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REVIEW OF CRYOGENIC MECHANICAL AND THERMAL PROPERTIES OF Al-Li ALLOYS AND ALLOY 2219

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**U.S. DEPARTMENT OF COMMERCE, Robert A. Mosbacher, Secretary
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CONTENTS

Executive Summary	vii
Composition Limits for Al-Li Alloys and Alloy 2219	vii
1. Tensile Properties	1
1.1. Introduction to Graphs	1
1.2. Alloy 8090	
1.2.1. T8 (8771, 8151) Tempers	
1.2.1.1. L Orientation Graphs	
1.2.1.1.1. Ultimate Tensile Strength	3
1.2.1.1.2. Tensile Yield Strength	4
1.2.1.1.3. Elongation	5
1.2.1.2. T Orientation Graphs	
1.2.1.2.1. Ultimate Tensile Strength	6
1.2.1.2.2. Tensile Yield Strength	7
1.2.1.2.3. Elongation	8
1.2.1.3. 45° from L Orientation Graphs	
1.2.1.3.1. Ultimate Tensile Strength	9
1.2.1.3.2. Tensile Yield Strength	10
1.2.1.3.3. Elongation	11
1.2.1.4. S Orientation Graphs	
1.2.1.4.1. Ultimate Tensile Strength	12
1.2.1.4.2. Tensile Yield Strength	13
1.2.1.4.3. Elongation	14
1.2.2. T3 Temper	
1.2.2.1. L Orientation Graphs	
1.2.2.1.1. Ultimate Tensile Strength	15
1.2.2.1.2. Tensile Yield Strength	16
1.2.2.1.3. Elongation	17
1.2.2.2. T Orientation Graphs	
1.2.2.2.1. Ultimate Tensile Strength	18
1.2.2.2.2. Tensile Yield Strength	19
1.2.2.2.3. Elongation	20
1.2.3. Data Table	21
1.2.3.1. Comments from the Data Table	32
1.2.4. Test Parameter Table	33
1.2.4.1. Comments from the Test Parameter Table	35
1.3. Alloy 2090	
1.3.1. T8 (81, 8E41, 8E50) Tempers	
1.3.1.1. L Orientation Graphs	
1.3.1.1.1. Ultimate Tensile Strength	36
1.3.1.1.2. Tensile Yield Strength	37
1.3.1.1.3. Elongation	38
1.3.1.2. T Orientation Graphs	
1.3.1.2.1. Ultimate Tensile Strength	39
1.3.1.2.2. Tensile Yield Strength	40
1.3.1.2.3. Elongation	41
1.3.1.3. 45° from L Orientation Graphs	
1.3.1.3.1. Ultimate Tensile Strength	42
1.3.1.3.2. Tensile Yield Strength	43
1.3.1.3.3. Elongation	44
1.3.1.4. S Orientation Graphs	
1.3.1.4.1. Ultimate Tensile Strength	45

	1.3.1.4.2.	Tensile Yield Strength	46
	1.3.1.4.3.	Elongation	47
1.3.2.		Data Table	48
	1.3.2.1.	Comments from the Data Table	53
1.3.3.		Test Parameter Table	54
	- 1.3.3.1.	Comments from the Test Parameter Table	55
1.4.		Alloy WLO49	
1.4.1.		T8 (851, 8) Tempers	
	1.4.1.1.	L Orientation Graphs	
		1.4.1.1.1. Ultimate Tensile Strength	56
		1.4.1.1.2. Tensile Yield Strength	57
		1.4.1.1.3. Elongation	58
	1.4.1.2.	T Orientation Graphs	
		1.4.1.2.1. Ultimate Tensile Strength	59
		1.4.1.2.2. Tensile Yield Strength	60
		1.4.1.2.3. Elongation	61
	1.4.1.3.	45° from L Orientation Graphs	
		1.4.1.3.1. Ultimate Tensile Strength	62
		1.4.1.3.2. Tensile Yield Strength	63
		1.4.1.3.3. Elongation	64
	1.4.1.4.	S Orientation Graph	
		1.4.1.4.1. Ultimate Tensile Strength	65
1.4.2.		T6 (651, 64, 68, 620) Tempers	
	1.4.2.1.	L Orientation Graphs	
		1.4.2.1.1. Ultimate Tensile Strength	66
		1.4.2.1.2. Tensile Yield Strength	67
		1.4.2.1.3. Elongation	68
	1.4.2.2.	T Orientation Graphs	
		1.4.2.2.1. Ultimate Tensile Strength	69
		1.4.2.2.2. Tensile Yield Strength	70
		1.4.2.2.3. Elongation	71
	1.4.2.3.	45° from L Orientation Graphs	
		1.4.2.3.1. Ultimate Tensile Strength	72
		1.4.2.3.2. Tensile Yield Strength	73
		1.4.2.3.3. Elongation	74
	1.4.2.4.	S Orientation Graph	
		1.4.2.4.1. Ultimate Tensile Strength	75
1.4.3.		T3 (351, 3) Tempers	
	1.4.3.1.	L Orientation Graphs	
		1.4.3.1.1. Ultimate Tensile Strength	76
		1.4.3.1.2. Tensile Yield Strength	77
		1.4.3.1.3. Elongation	78
	1.4.3.2.	T Orientation Graphs	
		1.4.3.2.1. Ultimate Tensile Strength	79
		1.4.3.2.2. Tensile Yield Strength	80
		1.4.3.2.3. Elongation	81
	1.4.3.3.	S Orientation Graph	
		1.4.3.3.1. Ultimate Tensile Strength	82
1.4.4.		Data Table	83
1.4.5.		Test Parameter Table	91
	1.4.5.1.	Comments from the Test Parameter Table	93
1.5.		Alloy 2219	
1.5.1.		T8 (87, 851) Tempers	
	1.5.1.1.	L Orientation Graphs	

	1.5.1.1.1.	Ultimate Tensile Strength	94
	1.5.1.1.2.	Tensile Yield Strength	95
	1.5.1.1.3.	Elongation	96
	1.5.1.2.	T Orientation Graphs	
	1.5.1.2.1.	Ultimate Tensile Strength	97
	1.5.1.2.2.	Tensile Yield Strength	98
	1.5.1.2.3.	Elongation	99
	1.5.1.3.	45° from L Orientation Graphs	
	1.5.1.3.1.	Ultimate Tensile Strength	100
	1.5.1.3.2.	Tensile Yield Strength	101
	1.5.1.3.3.	Elongation	102
	1.5.1.4.	S Orientation Graph	
	1.5.1.4.1.	Ultimate Tensile Strength	103
1.5.2.	T3 Temper		
	1.5.2.1.	L Orientation Graphs	
	1.5.2.1.1.	Ultimate Tensile Strength	104
	1.5.2.1.2.	Tensile Yield Strength	105
	1.5.2.1.3.	Elongation	106
	1.5.2.2.	T Orientation Graphs	
	1.5.2.2.1.	Ultimate Tensile Strength	107
	1.5.2.2.2.	Tensile Yield Strength	108
	1.5.2.2.3.	Elongation	109
	1.5.2.3.	S Orientation Graph	
	1.5.2.3.1.	Ultimate Tensile Strength	110
1.5.3.	Data Table		111
1.5.4.	Test Parameter Table		125
2.	Fracture Properties		127
2.1.	Introduction to Graphs		127
2.1.1.	Figure of CT Orientations		128
2.2.	Alloy 8090		
	2.2.1.	Fracture Toughness vs. Temperature Graph	129
	2.2.2.	Fracture Toughness vs. Tensile Yield Strength Graphs	
	2.2.2.1.	295 K	130
	2.2.2.2.	77 K	131
	2.2.2.3.	4 K	132
	2.2.3.	Data Table	133
	2.2.3.1.	Comments from the Data Table	135
	2.2.4.	Test Conditions Table	136
	2.2.4.1.	Comments from the Test Conditions Table	137
2.3.	Alloy 2090		
	2.3.1.	Fracture Toughness vs. Temperature Graph	138
	2.3.2.	Fracture Toughness vs. Tensile Yield Strength Graphs	
	2.3.2.1.	295 K	139
	2.3.2.2.	77 K	140
	2.3.2.3.	4 K	141
	2.3.3.	Data Table	142
	2.3.3.1.	Comments from the Data Table	144
	2.3.4.	Test Conditions Table	145
	2.3.4.1.	Comments from the Test Conditions Table	146
2.4.	Alloy WL049		
	2.4.1.	Fracture Toughness vs. Temperature Graph	147
	2.4.2.	Fracture Toughness vs. Tensile Yield Strength Graphs	
	2.4.2.1.	295 K	148
	2.4.2.2.	77 K	149

2.4.2.3.	4 K	150
2.4.3.	Data Table	151
2.4.3.1.	Comments from the Data Table	155
2.4.4.	Test Conditions Table	156
2.5.	Alloy 2219	
2.5.1.	Fracture Toughness vs. Temperature Graph	157
2.5.2.	Fracture Toughness vs. Tensile Yield Strength Graphs	
2.5.2.1.	295 K	158
2.5.2.2.	77 K	159
2.5.2.3.	4 K	160
2.5.3.	Data Table	161
2.5.4.	Test Conditions Table	164
3.	Elastic Properties	165
3.1.	Introduction to Graphs	165
3.1.1.	Temperature Dependence	165
3.1.2.	Effects of Alloying Elements, Cold Work, and Other Factors	165
3.2.	Young's Modulus Graph, Alloys 2090 and 2219	167
3.3.	Shear Modulus Graph, Alloys 2090 and 2219	168
3.4.	Bulk Modulus Graph, Alloys 2090 and 2219	169
3.5.	Poisson's Ratio, Alloys 2090 and 2219	170
3.6.	Density and Elastic Constants of Al-Li Alloys and Alloy 2219 at Ambient Temperature	171
3.7.	Elastic Constants of Al-Li Alloys and Alloy 2219 at Low Temperatures	172
4.	Thermal Properties	173
4.1.	Specific Heat	173
4.1.1.	Introduction to Graph	173
4.1.2.	Graph for Alloys 8090, 2090, 2024(2219)	174
4.1.3.	Specific Heat of Al-Li Alloys and Alloy 2219	175
4.2.	Thermal Conductivity	176
4.2.1.	Introduction to Graph	176
4.2.2.	Graph for Alloys 8090, 2090, 2219	177
4.2.3.	Thermal Conductivity of Al-Li Alloys and Alloy 2219	178
4.3.	Mean Thermal Expansion	179
4.3.1.	Introduction to Graph	179
4.3.2.	Graph for Alloys 8090, 2090, 2219	180
4.3.3.	Mean Thermal Expansion of Al-Li Alloys and Alloy 2219	181
5.	Acknowledgements	182
6.	References	183

EXECUTIVE SUMMARY

The review of cryogenic mechanical and thermal properties presented here is part of a broader National Institute of Standards and Technology (NIST) program to assess new high-strength Al-Li alloys for use in the cryogenic tankage of the Advanced Launch System (ALS). The purpose of the NIST program has been to assess the relative suitability of high-strength Al-Li alloys and alloy 2219 for use in ALS cryogenic tanks. In this report, the cryogenic data on Al-Li alloys 8090, 2090, WL049,* and Al alloy 2219 have been summarized. Properties covered in this survey are tensile strength, yield strength, elongation, fracture toughness, elastic constants, specific heat, thermal conductivity, and thermal expansion.

Composition Limits for Al-Li Alloys and Alloy 2219 in wt%.

Elements	ALLOY			
	8090	2090	WL049	2219
Cu	1.0-1.6	2.4-3.0	4.0-6.3	5.8-6.8
Li	2.2-2.7	1.9-2.6	1.3	--
Mg	0.6-1.3	0.25	0.4	0.02
Zr	0.04-0.16	0.08-0.15	0.14	0.10-0.25
Si	0.20	0.10	--	0.20
Fe	0.30	0.12	--	0.30
Ti	0.10	0.15	0.03	0.02-0.10
Cr	0.10	0.05	--	--
Zn	0.25	0.10	--	0.10
Ag	--	--	0.4	--
Mn	0.10	0.05	--	0.20-0.40
Others, each	0.05	0.05	--	--
Others, total	0.15	0.15	--	--
Al	Remainder	Remainder	Remainder	Remainder

* The WL049 alloy does not have a generic specification at this time and is commonly termed WELDALITE 049. Trade names are furnished to identify the material adequately. Such identification does not imply recommendation or endorsements by NIST, nor does it imply that the materials identified are necessarily the best available for the purpose.

1. TENSILE PROPERTIES

1.1. Introduction to Graphs

In general, only measurement sets that included cryogenic data were included in the graphs and tables. However, some ambient temperature values, such as the producers' typical values, are presented. The horizontal scale of the graphs was extended to 600 K because some cryogenic data sets also included measurements above ambient temperatures and it was considered useful to present the additional information. When available, data are provided for longitudinal (L), transverse (T), 45° from the rolling direction, and through-thickness (S) orientations. The graphs show data for the T8 temper for all the alloys. Additional graphs are provided for the T3 temper for alloys 8090, WL049, and 2219, and the T6 temper for alloy WL049. The graphs are organized in descending order by temper for each alloy.

All tensile property data points shown graphically are listed and referenced in the tables following the graphs. A reference number is provided in the legend of each graph. Two formats are used in the tensile property tables: (1) data, and (2) test parameters, including further documentation. The data tables present temperature and tensile properties, including reduction of area (not presented in the graphs). This is followed by information on orientation, temper, product form and thickness, thermomechanical processing, grain size, hardness, number of tests per data point, and a reference and note number. The reference and note number (which corresponds to the reference number on the graphs) is a guide to the accompanying test parameter table. The test parameter table gives information on the strain rate during testing; specimen type, dimensions, and location; exposure time at test temperature (available chiefly for data above ambient temperature); supplier; year produced; lot number; product dimensions; and chemistry. The tables are ordered by temper, starting with T8 tempers and ending with T3 or annealed (0) tempers. Some cryogenic data is presented in the tables but not in the graphs; for example, data on the T4 temper of alloy 2090.

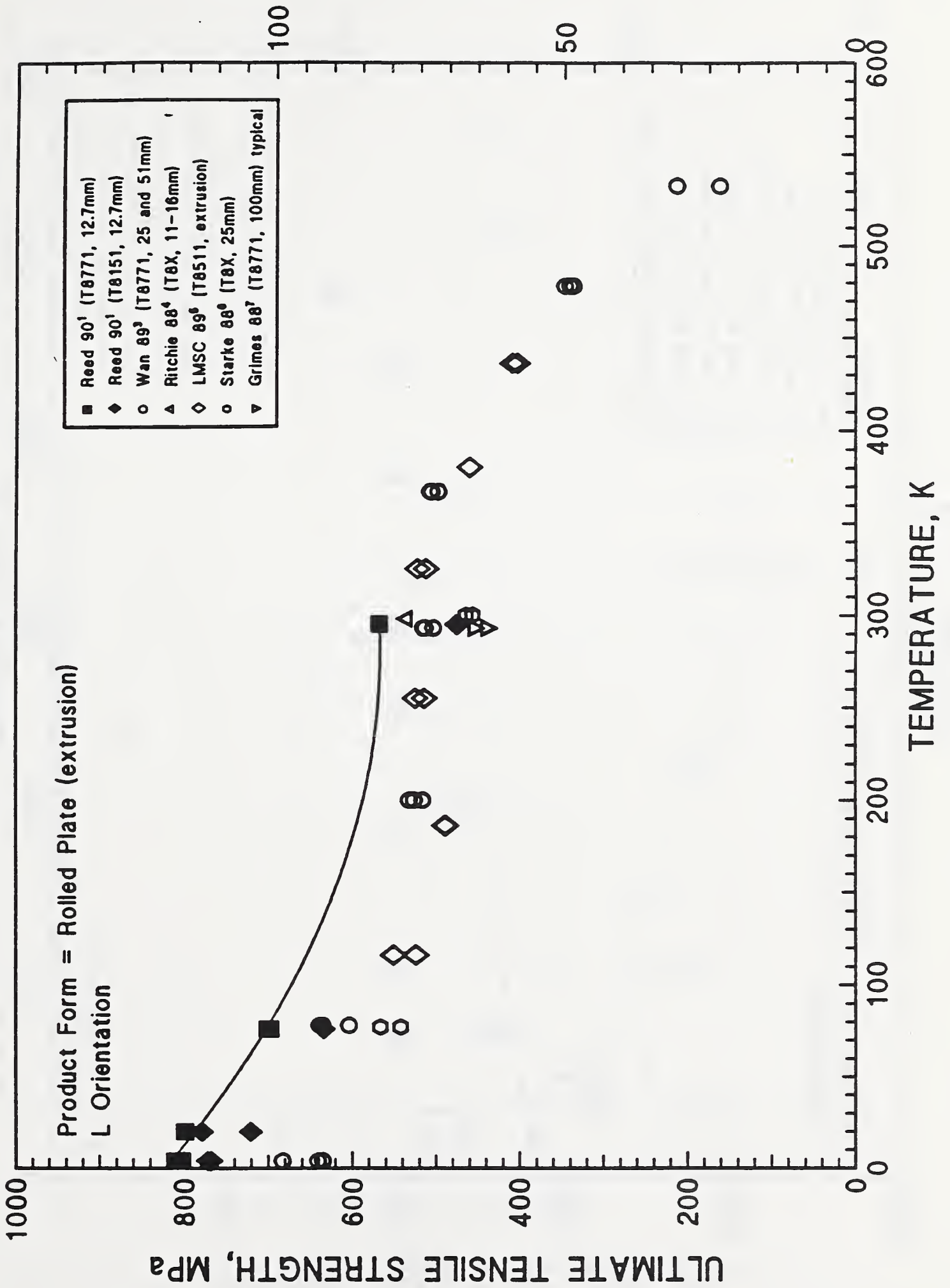
Much of the cryogenic data, especially on current production vintages and tempers, are from recent measurements at the National Institute of Standards and Technology (NIST), under sponsorship of the Advanced Launch System (ALS) program. For more detailed information on measurement techniques, stress-strain curves, and microstructure, see ref. 1. The NIST data are denoted by solid square and solid diamond symbols on the graphs. A smoothed line connects the NIST data points corresponding to tempers under consideration for use in the ALS program. The position of the line and the indicated temperature dependence generally are based on measurements made on two specimens at 4, 20, 76, and 295 K. The material in the NIST program was usually 12.7-mm (0.5-in) plate; and only ultimate tensile strength measurements were obtained from tests in the S orientation.

The four graphs of alloy 2219-T8 data in the L and T orientations for tensile yield strength and ultimate tensile strength include dashed lines. These lines, labeled MIL-HNBK-5E,² were derived from curves presented in

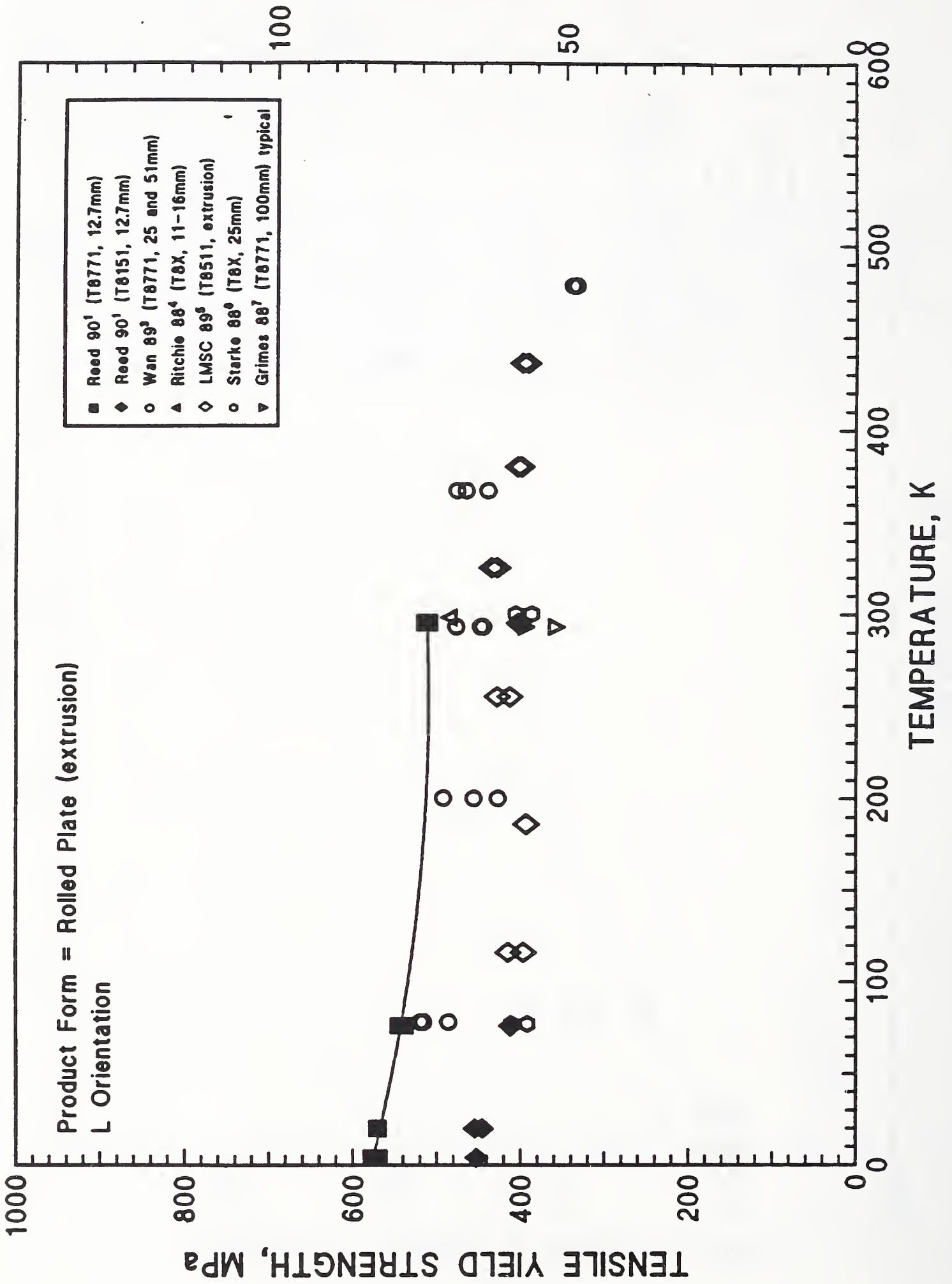
Figures 3.2.6.41(a) and (b) of that handbook² which give cryogenic values as a percentage of the room temperature value for ultimate and yield strengths, respectively. The room temperature values used to obtain the curves on our graphs for ultimate and yield strengths came from Table 3.2.6.0(b) from the MIL-HNBK-5E handbook. These values are "A basis" minimums and indicate that 99% of the data should fall on or above the curve, with a confidence level of 95%. (Please note that this information is provided on the graphs by the asterisked footnote.)

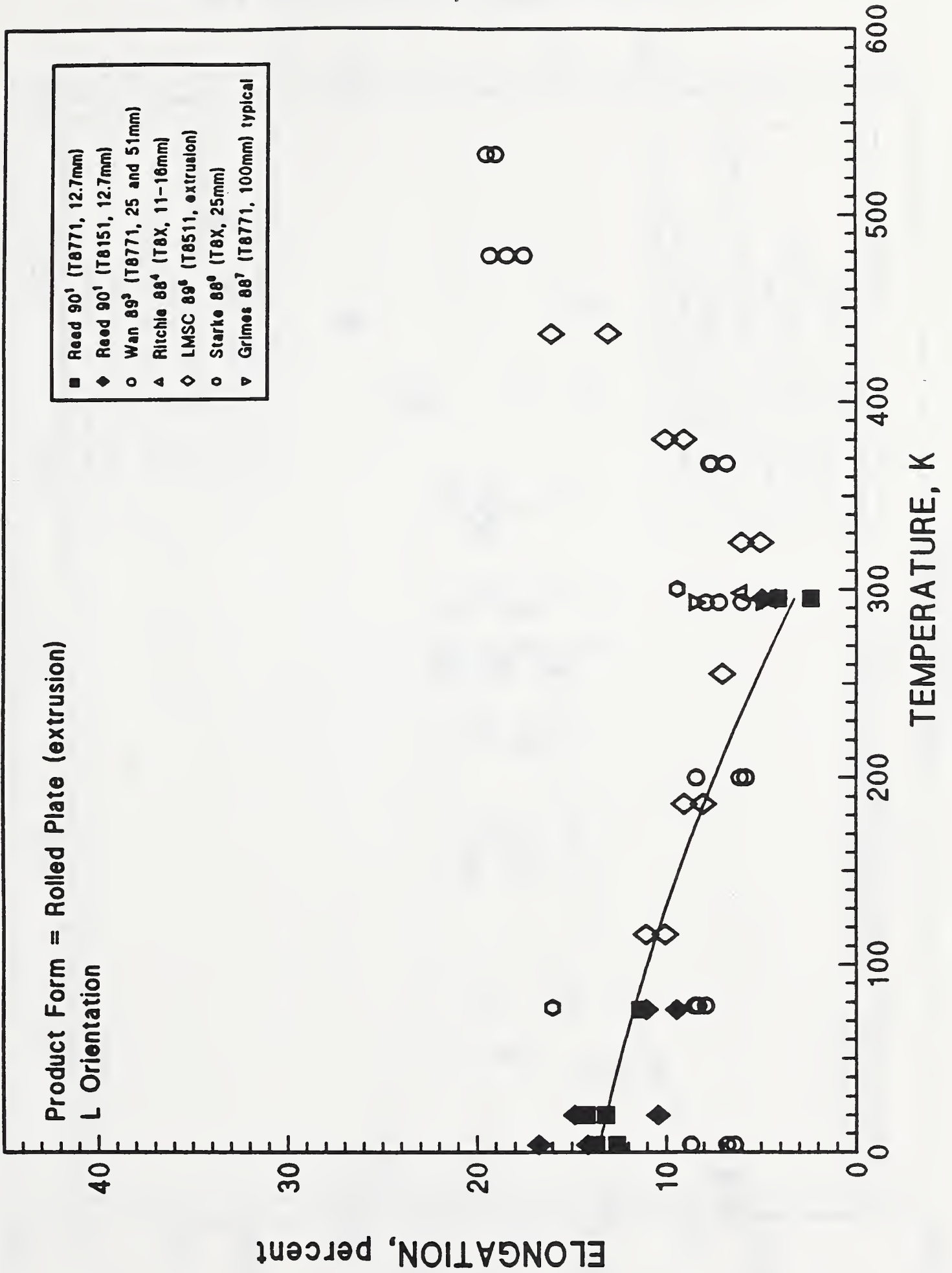
Most of the cryogenic data do not fall on or above the handbook-derived minimum line for temper T87. We do not have a complete explanation for why this occurred. It is to be expected that the solid squares, temper T851, consistently would fall below the line. Very thick plate results frequently fall below the line. The "A basis" value does not pertain to plates of these thicknesses. At thicknesses of 100-125 mm the "A basis" line would fall 21 and 14 MPa lower for ultimate and yield strengths, respectively, in the T orientation. No value is provided for thicker plate in the L orientation.

ULTIMATE TENSILE STRENGTH, ksi

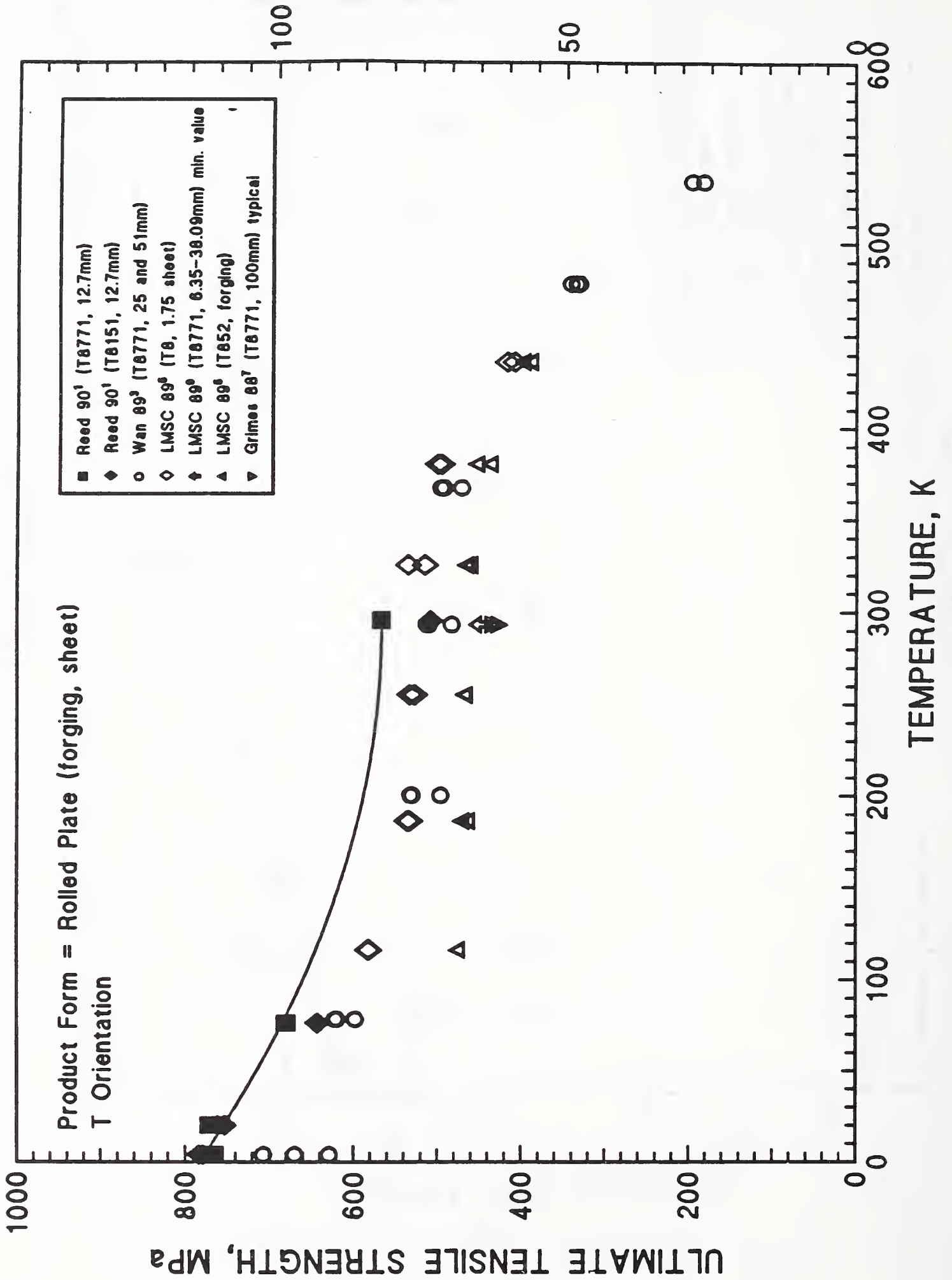


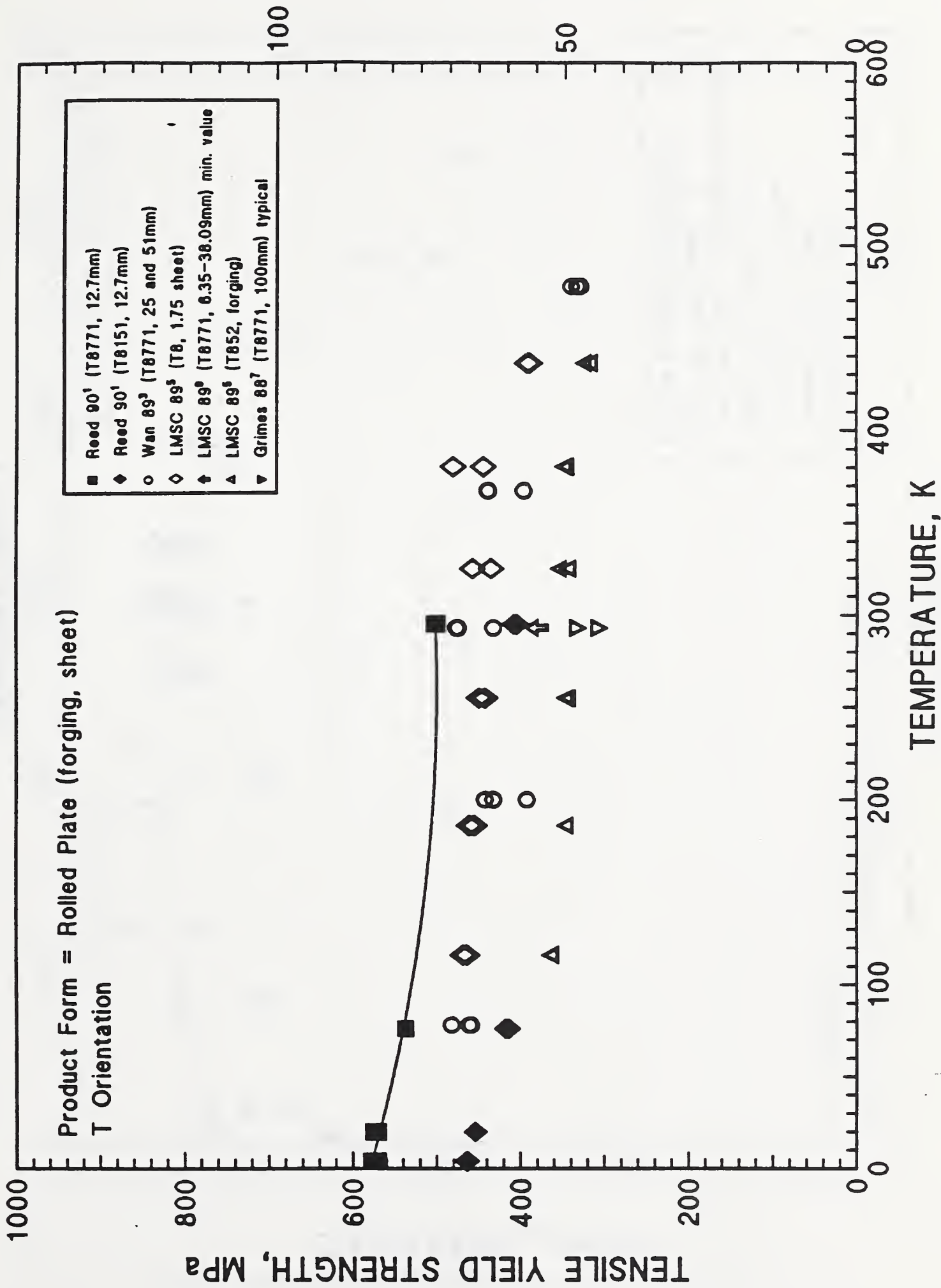
TENSILE YIELD STRENGTH, ksi

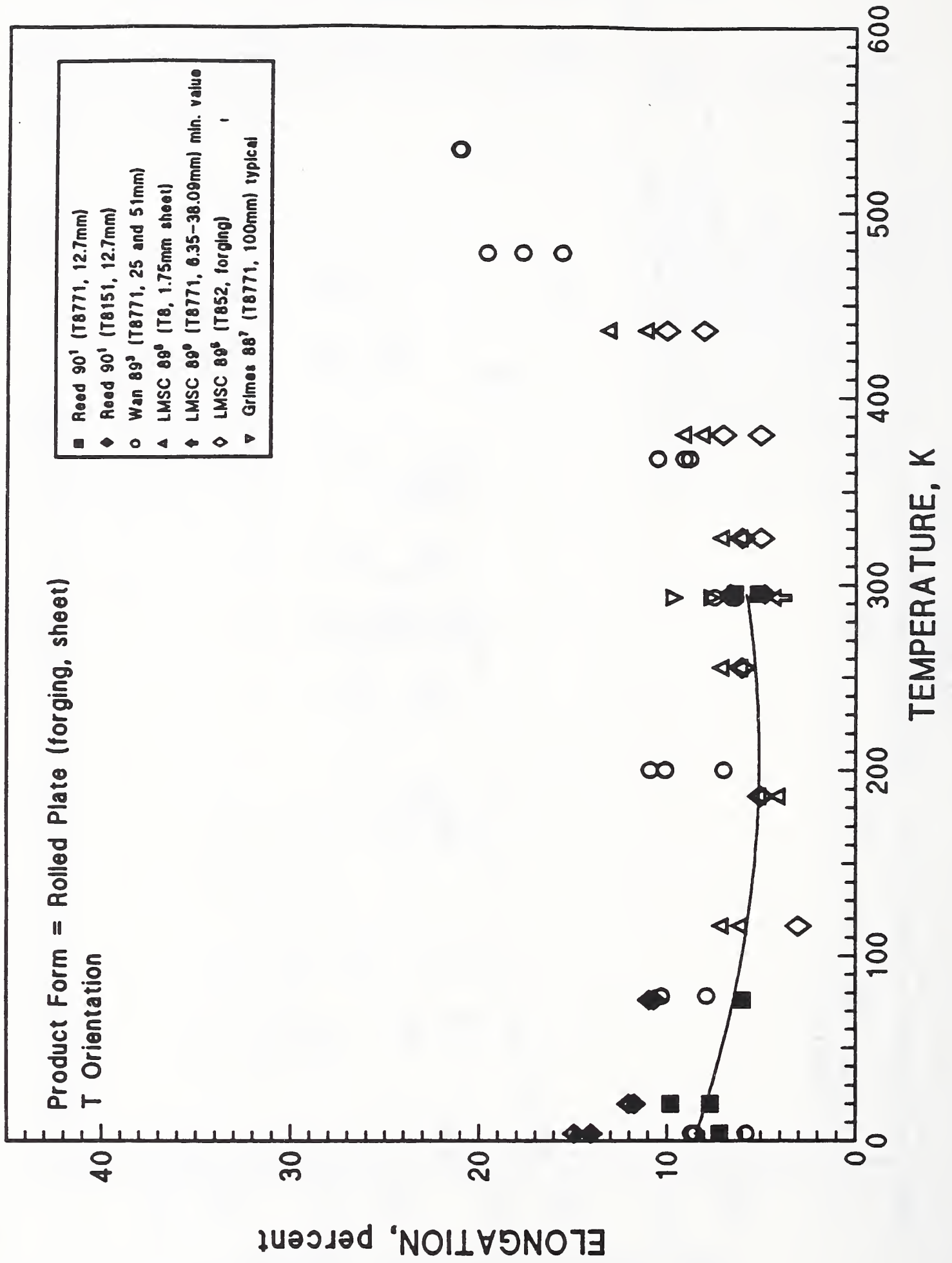




ULTIMATE TENSILE STRENGTH, ksi

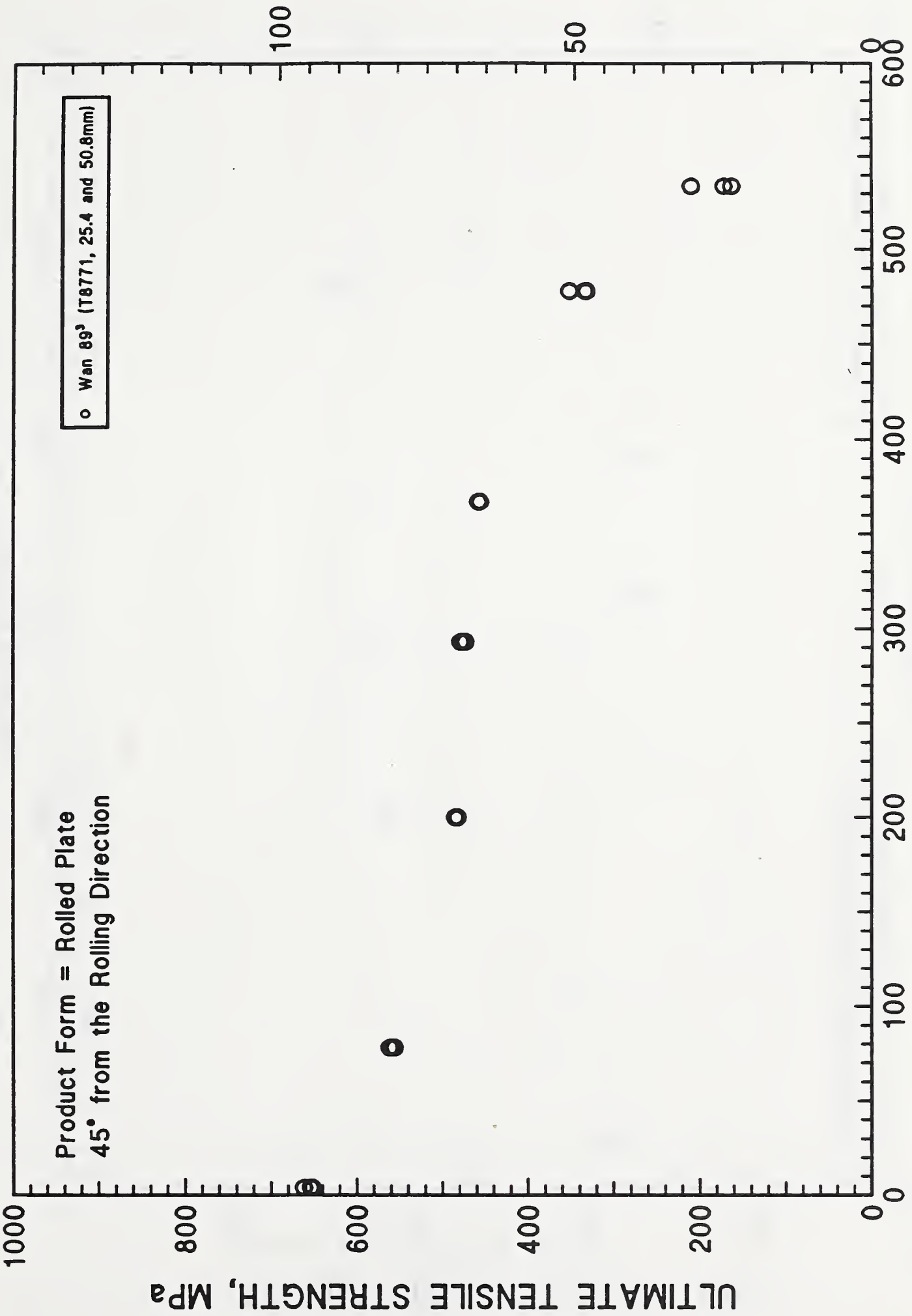






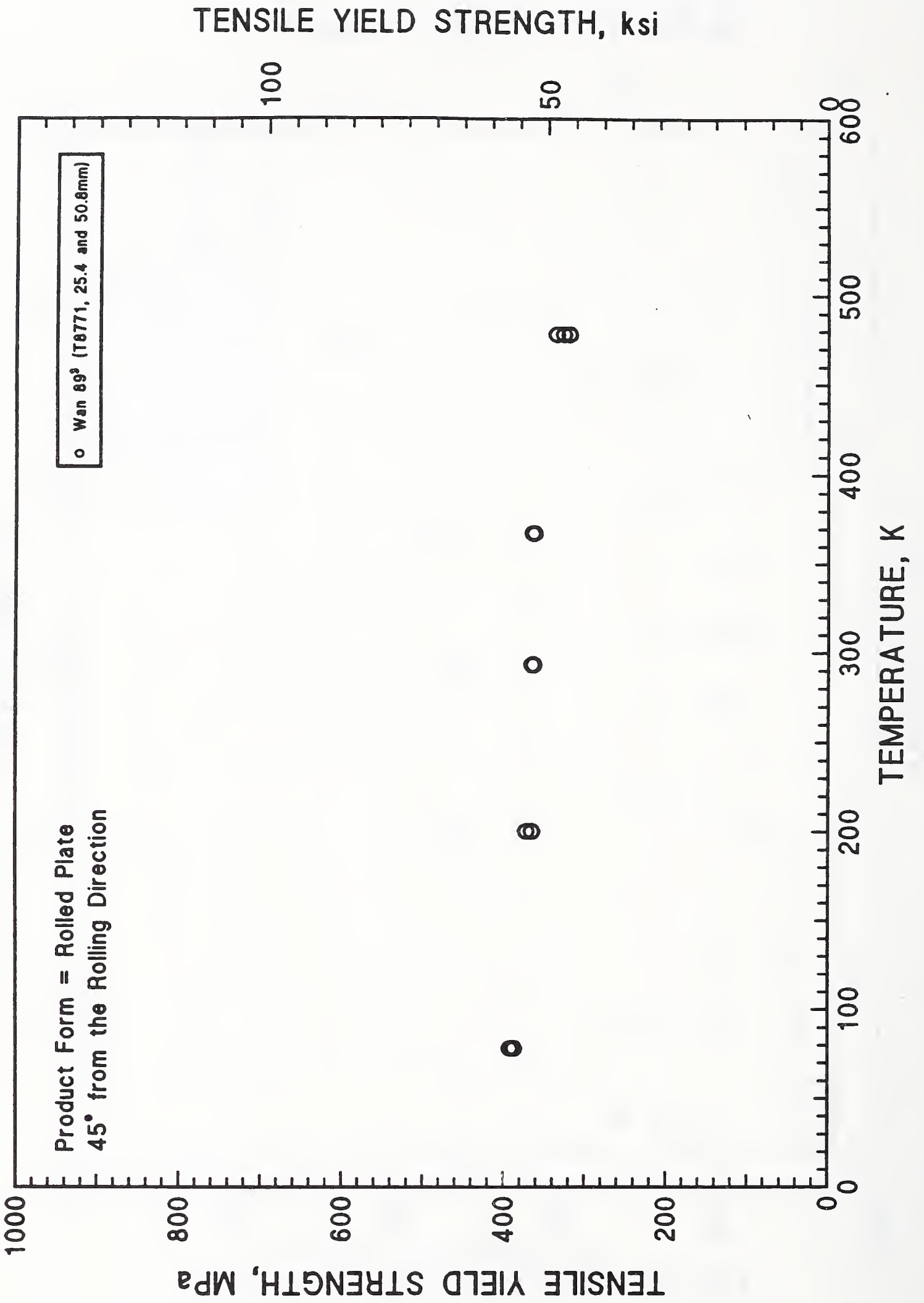
8090-T8

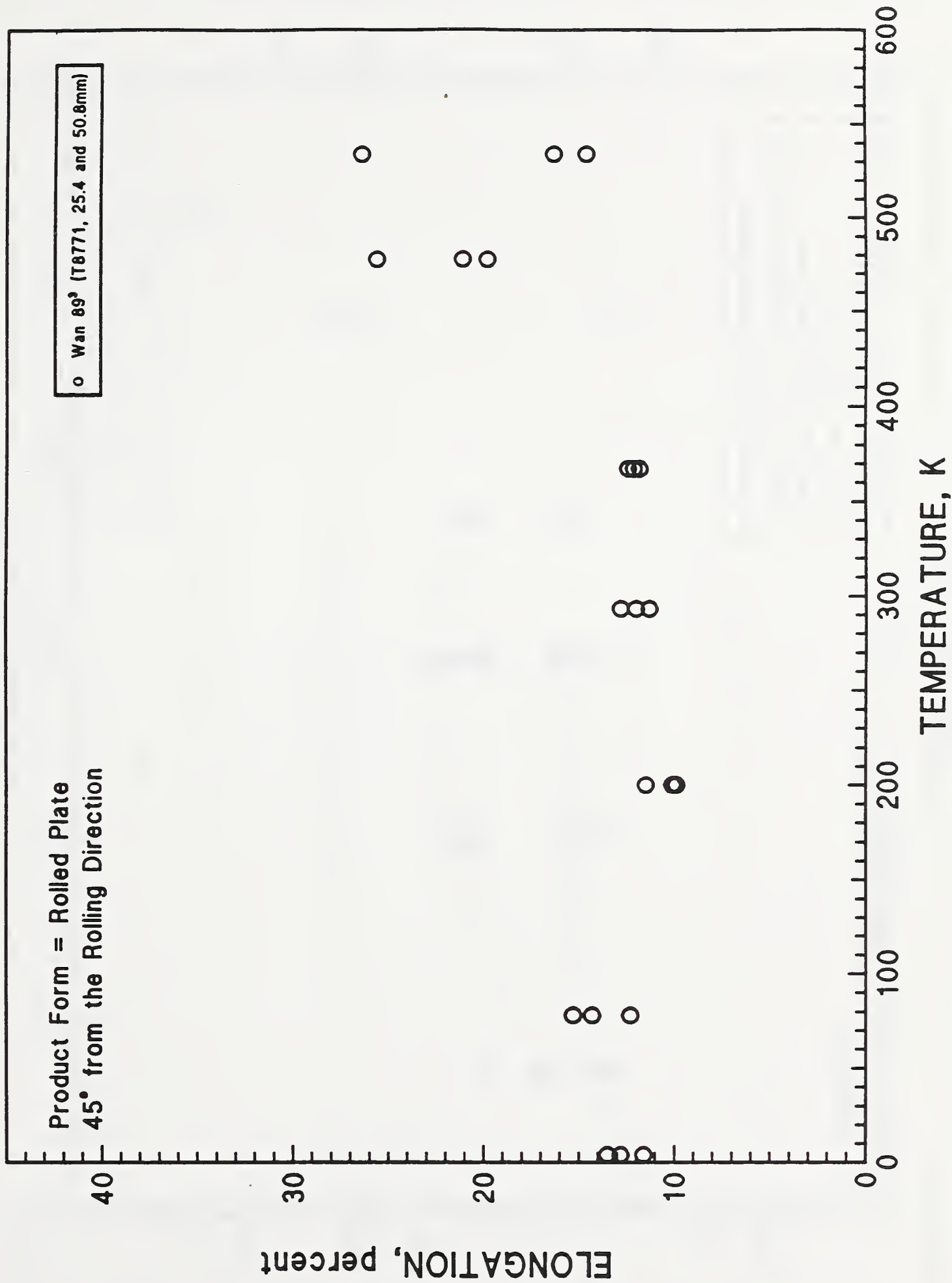
ULTIMATE TENSILE STRENGTH, ksi



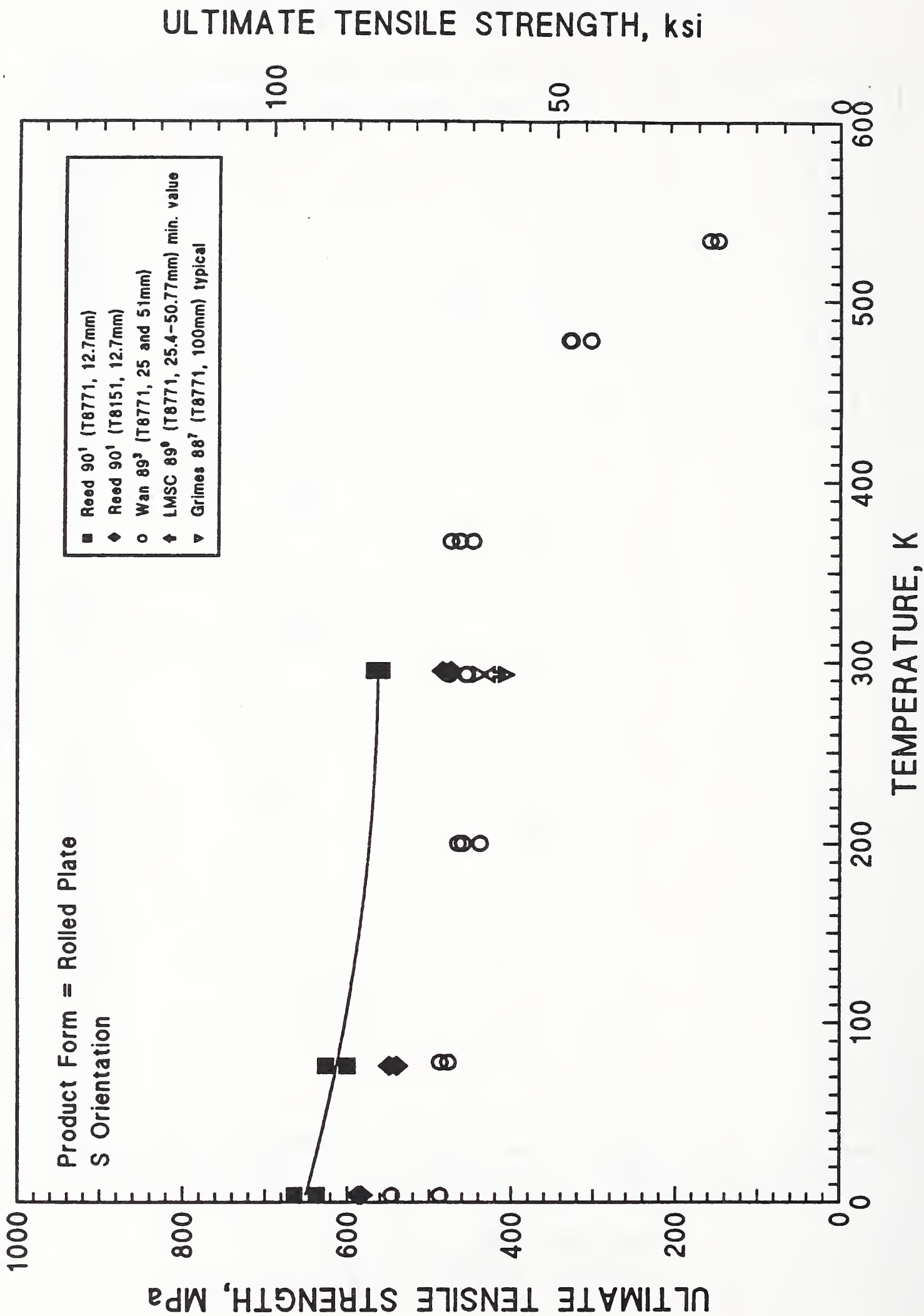
TEMPERATURE, K

8090-T8

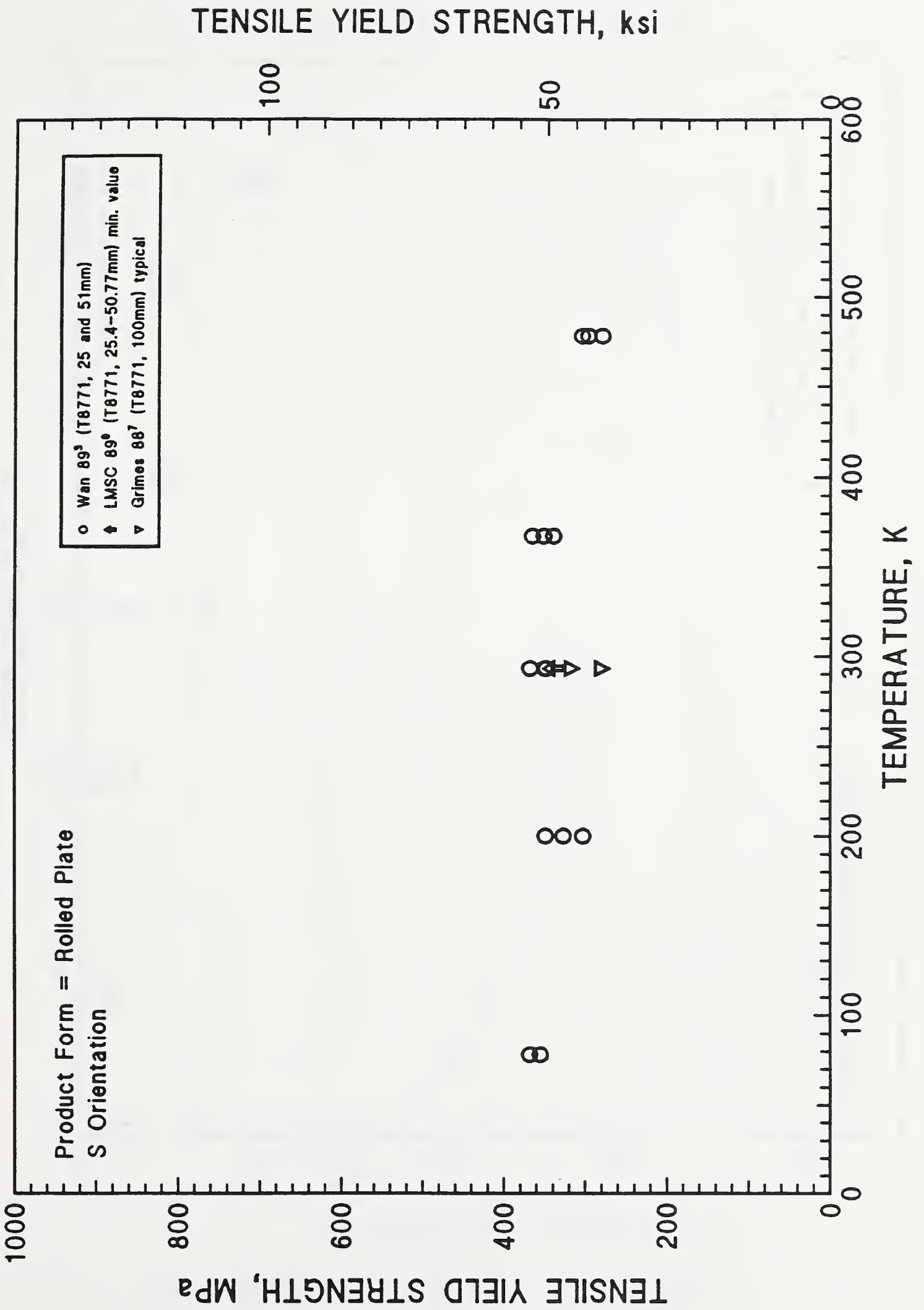


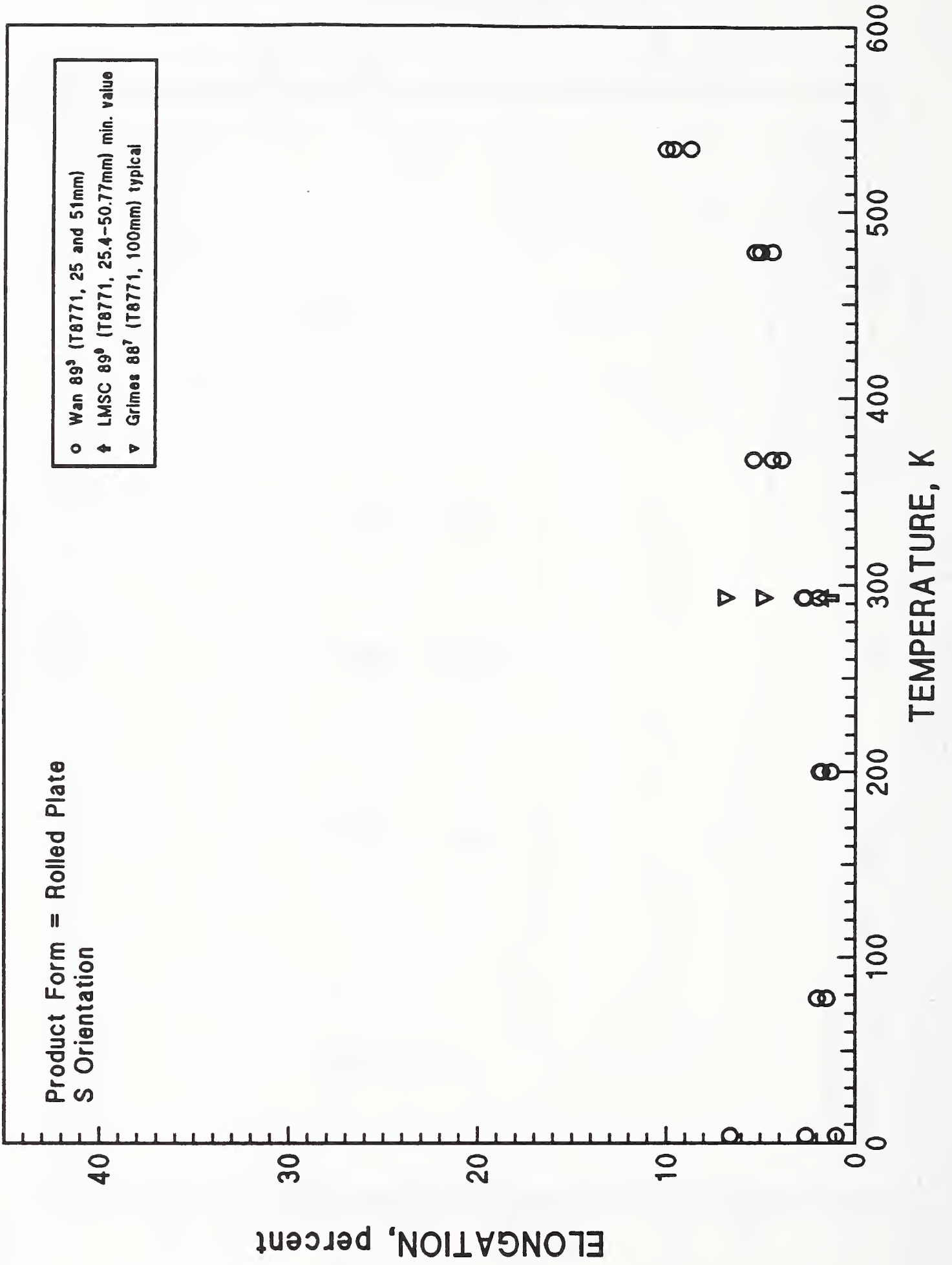


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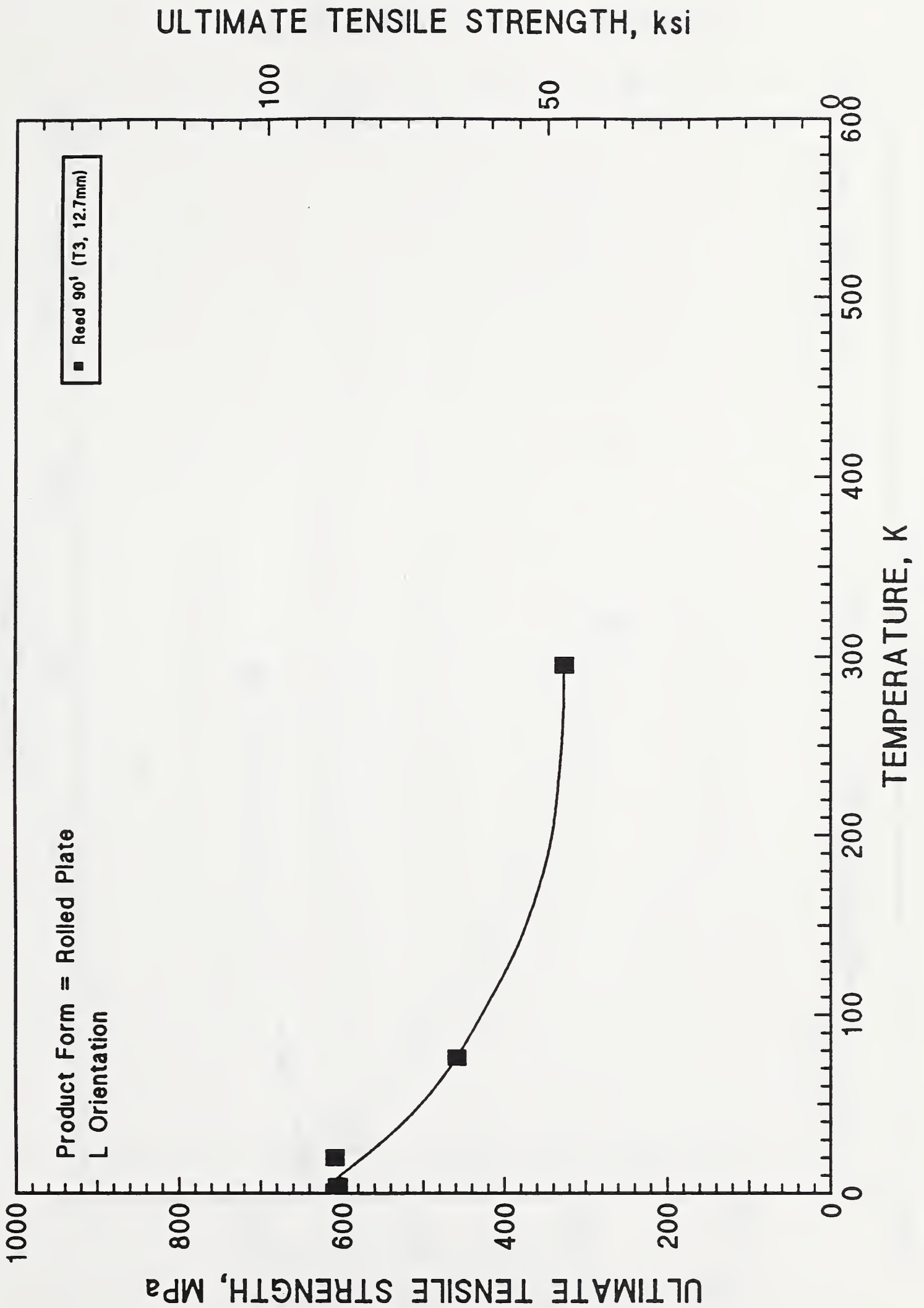


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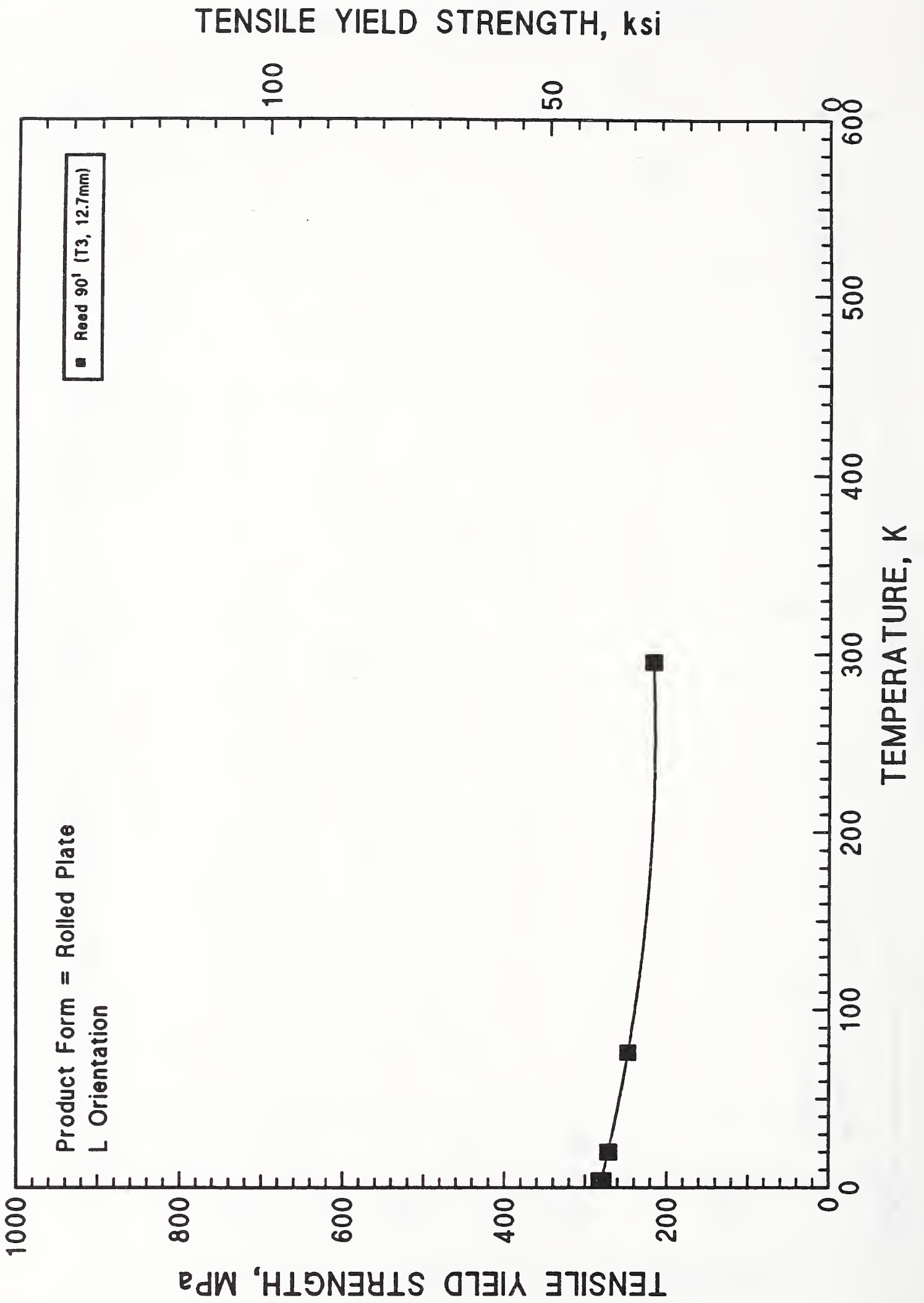


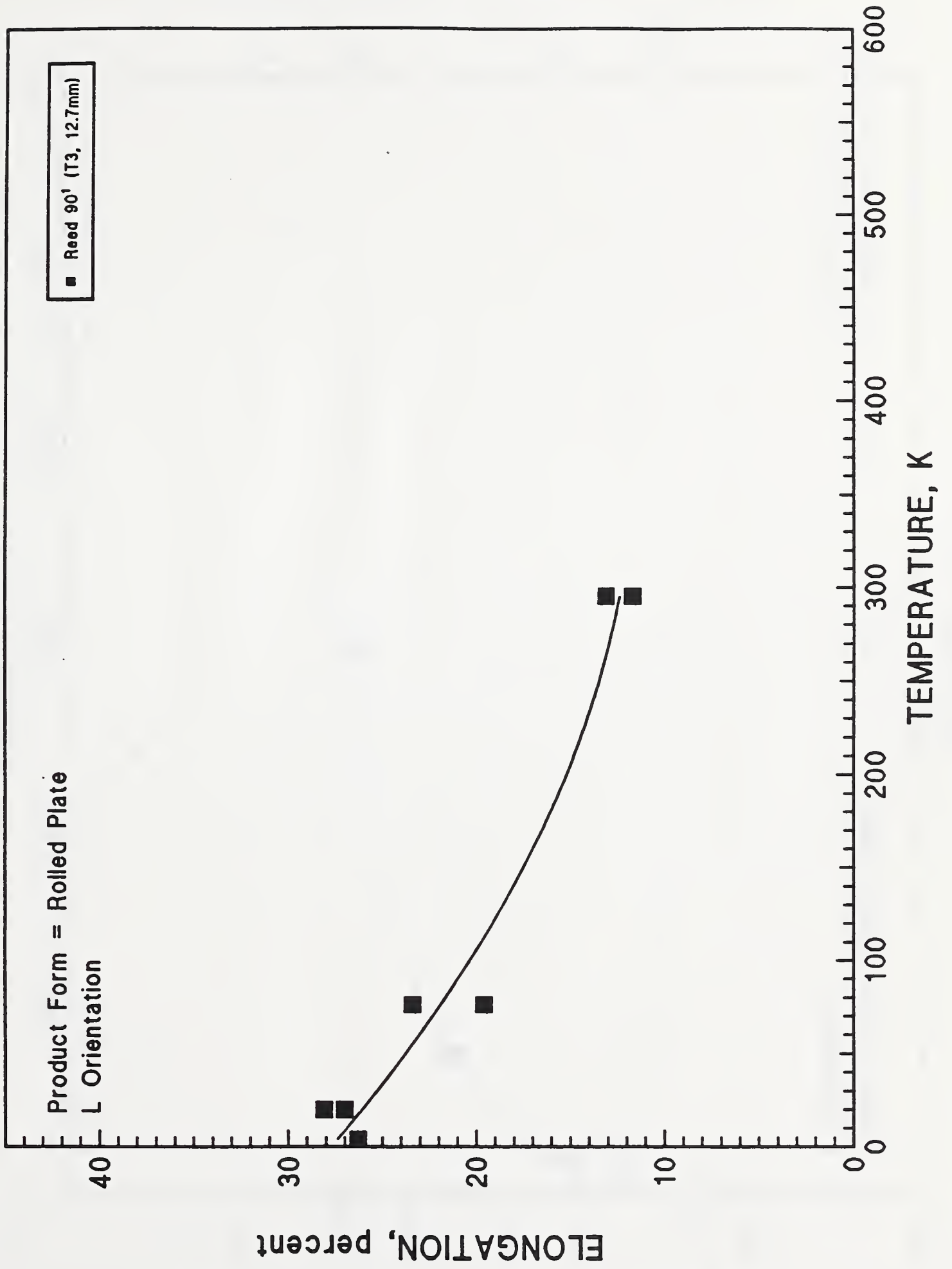


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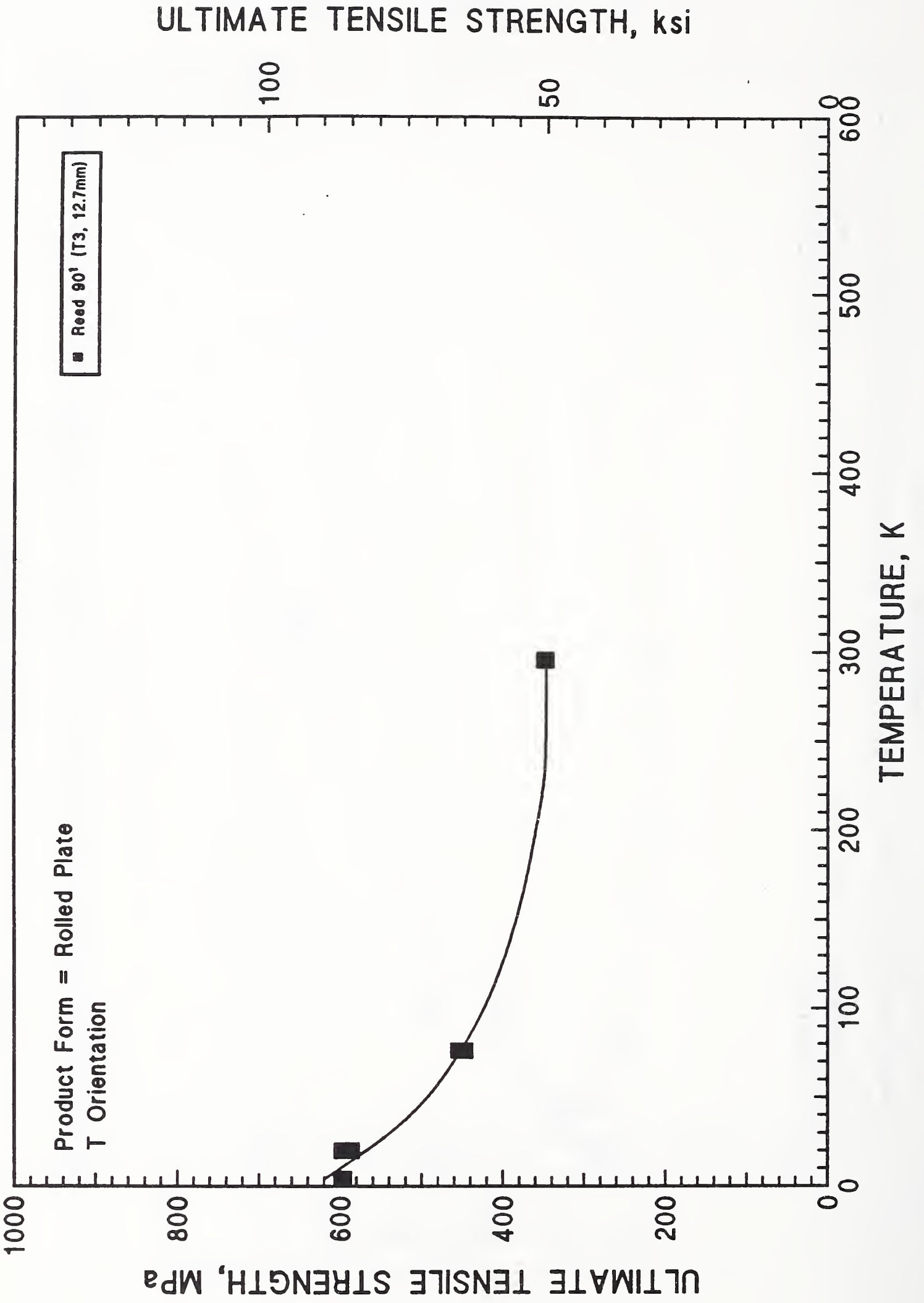


8090-T3

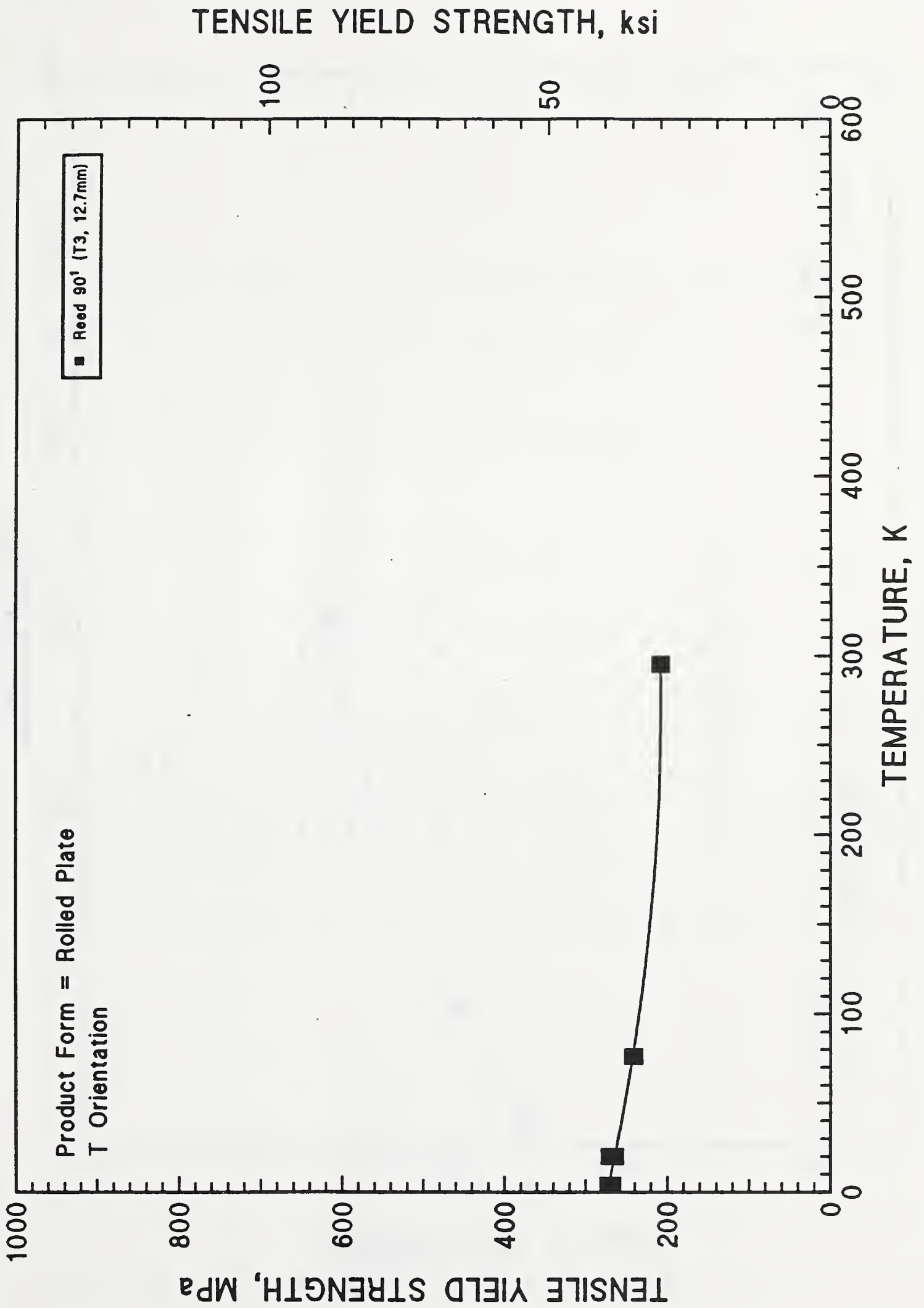




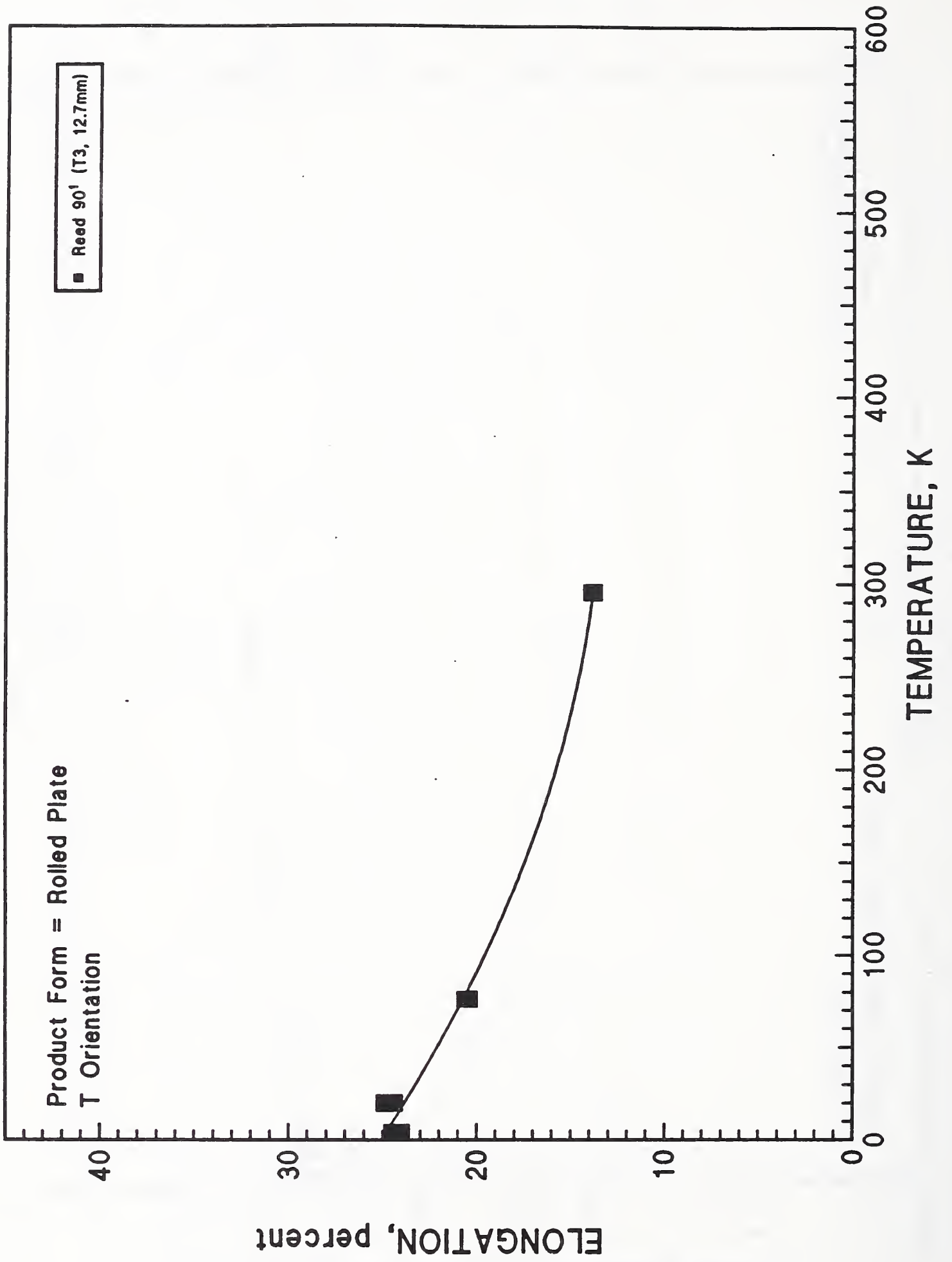
8090-T3



8090-T3



8090-T3



Al-Li ALLOY 8090

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Tempor. T8771	Product Form	Product Thickness mm	Aging Temp. °C	Aging Time h	Stretch %	Temp. °C	Time h	Soln. Treat. Cond.	Quench	Grain Size μm	Hardness	No. of Tests/ Date Pt
1A	295	567.	509.	4.1	6.4	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
1A	295	567.	514.	2.4	4.8	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
1A	76	701.	546.	11.4	11.	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
1A	76	697.	538.	NA	NA	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
1A	20	788.	570.	13.2	11.7	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
1A	20	799.	571.	14.2	14.1	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
1A	4	802.	569.	12.6	13.2	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
1A	4	811.	578.	13.7	17.1	L	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
3A	533	161.	NA	19.	82.7	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	WQ	NA	NA	1
3A	533	212.	NA	19.5	81.9	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	WQ	NA	NA	1
3A	478	340.	338.	19.3	51.4	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	WQ	NA	NA	1
3A	478	336.	333.	18.4	61.7	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	WQ	NA	NA	1
3A	478	346.	338.	17.5	58.6	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	WQ	NA	NA	1
3A	367	507.	476.	7.7	10.2	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	WQ	NA	NA	1
3A	367	497.	439.	7.6	11.1	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	WQ	NA	NA	1
3A	367	505.	465.	6.8	15.1	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	WQ	NA	NA	1
3A	293	503.	448.	6.	9.4	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	WQ	NA	NA	1
3A	293	513.	445.	7.9	6.5	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	WQ	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPe	Y.S. MPe	Elong. %	R.A. %	Orient. Z	Temper	Product Form	Product Thickness mm	Aging		Soln. Treat.		Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
										Temp. °C	Time h	Temp. °C	Time h				
3A 293	515.	477.	7.2	9.4	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3A 200	526.	427.	8.4	11.8	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3A 200	532.	492.	6.1	9.2	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3A 200	516.	456.	5.8	13.1	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3A 78	635.	520.	8.5	3.2	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3A 78	604.	486.	7.9	12.7	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3A 78	639.	516.	8.3	7.7	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3A 4	683.	NA	6.4	12.6	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3A 4	635.	NA	6.8	16.3	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3A 4	641.	NA	8.7	18.3	L	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
7A 293	440.	361.	8.5	NA	L	T8771	Rolled Plate	100	170	16.	NA	NA	NA	NA	NA	NA	*
7B 293	455	397.	5.	NA	L	T8771	Rolled Plate	100	170	16.	NA	NA	NA	NA	NA	NA	*
5A 436	408.	397.	16.	NA	L	T8511	Extrusion	6.35	149	96.	3.5-4.0	545	1.	HQ	NA	NA	1
5A 436	402.	390.	13.	NA	L	T8511	Extrusion	6.35	149	96.	3.5-4.0	545	1.	HQ	NA	NA	1
5A 380	459.	398.	10.	NA	L	T8511	Extrusion	6.35	149	96.	3.5-4.0	545	1.	HQ	NA	NA	1
5A 380	459.	403.	9.	NA	L	T8511	Extrusion	6.35	149	96.	3.5-4.0	545	1.	HQ	NA	NA	1
5A 325	511.	427.	6.	NA	L	T8511	Extrusion	6.35	149	96.	3.5-4.0	545	1.	HQ	NA	NA	1
5A 325	521.	434.	5.	NA	L	T8511	Extrusion	6.35	149	96.	3.5-4.0	545	1.	HQ	NA	NA	1
5A 255	513.	412.	7.	NA	L	T8511	Extrusion	6.35	149	96.	3.5-4.0	545	1.	HQ	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper	Product Form	Product Thickness mm	Aging Temp. °C	Aging Time h	Stretch Z	Temp. °C	Time h	Soln. Treat.	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
5A	255	524	427	7	NA	L	T8511	Extrusion	6.35	149	96	3.5-4.0	545	1		HQ	NA	NA	1
5A	186	489	392	8	NA	L	T8511	Extrusion	6.35	149	96	3.5-4.0	545	1		HQ	NA	NA	1
5A	186	487	393	9	NA	L	T8511	Extrusion	6.35	149	96	3.5-4.0	545	1		HQ	NA	NA	1
5A	116	523	386	10	NA	L	T8511	Extrusion	6.35	149	96	3.5-4.0	545	1		HQ	NA	NA	1
5A	116	550	414	11	NA	L	T8511	Extrusion	6.35	149	96	3.5-4.0	545	1		HQ	NA	NA	1
1C	295	473	401	4.9	3.8	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA		NA	NA	NA	1
1C	295	475	403	4.2	4.5	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA		NA	NA	NA	1
1C	76	633	411	9.4	9.7	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA		NA	NA	NA	1
1C	76	633	412	11	7.7	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA		NA	NA	NA	1
1C	20	720	445	10.4	5.7	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA		NA	NA	NA	1
1C	20	778	454	14.8	12.7	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA		NA	NA	NA	1
1C	4	767	452	16.7	14.1	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA		NA	NA	NA	1
1C	4	771	452	14.1	13.1	L	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA		NA	NA	NA	1
4A	298	534	482	6	NA	L	T8X	Rolled Plate	11-16	190	16	3	NA	NA		NA	L:1500; T:350; S:40	NA	1
6A	300	456	387	9.4	NA	L	T8X	Rolled Plate	25	190	4	2-2.5	NA	NA		NA	NA	NA	1
6A	300	464	406	9.4	NA	L	T8X	Rolled Plate	25	190	8	2-2.5	NA	NA		NA	NA	NA	1
6A	77	542	392	16	NA	L	T8X	Rolled Plate	25	190	4	2-2.5	NA	NA		NA	NA	NA	1
6A	77	566	411	16	NA	L	T8X	Rolled Plate	25	190	8	2-2.5	NA	NA		NA	NA	NA	1
8A	195	495	450	6	NA	L	T651	Rolled Plate	6.35-38.1	NA	NA	NA	NA	NA		NA	NA	NA	*

*See Comments

Ref & Note No.	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper	Product Form	Product Thickness mm	Aging Temp. °C	Aging Time h	Stretch %	Soln. Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
1E 297	328.	218.	11.7	18.7	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	118.5	1
1E 297	326.	216.	13.1	17.4	L	T3	Rolled Plate	NA	NA	NA	NA	NA	NA	NA	NA	118.5	1
1E 76	457.	248.	19.6	29.8	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	118.5	1
1E 78	460.	248.	23.4	24.7	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	118.5	1
1E 20	810.	270.	28.1	26.5	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	118.5	1
1E 20	607.	272.	27.	24.3	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	118.5	1
1E 4	604.	278.	26.6	30.	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	118.5	1
1E 4	608.	283.	26.3	27.5	L	T3	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	118.5	1
1A 295	567.	499.	5.2	11.	T	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	1
1A 295	566.	502.	6.4	12.6	T	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	1
1A 78	682.	NA	NA	NA	T	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	1
1A 78	679.	537.	6.	5.6	T	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	1
1A 20	772.	570.	9.8	9.5	T	T8771	Rolled Plate	12.7	NA	NA	8	NA	NA	NA	NA	NA	1
1A 20	766.	575.	7.7	7.2	T	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	1
1A 4	764.	578.	NA	NA	T	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	1
1A 4	768.	570.	7.2	7.2	T	T8771	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	1
3A 534	182.	NA	21.	74.9	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1
3A 534	196.	NA	21.1	70.7	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1
3A 478	331.	328.	15.6	53.1	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	I.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper	Product Form	Thickness mm	Aging		Temp. °C	Stretch %	Temp. °C	Time h	Soln. Treat.	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Date Pt
										Time h	%									
3A 478	341.	339.	17.7	54.8	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 478	334.	332.	19.6	59.6	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 367	492.	438.	9.1	14.6	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 367	496.	439.	8.8	14.	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 367	471.	396.	10.5	26.6	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 293	513.	476.	7.5	6.7	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 293	483.	432.	6.4	11.2	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 293	510.	474.	6.6	5.1	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 200	530.	432.	10.8	6.4	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 200	532.	442.	10.1	7.8	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 200	496.	392.	7.	5.5	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 78	622.	461.	10.3	7.3	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 78	620.	459.	10.3	7.2	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 78	598.	482.	7.8	12.7	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 4	670.	NA	8.5	16.5	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 4	629.	NA	8.7	17.8	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
3A 4	707.	NA	5.8	10.1	T	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1			
7C 293	430.	310.	9.8	NA	T	T8771	Rolled Plate	100	NA	NA	NA	NA	NA	NA	NA	NA	*			
7D 293	437.	335.	7.8	NA	T	T8771	Rolled Plate	100	NA	NA	NA	NA	NA	NA	NA	NA	*			

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper	Product Form	Product Thickness mm	Aging Temp. °C	Aging Time h	Stretch %	Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
9A	293	448.	379.	4.	NA	T	T8771	Rolled Plate	6.35-38.1	NA	NA	NA	NA	NA	NA	NA	NA	1
5C	436	386.	314.	6.	NA	T	T852	Forging	254	149	96.	4*	545	1.	HQ	NA	NA	1
5C	438	395.	321.	10.	NA	T	T852	Forging	254	149	96.	4*	545	1.	HQ	NA	NA	1
5C	380	434.	345.	5.	NA	T	T852	Forging	254	149	96.	4*	545	1.	HQ	NA	NA	1
5C	380	450.	342.	7.	NA	T	T852	Forging	254	149	96.	4*	545	1.	HQ	NA	NA	1
5C	325	483.	340.	5.	NA	T	T852	Forging	254	149	96.	4*	545	1.	HQ	NA	NA	1
5C	325	458.	351.	6.	NA	T	T852	Forging	254	149	96.	4*	545	1.	HQ	NA	NA	1
5C	255	485.	340.	6.	NA	T	T852	Forging	254	149	96.	4*	545	1.	HQ	NA	NA	1
5C	255	484.	343.	6.	NA	T	T852	Forging	254	149	96.	4*	545	1.	HQ	NA	NA	1
5C	188	461.	343.	5.	NA	T	T852	Forging	254	149	96.	4*	545	1.	HQ	NA	NA	1
5C	186	468.	343.	5.	NA	T	T852	Forging	254	149	96.	4*	545	1.	HQ	NA	NA	1
5C	116	473.	361.	3.	NA	T	T852	Forging	254	149	96.	4*	545	1.	HQ	NA	NA	1
5C	116	473.	360.	3.	NA	T	T852	Forging	254	149	96.	4*	545	1.	HQ	NA	NA	1
1C	295	507.	403.	6.6	7.1	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1C	295	508.	407.	4.6	5.9	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1C	78	642.	413.	10.9	10.5	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1C	76	643.	417.	10.7	10.	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1C	20	752.	453.	12.	9.5	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1C	20	760.	453.	11.7	11.4	T	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper	Product Form	Thickness mm	Product Thickness mm	Aging Temp. °C	Aging Time h	Stretch %	Temp. °C	Time h	Soln. Treat.	Quench Cond.	Grain Size µm	Hardness	No. of Tests/ Data Pt
1C	4	778.	462.	14.	14.7	T	T8151	Roller Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1C	4	783.	464.	14.9	14.3	T	T8151	Roller Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
5B	436	416.	391.	11.	NA	T	T8	Sheet	1.78	1.78	149	96.	2.5-3.0	545	1.	NA	HQ	NA	NA	1
5B	436	407.	388.	13.	NA	T	T8	Sheet	1.78	1.78	149	96.	2.5-3.0	545	1.	NA	HQ	NA	NA	1
5B	380	494.	479.	9.	NA	T	T8	Sheet	1.78	1.78	149	96.	2.5-3.0	545	1.	NA	HQ	NA	NA	1
5B	380	489.	443.	8.	NA	T	T8	Sheet	1.78	1.78	149	96.	2.5-3.0	545	1.	NA	HQ	NA	NA	1
5B	325	534.	456.	7.	NA	T	T8	Sheet	1.78	1.78	149	96.	2.5-3.0	545	1.	NA	HQ	NA	NA	1
5B	325	514.	434.	6.	NA	T	T8	Sheet	1.78	1.78	149	96.	2.5-3.0	545	1.	NA	HQ	NA	NA	1
5B	255	532.	448.	6.	NA	T	T8	Sheet	1.78	1.78	149	96.	2.5-3.0	545	1.	NA	HQ	NA	NA	1
5B	255	528.	441.	7.	NA	T	T8	Sheet	1.78	1.78	149	96.	2.5-3.0	545	1.	NA	HQ	NA	NA	1
5B	186	535.	460.	4.	NA	T	T8	Sheet	1.78	1.78	149	96.	2.5-3.0	545	1.	NA	HQ	NA	NA	1
5B	186	532.	454.	5.	NA	T	T8	Sheet	1.78	1.78	149	96.	2.5-3.0	545	1.	NA	HQ	NA	NA	1
5B	116	582.	468.	6.	NA	T	T8	Sheet	1.78	1.78	149	96.	2.5-3.0	545	1.	NA	HQ	NA	NA	1
5B	116	581.	463.	7.	NA	T	T8	Sheet	1.78	1.78	149	96.	2.5-3.0	545	1.	NA	HQ	NA	NA	1
8A	285	480.	420.	7.	NA	T	T651	Roller Plate	25-40	25-40	180	6.	0	NA	NA	NA	NA	NA	NA	*
1E	297	347.	209.	13.9	24.5	T	T3	Roller Plate	12.7	12.7	NA	NA	2	NA	NA	NA	NA	NA	118.5	1
1E	297	349.	207.	13.8	28.8	T	T3	Roller Plate	12.7	12.7	NA	NA	2	NA	NA	NA	NA	NA	118.5	1
1E	76	454.	240.	20.6	37.3	T	T3	Roller Plate	12.7	12.7	NA	NA	2	NA	NA	NA	NA	NA	118.5	1
1E	76	447.	243.	20.4	36.9	T	T3	Roller Plate	12.7	12.7	NA	NA	2	NA	NA	NA	NA	NA	118.5	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. T	Temper T3	Product Form	Product Thickness mm	Aging Temp. °C	Aging Time h	Stretch %	Soln. Temp. °C	Time h	Quench Cond.	Grain Size µm	Hardness	No. of Tests/ Data Pt
1E	20	598.	264.	24.9	28.2	T	T3	Rolled Plate	12.7	NA	NA	2	NA	NA	NA	NA	118.5	1
1E	20	586.	271.	24.4	28.1	T	T3	Rolled Plate	12.7	NA	NA	2	NA	NA	NA	NA	118.5	1
1E	4	586.	273.	24.	29.7	T	T3	Rolled Plate	12.7	NA	NA	2	NA	NA	NA	NA	118.5	1
1E	4	599.	267.	24.5	28.5	T	T3	Rolled Plate	12.7	NA	NA	2	NA	NA	NA	NA	118.5	1
10A	283	302.	142.	23.	40.	T	O	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	1
10A	273	283.	140.	25.5	50.1	T	O	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	1
10A	258	271.	140.	25.	58.5	T	O	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	1
10A	238	262.	142.	24.5	57.8	T	O	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	1
10A	218	250.	140.	26.5	65.6	T	O	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	1
10A	188	254.	142.	27.5	68.5	T	O	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	1
10A	173	257.	146.	30.	66.7	T	O	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	1
10A	153	257.	150.	30.	63.	T	O	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	1
10A	78	352.	167.	41.5	48.9	T	O	Rolled Plate	11	NA	NA	0	520	NA	W	NA	NA	1
3A	534	163.	NA	14.6	84.8	45°	T8771	Rolled Plate	25.4-50.8	178	96.	4-6	545	0.5	HQ	NA	NA	1
3A	534	172.	NA	16.3	85.1	45°	T8771	Rolled Plate	25.4-50.8	178	96.	4-6	545	0.5	HQ	NA	NA	1
3A	534	210.	NA	26.4	77.	45°	T8771	Rolled Plate	25.4-50.8	178	96.	4-6	545	0.5	HQ	NA	NA	1
3A	478	332.	319.	21.1	62.1	45°	T8771	Rolled Plate	25.4-50.8	178	96.	4-6	545	0.5	HQ	NA	NA	1
3A	478	352.	335.	25.6	58.5	45°	T8771	Rolled Plate	25.4-50.8	178	96.	4-6	545	0.5	HQ	NA	NA	1
3A	478	334.	326.	18.8	64.7	45°	T8771	Rolled Plate	25.4-50.8	178	96.	4-6	545	0.5	HQ	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong.		R.A. %	Orient. °	Temper °C	Product Form	Product Thickness mm	Aging		Stretch %	Soln. Temp. °C	Time		Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
				z	z						h	h								
3A 367	458.	363.	12.4	27.9	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 367	457.	364.	11.8	28.5	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 367	456.	362.	12.1	29.7	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 293	476.	365.	11.3	18.9	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 293	473.	363.	12.	12.4	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 293	479.	364.	12.8	20.	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 200	485.	372.	11.5	12.5	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 200	482.	365.	9.9	13.7	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 200	485.	365.	10.1	11.1	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 78	559.	392.	14.3	11.4	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 78	562.	387.	15.3	18.4	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 78	556.	387.	12.3	11.2	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 4	662.	NA	12.8	19.4	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 4	654.	NA	13.5	19.4	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
3A 4	652.	NA	11.6	19.4	45°	T8771	Rollled Plate	25.4-50.8	179	96.	96.	4-6	545	0.5	WQ	NA	NA	1		
1B 295	558.	NA	NA	NA	S	T8771	Rollled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1		
1B 295	567.	NA	NA	NA	S	T8771	Rollled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1		
1B 76	626.	NA	NA	NA	S	T8771	Rollled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1		
1B 76	600.	NA	NA	NA	S	T8771	Rollled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1		

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Index	Temper	Product Form	Thickness mm	Aging Temp. °C	Time h	Stretch %	Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/Data Pt
1B	4	664.	NA	NA	NA	S	T8771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	4	637.	NA	NA	NA	S	T8771	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
3B	534	159.	NA	0.7	36.7	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	534	149.	NA	0.6	31.5	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	534	159.	NA	10.	23.1	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	478	304.	279.	5.3	22.7	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	478	328.	286.	5.	24.6	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	478	330.	304.	4.4	15.8	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	367	447.	339.	5.4	13.7	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	367	474.	365.	4.4	3.8	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	367	463.	351.	3.9	12.2	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	293	456.	350.	2.7	11.3	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	293	476.	368.	2.	8.4	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	293	454.	348.	2.8	11.9	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	200	459.	349.	1.9	12.3	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	200	438.	327.	1.3	11.8	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	200	465.	303.	1.8	14.5	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	78	487.	368.	1.5	6.	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1
3B	78	477.	355.	2.	9.7	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	HQ	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	I.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Stretch X	Temp. °C	Time h	Quench Cond.	Grain Size µm	Hardness	No. of Tests/ Date Pl
3B	4	487.	NA	1.	1.	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1
3B	4	546.	NA	2.6	1.2	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1
3B	4	546.	NA	6.6	2.1	S	T8771	Rolled Plate	25.4-50.8	179	96.	4-6	545	0.5	WQ	NA	NA	1
7E	293	442.	320.	7.	NA	S	T8771	Rolled Plate	100	NA	NA	NA	NA	NA	NA	NA	NA	*
7F	293	410.	283.	5.	NA	S	T8771	Rolled Plate	100	NA	NA	NA	NA	NA	NA	NA	NA	*
9B	293	421.	338.	1.5	NA	S	T8771	Rolled Plate	25.4-50.8	NA	NA	NA	NA	NA	NA	NA	NA	*
1D	295	483.	NA	NA	NA	S	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	295	473.	NA	NA	NA	S	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	76	548.	NA	NA	NA	S	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	76	539.	NA	NA	NA	S	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	4	582.	NA	NA	NA	S	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	4	566.	NA	NA	NA	S	T8151	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
8B	293	435.	365.	2.	NA	S	T651	Rolled Plate	25-40	NA	NA	NA	NA	NA	NA	NA	NA	*

*See Comments

Comments from the Al-Li Alloy 8090 Data Table

Reference and
Note Number

3A-B--Temper T851 appears to be T8771, and is reported here as such.

5C--Cold work is in compression.

8A--Values reported are "typical" properties.

9A--Values reported are "minimum" properties.

TEST PARAMETERS
 Al-L1 ALLOY 8090

Ref & Strain Note No.	Rate 10 ⁻⁴ /s	Specimen		Expo Time min	Supplier	Yr. Prod.	Lot No.	Product L(m) X W(m)	Major Elements								Minor Elements wt%		
		Type	Diam mm						Thick mm	G.L. mm	Specimen Location	Li	Cu	Mg	Zr	Si		Fe	Ag
1A	2.2	Round	6.35	NA	25.4	Mid-Plane	5.	Alcan	1989	3503302A	1.635 X 0.925	2.36	1.2	0.7	0.11	0.02	0.06	NA	NA
1B	2.2	Round	2.5	NA	25.4	Random	5.	Alcan	1989	3503302A	1.635 X 0.925	2.36	1.2	0.7	0.11	0.02	0.06	NA	NA
1C	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Alcan	1989	35712859	1.533 X 0.925	2.36	1.2	0.7	0.11	0.02	0.06	NA	NA
1D	2.2	Round	2.5	NA	25.4	Random	5.	Alcan	1989	35712859	1.533 X 0.925	2.36	1.2	0.7	0.11	0.02	0.06	NA	NA
1E	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Alcan	1989	3518302A	0.254 X 0.254	2.34	1.2	0.6	0.12	0.03	0.05	NA	NA
3A	8.3	Round	12.7	NA	50.8	NA	2.	Alcan	1987	NA	NA	2.4*	1.3	0.8	0.12	0.1	0.3	NA	NA
3B	8.3	Round	12.7	NA	50.8	NA	2.	Alcan	1987	NA	NA	2.4*	1.3	0.8	0.12	0.1	0.3	NA	NA
4A	8.3	Round	12.7	NA	50.8	NA	2.	Alcan	1987	NA	NA	2.4*	1.3	0.8	0.12	0.1	0.3	NA	NA
5A	0.83	NA	NA	NA	NA	Random	30.	Alcan	NA	NA	NA	2.5*	1.2	0.7	0.12	0.04	0.08	NA	Na:0.001
5C	0.83	NA	NA	NA	NA	Random	30.	Alcan	NA	NA	0.46 X 0.25	2.5*	1.2	0.7	0.12	0.04	0.08	NA	Na:0.001
6A	1.0	Round	NA	NA	NA	NA	15.	Alcan	NA	NA	NA	2.28	0.9	0.9	0.13	0.06	0.13	NA	NA
5B	0.83	NA	NA	NA	NA	NA	30.	Alcan	NA	NA	1.22 X 3.66	2.5*	1.2	0.7	0.12	0.04	0.08	NA	Na:0.001
7A	NA	NA	NA	NA	NA	‡ the thickness	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7B	NA	NA	NA	NA	NA	‡ the thickness	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7C	NA	NA	NA	NA	NA	‡ the thickness	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7D	NA	NA	NA	NA	NA	‡ the thickness	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7E	NA	NA	NA	NA	NA	‡ the thickness	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7F	NA	NA	NA	NA	NA	‡ the thickness	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Ref & Strain Note No.	Specimen			G.L. mm	Specimen Location	Expo Time min	Supplier	Yr. Prod.	Lot No.	Product L(m) X W(m)	Major Elements							
	Type	Diam mm	Thick mm								Li	Cu	Mg	Zr wt%	Si	Fe	Ag	Minor Elements wt%
8A	NA	NA	NA	NA	NA	NA	Alcan	NA	NA	NA	2.5*	1.3	0.7	0.12	0.1	0.2	NA	NA
8B	NA	NA	NA	NA	NA	NA	Alcan	NA	NA	NA	2.5*	1.3	0.7	0.12	0.1	0.2	NA	Na:0.001
9A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.5*	1.2	0.7	0.09	0.04	0.08	NA	Na:0.001
9B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.5*	1.2	0.7	0.09	0.04	0.08	NA	Na:0.001
10A	4.6	Round	5.	NA	36.	NA	Alcan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Comments from the Al-Li Alloy 8090 Test Parameter Table

Reference and
Note Number

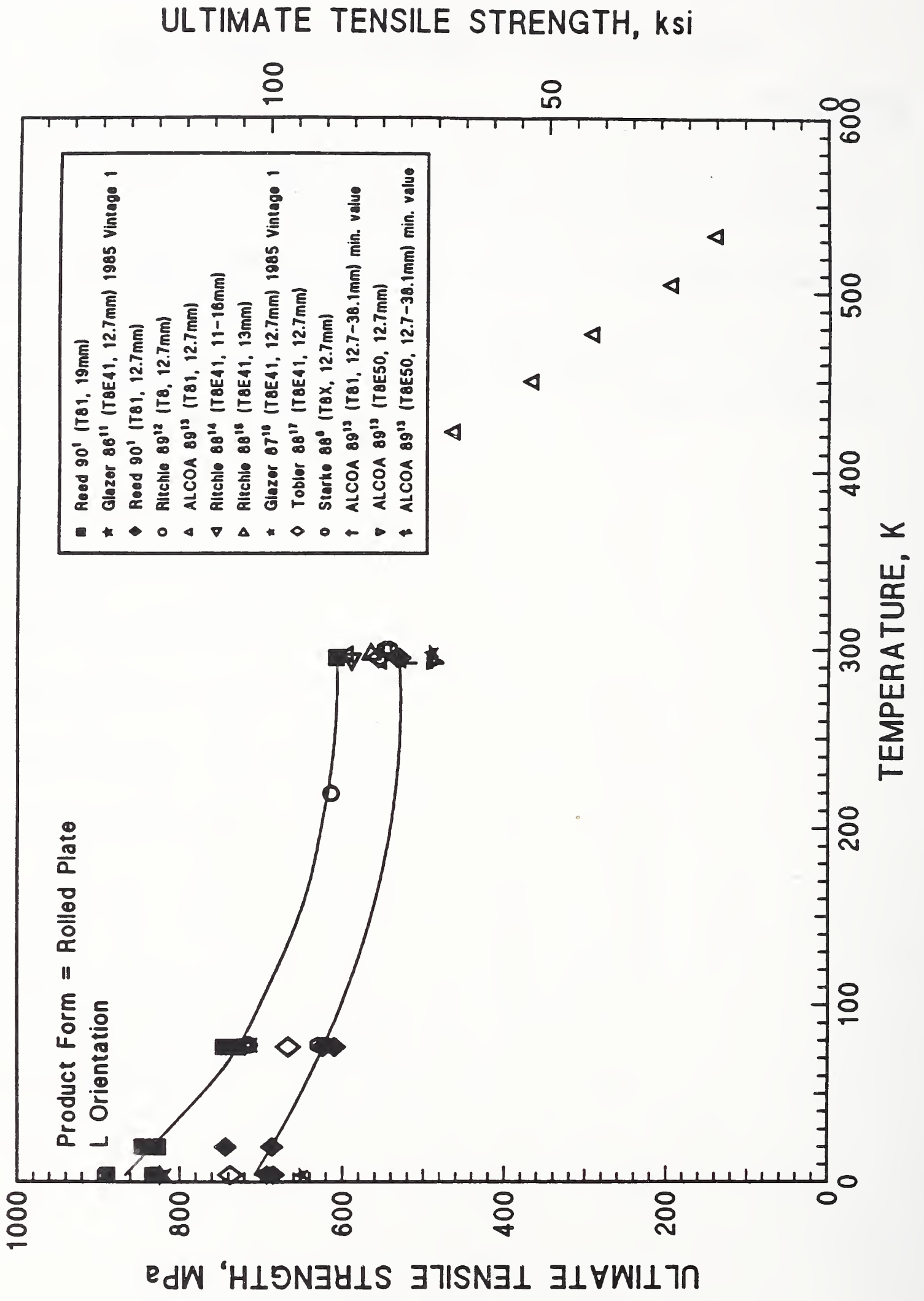
3A-B--Reported composition is based on typical values.

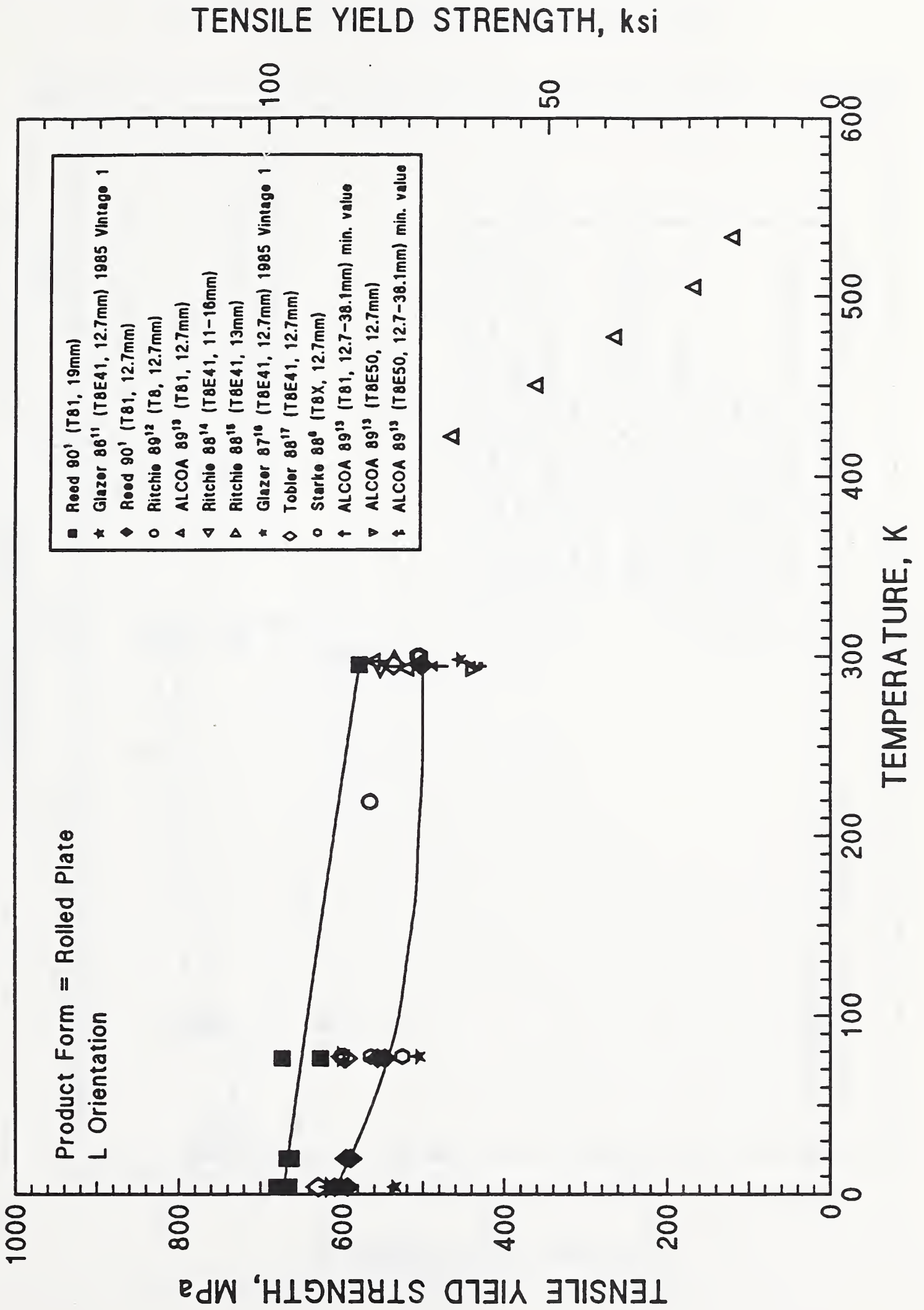
4A--Reported composition is based on nominal values.

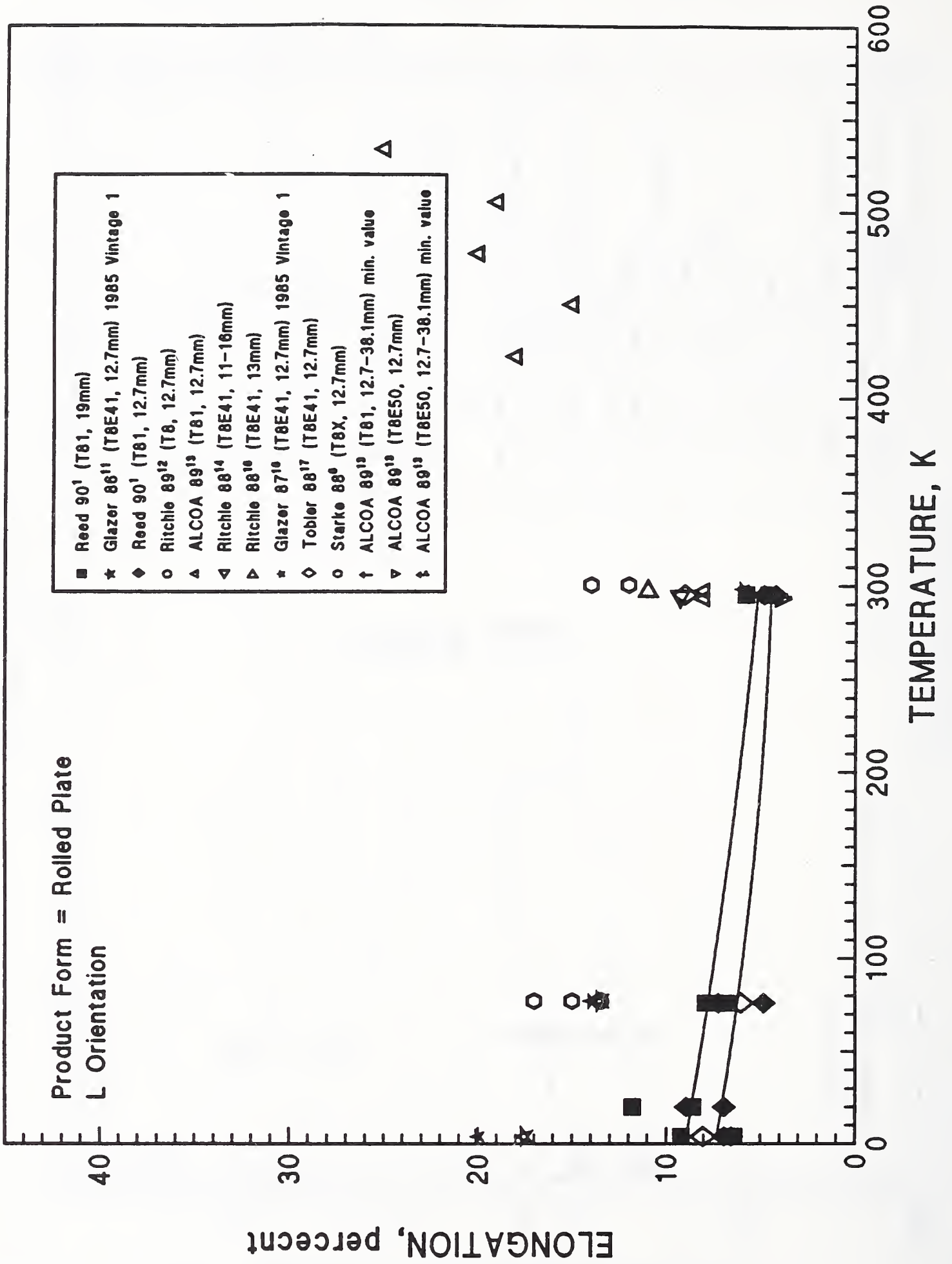
5A-C--Reported composition is the average of the range provided for in the Lockheed requirements.

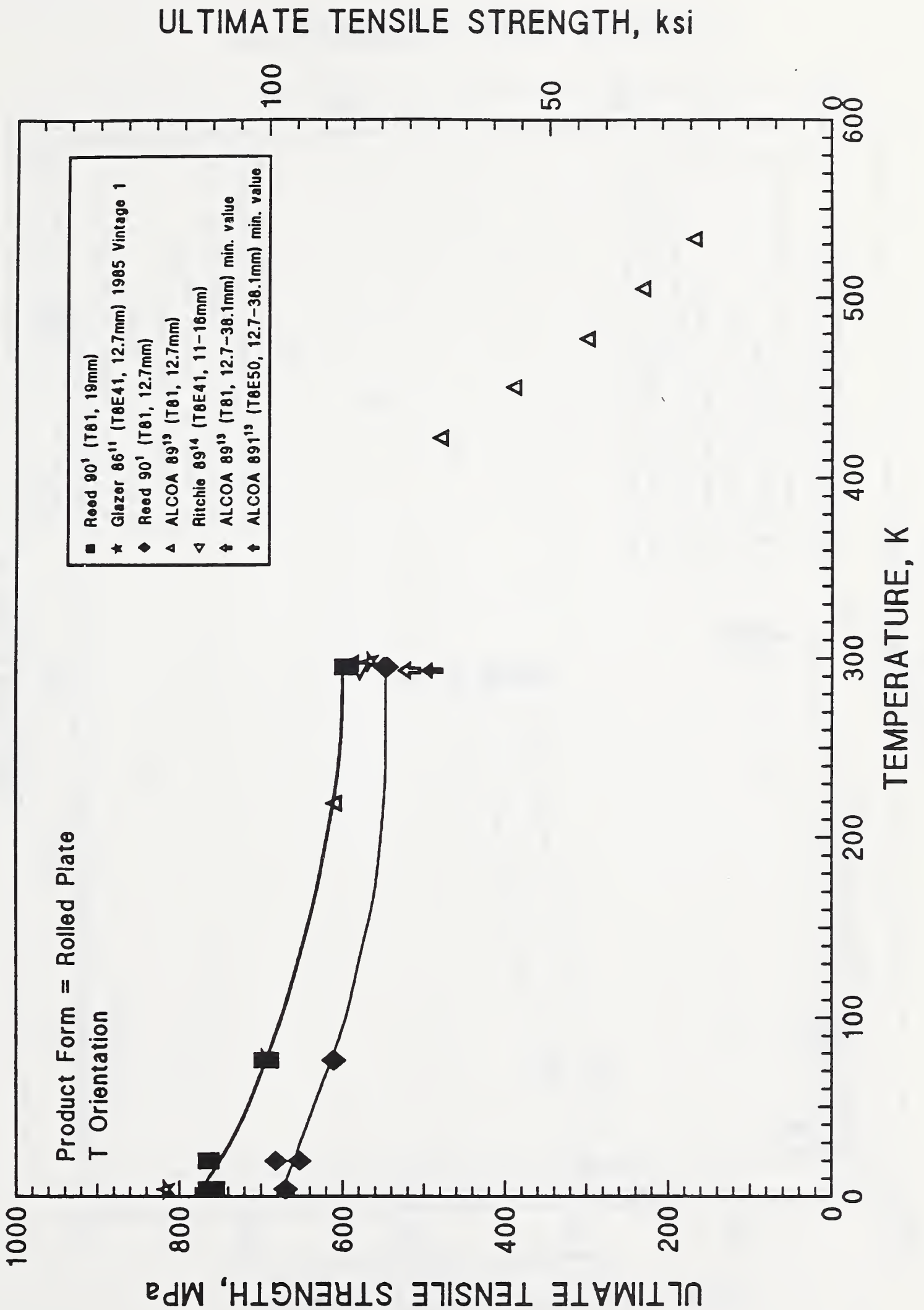
8A--Reported composition is based on nominal values.

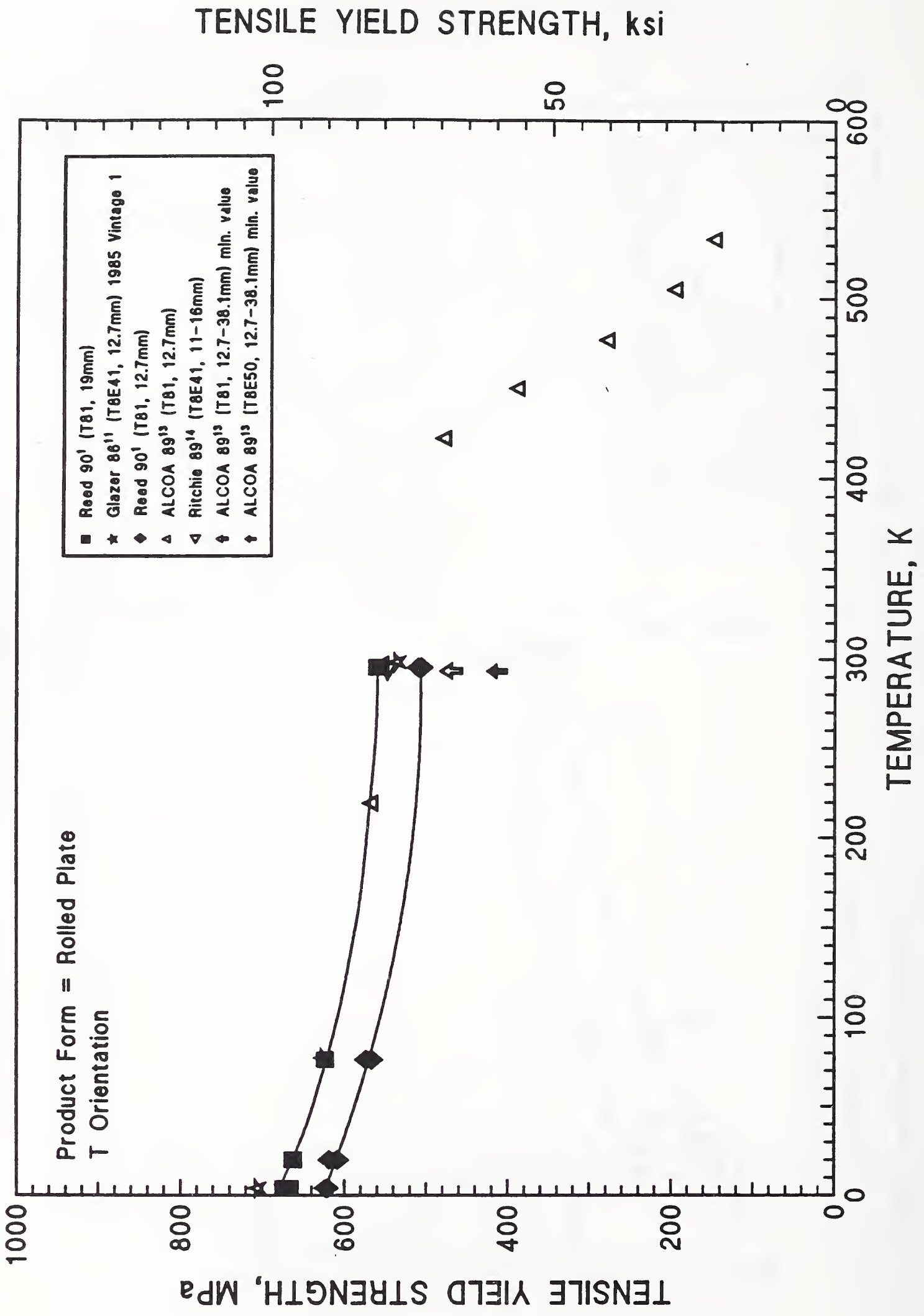
9A-B--Reported composition is the average of the range provided for in the Lockheed requirements.

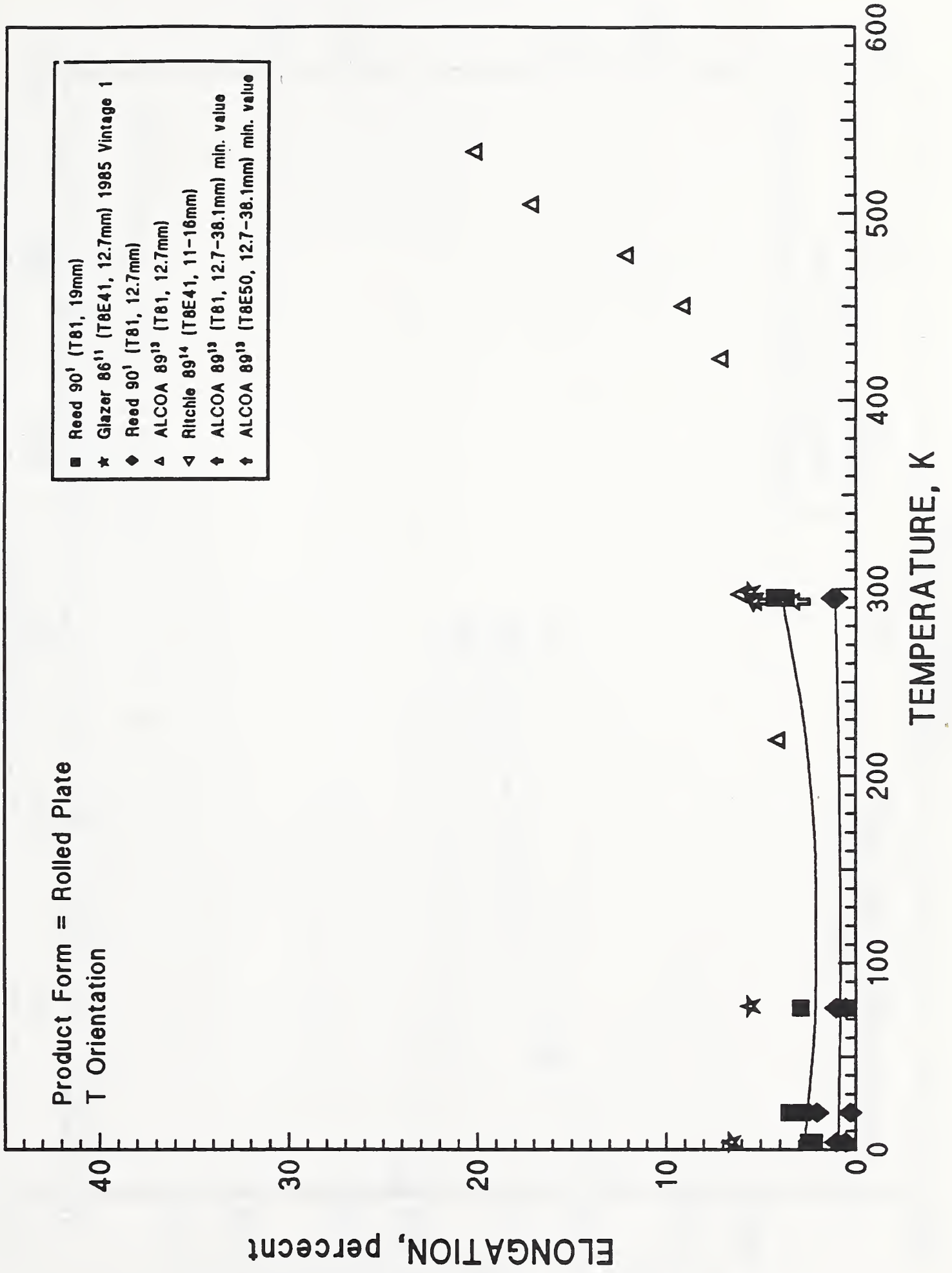


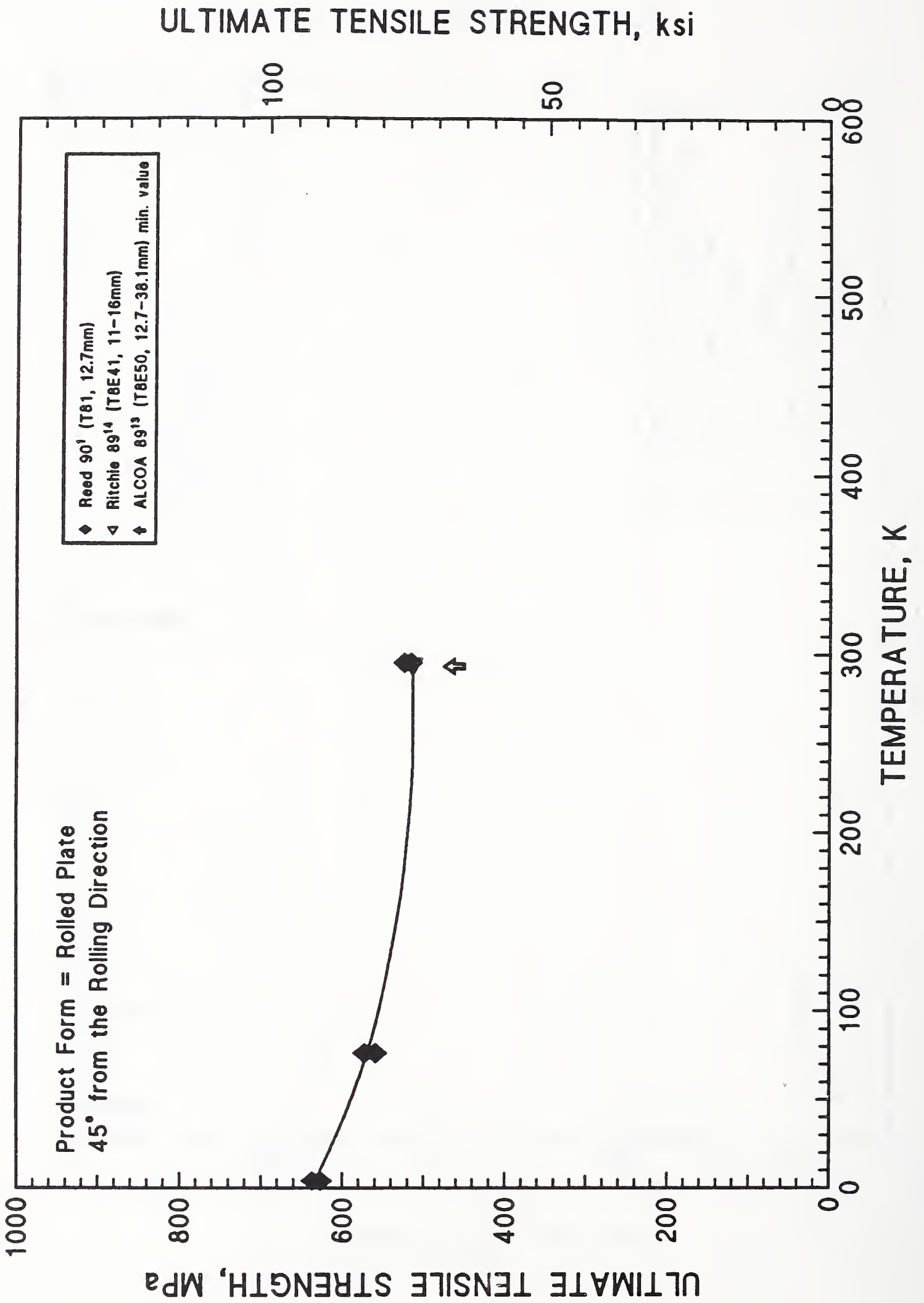


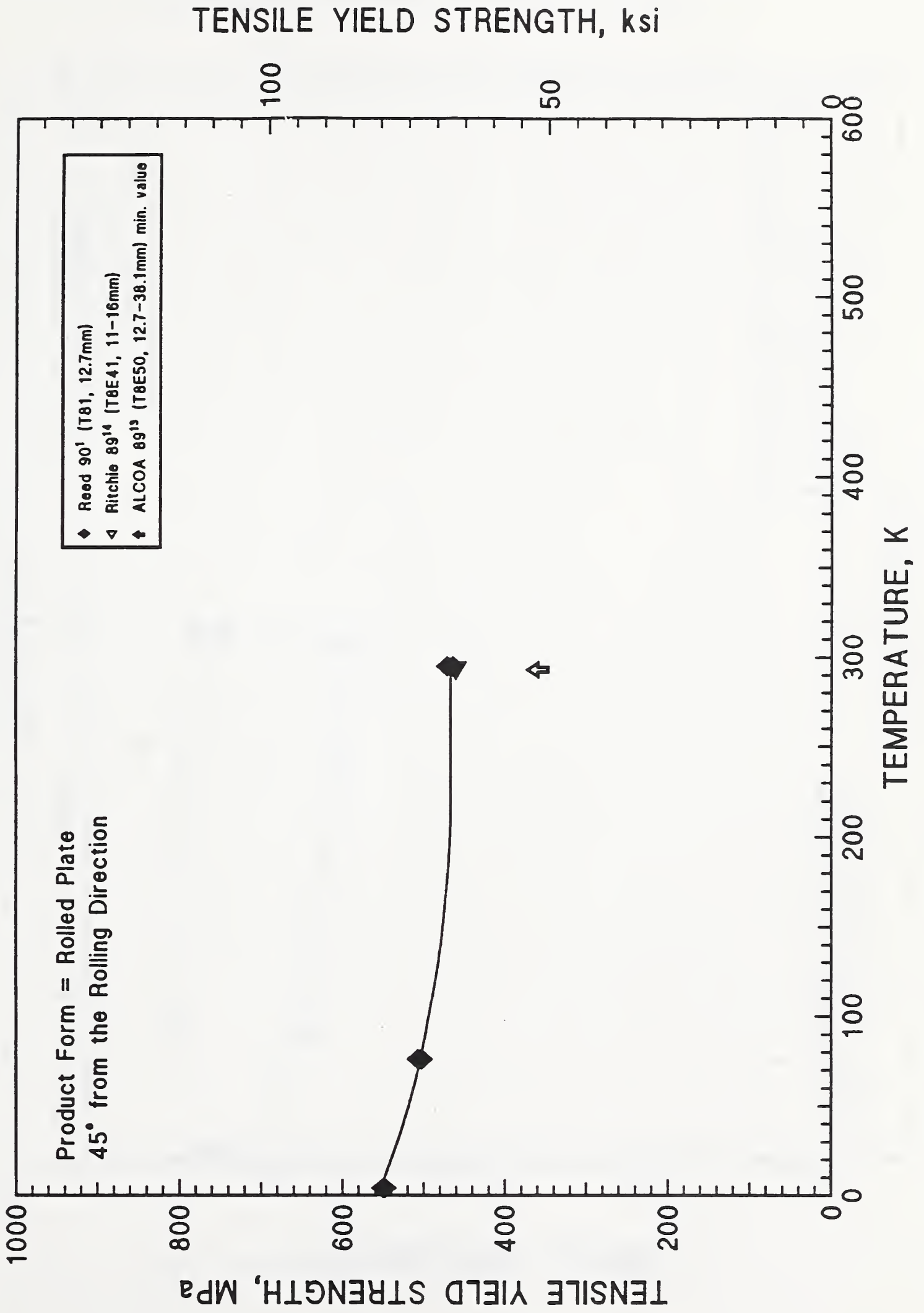


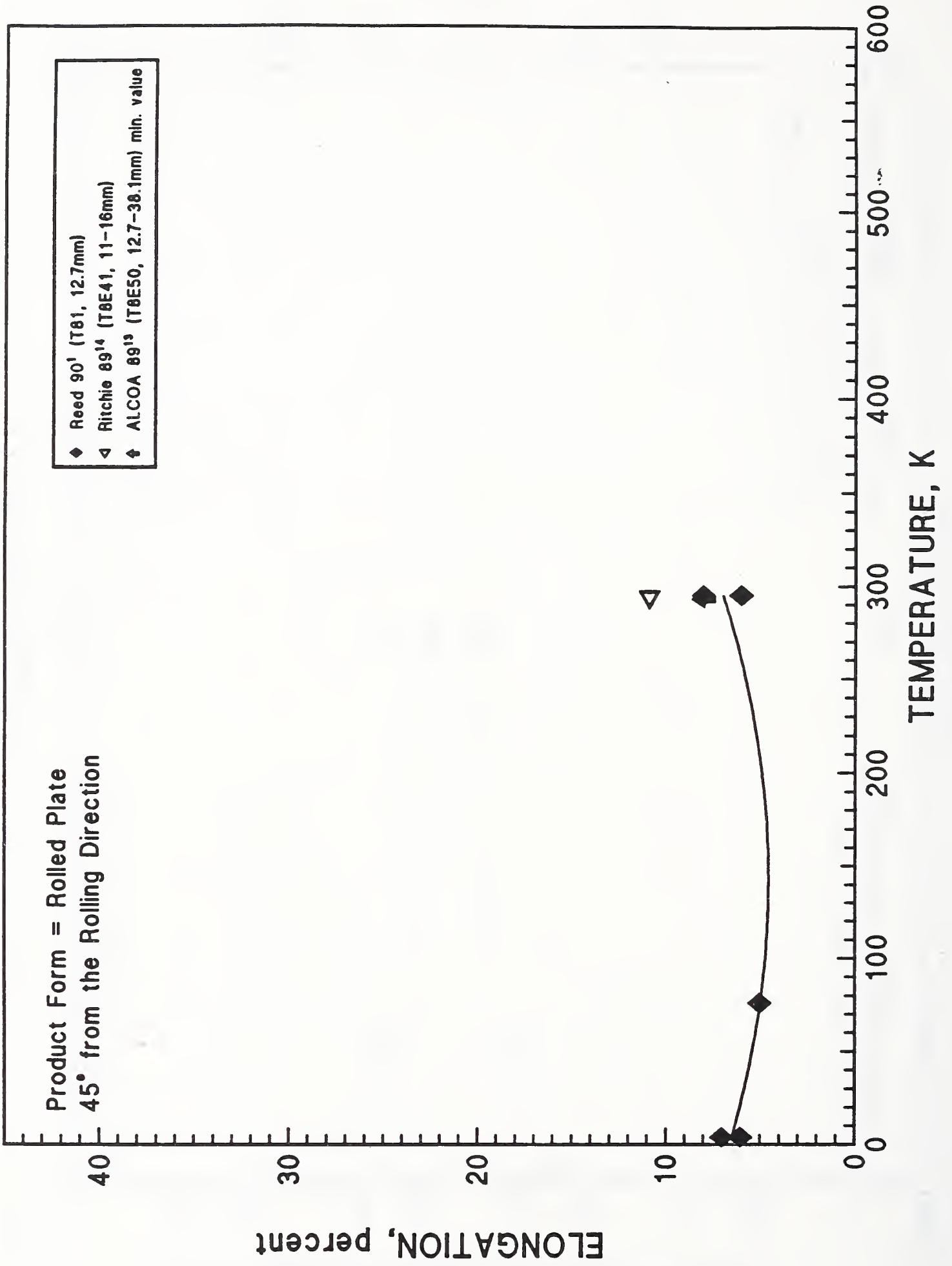


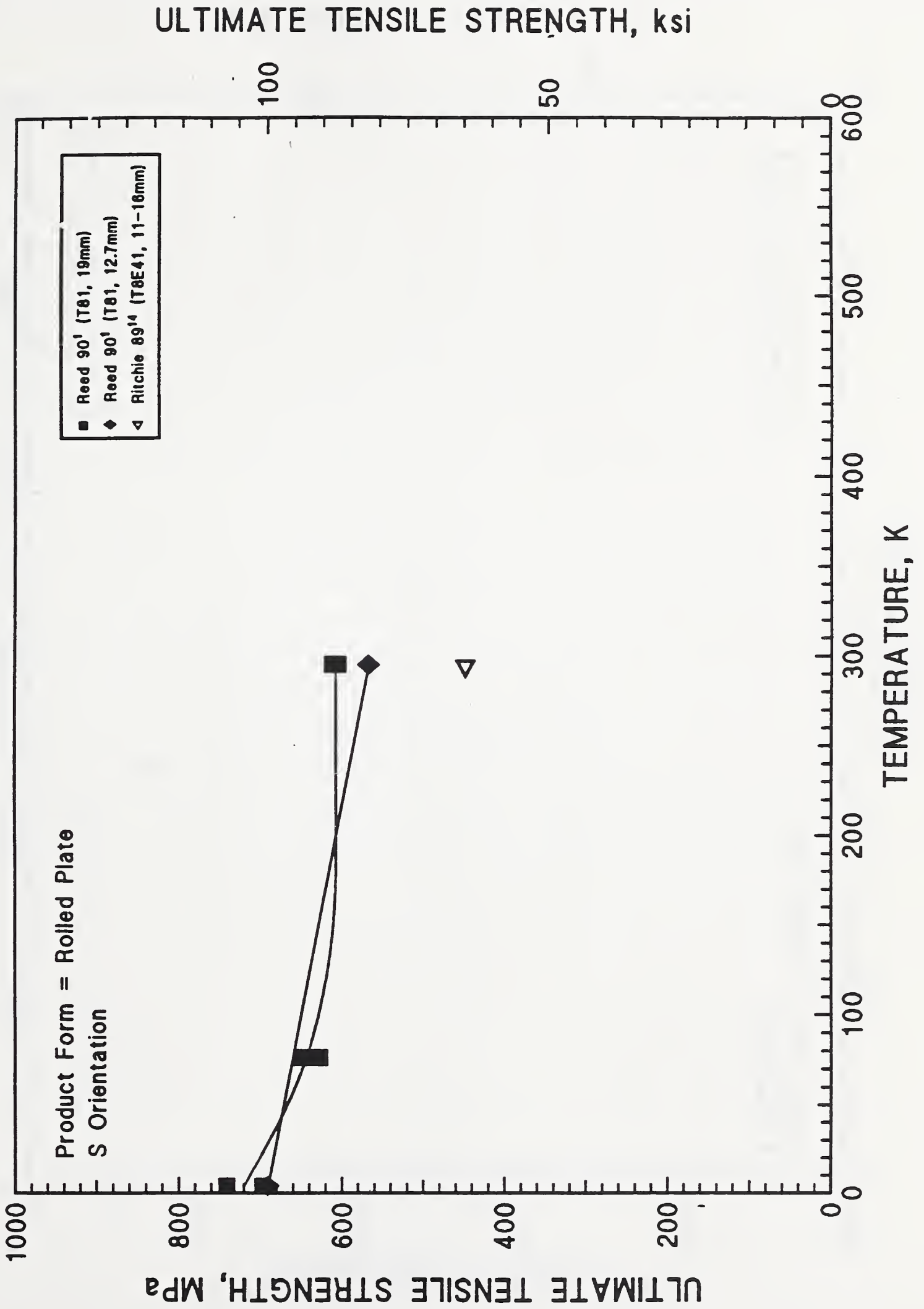




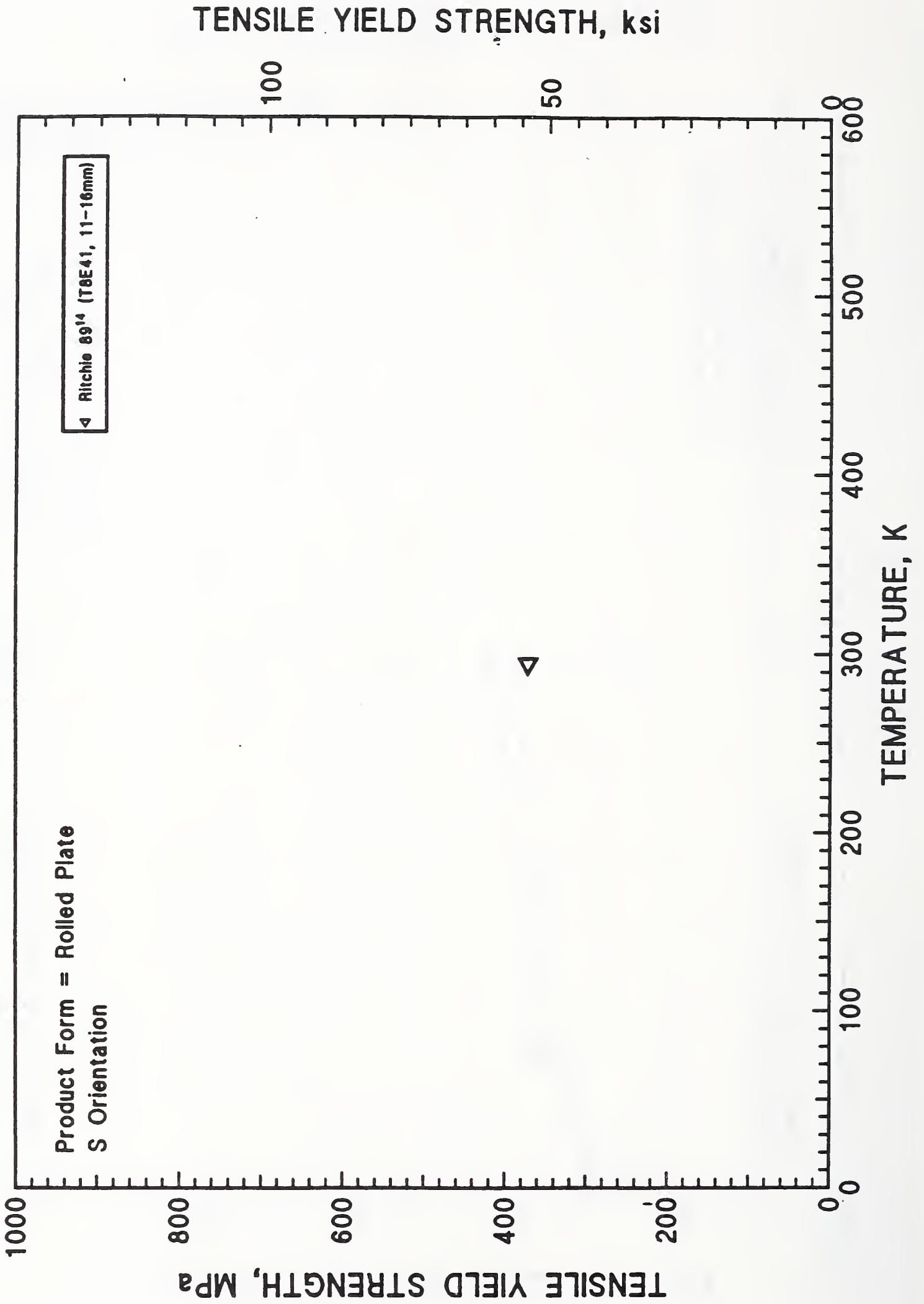


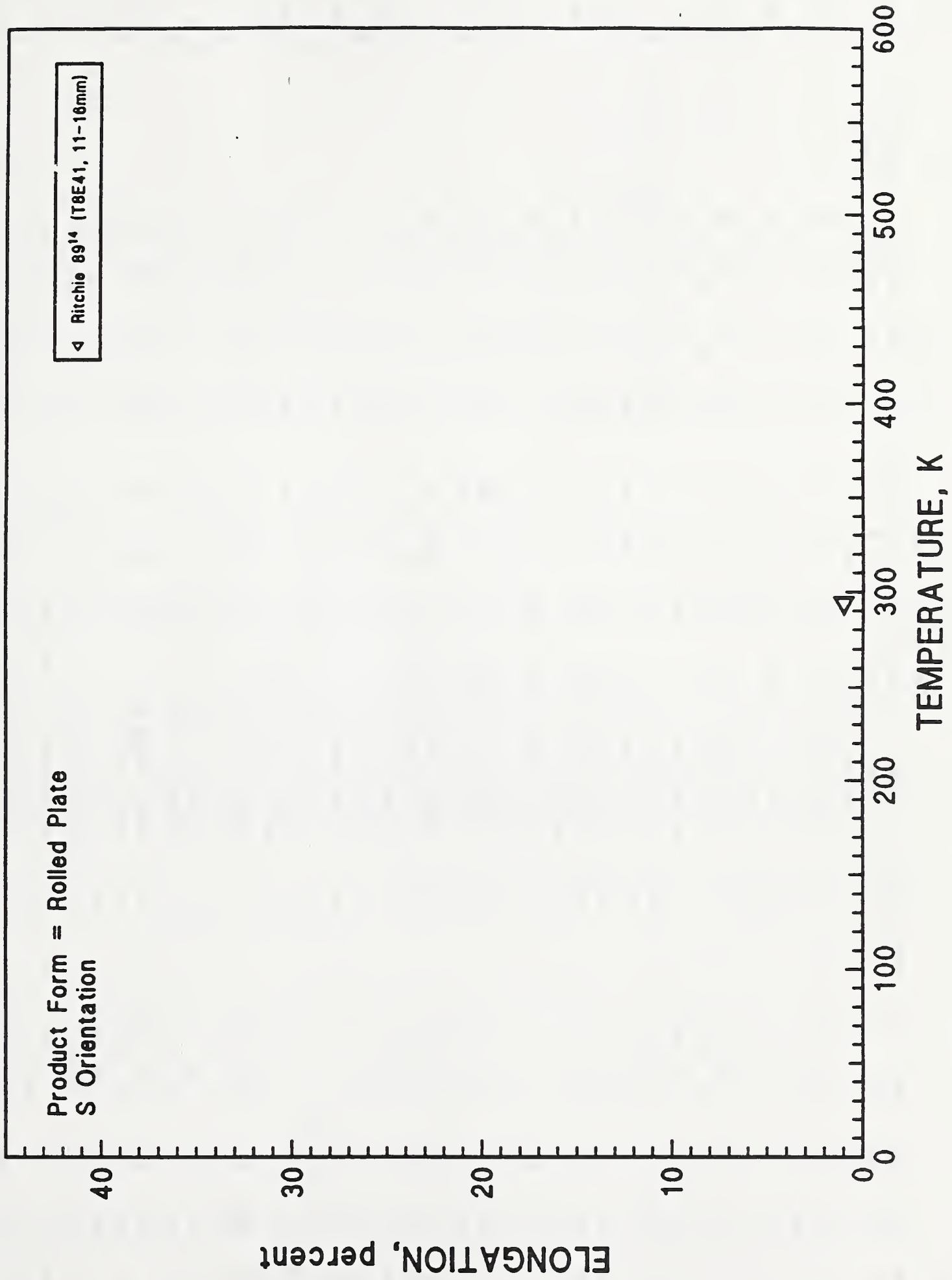






2090-T8





AL-L1 ALLOY 2090

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper	Product Form	Product Aging			Soln. Treat.			Grain Size μm	Hardness	No. of Tests/ Dete Pt
									Thickness mm	Temp. °C	Time h	Stretch %	Temp. °C	Time h			
1P	295	608.	578.	4.8	17.6	L	T81	Rolled Plate 19.05	NA	NA	NA	NA	NA	NA	198.3	1	
1P	295	608.	578.	5.8	17.4	L	T81	Rolled Plate 19.05	NA	NA	NA	NA	NA	NA	198.3	1	
1P	76	746.	673.	6.6	3.45	L	T81	Rolled Plate 19.05	NA	NA	NA	NA	NA	NA	198.3	1	
1P	76	730.	626.	7.9	0.72	L	T81	Rolled Plate 19.05	NA	NA	NA	NA	NA	NA	198.3	1	
1P	20	846.	667.	11.8	13.	L	T81	Rolled Plate 19.05	NA	NA	NA	NA	NA	NA	198.3	1	
1P	20	827.	662.	8.6	9.7	L	T81	Rolled Plate 19.05	NA	NA	NA	NA	NA	NA	198.3	1	
1P	4	833.	665.	9.2	7.28	L	T81	Rolled Plate 19.05	NA	NA	NA	NA	NA	NA	198.3	1	
1P	4	889.	680.	6.4	7.35	L	T81	Rolled Plate 19.05	NA	NA	NA	NA	NA	NA	198.3	1	
1H	295	532.	502.	4.6	6.9	L	T81	Rolled Plate 12.7	NA	NA	NA	NA	NA	NA	198.3	1	
1H	295	529.	500.	4.2	11.6	L	T81	Rolled Plate 12.7	NA	NA	NA	NA	NA	NA	198.3	1	
1H	76	623.	555.	7.2	7.9	L	T81	Rolled Plate 12.7	NA	NA	NA	NA	NA	NA	198.3	1	
1H	76	609.	546.	4.8	10.6	L	T81	Rolled Plate 12.7	NA	NA	NA	NA	NA	NA	198.3	1	
1H	20	686.	588.	6.9	11.9	L	T81	Rolled Plate 12.7	NA	NA	NA	NA	NA	NA	198.3	1	
1H	20	743.	594.	8.9	8.86	L	T81	Rolled Plate 12.7	NA	NA	NA	NA	NA	NA	198.3	1	
1H	4	692.	608.	6.5	20.3	L	T81	Rolled Plate 12.7	NA	NA	NA	NA	NA	NA	198.3	1	
1H	4	684.	582.	6.9	13.7	L	T81	Rolled Plate 12.7	NA	NA	NA	NA	NA	NA	198.3	1	
13A	293	552.	517.	8.	NA	L	T81	Rolled Plate 6.35-50.8	NA	NA	NA	NA	NA	NA	NA	*	
13B	533	138.	117.	25.	NA	L	T81	Rolled Plate 12.7	NA	NA	NA	NA	NA	NA	NA	1	

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Stretch %	Temp. °C	Time h	Soln. Treat.	Quench Cond.	Grain Size μm	Hardness	No. of Tests/Data Pt
13B	505	193.	165.	10.	NA	L	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
13B	477	290.	262.	20.	NA	L	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	2
13B	450	365.	359.	15.	NA	L	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
13B	422	462.	462.	18.	NA	L	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
13B	297	593.	558.	8.	NA	L	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
13C	293	517.	483.	4.	NA	L	T81	Rolled Plate	12.7-38.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	*
12A	219	614.	565.	NA	NA	L	T8	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
12A	77	715.	600.	13.5	NA	L	T8	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
13A	293	490.	441.	4.	NA	L	T8E50	Rolled Plate	6.35-50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	*
13C	293	490.	434.	5.	NA	L	T8E50	Rolled Plate	12.7-38.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	*
11A	77	715.	600.	13.5	NA	L	T8E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
11A	4	820.	615.	17.5	NA	L	T8E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
14A	293	589.	552.	9.3	NA	L	T8E41	Rolled Plate	11-16	163	24.	6	NA	NA	NA	NA	L:2500*; T:500; S:50	NA	1
15A	298	565.	535.	11.	NA	L	T8E41	Rolled Plate	13	163	24.	6	NA	NA	NA	NA	L:2500*; T:500; S:50	NA	1
16A	298	490.	455.	6.	NA	L	T8E41	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
16A	77	625.	505.	14.	NA	L	T8E41	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
16A	4	650.	535.	20.	NA	L	T8E41	Rolled Plate	12.7	NA	NA	6	NA	NA	NA	NA	NA	NA	1
17A	295	555.	535.	9.	15.	L	T8E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
17A	76	666.	595.	6.	8.	L	T8E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPe	Y.S. MPe	Elong. %		R.A. %	Orient. %	Temper	Product Form	Product Thickness mm	Aging		Stretch		SoIn. Treat.		Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
				z	z						Temp. °C	h	z	z	Temp. °C	h				
17A	4	737.	628.	8.	11.	L	T8E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
6B	300	548.	503.	14.	NA	L	T8X	Rolled Plate	12.7	190	4.	2	550	1.	NA	NA	NA	NA	NA	1
6B	300	542.	507.	12.	NA	L	T8X	Rolled Plate	12.7	190	8.	2	550	1.	NA	NA	NA	NA	NA	1
6B	77	630.	564.	15.	NA	L	T8X	Rolled Plate	12.7	180	8.	2	550	1.	NA	NA	NA	NA	NA	1
6B	77	619.	525.	17.	NA	L	T8X	Rolled Plate	12.7	190	4.	2	550	1.	NA	NA	NA	NA	NA	1
16B	298	270.	120.	19.	NA	L	T4	Rolled Plate	3.2	NA	NA	NA	550	0.5	WQ	NA	NA	NA	NA	1
16B	77	350.	155.	29.	NA	L	T4	Rolled Plate	3.2	NA	NA	NA	550	0.5	WQ	NA	NA	NA	NA	1
16B	4	435.	190.	25.	NA	L	T4	Rolled Plate	3.2	NA	NA	NA	550	0.5	WQ	NA	NA	NA	NA	1
1F	295	595.	557.	3.7	12.5	T	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	295	600.	561.	4.3	13.3	T	T81	Rolled Plate	19.05	NA	1A	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	76	688.	624.	0.4	3.51	T	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	76	699.	623.	2.9	5.16	T	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	20	761.	664.	3.5	7.53	T	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	20	767.	662.	2.8	5.97	T	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	4	754.	666.	2.2	5.56	T	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1F	4	767.	675.	2.5	3.84	T	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1H	295	544.	509.	1.	3.04	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1H	295	548.	505.	1.2	6.12	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1
1H	76	611.	573.	1.	4.93	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	198.3	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPe	Y.S. MPe	Elong. %	R.A. %	Orient. Z	Temper	Product Form	Product Thickness mm	Aging Temp. °C	Aging Time h	Stretch Z	Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
1H	76	609.	566.	0.5	3.28	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	198.3	1
1H	20	652.	618.	2.	2.09	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	198.3	1
1H	20	681.	608.	0.25	2.98	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	198.3	1
1H	4	668.	620.	0.5	3.68	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	198.3	1
1H	4	670.	622.	1.	3.91	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	198.3	1
13B	533	165.	145.	20.	NA	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
13B	505	228.	183.	17.	NA	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
13B	477	296.	276.	12.	NA	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	2
13B	450	476.	386.	9.	NA	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
13B	422	476.	386.	7.	NA	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
13B	287	586.	552.	6.	NA	T	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	4
13B	219	607.	565.	4.	NA	T	T61	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	2
13E	293	517.	469.	3.	NA	T	T61	Rolled Plate	12.7-38.1	NA	NA	NA	NA	NA	NA	NA	NA	*
13C	293	490.	414.	5.	NA	T	T8E50	Rolled Plate	12.7-38.1	NA	NA	NA	NA	NA	NA	NA	NA	*
11B	298	565.	535.	5.5	NA	T	T8E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
11B	77	695.	625.	5.5	NA	T	T8E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
11B	4	815.	705.	6.5	NA	T	T8E41	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
14A	293	579.	548.	5.4	NA	T	T8E41	Rolled Plate	11-16	163	24.	6	NA	NA	NA	L:2500*; T:500; S:50	NA	1
1H	295	515.	463.	4.	0.	45°	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	198.3	1

*See Comments

Ref & Note No.	T.S. K	Y.S. MPe	Elong. %	R.A. %	Orient. °	Temper	Product Form	Product Thickness mm	Aging		Soln. Treat.		Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
									Temp. °C	Time h	Stretch %	Temp. °C				
1H	295	523.	470.	6.	11.	45°	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
1H	76	558.	502.	3.	7.	45°	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
1H	76	572.	506.	4.	7.	45°	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
1H	4	636.	550.	5.	8.	45°	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
1H	4	626.	547.	5.	10.	45°	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
13C	293	462.	359.	8.	NA	45°	T8E50	Rolled Plate	12.7-38.1	NA	NA	NA	NA	NA	NA	*
14A	293	514.	460.	10.8	NA	45°	T8E41	Rolled Plate	11-16	163	24.	6	NA	L:2500*; T:500; S:50	NA	1
1G	295	604.	NA	NA	NA	S	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	198.3	1
1G	295	611.	NA	NA	NA	S	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	198.3	1
1G	76	627.	NA	NA	NA	S	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	198.3	1
1G	76	649.	NA	NA	NA	S	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	198.3	1
1G	4	741.	NA	NA	NA	S	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	198.3	1
1G	4	697.	NA	NA	NA	S	T81	Rolled Plate	19.05	NA	NA	NA	NA	NA	198.3	1
1I	295	566.	NA	NA	NA	S	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
1I	4	690.	NA	NA	NA	S	T81	Rolled Plate	12.7	NA	NA	NA	NA	NA	198.3	1
14B	293	448.	372.	1.	NA	S	T8E41	Rolled Plate	11-16	163	24.	6	NA	L:2500*; T:500; S:50	NA	1

*See Comments

Comments from the Al-Li Alloy 2090 Data Table

Reference and
Note Number

13A--Values reported are "typical" properties.

13C--Values reported are "minimum" properties.

13E--Values reported are "minimum" properties.

14A--Value reported is the average of the range of grain sizes.

14B--Value reported is the average of the range of grain sizes.

15A--Value reported is the average of the range of grain sizes.

TEST PARAMETERS
 Al-L1 ALLOY 2090

Ref & Strain Note No.	Rate 10 ⁻⁴ /s	Specimen		G.L. mm	Specimen Location	Expo Time min	Supplier	Yr. Prod.	Lot No.	Product L(m) X W(m)	Major Elements											Minor Elements wt%					
		Type	Diam mm								Thick mm	Li	Cu	Mg	Zr	Si	Fe	Ag	wt%	wt%							
		Round	6.35								NA										25.4		Mid-plane	5.	Alcoa	1989	103299
1F	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Alcoa	1989	103299	1.22 X 2.44	2.3	2.8	0.1	0.1	NA	0.07	NA	NA	NA	NA	NA	NA	NA	NA		
1G	2.2	Round	2.5	NA	25.4	Random	5.	Alcoa	1989	103299	1.22 X 2.44	2.3	2.8	0.1	0.1	NA	0.07	NA	NA	NA	NA	NA	NA	NA	NA	NA	
1H	2.2	Round	6.35	NA	25.4	Mid-plane	5.	Alcoa	1989	103301	1.22 X 2.44	2.3	2.7	0.	0.12	NA	0.08	NA	NA	NA	NA	NA	NA	NA	NA	NA	
1I	2.2	Round	2.5	NA	25.4	Random	5.	Alcoa	1989	103301	1.22 X 2.44	2.3	2.7	NA	0.12	NA	0.08	NA	NA	NA	NA	NA	NA	NA	NA	NA	
6B	1.0	Round	NA	NA	NA	NA	15.	Alcoa	NA	NA	NA	2.53	1.8	0.5	0.13	0.3	0.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	
11A	NA	Round	NA	NA	25.4	NA	NA	Alcoa	NA	NA	NA	2.2*	2.7	NA	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
11B	NA	Round	NA	NA	25.4	NA	NA	Alcoa	NA	NA	NA	2.2*	2.7	NA	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
12A	NA	NA	NA	NA	NA	NA	NA	Alcoa	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
13A	NA	Flet	NA	NA	NA	Random	NA	Alcoa	NA	NA	NA	2.3*	2.7	0.3	0.12	0.1	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	
13B	NA	Flet	NA	NA	NA	Random	NA	Alcoa	NA	NA	2.54	2.3*	2.7	0.3	0.12	0.1	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	
13C	NA	Flet	NA	NA	NA	Random	NA	Alcoa	NA	NA	NA	2.3*	2.7	0.3	0.12	0.1	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	
14A	NA	Round	6.4	NA	25.	Mid-plane	NA	Alcoa	NA	NA	NA	2.1*	2.9	0.	0.12	E-2	0.02	NA	NA	NA	NA	NA	NA	NA	NA	NA	
14B	NA	Round	6.4	NA	25.	Mid-plane	NA	Alcoa	NA	NA	NA	2.1*	2.9	0.	0.12	E-2	0.02	NA	NA	NA	NA	NA	NA	NA	NA	NA	
15A	NA	NA	NA	NA	NA	NA	NA	Alcoa	NA	NA	NA	2.05	2.9	0.	0.12	E-2	0.02	NA	NA	NA	NA	NA	NA	NA	NA	NA	
16A	6.0	Flet	9.5	3.2	41.	↳ the thickness	NA	Alcoa	NA	NA	NA	2.05	2.9	NA	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
16B	6.0	Flet	9.5	3.2	41.	↳ the thickness	NA	Alcoa	NA	NA	NA	2.05	2.9	NA	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
17A	2.2	Round	6.35	NA	25.4	NA	5.	Alcoa	NA	NA	1.22 X 1.22	2.05	2.9	NA	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Comments from the Al-Li Alloy 2090 Test Parameter Table

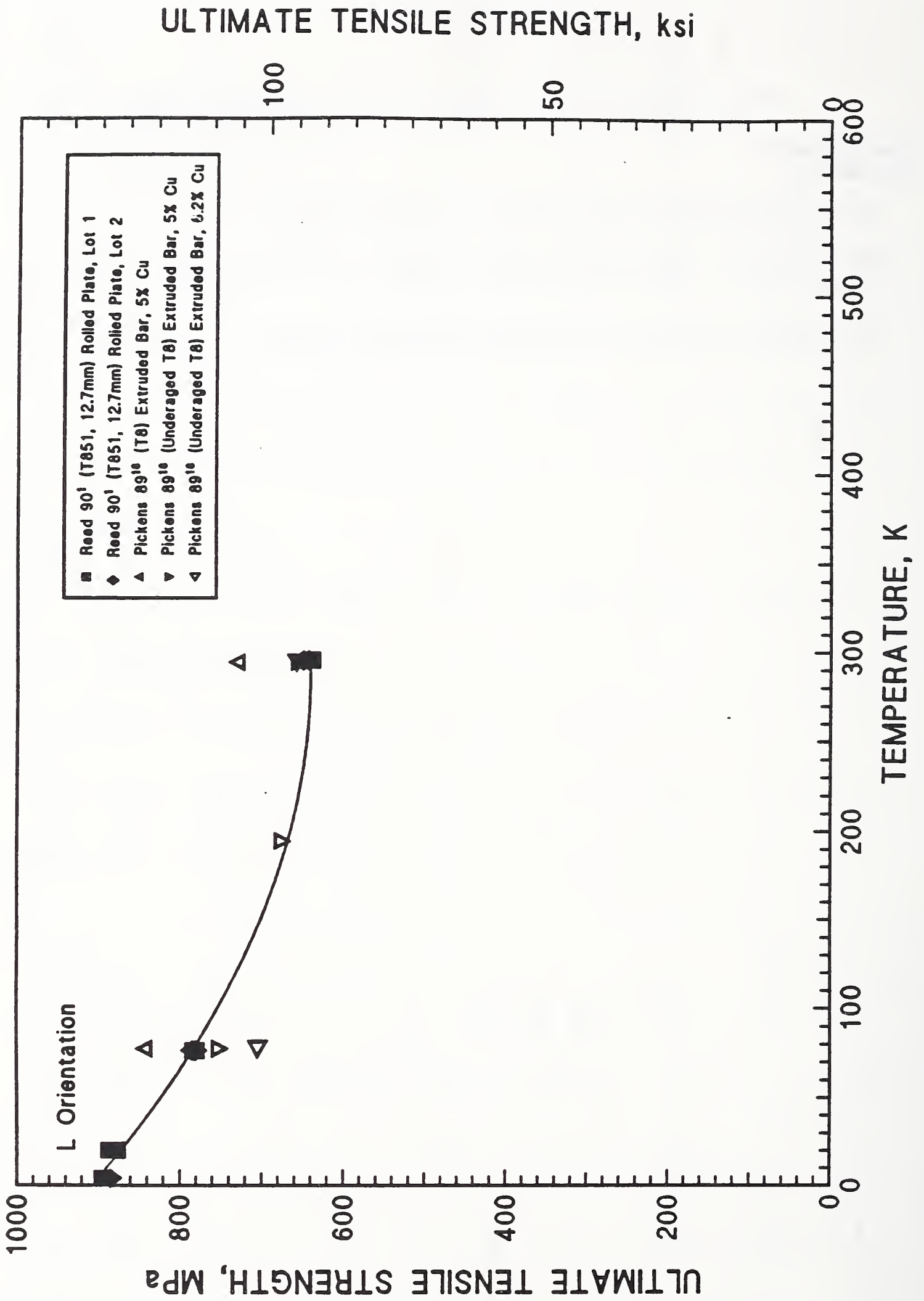
Reference and
Note Number

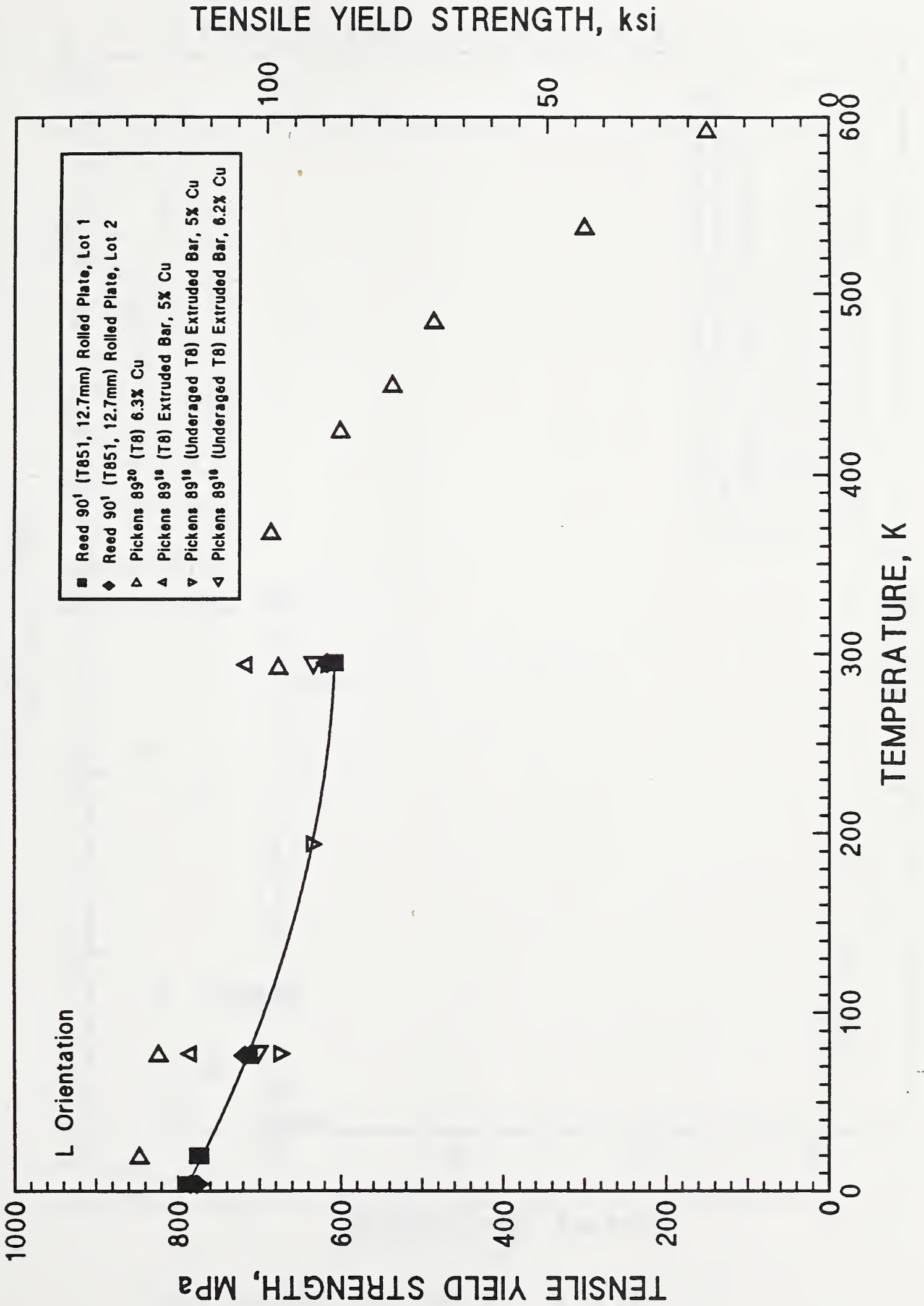
11A--Reported composition is based on nominal values.

13A-C--Reported composition is the average of the minimum and maximum values.

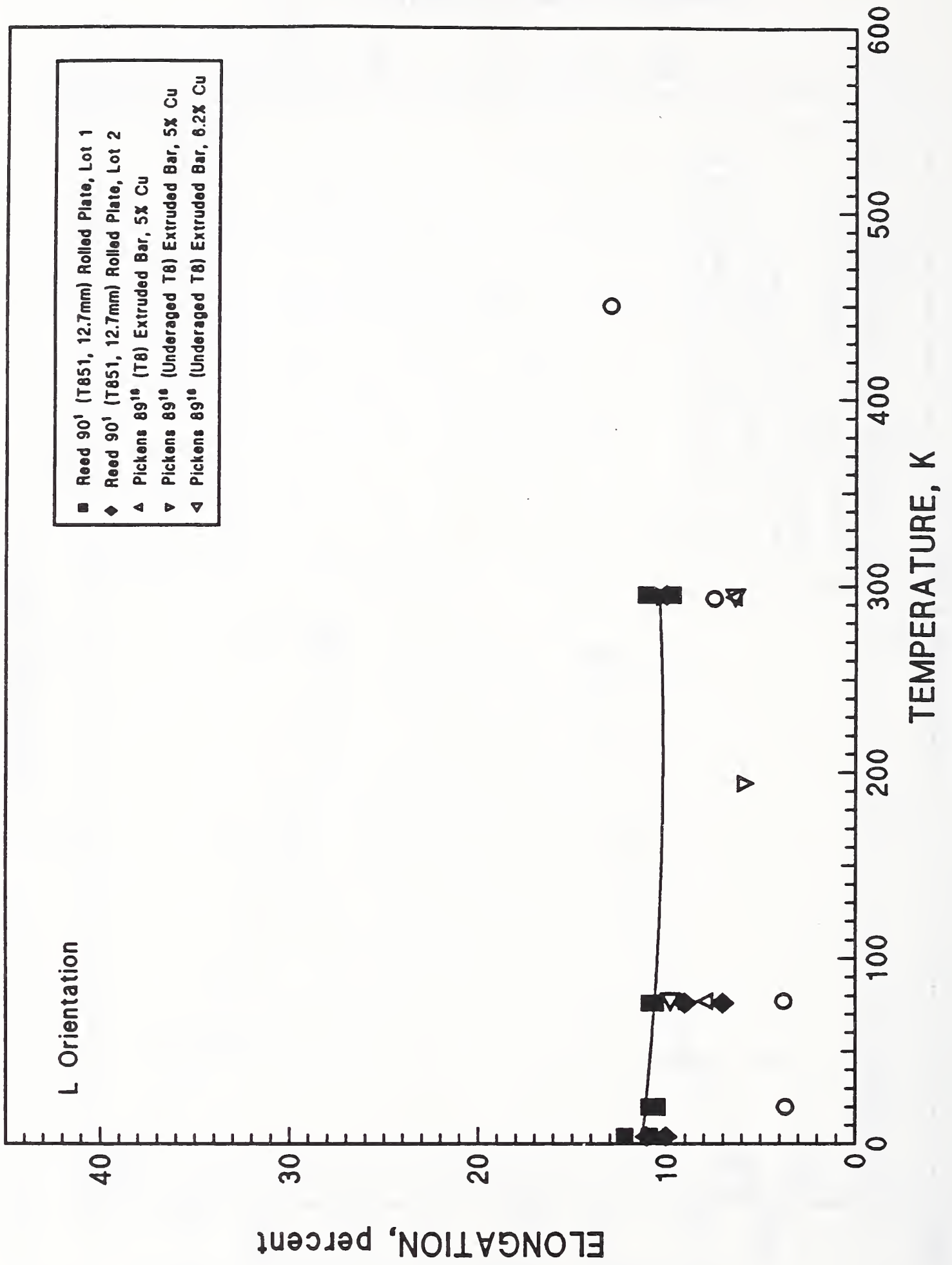
14A--Reported composition is based on nominal values.

WL049-T8

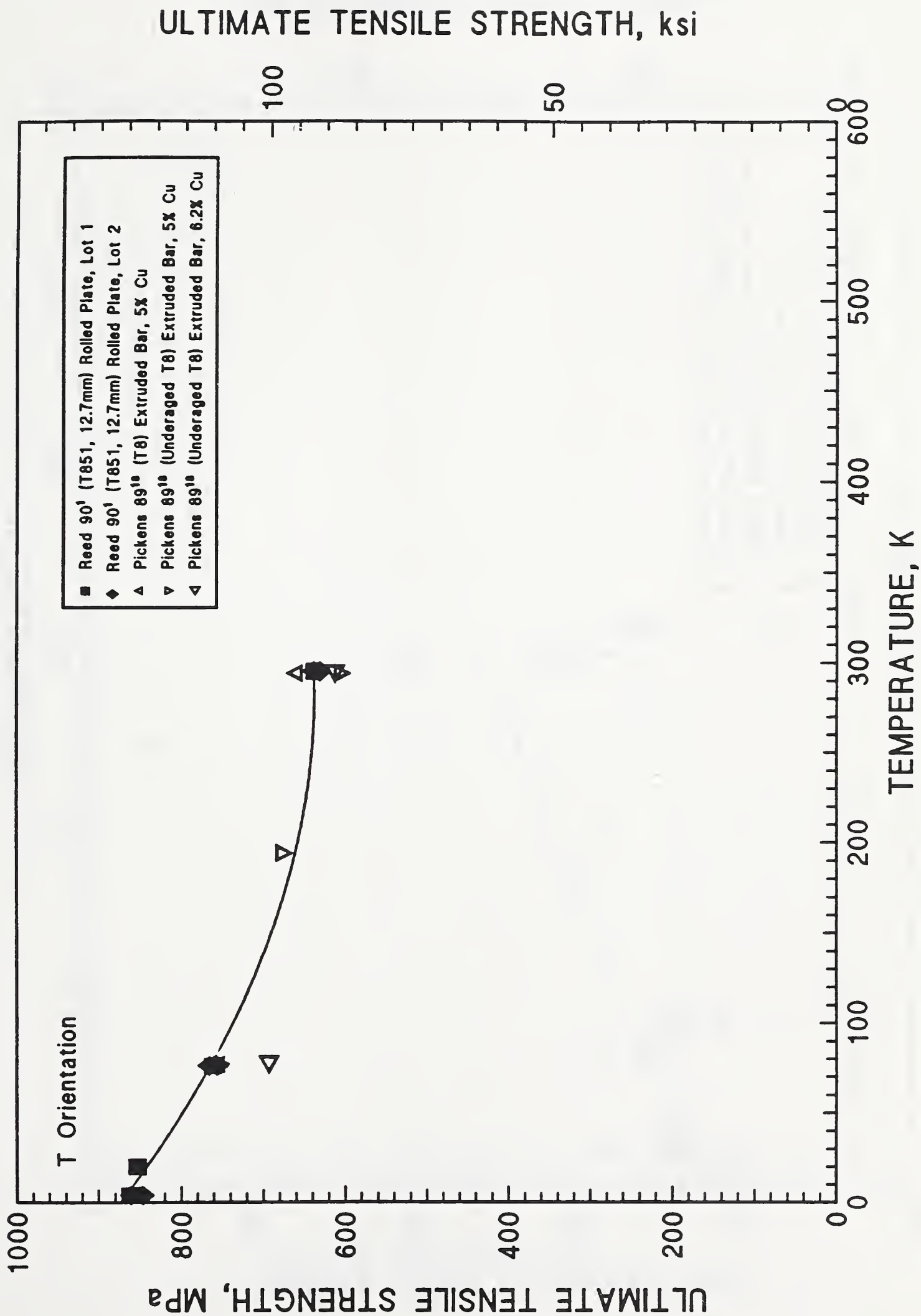


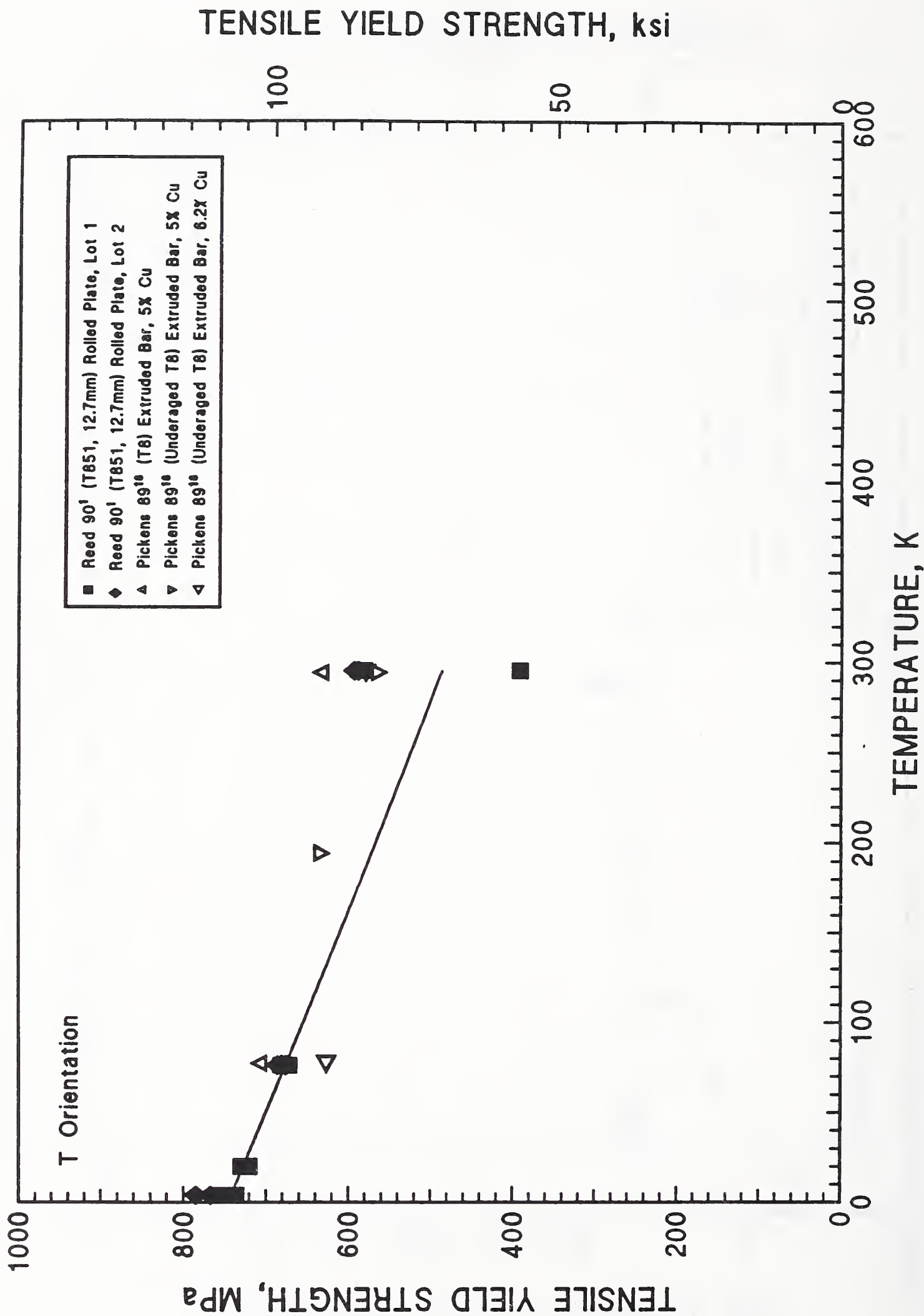


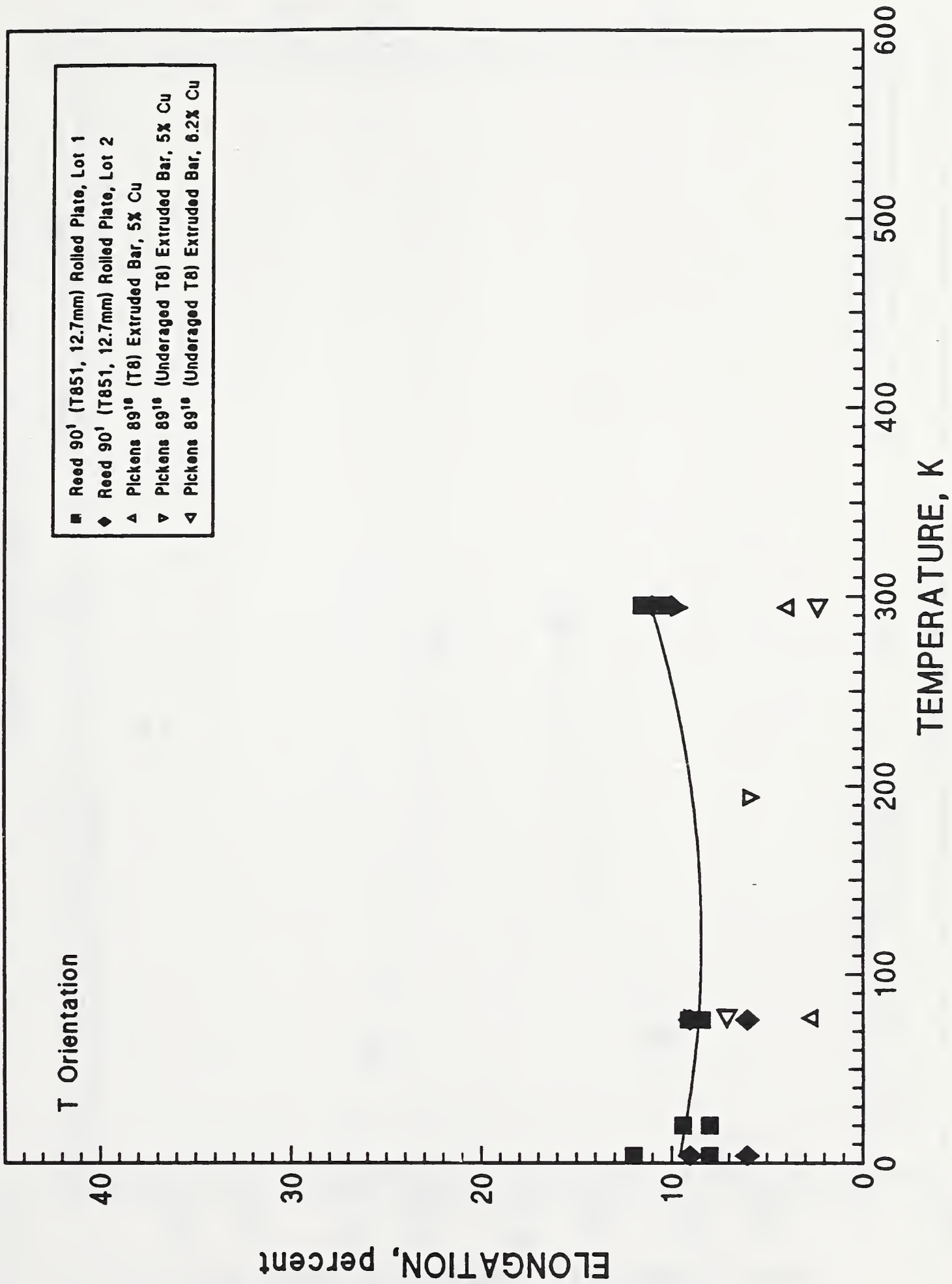
WLO49-T8



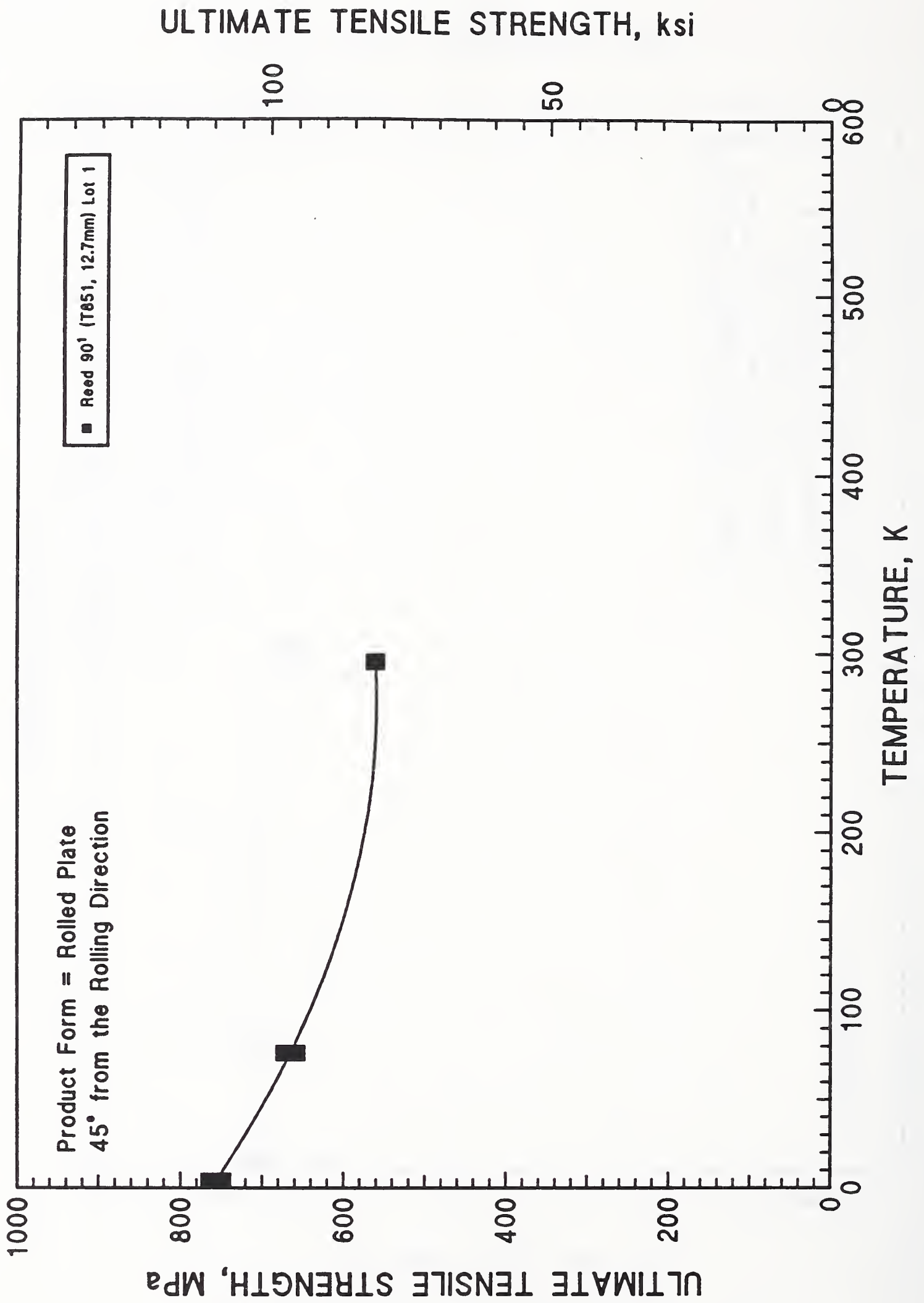
WLO49-T8



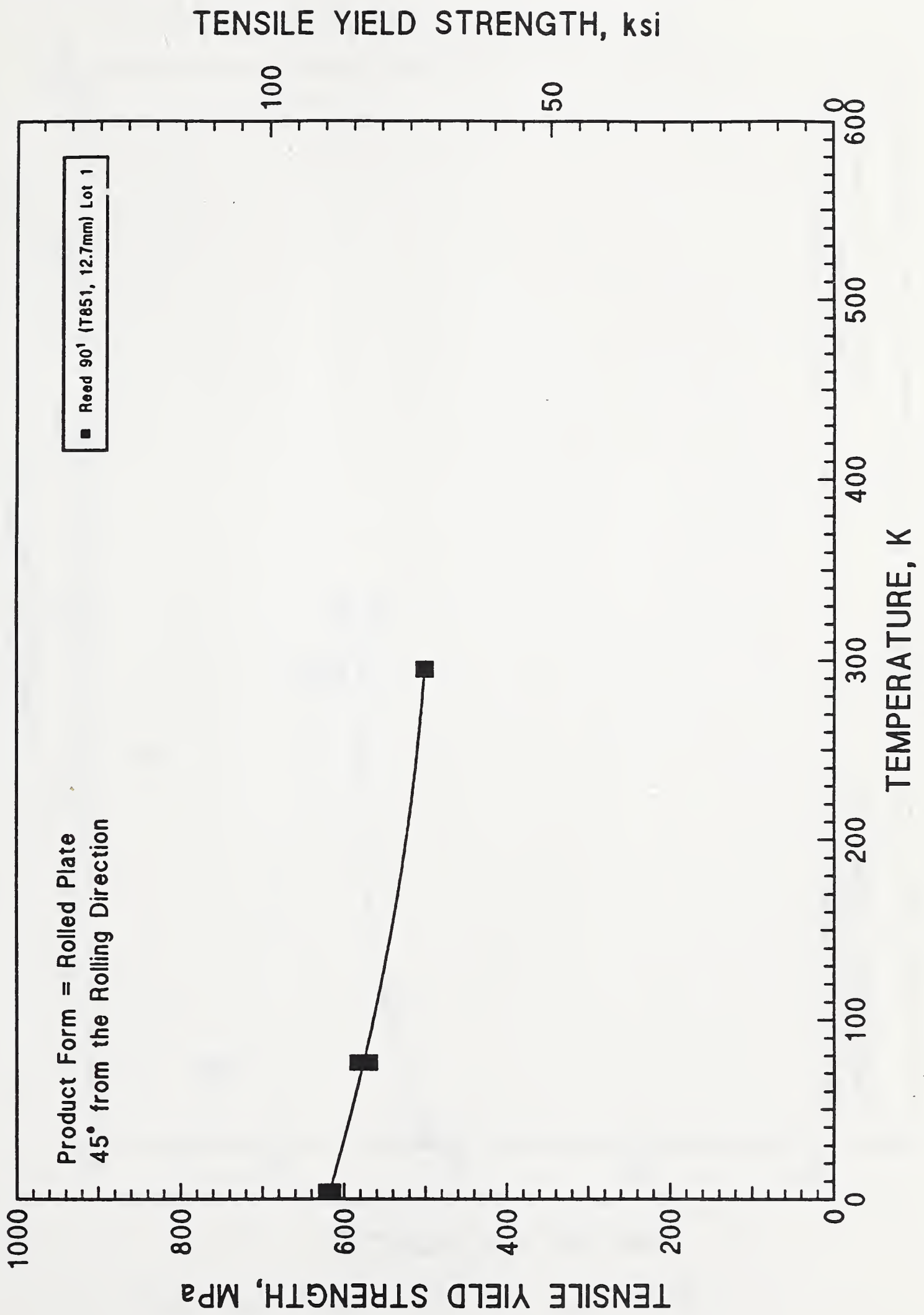


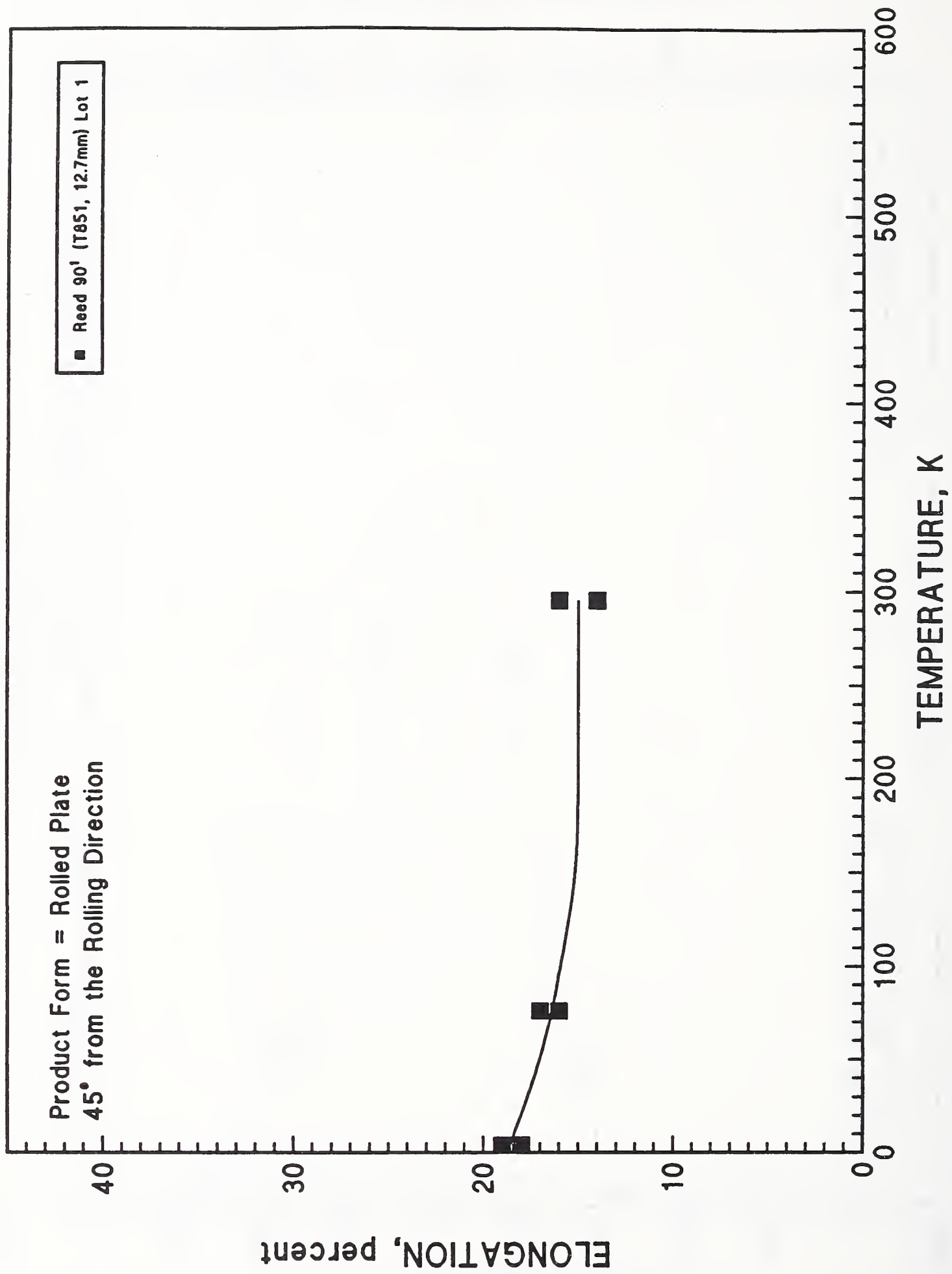


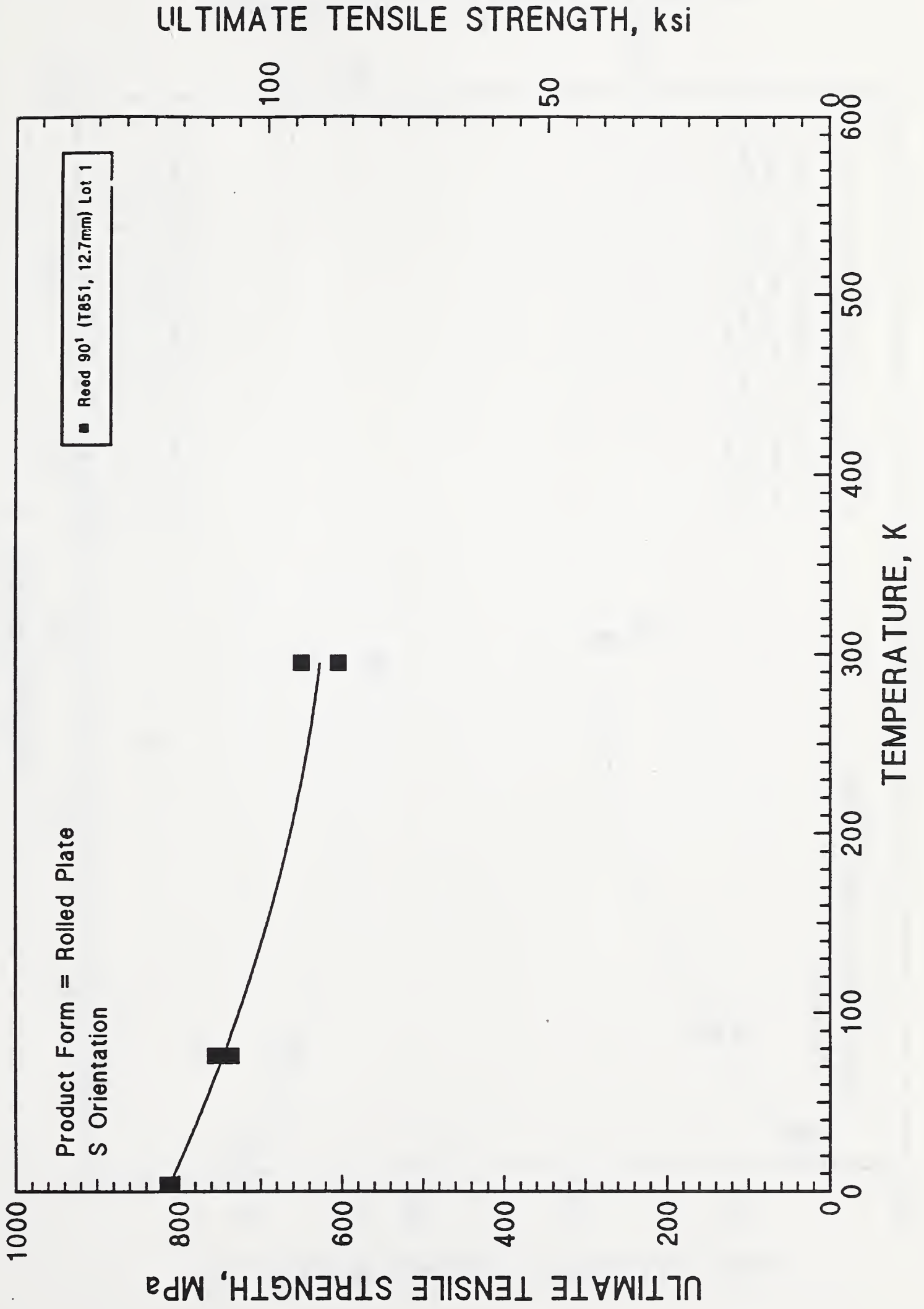
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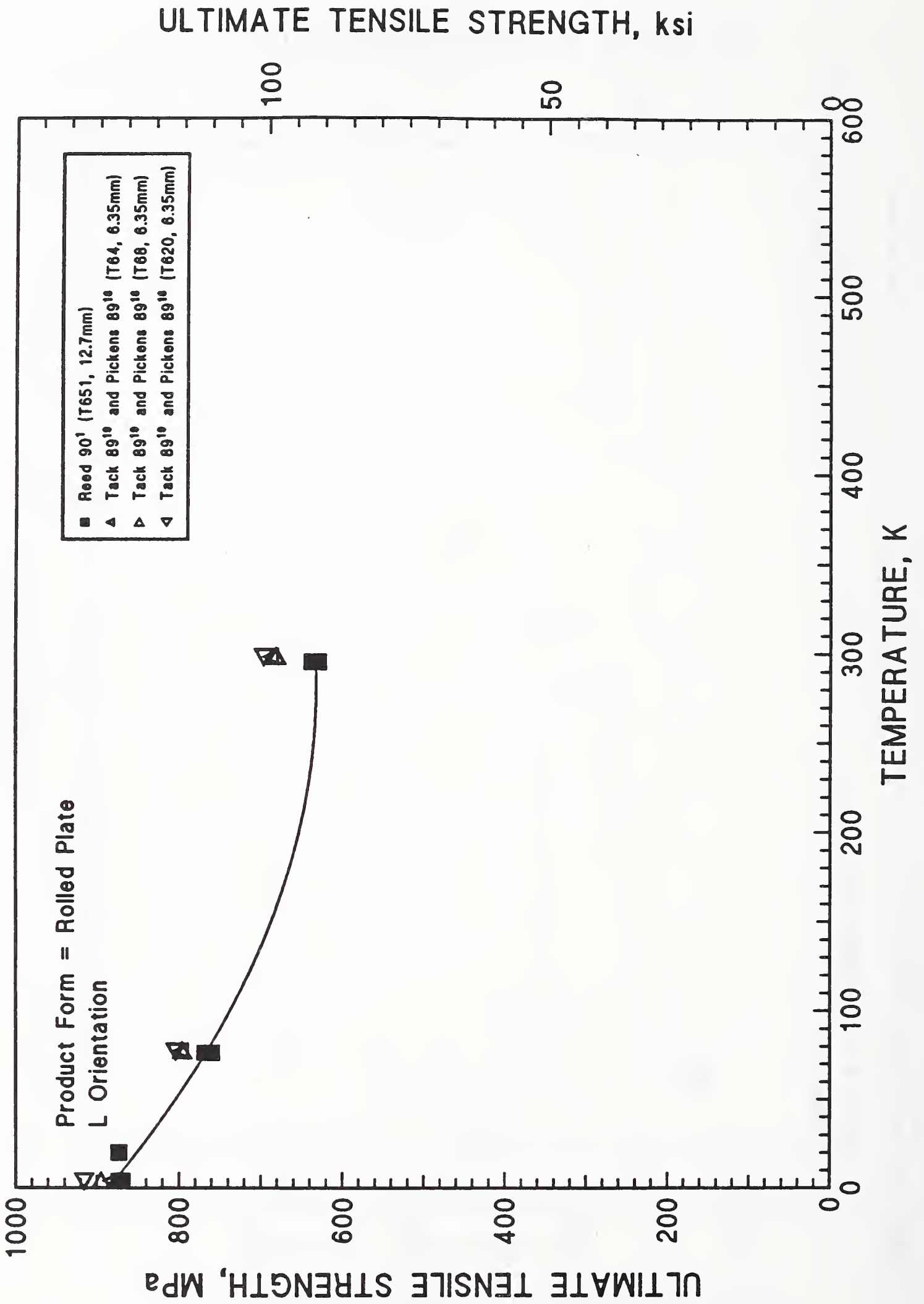
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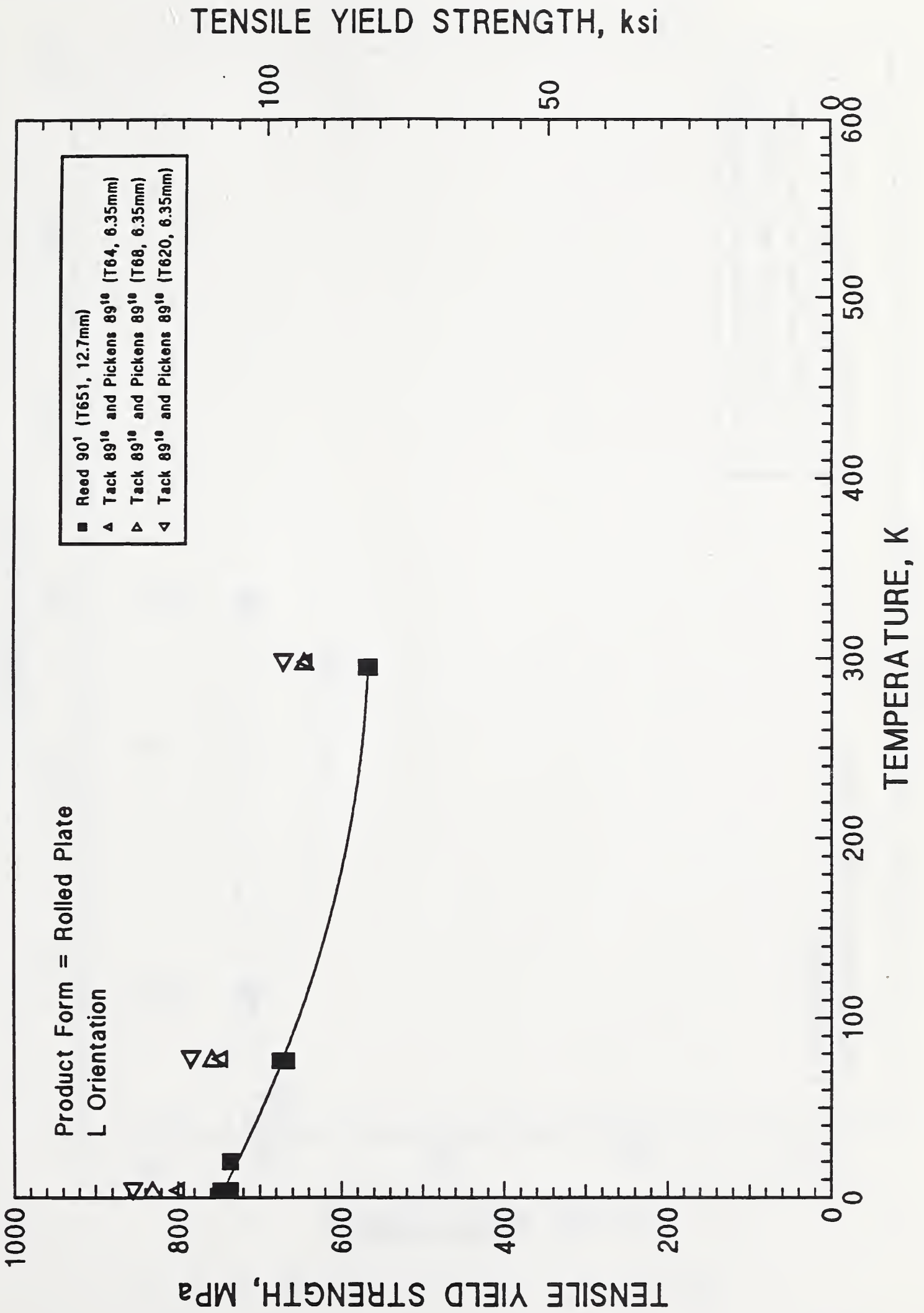




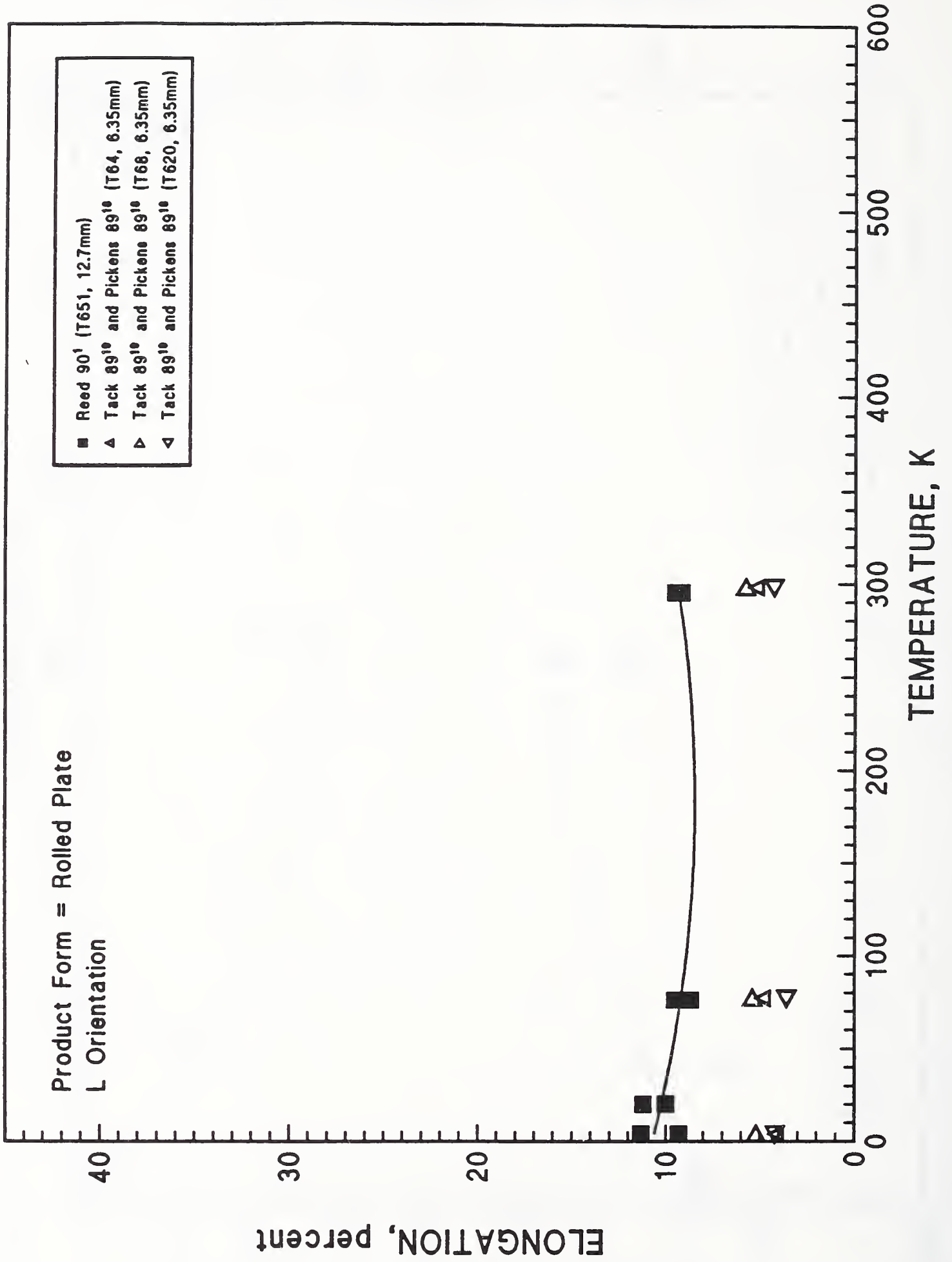


WL049-T6

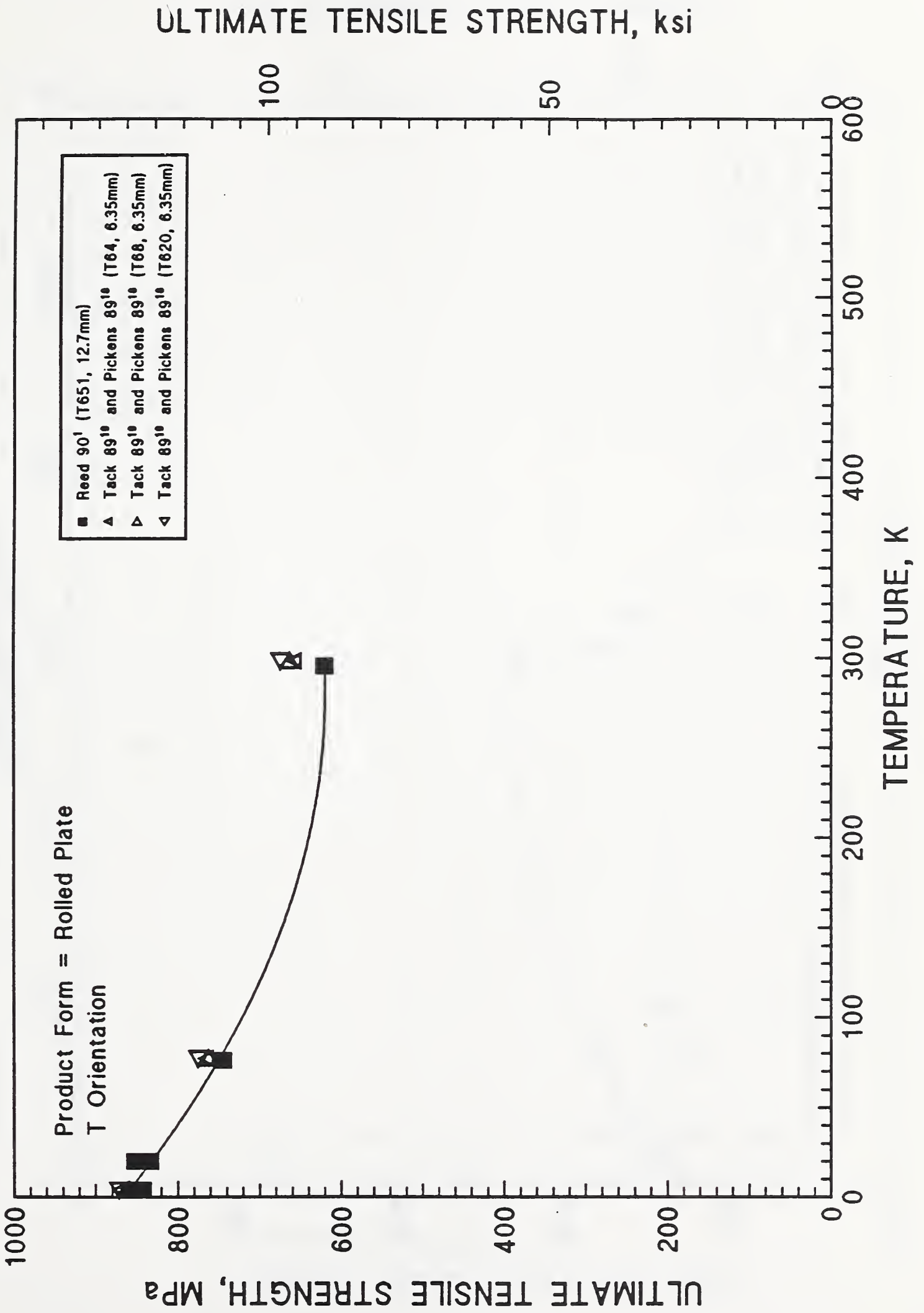




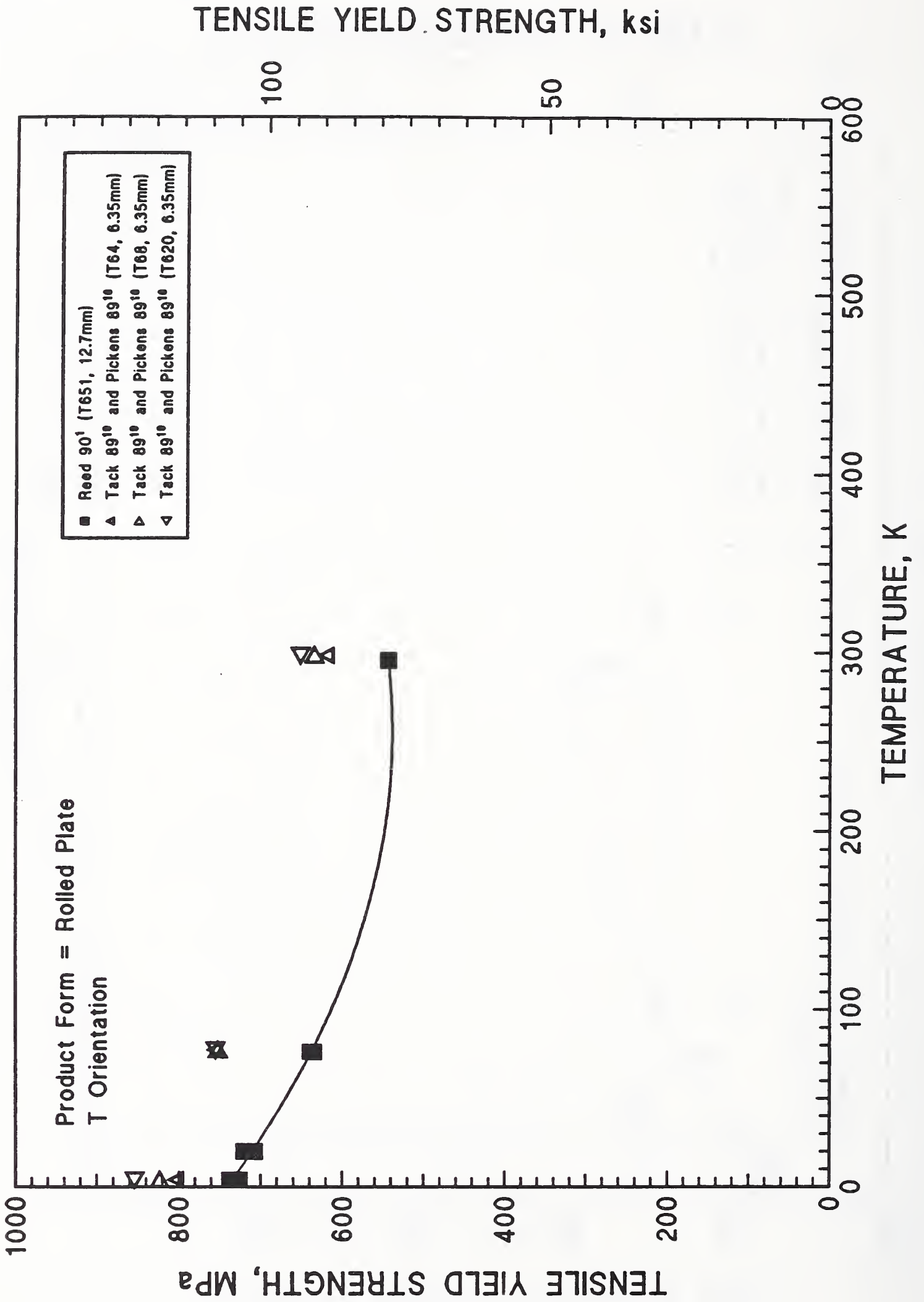
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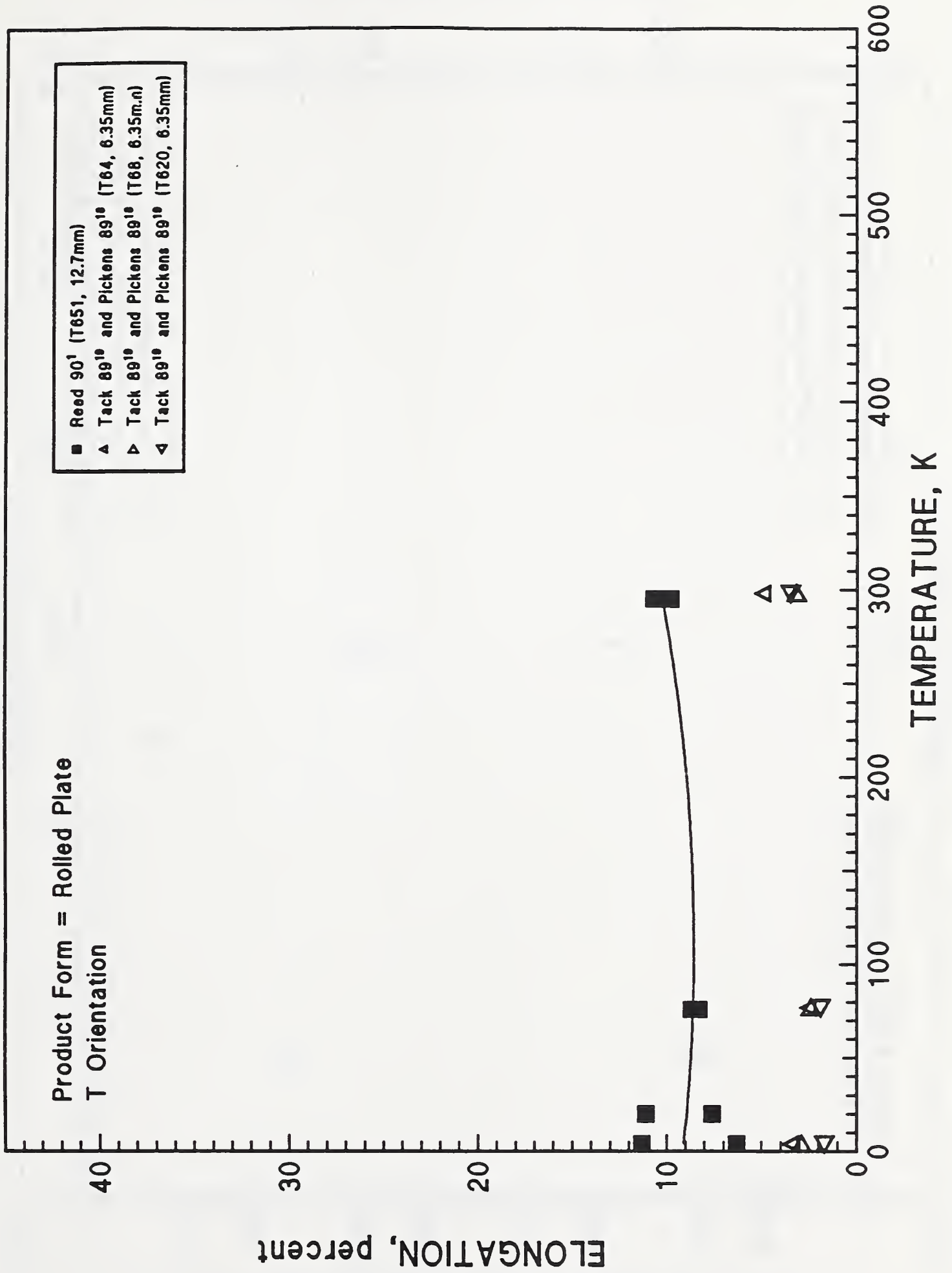


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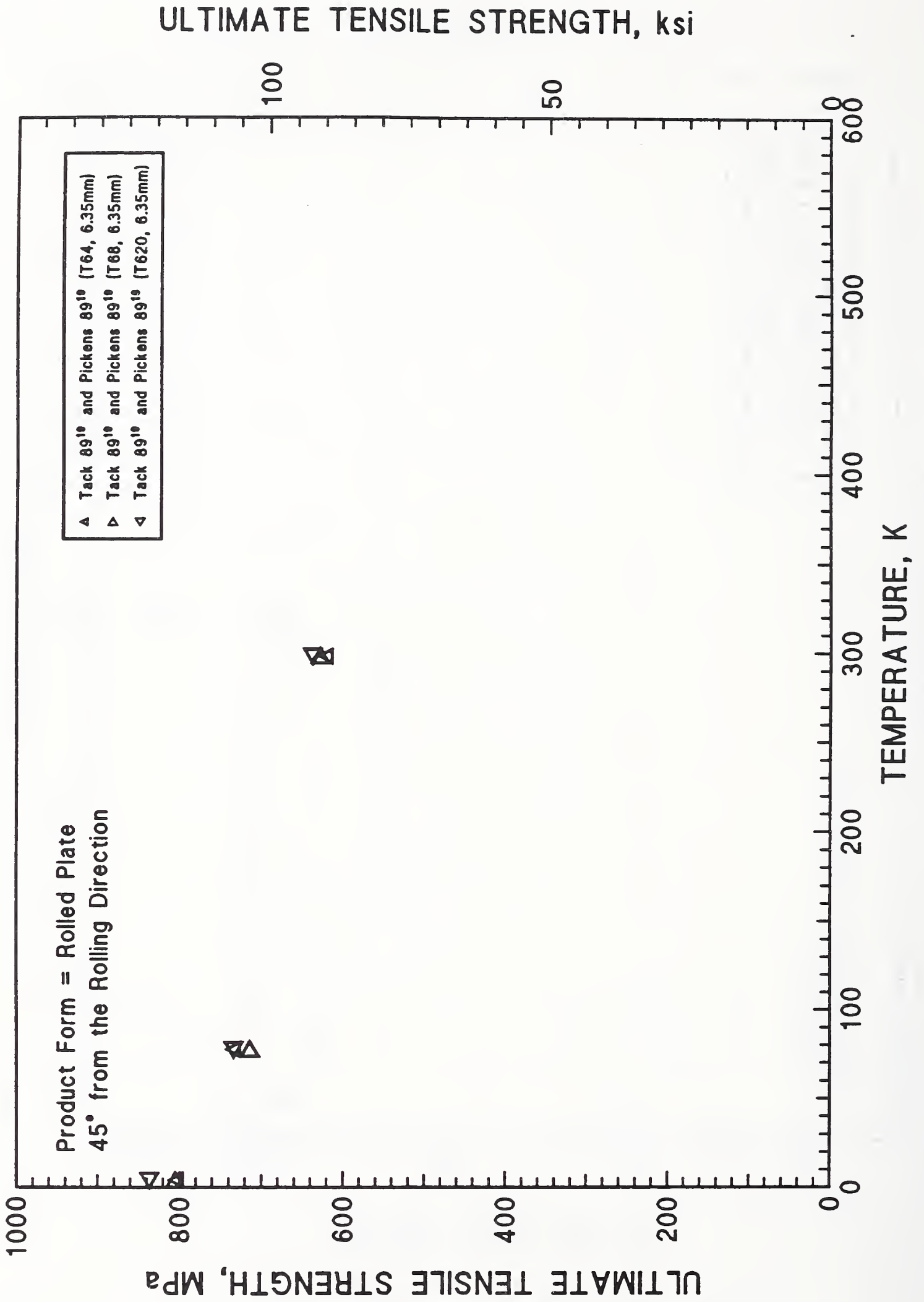


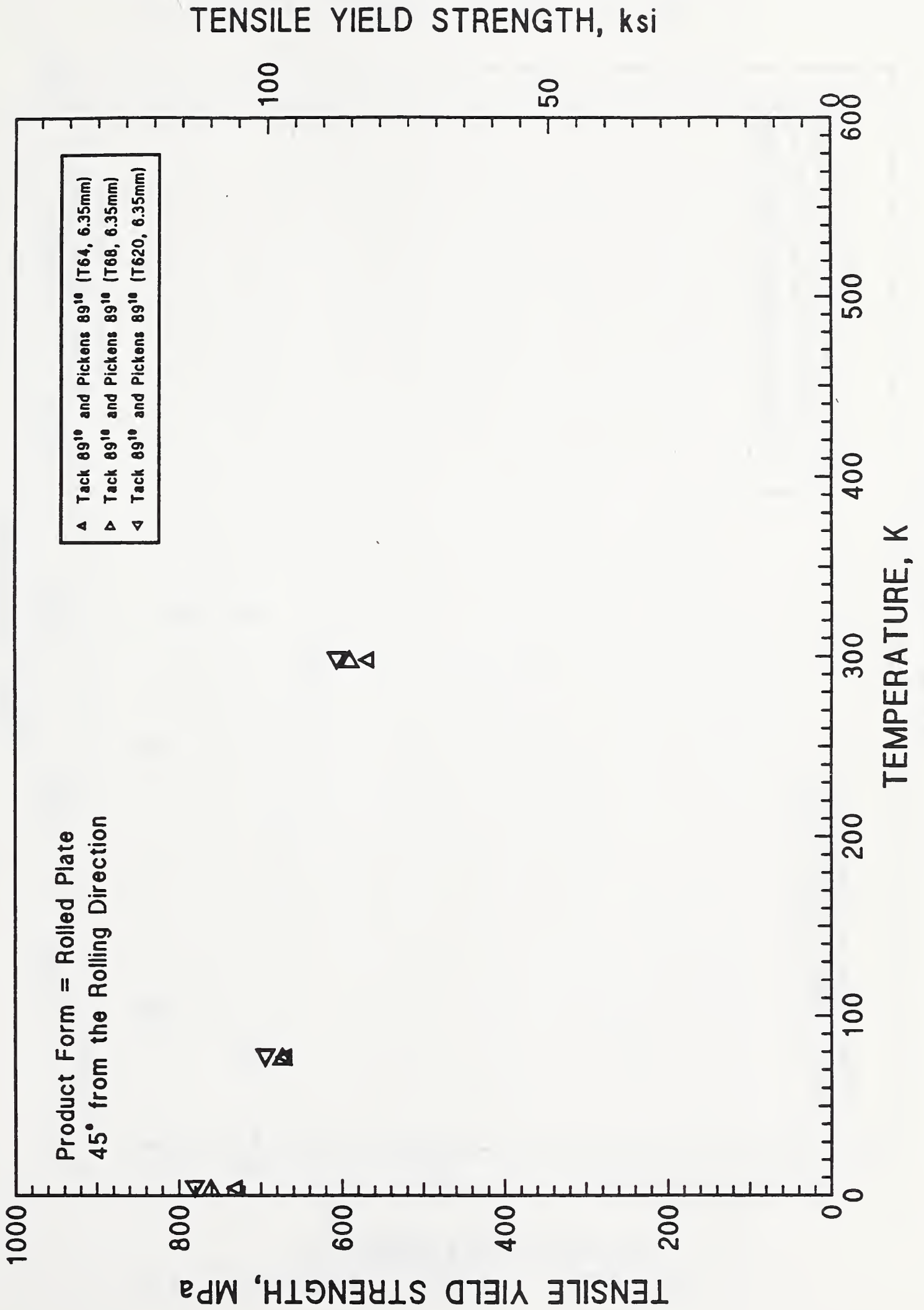
WLO49-T6



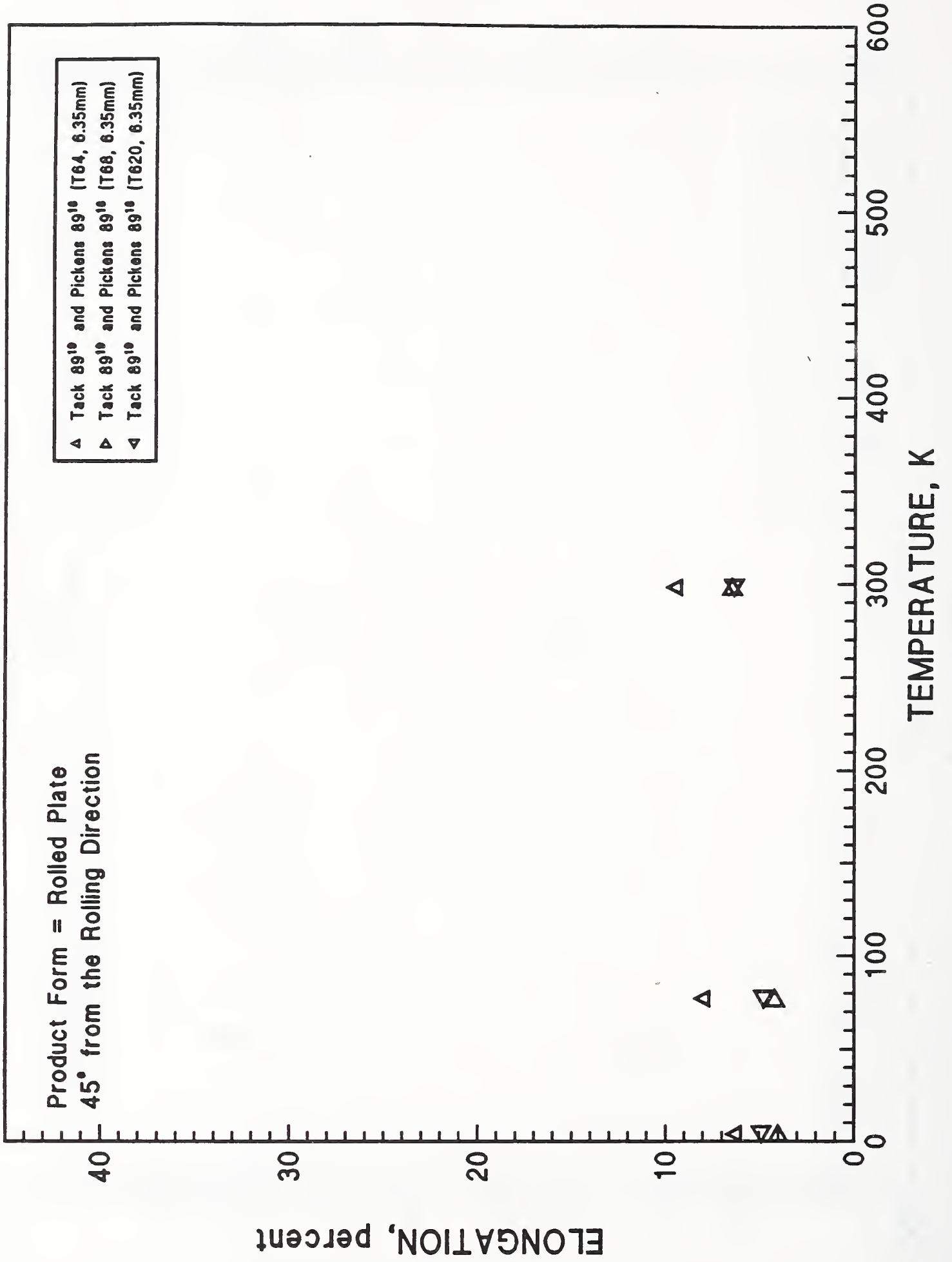


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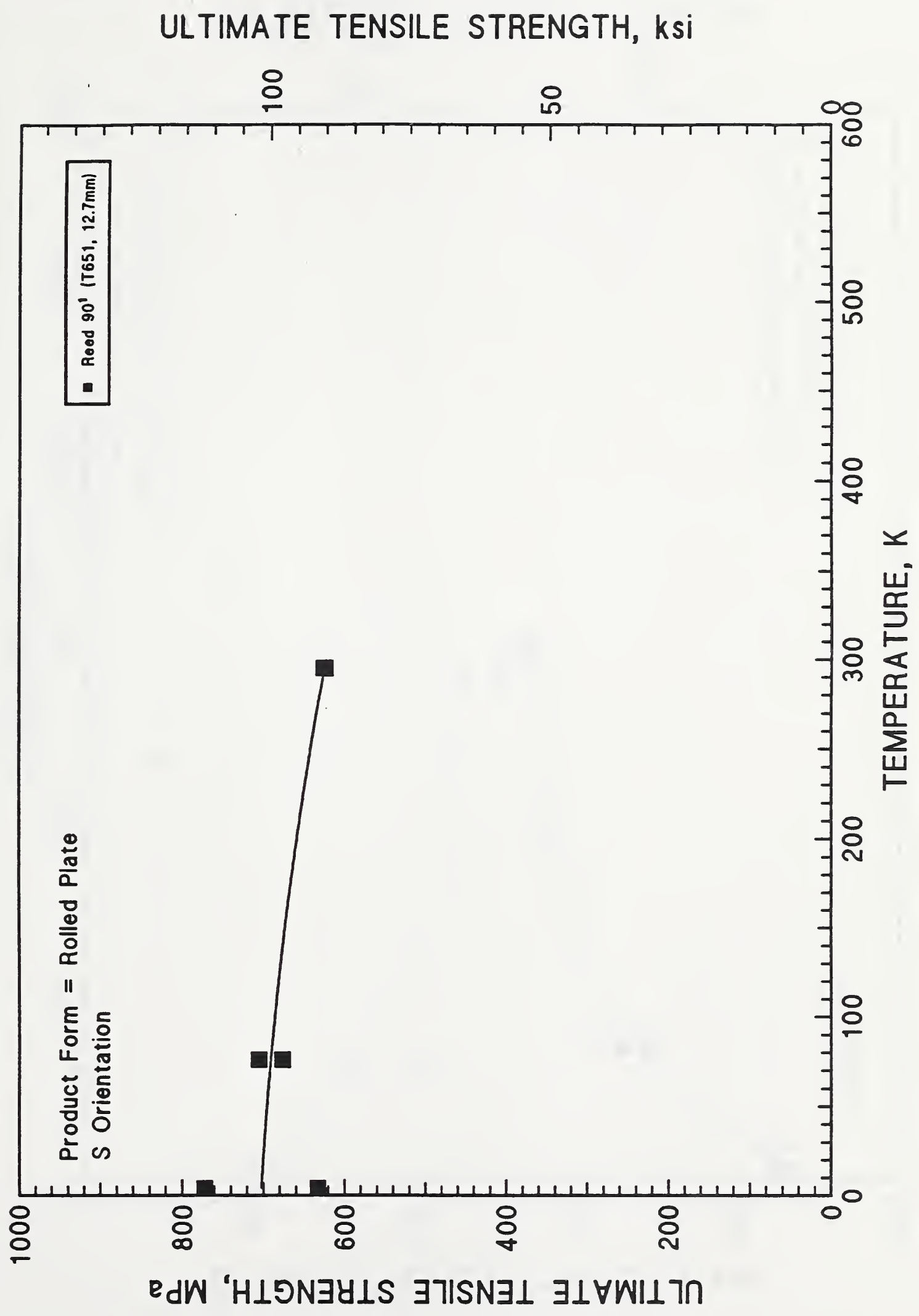




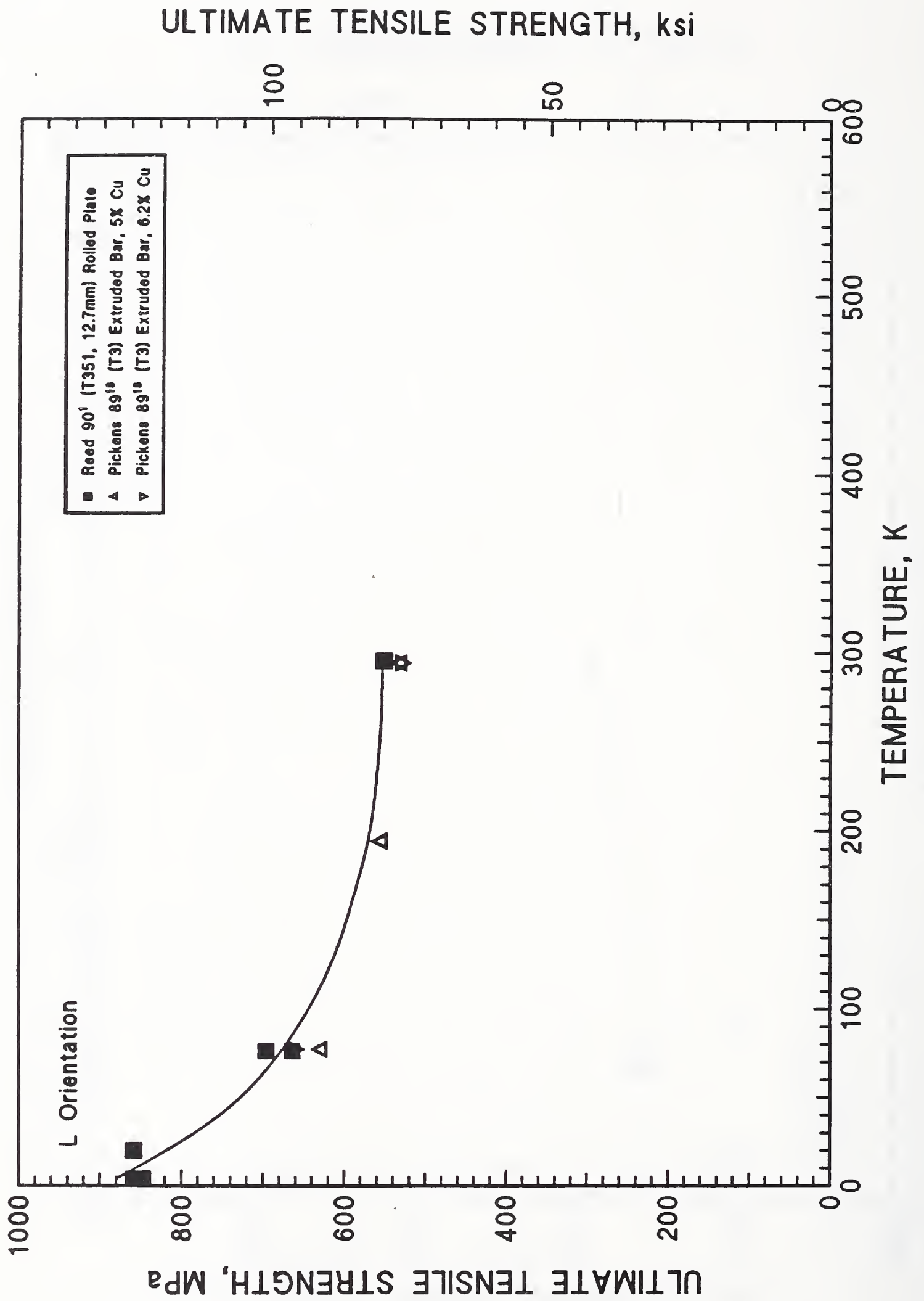
WLO49-T6

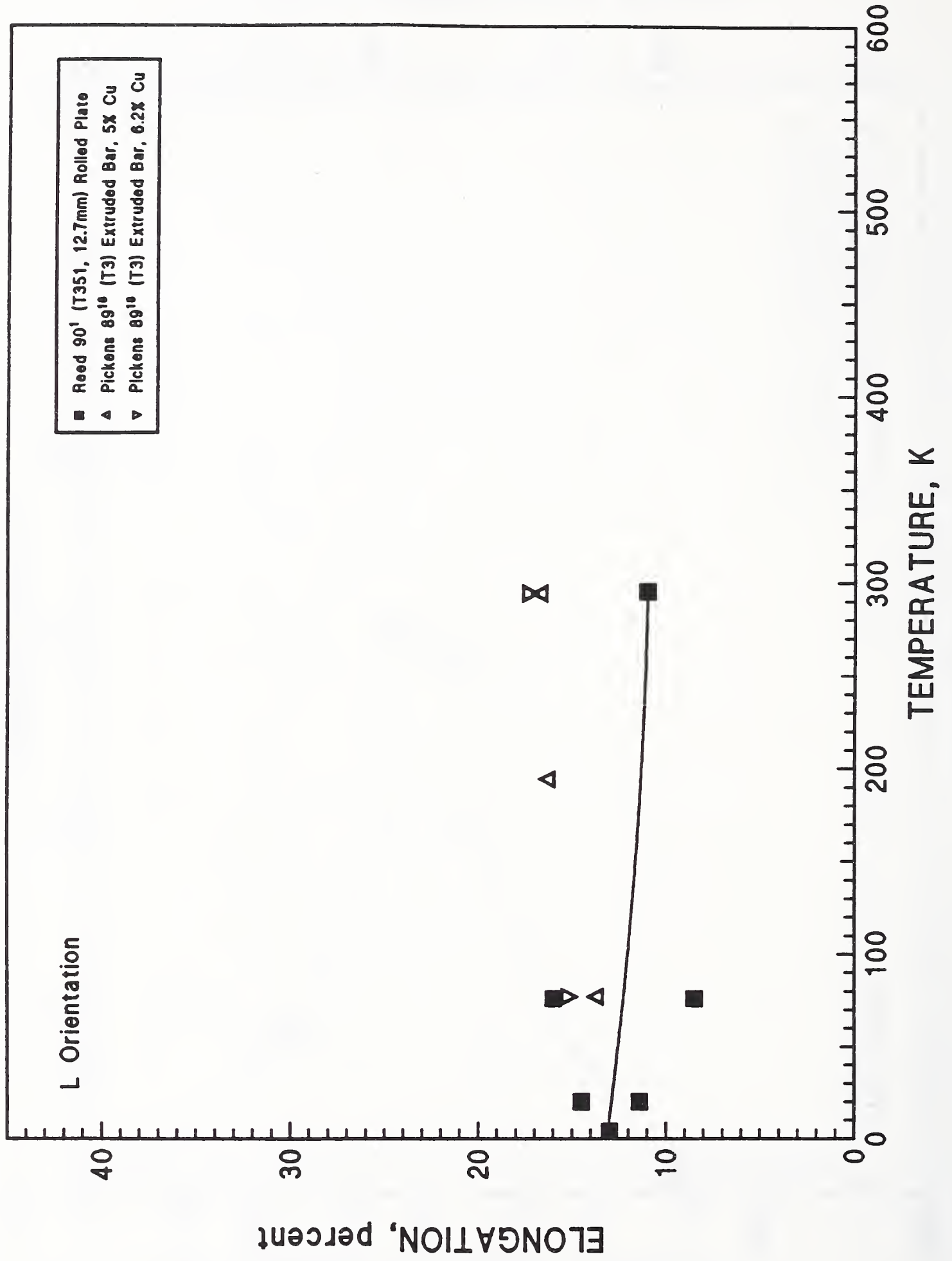


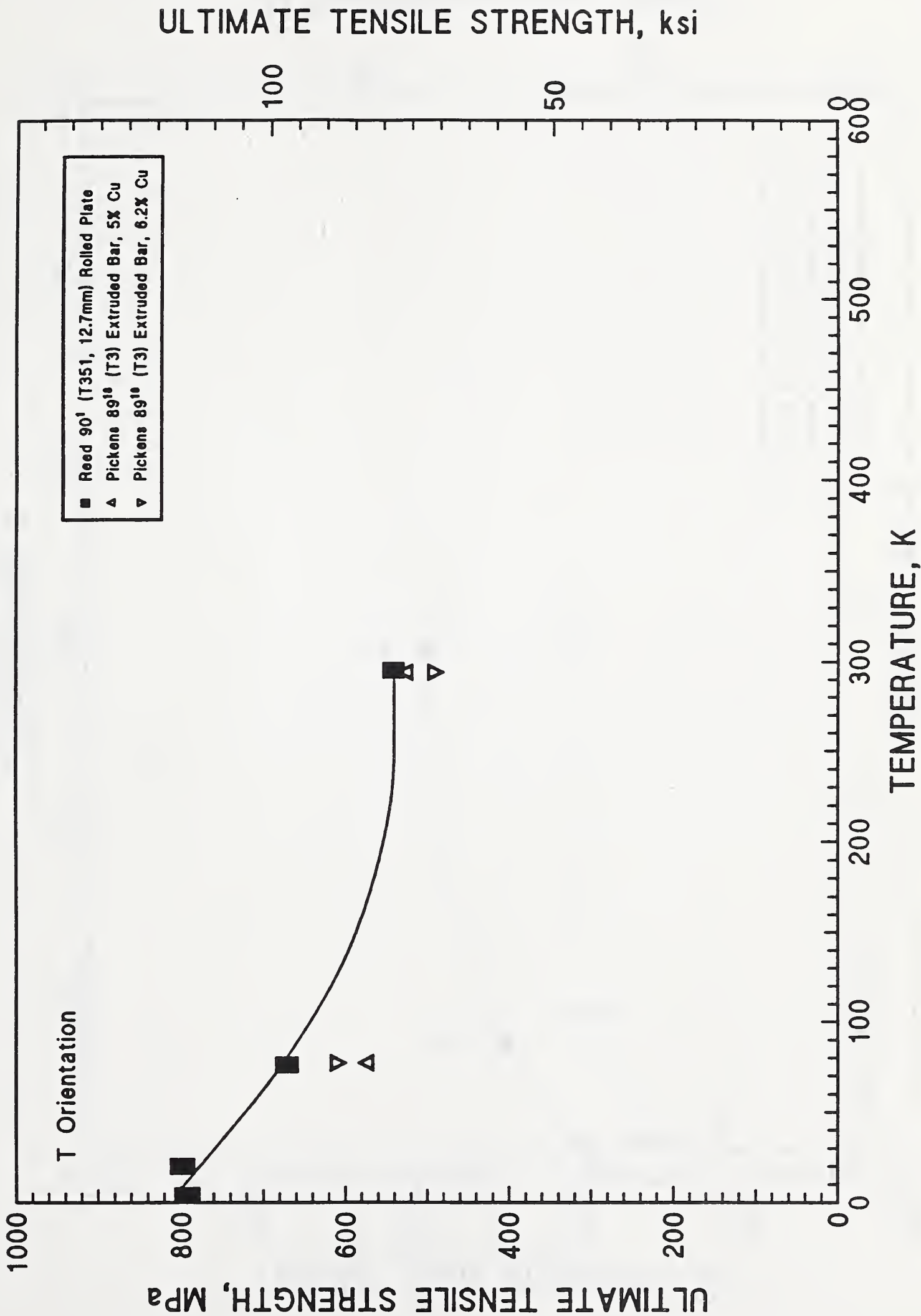
WLO49-T6



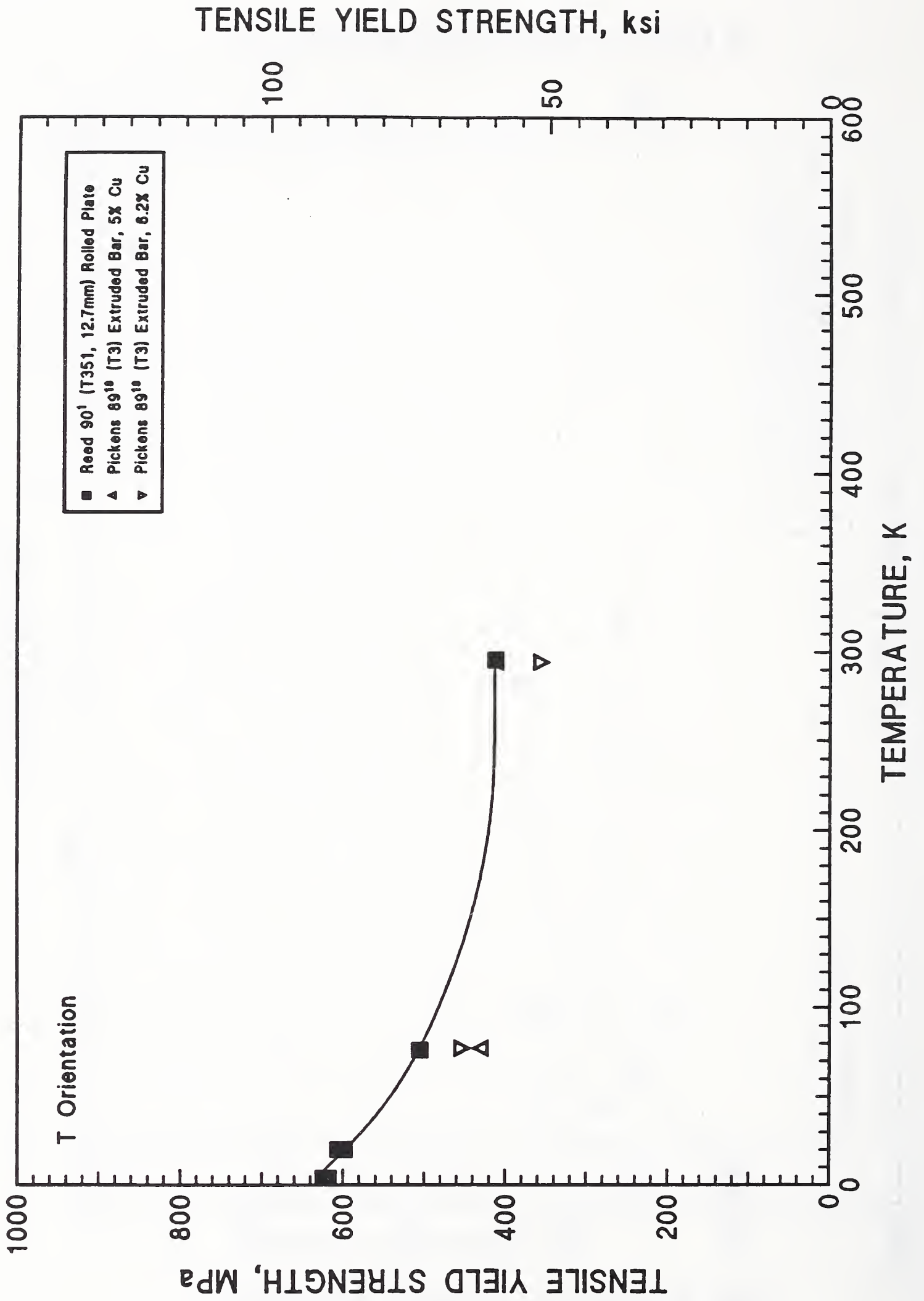
WL049-T3

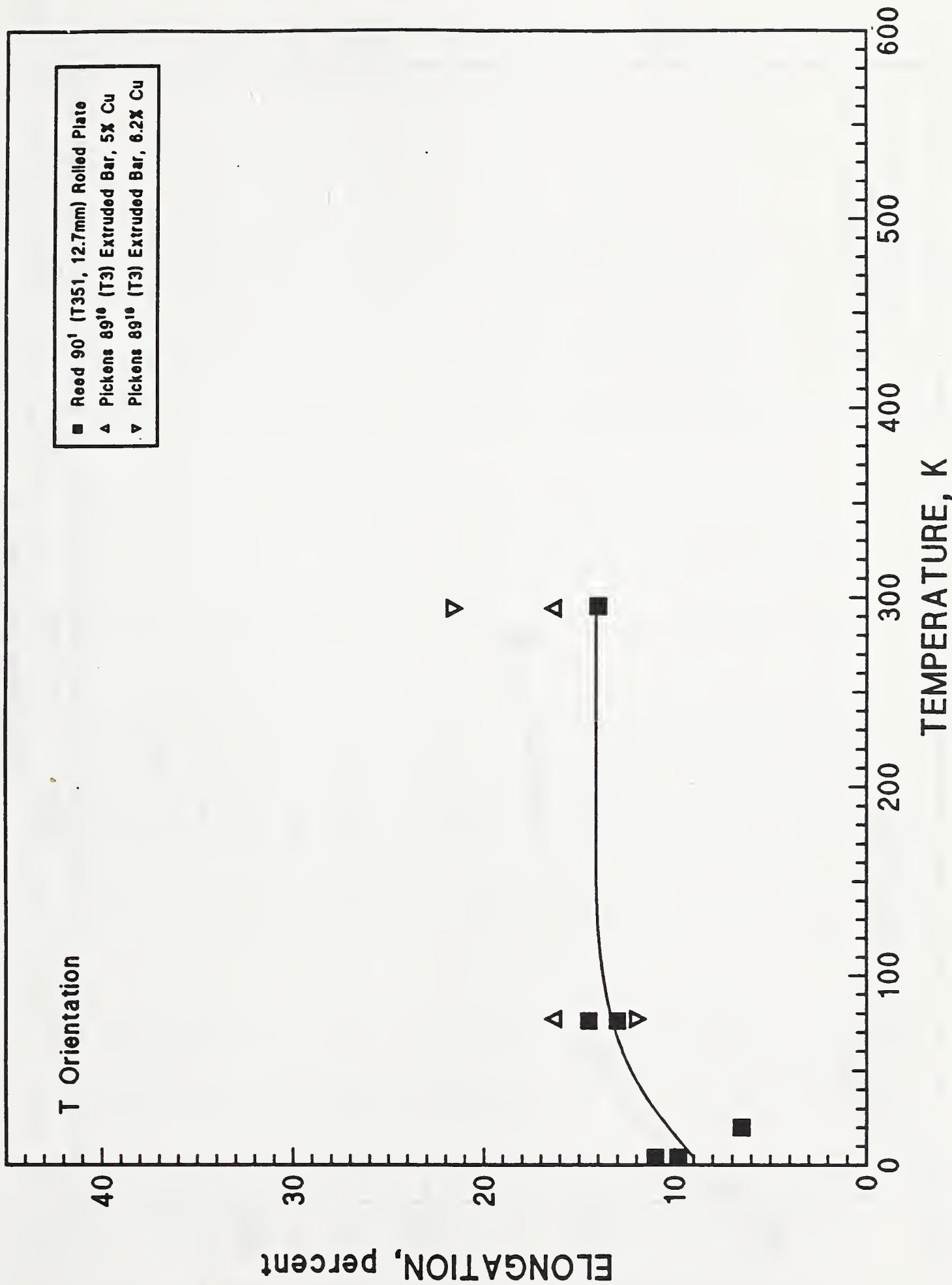




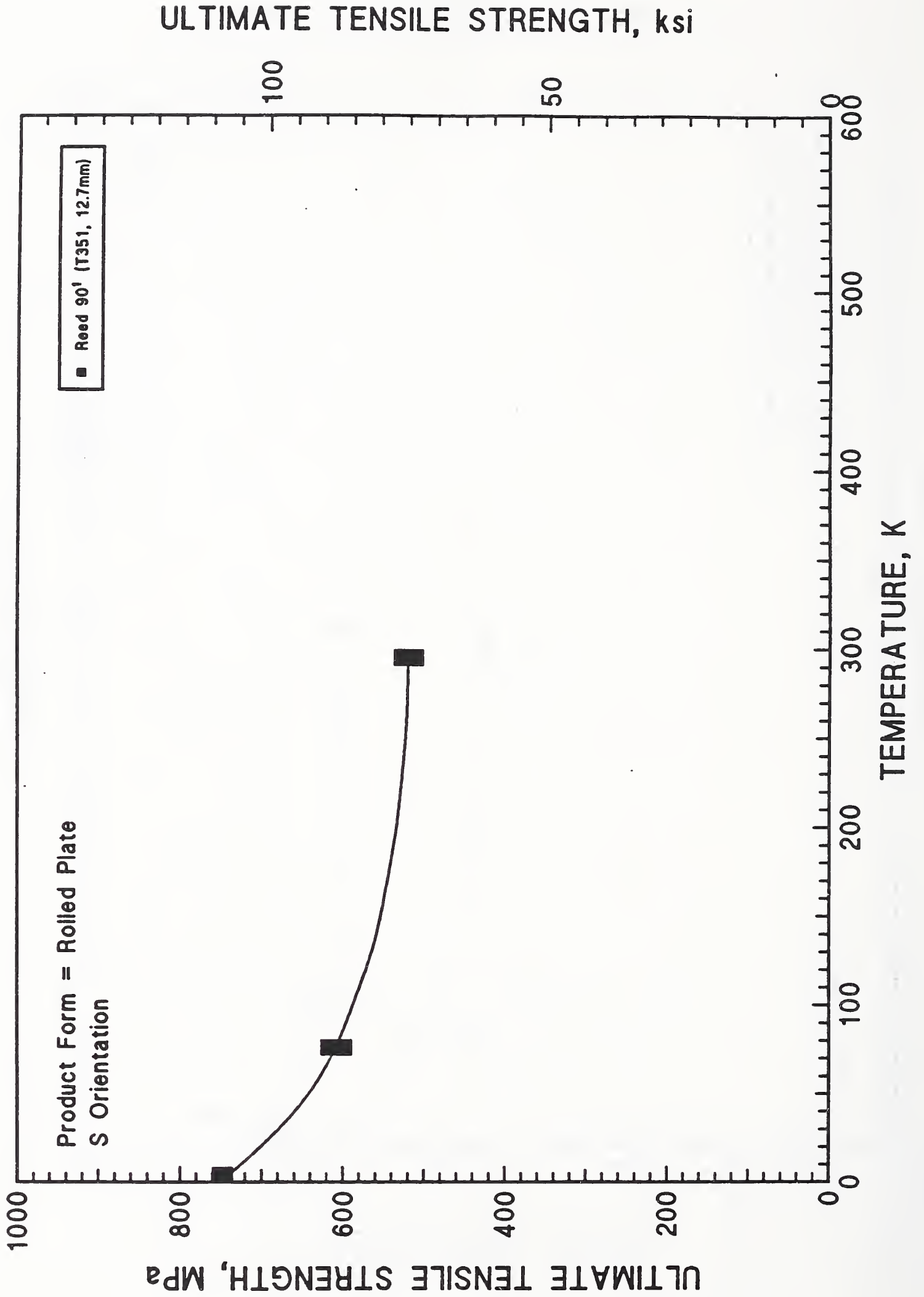


WLO49-T3





WLO49-T3



Al-L1 ALLOY WL049

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper	Product Form	Thickness mm	Product Aging		Soln. Treat.		Quench Cond.	Grain Size μm	Hardness	No. of Tests/Date Pt
										Temp. °C	Time h	Stretch %	Temp. °C				
1J	295	638.	606.	11.1	21.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	295	643.	608.	9.71	20.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	76	780.	712.	10.6	15.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	76	784.	712.	10.9	14.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	20	887.	772.	10.9	11.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	20	876.	776.	10.5	15.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	4	895.	783.	12.2	14.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1J	4	892.	787.	10.9	12.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1L	295	648.	615.	10.	23.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1L	295	641.	616.	10.	24.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1L	76	784.	717.	9.	17.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1L	76	780.	717.	7.	7.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1L	4	884.	784.	11.	14.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1L	4	884.	776.	10.	10.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
18A	294	727.	714.	6.3	NA	L	T8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	1
18A	77	840.	783.	7.8	NA	L	T8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	1
20B	593	NA	150.	NA	NA	L	T8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20B	593	NA	150.	NA	NA	L	T8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

*See Comments

Ref & Note No.	Temp. K	T.S. MPe	Y.S. MPe	Elong. %	R.A. %	Orient. Z	Temper	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Stretch Z	Temp. °C	Time h	Soln. Treat.	Grain Size μm	Hardness	No. of Tests/ Data Pt
20B 538	NA	300.	NA	NA	L	T8	NA	NA	NA	NA	NA	3	NA	NA	NA	NA	NA	NA
20B 485	NA	485.	NA	NA	L	T8	NA	NA	NA	NA	NA	3	NA	NA	NA	NA	NA	NA
20B 450	NA	536.	NA	NA	L	T8	NA	NA	NA	NA	NA	3	NA	NA	NA	NA	NA	NA
20B 425	NA	600.	NA	NA	L	T8	NA	NA	NA	NA	NA	3	NA	NA	NA	NA	NA	NA
20B 368	NA	885.	NA	NA	L	T8	NA	NA	NA	NA	NA	3	NA	NA	NA	NA	NA	NA
20B 293	NA	678.	NA	NA	L	T8	NA	NA	NA	NA	NA	3	NA	NA	NA	NA	NA	NA
20B 77	NA	847.	NA	NA	L	T8	NA	NA	NA	NA	NA	3	NA	NA	NA	NA	NA	NA
20B 20	NA	847.	NA	NA	L	T8	NA	NA	NA	NA	NA	3	NA	NA	NA	NA	NA	NA
18A 294	858.	618.	10.3	NA	L	UAT8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18A 194	678.	836.	8.	NA	L	UAT8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18A 77	755.	876.	9.1	NA	L	UAT8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18B 294	657.	833.	6.4	NA	L	UAT8	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
18B 77	705.	701.	9.8	NA	L	UAT8	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1M 295	637.	569.	8.5	17.8	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1M 295	828.	565.	8.7	15.5	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1M 76	768.	675.	7.2	11.	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1M 76	760.	667.	8.8	13.3	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1M 20	873.	736.	9.55	11.8	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1M 20	873.	736.	10.5	11.	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

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Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper	Product Form	Thickness mm	Aging		Stretch %	Temp. °C	Time h	Soln. Treat.	Quench Cond.	Grain Size μm	Hardness	No. of Tests/Data Pt
										Temp. °C	Time h								
1M	4	869.	736.	7.55	11.	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	4	873.	748.	8.35	11.6	L	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18B	4	895.	831.	5.2	NA	L	T6	Rolled Plate	6.35	180	8.	NA	504	1.	WQ	NA	NA	NA	3
18B	4	916.	855.	4.2	NA	L	T6	Rolled Plate	6.35	180	20.	NA	504	1.	WQ	NA	NA	NA	3
18B	4	880.	798.	4.	NA	L	T6	Rolled Plate	6.35	180	4.	NA	504	1.	WQ	NA	NA	NA	3
19A	298	696.	670.	4.3	NA	L	T6	Rolled Plate	6.35	180	20.	NA	504	1.	WQ	NA	NA	NA	3
19A	298	684.	641.	5.1	NA	L	T6	Rolled Plate	6.35	180	4.	NA	504	1.	WQ	NA	NA	NA	3
19A	298	681.	645.	5.0	NA	L	T6	Rolled Plate	6.35	180	8.	NA	504	1.	WQ	NA	NA	NA	3
19A	77	796.	758.	5.4	NA	L	T6	Rolled Plate	6.35	180	8.	NA	504	1.	WQ	NA	NA	NA	3
19A	77	804.	784.	3.6	NA	L	T6	Rolled Plate	6.35	180	20.	NA	504	1.	WQ	NA	NA	NA	3
19A	77	794.	745.	4.7	NA	L	T6	Rolled Plate	6.35	180	4.	NA	504	1.	WQ	NA	NA	NA	3
20A	293	563.	396.	18.3	NA	L	T4	Extrusion	9.5	NA	1300.	0	504	0.8	WQ	NA	NA	NA	1
20A	77	734.	552.	13.6	NA	L	T4	Extrusion	9.5	NA	4300.	0	504	0.8	WQ	NA	NA	NA	1
10	295	552.	454.	NA	NA	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
10	295	550.	452.	9.85	10.9	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
10	76	696.	581.	11.6	13.9	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
10	76	664.	584.	8.5	13.2	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
10	20	859.	700.	11.4	11.7	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
10	20	858.	706.	14.5	11.	L	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper	Product Form	Thickness mm	Product Thickness mm	Aging		Soin. Treat.		Grain Size μm	Hardness	No. of Tests/Data Pt
											Temp. °C	Time h	Stretch %	Temp. °C			
10	4	847.	708.	13.	14.7	L	T351	Rolled Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	1
10	4	859.	691.	13.	15.3	L	T351	Rolled Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	1
18A	294	529.	407.	16.6	NA	L	T3	Extruded Bar	19.05	19.05	NA	NA	NA	NA	NA	NA	1
18A	194	553.	431.	16.2	NA	L	T3	Extruded Bar	19.05	19.05	NA	NA	NA	NA	NA	NA	1
18A	77	627.	483.	13.6	NA	L	T3	Extruded Bar	19.05	19.05	NA	NA	NA	NA	NA	NA	1
18G	294	531.	407.	17.4	NA	L	T3	Extruded Bar	19.1	19.1	NA	NA	NA	NA	NA	NA	NA
18G	77	663.	512.	15.3	NA	L	T3	Extruded Bar	19.1	19.1	NA	NA	NA	NA	NA	NA	NA
18A	294	487.	330.	21.5	NA	L	Rev	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18A	194	454.	315.	19.	NA	L	Rev	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18A	77	577.	404.	25.2	NA	L	Rev	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1J	295	638.	391.	10.6	20.	T	T851	Rolled Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	1
1J	295	638.	581.	11.6	23.	T	T851	Rolled Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	1
1J	76	762.	682.	8.4	12.	T	T851	Rolled Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	1
1J	78	760.	672.	9.1	12.	T	T851	Rolled Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	1
1J	20	852.	720.	8.	9.	T	T851	Rolled Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	1
1J	20	854.	730.	9.4	10.	T	T851	Rolled Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	1
1J	4	863.	752.	6.7	12.	T	T851	Rolled Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	1
1J	4	855.	736.	6.5	8.	T	T851	Rolled Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	1
1L	295	637.	592.	11.	27.	T	T851	Rolled Plate	12.7	12.7	NA	NA	NA	NA	NA	NA	1

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temp. °C	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Stretch %	Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
1L	295	630.	587.	10.	27.	T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1L	76	755.	675.	6.	7.	T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1L	76	765.	685.	9.	15.	T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1L	4	846.	766.	6.	8.	T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1L	4	860.	784.	9.	14.	T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
18C	294	658.	630.	3.9	NA	T	T8	Extruded Bar	9.53	NA	NA	NA	NA	NA	NA	NA	NA	1
18D	77	753.	705.	2.62	NA	T	T8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	1
18D	294	607.	566.	9.8	NA	T	UAT8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	1
18D	194	678.	636.	6.	NA	T	UAT8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	1
18D	77	755.	676.	9.1	NA	T	UAT8	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	1
18H	294	612.	579.	2.4	NA	T	UAT8	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
18H	77	693.	627.	7.1	NA	T	UAT8	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
1M	295	621.	543.	9.4	17.8	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	295	619.	543.	7.8	16.3	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	76	744.	639.	5.3	11.8	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	76	744.	635.	6.3	10.2	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	20	853.	720.	NA	NA	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	20	833.	707.	5.3	8.7	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	4	860.	726.	8.9	8.7	T	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper. °C	Product Form	Thickness mm	Product Aging			Soln. Temp. °C	Time h	Treat. Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
										Temp. °C	Time h	Stretch %						
1M	4	842.	738.	NA	NA	T	T651	rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
18E	4	867.	800.	3.3	NA	T	T6	rolled Plate	6.35	180	4.	0	504	1.	HQ	NA	NA	3
18E	4	872.	854.	1.7	NA	T	T6	rolled Plate	6.35	180	20.	0	504	1.	HQ	NA	NA	3
18E	4	859.	823.	2.9	NA	T	T6	rolled Plate	6.35	180	8.	0	504	1.	HQ	NA	NA	3
19B	298	674.	651.	3.5	NA	T	T6	rolled Plate	6.35	180	20.	0	504	1.	HQ	NA	NA	3
19B	298	654.	616.	4.8	NA	T	T6	rolled Plate	6.35	180	4.	0	504	1.	HQ	NA	NA	3
19B	298	663.	634.	3.2	NA	T	T6	rolled Plate	6.35	180	8.	0	504	1.	HQ	NA	NA	3
19B	77	775.	755.	1.9	NA	T	T6	rolled Plate	6.35	180	20.	0	504	1.	HQ	NA	NA	3
19B	77	762.	752.	2.4	NA	T	T6	rolled Plate	6.35	180	8.	0	504	1.	HQ	NA	NA	3
19B	77	762.	752.	2.4	NA	T	T6	rolled Plate	6.35	180	4.	0	504	1.	HQ	NA	NA	3
10	295	544.	412.	14.	23.	T	T351	rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
10	295	538.	412.	14.	22.	T	T351	rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
10	76	667.	506.	13.	12.9	T	T351	rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
10	76	675.	505.	NA	13.2	T	T351	rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
10	20	793.	598.	NA	NA	T	T351	rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
10	20	803.	606.	NA	13.2	T	T351	rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
10	4	787.	618.	9.8	15.	T	T351	rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
10	4	798.	624.	11.	16.3	T	T351	rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
18D	294	523.	408.	16.2	NA	T	T3	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Tempar	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Stretch %	Temp. °C	Time h	Soln. Treat.	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
18D	77	571.	427.	16.2	NA	T	T3	Extruded Bar	19.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18G	294	483.	359.	21.7	NA	T	T3	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
18G	77	612.	452.	12.1	NA	T	T3	Extruded Bar	19.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1J	295	562.	502.	16.	37.	45°	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1J	295	559.	500.	14.	37	45°	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1J	76	657.	569.	NA.	32.	45°	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1J	76	673.	583.	17.	28.	45°	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1J	4	765.	614.	19.	22.	45°	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1J	4	748.	622.	18.	21.	45°	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18F	4	801.	729.	6.2	NA	45°	T6	Rolled Plate	6.35	180	4.	4	504	1.	WQ	NA	NA	NA	3
18F	4	837.	781.	4.9	NA	45°	T6	Rolled Plate	6.35	180	20.	4	504	1.	WQ	NA	NA	NA	3
18F	4	805.	761.	4.	NA	45°	T6	Rolled Plate	6.35	180	8.	4	504	1.	WQ	NA	NA	NA	3
18C	298	618.	566.	9.4	NA	45°	T6	Rolled Plate	6.35	180	4.	4	504	1.	WQ	NA	NA	NA	3
18C	298	637.	606.	6.4	NA	45°	T6	Rolled Plate	6.35	180	20.	4	504	1.	WQ	NA	NA	NA	3
18C	298	628.	590.	6.5	NA	45°	T6	Rolled Plate	6.35	180	8.	4	504	1.	WQ	NA	NA	NA	3
18C	77	714.	673.	4.2	NA	45°	T6	Rolled Plate	6.35	180	8.	4	504	1.	WQ	NA	NA	NA	3
18C	77	734.	694.	4.8	NA	45°	T6	Rolled Plate	6.35	180	20.	4	504	1.	WQ	NA	NA	NA	3
18C	77	731.	668.	7.9	NA	45°	T6	Rolled Plate	6.35	180	4.	4	504	1.	WQ	NA	NA	NA	3
1K	295	604.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper. °C	Product Form	Thickness mm	Aging		Soln. Treat.		Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
										Temp. °C	Time h	Stretch %	Temp. °C				
1K	295	649.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1K	76	755.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1K	76	736.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1K	4	809.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1K	4	814.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1N	295	623.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1N	295	625.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1N	76	676.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1N	76	705.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1N	4	772.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1N	4	633.	NA	NA	NA	S	T651	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1P	295	511.	NA	NA	NA	S	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1P	295	527.	NA	NA	NA	S	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1P	76	617.	NA	NA	NA	S	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1P	76	599.	NA	NA	NA	S	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1P	4	750.	NA	NA	NA	S	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
1P	4	745.	NA	NA	NA	S	T351	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Strain Note	Rate	Specimen			G.L. mm	Specimen Location	Expo Time min	Supplier	Yr. Prod.	Lot No.	Product L(m) X W(m)	Major Elements							
		Type	Diam mm	Thick mm								Li	Cu	Mg	Zr	Si	Fe	Ag	Minor Elements wt%
20A	NA	NA	NA	NA	NA	NA	Reynolds	NA	NA	NA	0.102	1.19	4.8	0.4	0.16	NA	NA	0.36	NA
20B	4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.3	6.2	0.4	0.14	NA	NA	0.4	T1: 0.03

Comments from the Al-Li Alloy WL049 Test Parameter Table

Reference and
Note Number

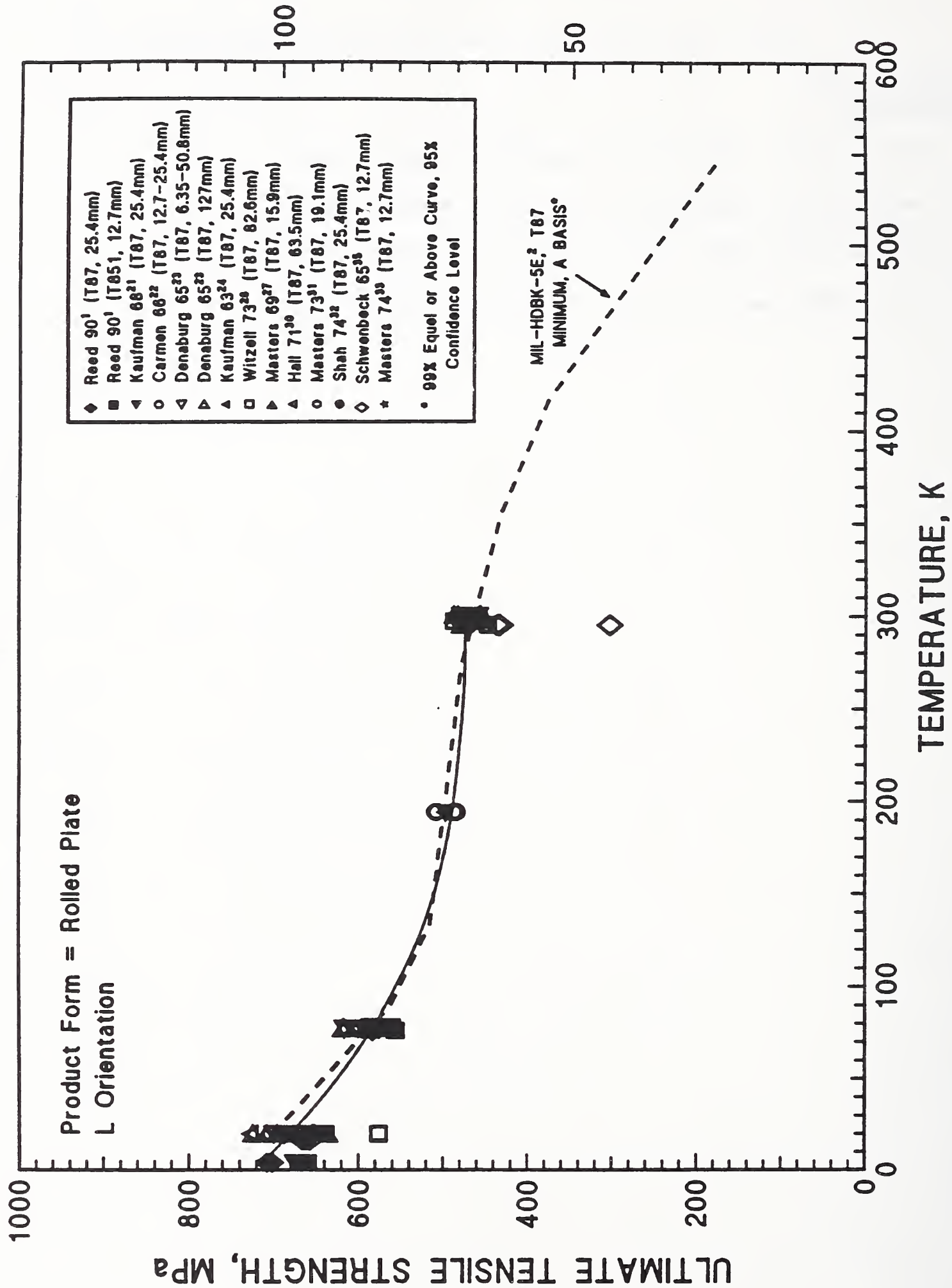
18B--Reported composition is based on nominal values.

18E--Reported composition is based on nominal values.

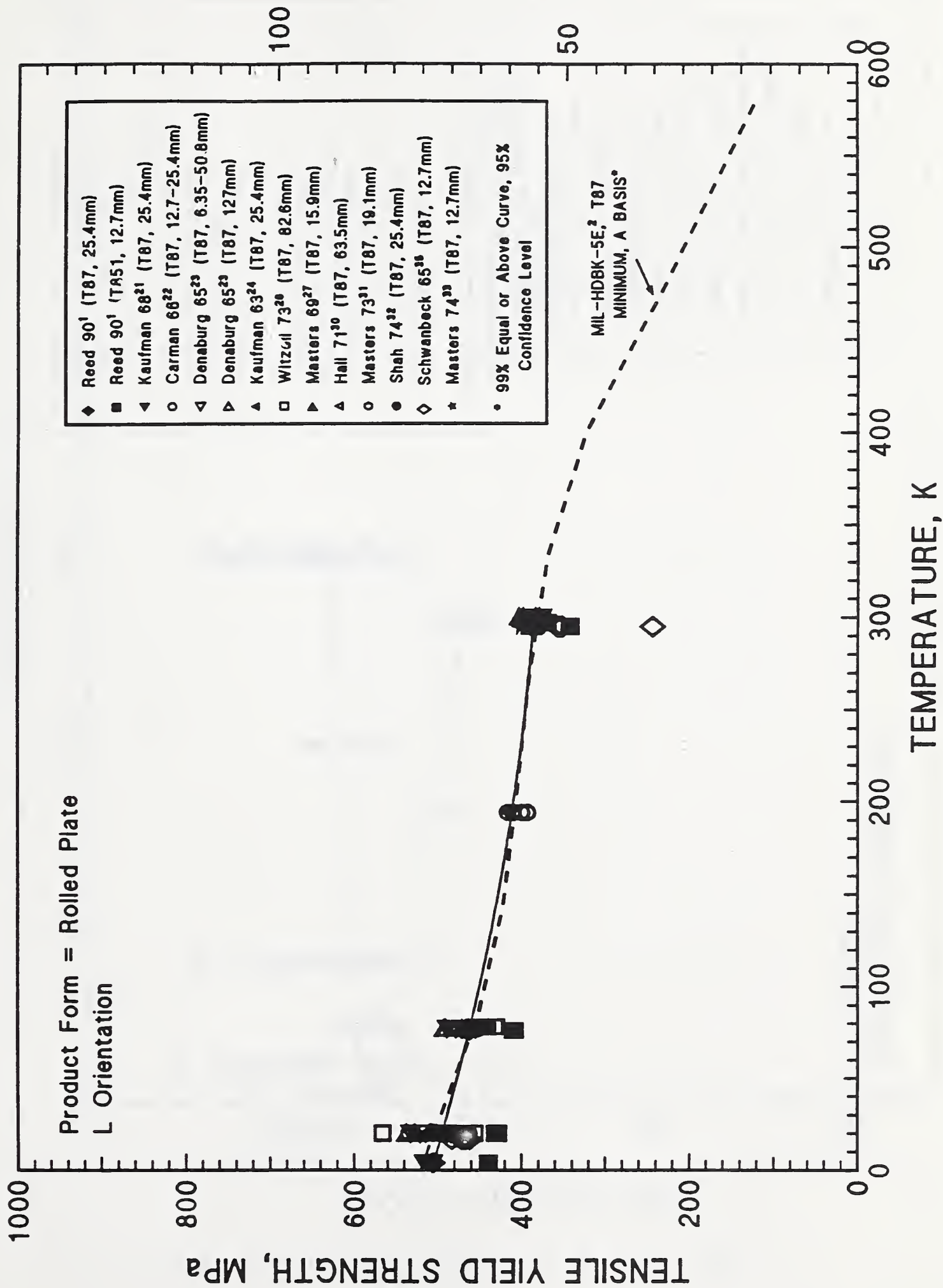
18F--Reported composition is based on nominal values.

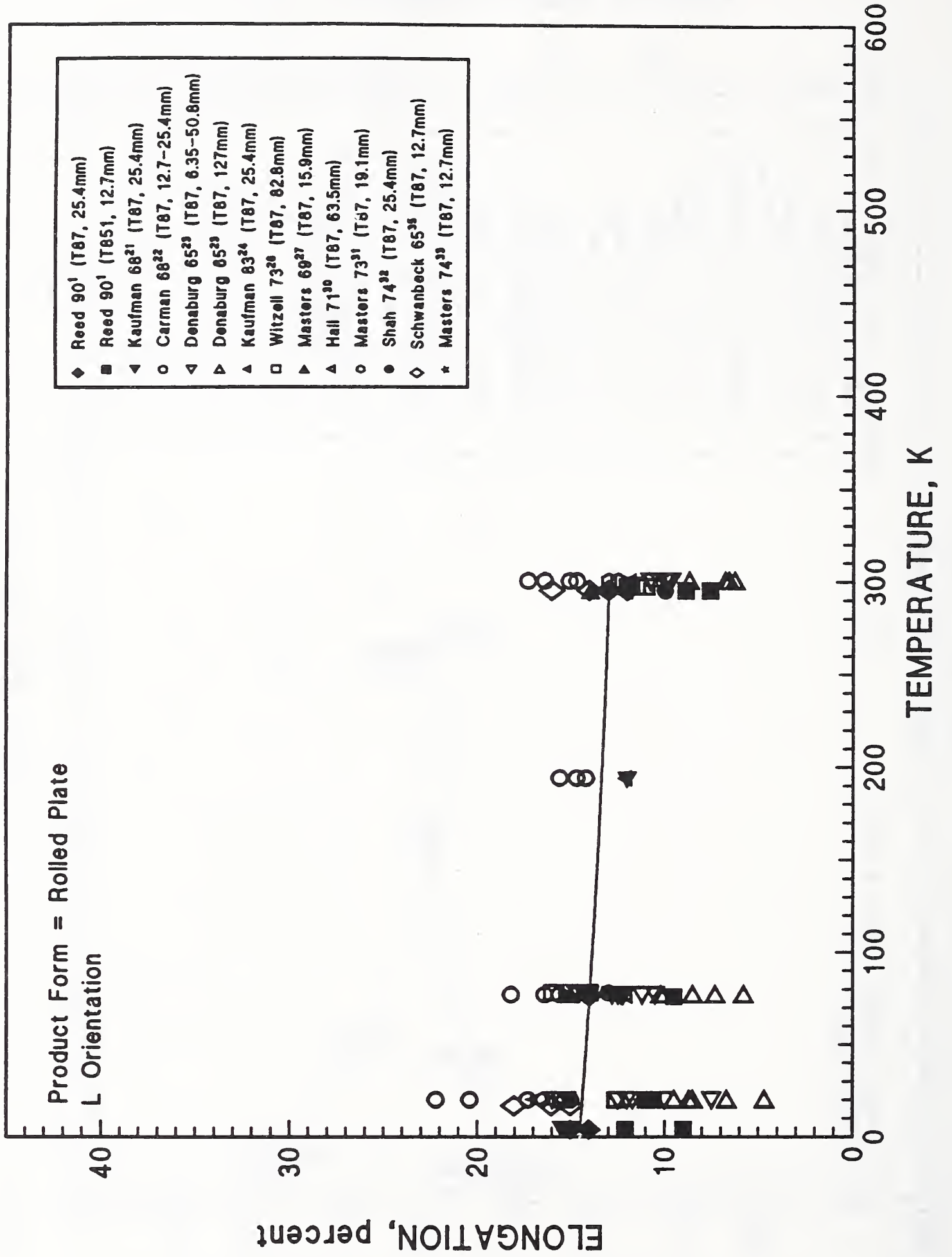
19A-C--Reported composition is based on nominal values.

ULTIMATE TENSILE STRENGTH, ksi



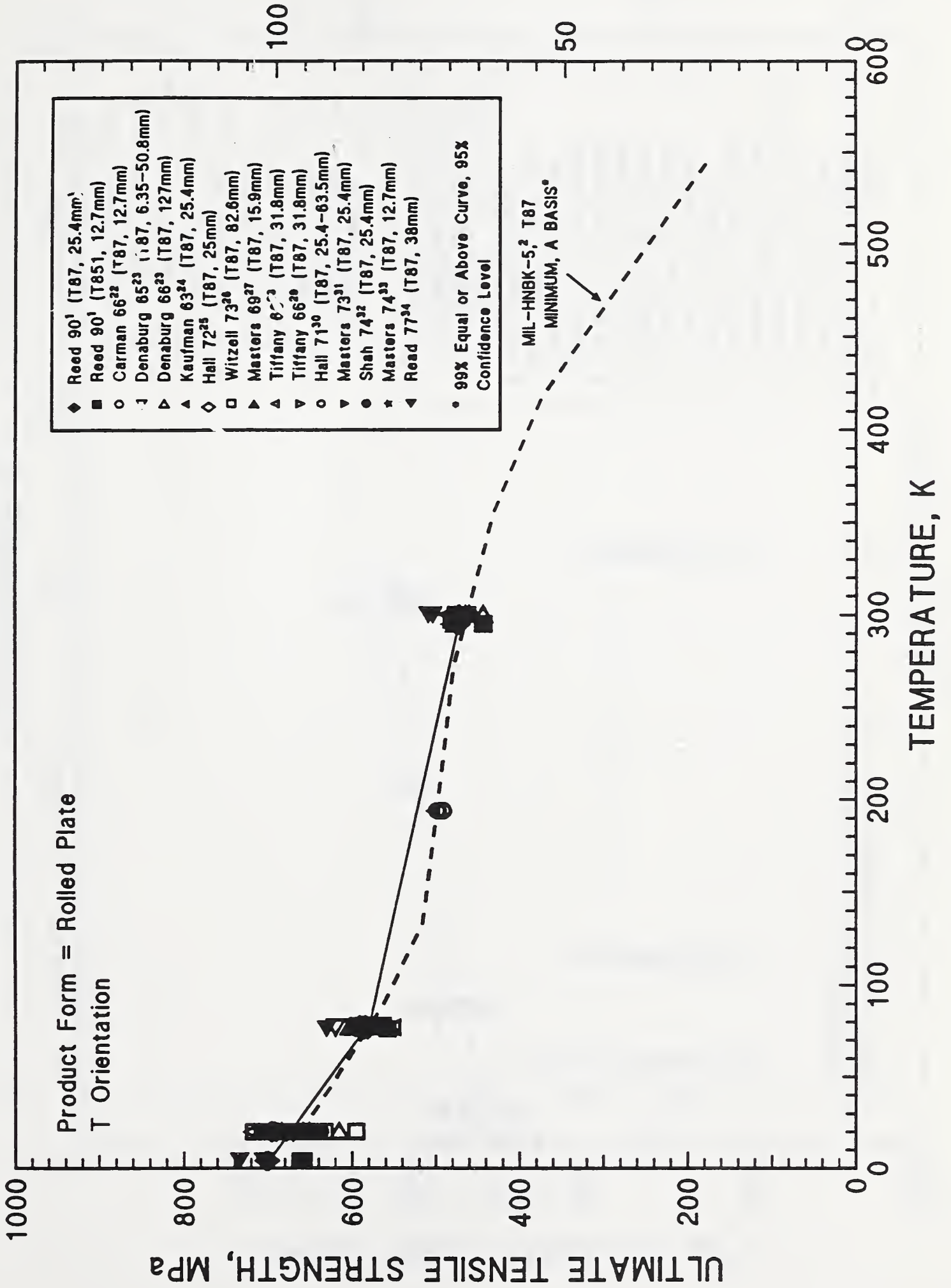
TENSILE YIELD STRENGTH, ksi



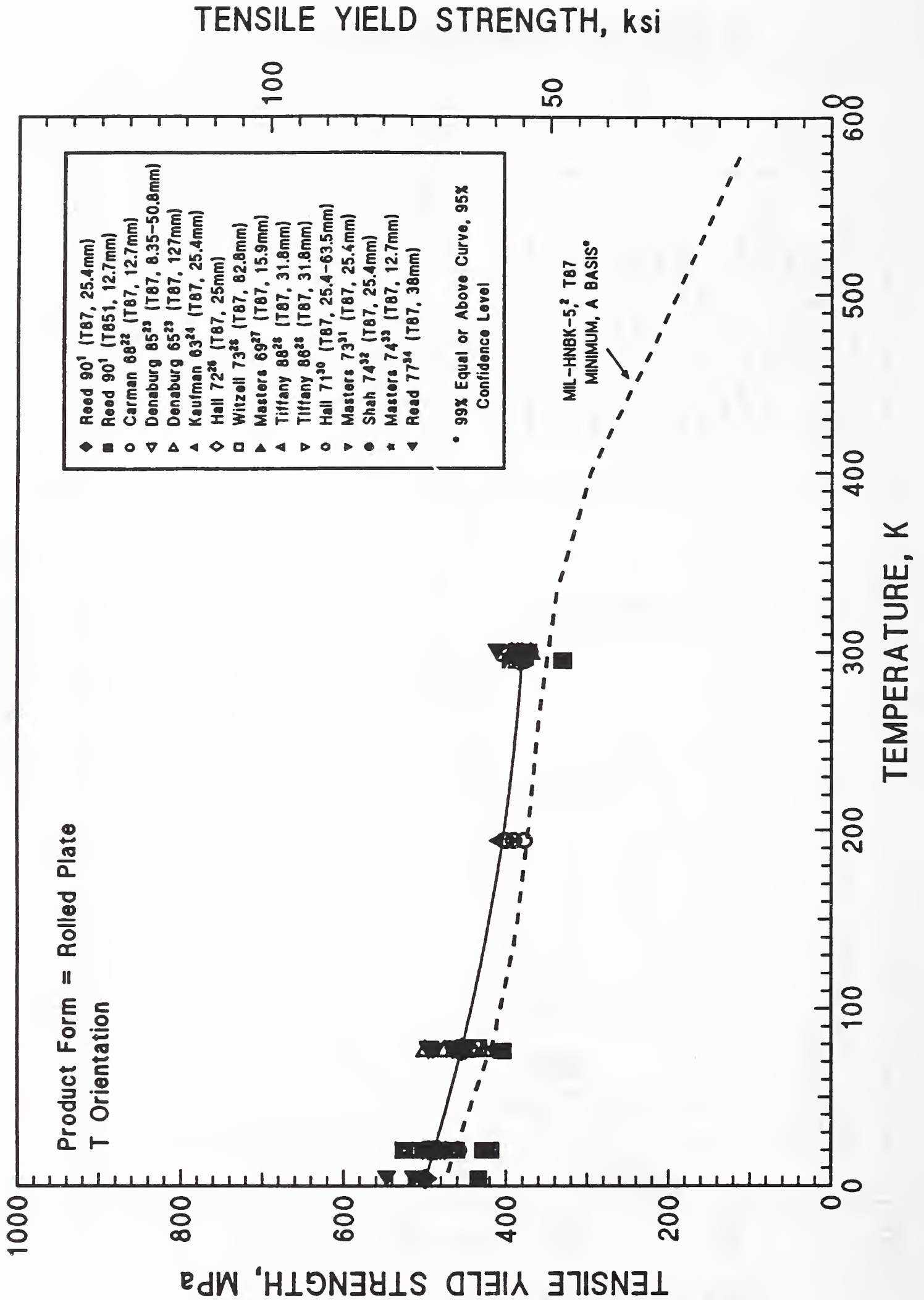


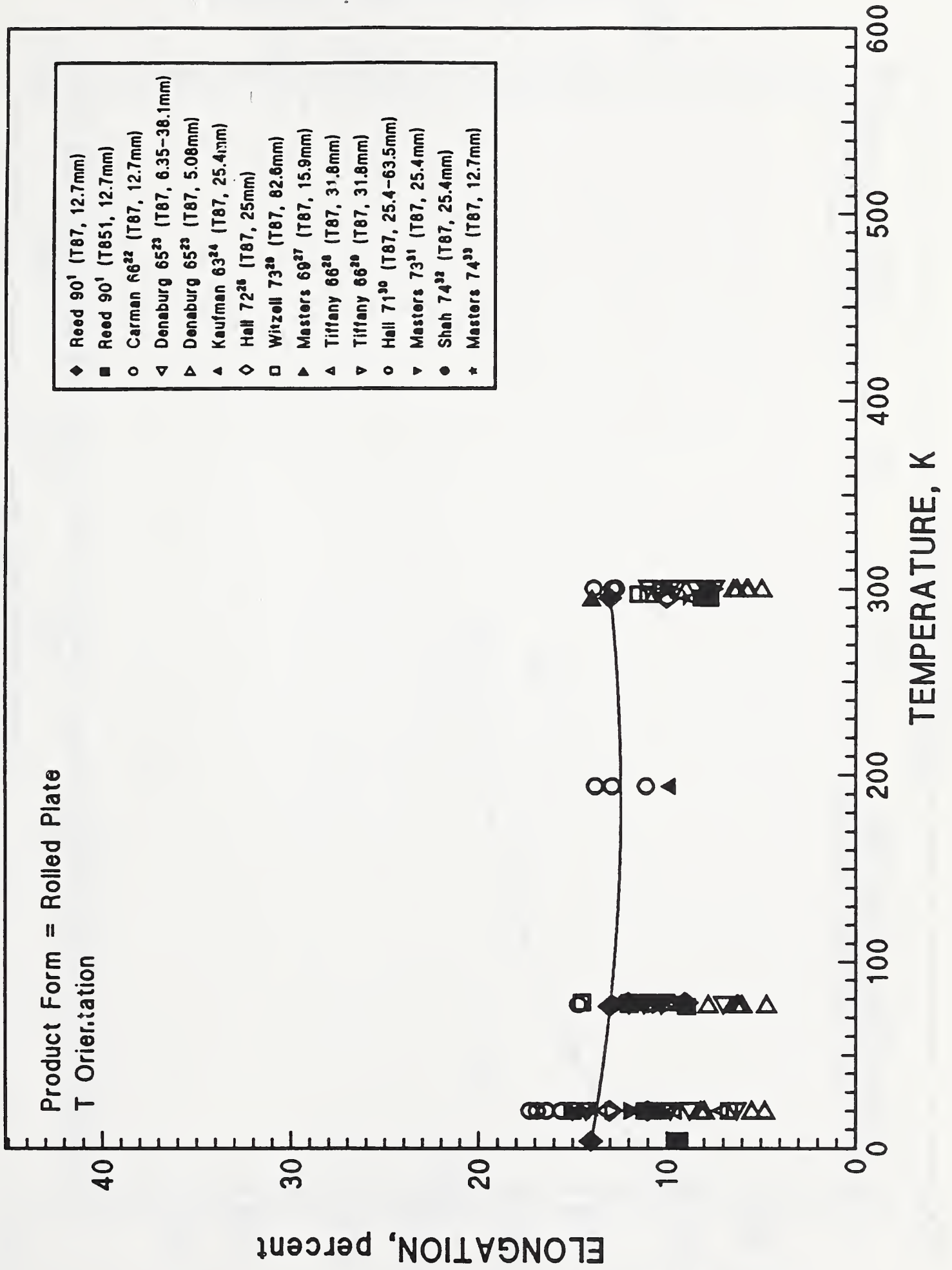
ULTIMATE TENSILE STRENGTH, ksi

2219-T8

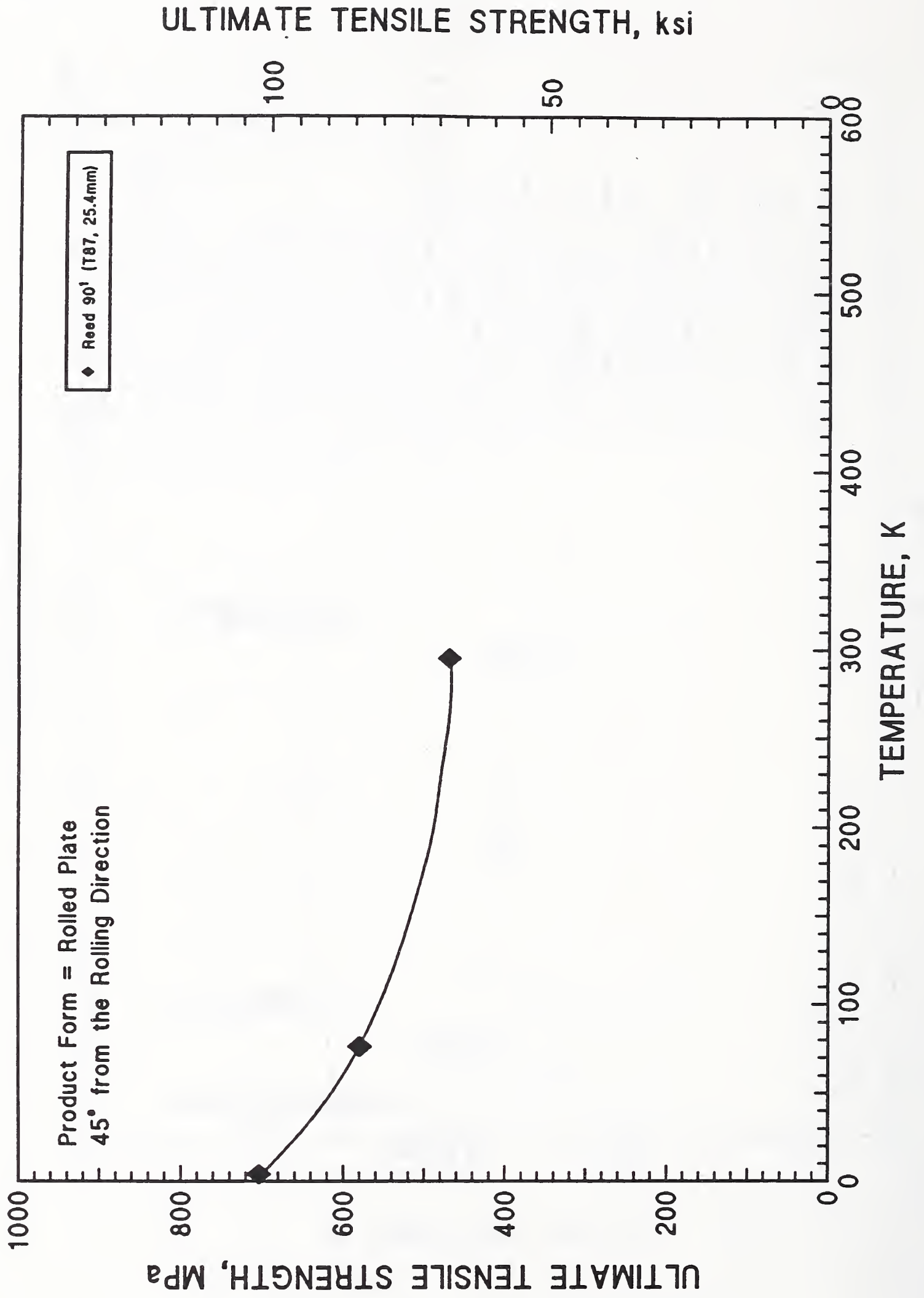


2219-T8

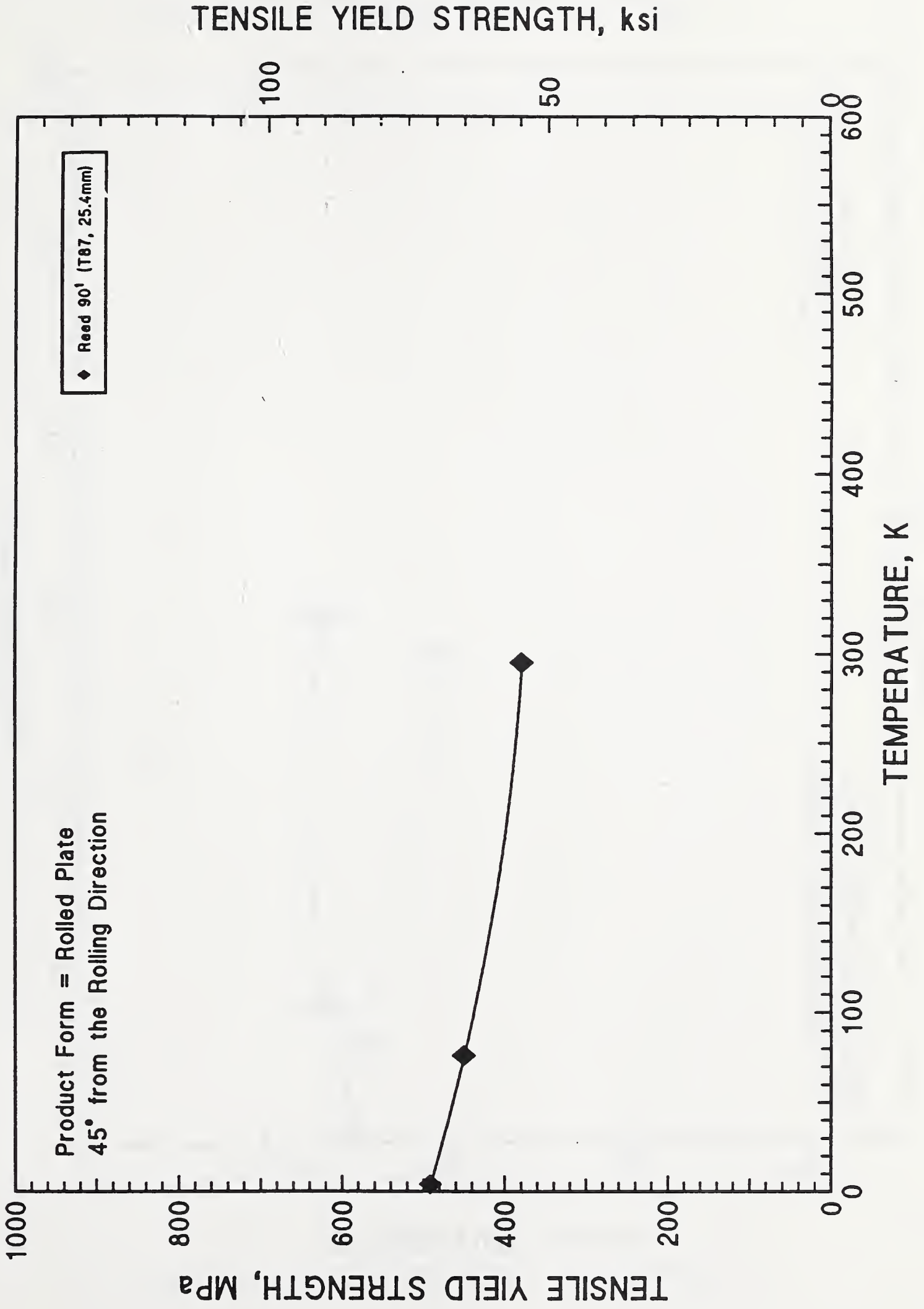




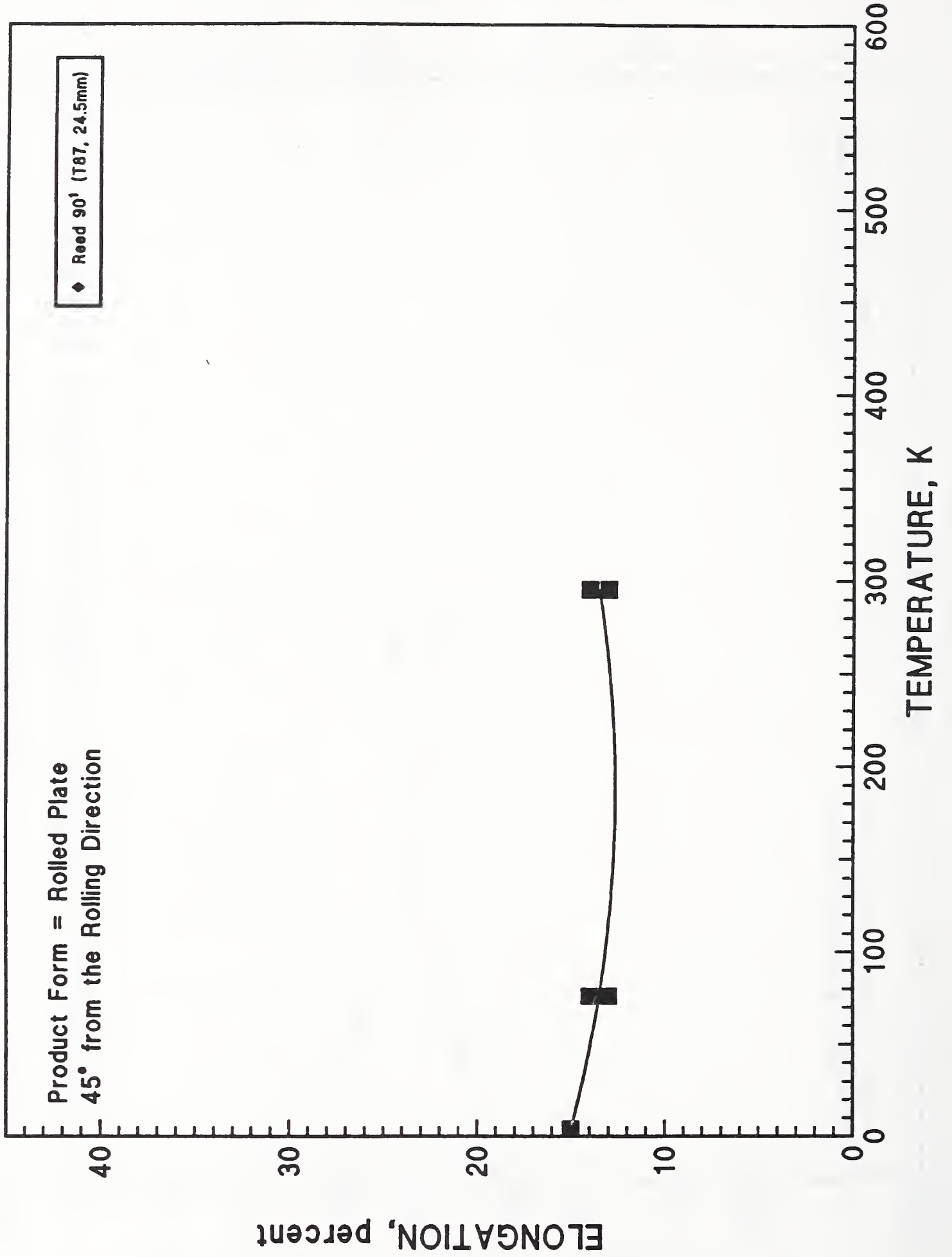
2219-T8

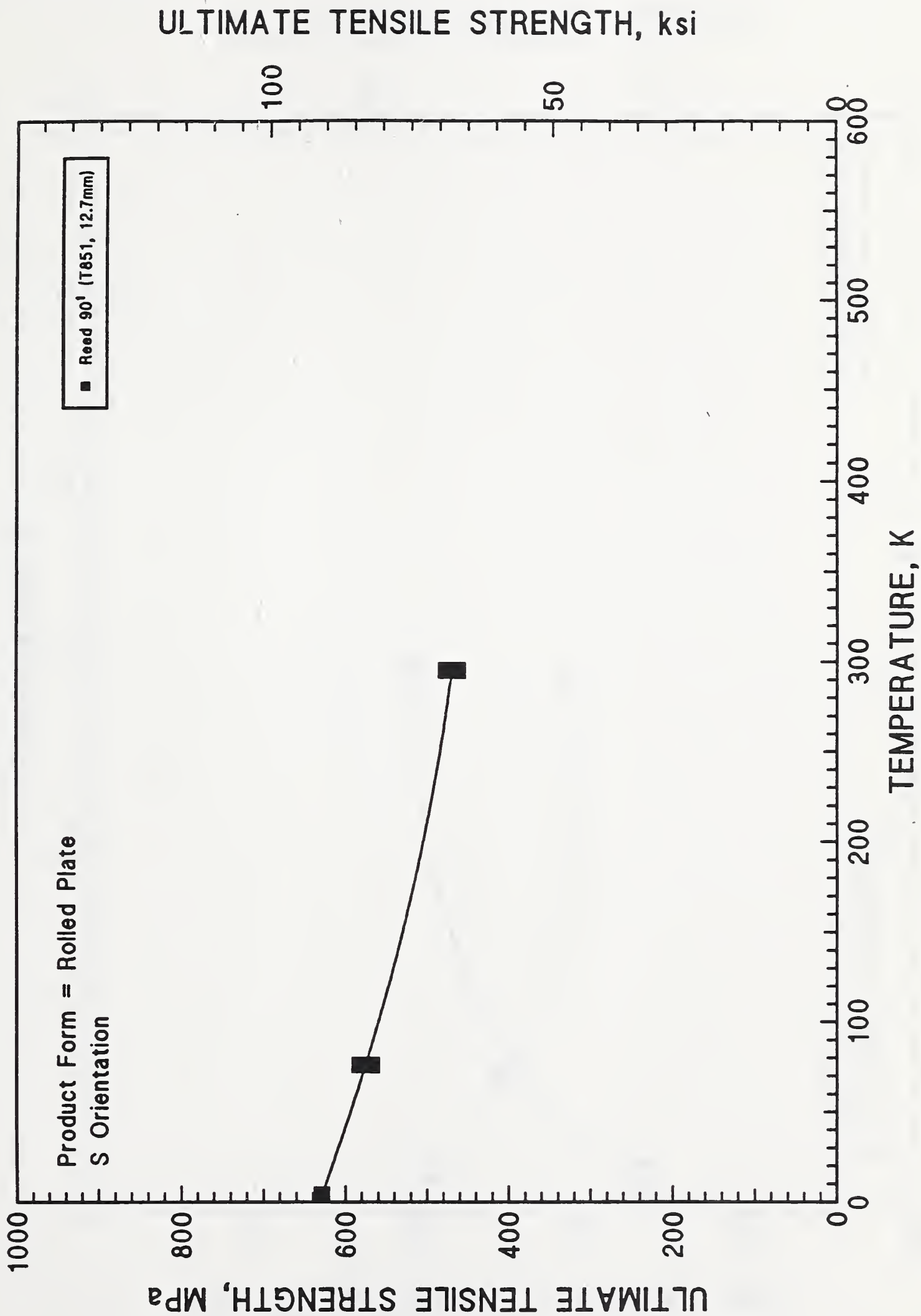


2219-T8

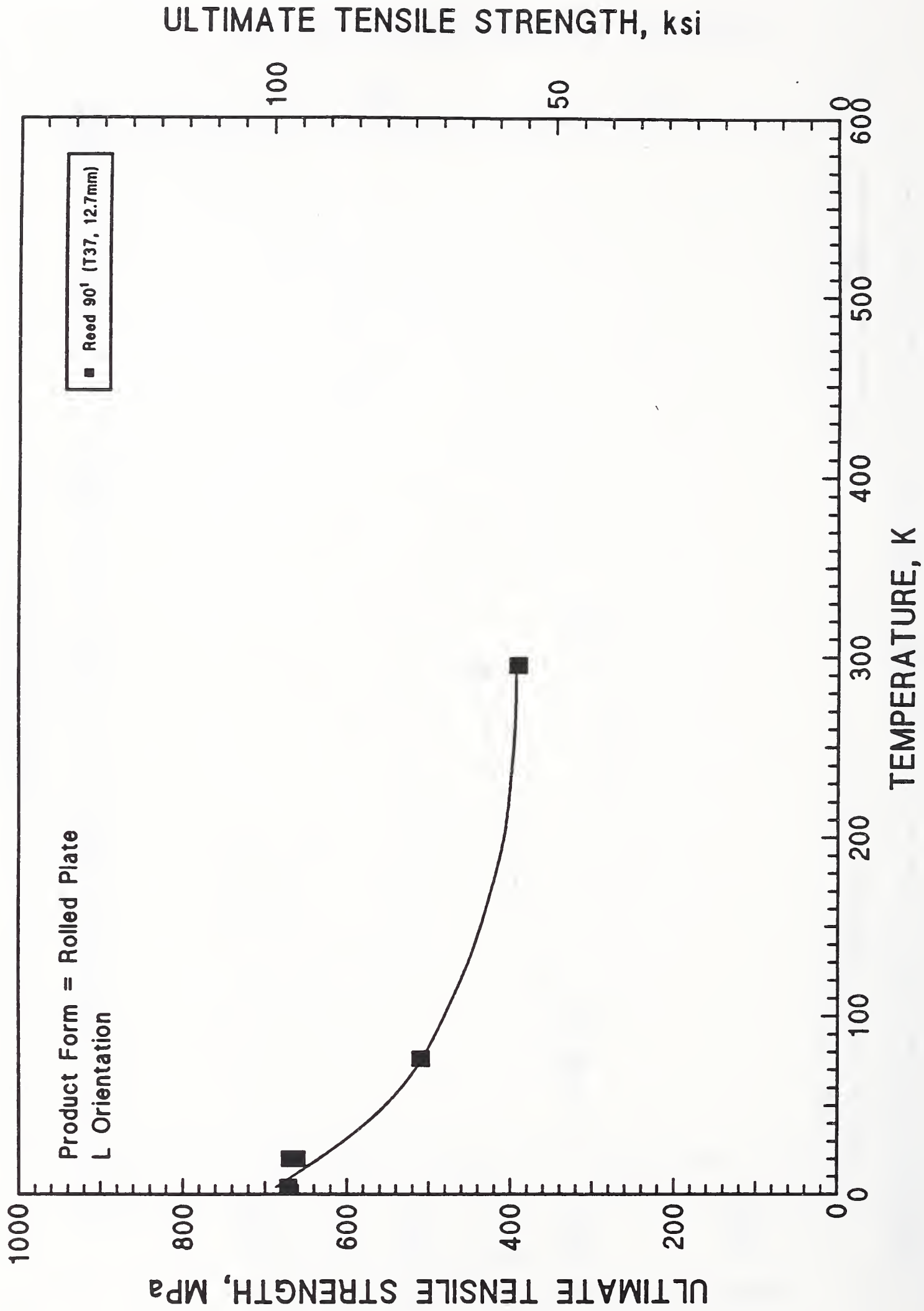


2219-T8

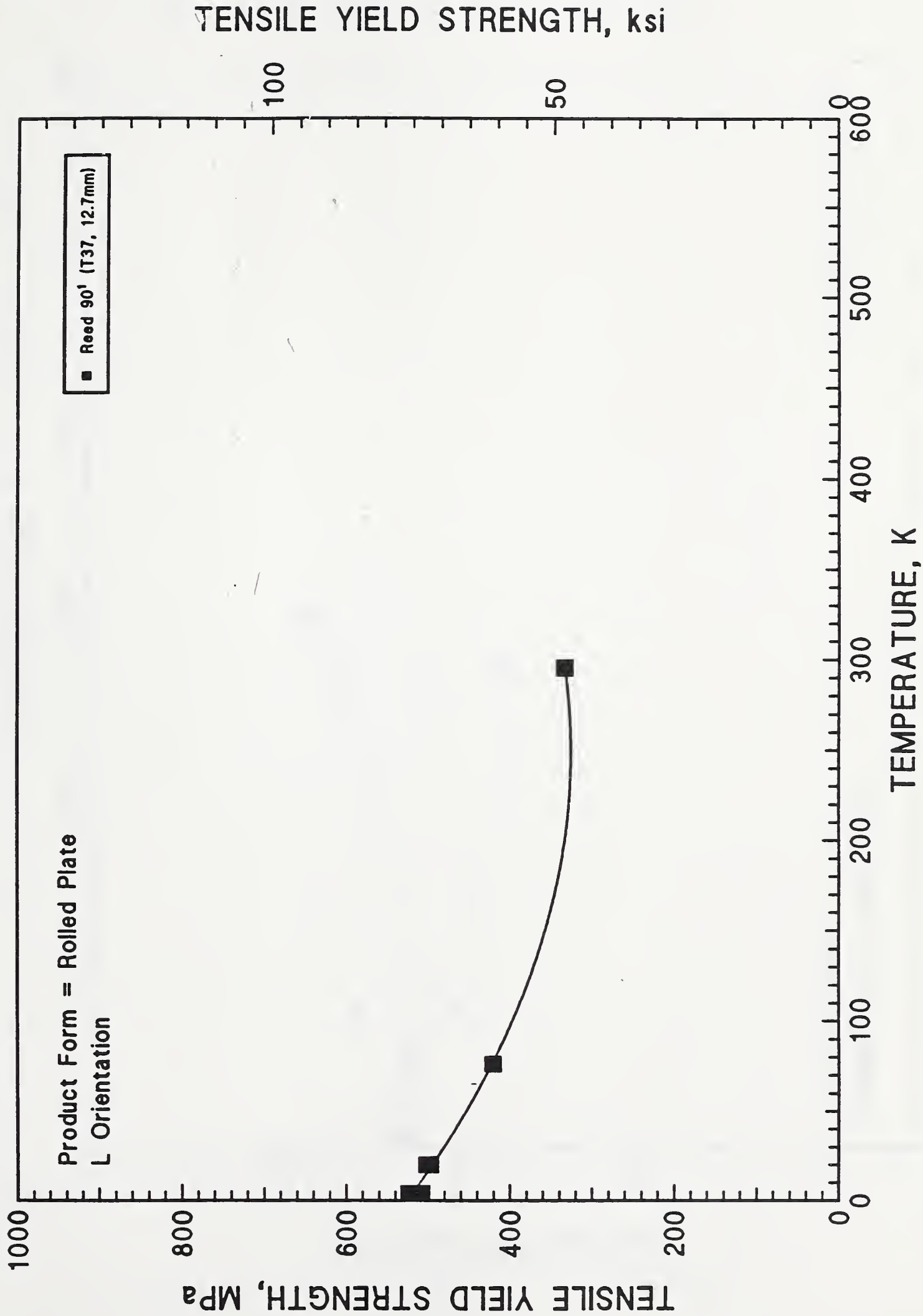




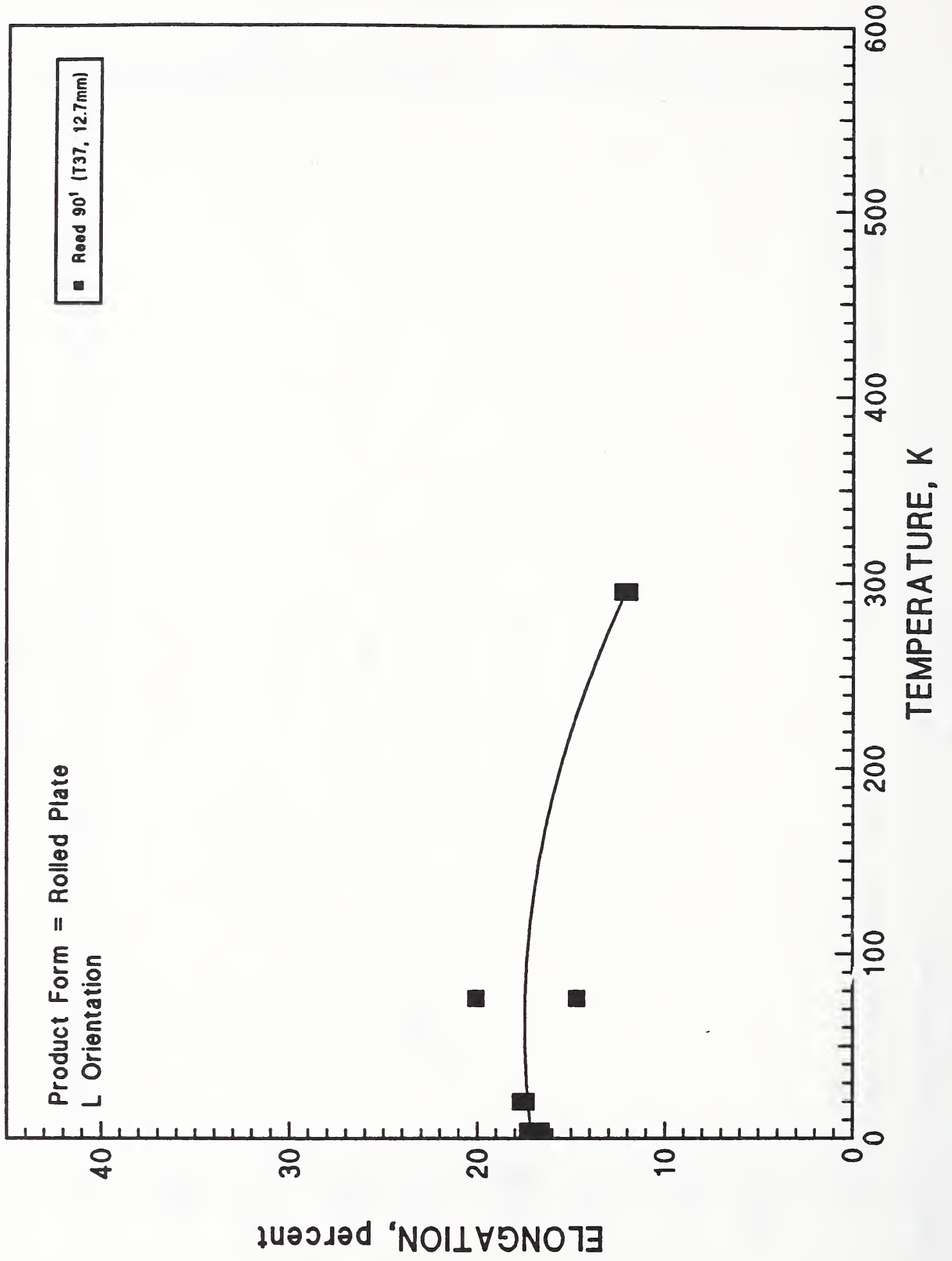
2219-T3



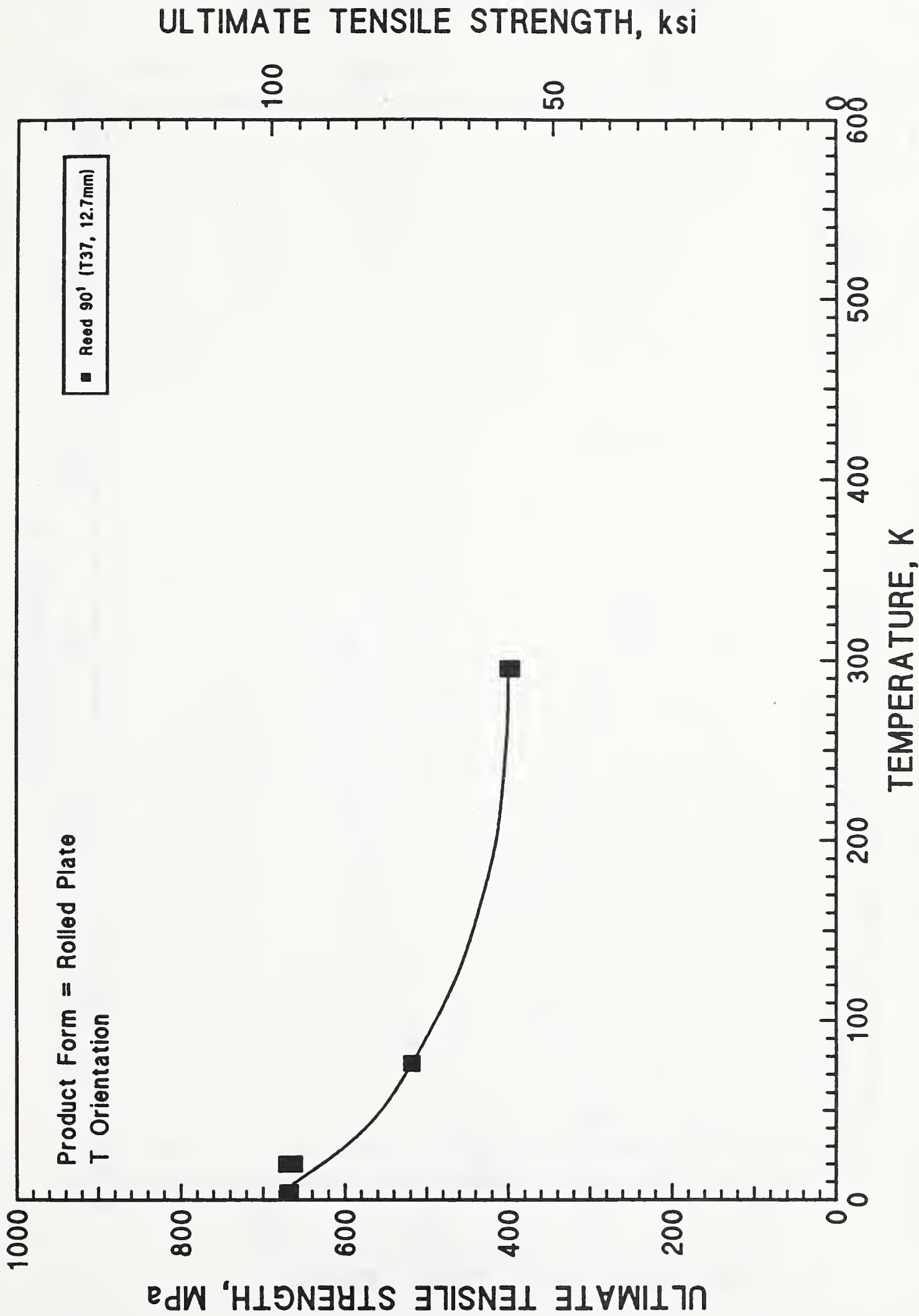
2219-T3



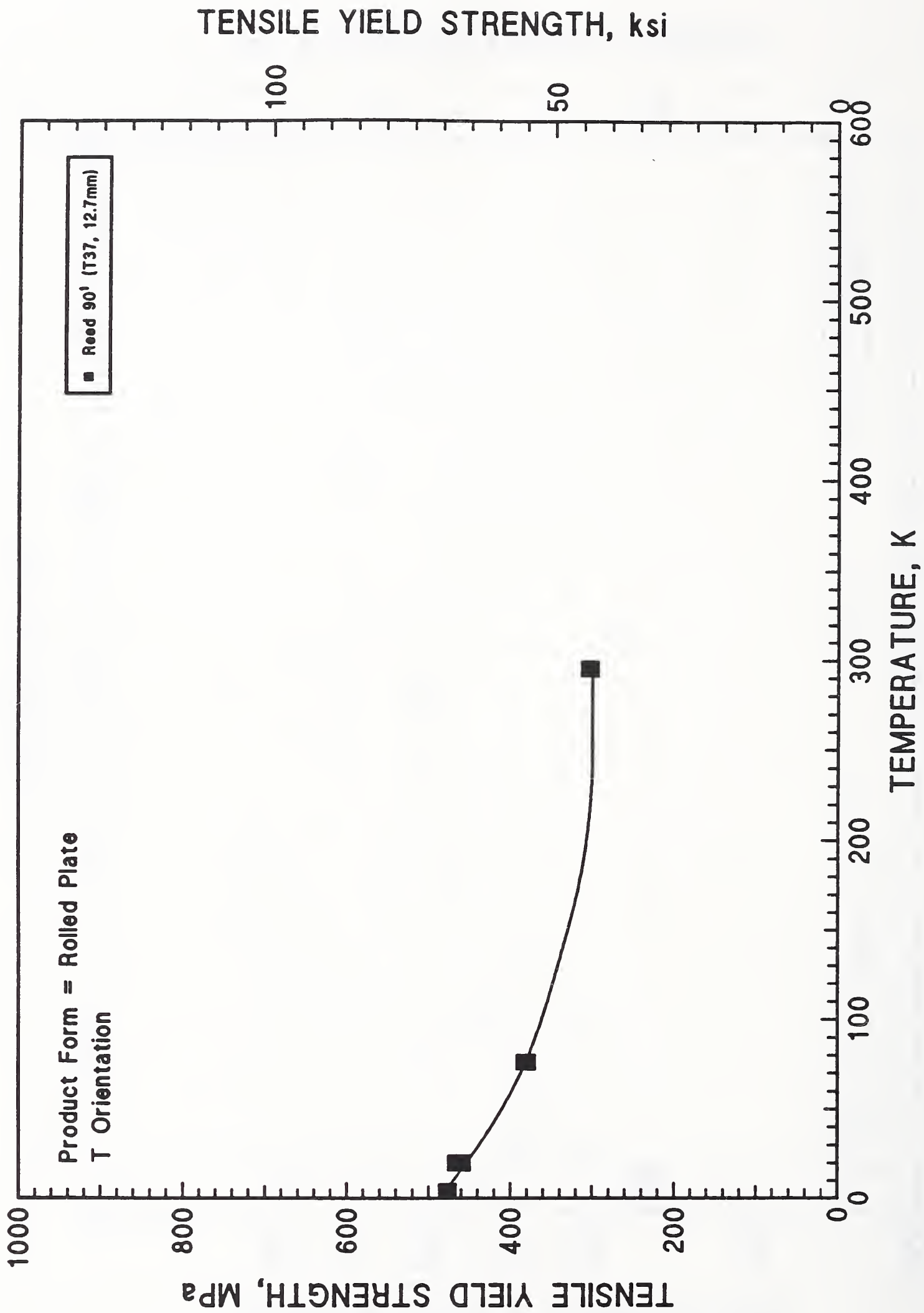
2219-T3

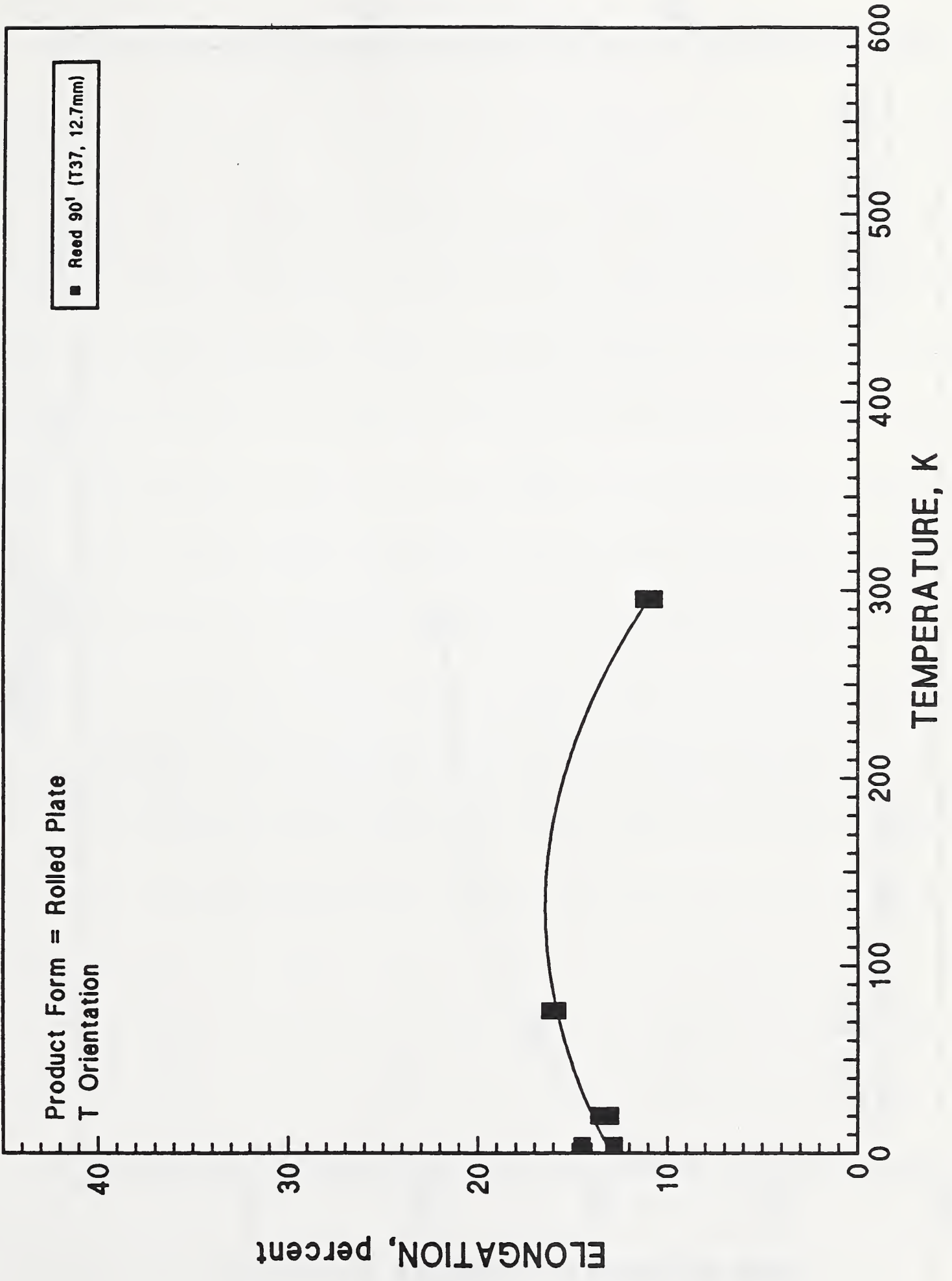


2219-T3

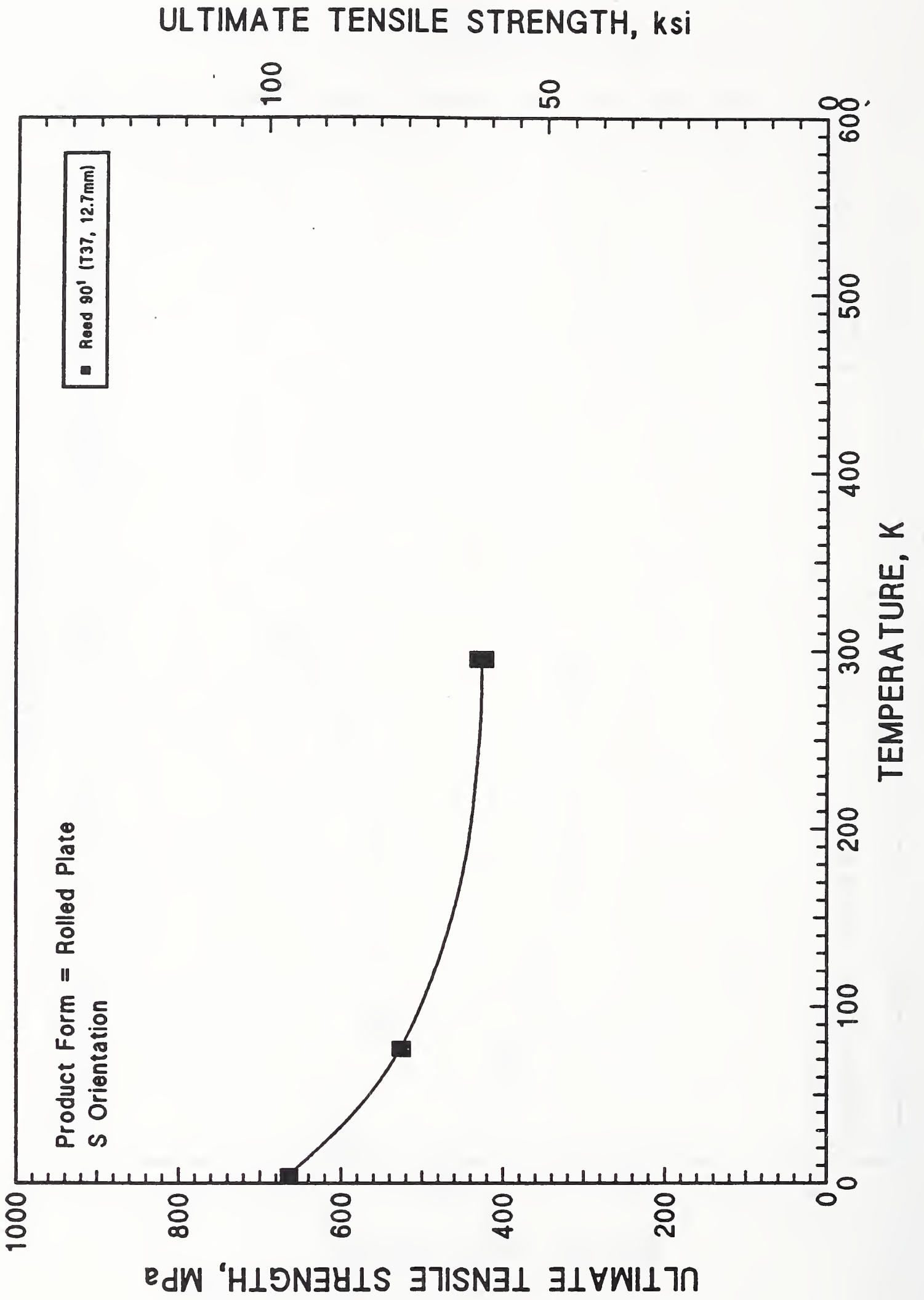


2219-T3





2219-T3



Al-L1 ALLOY 2218

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper	Product Form	Product Aging		Stretch %	Temp. °C	Time h	Soln. Treat. Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/Data Pt
									Thickness mm	Temp. °C								
1Q	295	472.	385.	13.	33.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
1Q	295	472.	387.	13.	31.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
1Q	76	582.	461.	14.	31.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
1Q	76	583.	464.	14.	31.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
1Q	4	707.	504.	15.	28.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
1Q	4	701.	506.	14.	28.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
21A	298	465.	383.	11.8	28.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
21A	193	496.	413.	12.	28.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
21A	77	576.	462.	14.	28.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
21A	20	680.	499.	15.2	21.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
21A	4	676.	518.	15.5	24.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
21A	4	672.	505.	15.	22.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
22A	300	463.	376.	17.3	30.8	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
22A	300	483.	395.	16.4	29.8	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1	
22A	300	456.	374.	14.7	28.8	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
22A	300	476.	390.	15.1	29.8	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1	
22A	194	508.	410.	14.7	28.8	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1	
22A	194	487.	400.	14.7	26.5	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	

*See Comments

Ref & Note No.	Temp. K	I.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Stretch Z	Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
22A	194	483.	393.	14.2	27.9	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	194	507.	416.	15.6	27.9	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	77	565.	462.	18.2	30.9	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	77	578.	485.	15.6	28.9	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	77	578.	457.	16.4	28.9	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	77	563.	452.	16.4	28.9	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	20	655.	491.	22.2	28.9	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	20	663.	502.	17.3	27.9	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	20	639.	487.	0.	27.9	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	20	703.	534.	20.4	25.5	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
23A	300	469.	385.	10.8	0.	L	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	NA	NA	1
23A	300	458.	376.	10.7	0.	L	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	NA	NA	1
23A	77	578.	454.	12.8	0.	L	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	NA	NA	1
23A	77	581.	481.	12.2	0.	L	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	NA	NA	1
23A	20	876.	485.	16.	0.	L	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	NA	NA	1
23A	20	665.	489.	12.5	0.	L	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	NA	NA	1
23B	300	469.	388.	9.8	0.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
23B	77	592.	470.	11.2	0.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
23B	20	687.	476.	10.	0.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPe	Y.S. MPe	Elong. %	R.A. %	Orient. %	Temper	Product Form	Thickness mm	Product Aging			Soln. Treat.			Grain Size μm	Hardness	No. of Tests/ Data Pt
										Temp. °C	Time h	Stretch %	Temp. °C	Time h	Quench Cond.			
23C	300	479.	382.	10.	0.	L	T87	Rolled Plate	50.8	NA	NA	NA	NA	NA	NA	NA	1	
23C	300	473.	393.	9.7	0.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
23C	77	601.	479.	12.5	0.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
23C	77	616.	489.	10.5	0.	L	T87	Rolled Plate	50.8	NA	NA	NA	NA	NA	NA	NA	1	
23C	20	673.	532.	12.	0.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1	
23C	20	700.	521.	7.5	0.	L	T87	Rolled Plate	50.8	NA	NA	NA	NA	NA	NA	NA	1	
23D	300	469.	388.	10.3	0.	L	T87	Rolled Plate	38.1	NA	NA	NA	NA	NA	NA	NA	1	
23D	77	594.	472.	12.3	0.	L	T87	Rolled Plate	38.1	NA	NA	NA	NA	NA	NA	NA	1	
23D	20	691.	514.	11.7	0.	L	T87	Rolled Plate	38.1	NA	NA	NA	NA	NA	NA	NA	1	
23E	300	455.	379.	6.3	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1	
23E	300	456.	379.	6.6	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1	
23E	300	482.	398.	8.7	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1	
23E	300	487.	403.	8.7	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1	
23E	300	457.	383.	6.8	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1	
23E	77	592.	471.	7.3	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1	
23E	77	591.	463.	7.3	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1	
23E	77	576.	466.	5.8	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1	
23E	77	619.	492.	10.2	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1	
23E	77	616.	490.	8.5	0.	L	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1	

*See Comments

Ref & Note No.	Temp. K	I.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper. °C	Product Form	Thickness mm	Product Thickness mm	Aging		Soain. Treat.		Grain Size μm	Hardness	No. of Tests/ Data Pt
											Temp. °C	Time h	Stretch %	Temp. °C			
23E	20	652.	507.	6.7	0.	L	T87	Rolled Plate	127	127	NA	NA	NA	NA	NA	NA	1
23E	20	708.	527.	6.52	0.	L	T87	Rolled Plate	127	127	NA	NA	NA	NA	NA	NA	1
23E	20	696.	510.	6.7	0.	L	T87	Rolled Plate	127	127	NA	NA	NA	NA	NA	NA	1
23E	20	725.	538.	9.5	0.	L	T87	Rolled Plate	127	127	NA	NA	NA	NA	NA	NA	1
24A	300	465.	388.	11.8	28.	L	T87	Rolled Plate	25.4	25.4	NA	NA	NA	NA	NA	NA	1
24A	194	496.	413.	12.	28.	L	T87	Rolled Plate	25.4	25.4	NA	NA	NA	NA	NA	NA	1
24A	78	576.	462.	14.	28.	L	T87	Rolled Plate	25.4	25.4	NA	NA	NA	NA	NA	NA	1
26A	297	476.	376.	12.	18.4	L	T87	Rolled Plate	82.6	82.6	NA	NA	NA	NA	NA	NA	1
26A	297	467.	368.	11.5	15.1	L	T87	Rolled Plate	82.6	82.6	NA	NA	NA	NA	NA	NA	1
26A	297	473.	372.	11.5	19.3	L	T87	Rolled Plate	82.6	82.6	NA	NA	NA	NA	NA	NA	1
26A	297	487.	382.	11.	15.1	L	T87	Rolled Plate	82.6	82.6	NA	NA	NA	NA	NA	NA	1
26A	78	560.	430.	15.	29.4	L	T87	Rolled Plate	82.6	82.6	NA	NA	NA	NA	NA	NA	1
26A	78	563.	432.	16.	28.8	L	T87	Rolled Plate	82.6	82.6	NA	NA	NA	NA	NA	NA	1
26A	78	587.	444.	14.	19.1	L	T87	Rolled Plate	82.6	82.6	NA	NA	NA	NA	NA	NA	1
26A	20	659.	566.	12.6	16.9	L	T87	Rolled Plate	82.6	82.6	NA	NA	NA	NA	NA	NA	1
26A	20	647.	490.	15.5	13.4	L	T87	Rolled Plate	82.6	82.6	NA	NA	NA	NA	NA	NA	1
26A	20	576.	456.	15.5	17.4	L	T87	Rolled Plate	82.6	82.6	NA	NA	NA	NA	NA	NA	1
27A	295	477.	387.	14.	29.	L	T87	Rolled Plate	15.9	15.9	NA	NA	NA	NA	NA	NA	1
27A	295	479.	386.	14.	31.	L	T87	Rolled Plate	15.9	15.9	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient.	Temper	Product Form	Product Thickness mm	Aging Temp. °C	Aging Time h	Stretch %	Soln. Temp. °C	Time h	Quench Cond.	Grain Size µm	Hardness	No. of Tests/ Date Pt
27A	77	592.	462.	15.	29.	L	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	NA	1
27A	77	587.	463.	15.	29.	L	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	NA	1
27A	20	635.	485.	0.	21.	L	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	NA	1
27A	20	647.	501.	0.	22.	L	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	NA	1
30A	295	476.	393.	12.	0.	L	T87	Rolled Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	1
30A	77	600.	483.	12.	0.	L	T87	Rolled Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	1
30A	20	724.	510.	11.	0.	L	T87	Rolled Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	1
31A	300	471.	392.	13.	27.8	L	T87	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1
31A	300	470.	381.	12.5	24.8	L	T87	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1
31A	78	574.	439.	14.	25.3	L	T87	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1
31A	78	583.	452.	15.	25.4	L	T87	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1
31A	20	682.	470.	16.5	20.	L	T87	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1
31A	20	683.	476.	16.5	18.5	L	T87	Rolled Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1
32A	295	469.	379.	10.	28.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
32A	78	572.	448.	13.	22.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
32A	20	669.	462.	15.	0.	L	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1
33A	295	479.	403.	12.	28.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
33A	295	477.	397.	12.	30.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
33A	20	693.	497.	17.	22.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. Z	Temper	Product Form	Product Thickness mm	Aging Temp. °C	Aging Time h	Stretch Z	Soln. Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
33A	20	680.	482.	17.	24.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
35A	205	432.	350.	16.	37.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	128 RB	1
35A	205	432.	357.	16.	34.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	128 RB	1
35A	205	435.	354.	14.	31.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	128 RB	1
35A	205	435.	352.	13.	31.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	128 RB	1
35A	205	301.	243.	12.	28.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	128 RB	1
35A	17	665.	463.	16.	27.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	128 RB	1
35A	17	685.	472.	16.	31.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	128 RB	1
35A	17	861.	488.	16.	23.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	128 RB	1
35A	17	857.	489.	15.	26.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1
35A	17	656.	481.	15.	27.	L	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	128 RB	1
1R	207	447.	340.	6.9	17.5	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1
1R	207	447.	343.	7.6	20.2	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1
1R	76	558.	411.	9.5	18.4	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1
1R	76	557.	407.	9.5	23.6	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1
1R	20	638.	427.	11.	19.5	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1
1R	20	647.	432.	10.6	14.9	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1
1R	4	659.	438.	8.	17.	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1
1R	4	664.	441.	9.3	13.6	L	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %		R.A. %	Orient. Z	Temper	Product Form	Product Thickness mm	Aging Temp. °C	Aging Time h	Stretch Z	Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
				Z	Z														
1T	295	380.	333.	11.9	30.7	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	295	392.	333.	12.3	26.5	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	76	511.	420.	20.1	29.4	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	76	509.	421.	14.7	25.7	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	20	670.	497.	17.7	16.2	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	20	661.	502.	17.4	22.9	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	4	672.	524.	17.3	20.6	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	142.9	1
1T	4	671.	508.	16.6	24.3	L	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	142.9	1
1Q	295	471.	380.	13.	27.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	295	472.	382.	13.	29.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	76	584.	457.	13.	23.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	76	580.	454.	13.	24.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	20	717.	526.	15.	13.4	T	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	4	702.	498.	14.	22.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	4	698.	500.	14.	23.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	300	465.	375.	13.9	20.1	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	300	460.	380.	12.9	23.5	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	300	460.	378.	12.9	21.1	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
22A	300	465.	371.	12.7	0.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. T	Temper	Product		Aging		Soln. Treat.		Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
								Form	Thickness mm	Temp. °C	Time h	Stretch %	Temp. °C				
22A	194	491.	378.	11.1	19.1	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
22A	194	491.	391.	11.1	18.7	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
22A	194	497.	403.	13.8	19.1	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
22A	194	499.	400.	12.9	24.5	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
22A	77	579.	456.	12.9	21.1	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
22A	77	565.	445.	14.7	22.5	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
22A	77	573.	455.	12.9	24.5	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
22A	20	663.	525.	16.9	24.5	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
22A	20	662.	469.	16.4	19.1	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
22A	20	638.	459.	15.6	26.5	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
22A	20	663.	462.	17.3	23.5	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
23A	300	471.	381.	9.8	NA	T	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	NA	1
23A	300	464.	374.	11.3	NA	T	T87	Rolled Plate	9.525	NA	NA	NA	NA	NA	NA	NA	1
23A	77	594.	460.	9.8	NA	T	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	NA	1
23A	77	585.	449.	11.2	NA	T	T87	Rolled Plate	9.525	NA	NA	NA	NA	NA	NA	NA	1
23A	20	690.	485.	14.3	NA	T	T87	Rolled Plate	6.35	NA	NA	NA	NA	NA	NA	NA	1
23A	20	678.	476.	15.	NA	T	T87	Rolled Plate	9.525	NA	NA	NA	NA	NA	NA	NA	1
23B	300	468.	377.	8.5	NA	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
23B	77	585.	466.	10.3	NA	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Stretch %	Temp. °C	Time h	Soln. Treat.	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
23B	20	686.	486.	9.0	NA	T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23C	300	469.	385.	9.5	NA	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23C	300	472.	385.	8.	NA	T	T87	Rolled Plate	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23C	77	619.	495.	7.	NA	T	T87	Rolled Plate	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23C	77	597.	465.	9.3	NA	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23C	20	686.	486.	14.3	NA	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23C	20	682.	503.	6.3	NA	T	T87	Rolled Plate	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23D	300	464.	380.	7.5	NA	T	T87	Rolled Plate	38.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23D	77	582.	451.	7.	NA	T	T87	Rolled Plate	38.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23D	20	670.	481.	8.8	NA	T	T87	Rolled Plate	38.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	300	480.	381.	5.7	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	300	443.	370.	5.	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	300	464.	388.	6.3	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	300	473.	393.	6.5	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	300	471.	393.	5.8	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	77	580.	500.	6.2	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	77	581.	500.	6.	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	77	603.	478.	7.8	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
23E	77	554.	427.	4.7	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temp. °C	Product		Aging		SoIn. Treat.		Quench Cond.	Grain Size μm	Hardness	No. of Tests/Data Pt
								Form	Thickness mm	Temp. °C	Time h	Temp. °C	Time h				
23E	77	594.	461.	6.3	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	650.	402.	5.5	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	616.	474.	4.8	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	651.	497.	5.5	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	692.	502.	8.2	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
23E	20	684.	500.	6.	NA	T	T87	Rolled Plate	127	NA	NA	NA	NA	NA	NA	NA	1
24A	300	470.	388.	10.	19.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
24A	194	501.	410.	9.8	18.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
24A	78	585.	465.	11.8	20.	T	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	1
25A	295	473.	383.	10.	16.	T	T87	Rolled Plate	25	NA	NA	NA	NA	NA	NA	NA	1
25A	295	474.	383.	10.	13.	T	T87	Rolled Plate	25	NA	NA	NA	NA	NA	NA	NA	1
25A	78	583.	454.	9.	14.	T	T87	Rolled Plate	25	NA	NA	NA	NA	NA	NA	NA	1
25A	78	590.	452.	12.	15.	T	T87	Rolled Plate	25	NA	NA	NA	NA	NA	NA	NA	1
25A	20	696.	488.	13.	14.	T	T87	Rolled Plate	25	NA	NA	NA	NA	NA	NA	NA	1
25A	20	694.	494.	11.	12.	T	T87	Rolled Plate	25	NA	NA	NA	NA	NA	NA	NA	1
26A	297	478.	377.	11.5	9.6	T	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	297	481.	378.	11.	9.7	T	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	297	476.	381.	11.	15.5	T	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	78	563.	434.	14.5	25.1	T	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper	Product Form	Thickness mm	Aging Temp. °C	Time h	Stretch %	Soln. Treat.		Grain Size μm	Hardness	No. of Tests/Data Pt
													Temp. °C	Time h			
26A	78	592.	439.	11.	12.9	T	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	78	581.	453.	12.5	15.1	T	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	78	592.	439.	10.	16.5	T	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	20	585.	465.	11.	11.1	T	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
26A	20	633.	461.	6.7	13.	T	T87	Rolled Plate	82.6	NA	NA	NA	NA	NA	NA	NA	1
27A	295	478.	387.	14.	29.	T	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	1
27A	295	478.	386.	14.	31.	T	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	1
27A	77	598.	450.	12.	18.	T	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	1
27A	77	599.	456.	12.	19.	T	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	1
27A	20	654.	0.	0.	16.	T	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	1
27A	20	0.	482.	0.	16.	T	T87	Rolled Plate	15.9	NA	NA	NA	NA	NA	NA	NA	1
28A	300	463.	399.	10.5	16.	T	T87	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	1
28A	77	547.	456.	9.5	18.	T	T87	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	1
28A	20	697.	484.	7.	19.	T	T87	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	1
28A	20	716.	521.	9.5	25.	T	T87	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	1
29A	300	479.	386.	10.5	0.	T	T87	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	1
29A	300	480.	392.	10.	0.	T	T87	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	1
29A	77	591.	466.	10.	0.	T	T87	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	1
29A	77	592.	467.	10.5	0.	T	T87	Rolled Plate	31.75	NA	NA	NA	NA	NA	NA	NA	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Temper	Product Form	Thickness mm	Aging Temp. °C	Aging Time h	Stretch %	Temp. °C	Time h	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt		
																			0	1
29A	20	683.	479.	13.	0.	T	T67	Roller Plate	31.75	NA	NA	NA	NA	NA	NA	NA	NA	1		
29A	20	711.	530.	12.	0.	T	T67	Roller Plate	31.75	NA	NA	NA	NA	NA	NA	NA	NA	1		
30A	295	476.	375.	10.	0.	T	T67	Roller Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	1		
30A	295	476.	386.	8.	0.	T	T67	Roller Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1		
30A	77	593.	455.	12.	0.	T	T67	Roller Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1		
30A	77	593.	462.	11.	NA	T	T67	Roller Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	1		
30A	20	690.	476.	11.	0.	T	T67	Roller Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1		
30A	20	696.	503.	10.	NA	T	T67	Roller Plate	63.5	NA	NA	NA	NA	NA	NA	NA	NA	1		
31A	300	472.	374.	60.	10.4	T	T67	Roller Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1		
31A	300	474.	378.	7.5	11.9	T	T67	Roller Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1		
31A	78	594.	464.	10.5	12.8	T	T67	Roller Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1		
31A	78	585.	455.	11.	13.3	T	T67	Roller Plate	19.5	NA	NA	NA	NA	NA	NA	NA	NA	1		
31A	20	700.	498.	12.	11.6	T	T67	Roller Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1		
31A	20	693.	494.	14.5	14.8	T	T67	Roller Plate	19.1	NA	NA	NA	NA	NA	NA	NA	NA	1		
32A	295	476.	386.	8.	15.	T	T67	Roller Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1		
32A	78	593.	455.	12.	14.	T	T67	Roller Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1		
32A	20	690.	476.	11.	13.	T	T67	Roller Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	1		
33A	295	485.	402.	9.	19.	T	T67	Roller Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1		
33A	295	485.	399.	8.	17.	T	T67	Roller Plate	12.7	NA	NA	NA	NA	NA	NA	NA	NA	1		

*See Comments

Ref & Note No.	Temp. K	T.S. MPe	Y.S. MPe	Elong. %		R.A. %	Orient. %	Temp. °C	Product Form	Thickness mm	Aging		Soln. Treat.		Quench Cond.	Grain Size µm	Hardness	No. of Tests/ Data Pt
				z	z						Temp. °C	Time h	Temp. °C	Time h				
33A	20	700.	502.	15.	16.		T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
33A	20	702.	502.	14.	17.		T	T87	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	1
34A	300	503.	412.	NA	NA		T	T87	Rolled Plate	38.0	NA	NA	NA	NA	NA	NA	NA	1
34A	300	508.	411.	NA	NA		T	T87	Rolled Plate	38.0	NA	NA	NA	NA	NA	NA	NA	1
34A	76	630.	490.	NA	NA		T	T87	Rolled Plate	38.0	NA	NA	NA	NA	NA	NA	NA	1
34A	76	630.	496.	NA	NA		T	T87	Rolled Plate	38.0	NA	NA	NA	NA	NA	NA	NA	1
34A	4	706.	514.	NA	NA		T	T87	Rolled Plate	38.0	NA	NA	NA	NA	NA	NA	NA	1
34A	4	734.	547.	NA	NA		T	T87	Rolled Plate	38.0	NA	NA	NA	NA	NA	NA	NA	1
1R	297	444.	332.	7.7	13.6		T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.8	1
1R	297	443.	330.	6.2	16.3		T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.8	1
1R	76	559.	403.	9.	14.6		T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.8	1
1R	76	557.	406.	6.9	17.2		T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.8	1
1R	20	658.	429.	10.5	15.8		T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.8	1
1R	20	641.	419.	11.2	16.		T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.8	1
1R	4	663.	435.	9.6	15.8		T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.8	1
1R	4	658.	433.	9.3	13.6		T	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	154.8	1
1T	295	396.	303.	11.3	25.		T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	142.9	1
1T	295	400.	304.	10.7	24.3		T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	142.9	1
1T	76	518.	383.	16.2	20.		T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	142.9	1

*See Comments

Ref & Note No.	Temp. K	T.S. MPa	Y.S. MPa	Elong. %	R.A. %	Orient. %	Tempar	Product Form	Product Thickness mm	Aging		Stretch %	Temp. °C	Time h	Soln. Treat.	Quench Cond.	Grain Size μm	Hardness	No. of Tests/ Data Pt
										Temp. °C	Time h								
1T	76	518.	379.	15.8	22.	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	
1T	20	671.	467.	13.6	19.9	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	
1T	20	662.	459.	13.	16.2	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	
1T	4	667.	476.	12.8	17.2	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	
1T	4	670.	478.	14.5	15.4	T	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	
1Q	295	469.	379.	13.	30.	45°	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	295	468.	378.	14.	33.	45°	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	76	578.	449.	14.	28.	45°	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	76	580.	450.	13.	26.	45°	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	4	704.	491.	15.	27.	45°	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1Q	4	702.	491.	15.	28.	45°	T87	Rolled Plate	25.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1S	295	476.	NA	NA	NA	S	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1	
1S	295	462.	NA	NA	NA	S	T851	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	154.8	1	
1U	295	432.	NA	NA	NA	S	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	
1U	295	422.	NA	NA	NA	S	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	
1U	76	524.	NA	NA	NA	S	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	
1U	76	527.	NA	NA	NA	S	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	
1U	4	663.	NA	NA	NA	S	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	
1U	4	665.	NA	NA	NA	S	T37	Rolled Plate	12.7	NA	NA	NA	NA	NA	NA	NA	142.9	1	

*See Comments

TEST PARAMETERS
Al-Li ALLOY 2219

Ref & Strain Note No.	Rate 10 ⁻⁴ /s	Specimen		Expo Time min	Supplier	Yr. Prod.	Lot No.	Product L(m) X W(m)	Li	Major Elements wt%					Minor Elements wt%						
		Type	Diam mm							Thick mm	G.L. mm	Locotion	Cu	Mg		Zr	Si	Fe	Ag		
1Q	2.2	Round	6.35	NA	25.4	Mid-plane	5	NASA	1990	484881	0.307	X	0.307	NA	5.7	NA	0.01	0.07	0.02	NA	NA
1R	2.2	Round	6.35	NA	25.4	Mid-plane	5	Keiser	1989	429881	1.02	X	1.02	NA	5.7	0.	0.15	0.07	0.02	NA	NA
1S	2.2	Round	2.5	NA	25.4	Random	5	Keiser	1989	429881	1.02	X	1.02	NA	5.7	NA	0.15	0.07	0.02	NA	NA
1T	2.2	Round	6.35	NA	25.4	Mid-plane	5	Keiser	1989	486341	1.02	X	1.02	NA	5.7	0.	0.15	0.07	0.02	NA	NA
1U	2.2	Round	2.5	NA	25.4	Random	5	Keiser	1989	486341	1.02	X	1.02	NA	5.7	NA	0.15	0.07	0.02	NA	NA
21A	7.4	NA	12.7	NA	57.	NA	15	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
22A	NA	Round	4.06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.18	0.2	0.3	NA	NA
23A	NA	NA	NA	NA	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3	NA	NA
23B	NA	Flat	12.7	3.175	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3	NA	NA
23C	NA	Flat	25.4	3.175	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3	NA	NA
23D	NA	Flat	19.	3.175	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3	NA	NA
23E	NA	Flat	25.4	NA	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3	NA	NA
24A	NA	Flat	12.7	NA	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
25A	NA	Flat	13.	9.52	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
27A	NA	Round	12.8	NA	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
27A	.003	Flat	15.9	12.7	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3	NA	NA
28A	.003	Plate	12.7	NA	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3	NA	NA
29A	.003	Plate	12.7	NA	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3	NA	NA

Ref & Strain		Specimen			Expo		Supplier		Yr.		Lot		Product		Major Elements						
Note	Rate	Type	Diam	Thick	G.L.	Specimen	Time	Supplier	Yr.	Prod.	No.	Lot	Product	Li	Cu	Mg	Zr	Si	Fe	Ag	Minor Elements
No.	10-4/s		mm	mm	mm	Location	min						L(m) X W(m)				wt%				wt%
30A	.003	Flat	12.7	NA	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3	NA	NA
30B	.003	Flat	12.7	12.7	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3	NA	NA
31A	.003	Flat	19.1	12.7	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3	NA	NA
32A	.003	NA	NA	NA	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3	0.	0.17	0.2	0.3	NA	NA
33A	.002	Flat	12.7	7.62	50.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	5.9	003	0.12	0.12	0.25	NA	NA
34A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
35A	NA	NA	3.17	NA	12.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

2. FRACTURE TOUGHNESS

2.1. Introduction to Graphs

Fracture toughness data at room temperature are presented (with few exceptions) only when measurements at cryogenic temperatures are part of the data set. Thus, only K_{Ic} data on CT (compact tension) specimens are presented in this review. These data are currently available because measurements are relatively easy to carry out in conventional cryostats compared with wide-panel center-crack or part-through crack tests. Most of the measurements on current production vintages and tempers were carried out during the last year at NIST. These measurements are discussed more fully, including fracture mode and microstructural considerations, in another NIST report¹ on comparative cryogenic mechanical properties. A figure showing the possible specimen orientations with respect to the rolling direction precedes the figures.

All graphical data are presented and referenced in tables following the graphs. The properties presented in the data tables are the fracture toughness and yield strength, along with temper, product information, thermomechanical processing, grain size, hardness, number of tests per data point, and the reference and note number. The reference and note number is a guide to the accompanying test conditions table, which gives information on the specimen type and dimensions, precrack conditions, existence of side grooves or multiple specimens, invalidating criterion, chemistry, and procedures, including the test standard used.

NIST is currently engaged in a program to expand the cryogenic fracture toughness database by testing wider CT specimens [152-mm (6.0-in)] and 102-mm (4.0-in) panels with part-through cracks. The type of fracture toughness data presented in this new program is determined by design needs of the ALS program, where these alloys are under consideration for use in cryogenic tankage. Generally, a leak is equivalent to failure, so plane-strain conditions in CT specimens and part-through cracks in wide panel testing are more relevant than center-crack tests. Wide panel testing at temperatures of 20 and 4 K is quite limited.

Specific comments from the data table follow:

Reference and

Note Number

Alloy 8090:

8A--Values reported are "minimum" properties.

Alloy 2090:

36B--Value reported is a proposed minimum value.

12A--Value reported are "minimum" properties.

Alloy WL049:

6J-K--Values reported are the average of the range of grain sizes.

17A-E--Under the supplier column M.M. = Martin Marietta.

Specific comments from the test conditions table follow:

Reference and

Note Number

Alloy 8090:

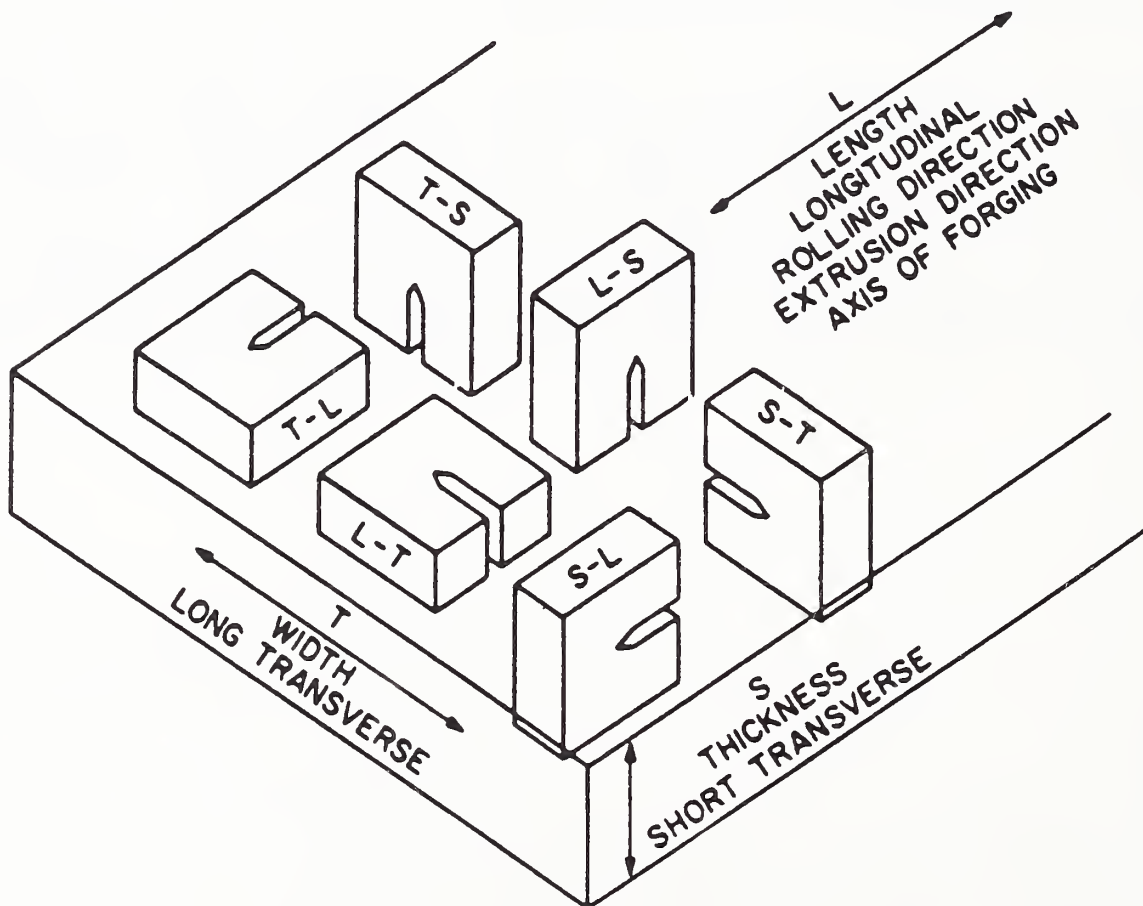
8A--Reported composition is the average of the range provided for in the Lockheed requirements.

Alloy 2090:

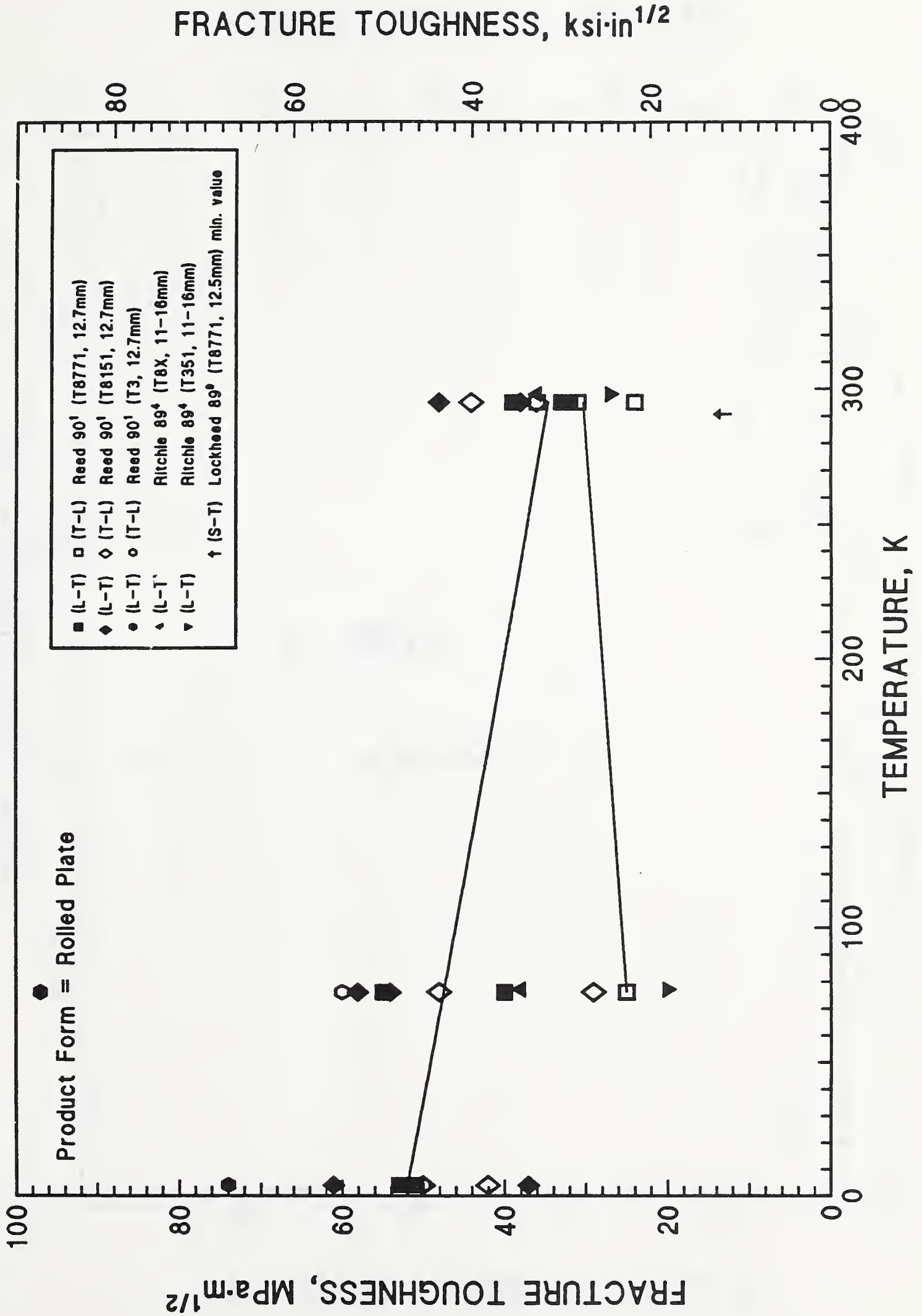
10A--Reported composition is based on nominal values.

12A--Reported composition is the average of the minimum and maximum values.

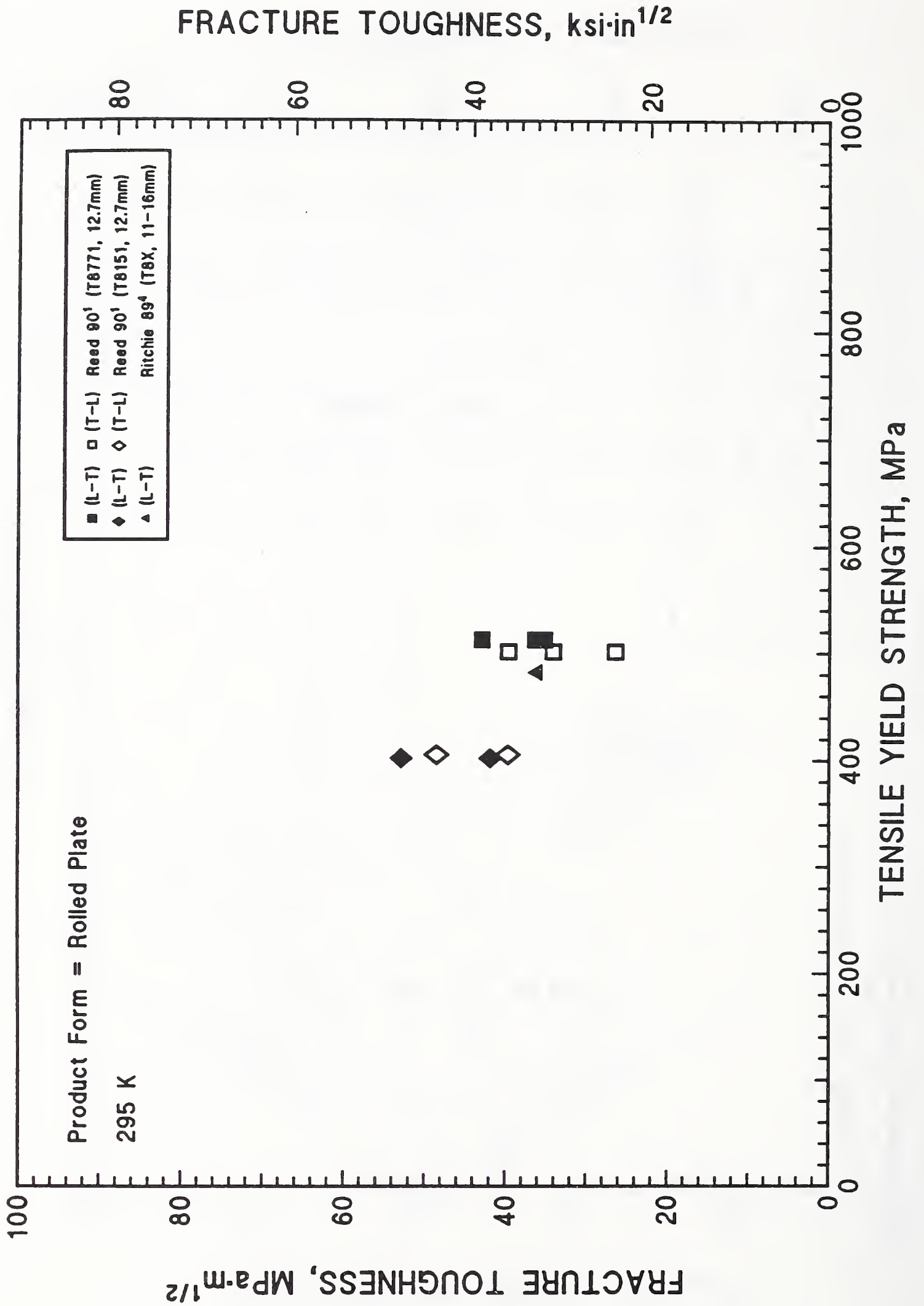
17A--Reported composition is based on nominal values.



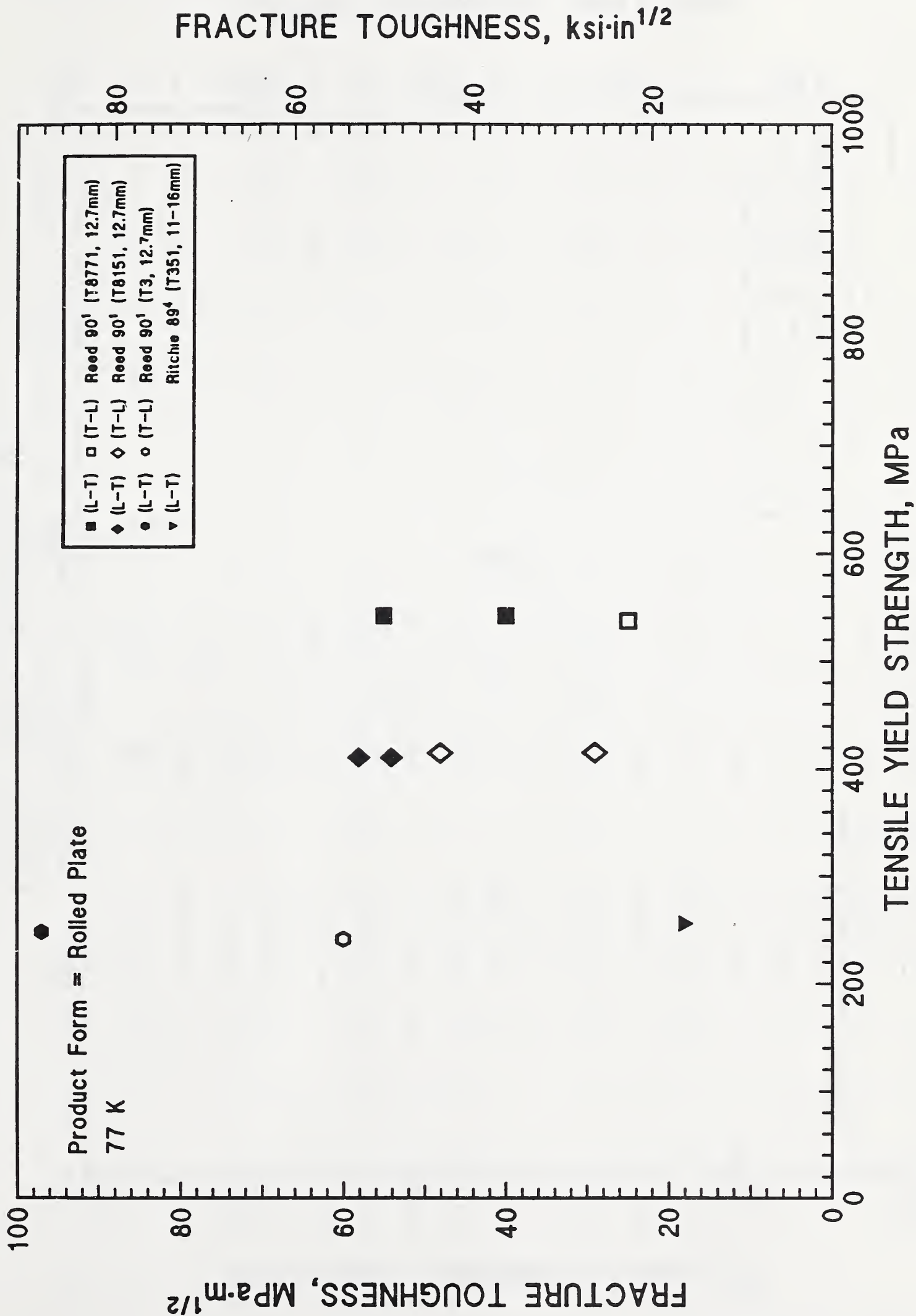
8090



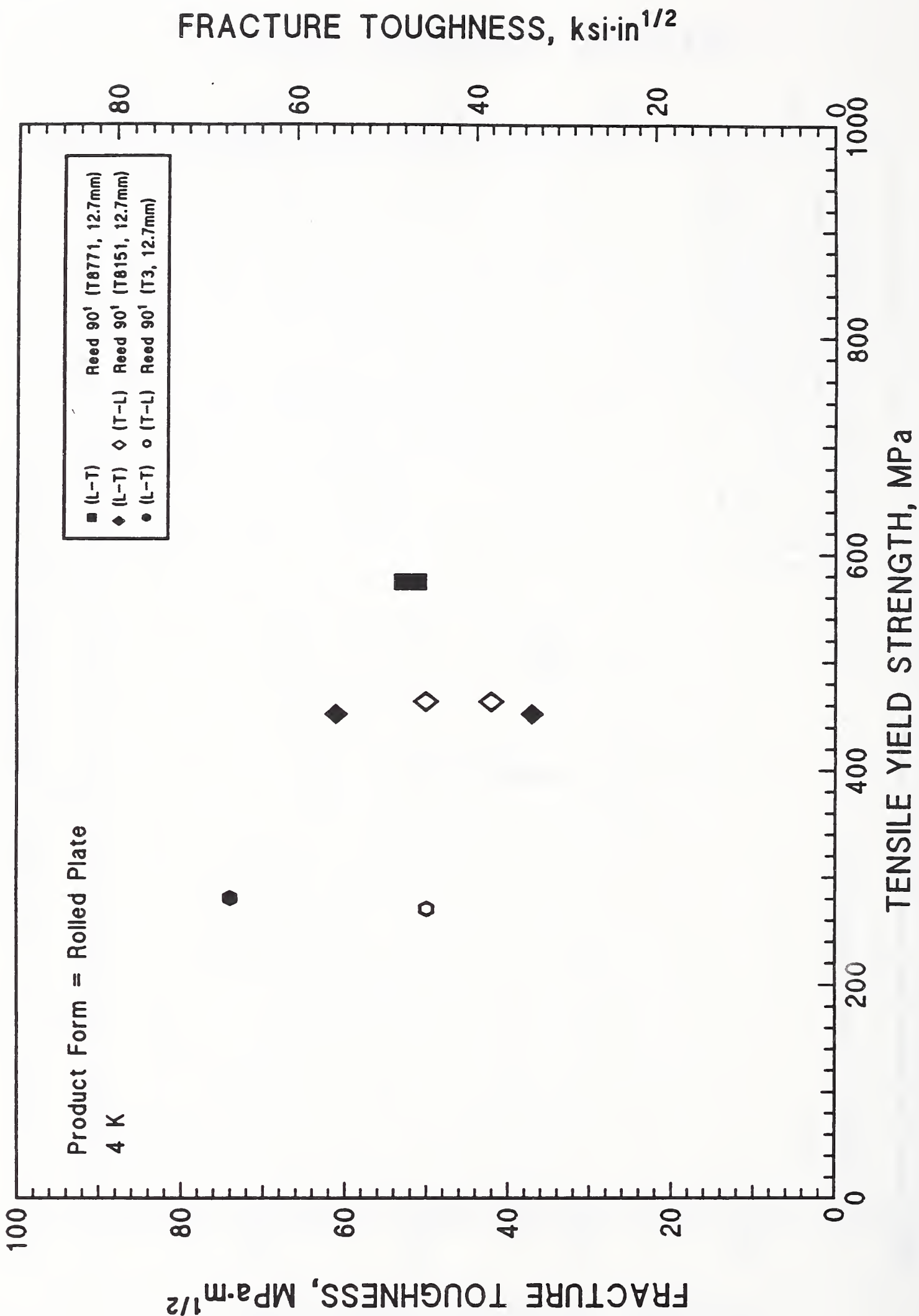
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8090



Fracture Toughness
Alloy 8090

Ref & Note	Temp. K	K	Y.S. MPa	Orient.	Temper	Product Form	Product Thickness mm	Supplier; Year; Lot Number	Aging		Soln Treat.		Quench		Grain Size			No. of Tests/ Data Pt	
									Temp. °C	h	Temp. °C	h	Cond.	L	X	T	X		ST
1A	295	39.	512.	L-T	T8771	Rollled Plate	12.7	ALCAN; '89 ;3503302B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1A	295	32.	512.	L-T	T8771	Rollled Plate	12.7	ALCAN; '89 ;3503302B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1A	295	33.	512.	L-T	T8771	Rollled Plate	12.7	ALCAN; '89 ;3503302B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	76	40.	542.	L-T	T8771	Rollled Plate	12.7	ALCAN; '89 ;3503302B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	76	55.	542.	L-T	T8771	Rollled Plate	12.7	ALCAN; '89 ;3503302B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	4	53.	574.	L-T	T8771	Rollled Plate	12.7	ALCAN; '89 ;3503302B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	4	51.	574.	L-T	T8771	Rollled Plate	12.7	ALCAN; '89 ;3503302B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1C	295	38.	402.	L-T	T8151	Rollled Plate	12.7	ALCAN; '89 ;35712859	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1C	295	48.	402.	L-T	T8151	Rollled Plate	12.7	ALCAN; '89 ;35712852	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	76	58.	411.	L-T	T8151	Rollled Plate	12.7	ALCAN; '89 ;35712859	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	76	54.	411.	L-T	T8151	Rollled Plate	12.7	ALCAN; '89 ;35712852	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	4	61.	452.	L-T	T8151	Rollled Plate	12.7	ALCAN; '89 ;35712852	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	4	37.	452.	L-T	T8151	Rollled Plate	12.7	ALCAN; '89 ;35712852	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
4B	298	36.	482.	L-T	T8X	Rollled Plate	12.7	ALCAN ;NA	180	16.	NA	NA	1500	350	40	NA	NA	NA	1
4C	77	38.	NA	L-T	T8X	Rollled Plate	12.7	ALCAN ;NA	180	16.	NA	NA	1500	350	40	NA	NA	NA	1
4A	77	20.	256.	L-T	T351	Rollled Plate	12.7	ALCAN ;NA	NA	NA	NA	NA	1500	350	40	NA	NA	NA	1
1E	76	87.	248.	L-T	T3	Rollled Plate	12.7	ALCAN; '89 ;3518302A	NA	NA	NA	NA	600	NA	20	118.5	V	1	1
1E	4	74.	280.	L-T	T3	Rollled Plate	12.7	ALCAN; '89 ;3518302A	NA	NA	NA	NA	600	NA	20	118.5	V	1	1

Ref & Note No.	Temp. K	K MPa/m	Y.S. MPa	Orient.	Temper	Product Form	Product Thickness mm	Supplier;		Aging		Cold Work		Soln Treat.		Quench Cond.	Grain Size			Hardness	No. of Tests/ Date Pt
								Year;	Lot Number	Temp. °C	h	z	Temp. °C	h	L		X	ST	μm		
1A	295	31.	501.	T-L	T8771	Rolled Plate	12.7	ALCAN; '89	; 3503302B	NA	NA	6	NA	NA	NA	NA	NA	NA	NA	NA	1
1A	295	36.	501.	T-L	T8771	Rolled Plate	12.7	ALCAN; '89	; 3503302B	NA	NA	6	NA	NA	NA	NA	NA	NA	NA	NA	1
1A	295	24.	501.	T-L	T8771	Rolled Plate	12.7	ALCAN; '89	; 3503302B	NA	NA	6	NA	NA	NA	NA	NA	NA	NA	NA	1
1B	76	25.	537.	T-L	T8771	Rolled Plate	12.7	ALCAN; '89	; 3503302B	NA	NA	6	NA	NA	NA	NA	NA	NA	NA	NA	1
1C	295	36.	405.	T-L	T8151	Rolled Plate	12.7	ALCAN; '89	; 35712859	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1C	295	44.	405.	T-L	T8151	Rolled Plate	12.7	ALCAN; '89	; 35712852	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	76	29.	415.	T-L	T8151	Rolled Plate	12.7	ALCAN; '89	; 35712852	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	76	48.	415.	T-L	T8151	Rolled Plate	12.7	ALCAN; '89	; 35712852	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	4	42.	463.	T-L	T8151	Rolled Plate	12.7	ALCAN; '89	; 35712852	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1D	4	50.	463.	T-L	T8151	Rolled Plate	12.7	ALCAN; '89	; 35712852	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1E	76	80.	241.	T-L	T3	Rolled Plate	12.7	ALCAN; '89	; 3518302A	NA	NA	2	NA	NA	NA	NA	NA	NA	20	118.5, V	1
1E	4	50.	270.	T-L	T3	Rolled Plate	12.7	ALCAN; '89	; 3518302A	NA	NA	2	NA	NA	NA	NA	NA	NA	20	118.5, V	1
9A	295	13.2	NA	T-S	T8771	Rolled Plate	12.7	NA	; NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

Comments from the Al-Li Alloy 8090 Data Table

Reference and
Note Number

9A--Values reported are "minimum" properties.

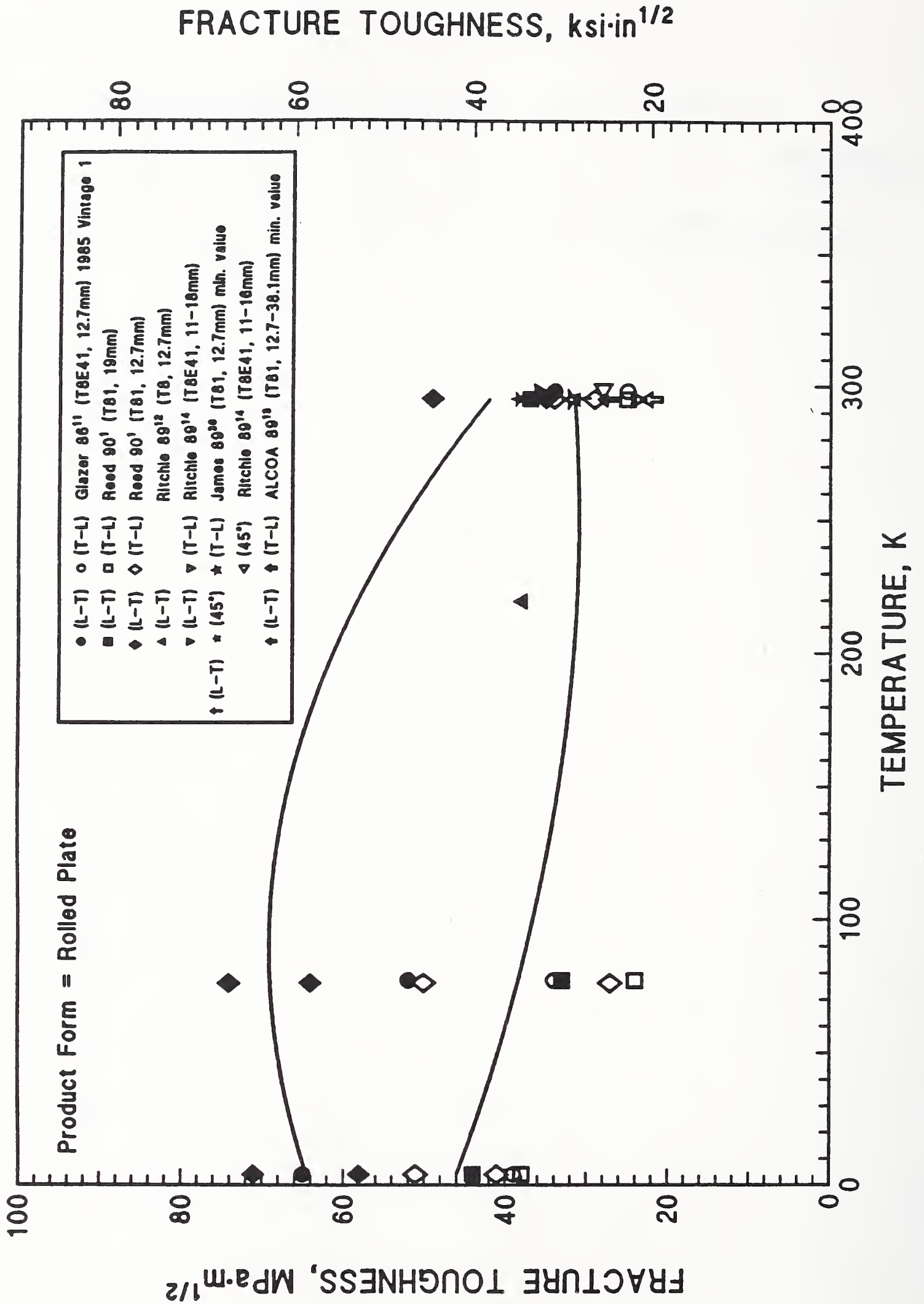
**Fracture Toughness
Test Conditions
Alloy 8090**

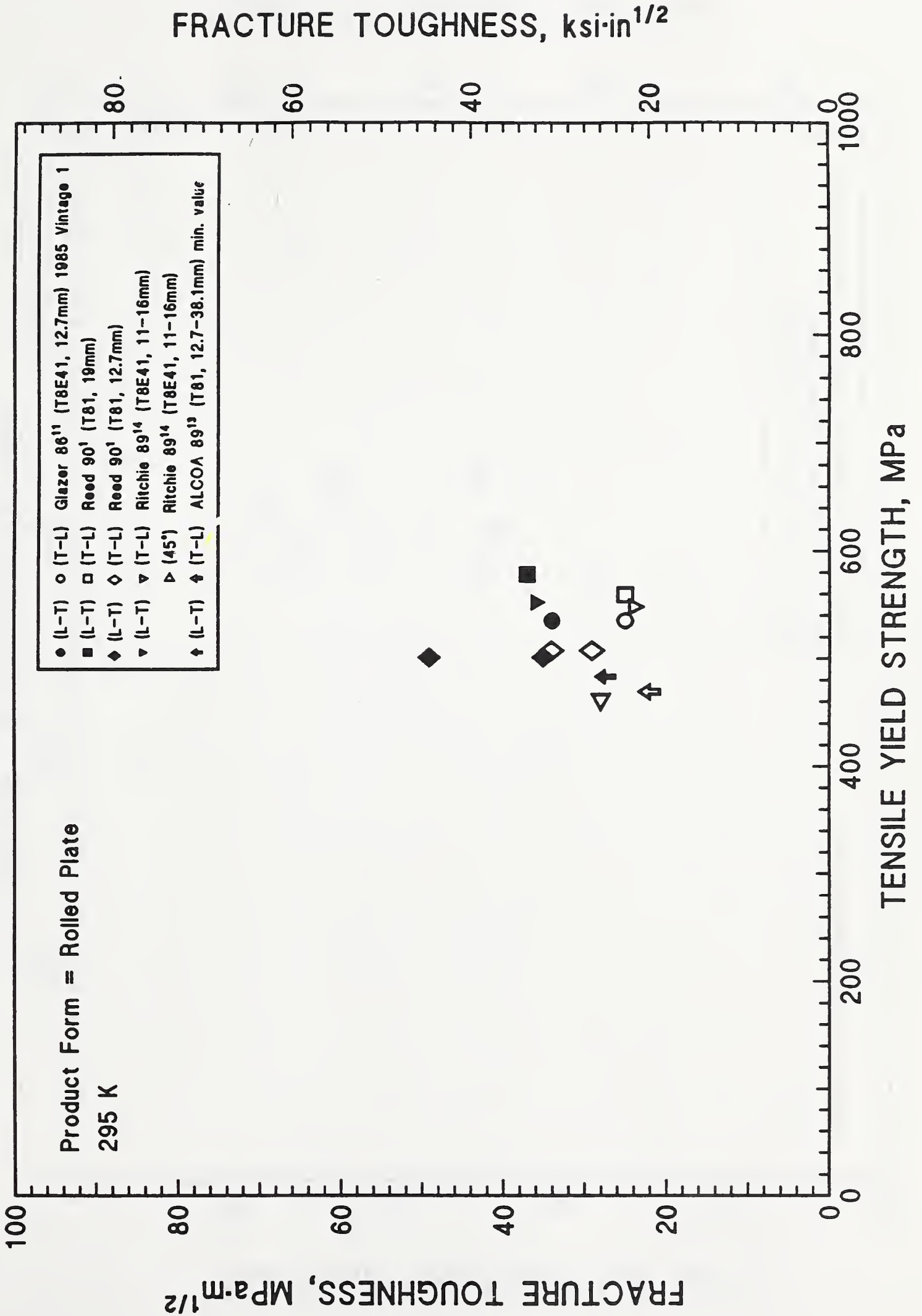
Ref & Note	Specimen Type	Specimen Dimensions			Precrack		Multi- Spec. no/#	Invalidating Criterion	Li	Major Elements					Procedures		
		B	W	a/W	Other	Temp K				Freq Hz	Side- Groove	Cu	Mg	Zr		Si	Fe
No.			mm							wt%							
1A	CT	12.7	50.8	NA	NA	295	20.	no	NA	2.36	1.2	0.7	0.11	0.02	0.06	NA	ASTM E813
1B	CT	12.7	50.8	NA	NA	76	20.	no	NA	2.36	1.2	0.7	0.11	0.02	0.06	NA	ASTM E813
1C	CT	12.7	50.8	NA	NA	295	20.	no	NA	2.36	1.2	0.7	0.11	0.02	0.06	NA	ASTM E813
1D	CT	12.7	50.8	NA	NA	76	20.	no	NA	2.36	1.2	0.7	0.11	0.02	0.06	NA	ASTM E813
1E	CT	12.7	50.8	NA	NA	76	20.	no	NA	2.34	1.2	0.6	0.12	0.03	0.05	NA	ASTM E813
4A	CT	7.6	NA	0.5	NA	NA	NA	NA	NA	2.50	1.3	0.7	0.12	0.1	0.2	NA	ASTM E399-83
4B	CT	7.6	NA	0.5	NA	NA	NA	NA	NA	2.50	1.3	0.7	0.12	0.1	0.2	NA	ASTM E399-83
4C	CT	7.6	NA	0.5	NA	NA	NA	NA	NA	2.5	1.3	0.7	0.12	0.1	0.2	NA	ASTM E399-83
9A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Comments from the Al-Li Alloy 8090 Test Conditions Table

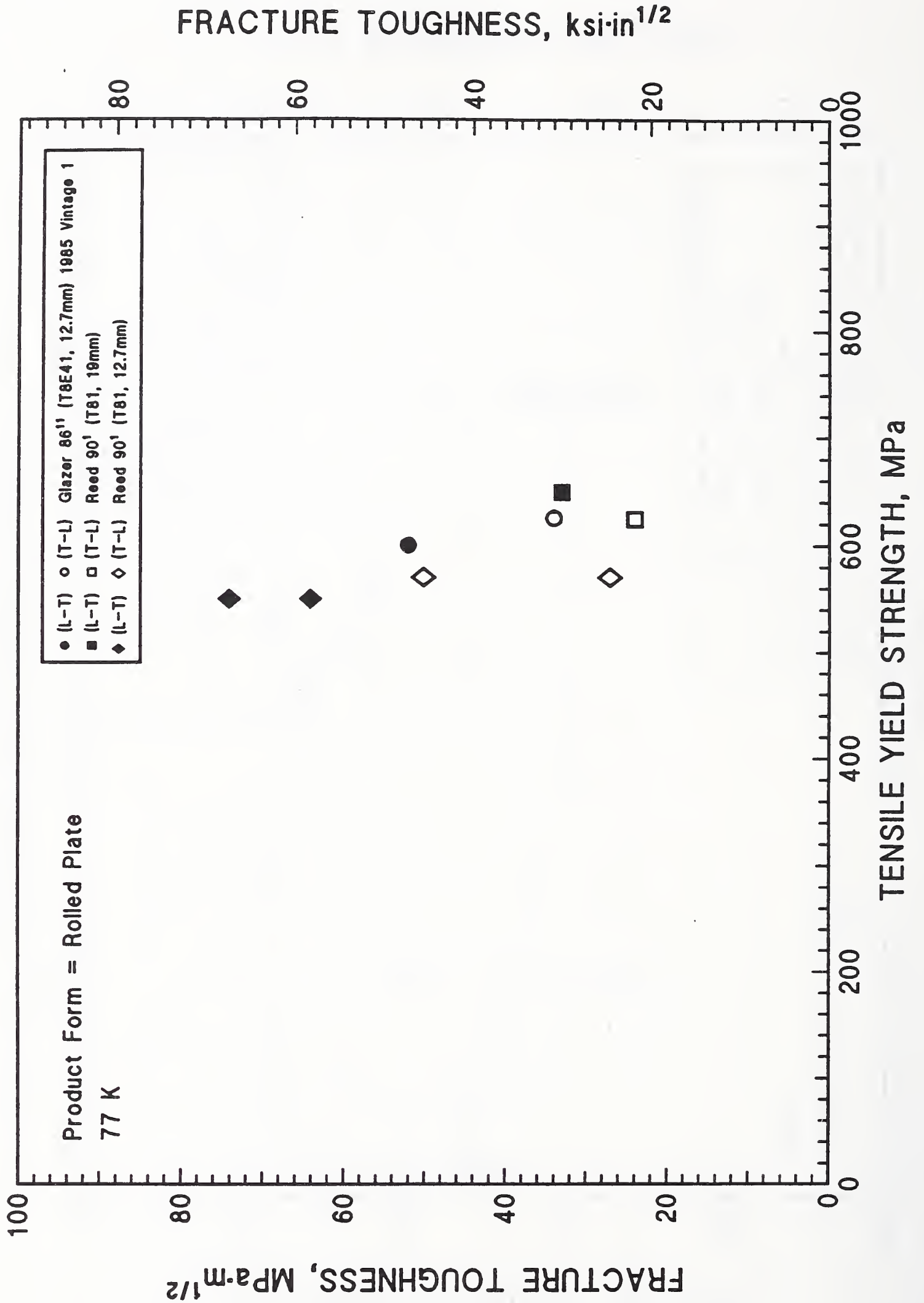
Reference and
Note Number

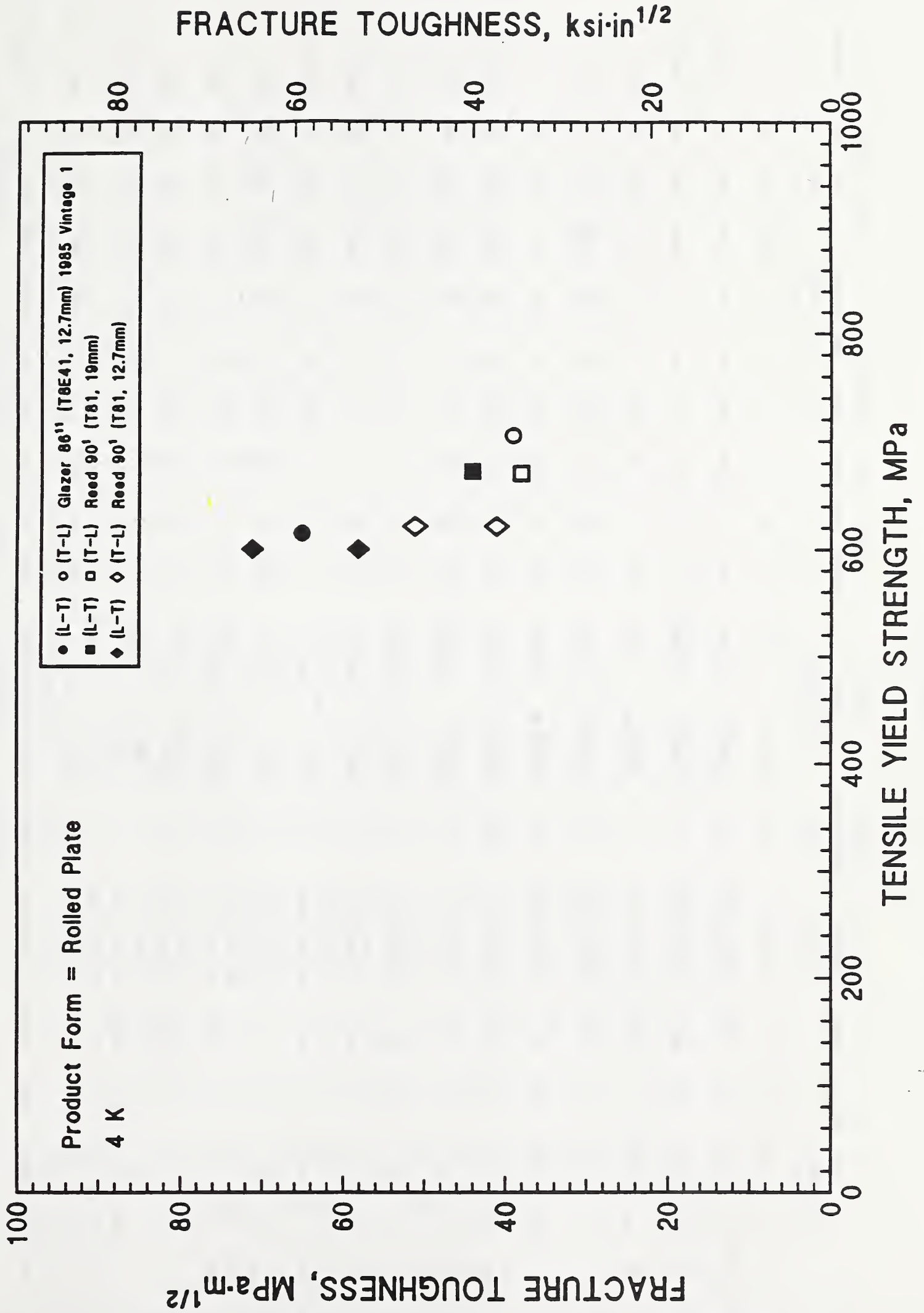
9A--Reported composition is the average of the range provided for in the Lockheed requirements.





2090





Fracture Toughness
Alloy 2090

Ref & Note No.	Temp. K	K MPa/m	Y.S. MPa	Orient.	Temper	Product Form	Product Thickness mm	Supplier; Year; Lot Number	Aging		Soln Treat.		Quench			Grain Size			Hardness	No. of Tests/ Data Pt
									Temp. °C	Time h	Temp. °C	Time h	Cond.	L	X	SI	L	X		
1F	295	49.	501.	L-T	T81	Rolled Plate	12.7	ALCOA; '89 ;103301	NA	NA	NA	NA	NA	2000	NA	200	NA	200	198.3, V	1
1F	295	35.	501.	L-T	T81	Rolled Plate	12.7	ALCOA; '89 ;103301	NA	NA	NA	NA	NA	2000	NA	200	NA	200	198.3, V	1
1G	77	64.	550.	L-T	T81	Rolled Plate	12.7	ALCOA; '89 ;103301	NA	NA	NA	NA	NA	2000	NA	200	NA	200	198.3, V	1
1G	77	74.	550.	L-T	T81	Rolled Plate	12.7	ALCOA; '89 ;103301	NA	NA	NA	NA	NA	2000	NA	200	NA	200	198.3, V	1
1G	4	71.	600.	L-T	T81	Rolled Plate	12.7	ALCOA; '89 ;103301	NA	NA	NA	NA	NA	2000	NA	200	NA	200	198.3, V	1
1G	4	58.	600.	L-T	T81	Rolled Plate	12.7	ALCOA; '89 ;103301	NA	NA	NA	NA	NA	2000	NA	200	NA	200	198.3, V	1
1H	295	37.	578.	L-T	T81	Rolled Plate	19.05	ALCOA; '89 ;103299	NA	NA	NA	NA	NA	2000	NA	100	NA	100	198.3, V	1
1I	77	33.	649.	L-T	T81	Rolled Plate	19.05	ALCOA; '89 ;103299	NA	NA	NA	NA	NA	2000	NA	100	NA	100	198.3, V	1
1I	4	44.	672.	L-T	T81	Rolled Plate	19.05	ALCOA; '89 ;103299	NA	NA	NA	NA	NA	2000	NA	100	NA	100	198.3, V	1
12A	219	38.	565.	L-T	T81	Rolled Plate	12.7	ALCOA ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
13A	295	27.5	483.	L-T	T81	Rolled Plate	25.4	NA ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	*
36B	295	27.5	NA	L-T	T81	Rolled Plate	12.7	NA ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	*
11A	298	34.	535.	L-T	T8E41	Rolled Plate	12.7	ALCOA ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
11A	77	52.	600.	L-T	T8E41	Rolled Plate	12.7	ALCOA ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
11A	4	85.	815.	L-T	T8E41	Rolled Plate	12.7	ALCOA ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
14A	298	36.	552.	L-T	T8E41	Rolled Plate	12.7	ALCOA ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1F	295	34.	507.	T-L	T81	Rolled Plate	12.7	ALCOA; '89 ;103301	NA	NA	NA	NA	NA	2000	NA	200	NA	200	198.3, V	1
1F	295	29.	507.	T-L	T81	Rolled Plate	12.7	ALCOA; '89 ;103301	NA	NA	NA	NA	NA	2000	NA	200	NA	200	198.3, V	1

Ref & Note No.	Temp. K	K MPa/m	Y.S. MPa	Orient.	Temper	Product Form	Product Thickness mm	Supplier;		Aging		Cold Work		Soln Treat.		Grain Size			No. of Tests/ Data Pt	
								Year;	Lot Number	Temp. °C	h	Temp. °C	h	Temp. °C	h	L	X	ST		Quench Cond.
1G	77	27.	570.	T-L	T01	Rolled Plate	12.7	ALCOA; '89	; 103301	NA	NA	MA	MA	NA	NA	2000	MA	200	198.3, V	1
1G	77	50.	570.	T-L	T01	Rolled Plate	12.7	ALCOA; '89	; 103301	NA	NA	MA	MA	NA	NA	2000	MA	200	198.3, V	1
1G	4	41.	621.	T-L	T01	Rolled Plate	12.7	ALCOA; '89	; 103301	NA	NA	MA	MA	NA	NA	2000	MA	200	198.3, V	1
1H	295	25.	559.	T-L	T01	Rolled Plate	19.05	ALCOA; '89	; 103299	NA	NA	MA	MA	NA	NA	2000	MA	100	198.3, V	1
1G	4	51.	621.	T-L	T01	Rolled Plate	12.7	ALCOA; '89	; 103301	NA	NA	MA	MA	NA	NA	2000	MA	200	MA	1
1I	77	24.	624.	T-L	T01	Rolled Plate	19.05	ALCOA; '89	; 103299	NA	NA	MA	MA	NA	NA	2000	MA	100	198.3, V	1
1I	4	38.	670.	T-L	T01	Rolled Plate	19.05	ALCOA; '89	; 103299	NA	NA	MA	MA	NA	NA	2000	MA	100	198.3, V	1
13A	295	22.	469.	T-L	T01	Rolled Plate	25.4	NA	; NA	NA	NA	MA	MA	NA	NA	MA	NA	NA	MA	1
36A	295	31.9	NA	T-L	T01	Rolled Plate	12.7	ALCOA	; 400-011	NA	NA	MA	MA	NA	NA	MA	NA	NA	MA	1
11A	298	25.	535.	T-L	T0E41	Rolled Plate	12.7	ALCOA	; NA	NA	NA	MA	MA	NA	NA	MA	NA	NA	MA	1
11A	77	34.	625.	T-L	T0E41	Rolled Plate	12.7	ALCOA	; NA	NA	NA	MA	MA	NA	NA	MA	NA	NA	MA	1
11A	4	39.	705.	T-L	T0E41	Rolled Plate	12.7	ALCOA	; NA	NA	NA	MA	MA	NA	NA	MA	NA	NA	MA	1
14A	298	24.	548.	T-L	T0E41	Rolled Plate	12.7	ALCOA	; NA	NA	NA	MA	MA	NA	NA	MA	NA	NA	MA	1
36A	295	38.5	NA	45°	T01	Rolled Plate	12.7	ALCOA	; 400-011	NA	NA	MA	MA	NA	NA	MA	NA	NA	MA	1
14A	298	28.	460.	45°	T0E41	Rolled Plate	12.7	ALCOA	; NA	NA	NA	MA	MA	NA	NA	MA	NA	NA	MA	1

Comments from the Alloy 2090 Data Table

Reference and
Note Number

37B--Value reported is a proposed minimum value.

13A--Value reported are "minimum" properties.

Fracture Toughness
Test Conditions
Alloy 2090

Ref & Note	Specimen No.	Specimen Type	Specimen Dimensions			Other	Precrack Temp K	Side- Groove	Multi- Spec. no/#	Invalidating Criterion	Major Elements						Procedures	
			B	W	e/W						mm	Li	Cu	Mg	Zr	Si		Fe
1F	CT		12.7	50.6	NA	NA	295	20.	no	NA	2.3	2.6	0.1	0.1	NA	0.07	NA	ASTM E813
1F	CT		12.7	50.6	NA	NA	295	20.	no	NA	2.3	2.6	0.1	0.1	NA	0.07	NA	ASTM E813
1G	CT		12.7	50.6	NA	NA	76	20.	no	NA	2.3	2.7	0.	0.12	NA	0.06	NA	ASTM E813
1H	CT		12.7	50.6	NA	NA	295	20.	no	NA	2.3	2.6	0.1	0.1	NA	0.07	NA	ASTM E813
1I	CT		12.7	50.6	NA	NA	76	20.	no	NA	2.3	2.6	0.1	0.1	NA	0.07	NA	ASTM E813
11A	CT		NA	NA	NA	NA	NA	NA	NA	NA	2.2	2.7	NA	0.12	NA	NA	NA	ASTM E813-01, E - 79 GPa
12A	CT		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	*****
13A	CT		NA	NA	NA	NA	NA	NA	NA	NA	2.3*	2.7	0.3	0.12	0.1	0.12	NA	*****
14A	CT		7.6	NA	NA	NA	NA	NA	NA	NA	2.05	2.9	003	0.12	E-2	0.02	NA	ASTM E399
36A	CT		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	*****
36B	CT		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	*****

Comments from the Alloy 2090 Test Conditions Table

Reference and
Note Number

11A--Reported composition is based on nominal values.

13A--Reported composition is the average of the minimum and maximum values.

18A--Reported composition is based on nominal values.

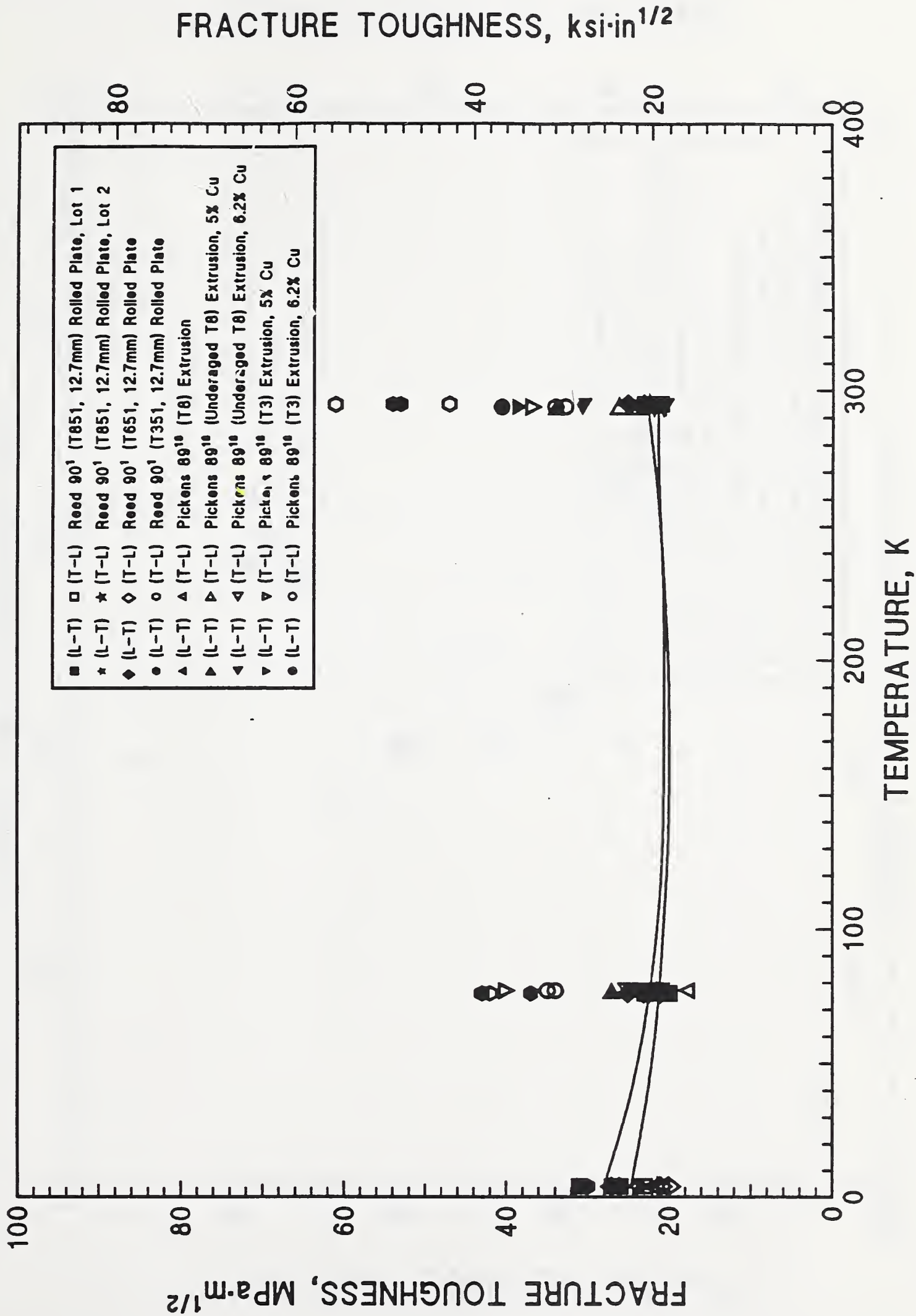
Comments from the Alloy WL049 Data Table

Reference and
Note Number

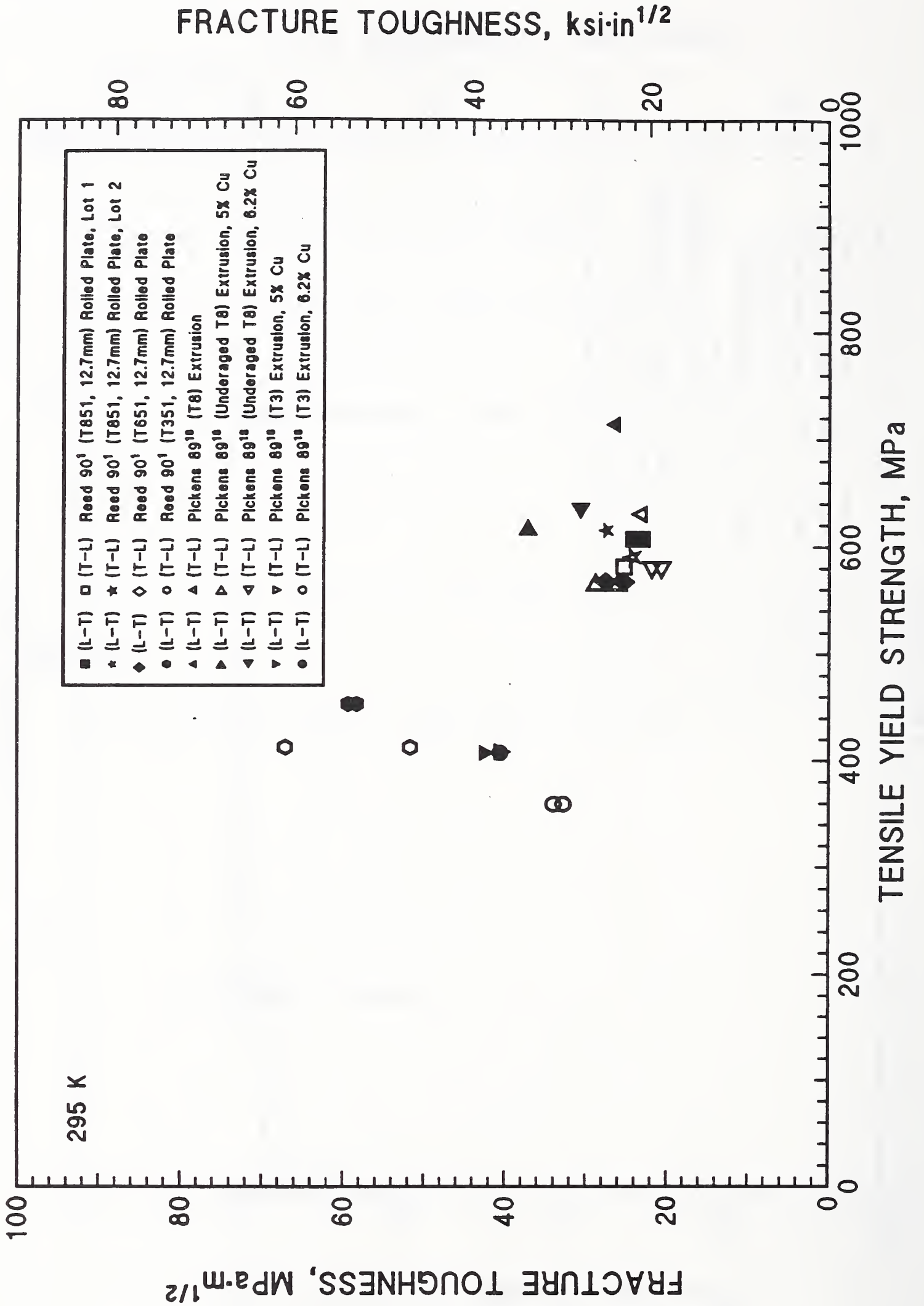
1J-K--Values reported are the average of the range of grain sizes.

18A-E--Under the supplier column M.M. = Martin Marietta.

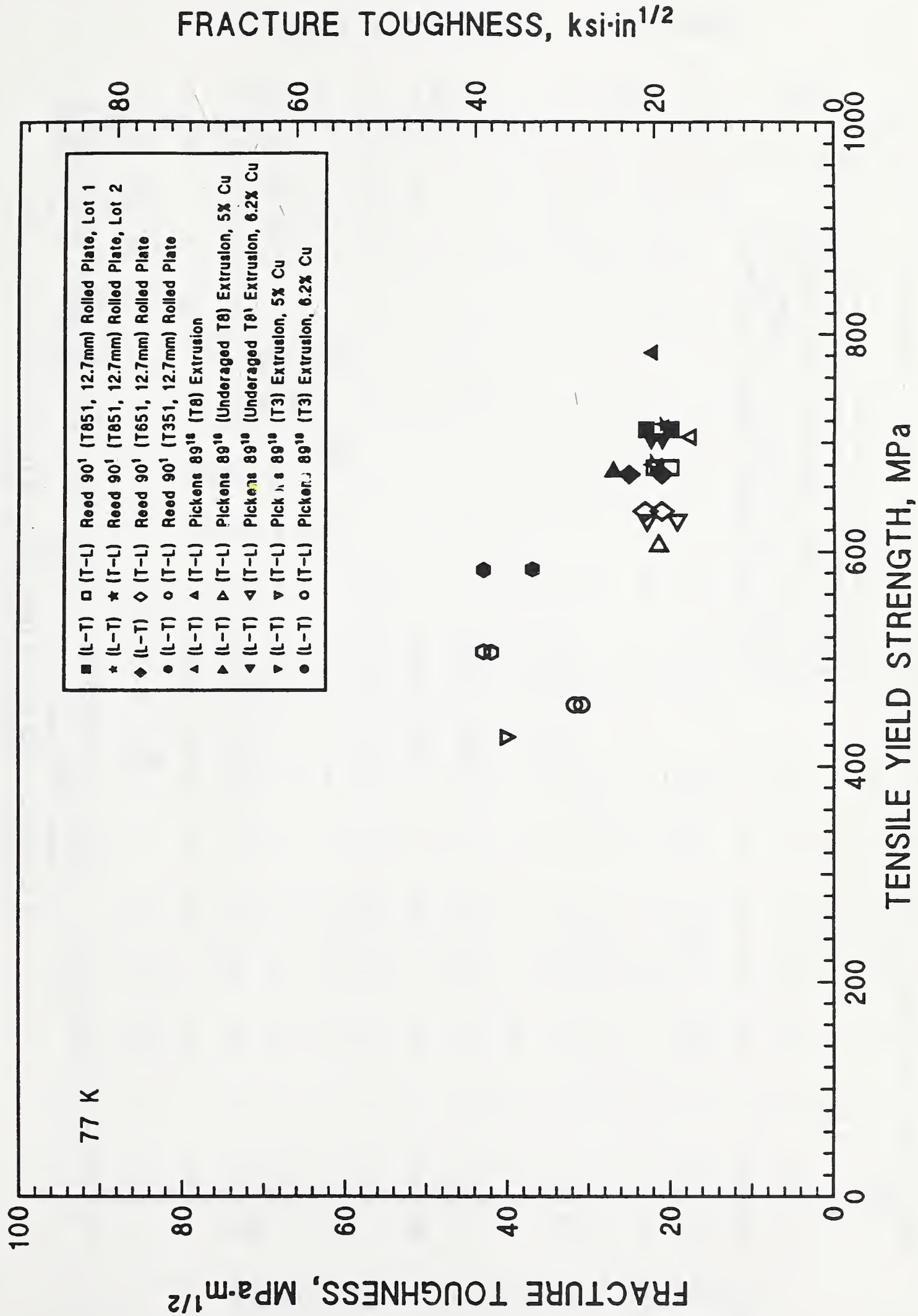
WLO49



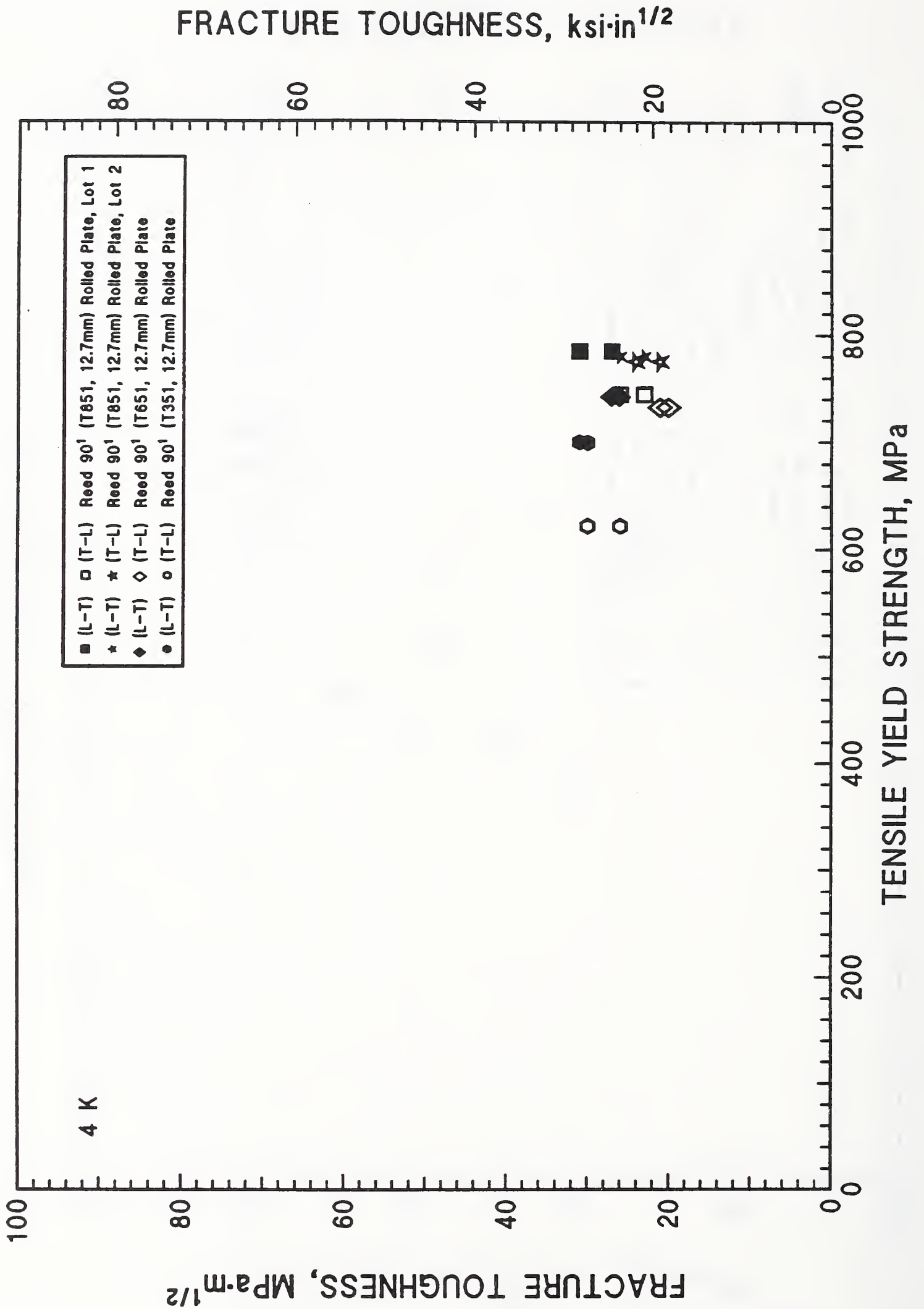
WL049



WL049



WLO49



Fracture Toughness
Alloy WL049

Ref & Note No.	Temp. K	K MPa/m	Y.S. MPa	Orient.	Temper	Product Form	Product Thickness mm	Supplier; Year; Lot Number	Aging Temp. °C	h	Cold Work %	Soln Treat. Temp. °C	Time h	Quench Cond.	Grain Size			Hardness	No. of Tests/ Data Pt
															L	X	ST		
1J	295	21.	607.	L-T	T851	Rolled Plate	12.7	Reynolds; '89;0387250A	NA	NA	NA	NA	NA	NA	4000*	1000	NA	NA	1
1J	295	22.	607.	L-T	T851	Rolled Plate	12.7	Reynolds; '89;0387250A	NA	NA	NA	NA	NA	NA	4000*	1000	NA	NA	1
1K	76	23.	712.	L-T	T851	Rolled Plate	12.7	Reynolds; '89;0387250A	NA	NA	NA	NA	NA	NA	4000	1000	NA	NA	1
1K	76	20.	712.	L-T	T851	Rolled Plate	12.7	Reynolds; '89;0387250A	NA	NA	NA	NA	NA	NA	4000*	1000	NA	NA	1
1K	4	27.	785.	L-T	T851	Rolled Plate	12.7	Reynolds; '89;0387250A	NA	NA	NA	NA	NA	NA	4000*	1000	NA	NA	1
1K	4	31.	785.	L-T	T851	Rolled Plate	12.7	Reynolds; '89;0387250A	NA	NA	NA	NA	NA	NA	4000*	1000	NA	NA	1
1V	295	25.	615.	L-T	T851	Rolled Plate	12.7	Reynolds; '90;900Z311A	NA	NA	NA	NA	NA	NA	4000*	1000	NA	NA	1
1W	4	26.	780.	L-T	T851	Rolled Plate	12.7	Reynolds; '90;900Z311A	NA	NA	NA	NA	NA	NA	4000	1000	NA	NA	1
1W	4	23.	780.	L-T	T851	Rolled Plate	12.7	Reynolds; '90;900Z311A	NA	NA	NA	NA	NA	NA	4000	1000	NA	NA	1
1W	76	21.	717.	L-T	T851	Rolled Plate	12.7	Reynolds; '90;900Z311A	NA	NA	NA	NA	NA	NA	4000*	1000	NA	NA	1
18A	294	24.	714.	L-T	T8	Extruded Bar	19.05	M.M. ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18A	77	22.3	783.	L-T	T8	Extruded Bar	19.05	M.M. ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18B	294	33.8	618.	L-T	UAT8	Extruded Bar	19.05	M.M. ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18B	77	27.	676.	L-T	UAT8	Extruded Bar	19.05	M.M. ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18E	294	27.8	633.	L-T	UAT8	Extruded Bar	19.1	M.M. ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18E	77	22.4	701.	L-T	UAT8	Extruded Bar	19.1	M.M. ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18E	77	21.	701.	L-T	UAT8	Extruded Bar	19.1	M.M. ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1L	295	25.	567.	L-T	T651	Rolled Plate	12.7	Reynolds; '89;0387240A	NA	NA	NA	NA	NA	NA	1000	500	NA	NA	1

Ref & Note No.	Temp. K	Y.S. MPa/m	Orient.	Temper	Product Form	Product Thickness mm	Supplier;		Aging		Cold Work		SoIn Treat.		Quench Cond.	Grain Size			Hardness	No. of Tests/ Date Pt
							Year;	Lot Number	Temp. °C	h	Temp. °C	%	Temp. °C	h		L	X	SI		
1L	295	23.	567.	L-T	T651	Rolled Plate	12.7	Reynolde; '89;0387240A	NA	NA	NA	NA	NA	NA	NA	1000	500	NA	NA	1
1M	76	25.	671.	L-T	T651	Rolled Plate	12.7	Reynolde; '89;0387240A	NA	NA	NA	NA	NA	NA	NA	1000	500	NA	NA	1
1M	76	21.	671.	L-T	T651	Rolled Plate	12.7	Reynolde; '89;0387240A	NA	NA	NA	NA	NA	NA	NA	1000	500	NA	NA	1
1M	4	26.	742.	L-T	T651	Rolled Plate	12.7	Reynolde; '89;0387240A	NA	NA	NA	NA	NA	NA	NA	1000	500	NA	NA	1
1M	4	27.	742.	L-T	T651	Rolled Plate	12.7	Reynolde; '89;0387240A	NA	NA	NA	NA	NA	NA	NA	1000	500	NA	NA	1
1N	295	53.	453.	L-T	T351	Rolled Plate	12.7	Reynolde; '89;0387230A	NA	NA	NA	NA	NA	NA	NA	800	400	NA	NA	1
1N	295	54.	453.	L-T	T351	Rolled Plate	12.7	Reynolde; '89;0387230A	NA	NA	NA	NA	NA	NA	NA	800	400	NA	NA	1
1O	77	37.	583.	L-T	T351	Rolled Plate	12.7	Reynolds; '89;0387230A	NA	NA	NA	NA	NA	NA	NA	800	400	NA	NA	1
1O	76	43.	583.	L-T	T351	Rolled Plate	12.7	Reynolds; '89;0387230A	NA	NA	NA	NA	NA	NA	NA	800	400	NA	NA	1
1O	4	30.	699.	L-T	T351	Rolled Plate	12.7	Reynolds; '89;0387230A	NA	NA	NA	NA	NA	NA	NA	800	400	NA	NA	1
1O	4	31.	699.	L-T	T351	Rolled Plate	12.7	Reynolds; '89;0387230A	NA	NA	NA	NA	NA	NA	NA	800	400	NA	NA	1
18C	294	38.7	407.	L-T	T3	Extruded Bar	19.05	M.M.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18D	294	36.9	407.	L-T	T3	Extruded Bar	19.1	M.M.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1J	295	23.	581.	T-L	T651	Rolled Plate	12.7	Reynolde; '89;0387250A	NA	NA	NA	NA	NA	NA	4000*	1000	NA	NA	NA	1
1J	295	23.	581.	T-L	T651	Rolled Plate	12.7	Reynolds; '89;0387250A	NA	NA	NA	NA	NA	NA	4000*	1000	NA	NA	NA	1
1K	76	22.	677.	T-L	T651	Rolled Plate	12.7	Reynolds; '89;0387250A	NA	NA	NA	NA	NA	NA	4000*	1000	NA	NA	NA	1
1K	76	20.	677.	T-L	T651	Rolled Plate	12.7	Reynolds; '89;0387250A	NA	NA	NA	NA	NA	NA	4000*	1000	NA	NA	NA	1
1K	4	26.	744.	T-L	T651	Rolled Plate	12.7	Reynolds; '89;0387250A	NA	NA	NA	NA	NA	NA	4000	1000	NA	NA	NA	1
1K	4	23.	744.	T-L	T651	Rolled Plate	12.7	Reynolds; '89;0387250A	NA	NA	NA	NA	NA	NA	4000*	1000	NA	NA	NA	1

Ref & Nota No.	Temp. K	Y.S. MPa/m	Orient.	Tempar	Product Form	Product Thickness mm	Supplier;		Aging		Soln Treat.		Grain Size			Hardness	No. of Tests/ Data Pt
							Year;	Lot Number	Temp. °C	Time h	Temp. °C	Time h	Quench	Cond.	L		
1V	295	22.	590.	T-L	T651	Rollad Plata	12.7	Reynolds; '90; 900Z311A	NA	NA	NA	NA	4000*	1000	NA	NA	1
1W	4	24.	775.	T-L	T651	Rollad Plata	12.7	Reynolds; '90; 900Z311A	NA	NA	NA	NA	4000	1000	NA	NA	1
1W	76	22.	680.	T-L	T651	Rollad Plata	12.7	Reynolds; '90; 900Z311A	NA	NA	NA	NA	4000*	1000	NA	NA	1
1W	4	21.	775.	T-L	T651	Rollad Plata	12.7	Reynolds; '90; 900Z311A	NA	NA	NA	NA	4000*	1000	NA	NA	1
18A	294	21.	630.	T-L	T6	Extruded Bar	19.05	M.M. ; NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18A	77	17.5	705.	T-L	T6	Extruded Bar	19.05	M.M. ; NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18B	294	26.2	566.	T-L	UAT6	Extruded Bar	19.05	M.M. ; NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18B	294	23.7	566.	T-L	UAT8	Extruded Bar	19.05	M.M. ; NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18B	77	21.5	607.	T-L	UAT8	Extruded Bar	19.05	M.M. ; NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18E	294	16.6	579.	T-L	UAT8	Extruded Bar	19.1	M.M. ; NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18E	294	19.9	579.	T-L	UAT6	Extruded Bar	19.1	M.M. ; NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18E	77	22.9	627.	T-L	UAT8	Extruded Bar	19.1	M.M. ; NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18E	77	19.2	627.	T-L	UAT8	Extruded Bar	19.1	M.M. ; NA	NA	NA	NA	NA	NA	NA	NA	NA	1
1M	76	21.	637.	T-L	T651	Rollad Plata	12.7	Reynolds; '89; 0367240A	NA	NA	NA	NA	1000	500	NA	NA	1
1M	76	23.	637.	T-L	T651	Rollad Plata	12.7	Reynolds; '69; 0367240A	NA	NA	NA	NA	1000	500	NA	NA	1
1M	4	21.	732.	T-L	T651	Rollad Plata	12.7	Reynolds; '69; 0367240A	NA	NA	NA	NA	1000	500	NA	NA	1
1M	4	20.	732.	T-L	T651	Rollad Plata	12.7	Reynolds; '69; 0367240A	NA	NA	NA	NA	1000	500	NA	NA	1
1N	295	61.	412.	T-L	T351	Rollad Plata	12.7	Reynolds; '89; 0367230A	NA	NA	NA	NA	600	400	NA	NA	1
1N	295	47.	412.	T-L	T351	Rollad Plata	12.7	Reynolds; '69; 0367230A	NA	NA	NA	NA	800	400	NA	NA	1

Ref & Note No.	Temp. K	K MPa/m	Y.S. MPa	Orient.	Temper	Product Form	Product Thickness mm	Supplier;		Aging		Cold Work		Soln Treat.		Grain Size			No. of Tests/ Data Pt	
								Year;	Lot Number	Temp. °C	Time h	Temp. °C	Time h	Temp. °C	Time h	Quench Cond.	L	T		X
10	77	43.	506.	T-L	T351	Rolled Plate	12.7	Reynolds;	'89;0387230A	NA	NA	NA	NA	NA	NA	800	NA	400	NA	1
10	76	42.	506.	T-L	T351	Rolled Plate	12.7	Reynolds;	'89;0387230A	NA	NA	NA	NA	NA	NA	800	NA	400	NA	1
10	4	26.	621.	T-L	T351	Rolled Plate	12.7	Reynolds;	'89;0387230A	NA	NA	NA	NA	NA	NA	800	NA	400	NA	1
10	4	30.	621.	T-L	T351	Rolled Plate	12.7	Reynolds;	'89;0387230A	NA	NA	NA	NA	NA	NA	800	NA	400	NA	1
18C	284	37.7	408.	T-L	T3	Extruded Bar	19.05	M.M.	;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18C	77	40.3	427.	T-L	T3	Extruded Bar	19.05	M.M.	;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18D	284	29.8	359.	T-L	T3	Extruded Bar	19.1	M.M.	;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18D	294	30.9	359.	T-L	T3	Extruded Bar	19.1	M.M.	;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18D	77	31.8	457.	T-L	T3	Extruded Bar	19.1	M.M.	;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
18D	77	30.9	457.	T-L	T3	Extruded Bar	19.1	M.M.	;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

Comments from the Al-Li Alloy WL049 Data Table

Reference and
Note Number

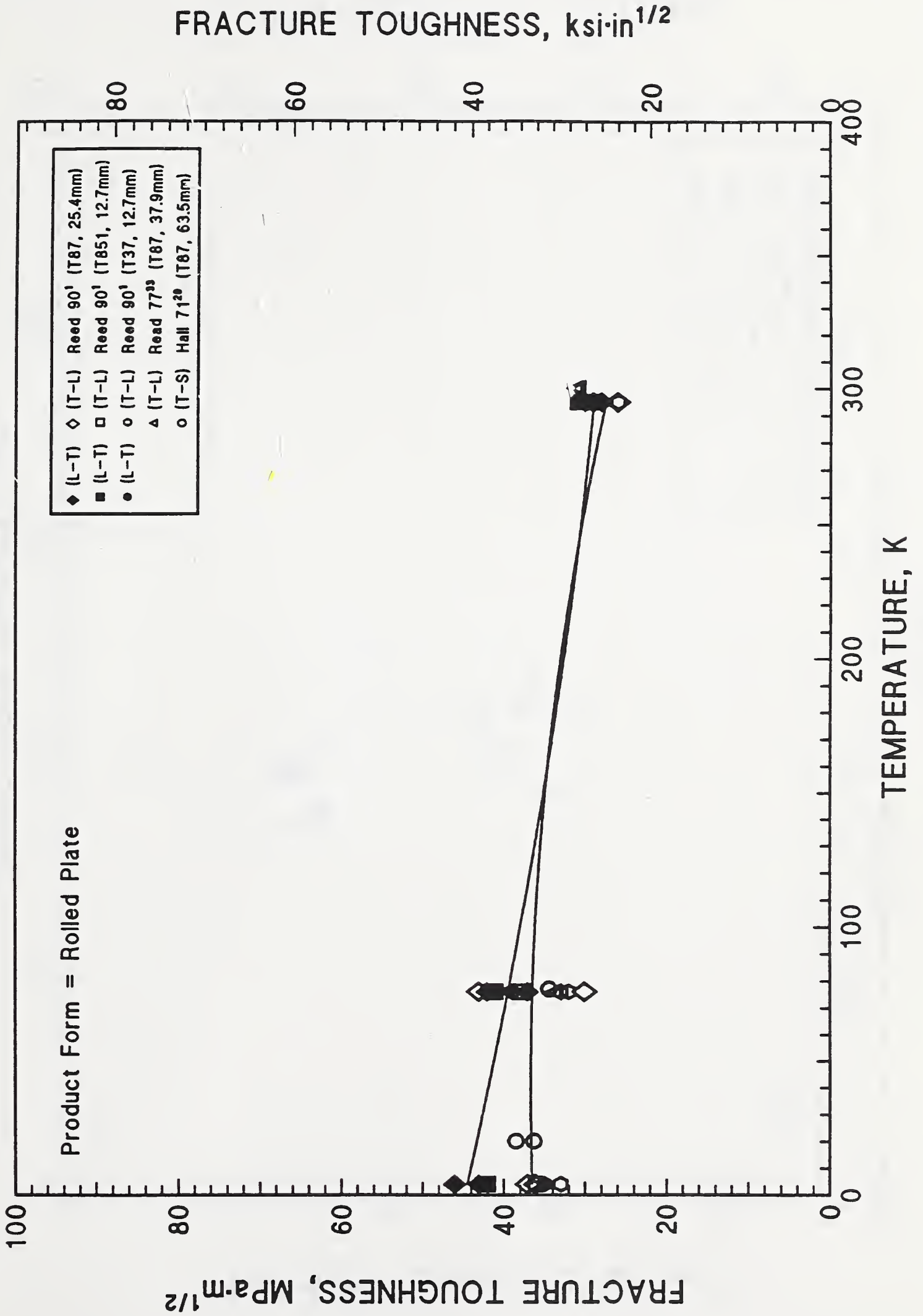
1J-K--Values reported are the average of the range of grain sizes.

18A-E--Under the supplier column, M.M. = Martin Marietta.

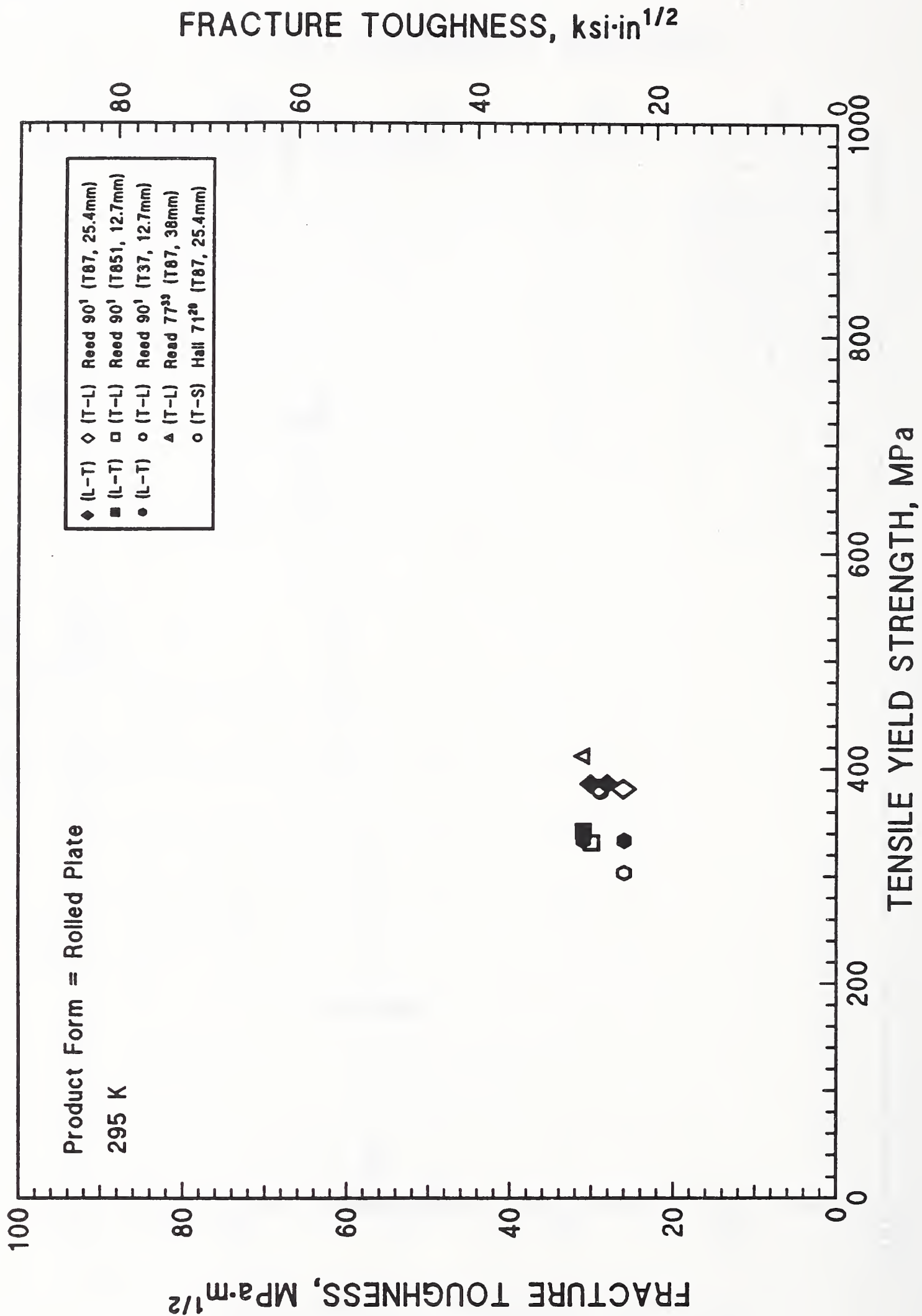
Fracture Toughness
Test Conditions
Alloy ML049

Ref & Note	Specimen Type	Specimen Dimensions			Precrack Temp K	Precrack Freq Hz	Side- Groove	Multi- Spec. no/#	Invalidating Criterion	Major Elements							Procedures
		B	W	e/W mm						Other	Li	Cu	Mg	Zr	Si	Fe	
1J	CT	12.7	50.8	NA	NA	285	20.	no	NA	0.38	4.7	0.4	0.12	0.02	0.03	0.37	ASTM E813
1K	CT	12.7	50.8	NA	NA	76	20.	no	NA	0.38	4.7	0.4	0.12	0.02	0.03	0.37	ASTM E813
1L	CT	12.7	50.8	NA	NA	285	20.	no	NA	1.28	4.7	0.4	0.12	0.02	0.03	0.35	ASTM E813
1M	CT	12.7	50.8	NA	NA	76	20.	no	NA	1.28	4.7	0.4	0.12	0.02	0.03	0.35	ASTM E813
1N	CT	12.7	50.8	NA	NA	285	20.	no	NA	1.28	4.7	0.4	0.12	0.02	0.03	NA	ASTM E813
1O	CT	12.7	50.8	NA	NA	76	20.	no	NA	1.28	4.7	0.4	0.12	0.02	0.03	NA	ASTM E813
18A	CT	NA	NA	NA	NA	NA	NA	NA	NA	1.3	5.	0.4	0.14	NA	NA	0.4	ASTM E399
18B	CT	NA	NA	NA	NA	NA	NA	NA	NA	1.3	5.	0.4	0.14	NA	NA	0.4	ASTM E399
18C	CT	NA	NA	NA	NA	NA	NA	NA	NA	1.3	5.	0.4	0.14	NA	NA	0.4	ASTM E399
18D	CT	NA	NA	NA	NA	NA	NA	NA	NA	1.4	6.2	0.4	0.14	NA	NA	0.4	ASTM E399
18E	CT	NA	NA	NA	NA	NA	NA	NA	NA	1.4	6.2	0.4	0.14	NA	NA	0.4	ASTM E399

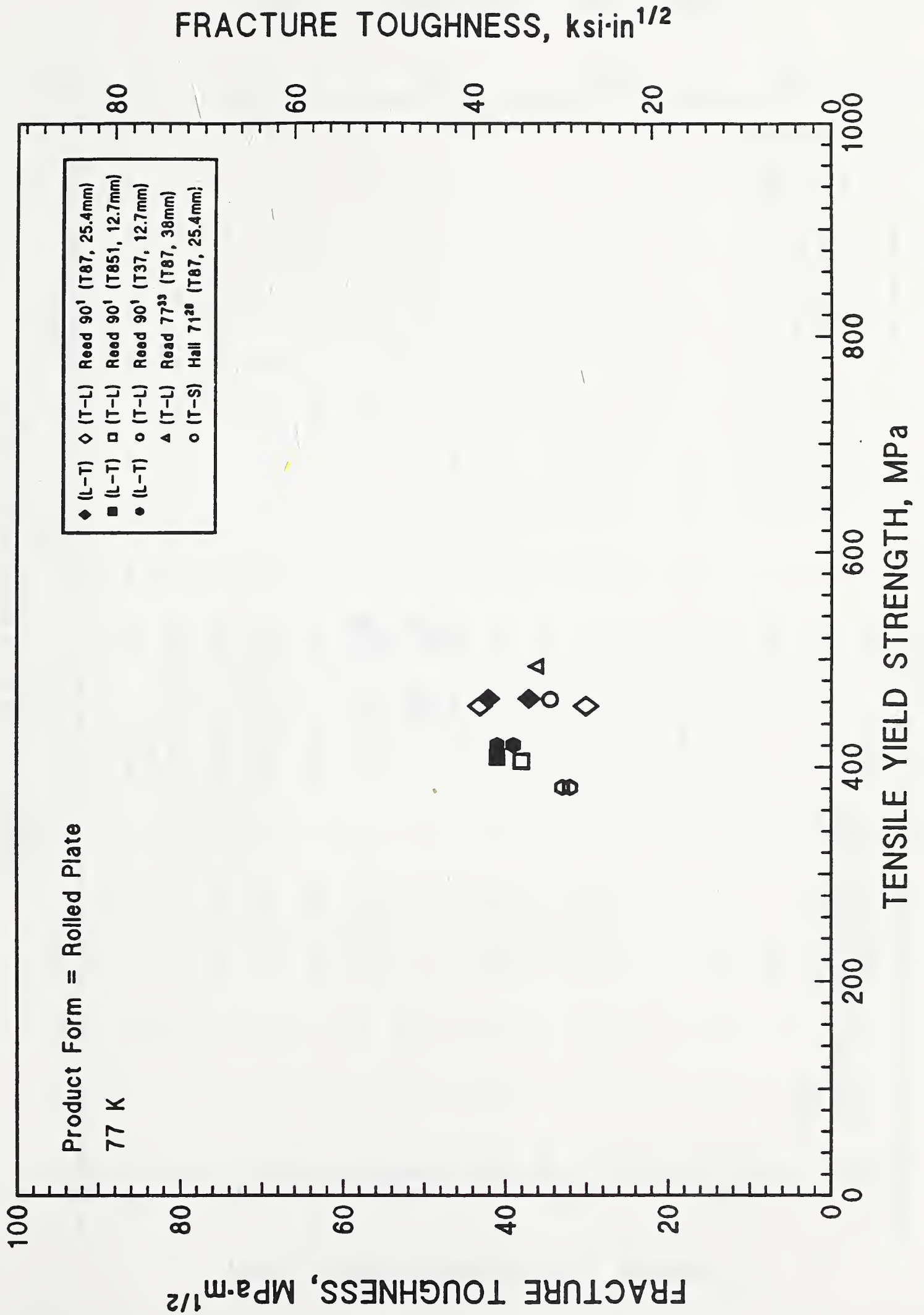
2219



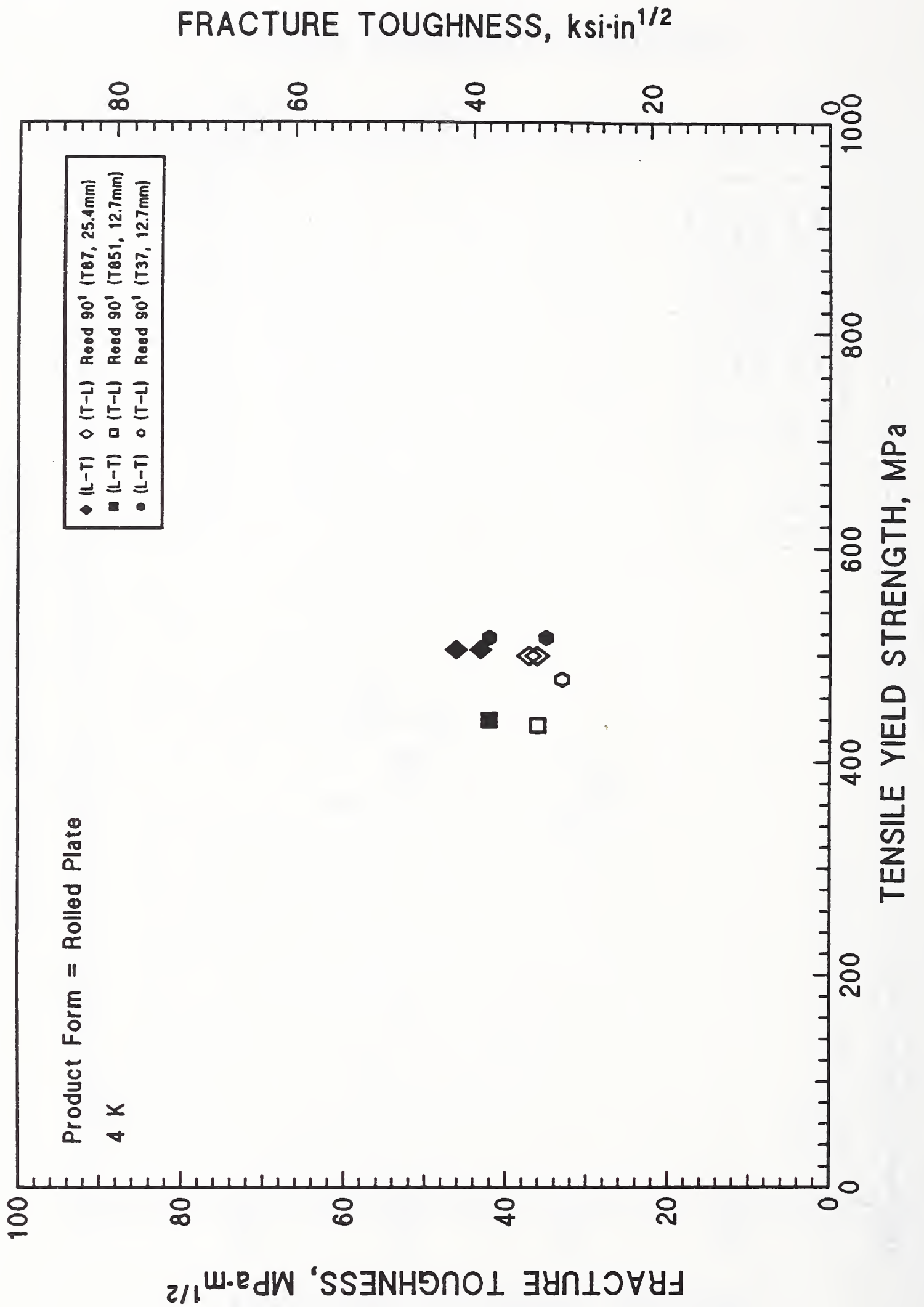
2219



2219



2219



Fracture Toughness
Alloy 2219

Ref & Note No.	Temp. K	K MPe/m	Y.S. Orient. MPe	Temper	Product Form	Product Thickness mm	Supplier; Year; Lot Number	Aging		Soln Treat.		Quench Cond.	Grain Size			Hardness	No. of Tests/ Data Pt
								Temp. °C	h	Temp. °C	h		L	X	ST		
1P	295	30.	386.	L-T	T87	25.4	NASA; '90 ; 484881	NA	NA	NA	NA	NA	300	50	NA	NA	1
1P	295	28.	386.	L-T	T87	25.4	NASA; '90 ; 484881	NA	NA	NA	NA	NA	300	50	NA	NA	1
1Q	77	42.	463.	L-T	T87	25.4	NASA; '90 ; 484881	NA	NA	NA	NA	NA	300	50	NA	NA	1
1Q	77	37.	463.	L-T	T87	25.4	NASA; '90 ; 484881	NA	NA	NA	NA	NA	300	50	NA	NA	1
1Q	4	46.	505.	L-T	T87	25.4	NASA; '90 ; 484881	NA	NA	NA	NA	NA	300	50	NA	NA	1
1Q	4	43.	505.	L-T	T87	25.4	NASA; '90 ; 484881	NA	NA	NA	NA	NA	300	50	NA	NA	1
1R	295	31.	342.	L-T	T851	12.7	Kaiser; '89 ; 429881	NA	NA	NA	NA	NA	175	NA	50	154.8, V	1
1S	76	41.	409.	L-T	T851	12.7	Kaiser; '89 ; 429881	NA	NA	NA	NA	NA	175	NA	50	154.8, V	1
1S	4	42.	439.	L-T	T851	12.7	Kaiser; '89 ; 429881	NA	NA	NA	NA	NA	175	NA	50	154.8, V	1
1T	295	26.	333.	L-T	T37	12.7	Kaiser; '89 ; 486341	NA	NA	NA	NA	NA	175	NA	50	142.9, V	1
1T	295	31.	333.	L-T	T37	12.7	Kaiser; '89 ; 486342	NA	NA	NA	NA	NA	175	NA	50	142.9, V	1
1U	76	39.	420.	L-T	T37	12.7	Kaiser; '89 ; 486341	NA	NA	NA	NA	NA	175	NA	50	142.9, V	1
1U	76	41.	420.	L-T	T37	12.7	Kaiser; '89 ; 486342	NA	NA	NA	NA	NA	175	NA	50	142.9, V	1
1U	4	42.	516.	L-T	T37	12.7	Kaiser; '89 ; 486342	NA	NA	NA	NA	NA	175	NA	50	142.9, V	1
1U	4	35.	516.	L-T	T37	12.7	Kaiser; '89 ; 486342	NA	NA	NA	NA	NA	175	NA	50	142.9, V	1
1P	295	26.	381.	T-L	T87	25.4	NASA; '90 ; 484881	NA	NA	NA	NA	NA	300	50	NA	NA	1
1P	295	29.	381.	T-L	T87	25.4	NASA; '90 ; 484881	NA	NA	NA	NA	NA	300	50	NA	NA	1
1Q	76	43.	456.	T-L	T87	25.4	NASA; '90 ; 484881	NA	NA	NA	NA	NA	300	50	NA	NA	1

Ref & Note No.	Temp. K	Y.S. MPa/m	Orient.	Temper	Product Form	Product Thickness mm	Supplier;		Aging		Soln Treat.		Quench			Grain Size			Hardness	No. of Tests/ Dete Pt
							Year;	Lot Number	Temp. °C	h	Temp. °C	h	Temp. °C	h	Cond.	L	X	T		
1Q	76	30.	456.	I-L	T87	Rolled Plate	25.4	NASA;'90	;484881	NA	NA	NA	NA	NA	300	50	NA	NA	NA	1
1Q	4	37.	499.	I-L	T87	Rolled Plate	25.4	NASA;'90	;484881	NA	NA	NA	NA	NA	300	50	NA	NA	NA	1
1Q	4	36.	499.	I-L	T87	Rolled Plate	25.4	NASA;'90	;484881	NA	NA	NA	NA	NA	300	50	NA	NA	NA	1
33A	300	30.6	412.	I-L	T87	Rolled Plate	38.	NA	;NA	NA	NA	NA	NA	NA	NA	3000	NA	B 81.1	1	
33A	300	31.	412.	I-L	T87	Rolled Plate	38.	NA	;NA	NA	NA	NA	NA	NA	NA	3000	NA	B 81.1	1	
33A	76	33.5	493.	I-L	T87	Rolled Plate	38.	NA	;NA	NA	NA	NA	NA	NA	NA	3000	NA	B 81.1	1	
33A	76	37.2	493.	I-L	T87	Rolled Plate	38.	NA	;NA	NA	NA	NA	NA	NA	NA	3000	NA	B 81.1	1	
1R	295	30.	331.	I-L	T851	Rolled Plate	12.7	Keisler;'89	;429881	NA	NA	NA	NA	NA	175	NA	50	154.8, V	1	
1S	76	38.	405.	I-L	T851	Rolled Plate	12.7	Keisler;'69	;429881	NA	NA	NA	NA	NA	175	NA	50	154.8, V	1	
1S	4	36.	434.	I-L	T851	Rolled Plate	12.7	Keisler;'69	;429881	NA	NA	NA	NA	NA	175	NA	50	154.8, V	1	
1T	295	26.	303.	I-L	T37	Rolled Plate	12.7	Keisler;'69	;486341	NA	NA	NA	NA	NA	175	NA	50	142.9, V	1	
1T	295	26.	303.	I-L	T37	Rolled Plate	12.7	Keisler;'69	;486342	NA	NA	NA	NA	NA	175	NA	50	142.9, V	1	
1U	4	33.	477.	I-L	T37	Rolled Plate	12.7	Keisler;'69	;486341	NA	NA	NA	NA	NA	175	NA	50	142.9, V	1	
1U	76	32.	381.	I-L	T37	Rolled Plate	12.7	Keisler;'69	;486342	NA	NA	NA	NA	NA	175	NA	50	142.9, V	1	
1U	76	33.	381.	I-L	T37	Rolled Plate	12.7	Keisler;'69	;486342	NA	NA	NA	NA	NA	175	NA	50	142.9, V	1	
1U	4	33.	477.	I-L	T37	Rolled Plate	12.7	Keisler;'69	;486342	NA	NA	NA	NA	NA	175	NA	50	142.9, V	1	
29A	295	29.	379.	T-S	T87	Rolled Plate	63.5	NA	;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
29A	295	28.7	379.	T-S	T87	Rolled Plate	63.5	NA	;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	
29A	77	34.5	462.	T-S	T87	Rolled Plate	63.5	NA	;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	

Ref & Note No.	Temp. K	K MPa/m	Y.S. MPa	Orient.	Temper	Product Form	Product Thickness mm	Supplier; Year; Lot Number	Aging		Cold Work		Soln Treat.		Quench		Grain Size			Hardness	No. of Tests/ Data Pt
									Temp. °C	h	Temp. °C	%	Temp. °C	h	Cond.	L	X	I	X		
29A	77	34.4	462.	T-S	T67	Rolled Plate	63.5	NA ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
29A	20	36.3	503.	T-S	T67	Rolled Plate	63.5	NA ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
29A	20	38.5	503.	T-S	T67	Rolled Plate	63.5	NA ;NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1

3. ELASTIC CONSTANTS

3.1. Introduction to Graphs

3.1.1. Temperature Dependence

Cryogenic elastic constant data are available only for 2090-T81 (Young's modulus, E, and Poisson's ratio, ν) and 2219-T87 (E, ν , bulk modulus, B, and shear modulus, G). These data are presented as functions of temperature in four graphs and a table following this discussion. The reason that different values of E (77.7 and 74.7 GPa) were obtained for 2219-T87 at ambient temperature in the same laboratory is not understood. It is likely that the values reported in the earlier measurements are systematically too high, but the temperature dependence has not been remeasured. (A later measurement at room temperature gave a value of 74.8 GPa.) The value given in MIL-HNBK-5E³⁵ for E for alloy 2219 plate is 72.4 GPa. There is considerable disagreement in the literature about the correct value of E at ambient temperature for pure Al and, therefore, for Al alloyed with small (< 5%) amounts of other elements (see Section 3.2. below). Because there is so much uncertainty in the literature, and because so little cryogenic data are available, a table of ambient-temperature values of elastic constants from various sources for the Al-Li alloys 8090, 2090, and WL049, and alloy 2219 follows the presentation of the cryogenic data. After a value of E at ambient temperature is chosen, the following equation may be used to estimate values for $4 \text{ K} \leq T \leq 295 \text{ K}$:

$$E(T) = E(295 \text{ K}) [1.1 + 1.2 \times 10^{-4}T - 4.0 \times 10^{-6}T^2 + 1.1 \times 10^{-8}T^3 - 1.2 \times 10^{-11}T^4]. \quad (1)$$

Values derived from Equation (1) should be used with caution because it is based on the one set of measurements available for 2090.³⁷

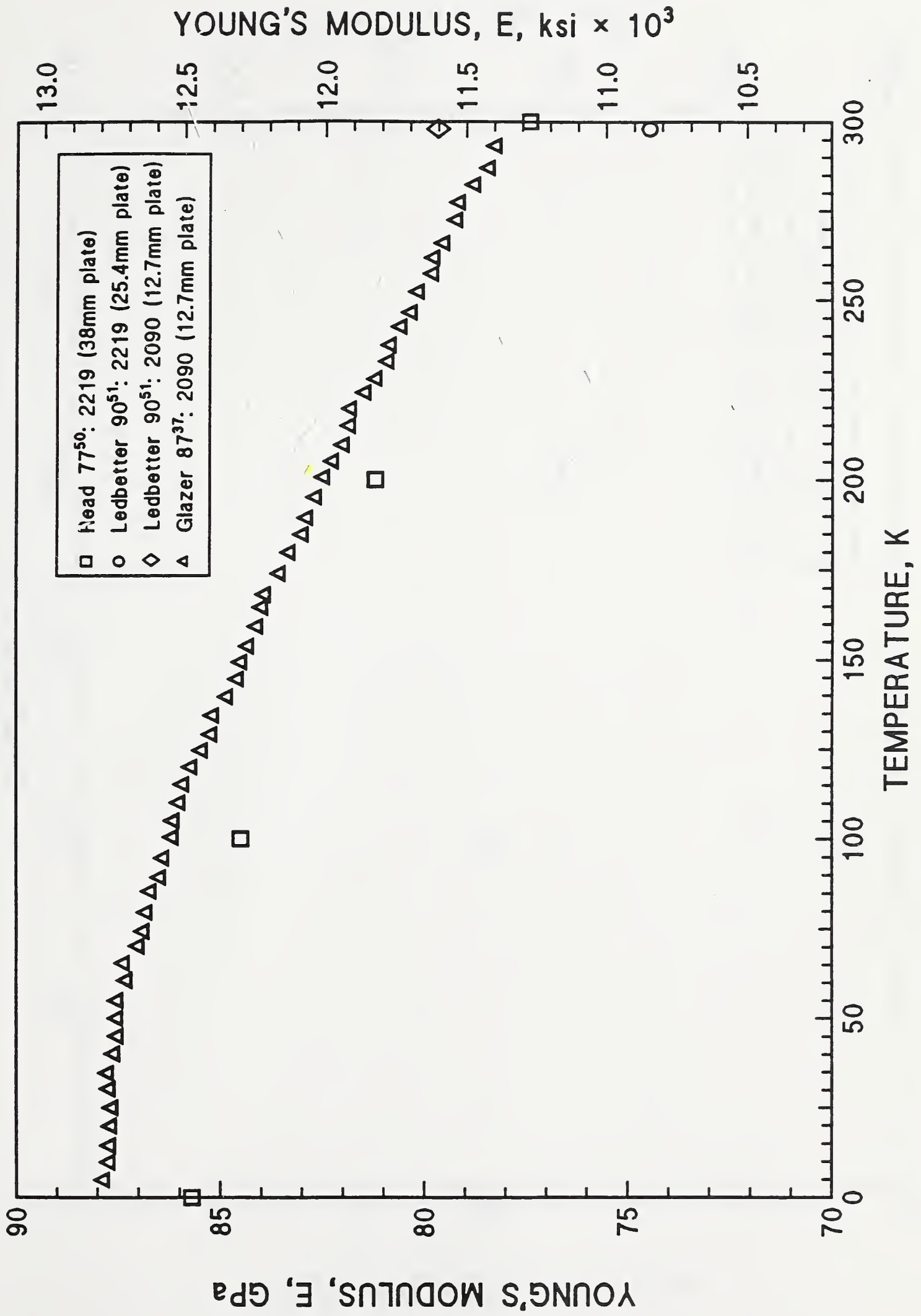
3.1.2. Effects of Alloying Elements, Cold Work, and Other Factors

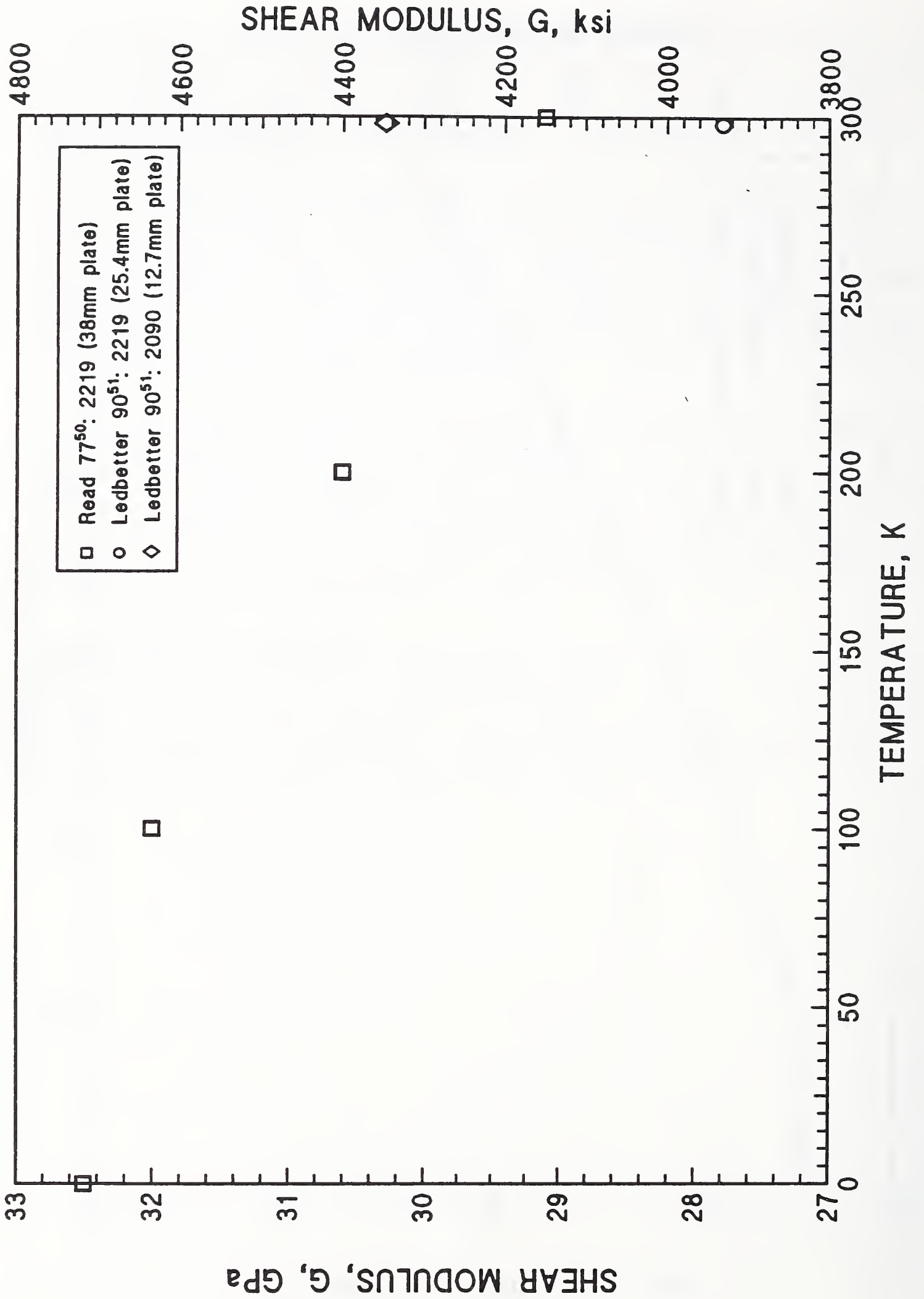
Several sets of measurements are available on the increase in E with alloying additions of Li;^{38,39} Li and Mg;³⁸ and Li and Cu.³⁹ References 38 and 39 give 66 and 62 GPa, respectively, as the ambient temperature value of E for high purity Al. Measured values of E for Al-2% Li were 79 GPa³⁸ and 73 GPa.³⁹ E was found to be 82 GPa³⁹ for Al-2024-2%Li. The composition of Al-alloy 2024 (4.5Cu, 1.5Mg, 0.6Mn) is very similar to the composition of Al-alloy 2019 (5.8-6.8Cu, 0.2-0.4Mn). However, values of E for pure Al in the literature derived from the single-crystal elastic constants measured by dynamic methods are usually about 10% higher than the values in these two references,^{38,39} averaging around 70 to 72 GPa. (Values of Al-Li and Al-Cu-Li alloys would be expected to be correspondingly higher.) Reed⁴⁰ presents a table of Al single-crystal elastic constants from several sources and uses the average of these constants to calculate an E of 70.4 GPa. The calculation is based on a formula presented by Hill⁴¹ in the early 1950s. The discrepancy between values calculated from single-crystal elastic constants using the Hill formula and static measurements of Noble³⁸ was noted by Muller et al.,⁴² but the explanation advanced, microplasticity, may not be sufficient to explain such a large disparity in the values. To validate his formula, Hill used a set of

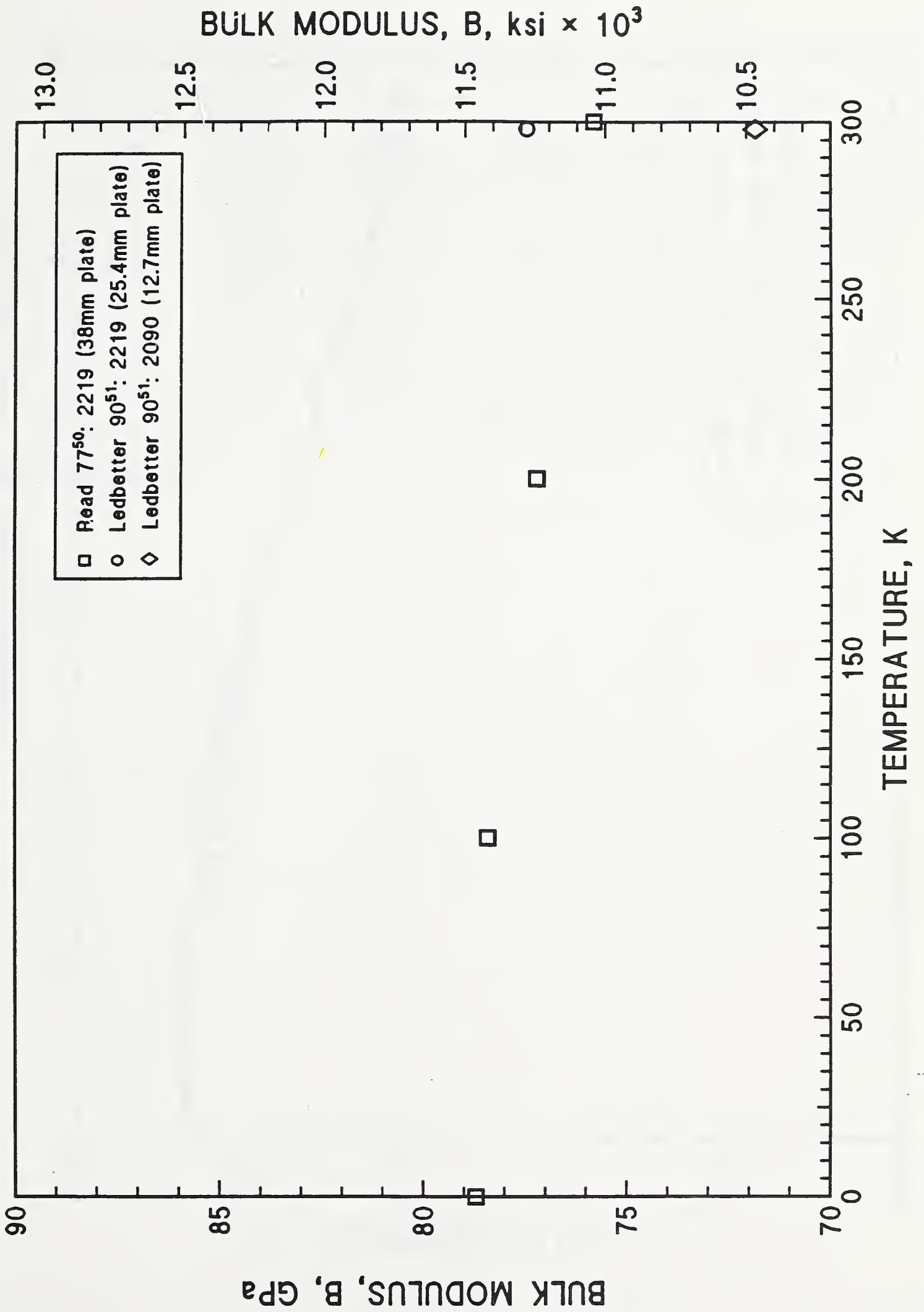
measurements on elastic constants of four common elements (including Al) whose origin is not well documented. Several dynamic measurements^{43,44,45} not based on single-crystal elastic constants and the Hill formula give about 70 GPa for E of pure Al. This disagrees with values of 66, 64, and 65 GPa obtained by static measurements⁴⁶ on commercially pure Al (99.5%) as well as the values quoted above,^{38,39} which are also derived from static measurements. Differences between static and dynamic measurements should be only about a percent,⁴⁷ and so the discrepancy should not be attributable to dissimilar measurement techniques. The Hill formula is frequently employed in the literature of basic science to calculate polycrystalline elastic constant values from single-crystal measurements. However, to our knowledge, it has not been tested against carefully evaluated measurements on polycrystalline specimens of a wide variety of elements. Furthermore, the disagreement of predicted values of E with static measurements (commonly used in the aerospace industry) has not been widely recognized.

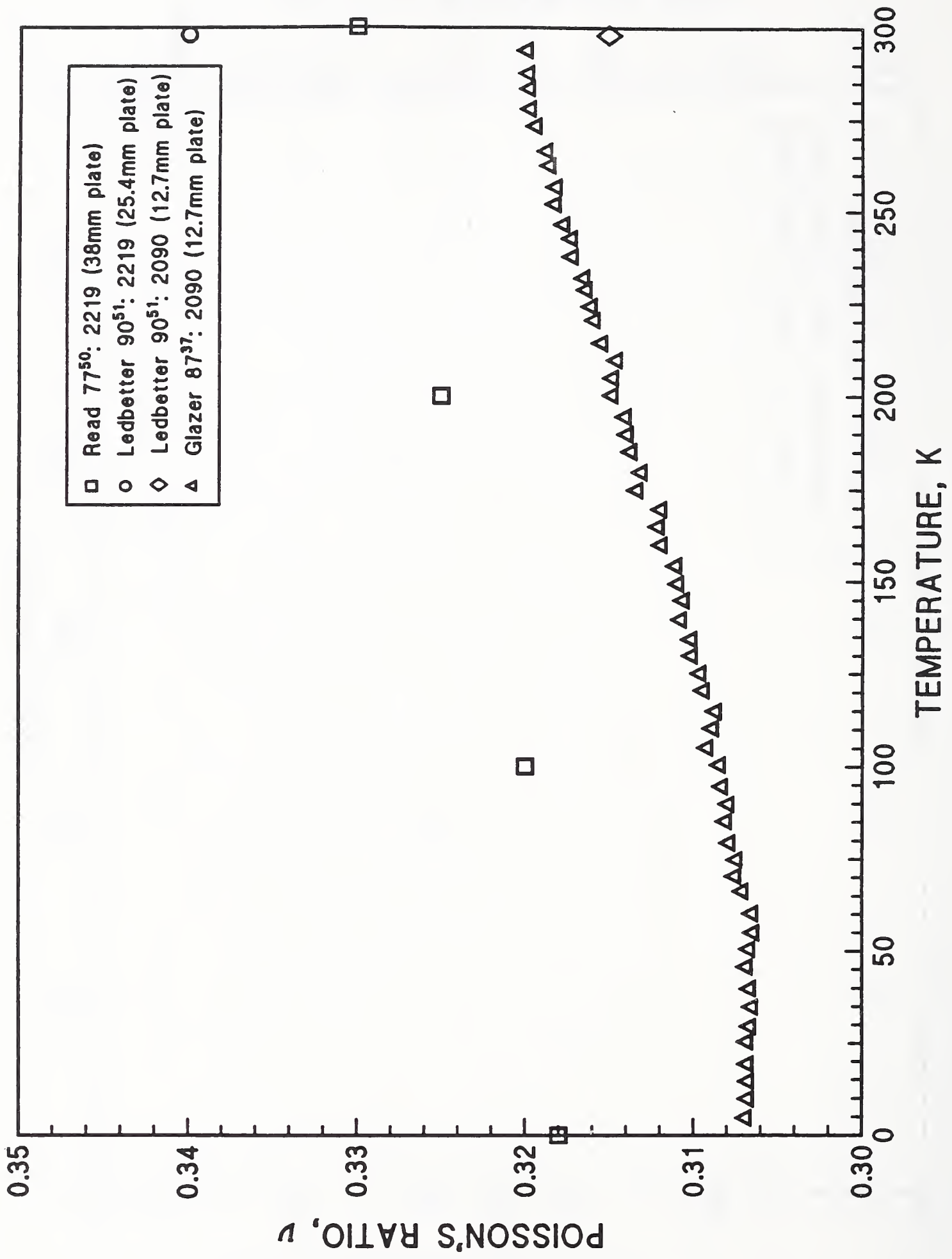
A calculation by Wawra⁴⁸ for Al gives a directional dependence for E of pure Al, such that $E_{111} = 73.8$ GPa and $E_{100} = 63.2$ GPa, which is approximately the size of the discrepancy in the measurements. Most polycrystalline Al is probably not strongly textured, however, and texture has not been reported with the measurements of E. Warwa⁴⁸ also reports a decrease of E of up to $\approx 3\%$ over a range of cold work from 0 to 100%. Decreasing the purity of the Al from 99.99 to 99.6% increased E^{48} by about 3% to a value of 72.8 GPa. These latter effects do not appear large enough to explain the discrepancy.

Varying the aging time of Al-Li alloys also has an effect on E.⁴⁹ Effects were less than 2% for aging temperature of 230, 210, and 190°C with aging times of up to 1000 h. This work was carried out on a binary Al-2.5wt%Li alloy using an ultrasonic measurement technique. Another recent paper⁴⁷ also presents results of aging treatment and specimen thickness on E and other elastic constants of 2090-T8E50 as a function of the angle from rolling direction. Effects again are small, $\approx 2-3\%$, but the anisotropy in E can be as much as 6% at 45° from the rolling direction.









Density and Elastic Constants of Al-Li Alloys and Alloy 2219 at Ambient Temperature.

Alloy	Density, kg/m ³ × 10 ³	Young's Modulus, E, GPa	Shear Modulus, G, GPa	Bulk Modulus, B, GPa	Poisson's Ratio, ν	Ref. No.	Method of Analysis
8090-T8771	--	79.3	--	--	0.292	5	1
2090-T81	2.60	79.65	30.28	71.83	0.3152	51	2
2090-T81	2.59	78.28	29.65	72.56	0.320	37	2
2090-T8E50	--	78.60	--	--	--	47	2
2090-T83	--	73.3	--	--	0.35	36	1
WL049-T851	2.71	76.60	28.83	74.46	0.3285	51	2
WL049-T851	2.70	77.9	--	--	--	52	2
2219-T87	2.82	74.46	27.79	77.45	0.3398	51	2
2219-T87	--	77.4	29.1	75.8	0.330	33	2

- 1 Static measurement.
- 2 Dynamic measurement.

Elastic Constants of Al-Li Alloys and Alloy 2219 at Low Temperatures.

Alloy	Temp., K	Young's Modulus, E, GPa	Shear Modulus, G, GPa	Bulk Modulus, B, GPa	Poisson's Ratio, ν	Ref. No.	Method of Analysis
2219	0	85.7	32.5	78.7	0.318	50	2
	100	84.5	32.0	78.4	0.320	50	2
	200	81.2	30.6	77.2	0.325	50	2
	300	77.4	29.1	75.8	0.330	50	2
2219	298	74.5	27.8	77.5	0.340	51	2
2090	298	79.7	30.3	71.8	0.315	51	2
2090	5	87.8	--	--	0.307	37	2
	10	87.7	--	--	0.307	37	2
	15	87.7	--	--	0.307	37	2
	20	87.7	--	--	0.307	37	2
	25	87.6	--	--	0.307	37	2
	30	87.7	--	--	0.307	37	2
	35	87.7	--	--	0.306	37	2
	40	87.6	--	--	0.307	37	2
	45	87.5	--	--	0.307	37	2
	50	87.5	--	--	0.307	37	2
	55	87.5	--	--	0.306	37	2
	60	87.3	--	--	0.306	37	2
	65	87.3	--	--	0.307	37	2
	70	87.0	--	--	0.307	37	2
	75	86.9	--	--	0.307	37	2
	80	86.8	--	--	0.308	37	2
	85	86.7	--	--	0.308	37	2
	90	86.5	--	--	0.308	37	2
	95	86.4	--	--	0.308	37	2
	100	86.1	--	--	0.308	37	2
	105	86.1	--	--	0.309	37	2
	110	86.0	--	--	0.309	37	2
	115	85.9	--	--	0.309	37	2
	120	85.7	--	--	0.309	37	2
	125	85.4	--	--	0.310	37	2
	130	85.2	--	--	0.310	37	2
	135	85.2	--	--	0.310	37	2
	140	84.8	--	--	0.311	37	2
	145	84.5	--	--	0.311	37	2
	150	84.5	--	--	0.311	37	2
	155	84.3	--	--	0.311	37	2
	160	84.1	--	--	0.312	37	2
	165	84.0	--	--	0.312	37	2
	170	83.9	--	--	0.312	37	2
	175	83.5	--	--	0.313	37	2
	180	83.3	--	--	0.313	37	2
	185	83.0	--	--	0.314	37	2
	190	82.9	--	--	0.314	37	2
	195	82.7	--	--	0.314	37	2

1 Static measurement.

2 Dynamic measurement.

4. THERMAL PROPERTIES

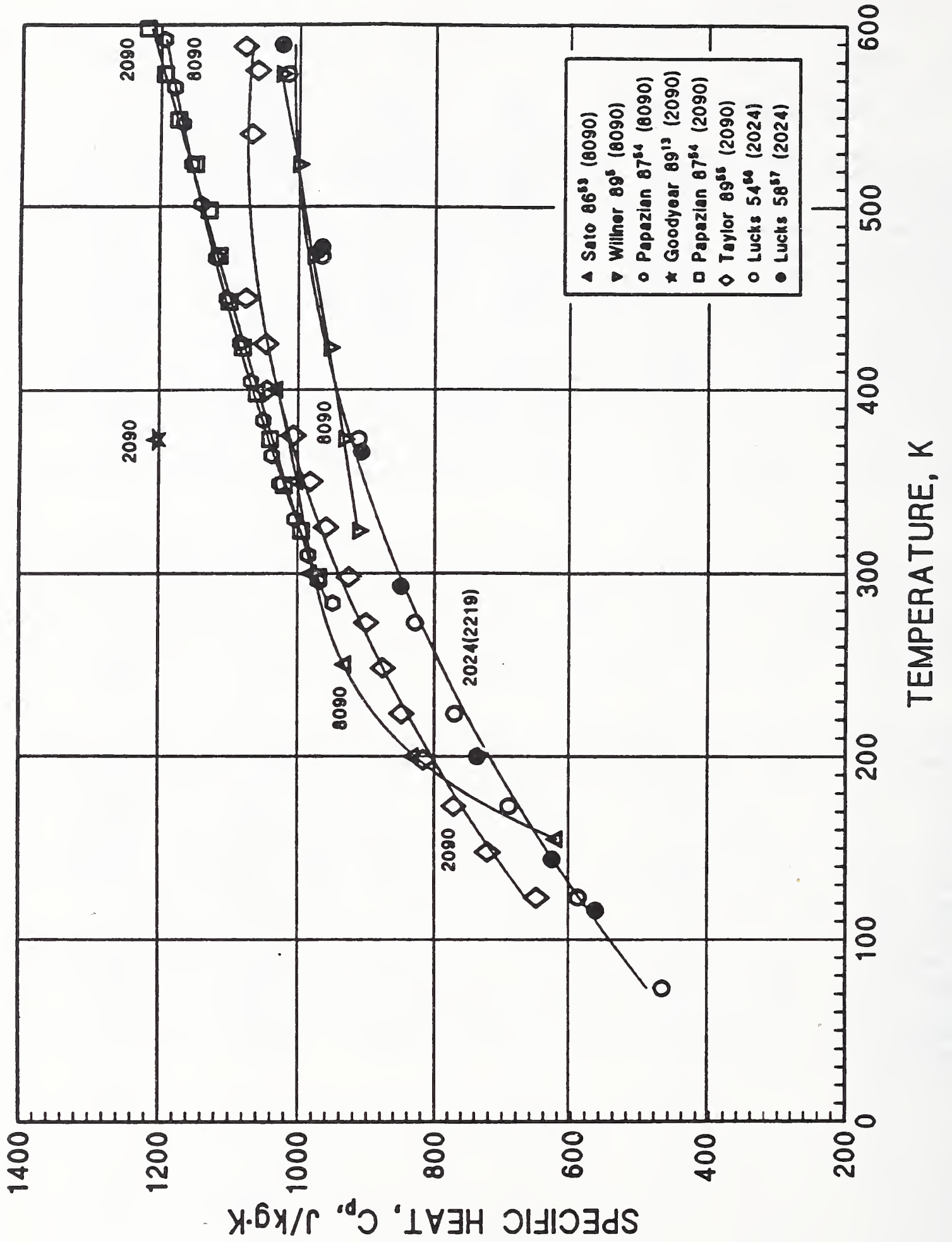
4.1. Specific Heat

4.1.1. Introduction to Graph

The available specific heat data from cryogenic temperatures to the melting point are presented in the figure and table. Measurements are available only on alloys 8090 and 2090 between 123 and 598 K. Some of these data were obtained by differential scanning calorimetry to indicate the dissolution temperature of precipitates produced by various aging treatments and the formation of subsequent phases. These are shown in a smoothed form,^{53,54,55} or are omitted⁵³ above 400 K. As shown by Papazian,⁵⁴ changes in the aging treatment move the position of the peaks and valleys along the curve to higher and lower temperatures. Taylor⁵⁵ identified the peak at ≈ 510 K in his specific heat data as the melting point of Li. However, a peak at this position is not observed in the other specific heat measurements of alloy 2090, and it seems more probable that peaks can be identified with the aging treatment. Consult the original references, which specify aging treatments, for specific heat data on alloys 8090 and 2090 with the fine structure in the curves (important only above 400 K).

At present, there are no specific heat data for alloys WL049 or 2219 in the cryogenic temperature range. The curve for the specific heat of alloy 2219 vs. temperature presented in Figure 3.2.6.0. of MIL-HDBK 5E appears to be based upon data from Al-alloy 2024.^{2,56,57} The composition of alloy 2024 (4.5Cu, 1.5Mg, and 0.6Mn), is similar to the composition of alloy 2219 (5.8-6.8Cu, and 0.2-0.4Mn). These data, labeled 2024(2219), are also given in the figure.

The specific heat of an alloy can be approximated, near ambient temperature, by a linear combination of the specific heats of the constituent elements.⁵⁸ Because the specific heat of Li is about 4 times larger than the specific heat of Al, and about 9 times larger than that of Cu, the specific heats of alloys 8090 and 2090 should be about 10% higher than that of alloy 2219. This is similar to what is shown in the specific heat figure for the data of Sato⁵³ on alloy 8090 and Papazian⁵⁴ on alloy 2090. However, the higher temperature data on alloy 8090⁴ appear quite similar to those of alloy 2024(2219), and, therefore, are probably too low. Variations in aging conditions and chemistry for individual heats can result in changes in the fine structure of a specific heat curve for Al-Li alloys, especially above ambient temperatures. This could account for this apparent discrepancy, and perhaps, also for one unexpectedly high value of specific heat¹² at 100°C. More measurements of the specific heat on current production heats of Al-Li alloys would be very desirable.



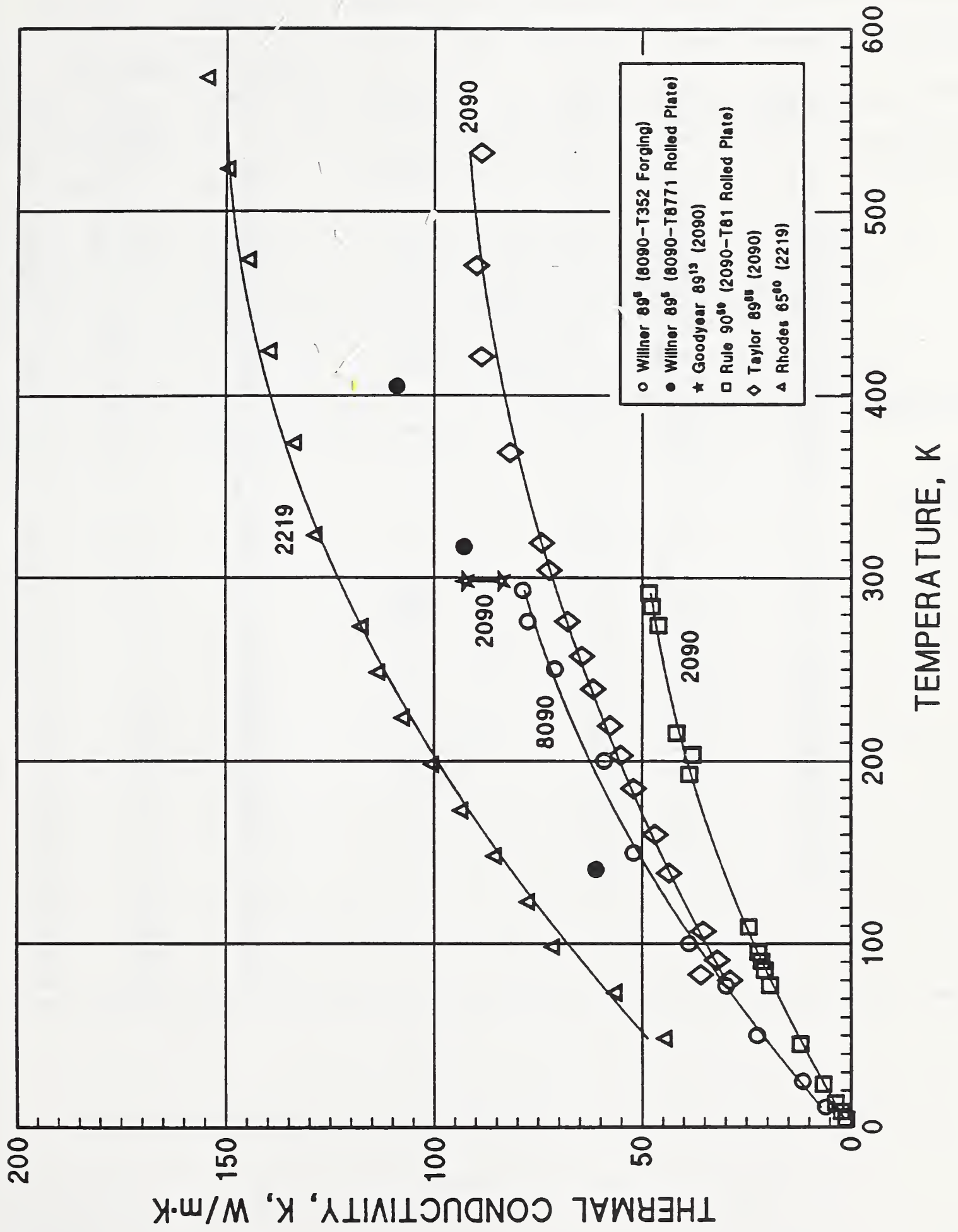
Specific Heat of Al-Li Alloys and Alloy 2219.

Alloy	Temp., K	C _p , J/kg·K	Ref. No.	Alloy	Temp., K	C _p , J/kg·K	Ref. No.
8090	155	620	54	2090	123	649	56
	200	830	54		148	720	56
	250	930	54		173	770	56
	300	980	54		198	815	56
	350	1000	54		223	847	56
	400	1030	54		248	875	56
8090	323	913	5	273	900	56	
	373	934	5	298	925	56	
	423	956	5	325	958	56	
	473	980	5	350	981	56	
	523	1002	5	375	1006	56	
	573	1027	5	400	1045	56	
	623	1047	5	425	1046	56	
	673	1070	5	450	1075	56	
8090	284	949	55	540	1068	56	
	296	969	55	575	1060	56	
	310	985	55	588	1078	56	
	329	1005	55	2024(2219)	73	469	57
	349	1026	55	123	590	57	
	364	1038	55	173	690	57	
	383	1051	55	223	770	57	
	404	1069	55	273	828	57	
	426	1085	55	373	912	57	
	450	1104	55	473	967	57	
	472	1120	55	573	1017	57	
	501	1141	55	2024(2219)	116	565	58
	523	1155	55	144	628	58	
	546	1168	55	200	736	58	
	566	1181	55	293	849	58	
	592	1195	55	366	908	58	
	2090	373	1203	13	478	966	58
	2090	298	970	55	589	1025	58
	323	995	55				
	348	1020	55				
	373	1040	55				
	398	1060	55				
	423	1080	55				
	448	1100	55				
	473	1115	55				
	498	1130	55				
	523	1150	55				
	548	1175	55				
	573	1195	55				
	598	1220	55				

4.2. Thermal Conductivity

4.2.1. Introduction to Graph

Thermal conductivity data for alloys 8090, 2090, and 2219 between 4 and 573 K are given in the accompanying thermal conductivity figure and table. No data on WL049 are currently available. The solid lines shown in the figure represent the fit of second-order polynomials to the data for alloy 8090,⁴ alloy 2090,^{53,59} and alloy 2219.⁶⁰ The data of Rule⁵⁹ appear to be anomalously low. However, thermal conductivity of Al alloys at low temperatures is composition and cold-work sensitive.⁶¹



Thermal Conductivity of Al-Li Alloys and Alloy 2219.

Alloy	Temp., K	K, W/m·K	Ref. No.	Alloy	Temp., K	K, W/m·K	Ref. No.
8090-T352	11	6.1	5	2090	80	28.8	56
	25	11.6	5		83	35.8	56
	50	22.5	5		91	31.9	56
	77	29.9	5		107	35.2	56
	100	38.8	5		139	43.4	56
	150	52.1	5		160	46.7	56
	200	59.2	5		185	51.9	56
	250	71.0	5		203	55.0	56
	276	77.5	5		219	57.6	56
	293	78.7	5		239	61.7	56
	8090-T8771	141	61.1		5	257	64.4
317		92.8	5	276	67.8	56	
404		109.	5	304	72.2	56	
2090	298	87.9	13	319	74.0	56	
2090-T81	4	1.1	60	368	81.6	56	
	8	2.2	60	420	88.5	56	
	13	3.6	60	470	89.7	56	
	23	6.6	60	532	88.5	56	
	45	12.1	60	2219	48	44	61
	77	19.4	60		73	56	61
	85	20.6	60		98	71	61
	90	21.4	60		123	77	61
	95	22.1	60		148	85	61
	109	24.4	60		173	93	61
	193	38.6	60		198	100	61
	203	37.9	60		223	107	61
	215	41.7	60		248	113	61
	274	46.1	60		273	117	61
	284	47.7	60		323	128	61
	292	48.4	60		373	133	61
					423	139	61
			473		144	61	
			523		149	61	
			573		154	61	

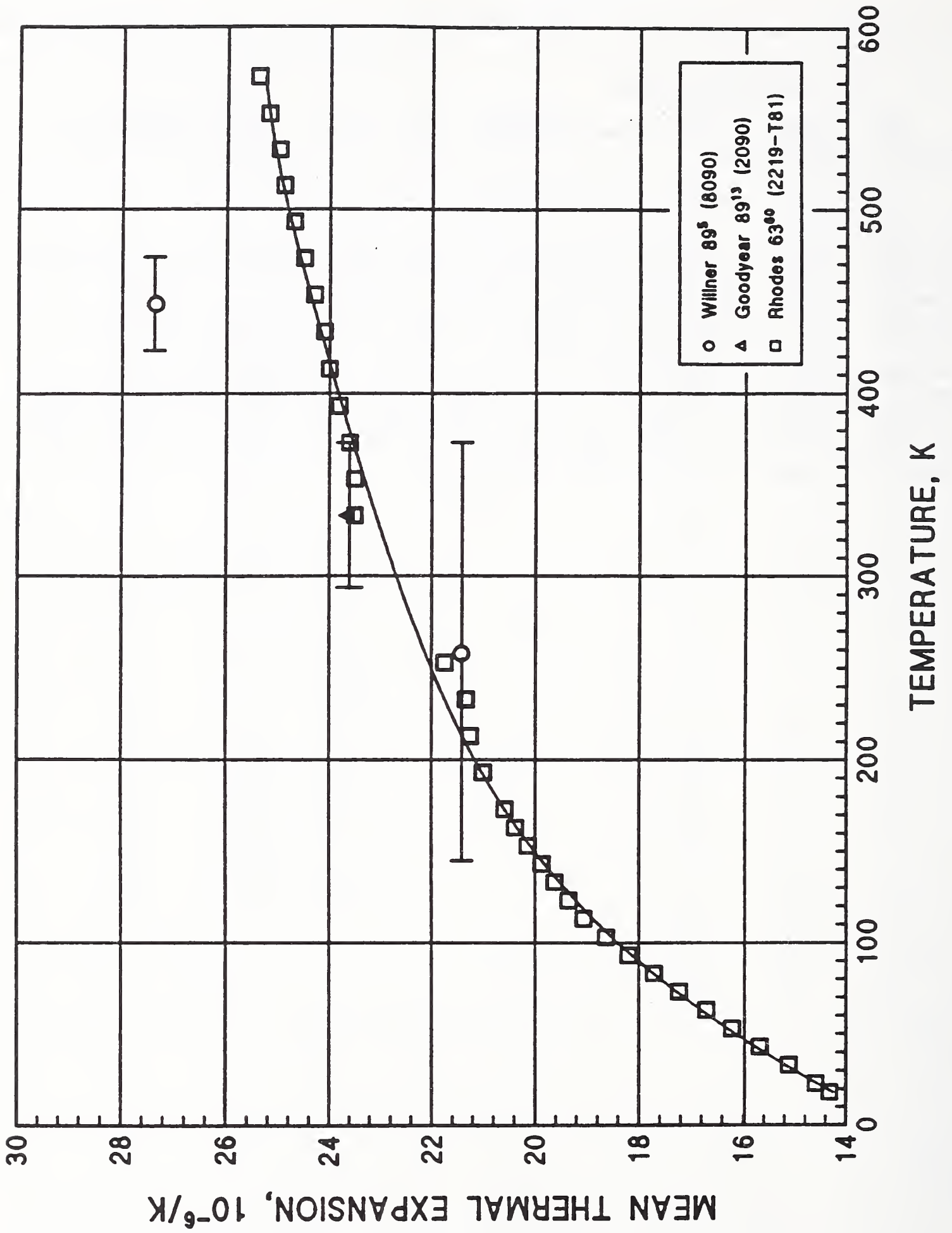
4.3. Mean Thermal Expansion

4.3.1. Introduction to Graph

The figure on mean thermal expansion presents the data available on the property, defined as

$$\Delta L/L \cdot \Delta T = [L(293 \text{ K}) - L(T)]/[L(293 \text{ K}) (293 \text{ K} - T)].$$

Only data for alloy 2219-T87 are available over a wide temperature range, from 18 to 573 K. The values presented for alloys 8090 and 2090 are averages obtained over the temperature range indicated in the graph. Near 293 K, the quantity $\Delta L/L \cdot \Delta T$ becomes less accurate, because a smaller length change is measured. Mean thermal expansion data for alloy 2219 near 293 K were eliminated if a wide degree of scatter was evident. Although only one set of thermal expansion data for alloy 2219 is available, that data set is in fair agreement with several sets of data for alloy 6061 (0.6 Si, 0.27 Cu, 1.0 Mg, 0.2 Cr) over a similar temperature range. The data are also presented in the thermal expansion table that follows the graph.



Mean Thermal Expansion of Al-Li Alloys and Alloy 2219.

Alloy	Temp., K	$\frac{1}{L} \frac{\Delta L}{\Delta T},$ $10^{-5}K^{-1}$	Ref. No.
8090	258	27.4	5
	448	21.4	5
2090	333	23.6	13
2219-T81	18	14.3	61
	23	14.6	61
	33	15.1	61
	43	15.7	61
	53	16.2	61
	63	16.7	61
	73	17.2	61
	83	17.7	61
	93	18.2	61
	103	18.6	61
	113	19.1	61
	123	19.4	61
	133	19.6	61
	143	19.9	61
	153	20.1	61
	163	20.4	61
	173	20.6	61
	193	21.0	61
	213	21.3	61
	233	21.3	61
	253	21.8	61
	333	23.5	61
	353	23.5	61
373	23.6	61	
393	23.8	61	
413	24.0	61	
433	24.1	61	
453	24.3	61	
473	24.5	61	
493	24.7	61	
513	24.9	61	
533	25.0	61	
553	25.2	61	
573	25.4	61	

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6. REFERENCES

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The review of cryogenic mechanical and thermal properties presented here is part of a broader National Institute of Standards and Technology (NIST) program to assess new high-strength Al-Li alloys for use in the cryogenic tankage of the Advanced Launch System (ALS). The purpose of the NIST program has been to assess the relative suitability of high-strength Al-Li alloys and alloy 2219 for use in ALS cryogenic tanks. In this report, the cryogenic data on Al-Li alloys 8090, 2090, WL049, and Al alloy 2219 have been summarized. Properties covered in this survey are tensile strength, yield strength, elongation, fracture toughness, elastic constants, specific heat, thermal conductivity, and thermal expansion.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

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