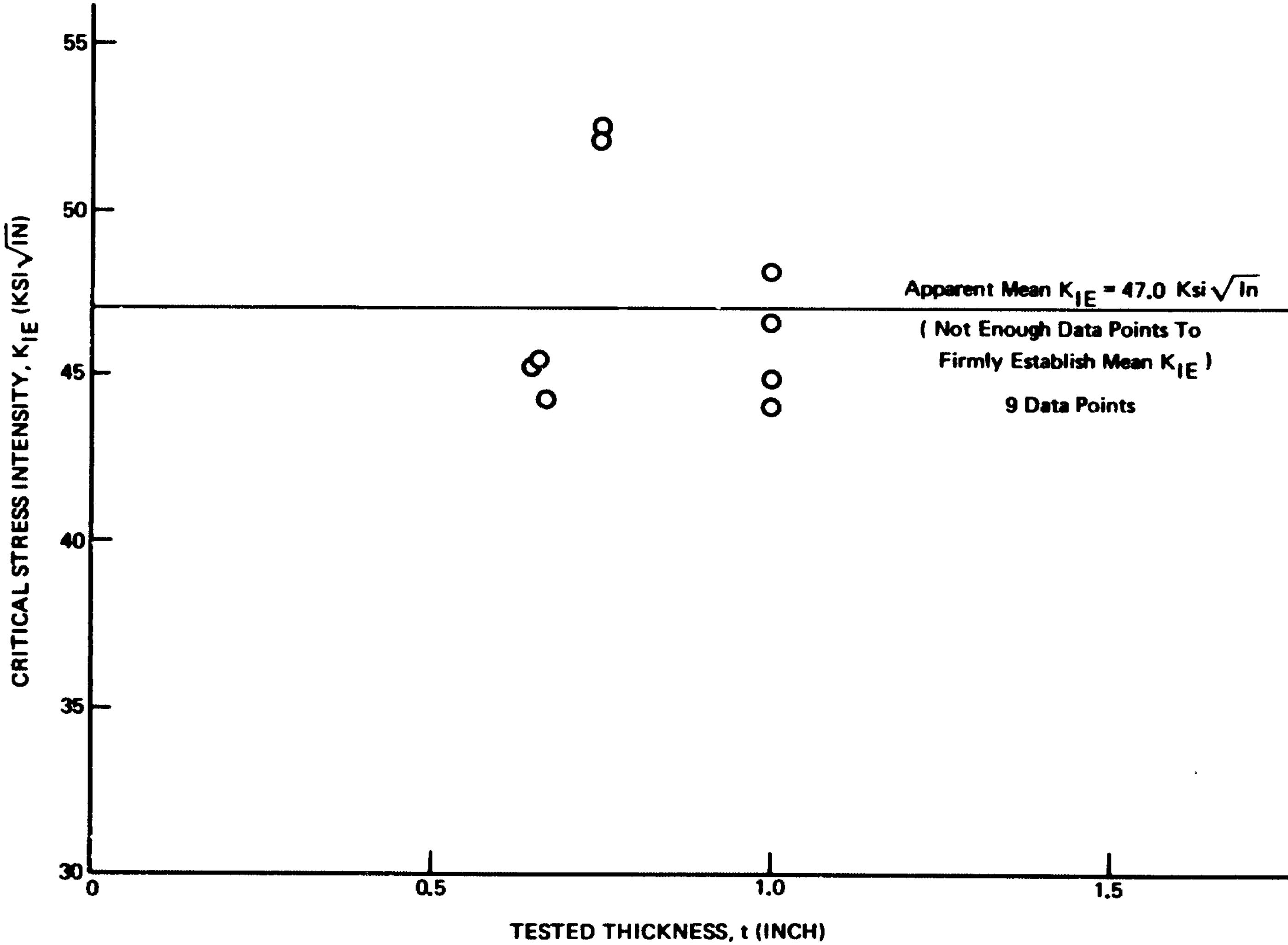


Figure 53: Liquid Hydrogen Temperature (−423° F) Critical Stress Intensity Vs. Tested Thickness, 2219-T87 Aluminum Alloy, WT Propagation Direction

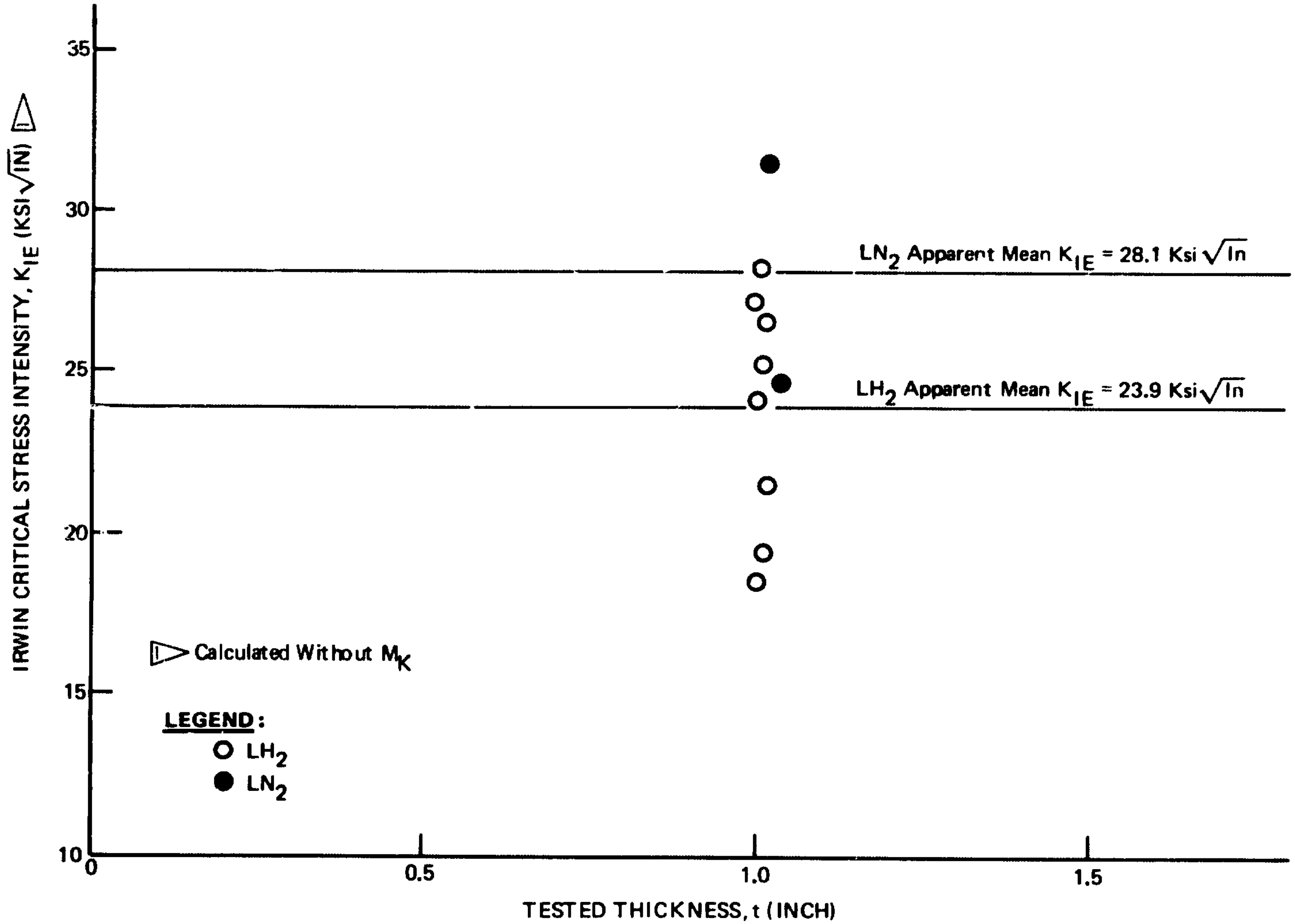


Figure 54: Liquid Nitrogen Temperature (−320°F) and Liquid Hydrogen Temperature (−423°F) Irwin Critical Stress Intensity Vs. Tested Thickness 2219–T87 Aluminum Alloy GTA Weldments, No Post Weld Heat Treatment

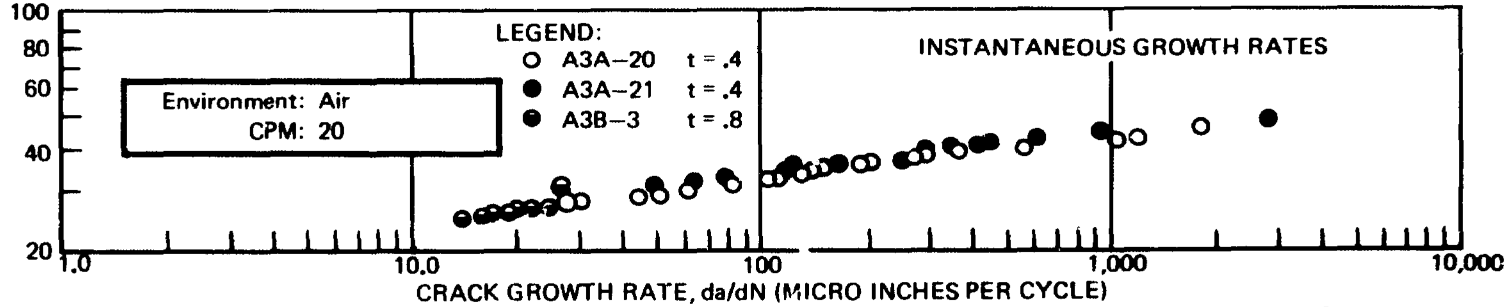


Figure 55: Cyclic Flaw Growth Rates for 0.40 and 0.80–Inch–Thick 2219–T87 Aluminum Base Metal at 72^{0}F for the WT Propagation Direction (Reference 5)

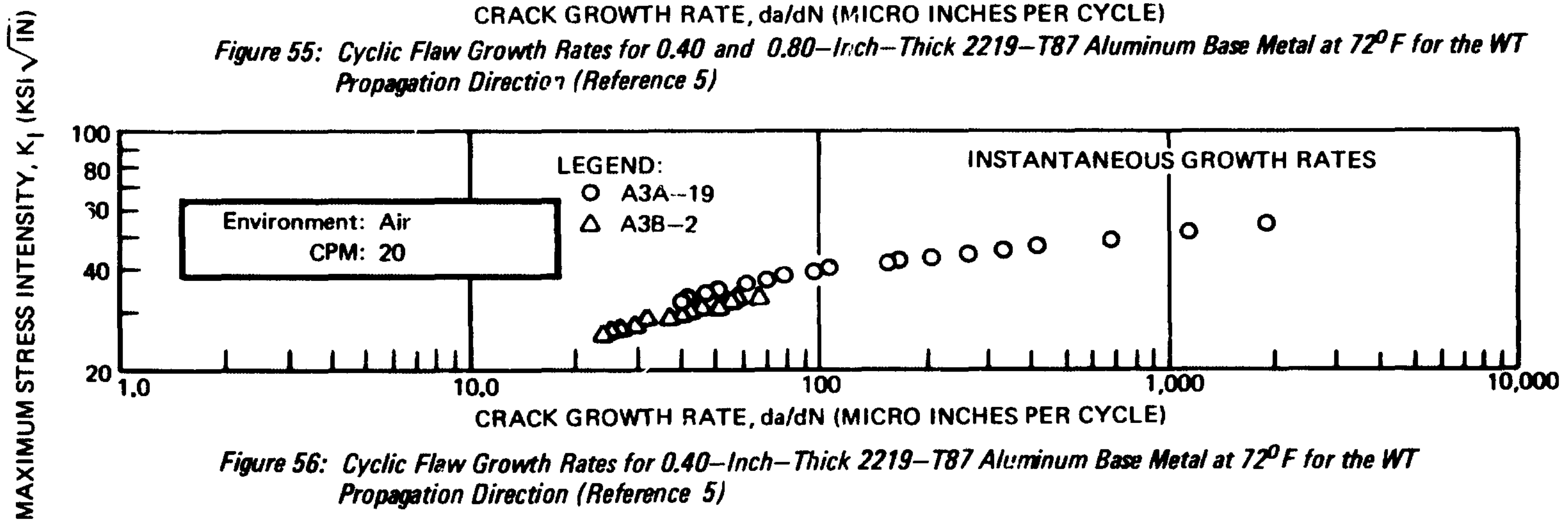


Figure 56: Cyclic Flaw Growth Rates for 0.40–Inch–Thick 2219–T87 Aluminum Base Metal at 72^{0}F for the WT Propagation Direction (Reference 5)

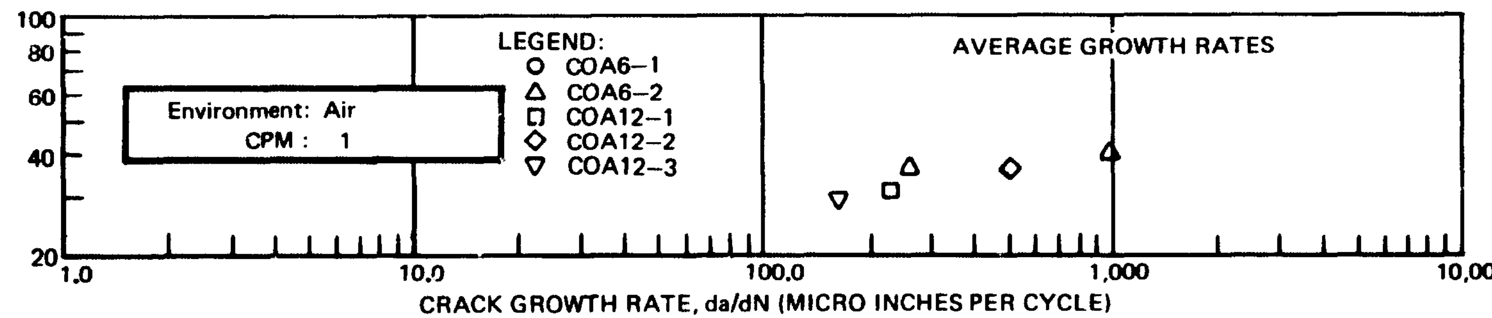


Figure 57: Cyclic Flaw Growth Rates for 0.60 and 1.25–Inch–Thick 2219–T87 Aluminum Base Metal at 72^{0}F for the WT Propagation Direction (Reference 13)

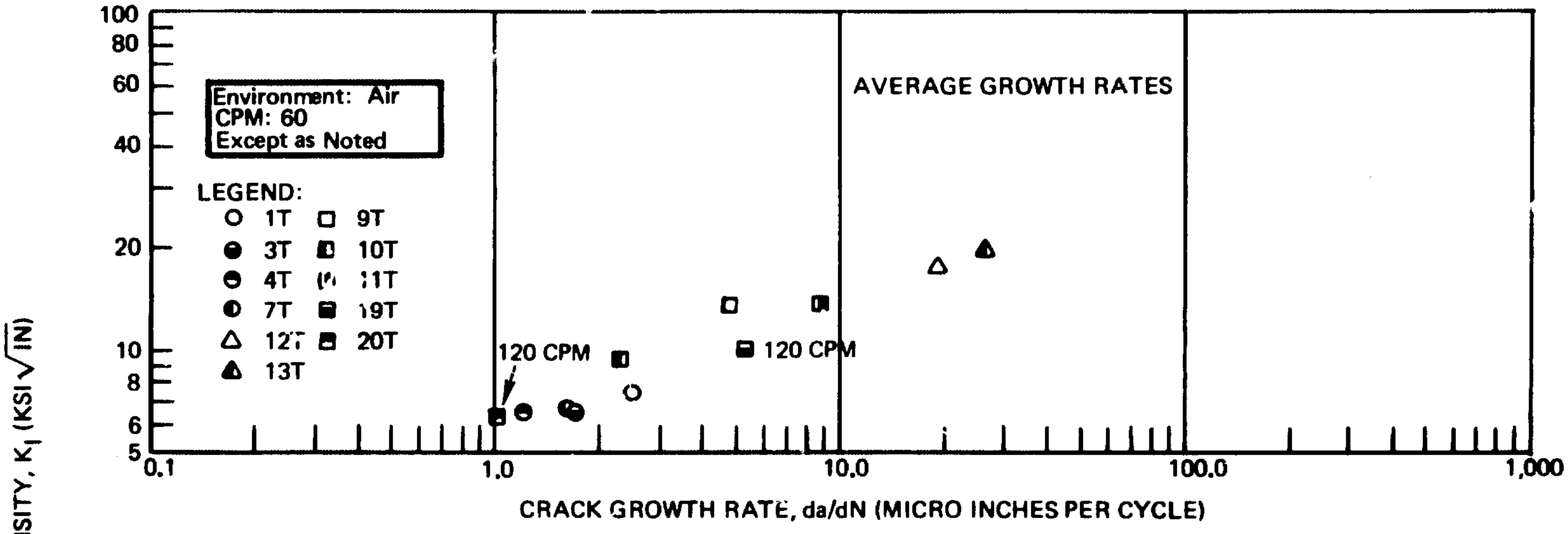


Figure 58: Cyclic Flaw Growth Rates for 0.125–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 26)

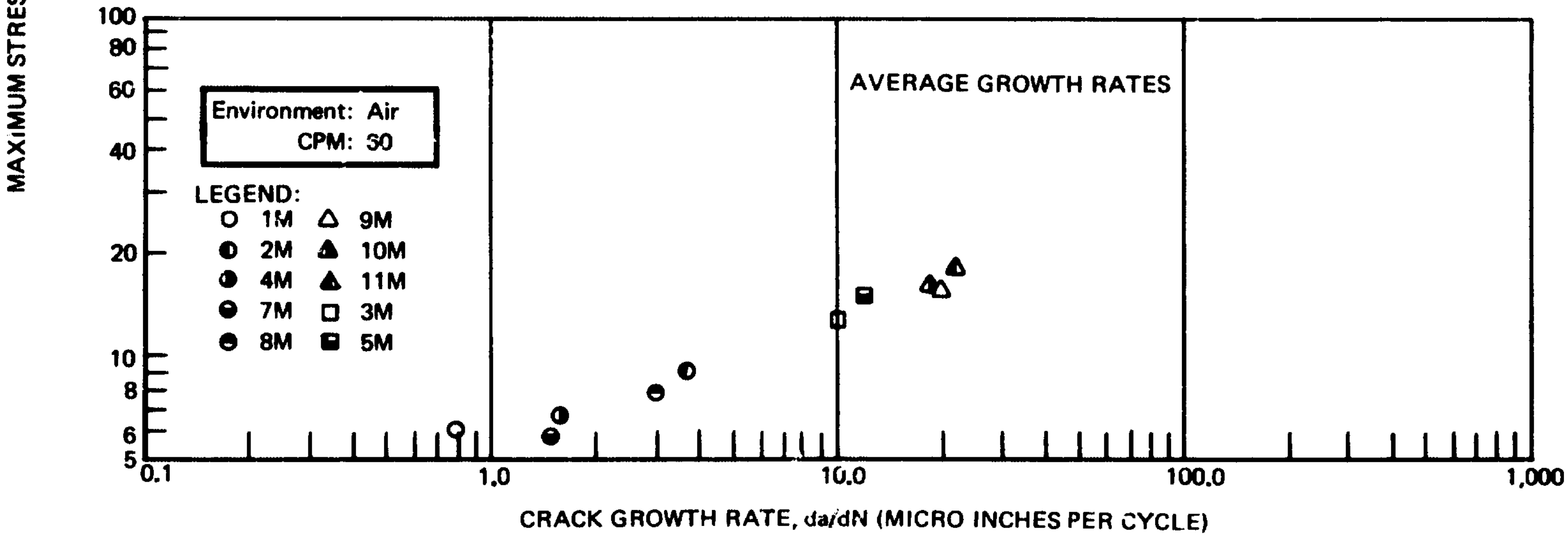


Figure 59: Cyclic Flaw Growth Rates for 0.125–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 26)

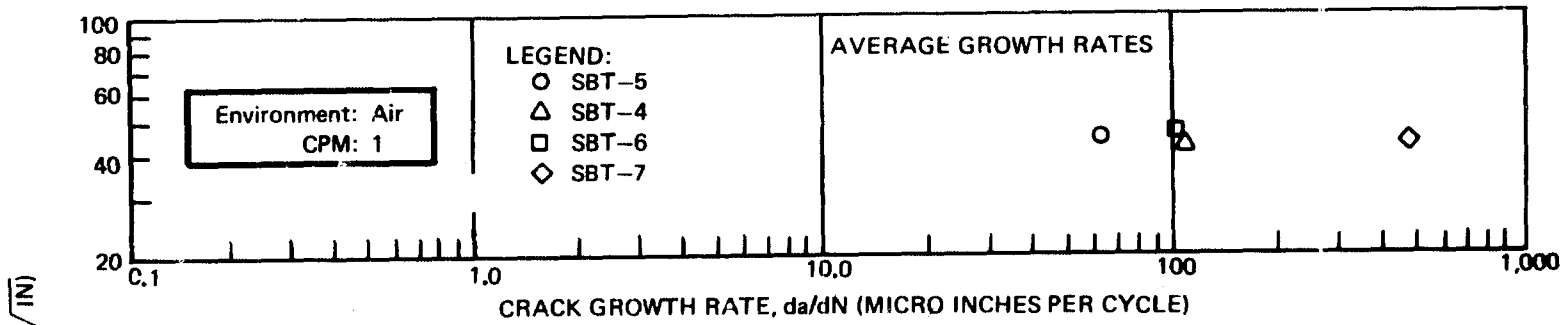


Figure 60: Cyclic Flaw Growth Rates for 1.00–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 6)

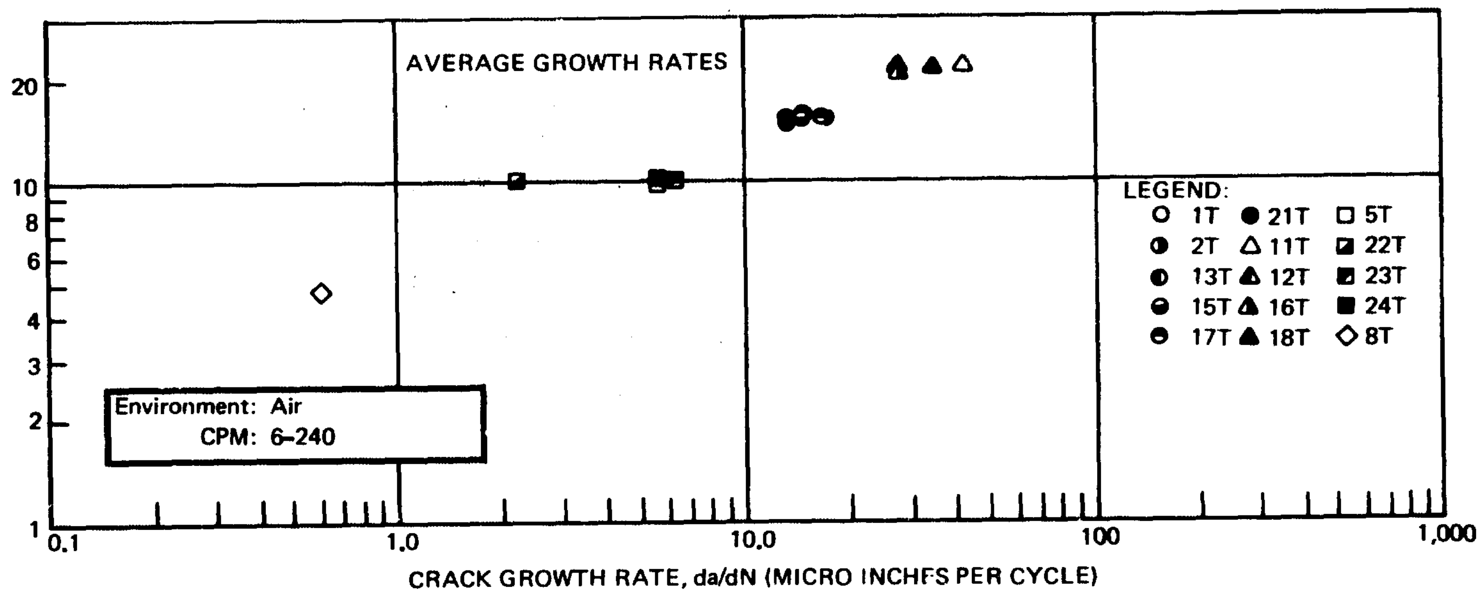


Figure 61: Cyclic Flaw Growth Rates for 0.250–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 26)

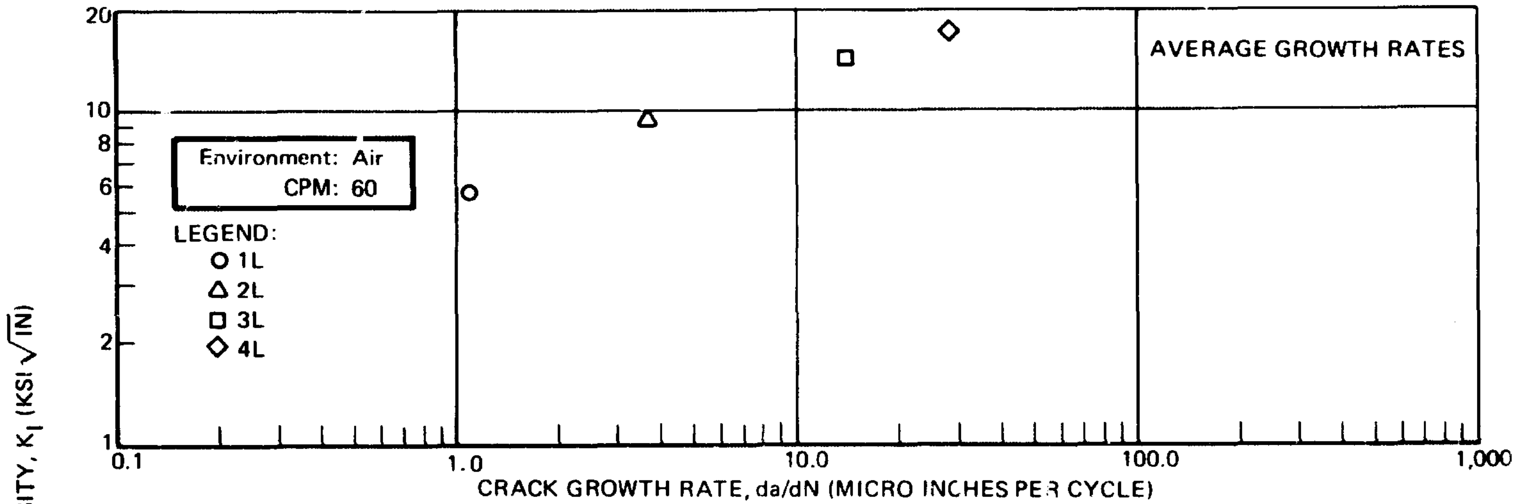


Figure 62: Cyclic Flaw Growth Rates for 0.125–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the RT Propagation Direction (Reference 26)

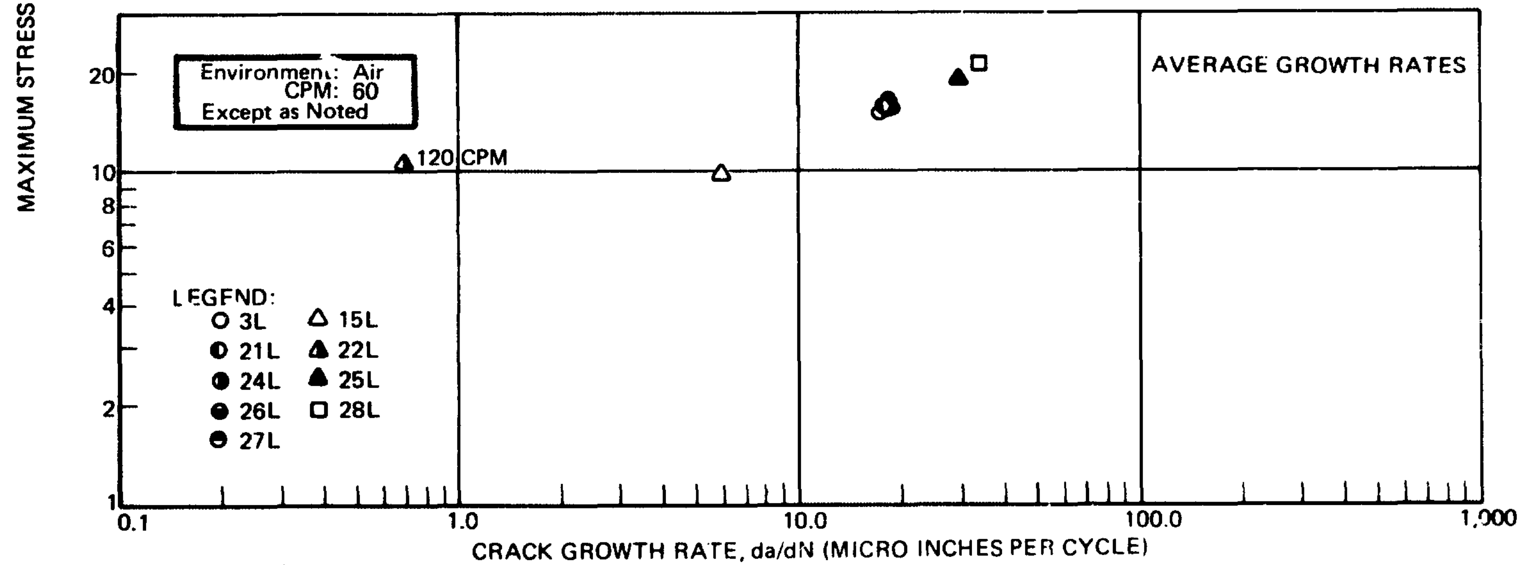


Figure 63: Cyclic Flaw Growth Rates for 0.250–Inch–Thick 2219 -T87 Aluminum Base Metal at 72°F for the RT Propagation Direction (Reference 26)

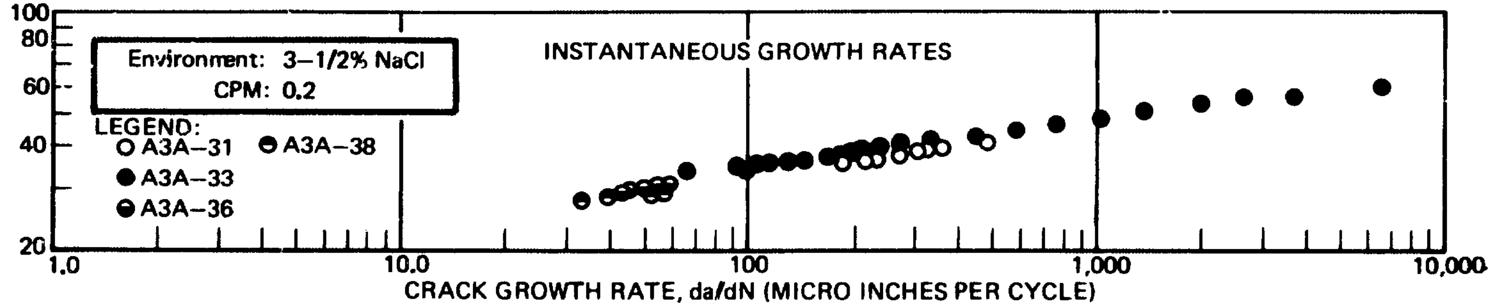


Figure 64: Cyclic Flaw Growth Rates for 0.40–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)

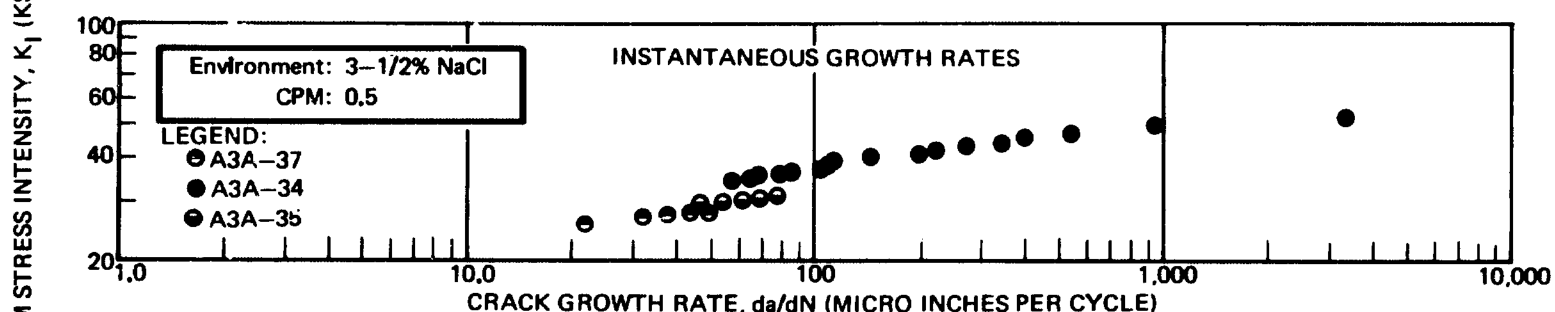


Figure 65: Cyclic Flaw Growth Rates for 0.400–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)

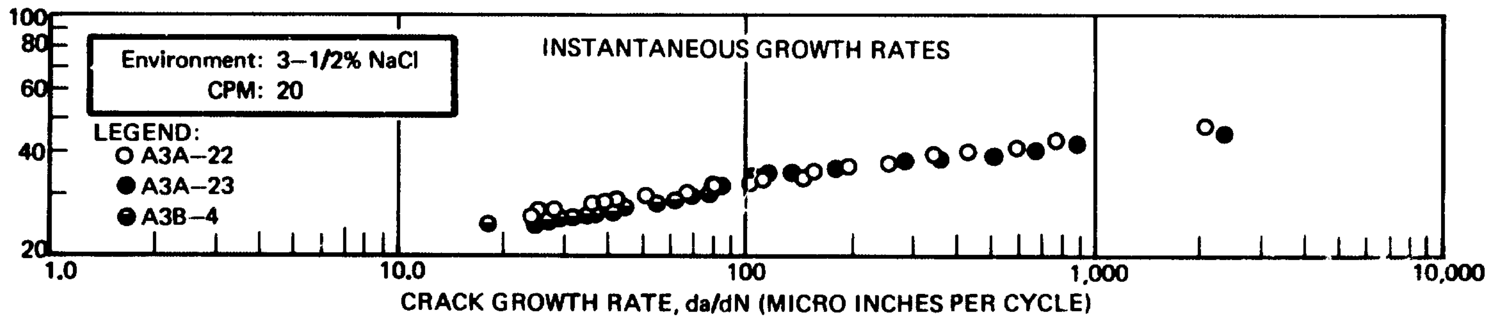


Figure 66: Cyclic Flaw Growth Rates for 0.40 and 0.80–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 5)

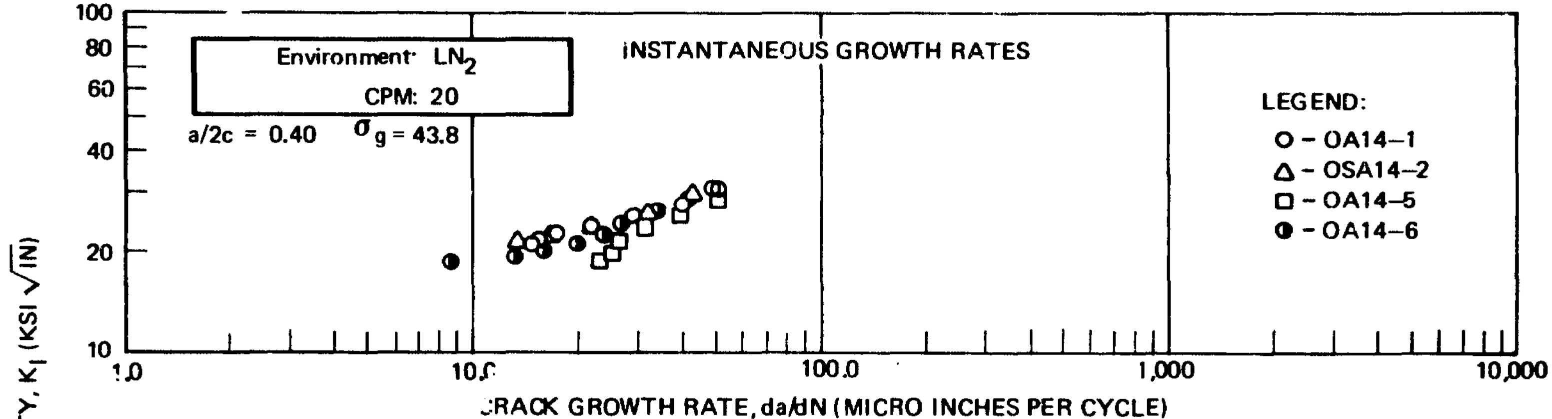


Figure 67: Cyclic Fl…w Growth Rates for 0.150–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 2)

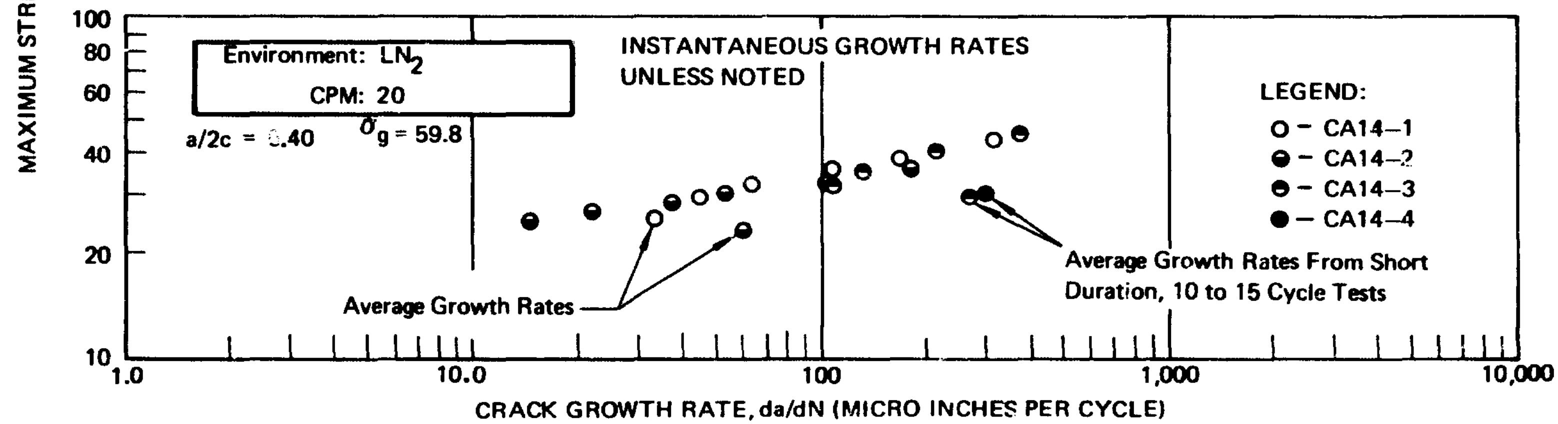


Figure 68: Cyclic Flaw Growth Rates for 0.150–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 2)

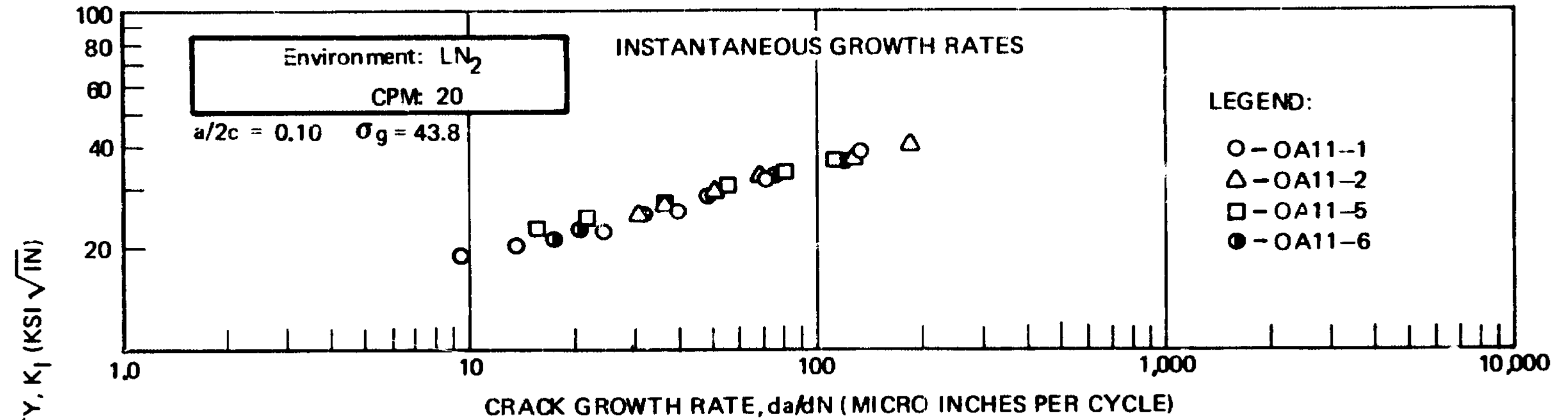


Figure 69: Cyclic Flaw Growth Rates for 0.150–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 2)

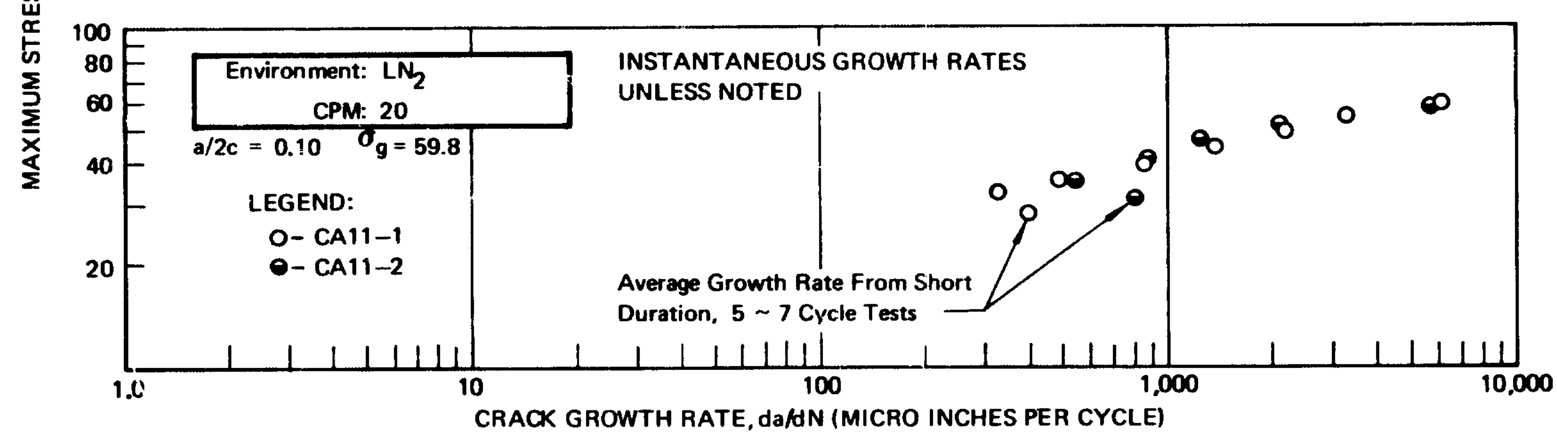


Figure 70: Cyclic Flaw Growth Rates for 0.150–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 2)

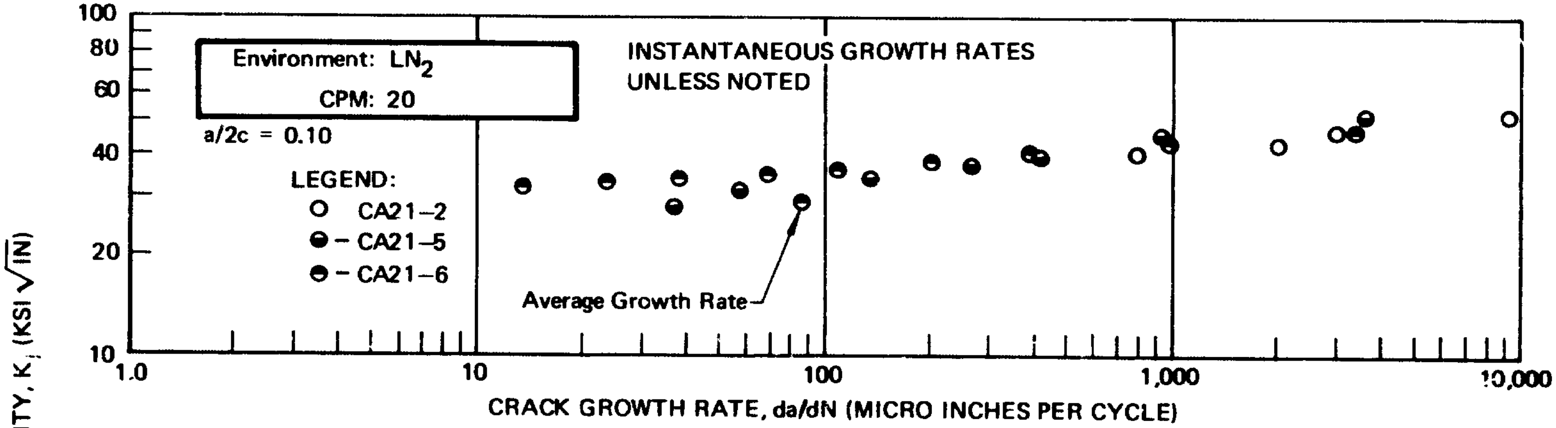


Figure 71: Cyclic Flaw Growth Rates for 0.200–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 2)

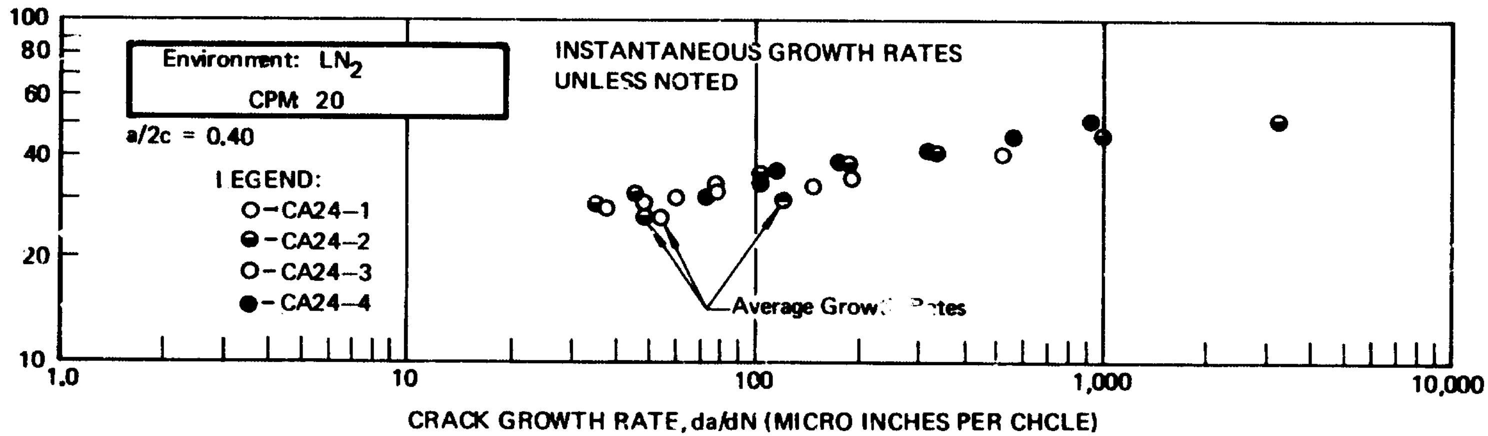


Figure 72: Cyclic Flaw Growth Rates for 0.200–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 2)

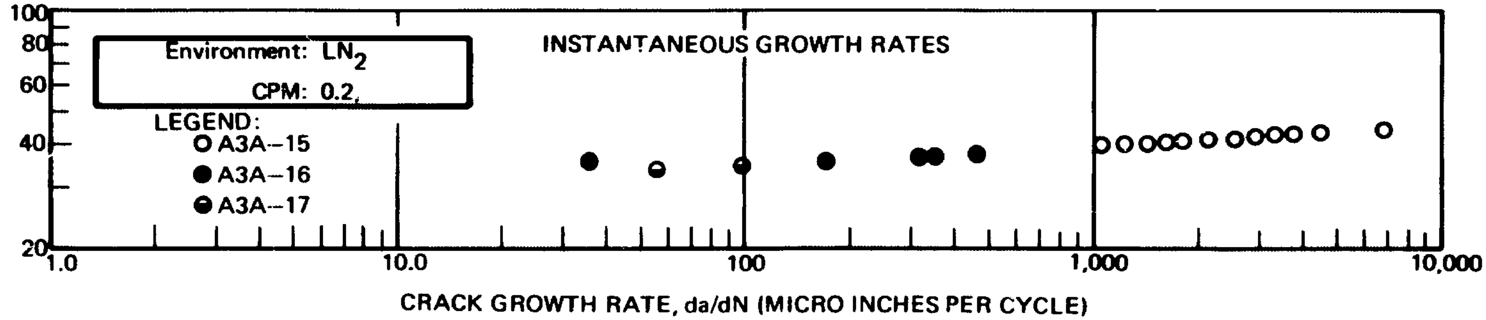


Figure 73: Cyclic Flaw Growth Rates for 0.400–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 5)

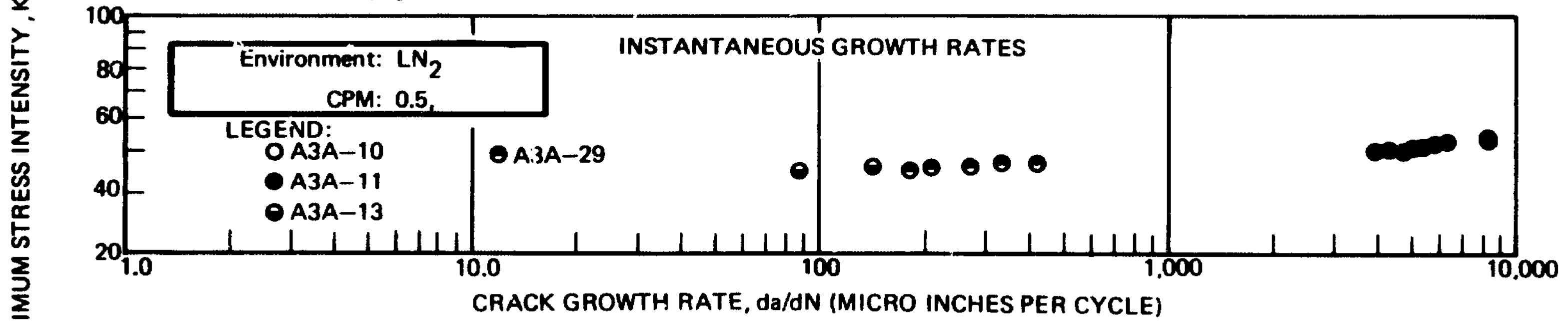


Figure 74: Cyclic Flaw Growth Rates for 0.400–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 5)

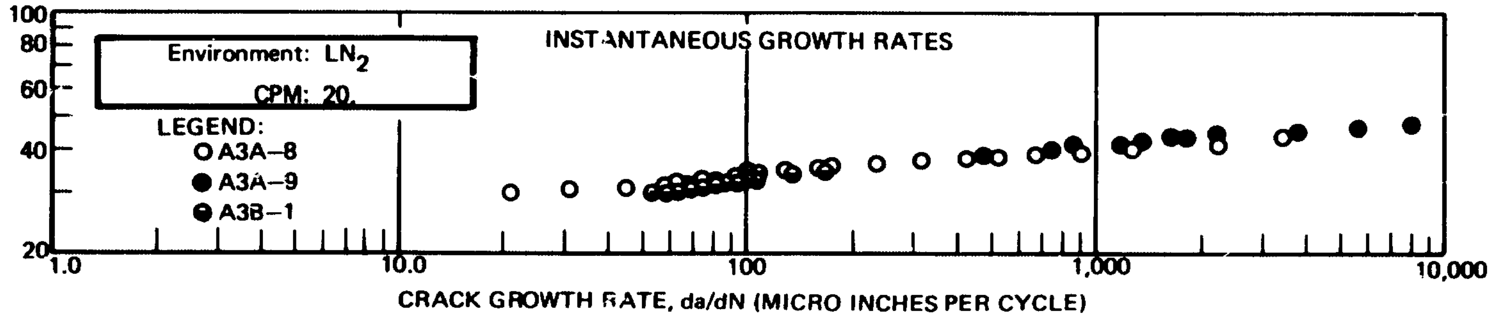


Figure 75: Cyclic Flaw Growth Rates for 0.40 and 0.80–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 5)

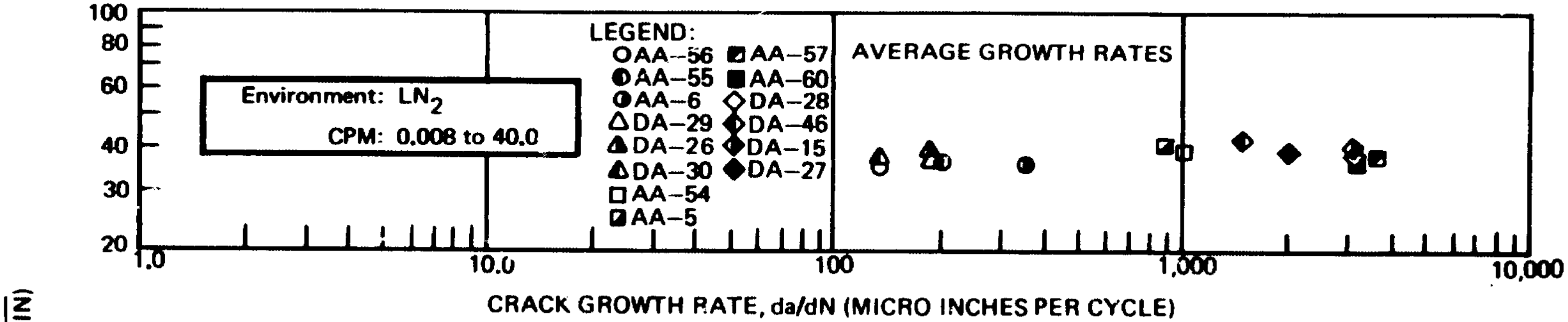


Figure 76: Cyclic Flaw Growth Rates for 0.65–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 14)

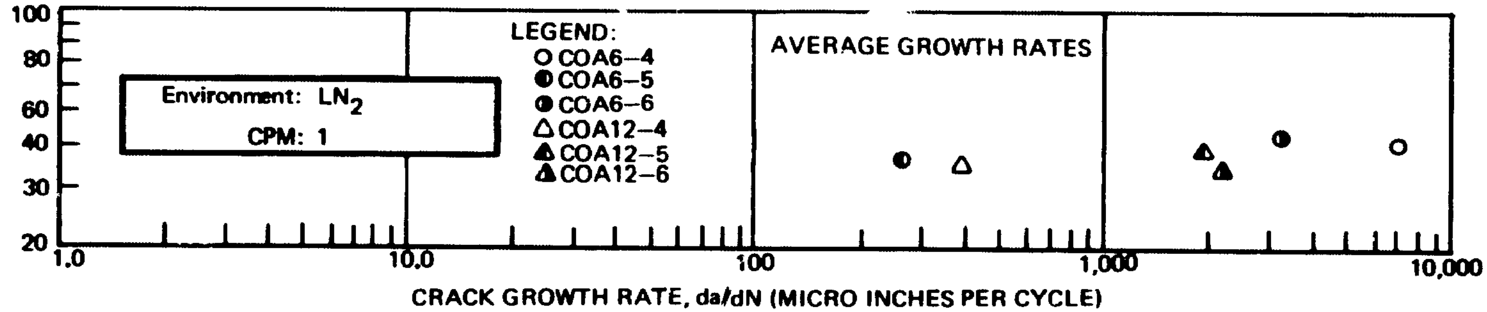


Figure 77: Cyclic Flaw Growth Rates for 0.60 and 1.25–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 13)

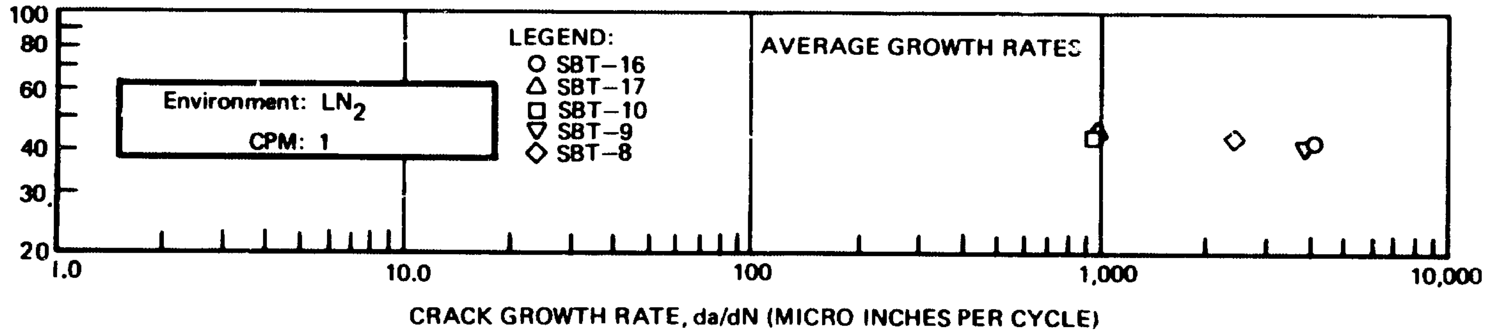


Figure 78: Cyclic Flaw Growth Rates for 1.00–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 6)

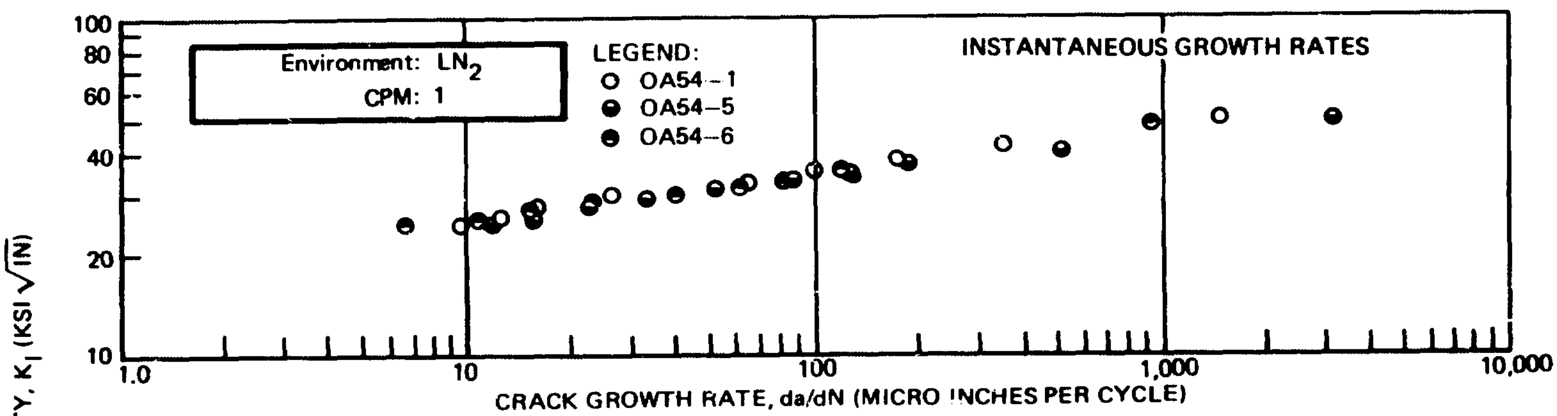


Figure 79: Cyclic Flaw Growth Rates for 0.500–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 2)

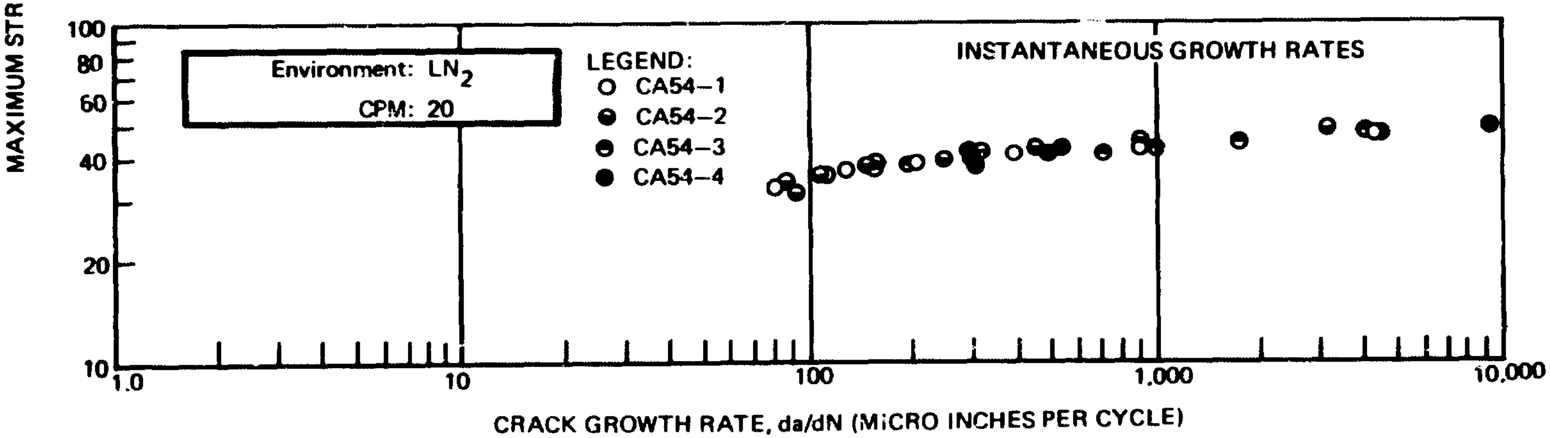


Figure 80: Cyclic Flaw Growth Rates for 0.500–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 2)

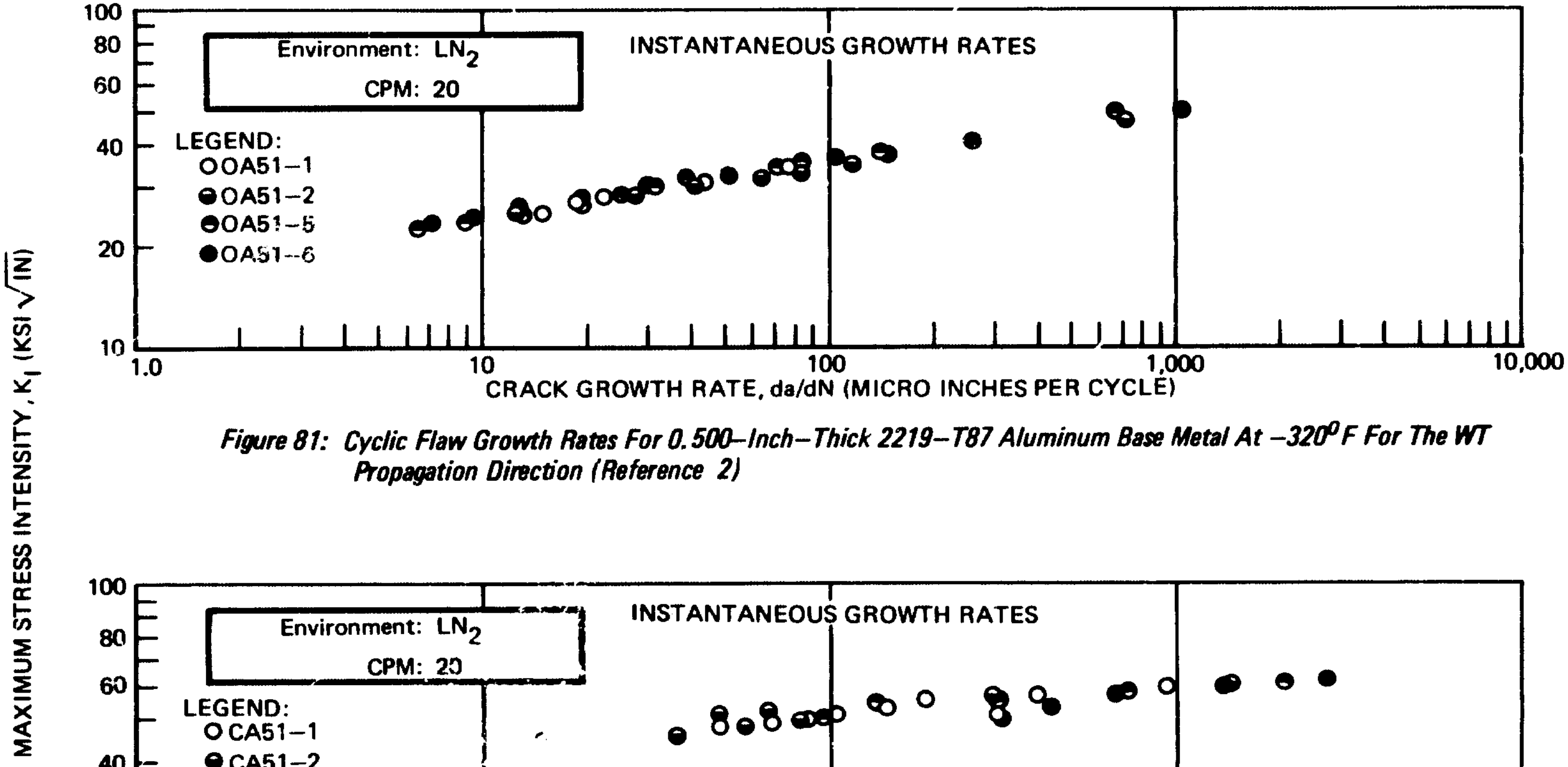


Figure 81: Cyclic Flaw Growth Rates For 0.500–Inch–Thick 2219–T87 Aluminum Base Metal At –320^{0}F For The WT Propagation Direction (Reference 2)

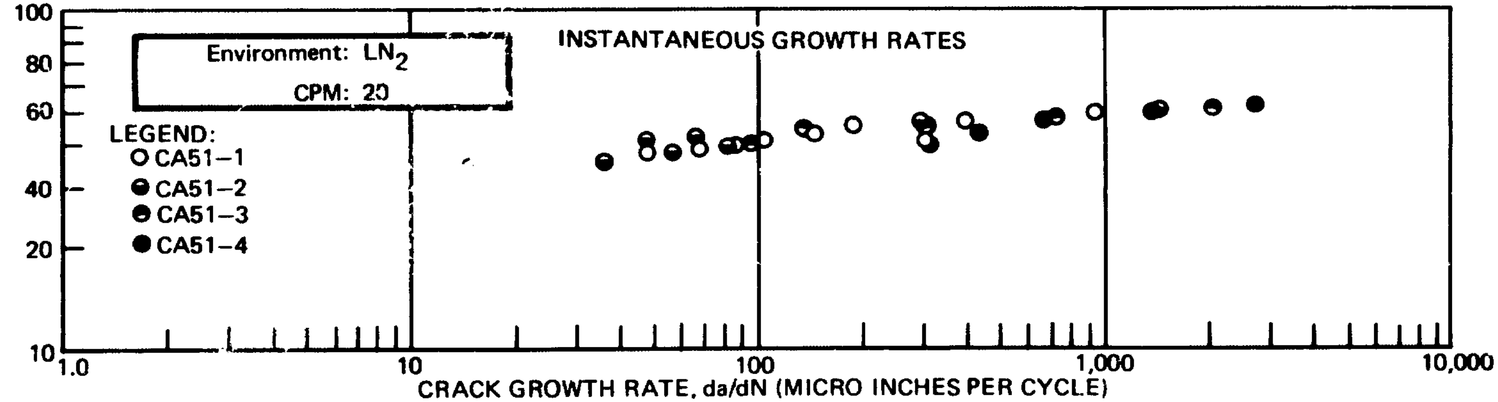


Figure 82: Cyclic Flaw Growth Rates For 0.500–Inch–Thick 2219–T87 Aluminum Base Metal At –320^{0}F for the WT Propagation Direction (Reference 2)

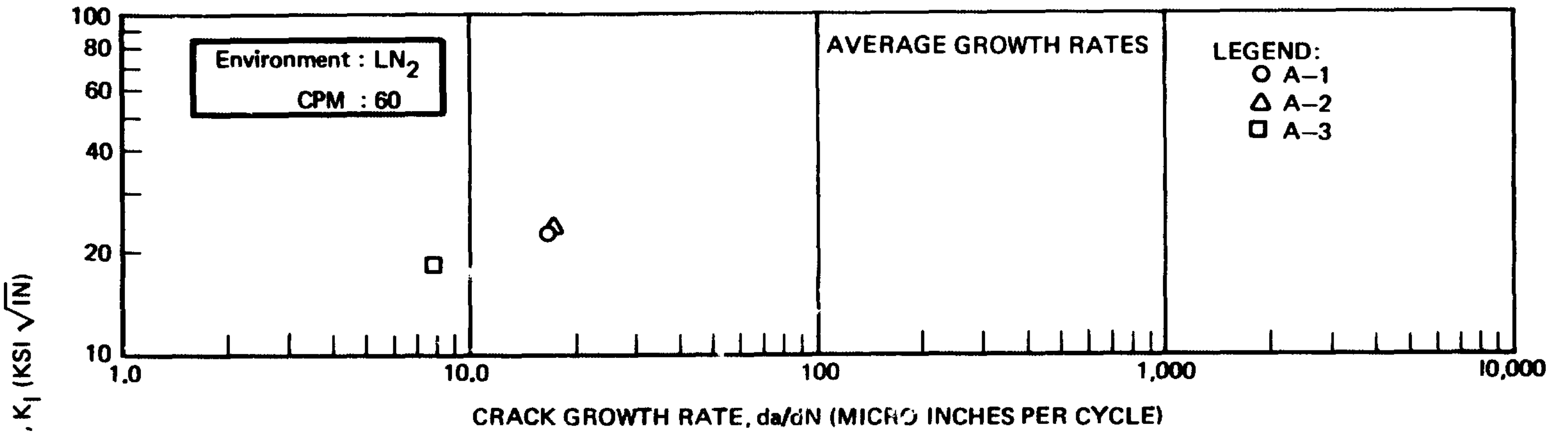


Figure 83: Cyclic Flaw Growth Rates for 0.625–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the RT Propagation Direction (Reference 3)

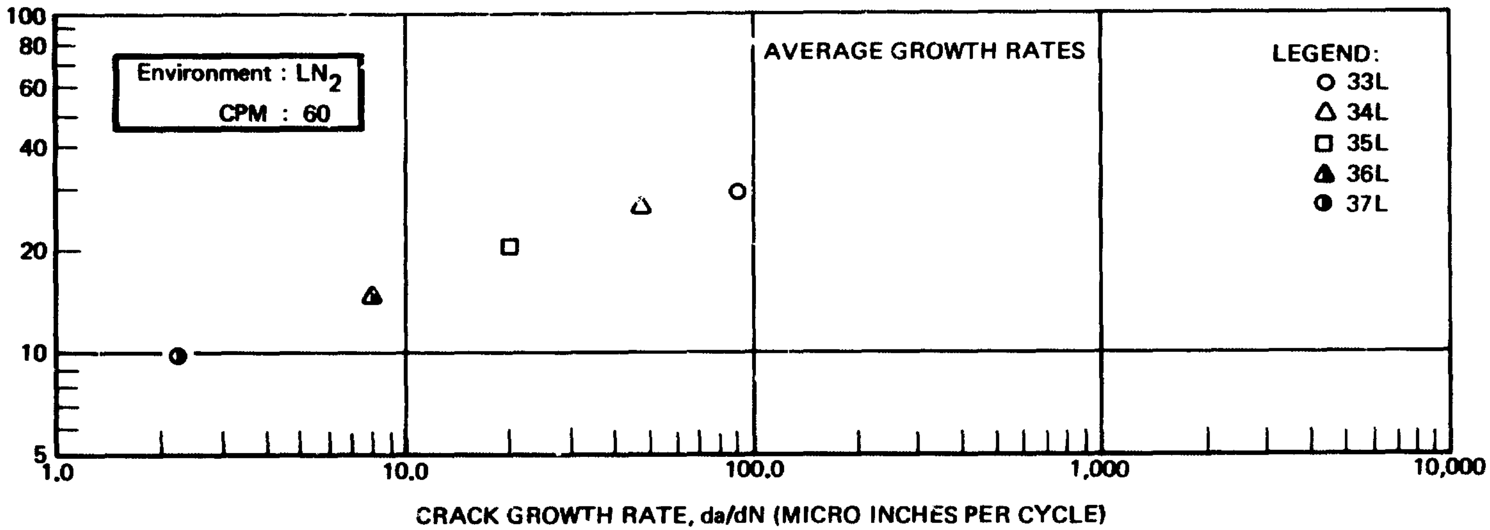


Figure 84: Cyclic Flaw Growth Rates for 0.250–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the RT Propagation Direction (Reference 26)

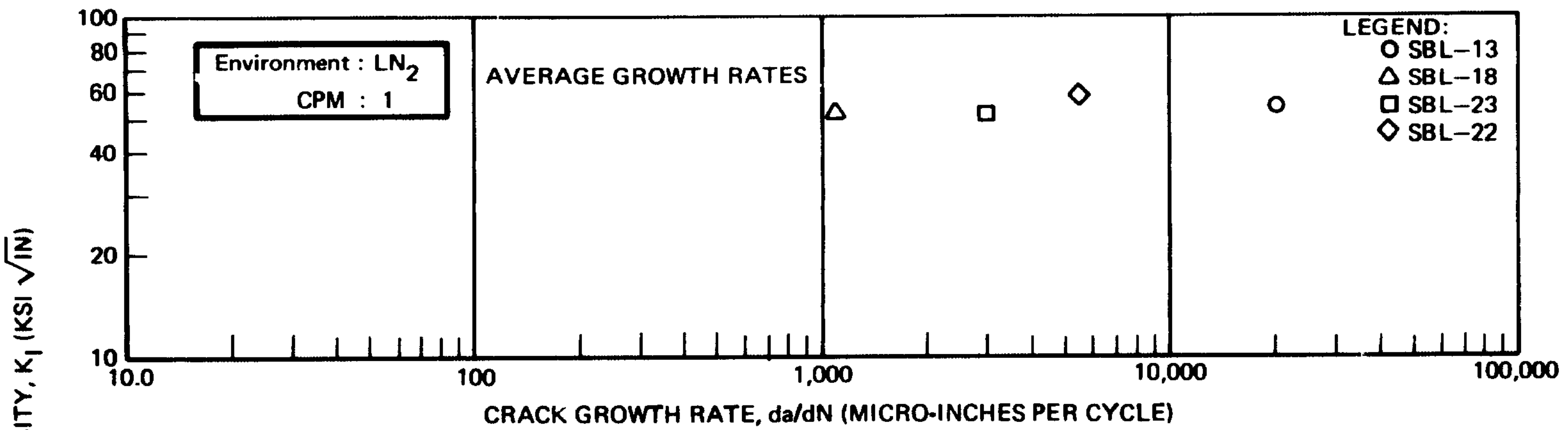


Figure 85: Cyclic Flaw Growth Rates for 1.00–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the RT Propagation Direction (Reference 6)

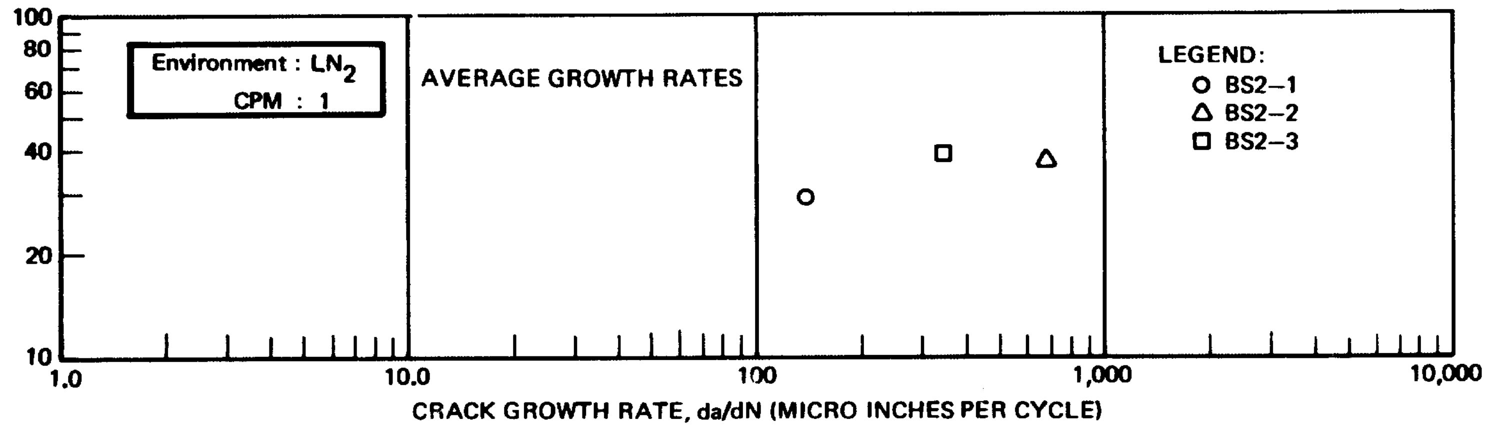


Figure 86: Cyclic Flaw Growth Rates for 0.500–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the RT Propagation Direction (Reference 23)

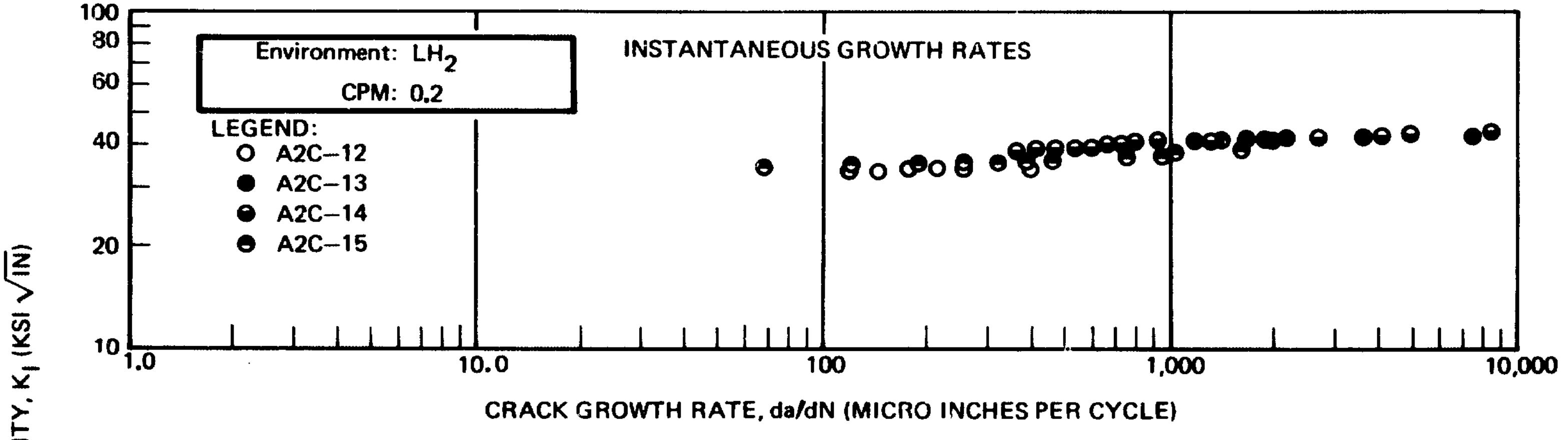


Figure 87: Cyclic Flaw Growth Rates for 0.400–Inch–Thick 2219–T87 Aluminum Base Metal at –423°F for the WT Propagation Direction (Reference 5)

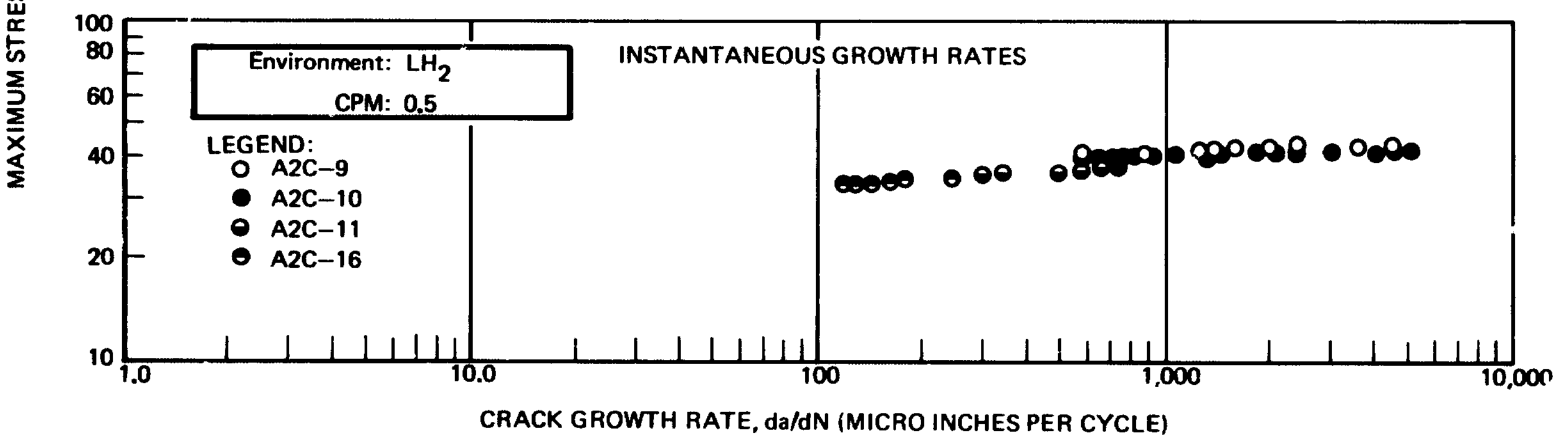


Figure 88: Cyclic Flaw Growth Rates for 0.400–Inch–Thick 2219–T87 Aluminum Base Metal at –423°F for the WT Propagation Direction (Reference 5)

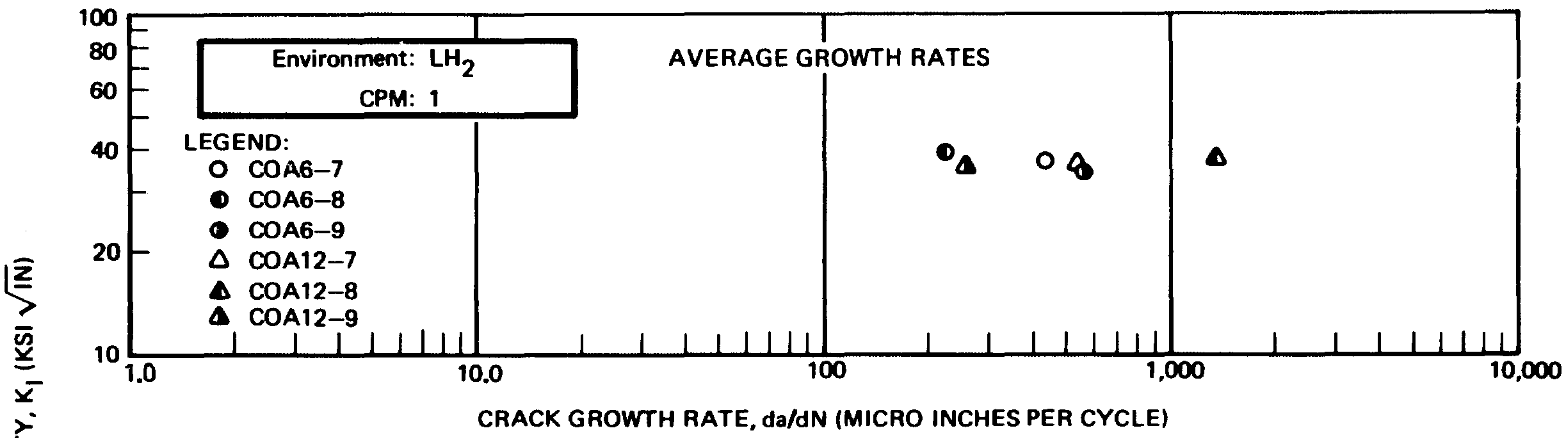


Figure 89: Cyclic Flaw Growth Rates for 0.60 and 1.25-Inch-Thick 2219-T87 Aluminum Base Metal at -423^0F for the WT Propagation Direction (Reference 13)

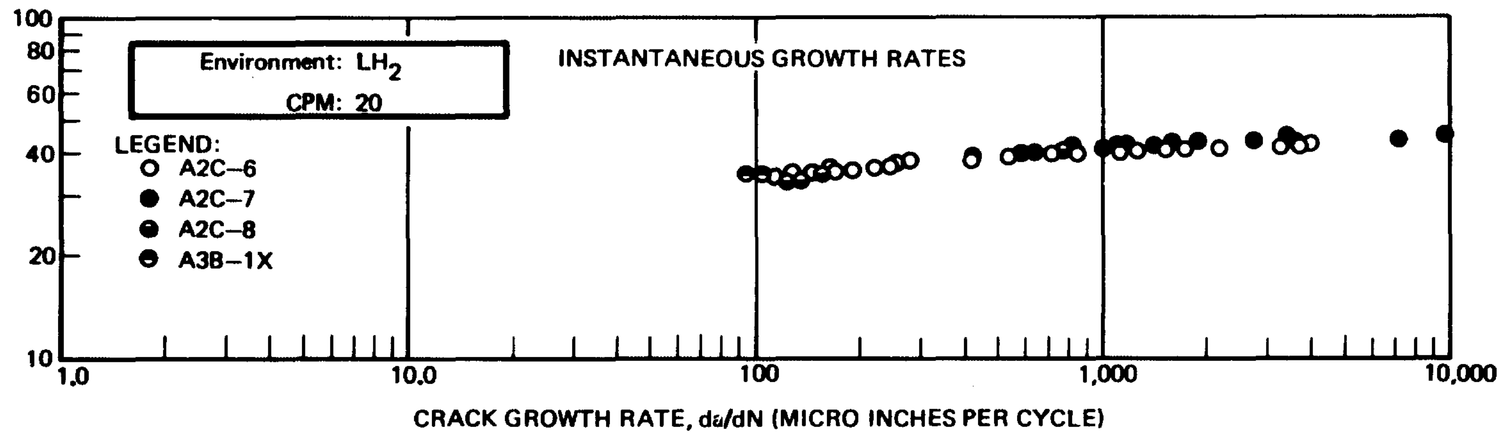


Figure 90: Cyclic Flaw Growth Rates for 0.40 and 0.80-Inch-Thick 2219-T87 Aluminum Base Metal at -423^0F for the WT Propagation Direction (Reference 5)

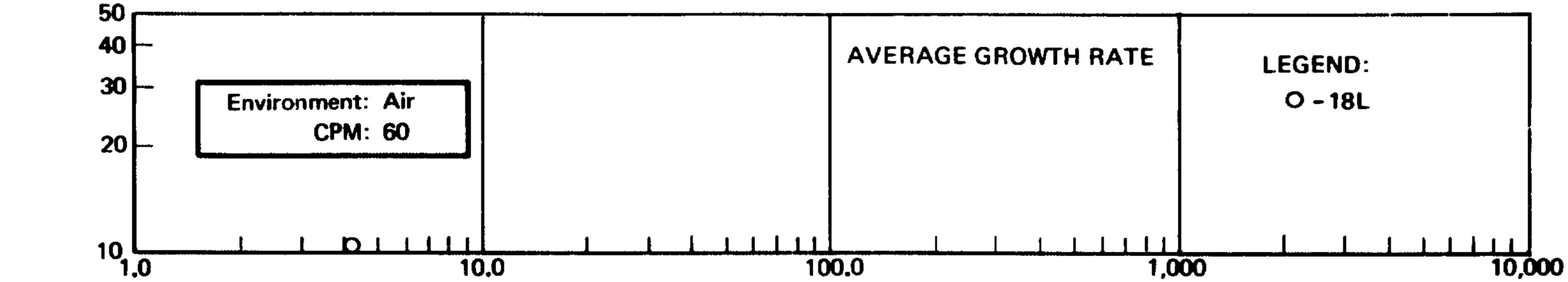


Figure 91: Cyclic Flaw Growth Rates for 0.250–Inch–Thick 2219–T87 Aluminum Base Metal at 350^{0}F for the RT Propagation Direction (Reference 26)

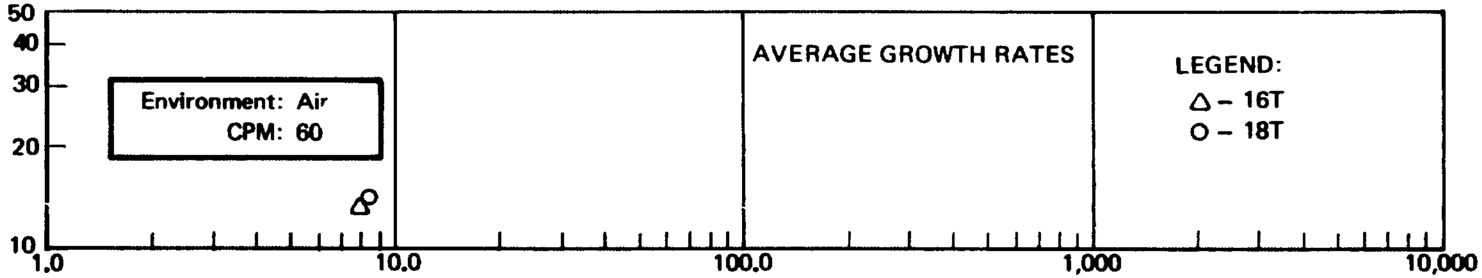


Figure 92: Cyclic Flaw Growth Rates for 0.125–Inch–Thick 2219–T87 Aluminum Base Metal at 350^{0}F for the WT Propagation Direction (Reference 26)

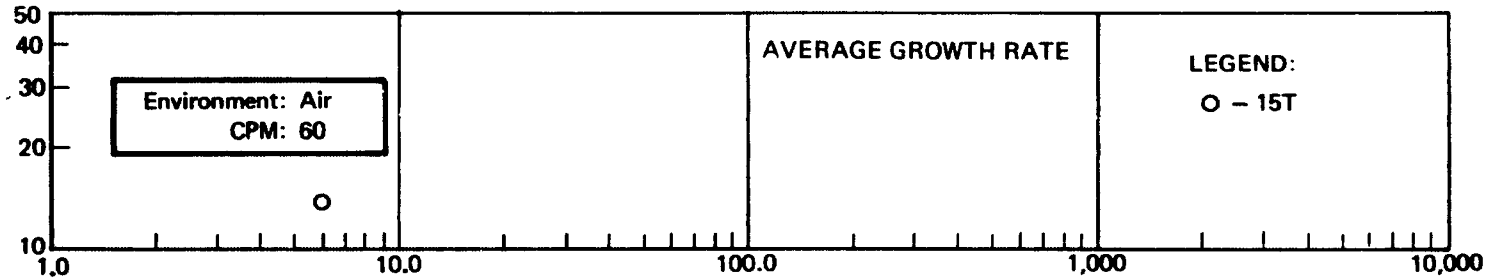


Figure 93: Cyclic Flow Growth Rates for 0.125–Inch–Thick 2219–T87 Aluminum Base Metal at 300^{0}F for the WT Propagation Direction (Reference 26)

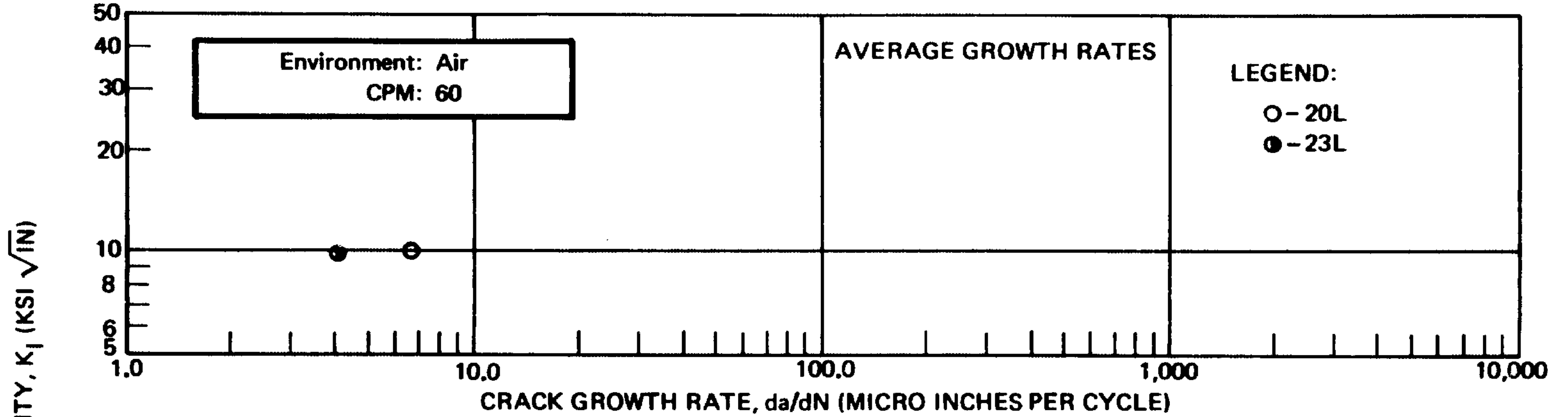


Figure 94: Cyclic Flaw Growth Rates for 0.250–Inch–Thick 2219–T87 Aluminum Base Metal at 400^{0}F for the RT Propagation Direction (Reference 26)

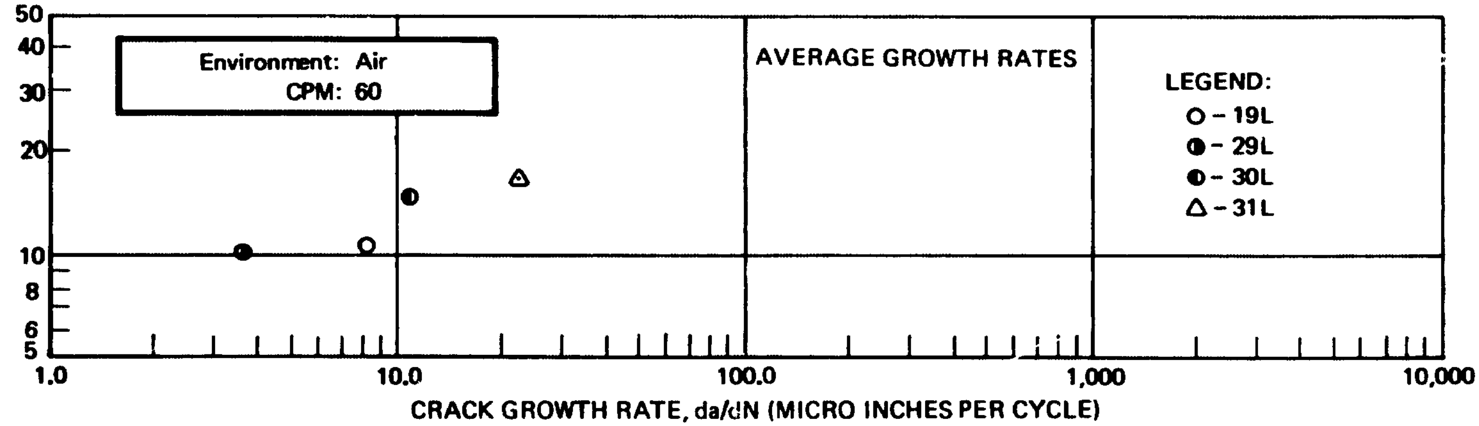


Figure 95: Cyclic Flaw Growth Rates for 0.250–Inch–Thick 2219–T87 Aluminum Base Metal at 350^{0}F for the RT Propagation Direction (Reference 26)

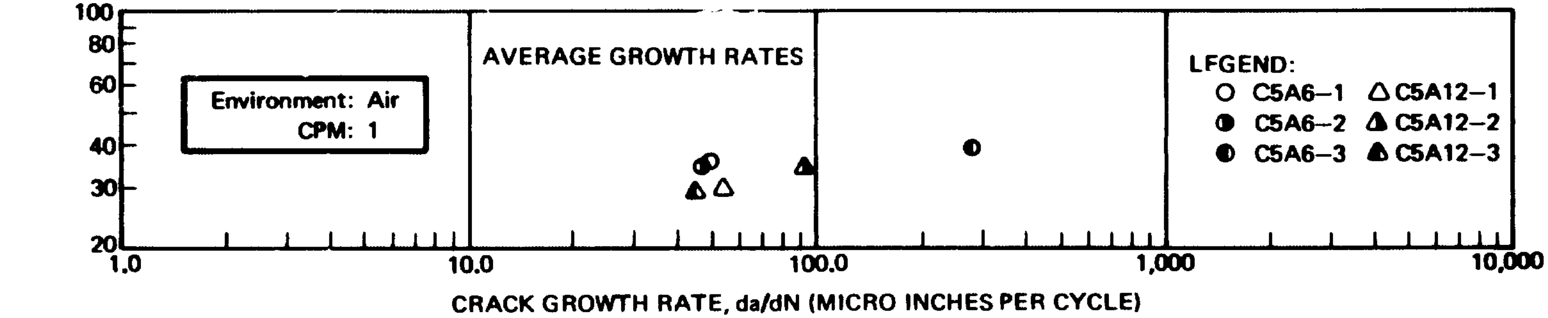


Figure 96: Cyclic Fla v Growth Rates for 0.60 and 1.25–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for WT Propagation Direction, R = 0.5 (Reference 13)

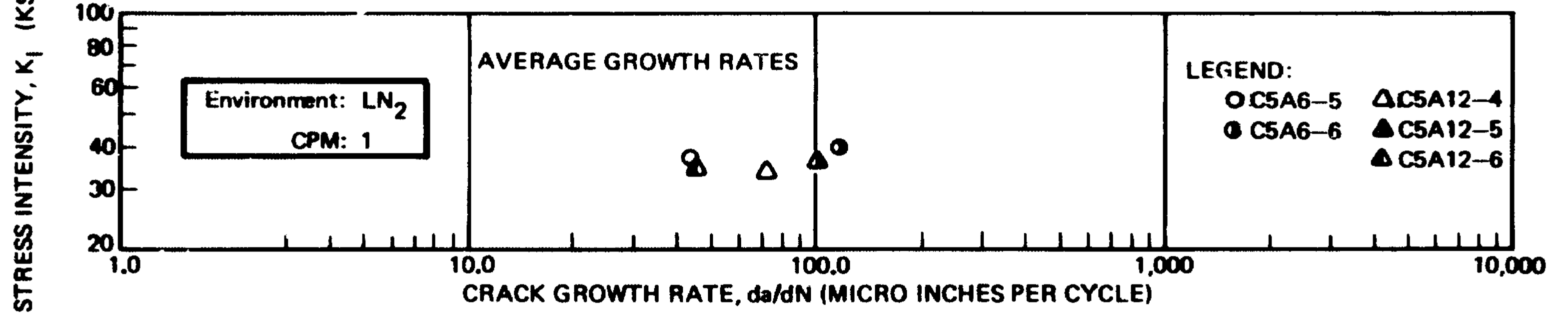


Figure 97: Cyclic Flaw Growth Rates for 0.60 and 1.25–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction, R = 0.5 (Reference 13)

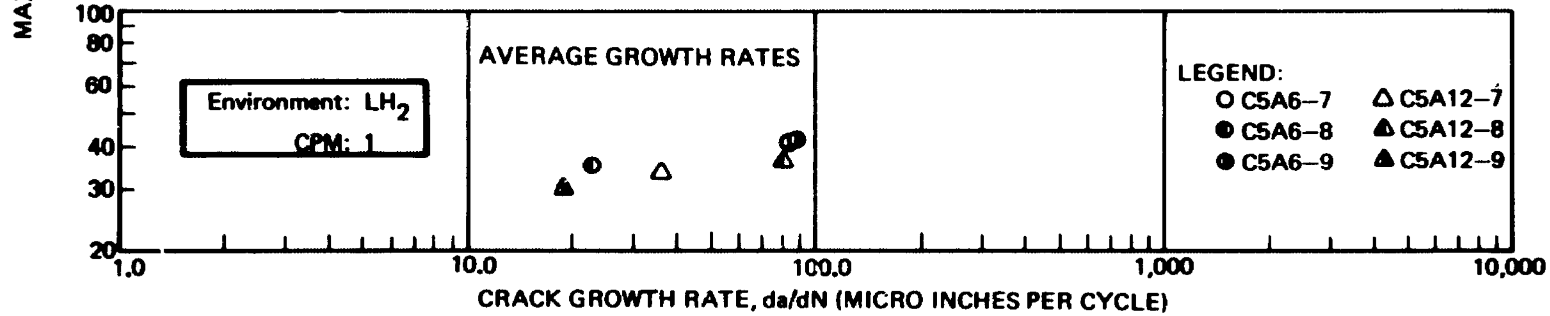


Figure 98: Cyclic Flaw Growth Rates for 0.60 and 1.25–Inch–Thick 2219–T87 Aluminum Base Metal at –423°F for the WT Propagation Direction, R = 0.5 (Reference 13)

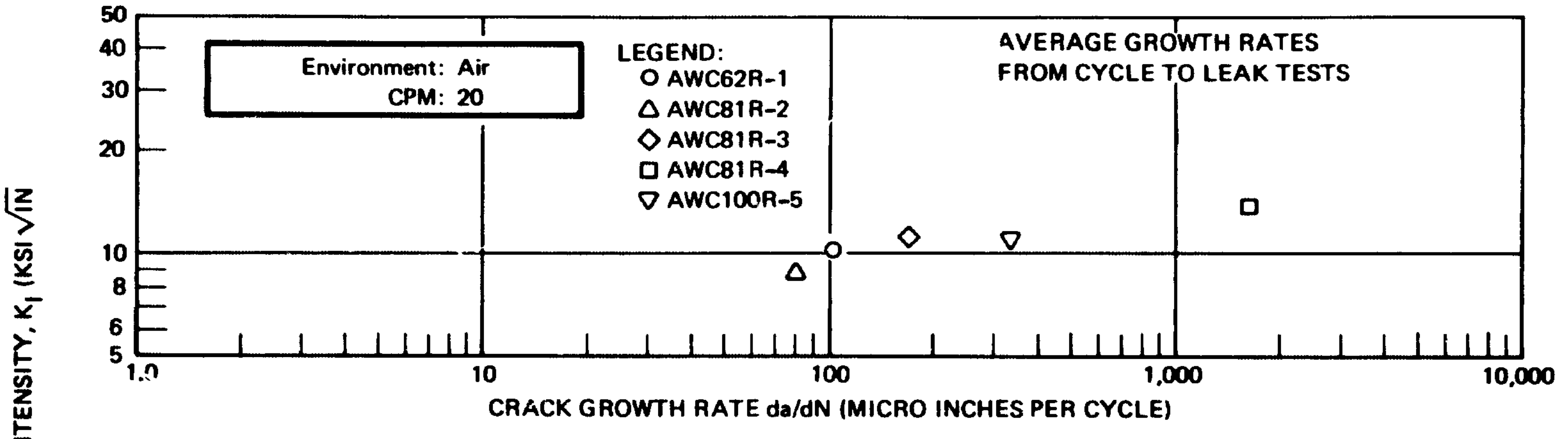


Figure 99: CyclicFlaw Growth Rates for 0.125-Inch-Thick 2219 Aluminum Weldments at 72°F (Reference 3)

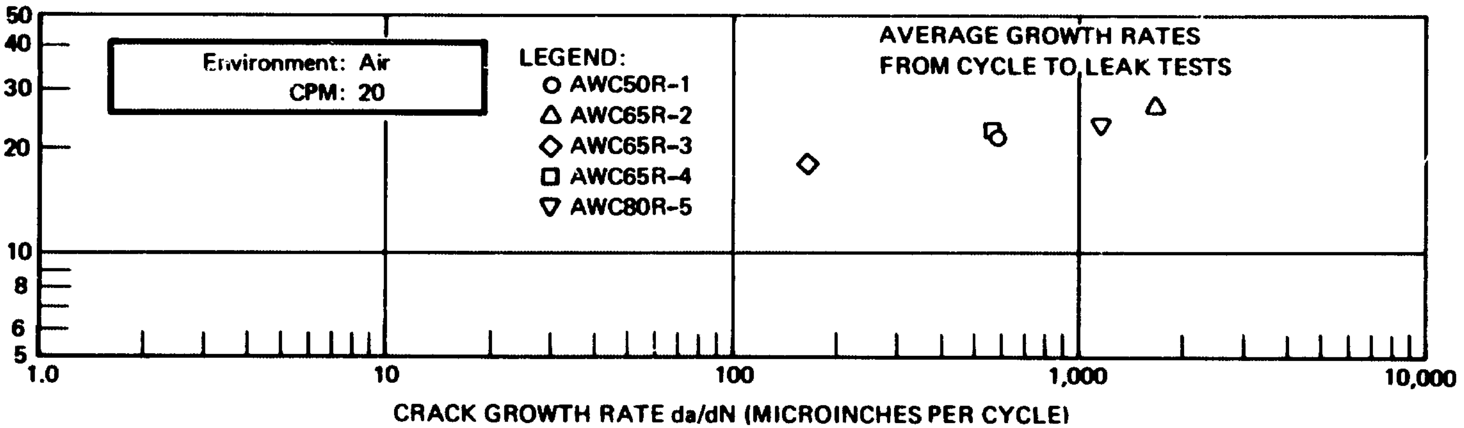


Figure 100: Cyclic Flaw Growth Rates for 1.00-Inch-Thick 2219 Aluminum Weldments at 72°F (Reference 3)

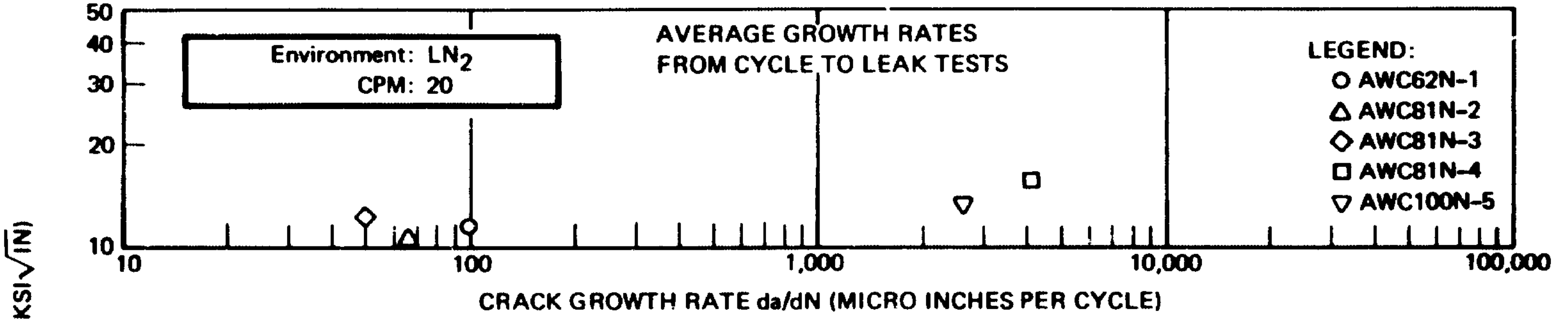


Figure 101: Cyclic Flaw Growth Rates for 0.125-Inch-Thick 2219 Aluminum Weldments at -320^{0} F (Reference 3)

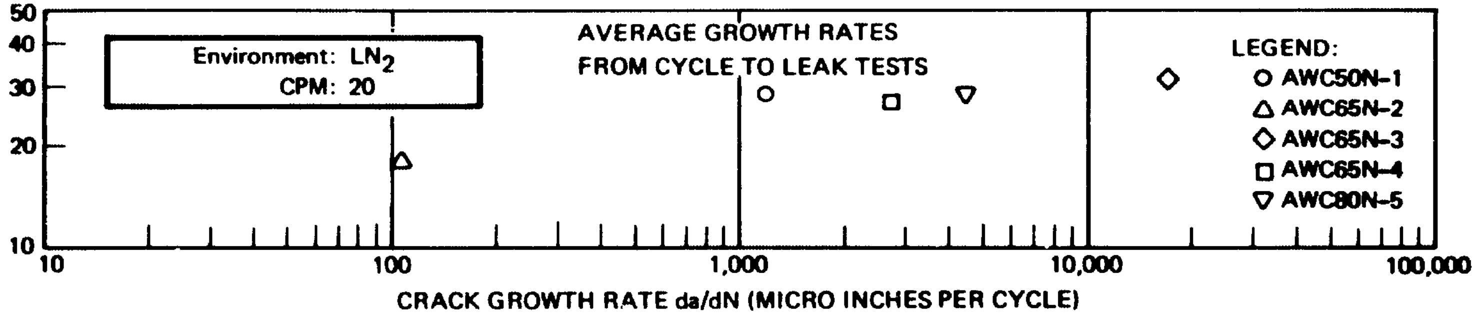


Figure 102: Cyclic Flaw Growth Rates for 1.00-Inch-Thick 2219 Aluminum Weldments at -320^{0} F (Reference 3)

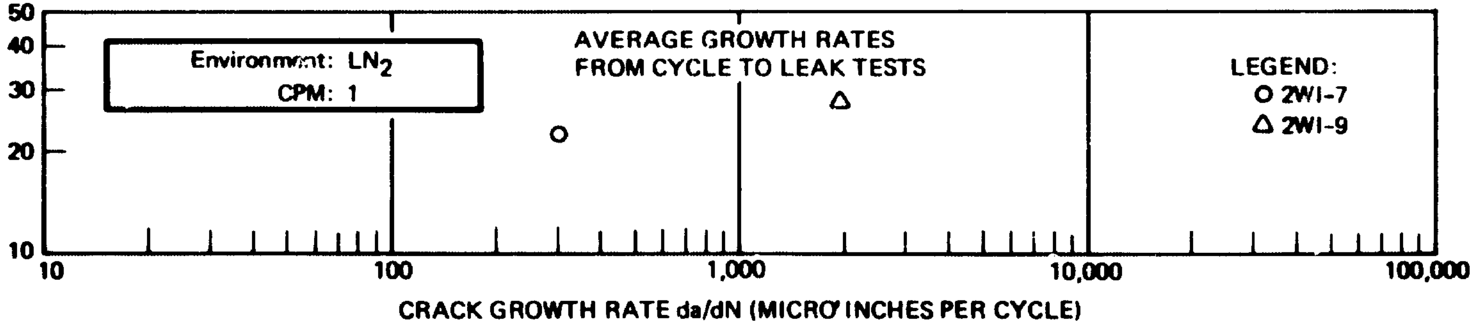


Figure 103: Cyclic Flaw Growth Rates for 1.00-Inch-Thick 2219 Aluminum Weldments at -320^{0} F (Reference 23)

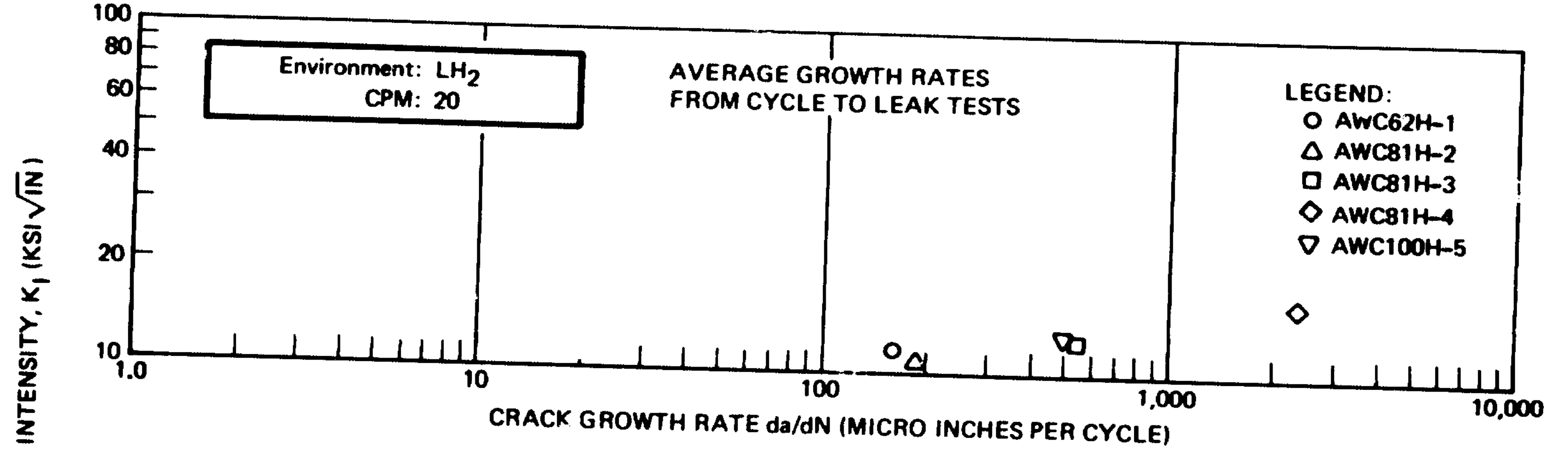


Figure 104: Cyclic Flaw Growth Rates for 0.125-Inch-Thick 2219 Aluminum Weldments at -423°F (Reference 3)

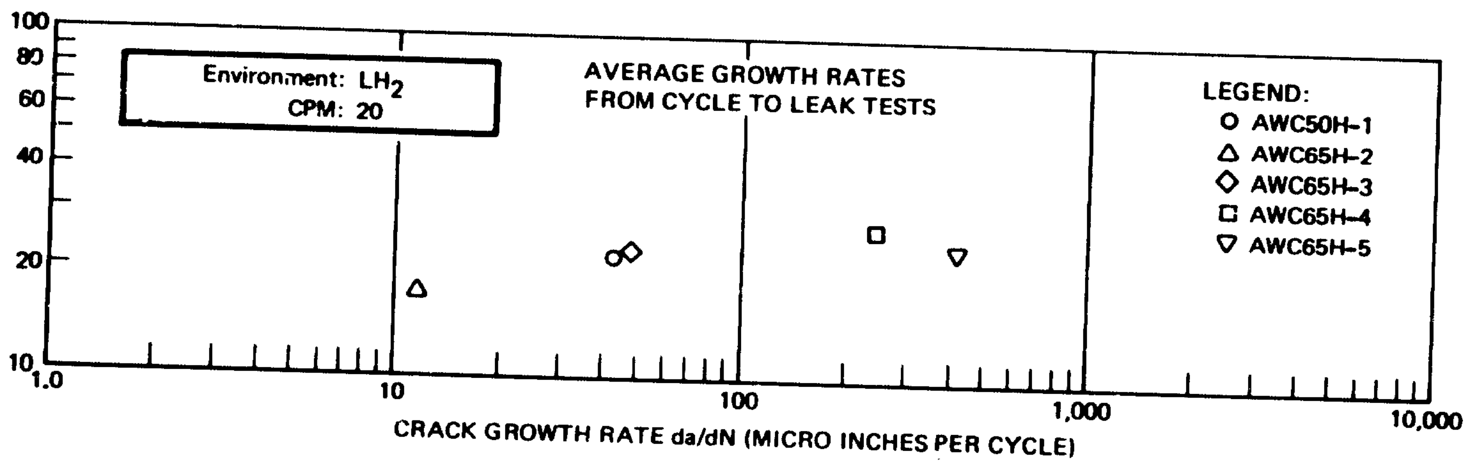


Figure 105: Cyclic Flaw Growth Rates for 1.00-Inch-Thick 2219 Aluminum Weldments at -423°F (Reference 3)

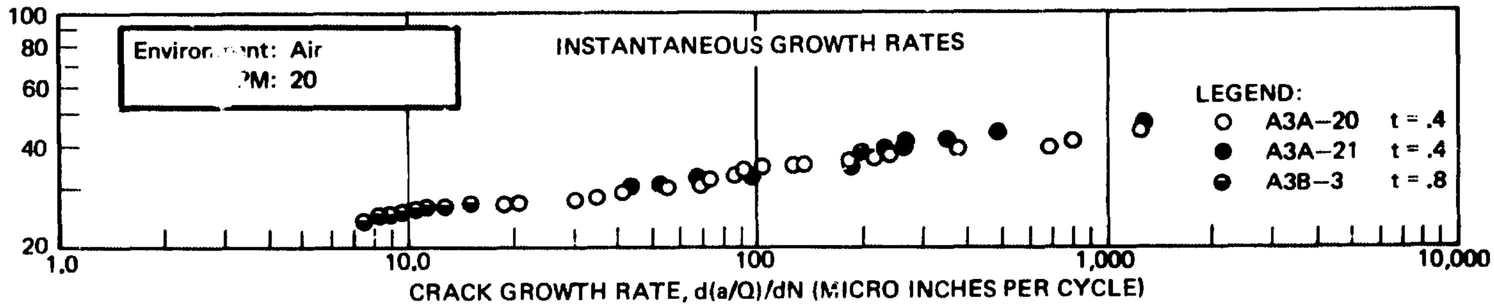


Figure 106: Cyclic Flaw Growth Rates for 0.40 and 0.80–Inch–Thick 2219–T87 Aluminum Base Metal at 72° F for the WT Propagation Direction (Reference 5)

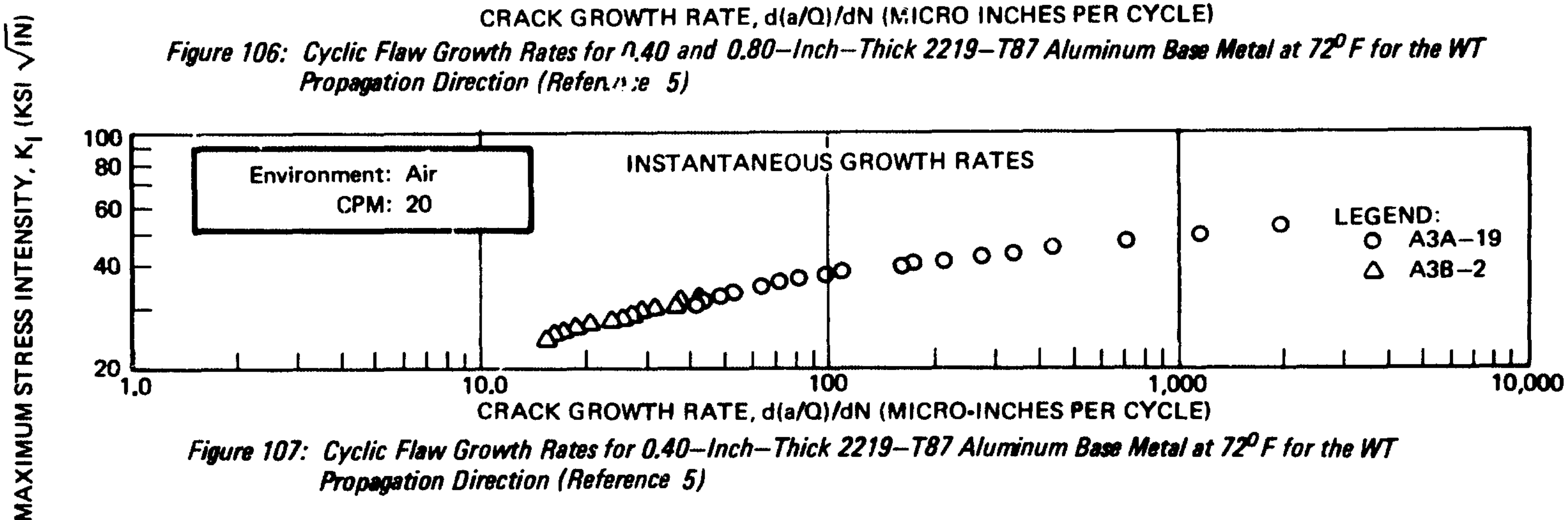


Figure 107: Cyclic Flaw Growth Rates for 0.40–Inch–Thick 2219–T87 Aluminum Base Metal at 72° F for the WT Propagation Direction (Reference 5)

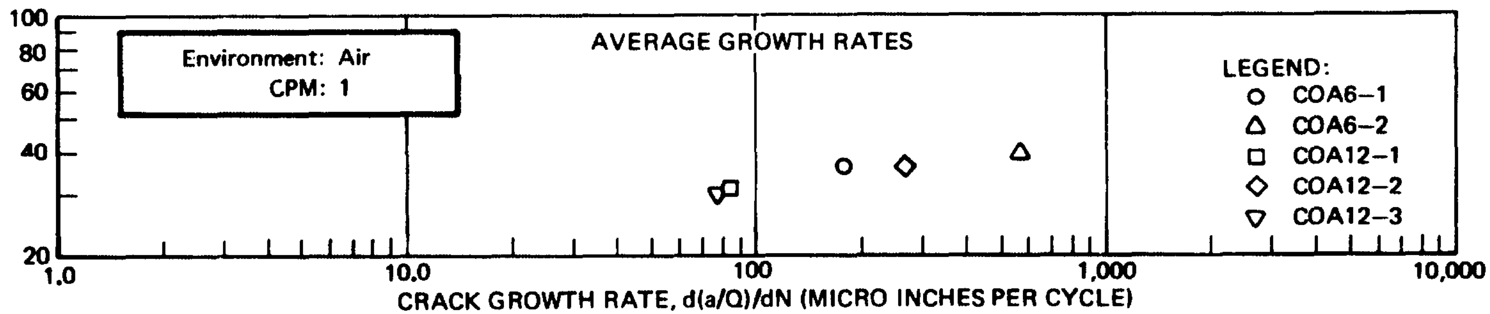


Figure 108: Cyclic Flaw Growth Rates for 0.60 and 1.25–Inch–Thick 2219–T87 Aluminum Base Metal at 72° F for the WT Propagation Direction (Reference 13)

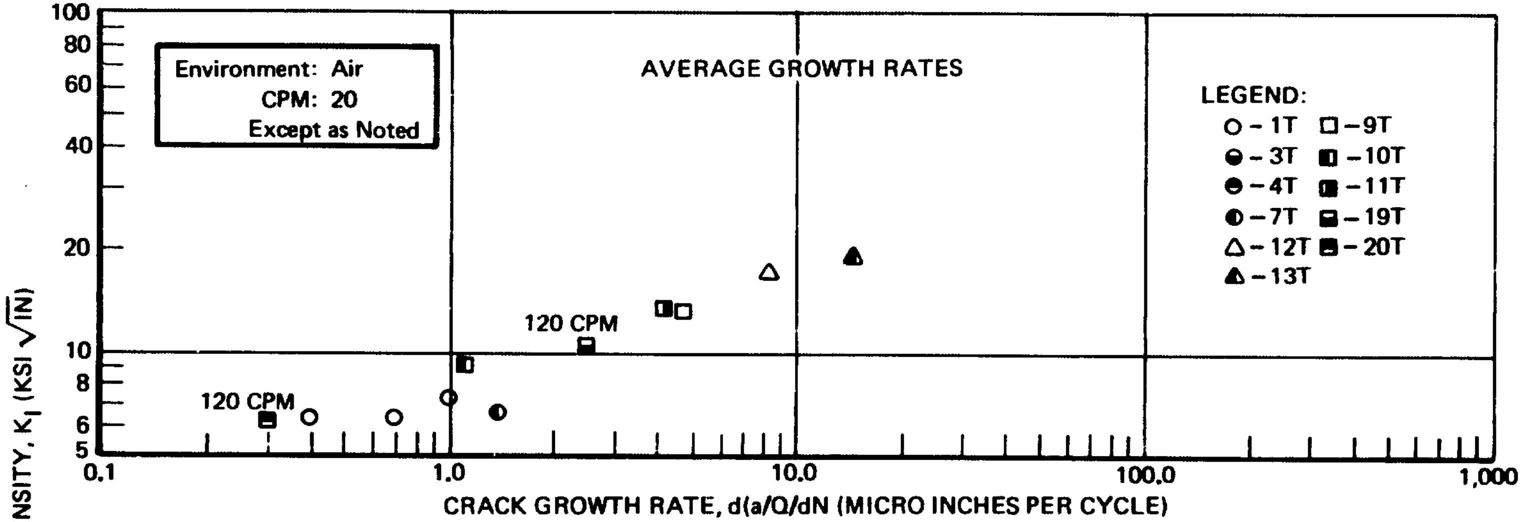


Figure 109: Cyclic Flaw Growth Rates for 0.125–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 26)

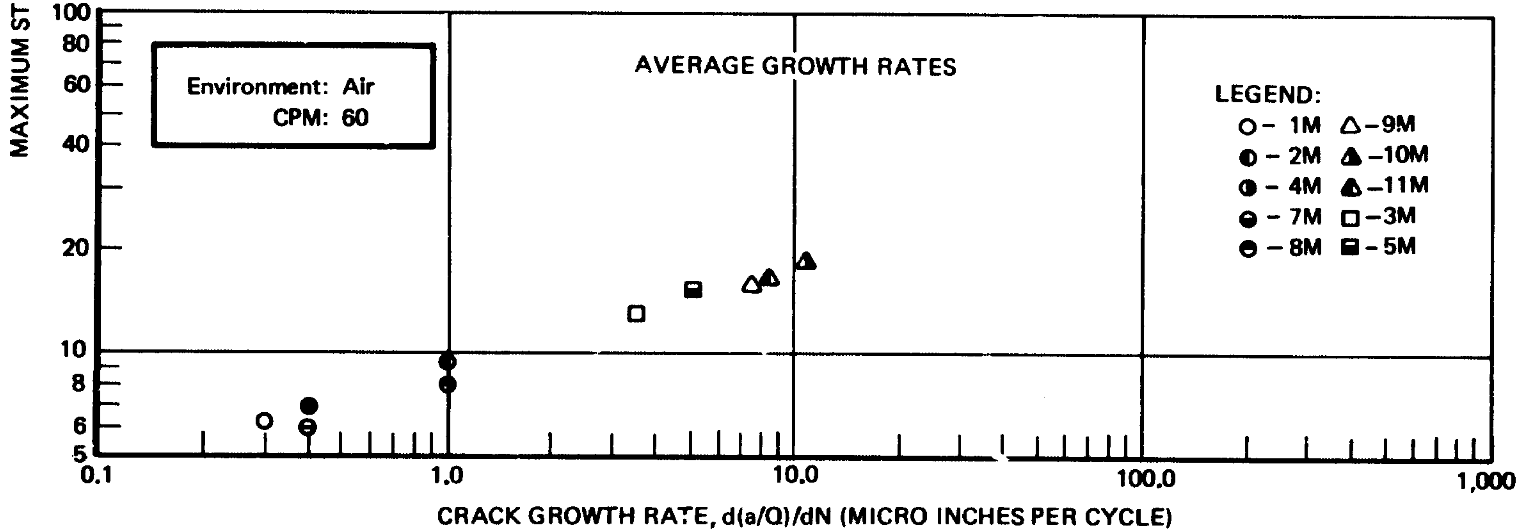


Figure 110: Cyclic Flaw Growth Rates for 0.125–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 26)

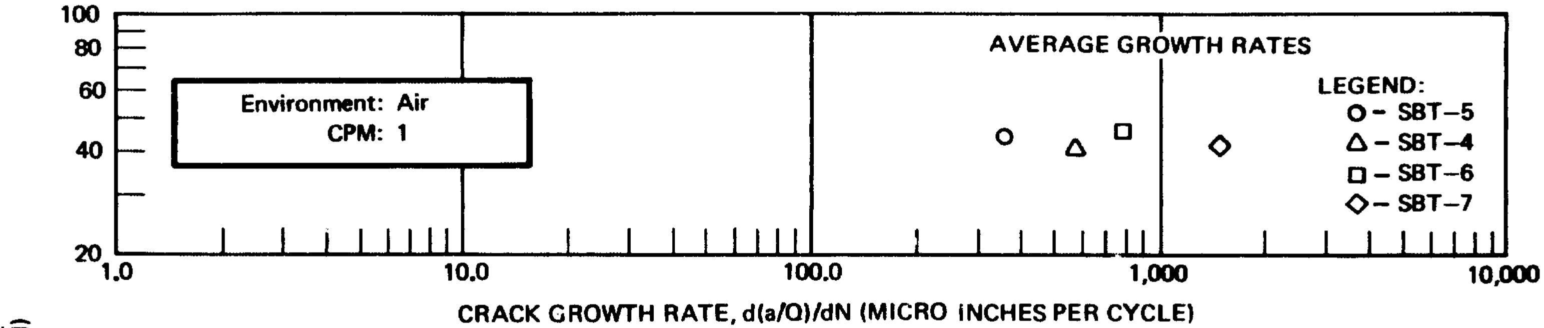


Figure 111: Cyclic Flaw Growth Rates for 1.00–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 6)

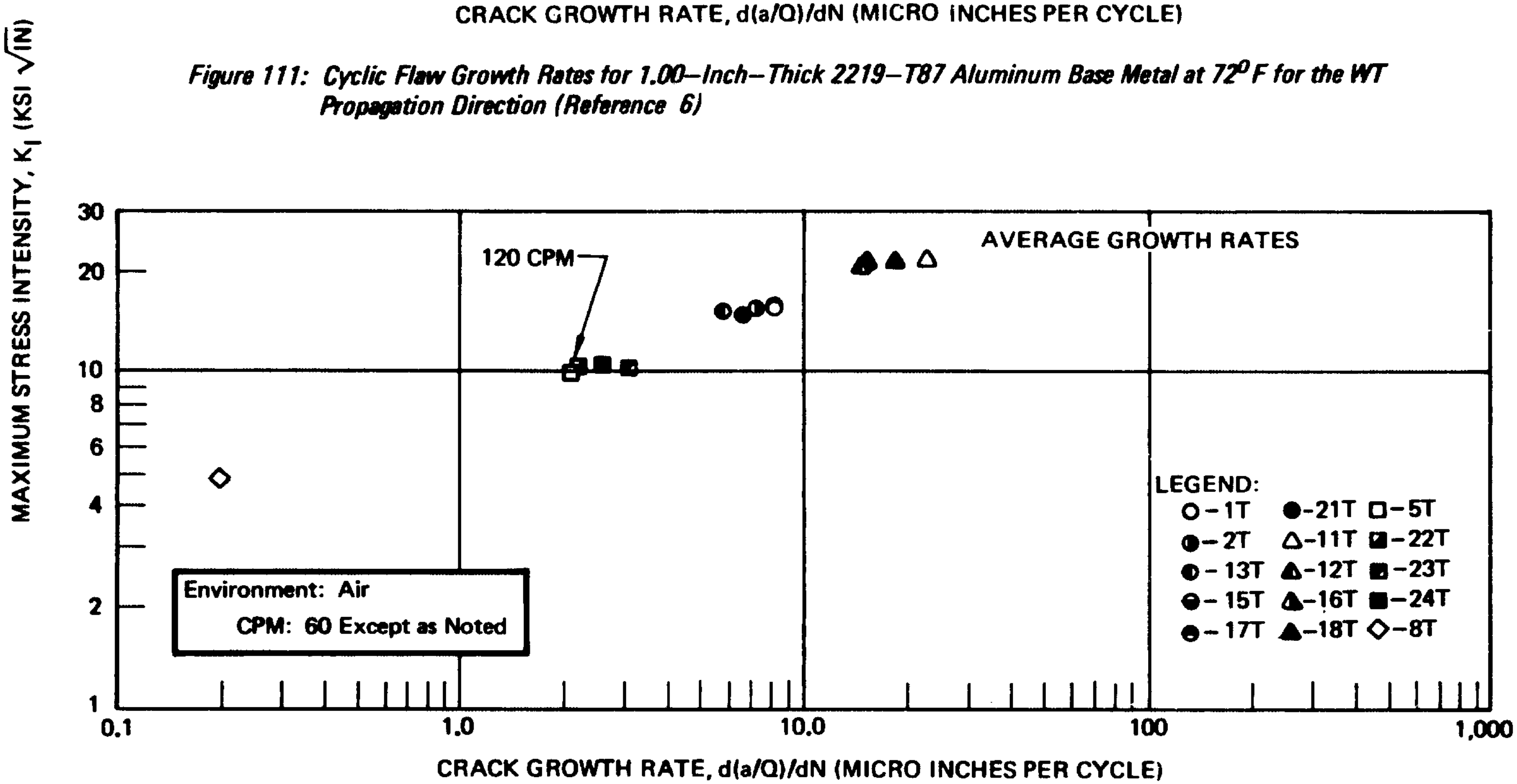


Figure 112: Cyclic Flaw Growth Rates for 0.250–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the WT Propagation Direction (Reference 26)

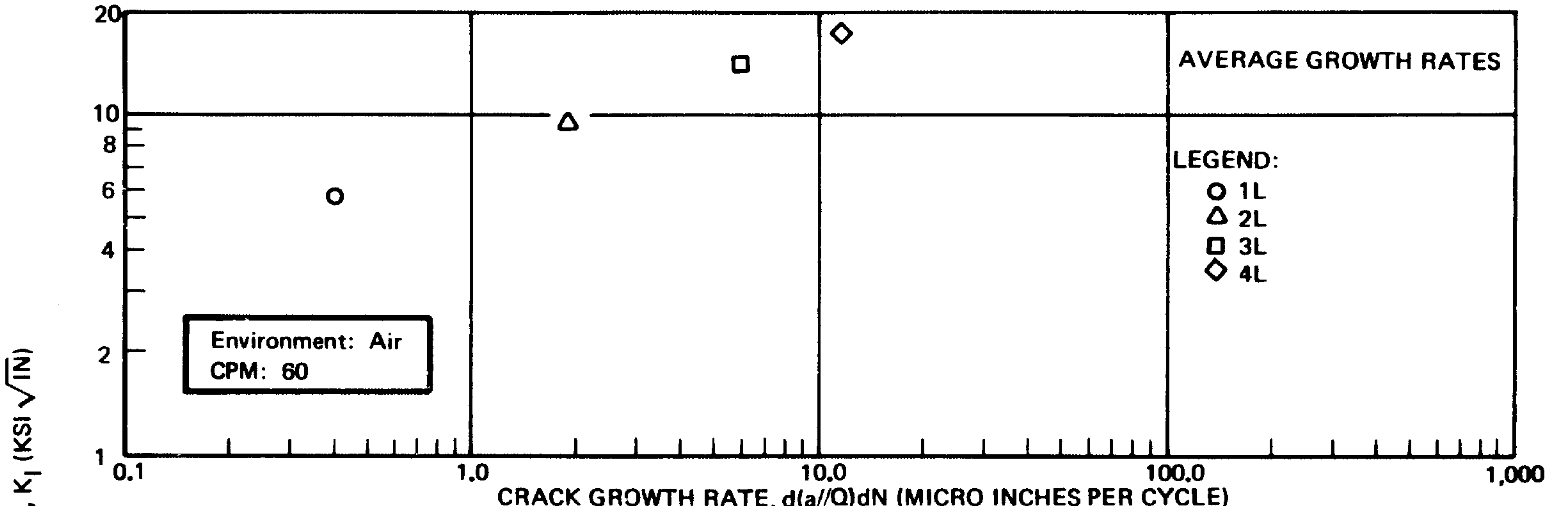


Figure 113: Cyclic Flaw Growth Rates for 0.125–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the RT Propagation (Reference 26)

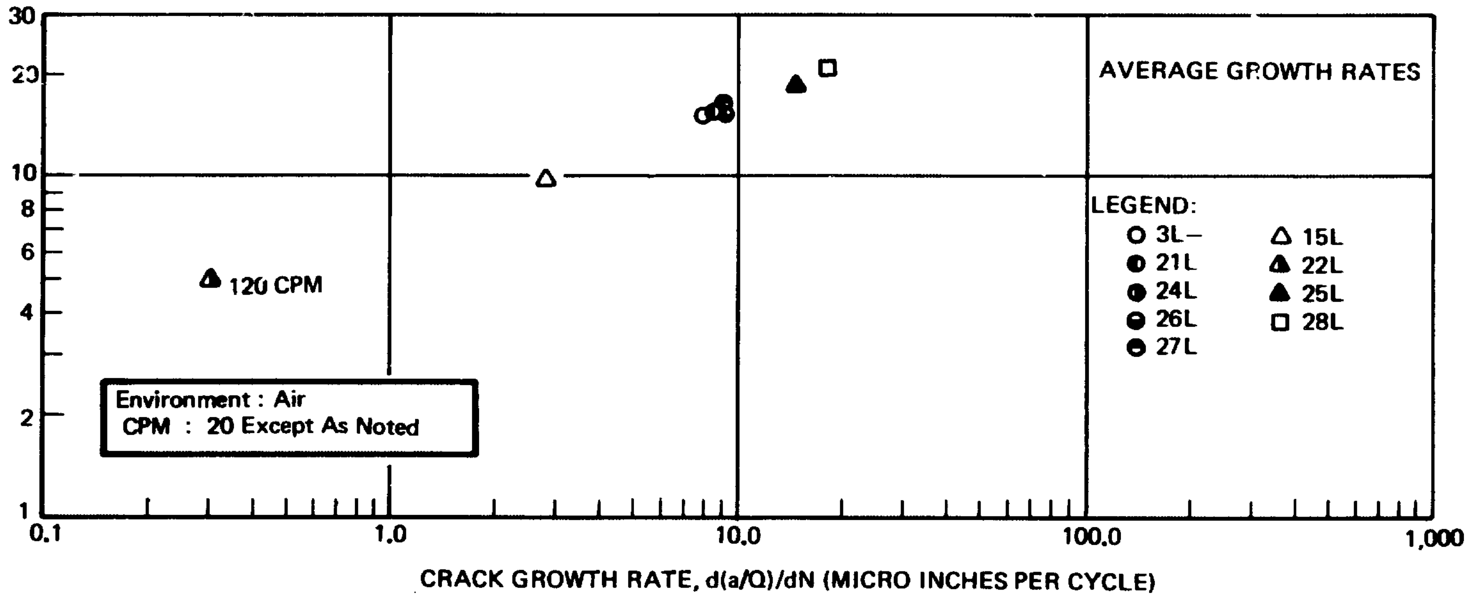


Figure 114: Cyclic Flaw Growth Rates for 0.250–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the RT Propagation (Reference 26)

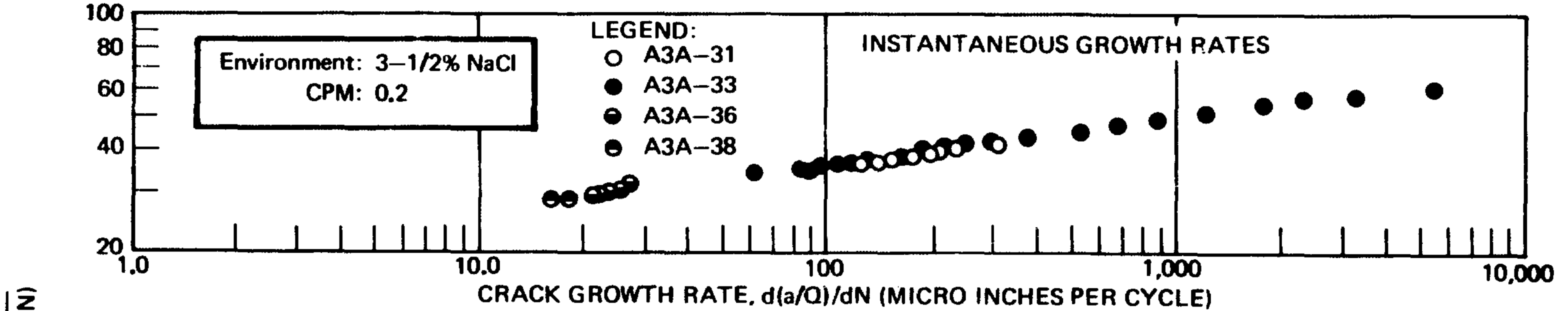


Figure 115: Cyclic Flaw Growth Rates for 0.40–Inch–Thick 2219–T87 Aluminum Base Metal at 72^{0}F for the WT Propagation Direction (Reference 5)

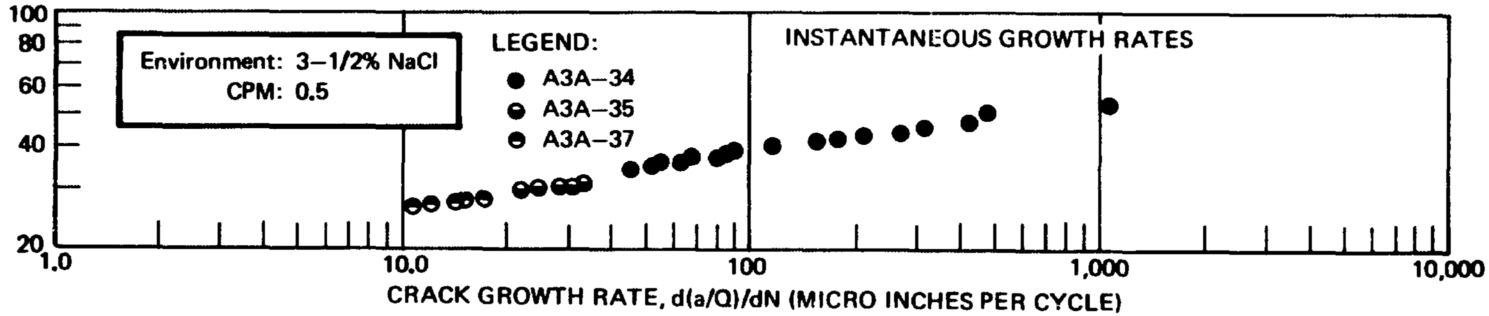


Figure 116: Cyclic Flaw Growth Rates for 0.40–Inch– Thick 2219–T87 Aluminum Base Metal at 72^{0}F for the WT Propagation Direction (Reference 5)

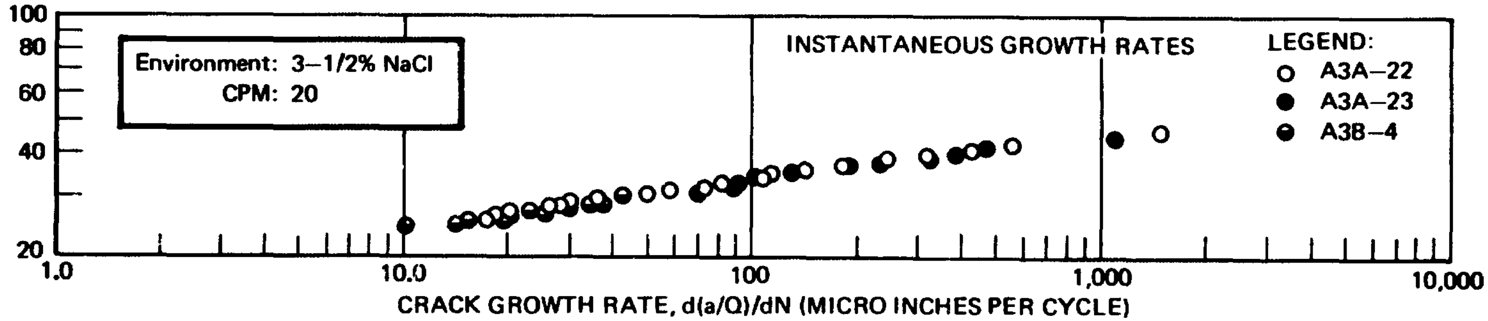


Figure 117: Cyclic Flaw Growth Rates for 0.40 and 0.80–Inch–Thick 2219–T87 Aluminum Base Metal at 72^{0}F for the WT Propagation Direction (Reference 5)

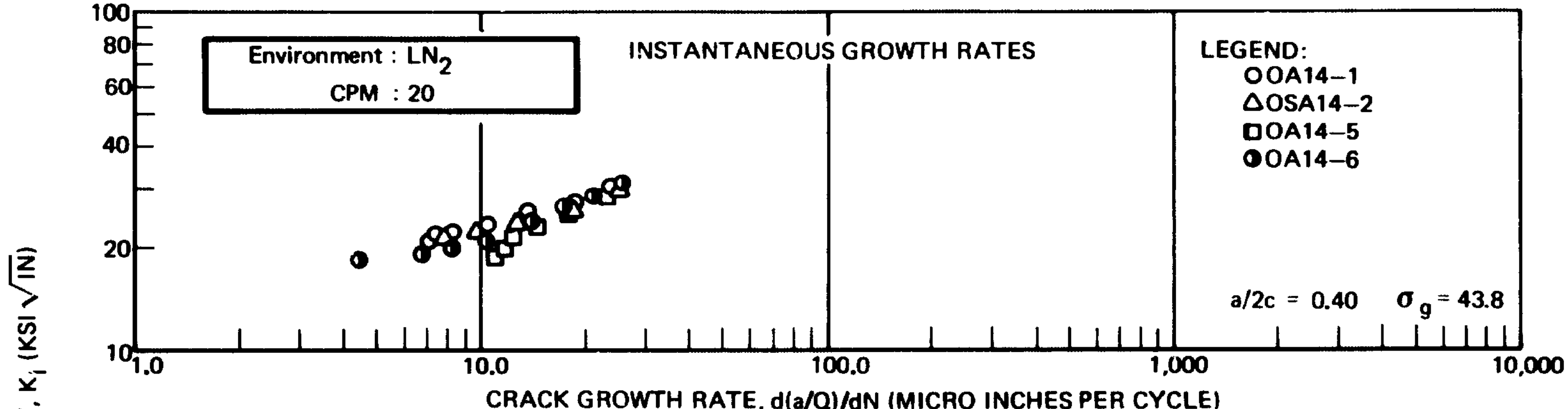


Figure 118: Cyclic Flaw Growth Rates for 0.150–Inch–Thick 2219–T87 Aluminum Base Metal at –320^{0}F for the WT Propagation Direction (Reference 2)

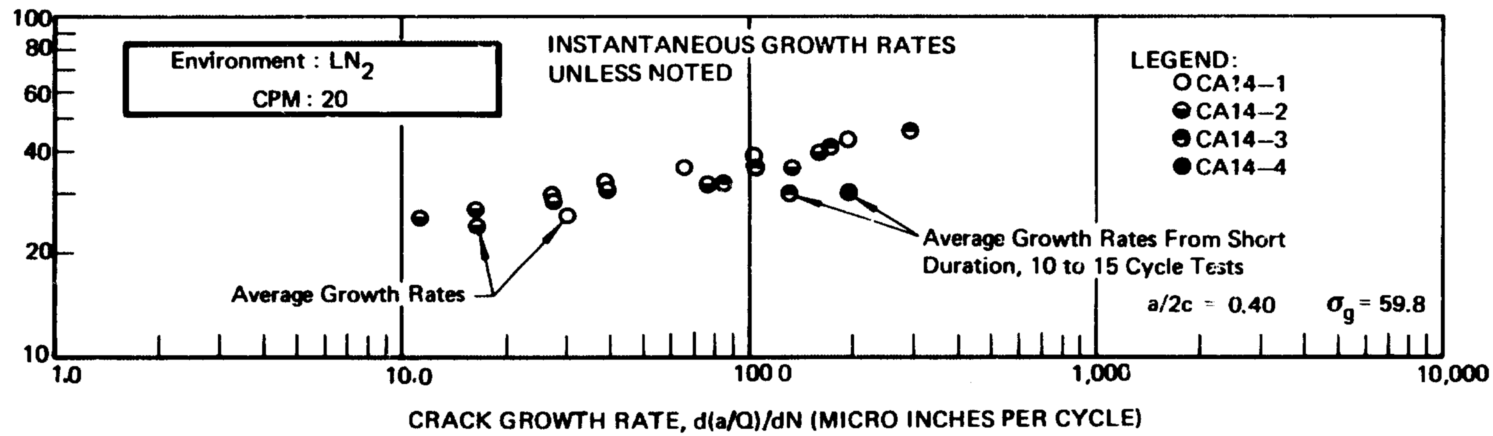


Figure 119: Cyclic Flaw Growth Rates for 0.150–Inch–Thick 2219–T87 Aluminum Base Metal at –320^{0}F for the WT Propagation Direction (Reference 2)

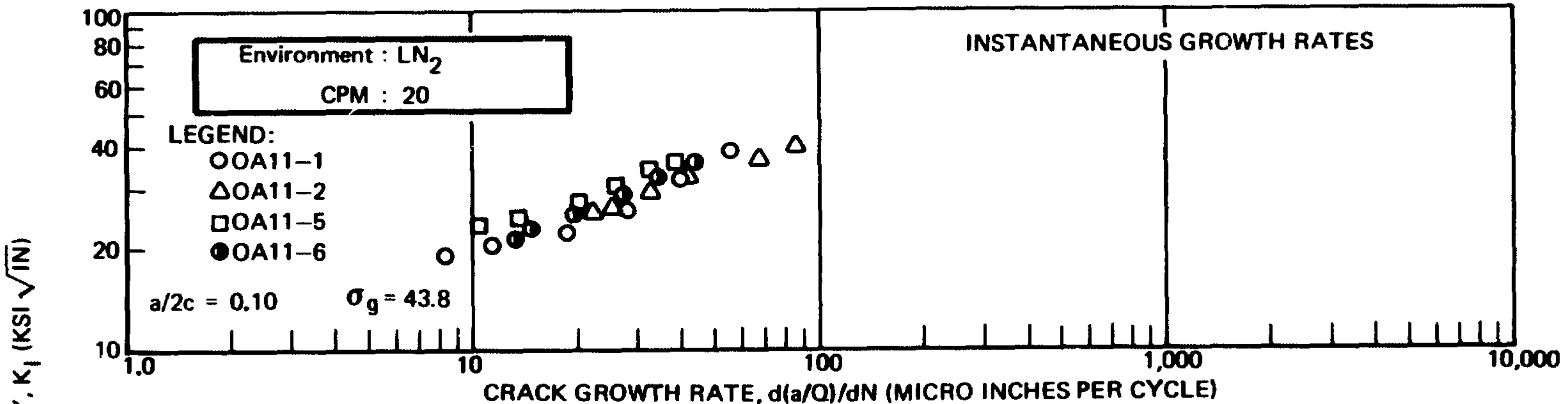


Figure 120: Cyclic Flaw Growth Rates for 0.150–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 2)

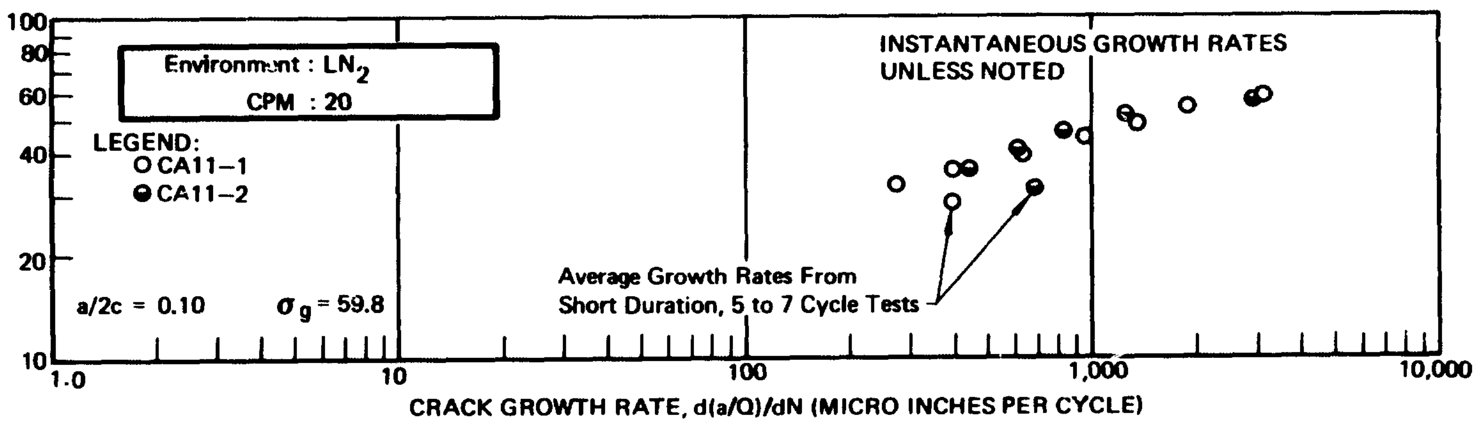


Figure 121: Cyclic Flaw Growth Rates for 0.150–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 2)

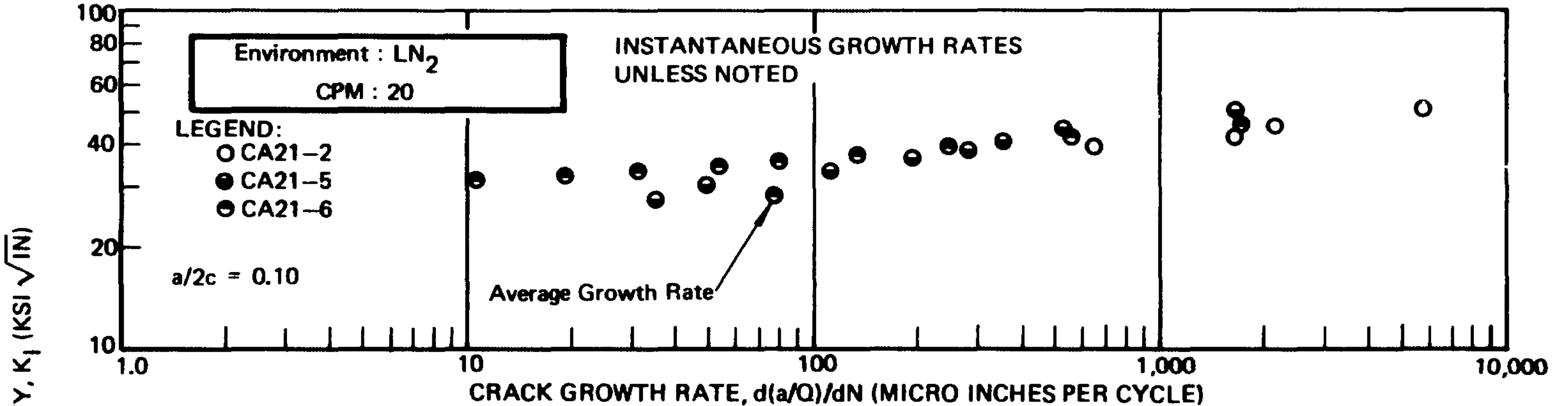


Figure 122: Cyclic Flaw Growth Rates for 0.200–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 2)

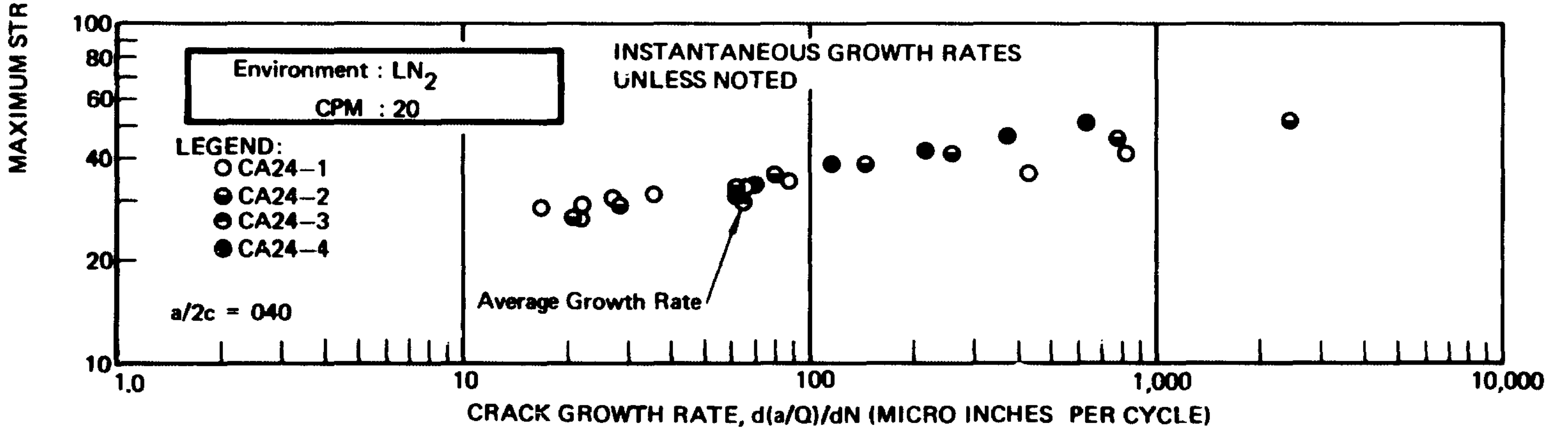


Figure 123: Cyclic Flaw Growth Rates for 0.200–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 2)

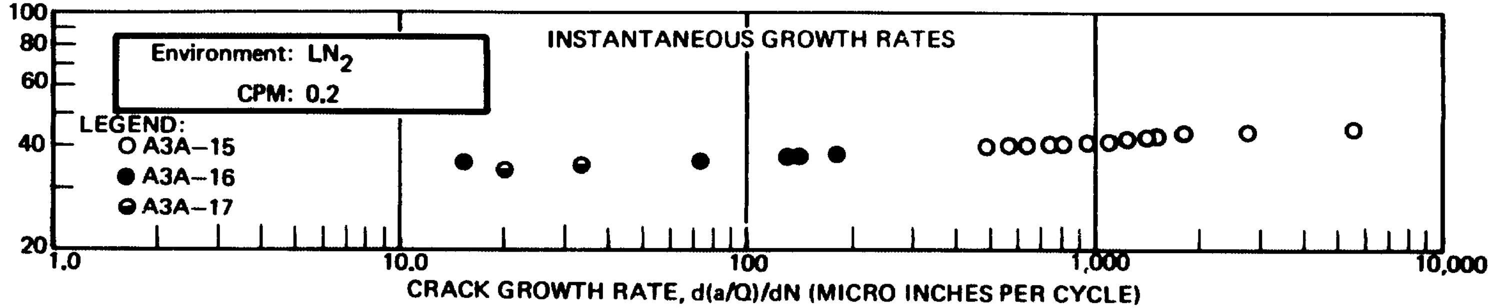


Figure 124: Cyclic Flaw Growth Rates for 0.400–Inch–Thick 2219–T87 Aluminum Base Metal at –320^{0}F for the WT Propagation Direction (Reference 5)

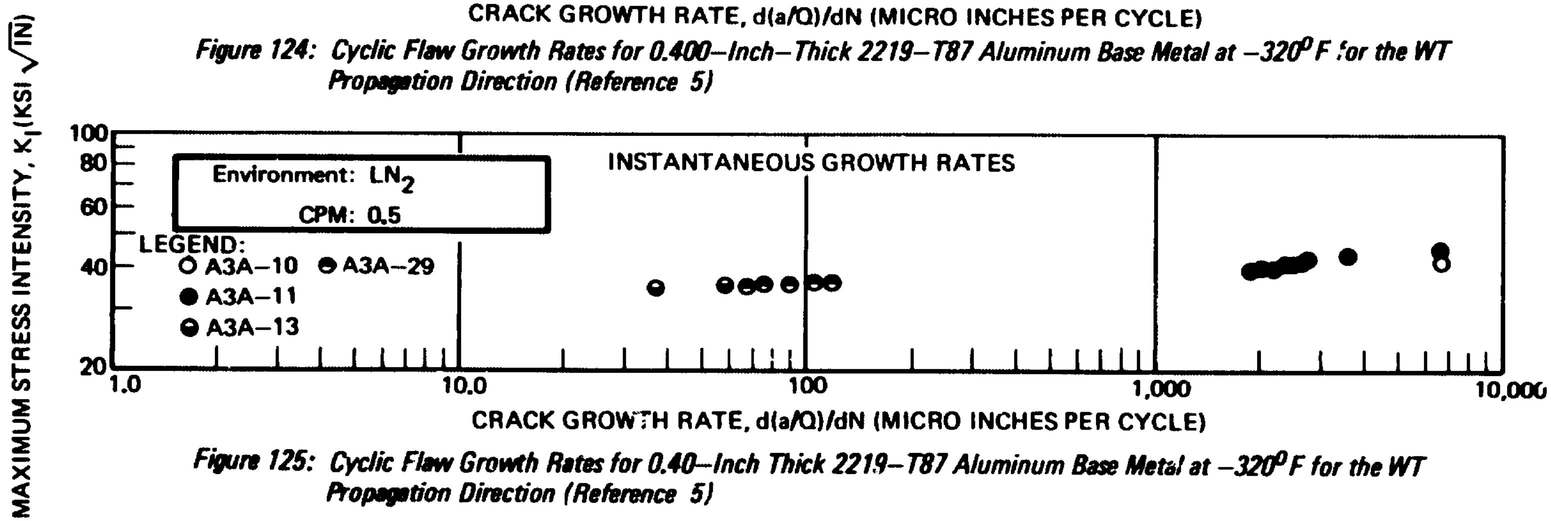


Figure 125: Cyclic Flaw Growth Rates for 0.40–Inch Thick 2219–T87 Aluminum Base Metal at –320^{0}F for the WT Propagation Direction (Reference 5)

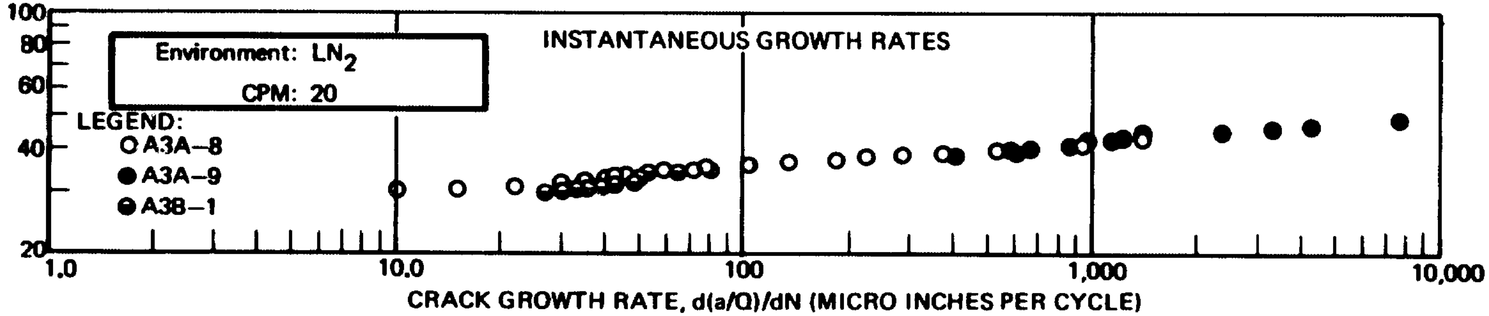


Figure 126: Cyclic Flaw Growth Rates for 0.40 and 0.80–Inch–Thick 2219–T87 Aluminum Base Metal at –320^{0}F for the WT Propagation Direction (Reference 5)

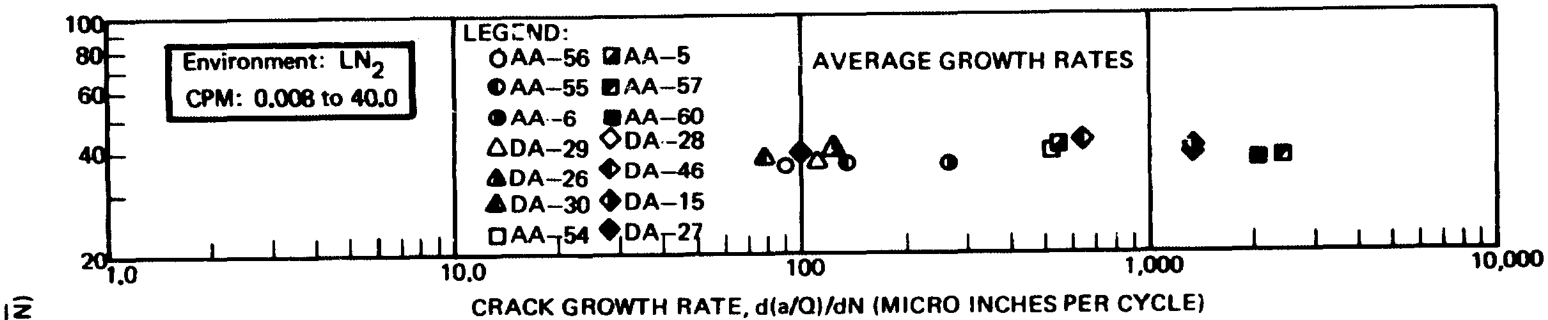


Figure 127: Cyclic Flaw Growth Rates for 0.65–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 14)

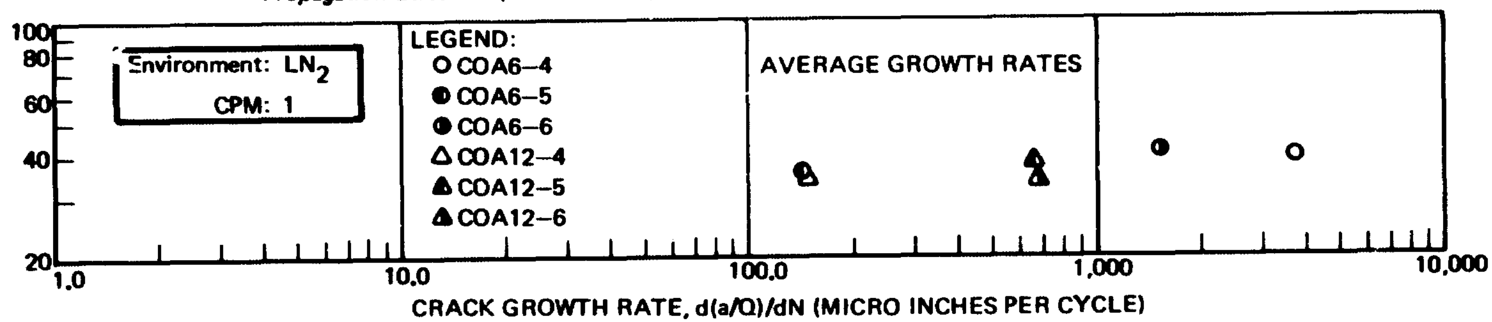


Figure 128: Cyclic Flaw Growth Rates for 0.60 and 1.25–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 13)

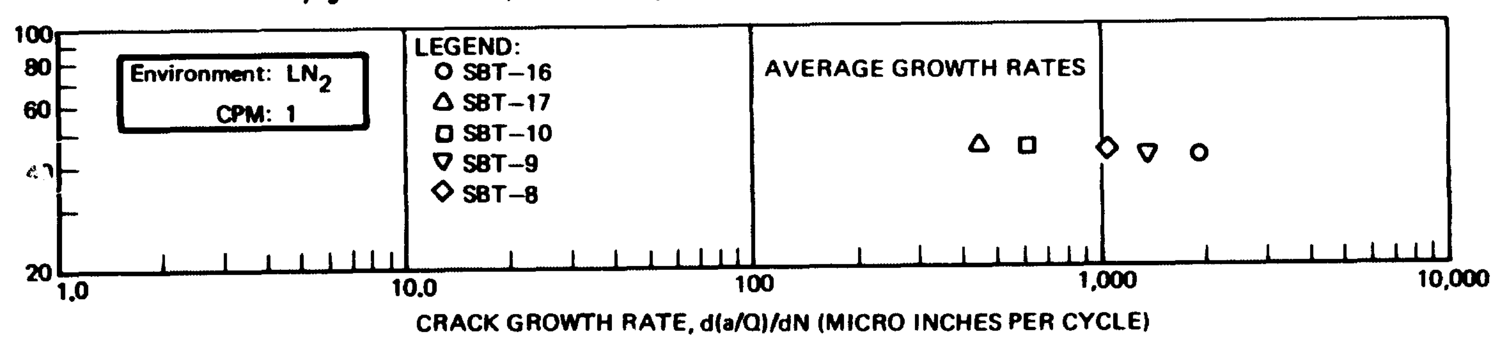


Figure 129: Cyclic Flaw Growth Rates for 1.00–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction (Reference 6)

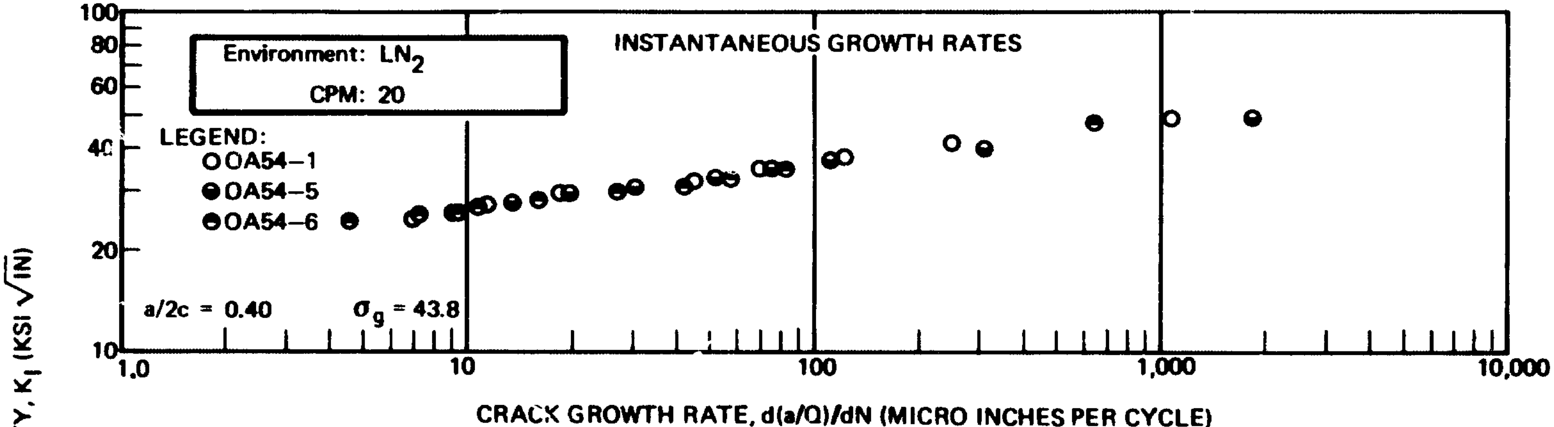


Figure 130: Cyclic Flaw Growth Rates for 0.50C–Inch–Thick 2219–T87 Aluminum Base Metal at –320^0 F for the WT Propagation Direction (Reference 2)

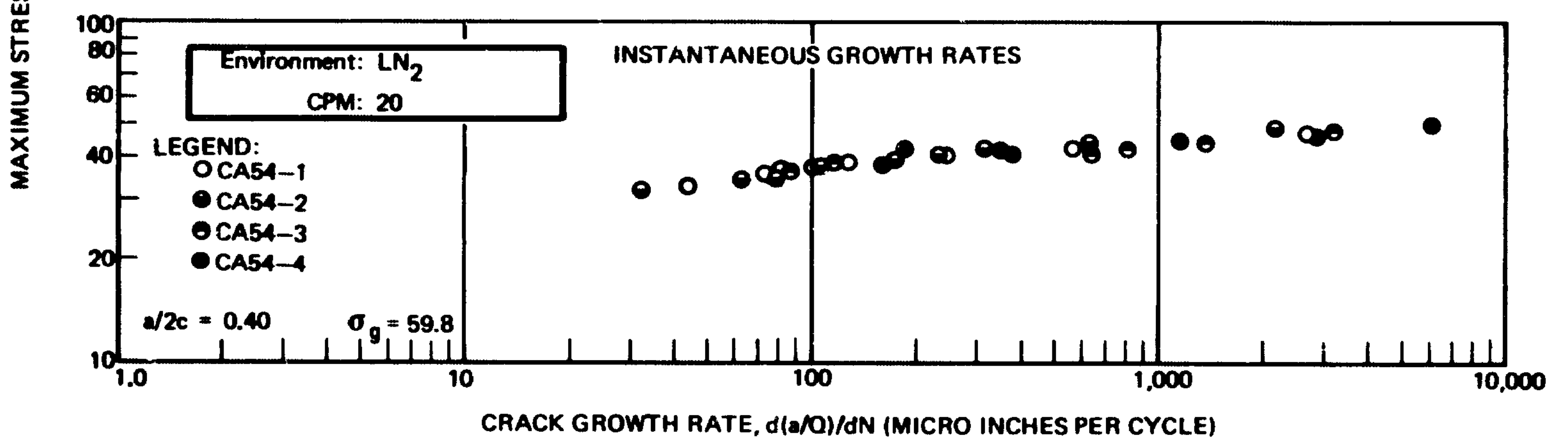


Figure 131: Cyclic Flaw Growth Rates for 0.500–Inch–Thick 2219–T87 Aluminum Base Metal at –320^0 F for the WT Propagation Direction (Reference 2)

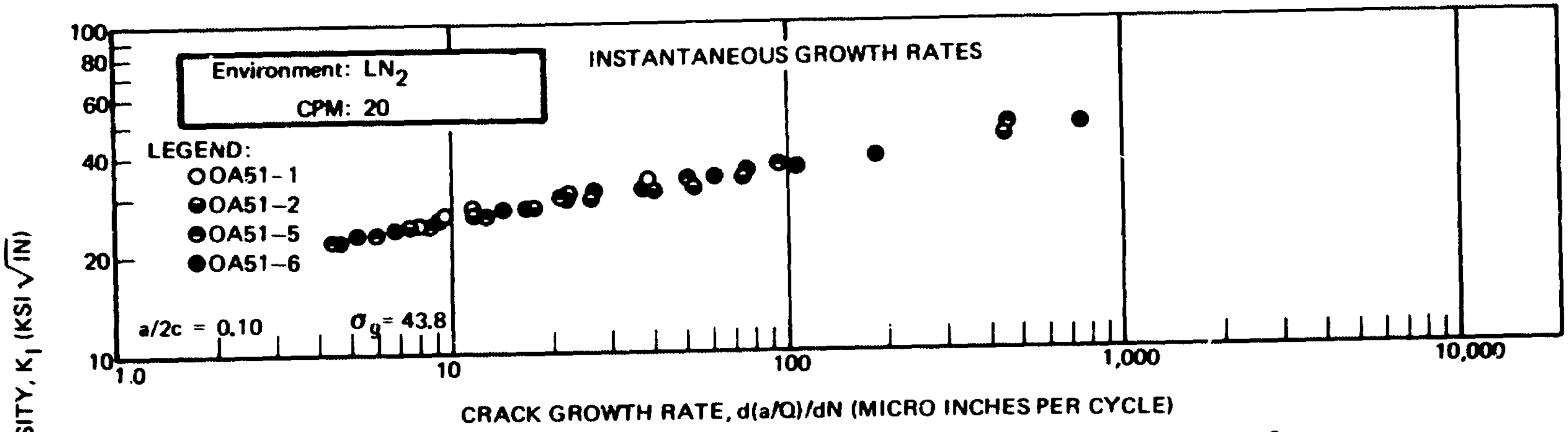


Figure 132: Cyclic Flaw Growth Rates for 0.500–Inch–Thick 2219–T87 Aluminum Base Metal at –320° F for the WT Propagation Direction (Reference 2)

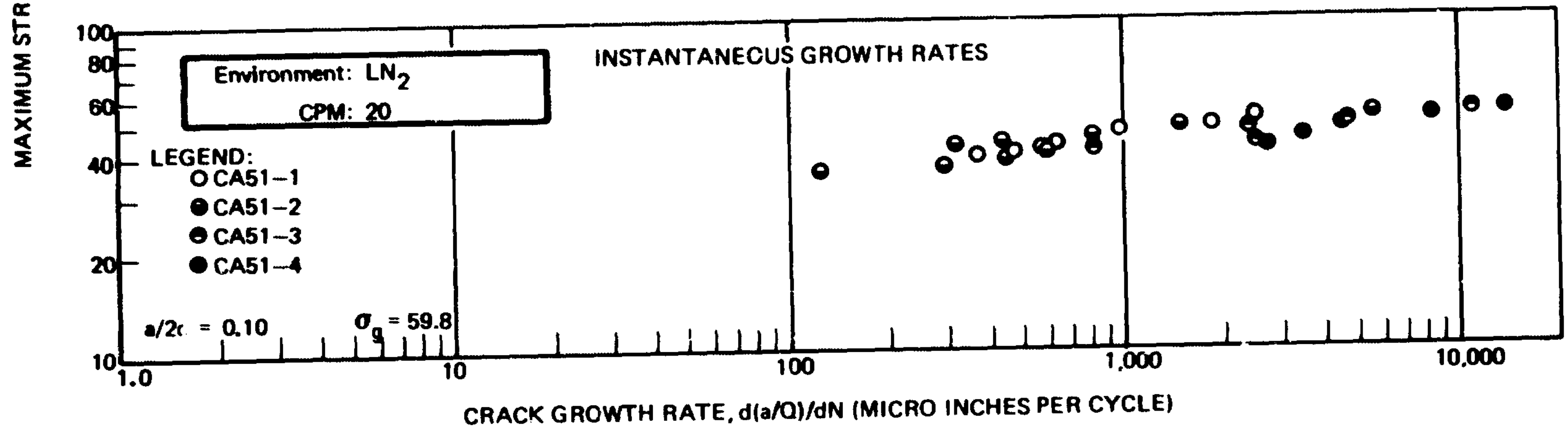


Figure 133: Cyclic Flaw Growth Rates for 0.500–Inch–Thick 2219–T87 Aluminum Base Metal at –320° F for the WT Propagation Direction (Reference 2)

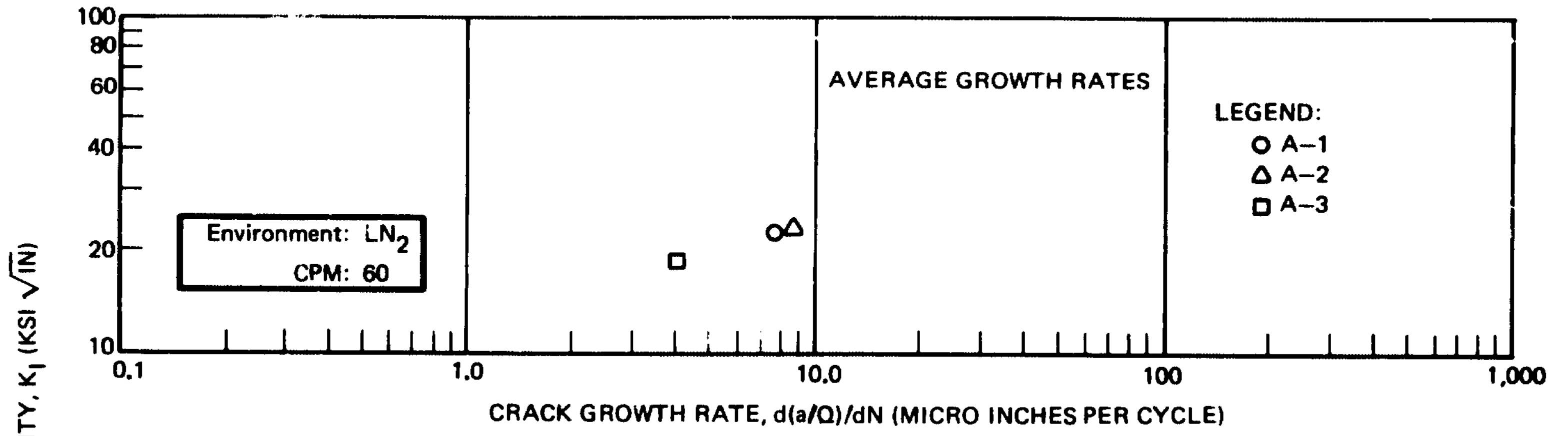


Figure 134: Cyclic Flaw Growth Rates for 0.625–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the RT Propagation Direction (Reference 3)

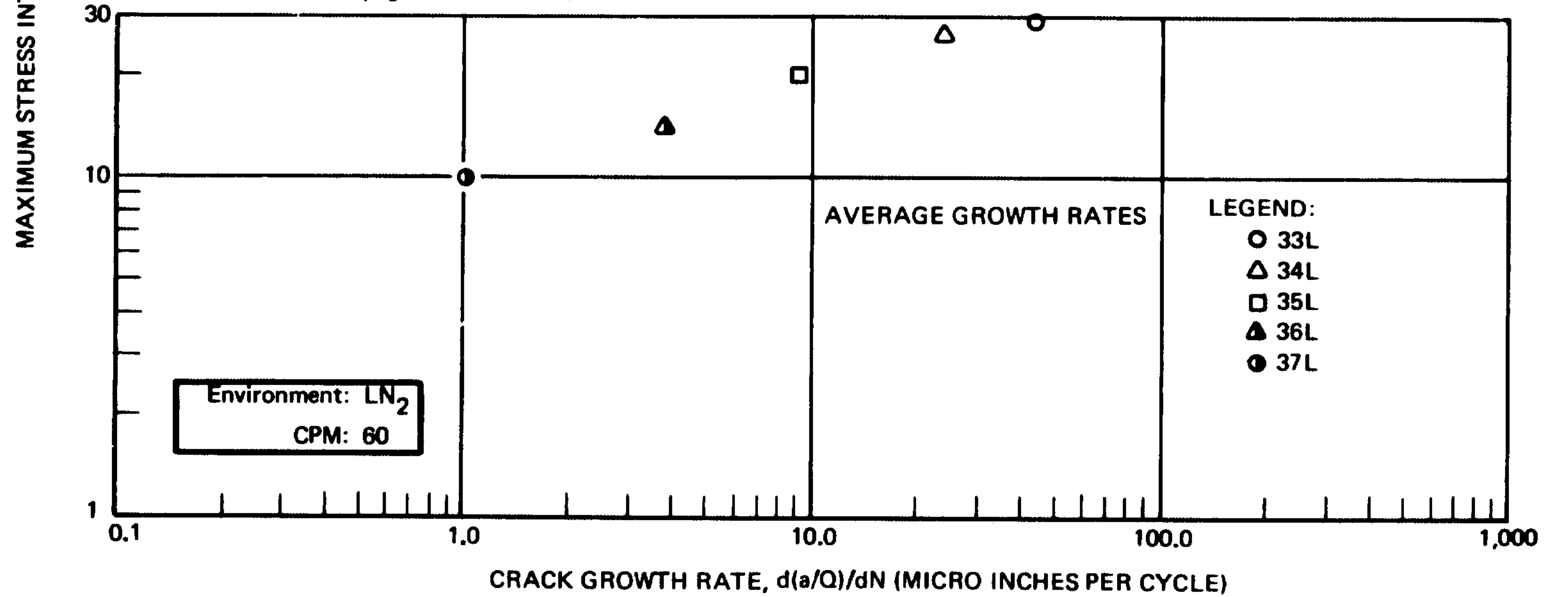


Figure 135: Cyclic Flaw Growth Rates For 0.250–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the RT Propagation Direction (Reference 26)

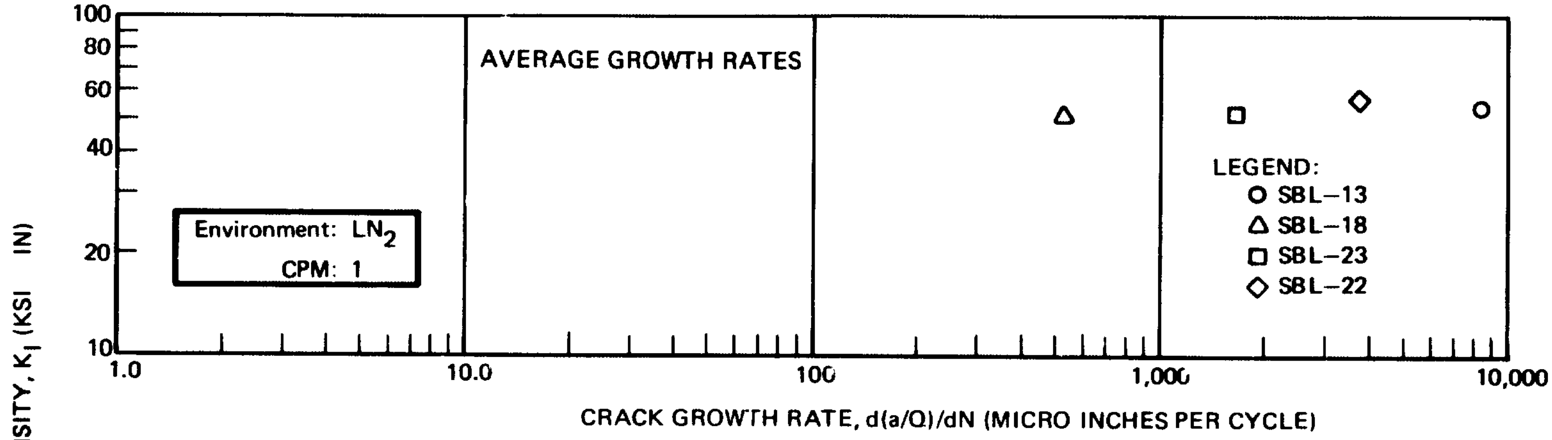


Figure 136: Cyclic Flaw Growth Rates for 1.00–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the RT Propagation Direction (Reference 6)

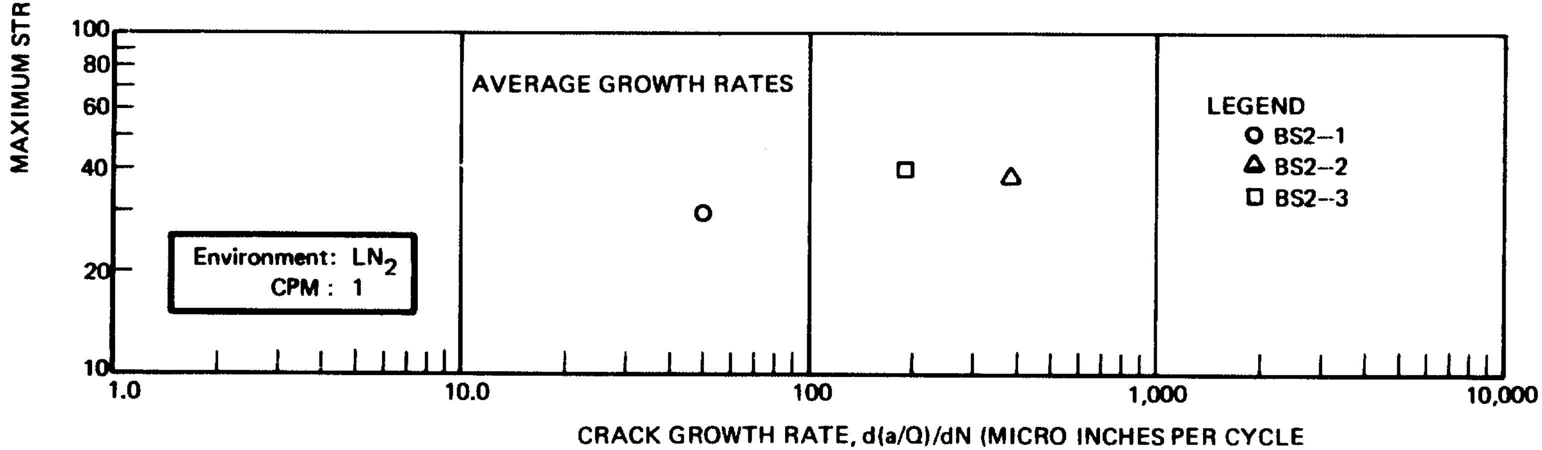


Figure 137: Cyclic Flaw Growth Rates for 0.500–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the RT Propagation Direction (Reference 23)

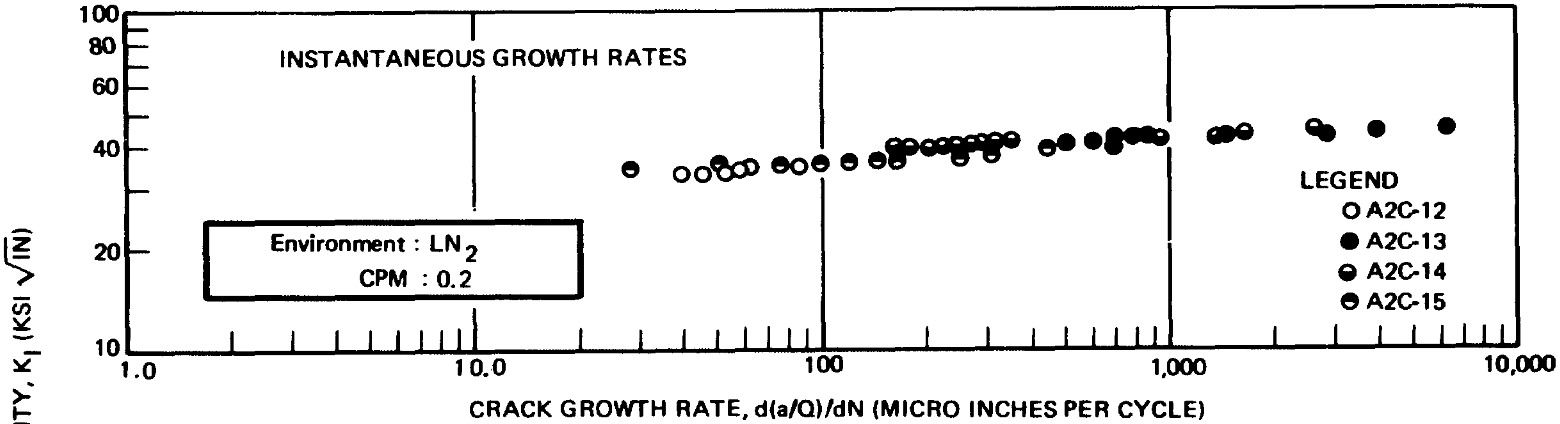


Figure 138: Cyclic Flaw Growth Rates for 0.400–Inch–Thick 2219–T87 Aluminum Base Metal at –423^{0}F for the WT Propagation Direction (Reference 5)

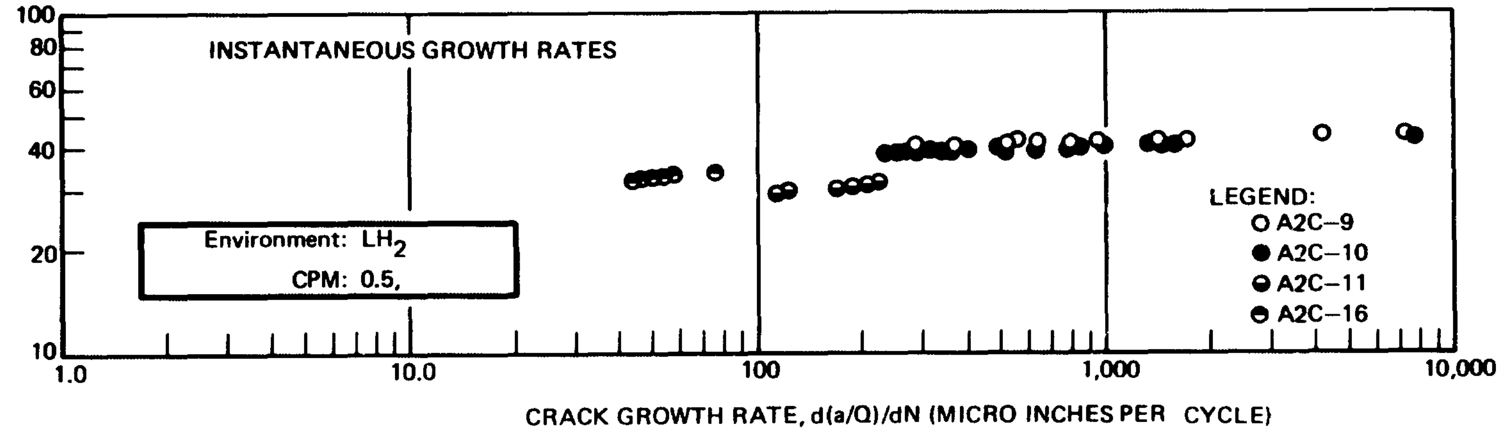


Figure 139: Cyclic Flaw Growth Rates for 0.400–Inch–Thick 2219–T87 Aluminum Base Metal at –423^{0}F for the WT Propagation Direction (Reference 5)

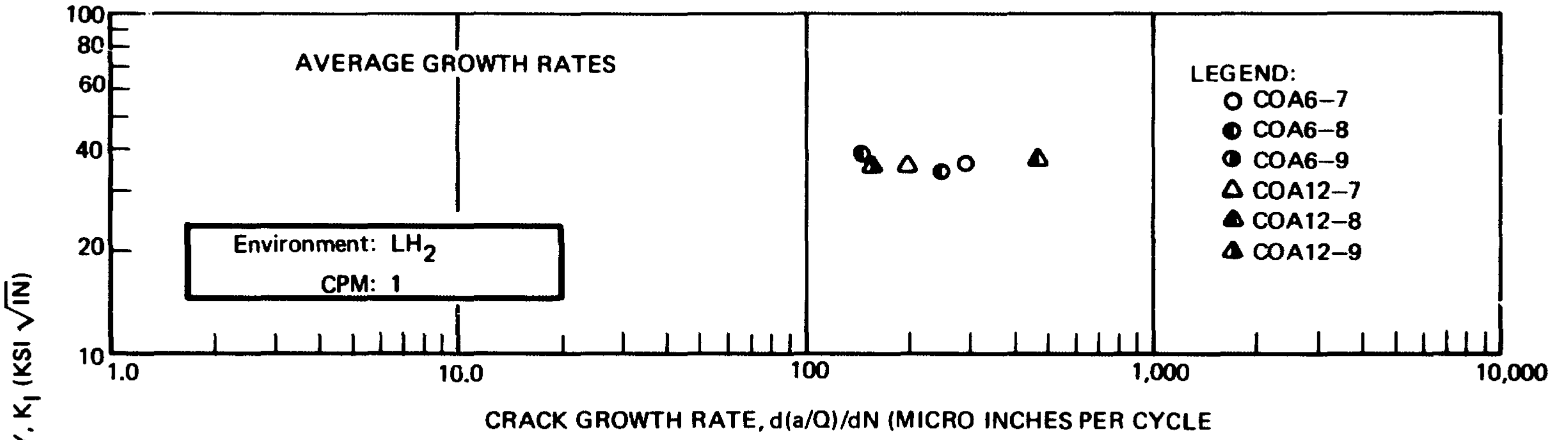


Figure 140: Cyclic Flaw Growth Rates for 0.60 and 0.125 –Inch–Thick 2219–T87 Aluminum Base Metal at –423° F for the WT Propagation Direction (Reference 13)

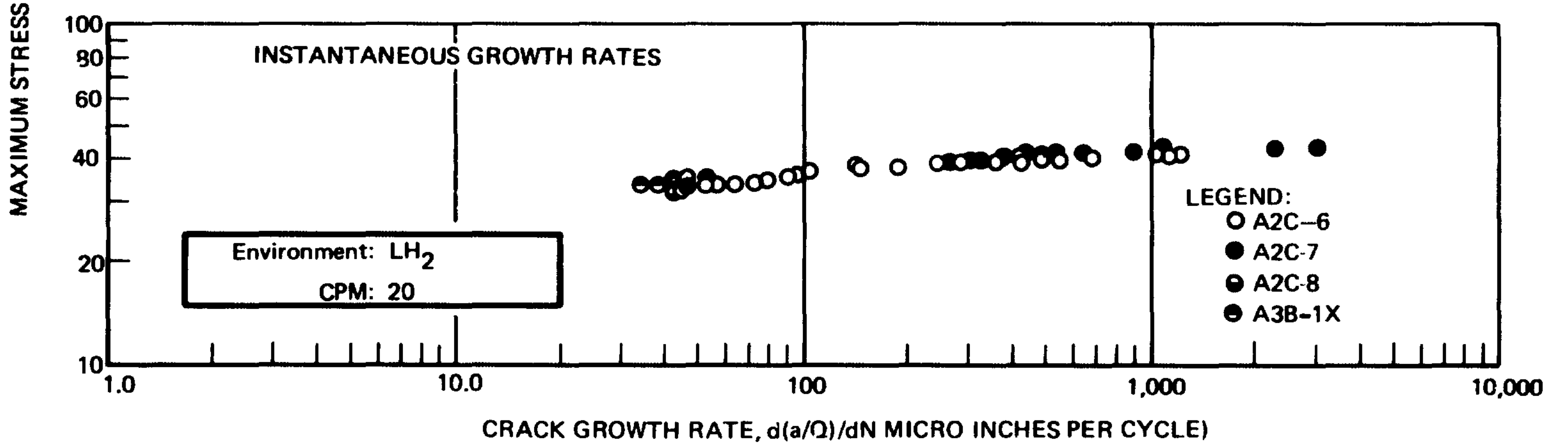


Figure 141: Cyclic Flaw Growth Rates for 0.400 and 0.800–Inch–Thick 2219–T87 Aluminum Base Metal at –423° F for the WT Propagation Direction (Reference 5)

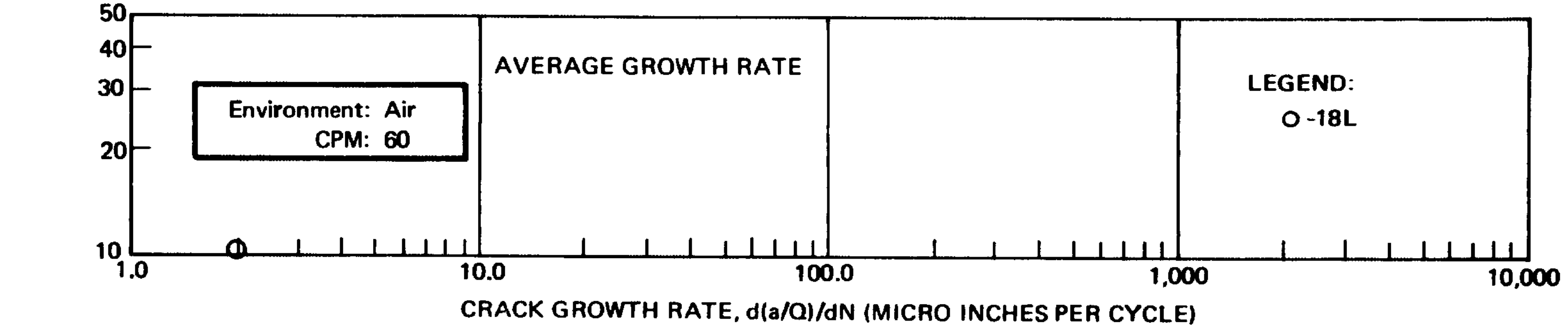


Figure 142: Cyclic Flaw Growth Rates for 0.250–Inch–Thick 2219–T87 Aluminum Base Metal at 300°F for the RT Propagation Direction (Reference 26)

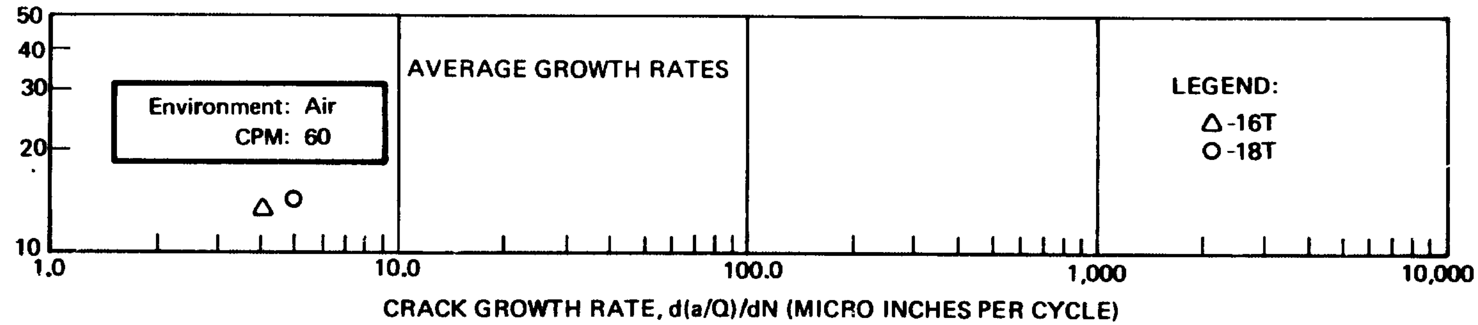


Figure 143: Cyclic Flaw Growth Rates for 0.125–Inch–Thick 2219–T87 Aluminum Base Metal at 350°F for the WT Propagation Direction (Reference 26)

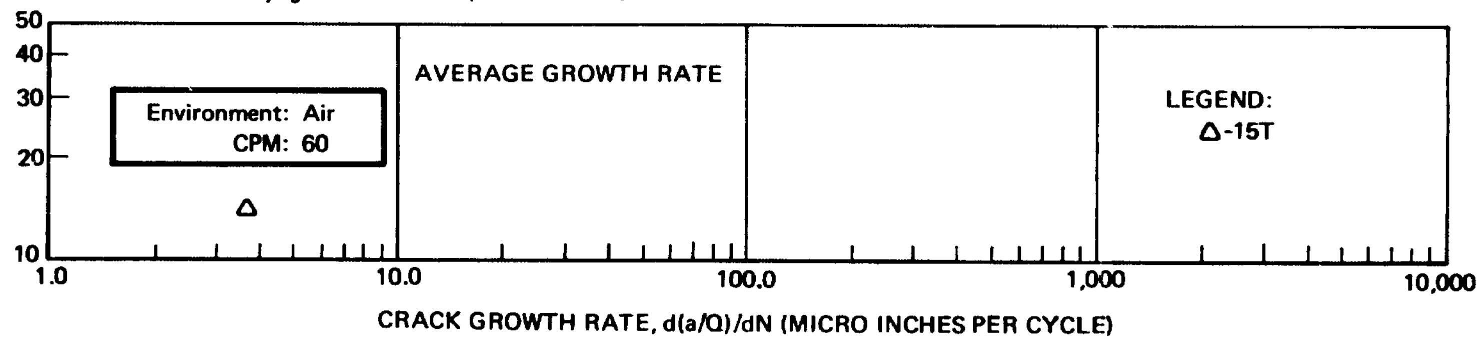


Figure 144: Cyclic Flaw Growth Rates for 0.125–Inch–Thick 2219–T87 Aluminum Base Metal at 300°F for the WT Propagation Direction (Reference 26)

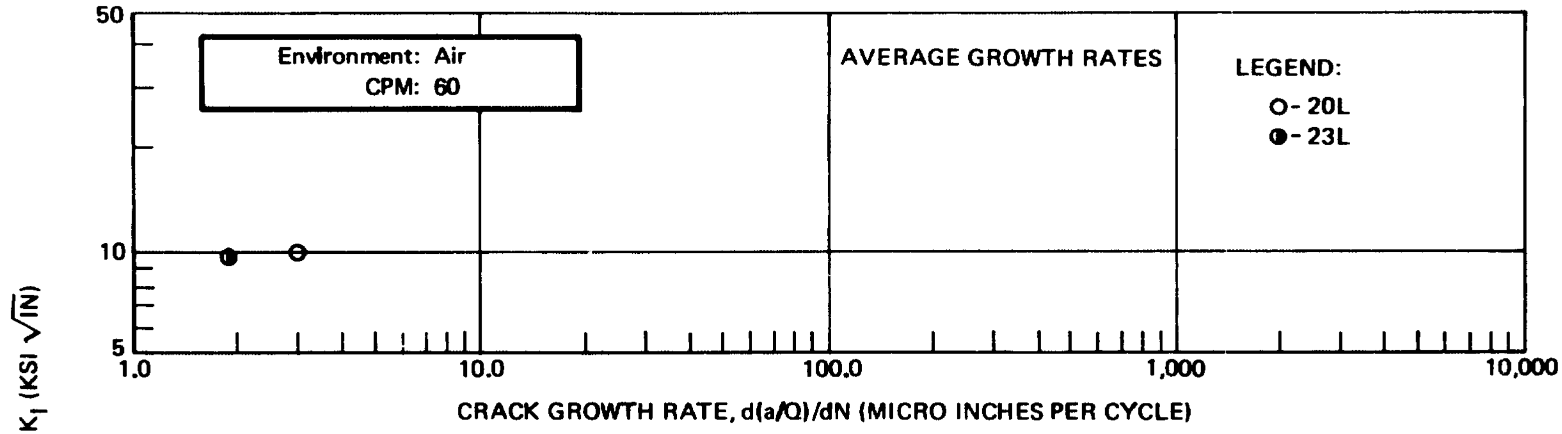


Figure 145: Cyclic Flaw Growth Rates for 0.250–Inch–Thick 2219–T87 Aluminum Base Metal at 400°F for the RT Propagation Direction (Reference 26)

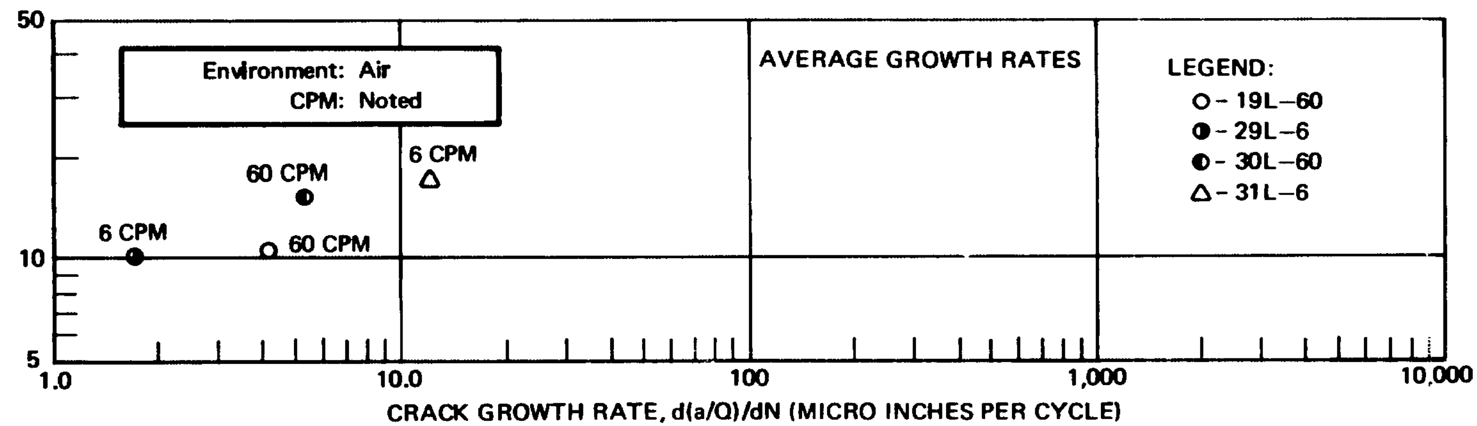


Figure 146: Cyclic Flaw Growth Rates for 0.250–Inch–Thick 2219–T87 Aluminum Base Metal at 350°F for the RT Propagation Direction (Reference 26)

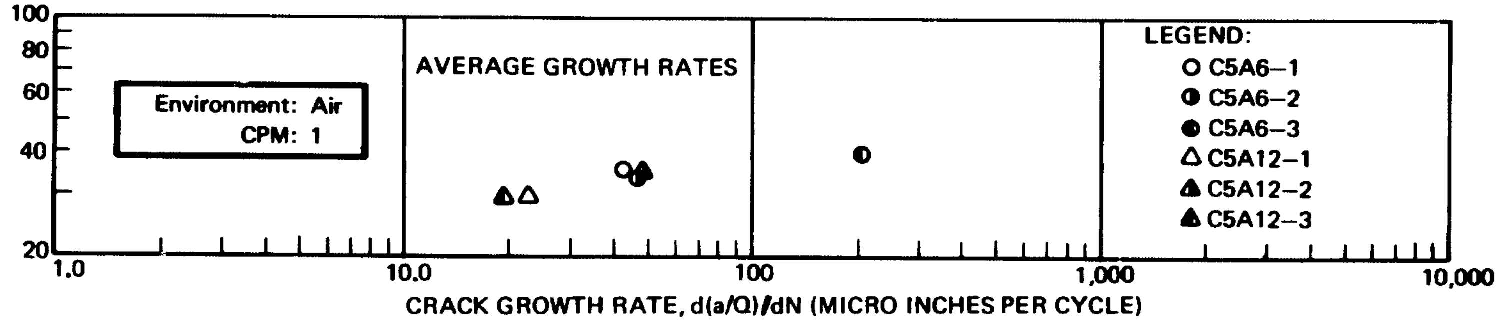


Figure 147: Cyclic Flaw Growth Rates for 0.60 and 1.25–Inch–Thick 2219–T87 Aluminum Base Metal at 72°F for the WT Propagation Direction, R = 0.5 (Reference 13)

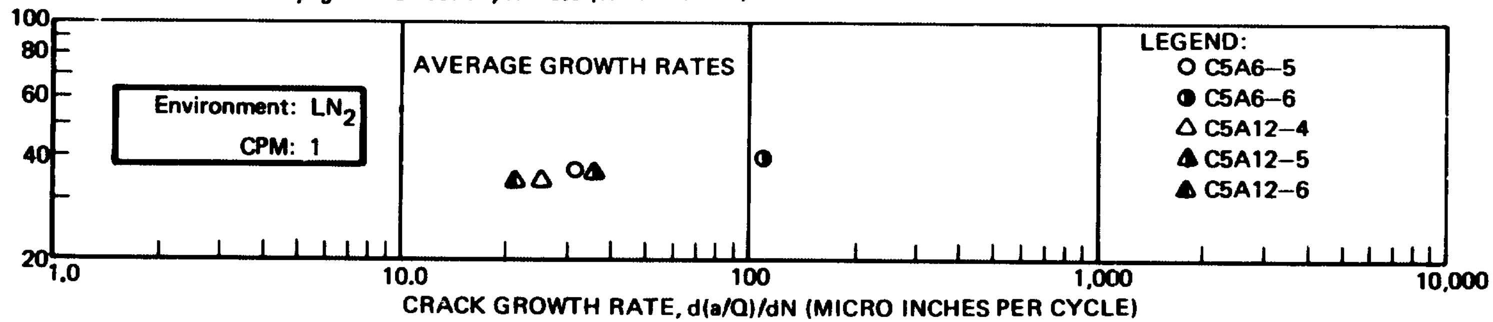


Figure 148: Cyclic Flaw Growth Rates for 0.60 and 1.25–Inch–Thick 2219–T87 Aluminum Base Metal at –320°F for the WT Propagation Direction, R = 0.5 (Reference 13)

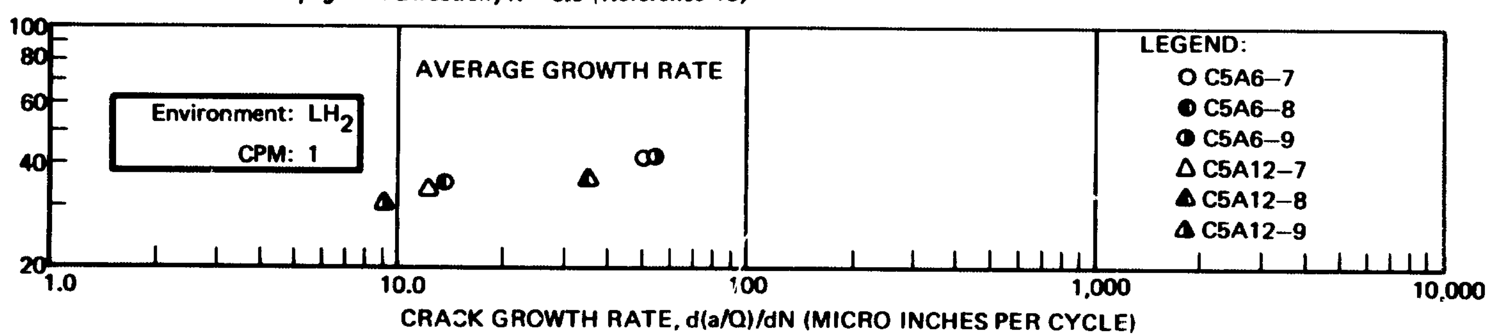


Figure 149: Cyclic Flaw Growth Rates for 0.60 and 1.25–Inch–Thick 2219–T87 Aluminum Base Metal at –423°F for the WT Propagation Direction, R = 0.5 (Reference 13)

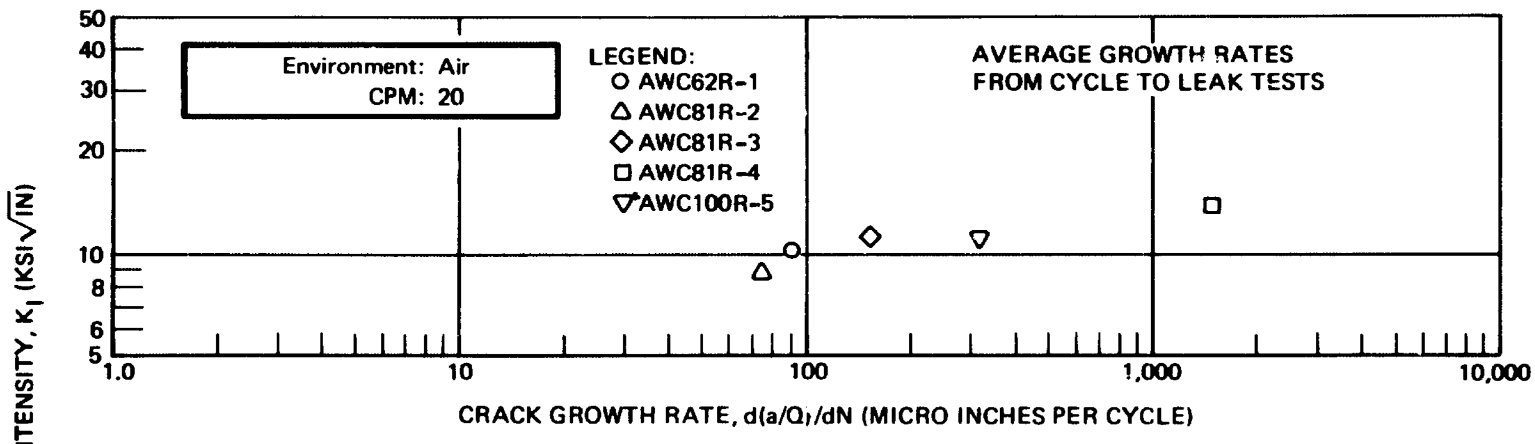


Figure 150: Cyclic Flaw Growth Rates for 0.125-Inch-Thick 2219 Aluminum Weldments at 72^{0}F (Reference 3)

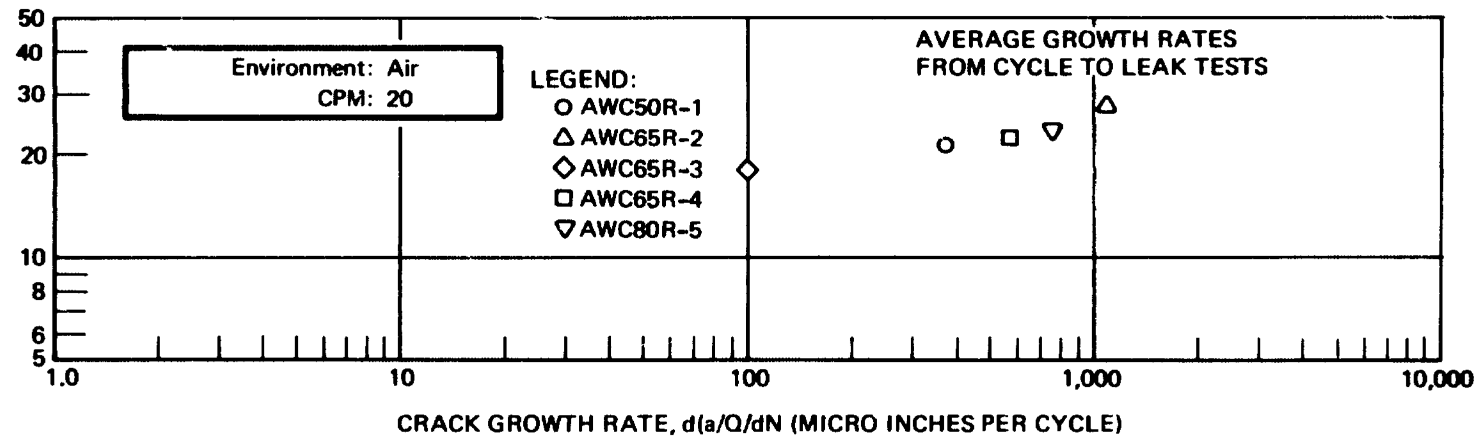


Figure 151: Cyclic Flaw Growth Rates for 1.00-Inch-Thick 2219 Aluminum Weldments at 72^{0}F (Reference 3)

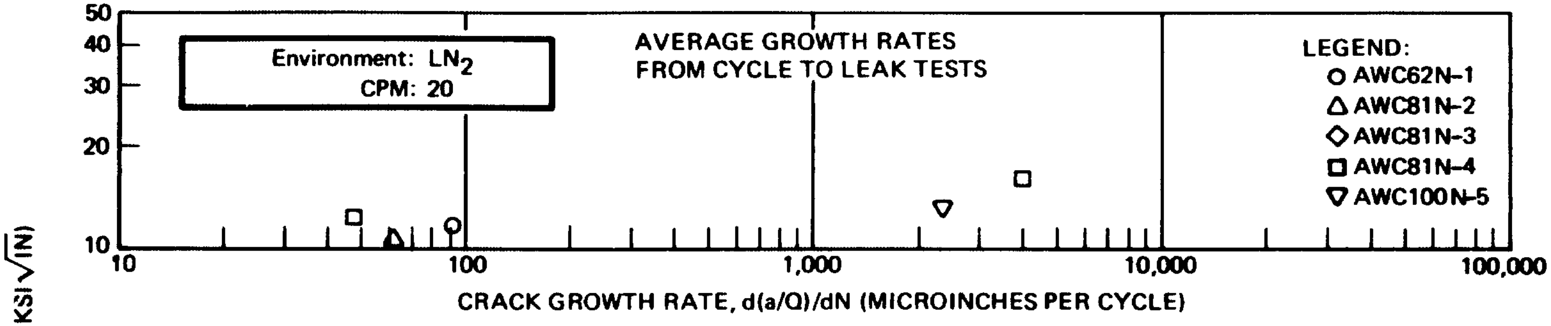


Figure 152: Cyclic Flaw Growth Rates for 0.125-Inch-Thick 2219 Aluminum Weldments at -320°F (Reference 3)

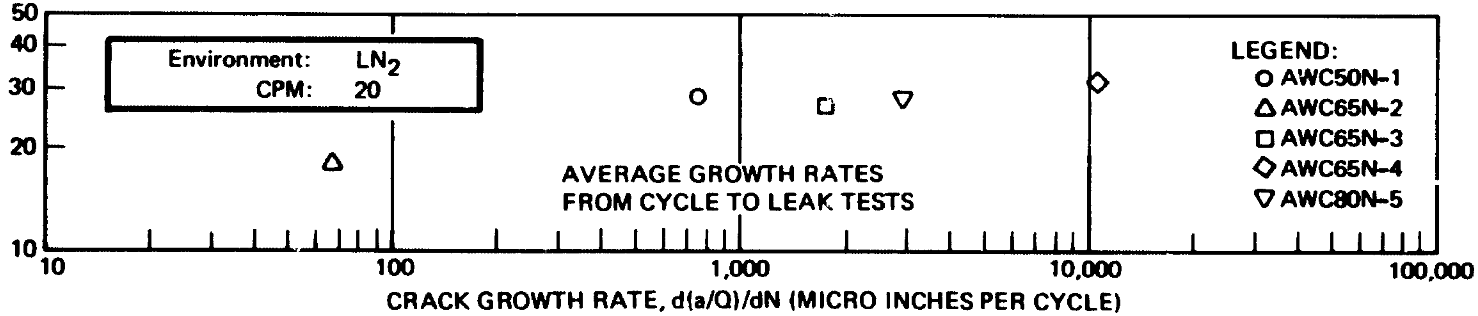


Figure 153: Cyclic Flaw Growth Rates for 1.00-Inch-Thick 2219 Aluminum Weldments at -320°F (Reference 3)

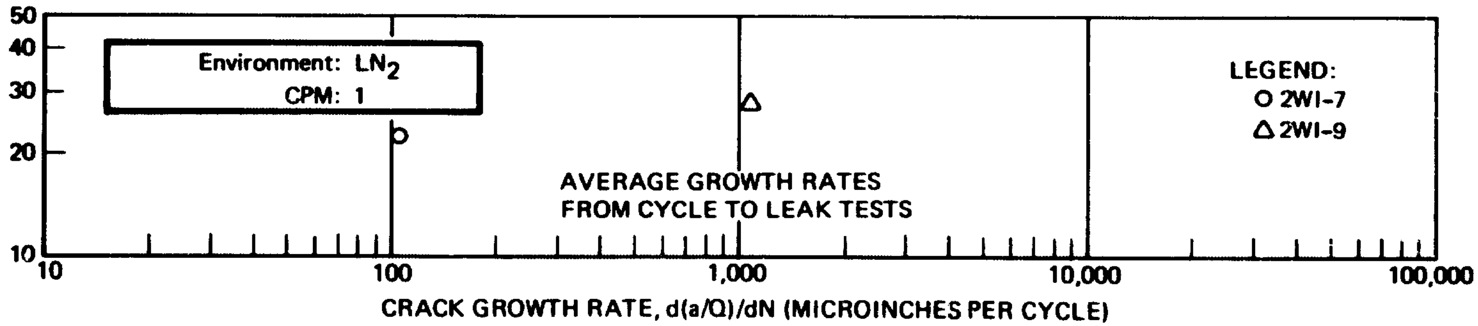


Figure 154: Cyclic Flaw Growth Rates for 1.00-Inch-Thick 2219 Aluminum Weldments at -320°F (Reference 23)

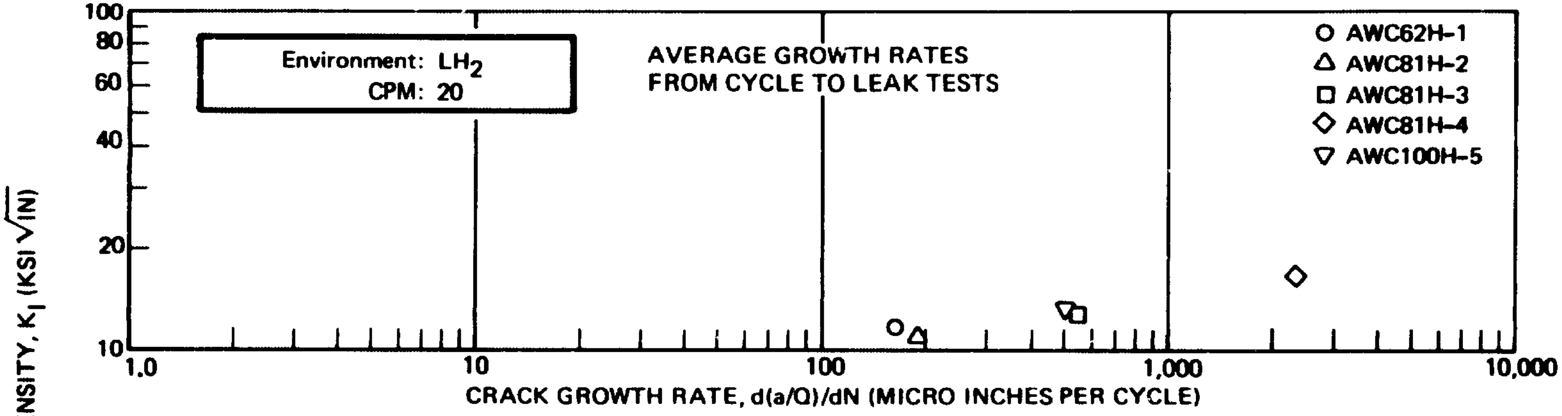


Figure 155: Cyclic Flaw Growth Rates for 0.125-Inch-Thick 2219 Aluminum Weldments at -423° F (Reference 3)

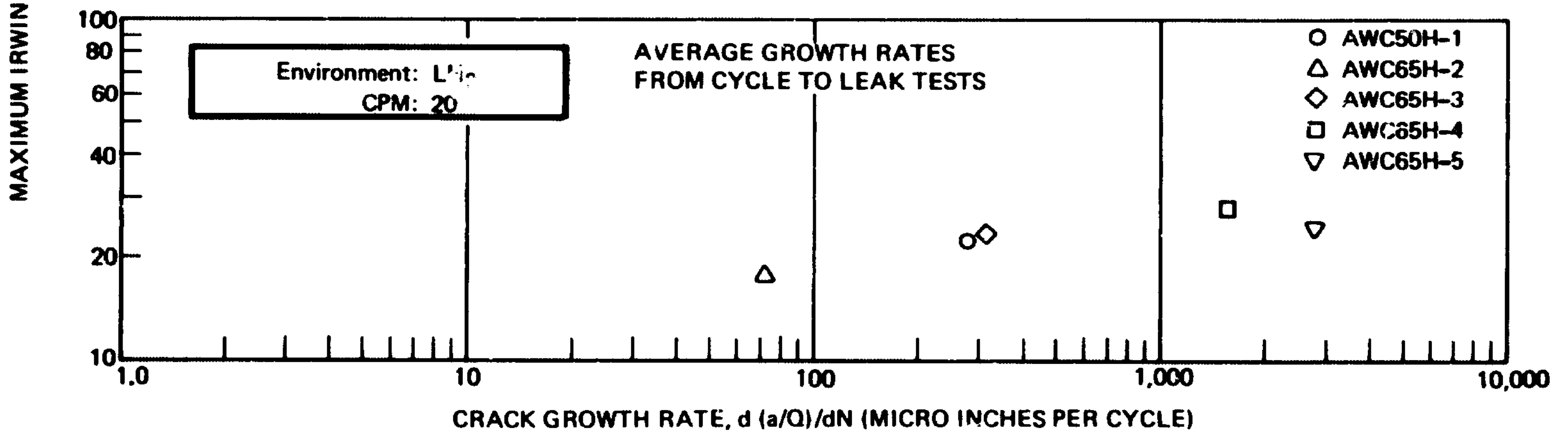


Figure 156: Cyclic Flaw Growth Rates for 1.00-Inch-Thick 2219 Aluminum Weldments at -423° F (Reference 3)

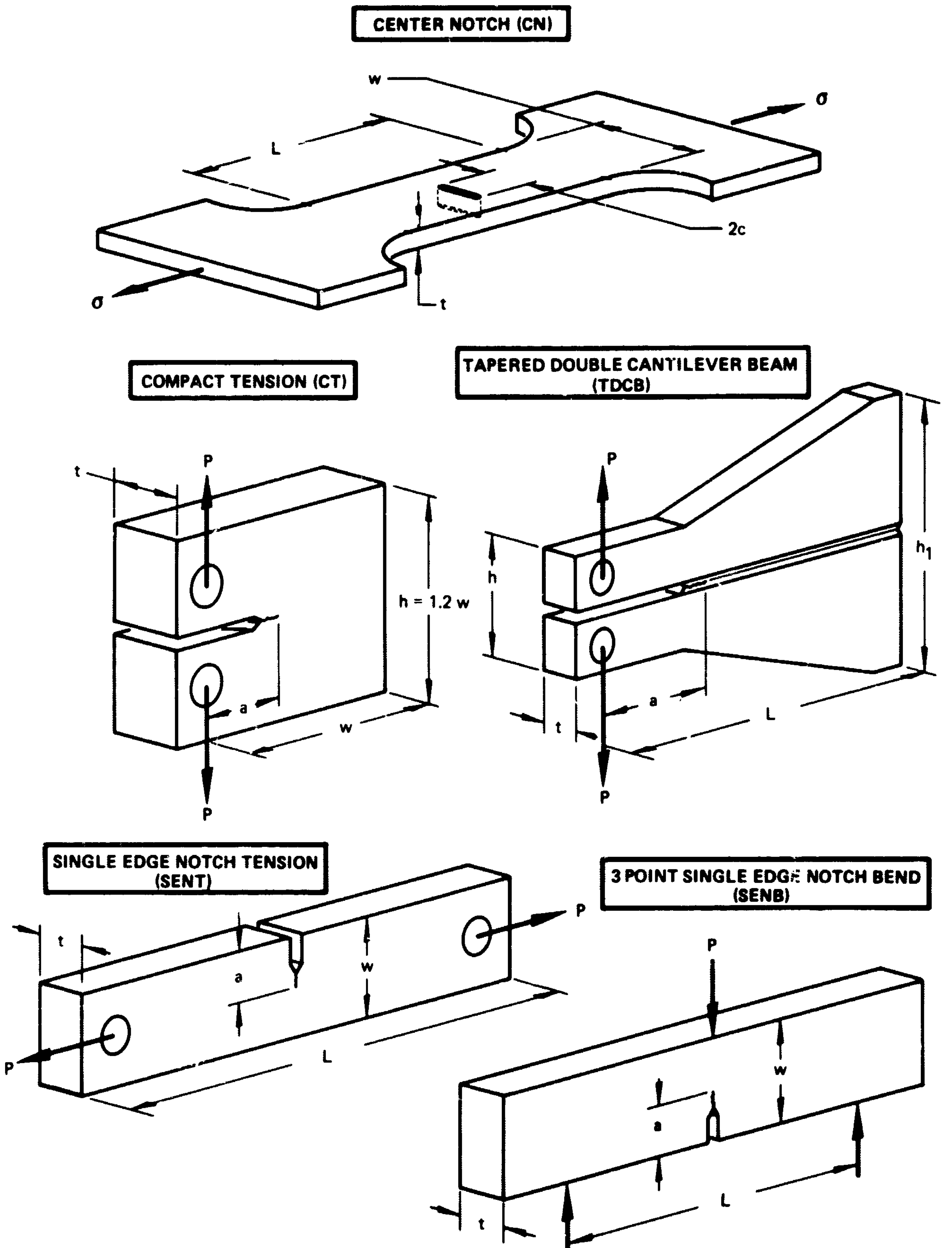


Figure A-1: Fracture Specimen Configurations

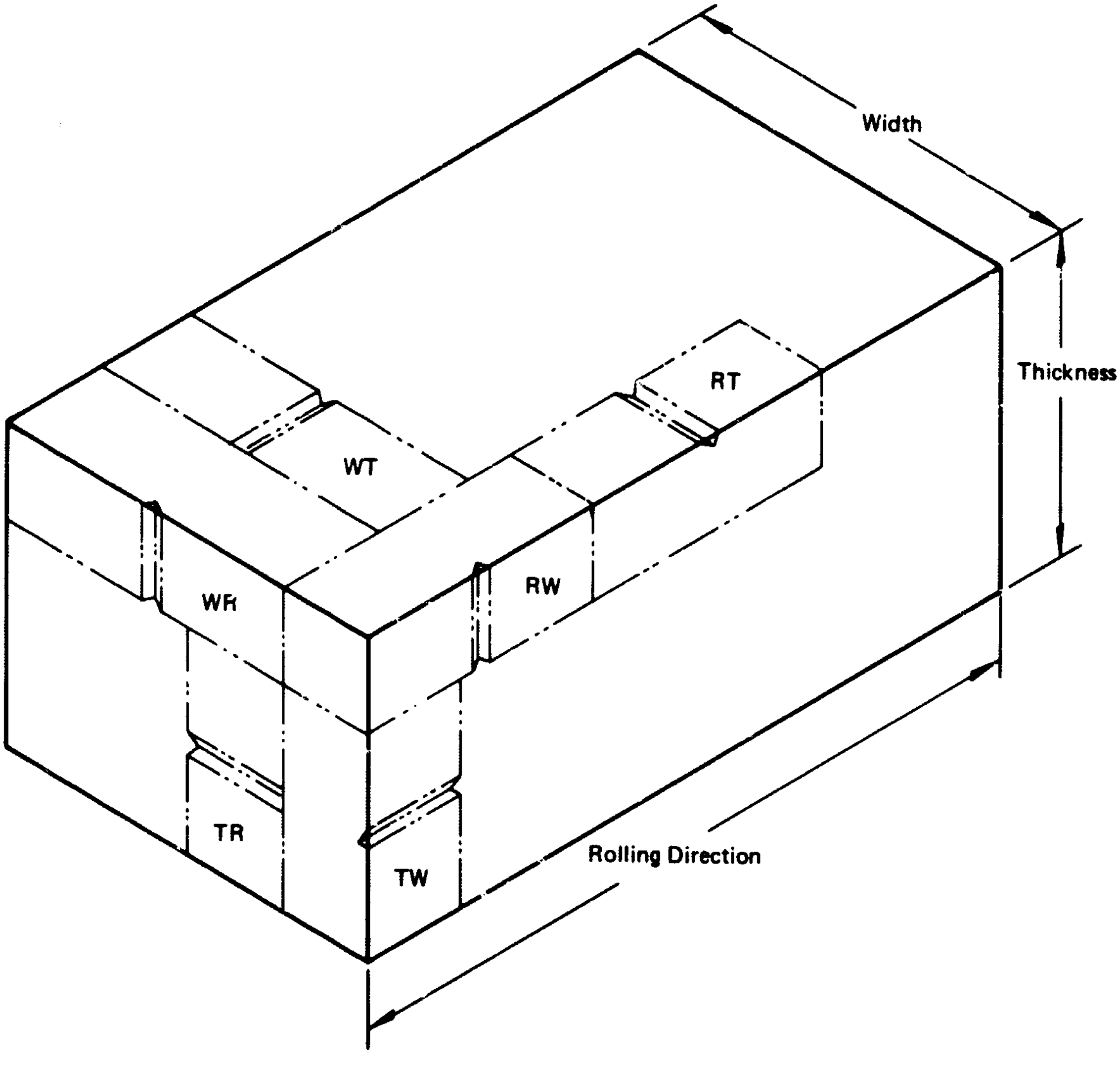
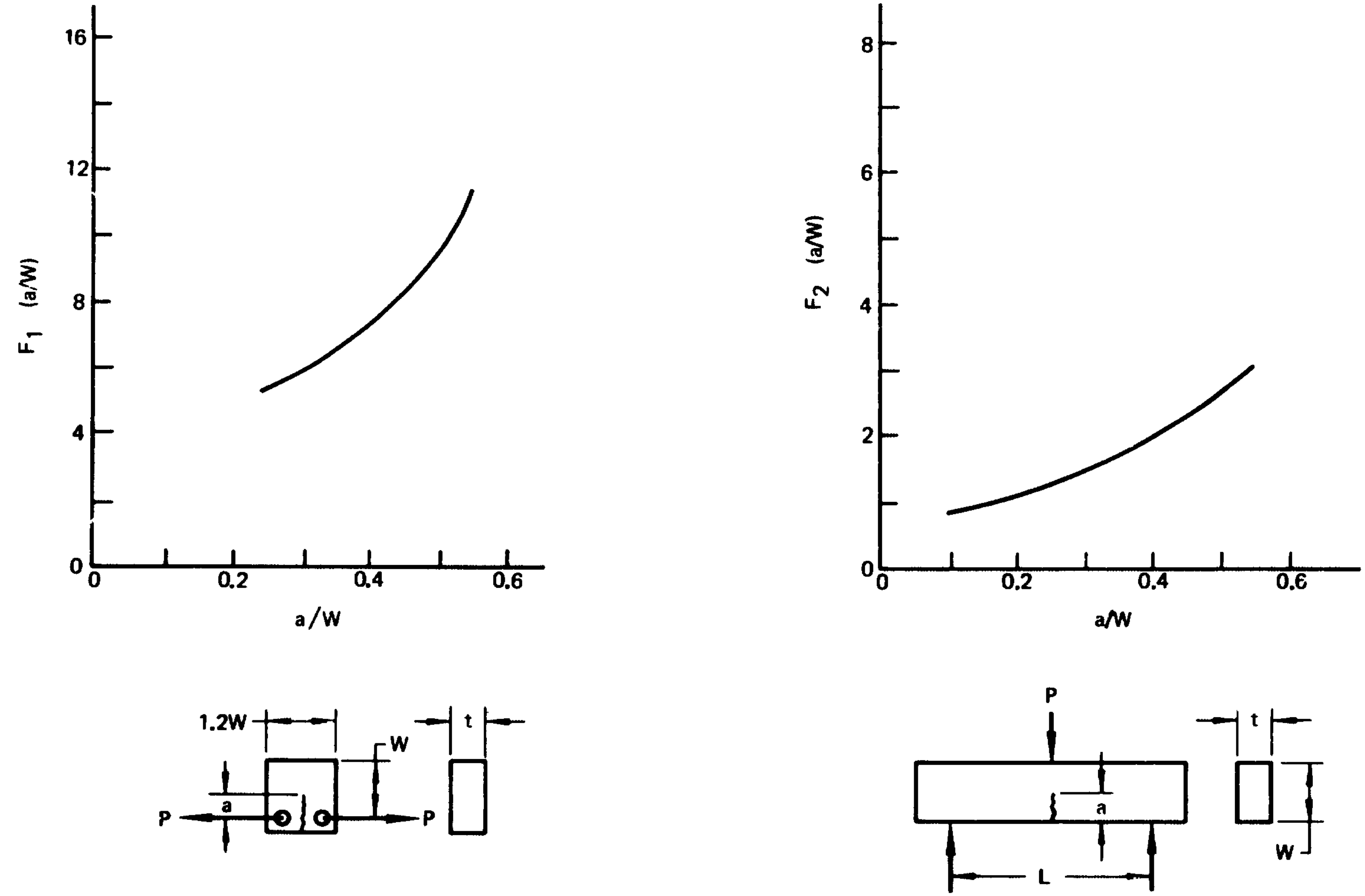


Figure A-2: Propagation Direction Code



$$K_I = \frac{P}{tW^{1/2}} \cdot F_1\,(a/W)$$

$$K_I = \frac{PL}{tW^{3/2}} \cdot F_2\,(a/W)$$

Figure A-3 : Stress Intensity Expressions For CT and SENB Specimens

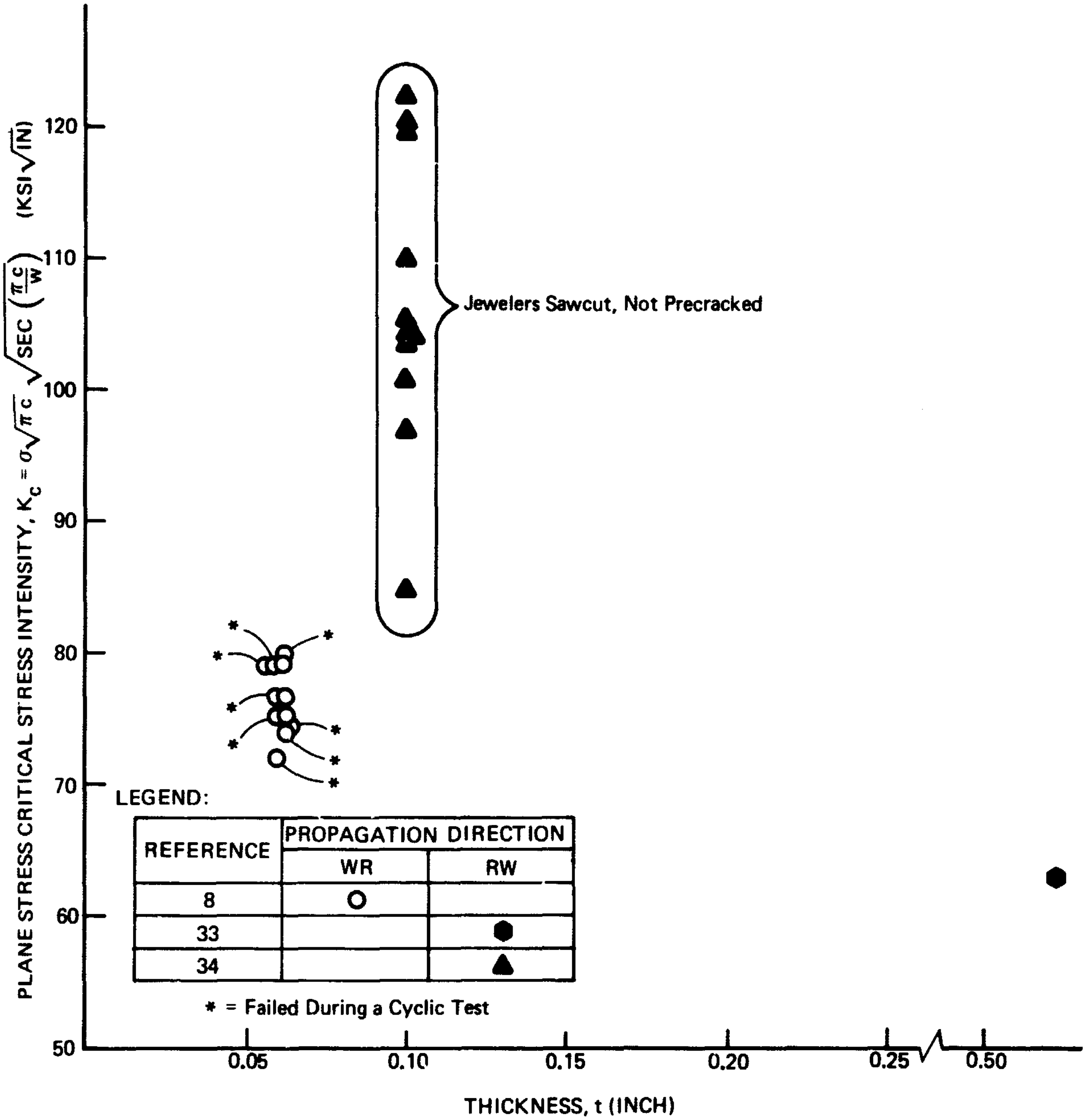


Figure A-4 : Plane Stress Critical Stress Intensity Vs. Thickness, 2219-T87 Aluminum Alloy Tested in Room Temperature Air

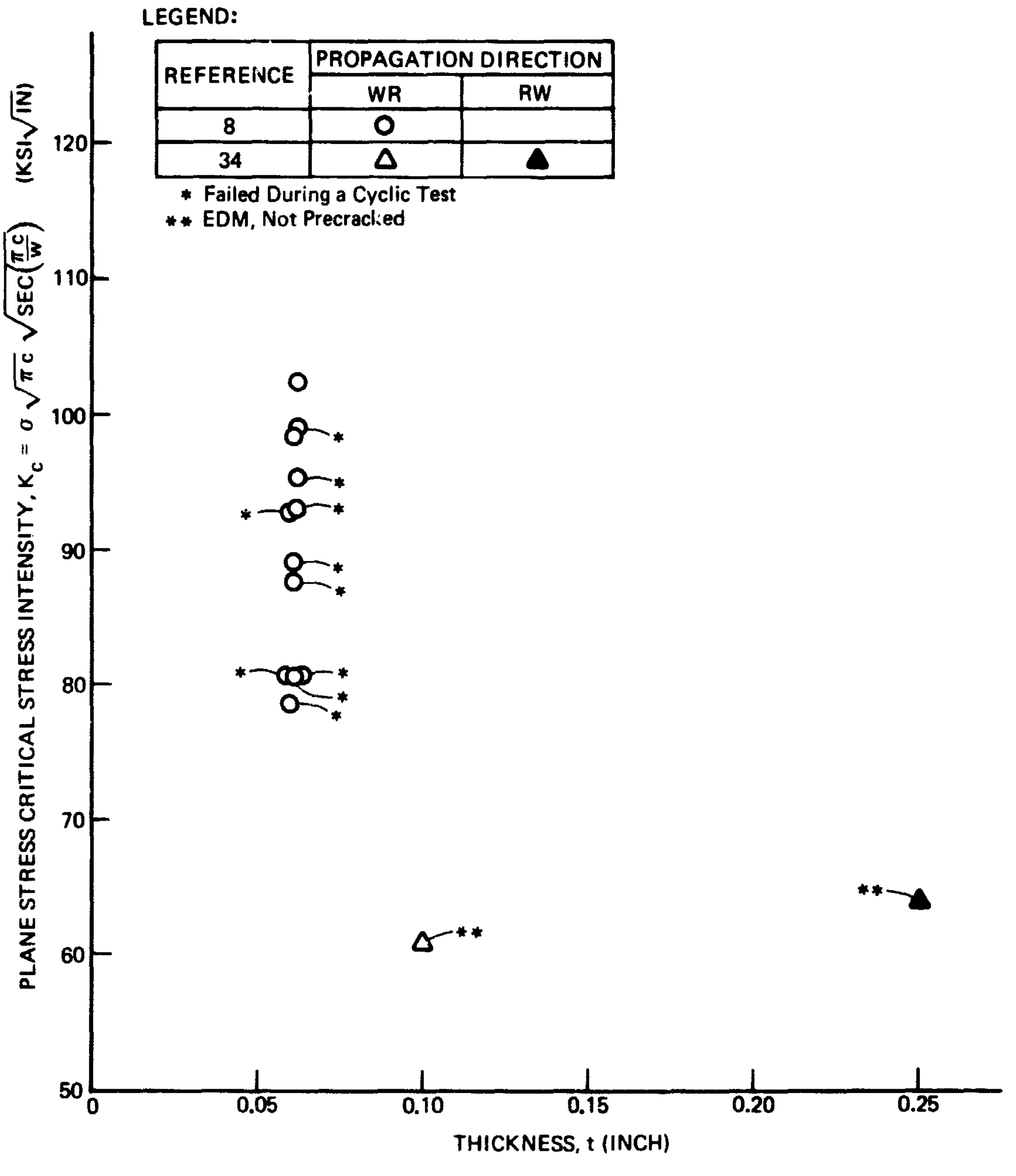


Figure A-5: Plane Stress Critical Stress Intensity Vs. Thickness, 2219-T87 Aluminum Alloy Tested in -320^{0}F Liquid Nitrogen

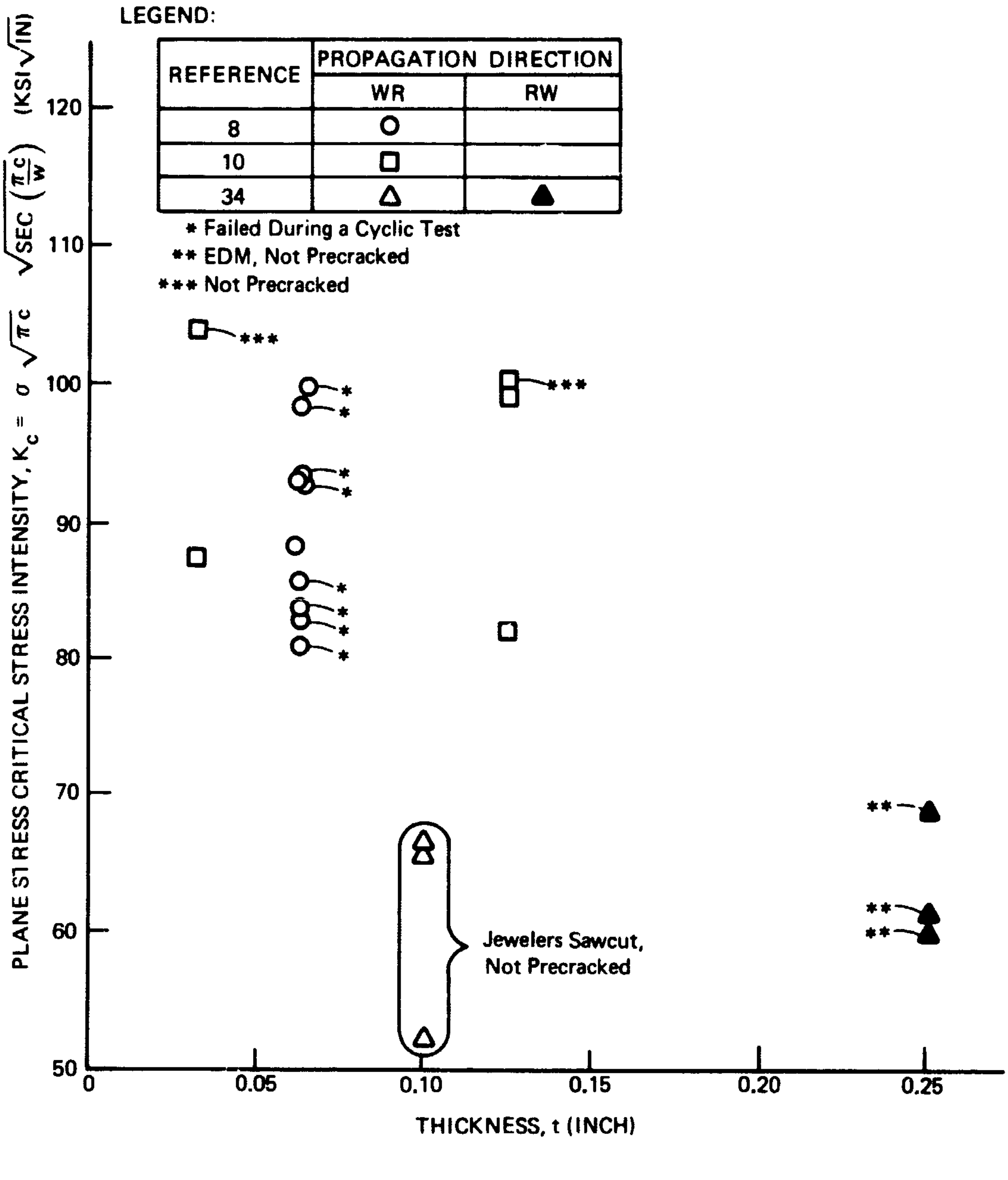
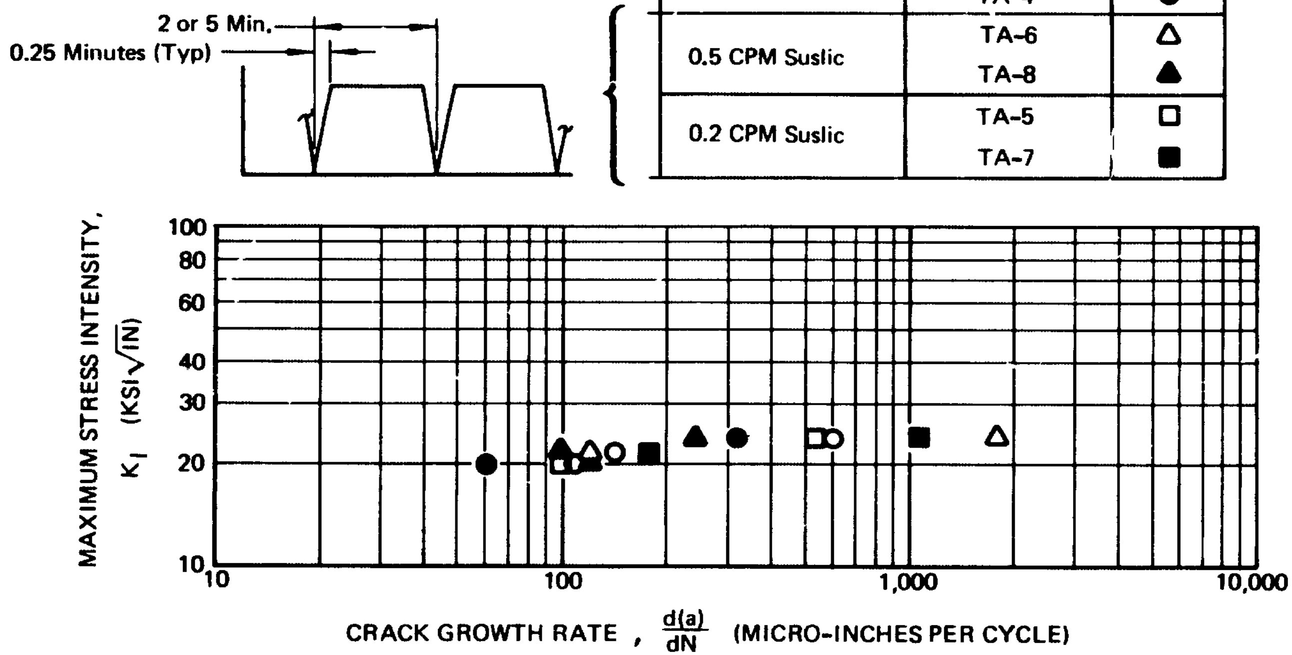


Figure A-6 : Plane Stress Critical Stress Intensity Vs. Thickness, 2219-T87 Aluminum Alloy Tested in -423°F Liquid Hydrogen



TEST TYPE	SPECIMEN NO.	SYMBOL
20 CPM Sine Wave	TA-3	○
	TA-4	●
0.5 CPM Suslic	TA-6	△
	TA-8	▲
0.2 CPM Suslic	TA-5	□
	TA-7	■

Figure A-7 : Average Stress Intensity, K_I, Vs. Crack Growth Rate, $\frac{da}{dN}$, 1.0 Inch Thick 2219-T87 Aluminum Alloy Tapered DCB Specimens Tested at Room Temperature in 3-1/2% NaCl Solution. WR Propagation Direction (Reference 5)

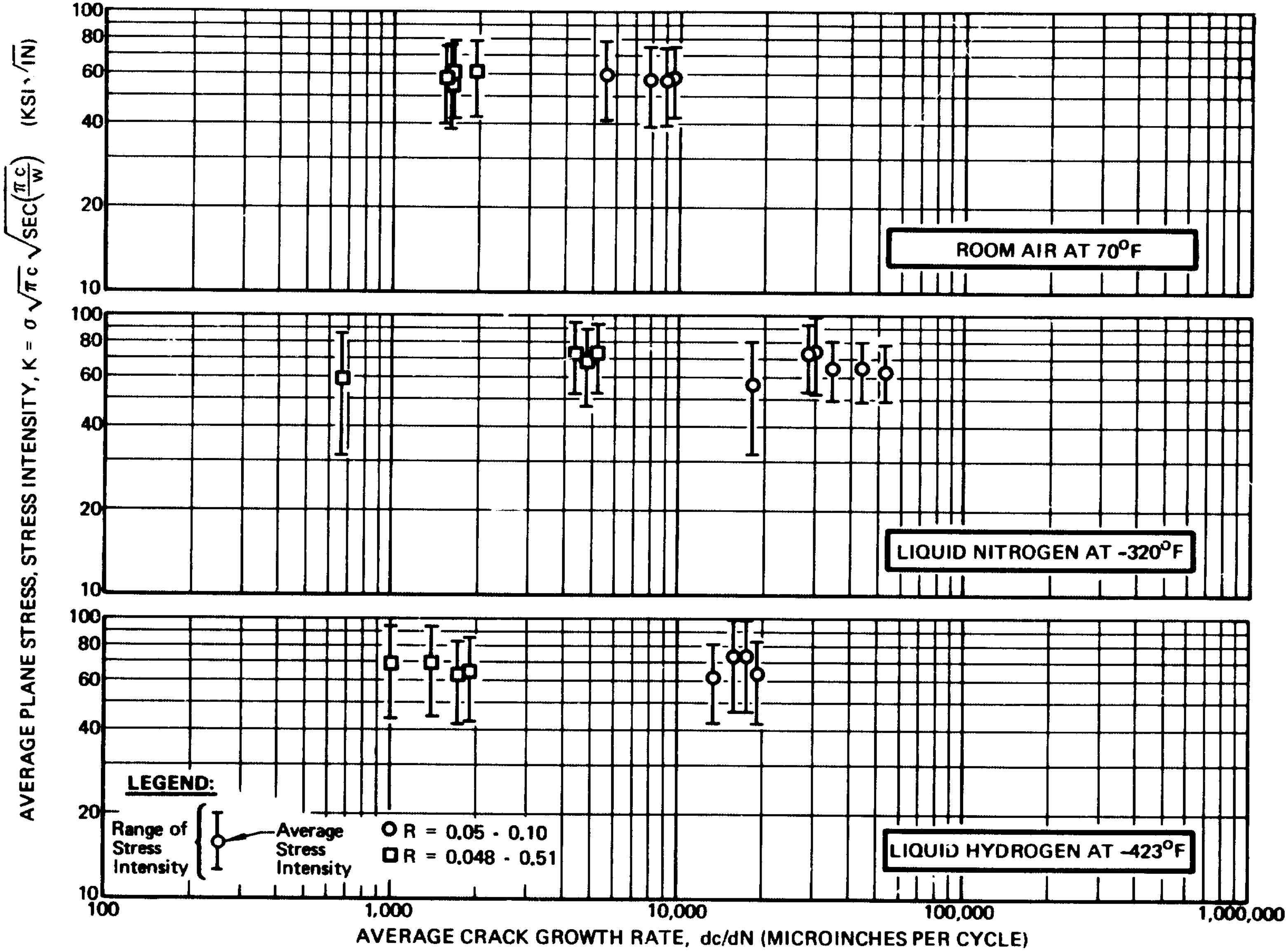


Figure A- 8 : Average Plane Stress Stress Intensity Vs. Average Growth Rate, 2219-T87 Aluminum Alloy, 0.063 Inch Sheet, WR Propagation Direction (All Points From Reference 8)

Table 1 : Ultimate and Yield Strength Summary 2219-T87 Aluminum Alloy Longitudinal Grain

PROPERTY	TEMPERATURE		
	$-423^{o}F$	$-320^{o}F$	RT
Mean F_{tu} (Ksi)	99.3	83.8	68.7
99% P, 95% C F_{tu} (Ksi)	90.5	77.9	64.3
Mean F_{ty} (Ksi)	72.2	65.9	56.7
99% P, 95% C F_{ty} (Ksi)	65.8	59.4	51.4

Table 2 : Ultimate and Yield Strength Summary 2219-T87 Aluminum Alloy Long Transverse Grain

PROPERTY	TEMPERATURE		
	$-423^{o}F$	$-320^{o}F$	RT
Mean F_{tu} (Ksi)	100.4	84.8	69.0
99% P, 95% C F_{tu} (Ksi)	94.1	78.7	64.6
Mean F_{ty} (Ksi)	71.8	65.9	56.2
99% P, 95% C F_{ty} (Ksi)	64.7	59.8	50.7

Table 3 : Ultimate and Yield Strength Summary, GTA Welded 2219-T87 Aluminum Alloy, No Post Weld Heat Treatment

PROPERTY	TEMPERATURE		
	-423°F	-320°F	RT
Mean F_{tu} (Ksi)	62.9	54.4	41.8
99% P, 95% C F_{tu} (Ksi)	50.6	45.6	34.1
Mean F_{ty} (Ksi)	30.2 [1]	28.6 [1]	24.6 [1]
99% P, 95% C F_{ty} (Ksi)	[2]	[2]	[2]

[1] "Apparent" Mean Values Reported, Not Enough Data Points To Firmly Establish Mean F_{ty}

[2] Not Enough Data Points Were Found for an Accurate Determination

Table 4 : Ultimate Strength Summary, GMA Welded 2219-T87 Aluminum Alloy, No Post Weld Heat Treatment

PROPERTY	TEMPERATURE		
	-423°F	-320°F	RT
Mean F_{tu} (Ksi)	62.7	56.0	42.9
99% P, 95% C F_{tu} (Ksi)	45.8	42.3	34.7

Table 5 : Mean Values of Fracture Toughness, K_{IE}, 2219-T87 Aluminum Alloy (From Surface Flawed Specimen Tests)

PROPAGATION DIRECTION	TEMPERATURE		
	-423°F	-320°F	RT
RT	52.3 Ksi$\sqrt{\text{In}}$ ▷1	48.6 Ksi$\sqrt{\text{In}}$	46.2 Ksi$\sqrt{\text{In}}$ ▷1
WT	47.0 Ksi$\sqrt{\text{In}}$ ▷1	47.0 Ksi$\sqrt{\text{In}}$	41.3 Ksi$\sqrt{\text{In}}$

▷1 "Apparent" Mean Values Reported, Not Enough Data Points To Firmly Establish Mean K_{IE}

Table 6 : Mean Values of Fracture Toughness, K_{IE}, GTA Welded 2219-T87 Aluminum Alloy (From Surface Flawed Specimen Tests)

TEMPERATURE		
-423°F	-320°F	RT
▷1 23.9 Ksi$\sqrt{\text{In}}$	▷1 28.1 Ksi$\sqrt{\text{In}}$	NA

▷1 "Apparent" Mean Values Reported, Not Enough Data Points To Firmly Establish Mean K_{IE}

Table 7 : Threshold Values for 2219-T87 Aluminum Alloy Base Metal

TEMP (^oF)	ENVIRONMENT	PROPAGATION DIRECTION	THICKNESS (INCH)	NO. OF POINTS	K_{TH} ($KSI\sqrt{IN}$)	K_{IE} ($KSI\sqrt{IN}$)	SOURCE OF K_{IE}	K_{TH}/K_{IE}	REF	COMMENTS
72	Air	WT	0.125	6	> 23.0	–	–	–	26	Not Enough Data For Analysis
			1.00	4	40.8	42.6	Avg. of 3 Points From Ref.	0.96	6	24 Hour Test
			0.60	3	< 39.0	43.9	Avg. of 28 Points From Ref.	< 0.89	22	20 Hour Test
			0.65	34	32.0 to 33.6	37.7	Avg. of 27 Points From Ref.	0.85 to 0.89	14	24 – 38 Hour Tests
			0.50	9	> 36.9	44.4	Avg. of 9 Points From Ref.	> 0.83	24	20.4 Hour Test
	3½% NaCl	WT	1.00	2	39.4	42.6	Avg. of 3 Points From Ref	0.92	6	24 Hour Test
			0.60	1	> 39.1	43.4	Endpoint	< 0.90	22	16 Hour Test
			0.40	3	34.1	41.3	Overall Mean	0.83	5	10 Hour Test
	GH_2	WT	0.60	2	> 38.7	44.5	Endpoint	> 0.87	22	10 Hour Test
	Distilled H_2O	WT	0.60	2	> 39.4	43.9	Avg. of 28 Points From Ref.	> 0.90	22	16 Hour Test
	Dye Penetrant	WT	0.60	2	> 37.2	44.7	Endpoint	> 0.83	22	15 Hour Test
	FLOX	WT	0.60	3	38.8	44.1	Endpoint	0.88	22	10 Hour Test
	OF_2	WT	0.60	2	39.0	43.0	Endpoint	0.91	22	11 Hour Test
	Argon	WT	0.60	1	39.1 ?	43.9	Avg. of 28 Points From Ref.	0.89 ?	22	Only 1 Data Point From A 1 Hour Sustained Test
	Trichloroethylene	WT	0.60	2	39.7	44.6	Endpoint	0.89	22	16.2 Hour Test
	GO_2	WT	0.60	2	39.1	44.3	Endpoint	0.88	22	12 Hour Test
	172 db Noise Level	WT	1.00	1	< 43.7	–	–	–	6	Not Enough Data for Analysis
		RT	1.00	1	< 51.0	–	–	–	6	Not Enough Data for Analysis
-230	172 db Noise Level, GN_2	RT	1.00	3	> 52.1	58.3	Avg. of 2 Points From Ref.	> 0.89	6	4.74 Hour Test , K_{IE} was Taken From Tests at -320^oF

Table 7 : Threshold Values for 2219-T87 Aluminum Alloy Base Metal (Continued)

TEMP. (^oF)	ENVIRONMENT	PROPAGATION DIRECTION	THICKNESS (INCH)	NO. OF POINTS	K_{TH} ($KSI\sqrt{IN}$)	K_{IE} ($KSI\sqrt{IN}$)	SOURCE OF K_{IE}	K_{TH}/K_{IE}	REF	COMMENTS
-320	LN_2	WT	1.00	3	42.9	47.2	Avg. of 2 Points From Ref.	0.91	6	24 Hour Test
			0.40	4	40.1	47.0	Overall Mean	0.85	5	10 Hour Test
			0.65	18	34.4 -36.5	42.0	Avg. of 5 Points From Ref.	0.82 -0.87	14	24.6 - 120.0 Hour Tests
		RT	1.00	5	51.0	58.3	Avg. of 2 Points From Ref.	0.87	6	21.75 Hour Test
			0.50	3	–	–		–	23	Not Enough Data for Analysis
	GH_2	WT	0.60	2	> 41.2	47.0	Overall Mean	> 0.87	22	20.1 Hour Test
	FLOX	WT	0.60	2	> 40.6	47.0	Overall Mean	> 0.86	22	10.1 Hour Test
	OF_2	WT	0.60	2	> 41.1	47.0	Overall Mean	> 0.87	22	10 Hour Test
	LO_2	WT	0.60	2	> 41.0	47.0	Overall Mean	> 0.87	22	10 Hour Test
-413	GH_2	WT	0.60	3	> 45.2	47.0	Overall Apparent Mean	> 0.96	22	10 Hour Test, K_{IE} was Taken From Tests at -423^oF
-423	LH_2	WT	0.60	3	> 44.2	47.0	Overall Apparent Mean	> 0.94	22	20 Hour Test
			0.65	7	> 40.1	45.0	Avg. of 3 Points From Ref	> 0.89	14	44 Hour Test
			0.40	5	35.6 - 38.4	47.0	Overall Apparent Mean	0.75 - 0.82	5	4.3 - 10.0 Hour Tests, Not Enough Data to Accurately Determine K_{TH}

Table 8 : Threshold Values for GTA Welded 2219-T87 Aluminum Alloy

TEMP. (°F)	ENVIRONMENT	THICKNESS (INCH)	NO OF POINTS	K_{TH} [1] ($KSI\sqrt{IN}$)	K_{IE} ($KSI\sqrt{IN}$)	SOURCE OF K_{IE}	K_{TH}/K_{IE}	REF	COMMENTS
72	Air	0.90	2	23.7	–	–	–	22	16 Hour Test
		0.95	6	–	–	–	–	24	Large Amounts of Reported Growth at High Stress Levels Preclude Threshold Determination
	3½% NaCl	0.90	2	< 23.8	–	–	–	22	23.9 Hour Test, Not Enough Data
	GH_2	0.90	2	24.0	–	–	–	22	14.9 Hour Test
	Distilled H_2O	0.90	2	23.8	–	–	–	22	15.8 Hour Test
	Dye Penetrant	0.90	2	23.8	–	–	–	22	16 Hour Test
	FLOX	0.90	2	23.6	–	–	–	22	10 Hour Test
	OF_2	0.90	3	23.8	–	–	–	22	10 Hour Test
	Trichloroethylene	0.90	2	23.9	–	–	–	22	12 Hour Test
	GO_2	0.90	2	23.8	–	–	–	22	13.5 Hour Test
-320	LN_2	1.00	4	>29.1	–	–	–	23	9.8 Hour Test
		0.90	1	27.3	–	–	–	22	6 Hour Test
		0.95	6	–	–	–	–	24	Large Amounts of Reported Growth at High Stress Levels Preclude Threshold Determination
	GH_2	0.90	2	27.1	–	–	–	22	10 Hour Test
	FLOX	0.90	2	23.3	–	–	–	22	11.3 Hour Test
	OF_2	0.90	2	23.3	–	–	–	22	10 Hour Test
	LO_2	0.90	2	27.0	–	–	–	22	10 Hour Test
-413	GH_2	0.90	5	26.9	–	–	–	22	10 Hour Test
-423	LH_2	0.90	2	27.3	–	–	–	22	11.1 Hour Test

[1] IRWIN K, NO M_K USED IN CALCULATION

Table 9: Room Temperature (70^oF-75^oF) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Longitudinal Grain Direction.

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t OR DIA	W	TEST DATA SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	RESULTS F_{tu} (KSI)	△ F_{ty} (KSI)	ELONGATION %	GAGE LENGTH	% AREA REDUCTION	μ	F (PSI × 10^6)	REFERENCE
1	0.032	SHEET	0.032	0.50	NA	NA	70.0	58.8	8	2.0	–	–	–	10
2	0.032	SHEET	0.032	0.50	NA	NA	70.3	59.1	8	2.0	–	–	–	10
3	0.032	SHEET	0.032	0.50	NA	NA	71.0	59.9	8	2.0	–	–	–	10
A1	0.06	SHEET	0.0615	0.50	NA	0.005	69.7	58.2	10	2.0	–	–	9.6	8
A2	0.06	SHEET	0.0610	0.50	NA	0.005	69.5	58.3	9	2.0	–	–	9.8	8
B1	0.06	SHEET	0.0614	0.50	NA	0.005	70.4	59.1	10	2.0	–	–	9.2	8
B2	0.06	SHEET	0.0610	0.50	NA	0.005	70.1	58.9	9	2.0	–	–	9.7	8
C1	0.06	SHEET	0.0614	0.50	NA	0.005	70.1	58.8	11	2.0	–	–	9.7	8
C2	0.06	SHEET	0.0610	0.50	NA	0.005	70.4	58.1	10	2.0	–	–	9.7	8
D1	0.06	SHEET	0.0620	0.50	NA	0.005	69.9	58.6	10	2.0	–	–	9.6	8
D2	0.06	SHEET	0.0615	0.50	NA	0.005	70.1	58.7	9	2.0	–	–	9.5	8
E1	0.06	SHEET	0.0600	0.50	NA	0.005	69.6	58.3	9	2.0	–	–	9.7	8
E2	0.06	SHEET	0.0585	0.50	NA	0.005	70.1	58.8	10	2.0	–	–	10.1	8
F1	0.06	SHEET	0.0605	0.50	NA	0.005	70.1	58.8	9	2.0	–	–	9.9	8
F2	0.06	SHEET	0.0602	0.50	NA	0.005	70.0	58.7	10	2.0	–	–	9.7	8
G1	0.06	SHEET	0.0610	0.50	NA	0.005	69.9	58.7	10	2.0	–	–	9.6	8
G2	0.06	SHEET	0.0606	0.50	NA	0.005	70.1	59.1	10	2.0	–	–	9.9	8
H1	0.06	SHEET	0.0615	0.50	NA	0.005	69.7	58.4	10	2.0	–	–	9.8	8
H2	0.06	SHEET	0.0616	0.50	NA	0.005	69.7	58.4	10	2.0	–	–	9.8	8
I1	0.06	SHEET	0.0620	0.50	NA	0.005	69.6	57.9	10	2.0	–	–	10.0	8
I2	0.06	SHEET	0.0620	0.50	NA	0.005	69.7	58.2	10	2.0	–	–	9.8	8

△ 0.2% OFFSET

Table 9: Room Temperature (70°F–75°F) Tensile properties of 2219-T87 Aluminum Alloy Base Metal, Longitudinal Grain Direction (Continued)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			T OF DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	F_{ty} ① (KSI)	ELONGATION		% AREA REDUCTION	ν	E ($PSI \times 10^6$)	
										GAGE LENGTH				
J1	0.06	SHEET	0.0620	0.50	NA	0.005	69.7	57.6	10	2.0	–	–	9.9	8
J2	0.06	SHEET	0.0620	0.50	NA	0.005	69.8	58.3	10	2.0	–	–	9.9	8
K1	0.06	SHEET	0.0620	0.50	NA	0.005	68.8	57.1	–	2.0	–	0.295	9.6	8
K2	0.06	SHEET	0.0615	0.50	NA	0.005	69.7	58.4	10	2.0	–	–	9.7	8
L1	0.06	SHEET	0.0620	0.50	NA	0.005	68.5	56.7	–	2.0	–	0.292	9.8	8
L2	0.06	SHEET	0.0615	0.50	NA	0.005	69.5	58.3	9	2.0	–	–	9.8	8
M1	0.06	SHEET	0.0630	0.50	NA	0.005	68.6	56.3	–	2.0	–	0.266	9.8	8
M2	0.06	SHEET	0.0620	0.50	NA	0.005	69.6	58.2	9	2.0	–	–	9.8	8
N1	0.06	SHEET	0.0625	0.50	NA	0.006	68.9	56.8	–	2.0	–	0.319	9.8	8
N2	0.06	SHEET	0.0620	0.50	NA	0.006	69.6	58.2	10	2.0	–	–	9.6	8
O1	0.06	SHEET	0.0630	0.50	NA	0.005	69.3	57.1	–	2.0	–	0.284	10.1	8
O2	0.06	SHEET	0.0615	0.50	NA	0.005	71.2	59.2	10	2.0	–	–	9.9	8
P1	0.06	SHEET	0.0645	0.50	NA	0.006	69.0	57.2	–	2.0	–	0.296	9.7	8
P2	0.06	SHEET	0.0634	0.50	NA	0.005	70.6	59.2	10	2.0	–	–	9.8	8
TAL-1	0.125	SHEET	0.0620	0.50	NA	0.005	67.3	55.7	8	2.0	35	–	–	16
TAL-2	0.125	SHEET	0.0623	0.50	NA	0.006	66.5	54.9	8	2.0	34	0.372	10.8	16
TAL-5	0.125	SHEET	0.1247	0.50	NA	0.006	67.7	55.8	10	2.0	33	–	–	16
TAL-6	0.125	SHEET	0.1256	0.50	NA	0.005	67.1	55.2	11	2.0	35	0.329	11.1	16
7	0.125	SHEET	0.125	0.5	NA	NA	68.9	58.0	11	2.0	–	–	–	10
8	0.125	SHEET	0.125	0.5	NA	NA	68.5	57.2	10	2.0	–	–	–	10
9	0.125	SHEET	0.125	0.5	NA	NA	68.7	57.5	10	2.0	–	–	–	10

① 0.2% OFFSET

Table 9: Room Temperature (70°F–75°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Longitudinal Grain Direction (Continued)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	μ	E (PSI × 10^{-6})	
TCU-19-C	0.125	SHEET	0.125	0.50	NA	NA	67.61	53.83	9.5	2.0	–	–	–	12
TCU-19-D	0.125	SHEET	0.125	0.50	NA	NA	67.71	54.45	9.5	2.0	–	–	–	12
ALR-1	0.125	SHEET	0.1242	0.50	NA	0.005	68.2	55.9	10	2.0	35	0.30	10.5	3
AILR-1	0.125	SHEET	0.1240	0.50	NA	0.005	67.9	55.8	11	2.0	36	–	10.4	3
TAL-9	0.50	PL	0.3015	0.50	NA	0.005	69.4	58.4	12	2.0	28	–	–	16
TAL-10	0.50	PL	0.3018	0.50	NA	0.005	69.2	57.6	12	2.0	30	0.309	10.0	16
NA	0.50	PL	0.16	–	0.15	NA	70.0	57.3	16.4	1.0	29.9	–	–	11
NA	0.50	PL	0.16	–	0.15	NA	69.0	56.5	15.1	1.0	29.9	–	–	11
NA	0.50	PL	0.50	0.50	NA	0.005	67.2	53.6	13.5	2.0	–	–	9.9	17
NA	0.50	PL	0.50	0.50	NA	0.005	66.6	53.5	13.5	2.0	–	–	9.5	17
NA	0.50	PL	0.50	0.50	NA	0.005	67.1	54.1	13.0	2.0	–	–	9.3	17
NA	0.50	PL	0.50	0.50	NA	0.005	66.6	53.9	13.0	2.0	–	–	9.4	17
NA	0.50	PL	0.50	0.50	NA	0.005	66.4	54.1	12.0	2.0	–	–	9.7	17
ALR-1	0.625	PL	0.6240	0.50	NA	0.005	69.5	56.0	14	2.0	31	0.30	11.3	3
ALR-2	0.625	PL	0.6255	0.50	NA	0.005	69.2	56.1	14	2.0	29	–	9.7	3
TCU-19-A	0.75	PL	0.200	0.625	NA	NA	70.37	56.91	13.5	2.0	–	–	–	12
TCU-19-B	0.75	PL	0.200	0.625	NA	NA	69.79	56.44	11.5	2.0	–	–	–	12
TA-1	1.0	PL	0.75	0.50	NA	0.005	68.1	55.3	12.5	2.0	24.8	0.332	10.6	2
TA-2	1.0	PL	0.75	0.50	NA	0.005	68.3	55.4	13.0	2.0	27.8	0.313	10.0	2
TA-7	1.0	PL	0.15	0.50	NA	0.005	67.1	54.4	11.0	2.0	30.9	0.340	10.7	2
TA-8	1.0	PL	0.15	0.50	NA	0.005	67.1	54.6	10.5	2.0	30.3	0.344	11.0	2

[1] 0.2% OFFSET

Table 9: Room Temperature (70°F - 75°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Longitudinal Grain Direction (Continued)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMENS DIMENSION (INCH)		TEST DATA				RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	ENVIRON-MENT	TEMPERA-TURE (°F)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	[1] F_{ty} (KSI)	%	GAGE LENGTH	% AREA REDUCTION	μ	E (PSI x 10^{6})	
ITL-1	1.0	PL	0.249	–	NA	AIR	RT	NA	67.8	55.6	10	1.0	24	–	–	6
L2-1	1.0	PL	0.25	–	NA	AIR	RT	0.005	68.8	56.6	10	1.0	25	–	–	15
L2-2	1.0	PL	0.27	–	NA	AIR	RT	0.005	69.1	57.1	10	1.0	30	–	–	15
NA	1.0	PL	NA	NA	NA	AIR	RT	NA	72.0	57.9	–	–	–	–	–	9
NA	1.0	PL	0.505	–	NA	AIR	75	0.005	65.6	53.5	15.0	2.0	–	–	9.2	17
NA	1.0	PL	0.505	–	NA	AIR	75	0.005	65.6	54.0	13.5	2.0	–	–	9.5	17
NA	1.0	PL	0.505	–	NA	AIR	75	0.005	65.2	53.3	14.0	2.0	–	–	9.6	17
NA	1.0	PL	0.505	–	NA	AIR	75	0.005	65.5	53.9	15.0	2.0	–	–	9.7	17
NA	1.0	PL	0.505	–	NA	AIR	75	0.005	66.1	54.2	14.0	2.0	–	–	10.0	17
NA	1.5	PL	0.505	–	NA	AIR	75	0.005	66.8	54.2	10.0	2.0	–	–	9.5	17
NA	1.5	PL	0.505	–	NA	AIR	75	0.005	67.4	54.4	10.0	2.0	–	–	9.9	17
NA	1.5	PL	0.505	–	NA	AIR	75	0.005	66.0	53.7	10.0	2.0	–	–	9.6	17
NA	1.5	PL	0.505	–	NA	AIR	75	0.005	65.8	53.7	10.0	2.0	–	–	10.0	17
NA	1.5	PL	0.505	–	NA	AIR	75	0.005	65.0	52.4	10.0	2.0	–	–	10.1	17
AL25-1	2.5	PL	0.50	0.50	NA	AIR	RT	0.005	69.1	46.8	12	2.0	23	–	–	15
AL25-2	2.5	PL	0.50	0.50	NA	AIR	RT	0.005	69.5	56.9	12	2.0	23	–	–	15
NA	2.5	PL	0.125	–	NA	AIR	RT	NA	68.0	56.0	10.0	NA	–	–	–	7
NA	4.0	PL	0.125	–	NA	AIR	RT	NA	71.1	60.6	9.0	NA	–	–	–	7

[1] 0.2% OFFSET

Table 10: Room Temperature (70°F–75°F) Tensile Properties of 2219–T87 Aluminum Alloy Base Metal, Long Transverse Grain Direction

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS								REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN-MIN)	F_{tu} (KSI)	F_{ty} ▷ (KSI)	ELONGATION %	GAGE LENGTH	% AREA REDUCTION	e	E ($PSI \times 10^6$)		
4	0.032	SHEET	0.032	0.50	NA	NA	71.5	61.2	8	2.0	–	–	–		10
5	0.032	SHEET	0.032	0.50	NA	NA	71.0	56.7	8	2.0	–	–	–		10
6	0.032	SHEET	0.032	0.50	NA	NA	72.3	59.5	8	2.0	–	–	–		10
A1	0.06	SHEET	0.0602	0.50	NA	0.005	71.1	60.0	8	2.0	–	–	10.0		8
A2	0.06	SHEET	0.0604	0.50	NA	0.005	70.6	58.8	10	2.0	–	–	9.8		8
B1	0.06	SHEET	0.0610	0.50	NA	0.005	70.1	58.2	8	2.0	–	–	10.4		8
B2	0.06	SHEET	0.0605	0.50	NA	0.005	70.7	58.8	9	2.0	–	–	9.6		8
C1	0.06	SHEET	0.0610	0.50	NA	0.006	70.3	58.2	9	2.0	–	–	9.6		8
C2	0.06	SHEET	0.0610	0.50	NA	0.005	70.2	58.2	10	2.0	–	–	9.9		8
D1	0.06	SHEET	0.0612	0.50	NA	0.006	70.5	58.1	8	2.0	–	–	9.9		8
D2	0.06	SHEET	0.0615	0.50	NA	0.005	70.3	58.0	10	2.0	–	–	9.7		8
E1	0.06	SHEET	0.0595	0.50	NA	0.006	70.3	58.5	9	2.0	–	–	9.8		8
E2	0.06	SHEET	0.0595	0.50	NA	0.006	70.3	58.7	10	2.0	–	–	9.9		8
F1	0.06	SHEET	0.0600	0.50	NA	0.005	70.1	58.4	9	2.0	–	–	9.7		8
F2	0.06	SHEET	0.0600	0.50	NA	0.006	70.2	58.4	10	2.0	–	–	9.7		8
G1	0.06	SHEET	0.0606	0.50	NA	0.005	70.3	58.2	11	2.0	–	–	5.3		8
G2	0.06	SHEET	0.0606	0.50	NA	0.006	70.3	58.2	10	2.0	–	–	10.0		8
H1	0.06	SHEET	0.0615	0.50	NA	3.006	70.1	57.6	10	2.0	–	–	9.4		8
H2	0.06	SHEET	0.0610	0.50	NA	0.006	70.4	58.1	11	2.0	–	–	9.7		8
I1	0.06	SHEET	0.0620	0.50	NA	0.005	69.6	57.2	10	2.0	–	–	9.9		8
I2	0.06	SHEET	0.0620	0.50	NA	0.0?5	69.6	57.1	11	2.0	–	–	9.6		8

▷ 0.2% OFFSET

Table 10: Room Temperature (70°F–75°F) Tensile Properties of 2219–T87 Aluminum Alloy Base Metal, Long Transverse Grain Direction (Continued)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	F_{ty} ▲ (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	μ	E (PSI × 10^{-6})	
J1	0.06	SHEET	0.0620	0.50	NA	0.005	69.8	57.2	10	2.0	–	–	9.6	8
J2	0.06	SHEET	0.0618	0.50	NA	0.005	69.9	57.1	11	2.0	–	–	9.8	8
K1	0.06	SHEET	0.0620	0.50	NA	0.005	69.1	56.4	–	2.0	–	0.299	9.9	8
K2	0.06	SHEET	0.0615	0.50	NA	0.005	69.7	57.2	11	2.0	–	–	10.2	8
L1	0.06	SHEET	0.0625	0.50	NA	0.005	68.6	55.8	–	2.0	–	0.329	10.3	8
L2	0.06	SHEET	0.0615	0.50	NA	0.005	70.0	57.6	12	2.0	–	–	9.8	8
M1	0.06	SHEET	0.0620	0.50	NA	0.005	69.2	56.7	–	2.0	–	0.321	10.0	8
M2	0.06	SHEET	0.0615	0.50	NA	0.005	70.1	–	10	2.0	–	–	–	8
N1	0.06	SHEET	0.0620	0.50	NA	0.005	69.3	56.3	–	2.0	–	0.305	9.9	8
N2	0.06	SHEET	0.0615	0.50	NA	0.005	70.0	57.4	11	2.0	–	–	9.5	8
O1	0.06	SHEET	0.0630	0.50	NA	0.005	69.8	56.3	–	2.0	–	0.289	10.0	8
O2	0.06	SHEET	0.0620	0.50	NA	0.005	70.6	57.6	11	2.0	–	–	9.7	8
P1	0.06	SHEET	0.0640	0.50	NA	0.005	69.7	56.9	–	2.0	–	–	9.7	8
P2	0.06	SHEET	0.0632	0.50	NA	0.005	70.3	57.7	10	2.0	–	–	10.0	8
10	0.125	SHEET	0.125	0.50	NA	NA	70.4	58.3	9	2.0	–	–	–	10
11	0.125	SHEET	0.125	0.50	NA	NA	70.3	58.1	10	2.0	–	–	–	10
12	0.125	SHEET	0.125	0.50	NA	NA	70.2	58.1	10	2.0	–	–	–	10
TAT-1	0.125	SHEET	0.0625	0.50	NA	0.005	67.9	54.2	8	2.0	–	–	–	16
TAT-2	0.125	SHEET	0.0628	0.50	NA	0.005	66.5	53.4	8	2.0	–	0.328	11.0	16
TAT-5	0.125	SHEET	0.1252	0.50	NA	0.005	68.5	56.6	10	2.0	–	–	–	16
TAT-6	0.125	SHEET	0.1258	0.50	NA	0.005	68.1	56.5	9	2.0	–	0.338	11.8	16

▲ 0.2% OFFSET

Table 10: Room Temperature (70° F–75° F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Long Transverse Grain Direction (Continued)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	μ	E (PSI × 10^{6})	
AITR-1	0.125	SHEET	0.1246	0.50	NA	0.005	68.9	56.2	10	2.0	27	–	10.6	3
AITR-2	0.125	SHEET	0.1244	0.50	NA	0.005	68.5	56.2	10	2.0	25	–	10.1	3
TAT-9	0.50	PL	0.3008	0.50	NA	0.005	70.3	58.3	9	2.0	19	–	–	16
TAT-10	0.50	PL	0.3003	0.50	NA	0.005	70.3	57.9	9	2.0	17	0.312	10.7	16
NA	0.50	PL	0.16	–	0.15	NA	66.7	56.1	12.9	1.0	23.5	–	–	11
NA	0.50	PL	0.16	–	0.15	NA	67.4	54.4	13.9	1.0	20.1	–	–	11
NA	0.50	PL	0.50	0.50	NA	0.005	67.4	56.5	10.0	2.0	–	–	9.9	17
NA	0.50	PL	0.50	0.50	NA	0.005	68.0	54.7	10.0	2.0	–	–	9.4	17
NA	0.50	PL	0.50	0.50	NA	0.005	66.8	53.8	12.0	2.0	–	–	10.0	17
NA	0.50	PL	0.50	0.50	NA	0.005	67.3	54.4	10.0	2.0	–	–	10.0	17
NA	0.50	PL	0.50	0.50	NA	0.005	66.7	53.6	11.0	2.0	–	–	9.6	17
ATR-1	0.625	PL	0.6266	0.50	NA	0.005	68.3	56.0	14	2.0	31	–	9.8	3
ATR-2	0.625	PL	0.6240	0.50	NA	0.005	68.3	56.1	14	2.0	29	–	11.4	3
ITT-1	1.0	PL	0.249	–	NA	NA	67.8	54.7	9	1.0	21	–	–	6
NA	1.0	PL	NA	NA	NA	NA	72.0	56.2	–	–	–	–	–	9
TI-1	1.0	PL	0.25	–	NA	0.005	68.0	56.7	7	1.0	14	–	–	15
TI-2	1.0	PL	0.25	–	NA	0.005	68.6	56.0	7	1.0	13	–	–	15
AT-1	1.0	PL	0.50	0.50	NA	0.005	68.9	56.2	8	2.0	–	–	–	15
AT-2	1.0	PL	0.50	0.50	NA	0.005	68.8	56.7	8	2.0	–	–	–	15
AT-3	1.0	PL	0.50	0.50	NA	0.005	68.9	55.5	7	2.0	–	–	–	15
TA-20	1.0	PL	0.15	0.50	NA	0.005	68.0	56.2	8.0	2.0	11.7	0.338	10.8	2

[1] 0.2% OFFSET

Table 10: *Room Temperature (70° F–75° F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Long Transverse Grain Direction (Continued)*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t OR DIA	W	TEST DATA SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	RESULTS F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	GAGE LENGTH	% AREA REDUCTION	u	E (PSI × 10^6)	REFERENCE
TA-13	1.0	PL	0.75	0.50	NA	0.005	68.4	54.3	8.0	2.0	10.4	0.336	10.5	2
TA-14	1.0	PL	0.75	0.50	NA	0.005	68.7	54.8	7.5	2.0	11.9	0.327	10.3	2
TA-19	1.0	PL	0.15	0.50	NA	0.005	67.4	53.8	7.5	2.0	15.4	0.366	11.4	2
NA	1.0	PL	0.505	–	NA	0.005	67.3	53.0	13.0	2.0	–	–	9.5	17
NA	1.0	PL	0.505	–	NA	0.005	68.3	54.6	15.0	2.0	–	–	9.8	17
NA	1.0	PL	0.505	–	NA	0.005	66.9	53.1	15.0	2.0	–	–	9.4	17
NA	1.0	PL	0.505	–	NA	0.005	67.2	53.6	12.0	2.0	–	–	9.8	17
NA	1.0	PL	0.505	–	NA	0.005	65.7	53.4	12.0	2.0	–	–	9.7	17
AL-1	1.0	PL	0.3782	0.50	NA	0.005	68.6	56.5	10	2.0	16	–	–	5
AL-6	1.0	PL	0.3770	0.50	NA	0.005	68.7	56.5	10	2.0	13	–	–	5
TA-1	1.25	PL	0.500	–	NA	0.005	68.4	56.2	10.5	2.0	–	–	–	13
TA-2	1.25	PL	0.498	–	NA	0.005	68.6	56.8	10.0	2.0	–	–	–	13
A-1	1.25	PL	0.500	–	NA	0.005	70.1	57.9	10.5	2.0	16.0	–	–	14
NA	1.5	PL	0.505	–	NA	0.005	65.8	51.2	10.0	2.0	–	–	–	17
NA	1.5	PL	0.505	–	NA	0.005	64.4	52.3	10.0	2.0	–	–	10.1	17
NA	1.5	PL	0.505	–	NA	0.005	65.5	52.3	10.0	2.0	–	–	10.3	17
NA	1.5	PL	0.505	–	NA	0.005	66.3	52.6	10.0	2.0	–	–	10.1	17
NA	1.5	PL	0.505	–	NA	0.005	64.8	52.6	10.0	2.0	–	–	10.1	17
AT25-1	2.5	PL	0.50	0.50	NA	0.005	68.6	56.3	10	2.0	15	–	–	15
AT25-2	2.5	PL	0.50	0.50	NA	0.005	68.7	56.3	10	2.0	16	–	–	15
NA	2.5	PL	0.125	–	NA	NA	67.6	56.3	8.0	NA	–	–	–	7
NA	4.0	PL	0.125	–	NA	NA	70.3	58.1	8.5	NA	–	–	–	7

[1] 0.2% OFFSET

Table 11: Room Temperature ($70^{0}F-75^{0}F$) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Short Transverse Grain Direction

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	u	E (PSI x 10^{6})	
NA	2.5	PL	0.125	–	NA	NA	64.8	55.5	5.0	NA	–	–	–	7
NA	4.0	PL	0.125	–	NA	NA	62.4	57.0	3.0	NA	–	–	–	7

[1] 0.2% OFFSET

Table 12: Dry Ice and Acetone ($-110^{0}F$) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	u	E (PSI x 10^{6})	
NA	0.50	PL	0.16	–	0.15	NA	73.5	[illegible]	15.6	1.0	27.9	–	–	11 [2]
NA	0.50	PL	0.16	–	0.15	NA	73.8	59.5	14.7	1.0	28.9	–	–	11 [2]
NA	0.50	PL	0.16	–	0.15	NA	72.3	58.0	12.9	1.0	24.5	–	–	11 [3]
NA	0.50	PL	0.16	–	0.15	NA	72.1	58.5	13.8	1.0	19.1	–	–	11 [3]

[1] 0.2% OFFSET

[2] LONGITUDINAL GRAIN DIRECTION

[3] LONG TRANSVERSE GRAIN DIRECTION

Table 13: Liquid Nitrogen (−320°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Longitudinal Grain Direction

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH): t OR DIA	SPECIMEN DIMENSIONS (INCH): W	TEST DATA: SOAK TIME (HOURS)	TEST DATA: LOADING RATE (IN/IN-MIN)	RESULTS: F_{tu} (KSI)	RESULTS: [1] F_{ty} (KSI)	RESULTS: ELONGATION %	RESULTS: ELONGATION GAGE LENGTH	RESULTS: % AREA REDUCTION	RESULTS: μ	RESULTS: E (PSI × 10^{6})	REFERENCE
ALN-1	0.125	SHEET	0.1242	0.50	NA	0.005	78.0	61.1	12	2.0	29	0.29	11.4	3
AILN-1	0.125	SHEET	0.1235	0.50	NA	0.005	84.6	67.0	11	2.0	27	–	10.7	3
NA	0.50	PL	0.16	–	0.15	NA	83.8	67.5	15.6	1.0	28.9	–	–	11
NA	0.50	PL	0.16	–	0.15	NA	83.8	66.3	16.4	1.0	28.9	–	–	11
NA	0.50	PL	0.50	0.50	NA	0.005	84.1	67.5	15.5	2.0	–	–	10.6	17
NA	0.50	PL	0.50	0.50	NA	0.005	84.0	64.9	15.5	2.0	–	–	–	17
NA	0.50	PL	0.50	0.50	NA	0.005	84.5	66.5	14.0	2.0	–	–	11.8	17
NA	0.50	PL	0.50	0.50	NA	0.005	84.1	64.2	16.0	2.0	–	–	10.3	17
NA	0.50	PL	0.50	0.50	NA	0.005	83.8	63.7	17.0	2.0	–	–	10.4	17
ALN-1	0.625	PL	0.6288	0.50	NA	0.005	86.2	67.2	16	2.0	29	0.31	12.0	3
ALN-2	0.625	PL	0.6246	0.50	NA	0.005	86.9	67.0	16	2.0	29	–	13.8	3
ITL-2	1.0	PL	0.249	–	NA	NA	84.7	68.0	11	1.0	30	–	–	6
TA-3	1.0	PL	0.75	0.50	NA	0.005	83.3	63.7	14.0	2.0	26.3	0.209	10.9	2
TA-4	1.0	PL	0.75	0.50	NA	0.005	84.5	65.6	15.0	2.0	25.4	0.333	11.5	2
TA-9	1.0	PL	0.15	0.50	NA	0.005	82.7	65.3	12.5	2.0	26.5	0.322	11.7	2
TA-10	1.0	PL	0.15	0.50	NA	0.005	82.6	66.9	11.5	2.0	27.1	0.338	12.0	2
NA	1.0	PL	0.505	–	NA	0.005	81.3	62.9	17.0	2.0	–	–	12.0	17
NA	1.0	PL	0.505	–	NA	0.005	81.1	63.2	17.0	2.0	–	–	9.5	17
NA	1.0	PL	0.505	–	NA	0.005	81.1	63.5	17.0	2.0	–	–	12.7	17
NA	1.0	PL	0.505	–	NA	0.005	85.0	68.1	17.0	2.0	–	–	10.7	17
NA	1.0	PL	0.505	–	NA	0.005	81.7	65.6	18.0	2.0	–	–	10.4	17

[1] 0.2% OFFSET

Table 13: *Liquid Nitrogen (−320°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Longitudinal Grain Direction (Continued)*

SPECIMEN I. D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	F_{ty} (KSI) ▷	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	u	E (PSI x 10^6)	
L2-3	1.0	PL	0.25	–	NA	0.006	86.4	68.3	12	1.0	24	–	–	15
L2-4	1.0	PL	0.25	–	NA	0.006	86.4	68.0	11	1.0	21	–	–	15
AL25-3	2.4	PL	0.50	0.50	NA	0.006	86.8	70.0	12	2.0	19	–	–	15
AL25-4	2.5	PL	0.50	0.50	NA	0.006	88.9	70.5	13	2.0	19	–	–	15
NA	1.5	PL	0.505	–	NA	0.006	84.6	65.5	15.5	2.0	–	–	11.2	17
NA	1.5	PL	0.505	–	NA	0.006	84.3	66.0	14.0	2.0	–	–	11.3	17
NA	1.5	PL	0.505	–	NA	0.006	83.1	65.7	14.0	2.0	–	–	10.6	17
NA	1.5	PL	0.505	–	NA	0.005	84.6	64.0	13.0	2.0	–	–	10.6	17
NA	1.5	PL	0.505	–	NA	0.006	83.5	64.5	13.0	2.0	–	–	10.7	17

▷ 0.2% OFFSET

Table 14: Liquid Nitrogen (−320°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Long Transverse Grain Direction

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN-MIN)	F_{tu} (KSI)	▷ F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	u	E (PSI × 10^{-6})	
NA	0.08	SHEET	0.080	0.50	NA	0.005	86.4	71.4	10	2.0	–	0.321	11.6	8
NA	0.08	SHEET	0.0805	0.50	NA	0.005	98.4	71.3	9	2.0	–	0.317	11.2	8
AITN-1	0.125	SHEET	0.1246	0.50	NA	0.005	87.2	67.0	13	2.0	22	–	12.1	3
AITN-2	0.125	SHEET	0.1244	0.50	NA	0.005	87.0	66.9	12	2.0	24	–	11.6	3
NA	0.50	PL	0.16	–	0.15	NA	81.9	64.5	14.7	1.0	22.5	–	–	11
NA	0.50	PL	0.50	0.50	NA	0.005	85.1	67.2	11.5	2.0	–	–	11.2	17
NA	0.50	PL	0.50	0.50	NA	0.005	86.4	64.0	11.5	2.0	–	–	11.7	17
NA	0.50	PL	0.50	0.50	NA	0.005	83.7	64.3	9.9	2.0	–	–	11.1	17
NA	0.50	PL	0.50	0.50	NA	0.005	84.0	65.6	11.0	2.0	–	–	8.1	17
NA	0.50	PL	0.50	0.50	NA	0.005	84.7	67.4	12.0	2.0	–	–	12.4	17
ATN-1	0.625	PL	0.6250	0.50	NA	0.005	86.8	66.1	12	2.0	18	–	12.2	3
ATN-2	0.625	PL	0.6248	0.50	NA	0.005	86.7	65.2	12	2.0	18	–	11.0	3
T2-1	1.0	PL	0.25	–	NA	0.005	87.1	68.3	9	1.0	16	–	–	15
T2-2	1.0	PL	0.25	–	NA	0.005	87.0	68.0	8	1.0	16	–	–	15
AT-4	1.0	PL	0.50	0.50	NA	0.005	86.0	66.3	12	2.0	–	–	–	16
AT-5	1.0	PL	0.52	0.50	NA	0.005	86.3	65.1	11	2.0	–	–	–	16
AT-6	1.0	PL	0.50	0.50	NA	0.005	86.1	66.1	12	2.0	–	–	–	16
TA-15	1.0	PL	0.75	0.50	NA	0.005	84.8	66.0	11.0	2.0	13.3	0.328	11.8	2
TA-16	1.0	PL	0.75	0.50	NA	0.005	86.1	67.3	10.5	2.0	12.8	0.327	11.2	2
TA-21	1.0	PL	0.15	0.50	NA	0.005	84.0	65.1	10.0	2.0	18.4	0.340	12.8	2
TA-22	1.0	PL	0.15	0.50	NA	0.005	83.3	64.5	11.0	2.0	19.3	0.338	11.7	2

▷ 0.2% OFFSET

Table 14: Liquid Nitrogen (-320°F) Tensile Properties of 2219–T87 Aluminum Alloy Base Metal, Long Transverse Grain Direction (Continued)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t OR DIA	SPECIMEN DIMENSIONS (INCH) W	TEST DATA SOAK TIME (HOURS)	TEST DATA LOADING RATE (IN/IN/MIN)	RESULTS F_{tu} (KSI)	RESULTS F_{ty} (KSI) [1]	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	u	E (PSI x 10^{-6})	REFERENCE
AL-3	1.0	PL	0.3746	0.50	0.25	0.005	84.6	65.9	9	2.0	14	–	–	5
AL-4	1.0	PL	0.3756	0.50	0.25	0.005	85.6	65.5	12	2.0	15	–	–	5
ITT-2	1.0	PL	0.249	–	NA	NA	85.4	66.0	11	1.0	23	–	–	6
NA	1.0	PL	0.505	–	NA	0.005	83.1	64.5	15.0	2.0	–	–	11.3	17
NA	1.0	PL	0.505	–	NA	0.005	83.2	64.3	15.0	2.0	–	–	10.7	17
NA	1.0	PL	0.505	–	NA	0.005	82.6	64.4	15.0	2.0	–	–	11.3	17
NA	1.0	PL	0.505	–	NA	0.005	82.3	64.2	15.0	2.0	–	–	–	17
NA	1.0	PL	0.505	–	NA	0.005	82.2	61.8	15.0	2.0	–	–	–	17
A-2	1.25	PL	0.500	–	NA	0.005	79.4	66.1	9.5	2.0	18.0	–	–	14
TA-3	1.25	PL	0.500	–	NA	0.005	85.9	67.7	10.5	2.0	–	–	–	13
TA-4	1.25	PL	0.499	–	NA	0.005	85.7	67.8	10.0	2.0	–	–	–	13
AT25-3	2.5	PL	0.50	0.50	NA	0.005	88.4	68.5	13	2.0	17	–	–	15
AT25-4	2.5	PL	0.50	0.50	NA	0.005	84.5	66.9	9	2.0	9	–	–	15
NA	1.5	PL	0.505	–	NA	0.005	82.4	63.8	12.5	2.0	–	–	11.7	17
NA	1.5	PL	0.505	–	NA	0.005	82.7	63.0	12.5	2.0	–	–	11.1	17
NA	1.5	PL	0.505	–	NA	0.005	82.4	63.8	12.0	2.0	–	–	11.0	17
NA	1.5	PL	0.505	–	NA	0.005	82.9	63.8	12.5	2.0	–	–	10.6	17
NA	1.5	PL	0.505	–	NA	0.005	82.9	62.8	12.5	2.0	–	–	10.5	17

[1] 0.2% OFFSET

Table 15: *Liquid Hydrogen (−423°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Longitudinal Grain Direction*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS								REFERENCE	
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN·MIN)	F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	μ	E (PSI × 10^6)			
25	0.032	SHEET	0.032	0.50	NA	NA	102.3	76.0	16	2.0	–	–	–		10	
26	0.032	SHEET	0.032	0.50	NA	NA	101.5	73.4	16	2.0	–	–	–		10	
29	0.032	SHEET	0.032	0.50	NA	NA	101.8	75.9	16	2.0	–	–	–		10	
31	0.125	SHEET	0.125	0.50	NA	NA	98.7	73.2	18	2.0	–	–	–		10	
32	0.125	SHEET	0.125	0.50	NA	NA	98.6	73.9	18	2.0	–	–	–		10	
33	0.125	SHEET	0.125	0.50	NA	NA	98.7	74.8	17	2.0	–	–	–		10	
ALH-1	0.125	SHEET	0.1246	0.50	NA	0.005	96.4	71.3	–	–	28	0.36	10.9		3	[2]
ALH-2	0.125	SHEET	0.1240	0.50	NA	0.005	93.9	69.5	–	–	27	–	12.1		3	[2]
TAL-3	0.125	SHEET	0.0627	0.50	0.25	0.005	96.4	69.0	15	2.0	23	–	11.7		16	
TAL-7	0.125	SHEET	0.1248	0.50	0.25	0.005	97.1	69.8	16	2.0	24	–	12.0		16	
TAL-11	0.50	PL	0.3019	0.50	0.25	0.005	100.1	71.3	17	2.0	24	–	10.6		16	
NA	0.50	PL	0.16	–	0.15	NA	102.0	77.6	20.4	1.0	25.5	–	–		11	[3]
NA	0.50	PL	0.16	–	0.15	NA	96.1	72.8	17.3	1.0	27.9	–	–		11	[3]
NA	0.50	PL	0.50	0.50	NA	0.005	100.9	72.9	13.0	2.0	–	–	–		17	
NA	0.50	PL	0.50	0.50	NA	0.005	100.4	72.1	12.0	2.0	–	–	10.5		17	
NA	0.50	PL	0.50	0.50	NA	0.005	99.0	71.9	–	–	–	–	11.4		17	
NA	0.50	PL	0.50	0.50	NA	0.005	99.5	72.1	–	–	–	–	–		17	
NA	0.50	PL	0.50	0.50	NA	0.005	–	70.1	13.0	2.0	–	–	–		17	
ALH-1	0.625	PL	0.6258	0.50	NA	0.005	92.1	70.3	–	–	21	0.36	10.8		3	[2]
ALH-2	0.625	PL	0.6256	0.50	NA	0.005	93.8	72.7	–	–	22	–	9.9		3	[2]

[1] 0.2% OFFSET [2] Fty OBTAINED BY STRAIN GAGE [3] TESTED IN HELIUM GAS AT −423°F

Table 15: Liquid Hydrogen (−423°F) Tensile Properties of 2219–T87 Aluminum Alloy Base Metal, Longitudinal Grain Direction (Continued)

SPECIMEN I. D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	u	E (PSI x 10^{-6})	
TA-5	1.0	PL	0.75	0.50	NA	0.005	98.9	68.1	16.5	2.0	20.0	0.349	13.9	2
TA-6	1.0	PL	0.75	0.50	NA	0.005	99.0	69.0	16.5	2.0	18.5	0.387	14.6	2
TA-11	1.0	PL	0.15	0.50	NA	0.005	98.4	68.9	15.0	2.0	13.0	0.349	13.4	2
TA-12	1.0	PL	0.15	0.50	NA	0.005	99.6	–	15.5	2.0	14.6	0.388	–	2
NA	1.0	PL	0.505	–	NA	0.005	97.3	71.0	–	–	–	–	12.2	17
NA	1.0	PL	0.505	–	NA	0.005	97.8	71.0	17.0	2.0	–	–	11.7	17
NA	1.0	PL	0.505	–	NA	0.006	97.6	71.3	19.0	2.0	–	–	11.9	17
NA	1.0	PL	0.505	–	NA	0.005	97.8	72.4	–	–	–	–	11.7	17
NA	1.0	PL	0.505	–	NA	0.005	98.5	72.4	19.0	2.0	–	–	11.8	17
AL25-5	2.5	PL	0.50	0.50	NA	0.005	104.9	74.4	11	2.0	–	–	–	15
AL25-6	2.5	PL	0.50	0.50	NA	0.005	105.3	74.0	11	2.0	–	–	–	15
NA	1.5	PL	0.505	–	NA	0.005	101.5	71.9	15.0	2.0	–	–	11.8	17
NA	1.5	PL	0.505	–	NA	0.005	101.6	73.0	16.0	2.0	–	–	11.1	17
NA	1.5	PL	0.505	–	NA	0.005	102.4	73.1	15.5	2.0	–	–	–	17
NA	1.5	PL	0.505	–	NA	0.005	102.1	72.4	16.0	2.0	–	–	–	17
NA	1.5	PL	0.505	–	NA	0.005	102.4	73.5	16.0	2.0	–	–	10.7	17

[1] 0.2% OFFSET

Table 16: Liquid Hydrogen (-423°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Long Transverse Grain Direction

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t OR DIA	SPECIMEN DIMENSIONS (INCH) W	TEST DATA SOAK TIME (HOURS)	TEST DATA LOADING RATE (IN/IN-MIN)	RESULTS F_{tu} (KSI)	RESULTS F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	c	E (PSI × 10^{-6})	REFERENCE
28	0.032	SHEET	0.032	0.50	NA	NA	102.1	74.8	16	2.0	–	–	–	10
29	0.032	SHEET	0.032	0.50	NA	NA	101.8	73.2	15	2.0	–	–	–	10
30	0.032	SHEET	0.032	0.50	NA	NA	99.1	75.3	13	2.0	–	–	–	10
NA	0.06	SHEET	0.0620	0.50	NA	0.005	99.7	73.3	–	–	–	0.341	12.0	8
NA	0.06	SHEET	0.0635	0.50	NA	0.005	101.6	74.4	–	–	–	–	14.0	8
34	0.125	SHEET	0.125	0.50	NA	NA	103.2	76.9	14	2.0	–	–	–	10
35	0.125	SHEET	0.125	0.50	NA	NA	102.4	75.5	14	2.0	–	–	–	10
36	0.125	SHEET	0.125	0.50	NA	NA	102.7	76.2	14	2.0	–	–	–	10
ATH-1	0.125	SHEET	0.1247	0.50	NA	0.005	98.8	71.9	–	–	20	–	11.2	3 ⟨2⟩
ATH-2	0.125	SHEET	0.1248	0.50	NA	0.005	99.3	71.4	–	–	19	–	11.0	3 ⟨2⟩
TAT-3	0.125	SHEET	0.0624	0.50	0.25	0.005	97.8	67.2	13	2.0	19	–	12.1	16
TAT-7	0.125	SHEET	0.1251	0.50	0.25	0.005	101.3	71.2	16	2.0	20	–	11.8	16
TAT-11	0.50	PL	0.3000	0.50	0.25	0.005	101.8	72.8	14	2.0	17	–	11.0	16
TAT-12	0.50	PL	0.3011	0.50	0.25	0.005	101.5	72.8	15	2.0	16	–	10.9	16
NA	0.50	PL	0.50	0.50	NA	0.005	104.0	72.9	13.5	2.0	–	–	10.3	17
NA	0.50	PL	0.50	0.50	NA	0.005	101.5	71.9	13.5	2.0	–	–	12.2	17
NA	0.50	PL	0.50	0.50	NA	0.005	101.0	72.8	13.5	2.0	–	–	11.6	17
NA	0.50	PL	0.50	0.50	NA	0.005	101.9	–	14.0	2.0	–	–	–	17
NA	0.50	PL	0.50	0.50	NA	0.005	102.9	–	13.5	2.0	–	–	–	17
NA	0.50	PL	0.16	–	0.15	NA	96.1	67.0	17.3	1.0	23.5	–	–	11 ⟨3⟩
NA	0.50	PL	0.16	–	0.15	NA	92.5	66.5	15.6	1.0	26.5	–	–	11 ⟨[illegible]⟩

⟨1⟩ 0.2% OFFSET

⟨2⟩ F_{ty} OBTAINED BY STRAIN GAGE

⟨3⟩ TESTED IN HELIUM GAS AT -423°F

Table 16: *Liquid Hydrogen (–423°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Long Transverse Grain Direction (Continued)*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	u	E (PSI × 10^{-6})	
ATH-1	0.625	PL	0.6250	0.50	NA	0.006	94.9	–	–	–	16	–	12.4	3
ATH-2	0.625	PL	0.6250	0.50	NA	0.006	–	71.4	–	–	16	–	11.1	3 [2]
AL-2	1.0	PL	0.3743	0.50	0.25	0.006	100.7	71.7	11	2.0	12	–	–	5
AL-5	1.0	PL	0.3812	0.50	0.25	0.006	101.0	70.8	13	2.0	14	–	–	5
AT-1A	1.0	PL	0.50	0.50	NA	0.006	100.0	68.9	11	2.0	–	–	–	15
AT-2A	1.0	PL	0.50	0.50	NA	0.006	100.8	69.2	11	2.0	–	–	–	15
AT-3A	1.0	PL	0.50	0.50	NA	0.006	100.7	67.9	11	2.0	–	–	–	2
TA-17	1.0	PL	0.75	0.50	NA	0.006	101.5	72.2	12.0	2.0	11.6	.389	14.8	2
TA-18	1.0	PL	0.75	0.50	NA	0.006	100.5	71.7	14.5	2.0	14.8	.389	14.2	2
TA-23	1.0	PL	0.15	0.50	NA	0.006	98.7	70.2	13.0	2.0	13.5	.371	14.4	2
TA-24	1.0	PL	0.15	0.50	NA	0.006	100.8	72.2	13.5	2.0	14.2	.396	14.2	2
NA	1.0	PL	0.505	–	NA	0.006	100.2	72.4	–	–	–	–	12.5	17
NA	1.0	PL	0.505	–	NA	0.006	100.5	72.1	15.0	2.0	–	–	12.6	17
NA	1.0	PL	0.505	–	NA	0.006	98.8	70.0	13.0	2.0	–	–	12.2	17
NA	1.0	PL	0.505	–	NA	0.006	99.5	70.7	14.0	2.0	–	–	11.8	17
NA	1.0	PL	0.505	–	NA	0.006	100.8	72.3	13.0	2.0	–	–	13.3	17
TA-5	1.25	PL	0.503	–	NA	0.006	99.0	69.4	13.0	2.0	–	–	–	13
TA-6	1.25	PL	0.499	–	NA	0.006	103.1	76.9	12.0	2.0	–	–	–	13
A-3	1.25	PL	[illegible]	–	NA	0.006	101.1	71.6	7.0	2.0	19.0	–	–	14
A-4	1.25	PL	0.496	–	NA	0.006	103.9	75.5	9.5	2.0	25.0	–	–	14

[1] 0.2% OFFSET

[2] F_{ty} OBTAINED BY STRAIN GAGE

Table 16: Liquid Hydrogen (−423°F) Tensile Properties of 2219-T87 Aluminum Alloy Base Metal, Long Transverse Grain Direction (Continued)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	u	E (PSI x 10^{-6})	
AT25-5	2.5	PL	0.50	0.50	NA	0.005	100.9	72.6	11	2.0	–	–	–	15
AT25-6	2.5	PL	0.50	0.50	NA	0.005	100.8	72.9	10	2.0	–	–	–	15
NA	1.5	PL	0.505	–	NA	0.005	98.8	70.2	–	–	–	–	11.3	17
NA	1.5	PL	0.505	–	NA	0.005	99.0	70.0	12.0	2.0	–	–	10.9	17
NA	1.5	PL	0.505	–	NA	0.005	99.6	69.8	13.5	2.0	–	–	11.3	17
NA	1.5	PL	0.505	–	NA	0.005	99.7	70.0	15.0	2.0	–	–	11.7	17
NA	1.5	PL	0.505	–	NA	0.005	98.8	69.8	12.0	2.0	–	–	11.8	17

[1] 0.2% OFFSET

Table 17: Room Temperature (70°F–75°F) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment.

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t OR DIA	W	TEST DATA SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	RESULTS F_{tu} (KSI)	F_{ty} (KSI) [1]	ELONGATION %	GAGE LENGTH	% AREA REDUCTION	μ	E ($PSI \times 10^6$)	REFERENCE
NA	0.10	SHEET	0.10	0.50	NA	0.01	46.2	–	–	–	–	–	–	20 [2]
NA	0.10	SHEET	0.10	0.50	NA	0.01	50.4	–	–	–	–	–	–	20 [2]
NA	0.10	SHEET	0.10	0.50	NA	0.01	50.6	–	–	–	–	–	–	20 [2]
TWU-19 -W-1	0.125	SHEET	0.125	0.50	NA	NA	46.81	32.97	3.0	2.0	–	–	–	12
TWU-19 -W-2	0.125	SHEET	0.125	0.50	NA	NA	46.89	33.30	2.1	2.0	–	–	–	12
AWR-3	0.125	SHEET	0.1232	0.50	NA	0.005	38.0	27.9	3	2.0	22	–	9.5	3
AWR-4	0.125	SHEET	0.1218	0.50	NA	0.005	38.2	25.5	3	2.0	35	0.22	8.9	3
TAW-1	0.125	SHEET	0.0637	0.50	NA	0.005	38.2	25.7	2	2.0	–	–	–	16
TAW-2	0.125	SHEET	0.0630	0.50	NA	0.005	37.4	25.0	3	2.0	–	–	–	16
TAW-7	0.125	SHEET	0.1027	0.50	NA	0.005	38.[illegible]	26.6	3	2.0	–	–	–	16
TAW-8	0.125	SHEET	0.1004	0.50	NA	0.005	38.0	28.8	2	7.0	–	–	–	16
NA	0.50	PL	0.50	1.50	NA	0.005	40.9	NA	5.5	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	42.4	NA	5.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	41.3	NA	4.5	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	42.9	NA	6.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	42.3	NA	6.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	40.6	NA	4.5	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	41.9	NA	5.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	42.9	NA	5.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	42.1	NA	4.5	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	42.8	NA	5.0	2.0	–	–	–	17

[1] 0.2% OFFSET

[2] NO INFORMATION AVAILABLE ON WELD EDGE PREPARATION

Table 17: *Room Temperature (70° F–75° F) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy Square Butt Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment. (Continued)*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	F_{ty} [1] (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	μ	E ($PSI \times 10^{-6}$)	
NA	0.50	ℓ	0.50	1.50	NA	0.005	42.6	–	6.0	2.0	–	–	–	17
NA	0.50	ℓ	0.50	1.50	NA	0.005	40.7	–	5.0	2.0	–	–	–	17
NA	0.50	ℓ	0.50	1.50	NA	0.005	42.0	–	5.0	2.0	–	–	–	17
NA	0.50	ℓ	0.50	1.50	NA	0.005	42.1	–	6.0	2.0	–	–	–	17
NA	0.50	ℓ.	0.50	1.50	NA	0.005	42.2	–	5.0	2.0	–	–	–	17
NA	0.50	ℓ	0.50	1.50	NA	0.005	41.1	–	6.0	2.0	–	–	–	17
NA	0.50	ℓ	0.50	1.50	NA	0.005	38.9	–	6.0	2.0	–	–	–	17
NA	0.50	ℓ	0.50	1.50	NA	0.005	38.5	–	5.0	2.0	–	–	–	17
NA	0.50	ℓ	0.50	1.50	NA	0.005	37.2	–	5.0	2.0	–	–	–	17
NA	0.50	ℓ	0.50	1.50	NA	0.005	40.3	–	6.0	2.0	–	–	–	17
TWU-19-W-A	0.75	ℓ	0.200	0.625	NA	NA	35.12	20.89	7.4	2.0	–	–	–	12
TWU-19-W-B	0.75	ℓ	0.200	0.625	NA	NA	42.46	20.57	10.9	2.0	–	–	–	12
ITW-1	1.0	ℓ	0.250	–	NA	NA	38.1	20.9	11	1.0	29	–	–	6
NA	1.0	ℓ	1.00	2.00	NA	0.005	46.3	–	8.0	2.0	–	–	–	17
NA	1.0	ℓ	1.00	2.00	NA	0.005	40.1	–	6.5	2.0	–	–	–	17
NA	1.0	ℓ	1.00	2.00	NA	0.005	43.7	–	6.6	2.0	–	–	–	17
NA	1.0	ℓ	1.00	2.00	NA	0.005	46.0	–	6.0	2.0	–	–	–	17
NA	1.0	ℓ	1.00	2.00	NA	0.005	38.7	–	6.5	2.0	–	–	–	17
NA	1.0	ℓ	1.00	2.00	NA	0.005	42.5	–	–	–	–	–	–	17
NA	1.0	ℓ	1.00	2.00	NA	0.005	41.9	–	–	–	–	–	–	17
NA	1.0	ℓ	1.00	2.00	NA	0.005	41.7	–	–	–	–	–	–	17

[1] 0.2% OFFSET

Table 17: *Room Temperature (70°F–75°) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. 2319 Wire Used. No Post Weld Heat Treatment. (Continued)*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t OR DIA	SPECIMEN DIMENSIONS (INCH) W	TEST DATA SOAK TIME (HOURS)	TEST DATA LOADING RATE (IN/IN/MIN)	RESULTS F_{tu} (KSI)	RESULTS F_{ty} (KSI) [1]	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	μ	E (PSI x 10^{-6})	REFERENCE
NA	1.0	PL	1.00	2.00	NA	0.005	41.7	—	—	—	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	40.6	—	—	—	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	40.7	—	8.5	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	41.8	—	9.0	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	40.6	—	9.5	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	41.4	—	8.5	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	40.6	—	9.0	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	42.5	—	8.5	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	43.6	—	9.0	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	43.3	—	9.0	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	44.2	—	10.3	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	43.0	—	9.0	2.0	—	—	—	17
AWT-4	1.0	PL	0.50	0.50	NA	NA	40.5	20.3	9	2.0	—	—	—	15 [2]
AWT-5	1.0	PL	0.50	0.50	NA	NA	40.4	20.2	8	2.0	—	—	—	15 [2]
AWT-6	1.0	PL	0.50	0.50	NA	NA	40.3	19.8	8	2.0	—	—	—	15 [2]
AWR-1	1.0	PL	1.006	1.00	NA	0.005	42.9	22.1	8	2.0	19	—	—	3 [2]
AWR-2	1.0	PL	1.0142	1.00	NA	0.005	42.9	21.8	8	2.0	20	0.33	9.4	3 [2]

[1] 0.2% OFFSET

[2] NO FILLER WIRE USED

Table 18: *Liquid Nitrogen Temperature (-320°F) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment.*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE	
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	μ	E (PSI × 10^{6})		
NA	0.10	SHEET	0.10	0.50	NA	0.01	63.2	—	—	—	—	—	—	20	[2]
NA	0.10	SHEET	0.10	0.50	NA	0.01	61.0	—	—	—	—	—	—	20	[2]
NA	0.10	SHEET	0.10	0.50	NA	0.01	63.0	—	—	—	—	—	—	20	[2]
AWN-3	0.125	SHEET	0.1228	0.50	NA	0.005	53.8	30.9	4	2.0	22		10.1	3	
AWN-4	0.125	SHEET	0.1200	0.50	NA	0.005	56.0	32.5	4	2.0	25	0.27	9.8	3	
TAW-2	0.125	SHEET	0.0880	0.50	0.25	0.005	56.1	32.4	4	2.0	—	—	—	16	
TAW-4	0.125	SHEET	0.0851	0.50	0.25	0.005	56.2	33.7	4	2.0	—	—	—	16	
TAW-8	0.125	SHEET	0.1022	0.50	0.25	0.005	56.2	31.8	4	2.0	—	—	—	16	
TAW-10	0.125	SHEET	0.1088	0.50	0.25	0.005	52.3	29.0	4	2.0	—	—	—	16	
NA	0.50	PL	0.50	1.50	NA	0.005	48.8	—	3.0	2.0	—	—	—	17	
NA	0.50	PL	0.50	1.50	NA	0.005	53.8	—	6.0	2.0	—	—	—	17	
NA	0.50	PL	0.50	1.50	NA	0.005	51.6	—	4.5	2.0	—	—	—	17	
NA	0.50	PL	0.50	1.50	NA	0.005	54.0	—	6.0	2.0	—	—	—	17	
NA	0.50	PL	0.50	1.50	NA	0.005	57.5	—	5.5	2.0	—	—	—	17	
NA	0.50	PL	0.50	1.50	NA	0.005	48.7	—	3.0	2.0	—	—	—	17	
NA	0.50	PL	0.50	1.50	NA	0.005	53.4	—	5.0	2.0	—	—	—	17	
NA	0.50	PL	0.50	1.50	NA	0.005	55.4	—	5.0	2.0	—	—	—	17	
NA	0.50	PL	0.50	1.50	NA	0.005	50.8	—	4.0	2.0	—	—	—	17	
NA	0.50	PL	0.50	1.50	NA	0.005	52.1	—	5.0	2.0	—	—	—	17	
NA	0.50	PL	0.50	1.50	NA	0.005	46.1	—	3.5	2.0	—	—	—	17	
NA	0.50	PL	0.50	1.50	NA	0.005	52.1	—	5.0	2.0	—	—	—	17	

[1] 0.2% OFFSET

[2] NO INFORMATION AVAILABLE ON WELD EDGE PREPARATION

Table 18: *Liquid Nitrogen Temperature (-320°F) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment. (Continued)*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t OR DIA	W	TEST DATA SOAK TIME (HOURS)	LOADING RATE (IN/IN-MIN)	RESULTS F_{tu} (KSI)	▷ F_{ty} (KSI)	ELONGATION %	GAGE LENGTH	% AREA REDUCTION	μ	E ($PSI \times 10^6$)	REFERENCE
NA	0.5	L	0.50	1.50	NA	0.005	52.5	–	5.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	51.8	–	5.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	49.6	–	4.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	56.1	–	6.5	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	54.2	–	5.5	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	53.1	–	5.5	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	50.5	–	5.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	56.2	–	6.0	2.0	–	–	–	17
ITW-2	1.0	L	0.251	–	NA	NA	56.5	25.4	16	1.0	27	–	–	6
NA	1.0	L	1.00	2.00	NA	0.005	53.5	–	5.0	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	53.6	–	6.0	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	56.9	–	5.0	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	51.2	–	4.5	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	56.2	–	9.0	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	57.9	–	9.5	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	57.0	–	12.5	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	56.7	–	10.5	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	56.9	–	10.0	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	54.1	–	6.5	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	54.7	–	7.5	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	54.1	–	7.0	2.0	–	–	–	17

▷ 0.2% OFFSET

Taule 18: *Liquid Nitrogen Temperature (-320°F) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment. (Continued)*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS								REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	u	E (PSI x 10^{-6})	
NA	1.0	PL	1.00	2.00	NA	0.005	53.9	—	7.0	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	52.7	—	7.0	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	56.0	—	7.5	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	55.4	—	7.5	2.0	—	—	—	17
NA	1.0	PL	1.00	2.00	NA	0.005	53.4	—	7.5	2.0	—	—	—	17
AWT-7	1.0	PL	0.50	0.50	NA	NA	55.9	24.5	9	2.0	—	—	—	15 [2]
AWT-8	1.0	PL	0.50	0.50	NA	NA	56.3	25.2	9	2.0	—	—	—	15 [2]
AWT-9	1.0	PL	0.50	0.50	NA	NA	56.2	24.7	9	2.0	—	—	—	15 [2]
AWN-1	1.0	PL	1.0175	1.00	NA	0.005	54.7	25.9	7	2.0	13	–	10.7	3 [2]
AWN-2	1.0	PL	1.0230	1.00	NA	0.005	56.2	27.7	7	2.0	15	0.29	11.4	3 [2]

[1] 0.2% OFFSET

[2] NO FILLER WIRE USED

Table 19: *Liquid Hydrogen Temperature (-423°F) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment.*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	e	E (PSI × 10^6)	
NA	0.10	SHEET	0.10	0.50	NA	0.01	72.2	–	–	–	–	–	–	20 [3]
NA	0.10	SHEET	0.10	0.50	NA	0.01	66.9	–	–	–	–	–	–	20 [3]
NA	0.10	SHEET	0.10	0.50	NA	0.01	70.0	–	–	–	–	–	–	20 [3]
NA	0.10	SHEET	0.10	0.50	NA	0.01	65.5	–	–	–	–	–	–	20 [3]
NA	0.10	SHEET	0.10	0.50	NA	0.01	68.7	–	–	–	–	–	–	20 [3]
NA	0.10	SHEET	0.10	0.50	NA	0.01	64.2	–	–	–	–	–	–	20 [3]
AWH-3	0.125	SHEET	0.1298	0.50	NA	0.005	68.7	34.2	–	–	–	–	10.9	3 [2]
AWH-4	0.125	SHEET	0.1200	0.50	NA	0.005	62.8	26.7	–	–	–	0.31	10.6	3 [2]
NA	0.50	PL	0.50	1.50	NA	0.005	54.6	–	3.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	62.6	–	3.5	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	56.1	–	2.5	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	57.8	–	3.5	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	59.5	–	4.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	56.6	–	3.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	57.8	–	4.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	66.7	–	4.5	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	64.6	–	4.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	66.9	–	4.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	58.2	–	3.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	62.2	–	4.0	2.0	–	–	–	17
NA	0.50	PL	0.50	1.50	NA	0.005	62.4	–	4.0	2.0	–	–	–	17

[1] 0.2% OFFSET

[2] F_{ty} DETERMINED BY STRAIN GAGE ON WELD

[3] NO INFORMATION AVAILABLE ON WELD EDGE PREPARATION

Table 19: *Liquid Hydrogen Temperature (-423°F) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment. (Continued)*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS								REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN-MIN)	F_{tu} (KSI)	F_{ty} (KSI) ▷1	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	e	E (PSI × 10^6)		
NA	0.50	PL	0.50	1.50	NA	0.005	59.9	–	3.5	2.0	–	–	–		17
NA	0.50	PL	0.50	1.50	NA	0.005	62.4	–	4.5	2.0	–	–	–		17
NA	0.50	PL	0.50	1.50	NA	0.005	60.5	–	4.0	2.0	–	–	–		17
NA	0.50	PL	0.50	1.50	NA	0.005	59.2	–	4.0	2.0	–	–	–		17
NA	0.50	PL	0.50	1.50	NA	0.005	56.9	–	3.5	2.0	–	–	–		17
NA	0.50	PL	0.50	1.50	NA	0.005	58.9	–	4.5	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	64.5	–	5.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	58.4	–	6.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	65.3	–	6.5	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	66.1	–	8.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	68.2	–	8.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	67.0	–	8.5	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	65.2	–	7.5	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	67.2	–	8.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	63.8	–	5.5	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	68.4	–	6.5	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	62.6	–	6.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	62.3	–	6.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	57.6	–	5.5	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	58.1	–	6.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	58.0	–	5.5	2.0	–	–	–		17

▷1 0.2% OFFSET

Table 19: *Liquid Hydrogen Temperature (−423°F) Tensile Properties of GTA Welded 2219–T87 Aluminum Alloy. Square Butt Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment. (Continued)*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t OR DIA	W	TEST DATA SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	RESULTS F_{tu} (KSI)	F_{ty} (KSI) [1]	ELONGATION %	GAGE LENGTH	% AREA REDUCTION	u	E (PSI x 10^{6})	REFERENCE
NA	1.0	PL	1.00	2.00	NA	0.005	59.8	–	5.5	2.0	–	–	–	17
NA	1.0	PL	1.00	2.00	NA	0.005	58.8	–	5.5	2.0	–	–	–	17
AWT-1	1.0	PL	0.50	0.50	NA	NA	67.0	31.5	11	2.0	–	–	–	15 [3]
AWT-2	1.0	PL	0.50	0.50	NA	NA	68.6	27.6	11	2.0	–	–	–	15 [3]
AWT-3	1.0	PL	0.50	0.50	NA	NA	67.2	27.1	10	2.0	–	–	–	15 [3]
AWH-1	1.0	PL	1.0090	1.00	NA	0.005	65.6	33.3	–	–	9	–	10.4	3 [2] [3]
AWH-2	1.0	PL	1.0185	1.00	NA	0.005	62.6	30.9	–	–	9	0.36	9.3	3 [2] [3]

[1] 0.2% OFFSET
[2] F_{ty} DETERMINED BY STRAIN GAGE ON WELD
[3] NO FILLER WIRE USED

Table 20: Room Temperature ($70^0 F-75^0 F$) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy Square Butt Weld Edge Preparation. 2319 Filler Wire Used. Aged After Welding. (2)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	(1) F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	u	E (PSI × 10^6)	
TWU-19-A-1	0.125	SHEET	0.125	0.500	NA	NA	51.57	43.48	1.3	2.0	–	–	–	12
TWU-19-A-2	0.125	SHEET	0.125	0.500	NA	NA	51.70	43.51	2.1	2.0	–	–	–	12
TWU-19-A-3	0.750	PL	0.200	0.625	NA	NA	34.69	31.78	0.8	2.0	–	–	–	12
TWU-19-A-4	0.750	PL	0.200	0.625	NA	NA	44.74	31.91	1.5	2.0	–	–	–	12

(1) 0.2% OFFSET

(2) NATURALLY AGED 4 DAYS, THEN ARTIFICALLY AGED 24 HOURS AT $325^0F \pm 10^0F$

Table 21: Room Temperature ($70^0 F-75^0 F$) Tensile Properties of GTA Welded 2219-T87 Aluminum Alloy Square Butt Weld Edge Preparation. 2319 Filler Wire Used. Solution Treated and Artifically Aged After Welding. (2)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	(1) F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	u	E (PSI × 10^6)	
TWU-19-S-1	0.125	SHEET	0.125	0.500	NA	NA	69.98	52.88	12.3	2.0	–	–	–	12
TWU-19-S-2	0.125	SHEET	0.125	0.500	NA	NA	69.86	52.41	12.0	2.0	–	–	–	12
TWU-19-S-3	0.125	PL	0.200	0.625	NA	NA	61.50	42.42	10.5	2.0	–	–	–	12
TWU-19-S-4	0.750	PL	0.200	0.625	NA	NA	62.10	43.24	8.5	2.0	–	–	–	12

(1) 0.2% OFFSET

(2) 0.125 SHEET WAS SOLUTION TREATED IN NEUTRAL SALT FOR 55 MINUTES AT $995^0F \pm 10^0F$, NATURALLY AGED 4 DAYS, THEN ARTIFICALLY AGED 24 HOURS AT $325^0F \pm 10^0F$

0.750 PL WAS SOLUTION TREATED IN NEUTRAL SALT FOR 70 MINUTES AT $995^0F \pm 10^0F$, NATURALLY AGED 4 DAYS, THEN ARTIFICALLY AGED 36 HOURS AT $375^0F \pm 10^0F$

Table 22: Room Temperature ($70^{\circ}F-75^{\circ}F$) Tensile Properties of GMA Welded 2219-T87 Aluminum Alloy. Double 70° "V" Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment.

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t OR DIA	W	TEST DATA SOAK TIME (HOURS)	LOADING RATE (IN/IN-MIN)	RESULTS F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	GAGE LENGTH	% AREA REDUCTION	e	E (PSI × 10^{6})	REFERENCE
NA	0.5	L	0.50	1.50	NA	0.005	42.2	–	5.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	41.5	–	7.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	42.0	–	6.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	42.1	–	7.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	41.6	–	6.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	36.8	–	5.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	38.9	–	5.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	36.4	–	5.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	36.3	–	5.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	38.0	–	4.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	43.7	–	3.5	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	41.8	–	5.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	42.1	–	4.0	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	43.1	–	4.3	2.0	–	–	–	17
NA	0.5	L	0.50	1.50	NA	0.005	43.3	–	3.8	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	42.3	–	7.5	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	43.7	–	6.5	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	42.8	–	7.0	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	41.2	–	7.0	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	42.3	–	8.0	2.0	–	–	–	17
NA	1.0	L	1.00	2.00	NA	0.005	38.9	–	6.0	2.0	–	–	–	17

[1] 0.2% OFFSET

Table 22: *Room Temperature (70° F–75° F) Tensile Properties of GMA Welded 2219-T87 Aluminum Alloy. Double 70° "V" Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment. (Continued)*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS							REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	F_{tu} (KSI)	△ F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	μ	E (PSI x 10^{-6})	
NA	1.0	PL	1.00	2.00	NA	0.005	40.7	–	4.5	2.0	–	–	–	17
NA	1.0	PL	1.00	2.00	NA	0.005	41.7	–	4.5	2.0	–	–	–	17
NA	1.0	PL	1.00	2.00	NA	0.005	41.7	–	5.5	2.0	–	–	–	17
NA	1.0	PL	1.00	2.00	NA	0.005	42.3	–	4.0	2.0	–	–	–	17
NA	1.0	PL	1.00	2.00	NA	0.005	45.7	–	5.0	2.0	–	–	–	17
NA	1.0	PL	1.00	2.00	NA	0.005	45.4	–	4.8	2.0	–	–	–	17
NA	1.0	PL	1.00	2.00	NA	0.005	45.7	–	5.3	2.0	–	–	–	17
NA	1.0	PL	1.00	2.00	NA	0.005	45.7	–	6.0	2.0	–	–	–	17
NA	1.0	PL	1.00	2.00	NA	0.005	45.1	–	5.0	2.0	–	–	–	17
NA	1.5	PL	1.50	1.50	NA	0.005	44.2	–	6.0	2.0	–	–	–	17
NA	1.5	PL	1.50	1.50	NA	0.005	46.0	–	6.0	2.0	–	–	–	17
NA	1.5	PL	1.50	1.50	NA	0.005	45.4	–	6.0	2.0	–	–	–	17
NA	1.5	PL	1.50	1.50	NA	0.005	46.0	–	6.5	2.0	–	–	–	17
NA	1.5	PL	1.50	1.50	NA	0.005	46.3	–	7.5	2.0	–	–	–	17
NA	1.5	PL	1.50	1.50	NA	0.005	45.8	–	7.0	2.0	–	–	–	17
NA	1.5	PL	1.50	1.50	NA	0.005	46.1	–	7.0	2.0	–	–	–	17
NA	1.5	PL	1.50	1.50	NA	0.005	45.2	–	7.0	2.0	–	–	–	17
NA	1.5	PL	1.50	1.50	NA	0.005	46.0	–	6.0	2.0	–	–	–	17
NA	1.5	PL	1.50	1.50	NA	0.005	45.9	–	6.0	2.0	–	–	–	17
NA	1.5	PL	1.50	1.50	NA	0.005	46.7	–	6.0	2.0	–	–	–	17
NA	1.5	PL	1.50	1.50	NA	0.005	43.0	–	5.5	2.0	–	–	–	17

△ 0.2% OFFSET

Table 23: Liquid Nitrogen Temperature (-320°F) Tensile Properties of GMA Welded 2219-T87 Aluminum Alloy. Double 70° "V" Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment.

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) OR DIA	SPECIMEN DIMENSIONS (INCH) W	TEST DATA SOAK TIME (HOURS)	TEST DATA LOADING RATE (IN/IN/MIN)	RESULTS F_{tu} (KSI)	RESULTS ▷ F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	e	E (PSI x 10^6)	REFERENCE
NA	0.5	R	0.50	1.50	NA	0.005	56.9	–	7.5	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	57.1	–	7.0	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	53.4	–	5.0	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	56.9	–	5.0	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	54.2	–	10.0	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	43.1	–	3.0	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	46.1	–	5.0	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	44.9	–	3.0	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	47.3	–	3.5	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	50.3	–	2.5	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	58.6	–	4.5	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	58.6	–	5.0	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	58.5	–	4.0	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	60.7	–	4.5	2.0	–	–	–	17
NA	0.5	R	0.50	1.50	NA	0.005	60.5	–	5.0	2.0	–	–	–	17
NA	1.0	R	1.00	2.00	NA	0.005	54.6	–	5.0	2.0	–	–	–	17
NA	1.0	R	1.00	2.00	NA	0.005	51.9	–	5.5	2.0	–	–	–	17
NA	1.0	R	1.00	2.00	NA	0.005	53.9	–	5.0	2.0	–	–	–	17
NA	1.0	R	1.00	2.00	NA	0.005	51.1	–	4.5	2.0	–	–	–	17
NA	1.0	R	1.00	2.00	NA	0.005	51.2	–	5.5	2.0	–	–	–	17
NA	1.0	R	1.00	2.00	NA	0.005	57.8	–	5.5	2.0	–	–	–	17

▷ 0.2% OFFSET

Table 23: Liquid Nitrogen Temperature (-320°F) Tensile Properties of GMA Welded 2219-T87 Aluminum Alloy. Double 70° "V" Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment. (Continued)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t OR DIA	W	TEST DATA SOAK TIME (HOURS)	LOADING RATE (IN/IN/MIN)	RESULTS F_{tu} (KSI)	[1] F_{ty} (KSI)	ELONGATION %	GAGE LENGTH	% AREA REDUCTION	u	E (PSI × 10^6)	REFERENCE
NA	1.0	PL	1.00	2.00	NA	0.006	57.1	-	5.5	2.0	-	-	-	17
NA	1.0	PL	1.00	2.00	NA	0.006	57.6	-	6.0	2.0	-	-	-	17
NA	1.0	PL	1.00	2.00	NA	0.006	62.8	-	5.5	2.0	-	-	-	17
NA	1.0	PL	1.00	2.00	NA	0.006	59.6	-	5.5	2.0	-	-	-	17
NA	1.0	PL	1.00	2.00	NA	0.006	62.6	-	5.5	2.0	-	-	-	17
NA	1.0	PL	1.00	2.00	NA	0.006	62.5	-	5.5	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.006	56.8	-	5.0	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.006	56.9	-	5.0	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.006	58.2	-	5.5	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.005	56.5	-	5.5	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.006	57.8	-	5.5	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.006	57.7	-	5.5	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.005	56.7	-	4.5	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.006	56.0	-	4.5	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.005	58.7	-	6.5	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.005	57.6	-	6.0	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.005	57.7	-	5.0	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.006	58.1	-	5.5	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.006	59.3	-	5.5	2.0	-	-	-	17
NA	1.5	PL	1.50	1.50	NA	0.006	53.5	-	5.5	2.0	-	-	-	17

[1] 0.2% OFFSET

Table 24: *Liquid Hydrogen Temperature (−423° F) Tensile Properties of GMA Welded 2219–T87 Aluminum Alloy. Double 70° "V" Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS								REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN-MIN)	F_{tu} (KSI)	△ F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	e_u	E (PSI × 10^6)		
NA	0.5	PL	0.50	1.50	NA	0.006	68.6	–	6.5	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.006	61.3	–	5.0	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.006	60.6	–	5.0	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.006	61.2	–	5.0	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.006	63.5	–	5.5	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.005	48.6	–	2.5	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.006	52.4	–	3.0	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.006	50.8	–	2.5	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.006	51.6	–	2.5	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.006	48.8	–	3.0	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.006	71.2	–	4.0	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.006	68.9	–	3.8	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.006	71.5	–	4.0	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.005	72.6	–	4.3	2.0	–	–	–		17
NA	0.5	PL	0.50	1.50	NA	0.006	70.1	–	3.8	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.006	61.5	–	4.5	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.006	62.4	–	3.5	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.006	58.6	–	4.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	60.1	–	4.5	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.006	56.2	–	4.5	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.006	64.5	–	5.0	2.0	–	–	–		17

△ 0.2% OFFSET

Table 24: *Liquid Hydrogen Temperature (−423°F) Tensile Properties of GMA Welded 2219-T87 Aluminum Alloy. Double 70° "V" Weld Edge Preparation. 2319 Filler Wire Used. No Post Weld Heat Treatment (Continued)*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)		TEST DATA		RESULTS								REFERENCE
			t OR DIA	W	SOAK TIME (HOURS)	LOADING RATE (IN/IN-MIN)	F_{tu} (KSI)	▷1 F_{ty} (KSI)	ELONGATION %	ELONGATION GAGE LENGTH	% AREA REDUCTION	u	E (PSI × 10^{-6})		
NA	1.0	PL	1.00	2.00	NA	0.005	65.4	–	4.5	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	63.6	–	5.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	67.6	–	4.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	66.9	–	4.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	67.5	–	4.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	67.0	–	4.0	2.0	–	–	–		17
NA	1.0	PL	1.00	2.00	NA	0.005	66.0	–	4.0	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	61.7	–	5.0	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	63.2	–	5.0	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	62.6	–	4.0	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	60.7	–	4.0	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	58.4	–	4.5	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	65.1	–	6.0	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.006	61.2	–	4.5	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	63.8	–	5.5	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	66.8	–	6.0	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	64.0	–	4.0	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	66.2	–	4.5	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	62.6	–	4.0	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	62.7	–	4.5	2.0	–	–	–		17
NA	1.5	PL	1.50	1.50	NA	0.005	62.7	–	4.5	2.0	–	–	–		17

▷1 0.2% OFFSET

Table 25: Room Temperature ($70^{o}-75^{o}F$) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. RT Propagation Direction

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)					PRECRACKING			TEST PREP.		TESTING	RESULTS				REFERENCE
			t	W	L	a	2C	σ (KSI)	R	CYCLES ($\times$ 1,000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	LOADING RATE (KSI/MIN)	σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) KSI$\sqrt{IN.}$	K_{IE} KSI$\sqrt{IN.}$	
AB54R-1	0.625	RL	0.638	22.0	20.0	0.530	5.380	≤16	NA	NA	NA	AIR	NA	21.7	0.43	29.86	48.23	3
AB45R-1	0.625	RL	0.644	6.75	10.0	0.432	1.190	≤16	NA	NA	NA	AIR	NA	42.3	0.83	41.10	45.60	3
AB54R-1	0.625	RL	0.629	6.75	10.0	0.485	1.370	≤16	NA	NA	NA	AIR	NA	39.8	0.81	41.22	48.32	3
AB54R-1	0.625	RL	0.641	6.75	10.0	0.527	1.440	≤16	NA	NA	NA	AIR	NA	35.8	0.74	37.92	45.05	3
AB57R-1	0.625	RL	0.672	12.0	11.0	0.530	1.343	≤16	NA	NA	NA	AIR	NA	37.2	0.71	38.36	43.33	3
AB57R-2	0.625	RL	0.644	12.0	11.0	0.538	1.353	≤16	NA	NA	NA	AIR	NA	39.0	0.75	40.49	46.70	3

Table 26: *Room Temperature (70^0–75^0 F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t	W	L	a	2C	PRECRACKING σ (KSI)	R	CYCLES (x 1,000)	TEST PREP SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING LOADING RATE (KSI/MIN)	RESULTS σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) KSI$\sqrt{IN}$	K_{IE} KSI$\sqrt{IN}$	REFERENCE
AL-8	1.0	PL	0.500	6.00	10.0	0.255	0.960	15	0.1	NA	NA	AIR	NA	47.92	0.88	40.3	44.6	21
AS-1	1.0	PL	0.578	6.00	8.0	0.291	1.010	12	NA	NA	NA	1	NA	45.8	0.88	40.1	43.4	22
AT-1	1.0	PL	0.589	6.01	8.0	0.330	1.055	12	NA	NA	NA	2	NA	44.8	0.87	40.5	44.6	22
AT-2	1.0	PL	0.603	6.00	8.0	0.304	1.030	12	NA	NA	NA	2	NA	44.8	0.87	39.7	43.0	22
AD-1	1.0	PL	0.603	6.00	8.0	0.377	[illegible]	12	NA	NA	NA	3	NA	41.3	0.82	38.3	42.5	22
AD-2	1.0	PL	0.604	6.00	8.0	0.304	1.030	12	NA	NA	NA	3	NA	46.4	0.89	41.2	44.7	22
H-1	1.0	PL	0.601	6.00	8.0	0.320	1.050	12	NA	NA	NA	GH_2	NA	44.9	0.87	40.3	44.1	22
H-2	1.0	PL	0.603	6.00	8.0	0.320	1.090	12	NA	NA	NA	GH_2	NA	44.5	0.87	40.5	44.5	22
H-3	1.0	PL	0.600	6.00	8.0	0.323	1.030	12	NA	NA	NA	GH_2	NA	44.7	0.87	39.9	43.6	22
H-4	1.0	PL	0.600	6.00	8.0	0.320	1.030	12	NA	NA	NA	GH_2	NA	44.7	0.87	39.9	43.5	22
H-5	1.0	PL	0.599	6.00	8.0	0.365	1.090	12	NA	NA	NA	GH_2	NA	43.4	0.86	40.1	44.4	22
H-7	1.0	PL	0.605	6.00	8.0	0.350	1.120	12	NA	NA	NA	GH_2	NA	42.1	0.83	39.0	43.3	22
H-10	1.0	PL	0.600	6.00	8.0	0.332	1.070	12	NA	NA	NA	GH_2	NA	43.5	0.85	39.5	43.4	22
X-2	1.0	PL	0.604	6.00	8.0	0.353	1.130	12	NA	NA	NA	LH_2	NA	41.7	0.82	38.8	43.1	22
H-9	1.0	PL	0.600	6.01	8.0	0.340	1.130	12	NA	NA	NA	LH_2	NA	42.4	0.83	39.3	43.7	22
H-8	1.0	PL	0.598	6.00	8.0	0.330	1.080	12	NA	NA	NA	LH_2	NA	43.1	0.84	39.2	43.2	22
O-1	1.0	PL	0.602	6.00	8.0	0.315	1.080	12	NA	NA	NA	GO_2	NA	44.9	0.87	40.6	44.6	22
O-2	1.0	PL	0.600	6.00	8.0	0.343	1.110	12	NA	NA	NA	GO_2	NA	44.2	0.87	40.9	45.3	22
O-3	1.0	PL	0.600	6.00	8.0	0.344	1.080	12	NA	NA	NA	LO_2	NA	43.9	0.86	40.2	44.3	22
O-4	1.0	PL	0.599	6.00	8.0	0.365	1.140	12	NA	NA	NA	LO_2	NA	41.8	0.83	39.2	43.8	22

1 3-1/2% NaCl

2 TRICHLOROETHYLENE

3 DYE PENETRANT

Table 26: Room Temperature (70° F–75° F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction (Continued)

SPECIMEN I.D	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t	W	L	a	2c	PRECRACKING σ (KSI)	R	CYCLES (x 1,000)	TEST PREP. SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING LOADING RATE (KSI/MIN)	RESULTS σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) KSI$\sqrt{IN}$	K_{IE} KSI$\sqrt{IN}$	REFERENCE	
C-2	1.25	RL	0.652	6.00	8.0	0.291	0.912	27.9	NA	2	NA	AIR	≈ 20	43.9	0.80	36.8	38.8	14	1 2
CA-44	1.25	RL	0.653	6.00	8.0	0.228	0.833	18.0	NA	5	NA	AIR	≈ 20	47.7	0.86	37.6	39.5	14	1
C-4	1.25	RL	0.671	6.00	8.0	0.286	0.925	27.9	NA	2	NA	AIR	≈ 20	44.5	0.81	37.5	39.4	14	1 2
C-6	1.25	RL	0.650	6.00	8.0	0.292	0.947	27.9	NA	2	NA	AIR	≈ 20	42.3	0.77	35.9	38.0	14	1
C-7	1.25	RL	0.652	6.00	8.0	0.323	1.018	27.9	NA	2	NA	AIR	≈ 20	40.8	0.76	35.9	38.4	14	1
C-9	1.25	RL	0.653	6.00	8.0	0.298	0.954	27.9	NA	2	NA	AIR	≈ 20	41.7	0.76	35.5	37.7	14	1
AA-21	1.25	RL	0.656	6.00	8.0	0.372	1.385	20	NA	4	NA	LH_2/AIR	≈ 20	30.6	0.59	30.1	34.2	14	1
AA-19	1.25	RL	0.655	6.00	8.0	0.368	1.382	20	NA	2	NA	LH_2/AIR	≈ 20	32.3	0.62	31.7	36.1	14	1
AA-61	1.25	RL	0.661	6.00	8.0	0.311	1.213	15	NA	5	NA	LH_2/AIR	≈ 20	34.5	0.64	31.6	34.5	14	1
CA-45	1.25	RL	0.658	6.00	8.0	0.261	0.945	27.9	NA	3	NA	LH_2/AIR	≈ 20	46.9	0.85	39.4	41.5	14	1
DA-22	1.25	RL	0.662	6.00	8.0	0.215	0.659	15	NA	15	NA	LH_2/AIR	≈ 20	48.5	0.86	34.9	36.1	14	1
DA-20	1.25	RL	0.656	6.00	8.0	0.387	1.139	20	NA	12	NA	LH_2/AIR	≈ 20	34.1	0.65	31.7	34.7	14	1
C-8	1.25	RL	0.604	6.00	8.0	0.248	0.854	27.9	NA	2	NA	AIR	≈ 20	44.5	0.81	35.6	37.5	14	1 2
C-3	1.25	RL	0.660	6.00	8.0	0.306	0.928	27.9	NA	2	NA	AIR	≈ 20	44.6	0.82	37.9	40.0	14	1 2
C-1	1.25	RL	0.663	6.00	8.0	0.287	0.902	27.9	NA	2	NA	AIR	≈ 20	46.0	0.84	38.5	40.5	14	1 2
C-5	1.25	RL	0.645	6.00	8.0	0.290	0.928	27.9	NA	2	NA	AIR	≈ 20	44.5	0.81	37.6	39.8	14	1 2
SA6-1	1.25	RL	0.608	6.00	8.0	0.257	0.944	20-25	NA	4-20	NA	AIR	≈ 20	40.8	0.76	33.7	35.9	13	
2A3R-1	1.0	RL	0.752	7.00	8.0	0.[illegible]60	1.44	10	0.06	14.0	0.25	AIR	40	41.6	0.80	41.9	46.1	15	
2A3R-2	1.0	RL	0.752	7.00	8.0	0.370	1.44	10	0.06	15.0	0.25	AIR	40	42.1	0.82	42.7	47.1	15	
SBT-20	1.0	RL	1.01	6.00	11.0	0.340	1.37	25	0.06	4-6	NA	NA	20-30	38.7	0.755	37.7	39.8	52	

1 PREVIOUSLY SUSTAINED AND MARKED

2 MAXIMUM SUSTAINED GROWTH NOT AT $\alpha = 0°$

Table 26: Room Temperature ($70^0 F-75^0 F$) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction (Continued)

SPECIMEN I.D	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t	W	L	a	2C	PRECRACKING σ (KSI)	R	CYCLES (x 1,000)	TEST PREP. SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING LOADING RATE (KSI/MIN)	RESULTS σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) $KSI\sqrt{IN}$	K_{IE} $KSI\sqrt{IN}$	REFERENCE	
OF-1	1.0	PL	0.595	5.97	8.0	0.320	1.010	12	NA	NA	NA	OF_2	NA	44.6	0.87	39.5	43.0	22	
OF-3	1.0	PL	0.596	6.00	8.0	0.320	1.020	12	NA	NA	NA	OF_2	NA	43.8	0.85	38.9	42.4	22	
OF-2	1.0	PL	0.601	5.97	8.0	0.320	1.000	12	NA	NA	NA	OF_2	NA	44.5	0.86	39.3	42.6	22	
OF-4	1.0	PL	0.604	6.00	8.0	0.370	1.200	12	NA	NA	NA	OF_2	NA	39.8	0.79	37.9	42.9	22	
X-1	1.0	PL	0.602	6.00	8.0	0.310	1.080	12	NA	NA	NA	FLOX	NA	44.6	0.86	40.2	44.1	22	
FX-2	1.0	PL	0.598	6.00	8.0	0.325	1.090	12	NA	NA	NA	FLOX	NA	45.8	0.89	41.9	46.2	22	
FX-1	1.0	PL	0.598	6.00	8.0	0.370	1.340	12	NA	NA	NA	FLOX	NA	39.7	0.80	39.2	45.7	22	
FX-3	1.0	PL	0.597	6.00	8.0	0.345	1.080	12	NA	NA	NA	FLOX	NA	45.3	0.89	41.6	45.9	22	
FX-4	1.0	PL	0.600	6.00	8.0	0.365	1.070	12	NA	NA	NA	FLOX	NA	43.8	0.86	40.2	44.3	22	
AA-2	1.25	PL	0.668	6.00	8.0	0.299	1.250	20-25	NA	4-25	NA	AIR	≈20	37.6	0.71	34.8	37.7	14	
CA-8	1.25	PL	0.657	6.00	8.0	0.223	0.772	20-25	NA	4-25	NA	AIR	≈20	46.6	0.83	35.6	37.2	14	
AA-51	1.25	PL	0.661	6.00	8.0	0.324	1.272	22.6	NA	1	NA	AIR	≈20	33.8	0.64	31.6	34.9	14	1 2
AA-1	1.25	PL	0.660	6.00	8.0	0.349	1.362	22.6	NA	1	NA	AIR	≈20	35.8	0.68	34.8	39.1	14	1 2
CA-39	1.25	PL	0.661	6.00	8.0	0.276	0.872	27.9	NA	4	NA	AIR	≈20	42.8	0.78	35.0	36.6	14	1 2
CA-42	1.25	PL	0.680	6.00	8.0	0.241	0.887	27.9	NA	2	NA	AIR	≈20	45.4	0.82	36.7	38.6	14	1 2
CA-10	1.25	PL	0.643	6.01	8.0	0.246	0.809	27.9	NA	2	NA	AIR	≈20	46.0	0.83	36.2	37.8	14	1 2
DA-32	1.25	PL	0.668	6.00	8.0	0.182	0.606	32.1	NA	1	NA	AIR	≈20	50.8	0.90	34.9	36.1	14	1
DA-25	1.25	PL	0.664	6.00	8.0	0.190	0.783	32.1	NA	1	NA	AIR	≈20	47.7	0.85	35.6	37.2	14	1
CA-43	1.25	PL	0.658	6.00	8.0	0.233	0.845	18.0	NA	5	NA	AIR	≈20	47.2	0.85	37.5	39.3	14	1
CA-41	1.25	PL	0.656	6.00	8.0	0.258	0.892	27.9	NA	2	NA	AIR	≈20	43.6	0.79	35.6	37.4	14	1

1 PREVIOUSLY SUSTAINED AND MARKED

2 MAXIMUM SUSTAINED GROWTH NOT AT $\alpha = 0^0$

Table 26: Room Temperature (70^0F - 75^0F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction (Continued)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)					PRECRACKING			TEST PREP.		TESTING	RESULTS				REFERENCE
			t	W	L	a	2c	σ (KSI)	R	CYCLES (x 1000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	LOADING RATE (KSI/MIN)	σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) (KSI $\sqrt{IN.}$)	K_{IE} (KSI $\sqrt{IN.}$)	
RB2-3A	0.25	SHEET	0.25	6.00	9.0	0.178	0.765	12	0.24	10	NA	AIR	NA	44.6	0.87	32.5	41.7	24
RB5-1A	1.0	RL	0.50	6.00	10.0	0.230	0.980	12	0.06	10	NA	AIR	NA	42.7	0.82	35.1	38.6	24
RB5-1B	1.0	RL	0.50	6.00	10.0	0.225	0.980	12	0.06	10	NA	AIR	NA	39.4	0.76	32.1	35.1	24
RB5-6A	1.0	RL	0.50	6.00	10.0	0.205	0.860	12	0.06	15	NA	AIR	NA	43.7	0.83	33.9	36.4	24
RB5-2A	1.0	RL	0.50	7.50	10.0	0.310	1.380	10	0.06	8	NA	AIR	NA	42.0	0.84	40.5	49.2	24
RB5-2B	1.0	RL	0.50	7.50	10.0	0.310	1.375	12	0.06	4	NA	AIR	NA	40.8	0.82	39.2	47.6	24
RB5-3A	1.0	RL	0.50	10.00	10.0	0.345	1.590	10	0.06	5.7	NA	AIR	NA	37.9	0.75	38.5	49.4	24
RB5-3B	1.0	RL	0.50	10.00	10.0	0.345	1.590	10	0.06	5	NA	AIR	NA	37.8	0.75	38.4	49.3	24
RB5-4B	1.0	RL	0.50	10.00	10.0	0.395	1.790	12	0.06	3.6	NA	AIR	NA	35.0	0.72	37.7	51.8	24
SBT-2	1.0	RL	1.01	6.00	11.0	0.360	1.30	25	0.06	4-6	NA	AIR	20-30	43.0	0.80	42.1	44.2	6
SBT-11	1.0	RL	1.01	6.00	11.0	0.310	1.31	25	0.06	4-6	NA	AIR	20-30	43.5	0.80	41.4	43.7	6
A-5	2.5	RL	1.097	6.00	9.0	0.532	1.360	10	0.06	5.0	0.25	AIR	35	33.6	0.67	34.7	35.9	15
A-6	2.5	RL	1.094	5.99	9.0	0.545	1.390	10	0.06	5.0	0.25	AIR	35	33.8	0.68	35.3	36.5	15
A-7	2.5	RL	1.094	6.00	9.0	0.366	1.475	12	0.06	7.0	0.25	AIR	35	36.9	0.72	37.3	39.3	15
A-8	2.5	RL	1.096	6.01	9.0	0.360	1.475	12	0.06	8.0	0.25	AIR	35	37.5	0.73	37.8	40.0	15
SA 12-1	1.25	RL	1.240	6.00	8.0	0.364	1.370	20-25	NA	4-20	NA	AIR	≈20	35.6	0.66	35.0	36.5	13

Table 27: Liquid Nitrogen Temperature (-320°F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. RT Propagation Direction

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)					PRECRACKING			TEST PREP.		TESTING	RESULTS				REFERENCE	
			t	W	L	a	2C	σ (KSI)	R	CYCLES (x 1,000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	LOADING RATE (KSI/MIN)	σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) KSI$\sqrt{IN}$	K_{IE} KSI$\sqrt{IN}$		
BSI-1	0.50	PL	0.50	6.00	11.0	0.20	0.56	NA	NA	NA	NA	AIR	NA	54.0	0.82	36.1	37.2	23	
BSI-2	0.50	PL	0.51	6.00	11.0	0.22	0.58	NA	NA	NA	NA	AIR	NA	54.6	0.83	37.4	38.5	23	
BSI-3	0.50	PL	0.51	6.00	11.0	0.21	0.56	NA	NA	NA	NA	AIR	NA	54.7	0.83	36.7	37.8	23	
AB24N-2	0.625	PL	0.638	11.0	20.0	0.272	2.449	≤16	NA	NA	NA	AIR	NA	44.4	0.73	44.49	50.16	3	
AB36N-2	0.625	PL	0.647	11.0	20.0	0.375	3.615	≤16	NA	NA	NA	AIR	NA	35.6	0.62	41.54	52.97	3	▷1
AB45N-1	0.625	PL	0.633	14.5	20.0	0.450	4.610	≤16	NA	NA	NA	AIR	NA	28.1	0.51	35.75	51.70	3	▷1
AB54N-1	0.625	PL	0.643	22.0	20.0	0.525	5.405	≤16	NA	NA	NA	AIR	NA	21.5	0.38	29.34	46.89	3	
AB54N-2	0.625	PL	0.639	22.0	20.0	0.533	5.385	≤16	NA	NA	NA	AIR	NA	19.7	0.35	27.00	43.74	3	
AB57N-2	0.625	PL	0.643	22.0	20.0	0.555	5.525	≤16	NA	NA	NA	AIR	NA	21.3	0.39	29.77	49.14	3	▷1
AB24N-1	0.625	PL	0.643	5.50	10.0	0.247	0.971	≤16	NA	NA	NA	AIR	NA	56.7	0.89	47.67	50.57	3	
AB36N-3	0.625	PL	0.638	9.0	6.0	0.351	1.303	≤16	NA	NA	NA	AIR	NA	45.6	0.73	44.06	49.71	3	
AB45N-3	0.625	PL	0.642	12.0	11.0	0.470	1.750	≤16	NA	NA	NA	AIR	NA	35.9	0.58	39.67	49.77	3	
AB54N-4	0.625	PL	0.646	12.0	11.0	0.555	2.030	≤16	NA	NA	NA	AIR	NA	31.5	0.53	37.40	50.27	3	
AB36N-1	0.625	PL	0.641	5.50	10.0	0.311	0.889	≤16	NA	NA	NA	AIR	NA	53.4	0.85	44.86	47.19	3	
AB36N-2	0.625	PL	0.637	5.50	10.0	0.369	0.964	≤16	NA	NA	NA	AIR	NA	50.9	0.82	44.72	47.34	3	
AB45N-1	0.625	PL	0.646	6.75	10.0	0.432	1.170	≤16	NA	NA	NA	AIR	NA	45.8	0.75	43.91	48.42	3	
AB45N-2	0.625	PL	0.632	6.75	10.0	0.417	1.165	≤16	NA	NA	NA	AIR	NA	49.3	0.81	47.24	52.45	3	
AB54N-2	0.625	PL	0.630	6.75	10.0	0.472	1.370	≤16	NA	NA	NA	AIR	NA	44.3	0.75	45.56	53.38	3	
AB57N-1	0.625	PL	0.642	12.0	11.0	0.546	1.371	≤16	NA	NA	NA	AIR	NA	37.9	0.61	39.14	46.41	3	
AB57N-2	0.625	PL	0.626	12.0	11.0	0.554	1.404	≤16	NA	NA	NA	AIR	NA	40.7	0.66	42.74	50.7	3	
SBL-17	1.00	PL	1.00	6.00	11.0	0.320	1.31	25	0.06	4-6	NA	AIR	20-30	57.8	0.89	56.1	58.2	6	
SBL-12	1.00	PL	1.00	6.00	11.0	0.290	1.26	25	0.06	4-6	NA	AIR	20-30	58.1	0.89	54.6	57.4	6	

▷1 $\frac{W}{2C} < 4$

Table 28: Liquid Nitrogen Temperature (-320°F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction

SPECIMEN I.D	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)					PRECRACKING			TEST PREP		TESTING	RESULTS				REFERENCE
			t	W	L	a	2C	σ (KSI)	R	CYCLES (× 1,000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	LOADING RATE (KSI/MIN)	σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) KSI$\sqrt{IN}$	K_{IE} KSI$\sqrt{IN}$	
AL-9	1.0	PL	0.5	6.0	10.0	0.255	0.945	15	0.1	18	0.15	AIR	NA	53.12	0.87	44.4	49.0	21
AL-10	1.0	PL	0.5	6.0	10.0	0.200	0.890	15	0.1	20	0.15	AIR	NA	56.00	0.89	43.0	46.2	21
AL-12	1.0	PL	0.5	6.0	10.0	0.230	0.970	15	0.1	20	0.15	AIR	NA	53.00	0.86	43.0	46.9	21
AS54-8	1.0	PL	0.501	5.00	7.0	0.430	1.170	12	NA	NA	NA	AIR	NA	45.7	0.83	43.9	53.0	2
AS52-5	1.0	PL	0.500	9.00	14.0	0.333	1.370	8	NA	NA	NA	AIR	NA	46.8	0.77	45.5	56.2	2
AS52-6	1.0	PL	0.501	9.00	14.0	0.382	1.600	8	NA	NA	NA	AIR	NA	41.3	0.70	42.9	56.5	2
AS52-7	1.0	PL	0.496	8.99	14.0	0.402	1.720	8	NA	NA	NA	AIR	NA	39.1	0.68	41.7	57.1	2
AS51-3	1.0	PL	0.502	12.0	21.0	0.220	2.23	8	NA	NA	NA	AIR	NA	48.7	0.79	45.0	51.4	2
AS51-4	1.0	PL	0.500	16.0	21.0	0.270	2.85	8	NA	NA	NA	AIR	NA	30.4	0.63	38.6	47.8	2
AS51-5	1.0	PL	0.502	16.0	21.0	0.330	3.42	6	NA	NA	NA	AIR	NA	31.1	0.53	34.1	46.9	2
AS51-6	1.0	PL	0.501	20.0	21.0	0.425	4.62	6	NA	NA	NA	AIR	NA	22.0	0.40	27.2	44.8	2
AS51-7	1.0	PL	0.497	20.0	21.0	0.405	4.36	6	NA	NA	NA	AIR	NA	22.3	0.39	26.9	43.0	2
AS51-8	1.0	PL	0.498	20.0	21.0	0.375	4.20	6	NA	NA	NA	AIR	NA	24.5	0.43	28.6	43.3	2
AS54-5	1.0	PL	0.501	5.00	7.0	0.360	0.940	15	NA	NA	NA	AIR	NA	51.6	0.88	44.9	49.8	2
AS54-6	1.0	PL	0.502	5.00	7.0	0.400	1.080	15	NA	NA	NA	AIR	NA	48.4	0.85	45.0	52.6	2
AS54-7	1.0	PL	0.500	5.00	7.0	0.410	1.120	12	NA	NA	NA	AIR	NA	46.7	0.83	43.9	52.0	2
SA6-2	1.25	PL	0.608	6.00	8.0	0.274	1.016	20-25	NA	4-20	NA	AIR	≈ 20	44.1	0.69	37.6	40.5	13
AA-3	1.25	PL	0.655	6.00	8.0	0.295	1.238	20-25	NA	4-25	NA	AIR	≈ 20	41.7	0.68	38.1	41.6	14
CA-7	1.25	PL	0.666	6.00	8.0	0.220	0.778	20-25	NA	4-25	NA	AIR	≈ 20	54.1	0.85	41.4	43.3	14
CA-47	1.25	PL	0.649	6.00	8.0	0.246	0.851	32.5	NA	1	NA	LN_2	≈ 20	55.4	0.88	44.6	46.8	14

1. PREVIOUSLY SUSTAINED AND MARKED
2. MAXIMUM SUSTAINED GROWTH NOT AT $\alpha = 0°$

Table 28: Liquid Nitrogen Temperature (-320°F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction (Continued)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)					PRECRACKING			TEST PREP.		TEST-ING	RESULTS				REFERENCE
			t	W	L	a	2c	σ (KSI)	R	CYCLES (X 1000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	LOADING RATE (KSI/MIN)	σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) (KSI $\sqrt{IN.}$)	K_{IE} (KSI $\sqrt{IN.}$)	
NB2-1A	0.25	SHEET	0.25	6.00	9.0	0.136	0.805	12	0.24	14	NA	AIR	NA	53.8	0.83	36.8	44.0	24
NB2-1B	0.25	SHEET	0.25	6.00	9.0	0.132	0.810	12	0.24	14	NA	AIR	NA	56.9	0.87	38.9	46.1	24
NB2-1C	0.25	SHEET	0.25	6.00	9.0	0.130	0.800	12	0.24	14	NA	AIR	NA	57.8	0.89	39.3	46.3	24
NB2-2A	0.25	SHEET	0.25	6.00	9.0	0.148	0.665	12	0.24	14	NA	AIR	NA	56.9	0.87	38.5	46.0	24
NB2-2B	0.25	SHEET	0.25	6.00	9.0	0.154	0.680	12	0.24	15	NA	AIR	NA	54.9	0.84	37.6	45.5	24
NB2-3A	0.25	SHEET	0.25	6.00	9.0	0.186	0.770	12	0.24	14	NA	AIR	NA	50.0	0.78	36.6	47.6	24
NB2-3B	0.25	SHEET	0.25	6.00	9.0	0.191	0.765	12	0.24	14	NA	AIR	NA	50.0	0.78	36.8	48.0	24
NB5-2A	1.00	PL	0.50	7.50	10.0	0.315	1.380	10	0.06	7	NA	AIR	NA	45.1	0.75	43.2	52.7	24
NB5-2B	1.00	PL	0.50	7.50	10.0	0.315	1.380	10	0.06	7.5	NA	AIR	NA	45.5	0.76	43.7	53.2	24
NB5-3A	1.00	PL	0.50	10.00	10.0	0.350	1.580	10	0.06	5.8	NA	AIR	NA	37.8	0.63	38.1	48.9	24
NB5-3B	1.00	PL	0.50	10.00	10.0	0.340	1.580	10	0.06	5	NA	AIR	NA	38.6	0.64	38.6	49.2	24
NB5-4A	1.00	PL	0.50	10.00	10.0	0.385	1.790	12	0.06	3.5	NA	AIR	NA	35.6	0.59	37.7	51.2	24
NB5-4B	1.00	PL	0.50	10.00	10.0	0.380	1.780	12	0.06	3	NA	AIR	NA	35.6	0.60	37.6	50.7	24
NB5-5A	1.00	PL	0.50	10.00	10.0	0.430	2.040	10	0.06	5	NA	AIR	NA	29.2	0.51	32.6	47.2	24
NB5-5B	1.00	PL	0.50	10.00	10.0	0.420	2.030	10	0.06	6	NA	AIR	NA	31.4	0.55	34.9	50.2	24
NB5-1A	1.00	PL	0.50	6.00	9.0	0.230	0.960	10	0.06	25	NA	AIR	NA	43.7	0.70	35.3	38.7	24
NB5-1B	1.00	PL	0.50	6.00	9.0	0.235	0.970	12	0.06	10	NA	AIR	NA	37.7	0.66	30.3	33.3	24

Table 28: Liquid Nitrogen Temperature (-320° F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction (Continued)

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t	W	L	a	2C	PRECRACKING σ (KSI)	R	CYCLES (x 1,000)	TEST PREP. SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING LOADING RATE (KSI/MIN)	RESULTS σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) KSI$\sqrt{IN.}$	K_{IE} KSI$\sqrt{IN.}$	REFERENCE
CA-48	1.25	RL	0.659	6.00	8.0	0.241	0.795	32.5	NA	1	NA	LN_2	≈ 20	49.5	0.78	38.4	40.1	14 [1]
AC-7	1.25	RL	0.650	6.00	8.0	0.313	0.912	25	NA	1.5	NA	LN_2	≈ 20	43.0	0.69	36.0	38.0	14 [1]
2A3N-1	1.0	RL	0.753	7.00	8.0	0.380	1.44	10	0.06	14.0	0.25	AIR	40	43.4	0.72	43.8	48.4	15
2A3N-2	1.0	RL	0.749	7.00	8.0	0.380	1.44	10	0.06	14.0	0.25	AIR	40	42.4	0.70	42.7	47.3	15
AS72-3	1.0	RL	0.751	8.97	14.0	0.430	1.84	8	NA	NA	NA	AIR	NA	43.6	0.73	48.5	56.7	2
AS72-4	1.0	RL	0.749	12.0	21.0	0.620	2.62	8	NA	NA	NA	AIR	NA	31.0	0.55	40.5	55.9	2
SBT-23	1.00	RL	1.01	6.00	11.0	0.320	1.34	25	0.06	4-6	NA	AIR	20-30	44.7	0.69	42.6	45.0	6
SBT-1	1.00	RL	1.01	6.00	11.0	0.380	1.36	25	0.06	4-6	NA	AIR	20-30	47.2	0.74	47.0	49.5	6
A-1	2.5	RL	1.102	6.01	9.0	0.539	1.370	10	0.06	4.0	0.25	AIR	35	37.4	0.61	38.7	39.9	15
A-2	2.5	RL	1.098	6.00	9.0	0.540	1.370	10	0.06	5.0	0.25	AIR	35	34.8	0.57	35.9	37.1	15
A-3	2.5	RL	1.102	6.01	9.0	0.368	1.480	12	0.06	8.0	0.25	AIR	35	39.5	0.63	39.6	41.8	15
A-4	2.5	RL	1.100	6.01	9.0	0.360	1.480	12	0.06	6.5	0.25	AIR	35	38.6	0.61	38.5	40.7	15
SA13-2	1.25	RL	1.231	6.00	8.0	0.342	1.341	20-25	NA	4-20	NA	AIR	≈ 20	40.3	0.63	38.8	40.4	13

[1] PREVIOUSLY SUSTAINED AND MARKED

Table 29: *Liquid Hydrogen Temperature (−423° F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. RT Propagation Direction*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)					PRECRACKING			TEST PREP.		TESTING	RESULTS				REFERENCE
			t	W	L	a	2C	σ (KSI)	R	CYCLES (x 1,000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	LOADING RATE (KSI/MIN)	σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) KSI$\sqrt{IN.}$	K_{IE} KSI$\sqrt{IN.}$	
AB24H-1	0.625	RL	0.644	9.00	6.0	0.225	2.425	≤16	NA	NA	NA	AIR	NA	49.7	0.75	46.29	50.73	3 [1]
AB24H-2	0.625	RL	0.643	9.00	6.0	0.228	2.430	≤16	NA	NA	NA	AIR	NA	49.6	0.75	46.53	51.06	3 [1]
AB36H-1	0.625	RL	0.647	5.50	10.0	0.355	0.956	≤16	NA	NA	NA	AIR	NA	54.7	0.83	47.77	50.56	3
AB36H-2	0.625	RL	0.625	5.50	10.0	0.352	0.930	≤16	NA	NA	NA	AIR	NA	56.9	0.86	49.23	52.06	3
AB45H-1	0.625	RL	0.641	6.75	10.0	0.422	1.176	≤16	NA	NA	NA	AIR	NA	49.9	0.77	47.88	53.09	3
AB45H-2	0.625	RL	0.633	6.75	10.0	0.410	1.161	≤16	NA	NA	NA	AIR	NA	51.2	0.79	46.81	54.15	3
AB54H-1	0.625	RL	0.642	6.75	10.0	0.476	1.361	≤16	NA	NA	NA	AIR	NA	44.3	0.70	45.32	52.62	3
AB54H-2	0.625	RL	0.627	6.75	10.0	0.476	1.371	≤16	NA	NA	NA	AIR	NA	44.8	0.71	45.99	54.00	3

[1] $\frac{W}{2C} < 4$

Table 30: Liquid Hydrogen Temperature (−423° F) Surface Flawed Fracture Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)					PRECRACKING			TEST PREP.		TESTING	RESULTS				REFERENCE
			t	W	L	a	2C	σ (KSI)	R	CYCLES (× 1,000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	LOADING RATE (KSI/MIN)	σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) $KSI\sqrt{IN.}$	K_{IE} $KSI\sqrt{IN.}$	
AA-4	1.25	RL	0.650	6.00	8.0	0.333	1.219	20-25	NA	4-25	NA	AIR	20	44.1	0.65	41.0	45.3	14
CA-9	1.25	RL	0.657	6.00	8.0	0.229	0.789	20-25	NA	4-25	NA	AIR	20	56.5	0.80	43.5	45.5	14
DA-16	1.25	RL	0.669	6.00	8.0	0.174	0.600	20-25	NA	4-25	NA	AIR	20	63.6	0.88	43.2	44.3	14
2A3H-1	1.0	RL	0.750	7.00	8.0	0.37[illegible]	1.44	10	0.06	15.0	0.25	AIR	40	46.7	0.74	47.2	52.1	15
2A3H-2	1.0	RL	0.751	7.00	8.0	0.384	1.44	10	0.06	14.0	0.25	AIR	40	46.8	0.76	47.5	52.5	15
A-9	2.5	RL	1.002	5.00	8.0	0.480	1.285	10	0.06	5.5	0.25	AIR	45	42.5	0.65	42.4	44.1	15 ▷1
A-10	2.5	RL	1.000	5.01	8.0	0.480	1.285	10	0.06	5.0	0.25	AIR	45	43.2	0.66	43.2	44.9	15 ▷1
A-11	2.5	RL	1.004	5.00	8.0	0.313	1.310	12	0.06	7.0	0.25	AIR	45	47.0	0.69	44.2	46.6	15 ▷1
A-12	2.5	RL	1.004	5.00	8.0	0.305	1.310	12	0.06	6.0	0.25	AIR	45	48.7	0.71	45.6	48.1	15 ▷1

▷1 $\frac{W}{2C} < 4$

Table 31: *Liquid Nitrogen Temperature (-320°F) Surface Flawed Fracture Tests of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. No Filler Wire. No Post Weld Heat Treatment*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)					PRECRACKING			TEST PREP.		TESTING	RESULTS				REFERENCE
			t	W	L	a	2C	σ (KSI)	R	CYCLES (x 1,000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	LOADING RATE (KSI/MIN)	σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) KSI$\sqrt{IN.}$	K_{IE} KSI$\sqrt{IN.}$	
1AW63N-2	1.00	RL	1.013	24.0	26	0.710	4.245	≈ 10	NA	NA	NA	AIR	NA	19.8	0.82	31.49		3
1AW75N-3	1.00	RL	1.037	30.0	26	0.735	5.035	≈ 10	NA	NA	NA	AIR	NA	15.4	0.63	24.69		3

Table 32: *Liquid Hydrogen Temperature (-423°F) Surface Flawed Fracture Tests of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. No Filler Wire. No Post Weld Heat Treatment*

SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)					PRECRACKING			TEST PREP.		TESTING	RESULTS				REFERENCE
			t	W	L	a	2C	σ (KSI)	R	CYCLES (x 1,000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	LOADING RATE (KSI/MIN)	σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_I (IRWIN) KSI$\sqrt{IN.}$	K_{IE} KSI$\sqrt{IN.}$	
1AW50H-1	1.0	RL	1.002	[illegible]	20	0.500	3.355	≈ 10	NA	NA	NA	AIR	NA	14.3	0.49	18.48		3
1AW63H-3	1.0	RL	1.010	20.0	26	0.620	4.165	≈ 10	NA	NA	NA	AIR	NA	17.3	0.60	25.21		3
1AW75H-1	1.0	RL	1.016	24.0	26	0.700	4.215	≈ 10	NA	NA	NA	AIR	NA	14.3	0.49	21.50		3
1AW90H-3	1.0	RL	1.010	30.0	26	0.840	5.970	≈ 10	NA	NA	NA	AIR	NA	11.6	0.41	19.41		3
3AW75H-3	1.0	RL	1.014	13.5	20	0.710	2.335	≈ 10	NA	NA	NA	AIR	NA	20.8	0.70	26.58		3
3AW83H-3	1.0	RL	1.007	16.0	20	0.775	2.490	≈ 10	NA	NA	NA	AIR	NA	20.7	0.71	28.29		3
3AW90H-3	1.0	RL	0.998	16.0	20	0.835	2.895	≈ 10	NA	NA	NA	AIR	NA	18.8	0.66	27.20		3
3AW96H-3	1.0	RL	1.000	16.0	20	0.870	2.985	≈ 10	NA	NA	NA	AIR	NA	17.0	0.61	24.91		3

Table 33: Room Temperature ($70^{o}F-75^{o}F$) Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy.

ENVIRONMENT	SPECIMEN I D	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCH) t	W	L	a	2C	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_i (INCH)	$2C_i$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI $\sqrt{IN.}$)	K_{Ii} (KSI $\sqrt{IN.}$)	K_{If} (IRWIN) (KSI $\sqrt{IN.}$)	K_{If} (KSI $\sqrt{IN.}$)	COMMENTS	REFERENCE
AIR	21T	0.125	SH	WT	0.1257	1.504	NA	0.063	0.245	20	NA	NA	NA	AIR	45.0	0.82	0.063	NA	67.1	18.9	21.0			NF 3	26
	24T	0.125	SH	WT	0.1252	1.504	NA	0.066	0.264	20	NA	NA	NA	AIR	46.7	0.85	0.073	NA	68.4	20.4	23.0			NF 3	26
	25T	0.125	SH	WT	0.1252	1.502	NA	0.065	0.253	20	NA	NA	NA	AIR	46.7	0.85	0.078	NA	72.0	20.1	22.4	--		NF 3	26
	22T	0.125	SH	WT	0.1257	1.506	NA	0.063	0.254	20	NA	NA	NA	4	45.0	0.82	0.063	NA	67.1	19.1	21.3		--	NF 3	26
	23T	0.125	SH	WT	0.1255	1.518	NA	0.064	0.252	20	NA	NA	NA	4	46.2	0.84	0.064	NA	68.4	19.7	22.0	—		NF 3	26
	26T	0.125	SH	WT	0.1257	1.509	NA	0.063	0.252	20	NA	NA	NA	4	46.4	0.84	0.077	NA	72.0	19.8	21.9	--		NF 3	26
	SBT-3	1.0	RL	WT	1.01	6.0	11	0.32	1.41	25	NA	4-6	NA	AIR	39.5	0.80	—	-	32.50	38.4	40.6	38.4	40.6	NG	6
	SBT-12	1.0	RL	WT	1.01	6.0	11	0.28	1.32	25	NA	4-6	NA	AIR	41.6	0.86	-	—	34.75	38.6	40.5	38.6	40.5	NG	6
	SBT-13	1.0	RL	WT	1.01	6.0	11	0.31	1.28	25	NA	4-6	NA	AIR	43.3	0.84	0.356	1.28	0.05	41.1	43.2	42.2	44.3	FAILURE	6
	SBT-14	1.0	RL	WT	1.01	6.0	11	0.27	1.26	25	NA	4-6	NA	AIR	42.8	0.87		-	24.0	39.0	40.8	39.0	40.8	NG	6
	AR-2	1.0	RL	WT	0.606	6.00	8.0	0.252	0.925	12	NA	NA	NA	AIR	44.5	0.80	0.260	0.925	L/U	36.8	39.1	37.0	39.4	NF	22
	AR-3	1.0	RL	WT	0.607	5.98	8.0	0.243	0.925	12	NA	NA	NA	AIR	44.5	0.80	0.25	0.925	1.0	36.6	38.7	36.8	39.1	NF	22
	AR-4	1.0	RL	WT	0.591	6.00	8.0	0.249	0.915	12	NA	NA	NA	AIR	44.5	0.80	0.259	0.915	20.0	36.6	39.0	36.9	39.3	NF	22
	C4-1	1.25	RL	WT	0.653	6.00	8.0	0.051	0.178	30	NA	6	NA	AIR	45.0	0.78	0.051	0.178	1.0	16.4	16.5	16.4	16.5	NG	14
	AC-7	1.25	RL	WT	0.650	6.00	8.0	0.214	0.834	15	NA	9	NA	AIR	33.0	0.57	0.218	0.834	1.0	25.0	26.3	25.1	26.4	NF 1	14
	AC-7	1.25	RL	WT	0.650	6.00	8.0	0.258	0.872	20	NA	15	NA	LN2	39.1	0.68	0.272	0.876	1.0	31.4	32.9	31.8	33.3	NF 1 2	14
	AC-8	1.25	RL	WT	0.661	6.00	8.0	0.175	0.828	15	NA	7	NA	AIR	23.7	0.41	0.175	0.828	1.0	16.8	17.6	16.8	17.6	NG	14
	AC-8	1.25	RL	WT	0.661	6.00	8.0	0.260	0.887	27.9	NA	6	NA	LN2	27.9	0.48	0.260	0.887	1.0	22.2	23.3	22.2	23.3	NG 2	14

L/U = LOAD/UNLOAD TEST
NF = GROWTH WITH NO FAILURE
NG = NO GROWTH

1 MAXIMUM GROWTH DID NOT OCCUR AT $a = 0^{o}$

2 TESTED PREVIOUSLY

3 PRECRACKED IN BENDING

4 10% NaOH ETCH

Table 33: Room Temperature ($70^{o}F-75^{o}F$) Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy (Continued)

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCH) t	W	L	a_i	$2C_i$	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (INCH)	$2C_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI$\sqrt{IN.}$)	K_{Ii} (KSI$\sqrt{IN.}$)	K_{If} (IRWIN) (KSI$\sqrt{IN.}$)	K_{If} (KSI$\sqrt{IN.}$)	COMMENTS	REFERENCE
AIR (Cont)	AA-50	1.25	PL	WT	0.668	6.00	8.0	0.335	1.317	15	NA	4	NA	AIR	33.8	0.58	–	–	0.1	32.2	35.6	–	–	FAILURE [1]	14
	AA-51	1.25	PL	WT	0.661	6.00	8.0	0.304	1.210	15	NA	5	NA	AIR	32.0	0.52	0.310	1.253	15.3	29.0	31.7	29.4	32.3	NF [1]	14
	AA-1	1.25	PL	WT	0.660	6.00	8.0	0.322	1.191	10	NA	20	NA	AIR	33.8	0.58	0.347	1.360	38.6	31.0	33.9	32.7	36.7	NF [1]	14
	CA-37	1.25	PL	WT	0.665	6.00	8.0	0.205	0.763	15	NA	9	NA	AIR	41.9	0.72	0.210	0.775	24.0	31.1	32.6	31.4	32.9	NF [1]	14
	CA-37	1.25	PL	WT	0.665	6.00	8.0	0.212	0.815	27.9	NA	1	NA	AIR	44.2	0.76	0.215	0.818	20.3	33.9	35.6	34.0	35.7	NF [1] [2]	14
	CA-37	1.25	PL	WT	0.665	6.00	8.0	0.224	0.816	27.9	NA	1	NA	AIR	46.5	0.80	–	...	0.7	36.2	38.0	...		FAILURE [1] [2]	14
	CA-12	1.25	PL	WT	0.656	6.00	8.0	0.263	0.831	15	NA	25	NA	AIR	43.0	0.74	...	–	0.9	34.3	35.8	–	–	FAILURE	14
	CA-39	1.25	PL	WT	0.661	6.00	8.0	0.207	0.761	15	NA	10	NA	AIR	39.5	0.68	0.216	0.771	19.0	29.2	30.6	29.6	31.0	NF [1]	14
	CA-39	1.25	PL	WT	0.661	6.00	8.0	0.225	0.785	27.9	NA	1	NA	AIR	41.9	0.72	0.229	0.811	21.5	31.9	33.4	32.4	34.0	NF [1] [2]	14
	CA-39	1.25	PL	WT	0.661	6.00	8.0	0.240	0.810	27.9	NA	1	NA	AIR	44.2	0.76	0.243	0.829	1.6	34.6	36.1	34.9	36.5	NF [1] [2]	14
	CA-42	1.25	PL	WT	0.680	6.00	8.0	0.200	0.779	15	NA	11	NA	AIR	34.9	0.60	0.202	0.779	17.2	25.6	26.8	25.7	26.9	NF [1]	14
	CA-42	1.25	PL	WT	0.680	6.00	8.0	0.226	0.851	27.9	NA	2	NA	AIR	41.9	0.72	0.228	0.851	4.6	32.8	34.5	32.8	34.5	NF [1] [2]	14
	CA-10	1.25	PL	WT	0.643	6.01	8.0	0.217	0.766	15	NA	12	NA	AIR	43.0	0.74	0.228	0.778	38.1	32.4	33.9	32.8	34.3	NF [1]	14
	DA-32	1.25	PL	WT	0.668	6.00	8.0	0.161	0.560	15	NA	14	NA	AIR	48.1	0.83	0.176	0.603	24.0	31.4	32.2	32.6	33.7	NF	14
	DA-25	1.25	PL	WT	0.664	6.00	8.0	0.165	0.597	15	NA	10	NA	AIR	34.8	0.60	0.176	0.603	14.2	22.7	23.4	23.1	23.8	NF	14
	CA-43	1.25	PL	WT	0.658	6.00	8.0	0.219	0.833	15	NA	18	NA	AIR	40.0	0.69	0.225	0.338	123.7	30.8	32.4	31.0	32.6	NF	14
	CA-41	1.25	PL	WT	0.656	6.00	8.0	0.220	0.805	15	NA	13	NA	AIR	32.5	0.56	0.220	0.805	115.6	24.5	25.7	24.5	25.7	NG	14
	C-8	1.25	PL	WT	0.604	6.00	8.0	0.215	0.813	15	NA	15	NA	AIR	40.0	0.69	0.223	0.813	0.02	30.5	32.1	30.7	32.3	NF [1]	14

NF = GROWTH WITH NO FAILURE
NG = NO GROWTH

[1] MAXIMUM GROWTH DID NOT OCCUR AT $a = 0^{o}$

[2] TESTED PREVIOUSLY

Table 33: Room Temperature (70°F–75°F) Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy (Continued)

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCH) t	W	L	a_i	$2c_i$	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP. SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (INCH)	$2c_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI $\sqrt{IN.}$)	K_{Ii} (KSI $\sqrt{IN.}$)	K_{If} (IRWIN) (KSI $\sqrt{IN.}$)	K_{If} (KSI $\sqrt{IN.}$)	COMMENTS	REFERENCE
AIR (Cont)	C-4	1.25	PL	WT	0.671	6.00	8.0	0.248	0.858	15	NA	17	NA	AIR	40.0	0.69	0.256	0.861	1.33	31.8	33.4	32.0	33.5	NF 1	14
	C-6	1.25	PL	WT	0.656	6.00	8.0	0.236	0.847	15	NA	15	NA	AIR	23.7	0.41	0.247	0.858	1.00	18 2	19.1	18.4	19.3	NF	14
	C-7	1 25	PL	WT	0.652	6.00	8.0	0.252	0.861	15	NA	15	NA	AIR	23.7	0.41	0.259	0.867	4.70	18 5	19.4	18.7	19.5	NF	14
	C-9	1.25	PL	WT	0.653	6.00	8.0	0.233	0.828	15	NA	15	NA	AIR	23.7	0.41	0.238	0.834	30.00	18 0	18.9	18.2	19.0	NF	14
	C8-1	1.25	PL	WT	0.655	6.00	8.0	0.148	0.561	20	NA	6	NA	AIR	45.0	0.78	0.150	0.561	1.0	28 7	29.4	28.8	29.5	NF	14
	C6-1	1.25	PL	WT	0.653	6.00	8.0	0.095	0.322	25	NA	6	NA	AIR	45.0	0.78	0.095	0 372	1.0	22.2	22.5	22.2	22.5	NG	14
	C-3	1.25	PL	WT	0.660	6.00	8.0	0.262	0.848	15	NA	20	NA	AIR	40.0	0.69	0.265	0.851	0.08	32.0	33.4	32.1	33.5	NF 1	14
	C-1	1 25	PL	WT	0.663	6.00	8.0	0.241	0.843	15	NA	15	NA	AIR	40.0	0.69	0.248	0.846	0.17	31.5	33.0	31.7	33.2	NF 1	14
	C-5	1.25	PL	WT	0.645	6.00	8.0	0.245	0.860	15	NA	15	NA	AIR	40.0	0.69	0.250	0.860	0.33	31.8	33.4	31.9	33.4	NF 1	14
	C-2	1.25	PL	WT	0.652	6.00	8.0	0.247	0.853	15	NA	15	NA	AIR	40.0	0.69	0.256	0.853	0.67	31.7	33.3	31.9	33.4	NF 1	14
	CA-44	1.25	PL	WT	0.663	6.00	8.0	0.218	0.830	15	NA	18	NA	AIR	40.0	0.69	0.223	0.831	1.00	30.7	32.3	30.9	32.4	NF	14
	A3A-27	1.0	PL	WT	0.400	5.002	7.0	0.143	0.570	NA	NA	NA	NA	AIR	50.0	0.90	0.148	0.570	L/U	32.4	34 3	32.6	34.5	NF	5
3-1/2% NaCL	A3A-26	1.0	PL	WT	0.399	5.004	7.0	0.191	0.568	NA	NA	NA	NA	AIR	50.0	0.90	0.149	0.568	10.0	32.3	34.1	32.6	34.5	NF	5
	A3A-28	1.0	PL	WT	0.402	5.006	7.0	0.169	0.649	NA	NA	NA	NA	AIR	49.2	0.88	0.183	0.652	10.0	34.2	36.6	34.7	37.3	NF	5
	A3A-30	1.0	PL	WT	0.405	5.005	7.0	0.121	0.470	NA	NA	NA	NA	AIR	50.0	0 90	0.125	0.470	10 0	29 6	31.0	29 7	31.1	NF	5
	AS-1	1.0	PL	WT	0.598	6.00	8.0	0.249	0.920	12	NA	NA	NA	AIR	44.6	0.80	0.253	0.920	16.0	36 7	39.1	36.9	39.2	NF	22
	SBT-18	1.0	PL	WT	1.01	6.0	11	0.31	1.29	25	NA	4-6	NA	AIR	39.7	0.87	–	–	24.0	37.4	39 4	37.4	39.4	NG	6
	SBT-15	1.0	PL	WT	1.01	6.0	11	0.32	1.37	25	NA	4-6	NA	AIR	40.7	0.81	0.45	1.54	1.75	39.4	41.6	43.7	40 5	FAILURE	6

L/U = LOAD/UNLOAD TEST
NF = GROWTH WITH NO FAILURE
NG = NO GROWTH

1 MAXIMUM GROWTH DID NOT OCCUR AT $a = 0°$

Table 33: Room Temperature (70^0 F–75^0 F) Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy (Continued)

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCH) t	W	L	a_i	$2C_i$	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (INCH)	$2C_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI$\sqrt{IN.}$)	K_{Ii} (KSI$\sqrt{IN.}$)	K_{If} (IRWIN) (KSI$\sqrt{IN.}$)	K_{If} (KSI$\sqrt{IN.}$)	COMMENTS	REFERENCE
GH_2	H-1	1.0	PL	WT	0.601	6.00	8.0	0.243	0.920	12	NA	NA	NA	AIR	44.6	0.80	0.246	0.920	10.0	36.6	38.8	36.7	38.9	NF	22
	H-2	1.0	PL	WT	0.603	6.00	8.0	0.240	0.920	12	NA	NA	NA	AIR	44.6	0.80	0.243	0.920	10.0	36.5	38.7	36.6	38.8	NF	22
DISTILLED H_2O	AW-1	1.0	PL	WT	0.600	6.00	8.0	0.255	0.925	12	NA	NA	NA	AIR	44.6	0.80	0.263	0.925	16.0	37.0	39.4	37.2	39.6	NF	22
	AW-2	1.0	PL	WT	0.605	6.00	8.0	0.246	0.925	12	NA	NA	NA	AIR	44.6	0.80	0.251	0.925	27.1	36.7	39.0	36.9	39.2	NF	22
DYE PENETRANT	AD-1	1.0	PL	WT	0.603	6.00	8.0	0.264	0.925	12	NA	NA	NA	AIR	44.6	0.80	0.274	0.925	15.0	37.2	39.6	37.4	39.9	NF 1	22
	AD-2	1.0	PL	WT	0.604	6.00	8.0	0.264	0.930	12	NA	NA	NA	AIR	42.0	0.76	0.269	0.930	16.1	34.9	37.2	35.0	37.4	NF	22
FLOX	X-1	1.0	PL	WT	0.602	6.00	8.0	0.243	0.920	12	NA	NA	NA	AIR	44.6	0.80	0.246	0.920	10.0	36.6	38.8	36.7	38.9	NF	22
	FX-2	1.0	PL	WT	0.598	6.00	8.0	0.237	0.915	12	NA	NA	NA	AIR	44.6	0.80	0.240	0.915	8.0	36.3	38.5	36.4	38.6	NF	22
	FX-1	1.0	PL	WT	0.598	6.00	8.0	0.240	0.915	12	NA	NA	NA	AIR	44.6	0.80	0.246	0.915	0.3	36.4	38.6	36.6	38.9	NF	22
OF_2	OF-1	1.0	PL	WT	0.595	5.97	8.0	0.243	0.925	12	NA	NA	NA	AIR	44.6	0.80	0.249	0.925	11.0	36.6	39.0	36.8	39.2	NF	22
	OF-3	1.0	PL	WT	0.596	6.00	8.0	0.243	0.915	12	NA	NA	NA	AIR	44.6	0.80	0.249	0.915	10.4	36.0	38.2	36.2	38.5	NF	22
ARGON	AA-1	1.0	PL	WT	0.604	6.00	8.0	0.246	0.925	12	NA	NA	NA	AIR	44.5	0.80	0.256	0.925	L/U	36.6	38.9	36.9	39.3	NF	22
	AA-2	1.0	PL	WT	0.610	6.00	8.0	0.252	0.925	12	NA	NA	NA	AIR	44.5	0.80	0.262	0.925	1.0	36.8	39.1	37.1	39.5	NF	22
TRICHLORO-ETHYLENE	AT-1	1.0	PL	WT	0.589	6.01	8.0	0.264	0.923	12	NA	NA	NA	AIR	44.6	0.80	0.269	0.923	16.2	37.2	39.7	37.3	39.9	NF	22
	AT-2	1.0	PL	WT	0.603	6.00	8.0	0.252	0.925	12	NA	NA	NA	AIR	42.0	0.76	0.257	0.925	15.7	34.6	36.7	34.7	36.9	NF	22
GO_2	O-1	1.0	PL	WT	0.602	6.00	8.0	0.246	0.930	12	NA	NA	NA	AIR	44.6	0.80	0.255	0.930	10.0	36.8	39.1	37.0	39.4	NF	22
	O-2	1.0	PL	WT	0.600	6.00	8.0	0.249	0.920	12	NA	NA	NA	AIR	44.6	0.80	0.258	0.920	12.0	36.7	39.1	37.0	39.4	NF	22
172 dB NOISE LEVEL	NBT-19	1.0	PL	WT	1.01	6.0	11	0.31	1.33	25	NA	4-6	NA	AIR	43.3	0.84	0.38	1.33	0	41.5	43.7	43.2	45.4	FAILURE	6
	NBL-20	1.0	PL	RT	1.00	6.0	11	0.32	1.29	25	NA	4-6	NA	AIR	49.8	0.76	–	–	0.01	48.4	51.0	48.4	51.0	FAILURE	6

L/U = LOAD/UNLOAD TEST
NF = GROWTH WITH NO FAILURE

1 LOADED TWICE, ONCE FOR 5 HOURS AND ONCE FOR 10 HOURS

Table 33: Room Temperature (70°F - 75°F) Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy (Continued)

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM		SPECIMEN DIMENSIONS (INCH) t	W	L	a_i	$2C_i$	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (INCH)	$2C_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI $\sqrt{IN.}$)	K_{Ii} (KSI $\sqrt{IN.}$)	K_{If} (IRWIN) (KSI $\sqrt{IN.}$)	K_{If} (KSI $\sqrt{IN.}$)	COMMENTS	REFERENCE
AIR Cont'd	SRB5-1	1.0	PL	WT	0.50	6.00	10.0	0.202	0.860	12	NA	15	NA	AIR	40.1	0.73	0.206	0.860	44.8	30.7	32.9	30.9	33.2	NF [1]	24
	SRB5-2	1.0	PL	WT	0.50	6.00	10.0	0.200	0.860	10	NA	25	NA	AIR	38.5	0.70	0.204	0.860	29.1	29.3	31.4	29.5	31.6	NF [1]	24
	SRB5-4	1.0	PL	WT	0.50	6.00	10.0	0.189	0.860	12	NA	12	NA	AIR	29.1	0.53	0.189	0.860	90.6	21.5	23.0	21.5	23.0	NG [1]	24
	SRB5-4	1.0	PL	WT	0.50	6.00	10.0	0.189	0.860	20	NA	4	NA	AIR	43.5	0.79	0.190	0.860	22.9	33.0	35.4	33.1	35.5	NF [1] [2]	24
	SRB5-4	1.0	PL	WT	0.50	6.00	10.0	0.195	0.860	20	NA	8	NA	AIR	43.5	0.79	0.202	0.860	18.1	33.3	35.7	33.6	36.0	NF [1] [2]	24
	SRB5-5	1.0	PL	WT	0.50	6.00	10.0	0.195	0.860	12	NA	15	NA	AIR	44.6	0.81	0.200	0.860	20.4	34.2	36.7	34.5	36.9	NF [1]	24

NF = GROWTH WITH NO FAILURE

NG = NO GROWTH

[1] DOUBLE V WELD EDGE PREPARATION

[2] TESTED PREVIOUSLY

Table 34: -230°F Temperature Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCH) t	W	L	a_i	$2C_i$	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP. SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (INCH)	$2C_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI $\sqrt{IN.}$)	K_{IEi} (KSI $\sqrt{IN.}$)	K_{If} (IRWIN) (KSI $\sqrt{IN.}$)	K_{IEf} (KSI $\sqrt{IN.}$)	COMMENTS	REFERENCE
172 dB NOISE LEVEL	NBL-28	1.0	PL	RT	1.00	6.0	11	0.30	1.29	25	NA	4-6	NA	NA	49.1	0.85	–	–	24.01	46.3	48.7	46.3	48.7	NG	6
	NBL-21	1.0	PL	RT	1.00	6.0	11	0.28	1.28	25	NA	4-6	NA	NA	51.7	0.86	–	–	18.30	48.1	50.4	48.1	50.4	NG	6
	NBL-24	1.0	PL	RT	1.00	6.0	11	0.31	1.30	25.0	NA	4-6	NA	NA	51.7	0.80		–	4.74	49.4	52.1	49.4	52.1	NG	6

NG – NO GROWTH

Table 35: *Liquid Nitrogen Temperature (-320°F) Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy*

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCH) t	W	L	a_i	$2c_i$	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (INCH)	$2c_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI $\sqrt{IN.}$)	K_{Ii} (KSI $\sqrt{IN.}$)	K_{If} (IRWIN) (KSI $\sqrt{IN.}$)	K_{If} (KSI $\sqrt{IN.}$)	COMMENTS	REFERENCE
LN_2	A3A-5	1.0	PL	WT	0.397	5.006	7.0	0.145	0.528	NA	NA	NA	0.25	AIR	60.0	0.91	0.155	0.528	10.0	38.1	40.1	38.5	40.4	NF	5
	A3A-6	1.0	PL	WT	0.400	5.002	7.0	0.150	0.570	NA	NA	NA	0.25	AIR	60.0	0.91	0.188	0.728	7.7	39.3	41.5	44.2	48.3	NF ▷3	5
	A3A-12	1.0	PL	WT	0.398	5.004	7.0	0.116	0.430	NA	NA	NA	0.25	AIR	60.0	0.91	0.120	0.431	10.0	34.3	35.8	34.5	36.0	NF	5
	A3A-25	1.0	PL	WT	0.399	5.003	7.0	0.132	0.531	NA	NA	NA	0.25	AIR	60.0	0.91	0.142	0.535	L/U	37.5	40.0	38.1	40.2	NF	5
	AA-58	1.25	PL	WT	0.660	6.00	8.0	0.321	1.196	15	NA	5	NA	AIR	39.6	0.60	--		0.03	36.4	39.8	—		FAILURE	14
	AA-49	1.25	PL	WT	0.666	6.00	8.0	0.305	1.192	15	NA	5	NA	AIR	37.5	0.57	0.330	1.356	19.7	33.9	36.9	35.8	39.8	NF ▷1	14
	AA-49	1.25	PL	WT	0.666	6.00	8.0	0.332	1.358	25	NA	1	NA	LN_2	39.6	0.60	—	—	0.12	38.0	42.2	—	—	FAILURE ▷1 ▷2	14
	AA-52	1.25	PL	WT	0.663	6.00	8.0	0.313	1.192	15	NA	5	NA	AIR	38.5	0.58	0.313	1.192	0.003	35.1	38.3	35.1	38.3	NG	14
	CA-11	1.25	PL	WT	0.658	6.00	8.0	0.229	0.804	15	NA	10	NA	AIR	48.6	0.74	—	—	17.1	37.5	39.3	—	—	FAILURE	14
	CA-38	1.25	PL	WT	0.664	6.00	8.0	0.207	0.785	15	NA	11	NA	AIR	48.7	0.74	0.212	0.800	18.8	36.6	38.4	37.0	38.8	NF ▷1	14
	CA-38	1.25	PL	WT	0.664	6.00	8.0	0.228	0.814	32.5	NA	1	NA	LN_2	51.4	0.78	0.237	0.840	21.8	40.0	41.9	40.7	42.6	NF ▷1 ▷2	14
	CA-38	1.25	PL	WT	0.664	6.00	8.0	0.241	0.849	32.5	NA	1	NA	LN_2	54.1	0.82	—	—	0.21	43.3	45.4	—	—	FAILURE ▷1 ▷2	14
	CA-47	1.25	PL	WT	0.649	6.00	8.0	0.216	0.848	15	NA	10	NA	AIR	50.1	0.76	0.242	0.849	24.6	39.0	41.0	39.8	41.8	NF ▷1	14
	DA-17	1.25	PL	WT	0.641	6.00	8.0	0.168	0.599	15	NA	16	NA	AIR	56.4	0.85	0.170	0.600	48.0	38.0	39.3	38.1	39.4	NF	14
	DA-35	1.25	PL	WT	0.658	6.00	8.0	0.165	0.545	15	NA	20	NA	AIR	59.5	0.90	·	—	0.05	38.9	40.0	—		FAILURE	14
	DA-31	1.25	PL	WT	0.665	6.00	8.0	0.156	0.574	15	NA	18	NA	AIR	56.4	0.85	0.184	0.600	18.9	37.0	38.0	38.6	39.8	NF ▷1	14
	AC-9	1.25	PL	WT	0.655	6.00	8.0	0.227	0.784	15	NA	11	NA	AIR	30.1	0.46	0.227	0.784	1.0	22.5	23.5	22.5	23.5	NG	14
	AC-9	1.25	PL	WT	0.655	6.00	8.0	0.321	1.053	20	NA	15	NA	LN_2	33.6	0.51	0.326	1.058	1.0	29.4	31.6	29.6	31.8	NF ▷2	14

L/U = LOAD / UNLOAD TEST
NF = GROWTH WITH NO FAILURE
NG = NO GROWTH
▷1 MAXIMUM GROWTH DID NOT OCCUR AT $\alpha = 0°$
▷2 TESTED PREVIOUSLY
▷3 UNLOADED JUST PRIOR TO FAILURE, DELAMINATED

Table 35: Liquid Nitrogen Temperature (-320°F) Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy (Continued)

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCH) t	W	L	a_i	$2c_i$	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (INCH)	$2c_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI$\sqrt{IN.}$)	K_{Ii} (KSI$\sqrt{IN.}$)	K_{If} (IRWIN) (KSI$\sqrt{IN.}$)	K_{If} (KSI$\sqrt{IN.}$)	COMMENTS	REFERENCE
LN_2 (CONT)	DA-31	1.25	PL	WT	0.665	6.00	8.0	0.191	0.619	37.6	NA	1	NA	LN_2	59.5	0.90	–	–	0.02	41.6	43.1	–		FAILURE (1) (2)	14
	CA-40	1.25	PL	WT	0.673	6.00	8.0	0.212	0.795	15	NA	13	NA	AIR	43.3	0.66	0.224	0.812	120.0	32.5	34.1	33.1	34.7	NF	14
	CA-40	1.25	PL	WT	0.673	6.00	8.0	0.238	0.864	32.5	NA	1	NA	LN_2	48.7	0.74	–	–	0.2	38.7	40.7	–	–	FAILURE (2)	14
	CA-48	1.25	PL	WT	0.659	6.00	8.0	0.213	0.750	15	NA	10	NA	AIR	37.9	0.57	0.216	0.750	125.1	27.8	29.1	27.9	29.1	NF	14
	AC-7	1.25	PL	WT	0.650	6.00	8.0	0.312	0.912	20	NA	30	NA	LN_2	32.0	0.48	0.312	0.912	1.0	26.5	27.9	26.5	27.9	NG	14
	SBT-24	1.0	PL	WT	1.01	6.0	11	0.30	1.28	25	NA	4~6	NA	AIR	44.0	0.75	–	–	24.0	40.8	42.9	40.8	42.9	NG	6
	SBT-21	1.0	PL	WT	1.00	6.0	11	0.29	1.30	25	NA	4~6	NA	AIR	45.5	0.71	0.37	1.42	0.25	42.1	44.2	45.6	48.2	FAILURE	6
	SBT-22	1.0	PL	WT	1.01	6.0	11	0.31	1.28	25	NA	4~6	NA	AIR	46.2	0.75	0.40	1.35	1.75	43.3	45.6	46.3	48.5	FAILURE	6
	SBL-26	1.0	PL	RT	1.01	6.0	11	0.29	1.29	25	NA	4~6	NA	AIR	52.0	0.83	–	–	21.75	48.6	51.0	48.6	51.0	NG	6
	SBL-27	1.0	PL	RT	1.01	6.0	11	0.30	1.28	25	NA	4~6	NA	AIR	54.0	0.86	0.39	1.50	3.00	50.9	53.6	56.4	59.7	FAILURE	6
	SBL-16	1.0	PL	RT	1.00	6.0	11	0.29	1.27	25	NA	4~6	NA	AIR	55.0	0.87	0.35	1.40	3.00	51.5	54.1	55.1	58.3	FAILURE	6
	SBL-15	1.0	PL	RT	1.00	6.0	11	0.30	1.30	25	NA	4~6	NA	AIR	56.3	0.89	0.37	1.40	0.40	53.6	56.5	57.2	60.4	FAILURE	6
	SBL-14	1.0	PL	RT	1.00	6.0	11	0.30	1.27	25	NA	4~6	NA	AIR	57.4	0.87	–	–	0.10	55.7	58.6	55.7	58.6	FAILURE	6
	BS3-1	0.5	PL	RT	0.50	6.00	11	0.19	0.76	25	NA	NA	NA	AIR	54.5	0.80	?	?	0.15	40.2	42.7	–	–	FAILURE	23
	BS3-2	0.5	PL	RT	0.50	6.00	11	0.18	0.75	25	NA	NA	NA	AIR	54.0	0.80	0.21	0.78	4.75	39.2	41.6	40.9	43.6	NF	23
	BS3-3	0.5	PL	RT	0.50	5.99	11	0.19	0.76	25	NA	NA	NA	AIR	53.0	0.78	?	?	0.90	39.0	41.4	–	–	FAILURE	23
GH_2	H-3	1.0	PL	WT	0.600	6.00	8.0	0.242	0.920	12	NA	NA	NA	AIR	47.0	0.71	0.248	0.920	1.0	38.1	40.5	38.3	40.7	NF	22
	H-4	1.0	PL	WT	0.600	6.00	8.0	0.261	0.920	12	NA	NA	NA	AIR	47.0	0.71	0.267	0.920	20.1	38.7	41.2	38.8	41.4	NF	22

NF = GROWTH WITH NO FAILURE
NG = NO GROWTH
(1) MAXIMUM GROWTH DID NOT OCCUR AT $a = 0°$
(2) TESTED PREVIOUSLY

Table 35: Liquid Nitrogen Temperature (-320°F) Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy (Continued)

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCH) t	W	L	a_i	$2C_i$	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (INCH)	$2C_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI $\sqrt{IN.}$)	K_{Ii} (KSI $\sqrt{IN.}$)	K_{If} (IRWIN) (KSI $\sqrt{IN.}$)	K_{If} (KSI $\sqrt{IN.}$)	COMMENTS	REFERENCE
FLOX	FX-3	1.0	PL	WT	0.597	6.00	8.0	0.237	0.920	12	NA	NA	NA	AIR	47.0	0.71	0.240	0.920	8.0	38.0	40.3	38.1	40.4	NF	22
	FX-4	1.0	PL	WT	0.600	6.00	8.0	0.246	0.920	12	NA	NA	NA	AIR	47.0	0.71	0.249	0.920	10.1	38.2	40.6	38.3	40.7	NF	22
OF_2	OF-2	1.0	PL	WT	0.601	5.97	8.0	0.240	0.925	12	NA	NA	NA	AIR	47.0	0.71	0.249	0.925	10.0	38.7	41.1	39.0	41.5	NF	22
	OF-4	1.0	PL	WT	0.604	6.[illegible]	8.0	0.243	0.920	12	NA	NA	NA	AIR	47.0	0.71	0.249	0.920	10.1	38.2	40.5	38.3	40.7	NF	22
LO_2	O-3	1.0	PL	WT	0.600	6.00	8.0	0.252	0.925	12	NA	NA	NA	AIR	47.0	0.71	0.258	0.925	10.0	38.5	41.0	38.7	41.2	NF	22
	O-7	1.0	PL	WT	0.599	6.00	8.0	0.252	0.920	12	NA	NA	NA	AIR	47.0	0.71	0.261	0.920	10.0	38.4	40.9	38.7	41.2	NF	22

NF = GROWTH WITH NO FAILURE

Table 36: -413°F Temperature Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCH) t	W	L	a_i	$2C_i$	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (INCH)	$2C_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI $\sqrt{IN.}$)	K_{Ii} (KSI $\sqrt{IN.}$)	K_{If} (IRWIN) (KSI $\sqrt{IN.}$)	K_{If} (KSI $\sqrt{IN.}$)	COMMENTS	REFERENCE
GH_2	H-5	1.0	PL	WT	0.599	6.00	8.0	0.240	0.910	12	NA	NA	NA	AIR	50.8	0.74	0.246	0.910	20.0	41.1	43.6	41.3	43.8	NF	22
	H-7	1.0	PL	WT	0.605	6.00	8.0	0.268	0.935	12	NA	NA	NA	AIR	50.8	0.74	0.270	0.935	10.0	42.3	45.2	42.4	45.2	NF	22
	H-10	1.0	PL	WT	0.600	6.00	8.0	0.243	0.970	12	NA	NA	NA	AIR	45.1	0.65	0.243	0.970	1.0	37.6	40.1	37.6	40.1	NG	22

NF = GROWTH WITH NO FAILURE
NG = NO GROWTH

Table 37: *Liquid Hydrogen Temperature ($-423^{\circ}F$) Surface Flawed Sustained Load Tests of 2219-T87 Aluminum Alloy*

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCH) t	W	L	a_i	$2C_i$	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (INCH)	$2C_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI$\sqrt{IN.}$)	K_{Ii} (KSI$\sqrt{IN.}$)	K_{If} (IRWIN) (KSI$\sqrt{IN.}$)	K_{If} (KSI$\sqrt{IN.}$)	COMMENTS	REFERENCE
LH_2	A2C-5	1.0	PL	WT	0.400	2.250	4.0	0.113	0.443	NA	NA	NA	0.25	AIR	65.0	0.91	0.120	0.443	L/U	37.3	38.9	37.7	39.4	NF	5
	A2C-2X	1.0	PL	WT	0.403	2.254	4.0	0.090	0.370	NA	NA	NA	0.25	AIR	65.0	0.91	0.092	0.370	L/U	33.8	34.6	33.9	34.8	NF	5
	A2C-4	1.0	PL	WT	0.399	2.249	4.0	0.109	0.438	NA	NA	NA	0.25	AIR	65.0	0.91	?	?	4.3	36.9	38.4	—	—	FAILURE	5
	A2C-17	1.0	PL	WT	0.400	2.251	4.0	0.122	0.500	NA	NA	NA	0.25	AIR	65.0	0.91	0.164	0.540	2.2	39.3	41.3	41.3	44.5	FAILURE (1)	5
	A2C-1X	1.0	PL	WT	0.402	2.251	4.0	0.098	0.377	NA	NA	NA	0.25	AIR	65.0	0.91	0.102	0.377	10.0	35.5	35.6	35.8	35.9	NF	5
	AA-21	1.25	PL	WT	0.656	6.00	8.0	0.305	1.166	15	NA	4	NA	AIR	30.9	0.42	0.305	1.166	12.4	27.5	29.9	27.5	29.9	NG	14
	AA-19	1.25	PL	WT	0.655	6.00	8.0	0.308	1.210	15	NA	4	NA	AIR	35.3	0.48	0.313	1.228	10.9	31.9	34.9	32.2	35.3	NF	14
	AA-61	1.25	PL	WT	0.661	6.00	8.0	0.274	1.123	15	NA	3	NA	AIR	39.7	0.54	0.286	1.123	10.3	34.4	37.0	34.8	37.4	NF	14
	CA-[illegible]	1.25	PL	WT	0.658	6.00	8.0	0.211	0.761	15	NA	11	NA	AIR	50.9	0.69	0.219	0.767	9.9	37.9	39.6	38.2	40.0	NF	14
	DA-22	1.25	PL	WT	0.662	6.00	8.0	0.157	0.564	15	NA	10	NA	AIR	44.6	0.61	0.157	0.564	10.8	28.3	29.1	28.3	29.1	NG	14
	DA-20	1.25	PL	WT	0.656	6.00	8.0	0.267	0.758	15	NA	12	NA	AIR	50.9	0.69	0.271	0.808	11.8	39.1	40.5	40.2	41.8	NF	14
	DA-18	1.25	PL	WT	0.670	6.00	8.0	0.189	0.598	15	NA	18	NA	AIR	57.2	0.78	0.199	0.601	44.0	38.9	40.1	39.2	40.5	NF	14
	X-2	1.0	PL	WT	0.604	6.00	8.0	0.237	0.920	12	NA	NA	NA	AIR	50.8	0.74	0.240	0.920	L/U	41.1	43.6	41.2	43.7	NF	22
	H-9	1.0	PL	WT	0.600	6.01	8.0	0.243	0.940	12	NA	NA	NA	AIR	50.8	0.74	0.249	0.940	20.0	41.6	44.2	41.8	44.5	NF	22
	H-8	1.0	PL	WT	0.593	6.00	8.0	0.252	0.925	12	NA	NA	NA	AIR	50.8	0.74	0.258	0.925	1.0	41.7	44.4	41.9	44.6	NF	22

L/U = LOAD/UNLOAD TEST
NF = GROWTH WITH NO FAILURE
NG = NO GROWTH

(1) FINAL FLAW SIZE ESTIMATED

Table 38: *Room Temperature (70° F–75° F) Surface Flawed Sustained Load Tests of GTA Welded 2219–T87 Aluminum Alloy. Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment.*

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t	W	L	a_i	$2c_i$	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (INCH)	$2c_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI $\sqrt{IN.}$)	K_{Ii} (KSI $\sqrt{IN.}$)	K_{If} (IRWIN) (KSI $\sqrt{IN.}$)	K_{If} (KSI $\sqrt{IN.}$)	COMMENTS	REFERENCE
AIR	WDP-1A	1.0	PL	0.904	6.00	8.0	0.430	1.475	12	NA	NA	NA	AIR	22.0	1.09	0.475	1.475	L/U	23.9		24.2	.	NF	22
	WAP-2	1.0	PL	0.913	5.99	8.0	0.415	1.470	12	NA	NA	NA	AIR	22.0	1.09	0.440	1.470	16.0	23.7		23.9		NF	22
3-1/2% NaCl	WS-1	1.0	PL	0.898	5.90	8.0	0.420	1.475	12	NA	NA	NA	AIR	22.0	1.09	0.495	1.475	23.9	23.8		24.3		NF	22
	WS-2	1.0	PL	0.902	5.90	8.0	0.435	1.465	12	NA	Na	NA	AIR	22.0	1.09	0.465	1.465	14.6	23.9		24.1		NF	22
GH_2	WH-1	1.0	PL	0.908	5.90	8.0	0.440	1.500	12	NA	NA	NA	AIR	22.0	1.09	0.475	1.500	13.4	24.1		24.3		NF	22
	WH-3	1.0	PL	0.900	5.90	8.0	0.440	1.480	12	NA	NA	NA	AIR	22.0	1.09	0.470	1.480	14.9	24.0		24.2		NF	22
DISTILLED H_2O	WDW-1	1.0	PL	0.909	5.90	8.0	0.415	1.475	12	NA	NA	NA	AIR	21.0	1.04	0.457	1.475	L/U	22.7		23.0		NF	22
	WDW-2	1.0	PL	0.900	5.90	8.0	0.420	1.475	12	NA	NA	NA	AIR	22.0	1.09	0.455	1.475	15.8	23.8		24.1		NF	22
DYE PENETRANT	WDP-1	1.0	PL	0.899	5.90	8.0	0.425	1.465	12	NA	NA	NA	AIR	20.0	1.00	0.447	1.465	L/U	21.6		21.8		NF	22
	WDP-2	1.0	PL	0.900	5.90	8.0	0.430	1.460	12	NA	NA	NA	AIR	22.0	1.09	0.463	1.460	16.0	23.8		24.0		NF	22
FLOX	WFX-1	1.0	PL	0.908	5.90	8.0	0.425	1.465	12	NA	NA	NA	AIR	22.0	1.09	0.465	1.465	3.0	23.8		24.1		NF	22
	WFX-2	1.0	PL	0.905	5.90	8.0	0.420	1.450	12	NA	NA	NA	AIR	22.0	1.09	0.460	1.450	10.0	23.6		23.9		NF	22
OF_2	WOF-2	1.0	PL	0.917	5.90	8.0	0.430	1.475	12	NA	NA	NA	AIR	22.0	1.09	0.470	1.475	9.6	23.5		24.2		NF	22
	WOF-1	1.0	PL	0.900	5.90	8.0	0.425	1.475	12	NA	NA	NA	AIR	22.0	1.09	0.465	1.475	10.0	23.8		24.1		NF	22
	WOF-5	1.0	PL	0.924	5.90	8.0	0.425	1.480	12	NA	NA	NA	AIR	22.0	1.09	0.465	1.480	10.1	23.9		24.2		NF	22
TRICHLORO-ETHYLENE	WT-1	1.0	PL	0.901	5.90	8.0	0.430	1.475	12	NA	NA	NA	AIR	18.0	0.90	0.440	1.475	L/U	19.2		19.3		NF	22
	WT-2	1.0	PL	0.898	5.90	8.0	0.425	1.480	12	NA	NA	NA	AIR	22.0	1.09	0.455	1.480	12.0	23.9		24.1		NF	22
GO_2	WO-1	1.0	PL	0.893	5.89	8.0	0.425	1.475	12	NA	NA	NA	AIR	22.0	1.09	0.460	1.475	13.5	23.8		24.1		NF	22
	WO-2	1.0	PL	0.906	5.88	8.0	0.450	1.485	12	NA	NA	NA	AIR	22.0	1.09	0.485	1.485	9.8	24.1		24.3		NF	22

L/U = LOAD/UNLOAD TEST
NF = GROWTH WITH NO FAILURE

Table 38: Room Temperature (70° F - 75° F Surface Flawed Sustained Load Tests of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment (Continued)

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)					PRECRACKING			TEST PREP		TESTING		RESULTS								COMMENTS	REFERENCE
				t	W	L	a_i	$2C_i$	σ (KSI)	R	CYCLES (x 1000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (INCH)	$2C_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI$\sqrt{IN.}$)	K_{Ii} (KSI$\sqrt{IN.}$)	K_{If} (IRWIN) (KSI$\sqrt{IN.}$)	K_{If} (KSI$\sqrt{IN.}$)			
AIR (Cont'd)	SRW1-1	1.0	PL	0.95	6.00	9.0	0.460	1.960	10	NA	2.7	NA	AIR	27.7	1.32	0.520	1.970	67.0	33.3		34.2		NF	24
	SRW1-2	1.0	PL	0.95	6.00	9.0	0.445	1.950	10	NA	2.8	NA	AIR	28.5	1.36	0.530	1.950	24.6	34.0		35.2		NF	24
	SRW1-3	1.0	PL	0.95	6.00	9.0	0.450	1.960	10	NA	3.6	NA	AIR	29.1	1.39	0.525	2.010	28.1	34.8		36.2		NF	24
	SRW1-4	1.0	PL	0.95	6.00	9.0	0.450	1.960	10	NA	1.8	NA	AIR	26.8	1.28	0.530	1.960	24.0	32.1		33.1		NF	24
	SRW1-5	1.0	PL	0.95	6.00	9.0	0.450	1.960	10	NA	2.0	NA	AIR	30.0	1.43	0.550	1.960	42.5	35.9		37.3		NF	24
	SRW1-6	1.0	PL	0.95	6.00	9.0	0.450	1.950	10	NA	2.0	NA	AIR	29.7	1.41	0.510	1.950	19.3	35.5		36.4		NF	24

NF = GROWTH WITH NO FAILURE

DOUBLE V WELD EDGE PREPARATION

Table 39: Liquid Nitrogen Temperature (-320°F) Surface Flawed Sustained Load Tests of GTA Welded 2219-T87 Aluminum Alloy, Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t	W	L	a_i	$2c_i$	PRECRACKING σ (KSI)	R	CYCLES (x 1000)	TEST PREP SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (INCH)	$2c_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI $\sqrt{IN.}$)	K_{Ii} (KSI $\sqrt{IN.}$)	K_{If} (IRWIN) (KSI $\sqrt{IN.}$)	K_{If} (KSI $\sqrt{IN.}$)	COMMENTS	REFERENCE
LN_2	3W1-3	1.0	PL	0.99	6.01	6	0.34	1.48	12	NA	NA	NA	AIR	25.0	0.98	0.41	1.50	46.2	26.0		27.0		NF	23
	3W1-4	1.0	PL	0.97	6.01	6	0.30	1.48	12	NA	NA	NA	AIR	25.0	0.98	0.35	1.48	20.0	25.2		26.1		NF	23
	3W1-4	1.0	PL	0.97	6.01	6	0.35	1.48	12	NA	NA	NA	AIR	27.8	1.10	0.39	1.50	9.8	29.1		29.9		NF	23
	3W1-6	1.0	PL	0.99	6.01	6	0.32	1.48	12	NA	NA	NA	AIR	27.5	1.08	?	?	0.17	28.2		-		FAILED (1)	23
	WAN-1	1.0	PL	0.915	5.99	8.0	0.430	1.495	12	NA	NA	NA	AIR	25.0	1.01	0.500	1.495	6.0	27.3		27.7		NF	22
GH_2	WH-5	1.0	PL	0.905	5.90	8.0	0.425	1.475	12	NA	NA	NA	AIR	25.0	1.01	0.536	1.475	10.0	27.1		27.8		NF	22
	WH-7	1.0	PL	0.897	5.90	8.0	0.425	1.470	12	NA	NA	NA	AIR	25.0	1.01	0.450	1.470	L/U	27.1		27.3		NF	22
FLOX	WFX-3	1.0	PL	0.910	5.97	8.0	0.425	1.470	12	NA	NA	NA	AIR	22.0	0.89	0.450	1.470	8.0	23.4		23.6		NF	22
	WFX-4	1.0	PL	0.895	5.90	8.0	0.420	1.460	12	NA	NA	NA	AIR	22.0	0.89	0.445	1.470	11.3	23.3		23.6		NF	22
OF_2	WOF-4	1.0	PL	0.908	5.90	8.0	0.423	1.475	12	NA	NA	NA	AIR	22.0	0.89	0.453	1.475	6.6	23.4		23.7		NF	22
	WOF-6	1.0	PL	0.898	5.90	8.0	0.415	1.470	12	NA	NA	NA	AIR	22.0	0.89	0.436	1.470	10.0	23.3		23.5		NF	22
LO_2	WO-3	1.0	PL	0.895	5.90	8.0	0.410	1.985	12	NA	NA	NA	AIR	25.0	1.01	0.470	1.485	10.0	27.0		27.5		NF	22
	WS-1	1.0	PL	0.903	5.90	8.0	0.430	1.460	12	NA	NA	NA	AIR	25.0	1.01	0.465	1.460	L/U	27.0		27.3		NF	22

L/U = LOAD/UNLOAD TEST

NF = GROWTH WITH NO FAILURE

(1) TESTED PREVIOUSLY

Table 39: Liquid Nitrogen Temperature (-320°F) Surface Flawed Sustained Load Tests of GTA Welded 2219-T87 Aluminum Alloy. Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMAN DIMENSIONS (INCH)					PRECRACKING			TEST PREP		TESTING		PESULTS							COMMENTS	REFERENCE
				t	W	L	a_i	$2c_i$	σ (KSI)	R	CYCLES (x 1000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (INCH)	$2c_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI $\sqrt{IN.}$)	K_{Ii} (KSI $\sqrt{IN.}$)	K_{If} (IRWIN) (KSI $\sqrt{IN.}$)	K_{If} (KSI $\sqrt{IN.}$)		
LN_2 (Cont'd)	SNW1-1	1.0	PL	0.95	6.00	9.0	0.450	1.960	10	NA	2	NA	AIR	28.5	1.10	0.525	1.960	23.5	34.1		35.2		NF	24
	SNW1-3	1.0	PL	0.95	6.00	9.0	0.440	1.955	10	NA	2	NA	AIR	31.0	1.19	0.510	1.960	24.0	36.9		38.1		NF	24
	SNW1-6	1.0	PL	0.95	6.00	9.0	0.455	1.950	10	NA	2.2	NA	AIR	31.0	1.19	–	–	0.12	37.2		–		FAILURE	24
	SNW1-7	1.0	PL	0.95	6.00	9.0	0.450	1.960	10	NA	2	NA	AIR	30.1	1.16	0.505	1.960	29.0	36.0		36.9		NF	24
	SNW1-8	1.0	PL	0.95	6.00	9.0	0.450	1.950	10	NA	2	NA	AIR	31.5	1.21	0.580	1.950	15.2	37.7		39.4		NF	24
	SNW1-9	1.0	PL	0.95	6.00	9.0	0.450	1.960	10	NA	2	NA	AIR	30.5	1.07	0.520	1.960	15.1	36.5		37.6		NF	24

NF = GROWTH WITH NO FAILURE

DOUBLE V WELD EDGE PREPARATION

Table 40: −413°F Temperature Surface Flawed Sustained Load Tests of GTA Welded 2219-T87 Aluminum Alloy Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)					PRECRACKING			TEST PREP		TESTING		RESULTS								COMMENTS	REFERENCE
				t	W	L	a_i	2C	σ (KSI)	R	CYCLES (x 1000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (INCH)	$2C_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI$\sqrt{IN.}$)	K_{Ii} (KSI$\sqrt{IN.}$)	K_{If} (IRWIN) (KSI$\sqrt{IN.}$)	K_{If} (KSI$\sqrt{IN.}$)		
GH_2	WH-8	1.0	PL	0.890	[illegible]	8.0	0.410	1.465	12	NA	NA	NA	AIR	25.0	0.87	0.480	1.465	10.0	26.9		27.4		NF	22
	WH-14	1.0	PL	0.913	5.88	8.0	0.400	1.480	12	NA	NA	NA	AIR	22.0	0.77	0.420	1.480	10.0	22.9		23.1		NF	22
	WH-10	1.0	PL	0.909	5.90	8.0	0.417	1.465	12	NA	NA	NA	AIR	25.0	0.87	0.462	1.465	L/U	26.5		26.9		NF	22
	W423-2	1.0	PL	0.900	5.90	8.0	0.420	1.480	12	NA	NA	NA	AIR	22.0	0.77	0.431	1.480	L/U	23.1		23.2		NF	22
	WH-9	1.0	PL	0.903	5.89	8.0	0.415	1.460	12	NA	NA	NA	AIR	26.5	0.92			0.05	28.2				FAILURE	22

L/U = LOAD/UNLOAD TEST
NF = GROWTH WITH NO FAILURE

Table 41: Liquid Hydrogen Temperature (−423°F) Surface Flawed Sustained Load Tests of GTA Welded 2219-T87 Aluminum Alloy Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment

ENVIRONMENT	SPECIMEN I.D.	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH)					PRECRACKING			TEST PREP.		TESTING		RESULTS								COMMENTS	REFERENCE
				t	W	L	a_i	$2C_i$	σ (KSI)	R	CYCLES (x 1000)	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	σ_{MAX} (KSI)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (INCH)	$2C_f$ (INCH)	DURATION (HOURS)	K_{Ii} (IRWIN) (KSI$\sqrt{IN.}$)	K_{Ii} (KSI$\sqrt{IN.}$)	K_{If} (IRWIN) (KSI$\sqrt{IN.}$)	K_{If} (KSI$\sqrt{IN.}$)		
LH_2	WH-11	1.0	PL	0.902	5.90	8.0	0.433	1.475	12	NA	NA	NA	AIR	22.0	0.77	0.453	1.475	12.3	23.2		23.3		NF	22
	WO-4	1.0	PL	0.921	5.90	8.0	0.425	1.480	12	NA	NA	NA	AIR	25.6	0.89	0.495	1.490	11.1	27.3		28.0		NF	22

NF = GROWTH WITH NO FAILURE

Table 42: Room Temperature Air Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{in.}$)	K_{Ii} (Ksi$\sqrt{in.}$)	K_{If} (IRWIN) (Ksi$\sqrt{in.}$)	K_{If} (Ksi$\sqrt{in.}$)		
A3A-18	1.0	PLATE	0.402	5.006	7.0	0.088	0.317	NA	NA	NA	NA	AIR	20	0	A	50.0	0.90	0.294	1.000	1,685	24.6	25.1	44.1	53.9	(4, 5)	5
A3A-19	1.0	PLATE	0.401	5.007	7.0	0.086	0.833	NA	NA	NA	NA	AIR	20	0	A	50.0	0.90	0.252	1.116	926	29.6	30.7	44.3	54.0		5
A3B-2	1.0	PLATE	0.798	5.006	7.0	0.314	1.276	NA	NA	NA	NA	AIR	20	0	A	25.0	0.45	0.477	1.788	4,351	23.0	24.5	27.7	32.1	$W/2c < 4$	5
A3A-20	1.0	PLATE	0.402	5.002	7.0	0.086	0.317	NA	NA	NA	NA	AIR	20	0	A	52.8	0.96	0.234	0.773	1,012	26.1	26.6	41.4	46.3	(3)	5
A3A-21	1.0	PLATE	0.408	5.004	7.0	0.081	0.825	NA	NA	NA	NA	AIR	20	0	A	50.0	0.90	0.250	0.970	617	28.9	29.7	42.5	50.0	(3)	5
A3B-3	1.0	PLATE	0.803	5.006	7.0	0.308	1.283	NA	NA	NA	NA	AIR	20	0	A	25.0	0.95	0.390	1.446	4,000	22.9	24.4	25.0	27.3	$W/2c < 4$ (3	5
1T	0.1252	SHEET	0.1252	1.997	NA	0.073	0.296	20	NA	NA	NA	AIR	60	0.0286	A	14.00	0.25	0.083	0.307	4,000	6.1	7.2	6.4	7.7	(2)	26
3T	0.1252	SHEET	0.1252	1.993	NA	0.064	0.251	20	NA	NA	NA	AIR	60	0.0286	A	14.02	0.25	0.071	0.258	4,000	5.7	6.4	5.9	6.7	(2)	26
4T	0.1253	SHEET	0.1253	1.996	NA	0.065	0.255	20	NA	NA	NA	(1)	60	0.0286	A	14.00	0.25	0.070	0.256	4,000	5.7	6.4	5.8	6.6	(2)	26
7T	0.1254	SHEET	0.1254	1.998	NA	0.064	0.276	20	NA	NA	NA	(1)	60	0.0286	A	14.00	0.25	0.072	0.292	5,000	5.7	6.3	6.1	7.1	(2)	26
9T	0.1250	SHEET	0.1250	1.994	NA	0.064	0.251	20	NA	NA	NA	(1)	60	0.0143	A	28.10	0.51	0.075	0.267	1,000	11.6	12.9	12.2	14.0	(2)	26
10T	0.1250	SHEET	0.1250	1.996	NA	0.064	0.247	20	NA	NA	NA	(1)	60	0.020	A	20.05	0.36	0.071	0.260	3,000	8.2	9.1	8.5	9.6	(2)	26
11T	0.1250	SHEET	0.1251	1.995	NA	0.064	0.256	20	NA	NA	NA	(1)	60	0.0143	A	28.07	0.51	0.077	0.280	1,500	11.6	13.0	12.4	14.5	(2)	26
12T	0.1251	SHEET	0.1250	1.997	NA	0.063	0.249	20	NA	NA	NA	(1)	60	0.011	A	36.10	0.65	0.072	0.263	500	15.0	16.7	15.7	17.9	(2)	26
13T	0.1251	SHEET	0.1251	1.998	NA	0.063	0.246	20	NA	NA	NA	(1)	60	0.010	A	40.00	0.72	0.076	0.277	500	16.7	18.5	17.9	20.8	(2)	26
14T	0.1252	SHEET	0.1252	1.998	NA	0.064	0.250	20	NA	NA	NA	(1)	60	0.10	A	8.00	0.14	0.064	0.250	10,000	3.2	3.6	3.2	3.6	(2)	26
17T	0.1252	SHEET	0.1252	1.993	NA	0.065	0.253	20	NA	NA	NA	(1)	120	0.10	A	8.01	0.14	0.065	0.253	40,000	3.3	3.7	3.3	3.7	(2)	26
19T	0.1252	SHEET	0.1252	1.995	NA	0.064	0.272	20	NA	NA	NA	(1)	120	0.020	A	20.01	0.36	0.083	0.290	3,000	8.4	9.4	9.0	10.7	(2)	26
20T	0.1252	SHEET	0.1252	1.996	NA	0.063	0.246	20	NA	NA	NA	(1)	120	0.0286	A	14.00	0.25	0.068	0.248	5,000	5.6	6.3	5.8	6.4	(2)	26
1M	1.0	PLATE	0.1244	2.009	NA	0.060	0.244	20	NA	NA	NA	(1)	60	0.01	A	14.00	0.25	0.064	0.246	5,000	5.6	6.1	5.7	6.3	(2)	26
2M	1.0	PLATE	0.1259	2.012	NA	0.067	0.246	20	NA	NA	NA	(1)	60	0.01	A	19.74	0.36	0.078	0.250	3,000	8.1	9.0	8.4	9.5	(2)	26
3M	1.0	PLATE	0.1267	006	NA	0.063	0.245	20	NA	NA	NA	(1)	60	0.01	A	27.54	0.50	0.078	0.257	1,500	11.2	12.4	11.9	13.5	(4)	26

* SEE FIGURE 13
(1) 10% NaOH ETCH
(2) PRECRACKED IN BENDING
(3) CYCLED IN GASEOUS HELIUM
(4) FINAL FLAW SIZE ESTIMATED
(5) CYCLED TO FAILURE

Table 42: Room Temperature Air Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction (Continued)

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{Ii} (Ksi$\sqrt{\text{In.}}$)	K_{If} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{If} (Ksi$\sqrt{\text{In.}}$)		
4M	1.0	PLATE	0.1193	2.002	NA	0.064	0.245	20	NA	NA	NA	(1)	60	0.01	A	14.66	0.27	0.080	0.249	10,000	5.9	6.7	6.2	7.2	(2)	26
5M	1.0	PLATE	0.1194	2.002	NA	0.063	0.270	20	NA	NA	NA	(1)	60	0.01	A	29.28	0.53	0.087	0.300	2,000	12.3	14.0	13.6	16.6	(2)	26
6M	1.0	PLATE	0.1222	2.001	NA	0.074	0.318	20	NA	NA	NA	(1)	60	0.01	A	28.63	0.52	0.106	0.389	2,000	13.0	15.6	14.9	–	(2)	26
7M	1.0	PLATE	0.1197	2.001	NA	0.063	0.240	20	NA	NA	NA	(1)	60	0.01	A	12.53	0.23	0.085	0.254	15,000	5.0	5.6	5.4	6.3	(2)	26
8M	1.0	PLATE	0.1702	2.001	NA	0.065	0.249	20	NA	NA	NA	(1)	60	0.01	A	16.63	0.30	0.080	0.259	5,000	6.8	7.7	7.2	8.3	(2)	26
9M	1.0	PLATE	0.1258	2.008	NA	0.065	0.257	20	NA	NA	NA	(1)	60	0.01	A	31.67	0.57	0.085	0.278	1,000	13.3	14.8	14.3	16.8	(2)	26
10M	1.0	PLATE	0.1258	2.015	NA	0.065	0.250	20	NA	NA	NA	(1)	60	0.01	A	33.54	0.61	0.079	0.273	750	14.0	15.6	14.9	17.3	(2)	26
11M	1.0	PLATE	0.1218	2.010	NA	0.065	0.263	20	NA	NA	NA	(1)	60	0.01	A	36.77	0.67	0.076	0.283	500	15.6	17.7	16.5	19.4	(2)	26
12M	1.0	PLATE	0.1255	2.001	NA	0.065	0.263	20	NA	NA	NA	(1)	60	0.01	A	31.86	0.58	a = t	0.365	3,770	13.4	15.1	16.8	–	(2, 3)	26
14M	1.0	PLATE	0.1193	2.002	NA	0.063	0.257	20	NA	NA	NA	(1)	60	0.01	A	41.87	0.76	a = t	0.366	1,420	17.7	20.1	22.3	–	(2, 3)	26
1T	0.2385	PLATE	0.2385	3.015	NA	0.120	0.637	20	NA	NA	NA	(1)	60	0.01	A	20.83	0.38	0.145	0.655	1,500	12.5	14.4	13.3	16.1	(2)	26
2T	0.2357	PLATE	0.2357	3.008	NA	0.121	0.603	30	NA	NA	NA	(1)	60	0.01	A	21.18	0.38	0.143	0.627	1,500	12.6	14.5	13.3	16.0	(2)	26
5T	0.2388	PLATE	0.2388	3.018	NA	0.120	0.613	20	NA	NA	NA	(1)	60	0.01	A	13.88	0.25	0.143	0.627	5,000	8.2	9.4	8.7	10.4	(2)	26
8T	0.2377	PLATE	0.2379	3.014	NA	0.120	0.589	20	NA	NA	NA	(1)	120	0.01	A	6.97	0.13	0.143	0.595	40,000	4.1	4.7	4.3	5.1	(2)	26
11T	0.2380	PLATE	0.2380	3.018	NA	0.124	0.599	20	NA	NA	NA	(1)	6	0.01	A	27.84	0.50	0.167	0.679	1,000	16.8	19.4	18.7	23.6	(2)	26
12T	0.2370	PLATE	0.2370	3.011	NA	0.123	0.599	20	NA	NA	NA	AIR	60	0.01	A	28.03	0.51	0.151	0.646	1,000	16.9	19.5	18.2	22.2	(2)	26
13T	0.2382	PLATE	0.2382	3.012	NA	0.124	0.593	20	NA	NA	NA	AIR	6	0.01	A	20.91	0.38	0.144	0.623	1,500	12.5	14.4	13.2	15.7	(2)	26
15T	0.2370	PLATE	0.2370	3.014	NA	0.123	0.595	20	NA	NA	NA	(1)	6	0.01	A	21.01	0.38	0.145	0.625	1,500	12.5	14.4	13.3	15.9	(2)	26
16T	0.2378	PLATE	0.2378	3.008	NA	0.125	0.596	20	NA	NA	NA	(1)	240	0.01	A	27.96	0.51	0.153	0.643	1,000	16.9	19.5	18.2	22.2	(2)	26
17T	0.2374	PLATE	0.2374	3.010	NA	0.124	0.609	20	NA	NA	NA	(1)	240	0.01	A	20.99	0.38	0.149	0.639	1,500	12.6	14.6	13.4	16.3	(2)	26
18T	0.2370	PLATE	0.2370	3.008	NA	0.125	0.596	20	NA	NA	NA	AIR	6	0.01	A	28.05	0.51	0.160	0.658	1,000	17.0	19.6	18.5	23.0	(2)	26

* SEE FIGURE 13

(1) 10% NaOH ETCH

(2) PRECRACKED IN BENDING

(3) CYCLED TO BREAKTHROUGH

Table 42: Room Temperature Air Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy. WT Propagation Direction (Continued)

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{Ii} (Ksi$\sqrt{\text{In.}}$)	K_{If} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{If} (Ksi$\sqrt{\text{In.}}$)		
21T	0.2381	PLATE	0.2381	3.014	NA	0.120	0.605	20	NA	NA	NA	AIR	60	0.01	A	21.09	0.38	0.140	0.626	1,500	12.5	14.3	13.2	15.7	(2)	26
22T	0.2385	PLATE	0.2385	3.014	NA	0.126	0.601	20	NA	NA	NA	AIR	60	0.01	A	13.91	0.25	0.151	0.619	5,000	8.3	9.6	8.8	10.6	(2)	26
23T	0.2389	PLATE	0.2389	3.013	NA	0.122	0.609	20	NA	NA	NA	AIR	6	0.01	A	13.89	0.25	0.154	0.643	5,000	8.3	9.5	8.9	10.9	(2)	26
24T	0.2365	PLATE	0.2365	3.010	NA	0.124	0.612	20	NA	NA	NA	(1)	6	0.01	A	14.05	0.25	0.152	0.637	5,000	8.4	9.7	9.0	10.9	(2)	26
SBT-5	1.0	PLATE	1.01	6.0	11	0.31	1.35	25	0.06	4~6	NA	AIR	1	0	A	35.6	0.65	0.62	2.18	510	33.7	35.5	41.8	51.7	(3)	6
SBT-4	1.0	PLATE	1.01	6.0	11	0.33	1.34	25	0.06	4~6	NA	AIR	1	0	A	37.6	0.69	0.42	1.53	83	36.2	38.1	39.5	42.0	(3)	6
SBT-6	1.0	PLATE	1.01	6.0	11	0.30	1.28	25	0.06	4~6	NA	AIR	1	0	A	38.5	0.70	0.51	2.19	208	35.8	37.7	46.8	52.6	(3)	6
SBT-7	1.0	PLATE	1.01	6.0	11	0.32	1.35	25	0.06	4~6	NA	AIR	1	0	A	39.5	0.72	0.40	1.37	17	38.0	40.1	39.9	41.8	(3)	6
C0A6-1	1.25	PLATE	0.608	6.01	8.0	0.125	0.524	20~25	NA	4~20	NA	AIR	1	0	D	44.3	0.78	0.295	1.091	645	26.7	27.2	39.6	43.2	(3)	13
C0A6-2	1.25	PLATE	0.608	6.00	8.0	0.225	0.795	20~25	NA	4~20	NA	AIR	1	0	D	40.0	0.71	0.363	1.290	139	30.5	32.0	38.8	44.5	(3)	13
C0A6-3	1.25	PLATE	0.612	6.01	8.0	0.208	0.760	20~25	NA	4~20	NA	AIR	1	0	D	44.3	0.78	–	–	1	33.1	34.7	–	–	(3)	13
C0A12-1	1.25	PLATE	1.239	6.00	8.0	0.202	0.804	20~25	NA	4~20	NA	AIR	1	0	D	35.0	0.62	0.460	1.147	1,109	26.0	26.4	33.3	33.9	(3)	13
C0A12-2	1.25	PLATE	1.239	6.00	8.0	0.254	1.007	20~25	NA	4~20	NA	AIR	1	0	D	37.0	0.64	0.443	1.426	367	30.9	31.5	38.2	39.8	(3)	13
C0A12-3	1.25	PLATE	1.238	6.00	8.0	0.254	0.976	20~25	NA	4~20	NA	AIR	1	0	D	30.0	0.53	0.549	1.567	1,787	24.6	25.0	32.7	34.1	$W/2c < 4$ (3)	13
C5A6-1	1.25	PLATE	0.609	6.00	8.0	0.151	0.546	20~25	NA	4~20	NA	AIR	1	0.5	D	42.1	0.75	0.302	1.035	3,060	26.6	27.4	37.0	40.1	(3)	13
C5A6-2	1.25	PLATE	0.607	6.00	8.0	0.205	0.768	20~25	NA	4~20	NA	AIR	1	0.5	D	38.0	0.67	0.304	1.221	1,694	28.1	29.5	34.9	38.8	(3)	13
C5A6-3	1.25	PLATE	0.607	6.00	8.0	0.201	0.751	20~25	NA	4~20	NA	AIR	1	0.5	D	44.3	0.78	0.300	1.154	361	32.8	34.4	40.4	44.5	(3)	13
C5A12-1	1.25	PLATE	1.239	6.00	8.0	0.203	0.771	20~25	NA	4~20	NA	AIR	1	0.5	D	35.0	0.62	0.470	1.142	4,052	25.7	26.1	33.0	33.8	(3)	13
C5A12-2	1.25	PLATE	1.242	6.00	8.0	0.260	0.998	20~25	NA	4~20	NA	AIR	1	0.5	D	37.0	0.64	0.393	1.288	1,438	31.0	31.6	36.2	37.7	(3)	13
C5A12-3	1.25	PLATE	1.240	6.00	8.0	0.262	0.923	20~25	NA	4~20	NA	AIR	1	0.5	D	30.0	0.53	0.600	1.529	7,443	24.3	24.8	32.7	33.7	$W/2c_f < 4$ (3)	13

* SEE FIGURE 13

(1) 10% NaOH ETCH

(2) PRECRACKED IN BENDING

(3) CYCLED TO FAILURE

Table 43: *Room Temperature Air Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, RT Propagation Direction*

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{In.}$)	K_{Ii} (Ksi$\sqrt{In.}$)	K_{If} (IRWIN) (Ksi$\sqrt{In.}$)	K_{If} (Ksi$\sqrt{In.}$)		
1L	0.1256	SHEET	0.1256	2.019	NA	0.067	0.257	20	NA	NA	NA	(1)	60	0.01	A	11.85	0.22	0.083	0.271	15,000	4.9	5.5	5.2	6.0	(2)	26
2L	0.1256	SHEET	0.1256	2.013	NA	0.062	0.261	20	NA	NA	NA	(1)	60	0.01	A	19.78	0.36	0.076	0.275	3,000	8.1	9.0	8.6	9.9	(2)	26
3L	0.1257	SHEET	0.1257	2.016	NA	0.068	0.272	20	NA	NA	NA	(1)	60	0.0.1	A	27.63	0.50	0.089	0.300	1500	11.8	13.4	12.8	15.5	(2)	26
4L	0.1251	SHEET	0.1251	2.011	NA	0.064	0.249	20	NA	NA	NA	(1)	60	0.01	A	35.78	0.65	0.078	0.267	500	14.9	16.6	15.8	18.2	(2)	26
5L	0.1257	SHEET	0.1257	2.011	NA	0.066	0.256	20	NA	NA	NA	(1)	60	0.01	A	11.87	0.22	0.109	0.287	142,000	4.9	5.5	5.5	-	(2)	26
8L	0.1254	SHEET	0.1254	2.015	NA	0.071	0.286	20	NA	NA	NA	(1)	60	0.01	A	35.62	0.65	a_p=t	0.421	2,103	15.7	18.2	19.8	-	(2,3)	26
9L	0.1259	SHEET	0.1259	2.009	NA	0.066	0.248	20	NA	NA	NA	(1)	60	0.01	A	19.77	0.36	a_p=t	0.365	18,065	8.1	9.0	10.3	-	(2,3)	26
10L	0.1245	SHEET	0.1295	2.010	NA	0.067	0.253	20	NA	NA	NA	(1)	60	0.00	A	27.97	0.51	a_p=t	0.355	5,272	11.7	13.1	14.5	-	(2,3)	26
3L	0.250	PLATE	0.250	3.040	NA	0.127	0.617	20	NA	NA	NA	(1)	60	0.0333	A	19.76	0.36	0.180	0.676	3,000	12.0	13.7	13.4	16.7	(2)	26
15L	0.237	PLATE	0.237	3.045	NA	0.128	0.608	20	NA	NA	NA	(1)	60	0.05	A	13.87	0.25	0.158	0.644	5,000	8.4	9.7	9.0	11.0	(2)	26
21L	0.241	PLATE	0.241	3.015	NA	0.123	0.601	20	NA	NA	NA	(1)	60	0.0333	A	20.64	0.37	0.177	0.675	3,000	12.3	14.1	13.9	17.6	(2)	26
22L	0.242	PLATE	0.242	3.036	NA	0.128	0.622	20	NA	NA	NA	(1)	120	0.10	A	6.81	0.12	0.157	0.637	40,000	4.1	4.8	4.4	5.3	(2)	26
24L	0.235	PLATE	0.235	3.034	NA	0.125	0.599	20	NA	NA	NA	(1)	60	0.01	A	21.06	0.38	0.153	0.632	15,00	12.6	14.7	13.5	16.5	(2)	26
25L	0.235	PLATE	0.235	3.026	NA	0.124	0.593	20	NA	NA	NA	(1)	60	0.01	A	25.40	0.46	0.154	0.635	1,000	15.3	17.6	16.4	20.1	(2)	26
26L	0.237	PLATE	0.237	3.030	NA	0.126	0.608	20	NA	NA	NA	AIR	60	0.01	A	20.91	0.38	0.154	0.648	1,500	12.6	14.7	13.5	16.6	(2)	26
27L	0.243	PLATE	0.243	3.019	NA	0.128	0.597	20	NA	NA	NA	AIR	60	0.0333	A	20.46	0.37	0.184	0.691	3,000	12.4	14.2	14.0	17.9	(2)	26
28L	0.236	PLATE	0.236	3.026	NA	0.128	0.611	20	NA	NA	NA	(1)	60	0.010	A	28.03	0.51	0.154	0.652	750	17.2	20.0	18.3	22.5	(2)	26
SBL-3	1.0	PLATE	1.00	6.0	11	0.30	1.27	25	0.06	4∼6	NA	AIR	1	0.0	A	45.7	0.82	?	?	680	43.2	45.4	-	-	(4)	6
ABC 30R-1	A0.125	SHEET	0.067	6.75	10	0.031	0.553	≤16	NA	NA	NA	AIR	20	0.1	D	42.0	0.75	t	?	370	15.11	17.86	-	-	(3)	3
ABC 39R-3	0.125	SHEET	0.062	6.75	10	0.044	0.822	≤16	NA	NA	NA	AIR	20	0.1	D	32.0	0.57	t	?	106	13.37	20.02	-	-	(3)	3
ABC 39R-2	0.125	SHEET	0.066	6.75	10	0.038	0.800	≤16	NA	NA	NA	AIR	20	0.1	D	42.0	0.75	t	?	241	16.81	21.95	-	-	(3)	3

* SEE FIGURE 13

(1) 10% Na OH ETCH

(2) PRECRACKED IN BENDING

(3) CYCLED TO BREAKTHROUGH

(4) DELAMINATION, CYCLED TO FAILURE

Table 43: Room Temperature Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, RT Propagation Direction (Continued)

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{In.}$)	K_{Ii} (Ksi$\sqrt{In.}$)	K_{If} (IRWIN) (Ksi$\sqrt{In.}$)	K_{If} (Ksi$\sqrt{In.}$)		
ABC 39R-4	0.125	SHEET	0.068	6.76	10	0.042	0.800	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	52.0	0.93	t	?	22	22.64	30.87	—	—	(1)	3
ABC 48R-5	0.125	SHEET	0.061	6.75	10	0.046	0.967	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	42.0	0.75	t	?	8	18.50	29.25	—	—	(1)	3
ABC 25R-1	0.625	PLATE	0.645	6.74	10	0.230	0.569	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	36.0	0.64	?	?	2927	24.16	24.63	—	—	(2)	3
ABC 31R-2	0.625	PLATE	0.627	6.74	10	0.286	0.724	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	31.0	0.55	?	?	3909	23.30	23.94	—	—	(2)	3
ABC 31R-3	0.625	PLATE	0.638	6.74	10	0.278	0.740	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	41.0	0.73	?	?	1013	31.44	32.45	—	—	(2)	3
ABC 31R-4	0.625	PLATE	0.636	6.74	10	0.282	0.743	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	36.0	0.64	?	?	2737	27.49	28.36	—	—	(2)	3
ABC 38R-5	0.625	PLATE	0.643	6.74	10	0.350	0.875	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	36.0	0.64	?	?	798	27.95	31.11	—	—	(2)	3

* SEE FIGURE 13

(1) CYCLED TO BREAKTHROUGH

(2) CYCLED TO FAILURE

Table 44: *Room Temperature Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy in Salt Water, WT Propagation Direction*

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (× 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{Ii} (Ksi$\sqrt{\text{In.}}$)	K_{If} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{If} (Ksi$\sqrt{\text{In.}}$)		
A3A-22	1.0	PLATE	0.406	5.006	7.0	0.091	[illegible]	NA	NA	NA	NA	AIR	20	0	A	50.0	0.90	0.260	0.925	1595	24.8	25.3	42.1	49.5		5
A3A-23	1.0	PLATE	0.399	5.006	7.0	0.090	[illegible].815	NA	NA	NA	NA	AIR	20	0	A	50.0	0.90	0.222	0.920	396	30.0	31.3	40.8	47.1		5
A3B-4	1.0	PLATE	0.801	5.005	7.0	0.313	1.278	NA	NA	NA	NA	AIR	20	0	A	25.0	0.45	0.449	1.625	3430	23.0	24.5	26.6	30.0	$W/2c < 4$	5
A3A-34	1.0	PLATE	0.405	5.005	7.0	0.148	0.542	NA	NA	NA	NA	AIR	0.5	0	B	50.0	0.90	0.273	1.050	729	32.1	33.8	44.3	54.0		5
A3A-35	1.0	PLATE	0.405	5.004	7.0	0.115	0.413	NA	NA	NA	NA	AIR	0.5	0	B	50.0	0.90	0.145	0.462	481	28.1	29.2	30.3	31.5		5
A3A-37	1.0	PLATE	0.403	5.062	7.0	0.097	0.366	NA	NA	NA	NA	AIR	0.5	0	B	50.0	0.90	0.116	0.384	499	26.2	27.0	27.5	28.5		5
A3A-31	1.0	PLATE	0.406	5.004	7.0	0.161	0.620	NA	NA	NA	NA	AIR	0.2	0	C	50.0	0.90	0.206	0.755	155	34.0	36.1	37.9	41.7		5
A3A-33	1.0	PLATE	0.404	5.005	7.0	0.135	0.535	NA	NA	NA	NA	(1)	0.2	0	C	50.0	0.90	0.139	0.535	94	31.4	33.1	31.6	33.3		5
A3A-33	1.0	PLATE	0.404	5.005	7.0	0.158	0.538	NA	NA	NA	NA	AIR	0.2	0	C	50.0	0.90	0.298	1.235	402	32.4	33.9	47.3	61.2	(2,3,4)	5
A3A-36	1.0	PLATE	0.403	5.008	7.0	0.112	0.412	NA	NA	NA	NA	AIR	0.2	0	C	50.0	0.90	0.141	0.464	573	28.0	29.0	30.2	31.5		5
A3A-38	1.0	PLATE	0.406	5.000	7.0	0.098	0.367	NA	NA	NA	NA	AIR	0.2	0	C	51.8	0.93	0.120	0.403	493	27.4	28.2	29.2	30.3		5

* SEE FIGURE 13

(1) 3½% NaCl AND AIR

(2) PREVIOUSLY TESTED

(3) FINAL FLAW SIZE ESTIMATED

(4) CYCLED TO FAILURE

Table 45: -320°F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction (Thickness < 0.25 inch)

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{Ii} (Ksi$\sqrt{\text{In.}}$)	K_{If} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{If} (Ksi$\sqrt{\text{In.}}$)		
OA14-1	1.00	PLATE	0.152	3.50	6	0.085	0.250	NA	NA	NA	NA	AIR	20	0	A	43.8	0.67	a=t	0.400	2490	19.2	20.8	-	-	(2)	2
OSA14-2	1.00	PLATE	0.149	3.50	6	0.100	0.250	NA	NA	NA	NA	AIR	20	0	A	43.8	0.67	a=t	0.390	1818	19.5	20.9	-	-	(2)	2
OA14-5	1.00	PLATE	0.140	3.50	6	0.075	[illegible]	NA	NA	NA	NA	AIR	20	0	A	43.8	0.67	a=t	0.350	2026	17.5	18.6	-	-	(2)	2
OA14-6	1.00	PLATE	0.151	3.50	6	0.077	0.205	NA	NA	NA	NA	AIR	20	0	A	43.8	0.67	a=t	0.390	3180	17.6	18.4	-	-	(2)	2
OA11-1	1.00	PLATE	0.154	5.00	7	0.040	0.530	NA	NA	NA	NA	AIR	20	0	A	43.8	0.67	a=t	0.600	2768	17.4	18.5	-	-	(2)	2
OA11-2	1.00	PLATE	0.143	5.00	7	0.065	0.540	NA	NA	NA	NA	AIR	20	0	A	43.8	0.67	a=t	0.610	1072	21.3	24.4	-	-	(2)	2
OA11-5	1.00	PLATE	0.154	5.00	7	0.062	0.450	NA	NA	NA	NA	AIR	20	0	A	43.8	0.67	a=t	0.520	2021	20.4	22.4	-	-	(2)	2
OA11-6	1.00	PLATE	0.150	5.00	7	0.051	0.460	15	NA	NA	0.25	AIR	20	0	A	43.8	0.67	a=t	0.530	2150	19.0	20.7	-	-	(2)	2
CA14-1	1.0	PLATE	0.150	3.49	6	0.071	0.186	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.081	0.231	300	23.4	24.3	25.9	27.7		2
CA14-1	1.0	PLATE	0.150	3.49	6	0.085	0.243	20	NA	NA	0.25	LN_2 AIR	20	0	A	59.8	0.90	a=t	0.430	636	26.6	28.7	35.4	-	(1,2)	2
CA14-2	1.0	PLATE	0.149	3.49	6	0.068	0.176	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.080	0.190	200	22.8	23.5	23.8	24.5		2
CA14-2	1.0	PLATE	0.149	3.49	6	0.082	0.195	20	NA	NA	0.25	LN_2 AIR	20	0	A	59.8	0.90	0.135	0.383	1030	24.1	24.9	33.4	-	(1)	2
CA14-3	1.0	PLATE	0.151	3.50	6	0.098	0.255	12	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.102	0.264	15	27.4	29.6	27.9	30.4		2
CA14-3	1.0	PLATE	0.151	3.50	6	0.105	0.270	18	NA	NA	0.25	LN_2 AIR	20	0	A	59.8	0.90	a=t	0.450	255	28.3	30.8	36.0	-	(1,2)	2
CA14-4	1.0	PLATE	0.155	3.50	6	0.100	0.261	12	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.104	0.270	10	27.7	29.9	27.7	30.2		2
CA11-1	1.0	PLATE	0.150	5.00	7	0.045	0.530	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.048	0.530	7	26.1	28.2	26.9	29.2		2
CA11-1	1.0	PLATE	0.150	5.00	7	0.053	0.530	18	NA	NA	0.25	LN_2 AIR	20	0	A	59.8	0.90	a=t	?	93	27.9	30.6	-	-	(1,2)	2
CA11-2	1.0	PLATE	0.152	5.00	7	0.053	0.555	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	.057	.555	5	28.1	30.8	28.9	31.8		2
CA11-2	1.0	PLATE	0.152	5.00	7	0.063	0.555	18	NA	NA	0.25	LN_2 AIR	20	0	A	59.8	0.90	a=t	?	68	30.0	33.5	-	-	(1,2)	2
CA24-1	1.0	PLATE	0.203	3.50	6	0.092	0.222	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.102	0.240	186	25.7	26.2	26.7	27.3		2
CA24-1	1.0	PLATE	0.203	3.50	6	0.108	0.252	20	NA	NA	0.25	LN_2 AIR	20	0	A	59.8	0.90	a=t	0.450	720	27.4	28.1	-	-	(1,2)	2

* SEE FIGURE 13

(1) PREVIOUSLY TESTED

(2) CYCLED TO BREAKTHROUGH

Table 45: -320°F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction (Thickness <0.25 in) (Continued)

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{in.}$)	K_{Ii} (Ksi$\sqrt{in.}$)	K_{If} (IRWIN) (Ksi$\sqrt{in.}$)	K_{If} (Ksi$\sqrt{in.}$)		
CA24-2	1.0	PLATE	0.202	3.50	6	0.088	0.222	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.100	0.246	250	25.6	26.3	27.0	27.8		2
CA24-2	1.0	PLATE	0.202	3.50	6	0.102	0.252	20	NA	NA	0.25	LN2 AIR	20	0	A	59.8	0.90	a=t	0.59	757	27.3	28.2	-	-	(1,2)	2
CA24-3	1.0	PLATE	0.197	3.50	6	0.108	0.282	12	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.114	0.297	50	28.9	30.3	29.6	31.3		2
CA24-3	1.0	PLATE	0.197	3.50	6	0.120	0.309	20	NA	NA	0.25	LN2 AIR	20	0	A	59.8	0.90	0.19	0.57	240	30.2	37.7	40.5	-	(1,2)	2
CA24-4	1.0	PLATE	0.204	3.50	6	0.110	0.279	12	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.121	0.303	85	28.7	29.9	30.0	31.4		2
CA24-4	1.0	PLATE	0.204	3.50	6	0.124	0.312	20	NA	NA	0.25	LN2 AIR	20	0	A	59.8	0.90	a=t	0.570	362	30.4	32.1	-	-	(1,3)	2
CA21-2	1.0	PLATE	0.205	5.00	7	0.080	0.790	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.135	0.790	25	34.3	37.8	41.4	53.7	(1,2)	2
CA21-5	1.0	PLATE	0.201	4.00	6	0.042	0.550	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.050	0.550	131	25.3	26.0	27.2	28.2		2
CA21-5	1.0	PLATE	0.201	4.00	6	0.051	0.550	20	NA	NA	0.25	LN2 AIR	20	0	A	59.8	0.90	?	?	478	27.5	28.5	-	-	(1)	2
CA21-6	1.0	PLATE	0.204	4.00	6	0.043	0.555	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.056	0.555	153	25.7	26.6	28.7	30.6		2
CA21-6	1.0	PLATE	0.204	4.00	6	0.060	0.555	20	NA	NA	0.25	LN2 AIR	20	0	A	59.8	0.90	0.130	0.600	592	29.5	31.7	38.5	47.6	(1)	2

* SEE FIGURE 13

(1) PREVIOUSLY TESTED

(2) CYCLED TO FAILURE

(3) CYCLED TO BREAKTHROUGH

Table 46: -320°F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction (Thickness >0.25 inch)

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch) t	W	L	a_i	$2c_i$	PRECRACKING σ (Ksi)	R	CYCLES (x 1,000)	TEST PREP SOAK TIME (Hours)	PRIOR ENVIRONMENT	TESTING FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{in.}$)	K_{Ii} (Ksi$\sqrt{in.}$)	K_{If} (IRWIN) (Ksi$\sqrt{in.}$)	K_{If} (Ksi$\sqrt{in.}$)	COMMENTS	REFERENCE
A3A-8	1.0	PLATE	0.399	5.004	7.0	0.085	0.319	NA	NA	NA	0.25	AIR	20	0	A	60.0	0.91	0.235	0.590	853	29.5	30.1	42.0	44.0	(1,2)	5
A3A-9	1.0	PLATE	0.404	5.005	7.0	0.094	0.830	NA	NA	NA	0.25	AIR	20	0	A	60.0	0.91	0.180	0.835	40	36.8	38.4	45.5	50.2	(1,2)	5
A3B-1	1.0	PLATE	0.799	5.007	7.0	0.322	1.310	NA	NA	NA	0.25	AIR	20	0	A	30.0	0.45	0.447	1.550	1400	28.0	29.9	31.5	35.3	$W/2c < 4$	5
A3A-10	1.0	PLATE	0.400	5.006	7.0	0.154	0.570	NA	NA	NA	0.25	AIR	0.5	0	B	60.0	0.91	0.190	0.650	3.2	39.5	41.7	42.7	45.9	(1,2)	5
A3A-11	1.0	PLATE	0.399	5.005	7.0	0.138	0.530	NA	NA	NA	0.25	AIR	0.5	0	B	60.0	0.91	0.200	0.630	10.1	37.8	39.8	42.5	45.6	(1,2)	5
A3A-13	1.0	PLATE	0.398	5.006	7.0	0.108	0.393	NA	NA	NA	0.25	AIR	0.5	0	B	60.0	0.91	0.135	0.433	240	32.9	34.1	35.2	36.6		5
A3A-29	1.0	PLATE	0.400	5.005	7.0	0.108	0.440	NA	NA	NA	0.25	AIR	0.5	0	B	60.0	0.91	0.136	0.454	100	34.0	35.4	35.8	37.4		5
A3A-14	1.0	PLATE	0.403	5.005	7.0	0.144	0.572	NA	NA	NA	0.25	AIR	0.2	0	C	60.0	0.91	?	?	2.3	39.0	41.3	-	-	(2)	5
A3A-15	1.0	PLATE	0.395	5.004	7.0	0.140	0.527	NA	NA	NA	0.25	AIR	0.2	0	C	60.0	0.91	0.210	0.630	24.4	37.8	39.9	42.8	46.0	(1,2)	5
A3A-16	1.0	PLATE	0.399	5.005	7.0	0.121	0.438	NA	NA	NA	0.25	AIR	0.2	0	C	60.0	0.91	0.148	0.473	100	34.7	36.3	36.8	38.3		5
A3A-17	1.0	PLATE	0.401	5.007	7.0	0.105	0.390	NA	NA	NA	0.25	AIR	0.2	0	C	60.0	0.91	0.125	0.408	258	32.6	33.8	34.1	35.4		5
SBT-16	1.0	PLATE	1.01	6.0	11	0.31	1.31	25	.06	4~6	NA	AIR	1	0	A	38.5	0.58	0.46	1.56	36	35.9	37.8	41.0	43.8	(2) $W/2c_f < 4$	6
SBT-17	1.0	PLATE	1.01	6.0	11	0.30	1.31	25	.06	4~6	NA	AIR	1	0	A	38.5	0.58	0.59	1.82	299	35.6	37.5	45.0	49.6	(2) $W/2c_f < 4$	6
SBT-10	1.0	PLATE	1.01	6.0	11	0.31	1.31	25	.06	4~6	NA	AIR	1	0	A	40.0	0.61	0.45	1.75	146	37.4	39.4	44.0	47.6	(2) $W/2c_f < 4$	6
SBT-9	1.0	PLATE	1.01	6.0	11	0.30	1.29	25	.06	4~6	NA	AIR	1	0	A	42.0	0.64	0.32	1.29	5	38.9	40.9	39.5	41.6	(2)	6
SBT-8	1.0	PLATE	1.01	6.0	11	0.28	1.32	25	.06	4~6	NA	AIR	1	0	A	44.5	0.67	0.29	1.32	4	40.9	42.9	41.2	43.4	(2)	6
COA6-4	1.25	PLATE	0.604	6.01	8.0	0.160	0.567	20~25	NA	4~20	NA	AIR	1	0	D	54.0	0.80	0.232	0.706	9	35.3	36.5	40.2	41.8	(2)	13
COA6-5	1.25	PLATE	0.602	6.01	8.0	0.157	0.549	20~25	NA	4~20	NA	AIR	1	0	D	44.1	0.65	0.342	1.034	697	28.0	28.9	39.2	42.9	(2)	13
COA6-6	1.25	PLATE	0.614	6.00	8.0	0.245	1.002	20~25	NA	4~20	NA	AIR	1	0	D	44.1	0.65	0.316	1.122	22	36.6	39.0	39.8	43.8	(2)	13
COA12-4	1.25	PLATE	1.240	6.00	8.0	0.197	0.740	20~25	NA	4~20	NA	AIR	1	0	D	40.3	0.60	0.446	1.125	634	29.1	29.5	37.9	38.7	(2)	13
COA12-5	1.25	PLATE	1.242	6.00	8.0	0.257	1.028	20~25	NA	4~20	NA	AIR	1	0	D	40.3	0.60	0.473	1.265	109	33.8	34.5	40.0	41.1	(2)	13

* SEE FIGURE 13

(1) FINAL FLAW SIZE ESTIMATED

(2) CYCLED TO FAILURE

Table 46: -320°F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction (Thickness>0.25 inch) (Continued)

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{in.}$)	K_{Ii} (Ksi$\sqrt{in.}$)	K_{If} (IRWIN) (Ksi$\sqrt{in.}$)	K_{If} (Ksi$\sqrt{in.}$)		
COA12-6	1.25	PLATE	1.240	6.00	8.0	0.276	1.002	20 25	NA	4-20	NA	AIR	1	0	D	36.8	0.54	0.380	1.092	47	31.0	31.7	33.6	34.6	(2)	13
OA51-1	1.00	PLATE	0.502	8.00	10	0.114	0.390	15	NA	NA	0.25	AIR	20	0		43.8	0.67	0.260	0.740	4604	23.5	24.0	33.2	35.2		2
OA51-2	1.00	PLATE	0.501	8.00	10	0.114	0.385	15	NA	NA	0.25	AIR	20	0	A	43.8	0.67	0.420	1.35	3864	23.4	23.9	44.1	56.1		2
OA51-5	1.00	PLATE	0.507	8.00	10	0.095	0.320	15	NA	NA	0.25	AIR	20	0	A	43.8	0.67	0.425	1.50	6451	21.3	21.6	45.8	60.2		2
OA51-6	1.00	PLATE	0.502	8.00	10	0.093	0.325	15	NA	NA	0.25	AIR	20	0	A	43.8	0.67	0.380	1.47	6617	21.4	21.7	44.5	57.3		2
OA54-1	1.00	PLATE	0.504	5.00	7	0.133	0.352	15	NA	NA	0.25	AIR	20	0	A	43.8	0.67	0.400	1.35	4960	23.1	23.5	43.8	55.2		2
OA54-5	1.00	PLATE	0.500	5.00	7	0.123	0.360	15	NA	NA	0.25	AIR	20	0	A	43.8	0.67	0.450	1.32	4640	23.1	23.6	44.2	-		2
OA54-6	1.00	PLATE	0.500	5.00	7	0.124	0.352	15	NA	NA	0.25	LN2 AIR	20	0	A	43.8	0.67	0.236	0.600	3758	22.9	23.3	30.2	31.1		2
OA54-6	1.00	PLATE	0.500	5.00	7	0.240	0.600	15	NA	NA	0.25	AIR	20	0	A	43.8	0.67	0.440	1.48	1045	30.2	31.0	45.9	60.0		2
CA54-1	1.0	PLATE	0.499	4.51	6	0.132	0.310	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.166	0.395	421	30.4	30.7	34.3	34.8		2
CA54-1	1.0	PLATE	0.499	4.51	6	0.170	0.400	20	NA	NA	0.25	LN2 AIR	20	0	A	59.8	0.90	0.297	0.77	314	34.5	35.0	47.7	50.6	(1,2)	2
CA54-2	1.0	PLATE	0.504	4.51	6	0.131	0.310	17	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.166	0.365	380	30.4	30.7	33.0	33.3		2
CA54-2	1.0	PLATE	0.504	4.51	6	0.169	0.370	20	NA	NA	0.25	LN2 AIR	20	0	A	59.8	0.90	0.300	0.80	454	33.2	33.5	48.5	51.9	(1)	2
CA54-3	1.0	PLATE	0.504	4.50	6	0.162	0.417	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.205	0.530	220	35.1	35.9	39.6	40.5		2
CA54-3	1.0	PLATE	0.504	4.50	6	0.208	0.535	20	NA	NA	0.25	LN2 AIR	20	0	A	59.8	0.90	0.265	0.75	31	39.8	40.7	46.9	49.9	(1)	2
CA54-4	1.0	PLATE	0.501	4.50	6	0.166	0.420	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.204	0.560	150	35.3	36.0	40.5	41.8		2
CA54-4	1.0	PLATE	0.501	4.50	6	0.208	0.570	20	NA	NA	0.25	LN2 AIR	20	0	A	59.8	0.90	0.280	0.79	39	40.9	42.2	46.3	49.7	(1)	2
CA51-1	1.0	PLATE	0.502	8.00	10	0.102	0.790	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.152	0.790	53	37.6	38.7	42.8	45.5		2
CA51-1	1.0	PLATE	0.502	8.00	10	0.157	0.790	18	NA	NA	0.25	LN2 AIR	20	0	A	59.8	0.90	0.250	0.860	19	43.2	45.9	48.9	53.1	(1)	2
CA51-2	1.0	PLATE	0.502	8.00	10	0.079	0.800	15	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.120	0.800	97	34.2	35.0	39.9	41.6		2
CA51-2	1.0	PLATE	0.502	8.00	10	0.122	0.800	18	NA	NA	0.25	LN2 AIR	20	0	A	59.8	0.90	0.260	0.900	58	40.1	41.9	50.0	54.8	(1)	2

- SEE FIGURE 13

(1) PREVISOULY TESTED

(2) CYCLED TO FAILURE

Table 46: -320^{0}F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction (Thickness>0.25 inch) (Continued)

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX} / \sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{Ii} (Ksi$\sqrt{\text{In.}}$)	K_{If} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{If} (Ksi$\sqrt{\text{In.}}$)		
CA51-3	1.0	PLATE	0.492	8.00	10	0.102	1.05	12	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.123	1.05	11	38.9	40.2	41.8	44.0		2
CA51-3	1.0	PLATE	0.492	8.00	10	0.128	1.05	18	NA	NA	0.25	LN_2 AIR	20	0	A	59.8	0.90	0.210	1.05	11	42.4	44.8	49.9	54.8		2
CA51-4	1.0	PLATE	0.502	8.00	10	0.100	1.06	12	NA	NA	0.25	AIR	20	0	A	59.8	0.90	0.164	1.06	14	38.6	39.8	46.4	49.7		2
CA51-4	1.0	PLATE	0.502	8.00	10	0.169	1.06	18	NA	NA	0.25	LN_2 AIR	20	0	A	59.8	0.90	0.210	1.06	2	46.8	50.5	50.0	54.7		2
AA-56	1.25	PLATE	0.650	6.00	8.0	0.322	1.226	15	NA	5	NA	AIR	40	0	D	29.2	0.43	0.490	1.859	1262	26.7	29.4	32.9	42.1	$W/2c_f < 4$	14
AA-55	1.25	PLATE	0.658	6.00	8.0	0.317	1.175	15	NA	5	NA	AIR	1	0	D	29.2	0.43	0.529	1.940	1047	26.3	28.7	33.9	44.1	$W/2c_f < 4$	14
AA-6	1.25	PLATE	0.656	6.00	8.0	0.377	1.319	12	NA	11.5	NA	AIR	0.1	0	D	29.2	0.43	0.480	1.775	291	28.2	31.8	32.3	40.5	$W/2c_f < 4$	14
DA-29	1.25	PLATE	0.660	6.00	8.0	0.169	0.569	15	NA	18	NA	AIR	40	0	D	43.8	0.66	0.361	1.097	990	28.4	29.3	40.1	43.6		14
DA-26	1.25	PLATE	0.657	6.00	8.0	0.165	0.544	15	NA	18	NA	AIR	1	0	D	43.8	0.66	0.403	1.333	1260	27.9	28.7	43.6	49.6		14
DA-30	1.25	PLATE	0.663	6.00	8.0	0.161	0.548	15	NA	20	NA	AIR	0.1	0	D	43.8	0.66	0.392	1.203	1694	27.9	28.6	41.9	46.4		14
AA-54	1.25	PLATE	0.674	6.00	8.0	0.310	1.176	15	NA	4	NA	AIR	40	0	D	35.4	0.54	0.456	1.514	144	31.9	34.7	37.2	43.8	$W/2c_f < 4$	14
AA-5	1.25	PLATE	0.663	6.00	8.0	0.313	1.203	10	NA	15	NA	AIR	1	0	D	35.4	0.54	0.448	1.677	162	32.2	35.2	38.3	46.5	$W/2c_f < 4$	14
AA-57	1.25	PLATE	0.663	6.00	8.0	0.317	1.181	15	NA	6	NA	AIR	0.1	0	D	35.4	0.54	0.383	1.415	18	32.1	35.0	35.2	40.3		14
AA-60	1.25	PLATE	0.654	6.00	8.0	0.308	1.164	15	NA	6	NA	AIR	0.008	0	D	35.4	0.54	0.370	1.368	19	31.8	34.6	34.6	39.4		14
DA-28	1.25	PLATE	0.666	6.00	8.0	0.174	0.594	15	NA	18	NA	AIR	40	0	D	53.2	0.80	0.237	0.701	20	35.7	36.8	39.6	40.9		14
DA-46	1.25	PLATE	0.652	6.00	8.0	0.165	0.576	15	NA	16	NA	AIR	1	0	D	53.2	0.80	0.365	0.943	133	35.1	36.1	46.5	48.8		14
DA-15	1.25	PLATE	0.670	6.00	8.0	0.162	0.597	15	NA	15	NA	AIR	0.1	0	D	53.2	0.80	0.273	0.779	35	35.3	36.4	41.9	43.3		14
DA-27	1.25	PLATE	0.652	6.00	8.0	0.161	0.561	15	NA	16	NA	AIR	0.008	0	D	53.2	0.80	0.253	0.752	45	34.6	35.6	41.0	42.5		14
C5A12-4	1.25	PLATE	1.236	6.00	8.0	0.205	0.776	20~25	NA	4~20	NA	AIR	1	0.5	D	40.3	0.60	0.438	1.090	3226	29.7	30.2	37.3	38.1		13
C5A12-5	1.25	PLATE	1.240	6.00	8.0	0.270	1.037	20~25	NA	4~20	NA	AIR	1	0.5	D	40.3	0.60	0.345	1.105	749	34.3	35.1	36.5	37.8		13
C5A12-6	1.25	PLATE	1.259	6.00	8.0	0.268	1.028	20~25	NA	4~20	NA	AIR	1	0.5	D	32.0	0.47	0.699	1.914	9468	26.8	27.4	38.7	41.2		13
C5A6-4	1.25	PLATE	0.608	6.01	8.0	0.171	0.581	20~25	NA	4~20	NA	AIR	1	0.5	D	54.0	0.80	- - -	- - -	1	35.9	37.3	- - -	- - -	(1)	13
C5A6-5	1.25	PLATE	0.609	6.01	8.0	0.161	0.578	20~25	NA	4~20	NA	AIR	1	0.5	D	44.1	0.65	0.303	1.142	3239	28.5	29.5	39.7	43.7	(1)	13
C5A6-6	1.25	PLATE	0.609	6.00	8.0	0.220	0.772	20~25	NA	4~20	NA	AIR	1	0.5	D	44.1	0.65	0.295	1.219	642	33.1	34.7	40.2	44.6	(1)	13

* SEE FIGURE 13

(1) CYCLED TO FAILURE

Table 47: -320°F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, RT Propagation Direction

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (× 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX} / \sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{Ii} (Ksi$\sqrt{\text{In.}}$)	K_{If} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{If} (Ksi$\sqrt{\text{In.}}$)		
BS2-1	0.5	PLATE	0.51	6.00	11	0.16	0.50	25	NA	NA	NA	AIR	1	0	D	45.0	0.67	0.21	0.57	360	27.7	28.7	30.1	31.0		23
BS2-2	0.5	PLATE	0.50	6.00	11	0.18	0.52	25	NA	NA	NA	AIR	1	0	D	50.6	0.75	0.28	0.74	127	32.3	33.4	38.9	41.1	(3)	23
BS2-3	0.5	PLATE	0.50	6.00	11	0.15	0.50	25	NA	NA	NA	AIR	1	0	D	50.0	0.74	0.31	0.90	459	30.7	31.9	42.0	46.3	(3)	23
33L	0.2370	PLATE	0.2370	2.992	NA	0.125	0.600	20	NA	NA	NA	(1)	60	0.01	A	39.48	0.59	0.152	0.629	300	24.2	27.9	25.7	31.2	(2)	26
34L	0.2377	PLATE	0.2377	2.998	NA	0.130	0.620	20	NA	NA	NA	(1)	60	0.01	A	35.08	0.52	0.154	0.652	500	21.7	25.4	23.0	28.2	(2)	26
35L	0.2392	PLATE	0.2392	3.010	NA	0.128	0.601	20	NA	NA	NA	(1)	60	0.01	A	27.78	0.42	0.148	0.620	1000	16.9	19.5	17.6	21.2	(2)	26
36L	0.2394	PLATE	0.2394	3.009	NA	0.124	0.593	20	NA	NA	NA	(1)	60	0.01	A	20.82	0.31	0.136	0.603	1500	12.4	14.2	12.8	15.0	(2)	26
37L	0.2385	PLATE	0.2385	3.014	NA	0.126	0.602	20	NA	NA	NA	(1)	60	0.01	A	13.91	0.21	0.137	0.610	5000	8.3	9.6	8.5	10.1	(2)	26
SBL-13	1.0	PLATE	1.01	6.0	11	0.32	1.30	25	0.06	4~6	NA	AIR	1	0	A	51.4	0.76	0.40	1.39	4	49.2	51.8	52.4	55.0	(3)	6
SBL-18	1.0	PLATE	1.01	6.0	11	0.31	1.31	25	0.06	4~6	NA	AIR	1	0	A	43.0	0.63	0.65	1.98	311	40.3	42.5	52.8	59.7	(3)	6
SBL-23	1.0	PLATE	1.01	6.0	11	0.31	1.32	25	0.06	4~6	NA	AIR	1	0	A	46.3	0.68	0.49	1.76	62	43.8	46.1	52.4	57.0	(3)	6
SBL-22	1.0	PLATE	1.00	6.0	11	0.32	1.31	25	0.06	4~6	NA	AIR	1	0	A	49.5	0.73	0.51	2.02	36	46.9	48.8	59.2	66.0	(3)	6
ABC 25N-1	0.625	PLATE	0.642	6.74	10	0.232	0.577	≤16	NA	NA	NA	AIR	20	0.1	D	43.0	0.64	?	?	1774	27.05	29.62	-	-	(3)	3
ABC 31N-2	0.625	PLATE	0.624	6.75	10	0.311	0.769	≤16	NA	NA	NA	AIR	20	0.1	D	48.0	0.72	?	?	585	37.66	38.73	-	-	(3)	3
ABC 31N-3	0.625	PLATE	0.644	6.74	10	0.290	0.761	≤16	NA	NA	NA	AIR	20	0.1	D	43.0	0.64	?	?	977	33.24	34.31	-	-	(3)	3
ABC 31N-4	0.625	PLATE	0.642	6.74	10	0.276	0.742	≤16	NA	NA	NA	AIR	20	0.1	D	38.0	0.57	?	?	1723	28.79	29.72	-	-	(3)	3
ABC 38N-5	0.625	PLATE	0.630	6.74	10	0.345	0.882	≤16	NA	NA	NA	AIR	20	0.1	D	43.0	0.64	?	?	925	35.85	37.47	-	-	(3)	3
A-1	0.625	PLATE	0.638	6.75	10	0.246	0.608	≤16	NA	NA	NA	AIR	20	0.1	D	31.6	0.47	0.263	0.644	1000	21.70	22.12	22.35	22.78		3
A-2	0.625	PLATE	0.637	6.75	10	0.243	0.611	≤16	NA	NA	NA	AIR	20	0.1	D	31.6	0.47	0.295	0.735	3000	21.73	22.18	23.85	24.47		3
A-3	0.625	PLATE	0.631	6.75	10	0.298	0.762	≤16	NA	NA	NA	AIR	20	0.1	D	22.0	0.33	0.345	0.878	6000	16.77	17.29	18.01	18.80		3
ABC 30N-1	0.125	SHEET	0.068	6.75	10	0.032	0.610	≤16	NA	NA	NA	AIR	20	0.1	D	51.0	0.80	t	?	205	20.40	26.15	-	-	(4)	3

* SEE FIGURE 13

(1) 10% NaOH ETCH

(2) PRECRACKED IN BENDING

(3) CYCLED TO FAILURE

(4) CYCLED TO BREAKTHROUGH

Table 47: −320°F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, RT Propagation Direction (Continued)

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{in.}$)	K_{Ii} (Ksi$\sqrt{in.}$)	K_{If} (IRWIN) (Ksi$\sqrt{in.}$)	K_{If} (Ksi$\sqrt{in.}$)		
ABC 39N-2	0.125	SHEET	0.067	6.76	10	0.040	0.747	≤ 16	NA	NA	NA	AIR	20	0.1	D	41.0	0.64	t	?	23	16.48	21.98	-	-	(1)	3
ABC 39N-3	0.125	SHEET	0.069	6.76	10	0.045	0.830	≤ 16	NA	NA	NA	AIR	20	0.1	D	61.0	0.95	t	?	1	27.60	38.97	-	-	(1)	3
ABC 39N-3A	0.125	SHEET	0.065	6.76	10	0.040	0.795	≤ 16	NA	NA	NA	AIR	20	0.1	D	51.0	0.80	t	?	63	21.08	28.72	-	-	(1)	3
ABC 48N-5	0.125	SHEET	0.064	6.75	10	0.045	0.955	≤ 16	NA	NA	NA	AIR	20	0.1	D	51.0	0.80	t	?	1	22.40	33.5	-	-	(1)	3
ABC 35N-1	0.625	PLATE	0.063	6.76	10	0.037	0.690	≤ 16	NA	NA	NA	AIR	20	0.1	D	51.0	0.76	t	?	50	20.10	26.57	-	-	(1)	3
ABC 38N-2	0.625	PLATE	0.062	6.75	10	0.044	0.790	≤ 16	NA	NA	NA	AIR	20	0.1	D	51.0	0.76	t	?	2	21.89	32.72	-	-	(1)	3
ABC 40N-1	0.125	SHEET	0.101	6.76	10	0.040	0.855	≤ 16	NA	NA	NA	AIR	20	0.1	D	51.0	0.80	t	?	240	20.85	23.37	-	-	(1)	3
ABC 50N-2	0.125	SHEET	0.100	6.75	10	0.050	1.040	≤ 16	NA	NA	NA	AIR	20	0.1	D	51.0	0.80	t	?	75	23.30	28.31	-	-	(1)	3
ABC 60N-3	0.125	SHEET	0.101	6.76	10	0.058	1.240	≤ 16	NA	NA	NA	AIR	20	0.1	D	51.0	0.80	t	?	16	25.11	32.72	-	-	(1)	3
ABC 65N-6	0.125	SHEET	0.100	6.75	10	0.066	1.420	≤ 16	NA	NA	NA	AIR	20	0.1	D	51.0	0.80	t	?	2	26.79	38.10	-	-	(1)	3
ABC 70N-4	0.125	SHEET	0.100	6.76	10	0.070	1.420	≤ 16	NA	NA	NA	AIR	20	0.1	D	51.0	0.80	t	?	1	27.55	40.94	-	-	(1)	3
ABC 80N-5	0.125	SHEET	0.100	6.76	10	0.075	1.560	≤ 16	NA	NA	NA	AIR	20	0.1	D	51.0	0.80	t	?	1	28.53	44.88	-	-	(1)	3

* SEE FIGURE 13

(1) CYCLED TO BREAKTHROUGH

Table 48: −423°F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch): t	W	L	a_i	$2c_i$	PRECRACKING: σ (Ksi)	R	CYCLES (x 1,000)	TEST PREP: SOAK TIME (Hours)	PRIOR ENVIRONMENT	TESTING: FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	RESULTS: a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{\text{in.}}$)	K_{Ii} (Ksi$\sqrt{\text{in.}}$)	K_{If} (IRWIN) (Ksi$\sqrt{\text{in.}}$)	K_{If} (Ksi$\sqrt{\text{in.}}$)	COMMENTS	REFERENCE
A2C-6	1.0	PLATE	0.399	2.250	4.0	0.086	0.340	NA	NA	NA	0.25	AIR	20	0	A	65.0	0.91	0.187	0.470	244	32.6	33.3	40.6	41.7	(1,2)	5
A2C-7	1.0	PLATE	0.402	2.249	4.0	0.116	0.442	NA	NA	NA	0.25	AIR	20	0	A	65.0	0.91	0.185	0.520	47	37.5	39.1	42.4	44.2	(1,2)	5
A2C-8	1.0	PLATE	0.399	2.250	4.0	0.084	0.323	NA	NA	NA	0.25	AIR	20	0	A	65.0	0.91	0.109	0.340	175	32.0	32.6	33.9	34.9		5
A38-1X	1.0	PLATE	0.799	5.000	7.0	0.333	1.430	NA	NA	NA	0.25	AIR	20	0	A	32.5	0.46	0.368	1.430	274	31.2	33.7	31.8	34.8	$W/2C < 4$	5
A2C-9	1.0	PLATE	0.401	2.250	4.0	0.127	0.495	NA	NA	NA	0.25	AIR	0.5	0	B	71.3	0.91	0.170	0.540	14.5	39.5	41.5	42.6	44.7	(1)	5
A2C-10	1.0	PLATE	0.400	2.249	4.0	0.118	0.447	NA	NA	NA	0.25	AIR	0.5	0	B	71.3	0.91	0.173	0.500	27.5	37.7	39.4	41.4	43.2		5
A2C-11	1.0	PLATE	0.400	2.250	4.0	0.099	0.359	NA	NA	NA	0.25	AIR	0.5	0	B	71.3	0.91	0.126	0.383	53	34.1	35.1	36.1	37.3		5
A2C-16	1.0	PLATE	0.401	2.250	4.0	0.085	0.320	NA	NA	NA	0.25	AIR	0.5	0	B	71.3	0.91	0.102	0.333	110	31.9	32.6	33.3	34.3		5
A2C-12	1.0	PLATE	0.401	2.250	4.0	0.084	0.332	NA	NA	NA	0.25	AIR	0.2	0	C	71.3	0.91	0.106	0.338	110	32.2	32.9	33.7	34.7		5
A2C-13	1.0	PLATE	0.400	2.251	4.0	0.125	0.496	NA	NA	NA	0.25	AIR	0.2	0	C	71.3	0.91	0.170	0.540	9.6	39.4	41.4	42.6	44.7	(1)	5
A2C-14	1.0	PLATE	0.401	2.251	4.0	0.112	0.443	NA	NA	NA	0.25	AIR	0.2	0	C	71.3	0.91	0.185	0.525	58	37.2	38.8	42.5	44.5	(1)	5
A2C-15	1.0	PLATE	0.400	2.252	4.0	0.092	0.363	NA	NA	NA	0.25	AIR	0.2	0	C	71.3	0.91	0.146	0.412	105	33.7	34.6	37.7	38.9		5
COA6-7	1.25	PLATE	0.608	6.01	8.0	0.152	0.522	20~25	NA	4~20	NA	AIR	1	0	D	54.0	0.74	0.188	0.640	82	33.8	34.7	37.4	39.0	(2)	13
COA6-8	1.25	PLATE	0.609	6.01	8.0	0.153	0.538	20~25	NA	4~20	NA	AIR	1	0	D	44.1	0.60	0.392	1.296	1,043	27.5	28.3	43.1	49.9	(2)	13
COA6-9	1.25	PLATE	0.608	6.01	8.0	0.172	0.603	20~25	NA	4~20	NA	AIR	1	0	D	44.1	0.60	0.319	0.875	259	29.1	30.2	36.3	38.3	(2)	13
COA12-7	1.25	PLATE	1.240	6.00	8.0	0.211	0.776	20~25	NA	4~20	NA	AIR	1	0	D	40.3	0.55	0.558	1.294	635	29.8	30.2	40.7	41.4	(2)	13
COA12-8	1.25	PLATE	1.246	6.00	8.0	0.266	0.971	20~25	NA	4~20	NA	AIR	1	0	D	40.3	0.55	0.456	1.213	143	33.4	34.0	39.1	40.1	(2)	13
COA12-9	1.25	PLATE	1.237	6.00	8.0	0.273	1.017	20~25	NA	4~20	NA	AIR	1	0	D	32.0	0.44	0.665	2.208	1,497	26.8	27.4	40.3	44.3	(2)	13
C5A12-7	1.25	PLATE	1.240	6.00	8.0	0.201	0.785	20~25	NA	4~20	NA	AIR	1	0.5	D	40.3	0.55	0.427	1.063	6,238	29.6	30.0	36.8	37.5	(2)	13
C5A12-8	1.25	PLATE	1.239	6.00	8.0	0.265	0.988	20~25	NA	4~20	NA	AIR	1	0.5	D	40.3	0.55	0.389	1.203	1,542	33.5	34.2	38.2	39.6	(2)	13
C5A12-9	1.25	PLATE	1.239	6.00	8.0	0.261	0.967	20~25	NA	4~20	NA	AIR	1	0.5	D	32.0	0.44	0.469	1.417	10,866	26.1	26.7	32.8	34.0	(2)	13
C5A6-7	1.25	PLATE	0.606	6.01	8.0	0.152	0.570	20~25	NA	4~20	NA	AIR	1	0.5	D	54.0	0.74	0.274	0.924	1,475	34.7	35.8	45.0	48.0	(1)	13
C5A6-8	1.25	PLATE	0.607	6.00	8.0	0.159	0.546	20~25	NA	4~20	NA	AIR	1	0.5	D	44.1	0.60	0.334	1.056	7,530	27.8	28.7	39.2	42.9	(1)	13
C5A6-9	1.25	PLATE	0.606	6.00	8.0	0.216	0.761	20~25	NA	4~20	NA	AIR	1	0.5	D	44.1	0.60	0.392	1.301	1,985	32.7	34.3	43.2	50.1	(1)	13

* SEE FIGURE 13

(1) FINAL FLAW SIZE ESTIMATED

(2) CYCLED TO FAILURE

Table 49: -423^{o} F Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, RT Propagation Direction

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{In.}$)	K_{Ii} (Ksi$\sqrt{In.}$)	K_{If} (IRWIN) (Ksi$\sqrt{In.}$)	K_{If} (Ksi$\sqrt{In.}$)		
ABC30H-1	0.125	SHEET	0.065	6.74	10	0.024	0.633	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	49.3	0.70	t	?	398	17.10	19.90	-	-	(1)	3
ABC39H-2	0.125	SHEET	0.068	6.76	10	0.043	0.805	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	40.0	0.57	t	?	162	16.51	22.86	-	-	(1)	3
ABC 39H-3	0.125	SHEET	0.065	6.75	10	0.050	0.800	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	50.0	0.71	t	?	8	22.59	35.68	-	-	(1)	3
ABC 39H-4	0.125	SHEET	0.067	6.75	10	0.045	0.795	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	55.0	0.78	t	?	5	23.96	34.44	-	-	(1)	3
ABC 48H-5	0.125	SHEET	0.068	6.75	10	0.047	0.980	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	50.0	0.71	t	?	4	22.09	32.50	-	-	(1)	3
ABC 25H-1	0.625	PLATE	0.625	6.75	10	0.229	0.578	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	43.0	0.60	?	?	1373	28.97	29.58	-	-	(2)	3
ABC 31H-2	0.625	PLATE	0.629	6.74	10	0.274	0.750	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	20.0	0.28	0.310	0.801	3000	15.00	15.53	15.59	16.14		3
ABC 31H-3	0.625	PLATE	0.635	6.75	10	0.284	0.740	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	43.0	0.60	?	?	504	32.70	33.71	-	-	(2)	3
ABC 31H-4	0.625	PLATE	0.646	6.68	10	0.296	0.760	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	30.0	0.42	0.360	0.930	2000	22.91	23.60	25.33	26.60		3
ABC 38H-5	0.625	PLATE	0.631	6.75	10	0.342	0.875	$\leq$ 16	NA	NA	NA	AIR	20	0.1	D	43.0	0.60	?	?	315	35.61	37.70	-	-	(2)	3

(1) CYCLED TO BREAKTHROUGH

(2) CYCLED TO FAILURE

Table 50: Elevated Temperature Surface Flawed Cyclic Flaw Growth Tests of 2219-T87 Aluminum Alloy, WT and RT Propagation Direction

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{In.}$)	K_{Ii} (Ksi$\sqrt{In.}$)	K_{If} (IRWIN) (Ksi$\sqrt{In.}$)	K_{If} (Ksi$\sqrt{In.}$)		
18T	0.1252	SHEET	0.1252	1.996	NA	0.063	0.254	20	NA	NA	NA	(1)	60	0.10	A	28.00	0.72	0.080	0.299	2000	11.8	13.1	13.0	15.4	(2,3,6)	26
15T	0.1253	SHEET	0.1253	1.996	NA	0.065	0.269	20	NA	NA	NA	(1)	60	0.10	A	28.00	0.64	0.071	0.285	1000	12.0	13.5	12.4	14.3	(2,3,5,8)	26
16T	0.1252	SHEET	0.1252	1.996	NA	0.062	0.250	20	NA	NA	NA	(1)	60	0.10	A	28.00	0.72	0.070	0.265	1000	11.7	13.0	12.2	13.9	(2,3,6,8)	26
18L	0.235	PLATE	0.235	3.037	NA	0.126	0.608	20	NA	NA	NA	(1)	60	0.05	A	14.08	0.32	0.147	0.629	5000	8.5	9.9	8.9	10.8	(2,4,5)	26
19L	0.236	PLATE	0.236	3.041	NA	0.125	0.603	20	NA	NA	NA	(1)	60	0.05	A	13.95	0.36	0.165	0.671	5000	8.4	9.7	9.2	11.6	(2,4,6)	26
20L	0.236	PLATE	0.236	3.020	NA	0.125	0.594	20	NA	NA	NA	(1)	60	0.05	A	14.03	0.42	0.138	0.605	2000	8.4	9.8	8.7	10.3	(2,4,7)	26
23L	0.237	PLATE	0.237	3.030	NA	0.122	0.597	20	NA	NA	NA	(1)	60	0.05	A	13.92	0.41	0.130	0.603	2000	8.3	9.6	8.5	9.9	(2,4,7)	26
29L	0.238	PLATE	0.238	3.036	NA	0.129	0.614	20	NA	NA	NA	(1)	6	0.01	A	13.84	0.36	0.143	0.629	4000	8.4	9.8	8.7	10.4	(2,4,6)	26
30L	0.236	PLATE	0.236	3.026	NA	0.121	0.601	20	NA	NA	NA	(1)	60	0.01	A	21.01	0.54	0.137	0.615	1500	12.7	14.6	13.2	15.6	(2,4,6)	26
31L	0.237	PLATE	0.237	2.822	NA	0.121	0.613	20	NA	NA	NA	(1)	6	0.01	A	22.42	0.58	0.154	0.667	1500	13.6	15.7	14.8	18.3	(2,4,6)	26

* See Figure 13

(1) 10% NaOH Etch
(2) PRECRACKED IN BENDING
(3) WT PROPAGATION DIRECTION
(4) RT PROPAGATION DIRECTION
(5) TESTED AT 300°F
(6) TESTED AT 350°F
(7) TESTED AT 400°F
(8) TRACE OF DELAMINATION

Table 51: Room Temperature Surface Flawed Cyclic Flaw Growth Tests of GTA Welded 2219-T87 Aluminum Alloy Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment.

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (× 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{Ii} (Ksi$\sqrt{\text{In.}}$)	K_{If} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{If} (Ksi$\sqrt{\text{In.}}$)		
AWC50R-1	1.00	PLATE	1.003	16.0	20	0.510	1.630	≈ 10	NA	NA	NA	AIR	20	0.1	D	16.0	0.73	t	?	846	17.84		–	–	(1)	3
AWC65R-2	1.00	PLATE	1.001	16.0	20	0.630	2.090	≈ 10	NA	NA	NA	AIR	20	0.1	D	19.0	0.87	t	?	230	24.22		–	–	(1)	3
AWC65R-3	1.00	PLATE	0.999	16.0	20	0.660	[illegible]	≈ 10	NA	NA	NA	AIR	20	0.1	D	13.0	0.59	t	?	2095	16.21		–	–	(1)	3
AWC65R-4	1.00	PLATE	0.995	16.0	20	0.634	2.090	≈ 10	NA	NA	NA	AIR	20	0.1	D	16.0	0.73	t	?	420	20.10		–	–	(1)	3
AWC80R-5	1.00	PLATE	0.997	16.0	20	0.765	2.565	≈ 10	NA	NA	NA	AIR	20	0.1	D	16.0	0.73	t	?	203	22.21		–	–	(1)	3
AWC62R-1	0.125	SHEET	0.121	12.0	20	0.066	1.285	≈ 10	NA	NA	NA	AIR	20	0.1	D	17.0	0.64	t	?	545	8.79		–	–	(1)	3
AWC81R-2	0.125	SHEET	0.125	12.0	20	0.080	1.680	≈ 10	NA	NA	NA	AIR	20	0.1	D	14.0	0.52	t	?	561	7.87		–	–	(1)	3
AWC81R-3	0.125	SHEET	0.126	12.0	20	0.090	1.689	≈ 10	NA	NA	NA	AIR	20	0.1	D	17.0	0.64	t	?	217	10.25		–	–	(1)	3
AWC81R-4	0.125	SHEET	0.133	12.0	20	0.082	1.630	≈ 10	NA	NA	NA	AIR	20	0.1	D	21.0	0.79	t	?	33	12.41		–	–	(1)	3
AWC100R-5	0.125	SHEET	0.121	12.0	20	0.091	2.060	≈ 10	NA	NA	NA	AIR	20	0.1	D	17.0	0.64	t	?	92	10.35		–	–	(1)	3

* SEE FIGURE 13

(1) CYCLED TO BREAKTHROUGH

Table 52: *−320°F Surface Flawed Cyclic Flaw Growth Tests of GTA Welded 2219-T87 Aluminum Alloy Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment.*

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS								COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{\text{in.}}$)	K_{Ii} (Ksi$\sqrt{\text{in.}}$)	K_{If} (IRWIN) (Ksi$\sqrt{\text{in.}}$)	K_{If} (Ksi$\sqrt{\text{in.}}$)		
2WI-7	1.0	PLATE	0.99	6.01	6	0.28	0.89	12	NA	NA	NA	AIR	1	0	D	25.0	0.98	0.39	1.03	360	21.2		23.2		(2)	23
2WI-9	1.0	PLATE	0.97	6.01	6	0.29	0.91	12	NA	NA	NA	AIR	1	0	D	29.0	1.14	0.46	1.33	89	25.0		30.5		(1,2)	23
1079WFA-12	0.5	PLATE	0.47	6.00	6	0.20	1.34	12	NA	NA	NA	AIR	1	0	D	25.0	0.98	t	?	125	21.9		–		(1,2)	23
1079WFB-11	0.5	PLATE	0.47	6.00	6	0.23	1.36	12	NA	NA	NA	AIR	1	0	D	25.0	0.98	t	?	74	22.9		–		(1,2)	23
1079WFB-10	0.5	PLATE	0.48	6.01	6	0.20	1.34	12	NA	NA	NA	AIR	1	0	D	25.0	0.98	t	?	56	21.9		–		(3)	23
AWC50N-1	1.00	PLATE	0.988	16.0	20	0.500	1.615	≈10	NA	NA	NA	AIR	20	0.1	D	21.0	0.78	t	?	416	23.39		–		(3)	3
AWC65N-2	1.00	PLATE	0.988	16.0	20	0.640	2.070	≈10	NA	NA	NA	AIR	20	0.1	D	13.0	0.49	t	?	3206	15.98		–		(3)	3
AWC65N-3	1.00	PLATE	1.000	16.0	20	0.625	2.080	≈10	NA	NA	NA	AIR	20	0.1	D	19.0	0.71	t	?	139	23.73		–		(3)	3
AWC65N-4	1.00	PLATE	0.991	16.0	20	0.652	2.075	≈10	NA	NA	NA	AIR	20	0.1	D	22.0	0.82	t	?	21	27.95		–		(3)	3
AWC80N-5	1.00	PLATE	0.996	16.0	20	0.750	2.560	≈10	NA	NA	NA	AIR	20	0.1	D	19.0	0.71	t	?	56	26.21		–		(3)	3
AWC62N-1	0.125	SHEET	0.119	11.8	20	0.056	1.275	≈10	NA	NA	NA	AIR	20	0.1	D	20.0	0.63	t	?	637	9.55		–		(3)	3
AWC81N-2	0.125	SHEET	0.125	11.9	20	0.080	1.630	≈10	NA	NA	NA	AIR	20	0.1	D	17.0	0.54	t	?	669	9.56		–		(3)	3
AWC81N-3	0.125	SHEET	0.125	12.0	20	0.071	1.643	≈10	NA	NA	NA	AIR	20	0.1	D	20.0	0.63	t	?	1072	10.75		–		(3)	3
AWC81N-4	0.125	SHEET	0.124	11.9	20	0.077	1.645	≈10	NA	NA	NA	AIR	20	0.1	D	25.0	0.79	t	?	12	14.34		–		(3)	3
AWC100N-5	0.125	SHEET	0.126	12.0	20	0.098	2.090	≈10	NA	NA	NA	AIR	20	0.1	D	20.0	0.63	t	?	11	12.61		–		(3)	3

* See Figure 13

(1) 2319 Filler Wire Used

(2) Cycled to Failure

(3) Cycled to Breakthrough

Table 53: −423°F Surface Flawed Cyclic Flaw Growth Tests of GTA Welded 2219-T87 Aluminum Alloy Square Butt Weld Edge Preparation. No Filler Wire Used. No Post Weld Heat Treatment.

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (Inch)	FORM	SPECIMEN DIMENSIONS (Inch)					PRECRACKING			TEST PREP		TESTING					RESULTS							COMMENTS	REFERENCE
			t	W	L	a_i	$2c_i$	σ (Ksi)	R	CYCLES (x 1,000)	SOAK TIME (Hours)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC LOADING PROFILE *	σ_{MAX} (Ksi)	$\sigma_{MAX}/\sigma_{YIELD}$	a_f (Inch)	$2c_f$ (Inch)	DURATION (Cycles)	K_{Ii} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{Ii} (Ksi$\sqrt{\text{In.}}$)	K_{If} (IRWIN) (Ksi$\sqrt{\text{In.}}$)	K_{If} (Ksi$\sqrt{\text{In.}}$)		
AWC50H-1	1.00	PLATE	1.003	16.0	20	0.482	1.615	≈ 10	NA	NA	NA	AIR	20	0.1	D	17.00	0.53	t	?	1195	18.38		—	—	(1)	3
AWC65H-2	1.00	PLATE	1.000	16.0	20	0.635	2.080	≈ 10	NA	NA	NA	AIR	20	0.1	D	13.00	0.41	t	?	3089	15.90		—	—	(1)	3
AWC65H-3	1.00	PLATE	0.998	16.0	20	0.600	2.080	≈ 10	NA	NA	NA	AIR	20	0.1	D	17.00	0.53	t	?	822	20.73		—	—	(1)	3
AWC65H-4	1.00	PLATE	1.001	16.0	20	0.645	2.080	≈ 10	NA	NA	NA	AIR	20	0.1	D	20.00	0.62	t	?	148	24.86		—	—	(1)	3
AWC80H-5	1.00	PLATE	1.006	16.0	20	0.755	2.550	≈ 10	NA	NA	NA	AIR	20	0.1	D	16.90	0.53	t	?	60	22.92		—	—	(1)	3
AWC62H-1	0.125	SHEET	0.125	12.0	20	0.062	1.280	≈ 10	NA	NA	NA	AIR	20	0.1	D	20.0	0.66	t	?	348	10.06		—	—	(1)	3
AWC81H-2	0.125	SHEET	0.175	12.0	20	0.093	1.630	≈ 10	NA	NA	NA	AIR	20	0.1	D	17.1	0.56	t	?	156	10.29		—	—	(1)	3
AWC81H-3	0.125	SHEET	0.122	12.0	20	0.082	1.630	≈ 10	NA	NA	NA	AIR	20	0.1	D	20.0	0.66	t	?	68	11.56		—	—	(1)	3
AWC81H-4	0.125	SHEET	0.122	12.0	20	0.087	1.680	≈ 10	NA	NA	NA	AIR	20	0.1	D	25.0	0.83	t	?	15	15.30		—	—	(1)	3
AWC100H-5	0.125	SHEET	0.123	12.0	20	0.098	1.980	≈ 10	NA	NA	NA	AIR	20	0.1	D	20.0	0.66	t	?	47	12.65		—	—	(1)	3

* See Figure 13

(1) Cycled to Breakthrough

Table A–1 : Room Temperature, Liquid Nitrogen Temperature and Liquid Hydrogen Temperature Compact Tension Fracture Toughness Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction [1]

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t	W	a	PRECRACKING K_{MAX}	R	CYCLES (x1000) [2]	TEST PREP. SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING ENVIRONMENT	TEMPERATURE (°F)	LOADING RATE (x1000 LB/MIN.)	RESULTS 5% OFFSET LOAD, P_Q (KIPS)	P_{MAX} (KIPS)	K_I KSI$\sqrt{IN.}$	REFERENCE
B1-21	2.5	Plate	1.252	2.001	1.14	12.2	0.06	37	–	Air	Air	72	5.0	3.88	3.98	26.4	15
B1-22	↕	↕	1.252	2.002	1.11	↕	↕	35	–	↕	Air	72	5.0	4.05	4.13	26.1	↕
B1-23	↕	↕	1.251	2.001	1.14	↕	↕	31	0.25	↕	LN_2	-320	6.0	4.60	4.82	31.4	↕
B1-29	↕	↕	1.249	2.001	1.12	↕	↕	35	0.25	↕	LN_2	-320	6.0	4.72	4.82	31.3	↕
A2-6	↕	↕	1.251	2.000	1.11	↕	↕	35	0.25	↕	LH_2	-423	6.0	5.10	5.40	33.0	↕
A2-7	2.5	Plate	1.252	2.002	1.10	12.2	0.06	30	0.25	Air	LH_2	-423	6.0	5.53	5.60	35.0	15

[1] Loading Holes Were Smaller and Farther Apart Than Recommended in AST E399-70T

[2] Cycles to Grow Last 0.10" of Precrack

Table A–2 : Room Temperature, Liquid Nitrogen Temperature and Liquid Hydrogen Temperature Three Point Bend Fracture Toughness Tests of 2219-T87 Aluminum Alloy, WT Propagation Direction.

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (INCH)	FORM	SPECIMEN DIMENSIONS (INCH) t	W	L	a	PRECRACKING K_{MAX}	R	CYCLES (x1000) [1]	TEST PREP. SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING ENVIRONMENT	TEMPERATURE (°F)	LOADING RATE (x 1000 LB/MIN.)	RESULTS 5% OFFSET LOAD, P_Q (KIPS)	P_{MAX} (KIPS)	K_I KSI$\sqrt{IN}$	REFERENCE
1	2.5	Plate	1.250	2.500	10.0	1.27	12.0	0.06	280	–	Air	Air	72	10.0	6.53	6.56	36.2	15
B1-14	↕	↕	1.253	2.500	↕	1.24	↕	↕	60	–	↕	Air	72	10.0	6.94	6.96	36.4	15
B1-15	↕	↕	1.254	2.502	↕	1.23	↕	↕	64	0.25	↕	LN_2	-320	12.0	7.93	8.30	41.6	15
A2-3	↕	↕	1.249	2.502	↕	1.22	↕	↕	60	0.25	↕	LN_2	-320	12.0	8.36	8.72	43.3	15
B1-12	↕	↕	1.253	2.502	↕	1.24	↕	↕	60	0.25	↕	LH_2	-423	10.0	9.21	9.65	48.8	15
B1-13	2.5	Plate	1.255	2.503	10.0	1.22	12.0	0.06	60	0.25	Air	LH_2	-423	10.0	9.18	9.75	47.2	15

[1] Cycles to Grow Last 0.10" of Precrack

Table A-3 : Room Temperature Single Edge Notch Tension Fracture Toughness Tests of 2219-T87 Aluminum Alloy, [1]

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCHES)				$\sigma_{NET} / \sigma_{YIELD}$	K_I (KSI$\sqrt{IN}$)	REFERENCE
				NOMINAL THICKNESS, t	NOMINAL WIDTH, w	NOMINAL LENGTH, L	NOMINAL FLAW DEPTH, a			
NA	1.0	Plate	RW	1.0	5.0	13.0	1.50	0.47	31.6	9
↑	↑	↑	RW	↑	↑	↑	↑	0.47	34.4	↑
↓	↓	↓	WR	↓	↓	↓	↓	0.45	29.3	↓
NA	1.0	Plate	WR	1.0	5.0	13.0	1.50	0.45	30.4	9

[1] No Data Available On Precracking or on Fracture Loads

Table A-4. *Room Temperature (70° – 75° F) Through-The-Thickness Center Notched Fracture Tests of 2219-T87 Aluminum Alloy*

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCH)				TEST PREP.		TESTING	RESULTS			REFERENCE	
				t	W	L	$2c_{CRITICAL}$	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	LOADING RATE	σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_C KSI $\sqrt{IN}$		
AC	0.060	SHEET	WR	0.061	15.95	≃28	6.28	NA	NA	NA	22.76	0.65	79.2	8	1
MA	0.060	SHEET	WR	0.062	16.29	≃28	5.91	NA	NA	NA	23.09	0.62	76.7	8	1
DD	0.060	SHEET	WR	0.062	16.29	≃28	6.36	NA	NA	NA	21.56	0.61	75.3	8	1
X4A1	0.10	SHEET	RW	0.10	36.0	NA	5.45	NA	NA	NA	34.0	0.69	100.9	33	2
X4A2	0.10	SHEET	RW	0.10	24.0	NA	5.73	NA	NA	NA	33.9	0.76	105.4	33	2
X4A3	0.10	SHEET	RW	0.10	48.0	NA	5.58	NA	NA	NA	34.9	0.66	104.2	33	2
X4A5	0.10	SHEET	RW	0.10	12.0	NA	4.77	NA	NA	NA	27.9	0.79	84.8	33	2
X5A8	0.10	SHEET	RW	0.10	24.0	NA	9.58	NA	NA	NA	24.1	0.68	103.9	33	2
X4A9	0.10	SHEET	RW	0.10	24.0	NA	13.65	NA	NA	NA	17.8	0.61	104.1	33	2
X4A14	0.10	SHEET	RW	0.10	48.0	NA	15.05	NA	NA	NA	23.2	0.58	120.2	33	2
X4A15	0.10	SHEET	RW	0.10	48.0	NA	9.25	NA	NA	NA	28.2	0.60	110.0	33	2
X4A16	0.10	SHEET	RW	0.10	48.0	NA	14.20	NA	NA	NA	24.5	0.57	122.4	33	2
X4A17	0.10	SHEET	RW	0.10	48.0	NA	25.72	NA	NA	NA	15.4	0.57	119.9	33	2
X4A22	0.10	SHEET	RW	0.10	30.0	NA	19.70	NA	NA	NA	[illegible]	0.62	97.0	33	2
0	0.50	PLATE	RW	0.523	9.8	≃30	3.23	NA	NA	NA	26.1	0.70	62.9	32	1

1 PRECRACKING INFORMATION NOT AVAILABLE

2 CRACK INTRODUCED WITH JEWELERS SAW, NO PRECRACK

Table A-5. *Liquid Nitrogen Temperature (-320°F) Through-The-Thickness Center Notched Fracture Tests of 2219-T87 Aluminum Alloy*

SPECIMEN IDENTIFICATION	ORIGINAL THICKNESS (INCH)	FORM	PROPAGATION DIRECTION	SPECIMEN DIMENSIONS (INCH) t	W	L	$2c_{CRITICAL}$	TEST PREP. SOAK TIME (HOURS)	PRIOR ENVIRONMENT	TESTING LOADING RATE	RESULTS σ_{GROSS} (KSI)	$\sigma_{NET}/\sigma_{YIELD}$	K_C KSI $\sqrt{IN}$	REFERENCE	
NA	0.060	SHEET	WR	0.062	15.99	≃28	6.70	NA	NA	NA	28.07	0.67	102.4	8	1
KA	0.060	SHEET	WR	0.061	15.99	≃28	6.52	NA	NA	NA	27.52	0.65	98.4	8	1
X6A5	1.0	PLATE	WR	0.10	5.0	NA	1.70	NA	NA	NA	34.6	0.75	60.9	33	2
X1A4	0.25	PLATE	RW	0.25	5.0	NA	1.60	NA	NA	NA	37.8	0.79	64.0	33	3

1 PRECRACKING INFORMATION NOT AVAILABLE
2 CRACK INTRODUCED WITH JEWELERS SAW CUT, NO PRECRACK
3 CRACK INTRODUCED BY EDM, NO PRECRACK

Table A-6. *Liquid Hydrogen Temperature (-423°F) Through-The-Thickness Center Notched Fracture Tests of 2219-T87 Aluminum Alloy*

UF032A-2	0.032	SHEET	WR	0.032	12.0	≃30	2.02	NA	AIR	NA	48.1	0.73	87.2	10	1
UH032A-2	0.032	SHEET	WR	0.032	12.0	≃30	3.91	NA	AIR	NA	39.2	0.79	104.0	10	2
DC	0.060	SHEET	WR	0.062	15.93	≃28	6.41	NA	NA	NA	26.32	0.59	93.0	8	1
GA	0.060	SHEET	WR	0.061	15.99	≃28	5.98	NA	NA	NA	26.25	0.56	88.2	8	1
UF125A-1	0.125	SHEET	WR	0.125	16.0	≃30	6.81	NA	AIR	NA	26.85	0.63	99.1	10	1
UF125A-2	0.125	SHEET	WR	0.125	12.0	≃30	1.94	NA	AIR	NA	46.20	0.75	82.0	10	1
UH125A-1	0.125	SHEET	WR	0.125	12.0	≃30	3.40	NA	AIR	NA	41.2	0.78	100.2	10	2
X6A7	1.0	PLATE	WR	0.10	5.0	NA	1.80	NA	NA	NA	36.4	0.75	66.6	33	3
X6A8	1.0	PLATE	WR	0.10	5.0	NA	1.51	NA	NA	NA	40.1	0.75	65.5	33	3
X6A9	1.0	PLATE	WR	0.10	5.0	NA	0.61	NA	NA	NA	52.7	0.80	52.1	33	3
X1A3	0.25	PLATE	RW	0.25	5.0	NA	1.70	NA	NA	NA	34.9	0.73	61.5	33	4
X1A5	0.25	PLATE	RW	0.25	5.0	NA	1.60	NA	NA	NA	35.3	0.73	59.8	33	4
X1A6	0.25	PLATE	RW	0.25	5.0	NA	1.65	NA	NA	NA	39.9	0.80	68.9	33	4

1 PRECRACKING INFORMATION NOT AVAILABLE
2 NOT PRECRACKED
3 CRACK INTRODUCED WITH JEWELERS SAWCUT, NO PRECRACK
4 CRACK INTRODUCED BY EDM, NO PRECRACK

Table A-7. *Room Temperature (70^0 – 75^0F) Through-The-Thickness Center Notched Panel Cycle to Failure Tests of 0.060" Thick 2219-T87 Aluminum Alloy Sheet, WR Propagation Direction*

SPECIMEN IDENTIFICATION	SPECIMEN DIMENSIONS (INCH)				TEST PREP.		TESTING				RESULTS				REFERENCE	
	t	W	L	$2c_i$	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC σ_{MAX} (KSI)	σ_{MAX} AT FAILURE	$2c_{CRITICAL}$ (INCH)	DURATION (CYCLES)	K_i KSI$\sqrt{IN}$	K CRITICAL KSI $\sqrt{IN}$		
HD	0.061	15.92	≃28	0.72	NA	NA	45~60	0.05	36.26	36.01	2.62	121	38.6	74.3	8	[1]
AD	0.062	15.93	≃28	0.72	NA	NA	45~60	0.05	36.11	35.86	2.62	105	38.4	74.0	8	[1]
IA	0.061	15.92	≃28	0.72	NA	NA	45~60	0.50	36.75	35.73	2.82	689	39.1	76.7	8	[1]
EC	0.059	15.99	≃28	0.72	NA	NA	45~60	0.50	35.97	35.26	2.58	591	38.3	72.1	8	[1]
EA	0.060	15.99	≃28	2.00	NA	NA	45~60	0.05	22.50	21.79	6.66	423	40.3	79.1	8	[1]
BD	0.061	15.93	≃28	2.00	NA	NA	45~60	0.05	22.60	20.81	6.63	243	40.5	75.4	8	[1]
KD	0.062	15.93	≃28	2.15	NA	NA	45~60	0.50	22.34	23.27	6.08	1220	41.5	79.1	8	[1]
DB	0.062	15.93	≃28	2.17	NA	NA	45~60	0.50	22.35	21.54	6.81	1185	41.7	79.6	8	[1]

[1] PRECRACKING INFORMATION NOT AVAILABLE

Table A-8. *Liquid Nitrogen Temperature (-320^0F) Through-The-Thickness Center Notched Panel Cycle to Failure Tests of 0.060" Thick 2219-T87 Aluminum Alloy Sheet, WR Propagation Direction*

RE	0.063	16.01	≃28	0.25	NA	NA	45~60	0.05	50.26	48.90	1.71	40	31.5	80.7	8	[1]
CD	0.061	15.95	≃28	0.25	NA	NA	45~60	0.50	49.25	48.79	2.01	1326	30.9	87.6	8	[1]
ED	0.059	15.99	≃28	0.73	NA	NA	45~60	0.05	45.75	43.98	2.10	20	49.1	80.7	8	[1]
FC	0.060	15.92	≃28	0.72	NA	NA	45~60	0.05	45.70	43.89	2.00	12	48.1	78.6	8	[1]
AB	0.061	15.98	≃28	0.72	NA	NA	45~60	0.08	46.08	45.45	1.96	14	49.1	80.5	8	[1]
HB	0.061	15.92	≃28	0.73	NA	NA	45~60	0.51	43.42	43.27	2.61	199	46.6	89.1	8	[1]
KC	0.062	16.00	≃28	2.12	NA	NA	45~60	0.05	28.06	27.67	6.52	72	51.8	96.9	8	[1]
CB	0.061	15.92	≃28	2.10	NA	NA	45~60	0.05	28.26	26.64	6.29	73	51.9	92.8	8	[1]
AA	0.062	15.93	≃28	2.15	NA	NA	45~60	0.49	28.17	29.80	5.94	360	52.4	93.0	8	[1]
KB	0.062	15.99	≃28	2.12	NA	NA	45~60	0.50	28.12	27.26	6.32	477	51.9	95.2	8	[1]

[1] PRECRACKING INFORMATION NOT AVAILABLE

Table A-9. *Liquid Hydrogen (-423°F) Through-The-Thickness Center Notched Panel Cycle to Failure Tests of 0.060" Thick 2219-T87 Aluminum Alloy Sheet, WR Propagation Direction*

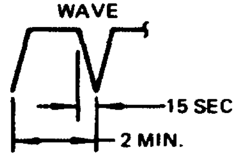
SPECIMEN IDENTIFICATION	SPECIMEN DIMENSIONS (INCH)				TEST PREP.		TESTING				RESULTS				REFERENCE	
	t	W	L	$2c_i$	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	CYCLIC σ_{MAX} (KSI)	σ_{MAX} AT FAILURE (KSI)	$2c_{CRITICAL}$ (INCH)	DURATION (CYCLES)	K_i (KSI $\sqrt{IN}$)	$K_{CRITICAL}$ (KSI $\sqrt{IN}$)		
QE	0.063	16.01	≃28	0.43	NA	NA	45 ~ 60	0.05	51.12	48.15	1.89	38	42.0	83.7	8	1
RC	0.063	16.01	≃28	0.43	NA	NA	45 ~ 60	0.10	51.58	49.90	1.65	45	42.4	80.9	8	1
RF	0.063	16.01	≃28	0.43	NA	NA	45 ~ 60	0.50	51.15	50.70	1.67	357	42.1	82.7	8	1
SH	0.063	16.01	≃28	0.45	NA	NA	45 ~ 60	0.50	51.01	50.25	1.82	358	42.9	85.6	8	1
QA	0.063	16.00	≃28	1.95	NA	NA	45 ~ 60	0.05	26.32	25.66	7.14	147	46.5	98.3	8	1
RG	0.065	16.01	≃28	1.95	NA	NA	45 ~ 60	0.05	26.43	24.90	7.55	177	46.7	99.8	8	1
RD	0.063	16.01	≃28	1.95	NA	NA	45 ~ 60	0.48	25.73	24.39	7.16	1855	45.4	93.6	8	1
QB	0.063	16.01	≃28	1.95	NA	NA	45 ~ 60	0.50	24.87	24.35	7.16	2565	43.9	93.5	8	1

1 PRECRACKING INFORMATION NOT AVAILABLE

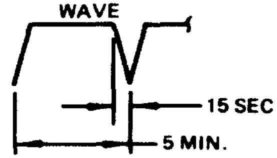
Table A-10: Tapered Double Cantilever Beam Specimen Cyclic Tests of 1.0 Inch 2219-T87 Aluminum Alloy in Room Temperature 3½% Salt Water Solution, WR Propagation Direction

SPECIMEN IDENTIFICATION	SPECIMEN DIMENSIONS (INCH)						TEST PREP.		TESTING			RESULTS				REFERENCE	
	THICKNESS, t (INCH)	THICKNESS AT SIDEGROOVE, t_g (INCH) [1]	h	h_1	L	a INITIAL	SOAK TIME (HOURS)	PRIOR ENVIRONMENT	FREQUENCY (CPM)	R	P_{MAX} (KIPS)	a_{FINAL} (INCH)	DURATION (CYCLES)	K_I $(KSI\sqrt{IN})$	da/dN (MICROINCHES PER CYCLE)		
TA-3	1.00	0.80	2.00	5.00	5.00	1.64	NA	AIR	20	0	3.675	1.91	2500	20.0	108	5	SINE WAVE
						1.95		3½% NaCl			3.920	2.09	1000	21.4	140		
						2.28					4.410	2.43	250	24.0	600		
TA-4	1.00	0.80	2.00	5.00	5.00	1.66	NA	AIR	20	0	3.675	1.69	500	20.0	60	5	
						1.78		3½% NaCl			3.920	1.87	500	21.4	180		
						1.88					4.410	1.96	250	24.0	320		
TA-6	1.00	0.80	2.00	5.00	5.00	1.69	NA	AIR	0.5	0	3.675	1.74	500	20.0	100	5	TRAPEZOIDAL WAVE
						1.82		3½% NaCl			3.920	1.88	500	21.4	120		
						1.93					4.410	2.38	250	24.0	1800		
TA-8	1.00	0.80	2.00	5.00	5.00	1.67	NA	AIR	0.5	0	3.675	1.74	500	20.0	120	5	
						1.77		3½% NaCl			3.920	1.82	500	21.4	100		
						1.89					4.410	1.95	250	24.0	240		
TA-5	1.00	0.80	2.00	5.00	5.00	1.66	NA	AIR	0.2	0	3.675	1.71	500	20.0	100	5	TRAPEZOIDAL WAVE
						1.83		3½% NaCl			3.920	1.92	500	21.4	180		
						1.96					4.410	2.09	250	24.0	520		
TA-7	1.00	0.80	2.00	5.00	5.00	3.05	NA	3½% NaCl	0.2	0	4.410	3.32	250	24.0	1080	5	

TRAPEZOIDAL WAVE



TRAPEZOIDAL WAVE



[1] GROOVE SHAPE WAS 60° "V" WITH 0.01 RADIUS