

MIL-HDBK-5H, Change Notice 1
1 October 2001

3.2.3 2024 ALLOY

3.2.3.0 *Comments and Properties*—2024 is a heat-treatable Al-Cu alloy which is available in a wide variety of product forms and tempers. The properties vary markedly with temper; those in T3 and T4 type tempers are noteworthy for their high toughness, while T6 and T8 type tempers have very high strength. This alloy has excellent properties and creep resistance at elevated temperatures. The T6 and T8 type tempers have very high resistance to corrosion. However, as shown in Table 3.1.2.3.1(a), 2024-T3, -T4, and -T42 rolled plate, rod and bar, and extruded shapes and 2024-T6 and -T62 forgings have a ‘D’ SCC rating. This is the lowest rating and means that SCC failures have occurred in service or would be anticipated if there is any sustained stress. In-service failures are caused by stresses produced by any combination of sources including solution heat treatment, straightening, forming, fit-up, clamping, sustained service loads or high service compression stresses that produce residual tensile stresses. These stresses may be tension or compression as well as the stresses due to the Poisson effect, because the actual failures are caused by the resulting sustained shear stresses. Pin-hole flaws in corrosion protection are sufficient for SCC. The weldability of the alloy is discussed in Section 3.1.3.4.

The properties of extrusions should be based upon the thickness at the time of quenching prior to machining. Selection of the mechanical properties based upon its final machined thickness may be unconservative; therefore, the thickness at the time of quenching to achieve properties is an important factor in the selection of the proper thickness column. For extrusions having sections with various thicknesses, consideration should be given to the properties as a function of thickness.

Material specifications for 2024 are presented in Table 3.2.3.0(a). Room-temperature mechanical properties are shown in Tables 3.2.3.0(b) through (j₂). The effect of temperature on the physical properties of this alloy is shown in Figure 3.2.3.0.

Table 3.2.3.0(a). Material Specifications for 2024 Aluminum Alloy

Specification	Form
AMS 4037	Bare sheet and plate
AMS 4035	Bare sheet and plate
AMS-QQ-A-250/4	Bare sheet and plate
AMS-QQ-A-250/5	Clad sheet and plate
AMS 4120	Bar and rod, rolled or cold-finished
AMS-QQ-A-225/6	Rolled or drawn bar, rod, and wire
AMS 4086	Tubing, hydraulic, seamless, drawn
AMS-WW-T-700/3	Tubing
AMS 4152	Extrusion
AMS 4164	Extrusion
AMS 4165	Extrusion
AMS-QQ-A-200/3	Extruded bar, rod, and shapes

The following temper designations are more specifically described than in Table 3.1.2.:

T81—The applicable designation for 2024-T3 sheet artificially aged to the required strength level.

T361—Solution heat treated and naturally aged followed by cold rolling and natural aging treatment.

T861—Solution heat treated and naturally aged followed by cold rolling and artificial aging treatment.

T72—Solution heat treated and aged by user in accordance with AMS 2770 to provide high resistance to stress-corrosion cracking, applicable only to sheet.

Click the image to view the Interactive Graph

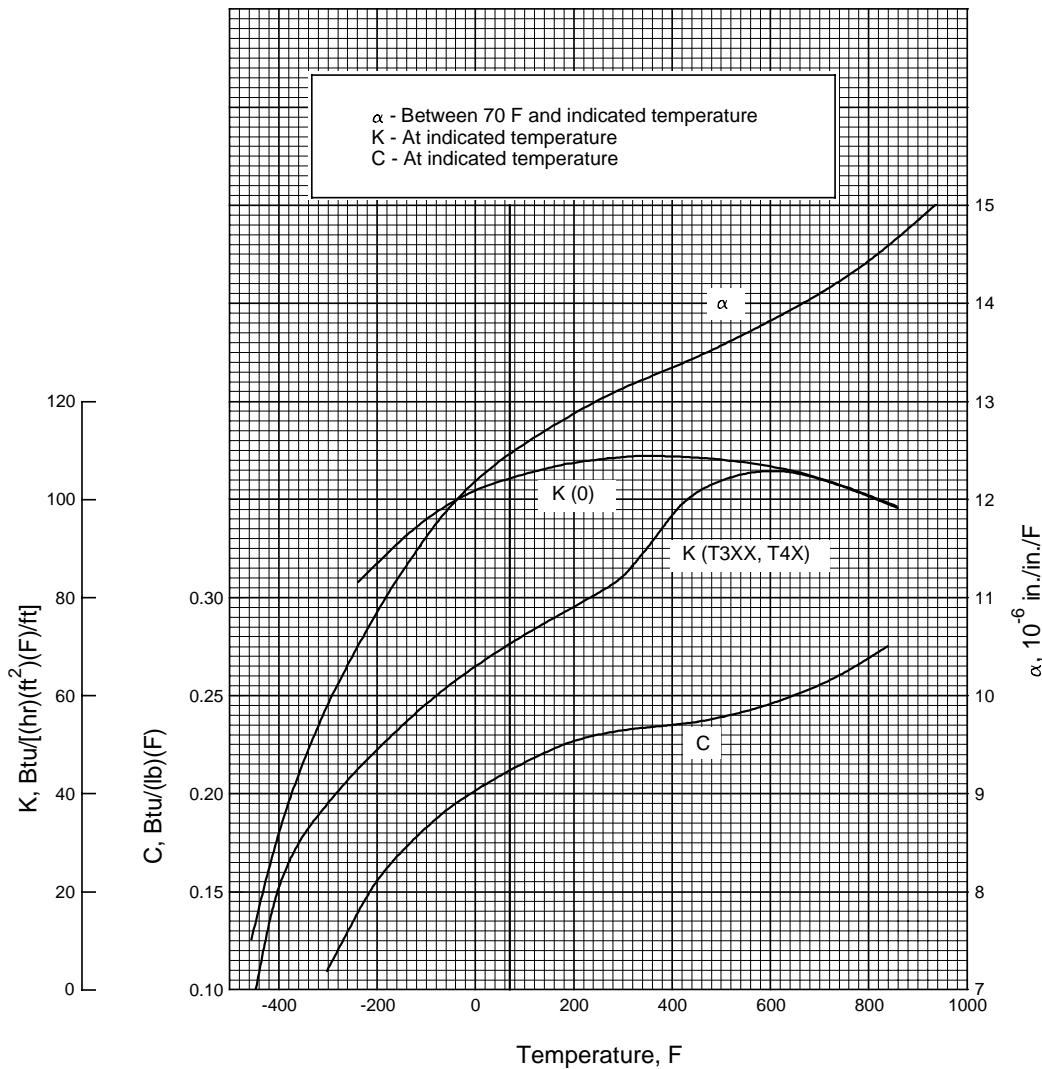


Figure 3.2.3.0 Effect of temperature on the physical properties of 2024 aluminum alloy.

The temper index for 2024 is as follows:

<u>Section</u>	<u>Temper</u>
3.2.3.1	T3, T351, T3510, T3511, T4, and T42
3.2.3.2	T361 (supersedes T36)
3.2.3.3	T62 and T72
3.2.3.4	T81, T851, T8510, and T8511
3.2.3.5	T861 (supersedes T86)

3.2.3.1 T3, T351, T3510, T3511, T4, and T42 Temper — Figures 3.2.3.1.1(a) through 3.2.3.1.5(b) present elevated temperature curves for various properties. Figures 3.2.3.1.6(a) through (q) present tensile and compressive stress-strain curves and tangent-modulus curves for various product forms and tempers at various temperatures. Figures 3.2.3.1.6(r) through (w) are full-range, stress-strain curves at room temperature for various product forms. Figures 3.2.3.1.8(a) through (i) provide S/N fatigue curves for unnotched and notched specimens for T3 and T4 tempers.

3.2.3.2 T361 (supersedes T36) Temper —

3.2.3.3 T62 and T72 Temper — Figures 3.2.3.3.1(a) through (d) and 3.2.3.3.5(a) and (b) show the effect of temperature on the tensile properties of the T62 temper. Figure 3.2.3.1.4 can be used for the elevated temperature curve for elastic moduli for this temper. Tensile and compressive stress-strain and tangent-modulus curves at room temperature are shown in Figure 3.2.3.3.6.

3.2.3.4 T81, T851, T852, T8510 and T8511 Temper — Figures 3.2.3.4.1(a) through (d), 3.2.3.4.2(a) and (b), 3.2.3.4.3(a) and (b), and 3.2.3.4.5(a) and (b) present elevated temperature curves for various mechanical properties for the T8XXX temper. Figures 3.2.3.4.1(e) and (f) contain graphs for determining tensile properties after complex thermal exposure. See Section 3.7.4.1 for a detailed discussion of their use. Figures 3.2.3.4.6(a) through (g) present tensile and compressive stress-strain and tangent-modulus curves for various products and tempers. Figures 3.2.3.4.6(h) through (j) are full-range stress-strain curves at room temperature for various product forms.

3.2.3.5 T861 (T86) Temper — Figures 3.2.3.5.1(a) through (d), 3.2.3.5.2(a) and (b), 3.2.3.5.3(a) through (c), and 3.2.3.5.5(a) and (b) present effect-of-temperature curves for various mechanical properties. Figures 3.2.3.5.6(a) through (d) present compressive stress-strain and tangent-modulus curves for sheet material at various temperatures. Graphical displays of the residual strength behavior of center-cracked tension panels are presented in Figures 3.2.3.5.10(a) and (b).

Table 3.2.3.0(b.). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Sheet and Plate

Specification	AMS 4037 and AMS-QQ-A-250/4														AMS-QQ-A-250/4														
	Sheet					Plate									Sheet		Plate												
Temper	T3				T351										T361														
	0.008- 0.009	0.010- 0.128	0.129- 0.249	0.250- 0.499	0.500- 1.000	1.001- 1.500	1.501- 2.000	2.001- 3.000	3.001- 4.000	0.020- 0.062	0.063- 0.249	0.250- 0.500																	
Basis	S	A	B	A	B	A	B	A	B	A	B	A	B	A	B	S	S												
Mechanical Properties:																													
F_{uw} , ksi:																													
L	64	64	65	65	66	64	66	63	65	62	64	62	64	60	62	57	59												
LT	63	63	64	64	65	64	66	63	65	62	64	62	64	60	62	57	59												
ST .....	...	...	...	...	...	...	...	...	...	...	...	...	...	52 ^a	54 ^a	49 ^a	51 ^a
F_y , ksi:																													
L	47	47	48	47	48	48	50	48	50	47	50	47	49	46	48	43	46												
LT	42	42	43	42	43	42	44	42	44	42	44	42	44	42	44	41	43												
ST .....	...	...	...	...	...	...	...	...	...	...	...	...	...	38 ^a	40 ^a	38 ^a	39 ^a
F_{cy} , ksi:																													
L	39	39	40	39	40	39	41	39	41	39	40	38	40	37	39	35	37												
LT	45	45	46	45	46	45	47	45	47	44	46	44	46	43	45	41	43												
ST .....	...	...	...	...	...	...	...	...	...	...	...	...	...	46	48	44	47
F_{su} , ksi	39	39	40	40	41	38	39	37	38	37	38	37	38	35	37	34	35												
F_{bru} ^b , ksi:																													
(e/D = 1.5)	104	104	106	106	107	97	100	95	98	94	97	94	97	91	94	86	89												
(e/D = 2.0)	129	129	131	131	133	119	122	117	120	115	119	115	119	111	115	106	109												
F_{bry} ^b , ksi:																													
(e/D = 1.5)	73	73	75	73	75	72	76	72	76	72	76	72	76	72	70	74	82												
(e/D = 2.0)	88	88	90	88	90	86	90	86	90	86	90	86	90	86	84	88	97												
e, percent (S-basis):																													
LT	10	c	...	c	...	12	...	8	...	7	...	6	...	4	...	4	...												
E , 10^3 ksi	10.5				10.7										10.5		10.7												
E_c , 10^3 ksi	10.7				10.9										10.7		10.9												
G , 10^3 ksi	4.0				4.0										4.0		4.0												
μ	0.33				0.33										0.33		0.33												
Physical Properties:																													
ω , lb/in.	0.100																												
C , K , and α	See Figure 3.2.3.0																												

a Caution: This specific alloy, temper, and product form exhibits poor stress-corrosion cracking resistance in this grain direction. It corresponds to an SCC resistance rating of D, as indicated in Table 3.1.2.3.1(a).

b Bearing values are "dry pin" values per Section 1.4.7.1. See Table 3.1.2.1.1.

c See Table 3.2.3.0(c).

d 10% for 0.500 inch.

Table 3.2.3.0(b₂). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Sheet and Plate—Continued

Specification	AMS-QQ-A-250/4		AMS 4035 and AMS-QQ-A-250/4					AMS-QQ-A-250/4				
Form	Coiled Sheet		Flat Sheet and Plate									
Temper	T4		T42 ^a					T62 ^a				
Thickness, in.	0.010-0.249		0.010-0.249	0.250-0.499	0.500-1.000	1.001-2.000	2.001-3.000	0.010-0.249	0.250-0.499	0.500-2.000	2.001-3.000	0.010-0.249
Basis	A	B	S	S	S	S	S	S	S	S	S	S
Mechanical Properties:												
F_{tu} , ksi:												
L	62	64	62	62	61	60	...	63	63	63	...	...
LT	62	64	62	62	61	60	58	64	64	63	63	60
F_{oy} , ksi:												
L	40	42	38	38	38	38	...	50	50	50	...	...
LT	40	42	38	38	38	38	38	50	50	50	50	46
F_{cy} , ksi:												
L	40	42	42	42	40	37	...	52	52	52	...	...
LT	40	42	41	41	41	41	...	53	52	48	...	...
F_{sw} , ksi	37	38	37	37	36	36	...	38	38	37	...	...
F_{bru}^b , ksi:												
(e/D = 1.5)	93	96	99	98	94	85 ^c	...	103	103	102 ^c	...	...
(e/D = 2.0)	118	122	123	123	121	119 ^c	...	134	134	132 ^c	...	...
F_{bry}^b , ksi:												
(e/D = 1.5)	56	59	67	67	67	67 ^c	...	80	80	80 ^c	...	...
(e/D = 2.0)	64	67	80	80	80	80 ^c	...	95	95	95 ^c	...	...
e, percent (S-basis):												
LT	d	...	d	12	8	d	4	5	5	5	5	5
E , 10 ³ ksi							See Table 3.2.3.0(d)					
E_s , 10 ³ ksi							See Table 3.2.3.0(d)					
G , 10 ³ ksi							See Table 3.2.3.0(d)					
μ							See Table 3.2.3.0(d)					
Physical Properties:												
ω , lb/in. ³							0.100					
C , Btu/(lb)(°F)							See Figure 3.2.3.0					
K , Btu/[(hr)/(ft ²)(°F)/ft]							71 (at 77°F) for T4X and 87 (at 77°F) for T6X, T7X, See Figure 3.2.3.0					
α , 10 ⁻⁶ in./in./°F							See Figure 3.2.3.0					

a Design allowables in some cases were based upon data obtained from testing samples of material, supplied in the O or F temper, which were heat treated to demonstrate response to heat treatment by suppliers. Properties obtained by the user may be different than those listed if the material has been formed or otherwise cold or hot worked, particularly in the annealed temper, prior to solution heat treatment.

b Bearing values are "dry pin" values per Section 1.4.7.1.

c See Table 3.1.2.1.1.

d See Table 3.2.3.0(c).

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Table 3.2.3.0(b₃). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Sheet and Plate—Continued

Specification	AMS-QQ-A-250/4							
	Sheet		Plate			Sheet		Plate
Form	T81		T851			T861		
	0.010- 0.249	0.250- 0.499	0.500- 1.000	1.001- 1.499	0.020- 0.062	0.063- 0.249	0.250- 0.500	
Basis	A	B	A	B	S	S	S	S
Mechanical Properties:								
F_{tu} , ksi:								
L	67	68	67	68	66	66	71	72
LT	67	68	67	68	66	66	70	71
F_{ty} , ksi:								
L	59	61	58	60	58	57	63	67
LT	58	60	58	60	58	57	62	66
F_{cy} , ksi:								
L	59	61	58	60	58	56	63	67
LT	58	60	59	61	58	57	65	69
F_{su} , ksi	40	41	38	39	37	37	40	40
F_{bru}^a , ksi:								
(e/D = 1.5)	100	102	102	103	100	100 ^b	108	110
(e/D = 2.0)	127	129	131	133	129	129 ^b	140	142
F_{bry}^a , ksi:								
(e/D = 1.5)	83	86	86	89	86	85 ^b	90	96
(e/D = 2.0)	94	97	101	105	101	99 ^b	105	112
e , percent (S-basis):								
LT	5	...	5	...	5	5	3	4
E , 10 ³ ksi					See Table 3.2.3.0(d)			
E_c , 10 ³ ksi					See Table 3.2.3.0(d)			
G , 10 ³ ksi					See Table 3.2.3.0(d)			
μ					See Table 3.2.3.0(d)			
Physical Properties:								
ω , lb/in. ³					0.100			
C , Btu/(lb)(°F) ...					See Figure 3.2.3.0			
K , Btu/[(hr)(ft ²)(°F)/ft]					87 (at 77°F)			
α , 10 ⁻⁶ in./in./°F ...					See Figure 3.2.3.0			

a Bearing values are “dry pin” values per Section 1.4.7.1.

b See Table 3.1.2.1.1.

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Table 3.2.3.0(c). Minimum Elongation Values for Bare 2024 Aluminum Alloy Sheet and Plate

Condition	Elongation (LT), percent
	T3, T4, and T42
Thickness, in.:	
0.010-0.020	12
0.021-0.249	15
0.250-0.499	12
0.500-1.000	8
1.001-1.500	7
1.501-2.000	6

Table 3.2.3.0(d). Modulus Values and Poisson's Ratio for Bare 2024 Aluminum Alloy Sheet and Plate, All Tempers

Property	<i>E</i>	<i>E_c</i>	<i>G</i>	μ
Thickness, in.:				
0.010-0.249	10.5	10.7	4.0	0.33
≥0.250	10.7	10.9	4.0	0.33

Table 3.2.3.0(e₁). Design Mechanical and Physical Properties of Clad 2024 Aluminum Alloy Sheet and Plate

Specification	AMS-QQ-A-250/5																																
Form	Flat sheet and plate																																
Temper	T3						T351																										
Thickness, in.	0.008-0.009		0.010-0.062		0.063-0.128		0.129-0.249		0.250-0.499		0.500-1.000 ^a		1.001-1.500 ^a		1.501-2.000 ^a		2.001-3.000 ^a		3.001-4.000 ^a														
Basis	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B															
Mechanical Properties:																																	
F_{uw} , ksi:																																	
L	59	60	60	61	62	63	63	64	62	64	61	63	60	62	60	62	58	60	55	57													
LT	58	59	59	60	61	62	62	63	62	64	61	63	60	62	60	62	58	60	55	57													
ST	52 ^b	54 ^b	49 ^b	51 ^b													
F_{ry} , ksi:																																	
L	44	45	44	45	45	47	45	47	46	48	45	48	45	48	45	47	44	46	39	41													
LT	39	40	39	40	40	42	40	42	40	42	40	42	40	42	40	42	40	42	39	41													
ST	38 ^b	40 ^b	38 ^b	39 ^b													
F_{cv} , ksi:																																	
L	36	37	36	37	37	39	37	39	37	39	37	39	37	39	36	38	35	37	33	35													
LT	42	43	42	43	43	45	43	45	43	45	42	45	42	44	42	44	41	43	39	41													
ST	46	48	44	47													
F_{sw} , ksi:																																	
F_{bru} , ksi:																																	
(e/D = 1.5)	96	97	97	99	101	102	102	104	94	97	92	95	91	94	91	94	88	91	83	86													
(e/D = 2.0)	119	121	121	123	125	127	127	129	115	119	113	117	111	115	111	115	107	111	102	106													
F_{bry} , ksi:																																	
(e/D = 1.5)	68	70	68	70	70	73	70	73	69	72	69	72	69	72	69	72	67	70	60														
(e/D = 2.0)	82	84	82	84	84	88	84	88	82	86	82	86	82	86	82	86	80	86	80	84													
e , percent (S-basis):																																	
LT	10	...	^d	...	15	...	15	...	12	...	8	...	7	...	6	...	4	...	4	...													
E , 10 ³ ksi:																																	
Primary	10.5						10.7																										
Secondary	9.5			10.0			10.2																										
E_c , 10 ³ ksi:																																	
Primary	10.7						10.9																										
Secondary	9.7			10.2			10.4																										
G , 10 ³ ksi																																	
μ																																	
Physical Properties:																																	
ω , lb/in. ³													0.100																				
C , K , and α																																	

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a These values, except in the ST direction, have been adjusted to represent the average properties across the whole section, including the 2-½ percent nominal cladding thickness.

b Caution: This specific alloy, temper, and product form exhibits poor stress-corrosion cracking resistance in this grain direction. It corresponds to an SCC resistance rating of D, as indicated in Table 3.1.2.3.1(a).

c Bearing values are “dry pin” values per Section 1.4.7.1. See Table 3.1.2.1.1.

d See Table 3.2.3.0(f).

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Table 3.2.3.0(e₂). Design Mechanical and Physical Properties of Clad 2024 Aluminum Alloy Sheet and Plate-Continued

Specification	AMS-QQ-A-250/5															
	Flat sheet and plate				Coiled sheet											
Temper	T361				T4											
	0.020- 0.062	0.063- 0.249	0.250- 0.499	0.500 ^a	0.010- 0.062	0.063- 0.128										
Basis	S	S	S	S	A	B	A	B								
Mechanical Properties:																
F_{tu} , ksi:																
L	62	65	65	64	58	59	61	62								
LT	61	64	64	63	58	59	61	62								
F_{ty} , ksi:																
L	53	53	53	52	36	38	38	39								
LT	47	48	48	47	36	38	38	39								
F_{cy} , ksi:																
L	44	45	45	44	36	38	38	39								
LT	50	51	51	50	36	38	38	39								
F_{su} , ksi	38	40	40	39	37	37	38	39								
F_{bru}^b , ksi:																
(e/D = 1.5)	101	105	105	104	96	97	101	102								
(e/D = 2.0)	125	131	131	129	119	121	125	127								
F_{bry}^b , ksi:																
(e/D = 1.5)	78	79	79	78	63	66	66	68								
(e/D = 2.0)	92	94	94	92	76	80	80	82								
e , percent (S-basis):																
LT	8	9	9	10	c	...	15	...								
E , 10 ³ ksi:																
Primary	10.5	10.5	10.7		10.5		10.5									
Secondary	9.5	10.0	10.2		9.5		10.0									
E_c , 10 ³ ksi:																
Primary	10.7	10.7	10.9		10.7		10.7									
Secondary	9.7	10.2	10.4		9.7		10.2									
G , 10 ³ ksi .....	...				0.33										
μ	0.100															
Physical Properties:																
ω , lb/in. ³	0.100															
C , K , and α .....	...														

a These values have been adjusted to represent the average properties across the whole section, including the 2-1/2 percent nominal cladding thickness.

b Bearing values are "dry pin" values per Section 1.4.7.1.

c See Table 3.2.3.0(f).

Table 3.2.3.0(e₃). Design Mechanical and Physical Properties of Clad 2024 Aluminum Alloy Sheet and Plate - Continued

Specification	AMS-QQ-A-250/5																					
	Flat sheet and plate																					
	T42 ^a								T62 ^a			T72 ^a										
Form	Thickness, in.		0.008-0.009		0.010-0.062		0.063-0.249		0.250-0.499	0.500-1.000 ^b	1.001-2.000 ^b	2.001-3.000 ^b	0.010-0.062									
	A	B	A	B	A ^c	B ^c	S ^c	S ^{c,d}	S	S	S ^c	S ^c	0.250-0.499	0.010-0.062								
Basis	S	S	S	S	S	S	S	S	S	S	S	S	S	S								
Mechanical Properties:																						
F_{ut} , ksi:																						
L	55	57	57	59	60	62	60	59	58	...	60	62	62	...								
LT	55	57	57	59	60	62	60	59	58	56	60	62	62	56								
F_{ly} , ksi:																						
L	34	35	34	35	36	38	36	36	36	...	47	49	49	...								
LT	34	35	34	35	36	38	36	36	36	36	47	49	49	43								
F_{ey} , ksi:																						
L	38	39	38	39	40	42	39	38	35	...	49	51	51	...								
LT	37	38	37	38	39	41	39	39	39	...	49	52	51	...								
F_{sw} , ksi	33	34	34	35	36	37	36	35	35	...	35	36	36	...								
F_{bru} , ksi:																						
(e/D = 1.5)	88	91	91	94	96	99	95	90	83	...	97	100	100	...								
(e/D = 2.0)	109	113	113	117	119	123	119	117	115	...	126	130	130	...								
F_{bry} , ksi:																						
(e/D = 1.5)	60	61	60	61	63	67	63	63	63	...	75	79	79	...								
(e/D = 2.0)	72	74	72	74	76	80	76	76	76	...	89	93	93	...								
e , percent (S-basis):																						
LT	10	...	^e	...	15	...	12	8	^e	4	5	5	5	5								
E , 10 ³ ksi:																						
Primary	10.5			10.5			10.7			10.5			10.7	10.5								
Secondary	9.5			10.0			10.2			10.0			10.2	9.5								
E_c , 10 ³ ksi:																						
Primary	10.7			10.7			10.9			10.7			10.9	10.7								
Secondary	9.7			10.2			10.4			10.2			10.4	9.7								
G , 10 ³ ksi . . . . .	...																				
μ	0.33																					
Physical Properties:																						
ω , lb/in. ³	0.100																					
C , K , and α . . . . .	...																				

- a Design allowables in some cases were based upon data obtained from testing samples of material, supplied in the O or F temper, which were heat treated to demonstrate response to heat treatment by suppliers. Properties obtained by the user may be different than those listed if the material has been formed or otherwise cold or hot worked, particularly in the annealed temper, prior to solution heat treatment.
- b These values have been adjusted to represent the average properties across the whole section, including 2½ percent per side nominal cladding thickness.
- c Bearing values are "dry pin" values per Section 1.4.7.1.
- d See Table 3.1.2.1.1.
- e See Table 3.2.3.0(f).

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Table 3.2.3.0(e₄). Design Mechanical and physical Properties of Clad 2024 Aluminum Alloy Sheet and Plate - Continued

Specification	AMS-QQ-A-250/5							
	Flat sheet and plate							
Form	T81		T851 ^a		T861 ^a			
	0.010-0.062	0.063-0.249	0.250-0.499	0.500-1.000 ^b	0.020-0.062	0.063-0.249	0.250-0.499	0.500 ^b
Basis	S	S	A	B	S	S	S	S
Mechanical Properties:								
F_{tu} , ksi:								
L	64	67	65	66	63	65	70	68
LT	62	65	65	66	63	64	69	68
F_{ty} , ksi:								
L	57	59	56	58	56	59	65	62
LT	54	56	56	58	56	58	64	62
F_{cy} , ksi:								
L	55	57	56	58	56	59	65	62
LT	55	57	57	59	56	61	67	65
F_{su} , ksi	38	39	37	37	36	36	39	39
F_{bru} , ksi:								
(e/D = 1.5)	96	100	99	100	96	99	107	105
(e/D = 2.0)	122	127	127	129	123	128	138	136
F_{bry} , ksi:								
(e/D = 1.5)	78	83	83	86	83	84	93	90
(e/D = 2.0)	90	94	98	101	98	99	109	105
e , percent (S-basis):								
LT	5	5	5	...	5	3	4	4
E , 10 ³ ksi:								
Primary	10.5	10.5	10.7		10.5	10.5	10.5	
Secondary	9.5	10.0	10.2		9.5	10.0	10.2	
E_c , 10 ³ ksi:								
Primary	10.7	10.7	10.9		10.7	10.7	10.9	
Secondary	9.7	10.2	10.4		9.7	10.2	10.4	
G , 10 ³ ksi .....			...		
μ			0.33					
Physical Properties:								
ω , lb/in. ³			0.100					
C , K , and α .....			...		

a Bearing values are "dry pin" values per Section 1.4.7.1.

b These values have been adjusted to represent the average properties across the whole section, including the 2-½ percent nominal cladding thickness.

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Table 3.2.3.0(f). Minimum Elongation Values for Clad 2024 Aluminum Alloy Sheet and Plate

Temper	Elongation (LT), percent
	T3, T4, T42
Thickness, in.:	
0.010-0.020	12
0.021-0.062	15
1.001-1.500	7
1.501-2.000	6

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Table 3.2.3.0(g). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Drawn Tubing

	AMS 4086 and WW-T-700/3		WW-T-700/3	
	Drawn tubing			
Temper	T3		T42 ^a	T81
	0.018-0.500		0.018-0.500	0.010-0.249
Basis	A	B	S	S
Mechanical Properties:				
F_{tu} , ksi:				
L	64	66	62	66
LT .....	...	...	...	...
F_{ty} , ksi:				
L	42	45	38	58
LT .....	...	...	...	...
F_{cy} , ksi:				
L	42	45	38	...
LT .....	...	...	...	...
F_{su} , ksi	39	40	38	...
F_{bru} , ksi:				
(e/D = 1.5)	96	99	93	...
(e/D = 2.0)	122	126	118	...
F_{bry} , ksi:				
(e/D = 1.5)	59	63	53	...
(e/D = 2.0)	67	72	61	...
e , percent (S-basis):				
L	b	...	b	b
E , 10^3 ksi			10.5	
E_c , 10^3 ksi			10.7	
G , 10^3 ksi			4.0	
μ			0.33	
Physical Properties:				
ω , lb/in. ³			0.100	
C , K , and α			See Figure 3.2.3.0	

a Design allowables were based upon data obtained from testing samples of material supplied in the O or F temper, which were heat treated to demonstrate response to heat treatment by suppliers. Properties obtained by the user, however, may be lower than those listed if the material has been formed or otherwise cold or hot worked, particularly in the annealed temper, prior to solution heat treatment.

b See Table 3.2.3.0(h).

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Table 3.2.3.0(h). Minimum Elongation Values for 2024 Aluminum Alloy Drawn Tubing

	Elongation (L), percent ^a
Temper	T3, T42
Wall Thickness, in.:	
0.018-0.024	10
0.025-0.049	12
0.050-0.259	14
0.260-0.500	16
Temper	T81
0.010-0.024
0.025-0.049	5
0.050-0.249	6

a Full section specimen.

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Table 3.2.3.0(i₁). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Bar and Rod; Rolled, Drawn, or Cold-Finished

Specification	AMS 4120 and AMS-QQ-A-225/6							AMS-QQ-A-225/6
Form	Bar and rod; rolled, drawn, or cold-finished							
Temper	T351							T361
Thickness, in.	0.500-1.000	1.001-2.000	2.001-3.000	3.001-4.000	4.001-5.000 ^a	5.001-6.000 ^a	6.001-6.500 ^a	≤0.375
Basis	S	S	S	S	S	S	S	S
Mechanical Properties:								
F_{tu} , ksi:								
L	62	62	62	62	62	62	62	69
LT	61 ^b	59 ^b	57 ^b	55 ^b	54 ^b	52 ^b	...	...
F_{ty} , ksi:								
L	45	45	45	45	45	45	45	52
LT	36 ^b	36 ^b	36 ^b	36 ^b	36 ^b	36 ^b	...	...
F_{cy} , ksi:								
L	34	34	34	34	34	34	...	...
LT	41	41	41	41	41	41	...	...
F_{su} , ksi	37	37	37	37	37	37	...	...
F_{brw} , ksi:								
(e/D = 1.5)	90	90	90	90	90	90	...	...
(e/D = 2.0)	115	115	115	115	115	115	...	...
F_{bry} , ksi:								
(e/D = 1.5)	63	63	63	63	63	63	...	...
(e/D = 2.0)	74	74	74	74	74	74	...	...
e , percent:								
L	10	10	10	10	10	10	10	10
E , 10 ³ ksi					10.5			
E_c , 10 ³ ksi					10.7			
G , 10 ³ ksi					4.0			
μ					0.33			
Physical Properties:								
ω , lb/in. ³					0.100			
C , K , and α					See Figure 3.2.3.0			

a For square, rectangular, hexagonal, or octagonal bar, minimum thickness is 4 inches, and maximum cross-sectional area is 36 square inches.

b Caution: This specific alloy, temper, and product form exhibits poor stress-corrosion cracking resistance in this grain direction. It corresponds to an SCC resistance rating of D, as indicated in Table 3.1.2.3.1(a).

Table 3.2.3.0(i₂). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Bar and Rod; Rolled, Drawn, or Cold-Finished—Continued

Specification	AMS 4120 and AMS-QQ-A-225/6										AMS-QQ-A-225/6
	Bar and rod; rolled, drawn, or cold-finished										
	T4 ^a										T42 ^b
Thickness, in.	0.125-0.499	0.500-1.000	1.001-2.000	2.001-3.000	3.001-4.000	4.001-4.500 ^c	4.501-5.000 ^d	5.001-6.000 ^c	6.001-6.500 ^d	6.501-8.000 ^d	≤ 6.500 ^c
Basis	S	S	S	S	S	S	S	S	S	S	S
Mechanical Properties:											
F_{ut} , ksi:											
L	62	62	62	62	62	62	62	62	62	58	62
LT	61 ^e	61 ^e	59 ^e	57 ^e	55 ^e	54 ^e	54 ^e	52 ^e	...	...	...
F_{ty} , ksi:											
L	45	42	42	42	42	42	40	40	40	38	40
LT	45 ^e	42 ^e	41 ^e	40 ^e	39 ^e	39 ^e	37 ^e	36 ^e	...	...	...
F_{cy} , ksi:											
L	36	33	33	33	33	33	32	32	...	...	...
LT .....	...	...	...	...	...	...	...	...	...	...	...
F_{sw} , ksi	37	37	37	37	37	37	37	37	37	...	...
F_{bru} , ksi:											
(e/D = 1.5)	93	93	93	93	93	93	93	93	...	...	...
(e/D = 2.0)	118	118	118	118	118	118	118	118	...	...	...
F_{bry} , ksi:											
(e/D = 1.5)	63	59	59	59	59	59	56	56	...	...	...
(e/D = 2.0)	72	67	67	67	67	67	64	64	...	...	...
e , percent:											
L	10	10	10	10	10	10	10	10	10	10	10
E , 10 ³ ksi						10.5					
E_c , 10 ³ ksi						10.7					
G , 10 ³ ksi						4.0					
μ						0.33					
Physical Properties:											
ω , lb/in. ³						0.100					
C and α						See Figure 3.2.3.0					
K, Btu/[(hr)(ft ²)(°F)/ft]					71 (at 77°F) for T4X (See Figure 3.2.3.0)						

a The T4 temper is obsolete and should not be specified for new designs.

b These properties apply when samples of material supplied in the O or F temper are heat treated to demonstrate response to heat treatment. Properties obtained by the user, however, may be lower than those listed if the material has been formed or otherwise cold or hot worked, particularly in the annealed temper, prior to solution heat treatment.

c For square, rectangular, hexagonal, or octagonal bar, maximum thickness is 4 inches, and maximum cross-sectional area is 36 square inches.

d Applies to rod only.

e Caution: This specific alloy, temper, and product form exhibits poor stress-corrosion cracking resistance in this grain direction. It corresponds to an SCC resistance rating of D, as indicated in Table 3.1.2.3.1(a).

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Table 3.2.3.0(i₃). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Bar and Rod; Rolled, Drawn, or Cold-Finished—Continued

Specification	AMS-QQ-A-225/6		
	Bar and rod; rolled, drawn, or cold finished		
Form	T6 ^a	T62 ^b	T851
Temper			
Thickness, ^c in.	≤6.500	≤6.500	0.500-6.500
Basis	S	S	S
Mechanical Properties:			
F_{tu} , ksi:			
L	62	60	66
LT .....	...	...	...
F_y , ksi:			
L	50	46	58
LT .....	...	...	...
F_{cy} , ksi:			
L .....	...	...	...
LT .....	...	...	...
F_{su} , ksi .....	...	...	...
F_{bru} , ksi:			
(e/D = 1.5) .....	...	...	...
(e/D = 2.0) .....	...	...	...
F_{bry} , ksi:			
(e/D = 1.5) .....	...	...	...
(e/D = 2.0) .....	...	...	...
e , percent:			
L	5	5	5
E , 10 ³ ksi		10.5	
E_c , 10 ³ ksi		10.7	
G , 10 ³ ksi		4.0	
μ		0.33	
Physical Properties:			
ω , lb/in. ³		0.100	
C and α		See Figure 3.2.3.0	
K , Btu/[(hr)(ft ²)(°F)/ft]		87 (at 77°F) for T6X and T8XX	

a The T6 temper is obsolete and should not be specified for new designs.

b These properties apply when samples of material supplied in the O or F temper are heat treated to demonstrate response to heat treatment. Properties obtained by the user, however, may be lower than those listed if the material has been formed or otherwise cold or hot worked, particularly in the annealed temper, prior to solution heat treatment.

c For square, rectangular, hexagonal, or octagonal bar, maximum thickness is 4 inches, and maximum cross-sectional area is 36 square inches.

Table 3.2.3.0(j₁). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Extrusion

Specification	AMS 4152, AMS 4164, AMS 4165, and AMS-QQ-A-200/3										AMS-QQ-A-200/3			
Form	Extruded bar, rod, and shapes													
Temper	T3, T3510, and T3511										T81, T8510, and T8511			
Thickness, ^a in.	≤0.249	0.250-0.499	0.500-0.749	0.750-1.499	1.500-2.999	3.000-4.499	1.500-2.999	3.000-4.499	0.050-0.249	0.250-1.499	1.500-4.500			
Cross-Section Area, in. ²	≤20				≤25				>25 - ≤32		≤20		≤32	
Basis	A	B	A	B	A	B	A	B	A	B	S	S	S	S
Mechanical Properties:														
F_{tu} , ksi:														
L	57	61	60	62	60	62	65	70	70	74	70	68	68	66
LT	54	58	56	57	54	56	56	60	55	58	54	57	53	64
F_{fy} , ksi:														
L	42	47	44	47	44	47	46	54	52	54	52	54	48	48
LT	37	41	38	40	37	39	37	43	39	41	39	41	36	36
F_{cy} , ksi:														
L	34	38	37	39	38	40	41	48	49	50	49	51	45	45
LT	41	45	41	44	40	43	40	47	42	44	41	43	39	38
F_{su} , ksi	29	31	31	32	30	31	33	35	34	36	33	35	33	32
F_{bru}^b , ksi:														
(e/D = 1.5)	84	90	78	81	78	80	84	90	88	93	86	91	86	94
(e/D = 2.0)	108	114	98	101	97	101	105	113	111	118	109	115	108	106
F_{bry}^b , ksi:														
(e/D = 1.5)	61	68	55	59	55	59	57	67	63	66	62	65	59	57
(e/D = 2.0)	71	79	67	71	67	71	69	81	77	80	75	78	71	69
e , percent (S-basis):														
L	12	...	12	...	12	...	10	...	10	...	10	...	8	8
E , 10 ³ ksi												10.8		
E_c , 10 ³ ksi												11.0		
G , 10 ³ ksi												4.1		
μ												0.33		
Physical Properties:														
ω , lb/in. ³												0.100		
C , K , and α												See Figure 3.2.3.0		

a The mechanical properties are to be based upon the thickness at the time of quench.

b Bearing values are “dry pin” values per Section 1.4.7.1.

Table 3.2.3.0(j₂). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Extrusion—Continued

Specification	AMS-QQ-A-200/3									
	Extruded bar, rod, and shapes									
	T42 ^a									
Cross-Sectional Area, in. ²	≤ 25									
Thickness or Diameter, ^b in.	≤ 0.249	0.250-0.499	0.500-0.749	0.750-0.999	1.000-1.249	1.250-1.499	1.500-1.749	1.750-1.999	2.000-2.249	2.250-2.499
Basis	S	S	S	S	S	S	S	S	S	S
Mechanical Properties:										
F_u , ksi:										
L	57	57	57	57	57	57	57	57	57	57
LT	55	54	52	51	49	47	45	43	41	39
F_{t_y} , ksi:										
L	38	38	38	38	38	38	38	38	38	38
LT	36	35	34	33	32	31	30	29	28	27
F_{cy} , ksi:										
L	38	38	38	38	38	38	38	38	38	38
LT	39	38	37	36	35	34	33	31	30	29
F_{su} , ksi	29	29	29	29	29	29	28	27	26	24
F_{bru}^c , ksi:										
(e/D = 1.5)	81	80	79	77	75	74	71	69	67	64
(e/D = 2.0)	99	98	97	95	93	91	89	86	83	81
F_{bry}^c , ksi:										
(e/D = 1.5)	56	55	53	51	49	47	44	41	39	36
(e/D = 2.0)	69	67	65	63	61	59	56	53	50	47
e , percent:										
L	12	12	12	10	10	10	10	10	10	10
E , 10 ³ ksi					10.8					
E_c , 10 ³ ksi						11.0				
G , 10 ³ ksi							4.1			
μ							0.33			
Physical Properties:										
ω , lb/in. ³						0.100				
C , K , and α							See Figure 3.2.3.0			

a Design allowables were based upon data obtained from testing samples of material supplied in the O or F temper, which were heat treated to demonstrate response to heat treatment by suppliers. Properties obtained by the user, however, may be lower than those listed if the material has been formed or otherwise cold or hot worked, particularly in the annealed temper, prior to solution heat treatment.

b The mechanical properties are to be based upon the thickness at the time of quench.

c Bearing values are "dry pin" values per Section 1.4.7.1.

Click the image to view the Interactive Graph

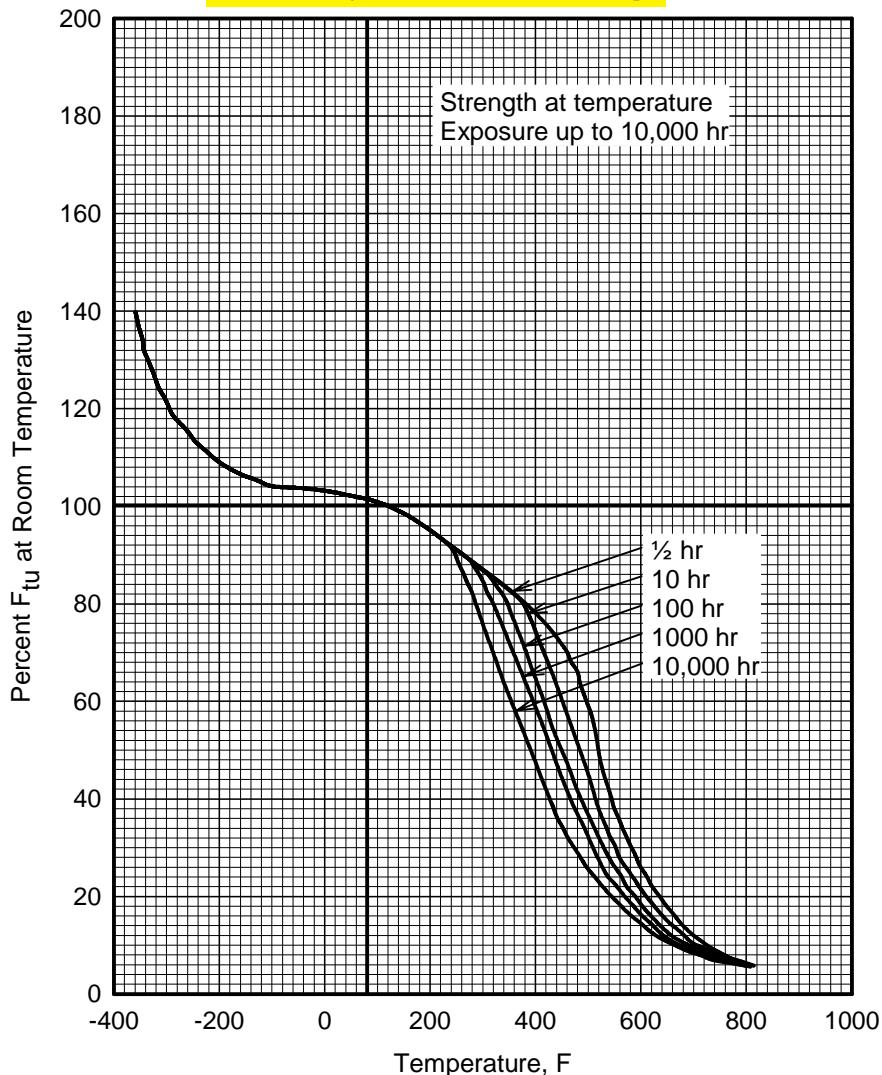


Figure 3.2.3.1.1(a). Effect of temperature on the tensile ultimate strength (F_{tu}) of 2024-T3, T351 and 2024-T4 aluminum alloy (all products except extrusions).

Click the image to view the Interactive Graph

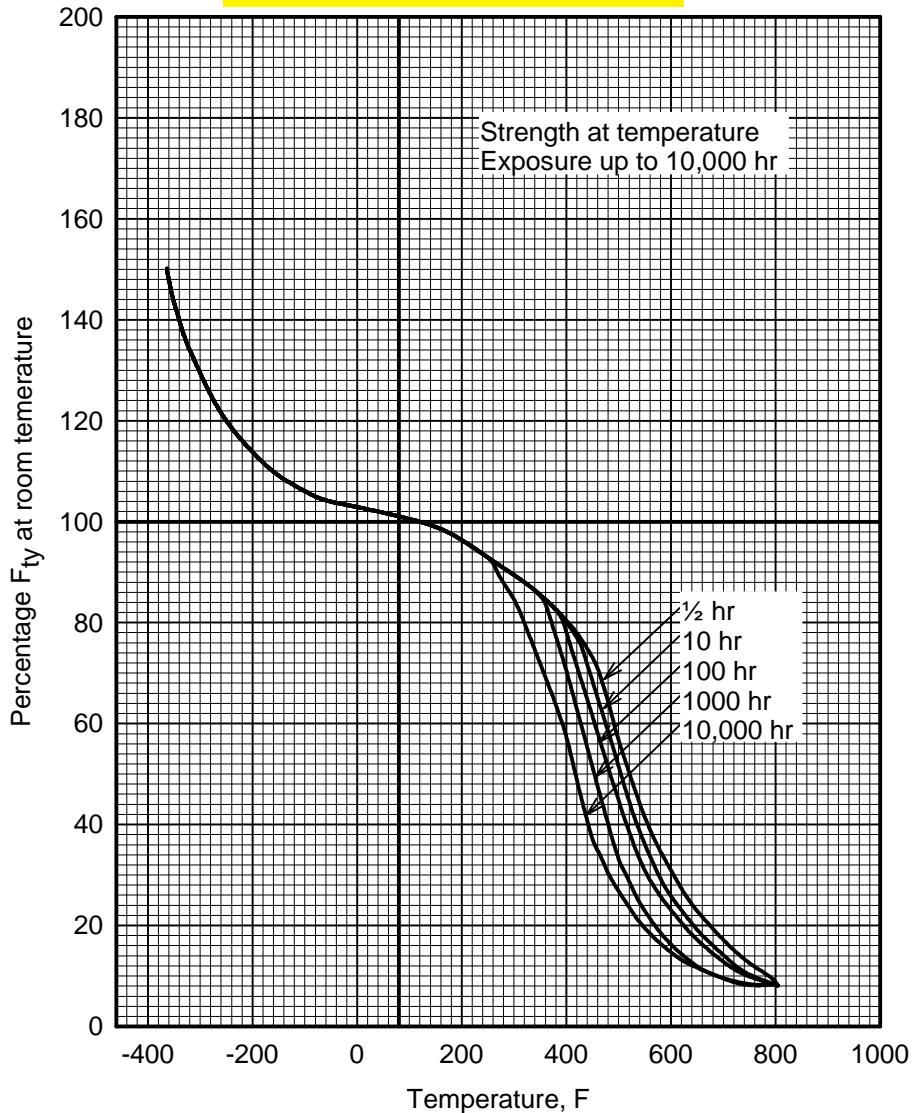


Figure 3.2.3.1.1(b). Effect of temperature on the tensile yield strength (F_{ty}) of 2024-T3, T351, and 2024-T4 aluminum alloy (all products except extrusions).

Click the image to view the Interactive Graph

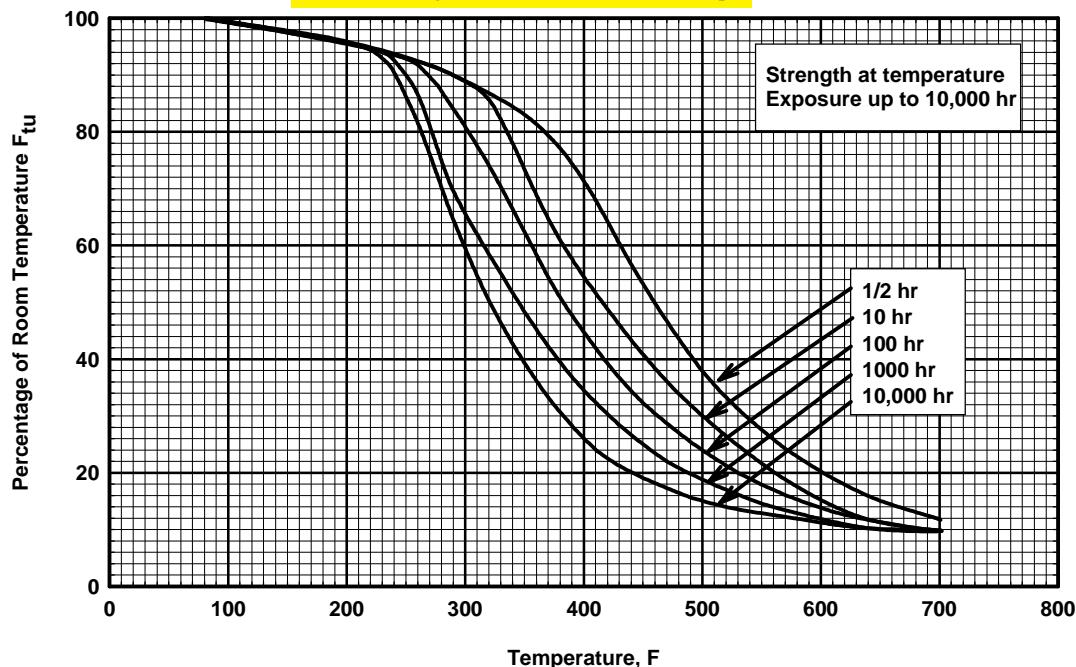


Figure 3.2.3.1.1(c). Effect of temperature on the tensile ultimate strength (F_{tu}) of 2024-T3, T3510, T3511, and T42 aluminum alloy extrusion.

Click the image to view the Interactive Graph

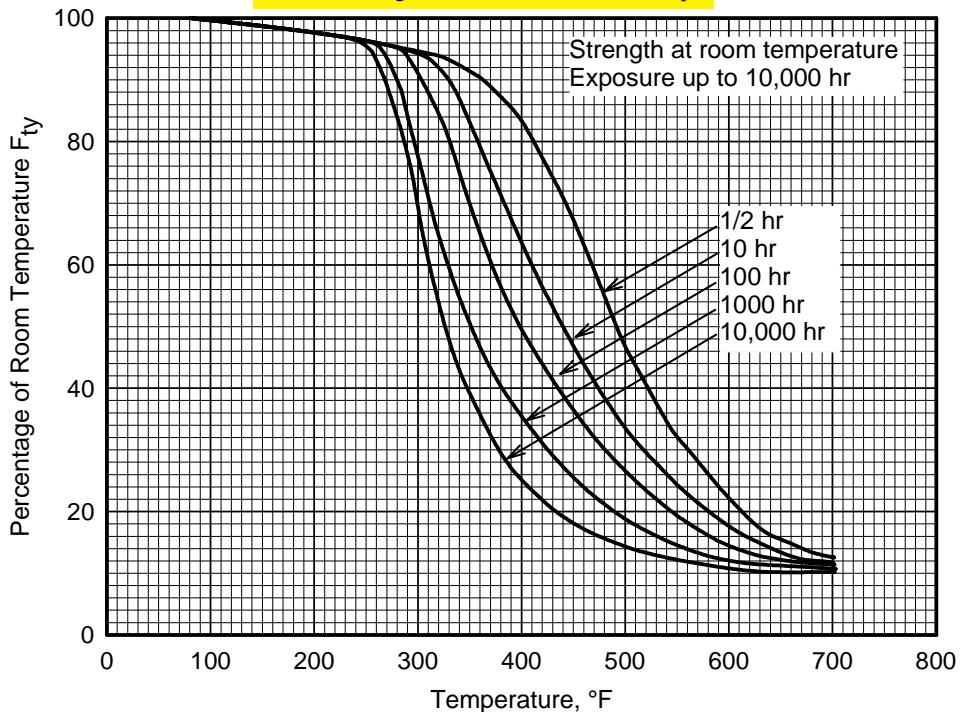


Figure 3.2.3.1.1(d). Effect of temperature on the tensile yield strength (F_{ty}) of 2024-T3, T3510, T3511, and T42 aluminum alloy extrusion.

Click the image to view the Interactive Graph

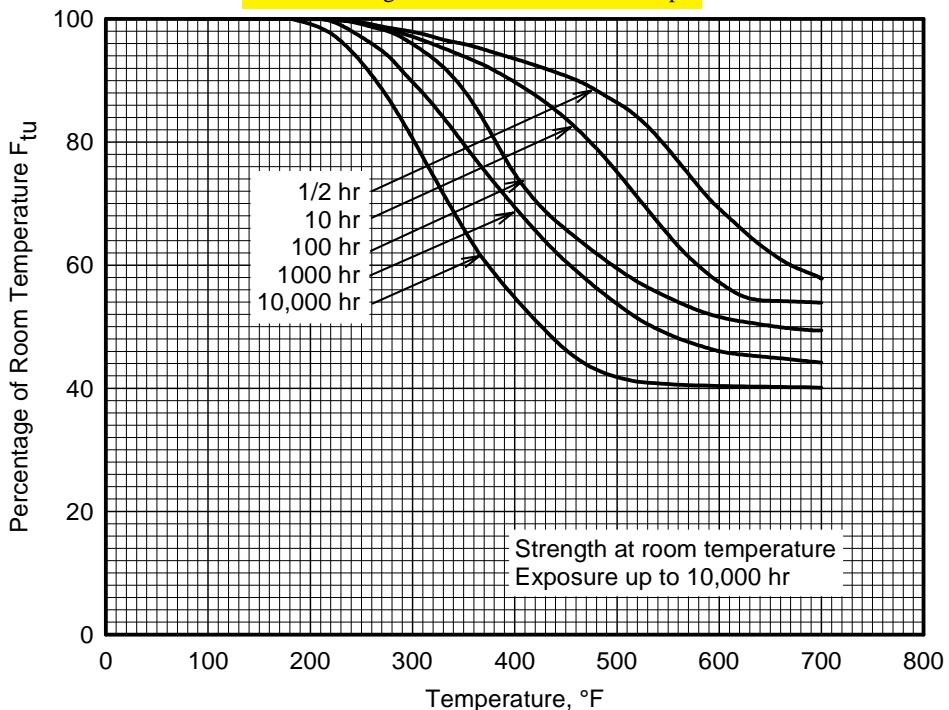


Figure 3.2.3.1.1(e). Effect of exposure at elevated temperatures on the room-temperature tensile ultimate strength (F_{tu}) of 2024-T3, T351, T3510, T3511, and T42 aluminum alloy (all products except thick extrusions).

Click the image to view the Interactive Graph

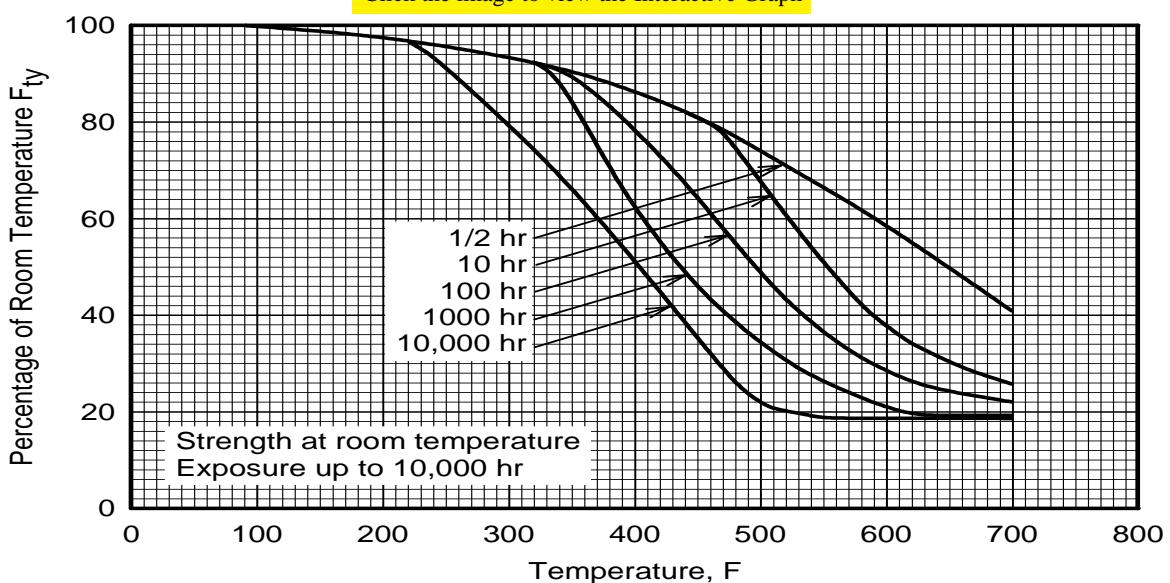


Figure 3.2.3.1.1(f). Effect of exposure at elevated temperatures on the room-temperature tensile yield strength (F_{ty}) of 2024-T3, T351, T3510, T3511, T4 and T42 aluminum alloy (all products except thick extrusions).

Click the image to view the Interactive Graph

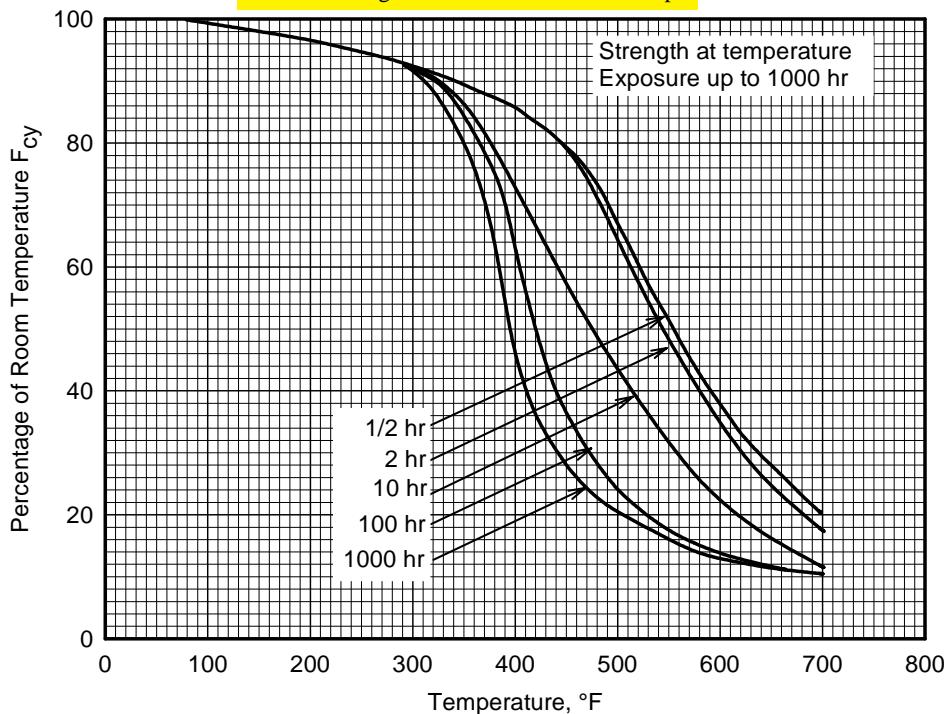


Figure 3.2.3.1.2(a). Effect of temperature on the compressive yield strength (F_{cy}) of flat clad 2024-T3, coiled clad 2024-T4 aluminum alloy sheet, and clad 2024-T351 aluminum alloy plate.

Click the image to view the Interactive Graph

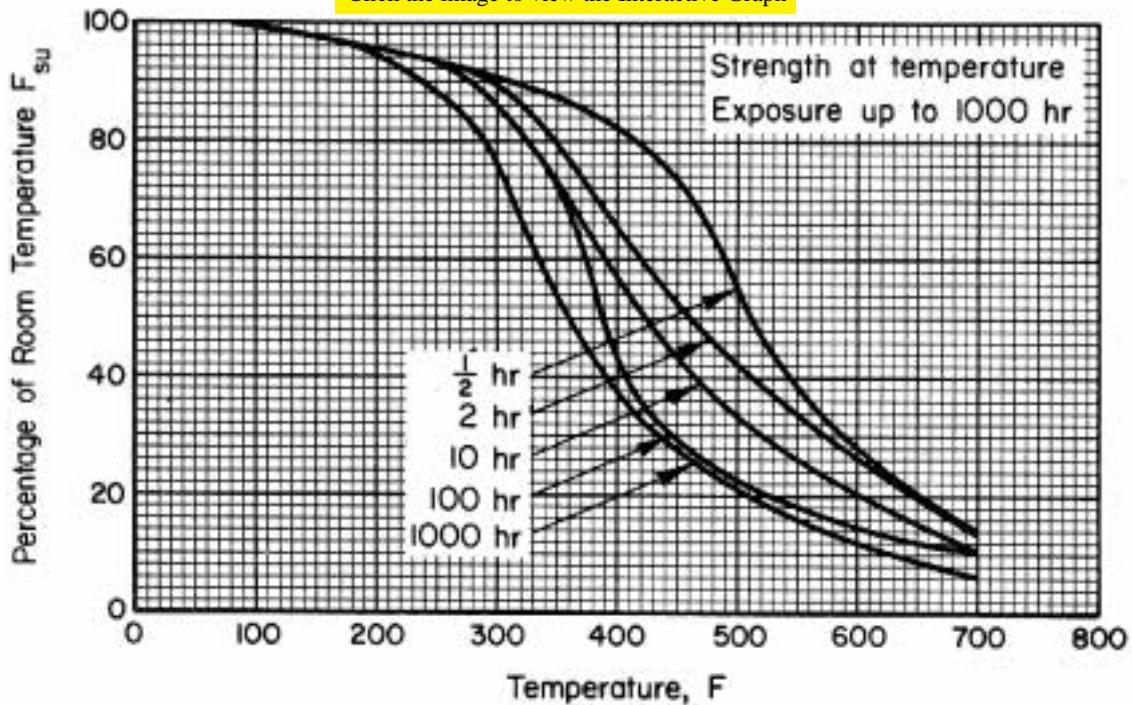


Figure 3.2.3.1.2(b). Effect of temperature on the shear ultimate strength (F_{su}) of flat clad 2024-T3, coiled clad 2024-T4 aluminum alloy sheet, and clad 2024-T351 aluminum alloy plate.

Click the image to view the Interactive Graph

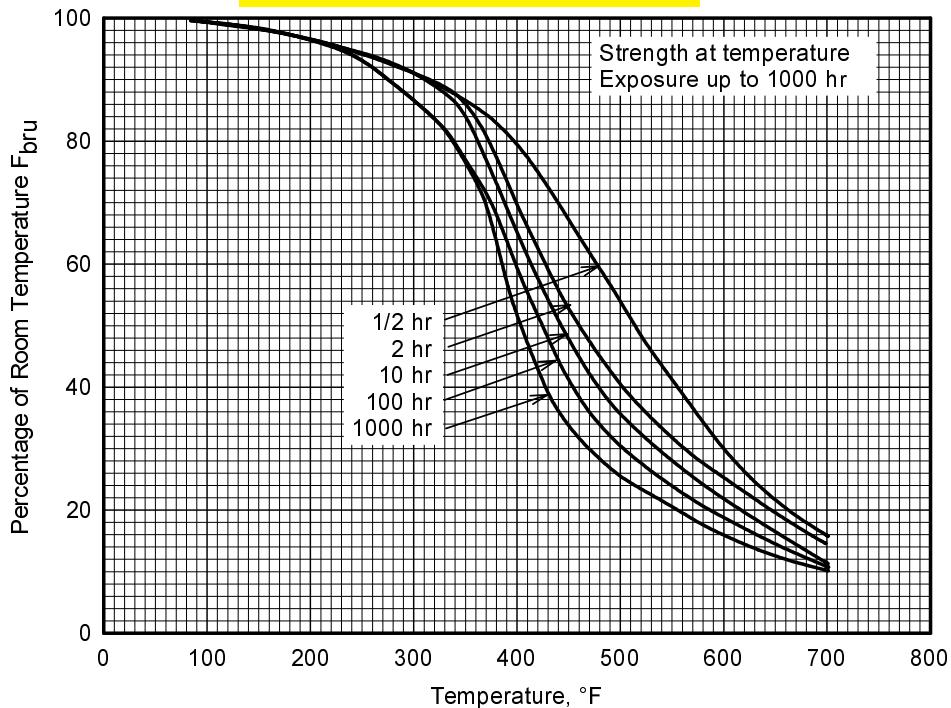


Figure 3.2.3.1.3(a). Effect of temperature on the bearing ultimate strength (F_{bru}) of flat clad 2024-T3, coiled clad 2024-T4 aluminum alloy sheet, and clad 2024-T351 aluminum alloy plate.

Click the image to view the Interactive Graph

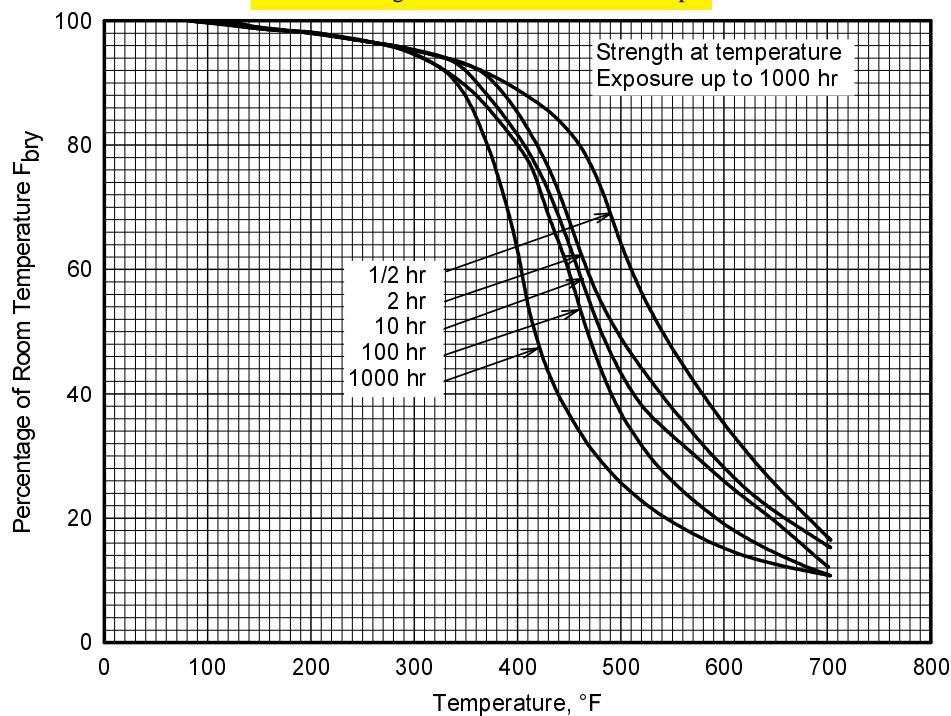


Figure 3.2.3.1.3(b). Effect of temperature on the bearing yield strength (F_{bry}) of flat clad 2024-T3, coiled clad 2024-T4 aluminum alloy sheet, and clad 2024-T351 aluminum alloy plate.

Click the image to view the Interactive Graph

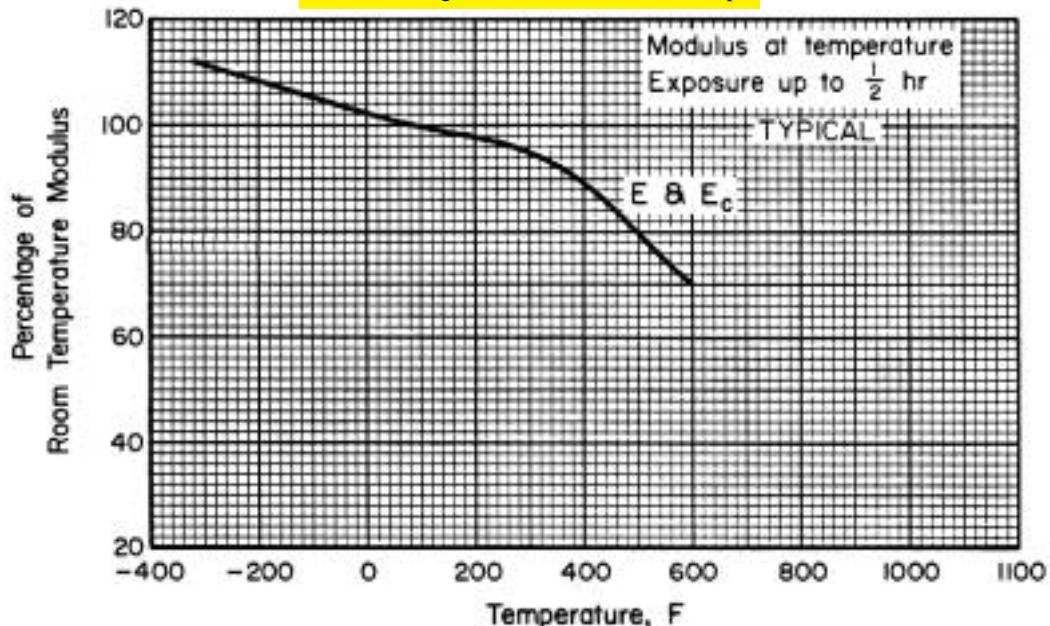


Figure 3.2.3.1.4. Effect of temperature on the tensile and compressive moduli (E and E_c) of 2024 aluminum alloy.

Click the image to view the Interactive Graph

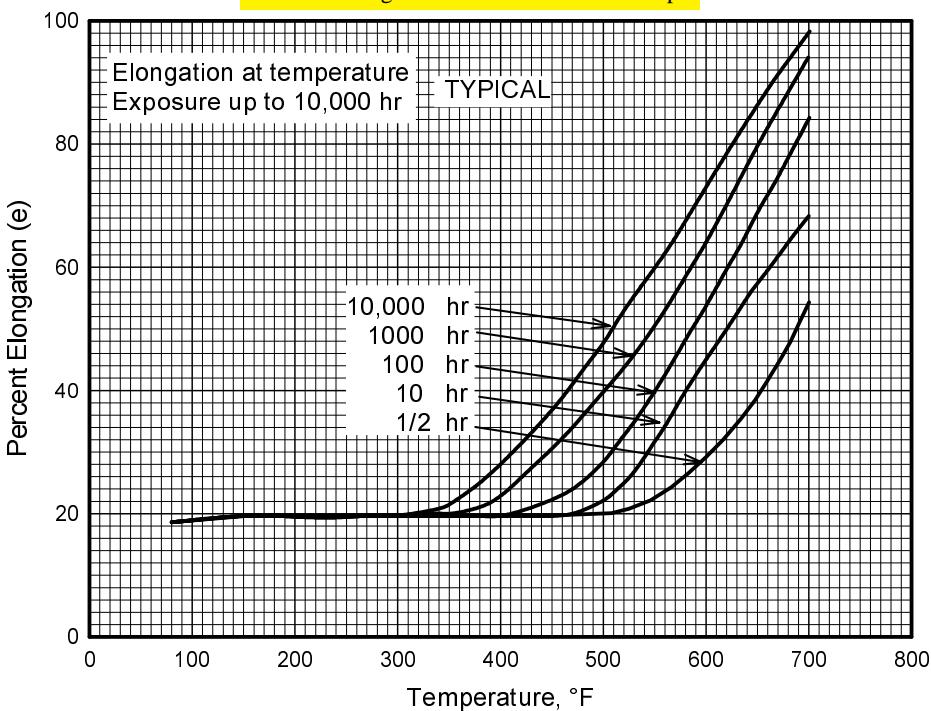


Figure 3.2.3.1.5(a). Effect of temperature on the elongation of 2024-T3, T351, T3510, T3511, T4, and T42 aluminum alloy (all products except thick extrusions).

Click the image to view the Interactive Graph.

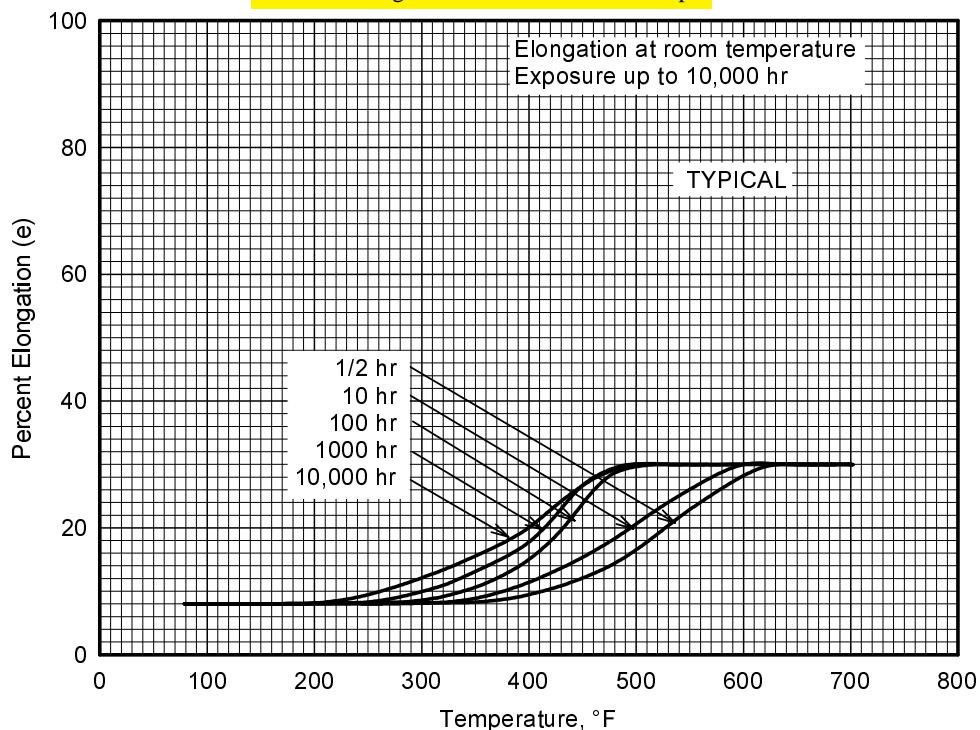


Figure 3.2.3.1.5(b). Effect of exposure at elevated temperature on the elongation(e) of 2024-T3, T351, T3510, T3511, T4 and T42 aluminum alloy (all products except thick extrusions).

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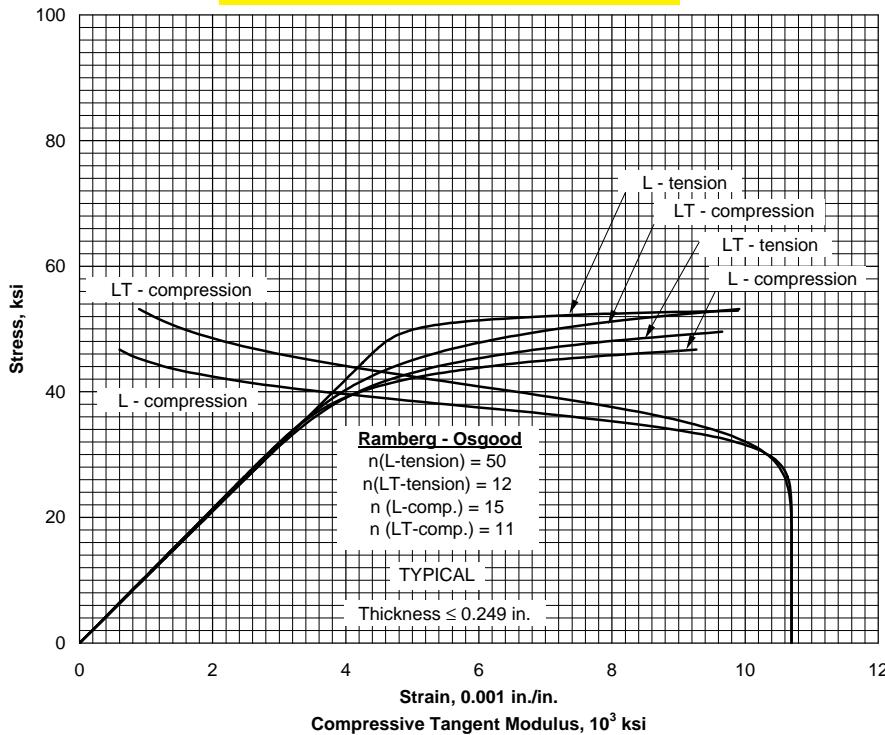


Figure 3.2.3.1.6(a). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for 2024-T3 aluminum alloy sheet at room temperature.

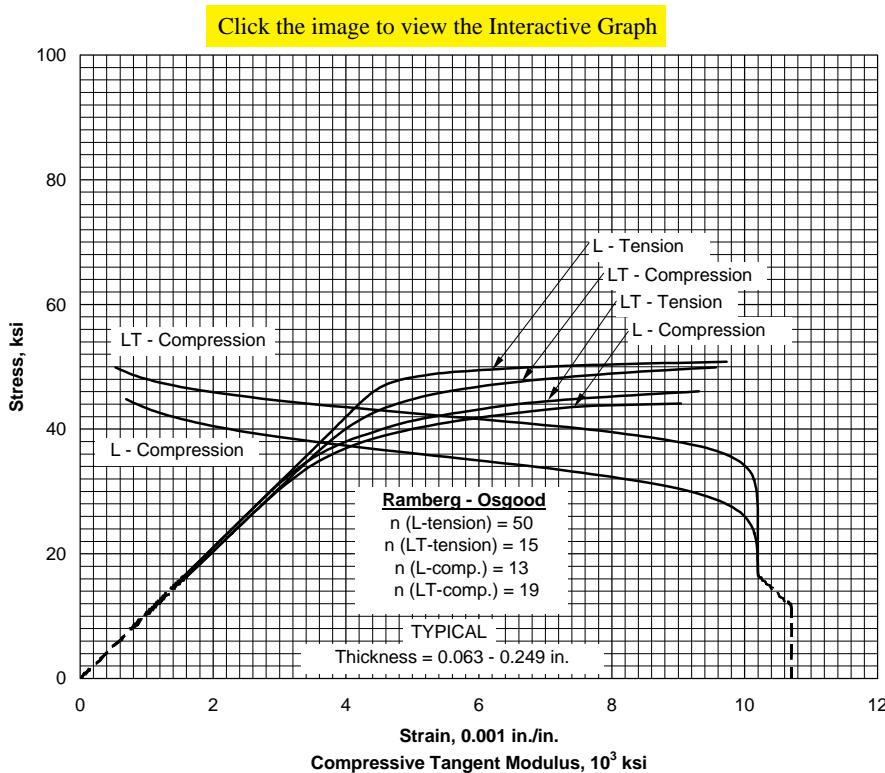


Figure 3.2.3.1.6(b). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for clad 2024-T3 aluminum alloy sheet at room temperature.

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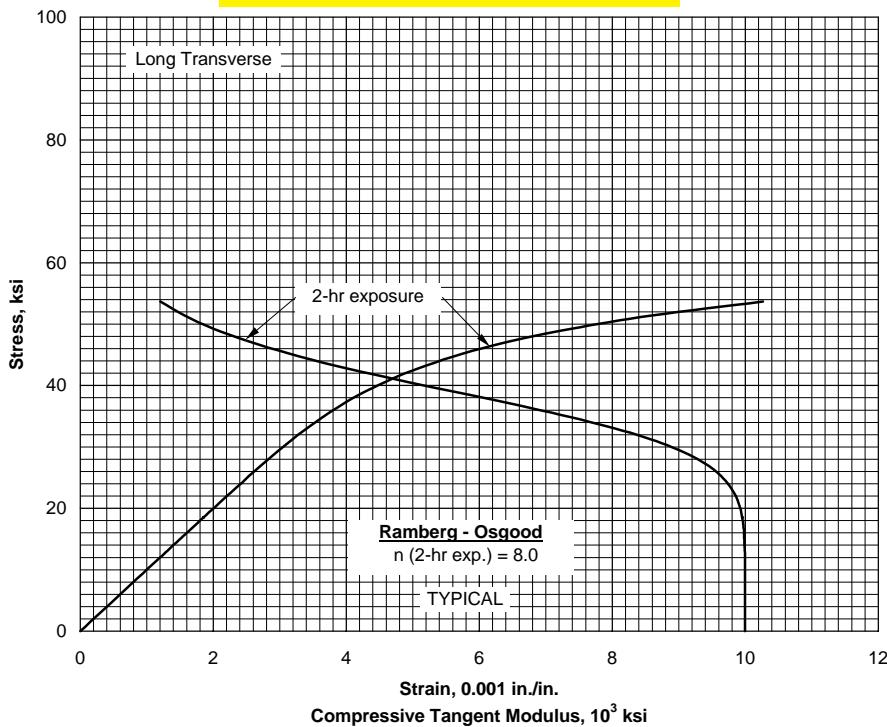


Figure 3.2.3.1.6(c). Typical compressive stress-strain and compressive tangent-modulus curves for clad 2024-T3 aluminum alloy sheet at 212° F.

Click the image to view the Interactive Graph

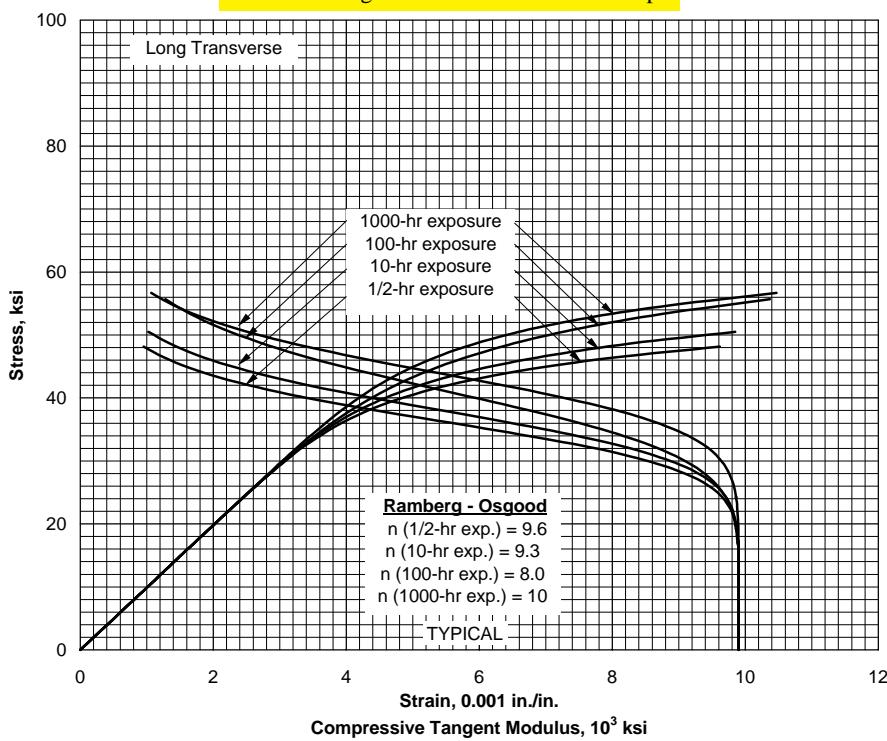


Figure 3.2.3.1.6(d). Typical compressive stress-strain and compressive tangent-modulus curves for clad 2024-T3 aluminum alloy sheet at 300° F.

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Click the image to view the Interactive Graph

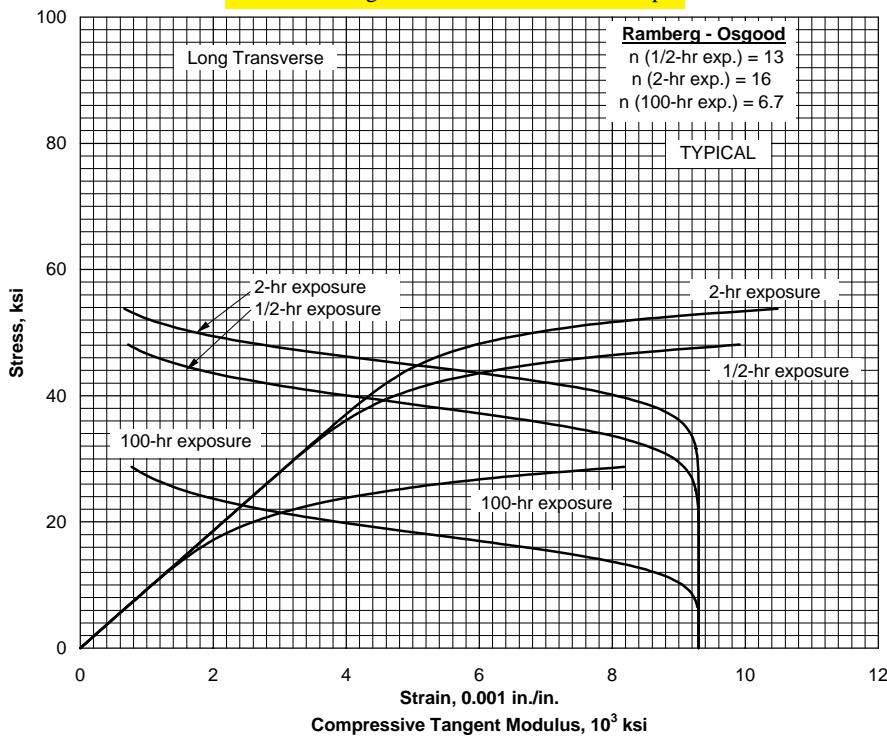


Figure 3.2.3.1.6(e). Typical compressive stress-strain and compressive tangent modulus curves for clad 2024-T3 aluminum alloy sheet at 400° F.

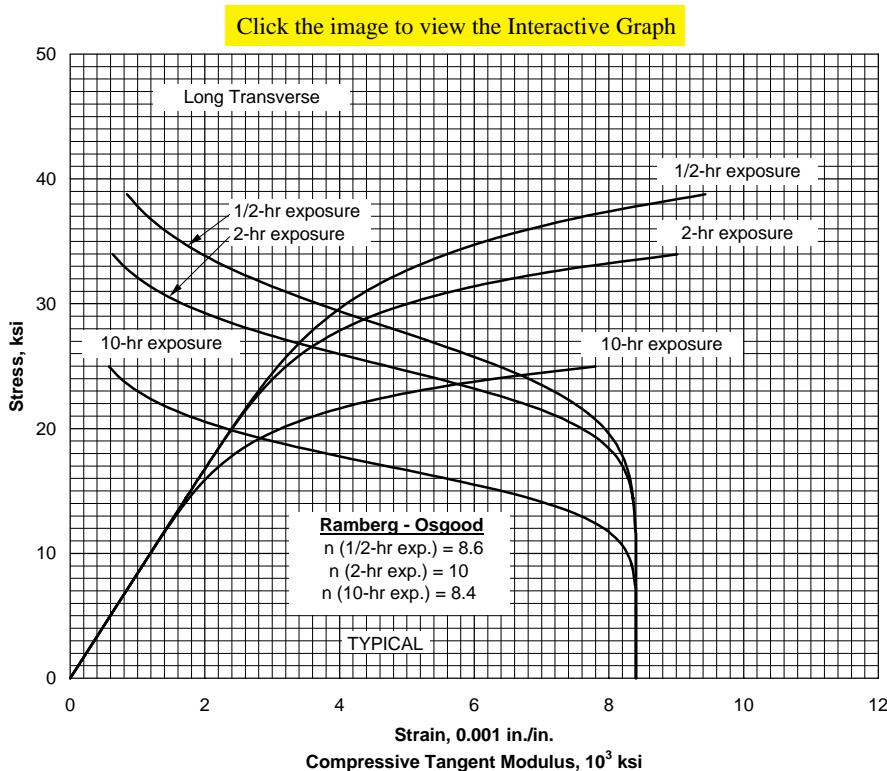


Figure 3.2.3.1.6(f). Typical compressive stress-strain and compressive tangent modulus curves for clad 2024-T3 aluminum alloy sheet at 500° F.

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Click the image to view the Interactive Graph

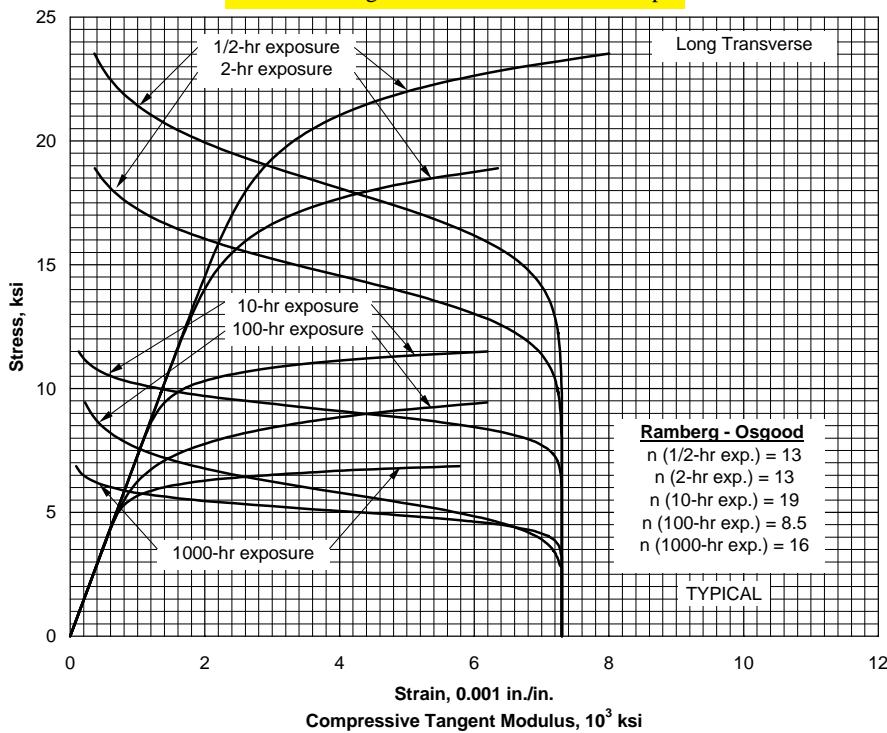


Figure 3.2.3.1.6(g). Typical compressive stress-strain and compressive tangent modulus curves for clad 2024-T3 aluminum alloy sheet at 600° F.

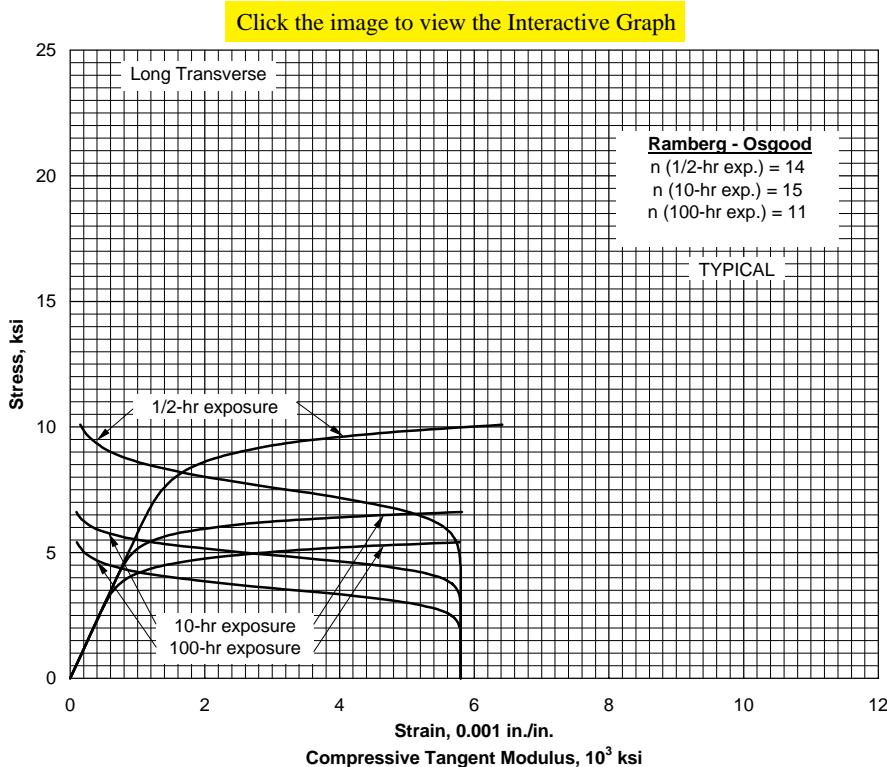


Figure 3.2.3.1.6(h). Typical compressive stress-strain and compressive tangent modulus curves for clad 2024-T3 aluminum alloy sheet at 700° F.

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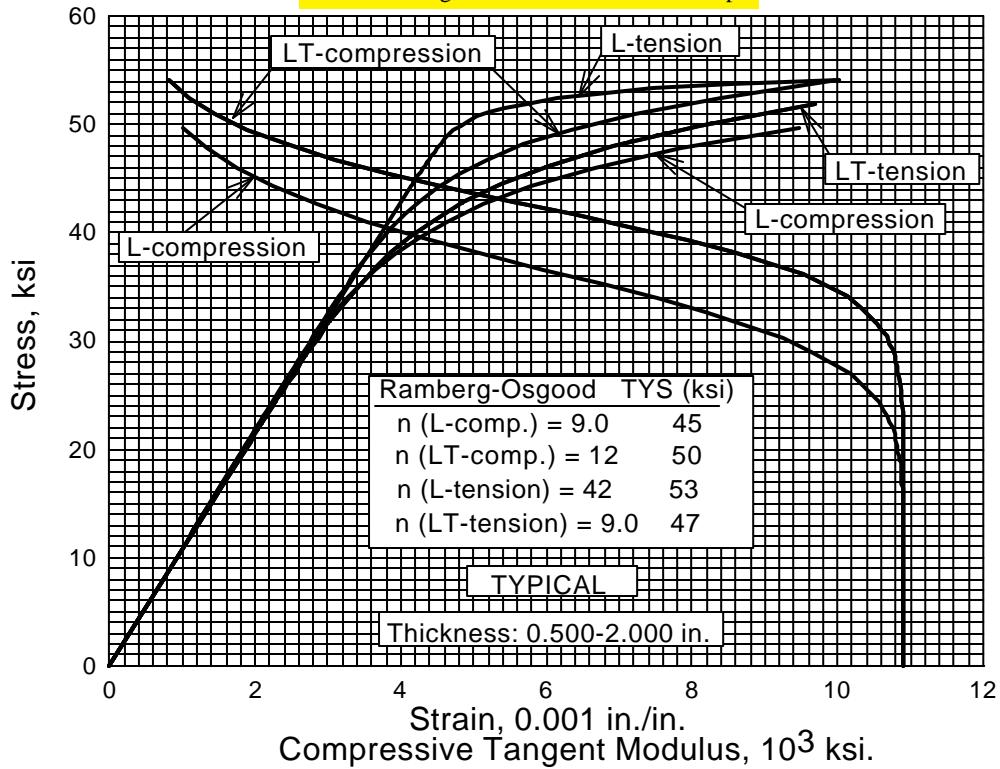


Figure 3.2.3.1.6(i). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for 2024-T351 aluminum alloy plate at room temperature.

Click the image to view the Interactive Graph

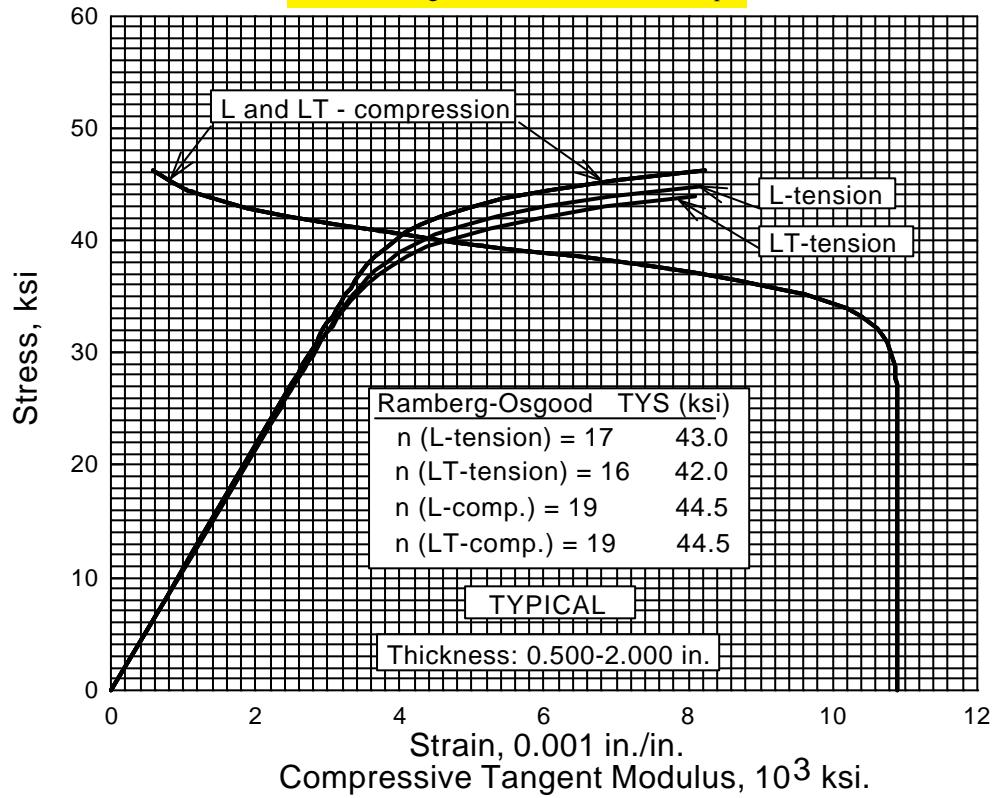


Figure 3.2.3.1.6(j). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for 2024-T42 aluminum alloy plate at room temperature.

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Click the image to view the Interactive Graph

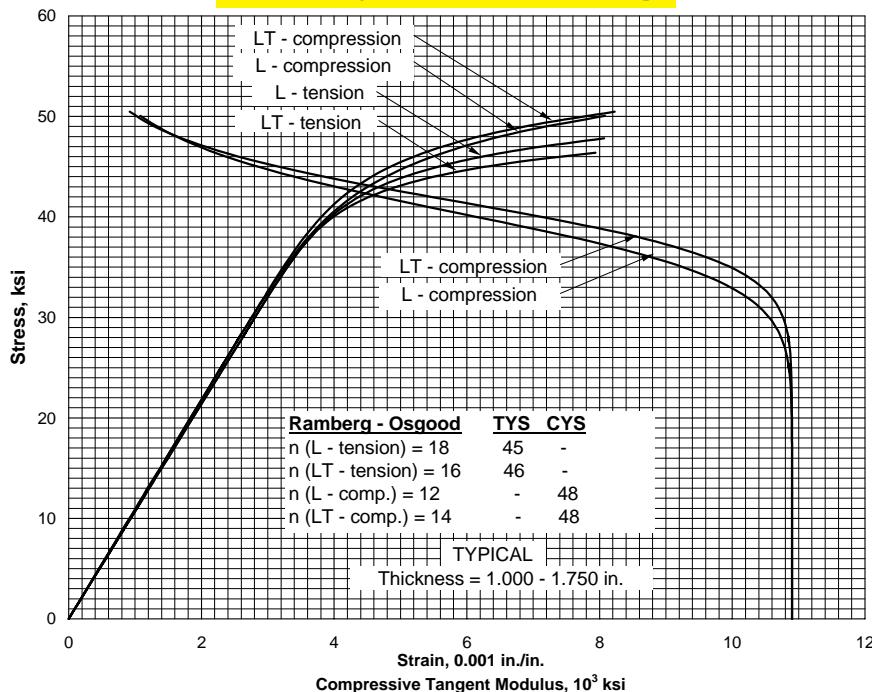


Figure 3.2.3.1.6(k) Typical tension and compressive stress-strain and compressive tangent-modulus curves for 2024-T42 aluminum alloy plate at room temperature. Note, the data to generate these curves may have been from clad product, however, they are shown here without secondary modulus since it could not be positively confirmed the product was cladded.

Click the image to view the Interactive Graph

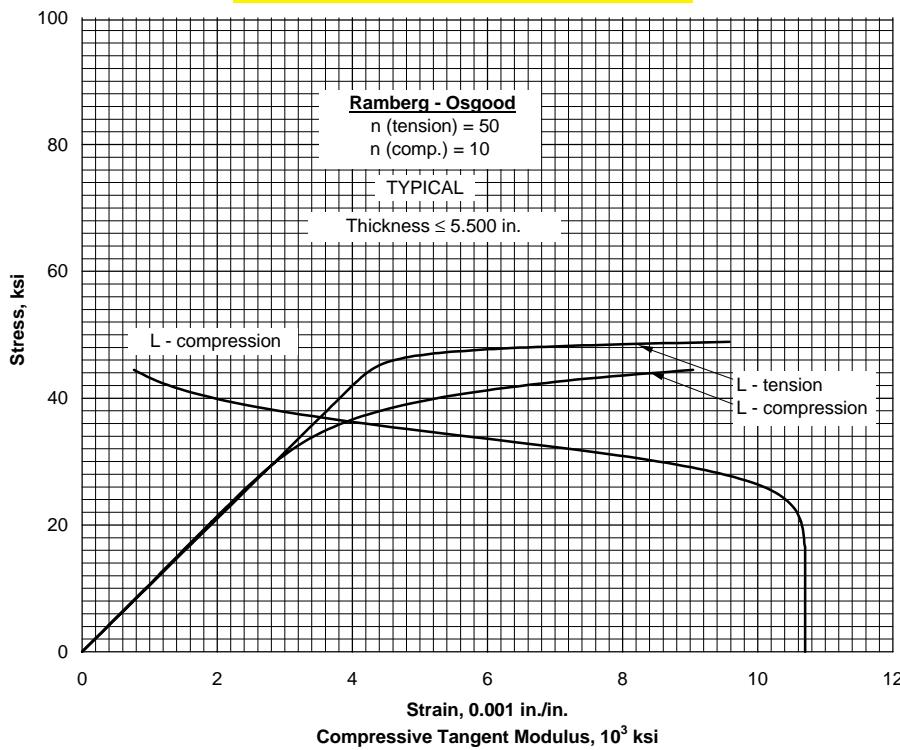


Figure 3.2.3.1.6(l). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for 2024-T4 aluminum alloy rolled bar, rod, and shapes at room temperature.

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Click the image to view the Interactive Graph

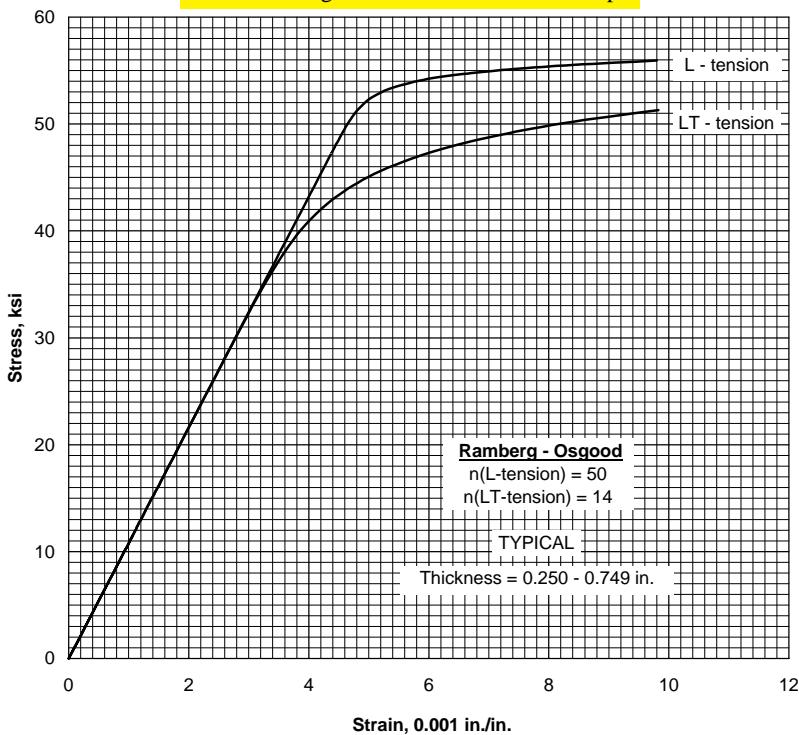


Figure 3.2.3.1.6(m). Typical tensile stress-strain curves for 2024-T351X aluminum alloy extrusion at room temperature.

Click the image to view the Interactive Graph

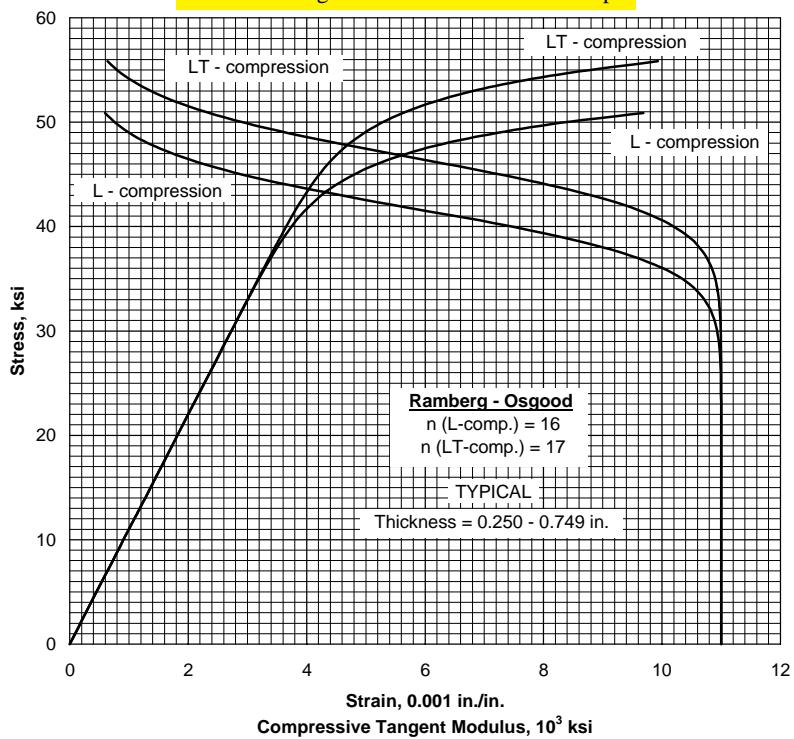


Figure 3.2.3.1.6(n). Typical compressive stress-strain and compressive tangent-modulus curves for 2024-T351X aluminum alloy extrusion at room temperature.

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Click the image to view the Interactive Graph

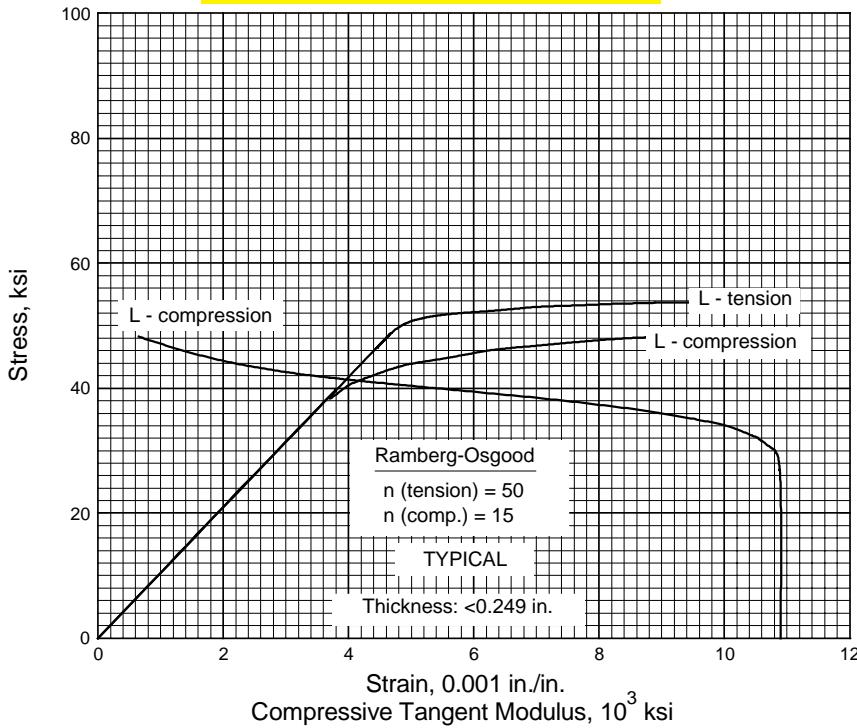


Figure 3.2.3.1.6(o). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for 2024-T3 aluminum alloy extrusion at room temperature.

Click the image to view the Interactive Graph

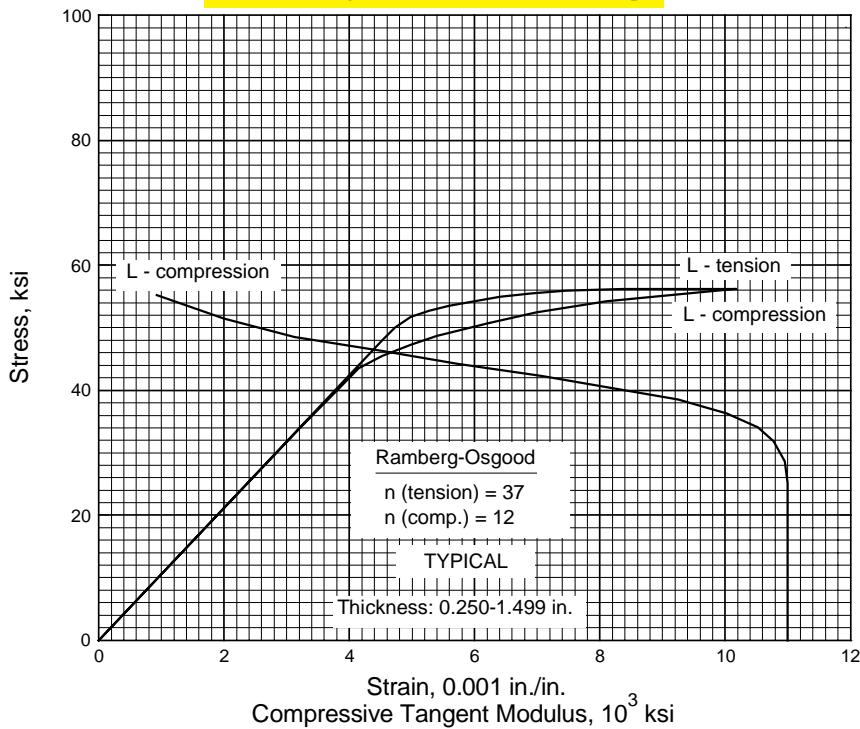


Figure 3.2.3.1.6(p). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for 2024-T3 aluminum alloy extrusion at room temperature.

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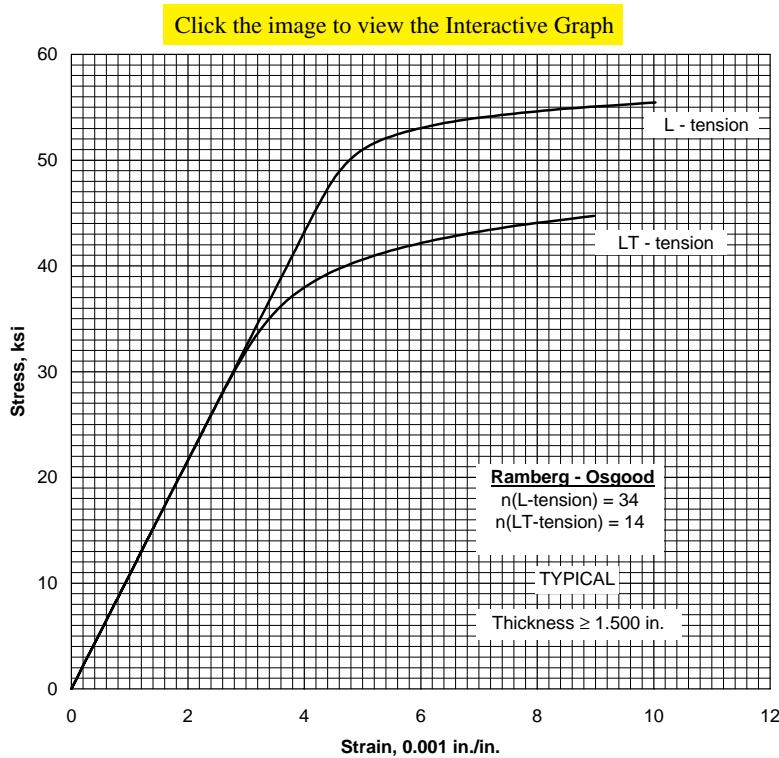


Figure 3.2.3.1.6(q). Typical tensile stress-strain curves for 2024-T42 aluminum alloy extrusion at room temperature.

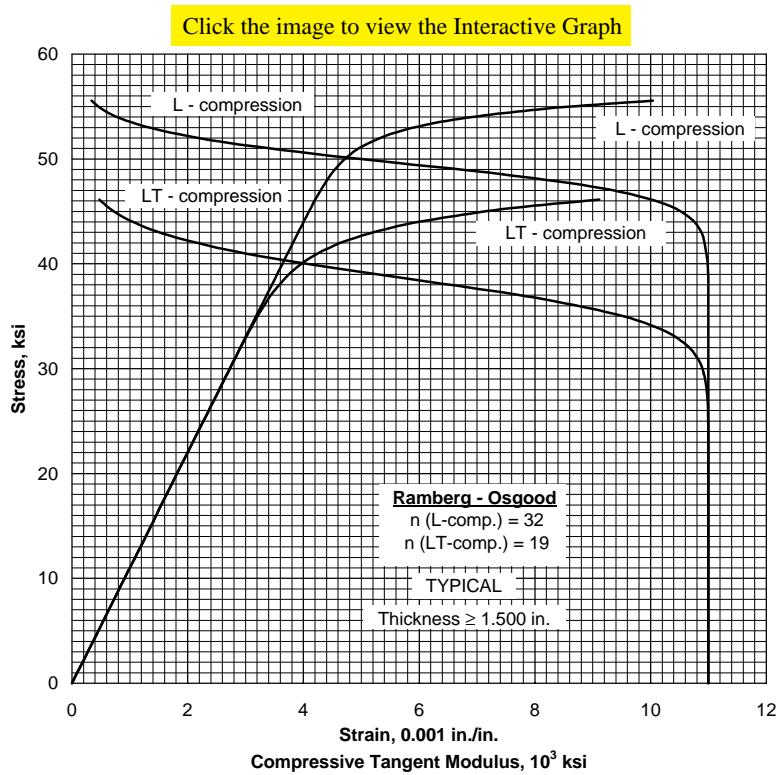


Figure 3.2.3.1.6(r). Typical compressive stress-strain and compressive tangent-modulus curves for 2024-T42 aluminum alloy extrusion at room temperature.

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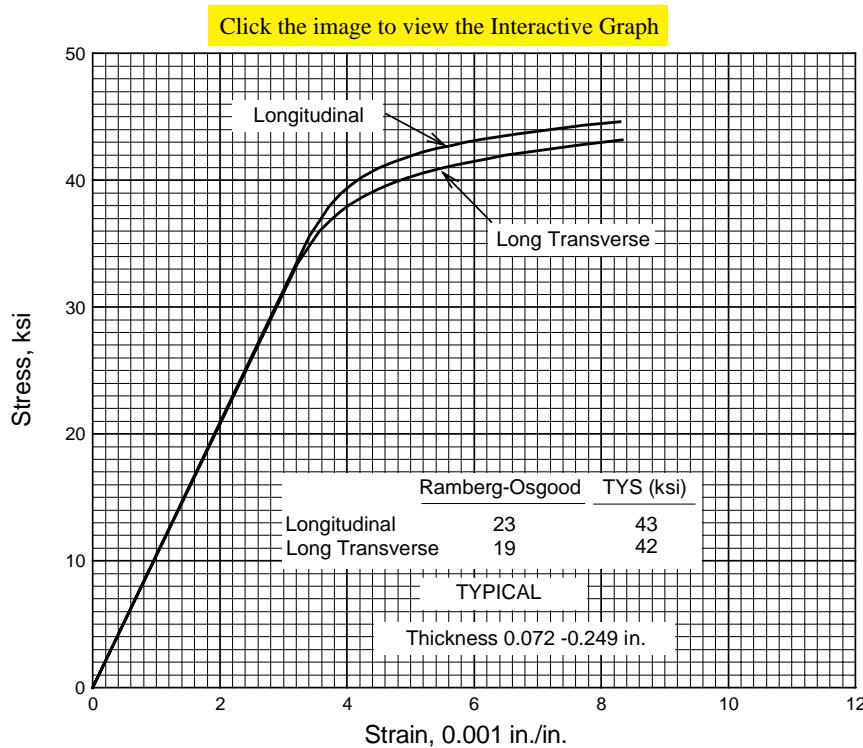


Figure 3.2.3.1.6(s). Typical tensile stress-strain curves for clad 2024-T42 aluminum alloy sheet at room temperature.

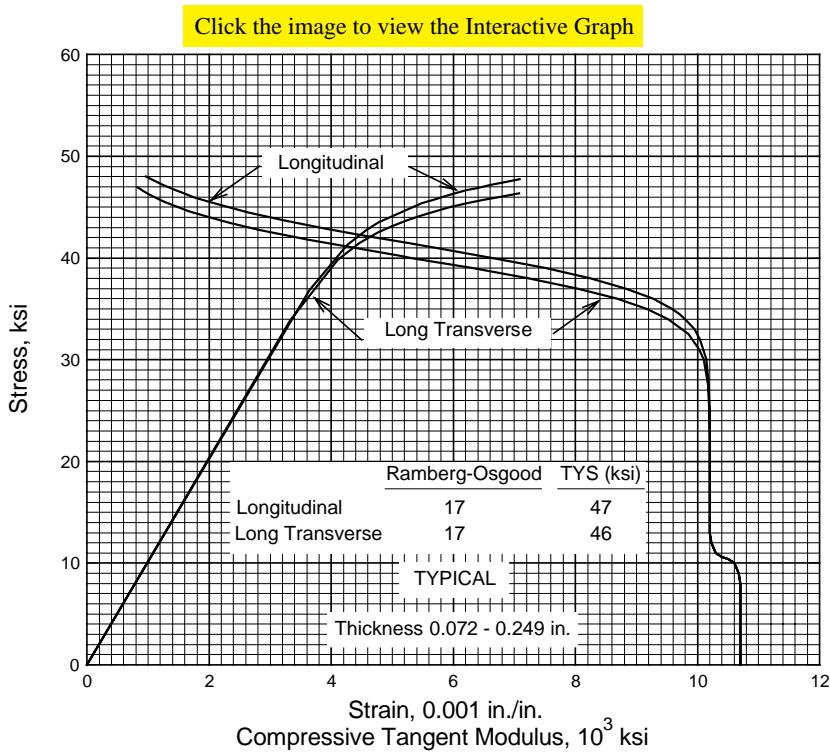


Figure 3.2.3.1.6(t). Typical compressive stress-strain and compressive tangent-modulus curves for clad 2024-T42 aluminum alloy sheet at room temperature.

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Click the image to view the Interactive Graph

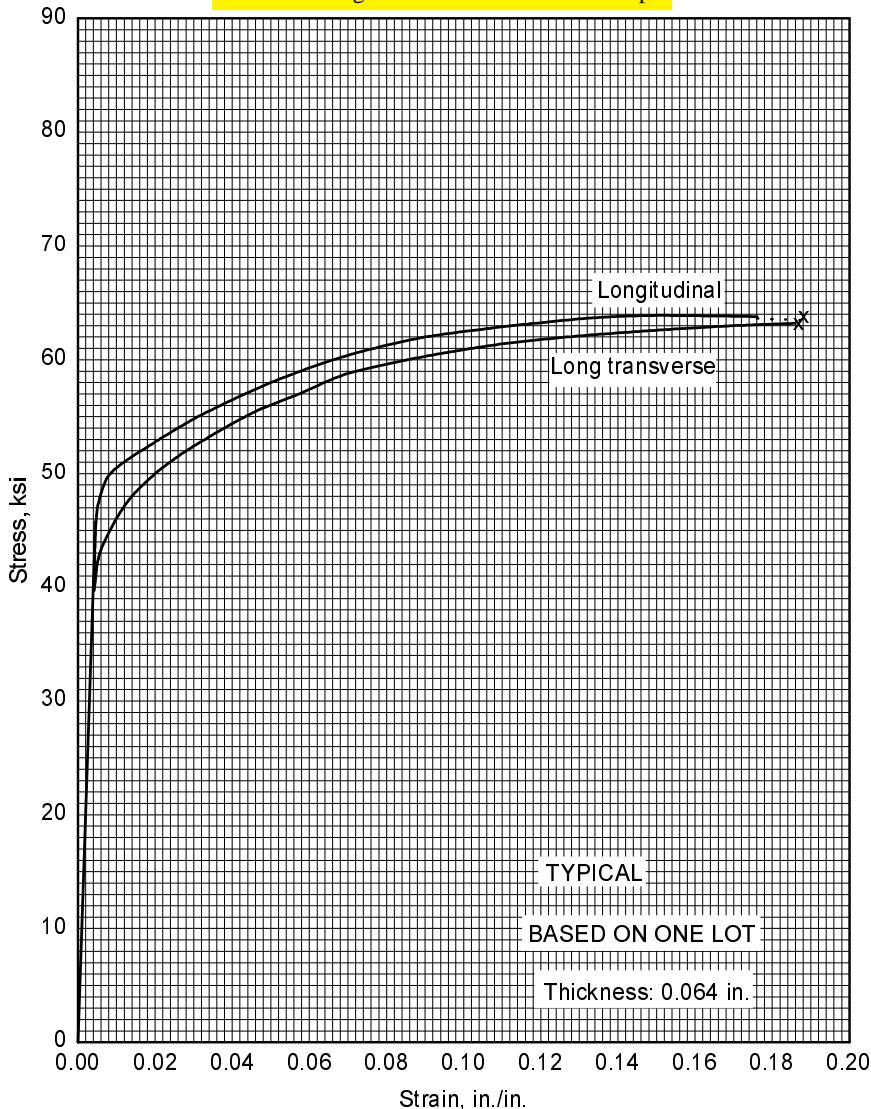


Figure 3.2.3.1.6(u). Typical tensile stress-strain curves (full range) for clad 2024-T3 aluminum alloy sheet at room temperature.

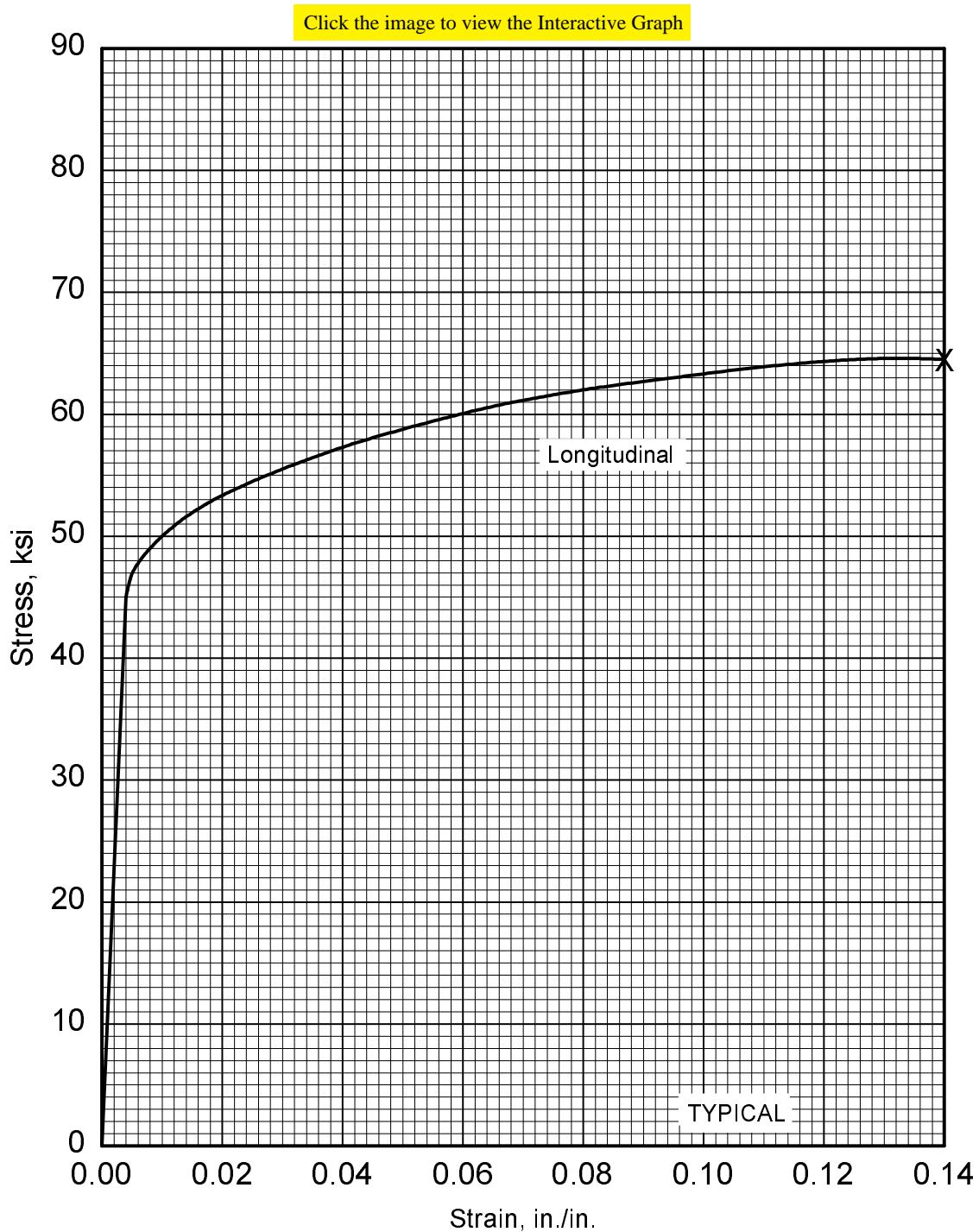


Figure 3.2.3.1.6(v). Typical tensile stress-strain curves (full range) for 2024-T351 aluminum alloy rolled rod at room temperature.

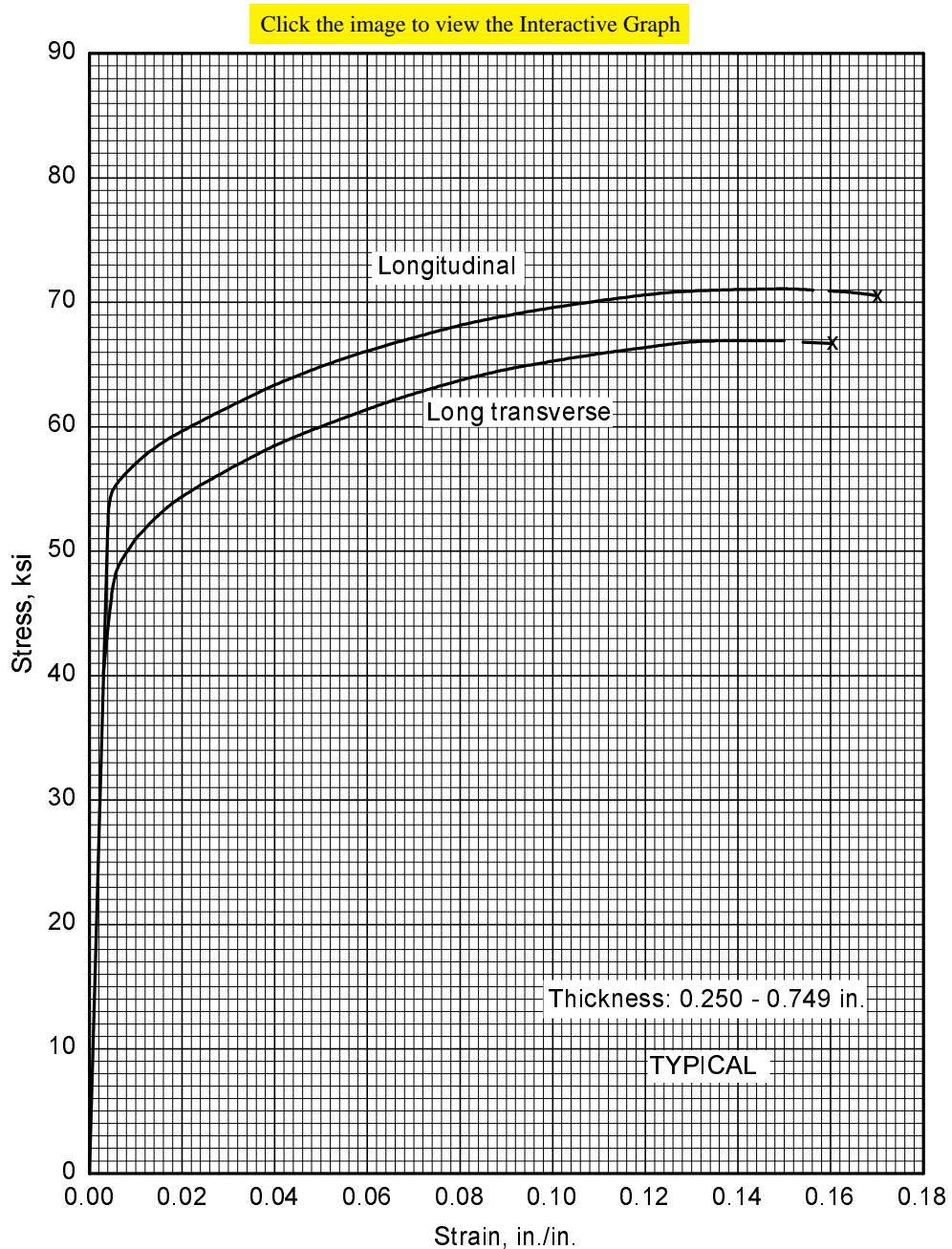


Figure 3.2.3.1.6(w). Typical tensile stress-strain curves (full range) for 2024-T351 aluminum alloy extrusion at room temperature.

Click the image to view the Interactive Graph

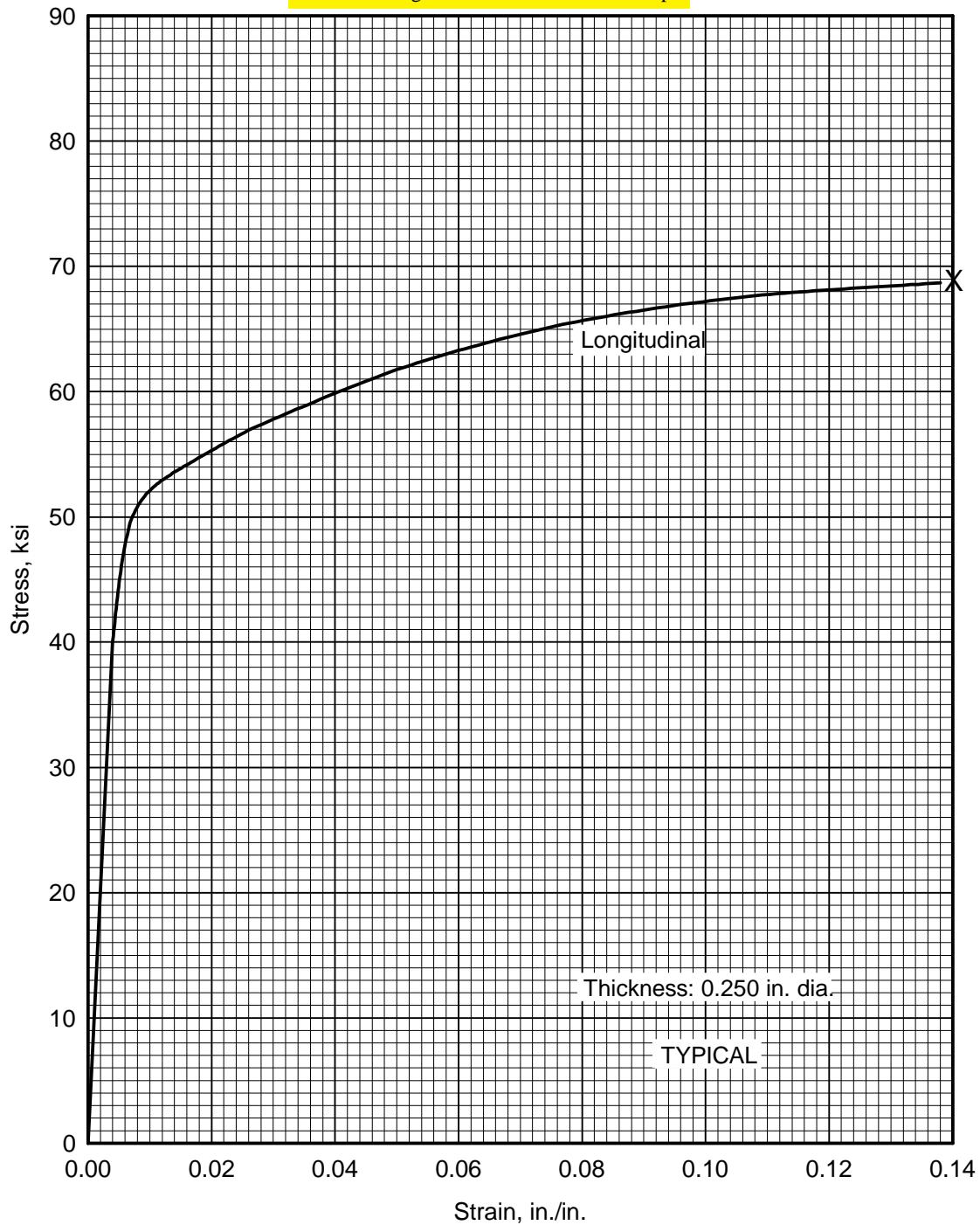


Figure 3.2.3.1.6(x). Typical stress-strain curves (full range) for 2024-T3 aluminum alloy extrusion at room temperature.

Click the image to view the Interactive Graph

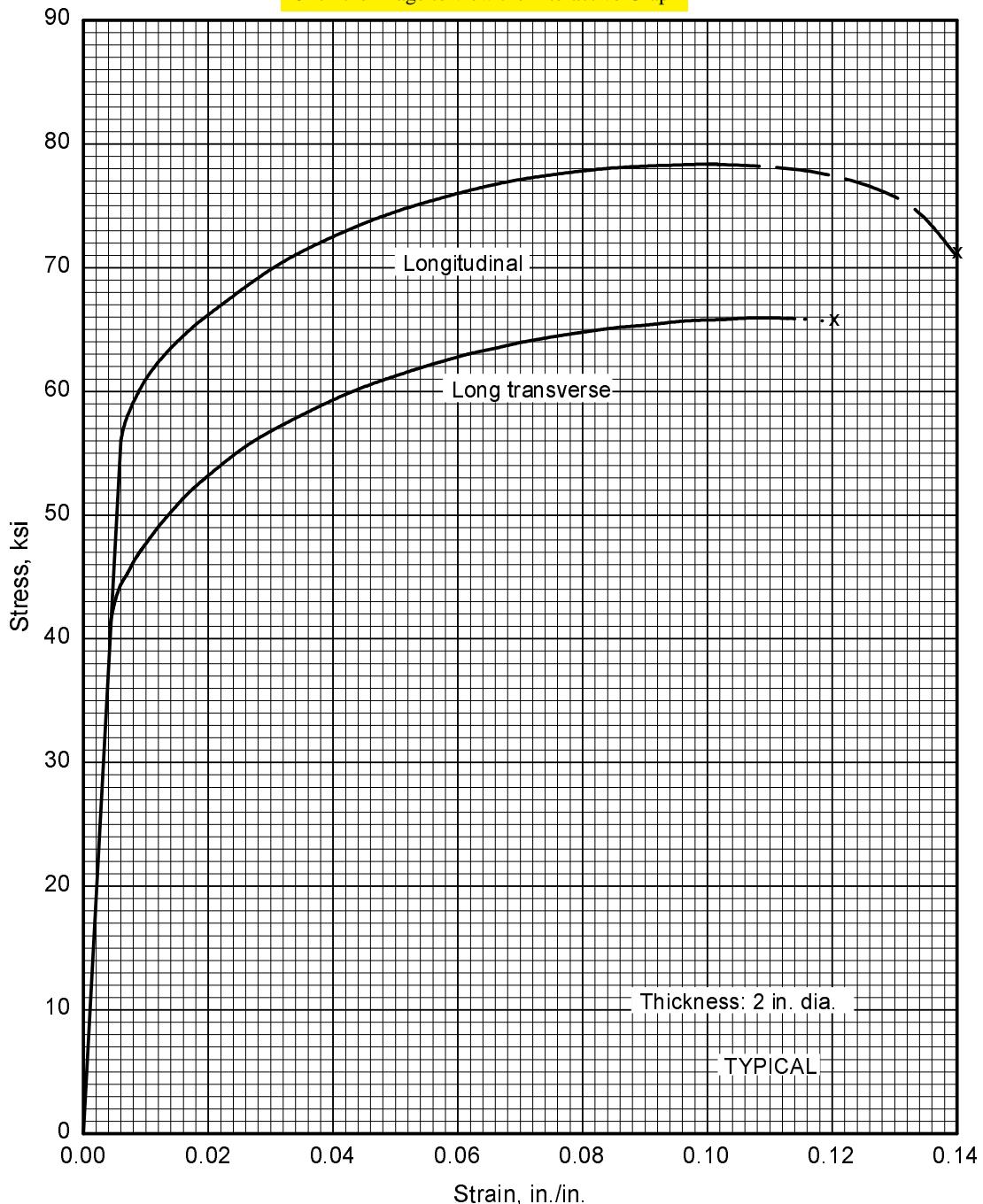


Figure 3.2.3.1.6(y). Typical tensile stress-strain curves (full range) for 2024-T3 aluminum alloy extrusion at room temperature.

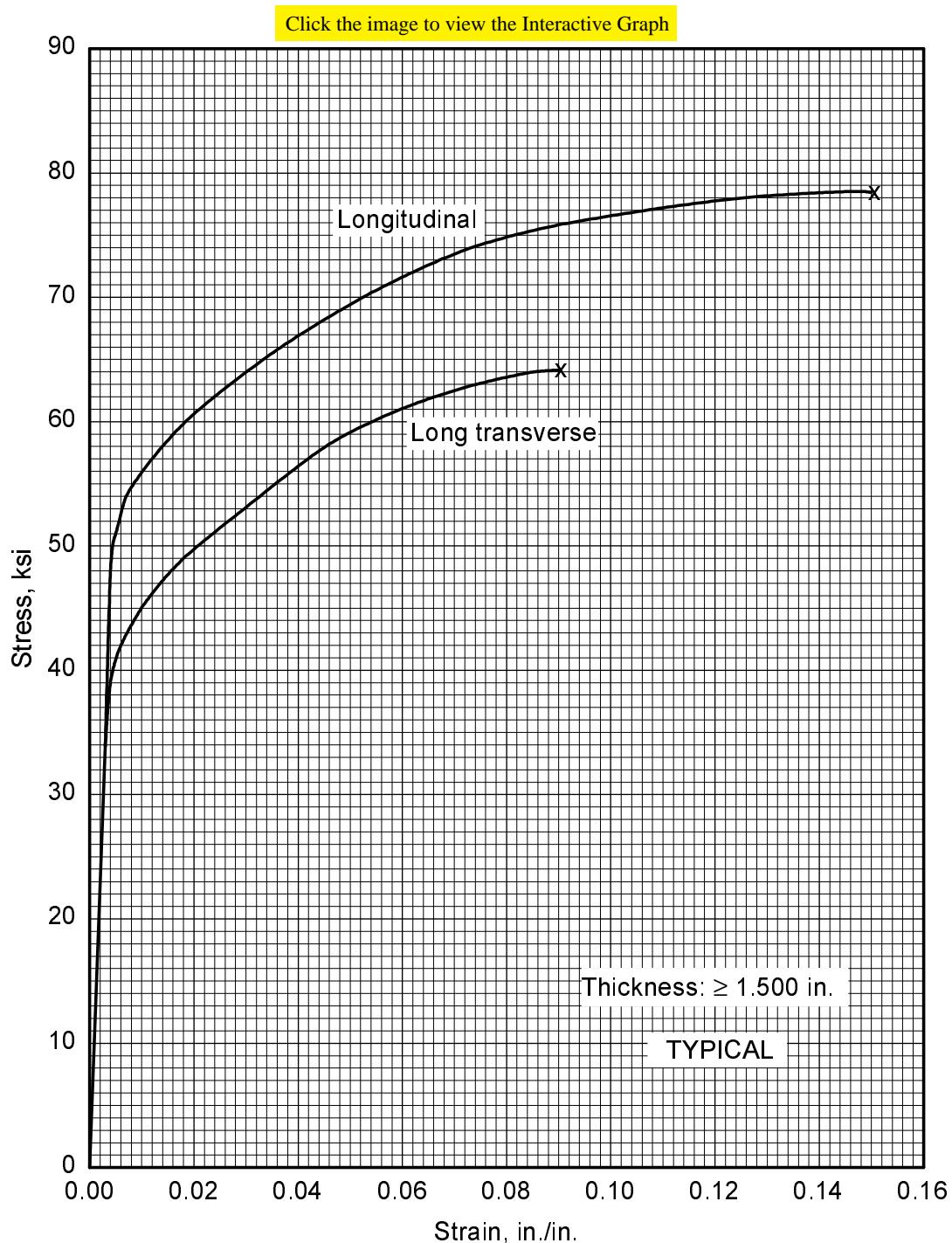


Figure 3.2.3.1.6(z). Typical tensile stress-strain curves (full range) for 2024-T42 aluminum alloy extrusion at room temperature.

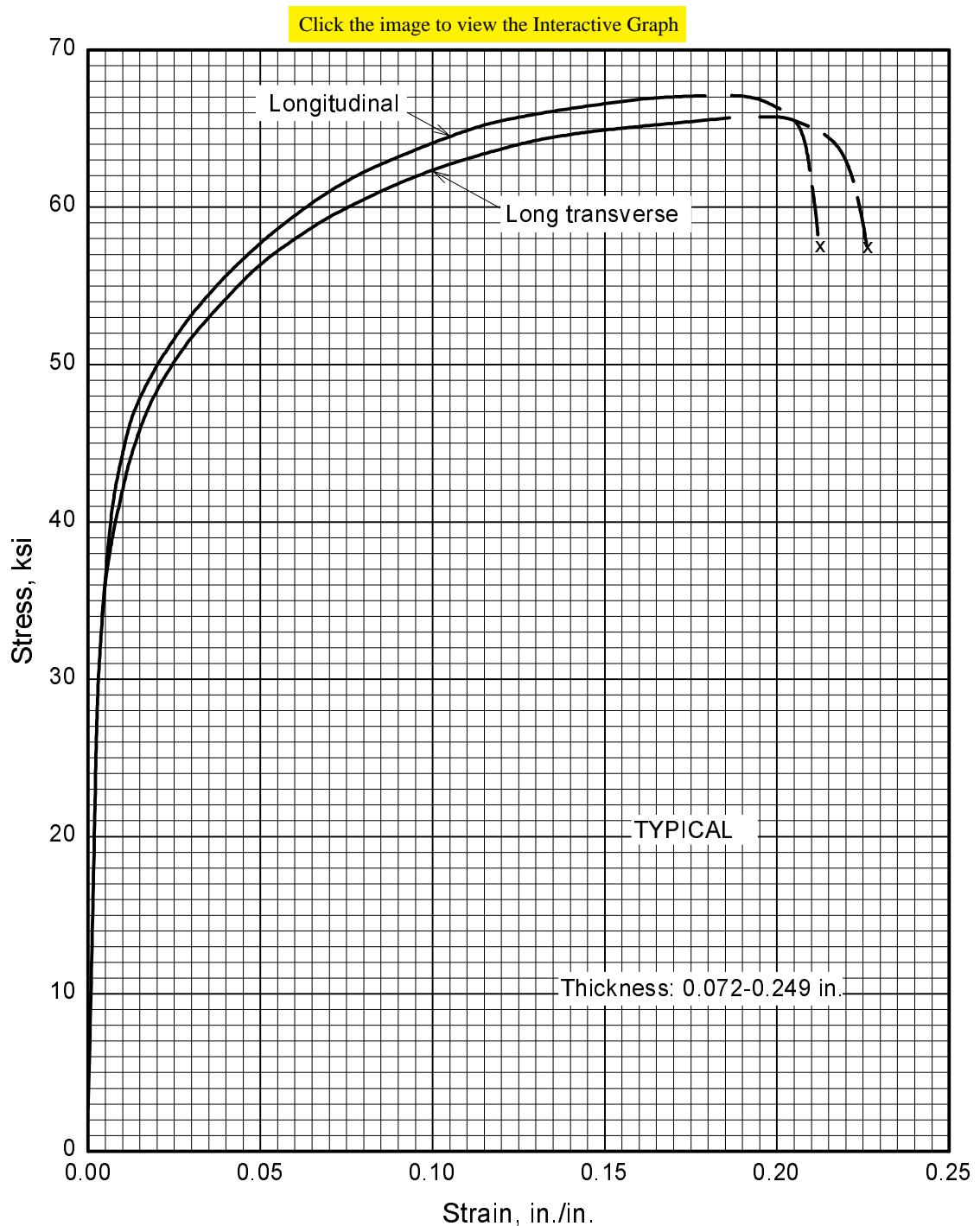


Figure 3.2.3.1.6(aa). Typical stress-strain curves (full range) for 2024-T42 aluminum alloy extrusion at room temperature.

Click the image to view the Interactive Graph

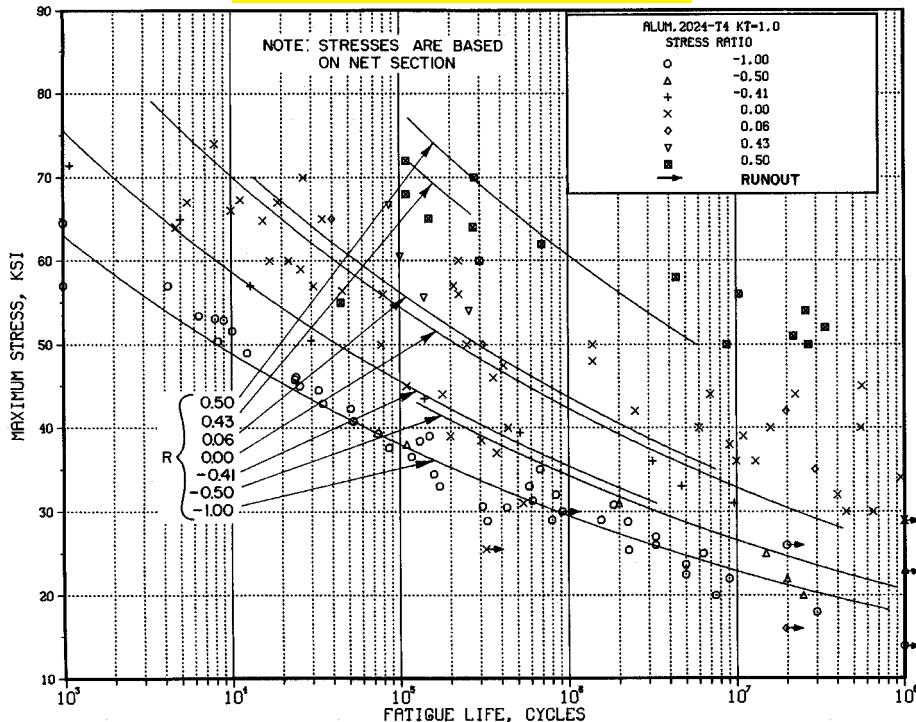


Figure 3.2.3.1.8(a). Best-fit S/N curves for unnotched 2024-T4 aluminum alloy, various wrought products, longitudinal direction.

Correlative Information for Figure 3.2.3.1.8(a)

Product Form: Rolled bar, 3/4 to 1/8 inch diameter
 Drawn rod, 3/4-inch diameter
 Extruded rod, 1-1/4-inch diameter
 Extruded bar, 1-1/4 x 4-inch

Test Parameters:
 Loading - Axial
 Frequency - 1800 to 3600 cpm
 Temperature - RT
 Environment - Air

<u>Properties:</u>	<u>TUS, ksi</u>	<u>TYS, ksi</u>	<u>Temp., °F</u>	<u>No. of Heats/Lots:</u>
	69	45	RT (rolled)	Not specified
	71	44	RT (drawn)	
	85	65	RT (extruded)	

Specimen Details: Unnotched
 0.160 to 0.400-inch diameter

Equivalent Stress Equation:
 $\log N_f = 20.83 - 9.09 \log (S_{eq})$
 $S_{eq} = S_{max} (1-R)^{0.52}$
 Standard Error of Estimate = 0.566
 Standard Deviation in Life = 1.324
 $R^2 = 82\%$

Surface Condition: Longitudinally polished
References: 3.2.1.1.8(a) through (c) and 3.2.3.1.8(i)

Sample Size = 134

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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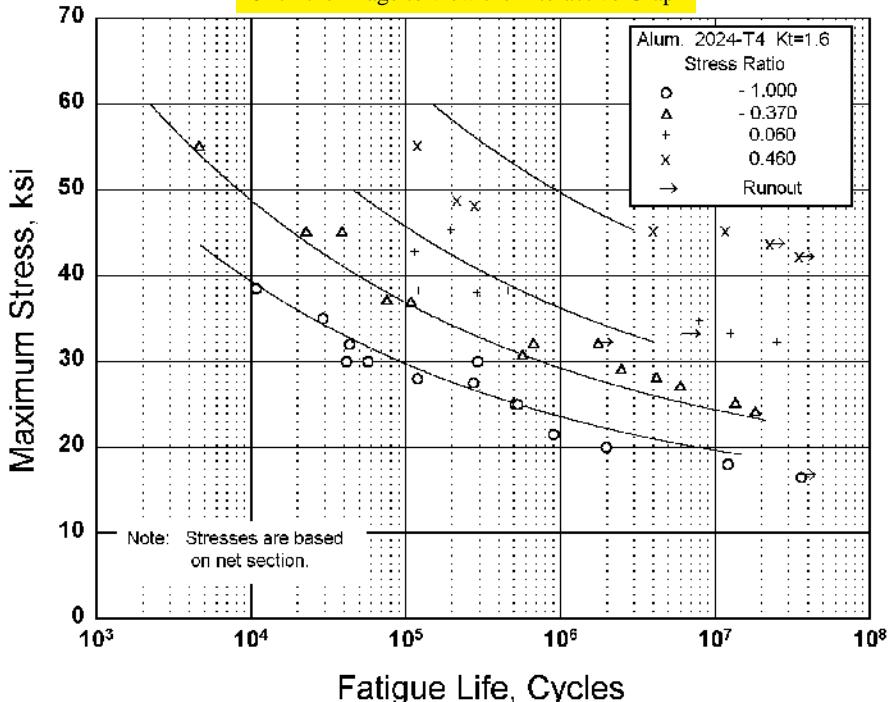


Figure 3.2.3.1.8(b). Best-fit S/N curves for notched, $K_t = 1.6$, 2024-T4 aluminum alloy bar, longitudinal direction.

Correlative Information for Figure 3.2.3.1.8(b)

Product Form: Rolled bar, 1-1/8-inch diameter

Test Parameters:

Loading - Axial

Frequency - 1800 to 3600 cpm

Temperature - RT

Environment - Air

Properties: TUS, ksi TYs, ksi Temp., °F

73 49 RT

Specimen Details: Semicircular
V-Groove, $K_t = 1.6$
0.450-inch gross diameter
0.400-inch net diameter
0.100-inch root radius, r
60° flank angle, ω

Surface Condition: As machined

No. of Heats/Lots: Not specified

Equivalent Stress Equation:

$$\log N_f = 12.25 - 5.16 \log (S_{eq} - 18.7)$$

$$S_{eq} = S_{max} (1-R)^{0.57}$$

Std. Error of Estimate, $\log (\text{Life}) = 0.414$

Standard Deviation, $\log (\text{Life}) = 0.989$

$$R^2 = 82\%$$

Sample Size = 38

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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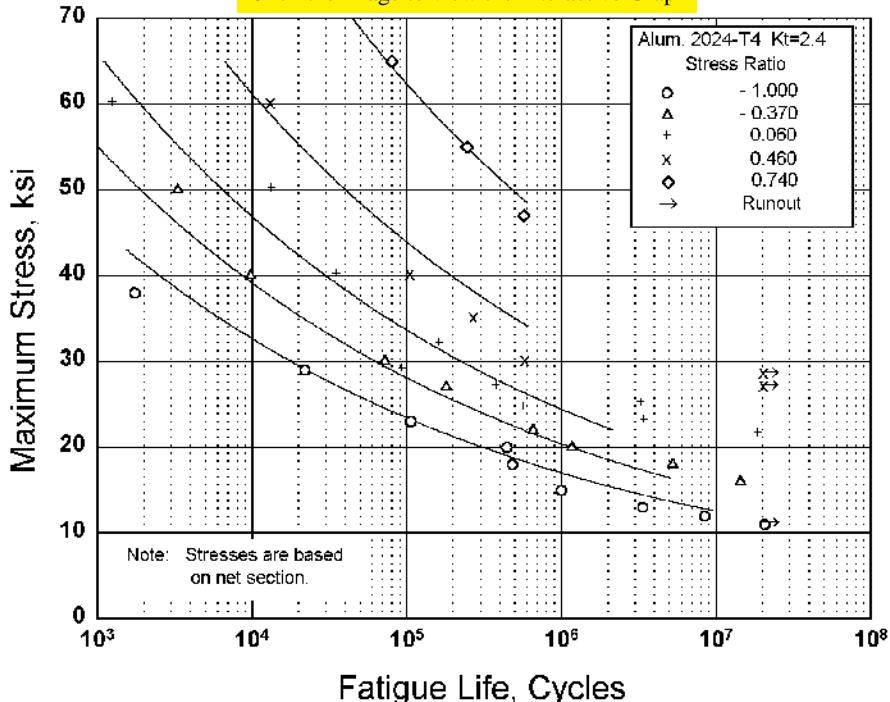


Figure 3.2.3.1.8(c). Best-fit S/N curves for notched, $K_t = 2.4$, 2024-T4 aluminum alloy bar, longitudinal direction.

Correlative Information for Figure 3.2.3.1.8(c)

Product Form: Rolled bar, 1-1/8-inch diameter

Test Parameters:

Loading - Axial

Frequency - 1800 to 3600 cpm

Temperature - RT

Environment - Air

Properties: TUS, ksi TYS, ksi Temp., °F
 73 49 RT

No. of Heats/Lots: Not specified

Specimen Details: Circumferential
 V-Groove, $K_t = 2.4$
 0.500-inch gross diameter
 0.400-inch net diameter
 0.032-inch root radius, r
 60° flank angle, ω

Equivalent Stress Equation:

$$\text{Log } N_f = 14.33 - 6.35 \log (S_{eq} - 3.2)$$

$$S_{eq} = S_{max} (1-R)^{0.48}$$

Std. Error of Estimate, Log (Life) = 0.310

Standard Deviation, Log (Life) = 1.084

$$R^2 = 92\%$$

Surface Condition: As machined

Sample Size = 33

Reference: 3.2.1.1.8(b)

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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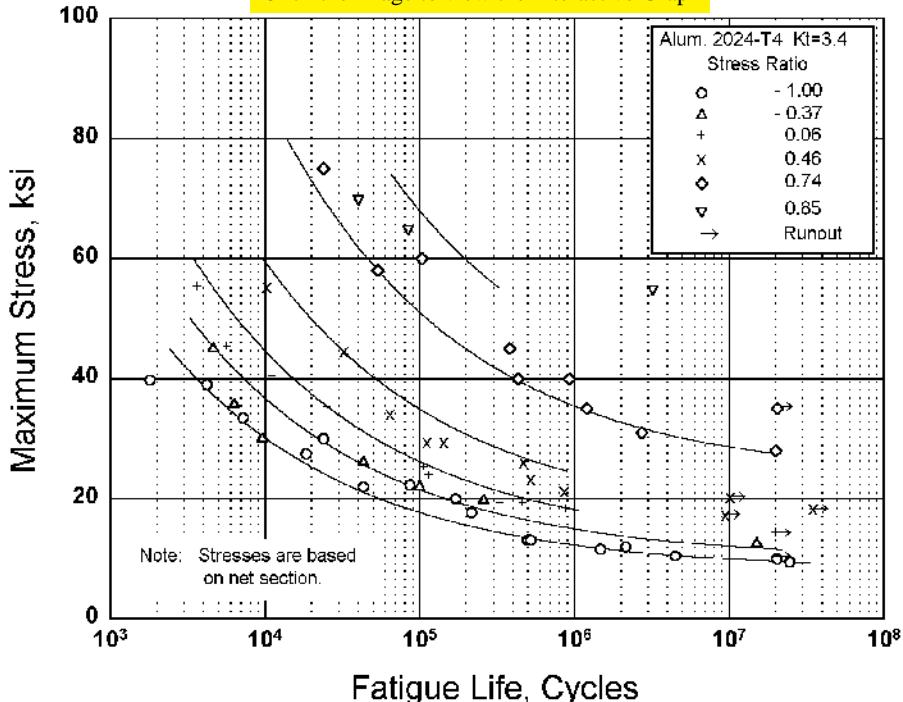


Figure 3.2.3.1.8(d). Best-fit S/N curves for notched, $K_t = 3.4$, 2024-T4 aluminum alloy, various wrought products, longitudinal direction.

Correlative Information for Figure 3.2.3.1.8(d)

Product Form: Rolled bar, 1-1/8-inch diameter
 Extruded bar, 1-1/4-inch diameter

Test Parameters:

Loading - Axial
 Frequency - 1800 to 3600 cpm
 Temperature - RT
 Environment - Air

Properties: TUS, ksi TYS, ksi Temp., °F
 74.2 — RT
 84.1 — (rolled)
 84.1 — RT
 (extruded)

No. of Heats/Lots: Not specified

Specimen Details: Circumferential
 V-Groove, $K_t = 3.4$
 0.450-inch gross diameter
 0.400-inch net diameter
 0.010-inch root radius, r
 60° flank angle, ω

Equivalent Stress Equation:

$$\text{Log } N_f = 8.18 - 2.76 \log (S_{eq} - 11.6)$$

$$S_{eq} = S_{max} (1-R)^{0.52}$$

Std. Error of Estimate, Log (Life) = 0.292

Standard Deviation, Log (Life) = 1.011

$$R^2 = 92\%$$

Sample Size = 51

Surface Condition: As machined

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

References: 3.2.1.1.8(b) and (c)

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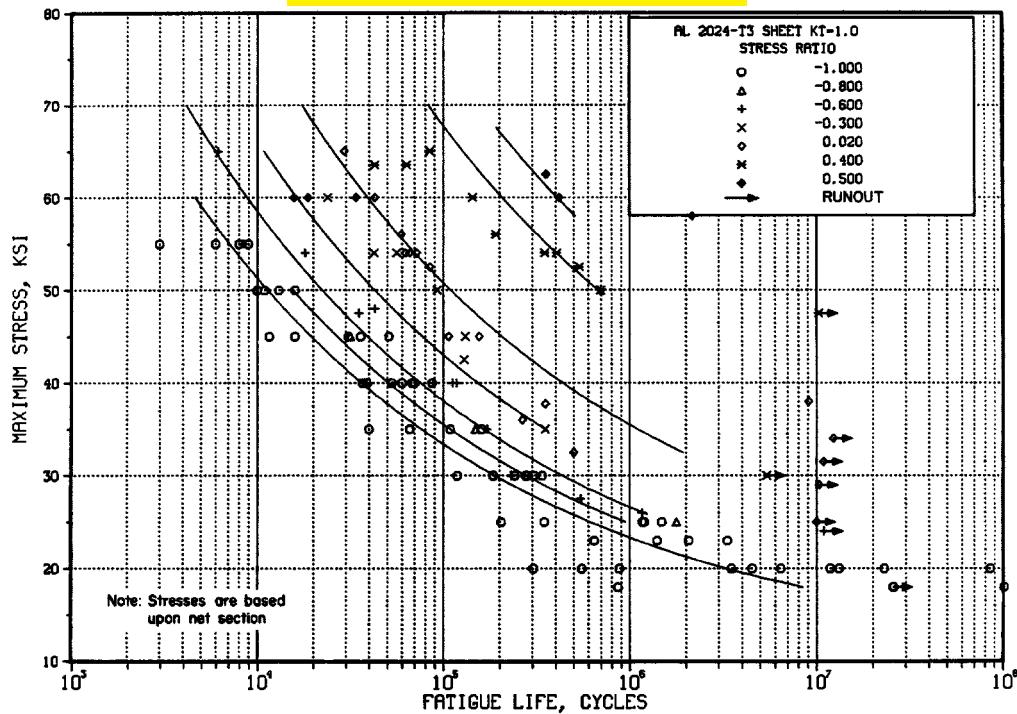


Figure 3.2.3.1.8(e). Best-fit S/N curves for unnotched 2024-T3 aluminum alloy sheet, longitudinal direction.

Correlative Information for Figure 3.2.3.1.8(e)

Product Form: Bare sheet, 0.090-inch

Test Parameters:

Loading - Axial

Frequency - 1100 to 1800 cpm

Properties: TUS, ksi TYS, ksi Temp., °F

No. of Heats/Lots: Not specified

72, 73 52, 54 RT

Specimen Details: Unnotched
0.8 to 1.0-inch width

Equivalent Stress Equation:

$$\text{Log } N_f = 11.1 - 3.97 \log (S_{eq} - 15.8)$$

$$S_{eq} = S_{max} (1-R)^{0.56}$$

Standard Error of Estimate = 0.38

Standard Deviation in Life = 0.90

$$R^2 = 82\%$$

Sample Size = 107

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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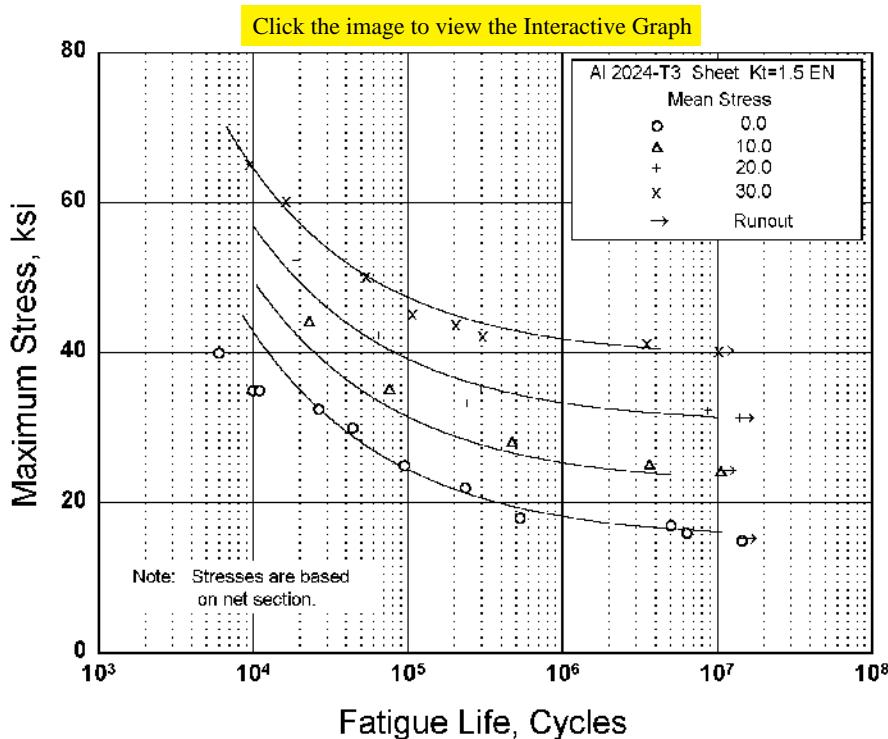


Figure 3.2.3.1.8(f). Best-fit S/N curves for notched, $K_t = 1.5$, 2024-T3 aluminum alloy sheet, longitudinal direction.

Correlative Information for Figure 3.2.3.1.8(f)

Product Form: Bare sheet, 0.090-inch

Test Parameters:

Loading - Axial

Frequency - 1100 to 1500 cpm

Temperature - RT

Environment - Air

<u>Properties:</u>	<u>TUS, ksi</u>	<u>TYs, ksi</u>	<u>Temp., °F</u>
	73	54	RT (unnotched)
	76	—	RT (notched $K_t = 1.5$)

No. of Heats/Lots: Not specified

Equivalent Stress Equation:

$$\log N_f = 7.5 - 2.13 \log (S_{eq} - 23.7)$$

$$S_{eq} = S_{max} (1-R)^{0.66}$$

Std. Error of Estimate, $\log (\text{Life}) = 0.30$

Standard Deviation, $\log (\text{Life}) = 0.95$

$$R^2 = 90\%$$

Sample Size = 26

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

Surface Condition: Electropolished

Reference: 3.2.3.1.8(d)

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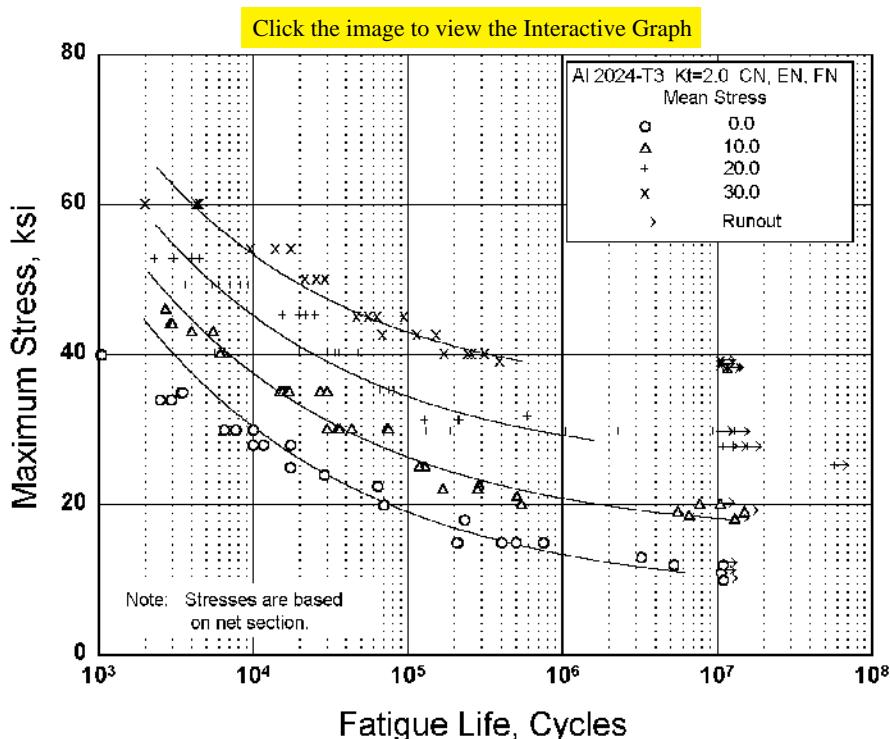


Figure 3.2.3.1.8(g). Best-fit S/N curves for notched, $K_t = 2.0$, 2024-T3 aluminum alloy sheet, longitudinal direction.

Correlative Information for Figure 3.2.3.1.8(g)

Product Form: Bare sheet, 0.090-inch

<u>Properties:</u>	<u>TUS, ksi</u>	<u>TYs, ksi</u>	<u>Temp., °F</u>
	73	54	RT (unnotched)
	73	—	RT (notched $K_t = 2.0$)

Specimen Details: Notched, $K_t = 2.0$

<u>Notch Type</u>	<u>Gross Width</u>	<u>Net Width</u>	<u>Notch Radius</u>
Center	4.50	1.50	1.50
Edge	2.25	1.50	0.3175
Fillet	2.25	1.50	0.1736

Surface Condition: Electropolished, machined and burrs removed with fine crocus cloth

References: 3.2.3.1.8(b) and (f)

Test Parameters:

Loading - Axial
Frequency - 1100 to 1800 cpm
Temperature - RT
Environment - Air

No. of Heats/Lots: Not specified

Equivalent Stress Equation:

$$\begin{aligned} \text{Log } N_f &= 9.2 - 3.33 \log (S_{eq} - 12.3) \\ S_{eq} &= S_{max} (1-R)^{0.68} \\ \text{Std. Error of Estimate, Log (Life)} &= 0.27 \\ \text{Standard Deviation, Log (Life)} &= 0.89 \\ R^2 &= 91\% \end{aligned}$$

Sample Size = 113

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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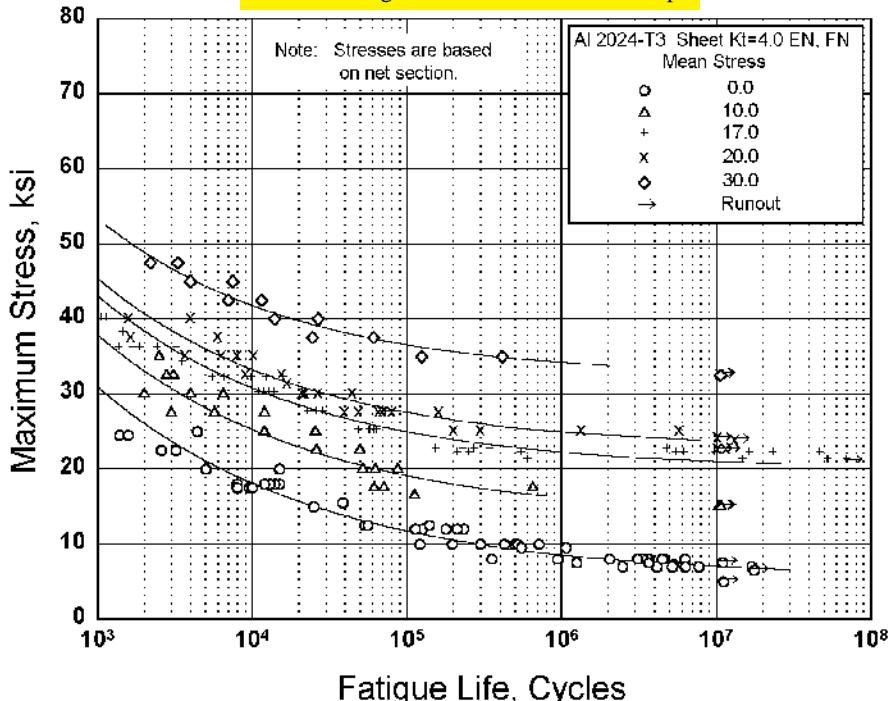


Figure 3.2.3.1.8(h). Best-fit S/N curves for notched, $K_t = 4.0$ of 2024-T3 aluminum alloy sheet, longitudinal direction.

Correlative Information for Figure 3.2.3.1.8(h)

Product Form: Bare sheet, 0.090-inch

Properties: TUS, ksi TYs, ksi Temp., °F

73	54	RT
		(unnotched)
67	—	RT
		(notched $K_t = 2.0$)

Specimen Details: Notched, $K_t = 2.0$

Notch Type	Gross Width	Net Width	Notch Radius
Center	2.25	1.50	0.057
Edge	4.10	1.50	0.070
Fillet	2.25	1.50	0.0195

Surface Condition: Electropolished, machined, and burrs removed with fine crocus cloth

References: 3.2.3.1.8(b), (e), (f), (g), and (h)

Test Parameters:

Loading - Axial
Frequency - 1100 to 1800 cpm
Temperature - RT
Environment - Air

No. of Heats/Lots: Not specified

Equivalent Stress Equation:

$$\begin{aligned} \text{Log } N_f &= 8.3 - 3.30 \log (S_{eq} - 8.5) \\ S_{eq} &= S_{max} (1-R)^{0.66} \\ \text{Std. Error of Estimate, Log (Life)} &= 0.39 \\ \text{Standard Deviation, Log (Life)} &= 1.24 \\ R^2 &= 90\% \end{aligned}$$

Sample Size = 126

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

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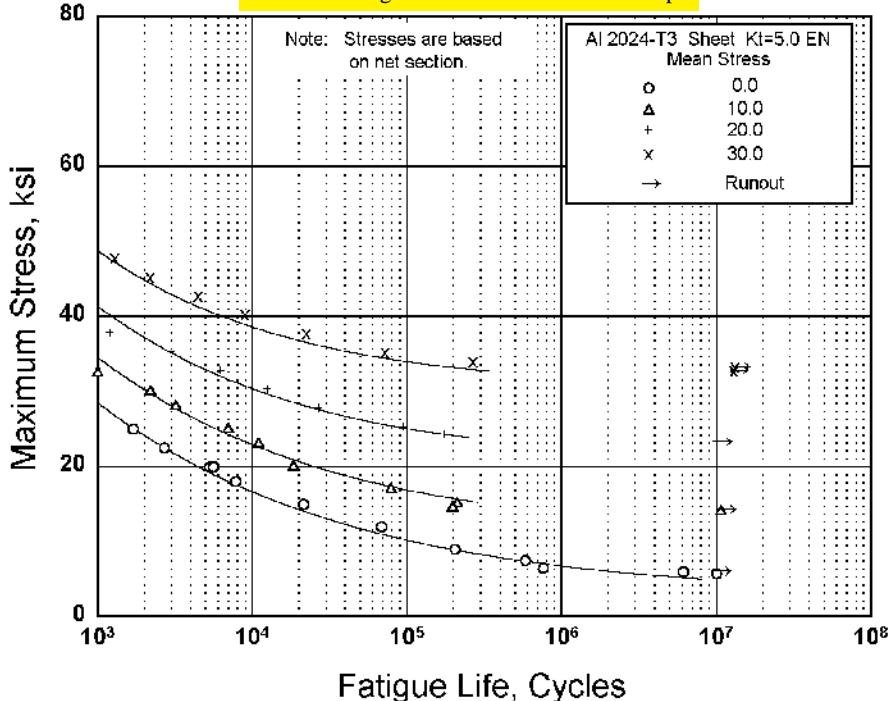


Figure 3.2.3.1.8(i). Best-fit S/N curves for notched, $K_t = 5.0$, 2024-T3 aluminum alloy sheet, longitudinal direction.

Correlative Information for Figure 3.2.3.1.8(i)

Product Form: Bare sheet, 0.090-inch

Test Parameters:

Loading - Axial

Frequency - 1100 to 1800 cpm

Temperature - RT

Environment - Air

Properties: TUS, ksi TYS, ksi Temp., °F

No. of Heats/Lots: Not specified

73	54	RT
		(unnotched)
62	—	RT
		(notched)
		$K_t = 5.0$

Equivalent Stress Equation:

$$\text{Log } N_f = 8.9 - 3.73 \log (S_{eq} - 3.9)$$

$$S_{eq} = S_{max} (1-R)^{0.56}$$

Std. Error of Estimate, Log (Life) = 0.39

Standard Deviation, Log (Life) = 1.24

$$R^2 = 90\%$$

Sample Size = 35

Specimen Details: Edge notched, $K_t = 5.0$
 2.25-inch gross width
 1.500-inch net width
 0.03125-inch notch radius
 0° flank angle

[Caution: The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above.]

Surface Condition: Electropolished

Reference: 3.2.3.1.8(c)

Click the image to view the Interactive Graph

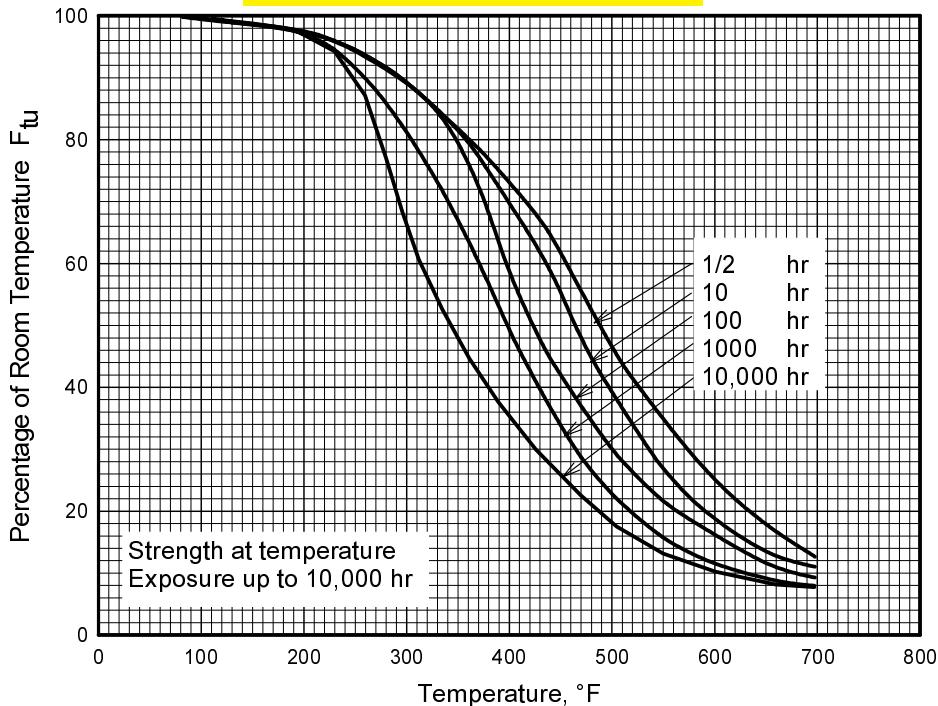


Figure 3.2.3.3.1(a). Effect of temperature on the tensile ultimate strength (F_{tu}) of 2024-T62 aluminum alloy (all products).

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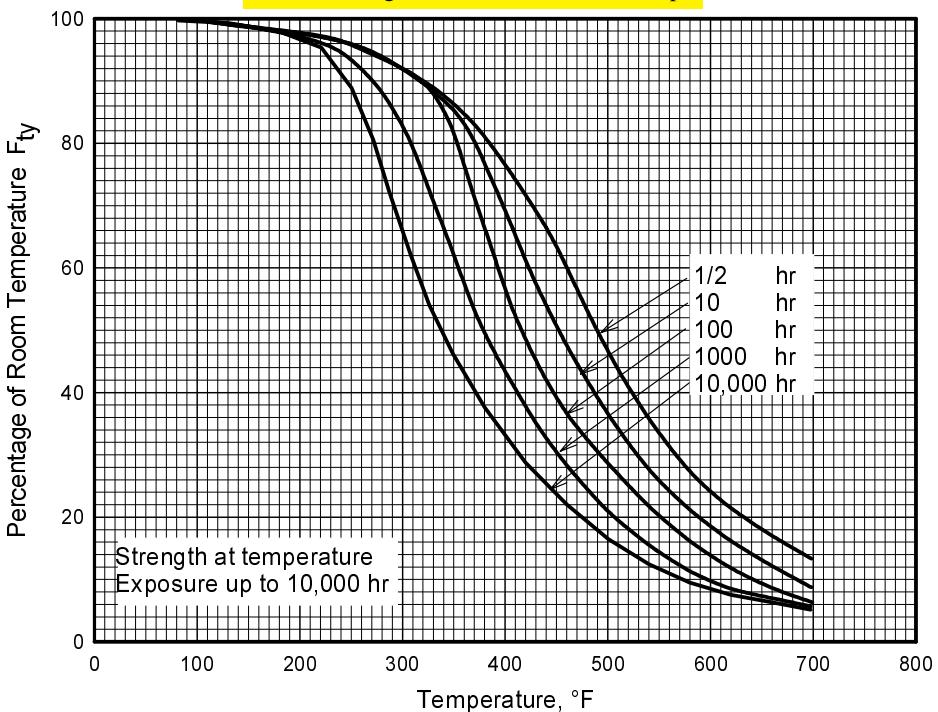


Figure 3.2.3.3.1(b). Effect of temperature on the tensile yield strength (F_{ty}) of 2024-T62 aluminum alloy (all products).

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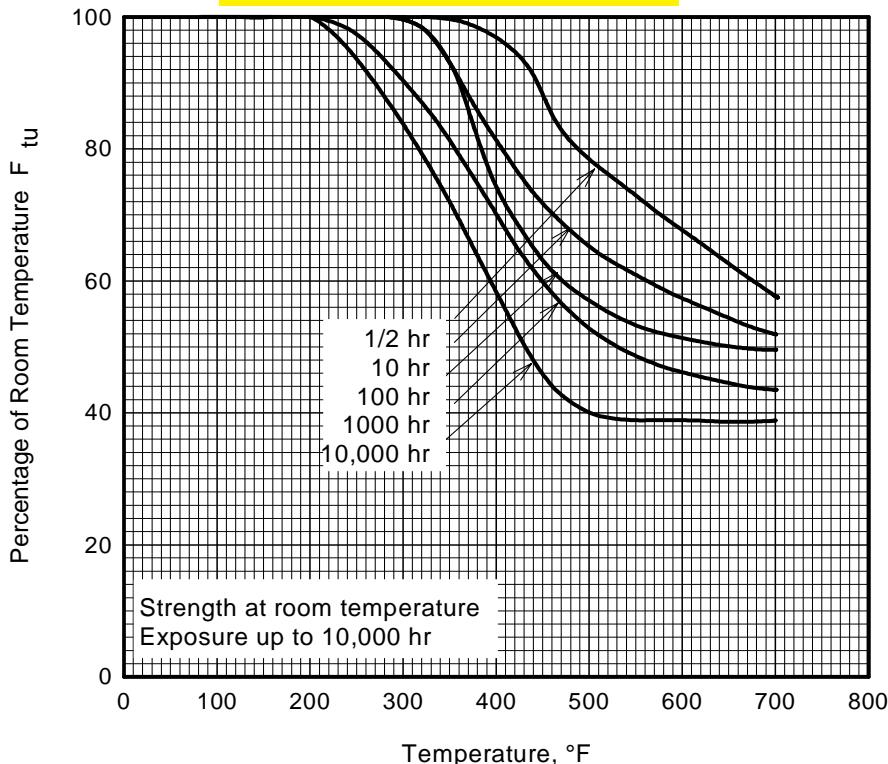


Figure 3.2.3.3.1(c). Effect of exposure at elevated temperatures on the room-temperature tensile ultimate strength (F_{tu}) of 2024-T62 aluminum alloy (all products).

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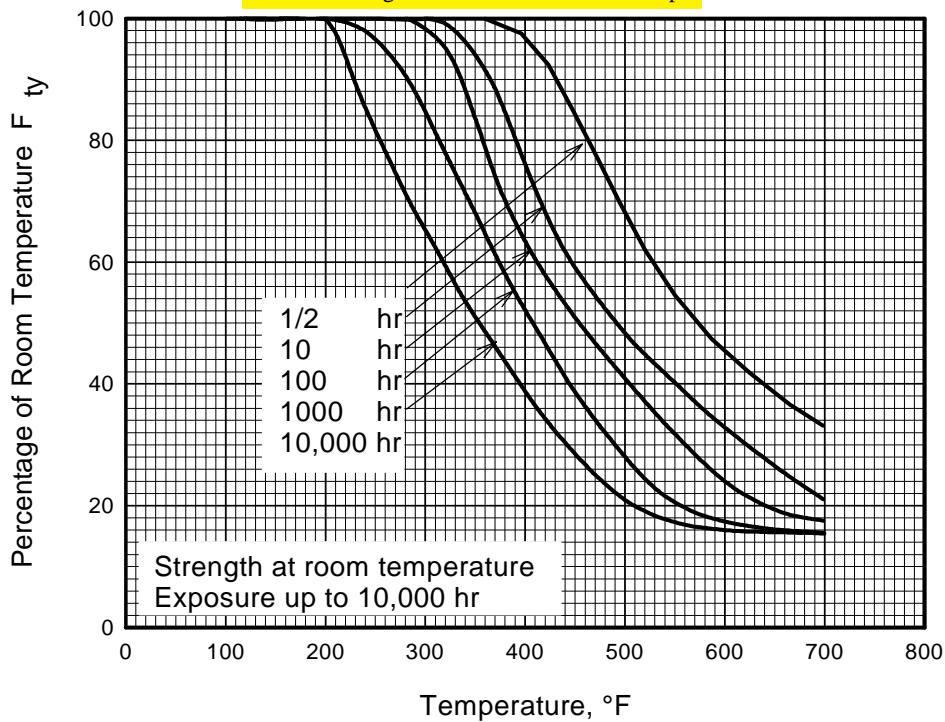


Figure 3.2.3.3.1(d). Effect of exposure at elevated temperatures on the room-temperature tensile yield strength (F_{ty}) of 2024-T62 aluminum alloy (all products).

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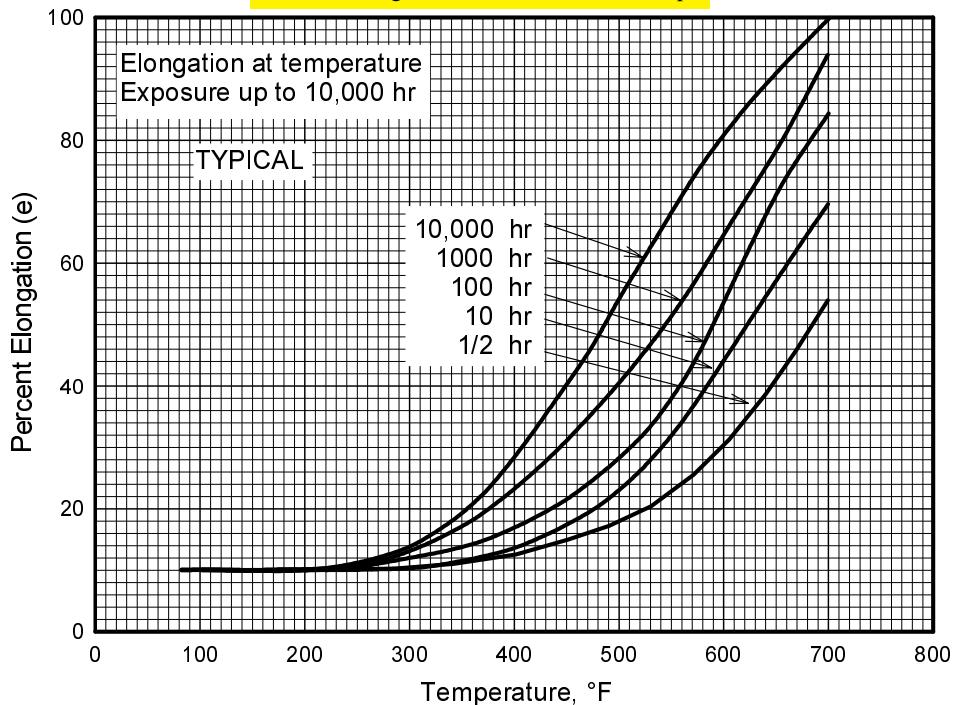


Figure 3.2.3.3.5(a). Effect of temperature on the elongation of 2024-T62 aluminum alloy (all products).

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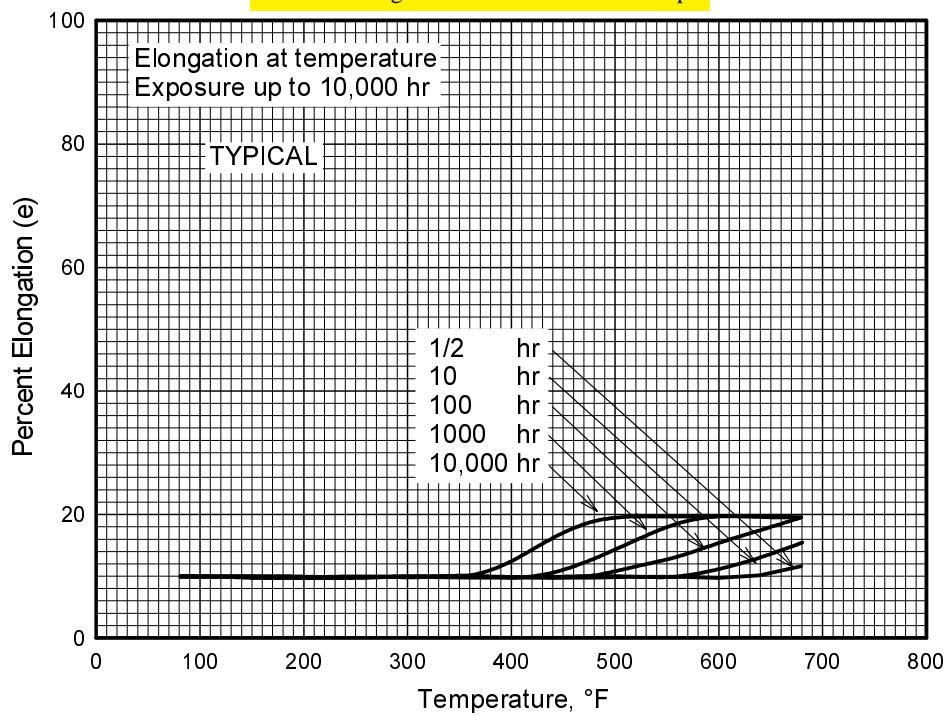


Figure 3.2.3.3.5(b). Effect of exposure at elevated temperatures on the elongation of 2024-T62 aluminum alloy (all products).

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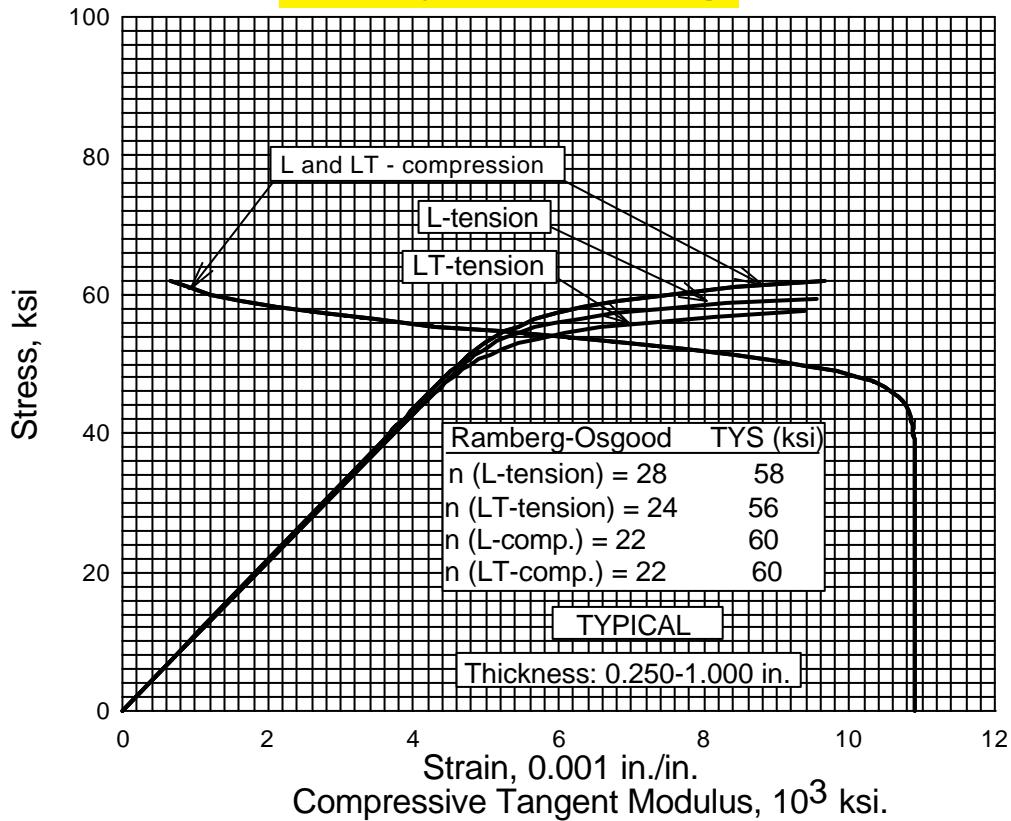


Figure 3.2.3.3.6(a). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for 2024-T62 aluminum alloy plate at room temperature.

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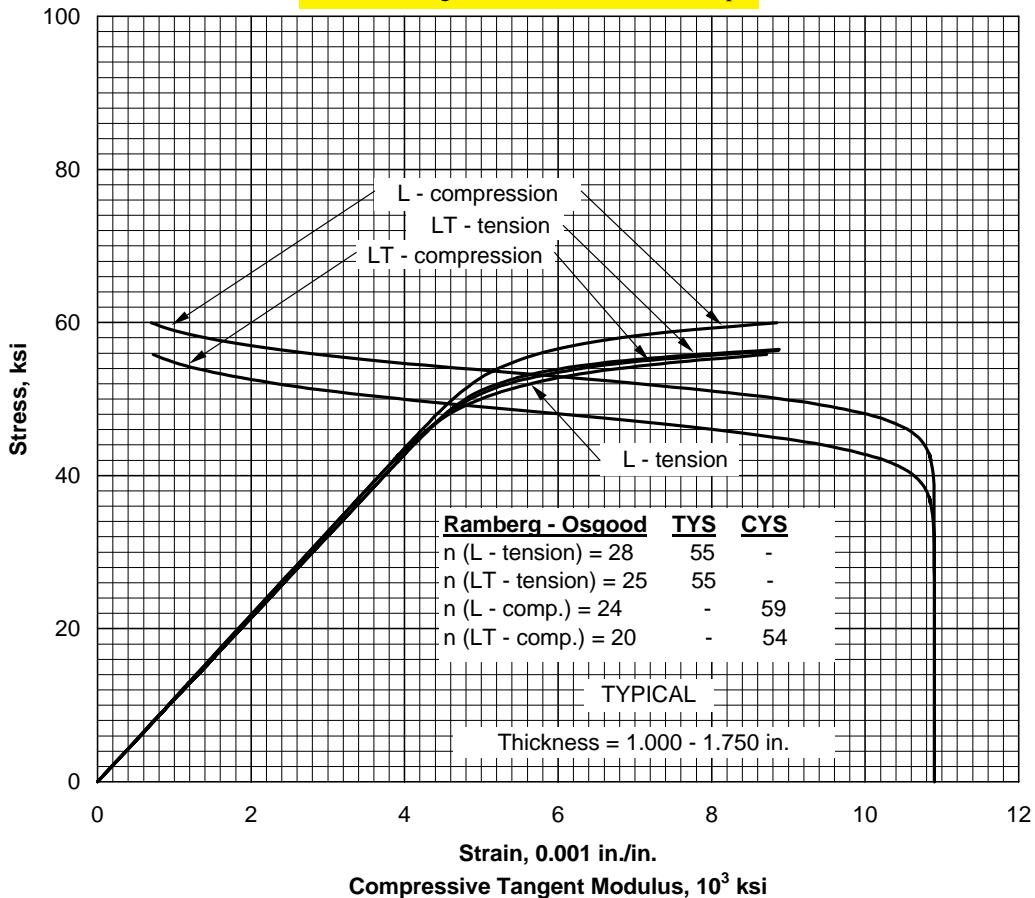


Figure 3.2.3.3.6(b) Typical tension and compression stress-strain and compression tangent modulus curves for 2024-T62 aluminum alloy plate at room temperature. Note, the data to generate these curves may have been from clad product, however, they are shown here without secondary modulus since it could not be positively confirmed the product was cladded.

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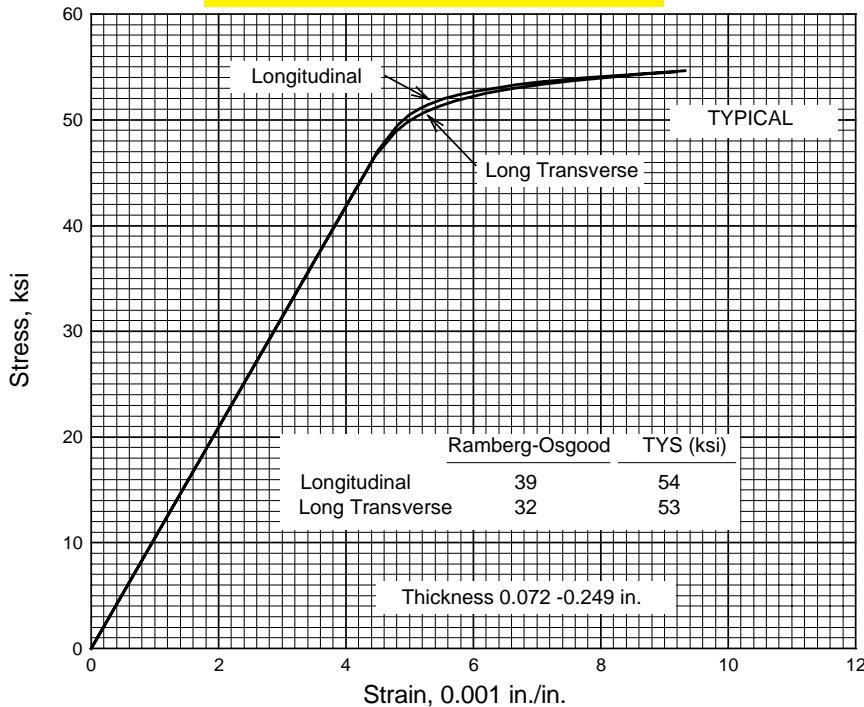


Figure 3.2.3.3.6(c). Typical tensile stress-strain curves for clad 2024-T62 aluminum alloy sheet at room temperature.

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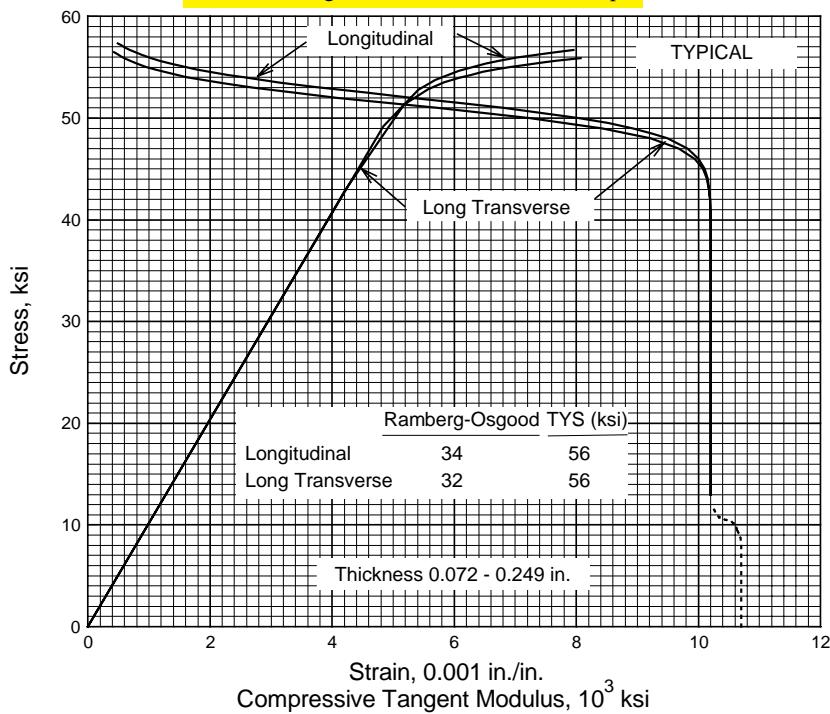


Figure 3.2.3.3.6(d). Typical compressive stress-strain and compressive tangent modulus curves for clad 2024-T62 aluminum alloy sheet at room temperature.

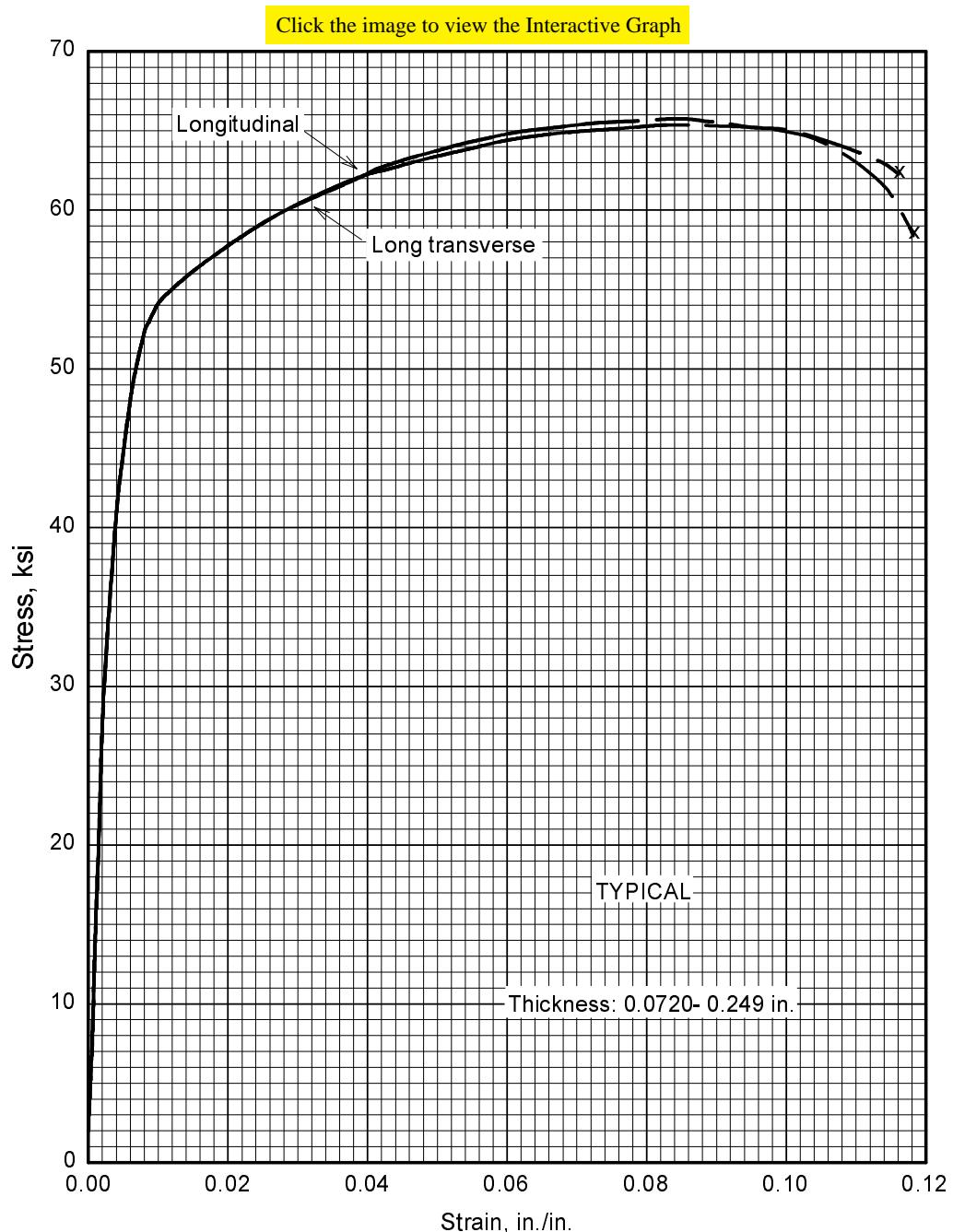


Figure 3.2.3.3.6(e). Typical stress-strain curves (full range) for clad 2024-T62 aluminum alloy sheet at room temperature.

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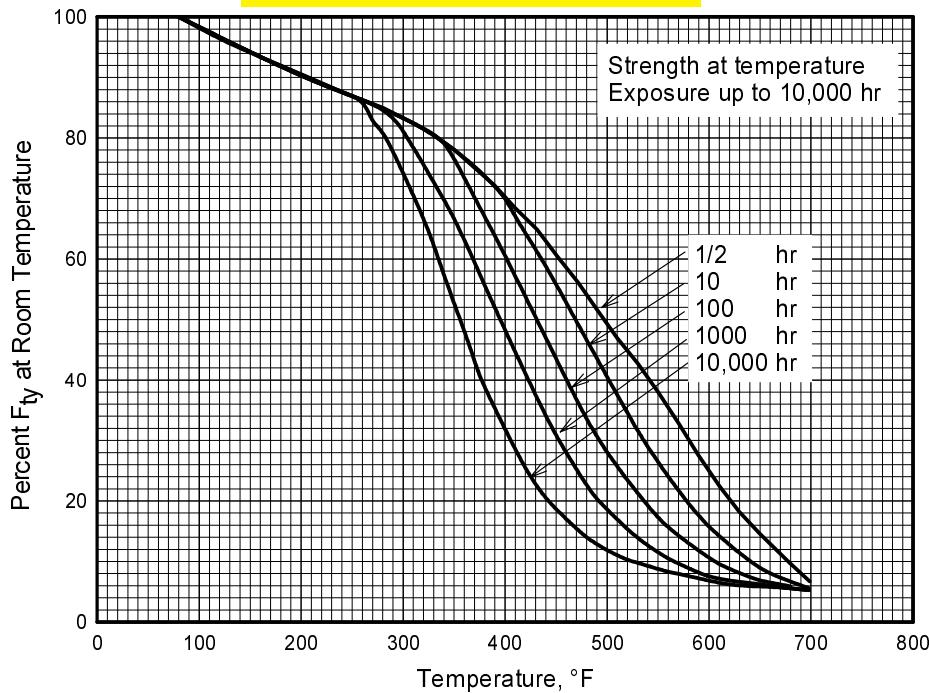


Figure 3.2.3.4.1(a). Effect of temperature on the tensile ultimate strength (F_{tu}) of 2024-T81, T851, T8510, and T8511 aluminum alloy (all products).

Click the image to view the Interactive Graph

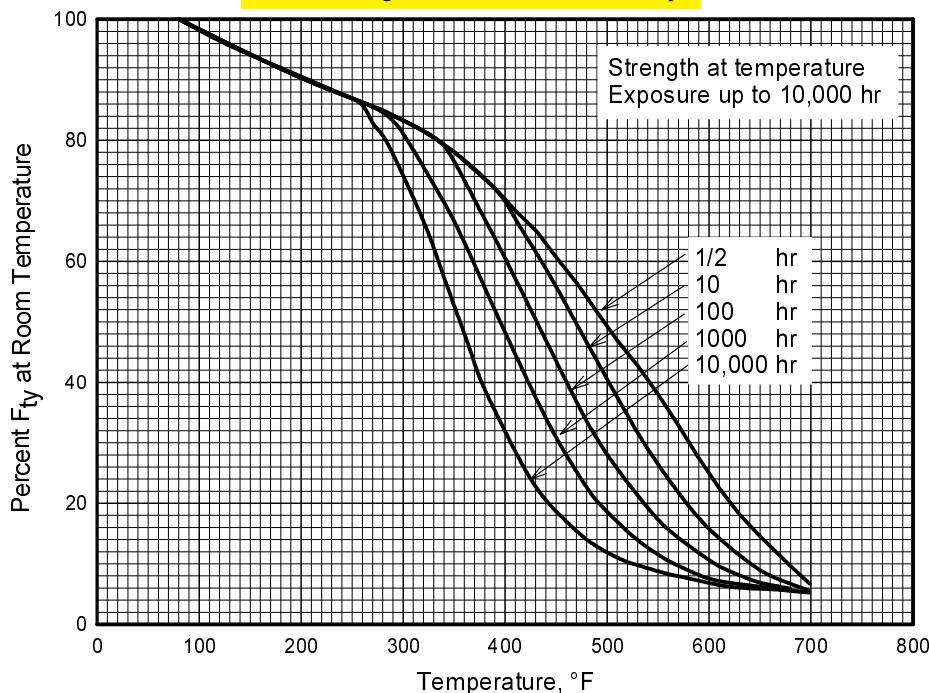


Figure 3.2.3.4.1(b). Effect of temperature on the tensile yield strength (f_{ty}) of 2024-T81, T851, T8510, and T8511 aluminum alloy (all products).

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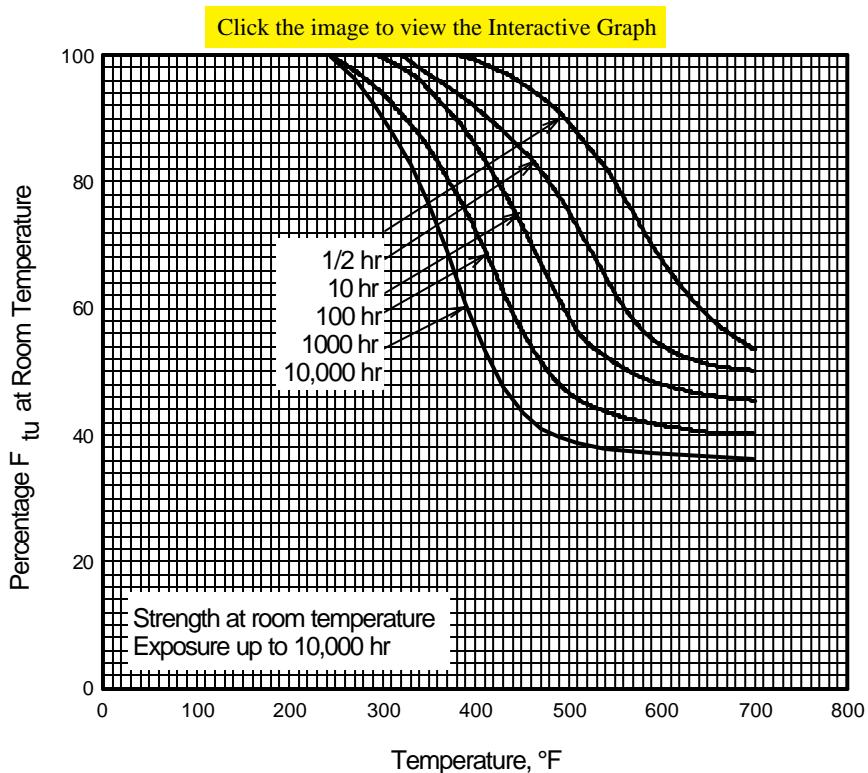


Figure 3.2.3.4.1(c). Effect of exposure at elevated temperatures on room-temperature tensile ultimate strength (F_{tu}) of 2024-T81 aluminum alloy sheet.

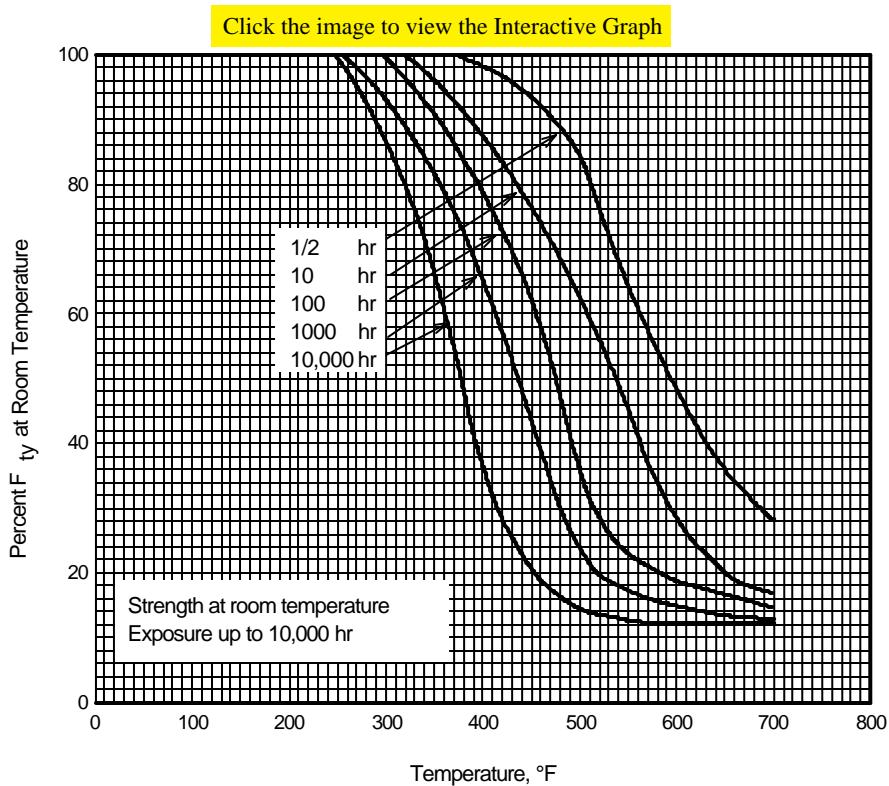


Figure 3.2.3.4.1(d). Effect of exposure at elevated temperatures on the room temperature tensile yield strength (F_{ty}) of 2024-T81 aluminum alloy sheet.

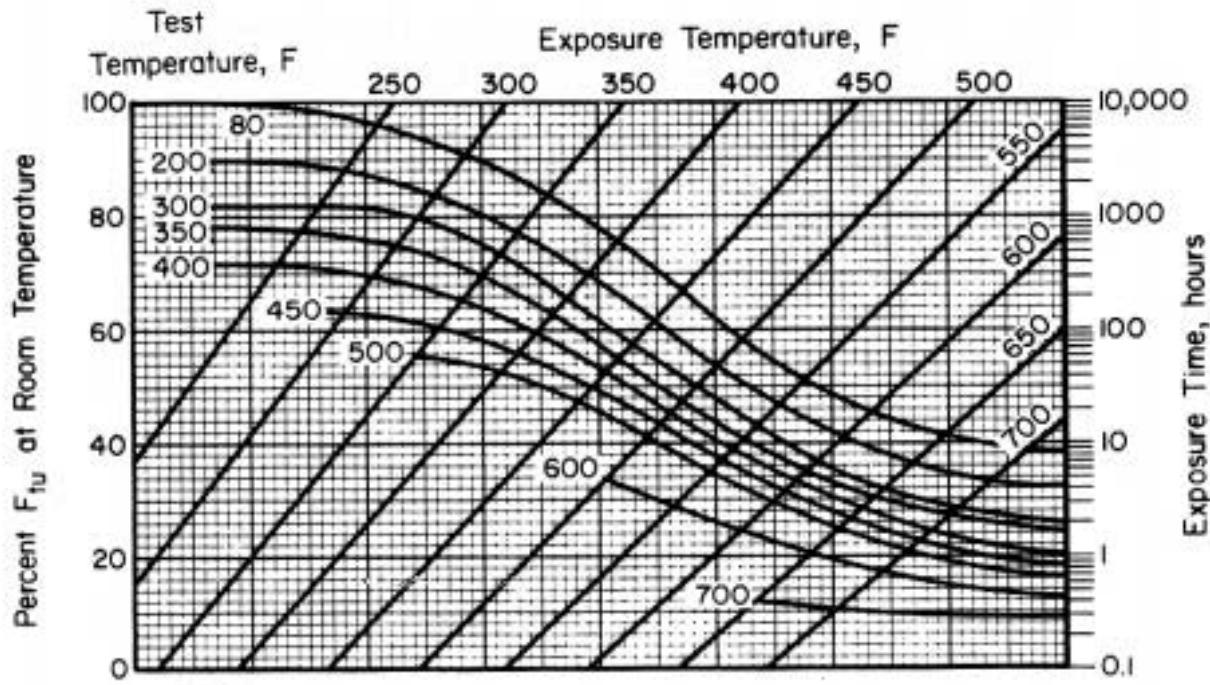


Figure 3.2.3.4.1(e). Effect of temperature on the tensile ultimate strength (F_{tu}) of 2024-T81 aluminum alloy clad sheet. Note: Instructions for use of these curves are presented in Section 3.7.4.1.

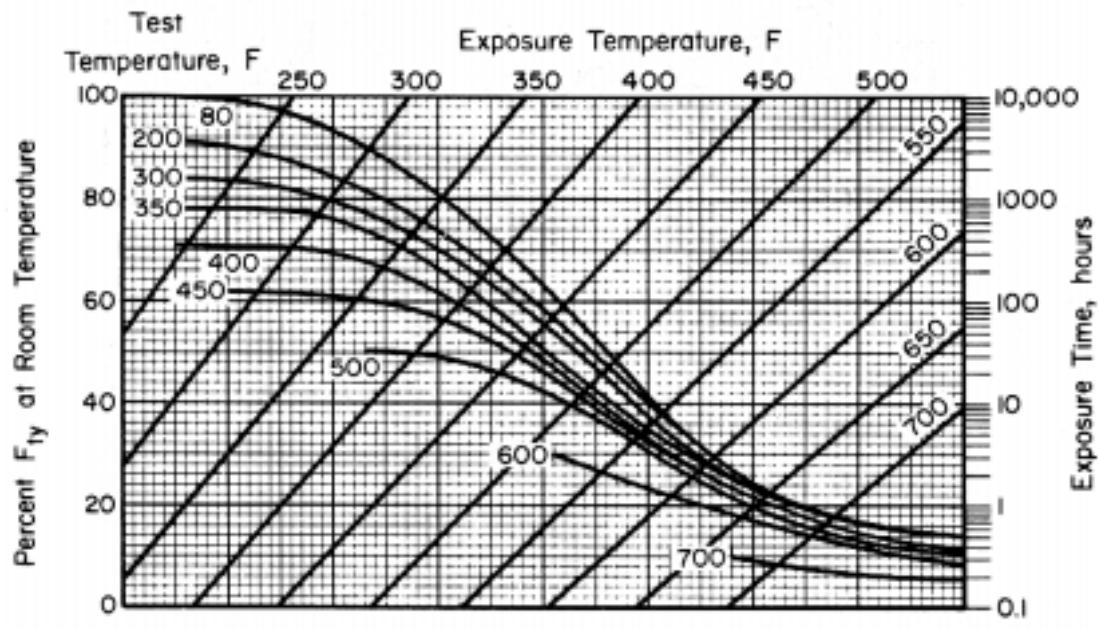


Figure 3.2.3.4.1(f). Effect of temperature on the tensile yield strength (F_{ty}) of 2024-T81 aluminum alloy clad sheet. Note: Instructions for use of these curves are presented in Section 3.7.4.1.

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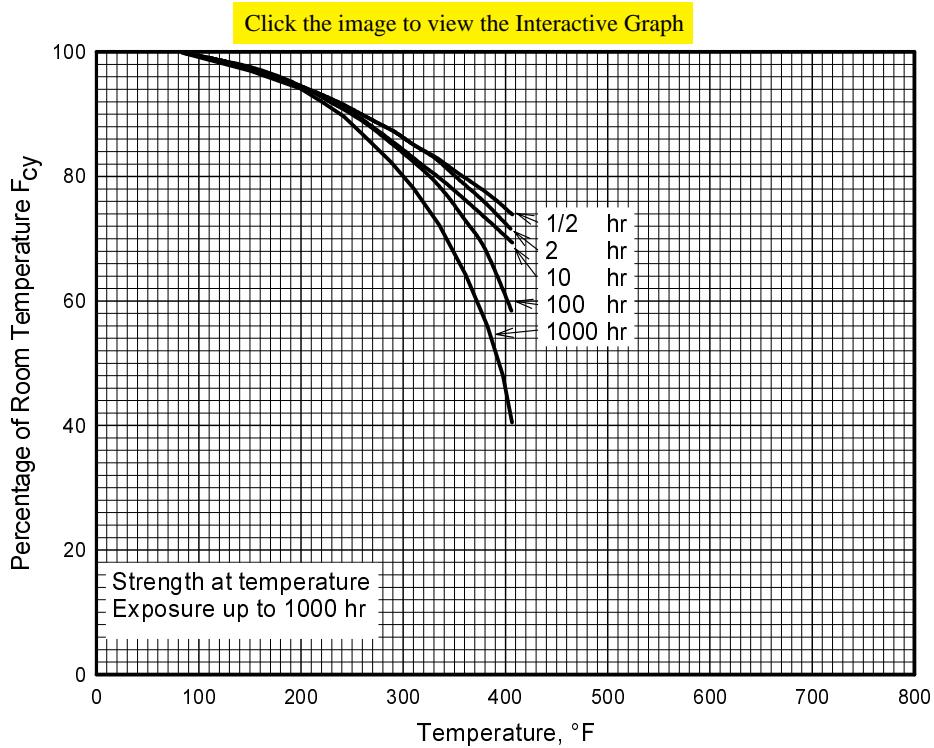


Figure 3.2.3.4.2(a). Effect of temperature on the tensile yield strength (F_{ty}) of 2024-T81, T851, T8510, and T8511 aluminum alloy (all products).

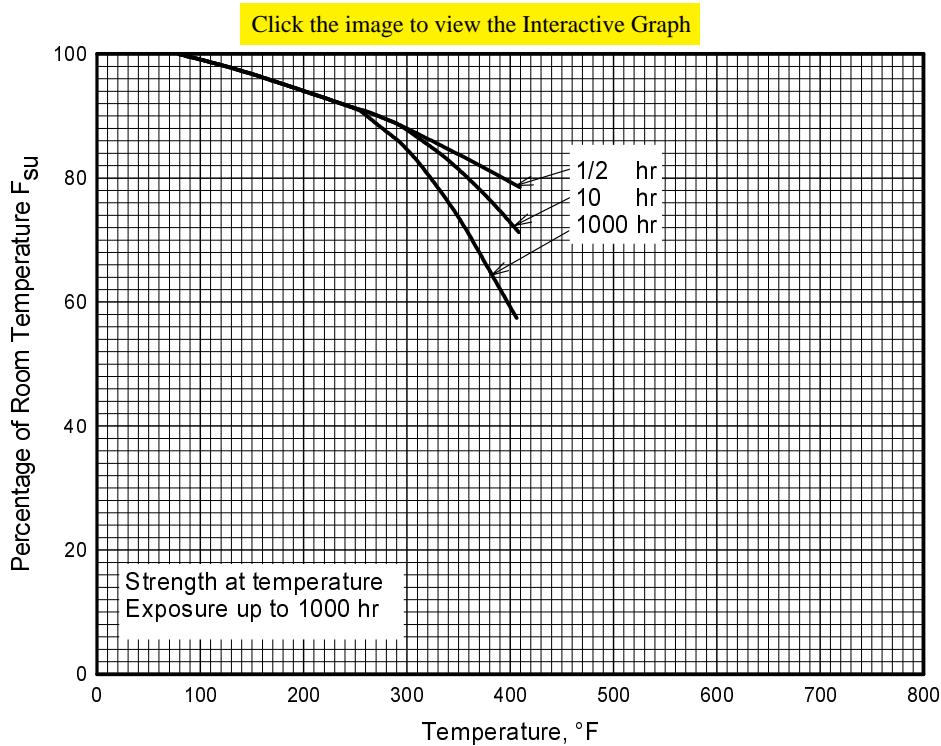


Figure 3.2.3.4.2(b). Effect of temperature on the shear ultimate strength (F_{su}) of 2024-T81, T851, T8510, and T8511 aluminum alloy (all products).

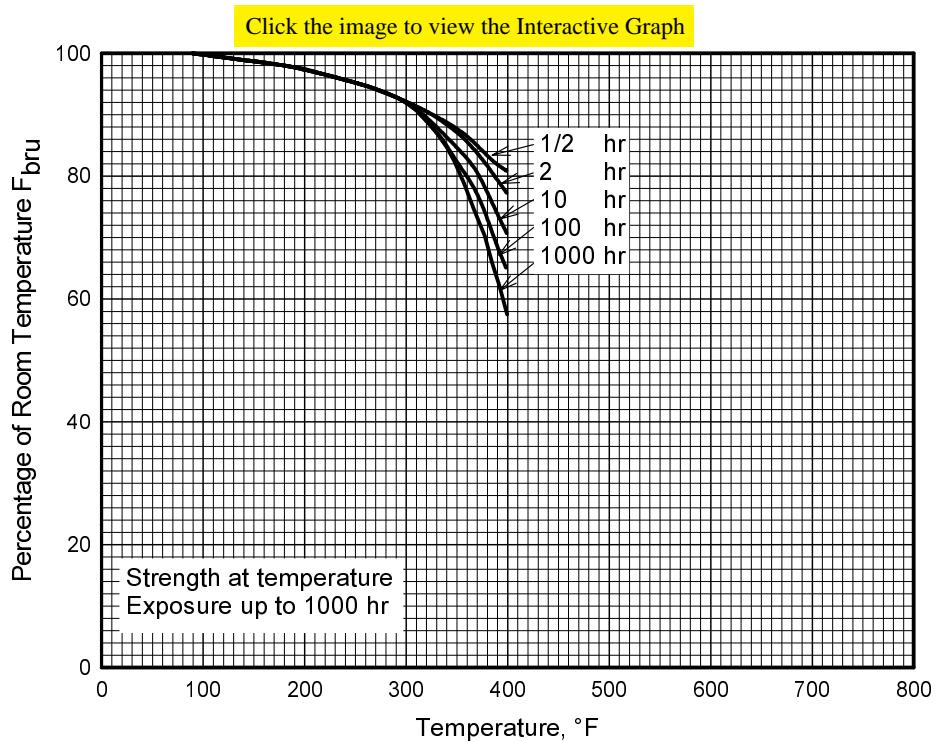


Figure 3.2.3.4.3(a). Effect of temperature on the bearing ultimate strength (F_{bru}) of 2024-T81, T851, T8510, and T8511 aluminum alloy (all products).

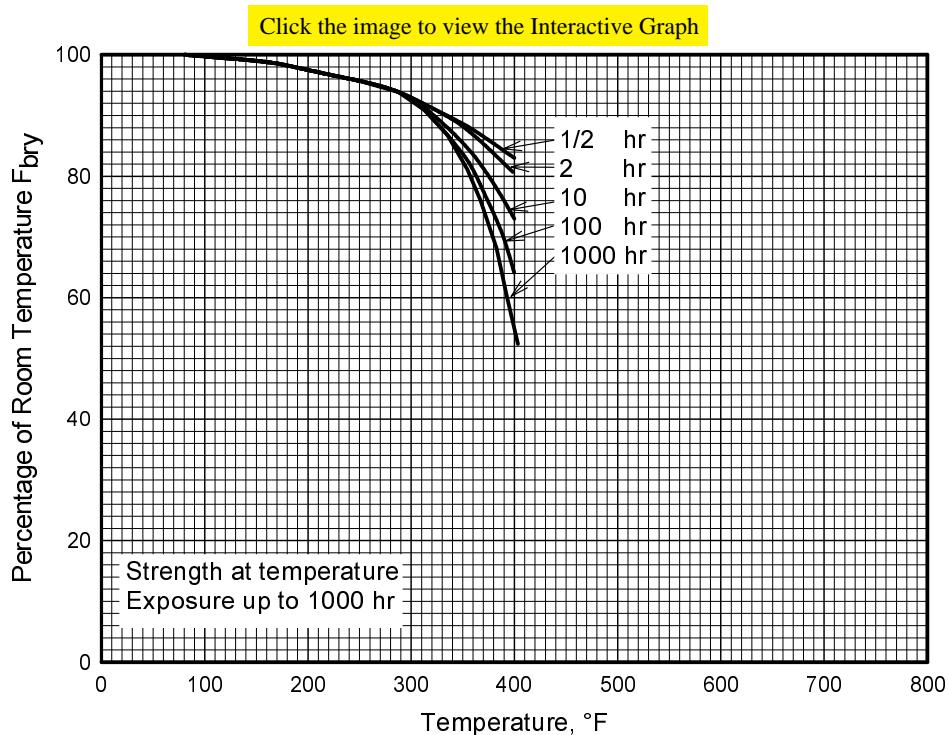


Figure 3.2.3.4.3(b). Effect of temperature on the bearing yield strength (F_{bry}) of 2024-T81, T851, T8510, and T8511 aluminum alloy (all products).

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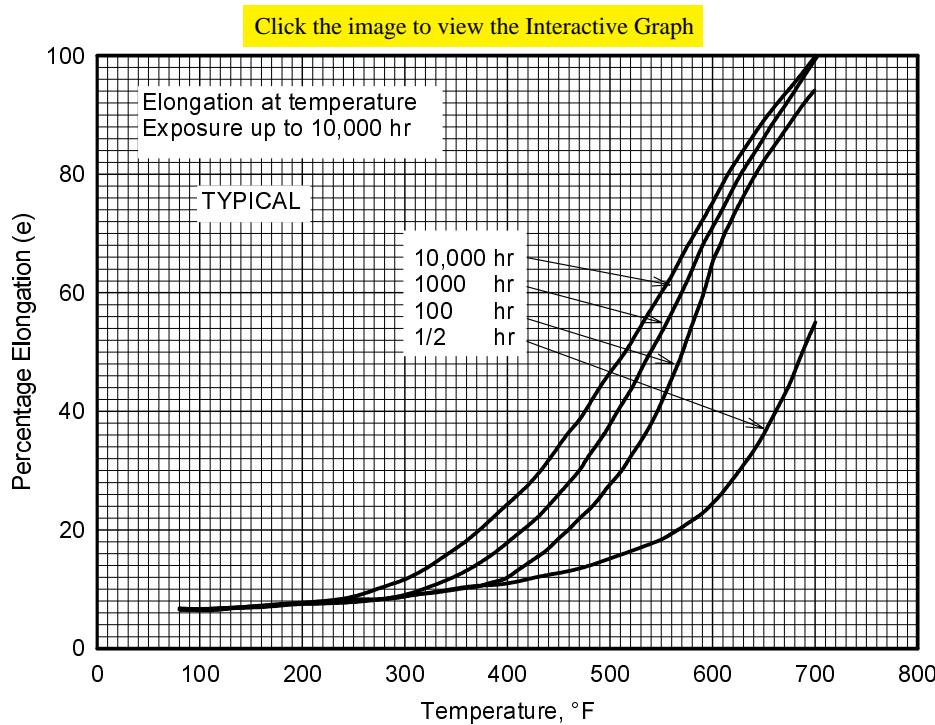


Figure 3.2.3.4.5(a). Effect of temperature on the elongation of 2024-T81, T851, T8510, and T8511 aluminum alloy (all products).

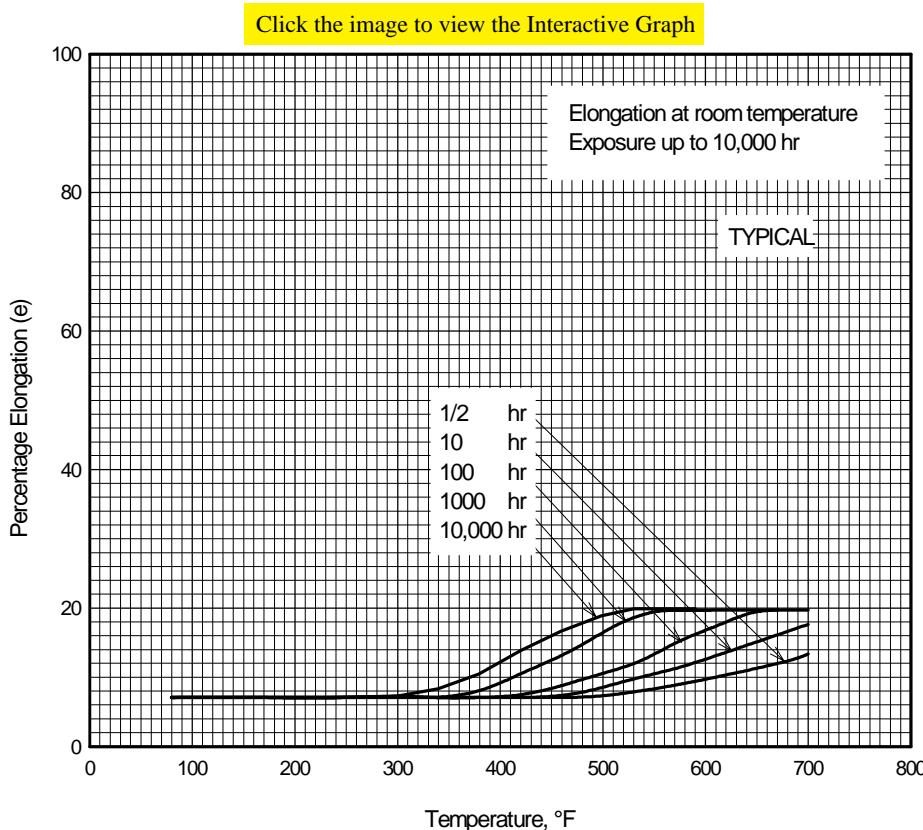


Figure 3.2.3.4.5(b). Effect of exposure at elevated temperatures on the room temperature elongation of 2024-T81, T851, T8510, and T8511 aluminum alloy (all products).

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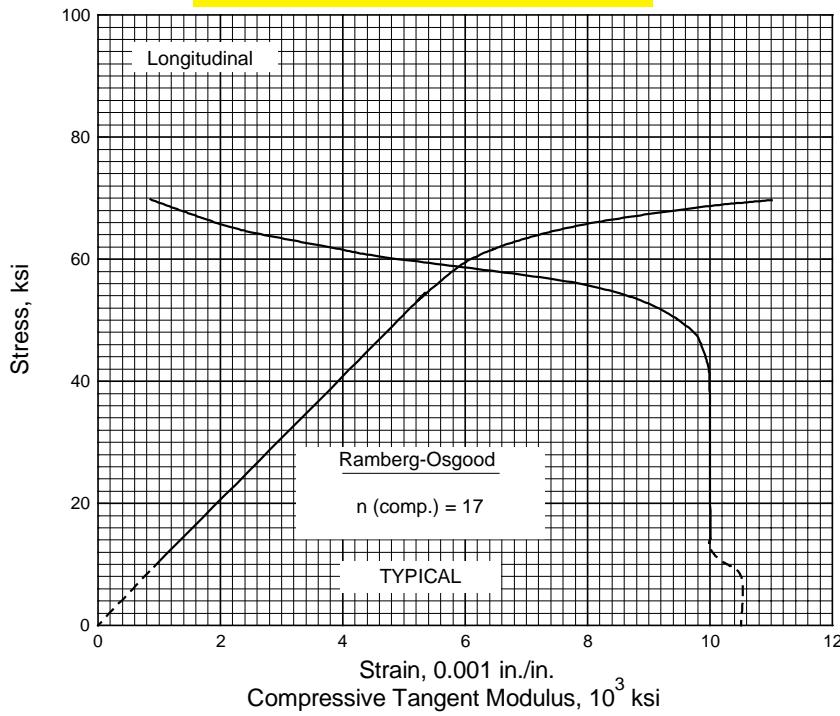


Figure 3.2.3.4.6(a). Typical compressive stress-strain and compressive tangent modulus curves for clad 2024-T81 aluminum alloy sheet at room temperature.

Click the image to view the Interactive Graph

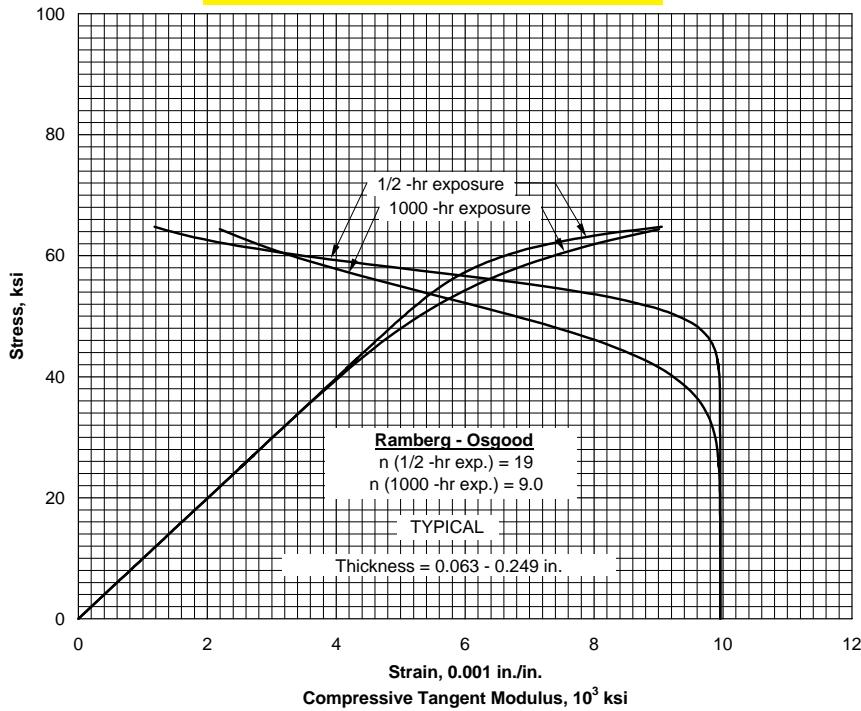


Figure 3.2.3.4.6(b). Typical compressive stress-strain and compressive tangent modulus curves for clad 2024-T81 aluminum alloy sheet at 200° F.

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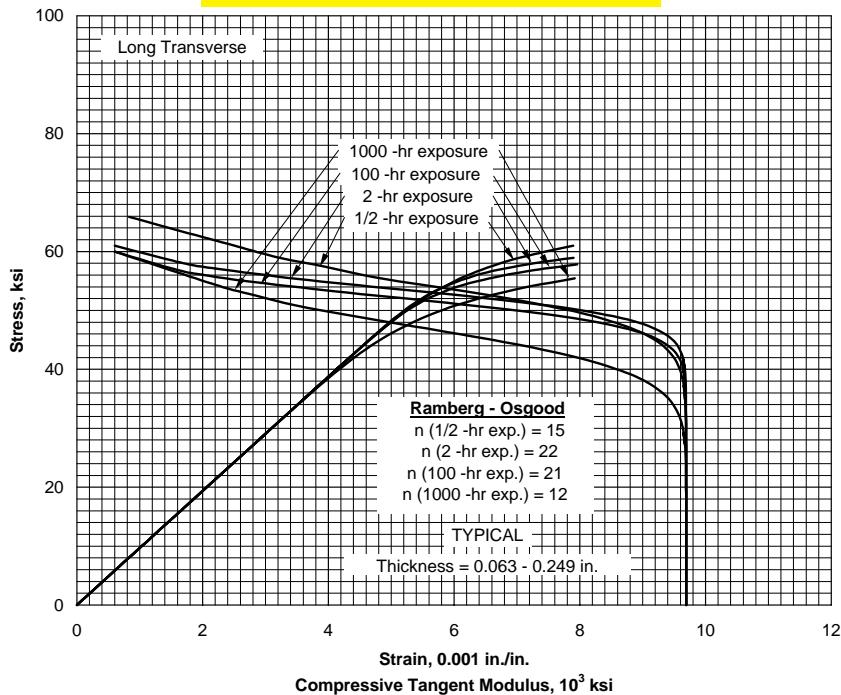


Figure 3.2.3.4.6(c). Typical compressive stress-strain and compressive tangent modulus curves for clad 2024-T81 aluminum alloy sheet at 300° F.

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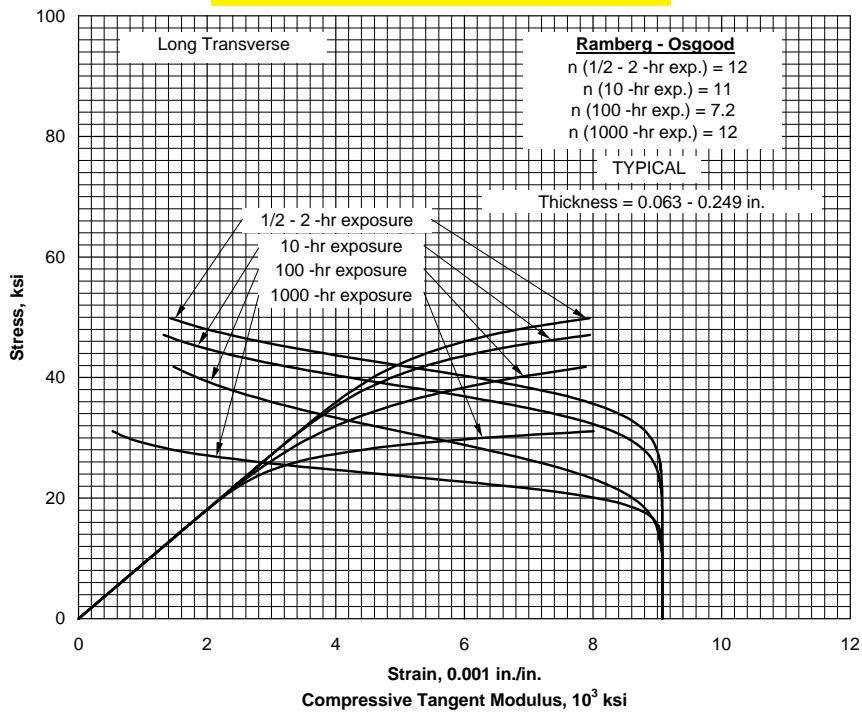


Figure 3.2.3.4.6(d). Typical compressive stress-strain and compressive tangent modulus curves for clad 2024-T81 aluminum alloy sheet at 400° F.

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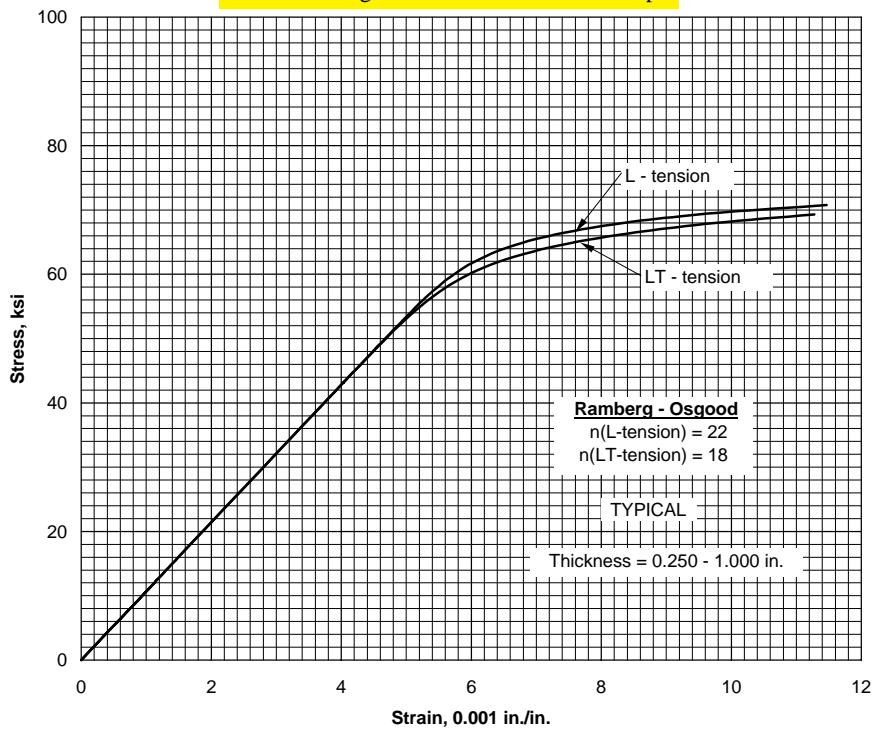


Figure 3.2.3.4.6(e). Typical tensile stress-strain curves for 2024-T851 aluminum alloy plate at room temperature.

Click the image to view the Interactive Graph

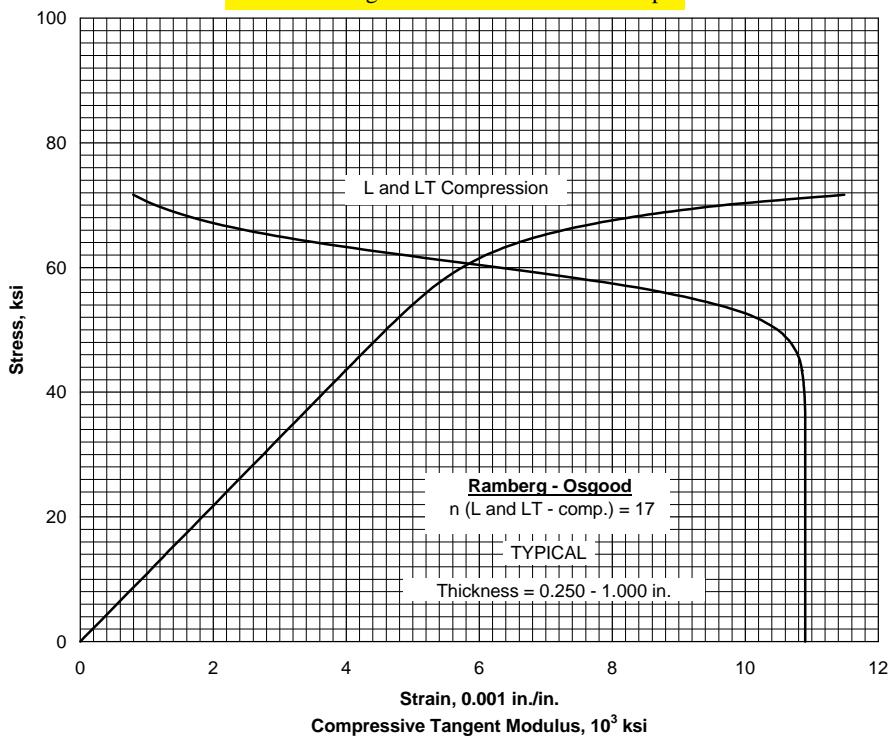


Figure 3.2.3.4.6(f). Typical compressive stress-strain and compressive tangent-modulus curves for 2024-T851 aluminum alloy plate at room temperature.

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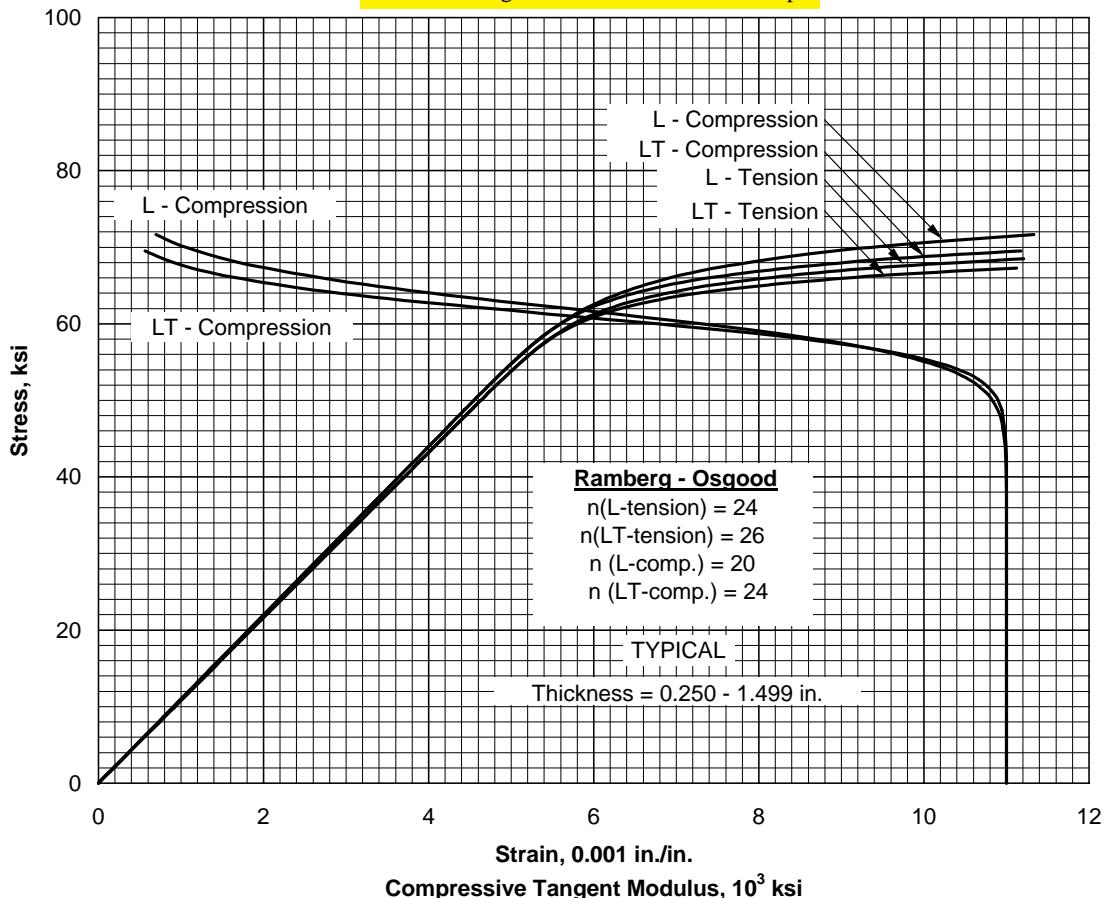


Figure 3.2.3.4.6(g). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for 2024-T851X aluminum alloy extrusion at room temperature.

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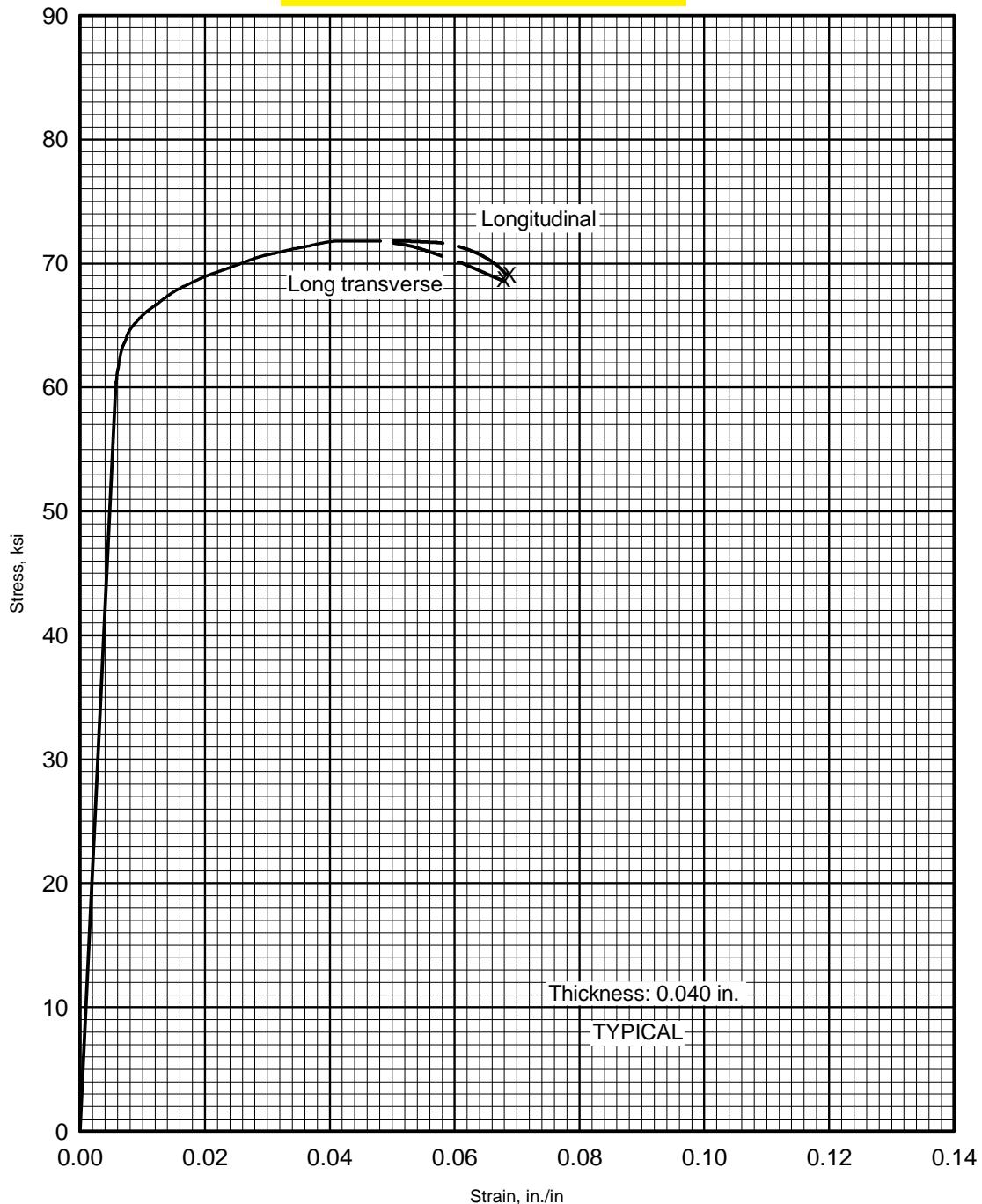


Figure 3.2.3.4.6(h). Typical tensile stress-strain curves (full range) for 2024-T81 aluminum alloy sheet at room temperature.

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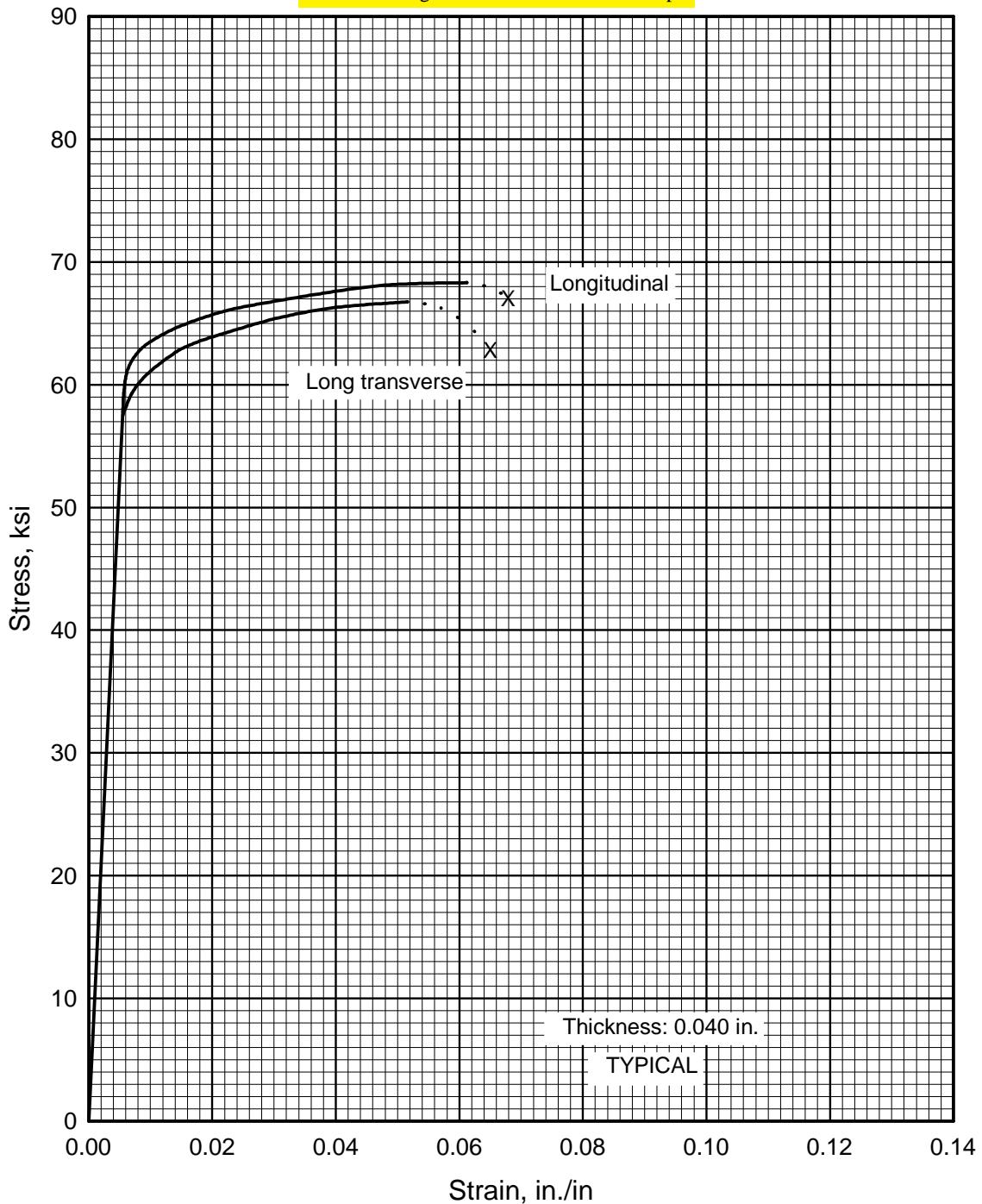


Figure 3.2.3.4.6(i). Typical tensile stress-strain curves (full range) for clad 2024-T81 aluminum alloy sheet at room temperature.

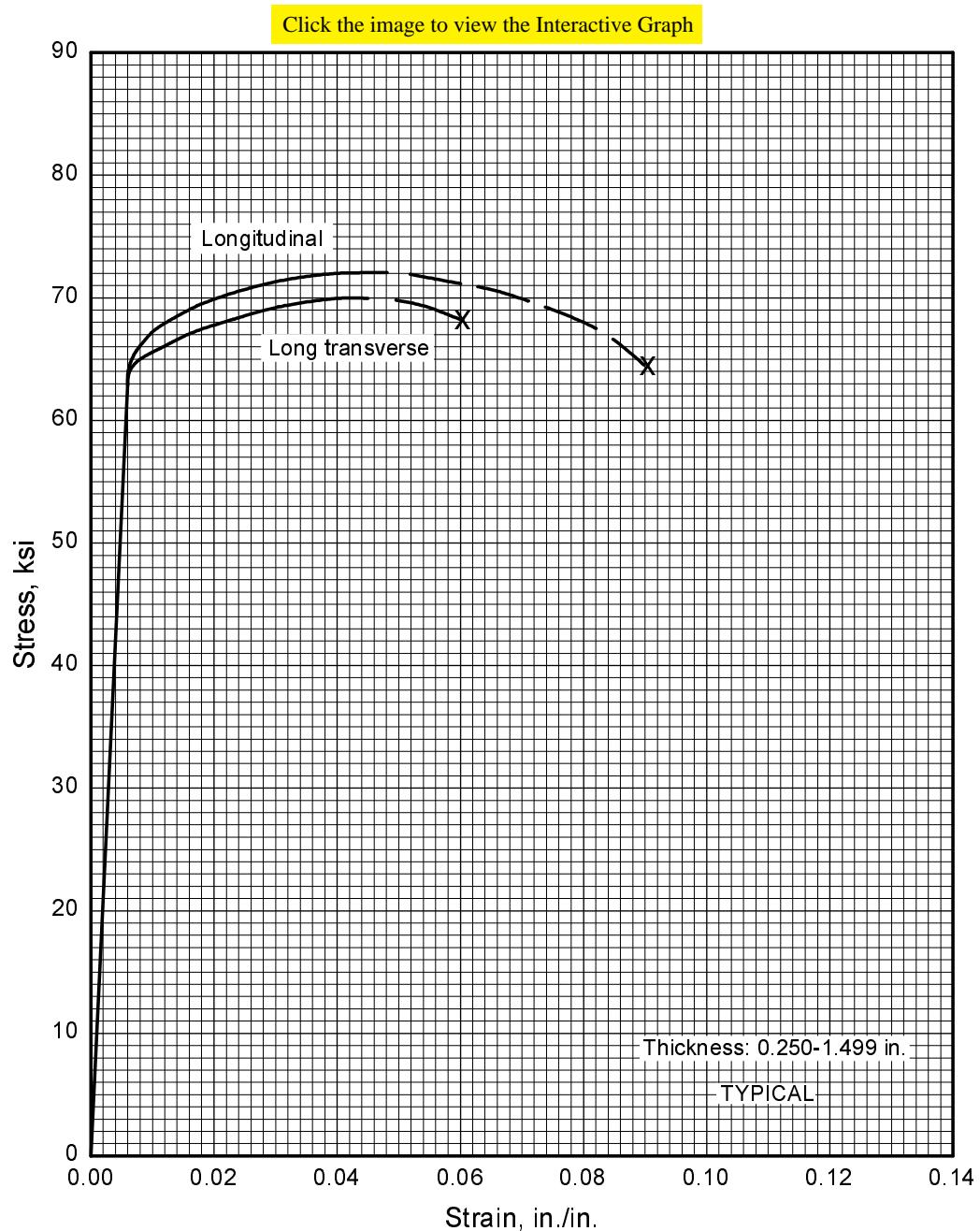


Figure 3.2.3.4.6(j). Typical tensile stress-strain curves (full range) for 2024-T851 aluminum alloy sheet at room temperature.

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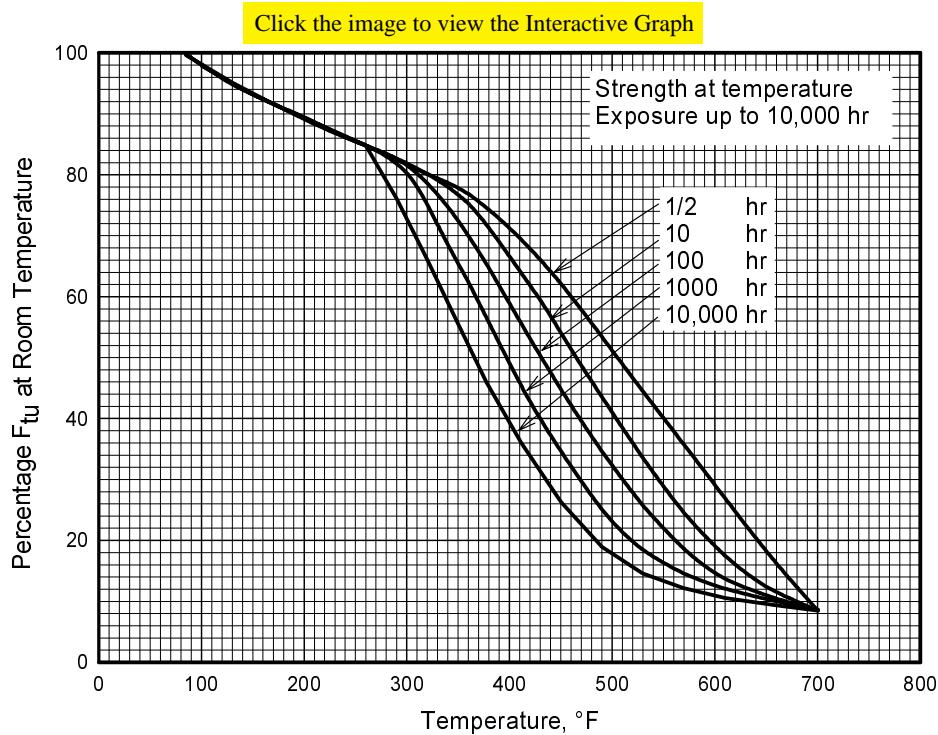


Figure 3.2.3.5.1(a). Effect of temperature on the tensile ultimate strength (F_{tu}) of 2024-T861 (T86) aluminum alloy sheet.

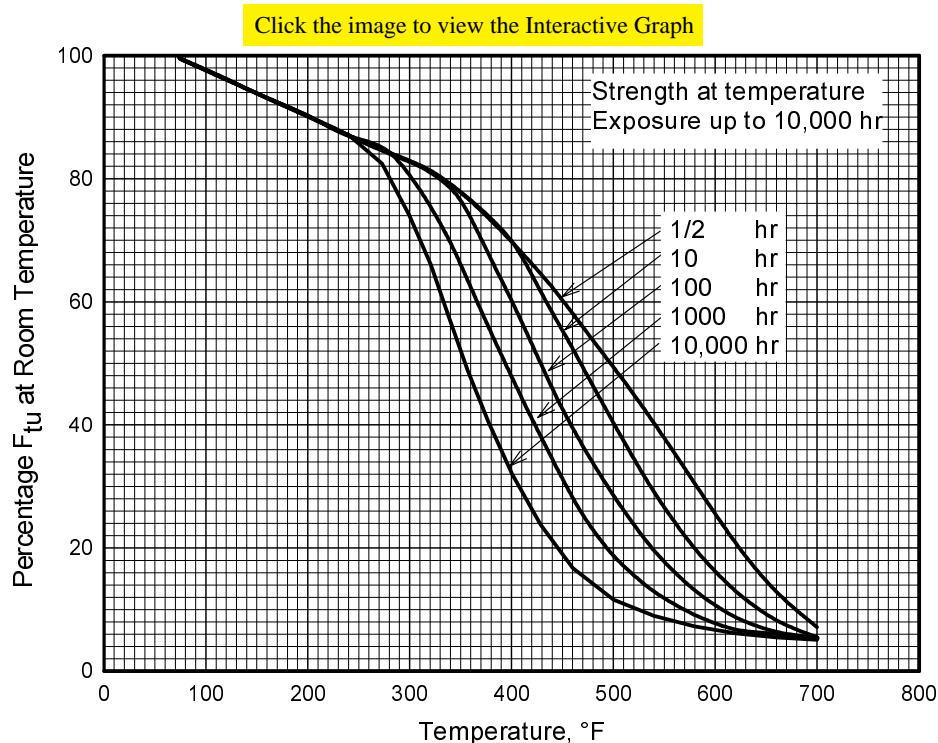


Figure 3.2.3.5.1(b). Effect of temperature on the tensile yield strength (F_{ty}) of 2024-T861 (T86) aluminum alloy sheet.

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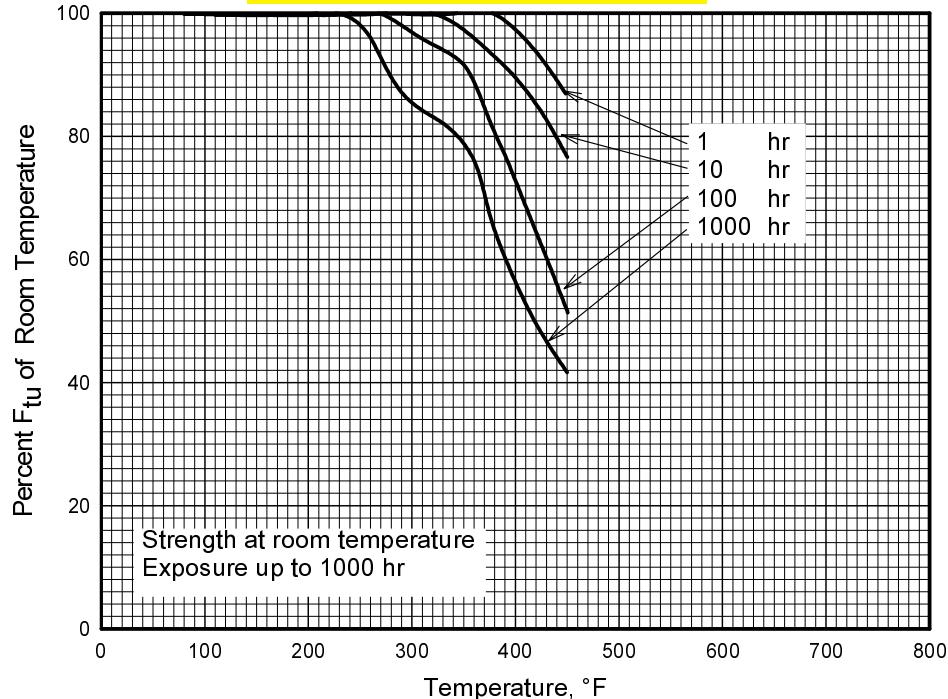


Figure 3.2.3.5.1(c). Effect of exposure at elevated temperatures on the room temperature tensile ultimate strength (F_{tu}) of 2024-T861 (T86) aluminum alloy sheet.

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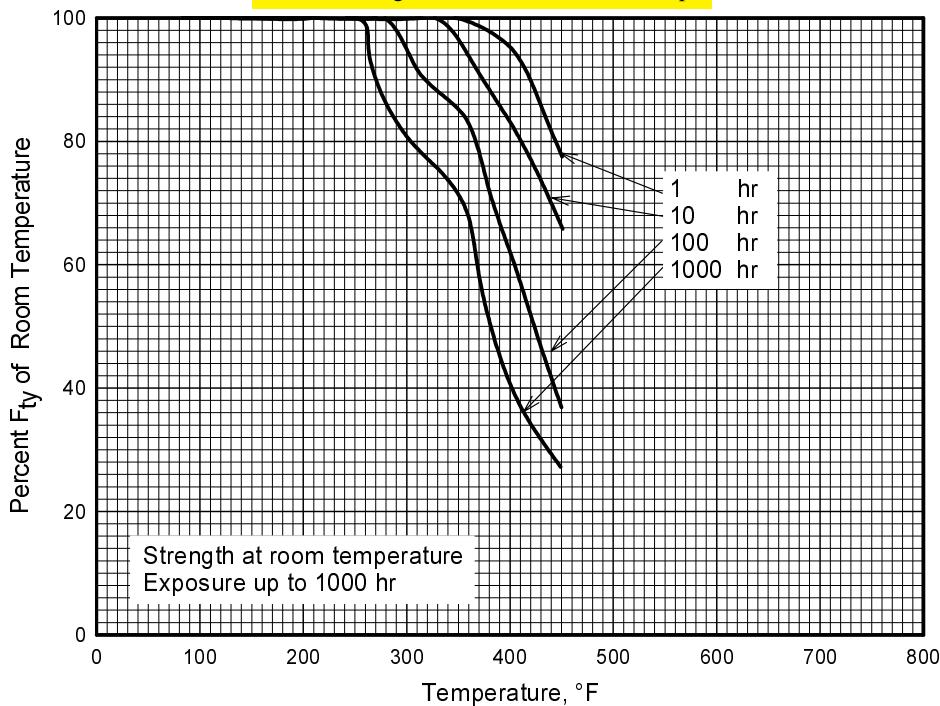


Figure 3.2.3.5.1(d). Effect of exposure at elevated temperatures on the room temperature tensile yield strength (F_{ty}) of 2024-T861 (T86) aluminum alloy sheet.

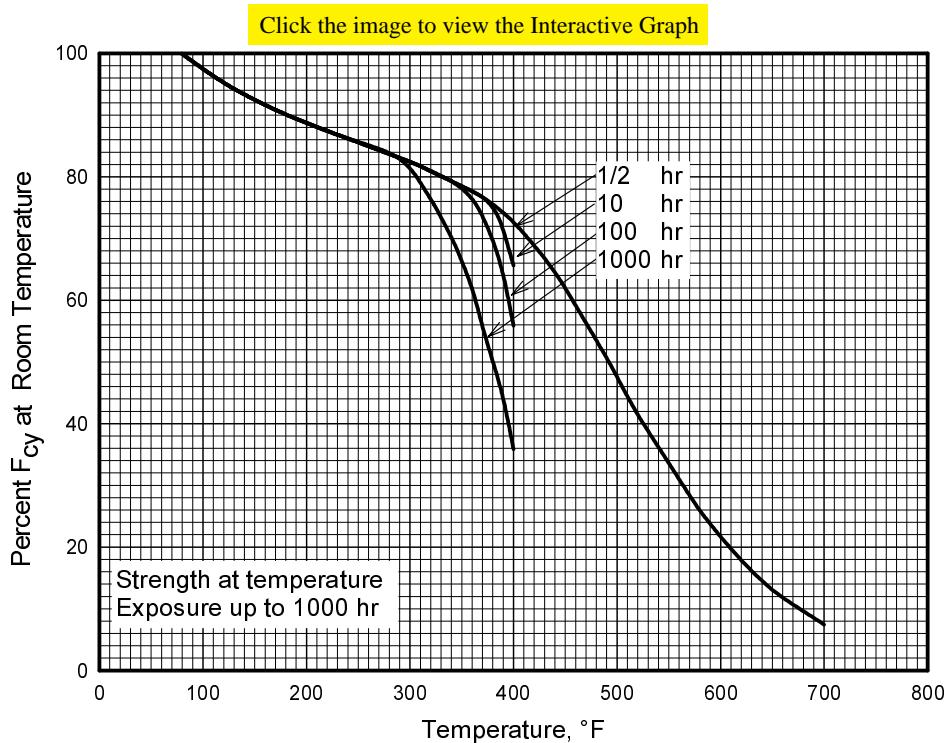


Figure 3.2.3.5.2(a). Effect of temperature on the compressive yield strength (F_{cy}) of 2024-T861 (T86) aluminum alloy sheet.

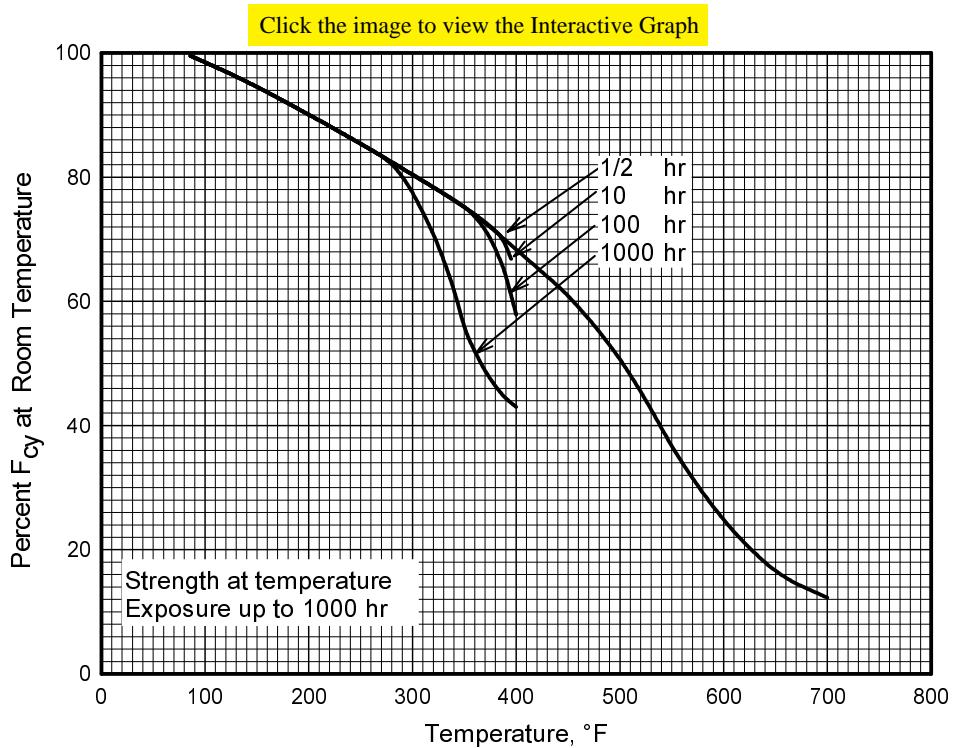


Figure 3.2.3.5.2(b). Effect of temperature on the shear ultimate strength (F_{su}) of 2024-T861 (T86) aluminum alloy sheet.

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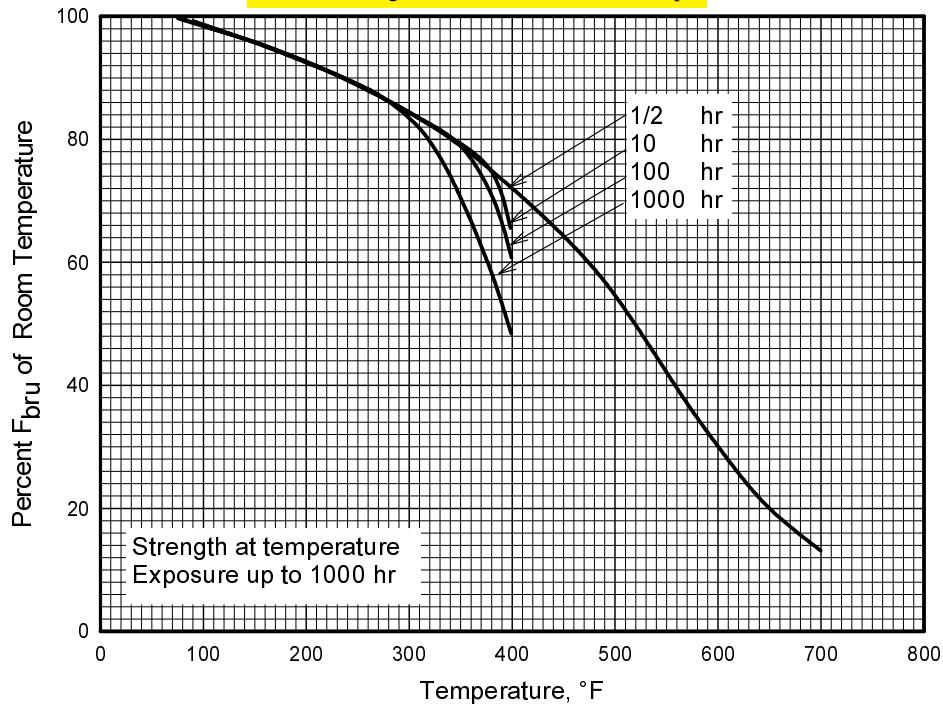


Figure 3.2.3.5.3(a). Effect of temperature on the bearing ultimate strength (F_{bru} , $e/D = 1.5$) of 2024-T861 (T86) aluminum alloy sheet.

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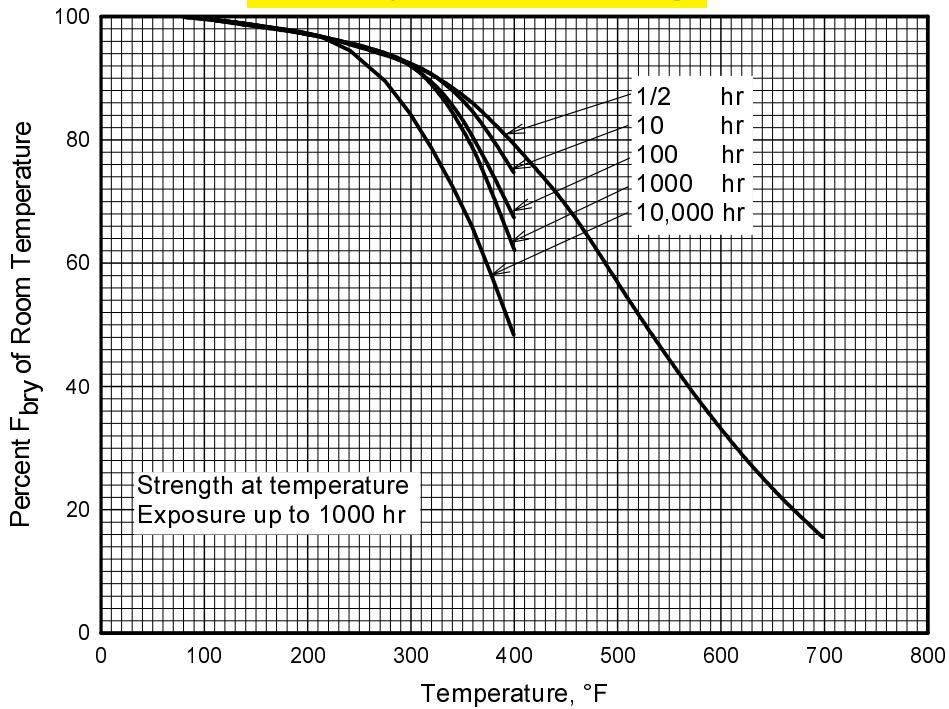


Figure 3.2.3.5.3(b). Effect of temperature on the bearing yield strength (F_{bry} , $e/D = 1.5$) of 2024-T861 (T86) aluminum alloy sheet.

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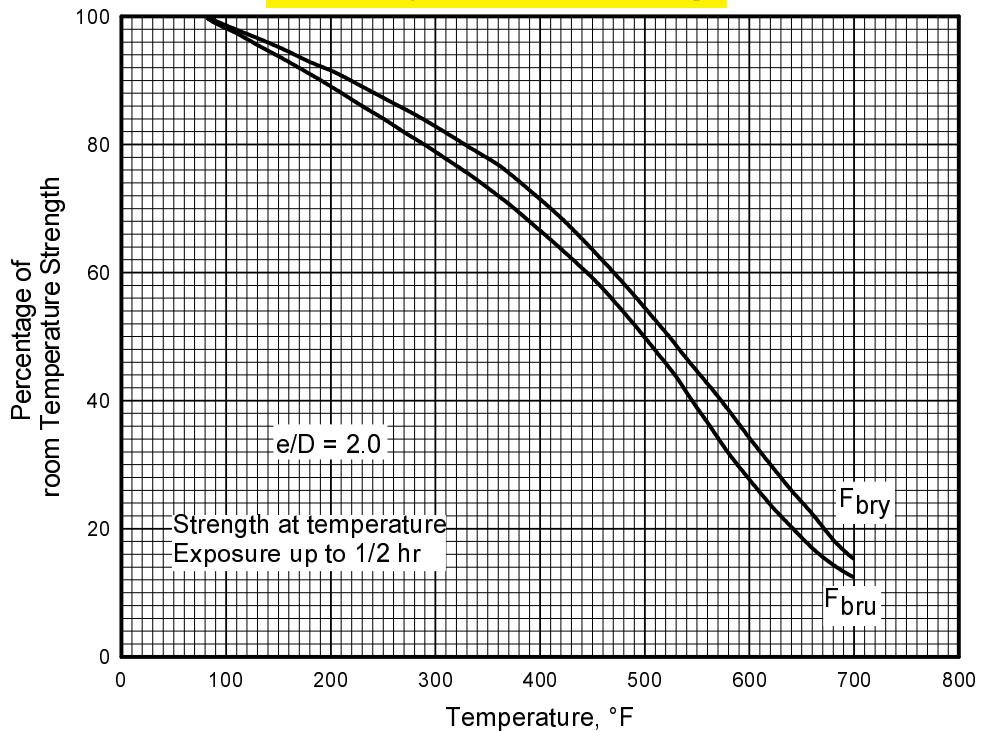


Figure 3.2.3.5.3(c). Effect of temperature on the bearing yield strength (F_{bru} , $e/D = 2.0$) and the bearing yield strength (F_{bry} , $e/D = 2.0$) of 2024-T861 (T86) aluminum alloy sheet.

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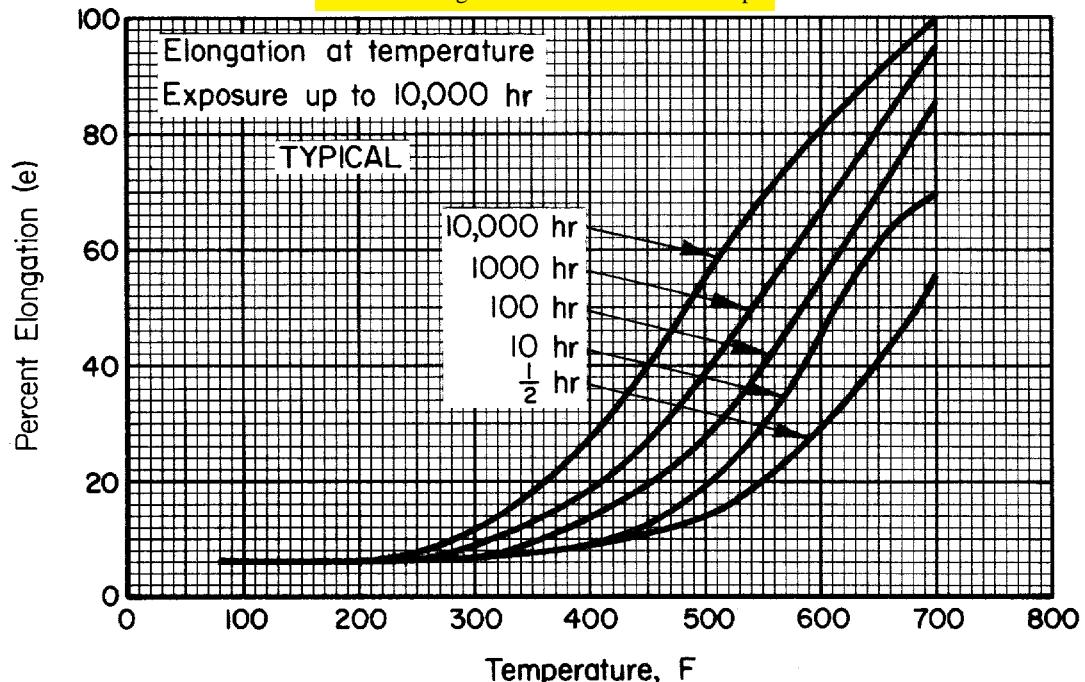


Figure 3.2.3.5.5(a). Effect of temperature on the elongation (e) of 2024-T861 (T86) aluminum alloy sheet.

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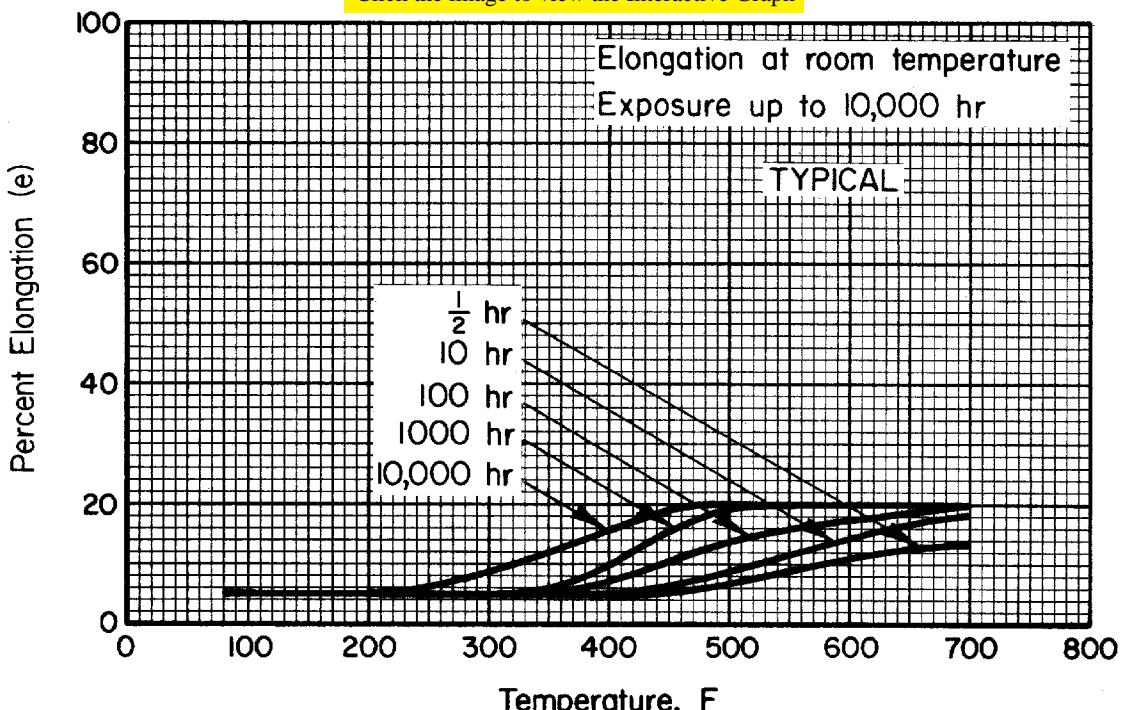


Figure 3.2.3.5.5(b). Effect of exposure at elevated temperatures on the room temperature elongation (e) of 2024-T861 (T86) aluminum alloy sheet.

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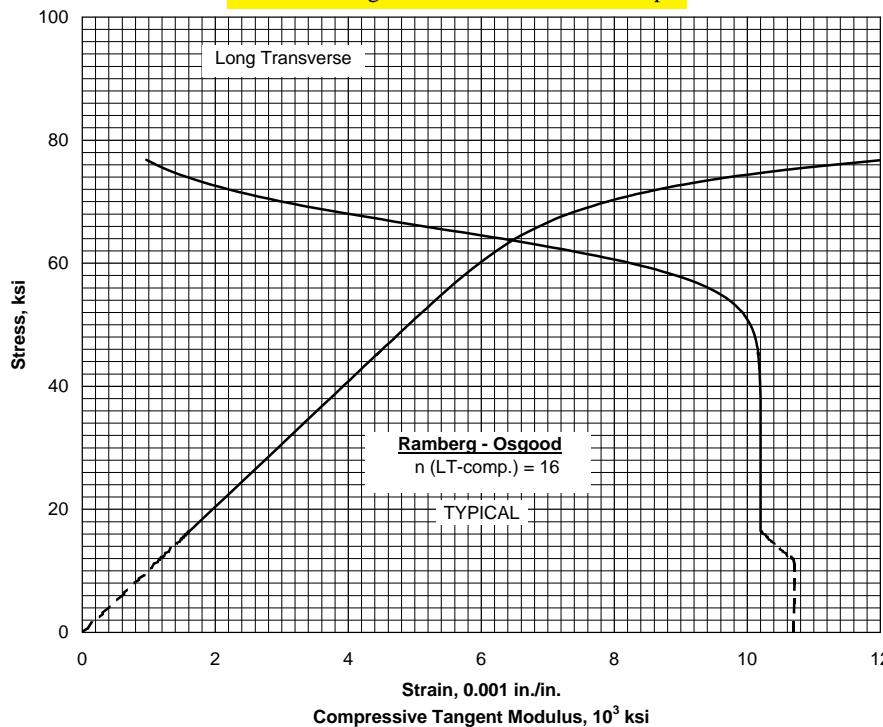


Figure 3.2.3.5.6(a). Typical compressive stress-strain and compressive tangent-modulus curves for clad 2024-T861 aluminum alloy sheet at room temperature.

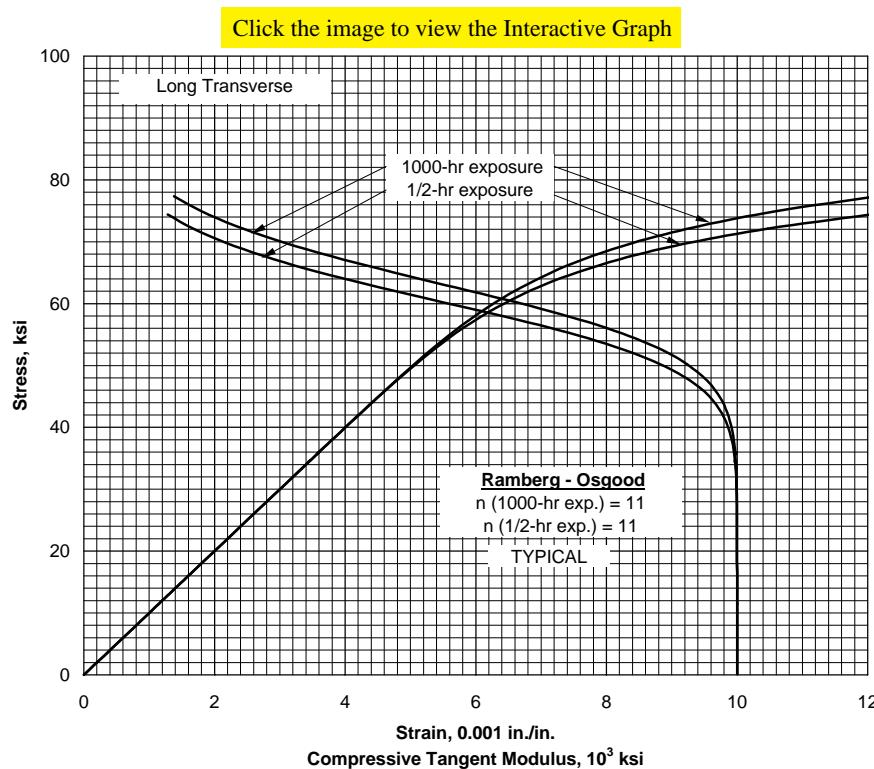


Figure 3.2.3.5.6(b). Typical compressive stress-strain and compressive tangent-modulus curves for clad 2024-T861 aluminum alloy sheet at 200° F.

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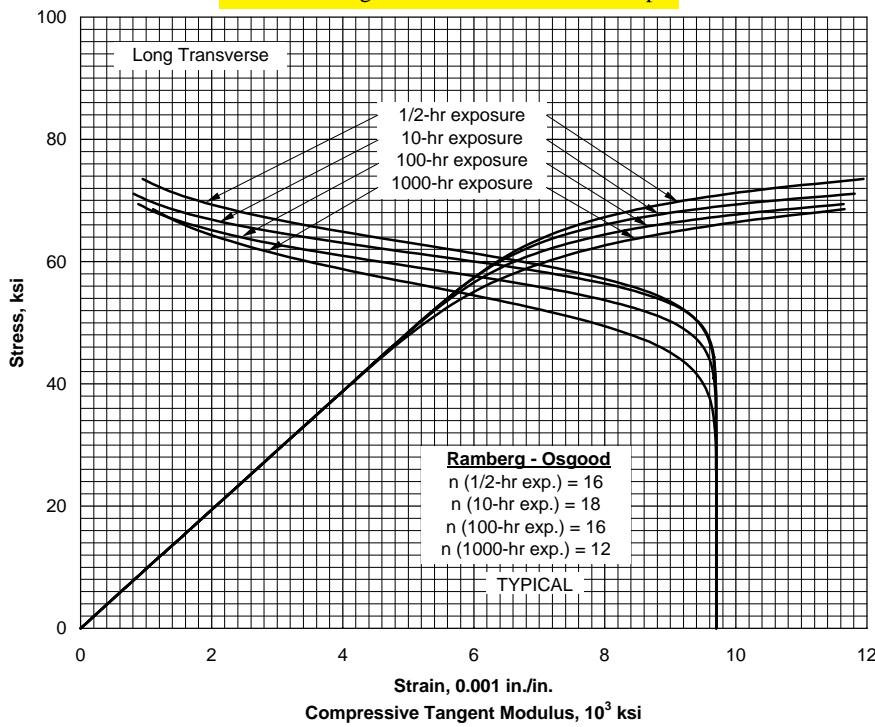


Figure 3.2.3.5.6(c). Typical compressive stress-strain and compressive tangent-modulus curves for clad 2024-T861 aluminum alloy sheet at 300° F.

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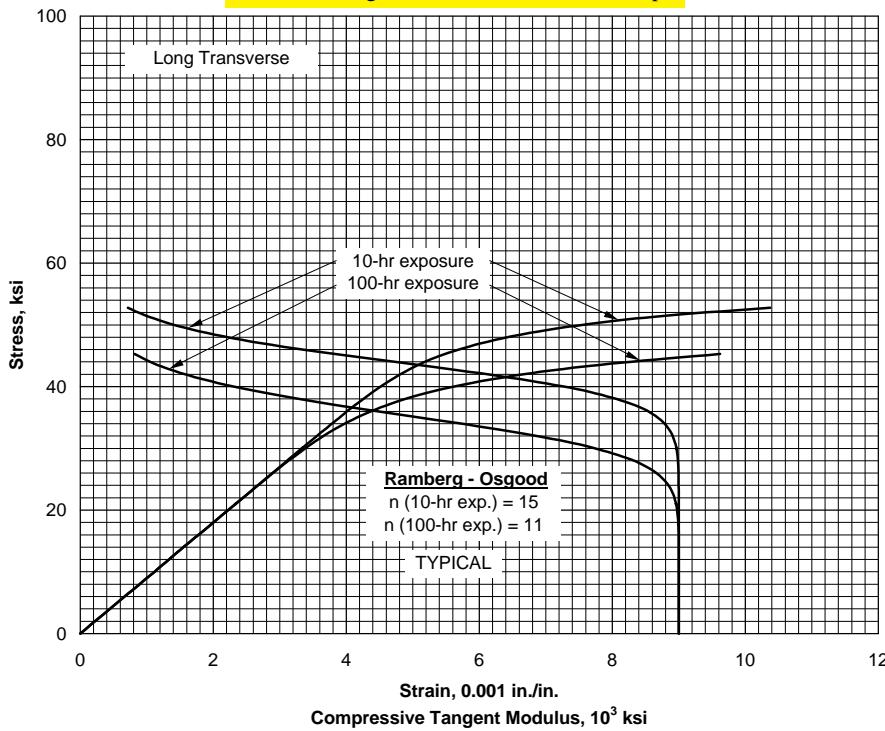


Figure 3.2.3.5.6(d). Typical compressive stress-strain and compressive tangent-modulus curves for clad 2024-T861 aluminum alloy sheet at 400° F.

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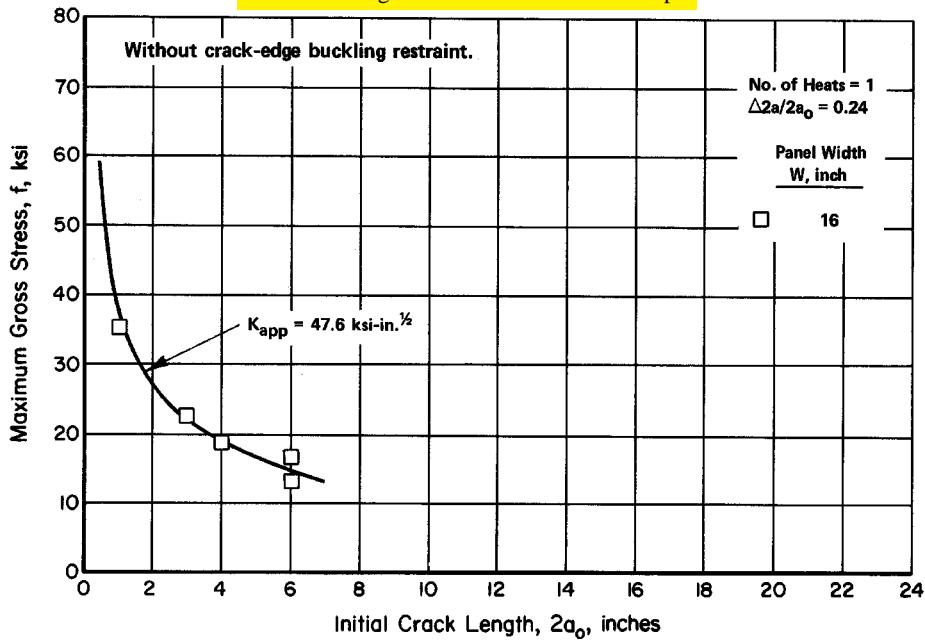


Figure 3.2.3.5.10(a). Residual strength behavior of 0.063-inch-thick 2024-T861 aluminum alloy sheet at room temperature. Crack orientation is T-L [Reference 3.1.2.1.6(d)].

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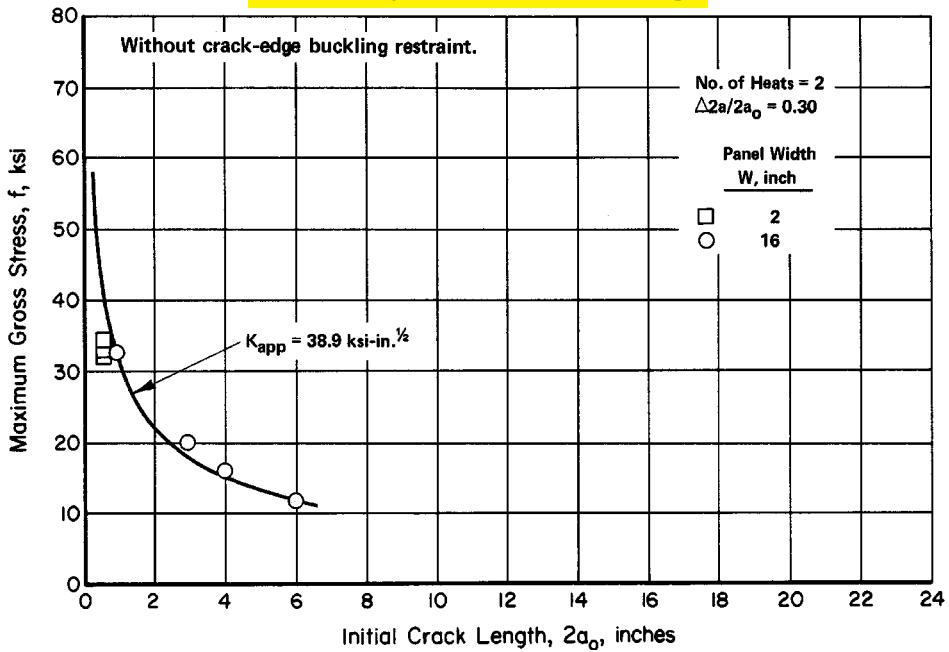


Figure 3.2.3.5.10(b). Residual strength behavior of 0.063-inch-thick 2024-T861 aluminum alloy sheet at room temperature. Crack orientation is T-L [Reference 3.1.2.1.6(d)].