1

Stress Analysis

1.1 Introduction to Stress Analysis

Stress analysis is defined as a method to determine the stress and deflection levels of a part, component, or assembly with specific geometry and features under applied external and internal loadings while the part, component, or assembly is constrained. The part, component, or assembly has specific mechanical and physical properties, which define the material characteristics of the part. Also, stress levels determined are compared with the strength allowable of the material used, and margins of safety are determined for the part under analysis. There are many ways a structure can be analyzed, including hand calculations based on standard methods, finite element analysis (FEA), and finally testing. Also, here in Chapter 1, material definitions, which include the mechanical properties, physical properties, and strength allowable, are discussed and presented for both commonly used metallic and composite materials in aerospace industries.

1.2 The Material Definitions

Stress analysis theories are based on the experimental concepts derived from the material behavior shown during tests. Before studying the stress analysis theory, fundamental concepts of the material behavior that describe the relationships between these fundamental behaviors of any material need to be explored. The properties, such as the modulus of elasticity of the material, Poisson's ratio effect, shear modulus, ultimate strength, shear strength, yield strength, stress concentration, and coefficient of thermal expansion, are often used to define this material behavior.

It is essential to be able to use the proper mechanical properties as we model and constitute the parts or assembly. For example, in FEA where one models a structural part, it is essential to have the proper elastic modulus, shear modulus, and Poisson's ratio to develop the correct corresponding stress levels under the applied loading. Likewise, in other cases when performing beam flexural analysis, where elastic modulus has to be defined to get the correct deflections, once again elastic modulus has to be of the proper value. Thus, in this chapter, the mechanical and physical properties of the commonly used metallic and composite materials that are used in the design and stress analysis of aircraft are presented.

The material tables presented are from the *Military Standard*. In these tables, one would find the mechanical properties as well as the material allowable for the specific metal condition and specification. The tensile, shear, and bearing allowable strengths are of most interest in aircraft stress analysis, and the direction in which they are sampled needs to be considered. The parts could be

Standard Methods for Aerospace Stress Analysis, First Edition. Amir Javidinejad.

Companion website: www.wiley.com/go/javidinejad

made from stocks that are limited in raw material dimensional direction and therefore the corresponding allowable must be used for the analysis of that part. It is common practice to use the lowest available B-basis allowable for comparison purposes in the margin of safety determinations.

Table 1.1 illustrates typical material properties normally used for carrying out stress analysis of solids.

Table 1.1 Engineering Material Properties

Material	Modulus of Elasticity, 10^6 psi	Modulus of Rigidity, 10^6 psi	Poisson's Ratio	Specific Weight, lb/in.^{3}	Coefficient of Thermal Expansion, 10^{-6}/°F	Ultimate Tensile Strength, 10^3 psi	Ultimate Shear Strength, 10^3 psi	Yield Strength, 10^3 psi
Steel								
ASTM-A36	29	11.2	0.3	0.284	6.5	58	–	36
ASTM-A242	29	11.2	0.3	0.284	6.5	70	–	50
ASTM-A441	29	11.2	0.3	0.284	6.5	67	–	46
ASTM-A572	29	11.2	0.3	0.284	6.5	60	–	42
ASTM-A514	29	11.2	0.3	0.284	6.5	110	–	100
Stainless								
Cold-rolled	28	10.8	0.3	0.286	9.6	125	–	75
Stainless								
Annealed	28	10.8	0.3	0.286	9.6	95	–	55
Aluminum								
2014-T4	10.6	4.1	0.3	0.101	12.8	62	38	42
2024-T4	10.6	4.1	0.3	0.101	12.9	68	41	47
6061-T6	10.0	3.7	0.3	0.098	13.1	45	30	40
7075-T6	10.4	3.9	0.3	0.101	12.0	83	48	73
Copper								
Annealed	17	6.4	0.3	0.322	9.4	32	22	10
Hard-drawn	17	6.4	0.3	0.322	9.4	57	29	53
Titanium								
Alloy (6Al&4V)	16.5	–	0.3	0.161	5.3	130	–	120
Plastic								
Nylon	0.4	–	0.4	0.041	80	11	–	6.5
Polyester (TP)	0.35	–	0.4	0.048	75	8	–	–
Elastomer	0.03	–	0.4	0.043		6.5	–	–
Vinyl	0.45	–	0.4	0.052	75	6	–	–
Rubber								
	10	4	0.5	0.033	4	2	–	–
Glass								
	9.6	4.1	0.2	0.079	44	7	–	–
Silicon								
	23.9	–	0.22	0.084	–	–	–	1.02

1.3 Stress–Strain Curves for Ductile Material

When a metallic specimen is tested in tension using standard procedures, the results are plotted as a "stress–strain diagram." This diagram would produce the material elastic modulus, the yield strength, the ultimate strength, and fracture point. For a typical steel material, yield strength is known clearly but for a material, such as aluminum, the yield point is more complicated to determine. Commonly, the stress value, corresponding to the stress where permanent strain is observed from the stress–strain curve data, is known as the yield strength of the material (Syld). When producing the stress–strain curve, the corresponding stress value to the permanent strain value, usually taken at 0.2% (0.002 in./in.) of the original gage length of the specimen being tested, is defined as the yield strength. A straight line is drawn from there (0.002 in./in. mark) to the stress–strain curve, and the stress at that point is known as the yield strength. The other point of interest on the stress–strain curve is the ultimate strength point where the highest capability or the ultimate strength of the material is observed. Also, the fracture point is the point of the material rupture where the material gives in to the applied loading (Figures 1.1 and 1.2).

A comparison between the commonly used metallic materials in the aerospace industry is shown in Figure 1.3. This comparison provides high-level insight into the stress–strain behavior of these typical materials. It is interesting to know that the proportional limits of the material or linear elastic region of these materials all follow the same pattern line. The yield, ultimate, and fracture strengths are all different and it appears stainless steel and nickel steel types would present a higher ultimate strength than other types. Also, aluminum and titanium types have a higher elongation among all of them presented.

This is a good reference source to consider when designing and selecting material for aerospace structures. For regions with high strength and low displacements, steel types are best suitable. For regions where both strength and elongation are required, aluminum types are best suitable.

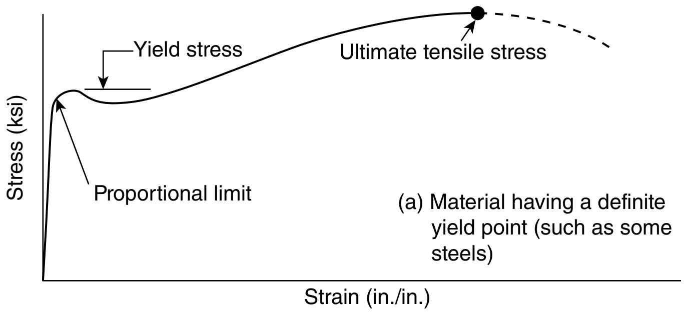

Figure 1.1 Stress–Strain Curve for a Typical Steel (*Source:* MIL-HNDBK-5H, 1998 / US Department of Defense/ Public domain)

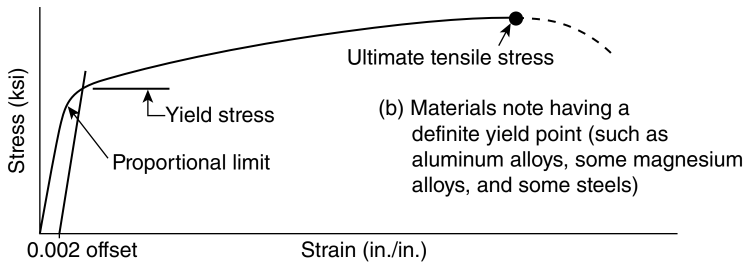

Figure 1.2 Stress–Strain Curve for a Typical Aluminum (*Source:* MIL-HNDBK-5H, 1998 / US Department of Defense/ Public domain)

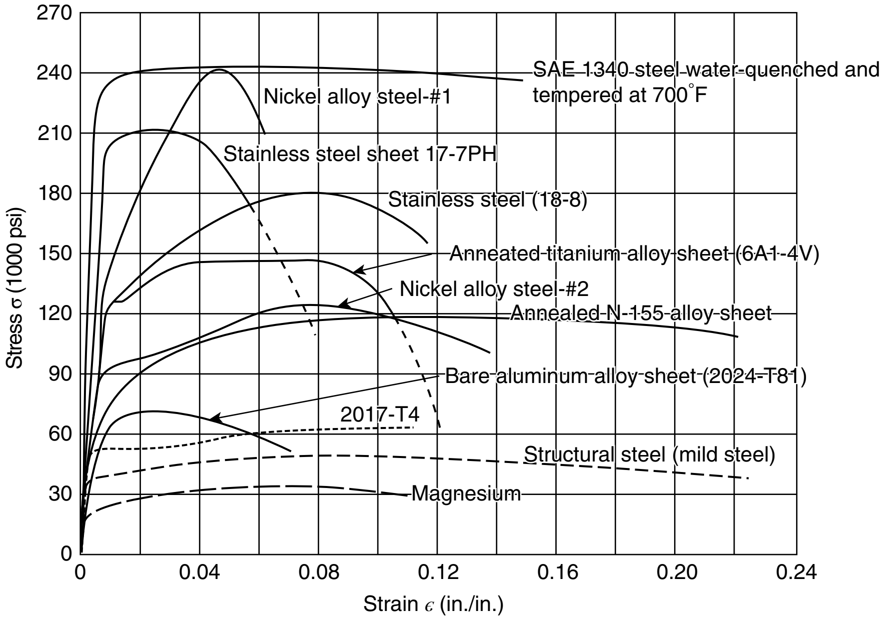

Figure 1.3 Stress–Strain Curve for a Typical Metallic Material (*Source:* Bruhn's, 1973 / S.R. Jacobs)

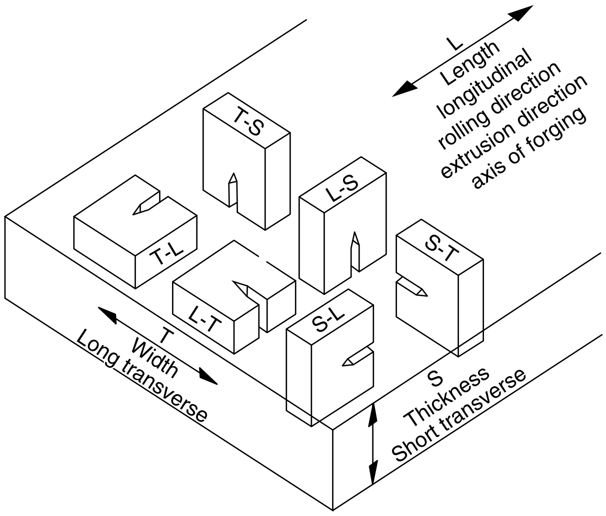

Figure 1.4 Material Grain Direction for a Typical Metallic Material (*Source:* MIL-HDBK-5J, 2003 / US Department of Defense/ Public domain)

Material allowable strength would be dependent on the grain direction of the material. Figure 1.4 illustrates the material grain direction for a rectangular slap of metallic material per length, width, and thickness basis.

Some of the widely used metallic materials in aerospace structures are tabulated here. In Tables 1.2–1.41, one would find the mechanical properties and the strength allowable of the indicated metallic material.

Table 1.2 Mechanical and Physical Properties of AISI 1025 Carbon Sheet, Tubing, and Bar

Specification	AMS 5046 and AMS-S-7952	AMS 5075, AMS 5077 and AMS-T-5066[a]	ASTM A 108
Form	Sheet, strip, and plate	Tubing	Bar
Condition	Annealed	Normalized	All
Thickness, in.	...	...	...
Basis	**S**	**S**	**S**[b]
Mechanical properties:			
F_{tu}, ksi			
L	55	55	55
LT	55	55	55
ST	...	...	55
F_{ty}, ksi:			
L	36	36	36
LT	36	36	36
ST	...	...	36
F_{cy}, ksi:			
L	36	36	36
LT	36	36	36
ST	...	...	36
F_{sw}, ksi:	35	35	35
F_{brw}, ksi:			
$(e/D = 1.5)$	...	...	...
$(e/D = 2.0)$	90	90	90
F_{bry}, ksi:			
$(e/D = 1.5)$	...	...	...
$(e/D = 2.0)$	...	...	...
e, present:			
L	...	c	c
LT	c	...	...
E, 10^3 ksi:		**29.0**	
E_c, 10^3 ksi:		**29.0**	
G, 10^3 ksi:		11.0	
μ		0.32	
Physical properties:			
ω, lb/in.^{3}		0.284	
C, Btu /(lb) (°F)		**0.116 (122—212 °F)**	
K, Btu/[(hr)(ft^2)(°F)/ft].		30.0 (at 32 °F)	
α, 10^{-6} in./in./°F		See Figure 2.2.1.0	

[a] Noncurrent specification.
[b] Design values are applicable only to parts for which the indicated F_{tg} has been substantiated by adequate quality control testing.
See applicable specification for variation in minimum elongation with ultimate strength.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.3 Mechanical and Physical Properties of Low-Alloy Steels Sheet, Plates, and Tubing

Alloy	AISI 4130		AISI 4135		AISI 8630		AISI 8735	
Specification [see Tables 2.3.1.0(a) and (b)] ...	AMS 6350 AMS 6528 AMS-S-6758		AMS 6352 AMS 6372		AMS 6281		AMS 6357	
Form	Sheet, strip, plate, bars, and forgings		Sheet, strip, plate, and tubing		Tubing		Sheet, strip, and plate	
Condition	Normalized and tempered, stress relieved[a]							
Thickness or diameter, in ...	≤0.188	>0.188	≤0.188	>0.188	≤0.188	>0.188	≤0.188	>0.188
Basis	**b**							
Mechanical properties:								
F_{tu}, ksi	95	90	95	90	95	90	95	90
F_{ty}, ksi	75	70	75	70	75	70	75	70
F_{cy}, ksi	75	70	75	70	75	70	75	70
F_{sw}, ksi	57	54	57	54	57	54	57	54
F_{bru}, ksi:								
($e/D = 1.5$)	...	...	...	...	...	...	...	...
($e/D = 2.0$)	200	190	200	190	200	190	200	190
F_{bry}, ksi:								
($e/D = 1.5$)	...	...	...	...	...	...	...	...
($e/D = 2.0$)	129	190	129	190	129	190	129	190
e, present:	See Table 2.3.1.0(d)							
E, 10^3 ksi:	**29.0**							
E_c, 10^3 ksi:	**29.0**							
G, 10^3 ksi:	11.0							
μ	0.32							
Physical properties:								
ω, lb/in.^{3}	0.283							
C, K, and α	**See Figure 2.3.1.0**							

[a] Design values are applicable only to parts for which the indicated F_{tw} has been substantiated by adequate quality control testing.
There is no statistical basis (T_{99} or T_{90}) or specification basis (S) to support the mechanical property values in this table. See Heat Treatment in Section 2.3.0.2.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.4 Mechanical and Physical Properties of 15-5PH Stainless Steel Bar

Specification	AMS 5659					
Form	Bar[a]					
Condition	H900	H925	H1025	H1075	H1100	H1150
Thickness or diam, in.	≤12	≤12	≤12	≤12	≤12	≤12
Basis	S	S	S	S	S	S
Mechanical properties:						
F_{tu}, ksi:						
L	190	170	155	145	140	135
T	190	170	155	145	140	135
F_{ty}, ksi:						
L	170	155	145	125	115	105
T	170	155	145	125	115	105
F_{cy}, ksi:						
L	...	...	143	...	...	99
T	...	...	143	...	...	99
F_{su}, ksi:	...	...	97	...	...	85
F_{bru},[b] ksi:						
$(e/D = 1.5)$	...	...	263	...	...	230
$(e/D = 2.0)$	...	...	332	...	...	293
F_{bry},[b] ksi:						
$(e/D = 1.5)$	...	...	211	...	...	166
$(e/D = 2.0)$	...	...	250	...	...	201
e, percent:						
L	10	10	12	13	14	16
T	6	7	8	9	10	11
RA, percent:						
L	35	38	45	45	45	50
T	20	25	32	33	34	35
E, 10^3 ksi:	28.5					
E_c, 10^3 ksi:	29.2					
G, 10^3 ksi:	11.2					
μ	0.27					
Physical properties:						
ω, lb/in.^{3}	0.283					
C, Btu/(lb) (°F)	...					
K, and α	See Figure 2.6.7.0					

[a] Forging, ring, and extrusion product forms are also covered by AMS 5659.
[b] Bearing values are "dry pin" values per Section 1.4.7.1.
Source: MIL-HNDBK-5J, 2003) / US Department of Defense/ Public domain.

Table 1.5 Mechanical and Physical Properties of 15-5PH Stainless Steel Plate

Specification	AMS 5862			
Form	Plate			
Condition	H1025[a]			
Thickness, in.	0.187–0.625	0.626–2.000	2.001–3.000	3.001–4.000
Basis	S	S	S	S
Mechanical properties:				
F_{tu}, ksi:				
L	154	154	154	...
LT	155	155	155	155
F_{ty}, ksi:				
L	143	143	143	...
LT	145	145	145	145
F_{cy}, ksi:				
L	150	150	150	...
LT	152	149	146	...
F_{su}, ksi:	97	97	96	...
F_{bru},[b] ksi:				
$(e/D = 1.5)$	257	257	257	...
$(e/D = 2.0)$	331	331	331	...
F_{bry},[b] ksi:				
$(e/D = 1.5)$	211	211	211	...
$(e/D = 2.0)$	246	246	246	...
e, percent:				
LT	8	12	12	12
RA, percent:				
LT	35	40	40	40
E, 10^3 ksi:	28.5			
E_c, 10^3 ksi:	29.2			
G, 10^3 ksi:	11.2			
μ	0.27			
Physical properties:				
ω, lb/in.^{3}	0.283			
C, Btu /(lb) (°F)	...			
K, and α	See Figure 2.6.7.0			

[a] The H900, H925, H1075, H1100, and H1150 conditions are included in AMS 5862.
[b] Bearing values are “dry pin” values per Section 1.4.7.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.6 Mechanical and Physical Properties of 17-4PH Stainless Steel Bar

Specification	AMS 5643										
Form	Bar										
Condition	H900		H925		H1025	H1075		H1100	H1150		H1150M[a]
Thickness or diameter, in	<8.000										
Basis	A	B	A	B	S	A	B	S	A	B	S[a]
Mechanical properties[b]:											
F_{tu}, ksi:											
L	190	195	170	178	155	143	150	140	125	134	115
T	...	...	...	...	...	...	...	...	...	...	...
F_{ty}, ksi:											
L	170	175	155[c]	167	145	125[d]	143	115	100	115	75
T	...	...	...	...	...	...	...	...	...	...	...
F_{cy}, ksi:											
L	170	175	...	...	139	...	...	...	90	104	...
T	...	...	...	...	...	...	...	...	...	...	...
F_{su}, ksi:	123	126	...	...	95	...	...	...	79	85	...
F_{bru}, ksi:											
($e/D = 1.5$)	313	322	...	...	263	...	...	...	213	228	...
($e/D = 2.0$)	380	390	...	...	232	...	...	...	270	289	...
F_{bry}, ksi:											
($e/D = 1.5$)	255	262	...	...	211	...	...	...	152	175	...
($e/D = 2.0$)	280	288	...	...	250	...	...	...	181	208	...
e, percent: (S-basis):											
L	10	...	10	...	12	13	...	14	16	...	18
E, 10^3 ksi:	28.5										
E_c, 10^3 ksi:	30.0										
G, 10^3 ksi:	11.2										
μ	0.27										
Physical properties:											
ω, lb/in.^{3}	0.282 (H900), 0.283 (H1075), 0.284 (H1150)										
C, K, and α	**See Figure 2.6.9.0**										

[a] Not covered by AMS 5643. S values are producer's guaranteed minimum tensile properties.
[b] Design allowables were based on data from samples of material, supplied in the solution-treated condition, which were aged to demonstrate response to heat treatment by suppliers.
[c] S-basis. Rounded T_{99} value = 157 ksi.
[d] S-basis. Rounded T_{90} value = 136 ksi.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.7 Mechanical and Physical Properties of 301 and Other (a, b, and c) Stainless Steel

Specification	AMS 5901	AMS 5517		AMS 5518		AMS 5902		AMS 5519	
Form	Sheet and strip								
Condition	Annealed	¼ Hard		½ Hard		¾ Hard		Full Hard	
Thickness, in.	≤0.187	...		...		...		...	
Basis	S	A	B	A	B	A	B	A	B
Mechanical properties:									
F_{tu}, ksi:									
L	73	124	129	141	151	157	168	174	185
LT	75	122	127	142	152	163	173	175	186
F_{ty}, ksi:									
L	26	69	83	93	110	118	135	137	153
LT	30	67	82	92	105	113	133	125	142
F_{cy}, ksi:									
L	23	44	54	61	69	75	88	83	94
LT	29	71	88	100	116	127	152	142	164
F_{su}, ksi:	50	66	69	77	82	88	93	95	100
F_{bru}, ksi:									
$(e/D = 1.5)$	...	...	...	...	...	...	...	...	...
$(e/D = 2.0)$	162	262	273	292	310	327	342	346	361
F_{bry}, ksi:									
$(e/D = 1.5)$	...	...	...	...	...	...	...	...	...
$(e/D = 2.0)$	55	123	149	167	189	202	234	222	249
e, percent: (S-basis):									
LT	40	25	...	[d]	...	[d]	...	[d]	...
E, 10^3 ksi:									
L	29.0	27.0		26.0		26.0		26.0	
LT	29.0	28.0		28.0		28.0		28.0	
E_c, 10^3 ksi:									
L	28.0	26.0		26.0		26.0		26.0	
LT	28.0	27.0		27.0		27.0		27.0	
G, 10^3 ksi:	11.2	10.6		10.5		10.5		10.5	
μ	0.27	0.27		0.27		0.27		0.27	
Physical properties:									
ω, lb/in.^{3}	0.286								
C, K, and α	See Figure 2.7.1.0								

[a] Properties also applicable to AISI 302 for the following: AMS 5516 for annealed condition, AMS 5903 for 1/4 H condition, AMS 5904 for 1/2H condition, AMS 5905 for 3/4H condition, and AMS 5906 for full hard condition.
[b] Properties also applicable to AISI 304 for the following: AMS 5513 for annealed condition, AMS 5910 for 1/4H condition, AMS 5911 for 1/2H condition, AMS 5912 for 3/4H condition, and AMS 5913 for full hard condition.
[c] Properties also applicable to AISI 316 for the following: AMS 5524 for annealed condition and AMS 5907 for 1/4H condition.
[d] See Table 2.7.1.0(c).
Note: Yield strength, particularly in compression, and modulus of elasticity in the longitudinal direction may be raised appreciably by thermal stress-relieving treatment in the range 500–800°F.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain

Table 1.8 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		
Form	Sheet					Plate												Sheet	Plate	
Temper	T3					T351												T361		
Thickness, in.	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	A	B	S	S	S
Mechanical properties:																				
F_{tu}, ksi:																				
L	64	64	65	65	66	64	66	63	65	62	64	62	64	60	62	57	59	68	69	67
LT	63	63	64	64	65	64	66	63	65	62	64	62	64	60	62	57	59	67	68	66
ST	...	...	...	...	...	...	...	...	...	...	...	...	...	52[a]	54[a]	49[a]	51[a]	...	...	...
F_{ty}, ksi:																				
L	47	47	48	47	48	48	50	48	50	47	50	47	49	46	48	43	46	56	56	54
LT	42	42	43	42	43	42	44	42	44	42	44	42	44	42	44	41	43	50	51	49
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	47	48	46
LT	45	45	46	45	46	45	47	45	47	44	46	44	46	43	45	41	43	53	54	52
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	42	42	41
F_{bru}, ksi:																				
$(e/D = 1.5)$	104	104	106	106	107	97	100	95	98	94	97	94	97	91	94	86	89	111	112	109
$(e/D = 2.0)$	129	129	131	131	133	119	122	117	120	115	119	115	119	111	115	106	109	137	139	135
F_{bry}, ksi:																				
$(e/D = 1.5)$	73	73	75	73	75	72	76	72	76	72	76	72	76	72	76	70	74	82	84	81
$(e/D = 2.0)$	88	88	90	88	90	86	90	86	90	86	90	86	90	86	90	84	88	97	99	96
e, percent (S-basis):																				
LT	10	[b]	...	[b]	...	12	...	8	...	7	...	6	...	4	...	4	...	8	9	9[c]
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] See Table 3.2.3.0(c).

[c] 10% for 0.500 in.

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

Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.9 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					T62[a]				T72[a]
Temper	T4		T42[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	0.500–1.000	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_{ty}, 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_{su}, 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_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]	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 on 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).

Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.10 Mechanical and Physical Properties of 2024 Aluminum Alloy Bar and Rod

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	A	B
Mechanical properties:																				
F_{tu}, 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_{ty}, 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_{cy}, 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_{su}, ksi:	37	37	37	38	38	39	39	40	37	38	36	37	35	37	35	37	34	35	32	34
F_{bru},[c] 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},[c] ksi:																				
($e/D = 1.5$)	68	70	68	70	70	73	70	73	69	72	69	72	69	72	69	72	69	72	67	70
($e/D = 2.0$)	82	84	82	84	84	88	84	88	82	86	82	86	82	86	82	86	82	86	80	84
e, percent (S-basis):																				
LT	10	...	[d]	...	15	...	15	...	12	...	8	...	7	...	6	...	4	...	4	...
E, 10^3 ksi:	10.5								10.7											
Primary																				
Secondary	9.5				10.0				10.2											
E_c, 10^3 ksi:	10.7								10.9											
Primary																				
Secondary	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] 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).

Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.11 Mechanical and Physical Properties of 2024 Aluminum Alloy Bar and Rod

Specification	AMS 4120 and AMS-QQ-A-225/6										AMS-QQ-A-225/6
Form	Bar and rod; rolled, drawn, or cold-finished										
Temper	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	4.001–4500[c]	4.501–5.000[d]	5.001–6.000[e]	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_{tu}, ksi:											...
L	62	62	62	62	62	62	62	62	62	58	62
LT	61[c]	61[c]	59[c]	57[c]	55[c]	54[c]	54[c]	52[c]	...	...	...
F_{ty}, ksi:											
L	45	42	42	42	42	42	40	40	40	38	40
LT	45[c]	42[c]	41[c]	40[c]	39[c]	39[c]	37[c]	36[c]	...	...	...
F_{cy}, ksi:											
L	36	33	33	33	33	33	32	32	...	...	...
LT	...	...	...	...	...	...	...	...	...	...	...
F_{su}, ksi:	37	37	37	37	37	37	37	37	37	37	...
F_{bru},[b] ksi:											
$(e/D = 1.5)$	93	93	93	93	93	93	93	93	93	93	...
$(e/D = 2.0)$	118	118	118	118	118	118	118	118	118	118	...
F_{bry},[b] 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 (S-basis):											
LT	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, K 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 in., and maximum cross-sectional area is 36 in.^{2}.

[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).

Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.12 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	3.000–4.999	0.050–0.249	0.250–1.499	1.500–4.500
Cross-sectional area, in.^{2}	≤ 20								≤ 25				>25 − ≤32		≤ 20		≤ 32
Basis	A	B	A	B	A	B	A	B	A	B	A	B	S	S	S	S	S
Mechanical properties:																	
F_{tu}, ksi:																	
L	57	61	60	62	60	62	65	70	70	74	70	74	68	68	64	66	66
LT	54	58	56	57	54	56	56	60	55	58	54	57	53	52	64	64	61
F_{ty}, ksi:																	
L	42	47	44	47	44	47	46	54	52	54	52	54	48	48	56	58	58
LT	37	41	38	40	37	39	37	43	39	41	39	41	36	36	55	57	57
F_{cy}, ksi:																	
L	34	38	37	39	38	40	41	48	49	50	49	51	45	45	57	59	59
LT	41	45	41	44	40	43	40	47	42	44	41	43	39	38	57	59	59
F_{su}, ksi:	29	31	31	32	30	31	33	35	34	36	33	35	33	32	35	36	36
F_{bru},[b] ksi:																	
(e/D = 1.5)	84	90	78	81	78	80	84	90	88	93	86	91	86	84	94	96	92
(e/D = 2.0)	108	114	98	101	97	101	105	113	111	118	109	115	108	106	123	123	117
F_{bry},[b] ksi:																	
(e/D = 1.5)	61	68	55	59	55	59	57	67	63	66	62	65	59	57	79	82	82
(e/D = 2.0)	71	79	67	71	67	71	69	81	77	80	75	78	71	69	93	96	96
e, percent (S-basis):																	
LT	12	...	12	...	12	...	10	...	10	...	10	...	8	8	4	5	5
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 on the thickness at the time of quench.
[b] Bearing values are "dry pin" values per Section 1.4.7.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.13 Mechanical and Physical Properties of 6061 Aluminum Alloy Plate

Specification	AMS 4026 and AMS-QQ-A-250/11				AMS-QQ-A-250/11		AMS 4025, AMS 4027 and AMS-QQ-A-250/11					
Form	Plate											
Temper	T451				T42[a]		T651 and T62[b]					
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[c]
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},[b] ksi:												
($e/D = 1.5$)	48	52	...	...	...	...	67	69	...	...	...	...
($e/D = 2.0$)	63	67	...	...	...	...	68	90	...	...	...	...
F_{bry},[b] ksi:												
($e/D = 1.5$)	22	25	...	...	...	...	50	53	...	...	...	...
($e/D = 2.0$)	26	29	...	...	...	...	58	61	...	...	...	...
e, percent (S-basis):												
LT	[d]	...	16	...	18	16	[d]	...	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] Design allowables were based on 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.

[b] Design allowables were based on 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.

[c] Properties for this thickness apply only to T651 temper.

[d] See Table 3.6.2.0(b_3).

Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.14 Mechanical and Physical Properties of 6061 Aluminum Alloy Tube and Pipe

Specification	AMS-WW-T-700/6		AMS 4080, AMS 4082, and AMS-WW-T-700/6
Form	Drawn tube		
Temper	T4	T42[a]	T6[b] and T62
Wall thickness, in	0.025–0.500	0.025–0.500	0.025–0.500
Outside diameter, in	...		
Basis	S	S	S
Mechanical properties:			
F_{tu}, ksi:			
L	30	30	42
F_{ty}, ksi:			
L	16	14	35
F_{cy}, ksi:			
L	14	...	34
F_{su}, ksi:	20	...	27
F_{bru}, ksi:			
$(e/D = 1.5)$	48	...	67
$(e/D = 2.0)$	63	...	88
F_{bry}, ksi:			
$(e/D = 1.5)$	22	...	49
$(e/D = 2.0)$	26	...	56
e, percent:			
L	c	c	c
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] Design allowables were based on 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.
[b] Design allowables were based on 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.
[c] See Table 3.6.2.0(c_2).
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.15 Mechanical and Physical Properties of 6061 Aluminum Alloy Hand Forged

Specification	AMS 4127, AMS 4248, AMS-A-22771, and AMS-QQ-A-367		
Form	Hand forging		
Temper	T6[a] 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] When hand forgings are machined before heat treatment, the section thickness at time of heat treatment will 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.

Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.16 Mechanical and Physical Properties of 6061 Aluminum Alloy Extruded Rod, Bar, and Shapes

Specification	AMS 4161, AMS 4172, and AMS-QQ-A-200/8	AMS-QQ-A-200/8	AMS 4160 and AMS-QQ-A-200/8	AMS 4150, AMS 4173 and AMS-QQ-A-200/8			
Form	Extruded rod, bar, and shapes						
Temper	T4, T4510, and T4511	T42[a]	T62[a]	T6, T6510, and T6511			
Cross-sectional area, $in.^2$	...	...	...	≤32			
Thickness[b], 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},[c] ksi:							
$(e/D = 1.5)$	42	...	...	64	69	52	57
$(e/D = 2.0)$	55	...	...	82	88	69	74
F_{bry},[c] 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[d]	10[d]	...	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] Design allowables were based on 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.
[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.
[d] For thicknesses ≤ 0.249 in. $e = 8\%$
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.17 Mechanical and Physical Properties of 7050 Aluminum Alloy Plate

Specification	AMS 4050															
Form	Plate															
Temper	T7451															
Thickness, in.	0.250–1.500		1.501–2.000		2.001–3.000		3.001–4.000		4.001–5.000		5.001–6.000		6.001–7.000		7.001–8.000	
Basis	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Mechanical properties:																
F_{tu}, ksi:																
L	74[a]	76	74	76	73[a]	75	72	74	71[a]	73	70[a]	72	69	72	68	71
LT	74	76	74[a]	76	73[a]	75	72	75	71[a]	74	70	73	69	72	68	71
ST	...	...	...	...	68	72	68[a]	71	67	70	66	69	66	68	65	67
F_{ty}, ksi:																
L	64[b]	67	64[b]	66	63[b]	66	62[b]	65	61[a]	65	60	63	59	62	58[b]	63
LT	64	66	64	66	63[b]	66	62	65	61	64	60	62	59	62	58	61
ST	...	...	...	...	59	61	57	60	57[b]	60	57	59	56	58	58[b]	58
F_{cy}, ksi:																
L	63	64	62	64	61	64	60	63	58	61	57	59	56	59	55	57
LT	66	68	67	69	66	69	65	68	64	67	63	66	60	63	59	62
ST	...	...	...	...	63	66	63	66	63	66	62	64	60	63	59	62
F_{su}, ksi:	42	43	43	44	43	44	43	45	43	45	43	45	44	46	44	46
F_{bru},[c] ksi:																
($e/D = 1.5$)	107	109	109	112	108	111	107	111	107	111	105	110	107	112	103	108
($e/D = 2.0$)	140	144	142	146	141	144	140	144	138	144	137	142	136	143	132	138
F_{bry},[b] ksi:																
($e/D = 1.5$)	86	89	89	92	89	93	90	94	90	95	91	94	84	89	83	87
($e/D = 2.0$)	101	104	104	107	104	109	104	109	105	110	105	108	99	105	98	102
e, percent (S-basis):																
L	10	...	10	...	9	...	9	...	9	...	8	...	7	...	6	...
LT	9	...	9	...	8	...	6	...	5	...	4	...	4	...	4	...
ST	...	...	...	...	3	...	3	...	3	...	3	...	3	...	3	...
E, 10^3 ksi:	10.3															
E_c, 10^3 ksi:	10.6															
G, 10^3 ksi:	3.9															
μ	0.33															
Physical properties:																
ω, lb/in.^{3}	0.102															
C, Btu /(lb) (°F) ...	0.23 (at 212°F)															
K, Btu/[(hr)(ft^2)(°F)/ft]	91 (at 77°F)															
α, 10^{-6} in./in./°F	12.8 (68–212°F)															

[a] S-basis values. Rounded T_{99} values for F_{tn} are as follows: for 0.250–1.500(L) = 75 ksi for 1.502–2.000(LT) = 75 ksi, for 2.001–3.000(L) and (LT) = 74 ksi, for 3.001–4.000(ST) = 69 ksi, for 4.001–5.000(L) and (LT) = 72 ksi, for 5.001–6.000(L) = 71 ksi.

[b] S-basis values. Rounded T_{99} values for F_{ty} are as follows: for 0.250–1.500(L) = 65 ksi, for 1.502–2.000(L) = 65 ksi, for 2.001–3.000 (L) = 65 ksi, (LT) = 64 ksi, for 3.001–4.000 (L) = 63 ksi, for 4.001–5.000(L) = 62 ksi, (ST) = 58 ksi, for 7.001–8.000(L) = 59 ksi, (ST) = 56 ksi.

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

Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.18 Mechanical and Physical Properties of 7050 Aluminum Alloy Plate

Specification	AMS 4201							
Form	Plate							
Temper	T7651							
Thickness in	0.250–1.000	1.001–1.500		1.501–2.000		2.001–2.500		2.501–3.000
Basis	S	A	B	A	B	A	B	S
Mechanical properties:								
F_{tu}, ksi:								
L	76	77	79	76	78	75	78	76
LT	76	76	79	75	78	75	78	76
ST	...	...	...	72	75	70	73	70
F_{ty}, ksi:								
L	66	66	71	66	70	66	70	66
LT	66	66	70	65	69	65	69	66
ST	...	...	...	59	63	60	62	60
F_{cy}, ksi:								
L	64	64	68	64	67	64	67	64
LT	68	68	73	68	72	68	72	69
ST	...	...	...	67	71	67	71	68
F_{su}, ksi:	43	44	46	44	46	45	47	46
F_{bru},[a] ksi:								
($e/D = 1.5$)	110	112	117	112	117	114	118	116
($e/D = 2.0$)	142	144	150	144	150	146	151	149
F_{bry},[a] ksi:								
($e/D = 1.5$)	87	90	96	91	96	93	98	96
($e/D = 2.0$)	102	105	111	105	112	107	114	110
e, percent: (S-basis):								
L	9	9	...	9	...	8	...	8
LT	8	8	...	8	...	7	...	7
ST	...	...	...	...	...	1.5	...	1.5
E, 10^3 ksi:	10.3							
E_c, 10^3 ksi:	10.8							
G, 10^3 ksi:	4.0							
μ	0.33							
Physical properties:								
ω, lb/in.^{3}	0.102							
C, Btu/(lb) (°F)	0.23 (at 212°F)							
K, Btu/[(hr)(ft^2)(°F)/ft]	89 (at 77°F)							
α, 10^{-6} in./in./°F	12.8 (68–212°F)							

[a] See Table 3.1.2.1.1. Bearing values are "dry pin" values per Section 1.4.7.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.19 Mechanical and Physical Properties of 7050 Aluminum Alloy Extrusion

Specification	AMS 4341				
Form	Extrusion				
Temper	T73511				
Cross-sectional area, in^2	≤32				
Thickness or diameter,[b] in	≤1.000	1.001–2.000	2.001–3.000	3.001–4.000	4.001–5.000
Basis	S	S	S	S	S
Mechanical properties:					
F_{tu}, ksi:					
L	70	70	70	70	70
LT	68	66	65	63	62
F_{ty}, ksi:					
L	60	60	60	60	60
LT	57	56	55	53	52
F_{cy}, ksi:					
L	60	60	60	61	61
LT	60	59	58	56	55
F_{su}, ksi:	39	39	38	37	36
F_{bru},[b] ksi:					
($e/D = 1.5$)	103	100	96	91	87
($e/D = 2.0$)	133	129	124	120	115
F_{bry},[b] ksi:					
($e/D = 1.5$)	82	80	78	76	74
($e/D = 2.0$)	97	95	93	91	88
e, percent:					
L	8	8	8	8	8
E, 10^3 ksi:	10.3				
E_c, 10^3 ksi:	10.7				
G, 10^3 ksi:	3.9				
μ	0.33				
Physical properties:					
ω, lb/in.^{3}	0.102				
C, Btu/(lb) (°F)	0.23 (at 212°F)				
K, Btu/[(hr)(ft^2)(°F)/ft]	93 (at 77°F)				
α 10^{-6} in./in./°F	12.8 (68–212°F)				

[a] The mechanical properties are to be based on the thickness at the time of quench.
[b] Bearing values are "dry pin" values per Section 1.4.7.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.20 Mechanical and Physical Properties of 7050 Aluminum Alloy Extrusion

Specification	AMS 4342				
Form	Extrusion[a]				
Temper	T74511				
Cross-sectional area, in^2	≤32				
Thickness or diameter,[b] in	≤1.000	1.001–2.000	2.001–3.000	3.001–4.000	4.001–5.000
Basis	S	S	S	S	S
Mechanical properties:					
F_{tu}, ksi:					
L	73	73	73	73	73
LT	71	69	68	64	64
F_{ty}, ksi:					
L	63	63	63	63	63
LT	60	59	58	56	54
F_{cy}, ksi:					
L	63	63	63	64	64
LT	63	62	61	59	57
F_{su}, ksi:	41	40	40	39	38
F_{bru},[c] ksi:					
$(e/D = 1.5)$	107	104	100	95	91
$(e/D = 2.0)$	139	135	130	125	121
F_{bry},[c] ksi:					
$(e/D = 1.5)$	86	84	82	80	78
$(e/D = 2.0)$	106	100	98	95	92
e, percent:					
L	7	7	7	7	7
E, 10^3 ksi:	10.3				
E_c, 10^3 ksi:	10.7				
G, 10^3 ksi:	3.9				
μ	0.33				
Physical properties:					
ω, lb/in.^{3}	0.102				
C, Btu/(lb)(°F)	0.23 (at 212°F)				
K, Btu/[(hr)(ft^2)(°F)/ft]	93 (at 77°F)				
α 10^{-6} in./in./°F	12.8 (68–212°F)				

[a] Excluding tubing.
[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.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.21 Mechanical and Physical Properties of 7050 Aluminum Alloy Extrusion

Specification	AMS 4340						
Form	Extrusion						
Temper	T76511						
Thickness,[a] in.	≤0.499		0.500–1.000	1.001–2.000	2.001–3.000	3.001–4.000	4.001–5.000
Basis	A	B	S	S	S	S	S
Mechanical properties:							
F_{tu}, ksi:							
L	77	79	79	79	79	79	79
LT	76	78	77	75	73	71	68
F_{ty}, ksi:							
L	68	71	69	69	69	69	69
LT	67	69	67	65	63	61	59
F_{cy}, ksi:							
L	68	71	69	69	69	69	69
LT	70	73	70	69	67	66	64
F_{su}, ksi:	42	44	43	43	42	41	40
F_{bru},[b] ksi:							
($e/D = 1.5$)	113	116	115	114	110	107	103
($e/D = 2.0$)	147	151	150	148	144	140	136
F_{bry},[b] ksi:							
($e/D = 1.5$)	94	98	94	92	89	86	82
($e/D = 2.0$)	109	114	110	108	104	98	93
e, percent: (S-basis):							
L	7	...	7	7	7	7	7
E, 10^3 ksi:	10.3						
E_c, 10^3 ksi:	10.7						
G, 10^3 ksi:	3.9						
μ	0.33						
Physical properties:							
ω, lb/in.^{3}	0.102						
C, Btu/(lb) (°F).	0.23 (at 212°F)						
K, Btu/[(hr)(ft^2)(°F)/ft].	89 (at 77°F)						
α 10^{-6} in./in./°F	12.8 (68–212°F)						

[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.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.22 Mechanical and Physical Properties of 7075 Aluminum Alloy Sheet and Plate

Specification	AMS 4050 and AMS-QQ-A-250/12						
Form	Sheet						
Temper	T6 and T62[a]						
Thickness, in.	0.008–0.011	0.012–0.039		0.040–0.125		0.126–0.249	
Basis	S	A	B	A	B	A	B
Mechanical properties:							
F_{tu}, ksi:							
L	...	76	78	78	80	78	80
LT	74	76	78	78	80	78	80
ST	...	...	...	...	...	...	...
F_{ty}, ksi:							
L	...	69	72	70	72	71	73
LT	63	67	70	68	70	69	71
ST	...	...	...	...	...	...	...
F_{cy}, ksi:							
L	...	68	71	69	71	70	72
LT	...	71	74	72	74	73	75
ST	...	...	...	...	...	...	...
F_{su}, ksi:	...	46	47	47	48	47	48
F_{bru}[c], ksi:							
($e/D = 1.5$)	...	118	121	121	124	121	124
($e/D = 2.0$)	...	152	156	156	160	156	160
F_{bry}[c], ksi:							
($e/D = 1.5$)	...	100	105	102	105	103	106
($e/D = 2.0$)	...	117	122	119	122	121	124
e, percent (S-basis):							
L	5	7	...	8	...	8	...
E, 10^3 ksi:		10.3					
E_c, 10^3 ksi:		10.6					
G, 10^3 ksi:		3.9					
μ		0.33					
Physical properties:							
ω, lb/in.^{3}		0.101					
C, *K*, and α		See Figure 3.7.6.0					

Form	Plate													
Temper	T651													
Thickness, in.	0.250–0.499		0.500–1.000		1.000–2.000		2.001–2.500		2.501–3.000		3.001–3.500		3.501–4.000	
Basis	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Mechanical properties:														
F_{tu}, ksi:														
L	77	79	77	79	76	78	75	77	71	73	70	72	66	68
LT	78	80	78	80	77	79	76	78	72	74	71	73	67	69
ST	...	...	...	...	...	...	70[b]	71[b]	66[b]	68[b]	65[b]	67[b]	61[b]	63[b]
F_{ty}, ksi:														
L	69	71	70	72	69	71	66	68	63	65	60	62	56	58
LT	67	69	68	70	67	69	64	66	61	63	58	60	54	56
ST	...	...	...	...	...	...	59[b]	61[b]	56[b]	58[b]	54[b]	55[b]	50[b]	52[b]
F_{cy}, ksi:														
L	67	69	68	70	66	68	62	64	58	60	55	57	51	52
LT	71	73	72	74	71	73	68	70	65	67	61	64	57	59
ST	...	...	...	...	...	...	67	70	64	66	61	63	57	59
F_{su}, ksi:	43	44	44	45	44	45	44	45	42	43	42	43	39	41
F_{bru}[c], ksi:														
($e/D = 1.5$)	117	120	117	120	116	119	114	117	108	111	107	110	101	104
($e/D = 2.0$)	145	148	145	148	143	147	141	145	134	137	132	135	124	128
F_{bry}[c], ksi:														
($e/D = 1.5$)	97	100	100	103	100	103	98	101	94	97	89	93	84	87
($e/D = 2.0$)	114	118	117	120	117	120	113	117	109	112	104	108	98	103
e, percent (S-basis):														
L	9	...	7	...	6	...	5	...	5	...	5	...	3	...
E, 10^3 ksi:	10.3													
E_c, 10^3 ksi:	10.6													
G, 10^3 ksi:	3.9													
μ	0.33													

[a] Design allowables were based on data obtained from testing T6 temper sheet and from testing samples of sheet, 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 worked, particularly in the annealed temper, prior to solution heat treatment.

[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.

Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.23 Mechanical and Physical Properties of 7075 Aluminum Alloy Plate

Specification ...	AMS 4044 and AMS-QQ-A-250/12						AMS-QQ-A-250/12							
Form	Plate													
Temper	T62[a]													
Thickness, in.	0.250–0.499		0.500–1.000		1.001–2.000		2.001–2.500		2.501–3.000		3.001–3.500		3.501–4.000	
Basis	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Mechanical properties:														
F_{tu}, ksi:														
L	74	76	74	76	73	75	72	74	69	71	68	70	64	66
LT	78	80	78	80	77	79	76	78	72	74	71	73	67	69
ST	...	...	...	...	...	...	70[b]	71[b]	66[b]	68[b]	65[b]	67[b]	61[b]	63[b]
F_{ty}, ksi:														
L	65	67	66	68	64	65	60	62	56	58	52	54	48	49
LT	67	69	68	70	67	69	64	66	61	63	58	60	54	56
ST	...	...	...	...	...	...	59[b]	61[b]	56[b]	58[b]	54[b]	55[b]	50[b]	52[b]
F_{cy}, ksi:														
L	70	72	70	72	68	70	63	65	59	61	55	57	50	52
LT	70	72	71	73	68	71	65	67	61	63	57	59	52	54
ST	...	...	...	...	...	...	63	65	60	62	57	59	53	55
F_{su}, ksi:	43	44	44	45	44	45	44	45	42	43	42	43	39	41
F_{bru}[c], ksi:														
$(e/D = 1.5)$	117	120	117	120	116	119	114	117	108	111	107	110	101	104
$(e/D = 2.0)$	145	148	145	148	143	147	141	145	134	137	132	135	124	128
F_{bry}[c], ksi:														
$(e/D = 1.5)$	97	100	100	103	100	103	98	101	94	97	89	93	84	87
$(e/D = 2.0)$	114	118	117	120	117	120	113	117	109	112	104	108	98	103
e, percent: (S-basis):														
LT	9	...	7	...	6	...	5	...	5	...	5	...	3	...
E, 10^3 ksi:	10.3													
E_c, 10^3 ksi:	10.6													
G, 10^3 ksi:	3.9													
μ	0.33													
Physical properties:														
ω, lb/in.^{3}	0.101													
C, K, and α	See Figure 3.7.6.0													

[a] Design allowables were based on data obtained from testing samples of plate, supplied in 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 worked, particularly in the annealed temper, prior to solution heat treatment.
[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.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.24 Mechanical and Physical Properties of 7075 Aluminum Alloy Plate

Specification	AMS-QQ-A-250/12	AMS 4078 and AMS-QQ-A-250/12												
Form	Sheet	Plate												
Temper	T73	T7351												
Thickness, in.	0.040–0.249	0.250–0.499	0.500–1.000		1.001–1.500		1.501–2.000		2.001–2.500		2.501–3.000		3.001–3.500	3.501–4.000
Basis	S	S	A	B	A	B	A	B	A	B	A	B	S	S
Mechanical properties:														
F_{tu}, ksi:														
L	67	68	68	70	67	69	66	68	65	67	63	65	62	60
LT	67	69	69	71	68	70	67	69	66	68	64[a]	66	63	61
ST	...	...	...	...	...	...	63	65	62	64	60	62	59	57
F_{ty}, ksi:														
L	56	57	57	59	57	59	55	57	52	55	49	53	49	48
LT	56	57	57	59	57	59	55	57	52[b]	55	49[b]	53	49	48
ST	...	...	...	...	...	...	52	54	49	52	47	50	47	46
F_{cy}, ksi:														
L	55	56	56	58	56	58	53	55	50	53	47	51	47	45
LT	58	59	59	61	59	61	57	59	54	57	51	55	51	50
ST	...	...	...	...	...	...	59	61	55	58	51	55	50	48
F_{su}, ksi:	38	38	38	39	38	40	39	40	39	40	38	39	38	37
F_{bru}[c], ksi:														
(e/D = 1.5)	105	102	103	106	103	106	102	106	102	105	100	103	99	96
(e/D = 2.0)	134	131	132	136	132	136	132	136	131	135	128	132	127	124
F_{bry}[c], ksi:														
(e/D = 1.5)	84	79	81	83	83	86	82	85	79	83	76	81	76	76
(e/D = 2.0)	102	95	97	100	99	102	97	101	93	99	89	96	89	88
e, percent (S-basis):														
LT	8	7	7	...	6	...	6	...	6	...	6	...	6	6
E, 10^3 ksi	10.3	10.3												
E_c, 10^3 ksi	10.5	10.6												
G, 10^3 ksi	3.9	3.9												
μ	0.33	0.33												
Physical properties:														
ω, lb/in.^{3}	0.101													
C, k and α	See Figure 3.7.6.0													

[a] S-basis. The rounded T_{99} values are as follows: $F_{tu}(LT)$ = 65 ksi and $F_{ty}(LT)$ = 52 ksi.
[b] S-basis. The rounded T_{99} value is as follows: $F_{n}(LT)$ = 53 ksi.
[c] Bearing values are "dry pin" values per Section 1.4.7.1. See Table 3.1.2.1.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.25 Mechanical and Physical Properties of 7075 Aluminum Alloy Sheet and Plate

Specification	AMS-QQ-A-250/24				
Form	Sheet and plate				
Temper	T76	T7651			
Thickness, in.	0.063–0.249	0.250–0.499	0.500–1.000	1.001–1.500	1.501–2.000
Basis	S	S	S	S	S
Mechanical properties:					
F_{tu}, ksi:					
L	72	71	70	70	70
LT	73	72	71	71	71
ST	...	...	...	...	65
F_{ty}, ksi:					
L	62	60	59	59	59
LT	62	61	60	60	60
ST	...	...	...	...	56
F_{cy}, ksi:					
L	61	60	59	59	59
LT	65	64	63	63	63
ST	...	...	...	...	63
F_{su}, ksi:	42	40	41	42	43
F_{bru},[a] ksi:					
($e/D = 1.5$)	112	109	108	108	108
($e/D = 2.0$)	145	141	140	140	140
F_{bry},[a] ksi:					
($e/D = 1.5$)	88	86	86	86	87
($e/D = 2.0$)	102	99	99	99	100
e, percent:					
LT	8	8	6	5	5
E, 10^3 ksi	10.3	10.3			
E_c, 10^3 ksi	10.5	10.6			
G, 10^3 ksi	3.9	3.9			
μ	0.33	0.33			
Physical properties:					
ω, lb/in.^{3}	0.101				
C, k and α	See Figure 3.7.6.0				

[a] Bearing values are "dry pin" values per Section 1.4.7.1. See Table 3.1.2.1.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.26 Mechanical and Physical Properties of 7075 Aluminum Alloy Sheet and Plate

Specification	AMS 4049								
Form	Sheet								
Temper	T6								
Thickness, in.	0.008–0.011	0.012–0.039		0.040–0.062		0.063–0.187		0.188–0.249	
Basis	S	A	B	A	B	A	B	A	B
Mechanical properties:									
F_{tu}, ksi:									
L	...	71	74	71	75	74	77	75	77
LT	68	71	74	71	75	74[a]	77	75	77
F_{ty}, ksi:									
L	...	62	65	63	66	66	69	66	68
LT	58	60	63	61	64	64	67	64	66
F_{cy}, ksi:									
L	...	61	64	62	65	65	68	65	67
LT	...	64	67	65	68	68	71	68	70
F_{su}, ksi:	...	42	44	42	45	44	46	45	46
F_{bru},[b] ksi:									
($e/D = 1.5$)	...	110	115	110	116	115	119	116	119
($e/D = 2.0$)	...	142	148	142	150	148	154	150	154
F_{bry},[b] ksi:									
($e/D = 1.5$)	...	90	94	91	96	96	100	96	99
($e/D = 2.0$)	...	105	110	106	112	112	117	112	115
e, percent: (S-basis):									
LT	5	8	...	9	...	9	...	9	...
E, 10^3 ksi:									
Primary	10.3					10.3		10.3	
Secondary	9.5					9.8		10.0	
E_c, 10^3 ksi:									
Primary	10.5					10.5		10.5	
Secondary	9.7					10.0		10.2	
G, 10^3 ksi	...					...		...	
μ	0.33					0.33		0.33	
Physical properties:									
ω, lb/in.^{3}	0.101								
C, K, and α.	...								

[a] S-Basis. The rounded T_{99} value is 75 ksi.
[b] Bearing values are "dry pin" values per Section 1.4.7.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.27 Mechanical and Physical Properties of 7075 Aluminum Alloy Sheet

Specification	AMS-QQ-A-250/13								
Form	Sheet								
Temper	T6 and T62[a]								
Thickness, in.	0.008–0.011	0.012–0.039		0.040–0.062		0.063–0.187		0.188–0.249	
Basis	S	A	B	A	B	A	B	A	B
Mechanical properties:									
F_{tu}, ksi:									
L	...	70	74	71	75	73	77	75	77
LT	68	70[b]	74	71	75	73[c]	77	75	77
F_{ty}, ksi:									
L	...	62	65	63	66	65	69	66	68
LT	58	60	63	61	64	63[d]	67	64	66
F_{cy}, ksi:									
L	...	61	64	62	65	64	68	65	67
LT	...	64	67	65	68	67	71	68	70
F_{su}, ksi:....................	...	42	44	42	45	44	46	45	46
F_{bru},[e] ksi:									
($e/D = 1.5$)	...	108	115	110	116	113	119	116	119
($e/D = 2.0$)	...	140	148	142	150	146	154	150	154
F_{bry},[e] ksi:..................									
($e/D = 1.5$)	...	90	94	91	96	96	100	96	99
($e/D = 2.0$)	...	105	110	106	112	110	117	112	115
e, percent: (S-basis):									
LT	5	7	...	8	...	8	...	8	...
E, 10^3 ksi:									
Primary	10.3					10.3		10.3	
Secondary	9.5					9.8		10.0	
E_c, 10^3 ksi:									
Primary	10.5					10.5		10.5	
Secondary	9.7					10.0		10.2	
G, 10^3 ksi:	...					...		...	
μ	0.33					0.33		0.33	
Physical properties:									
ω, lb/in.^{3}	0.101								
C, *K*, and α.	...								

[a] Design allowables were based on data obtained from testing T6 temper sheet and from testing samples of sheet, supplied in the O or F 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.
[b] S-Basis. The rounded T_{99} value is 71 ksi.
[c] S-Basis. The rounded T_{99} value is 75 ksi.
[d] S-Basis. The rounded T_{99} value is 64 ksi.
[e] Bearing values are "dry pin" values per Section 1.4.7.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.28 Mechanical and Physical Properties of 7075 Aluminum Alloy Plate

Specification	AMS 4049 and AMS-QQ-A-250/13													
Form	Plate													
Temper	T651													
Thickness, in.	0.250–0.499		0.500–1.000[a]		1.001–2.000[a]		2.001–2.500[a]		2.501–3.000[a]		3.001–3.500[a]		3.501–4.000[a]	
Basis	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Mechanical properties:														
F_{tu}, ksi:														
L	74	76	75	77	74	76	73	75	69	71	68	70	64	66
LT	75	77	76	78	75	77	74	76	70	72	69	71	65	67
ST	...	...	...	...	...	...	70[b]	71[b]	66[b]	68[b]	65[b]	67[b]	61[b]	63[b]
F_{ty}, ksi:														
L	67	69	68	70	67	69	64	66	61	63	58	60	54	56
LT	65	97	66	68	65	67	62	64	59	61	56	58	52	54
ST	...	...	...	...	...	...	59[b]	61[b]	56[b]	58[b]	54[b]	55[b]	50[b]	52[b]
F_{cy}, ksi:														
L	65	67	66	68	64	66	60	62	57	58	53	55	49	51
LT	69	71	70	72	69	71	65	68	62	64	59	61	55	57
ST	...	...	...	...	...	...	67	70	64	66	61	63	57	59
F_{su}, ksi:	42	43	42	44	42	44	43	44	41	42	40	42	38	39
F_{bru}[c], ksi:														
($e/D = 1.5$)	113	116	114	117	113	116	111	114	105	108	104	107	98	101
($e/D = 2.0$)	139	143	141	145	139	143	137	141	130	134	128	132	121	124
F_{bry}[c], ksi:														
($e/D = 1.5$)	94	97	97	100	97	100	95	98	90	94	86	89	80	84
($e/D = 2.0$)	111	114	113	116	113	117	110	113	105	109	100	104	93	97
e, percent (S-basis):														
LT	9	...	7	...	6	...	5	...	5	...	5	...	3	...
E, 10^3 ksi:														
Primary	10.3													
Secondary	10.0													
E_c, 10^3 ksi:														
Primary	10.6													
Secondary	10.3													
G, 10^3 ksi:	...													
μ	0.33													
Physical properties:														
ω, lb/in.^{3}	0.101													
C, K, and α	...													

[a] These values, except in the *ST* direction, have been adjusted to represent the average properties across the whole section, including the 1–1/2% per side 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
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.29 Mechanical and Physical Properties of 7075 Aluminum Alloy Plate

Specification	AMS-QQ-A-250/13													
Form	Plate													
Temper	T62[a]													
Thickness, in.	0.250–0.499		0.500–1.000[a]		1.001–2.000[a]		2.001–2.500[a]		2.501–3.000[a]		3.001–3.500[a]		3.501–4.000[a]	
Basis	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Mechanical properties:														
F_{tu}, ksi:														
L	72	73	72	74	72	73	71	72	67	69	66	68	62	64
LT	75	77	76	78	75	77	74	76	70	72	69	71	65	67
ST	...	...	...	...	...	...	70[b]	71[b]	66[b]	68[b]	65[b]	67[b]	61[b]	63[b]
F_{ty}, ksi:														
L	63	65	64	66	62	64	58	60	54	56	50	52	46	48
LT	65	67	66	68	65	67	62	64	59	61	56	58	52	54
ST	...	...	...	...	...	...	59[b]	61[b]	56[b]	58[b]	54[b]	55[b4]	50[b]	52[b]
F_{cy}, ksi:														
L	68	70	68	70	66	68	62	63	57	59	53	55	48	50
LT	68	70	69	71	66	68	62	65	59	61	55	57	50	52
ST	...	...	...	...	...	...	63	65	60	62	57	59	53	55
F_{su}, ksi:	42	43	42	44	42	44	43	44	41	42	40	42	38	39
F_{bru}[c], ksi:														
$(e/D = 1.5)$	113	116	114	117	113	116	111	114	105	108	104	107	98	101
$(e/D = 2.0)$	139	143	141	145	139	143	137	141	130	134	128	132	121	124
F_{bry}[c], ksi:														
$(e/D = 1.5)$	94	97	97	100	97	100	95	98	90	94	86	89	80	84
$(e/D = 2.0)$	111	114	113	116	113	117	110	113	105	109	100	104	93	97
e, percent (S-basis):														
LT	9	...	7	...	6	...	5	...	5	...	5	...	3	...
$E, 10^3$ ksi:														
Primary	10.3													
Secondary	10.0													
$E_c, 10^3$ ksi:														
Primary	10.6													
Secondary	10.3													
G, 10^3 ksi:	3.9													
μ	0.33													
Physical properties:														
ω, lb/in.^{3}	0.101													
C, K, and α	...													

[a] Design allowables were based on data obtained from testing samples of plate, supplied in the O or F 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.
[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.
These values, except in the *ST* direction, have been adjusted to represent the average properties across the whole section.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.30 Mechanical and Physical Properties of 7075 Aluminum Alloy Bar, Rod, and Shapes

Specification	AMS 4122, AMS 4123, AMS 4186, AMS 4187, and AMS-QQ-A-225/9								AMS 4124 and AMS-QQ-A-225 / 9	
Form	Bar, rod, and shapes: rolled, drawn, or cold-finished									
Temper	T6, T651, and T62[a]								T73[b] or T7351	
Thickness[c] in	≤1.000		1.001–2.000		2.001–3.000		3.001–4.000		0.375–2000	2.001–3.000
Basis	A	B	A	B	A	B	A	B	S	S
Mechanical properties:										
F_{tu}, ksi:										
L	77	79	77	79	77	79	77	79	68	68
LT	77[d]	79[d]	75[d]	77[d]	72[d]	74[d]	69[d]	71[d]	...	65[c]
F_{ty}, ksi:										
L	66	68	66	68	66	68	66	68	56	56
LT	66[d]	68[d]	66[d]	68[d]	63[d]	65[d]	60[d]	62[d]	...	52[c]
F_{cy}, ksi:										
L	64	66	64	66	64	66	64	66	54	54
LT	...	...	...	...	...	...	...	...	...	55[c]
F_{su}, ksi:	46	47	46	47	46	47	46	47	42	40
F_{bru},[e] ksi:										
($e/D = 1.5$)	100	103	100	103	100	103	100	103	101	101
($e/D = 2.0$)	123	126	123	126	123	126	123	126	131	131
F_{bry},[e] ksi:										
($e/D = 1.5$)	86	88	86	88	86	88	86	88	81	81
($e/D = 2.0$)	92	95	92	95	92	95	92	95	100	100
e, percent: (S-basis):										
L	7	...	7	...	7	...	7	...	10	10
E, 10^3 ksi:	10.3									
E_c, 10^3 ksi:	10.5									
G, 10^3 ksi:	3.9									
μ	0.33									
Physical properties:										
ω, lb/in.^{3}	0.101									
C, K, and α.	See Figure 3.7.6.0									

[a] Design allowables were based on data obtained from testing of T6 and T651 material and from samples of material, supplied in the O or F temper, which were heat treated to T62 temper to demonstrate response to heat treatment by suppliers.
[b] Design allowables were based on data obtained from testing T73 and T7351 temper material and from testing samples of material, supplied in the O or F temper, which were heat treated to T73 temper to demonstrate response to heat treatment by suppliers.
[c] For rounds (rod), the maximum diameter is 4 in.; for square bar, the maximum size is 3½ in.; for rectangular bar, the maximum thickness is 3 in. with corresponding width of 6 in.; for rectangular bar less than 3 in. in thickness, the maximum width is 10 in.
[d] 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).
[e] Bearing values are "dry pin" values per Section 1.4.7.1.
ST grain direction.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.31 Mechanical and Physical Properties of 7075 Aluminum Alloy Bar, Rod, and Shapes

Specification	AMS 4126, MIL-A-22771, and QQ-A-367							MIL-A-22771 and QQ-A-367						
Form	Die forging													
Temper	T6[a]							T652						
Thickness[b], in.	≤1.000		1.001–2.000		2.001–3.000		3.001–4.000	≤1.000		1.001–2.000		2.001–3.000		3.001–4.000
Basis	A	B	A	B	A	B	S	A	B	A	B	A	B	S
Mechanical properties[d]:														
F_{tu}, ksi:														
L	75	78	74	77	74	76	73	75	78	74	77	74	76	73
T^c	71[d]	...	71[d]	...	70[d]	...	70	71[d]	...	71[d]	...	70[d]	...	70
F_{ty}, ksi:														
L	64	67	63	66	63	65	62	64	67	63	66	63	65	62
T^c	61[d]	...	61[d]	...	60[d]	...	60	60[d]	...	60[d]	...	59[d]	...	59
F_{cy}, ksi:														
L	67	70	66	69	66	68	65	64	67	63	66	63	65	62
ST	64	68	64	67	63	66	63	65	69	65	68	64	67	64
F_{su}, ksi:	43	45	43	44	42	43	42	43	45	43	44	42	43	42
F_{br}^e, ksi:														
$(e/D = 1.5)$	105	109	104	108	104	106	102	105	109	104	108	104	106	102
$(e/D = 2.0)$	135	140	133	138	133	136	131	135	140	133	138	133	136	131
F_{bry}^e, ksi:														
$(e/D = 1.5)$	83	87	82	86	82	84	81	83	87	82	86	82	84	81
$(e/D = 2.0)$	96	100	94	99	94	97	93	96	100	94	99	94	97	93
e, percent: (S-basis):														
L	7	...	7	...	7	...	7	7	...	7	...	7	...	7
T^c	3	...	3	...	3	...	2	3	...	3	...	3	...	2
E, 10^3 ksi:	10.0													
E_c, 10^3 ksi:	10.4													
G, 10^3 ksi:	3.8													
μ	0.33													
Physical properties:														
ω, lb/in.^{3}	0.101													
C, K, and α.	See Figure 3.7.6.0													

[a] 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 time of heat treatment.
[b] Thickness at the time of heat treatment.
[c] 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.
[d] Specification value. T tensile properties are presented on an S basis only.
[e] Bearing values are “dry pin” values per Section 1.4.7.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.32 Mechanical and Physical Properties of 7075 Aluminum Alloy Bar, Rod, and Shapes

Specification	AMS 4141, AMS-A-22771, and AMS-QQ-A-367									AMS 4141	AMS 4147, AMS-A-22771, and AMS-QQ-A-367		
Form	Die forging												
Temper	T73[a,b]										T7352		
Thickness[c], in.	≤1.000		1.001–2.000		2.001–3.000		3.001–4.000		4.001–5.000	5.001–6.000	≤3.000		3.001–4.000
Basis	A	B	A	B	A	B	A	B	S	S	A	B	S
Mechanical properties[d]:													
F_{tu}, ksi:													
L	66[d]	71	66[d]	71	66	69	66[d]	69	62	61	66[e]	69	64
T[f]	62[g]	...	62[g]	...	62[g]	...	61[g]	...	59	58	62[g]	...	61
F_{ty}, ksi:													
L	56[d]	61	56	59	56	59	55[d]	59	53	51	56	59	53
T[f]	53[g]	...	53[g]	...	53[g]	...	52[g]	...	51	50	51[g]	...	49
F_{cy}, ksi:													
L	58	63	58	61	58	61	57	61	...	...	56	59	53
T[f]	55	60	55	59	55	59	54	58	...	...	55	60	53
F_{su}, ksi:	39	42	39	42	39	41	38	41	...	...	39	41	38
F_{bru},[h] ksi:													
$(e/D = 1.5)$	96	103	96	103	96	100	93	100	...	...	96	100	93
$(e/D = 2.0)$	125	135	125	135	125	131	122	131	...	...	125	131	122
F_{bry},[h] ksi:													
$(e/D = 1.5)$	78	85	78	83	78	83	77	83	...	...	78	83	74
$(e/D = 2.0)$	90	98	90	94	90	90	88	94	...	...	90	94	85
e, percent: (S-basis):													
L	7	...	7	...	7	...	7	...	7	6	7	...	7
T[f]	3	...	3	...	3	...	2	...	2	2	3	...	2
E, 10^3 ksi:	10.0												
E_c, 10^3 ksi:	10.4												
G, 10^3 ksi:	3.8												
μ	0.33												
Physical properties:													
ω, lb/in.^{3}	0.101												
C, K, and α	See Figure 3.7.6.0												

[a] 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.
[b] Design allowables were based on data obtained from testing die forgings, heat treated by suppliers, and supplied in T73 temper.
[c] Thickness at the time of heat treatment.
[d] Rounded T_{99} values for T73 temper ≤1.000 in., $F_{tu} = 68$ ksi; for $F_{ty} = 57$ ksi; 1.001–2.000 in., $F_{tg} = 68$ ksi; 3.001–4.000 in., $F_{tg} = 66$ ksi, for $F_{ty} = 56$ ksi.
[e] Rounded T_{99} values for T7352 temper, $F_{tu} \leq 1.000$ in. = 67 ksi.
[f] When AMS-A-22771 or AMS-QQ-A-367 apply, 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. When AMS 4141 applies, T indicates any grain direction within ±15° of being perpendicular to the forging flow lines.
[g] Specification value. T tensile properties are presented on an S basis only.
[h] Bearing values are "dry pin" values per Section 1.4.7.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.33 Mechanical and Physical Properties of 7075 Aluminum Alloy Bar, Rod, and Shapes

Specification	AMS 4126, AMS-A-22771, and AMS-QQ-A-367					AMS-A-22771 and AMS-QQ-A-367				
Form	Hand forging									
Temper	T6[a]					T652				
Thickness, in.	≤2.000	2.001–3.000	3.001–4.000	4.001–5.000	5.001–6.000	≤2.000	2.001–3.000	3.001–4.000	4.001–5.000	5.001–6.000
Basis	S	S	S	S	S	S	S	S	S	S
Mechanical properties:										
F_{tu}, ksi:										
L	74	73	71	69	68	74	73	71	69	68
LT	73	71	70	68	66	73	71	70	68	66
ST	...	69[b]	68[b]	66[b]	65[b]	...	69[b]	68[b]	66[b]	65[b]
F_{ty}, ksi:										
L	63	61	60	58	56	63	61	60	58	56
LT	61	59	58	56	55	61	59	58	56	55
ST	...	58[b]	57[b]	56[b]	55[b]	...	57[b]	56[b]	55[b]	54[b]
F_{cy}, ksi:										
L	63	61	...	...	...	63	61	...	...	...
LT	61	59	...	...	...	61	59	...	...	...
F_{su}, ksi:	44	44	43	41	41	44	44	43	41	41
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	9	9	8	7	6	9	9	8	7	6
LT	4	4	3	3	3	4	4	3	3	3
ST	...	3	2	2	2	...	2	1	1	1
E, 10^3 ksi:	10.0									
E_c, 10^3 ksi:	10.4									
G, 10^3 ksi:	3.8									
μ	0.33									
Physical properties:										
ω, lb/in.^{3}	0.101									
C, K, and α	See Figure 3.7.6.0									

[a] When hand forgings are machined before heat treatment, the section thickness at time of heat treatment will determine the minimum mechanical properties as long as the original (as-forged) thickness does not exceed the maximum thickness of the alloy as shown in the table. The maximum cross-sectional area of hand forgings is 256 in.^{2}

[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).

Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.34 Mechanical and Physical Properties of 7075 Aluminum Alloy Bar, Rod, and Shapes

Specification	AMS-A-22771 and AMS-QQ-A-367					AMS 4147, AMS-A-22771, and AMS-QQ-A-367					
Form	Hand forging										
Temper	T73[a]					T7352					
Thickness, in.	≤2.000	2.001–3.000	3.001–4.000	4.001–5.000	5.001–6.000	≤2.000	2.001–3.000	3.001–4.000		4.001–5.000	5.001–6.000
Basis	S	S	S	S	S	S	S	A	B	S	S
Mechanical properties:											
F_{tu}, ksi:											
L	66	66	64	62	61	66	66	64	67	62	61
LT	64	64	63	61	59	64	64	63	66	61	59
ST	...	61	60	58	57	...	61	60	63	58	57
F_{ty}, ksi:											
L	56	56	55	53	51	54	54	53	55	51	49
LT	54	54	53	51	50	52	52	50	53	48	46
ST	...	52	51	50	49	...	50	48	51	46	44
F_{cy}, ksi:											
L	56	56	...	...	...	55	55	52	55	49	46
LT	52	52	...	...	...	55	55	52	55	49	46
ST	...	...	...	...	...	55	55	53	56	51	49
F_{brw}, ksi:											
L	39	39	...	...	...	39	39	38	40	37	36
LT	...	...	...	...	...	36	36	37	38	36	35
ST	...	...	...	...		38	38	37	39	36	35
F_{bru},[b] ksi:											
($e/D = 1.5$)	...	...	...	...	...	86	88	89	93	86	84
($e/D = 2.0$)	...	...	...	...	...	120	120	118	123	114	110
F_{bry},[b] ksi:											
($e/D = 1.5$)	...	...	...	...	...	71	73	73	77	71	68
($e/D = 2.0$)	...	...	...	...	...	90	90	87	92	83	80
e, percent (S-basis):											
L	7	7	7	7	6	7	7	7	...	7	6
LT	4	4	3	3	3	4	4	3	...	3	3
ST	...	3	2	2	2	...	3	2	...	2	2
E, 10^3 ksi:	10.2										
E_c, 10^3 ksi:	10.4										
G, 10^3 ksi:	3.8										
μ	0.33										
Physical properties:											
ω, lb/in.^{3}	0.101										
C, K, and α	See Figure 3.7.6.0										

[a] When hand forgings are machined before heat treatment, the section thickness at time of heat treatment will 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. The maximum cross-sectional area of hand forgings is 256 in.^{2}

[b] Bearing values are "dry pin" values per Section 1.4.7.1. apes (MIL-HNDBK-5J, 2003)

Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.35 Mechanical and Physical Properties of 7075 Aluminum Alloy Extrusion

Specification	AMS-QQ-A-200/11														
Form	Extrusion (rod, bar and shapes)														
Temper	T6, T6510, T6511, and T62[a]														
Cross-sectional area, in.^{2}	≤20												>20, ≤32	≤32	
Thickness in.[b]	≤0.249		0.250–0.499		0.500–0.749		0.750–1.499		1.500–2.999		3.000–4.499			4.500–5.000	
Basis	A	B	A	B	A	B	A	B	A	B	A	B	S	A	B
Mechanical properties:															
F_{tu}, ksi:															
L	78	82	81	85	81	85	81	85	81	85	81	84	78	78	81
LT	75	79	78	82	77	81	75	79	71	75	67	69	64	63	65
ST	...	...	...	...	...	...	...	...	67[c]	71[c]	67[c]	69[c]	64[c]	63[c]	65[c]
F_{ty}, ksi:															
L	70	74	73	77	72	76	72	76	72	76	71	74	70	68	71
LT	66	70	69	72	67	71	65	69	61	65	56	59	55	52	55
ST	...	...	...	...	...	...	...	...	56[c]	59[c]	55[c]	58[c]	55[c]	52[c]	55[c]
F_{cy}, ksi:															
L	70	74	73	77	72	76	72	76	72	76	71	74	70	68	71
LT	72	76	74	78	73	77	71	75	67	71	62	64	61	57	60
ST	...	...	...	...	...	...	...	...	62	66	62	64	61	57	60
F_{su}, ksi:	41	44	43	45	43	45	43	45	42	44	40	42	39	38	40
F_{bru}[d], ksi:															
$(e/D = 1.5)$	111	117	115	121	115	120	113	119	110	115	106	110	102	101	105
$(e/D = 2.0)$	140	148	146	153	145	152	144	151	141	148	137	142	132	131	136
F_{bry}[d], ksi:															
$(e/D = 1.5)$	92	97	96	101	94	99	93	98	89	94	84	88	83	79	83
$(e/D = 2.0)$	108	114	113	119	111	117	110	116	106	112	101	105	100	95	100
e, percent (S-basis):															
L	7	...	7	...	7	...	7	...	7	...	7	...	6	6	...
E, 10^3 ksi:	10.4														
E_c, 10^3 ksi:	10.7														
G, 10^3 ksi:	4.0														
μ	0.33														
Physical properties:															
ω, lb/in.^{3}	0.101														
C, K, and α	See Figure 3.7.6.0														

[a] Design allowables were based on data obtained from testing T6, T6510, and T6511 temper extrusions and from testing samples of extrusion supplied in the O or F temper, which were heat treated to T62 temper 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.
[b] The mechanical properties are to be based upon the thickness at the time of quench.
[c] 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).
[d] Bearing values are “dry pin” values per Section 1.4.7.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.36 Mechanical and Physical Properties of 7075 Aluminum Alloy Extrusion

Specification	AMS-QQ-A-200/11													
Form	Extrusion (rod, bars, and shapes)													
Temper	T73[a], T73510, T73511													
Cross-sectional area, in.^{2}	≤20		≤25								≤20		>20, ≤32	
Thickness, in.[b]	0.062–0.249		0.250–0.499		0.500–0.749		0.750–1.499		1.500–2.999		3.000–4.499		3.000–4.499	
Basis	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Mechanical properties:														
F_{tu}, ksi:														
L	68[c]	72	70[d]	74	70[d]	73	70[d]	73	69[d]	74	68[c]	71	65[c]	70
LT	66	70	68	72	67	70	66	69	62	67	58	61	56	60
F_{ty}, ksi:														
L	58	61	60	63	60	63	60	63	59[d]	65	57[c]	62	55[c]	60
LT	56	59	57	60	57	60	56	58	51	56	46	50	44	48
F_{cy}, ksi:														
L	58	61	60	63	60	63	60	63	59	65	57	62	55	60
LT	59	62	60	63	60	63	58	61	54	59	49	53	47	51
F_{su}, ksi	37	39	38	40	38	39	38	39	37	40	37	38	35	38
F_{bru} [e], ksi:														
($e/D = 1.5$)	101	107	104	110	103	108	103	107	99	106	95	99	91	98
($e/D = 2.0$)	129	137	133	141	133	139	132	138	128	138	124	130	119	128
F_{bry} [e], ksi:														
($e/D = 1.5$)	82	86	84	89	84	88	83	87	79	87	72	79	70	76
($e/D = 2.0$)	97	102	100	105	100	105	98	103	93	103	86	94	83	91
e, percent (S-basis):														
L	7	....	8	....	8	....	8	...	8	...	7	...	7	....
E, 10^3 ksi	10.4													
E_c, 10^3 ksi	10.7													
G, 10^3 ksi	4.0													
μ	0.33													
Physical properties:														
ω, lb/in.^{3}	0.101													
C, K, and α	See Figure 3.7.6.0													

[a] Design allowables were based on data obtained from testing T7351X temper extrusions and from testing samples of extrusions supplied in the O or F temper, which were heat treated to T73 temper to demonstrate response to 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.
[b] The mechanical properties are to be based upon the thickness at the time of quench.
[c] S-basis. Rounded T_{99} values for cross sectional area ≤20 are as follows: for 0.062–0.249 $F_{tu}(L) = 69$ ksi, 3.000–4.499 $F_{tu}(L) = 69$ ksi, $F_{ty}(L) = 59$ ksi.
[d] S-basis. Rounded T_{99} values for cross sectional area ≤ 25 are as follows: 0.250–1.499 $F_{tu}(L) = 71$, 1.500–2.999 $F_{ty}(L) = 72$ ksi and $F_{ty}(L) = 62$ ksi.
[e] Bearing values are "dry pin" values per Section 1.4.7.1.
S-basis. Rounded T_{99} values for cross sectional area >20 and ≤32 are as follows: $F_{tu}(L) = 68$ ksi and $F_{ty}(L) = 57$ ksi.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.37 Mechanical and Physical Properties of 7075 Aluminum Alloy Extrusion

Specification	AMS-QQ-A-200/15						
Form	Extrusion (rod, bar, and shapes)						
Temper	T76.T76510.T76511						
Cross-sectional area, in.^{2}	≤20						
Thickness in.[a]	0.062–0.249		0.250–0.499	0.500–0.749		0.750–1.000	
Basis	A	B	S	A	B	A	B
Mechanical properties:							
F_{tu}, ksi:							
L	71	74	75	754	76	75	76
LT	68	71	72	71	73	70	71
F_{ty}, ksi:							
L	61	65	65	65	67	65	67
LT	57	61	61	60	62	59	61
F_{cy}, ksi:							
L	61	65	65	65	67	65	67
LT	62	66	66	65	67	64	66
F_{su}, ksi:	38	40	41	41	42	40	41
F_{bru},[b] ksi:							
$(e/D = 1.5)$	103	107	109	109	110	109	110
$(e/D = 2.0)$	131	137	139	139	141	139	141
F_{bry},[b] ksi:							
$(e/D = 1.5)$	82	88	88	88	90	88	90
$(e/D = 2.0)$	98	104	104	104	107	104	107
e, percent: (S-basis):							
L	7	...	7	7	...	7	...
E, 10^3 ksi:	10.4						
E_c, 10^3 ksi:	10.7						
G, 10^3 ksi:	4.0						
μ	0.33						
Physical properties:							
ω, lb/in.^{3}	0.101						
C, K, and α.	See Figure 3.7.6.0						

[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.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.38 Mechanical and Physical Properties of Pure Titanium

Specification	AMS-T-9046	AMS 4902 and AMS-T-9046	AMS 4900 and AMS-T-9046	AMS 4901 and AMS-T-9046	AMS 4921 and MIL-T-9047	MIL-T-9047[a]
Designation	CP-4	CP-3	CP-2	CP-1	CP-70	
Form	Sheet, strip, and plate				Bar	
Condition	Annealed				Annealed	
Thickness or diameter, in.	≤1.000				≤2.999[b]	3.000–4.000[b]
Basis	S	S	S	S	S	S
Mechanical properties:						
F_{tu}, ksi:						
L	35	50	65	80	80	80
LT	35	50	65	80	80[c]	80
ST	...	...	...	...	...	80
F_{ty}, ksi:						
L	25	40	55	70	70	70
LT	25	40	55	70	70[c]	70
ST	...	...	...	...	...	70
F_{cy}, ksi:						
L	...	...	...	70	...	...
LT	...	...	...	70	...	...
F_{su}, ksi	...	...	...	42	...	...
F_{bru}, ksi:						
$(e/D = 1.5)$	...	...	...	120	...	...
$(e/D = 2.0)$	...	...	...	...	...	...
F_{bry}, ksi:						
$(e/D = 1.5)$	...	...	...	101	...	...
$(e/D = 2.0)$	...	...	...	...	...	...
e, percent:						
L	24[d]	20[d]	18[d]	15[d]	15	15
LT	24[d]	20[d]	18[d]	15[d]	15[c]	15
ST	...	...	...	...	...	15
RA, percent:						
L	...	...	...	...	30	30
LT	...	...	...	...	30[c]	30
ST	...	...	...	...	...	30
E, 10^3 ksi:	15.5					
E_c, 10^3 ksi:	16.0					
G, 10^3 ksi:	6.5					
μ	...					
Physical properties:						
ω, lb/in.^{3}	0.163					
C, K and α	See Figure 5.2.1.0					

[a] Inactive for new design.
[b] Maximum of 16 in.^{2} cross-sectional area.
[c] Long transverse properties apply to rectangular bar only for thickness >0.500 in. and widths >3.000 in. For AMS 4921, $(e)(LT) = 12\%$ and $RA\ (LT) = 25\%$.
[d] Thickness of 0.025 in. and above.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.39 Mechanical and Physical Properties of Titanium Ti-6Al-4V Extrusion

Specification	AMS 4911 and AMS-T-9046[a], Comp. AB-1						AMS-T-9046[a], Comp. AB-1			
Form	Sheet		Plate				Sheet, strip, and plate			
Condition	Annealed						Solution treated and aged			
Thickness, in.	≤ 0.1875		0.1875–2.000		2.001–4.000		≤ 0.1875	0.1875–0.750	0.751–1.000	1.001–2.000
Basis	A	B	A	B	A	B	S	S	S	S
Mechanical properties:										
F_{tu}, ksi:										
L	134	139	130[b]	135	130[c]	137	160	160	150	145
LT	134	139	130[b]	138	130[c]	137	160	160	150	145
F_{ty}, ksi:										
L	126	131	120	125	118	123	145	145	140	135
LT	126	131	120[b]	131	118	129	145	145	140	135
F_{cy}, ksi:										
L	133	138	124	129	122	127	154	150	145	...
LT	135	141	130	142	128	140	162	...	...	...
F_{su}, ksi:	87	90	79	84	79	84	100	93	87	...
F_{bru}, ksi:										
$(e/D = 1.5)$	213[d]	221[d]	206[d]	214[d]	206[d]	217[d]	236	248	233	...
$(e/D = 2.0)$	272[d]	283[d]	260[d]	276[d]	260[d]	274[d]	286	308	289	...
F_{bry}, ksi:										
$(e/D = 1.5)$	171[c]	178[d]	164[d]	179[d]	161[d]	176[d]	210	210	203	...
$(e/D = 2.0)$	208[d]	217[d]	194[d]	212[d]	191[d]	209[d]	232	243	235	...
e, percent (S-basis):										
L	8[128]	...	10	...	10	...	5[129]	8	6	6
LT	8[128]	...	10	...	10	...	5[129]	8	6	6
E, 10^3 ksi:	16.0									
E_c, 10^3 ksi:	16.4									
G, 10^3 ksi:	6.2									
μ	0.31									
Physical properties:										
ω, lb/in.^{3}	0.160									
C, K and α	See Figure 4.5.1.0									

[a] MIL-T-9046 was canceled and superseded by AMS-T-9046
[b] The rounded T_{99} values are higher than specification values as follows: F_{tu} (L) = 131 ksi, and F_{tv} (LT) = 132 ksi, F_{ty} (LT) = 123 ksi.
[c] The rounded T_{99} values are higher than specification values as follows: F_{tu} (L) = 133 ksi, and F_{tv} (LT) = 133 ksi.
[d] Bearing values are “dry pin” values per Section 1.4.7.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.40 Mechanical and Physical Properties of Titanium Ti-6Al-4V Bar

Specification	AMS 4928												
Form	Bar												
Condition	Annealed												
Thickness or diameter, in.	<0.500	0.500–1.000		1.001–2.000		2.001–3.000		3.001–4.000		4.001–5.000		5.001–6.000	
Basis	S	A	B	A	B	A	B	A	B	A	B	A	B
Mechanical properties:													
F_{tu}, ksi:													
L	135	135[a]	142	134	140	130[a]	138	130	135	128	133	125	131
LT	135[b]	135[a]	144	135[a]	143	130[a]	142	130[a]	141	130[a]	139	130[a]	138
F_{ty}, ksi:													
L	125	125[c]	134	125[c]	131	120[c]	128	120	125	117	122	114	119
LT	125[b]	125[c]	134	125[c]	132	120[c]	131	120[c]	129	120[c]	127	119	125
F_{cy}, ksi:													
L	129	129	138	129	135	...	...	...	...	...	....	....	....
LT	...	...	...	....	...	...	...	...	...	...	...	...	...
F_{su}, ksi	83	83	87	82	86	...	...	...	....	...	...	....	....
F_{bru}, ksi:													
$(e/D = 1.5)$	201	201	212	200	209	...	...	...	...	....	....	...	...
$(e/D = 2.0)$	253	253	266	251	262	...	...	...	...	...	...	...	...
F_{bry}, ksi:													
$(e/D = 1.5)$	177	177	190	177	186	...	...	...	...	...	...	...	...
$(e/D = 2.0)$	205	205	220	205	215	...	...	...	...	...	...	...	...
e, percent (S-basis):													
L	10	10	...	10	...	10	...	10	...	10	...	10	...
LT	10[b]	10[b]	...	10[b]	...	10[b]	...	10	...	10	...	10	...
ST	...	...	...	...	...	10[b]	...	10	...	8	...	8	...
RA, percent (S-basis):													
L	25	25	...	25	...	25	...	25	...	20	...	20	...
LT	20[b]	20[b]	...	20[b]	...	20[b]	...	20	...	20	...	20	...
ST	...	...	...	...	...	15[b]	...	15	...	15	...	15	...
E, 10^3 ksi	16.9												
E_c, 10^3 ksi	17.2												
G, 10^3 ksi	6.5												
μ	0.31												
Physical properties:													
ω, lb/in.^{3}	0.160												
C, K and α	See Figure 5.4.1.0												

[a] S-basis. The rounded T_{∞} values for F_{tu} are as follows: 0.500-1.000 (*L*) = 137 ksi and (*LT*) = 140 ksi, 1.001–2.000 (*LT*) = 139 ksi, 2.001–3.000 (*L*) = 132 ksi and (*LT*) = 138 ksi, 3.001–4.000 (*LT*) = 136 ksi, 4.001–5.000 (*LT*) = 135 ksi, and 5.001–6.000 (*LT*) = 134 ksi.
[b] Applicable, providing *LT* or *ST* dimension is ≥2.500 in.
[c] S-basis. The rounded T_{∞} values for F_{ty} are as follows: 0.500–1.000 (*L*) and (*LT*) = 129 ksi, 1.001–2.000(*L*) = 126 ksi and (*LT*) = 127 ksi, 2.001–3.000 (*L*) = 123 ksi and (*LT*) = 127 ksi, 3.001–4.000 (*LT*) = 123 ksi, and 4.001–5.000 (*LT*) = 121 ksi.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.41 Mechanical and Physical Properties of Titanium Ti-6Al-4V Extrusion

Specification	AMS 4935				AMS 4934							
Form	Extrusion											
Condition	Annealed				Solution treated and aged							
Thickness or diameter, in.	≤2.000		2.001–3.000		<0.500		0.501–0.750		0.751–1.000		1.001–2.000	2.001–3.000
Basis	A	B	A	B	A	B	A	B	A	B	S	S
Mechanical properties:												
F_{tu}, ksi:												
L	130[a]	137	130[b]	135	155	163	151	157	147	153	140	130
LT[c]	130[a]	139	130	139	155	163	151	157	147	155	140	130
F_{ty}, ksi:												
L	120	124	118	122	138	147	138	143	133	140	130	120
LT[c]	120[a]	128	120	125	138	147	138	145	133	142	1330	120
F_{cy}, ksi:												
L	128	133	124	128	147	157	147	153	142	150	139	128
LT[c]	129	138	...	....	147	157	147	155	139	152	139	128
F_{su}, ksi	83	89	...	...	94	99	92	96	89	93	85	79
F_{bru}, ksi:												
$(e/D = 1.5)$	214	226	...	...	243	256	237	246	231	240	220	204
$(e/D = 2.0)$	264	278	...	...	311	327	303	315	295	307	281	261
F_{bry},[d] ksi:												
$(e/D = 1.5)$	180	186	...	...	208	222	208	216	201	212	196	182
$(e/D = 2.0)$	210	217	...	...	242	257	242	250	233	245	228	210
e, percent (S-basis):												
L	10	...	10	...	6	...	6	...	6	....	6	6
LT[c]	8	...	8	...	6	...	6	...	6	...	6	6
RA, percent (S-basis):												
L	20	...	20	...	12	....	12	...	12	...	12	12
LT[c]	15	....	15	...	12	...	12	...	12	...	12	12
E, 10^3 ksi	16.9											
E_c, 10^3 ksi	17.2											
G, 10^3 ksi	6.5											
μ	0.31											
Physical properties:												
ω, lb/in.^{3}	0.160											
C, K and α	See Figure 5.4.1.0											

[a] S-basis. The rounded T_{99} values are higher than specification values as follows: $F_{tu}(L)$ and $(LT) = 132$ ksi and $F_{ty}(LT) = 121$ ksi.
[b] S-basis. The rounded T_{99} values are higher than specification values as follows: $F_{tu}(L) = 132$ ksi and $F_{tu}(L) = 136$ ksi.
[c] Applicable, providing LT dimension is ≥2.500 in.
[d] Bearing values are "dry pin" values per Section 1.4.7.1.
Source: MIL-HNDBK-5J, 2003 / US Department of Defense/ Public domain.

Table 1.42 Alloy Material Elongation Properties

Alloy material	Percent elongation **(%)**
Steel	
ASTM-A36	20
ASTM-A242	18
ASTM-A441	18
ASTM-A572	20
ASTM-A514	18
Stainless cold-rolled	13
Stainless annealed	13
Aluminum	
2014-T4	12
2024-T4	19
6061-T6	17
7075-T6	11
Copper	
Annealed	50
Hard-drawn	50
Titanium	
Alloy (6Al&4V)	10

To better understand the ductility of alloy materials, the elongation limits of the materials should be examined and explored for stress analysis purposes. The typical elongation properties of metal alloys are illustrated in Table 1.42.

1.4 Stress–Strain Curve for Brittle Material

For brittle material, that rupture is sudden upon loading of the part, and no gradual behavior of the stress vs strain is observable before material fracture/rupture; all of the five (5) points of material interest on the stress–strain curve occur at the same location on the stress–strain curve. These five points of interest, proportional limit, elastic limit, yield strength, ultimate strength, and fracture strength, all are at the same point. Examples of the brittle material are glass, cast iron, and composite materials. For an illustration of this concept, refer to Figure 1.5.

Table 1.43 illustrates typical material properties normally used for carrying out stress analysis of composite laminates.

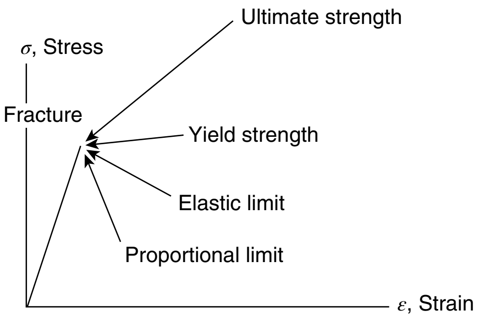

Figure 1.5 Stress–Strain Curve for typical Brittle Material
(Glass, Cast Iron, and Composites).

Table 1.43 Composite Lamina Material Properties

Material	Modulus E_L, Long. 10^6 psi	Modulus E_T, Transverse, 10^6 psi	Modulus G_{LT}, 10^6 psi	Poisson's Ratio, ν_{LT}	Density lb/in.^{3}	Tensile Strength Long. 10^3 psi	Tensile Strength Transverse 10^3 psi	Shear Strength, 10^3 psi
IM6/Epoxy	29.4	1.62	1.22	0.32	0.058	508	8.1	14.2
Kevlar/Epoxy	12.6	0.8	0.32	0.34	0.050	186	4.4	7.1
T300/5208	26.3	1.49	1.04	0.28	0.058	218	5.8	9.9
T300/934	21.5	1.4	0.66	0.30	0.054	191	6.2	7.0
AS/3501	20.0	1.3	1.03	0.30	0.058	210	7.5	13.5
AS4/3501-6	20.6	1.49	1.04	0.27	0.057	331	8.3	10.3
S-glass/Epoxy	6.2	1.29	0.65	0.27	0.072	186	7.1	10.0
E-glass/Epoxy	5.7	1.25	0.55	0.28	0.076	157	5.7	12.9

1.5 The General Methods

There are typically three (3) major approaches to substantiating an aerospace structure, testing, hand calculation, and FEA. In many instances, a minimum of two (2) approaches are utilized to perform stress analysis and structurally substantiate a part or assembly. In this case, one approach validates the other approach. For example, hand calculations are done and finite element modeling is done to validate the results, or testing is performed to validate the hand calculations. Any other combination is often acceptable too.

This has to be noted that usually for metallic materials where their mechanical properties and strength are determined by standard testing and results are available from sources such as the *Military Materials Handbook*, hand calculations, and FEA are preferred and acceptable methods of stress analysis. Also, it should be noted that for many principal structural elements where their failure causes a catastrophic failure of the aerospace vehicle, by government regulations testing is required for substantiation. In many cases when composite material layups are used in the structures design testing is needed along with any hand and FEA. A general approach for analysis is illustrated as shown in Figure 1.6.

1.6 The Structure of Stress Reports

The format structure of a stress analysis report is illustrated here in this section. Each section has its importance in relaying the technical data needed to perform and present a typical stress analysis report for structural substantiations.

Title Page – The document's analysis title, author(s) name(s), date of generation, revision level of the document, and the organization in charge of the generation of the document has to be presented on the first page of the report.

Table of Contents – A table of contents with the section number and the page number associated with each section has to be provided.

Table of Tables – A list of the tables presented in the report, with the table numbers and corresponding page numbers, has to be presented here.

Table of Figures – A list of the figures presented in the report, with the figure numbers and corresponding page numbers, has to be presented here.

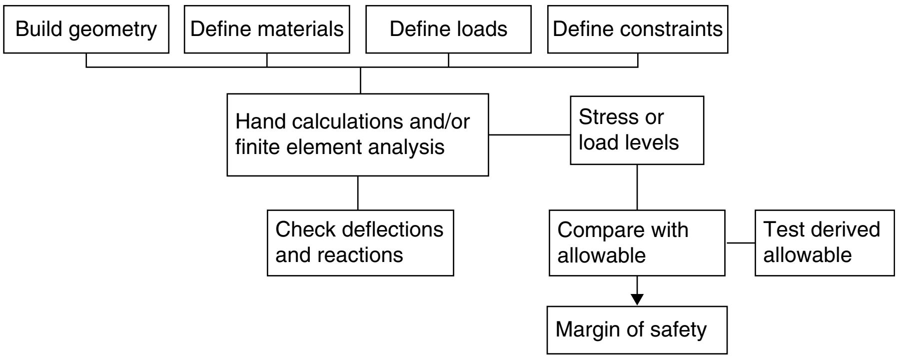

Figure 1.6 Stress Analysis Approach

Introduction – Where the design and the ultimate goal of the analysis are defined. A description of the design is usually illustrated by Computer Aided Design (CAD) and 2D drawings defining the geometry of the design of the part or assembly in question. Any regulations that would be satisfied by the analysis work shown and any assumptions made regarding either loads or locations and constraints or locations.

Applied Loads – The external and internal loads that would be applied to the part or assembly system will be presented here. The types of loading (i.e. inertia, landing, flight, pressure, and dynamic) will be described and defined here with their requirement source.

Constraints and Boundary Conditions – The points of attachments, the points where degrees of freedom would be constrained, any inertia relief conditions of constraints, and overall boundary conditions would be defined and illustrated here.

Material Selection – The material used for the buildup of the aerospace structure or assembly will be defined here. The mechanical and physical properties used such as the elastic modulus, Poisson's ratio, mass density, and strength allowable (ultimate or yield strengths) will be defined and illustrated here.

Free-Body-Diagram – Would be usually illustrated to show the applied external and internal loads and their direction along with the reaction points.

Results – If the analysis is a hand-calculation, then numerical values of the extreme stress, load, and displacements calculated would be presented here. If the analysis method is finite element modeling, then the maximum stress and deflection counters will be plotted and attached here. For dynamic analysis frequency response vs displacement amplitudes, mode shapes, and natural resonance frequencies need to be plotted and presented here.

For all calculations made a table of results summary has to be shown for each of the components analyzed and part number, material, and location in the assembly, the location of the analysis in the report, and the margin of safety calculated for it has to be shown in this table.

Any test correlations have to be discussed here or in a separate section by stating the validation of the results generated either by hand calculations or the FEA methods used.

Conclusion and Discussion – A concise summary and conclusion have to be given as to the nature of the passing or failing of the parts or assembly under analysis. Any discussion about the results has to be mentioned here to clarify any ambiguity of the results generated.

References – A complete list of references that includes, the requirements, analysis methods, regulations, test data reports, and any other stress analysis reports used as a reference has to be indicated here with the proper document names, authors, date of publication, and generating organization.

Appendix – The appendix is to be introduced to add any additional data that was not generated by this report but was used in generating this report and any length calculations, which do not have to be necessarily placed in the main body of the report such as excel spreadsheet and other numerical calculation data.

Problems

1 Define stress on a solid body and indicate the units used for stress in SI and English systems.

2 Define the stress and strain relationship in isotropic materials.

3 Define the material's Poisson's ratio and indicate a typical value of Poisson's ratio for metallic material.

4 Describe how the yield strength of a material can be determined from the stress and strain plot data from the material tensile tests.

5 For a typical aluminum and steel material compare the ultimate strength to yield strength values.

6 How do composite materials compare in strength-to-density ratio to the metallic material?

7 How does the elastic modulus compare to the shear modulus in typical aluminum materials? Can you derive an equation to define the elastic modulus relationship to the shear modulus?

8 On a flat plate with a circular hole in the middle, where would the stress concentration be at?

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