3.6.2 6061 ALLOY

3.6.2.0 *Comments and Properties* — 6061 has been used in a wide range of applications, including cryogenic applications requiring high toughness. Refer to Section 3.1.3.4 for comments regarding the weldability of the alloy.

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 non-conservative; 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 6061 are presented in Table 3.6.2.0(a). Room temperature mechanical and physical properties are shown in Tables 3.6.2.0(b) through 3.6.2.0(g). The effect of temperature on the physical properties is shown in Figure 3.6.2.0.

The temper index for 6061 is as follows:

Section	Temper
3.6.2.1	T4, T42, T451, T4510, and T4511
3.6.2.2	T6, T62, T651, T652, T6510, and T6511

Table 3.6.2.0(a). Material Specifications for 6061 Aluminum Alloy

Specification	Form
AMS 4025	Sheet and plate
AMS 4026	Sheet and plate
AMS 4027	Sheet and plate
AMS-QQ-A-250/11	Sheet and plate
AMS 4115	Bar and rod, rolled or cold-finished
AMS 4116	Bar and rod, cold-finished
AMS 4117	Bar and rod, rolled or cold-finished
AMS-QQ-A-225/8	Rolled bar, rod, and shapes
AMS 4128	Rolled bar, rod, and shapes
AMS 4150	Extruded rod, bar, and shapes
AMS 4160	Extrusion
AMS 4161	Extrusion
AMS 4172	Extrusion
AMS 4173	Extruded rod, bar, and shapes
AMS-QQ-A-200/8	Extruded rod, bar, shapes, and tubing
AMS-A-22771[a]	Forging
AMS 4080	Tubing, seamless drawn
AMS 4081	Tubing, seamless drawn
AMS 4082	Tubing, seamless drawn
AMS 4083	Tubing, seamless drawn
AMS-WW-T-700/6	Tubing, seamless drawn
AMS-T-7081	Tubing, seamless drawn
AMS 4127	Forging
AMS 4248	Hand forging
AMS-QQ-A-367[a]	Forging

a Inactive for new design.

Table 3.6.2.0(b_1). Design Mechanical and Physical Properties of 6061 Aluminum Alloy Sheet

Specification	AMS 4026 and AMS-QQ-A-250/11[a]		AMS-QQ-A-250/11[a]	AMS 4025, AMS 4027 and AMS-QQ-A-250/11[a]	
Form	Sheet				
Temper	T4		T42[b]	T6 and T62[c]	
Thickness, in.	0.010-0.249		0.010-0.249	0.010-0.249	
Basis	A	B	S	A	B
Mechanical Properties:					
F_{tu}, ksi:					
L	...	...	...	42	43
LT	30	32	30	42	43
F_{ty}, ksi:					
L	...	...	...	36	38
LT	16	18	14	35	37
F_{cy}, ksi:					
L	...	...	...	35	37
LT	16	18	...	36	38
F_{su}, ksi	20	21	...	27	28
F_{bru}, ksi:					
(e/D = 1.5)	48	51	...	67	69
(e/D = 2.0)	63	67	...	88	90
F_{bry}, ksi:					
(e/D = 1.5)	22	25	...	50	53
(e/D = 2.0)	26	29	...	58	61
e, percent (S-Basis):					
LT	[d]	...	[d]	[d]	...
E, 10^3 ksi	9.9				
E_c, 10^3 ksi	10.1				
G, 10^3 ksi	3.8				
μ	0.33				
Physical Properties:					
ω, lb/in.^{3}	0.098				
C, K, and α	See Figure 3.6.2.0				

a Mechanical properties were established under MIL-QQ-A-250/11.

b 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 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 Design allowables were based upon data obtained from testing T6 sheet and from testing samples of sheet, supplied in the O or F temper, which were heat treated to T62 temper to demonstrate response to heat treatment by suppliers. Properties obtained may be lower than those listed if the material has been formed or otherwise cold-worked, particularly in the annealed temper, prior to solution heat treatment.

d See Table 3.6.2.0(b_3).

Table 3.6.2.0(b_2). Design Mechanical and Physical Properties of 6061 Aluminum Alloy Plate

Specification	AMS 4026 and AMS-QQ-A-250/11 [a]				AMS-QQ-A-250/11 [a]		AMS 4025, AMS 4027 and AMS-QQ-A-250/11 [a]					
Form	Plate											
Temper	T451				T42[b]		T651 and T62[c]					
Thickness, in.	0.250-2.000		2.001-3.000		0.250-1.000	1.001-3.000	0.250-2.000		2.001-3.000		3.001-4.000	4.001-6.000[d]
Basis	A	B	A	B	S	S	A	B	A	B	S	S
Mechanical Properties:												
F_{tu}, ksi:												
L	...	...	...	...	...	...	42	43	...	...	...	...
LT	30	32	30	32	30	30	42	43	42	43	42	40
F_{ty}, ksi:												
L	...	...	...	...	...	...	36	38	...	...	...	...
LT	16	18	16	18	14	14	35	37	35	37	35	35
F_{cy}, ksi:												
L	...	...	...	...	...	...	35	37	...	...	...	...
LT	16	18	...	...	...	...	36	38	...	...	...	...
F_{su}, ksi	20	21	...	...	...	...	27	28	...	...	...	...
F_{bru}, ksi:												
(e/D = 1.5)	48	52	...	...	...	...	67	69	...	...	...	...
(e/D = 2.0)	63	67	...	...	...	...	88	90	...	...	...	...
F_{bry}, ksi:												
(e/D = 1.5)	22	25	...	...	...	...	50	53	...	...	...	...
(e/D = 2.0)	26	29	...	...	...	...	58	61	...	...	...	...
e, percent:												
LT	[e]	...	16	...	18	16	[e]	...	6	...	6	6
E, 10^3 ksi	9.9											
E_c, 10^3 ksi	10.1											
G, 10^3 ksi	3.8											
μ	0.33											
Physical Properties:												
ω, lb/in.^{3}	0.098											
C, K, and α,	See Figure 3.6.2.0											

a Mechanical properties were established under MIL-QQ-A-250/11.

b Design allowables were based upon data obtained from testing samples of material, supplied in the O temper, which were heat treated to demonstrate response to heat treatment by suppliers. Properties obtained by the user 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 Design allowables were based upon data obtained from testing T651 plate and from testing samples of plate, supplied in the O temper, which were heat treated to demonstrate response to heat treatment by suppliers. Properties obtained may be lower than those listed if the material has been formed or otherwise cold-worked, particularly in the annealed temper, prior to solution heat treatment.

d Properties for this thickness apply only to T651 temper.

Table 3.6.2.0(b_3). Minimum Elongation Values for 6061 Aluminum Alloy Sheet and Plate

Temper and Product	Thickness, inch	Elongation (LT), percent
T4 or T42 sheet	0.010-0.020	14
	0.021-0.249	16
T451 plate	0.250-1.000	18
	1.001-2.000	16
T6 or T62 sheet	0.010-0.020	8
	0.021-0.249	10
T651 or T62 plate	0.250-0.499	10
	0.500-1.000	9
	1.001-2.000	8

Table 3.6.2.0(c_1). Design Mechanical and Physical Properties of 6061 Aluminum Alloy Tube and Pipe

Specification	AMS 4081, AMS-WW-T-700/6 [a], AMS-T-7081 [b]			AMS-WW-T-700/6 [a], AMS-T-7081 [b]	AMS 4080, AMS 4082, AMS-WW-T-700/6 [a], and AMS-T-7081[b]	
Form	Drawn tube					
Temper	T4			T42[c]	T6[d] and T62	
Wall Thickness, in.	0.025-0.100		>0.100-0.500	0.025-0.500	0.025-0.500	
Outside Diameter, in.	...					
Basis	A	B	S	S	A	B
Mechanical Properties:						
F_{tu}, ksi:						
L	30[e]	34	30	30	42[f]	45
F_{ty}, ksi:						
L	16[e]	19	16	14	35[f]	39
F_{cy}, ksi: (S-Basis)						
L	14	...	14	...	34	...
F_{su}, ksi (S-Basis)	20	...	20	...	27	...
F_{bru}, ksi: (S-Basis)						
(e/D = 1.5)	48	...	48	...	67	...
(e/D = 2.0)	63	...	63	...	88	...
F_{bry}, ksi: (S-Basis)						
(e/D = 1.5)	22	...	22	...	49	...
(e/D = 2.0)	26	...	26	...	56	...
e, percent: (S-Basis)						
L	[g]	...	[g]	[g]	[g]	...
E, 10^3 ksi	9.9					
E_c, 10^3 ksi	10.1					
G, 10^3 ksi	3.8					
μ	0.33					
Physical Properties:						
ω, lb/in.^{3}	0.098					
C, K, and α	See Figure 3.6.2.0					

a Mechanical properties were established under MIL-QQ-T-700/6.
b Mechanical properties were established under MIL-T-7081.
c Design allowables were based upon data obtained from testing samples of material, supplied in the O temper, which were heat treated to demonstrate response to heat treatment by suppliers. Properties obtained by the user 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.
d Design allowables were based upon data obtained from testing T6 temper tube and from testing samples of tube, supplied in the O temper, which were heat treated to demonstrate response to heat treatment by suppliers. Properties obtained by the user may be lower than those listed if the material has been formed or otherwise cold-worked, particularly in the annealed temper, prior to solution heat treatment.
e A-Basis value is specification minimum. The rounded T_{99} for F_{tu} = 32 ksi, F_{ty} = 17 ksi
f A-Basis value is specification minimum. The rounded T_{99} for F_{tu} = 43 ksi, F_{ty} = 37 ksi
g See Table 3.6.2.0(c_2).

Table 3.6.2.0(c_2). Minimum Elongation Values for 6061 Aluminum Alloy Tubing

Temper	Wall Thickness, inch	Elongation (L), percent	
		Full-Section Specimen	Cut-Out Specimen
T4 or T42	0.025-0.049	16	14
	0.050-0.259	18	16
	0.260-0.500	20	18
T6 or T62	0.025-0.049	10	8
	0.050-0.259	12	10
	0.260-0.500	14	12

Table 3.6.2.0(d). Design Mechanical and Physical Properties of 6061 Aluminum Alloy Rolled, Drawn, or Cold-Finished Bar, Rod, and Shapes

Specification	AMS 4116 & AMS-QQ-A-225/8[a]	AMS 4128 & AMS-QQ-A-225/8[a]	AMS-QQ-A-225/8[a]	AMS 4117 & AMS-QQ-A-225/8[a]	AMS 4117 & AMS-QQ-A-225/8[a]	AMS 4115, AMS 4116, & AMS-QQ-A-225/8[a]
Form	Rolled, drawn, or cold-finished bar, rod and special shapes					
Temper	T4	T451	T42[b]	T6	T651	T62[b]
Cross-Sectional Area, in^2	≤50					
Thickness, in.	≤8.000	0.500-8.000	≤8.000	≤8.000	0.500-8.000	≤8.000
Basis	S	S	S	S	S	S
Mechanical Properties:						
F_{tu}, ksi:						
L	30	30	30	42	42	42
F_{ty}, ksi:						
L	16	16	14	35	35	35
F_{cy}, ksi:						
L	14	14	...	34	34	...
F_{su}, ksi	20	20	...	27	27	...
F_{bru}, ksi:						
(e/D = 1.5)	48	48	...	67	67	...
(e/D = 2.0)	63	63	...	88	88	...
F_{bry}, ksi:						
(e/D = 1.5)	22	22	...	49	49	...
(e/D = 2.0)	26	26	...	56	56	...
e, percent:						
L	18	18	18	10	10	10
E, 10^3 ksi	9.9					
E_c, 10^3 ksi	10.1					
G, 10^3 ksi	3.8					
μ	0.33					
Physical Properties:						
ω, $lb/in.^3$	0.098					
C, K, and α,	See Figure 3.6.2.0					

a Mechanical properties were established under MIL-QQ-A-225/8.

b 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.

Table 3.6.2.0(e). Design Mechanical and Physical Properties of 6061 Aluminum Alloy Die Forging

Specification	AMS 4127, AMS-A-22771[a], and AMS-QQ-A-367[b]
Form	Die forging
Temper	T6 and T652
Thickness, in.	≤ 4.000[c]
Basis	S
Mechanical Properties:	
F_{tu}, ksi:	
L	38
T[d]	38
F_{ty}, ksi:	
L	35
T[d]	35
F_{cy}, ksi:	
L	36
T[d]	36
F_{su}, ksi	25
F_{bru}, ksi:	
(e/D = 1.5)	61
(e/D = 2.0)	76
F_{bry}, ksi:	
(e/D = 1.5)	54
(e/D = 2.0)	61
e, percent:	
L	7
T[d]	5
E, 10^3 ksi	9.9
E_c, 10^3 ksi	10.1
G, 10^3 ksi	3.8
μ	0.33
Physical Properties:	
ω, lb/in.^{3}	0.098
C, *K*, and α	See Figure 3.6.2.0

a Mechanical properties were established under MILA-22771. Inactive for new design.
b Mechanical properties were established under MIL-QQ-A-367. Inactive for new design.
c Thickness at the time of heat treatment. When die forgings are machined before heat treatment, the mechanical properties are applicable provided the as-forged thickness is not greater than twice the thickness at the time of heat treatment.
d T indicates any grain direction not within ± 15° of being parallel to the forging flow lines. F_{cy}(T) values are based upon short transverse (ST) test data.

Table 3.6.2.0(f). Design Mechanical and Physical Properties of 6061 Aluminum Alloy Hand Forging

Specification	AMS 4127, AMS 4248, AMS-A-22771[a], and AMS-QQ-A-367[b]		
Form	Hand forging		
Temper	T6[c] and T652		
Cross-Sectional Area, in.^{2}	≤256		
Thickness, in.	≤2.000	2.001-4.000	4.001-8.000
Basis	S	S	S
Mechanical Properties:			
F_{tu}, ksi:			
L	38	38	37
LT	38	38	37
ST	...	37	35
F_{ty}, ksi:			
L	35	35	34
LT	35	35	34
ST	...	33	32
F_{cy}, ksi:			
L	36	36	35
LT	36	36	35
ST	...	34	33
F_{su}, ksi	25	25	24
F_{bru}, ksi:			
(e/D = 1.5)	61	61	59
(e/D = 2.0)	76	76	74
F_{bry}, ksi:			
(e/D = 1.5)	54	54	53
(e/D = 2.0)	61	61	59
e, percent:			
L	10	10	8
LT	8	8	6
ST	...	5	4
E, 10^3 ksi	9.9		
E_c, 10^3 ksi	10.1		
G, 10^3 ksi	3.8		
μ	0.33		
Physical Properties:			
ω, lb/in.^{3}	0.098		
C, K, and α	See Figure 3.6.2.0		

a Mechanical properties were established under MIL-A-22771. Inactive for new design.
b Mechanical properties were established under MIL-QQ-A-367. Inactive for new design.
c When hand forgings are machined before heat treatment, the section thickness at time of heat treatment shall determine the minimum mechanical properties as long as the original (as-forged) thickness does not exceed the maximum thickness for the alloy as shown in the table.

Table 3.6.2.0(g). Design Mechanical and Physical Properties of 6061 Aluminum Alloy Extruded Rod, Bar, and Shapes

Specification	AMS 4161, AMS 4172, & AMS-QQ-A-200/8[a]	AMS-QQ-A-200/8[a]	AMS 4160 & AMS-QQ-A-200/8[a]	AMS 4150, AMS 4173 & AMS-QQ-A-200/8[a]			
Form	Extruded rod, bar, and shapes						
Temper	T4, T4510, and T4511	T42[b]	T62[b]	T6, T6510, and T6511			
Cross-sectional area, in.^{2}	...	...	...	≤32			
Thickness,[c] in.	≤3.000	All	All	≤1.000		1.001-6.500	
Basis	S	S	S	A	B	A	B
Mechanical Properties:							
F_{tu}, ksi:							
L	26	26	38	38	41	38	41
LT	...	...	...	37	40	33	35
F_{ty}, ksi:							
L	16	12	35	35	38	35	38
LT	...	...	...	33	36	28	31
F_{cy}, ksi:							
L	14	...	...	34	37	34	37
LT	...	...	...	35	38	30	33
F_{su}, ksi	16	...	...	26	28	19	21
F_{bru}[d], ksi:							
(e/D = 1.5)	42	...	...	64	69	52	57
(e/D = 2.0)	55	...	...	82	88	69	74
F_{bry}[d], ksi:							
(e/D = 1.5)	22	...	...	54	58	42	46
(e/D = 2.0)	26	...	...	60	65	50	55
e, percent (S-Basis):							
L	16	16	10[e]	10[e]	...	10	...
E, 10^3 ksi	9.9						
E_c, 10^3 ksi	10.1						
G, 10^3 ksi	3.8						
μ	0.33						
Physical Properties:							
ω, lb/in.^{3}	0.098						
C, K, and α	See Figure 3.6.2.0						

a Mechanical properties were established under MIL-QQ-A-200/8.

b Design allowables were based upon data obtained from testing samples of material, supplied in the O to 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.

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

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

e For thicknesses ≤0.249 inch, e = 8%.

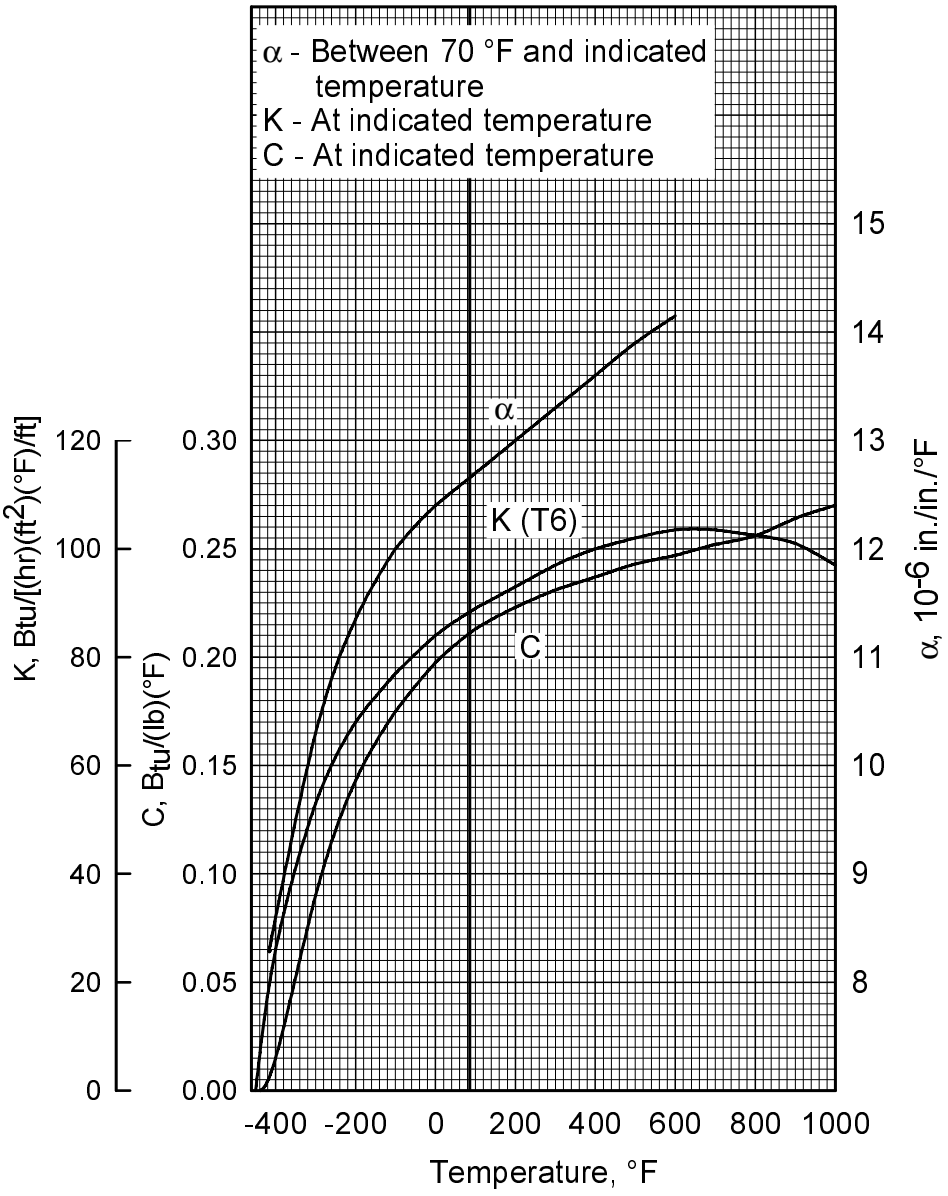

Figure 3.6.2.0. Effect of temperature on the physical properties of 6061 aluminum alloy.

3.6.2.1 ***T4, T42, T451, T4510, and T4511 Tempers*** — For effect of temperature on modulus values, use Figure 3.6.2.2.4.

3.6.2.2 ***T6, T62, T651, T652, T6510, and T6511 Tempers*** — Figures 3.6.2.2.1(a) through 3.6.2.2.1(d), 3.6.2.2.4, and 3.6.2.2.5(a) and 3.6.2.2.5(b) present elevated temperature curves for various mechanical properties. Figures 3.6.2.2.6(a) through 3.6.2.2.6(k) contain tensile and compression stress-strain curves at room temperature and elevated temperatures, and tangent-modulus curves at room temperature for various products and tempers. Figures 3.6.2.2.6(l) through 3.6.2.2.6(o) present full-range tensile stress-strain curves at room temperature for various products and tempers. Figure 3.6.2.2.8 contains unnotched fatigue data for various wrought products at room temperature.

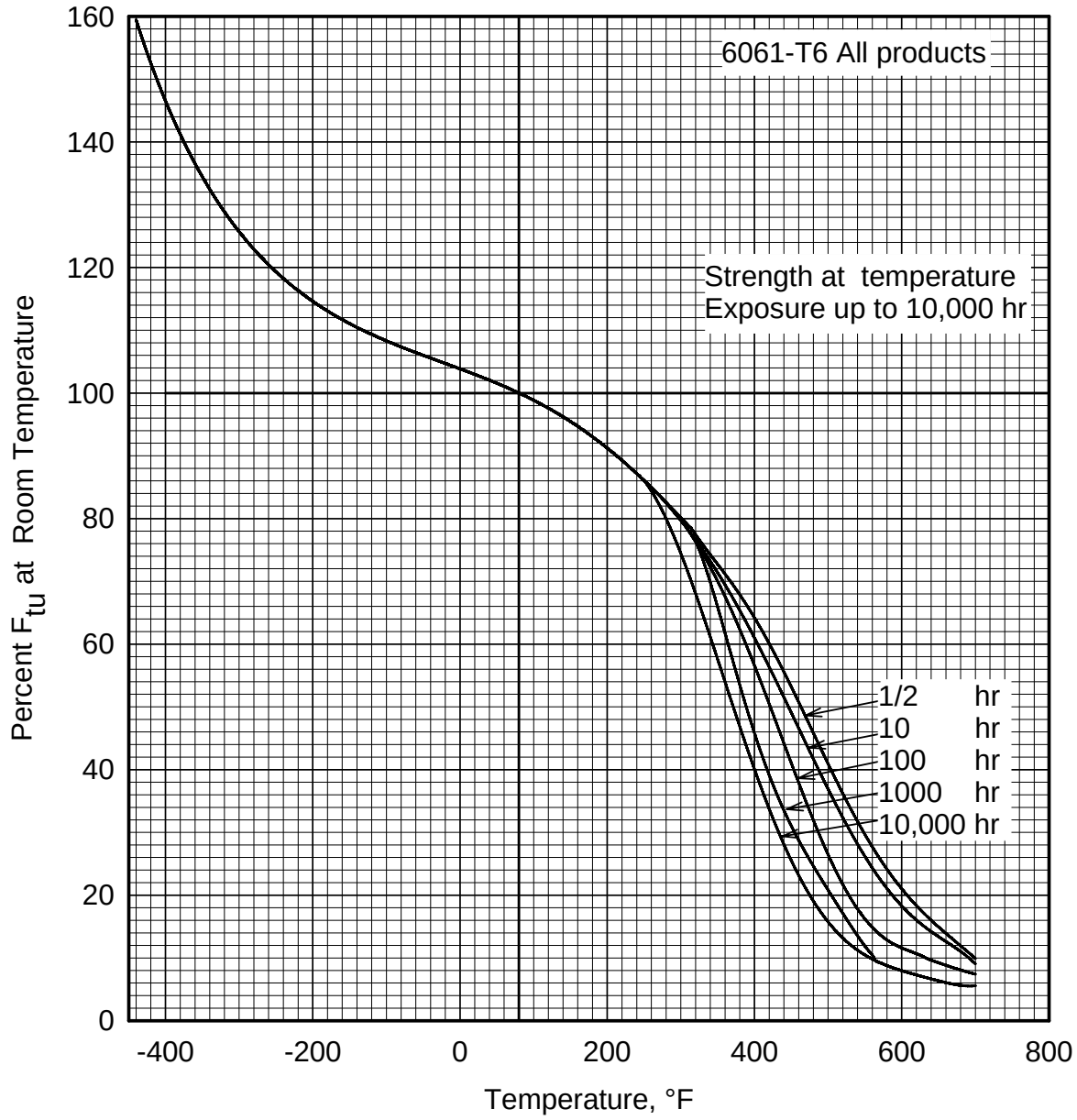

Figure 3.6.2.2.1(a). Effect of temperature on the tensile ultimate strength (F_{tu}) of 6061-T6 aluminum alloy (all products).

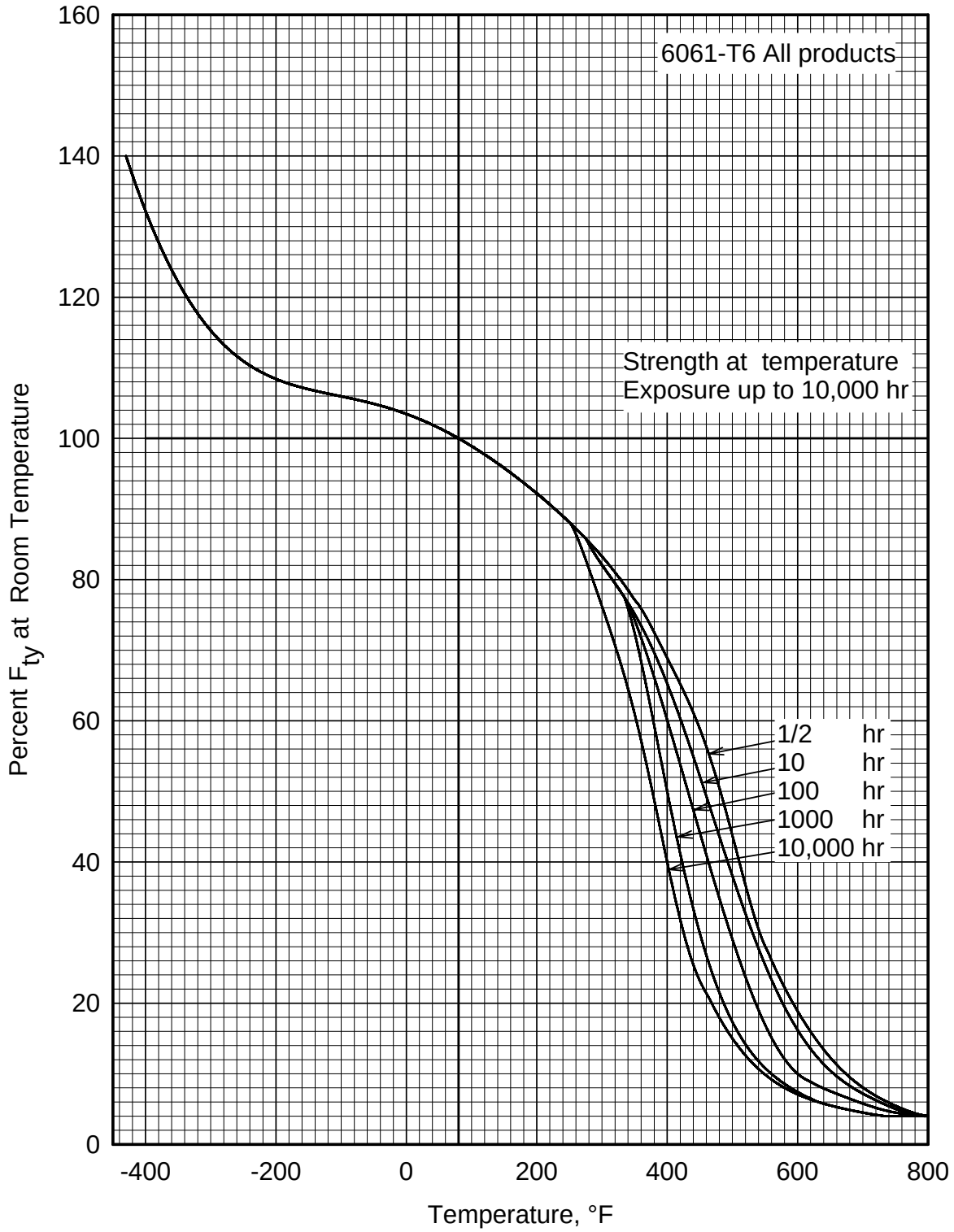

Figure 3.6.2.2.1(b). Effect of temperature on the tensile yield strength (F_{ty}) of 6061-T6 aluminum alloy (all products).

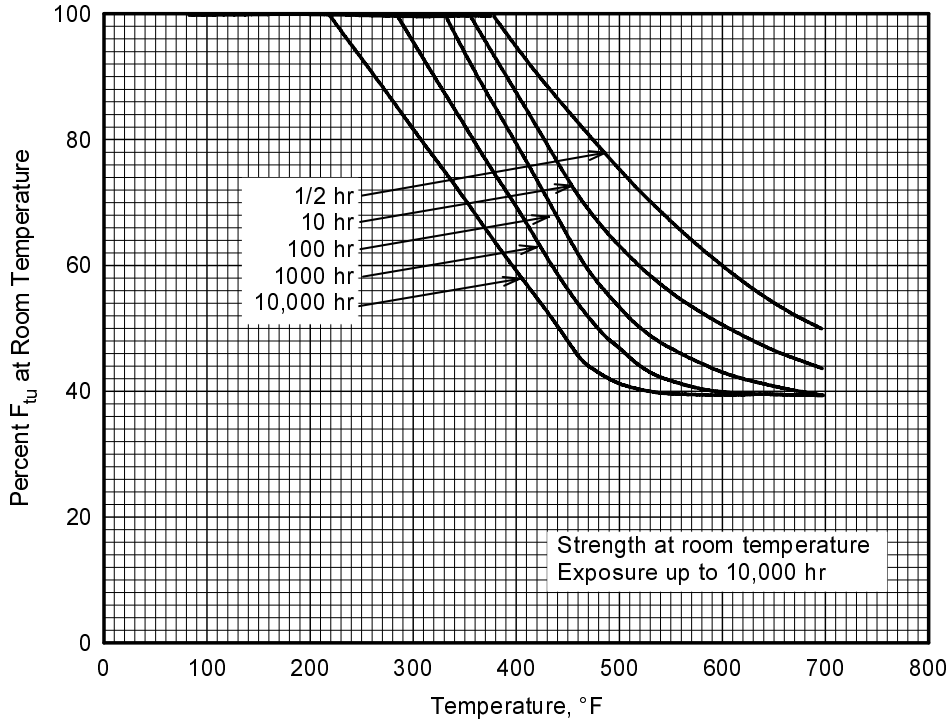

Figure 3.6.2.2.1(c). Effect of exposure at elevated temperatures on the room temperature tensile ultimate strength (F_{tu}) of 6061-T6 aluminum alloy (all products).

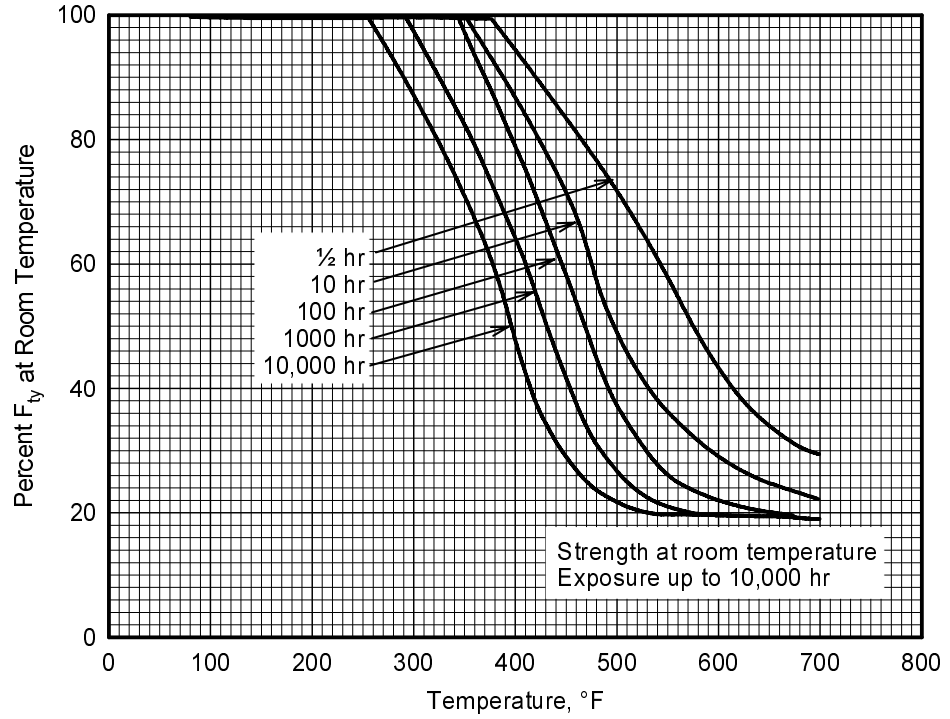

Figure 3.6.2.2.1(d). Effect of exposure at elevated temperatures on the room temperature tensile yield strength (F_{ty}) of 6061-T6 aluminum alloy (all products).

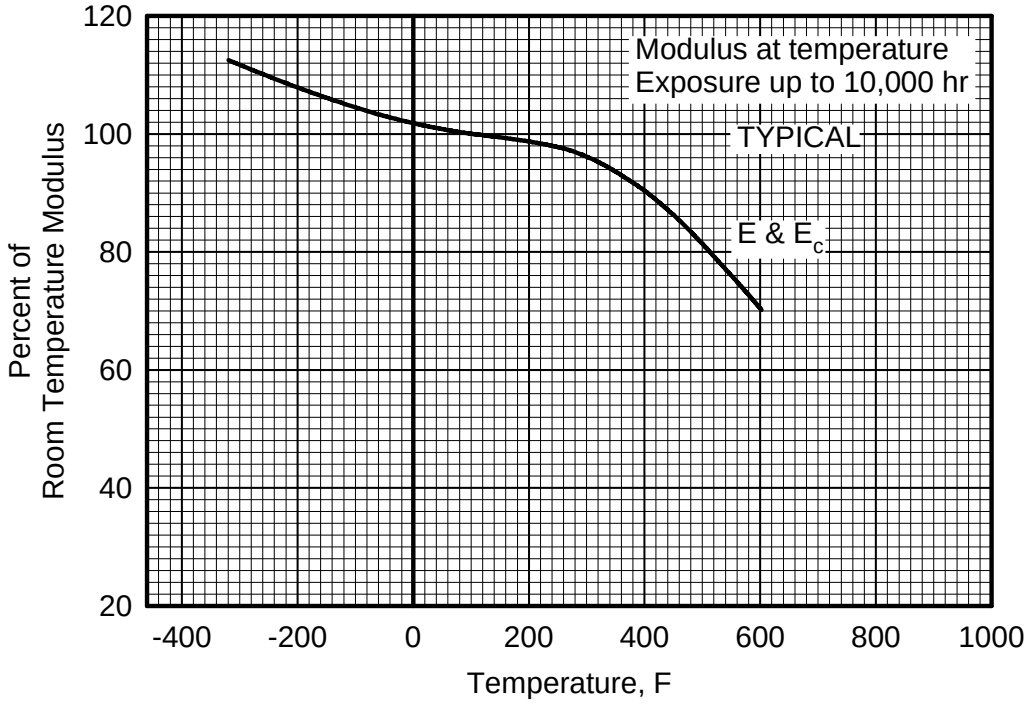

Figure 3.6.2.2.4. Effect of temperature on the tensile and compressive moduli (E and E_c) of 6061 aluminum alloy.

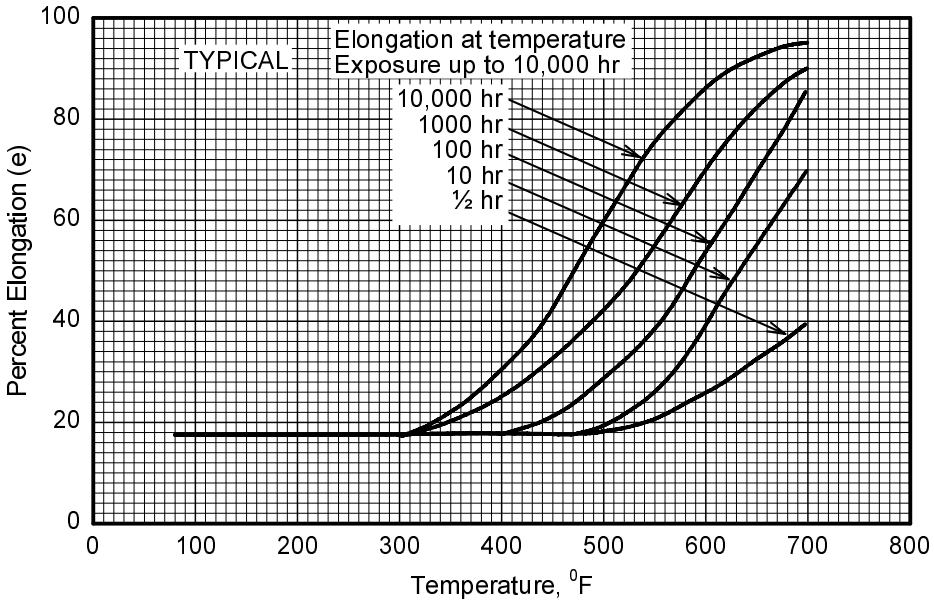

Figure 3.6.2.2.5(a). Effect of temperature on the elongation of 6061-T6 aluminum alloy (all products).

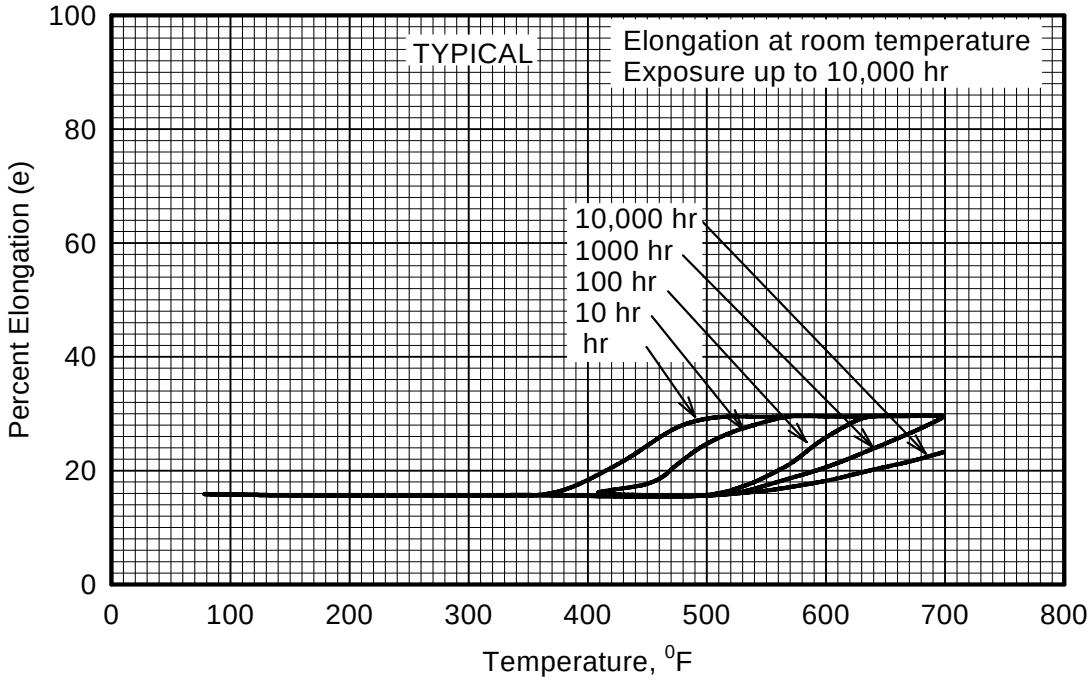

Figure 3.6.2.2.5(b). Effect of exposure at elevated temperatures on the room temperature elongation of 6061-T6 aluminum alloy (all products).

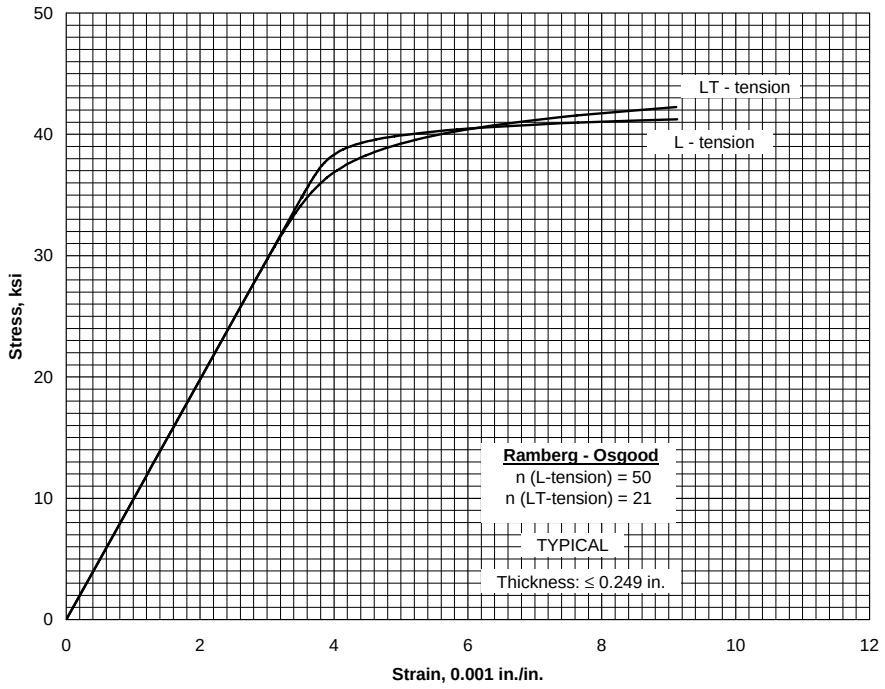

Figure 3.6.2.2.6(a). Typical tensile stress-strain curves for 6061-T6 aluminum alloy sheet at room temperature.

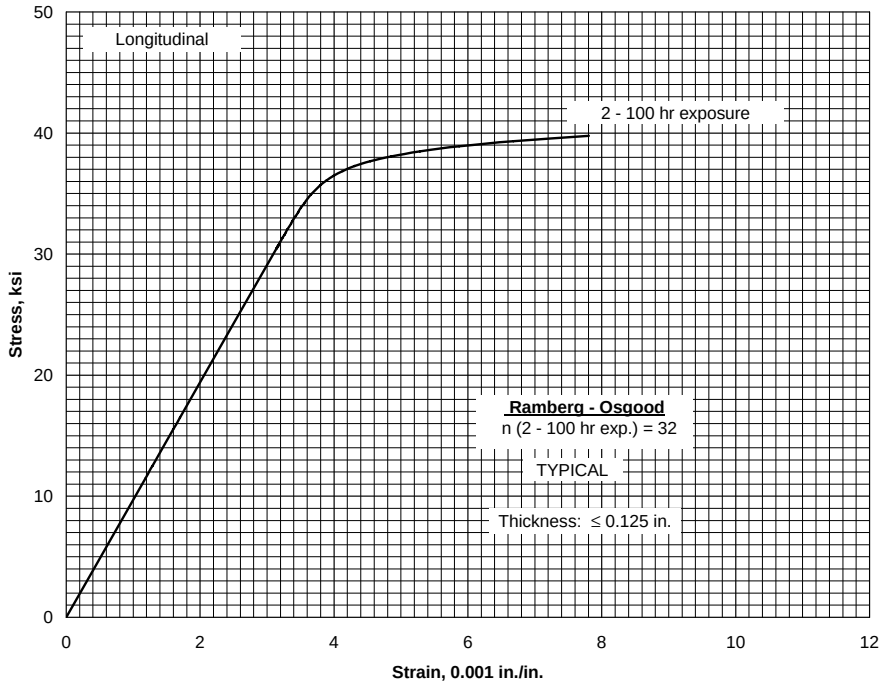

Figure 3.6.2.2.6(b). Typical tensile stress-strain curve for 6061-T6 aluminum alloy sheet at 200°F.

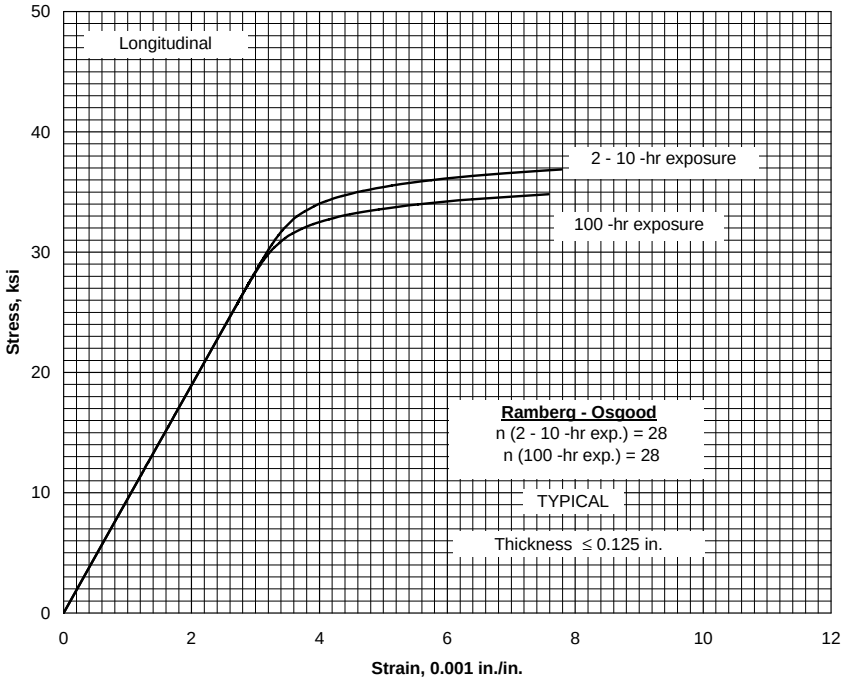

Figure 3.6.2.2.6(c). Typical tensile stress-strain curves for 6061-T6 aluminum alloy sheet at 300°F.

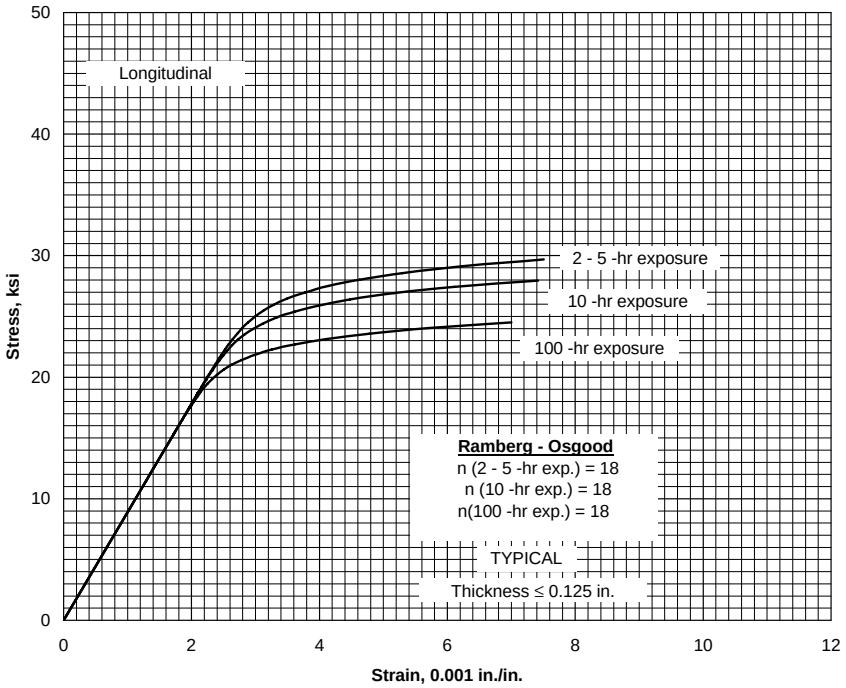

Figure 3.6.2.2.6(d). Typical tensile stress-strain curves for 6061-T6 aluminum alloy sheet at 400°F.

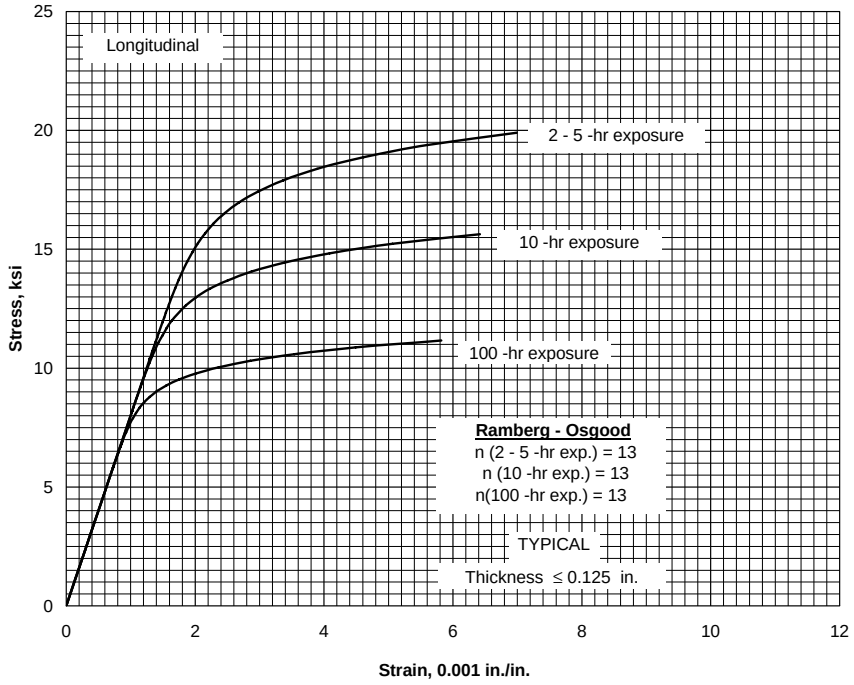

Figure 3.6.2.2.6(e). Typical tensile stress-strain curves for 6061-T6 aluminum alloy sheet at 500°F.

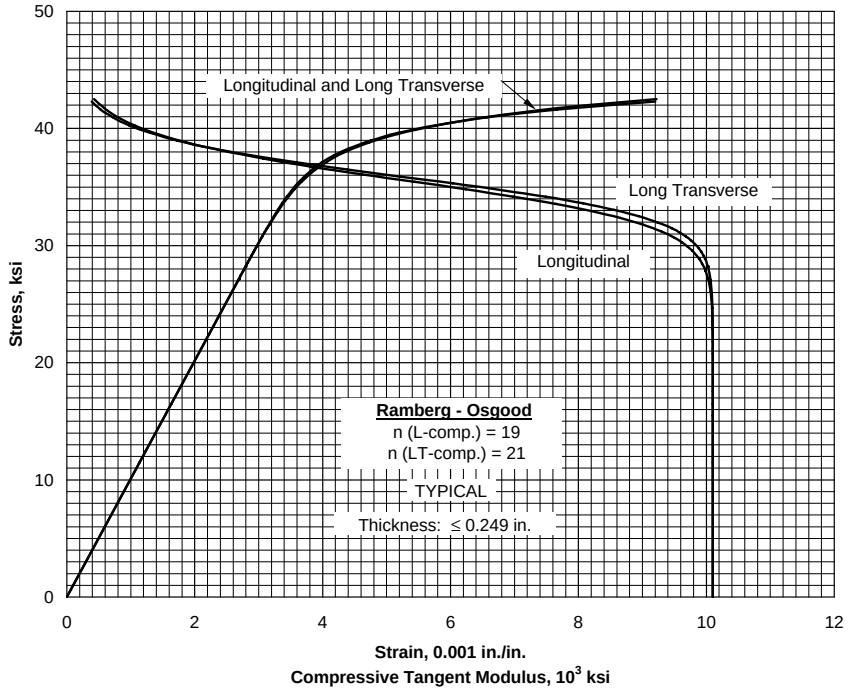

Figure 3.6.2.2.6(f). Typical compressive stress-strain and compressive tangent-modulus curves for 6061-T6 aluminum alloy sheet at room temperature.

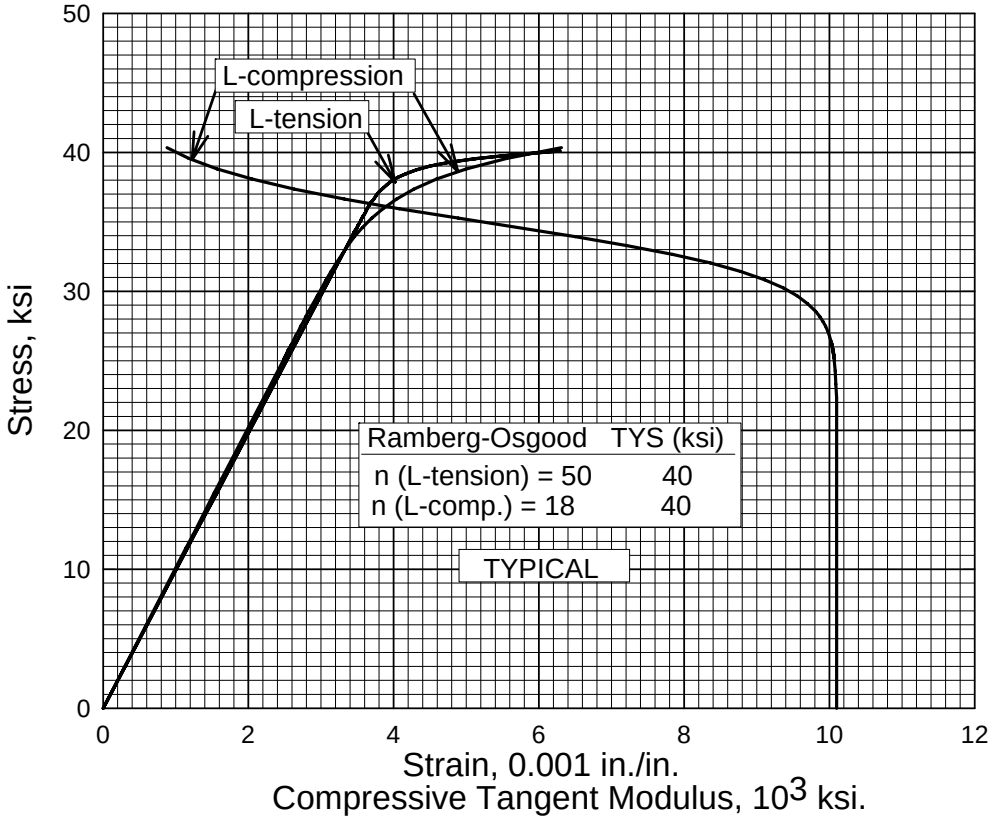

Figure 3.6.2.2.6(g). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for 6061-T6 aluminum alloy sheet at room temperature.

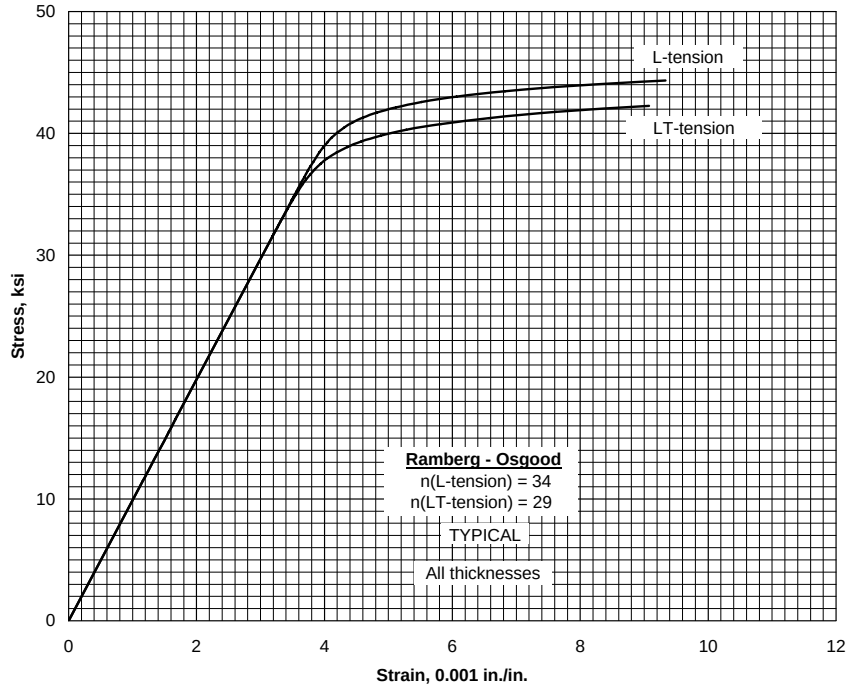

Figure 3.6.2.2.6(h). Typical tensile stress-strain curves for 6061-T6 aluminum alloy extrusion at room temperature.

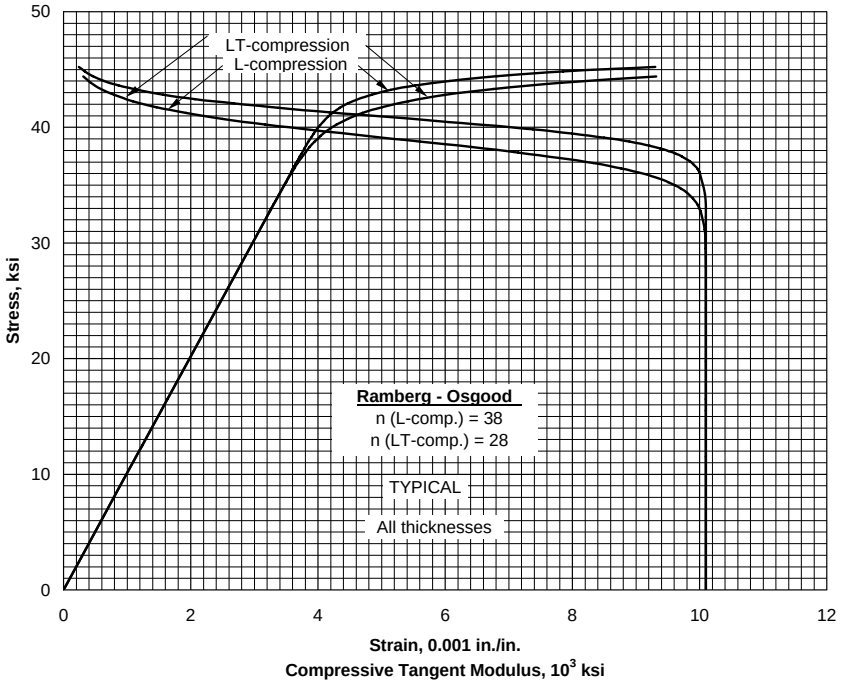

Figure 3.6.2.2.6(i). Typical compressive stress-strain and compressive tangent-modulus curves for 6061-T6 aluminum alloy extrusion at room temperature.

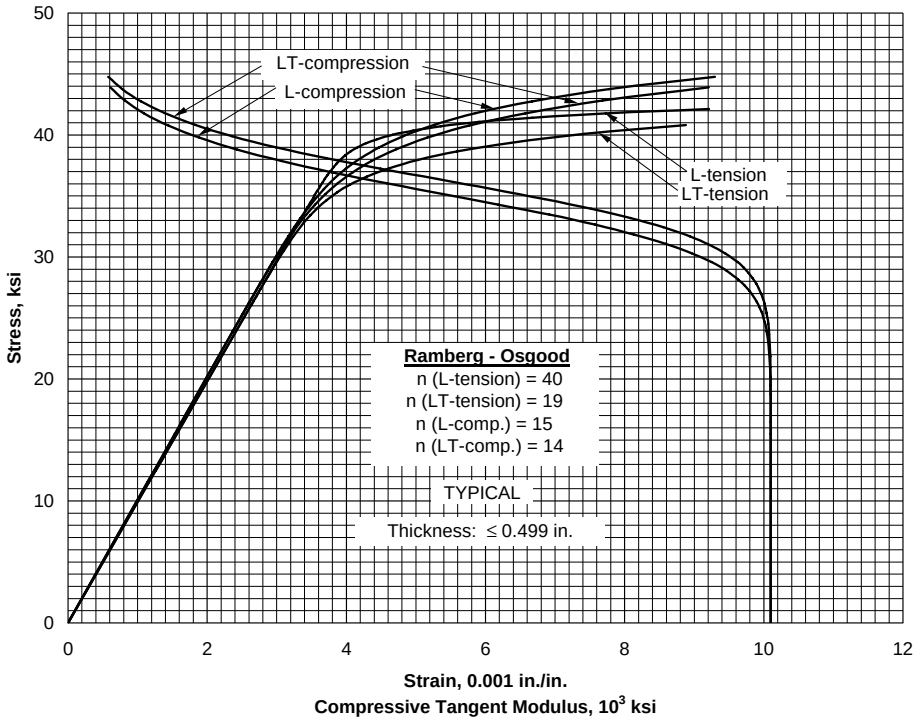

Figure 3.6.2.2.6(j). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for 6061-T651X aluminum alloy extrusion at room temperature.

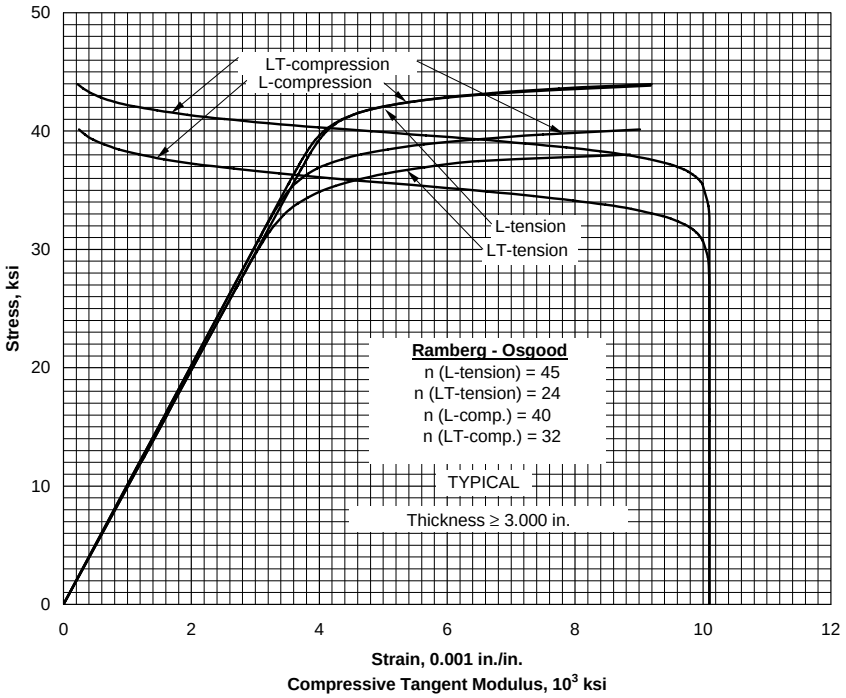

Figure 3.6.2.2.6(k). Typical tensile and compressive stress-strain and compressive tangent-modulus curves for 6061-T651X aluminum alloy extrusion at room temperature.

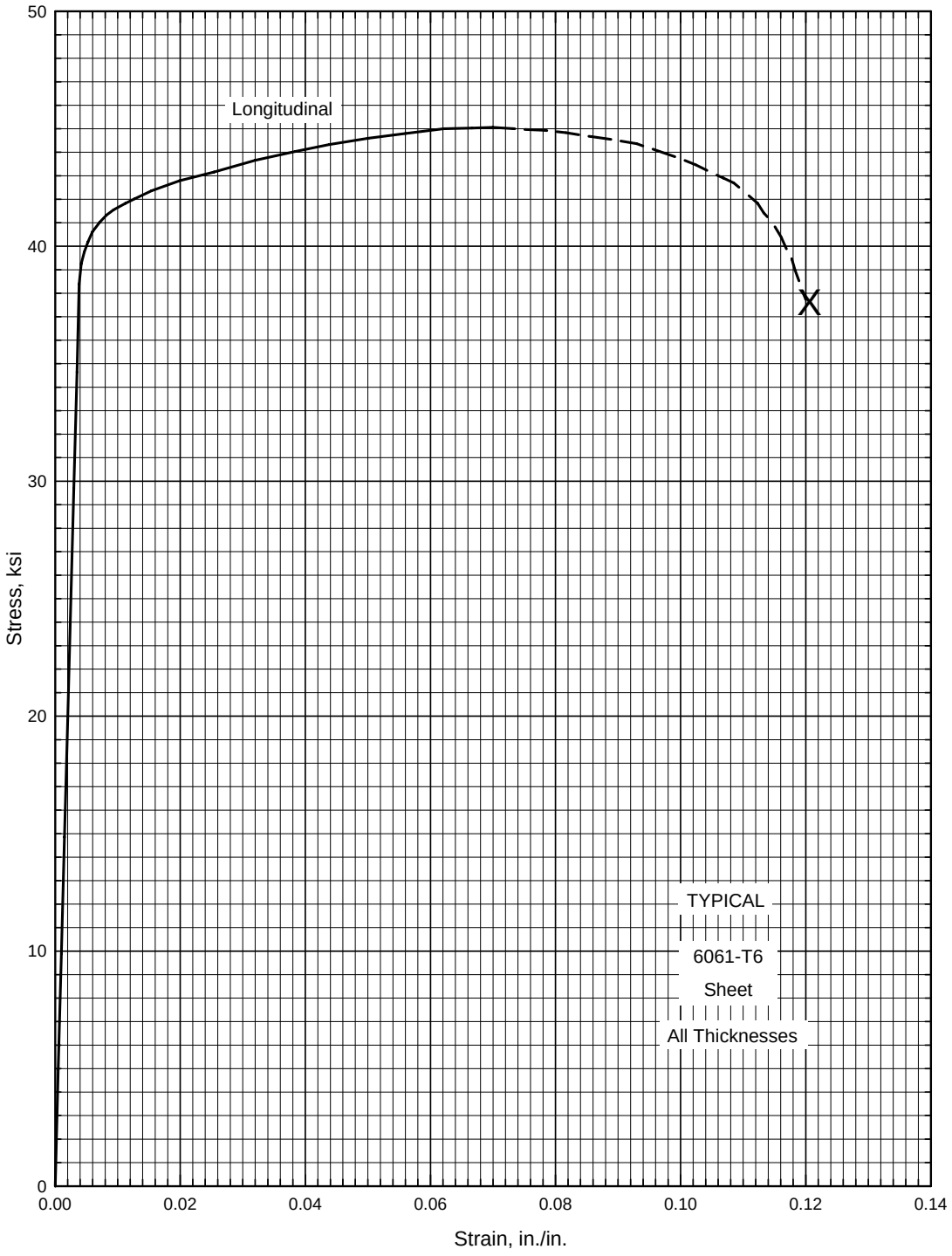

Figure 3.6.2.2.6(l). Typical stress-strain (full range) for 6061-T6 aluminum alloy sheet at room temperature.

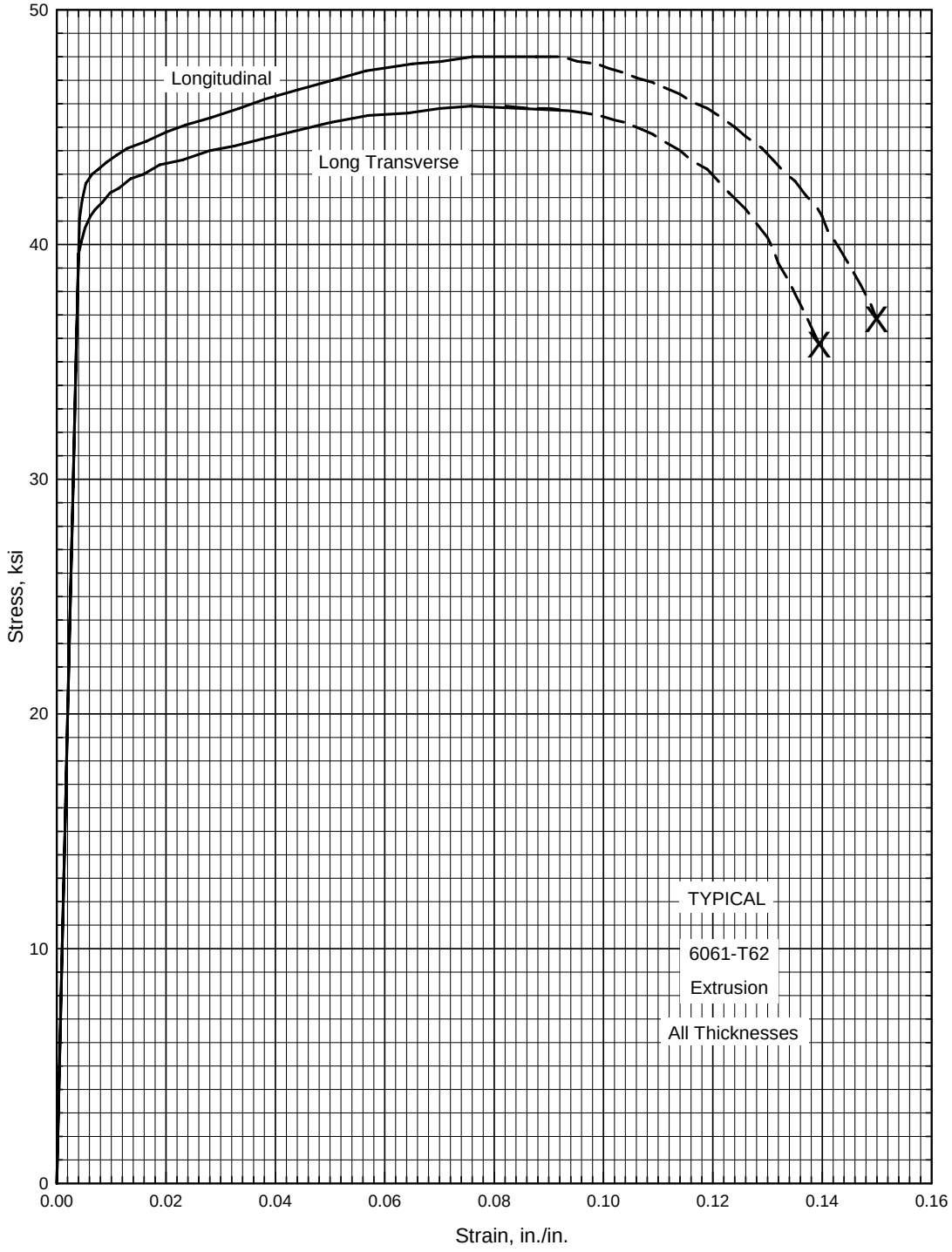

Figure 3.6.2.2.6(m). Typical stress-strain (full range) for 6061-T62 aluminum alloy extrusion at room temperature.

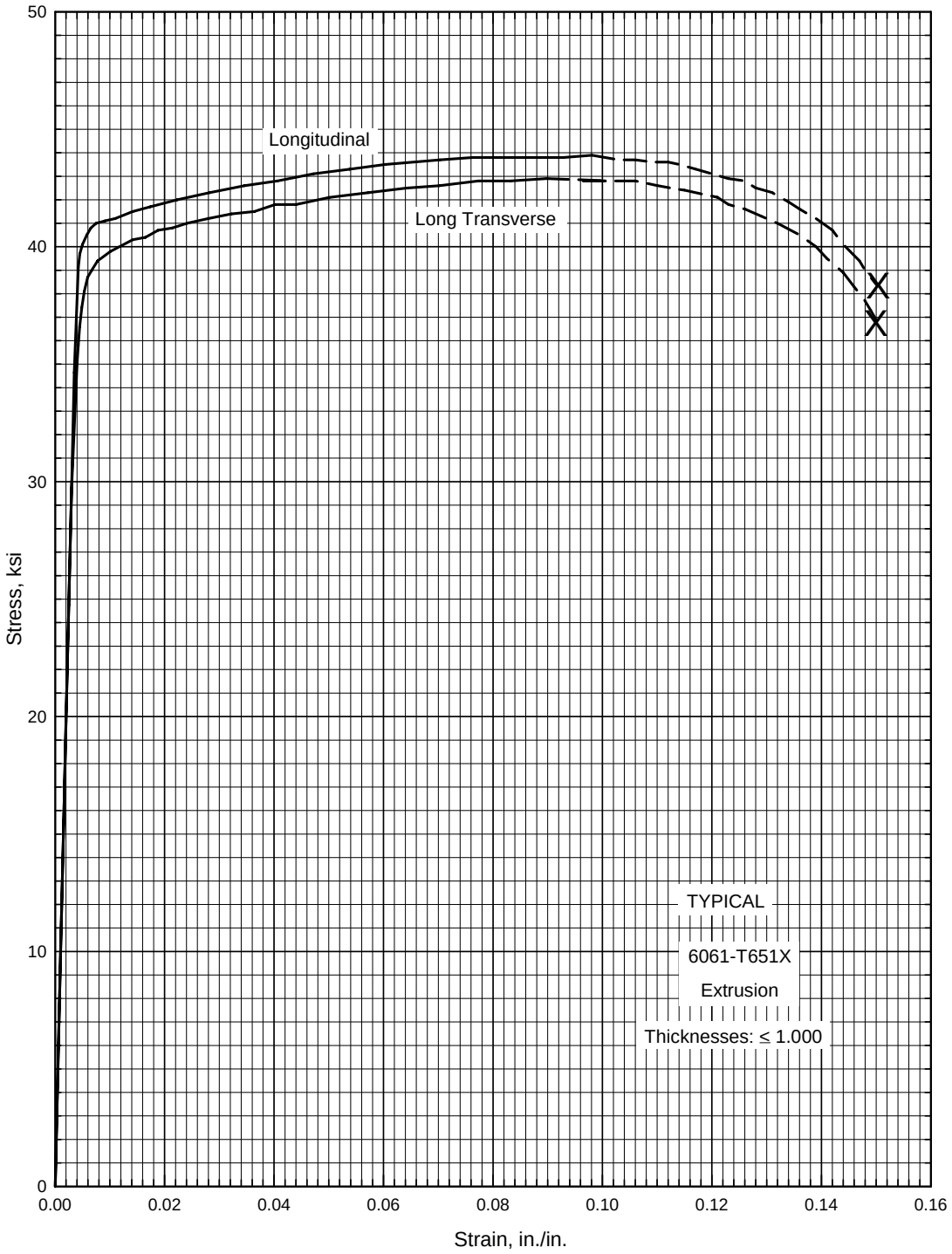

Figure 3.6.2.2.6(n). Typical stress-strain (full range) for 6061-T651X aluminum alloy extrusion at room temperature.

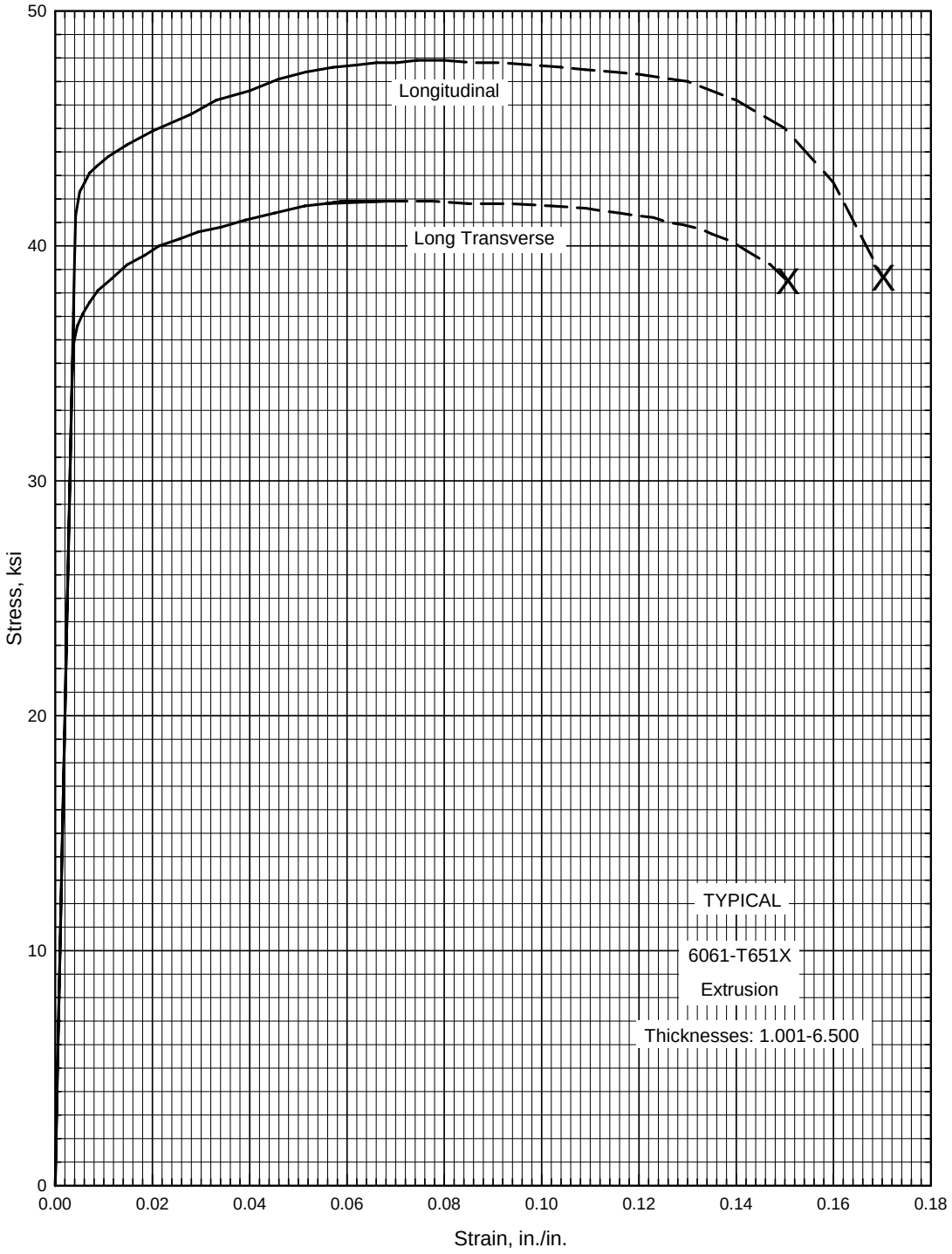

Figure 3.6.2.2.6(o). Typical stress-strain (full range) for 6061-T651X aluminum alloy extrusion at room temperature.

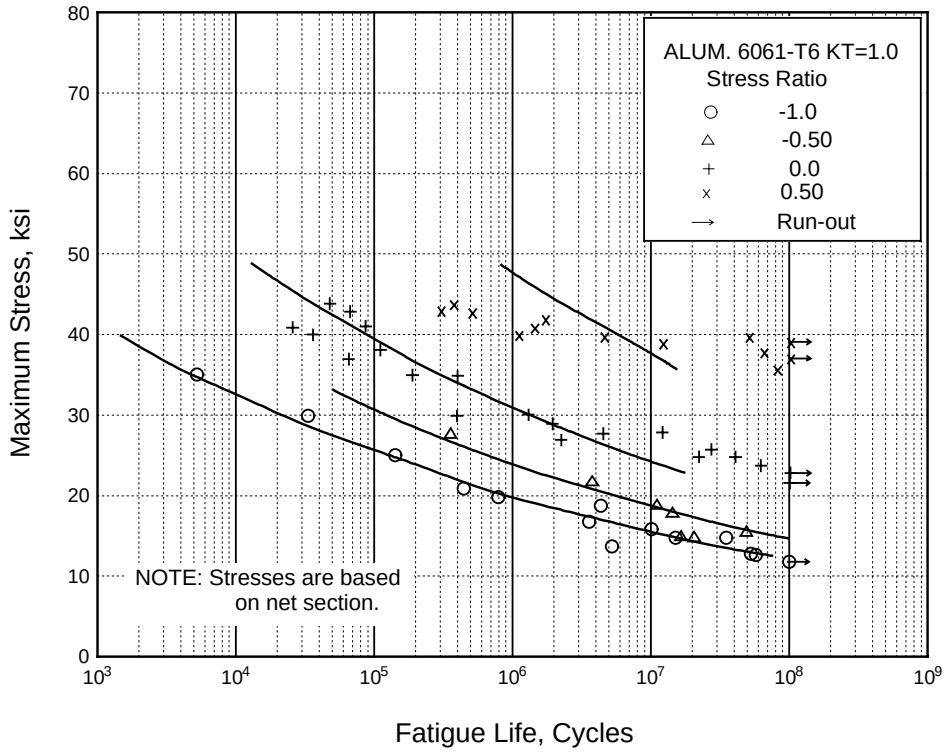

Figure 3.6.2.2.8. Best-fit S/N curves for unnotched 6061-T6 aluminum alloy, various wrought products, longitudinal direction.

Correlative Information for Figure 3.6.2.2.8

Product Form: Drawn rod, 0.7- inch diameter
Rolled bar, 1 x 7.5 inch

Properties:

TUS, ksi	TYS, ksi	Temp., °F
45	40	RT

Specimen Details: Unnotched
0.200-inch net diameter

Surface Condition: Not specified

Reference: 3.2.2.1.8(a)

Test Parameters:
Loading - Axial
Frequency - 2000 cpm
Temperature - RT
Environment - Air

No. of Heats/Lots: Not specified

Equivalent Stress Equation:
Log N_f = 20.68-9.84 log (S_{eq})
$S_{eq} = S_{max} (1-R)^{0.63}$
Std. Error of Estimate, Log (Life) = 0.48
Standard Deviation, Log (Life) = 1.18
R^2 = 83%

Sample Size = 55

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