CHAPTER 3

ALUMINUM

3.1 GENERAL

This chapter contains the engineering properties and related characteristics of wrought and cast aluminum alloys used in aircraft and missile structural applications.

General comments on engineering properties and the considerations relating to alloy selection are presented in this section. Mechanical and physical property data and characteristics pertinent to specific alloy groups or individual alloys are reported in Sections 3.2 through 3.9. Element properties are presented in Section 3.10.

Aluminum is a lightweight, corrosion-resistant structural material that can be strengthened through alloying and, dependent upon composition, further strengthened by heat treatment and/or cold working [Reference 3.1(a)]. Among its advantages for specific applications are low density, high strength-to-weight ratio, good corrosion resistance, ease of fabrication, and diversity of form.

Wrought and cast aluminum and aluminum alloys are identified by a four-digit numerical designation, the first digit indicates the alloy group, as shown in Table 3.1. For structural wrought aluminum alloys the last two digits identify the aluminum alloy. The second digit indicates modifications of the original alloy or impurity limits. For cast aluminum and aluminum alloys the second and third digits identify the aluminum alloy or indicate the minimum aluminum percentage. The last digit, which is to the right of the decimal point, indicates the product form: XXX.0 indicates castings, and XXX.1 and XXX.2 indicate ingot.

3.1.1 ALUMINUM ALLOY INDEX — The layout of this chapter is in accordance with this four-digit number system for both wrought and cast alloys [Reference 3.1(b)]. Table 3.1.1 is the aluminum alloy index that illustrates both the general section layout as well as details of those specific aluminum alloys presently contained in this chapter. The wrought alloys are in Sections 3.2 through 3.7; whereas the cast alloys are in Sections 3.8 and 3.9.

Table 3.1. Basic Designation for Wrought and Cast Aluminum Alloys [Reference 3.1(b)]

Alloy Group	Major Alloying Elements	Alloy Group	Major Alloying Groups
	Wrought Alloys		Cast Alloys
1XXX	99.00 percent minimum aluminum	1XX.0	99.00 percent minimum aluminum
2XXX	Copper	2XX.0	Copper
3XXX	Manganese	3XX.0	Silicon with added copper and/or magnesium
4XXX	Silicon	4XX.0	Silicon
5XXX	Magnesium	5XX.0	Magnesium
6XXX	Magnesium and Silicon	6XX.0	Unused Series
7XXX	Zinc	7XX.0	Zinc
8XXX	Other Elements	8XX.0	Tin
9XXX	Unused Series	9XX.0	Other Elements

Table 3.1.1. Aluminum Alloy Index

Section	Alloy Designation	Section	Alloy Designation
3.2	**2000 series wrought alloys**	3.6.2.	6061
3.2.1	2013	3.6.3	6151
3.2.2	2014	3.6.4	6156
3.2.3	2017	**3.7**	**7000 series wrought alloys**
3.2.4	2024	3.7.1	7010
3.2.5	2025	3.7.2	7040
3.2.6	2026	3.7.3	7049/7149
3.2.7	2027	3.7.4	7050
3.2.8	2050	3.7.5	7055
3.2.9	2056	3.7.6	7056
3.2.10	2090	3.7.7	7068
3.2.11	2098	3.7.8	7075
3.2.12	2099	3.7.9	7085
3.2.13	2124	3.7.10	7136
3.2.14	2196	3.7.11	7140
3.2.15	2198	3.7.12	7150
3.2.16	2219	3.7.13	7175
3.2.17	2297	3.7.14	7249
3.2.18	2397	3.7.15	7349
3.2.19	2424	3.7.16	7449
3.2.20	2519	3.7.17	7475
3.2.21	2524	**3.8**	**200.0 series cast alloys**
3.2.22	2618	3.8.1	A201.0
3.3	**3000 series wrought alloys**	**3.9**	**300.0 series cast alloys**
3.4	**4000 series wrought alloys**	3.9.1	354.0
3.5	**5000 series wrought alloys**	3.9.2	355.0
3.5.1	5052	3.9.3	C355.0
3.5.2	5083	3.9.4	356.0
3.5.3	5086	3.9.5	A356.0
3.5.4	5454	3.9.6	A357.0/F357.0
3.5.5	5456	3.9.7	D357.0/E357.0
3.6	**6000 series wrought alloys**	3.9.8	359.0
3.6.1	6013		

3.1.2 MATERIAL PROPERTIES — The properties of the aluminum alloys are determined by the alloy content and method of fabrication. Some alloys are strengthened principally by cold work, while others are strengthened principally by solution heat treatment and precipitation hardening [Reference 3.1(a)]. The temper designations, shown in Table 3.1.2 (which is based on Reference 3.1.2), are indicative of the type of strengthening mechanism employed.

Among the properties presented herein, some, such as the room temperature, tensile, compressive, shear and bearing properties, are either specified minimum properties or derived minimum properties related directly to the specified minimum properties. They may be directly useful in design. Data on the effect of temperature on properties are presented so that percentages may be applied directly to the room temperature minimum properties. Other properties, such as the stress-strain curve, fatigue and fracture toughness data, and modulus of elasticity values, are presented as average or typical values, which may be used in assessing the usefulness of the material for certain applications. Comments on the effect of temperature on properties are given in Sections 3.1.2.1.7 and 3.1.2.1.8; comments on corrosion resistance are given in Section 3.1.2.3; and comments on the effects of manufacturing practices on these properties are given in Section 3.1.3.

Table 3.1.2. Temper Designation System for Aluminum Alloys

Temper Designation System[a,b]

The temper designation system is used for all forms of wrought and cast aluminum and aluminum alloys except ingot. It is based on the sequences of basic treatments used to produce the various tempers. The temper designation follows the alloy designation, the two being separated by a hyphen. Basic temper designations consist of letters. Subdivisions of the basic tempers, where required, are indicated by one or more digits following the letter. These designate specific sequences of basic treatments, but only operations recognized as significantly influencing the characteristics of the product are indicated. Should some other variation of the same sequence of basic operations be applied to the same alloy, resulting in different characteristics, then additional digits are added to the designation.

Basic Temper Designations

F **as fabricated**. Applies to the products of shaping processes in which no special control over thermal conditions or strain-hardening is employed. For wrought products, there are no mechanical property limits.

O **annealed**. Applies to wrought products which are annealed to obtain the lowest strength temper, and to cast products which are annealed to improve ductility and dimensional stability. The O may be followed by a digit other than zero.

H **strain-hardened (wrought products only)**. Applies to products which have their strength increased by strain-hardening, with or without supplementary thermal treatments, to produce some reduction in strength. The H is always followed by two or more digits.

W **solution heat-treated**. An unstable temper applicable only to alloys which spontaneously age at room temperature after solution heat-treatment. This designation is specific only when the period of natural aging is indicated: for example, W ½ hr.

T **thermally treated to produce stable tempers other than F, O, or H**. Applies to products which are thermally treated, with or without supplementary strain-hardening, to produce stable tempers. The T is always followed by one or more digits.

Subdivisions of H Temper: Strain-hardened.

The first digit following H indicates the specific combination of basic operations, as follows:

H1 **strain-hardened only**. Applies to products which are strain-hardened to obtain the desired strength without supplementary thermal treatment. The number following this designation indicates the degree of strain-hardening.

H2 **strain-hardened and partially annealed**. Applies to products which are strain-hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing. For alloys that age-soften at room temperature, the H2 tempers have the same minimum ultimate tensile strength as the corresponding H3 tempers. For other alloys, the H2 tempers have the same minimum ultimate tensile strength as the corresponding H1 tempers and slightly higher elongation. The number following this designation indicates the degree of strain-hardening remaining after the product has been partially annealed.

H3 **strain-hardened and stabilized**. Applies to products which are strain-hardened and whose mechanical properties are stabilized either by a low-temperature thermal treatment or as a result of heat introduced during fabrication. Stabilization usually improves ductility. This designation is applicable only to those alloys which, unless stabilized, gradually age-soften at room temperature. The number following this designation indicates the degree of strain-hardening remaining after the stabilization treatment.

a From reference 3.1.2.
b Temper designations conforming to this standard for wrought aluminum and wrought aluminum alloys, and aluminum alloy castings may be registered with the Aluminum Association provided: (1) the temper is used or is available for use by more than one user, (2) mechanical property limits are registered, (3) characteristics of the temper are significantly different from those of all other tempers which have the same sequence of basic treatments and for which designations already have been assigned for the same alloy and product, and (4) the following are also registered if characteristics other than mechanical properties are considered significant: (a) test methods and limits for the characteristics or (b) the specific practices used to produce the temper.

Table 3.1.2. Temper Designation System for Aluminum Alloys (Continued)

The digit following the designations H1, H2, and H3 indicates the degree of strain hardening. Numeral 8 has been assigned to indicate tempers having an ultimate tensile strength equivalent to that achieved by a cold reduction (temperature during reduction not to exceed 120°F) of approximately 75 percent following a full anneal. Tempers between O (annealed) and 8 are designated by numerals 1 through 7. Material having an ultimate tensile strength about midway between that of the O temper and that of the 8 temper is designated by the numeral 4; about midway between the O and 4 tempers by the numeral 2; and about midway between 4 and 8 tempers by the numeral 6. Numeral 9 designates tempers whose minimum ultimate tensile strength exceeds that of the 8 temper by 2.0 ksi or more. For two-digit H tempers whose second digit is odd, the standard limits for ultimate tensile strength are exactly midway between those of the adjacent two digit H tempers whose second digits are even.

NOTE: For alloys which cannot be cold reduced an amount sufficient to establish an ultimate tensile strength applicable to the 8 temper (75 percent cold reduction after full anneal), the 6 temper tensile strength may be established by a cold reduction of approximately 55 percent following a full anneal, or the 4 temper tensile strength may be established by a cold reduction of approximately 35 percent after a full anneal.

The third digit[c], when used, indicates a variation of a two-digit temper. It is used when the degree of control of temper or the mechanical properties or both differ from, but are close to, that (or those) for the two-digit H temper designation to which it is added, or when some other characteristic is significantly affected.

NOTE: The minimum ultimate tensile strength of a three-digit H temper must be at least as close to that of the corresponding two-digit H temper as it is to the adjacent two-digit H tempers. Products of the H temper whose mechanical properties are below H_1 shall be variations of H_1.

Three-digit H Tempers

H_11 Applies to products which incur sufficient strain hardening after the final anneal that they fail to qualify as annealed but not so much or so consistent an amount of strain hardening that they qualify as H_1.

H112 Applies to products which may acquire some temper from working at an elevated temperature and for which there are mechanical property limits.

Subdivisions of T Temper: Thermally Treated

Numerals 1 through 10 following the T indicate specific sequences of basic treatments, as follows.[d]

T1 cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition. Applies to products which are not cold worked after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

T2 cooled from an elevated temperature-shaping process, cold worked, and naturally aged to a substantially stable condition. Applies to products which are cold worked to improve strength after cooling from an elevated temperature-shaping process, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

T3 solution heat-treated[e], cold worked, and naturally aged to a substantially stable condition. Applies to products which are cold-worked to improve strength after solution heat treatment or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

c Numerals 1 through 9 may be arbitrarily assigned as the third digit and registered with The Aluminum Association for an alloy and product to indicate a variation of a two-digit H temper (see footnote b).

d A period of natural aging at room temperature may occur between or after the operations listed for the T tempers. Control of this period is exercised when it is metallurgically important.

e Solution heat treatment is achieved by heating cast or wrought products to a suitable temperature, holding at that temperature long enough to allow constituents to enter into solid solution and cooling rapidly enough to hold the constituents in solution. Some 6000 series alloys attain the same specified mechanical properties whether furnace solution heat-treated or cooled from an elevated temperature shaping process at a rate rapid enough to hold constituents in solution. In such cases the temper designations T3, T4, T6, T7, T8, and T9 are used to apply to either process and are appropriate designations.

Table 3.1.2. Temper Designation System for Aluminum Alloys (Continued)

T4 solution heat-treated[f] and naturally aged to a substantially stable condition. Applies to products which are not cold worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

T5 cooled from an elevated temperature shaping process and artificially aged. Applies to products which are not cold worked after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

T6 solution heat-treated[f] and artificially aged. Applies to products which are not cold worked after solution heat-treatment or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.

T7 solution heat-treated[f] and overaged/stabilized. Applies to wrought products that are artificially aged after solution heat-treatment to carry them beyond a point of maximum strength to provide control of some significant characteristic. Applies to cast products that are artificially aged after solution heat-treatment to provide dimensional and strength stability.

T8 solution heat-treated[f], cold worked, and artificially aged. Applies to products which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

T9 solution heat-treated[f], artificially aged, and cold worked. Applies to products which are cold worked to improve strength.

T10 cooled from an elevated temperature shaping process, cold worked, and artificially aged. Applies to products which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

Additional digits[g], the first of which shall not be zero, may be added to designations T1 through T10 to indicate a variation in treatment which significantly alters the product characteristics[h] that are or would be obtained using the basic treatment.

The following specific additional digits have been assigned for stress-relieved tempers of wrought products:

Stress Relieved by Stretching

T_51 Applies to plate and rolled or cold-finished rod and bar when stretched the indicated amounts after solution heat-treatment or after cooling from an elevated temperature shaping process. The products receive no further straightening after stretching.

Plate .... 1½ to 3% permanent set.
Rolled or Cold-Finished
Rod and Bar .... 1 to 3% permanent set.
Die or Ring Forgings
and Rolled Rings .... 1 to 5% permanent set.

T_510 Applies to extruded rod, bar, shapes and tube and to drawn tube when stretched the indicated amounts after solution heat-treatment or after cooling from an elevated temperature shaping process. These products receive no further straightening after stretching.

Extruded Rod, Bar, Shapes
and Tube .... 1 to 3% permanent set.
Drawn Tube .... ½ to 3% permanent set.

f Solution heat treatment is achieved by heating cast or wrought products to a suitable temperature, holding at that temperature long enough to allow constituents to enter into solid solution and cooling rapidly enough to hold the constituents in solution. Some 6000 series alloys attain the same specified mechanical properties whether furnace solution heat-treated or cooled from an elevated temperature-shaping process at a rate rapid enough to hold constituents in solution. In such cases the temper designations T3, T4, T6, T7, T8, and T9 are used to apply to either process and are appropriate designations.

g Additional digits may be arbitrarily assigned and registered with the Aluminum Association for an alloy and product to indicate a variation of tempers T1 through T10 even though the temper representing the basic treatment has not been registered (see footnote b). Variations in treatment that do not alter the characteristics of the product are considered alternate treatments for which additional digits are not assigned.

h For this purpose, characteristic is something other than mechanical properties. The test method and limit used to evaluate material for this characteristic are specified at the time of the temper registration.

Table 3.1.2. Temper Designation System for Aluminum Alloys (Continued)

T_511

Applies to extruded rod, bar, shapes and tube and to drawn tube when stretched the indicated amounts after solution heat-treatment or after cooling from an elevated temperature shaping process. These products may receive minor straightening after stretching to comply with standard tolerances.

Stress Relieved by Compressing

T_52

Applies to products which are stress-relieved by compressing after solution heat-treatment or cooling from an elevated temperature shaping process to produce a set of 1 to 3 percent.

Stress Relieved by Combined Stretching and Compressing

T_54

Applies to die forgings which are stress relieved by restriking cold in the finish die.

NOTE: The same digits (51, 52, 54) may be added to the designation W to indicate unstable solution heat-treated and stress-relieved treatment.

The following temper designations have been assigned for wrought product test material heat-treated from annealed (O, O1, etc.) or F temper.[i]

T42 Solution heat-treated from annealed or F temper and naturally aged to a substantially stable condition.

T62 Solution heat-treated from annealed or F temper and artificially aged.

Temper designations T42 and T62 may also be applied to wrought products heat-treated from any temper by the user when such heat-treatment results in the mechanical properties applicable to these tempers.

Variations of O Temper: Annealed

A digit following the O, when used, indicates a product in the annealed condition have special characteristics. NOTE: As the O temper is not part of the strain-hardened (H) series, variations of O temper shall not apply to products which are strain-hardened after annealing and in which the effect of strain-hardening is recognized in the mechanical properties or other characteristics.

Assigned O Temper Variations

The following temper designation has been assigned for wrought products high temperature annealed to accentuate ultrasonic response and provide dimensional stability.

O1 Thermally treated at approximately same time and temperature required for solution heat treatment and slow cooled to room temperature. Applicable to products which are to be machined prior to solution heat treatment by the user. Mechanical Property limits are not applicable.

Designation of Unregistered Tempers

The letter P has been assigned to denote H, T and O temper variations that are negotiated between manufacturer and purchaser. The letter P immediately follows the temper designation that most nearly pertains. Specific examples where such designation may be applied include the following:

The use of the temper is sufficiently limited so as to preclude its registration. (Negotiated H temper variations were formerly indicated by the third digit zero.)

The test conditions (sampling location, number of samples, test specimen configuration, etc.) are different from those required for registration with the Aluminum Association.

The mechanical property limits are not established on the same basis as required for registration with the Aluminum Association.

i When the user requires capability demonstrations from T-temper, the seller shall note “capability compliance” adjacent to the specified ending tempers. Some examples are “-T4 to -T6 Capability Compliance as for aging” or “-T351 to -T4 Capability Compliance as for resolution heat treating.”

It should be recognized not all combinations of stress and environment have been investigated, and it may be necessary to evaluate an alloy under the specific conditions involved for certain critical applications.

3.1.2.1 *Mechanical Properties*

The design strength properties at room temperature are listed at the beginning of the section covering the properties of an alloy. The effect of temperature on these properties is indicated in figures that follow the tables

3.1.2.1.1 *Edgewise Bearing* — A reduction factor is used for edgewise bearing load in thick bare and clad plate of 2000 and 7000 series alloys. The results of bearing tests on longitudinal and long--transverse specimens taken edgewise from plate, die forging, and hand forging have shown that the edgewise bearing strengths are substantially lower than those of specimens taken parallel to the surface.

Table 3.1.2.1.1. Reductions for Edgewise Orientation of 2000, Al-Li, and 7000 Series Alloys

		Bearing Property Reduction, percent				
Alloy Family	Thickness, in.	1.0-2.0	2.0-4.0	4.0-6.0	6.0-8.0	8.0-10.0
2000 Series Al (excluding Al-Li)	F_{bru} (e/D = 1.5)	15	15	15		
	F_{bru} (e/D = 2.0)	10	10	10		
	F_{bry} (e/D = 1.5)	5	5	5		
	F_{bry} (e.D = 2.0)	5	5	5		
Al-Li Plates	F_{bru} (e/D = 1.5)	26	25	23	23	
	F_{bru} (e/D = 2.0)	23	22	20	19	
	F_{bry} (e/D = 1.5)	9	9	8	7	
	F_{bry} (e.D = 2.0)	8	8	6	5	
7000 Series Al	F_{bru} (e/D = 1.5)	15	15	20	19	16
	F_{bru} (e/D = 2.0)	10	10	15	15	12
	F_{bry} (e/D = 1.5)	5	5	6	6	6
	F_{bry} (e.D = 2.0)	5	5	2	2	2

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3.1.2.1.2 *Clad Sheet and Plate* - For clad sheet and plate (i.e., containing thin surface layers of material of a different composition for added corrosion protection), the strength values are representative of the composite (i.e., the cladding and the core). For sheet and thin plate (≤ 0.499 inch), the quality-control test specimens are of the full thickness so that the guaranteed tensile properties and the associated derived values for these products directly represent the composite. For plate ≥ 0.500 inch in thickness, the quality-control test specimens are machined from the core so the guaranteed tensile properties in specifications reflect the core material only, not the composite. Therefore, the design tensile properties for the thicker material are obtained by adjustment of the specification tensile properties and the other related properties to represent the composite, using the nominal total cladding thickness and the typical tensile properties of the cladding material.

For clad aluminum sheet and plate products, it is also important to distinguish between primary and secondary modulus values. The initial, or primary, modulus represents an average of the elastic moduli of the core and cladding; it applies only up to the proportional limit of the cladding. For example, the primary modulus of 2024-T3 clad sheet applies only up to about 6 ksi. Similarly, the primary modulus of 7075-T6 clad sheet applies only up to approximately 12 ksi. A typical use of primary moduli is for low-amplitude, high-frequency fatigue.

3.1.2.1.3 *Fatigue* — Fatigue S/N curves are presented for those alloys for which sufficient data are available. Data for both smooth and notched specimens are presented. The data from which the curves were developed were insufficient to establish scatter bands and do not have the statistical reliability of the room temperature mechanical properties; the values should be considered to be representative for the respective alloys.

The fatigue strengths of aluminum alloys, with both notched and unnotched specimens, are at least as high or higher at subzero temperatures than at room temperature [References 3.1.2.1.5(a) through 3.1.2.1.5(c)]. At elevated temperatures, the fatigue strengths are somewhat lower than at room temperature, the difference increasing with increase in temperature.

The data presented do not apply directly to the design of structures because they do not take into account the effect of stress raisers such as re-entrant corners, notches, holes, joints, rough surfaces, and other similar conditions that are present in fabricated parts. The localized high stresses induced in fabricated parts by such stress raisers are of much greater importance for repeated loading than they are for static loading and may reduce the fatigue life of fabricated parts far below that which would be predicted by comparing the smooth-specimen fatigue strength directly with the nominal calculated stresses for the parts in question. See References 3.1.2.1.5(d) through 3.1.2.1.5(q) for information on how to use high-strength aluminum alloys, Reference 3.1.2.1.5(r) for details on the static and fatigue strengths of high-strength aluminum alloy-bolted joints, Reference 3.1.2.1.5(s) for single-rivet fatigue test data, and Reference 1.4.9.3(b) for a general discussion of designing for fatigue. Fatigue crack growth data are presented in the various alloy sections.

3.1.2.1.4 *Fracture Toughness* — Typical values of plane-strain fracture toughness, K_{Ic}, [Reference 3.1.2.1.6(a)] for the high-strength aluminum alloy products are presented in Table 3.1.2.1.6. Minimum, average, and maximum values as well as coefficient of variation are presented for the alloys and tempers for which valid data are available [References 3.1.2.1.6(b) through 3.1.2.1.6(j)]. Although representative, these values do not have the statistical reliability of the room temperature mechanical properties.

Graphic displays of the residual strength behavior of middle tension panels are presented in the various alloy sections. The points denote the experimental data from which the curve of fracture toughness was derived.

3.1.2.1.5 *Cryogenic Temperatures* — In general, the strengths (including fatigue strengths) of aluminum alloys increase with decrease in temperature below room temperature [References 3.1.2.1.7(a) and 3.1.2.1.7(b)]. The increase is greatest over the range from about -100° to -423°F (liquid hydrogen temperature); the strengths at -452°F (liquid helium temperature) are nearly the same as at -423°F [References 3.1.2.1.7(c) and 3.1.2.1.7(d)]. For most alloys, elongation and various indices of toughness remain nearly constant or increase with decrease in temperature, while for the 7000 series, modest reductions are observed [References 3.1.2.1.7(d) and 3.1.2.1.7(e)]. None of the alloys exhibit a marked transition in fracture resistance over a narrow range of temperature indicative of embrittlement.

The tensile and shear moduli of aluminum alloys also increase with decreasing temperature so that at -100°F, -320°F, and -423°F, they are approximately 5, 10.5, and 11 percent, respectively, above the room temperature values [Reference 3.1.2.1.7(f)].

3.1.2.1.6 *Elevated Temperatures* — In general, the strengths of aluminum alloys decrease and toughness increases with increase in temperature and with time at temperature above room temperature; the effect is generally greatest over the temperature range from 212° to 400°F. Exceptions to the general trends are tempers developed by solution heat treatment without subsequent aging, for which the initial elevated temperature exposure results in some age hardening and reduction in toughness; further time at temperature beyond that required to achieve peak hardness results in the aforementioned decrease in strength and increase in toughness [Reference 3.1.2.1.8].

Table 3.1.2.1.4. Values of Room Temperature Plane-Strain Fracture Toughness of Aluminum Alloys[a]

Alloy/ Temper[b]	Product Form	Orientation[c]	Product Thickness, inches	Number of Sources	Sample Size	Date of Data Generation	Approved		Specimen Thickness, inches	K_{IC}, ksi $\sqrt{in.}$				
							Date	Item		Max.	Avg.	Min.	COV	Spec. Min.
2014-T651	Plate	L-T	≥0.5	1	24	1980-1983	10/85	85-03	0.5-1.0	25	22	19	8.4	
2014-T651	Plate	T-L	≥0.5	2	34	1980-1983	10/85	85-03	0.5-1.0	23	21	18	6.5	
2014-T652	Hand Forging	L-T	≥0.5	2	15	1973-1975	5/82	78-09	0.8-2.0	48	31	24	21.8	
2014-T652	Hand Forging	T-L	≥0.8	2	15	1973-1975	5/82	78-09	0.8-2.0	30	21	18	14.4	
2024-T351	Plate	L-T	≥1.0	2	11	1973-1975	5/82	78-09	0.8-2.0	43	31	27	16.5	
2024-T851	Plate	L-S	1.4-3.0	4	11	1973-1975	5/82	78-09	0.5-0.8	32	25	20	17.8	
2024-T851	Plate	L-T	≥0.5	11	102	1973-1975	5/82	78-09	0.4-1.4	32	23	15	10.1	
2024-T851	Plate	T-L	0.4-4.0	9	80	1973-1975	5/82	78-09	0.4-1.4	25	20	18	8.8	
2024-T852	Forging	T-L	2.0-7.0	3	20	1973-1975	5/82	78-09	0.7-2.0	25	19	15	15.5	
2024-T852	Hand Forging	L-T	----	4	35	1973-1975	5/82	78-09	0.8-2.0	38	28	19	18.4	
2024-T852	Hand Forging	T-L	----	2	17	1973-1975	5/82	78-09	0.7-2.0	22	18	14	14.4	
2027-T3511	Extrusion	L-T	0.75-1.50	1	272	2006	10/07	M07-11	0.8-1.4	60.9	52.4	40.6	9.1	40
2027-T3511	Extrusion	T-L	0.75-1.50	1	269	2006	10/07	M07-11	0.8-1.4	62.6	48.0	37.8	7.3	38
2050-T84	Plate	L-T	0.5-1.5	1	10	2006-2008	10/08	M08-33	1.0-1.5	45	40	37	6.0	33
2050-T84	Plate	T-L	0.5-1.5	1	21	2006-2008	10/08	M08-33	1.0-1.5	42	37	32	7.5	29
2050-T84	Plate	S-L	0.5-1.5	1	12	2006-2008	10/08	M08-33		37	35	32	4.5	25
2050-T84	Plate	L-T	1.5-2.0	1	10	2006-2008	10/08	M08-33	2.0	45	39	34	9.1	31
2050-T84	Plate	T-L	1.5-2.0	1	9	2006-2008	10/08	M08-33	2.0	42	34	30	10.7	27
2050-T84	Plate	S-L	1.5-2.0	1	12	2006-2008	10/08	M08-33		32	30	28	3.5	23
2050-T84	Plate	L-T	2.0-3.0	1	18	2006-2008	10/08	M08-33	2.0	41	37	31	9.0	28
2050-T84	Plate	T-L	2.0-3.0	1	13	2006-2008	10/08	M08-33	2.0	34	30	26	9.4	25
2050-T84	Plate	S-L	2.0-3.0	1	14	2006-2008	10/08	M08-33	0.75-1.0	30	27	24	6.5	23
2050-T84	Plate	L-T	3.0-4.0	1	11	2006-2008	10/08	M08-33	2.0	36	32	28	7.0	26
2050-T84	Plate	T-L	3.0-4.0	1	11	2006-2008	10/08	M08-33	2.0	29	28	26	3.7	23
2050-T84	Plate	S-L	3.0-4.0	1	14	2006-2008	10/08	M08-33	1.0	30	27	24	6.9	21
2050-T84	Plate	L-T	4.0-5.0	1	9	2006-2008	10/08	M08-33	2.0	34	31	27	9.8	25
2050-T84	Plate	T-L	4.0-5.0	1	9	2006-2008	10/08	M08-33	2.0	29	27	25	5.6	21
2050-T84	Plate	S-L	4.0-5.0	1	11	2006-2008	10/08	M08-33	1.0	29	27	24	5.8	21
2124-T851	Plate	L-T	1.5-2	2	159	2005	10/04	M04-15	1.5[d]	42	36	27	7.9	24
2124-T851	Plate	T-L	1.5-2	3	175	2005	10/04	M04-15	1.5[d]	39	30	22	7.4	20
2124-T851	Plate	S-L	1.5-2	3	126	2005	10/04	M04-15	0.75-1.0[d]	31	25	19	9.4	18

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a These values are for information only..

b Products that do not receive a mechanical stress-relieving process (e.g., -T73 and -T74 tempers) have the potential for induced residual stresses. As a result, care must be taken to prevent fracture toughness properties from bias resulting from residual stresses.

c Refer to Figures 1.4.12.3(a) and 1.4.12.3(b) for definition of symbols.

d Specimen thickness range was provided from one source.

e Varies with thickness.

f Determined using quadratic regression from 4 to 10 inches.

Table 3.1.2.1.4. Values of Room Temperature Plane-Strain Fracture Toughness of Aluminum Alloys[a]

Alloy/Temper[b]	Product Form	Orientation[c]	Product Thickness, inches	Number of Sources	Sample Size	Date of Data Generation	Approved		Specimen Thickness, inches	K_{IC}, ksi $\sqrt{in.}$				
							Date	Item		Max.	Avg.	Min.	COV	Spec. Min.
2124-T851	Plate	L-T	2-3	3	394	2005	10/04	M04-15	0.98-1.53	45	36	27	7.3	24
2124-T851	Plate	T-L	2-3	3	393	2005	10/04	M04-15	0.98-1.53	36	28	23	5.6	20
2124-T851	Plate	S-L	2-3	3	399	2005	10/04	M04-15	0.75-1.53	33	25	20	7.1	18
2124-T851	Plate	L-T	3-4	3	461	2005	10/04	M04-15	1.47-2.04	45	35	26	6.9	24
2124-T851	Plate	T-L	3-4	3	474	2005	10/04	M04-15	1.47-2.04	39	28	24	6.8	20
2124-T851	Plate	S-L	3-4	3	477	2005	10/04	M04-15	1.0-2.04	40	25	20	6.4	18
2124-T851	Plate	L-T	4-5	3	288	2005	10/04	M04-15	1.50-2.55	40	33	24	9.0	24
2124-T851	Plate	T-L	4-5	3	303	2005	10/04	M04-15	1.50-2.55	39	27	21	7.3	20
2124-T851	Plate	S-L	4-5	3	291	2005	10/04	M04-15	1.00-2.55	32	25	19	7.7	18
2124-T851	Plate	L-T	5-6	3	206	2005	10/04	M04-15	1.50-2.94	43	32	26	9.0	24
2124-T851	Plate	T-L	5-6	3	202	2005	10/04	M04-15	1.50-2.94	34	27	22	8.4	20
2124-T851	Plate	S-L	5-6	3	220	2005	10/04	M04-15	1.50-2.94	30	25	20	8.7	18
2219-T851	Plate	L-T	----	4	67	1973-1975	5/82	78-09	1.0-2.5	38	33	30	7.2	
2219-T851	Plate	T-L	≥1.0	6	108	1973-1975	5/82	78-09	0.8-2.5	37	29	20	10.1	
2219-T851	Plate	S-L	≥0.8	3	24	1973-1975	5/82	78-09	0.5-1.5	26	22	20	9.6	
2219-T851	Forging	S-L	----	1	85	1973-1975	5/82	78-09	1.0-1.5	34	25	19	12.1	
2219-T8511	Extrusion	T-L	----	1	19	1973-1975	5/82	78-09	1.8-2.0	34	29	23	12.3	
2219-T852	Forging	S-L	----	2	60	1973-1975	5/82	78-09	0.8-2.0	35	25	20	12.1	
2219-T852	Hand Forging	L-T	----	2	32	1973-1975	5/82	78-09	1.5-2.5	46	38	30	9.7	
2219-T852	Hand Forging	T-L	≥1.5	2	28	1973-1975	5/82	78-09	1.5-2.5	30	27	22	8.4	
2219-T87	Plate	L-T	≥1.5	3	11	1973-1975	5/82	78-09	0.8-2.0	28	26	25	3.7	
2219-T87	Plate	T-L	----	1	11	1973-1975	5/82	78-09	1.0	22	22	19	3.9	
2297-T87	Plate	L-T	1.0-3.0	1	13	2002-2006	4/06	M05-19	1.5	42	39	38	2.6	32
2297-T87	Plate	T-L	1.0-3.0	1	16	2002-2006	4/06	M05-19	1.5	33	31	27	5.3	27
2297-T87	Plate	S-L	1.0-3.0	1	8	2002-2006	4/06	M05-19	1.0	28	25	24	5.7	20
2297-T87	Plate	L-T	3-4	1	30	2002-2006	4/06	M05-19	1.5	50	40	33	11.3	31
2297-T87	Plate	T-L	3-4	1	33	2002-2006	4/06	M05-19	1.5	36	31	28	6.0	27
2297-T87	Plate	S-L	3-4	1	30	2002-2006	4/06	M05-19	1.0	32	25	20	11.0	20
2297-T87	Plate	L-T	4-5	1	51	2002-2006	4/06	M05-19	1.5	46	38	32	8.0	30
2297-T87	Plate	T-L	4-5	1	51	2002-2006	4/06	M05-19	1.5	37	30	26	7.1	26
2297-T87	Plate	S-L	4-5	1	52	202-2006	4/06	M05-19	1.0	30	24	19	8.7	18

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a These values are for information only..

b Products that do not receive a mechanical stress-relieving process (e.g., -T73 and -T74 tempers) have the potential for induced residual stresses. As a result, care must be taken to prevent fracture toughness properties from bias resulting from residual stresses.

c Refer to Figures 1.4.12.3(a) and 1.4.12.3(b) for definition of symbols.

d Specimen thickness range was provided from one source.

e Varies with thickness.

f Determined using quadratic regression from 4 to 10 inches.

Table 3.1.2.1.4. Values of Room Temperature Plane-Strain Fracture Toughness of Aluminum Alloys[a] (Continued)

Alloy/Temper[b]	Product Form	Orien-tation[c]	Product Thickness, inches	Number of Sources	Sample Size	Date of Data Generation	Approved		Specimen Thickness, inches	K_{IC}, ksi$\sqrt{in.}$				
							Date	Item		Max.	Avg.	Min.	COV	Spec. Min.
2297-T87	Plate	L-T	5-6	1	31	2002-2006	4/06	M05-19	1.5	49	37	31	10.1	29
2297-T87	Plate	T-L	5-6	1	29	2002-2006	4/06	M05-19	1.5	30	27	25	5.2	25
2297-T87	Plate	S-L	5-6	1	30	2002-2006	4/06	M05-19	1.0	27	23	18	7.9	18
2397-T87	Plate	L-T	3-4	1	48	2005-2006	4/06	M05-23	1.5	40	36	34	3.4	31
2397-T87	Plate	T-L	3-4	1	31	2005-2006	4/06	M05-23	1.5	35	33	28	3.8	27
2397-T87	Plate	S-L	3-4	1	48	2005-2006	4/06	M05-23	1.0	38	29	23	13.5	20
2397-T87	Plate	L-T	4-5	1	41	2005-2006	4/06	M05-23	1.5	40	36	34	3.1	32
2397-T87	Plate	T-L	4-5	1	17	2005-2006	4/06	M05-23	1.5	34	32	28	4.6	26
2397-T87	Plate	S-L	4-5	1	40	2005-2006	4/06	M05-23	1.5	32	26	19	11.7	18
2397-T87	Plate	L-T	5-6	1	33	2005-2006	4/06	M05-23	2.0	38	35	29	7.1	29
2397-T87	Plate	T-L	5-6	1	30	2005-2006	4/06	M05-23	2.0	43	34	29	10.5	25
2397-T87	Plate	S-L	5-6	1	31	2005-2006	4/06	M05-23	2.0	37	27	19	17.9	18
7040-T7451	Plate	L-T	3-4	1	16	1999	3/00	M00-03	2	39	37	34	5.2	26
7040-T7451	Plate	T-L	3-4	1	16	1999	3/00	M00-03	2	31	30	28	2.8	24
7040-T7451	Plate	S-L	3-4	1	14	1999	3/00	M00-03	2	33	31	29	4.2	30
7040-T7451	Plate	L-T	4-5	1	17	1999	3/00	M00-03	2	34	32	31	2.0	25
7040-T7451	Plate	T-L	4-5	1	17	1999	3/00	M00-03	2	27	26	26	1.5	24
7040-T7451	Plate	S-L	4-5	1	17	1999	3/00	M00-03	2	28	26	26	2.2	29
7040-T7451	Plate	L-T	5-6	1	17	1999	3/00	M00-03	2	34	32	30	2.7	23
7040-T7451	Plate	T-L	5-6	1	14	1999	3/00	M00-03	2	28	25	25	3.5	24
7040-T7451	Plate	S-L	5-6	1	16	1999	3/00	M00-03	2	28	27	26	2.7	27
7040-T7451	Plate	L-T	6-7	1	21	1999	3/00	M00-03	2	37	34	30	5.9	22
7040-T7451	Plate	T-L	6-7	1	21	1999	3/00	M00-03	2	29	27	25	2.8	23
7040-T7451	Plate	S-L	6-7	1	21	1999	3/00	M00-03	2	30	29	27	4.0	26
7040-T7451	Plate	L-T	7-8	1	18	1999	3/00	M00-03	2	33	32	30	3.2	22
7040-T7451	Plate	T-L	7-8	1	16	1999	3/00	M00-03	2	29	28	26	2.7	23
7040-T7451	Plate	S-L	7-8	1	13	1999	3/00	M00-03	2	31	29	26	4.6	26
7040-T7451	Plate	L-T	8-8.5	1	17	1999	3/00	M00-03	2	34	31	28	4.6	22
7040-T7451	Plate	T-L	8-8.5	1	13	1999	3/00	M00-03	2	26	24	23	5.0	22
7040-T7451	Plate	S-L	8-8.5	1	17	1999	3/00	M00-03	2	27	26	25	2.1	

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a These values are for information only..

b Products that do not receive a mechanical stress-relieving process (e.g., -T73 and -T74 tempers) have the potential for induced residual stresses. As a result, care must be taken to prevent fracture toughness properties from bias resulting from residual stresses.

c Refer to Figures 1.4.12.3(a) and 1.4.12.3(b) for definition of symbols.

d Specimen thickness range was provided from one source.

e Varies with thickness.

f Determined using quadratic regression from 4 to 10 inches.

Table 3.1.2.1.4. Values of Room Temperature Plane-Strain Fracture Toughness of Aluminum Alloys[a] (Continued)

Alloy/Temper[b]	Product Form	Orien-tation[c]	Product Thickness, inches	Number of Sources	Sample Size	Date of Data Generation	Approved		Specimen Thickness, inches	K_{IC}, ksi$\sqrt{in.}$				
							Date	Item		Max.	Avg.	Min.	COV	Spec. Min.
7049-T73	Die Forging	L-T	1.4	3	21	1973-1975	5/82	78-09	0.5-1.0	34	30	27	7.4	
7049-T73	Die Forging	S-L	≥0.5	3	46	1973-1975	5/82	78-09	0.5-1.0	26	22	18	9.7	
7049-T73	Hand Forging	L-T	≥0.5	2	28	1973-1975	5/82	78-09	0.5-1.0	37	30	23	12.1	
7049-T73	Hand Forging	T-L	2.0-7.1	2	27	1973-1975	5/82	78-09	1.0	28	22	18	12.5	
7049-T73	Hand Forging	S-L	1.0	2	24	1973-1975	5/82	78-09	0.8-1.0	22	19	14	14.2	
7050-T7351	Plate	L-T	1.0-6.0	2	31	1973-1975	5/82	78-09	1.0-2.0	43	35	28	11.3	
7050-T7351	Plate	T-L	2.0-6.0	1	29	1973-1975	5/82	78-09	1.5-2.0	35	30	25	8.5	
7050-T7351	Plate	S-L	2.0-6.0	1	30	1973-1975	5/82	78-09	0.8-1.5	30	28	25	4.6	
7050-T74	Die Forging	S-L	0.6-7.1	3	12	1973-1975	5/82	78-09	0.6-2.0	27	24	21	8.8	e
7050-T7451	Plate	L-T	1.00-1.99	3	764	2004-2006	10/07	M07-46	----	47	40	33	6.2	29
7050-T7451	Plate	L-T	2.00-2.99	3	1186	2004-2006	10/07	M07-46	----	44	38	32	5.2	27
7050-T7451	Plate	L-T	3.00-3.99	2	659	2004-2006	10/07	M07-46	----	42	36	31	4.6	26
7050-T7451	Plate	L-T	4.00-4.99	1	236	2004-2006	10/07	M07-46	----	43	34	29	6.6	25
7050-T7451	Plate	L-T	5.00-6.00	1	209	2004-2006	10/07	M07-46	----	40	31	27	6.0	24
7050-T7451	Plate	S-L	2.25-2.99	2	335	2004-2006	10/07	M07-46	----	34	30	23	5.4	21
7050-T7451	Plate	S-L	3.00-3.99	2	432	2004-2006	10/07	M07-46	----	33	28	23	5.8	21
7050-T7451	Plate	S-L	4.00-4.99	1	233	2004-2006	10/07	M07-46	----	31	27	21	6.0	21
7050-T7451	Plate	S-L	5.00-6.00	1	213	2004-2006	10/07	M07-46	----	30	26	22	5.6	21
7050-T7451	Plate	S-L	2.17-3.00	3	728	2004-2006	10/07	M07-46	----	35	27	22	7.4	--
7050-T7451	Plate	T-L	0.63-1.99	3	836	2004-2006	10/07	M07-46	----	41	33	28	5.3	25
7050-T7451	Plate	T-L	2.00-2.99	3	1188	2004-2006	10/07	M07-46	----	38	30	26	6.4	24
7050-T7451	Plate	T-L	3.00-3.99	2	643	2004-2006	10/07	M07-46	----	35	29	24	4.9	23
7050-T7451	Plate	T-L	4.00-4.99	1	230	2004-2006	10/07	M07-46	----	30	26	23	4.9	22
7050-T7451	Plate	T-L	5.00-6.00	1	209	2004-2006	10/07	M07-46	----	30	24	22	4.9	22
7050-T7452	Hand Forging	L-T	3.5-5.5	1	11	1973-1975	5/82	78-09	1.5	34	31	26	8.0	e
7050-T7452	Hand Forging	T-L	3.5-7.5	1	13	1973-1975	5/82	78-09	1.5	22	21	18	6.7	e
7050-T7452	Hand Forging	S-L	3.5-7.5	1	17	1973-1975	5/82	78-09	0.8-1.5	21	19	16	7.5	
7050-T76511	Extrusion	L-T	----	2	38	1973-1975	5/82	78-09	0.6-2.0	40	31	27	7.8	

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a These values are for information only..

b Products that do not receive a mechanical stress-relieving process (e.g., -T73 and -T74 tempers) have the potential for induced residual stresses. As a result, care must be taken to prevent fracture toughness properties from bias resulting from residual stresses.

c Refer to Figures 1.4.12.3(a) and 1.4.12.3(b) for definition of symbols.

d Specimen thickness range was provided from one source.

e Varies with thickness.

fDetermined using quadratic regression from 4 to 10 inches..

Table 3.1.2.1.4. Values of Room Temperature Plane-Strain Fracture Toughness of Aluminum Alloys[a] (Continued)

Alloy/Temper[b]	Product Form	Orientation[c]	Product Thickness, inches	Number of Sources	Sample Size	Date of Data Generation	Approved Date	Approved Item	Specimen Thickness, inches	K_{IC}, ksi$\sqrt{in.}$ Max.	Avg.	Min.	COV	Spec. Min.
7056-T7651	Plate	L-T	0.5-1.5	1	36	2005	4/08	M07-20	0.8-1.6	39	33	30	6.0	27
7056-T7651	Plate	T-L	0.5-1.5	1	35	2005	4/08	M07-20	0.8-1.6	31	28	26	5.3	23
7075-T651	Plate	L-T	≥0.6	7	99	1973-1975	4/82	78-09	0.5-2.0	30	26	20	7.6	
7075-T651	Plate	T-L	≥0.5	5	135	1973-1975	4/82	78-09	0.4-2.0	27	22	18	8.9	
7075-T651	Plate	S-L	----	2	37	1973-1975	4/82	78-09	0.5-1.5	22	18	14	10.4	
7075-T6510	Extrusion	L-T	0.7-3.5	1	26	1973-1975	4/82	78-09	0.5-1.2	32	27	23	7.8	
7075-T6510	Extrusion	T-L	0.7-3.5	1	25	1973-1975	4/82	78-09	0.5-1.2	28	24	21	8.0	
7075-T6510	Forged Bar	L-T	0.7-5.0	1	13	1973-1975	4/82	78-09	0.6-2.0	35	29	24	11.6	
7075-T73	Die Forging	T-L	≥0.5	1	22	1973-1975	4/82	78-09	0.5-0.8	25	21	18	9.9	
7075-T73	Hand Forging	L-T	----	2	10	1973-1975	4/82	78-09	1.0-1.5	39	31	29	8.8	
7075-T73	Hand Forging	T-L	≥1.0	2	14	1973-1975	4/82	78-09	1.0-1.5	27	23	20	9.0	
7075-T6510	Forged Bar	T-L	0.7-5.0	1	13	1973-1975	4/82	78-09	0.5-2.5	24	21	17	8.2	
7075-T7351	Plate	L-T	≥1.0	8	65	1973-1975	4/82	78-09	0.5-2.0	36	30	25	8.2	
7075-T7351	Plate	T-L	≥0.5	6	56	1973-1975	4/82	78-09	0.5-2.0	47	27	21	20.1	
7075-T7351	Plate	S-L	≥0.5	3	20	1973-1975	4/82	78-09	0.5-1.5	38	22	17	32.5	
7075-T73511	Extrusion	T-L	1.0-7.0	1	19	1973-1975	4/82	78-09	0.9-1.0	22	20	19	3.7	
7075-T73511	Extrusion	L-T	≥0.9	3	28	1973-1975	4/82	78-09	0.7-2.0	43	35	31	9.4	
7075-T73511	Extrusion	T-L	≥0.7	3	35	1973-1975	4/82	78-09	0.5-1.8	35	23	12	20.3	
7075-T73511	Extrusion	S-L	≥0.5	3	15	1973-1975	4/82	78-09	0.4-1.0	22	20	17	9.0	
7075-T7352	Hand Forging	L-T	----	2	27	1973-1975	4/82	78-09	0.8-2.0	39	33	30	9.2	
7075-T7352	Hand Forging	T-L	≥0.8	3	20	1973-1975	4/82	78-09	0.8-2.0	33	26	23	9.9	
7075-T7651	Plate	L-T	≥0.8	6	82	1973-1975	4/82	78-09	0.5-2.0	43	29	22	17.8	
7075-T7651	Plate	T-L	≥0.5	7	96	1973-1975	4/82	78-09	0.5-2.0	28	23	20	7.6	
7075-T7651	Plate	S-L	≥0.5	5	28	1973-1975	4/82	78-09	0.4-0.8	20	18	15	7.7	
7075-T7651	Clad Plate	L-T	0.5-0.6	2	30	1973-1975	4/82	78-09	0.5-0.6	30	25	22	7.1	
7075-T7651	Clad Plate	T-L	0.5-0.6	2	56	1973-1975	4/82	78-09	0.5-0.6	28	24	21	7.7	
7075-T76511	Extrusion	L-T	1.3-7.0	4	11	1973-1975	4/82	78-09	1.2-2.0	41	35	31	11.0	
7075-T76511	Extrusion	T-L	1.2	3	42	1973-1975	4/82	78-09	0.6-2.0	36	23	20	15.5	

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c Refer to Figures 1.4.12.3(a) and 1.4.12.3(b) for definition of symbols.

d Specimen thickness range was provided from one source.

e Varies with thickness.

f Determined using quadratic regression from 4 to 10 inches.

Table 3.1.2.1.4. Values of Room Temperature Plane-Strain Fracture Toughness of Aluminum Alloys[a] (Concluded)

Alloy/Temper[b]	Product Form	Orien-tation[c]	Product Thickness, inches	Number of Sources	Sample Size	Date of Data Generation	Approved		Specimen Thickness, inches	K_{IC}, ksi$\sqrt{in.}$				
							Date	Item		Max.	Avg.	Min.	COV	Spec. Min.
7085-T7452	Hand Forging	L-T	2.0-4.0	1	8	2005-2006	4/06	M06-16	1.0-1.5	50	42[f]	37	5.3[f]	30
7085-T7452	Hand Forging	T-L	2.0-4.0	1	12	2005-2006	4/06	M06-16	1.0-1.5	33	29[f]	26	6.4[f]	19
7085-T7452	Hand Forging	S-L	2.0-4.0	1	10	2005-2006	4/06	M06-16	0.75-1.5	33	27[f]	26	5.5[f]	19
7085-T7452	Hand Forging	L-T	4.0-6.0	1	7	2005-2006	4/06	M06-16	1.5	50	39[f]	35	5.7[f]	28
7085-T7452	Hand Forging	T-L	4.0-6.0	1	10	2005-2006	4/06	M06-16	1.5	31	27[f]	28	6.9[f]	19
7085-T7452	Hand Forging	S-L	4.0-6.0	1	10	2005-2006	4/06	M06-16	1.5	33	25[f]	24	5.9[f]	17
7085-T7452	Hand Forging	L-T	6.0-8.0	1	14	2005-2006	4/06	M06-16	1.5	39	36[f]	29	6.2[f]	26
7085-T7452	Hand Forging	T-L	6.0-8.0	1	15	2005-2006	4/06	M06-16	1.5	34	25[f]	21	7.4[f]	17
7085-T7452	Hand Forging	S-L	6.0-8.0	1	14	2005-2006	4/06	M06-16	1.5	29	23[f]	19	6.4[f]	16
7085-T7452	Hand Forging	L-T	8.0-10.0	1	22	2005-2006	4/06	M06-16	1.5	40	34[f]	25	6.5[f]	24
7085-T7452	Hand Forging	T-L	8.0-10.0	1	22	2005-2006	4/06	M06-16	1.5	34	23[f]	21	8.1[f]	15
7085-T7452	Hand Forging	S-L	8.0-10.0	1	21	2005-2006	4/06	M06-16	1.5	29	21[f]	19	7.1[f]	15
7085-T7452	Hand Forging	L-T	10.0-12.0	1	22	2005-2006	4/06	M06-16	1.5	41	31[f]	25	7.2[f]	22
7085-T7452	Hand Forging	T-L	10.0-12.0	1	23	2005-2006	4/06	M06-16	1.5	24	20[f]	18	9.3[f]	14
7085-T7452	Hand Forging	S-L	10.0-12.0	1	23	2005-2006	4/06	M06-16	1.5	22	20[f]	18	7.4[f]	13
7085-T7651	Plate	L-T	4.0-5.0	1	44	2005-2006	4/06	M06-16	2.0	40	36	30	6.4	29
7085-T7651	Plate	T-L	4.0-5.0	1	81	2005-2006	4/06	M06-16	2.0	30	28	26	3.5	24
7085-T7651	Plate	S-L	4.0-5.0	1	80	2005-2006	4/06	M06-16	2.0	32	29	25	4.7	24
7085-T7651	Plate	L-T	5.0-6.0	1	17	2005-2006	4/06	M06-16	2.0	33	31	28	4.5	27
7085-T7651	Plate	T-L	5.0-6.0	1	44	2005-2006	4/06	M06-16	2.0	28	26	23	4.4	22
7085-T7651	Plate	S-L	5.0-6.0	1	44	2005-2006	4/06	M06-16	2.0	36	28	22	8.7	23
7085-T7651	Plate	L-T	6.0-7.0	1	132	2005-2006	4/06	M06-16	2.0	36	31	28	4.4	26
7085-T7651	Plate	T-L	6.0-7.0	1	132	2005-2006	4/06	M06-16	2.0	28	24	21	4.0	21
7085-T7651	Plate	S-L	6.0-7.0	1	132	2005-2006	4/06	M06-16	2.0	31	26	22	5.6	22
7085-T7651	Plate	L-T	7.0-8.0	1	17	2005-2006	4/06	M06-16	2.0	32	30	28	3.6	
7085-T7651	Plate	T-L	7.0-8.0	1	17	2005-2006	4/06	M06-16	2.0	25	23	21	3.9	
7085-T7651	Plate	S-L	7.0-8.0	1	17	2005-2006	4/06	M06-16	2.0	30	26	24	5.1	

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c Refer to Figures 1.4.12.3(a) and 1.4.12.3(b) for definition of symbols.

d Specimen thickness range was provided from one source.

e Varies with thickness.

f Determined using quadratic regression from 4 to 10 inches.

Table 3.1.2.1.4. Values of Room Temperature Plane-Strain Fracture Toughness of Aluminum Alloys[a]

Alloy/Temper	Product Form[b]	Orientation[c]	Product Thickness, inches	Number of Sources	Sample Size	Date of Data Generation	Approved		Specimen Thickness, inches	K_{IC}, ksi$\sqrt{in.}$				
							Date	Item		Max.	Avg.	Min.	COV	Spec. Min.
7140-T7451	Plate	L-T	4-5	1	2	2005	4/06	M05-25	2	-	36[f]	-	7.84[f]	29
7140-T7451	Plate	T-L	4-5	1	4	2005	4/06	M05-25	2	32	31[f]	28	6.84[f]	24
7140-T7451	Plate	S-L	4-5	1	6	2005	4/06	M05-25	1	30	28[f]	26	4.52[f]	23
7140-T7451	Plate	L-T	5-6	1	80	2005	4/06	M05-25	2	42	33[f]	29	7.84[f]	26
7140-T7451	Plate	T-L	5-6	1	80	2005	4/06	M05-25	2	34	28[f]	25	6.84[f]	23
7140-T7451	Plate	S-L	5-6	1	2	2005	4/06	M05-25	1	-	27[f]	-	4.52[f]	22
7140-T7451	Plate	L-T	6-7	1	3	2005	4/06	M05-25	2	-	31[f]	-	7.84[f]	24
7140-T7451	Plate	T-L	6-7	1	3	2005	4/06	M05-25	2	-	25[f]	-	6.84[f]	21
7140-T7451	Plate	S-L	6-7	1	3	2005	4/06	M05-25	1	-	26[f]	-	4.52[f]	22
7140-T7451	Plate	L-T	7-8	1	21	2005	4/06	M05-25	2	32	29[f]	28	7.84[f]	22
7140-T7451	Plate	T-L	7-8	1	24	2005	4/06	M05-25	2	26	21[f]	22	6.84[f]	19
7140-T7451	Plate	S-L	7-8	1	20	2005	4/06	M05-25	1	27	26[f]	24	4.52[f]	22
7140-T7451	Plate	L-T	8-9	1	2	2005	4/06	M05-25	2	-	28[f]	-	7.84[f]	22
7140-T7451	Plate	T-L	8-9	1	2	2005	4/06	M05-25	2	-	23[f]	-	6.84[f]	19
7140-T7451	Plate	S-L	8-9	1	2	2005	4/06	M05-25	1	-	25[f]	-	4.52[f]	20
7140-T7451	Plate	L-T	9-10	1	18	2005	4/06	M05-25	2	30	28[f]	27	7.84[f]	22
7140-T7451	Plate	T-L	9-10	1	19	2005	4/06	M05-25	2	24	23[f]	21	6.84[f]	19
7140-T7451	Plate	S-L	9-10	1	16	2005	4/06	M05-25	1	26	25[f]	22	4.52[f]	20
7140-T7651	Plate	L-T	4-5	1	107	2006	4/08	M07-43	2	45	34	28	8.3	27
7140-T7651	Plate	T-L	4-5	1	109	2006	4/08	M07-43	2	30	26	23	5.2	22
7140-T7651	Plate	S-L	4-5	1	109	2006	4/08	M07-43	1	32	27	22	6.4	22
7140-T7651	Plate	L-T	5-6	1	210	2006	4/08	M07-43	2	37	32	26	7.1	25
7140-T7651	Plate	T-L	5-6	1	210	2006	4/08	M07-43	2	31	26	22	6.3	21
7140-T7651	Plate	S-L	5-6	1	210	2006	4/08	M07-43	1	30	26	22	1.5	22
7140-T7651	Plate	L-T	6-7	1	106	2006	4/08	M07-43	2	36	31	26	6.3	24
7140-T7651	Plate	T-L	6-7	1	106	2006	4/08	M07-43	2	31	27	22	7.1	20
7140-T7651	Plate	S-L	6-7	1	106	2006	4/08	M07-43	1	29	26	23	1.3	22

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c Refer to Figures 1.4.12.3(a) and 1.4.12.3(b) for definition of symbols.

d Specimen thickness range was provided from one source.

e Varies with thickness.

f Determined using quadratic regression from 4 to 10 inches.

Table 3.1.2.1.4. Values of Room Temperature Plane-Strain Fracture Toughness of Aluminum Alloys[a]

Alloy/Temper	Product Form[b]	Orien-tation[c]	Product Thickness, inches	Number of Sources	Sample Size	Date of Data Generation	Approved		Specimen Thickness, inches	K_{IC}, ksi$\sqrt{in.}$				
							Date	Item		Max.	Avg.	Min.	COV	Spec. Min.
7140-T7651	Plate	L-T	7-8	1	18	2006	4/08	M07-43	2	33	30	28	4.7	22
7140-T7651	Plate	T-L	7-8	1	18	2006	4/08	M07-43	2	26	24	22	3.9	19
7140-T7651	Plate	S-L	7-8	1	18	2006	4/08	M07-43	1	27	25	23	3.7	22
7140-T7651	Plate	L-T	8-9	1	3	2006	4/08	M07-43	2	...	30[f]	...	3.2[f]	20
7140-T7651	Plate	T-L	8-9	1	3	2006	4/08	M07-43	2	...	24[f]	...	2.3[f]	18
7140-T7651	Plate	S-L	8-9	1	3	2006	4/08	M07-43	1	...	25[f]	...	1.2[f]	20
7140-T7651	Plate	L-T	9-10	1	2	2006	4/08	M07-43	2	...	32[f]	...	3.2[f]	18
7140-T7651	Plate	T-L	9-10	1	2	2006	4/08	M07-43	2	...	23[f]	...	1.2[f]	17
7140-T7651	Plate	S-L	9-10	1	2	2006	4/08	M07-43	1	...	25[f]	...	10.2[f]	20
7150-T77511	Extrusion	L-T	0.76	1	52	2005	4/03	M02-14	0.5	36	31	26	7.7	24
7150-T77511	Extrusion	T-L	0.76	1	52	2005	4/03	M02-14	0.5	27	24	21	5.1	20
7175-T6/T6511	Extrusion	T-L	----	2	25	1973-1975	5/82	78-09	0.8-1.0	24	21	18	7.9	
7175-T651	Plate	L-T	----	1	17	1973-1975	5/82	78-09	0.7-0.8	30	26	24	9.2	
7175-T651	Plate	T-L	----	1	10	1973-1975	5/82	78-09	0.7-0.8	26	22	20	9.8	
7175-T6511	Extrusion	L-T	----	2	14	1973-1975	5/82	78-09	0.8-1.0	36	32	24	13.8	
7175-T7351	Plate	L-T	----	2	30	1973-1975	5/82	78-09	0.7-1.6	36	33	32	3.3	
7175-T7351	Plate	T-L	----	2	32	1973-1975	5/82	78-09	0.7-1.6	30	27	25	4.5	
7175-T73511	Extrusion	L-T	≥0.7	5	43	1973-1975	5/82	78-09	0.5-1.5	47	33	23	16.0	30
7175-T73511	Extrusion	T-L	≥0.5	5	43	1973-1975	5/82	78-09	0.5-1.5	35	25	20	10.9	22
7175-T74	Die Forging	L-T	≥0.5	3	14	1973-1975	5/82	78-09	0.5-1.0	38	30	22	15.0	27
7175-T74	Die Forging	T-L	≥0.5	2	13	1973-1975	5/82	78-09	0.5-1.0	33	24	21	15.7	21
7175-T74	Die Forging	S-L	≥0.5	4	41	1973-1975	5/82	78-09	0.5-0.8	31	26	20	8.6	21
7175-T74	Hand Forging	T-L	3.0-5.0	2	10	1973-1975	5/82	78-09	1.0-1.5	29	26	24	4.8	25
7175-T7651	Clad Plate	L-T	----	1	53	1973-1975	5/82	78-09	1.5	33	32	30	4.3	
7175-T7651	Clad Plate	T-L	----	1	50	1973-1975	5/82	78-09	0.6	28	27	25	3.1	
7175-T7651	Plate	L-T	----	1	12	1973-1975	5/82	78-09	1.5	32	32	31	1.7	
7175-T7651	Plate	T-L	----	1	11	1973-1975	5/82	78-09	1.5	26	25	24	3.3	
7175-T76511	Extrusion	L-T	1.4-3.8	2	48	1973-1975	5/82	78-09	0.6-2.0	39	33	27	10.7	
7175-T76511	Extrusion	T-L	≥0.6	4	49	1973-1975	5/82	78-09	0.6-1.8	31	22	20	9.8	

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c Refer to Figures 1.4.12.3(a) and 1.4.12.3(b) for definition of symbols.

d Specimen thickness range was provided from one source.

e Varies with thickness.

f Determined using quadratic regression from 4 to 10 inches.

Table 3.1.2.1.4. Values of Room Temperature Plane-Strain Fracture Toughness of Aluminum Alloys[a]

Alloy/Temper	Product Form[b]	Orientation[c]	Product Thickness, inches	Number of Sources	Sample Size	Date of Data Generation	Approved		Specimen Thickness, inches	K_{IC}, ksi$\sqrt{in.}$				
							Date	Item		Max.	Avg.	Min.	COV	Spec. Min.
7449-T7951	Plate	L-T	0.75-1	1	638	2004	10/06	M05-07	Full [d]	30	24	21	7.0	21
7449-T7951	Plate	T-L	0.75-1	1	626	2004	10/06	M05-07	Full [d]	27	22	19	6.2	19
7449-T7951	Plate	L-T	1-1.5	1	274	2004	10/06	M05-07	Full [d]	34	24	21	6.9	21
7449-T7951	Plate	T-L	1-1.5	1	313	2004	10/06	M05-07	Full [d]	25	22	19	5.4	19
7449-T7951	Plate	L-T	1.5-2.5	1	161	2004	10/06	M05-07	[d]	37	26	23	5.8	20
7449-T7951	Plate	T-L	1.5-2.5	1	197	2004	10/06	M05-07	[d]	26	23	21	4.5	18
7475-T651	Plate	L-T	----	3	34	1973-1975	5/82	78-09	0.9-2.0	49	38	33	9.2	30
7475-T651	Plate	T-L	0.6-2.0	2	143	1973-1975	5/82	78-09	0.6-2.0	43	34	27	9.8	28
7475-T651	Plate	S-L	≥0.6	1	23	1973-1975	5/82	78-09	0.5-1.0	36	28	20	14.9	
7475-T7351	Plate	L-T	1.3-4.0	8	151	1973-1975	5/82	78-09	1.3-3.0	60	47	34	10.4	e
7475-T7351	Plate	T-L	≥1.3	7	132	1973-1975	5/82	78-09	0.7-3.0	50	37	29	10.4	e
7475-T7351	Plate	S-L	≥0.7	7	74	1973-1975	5/82	78-09	0.5-1.5	36	30	25	8.7	25
7475-T7651	Plate	L-T	1.0-2.0	4	10	1973-1975	5/82	78-09	1.0-2.0	46	41	36	6.2	33
7475-T7651	Plate	T-L	≥1.0	2	15	1973-1975	5/82	78-09	0.9-2.0	50	36	29	14.5	30

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c Refer to Figures 1.4.12.3(a) and 1.4.12.3(b) for definition of symbols.

d Specimen thickness range was provided from one source.

e Varies with thickness.

f Determined using quadratic regression from 4 to 10 inches.

3.1.2.2 *Physical Properties* — Where available from the literature, the average values of certain physical properties are included in the room temperature tables for each alloy. These properties include density, ω, in lb/in.^{3}; the specific heat, C, in Btu/(lb)(°F); the thermal conductivity, K, in Btu/[(hr)(ft^2)(°F)/ft]; and the mean coefficient of thermal expansion, α, in in./in./°F. Where more extensive data are available to show the effect of temperature on these physical properties, graphs of physical property as a function of temperature are presented for the applicable alloys.

3.1.2.3 *Corrosion Resistance*

3.1.2.3.1 *Resistance to Stress-Corrosion Cracking* — In-service stress-corrosion cracking failures can be caused by stresses produced from a wide variety of sources, including solution heat treatment, straightening, forming, fit-up, clamping, and sustained service loads. These stresses may be tensile or compressive, and the stresses due to Poisson effects should not be ignored because SCC failures can be caused by sustained shear stresses. Pin-hole flaws in some corrosion protection coatings may also be sufficient to allow SCC to occur. The high-strength, heat-treatable wrought aluminum alloys in certain tempers are susceptible to stress-corrosion cracking, depending upon product, section size, direction and magnitude of stress [see References 3.1.2.3.1(a) through 3.1.2.3.1(d)]. These alloys include 2014, 2025, 2618, 7075, 7150, 7175, and 7475 in the T6-type tempers and 2014, 2024, 2124, and 2219 in the T3- and T4-type tempers. Other alloy-temper combinations, notably 2024, 2124, 2219, and 2519 in the T6- or T8-type tempers and 7010, 7049, 7050, 7075, 7149, 7175, and 7475 in the T73-type tempers, are decidedly more resistant and sustained tensile stresses of 50 to 75 percent of the minimum yield strength may be permitted without concern about stress corrosion cracking. The T74 and T76 tempers of 7010, 7075, 7475, 7049, 7149, and 7050 provide an intermediate degree of resistance to stress-corrosion cracking, i.e., superior to that of the T6 temper, but not as good as the T73 temper of 7075. To assist in the selection of materials, letter ratings indicating the relative resistance to stress corrosion cracking of various mill product forms of the wrought 2000, 6000, and 7000 series heat-treated aluminum alloys are presented in Table 3.1.2.3.1(a). This table is based upon ASTM G 64, which contains more detailed information regarding this rating system and the procedure for determining the ratings. In addition, more quantitative information in the form of the maximum specified tension stresses at which test specimens will not fail when subjected to the alternate immersion stress-corrosion test described in ASTM G 47 are shown in Tables 3.1.2.3.1(b) through 3.1.2.3.1(e) for various heat-treated aluminum product forms, alloys, and tempers.

Where short times at elevated temperatures of 150° to 500°F may be encountered, the precipitation heat-treated tempers of 2024 and 2219 alloys are recommended over the naturally aged tempers.

Alloys 5083, 5086, and 5456 should not be used under high constant applied stress for continuous service at temperatures exceeding 150°F, because of the hazard of developing susceptibility to stress corrosion cracking. In general, the H34 through H38 tempers of 5086, and the H32 through H38 tempers of 5083 and 5456 are not recommended, because these tempers can become susceptible to stress corrosion cracking.

For the cold forming of 5083 sheet and plate in the H112, H321, H323, and H343 tempers and 5456 sheet and plate in the H112 and H321 tempers, a minimum bend radius of 5T should be used. Hot forming of the O temper for alloys 5083 and 5456 is recommended, and is preferred to the cold-worked tempers to avoid excessive cold work and high residual stress. Cold-worked tempers of heat-treatable alloys are heated for subsequent hot forming, a slight decrease in mechanical properties, particularly yield strength, may result.

Table 3.1.2.3.1(a). Resistance to Stress Corrosion Ratings[a] for High-Strength Aluminum Alloy Products

Alloy and Temper[b]	Test Direction[c]	Rolled Plate	Rod and Bar[d]	Extruded Shapes	Forging
2013-T6511	LT	[f]	[f]	A	[f]
2014-T6	L	A	A	A	B
	LT	B[e]	D	B[e]	B[e]
	ST	D	D	D	D
2024-T3, T4	L	A	A	A	[f]
	LT	B[e]	D	B[e]	[f]
	ST	D	D	D	[f]
2024-T6	L	[f]	A	[f]	A
	LT	[f]	B	[f]	A[e]
	ST	[f]	B	[f]	D
2024-T8	L	A	A	A	A
	LT	A	A	A	A
	ST	B	A	B	C
2124-T8	L	A	[f]	[f]	[f]
	LT	A	[f]	[f]	[f]
	ST	B	[f]	[f]	[f]
2219-T351X, T37	L	A	[f]	A	[f]
	LT	B	[f]	B	[f]
	ST	D	[f]	D	[f]
2219-T6	L	A	A	A	A
	LT	A	A	A	A
	ST	A	A	A	A
2219-T85XX, T87	L	A	[f]	A	A
	LT	A	[f]	A	A
	ST	A	[f]	A	A
6061-T6	L	A	A	A	A
	LT	A	A	A	A
	ST	A	A	A	A
7040-T7451	L	A	[f]	[f]	[f]
	LT	A	[f]	[f]	[f]
	ST	B	[f]	[f]	[f]
7049-T73	L	A	[f]	A	A
	LT	A	[f]	A	A
	ST	A	[f]	B	A
7049-T76	L	[f]	[f]	A	[f]
	LT	[f]	[f]	A	[f]
	ST	[f]	[f]	C	[f]
7050-T74	L	A	[f]	A	A
	LT	A	[f]	A	A
	ST	B	[f]	B	B
7050-T76	L	A	A	A	[f]
	LT	A	B	A	[f]
	ST	C	B	C	[f]
7075-T6	L	A	A	A	A
	LT	B[e]	D	B[e]	B[e]
	ST	D	D	D	D
7075-T73	L	A	A	A	A
	LT	A	A	A	A
	ST	A	A	A	A

Table 3.1.2.3.1(a). Resistance to Stress-Corrosion Ratings[a] for High-Strength Aluminum Alloy Products (Continued)

Alloy and Temper[b]	Test Direction[c]	Rolled Plate	Rod and Bar[d]	Extruded Shapes	Forging
7075-T74	L	f	f	f	A
	LT	f	f	f	A
	ST	f	f	f	B
7075-T76	L	A	f	A	f
	LT	A	f	A	f
	ST	C	f	C	f
7085-T7651	ST	C	f	f	f
7149-T73	L	f	f	A	A
	LT	f	f	A	A
	ST	f	f	B	A
7175-T74	L	f	f	f	A
	LT	f	f	f	A
	ST	f	f	f	B
7475-T6	L	A	f	f	f
	LT	B[e]	f	f	f
	ST	D	f	f	f
7475-T73	L	A	f	f	f
	LT	A	f	f	f
	ST	A	f	f	f
7475-T76	L	A	f	f	f
	LT	A	f	f	f
	ST	C	f	f	f

a Ratings were determined from stress corrosion tests performed on at least ten random lots for which test results showed 90% conformance with 95% confidence when tested at the following stresses:

A - Equal to or greater than 75% of the specified minimum yield strength. A very high rating. SCC not anticipated in general applications if the total sustained tensile stress* is less than 75% of the minimum specified yield stress for the alloy, heat treatment, product form, and orientation.

B - Equal to or greater than 50% of the specified minimum yield strength. A high rating. SCC not anticipated if the total sustained tensile stress* is less than 50% of the specified minimum yield stress.

C - Equal to or greater than 25% of the specified minimum yield stress or 14.5 ksi, whichever is higher. An intermediate rating. SCC not anticipated if the total sustained tensile stress* is less than 25% of the specified minimum yield stress. This rating is designated for the short-transverse direction in improved products used primarily for high resistance to exfoliation corrosion in relatively thin structures where applicable short-transverse stresses are unlikely.

D - Fails to meet the criterion for the rating C. A low rating. SCC failures have occurred in service or would be anticipated if there is any sustained tensile stress* in the designated test direction. This rating is currently designated only for the short-transverse direction in certain materials.

NOTE - The above stress levels are not to be interpreted as "threshold" stresses and are not recommended for design. Other documents, such as MIL-STD-1568, NAS SD-24, and MSFC-SPEC-522A should be consulted for design recommendations.

* The sum of all stresses, including those from service loads (applied), heat treatment, straightening, forming, etc.

b The ratings apply to standard mill products in the types of tempers indicated, including stress-relieved tempers, and could be invalidated in some cases by application of nonstandard thermal treatments of mechanical deformation at room temperature by the user.

c Test direction refers to orientation of the stressing direction relative to the directional grain structure typical of wrought materials, which in the case of extrusions and forgings, may not be predictable from the geometrical cross section of the product.
L—Longitudinal: parallel to the direction of principal metal extension during manufacture of the product.
LT—Long Transverse: perpendicular to direction of principal metal extension. In products whose grain structure clearly shows directionality (width-to-thickness ratio greater than two), it is that perpendicular direction parallel to the major grain dimension.
ST—Short Transverse: perpendicular to direction of principal metal extension and parallel to minor dimension of grains in products with significant grain directionality.

d Sections with width-to-thickness ratio equal to or less than two for which there is no distinction between LT and ST.

e Rating is one class lower for thicker sections: extrusion, 1 inch and over; plate and forgings, 1.5 inches and over.

f Ratings not established because the product is not offered commercially.
NOTE: This table is based upon ASTM G 64.

Table 3.1.2.3.1(b). Maximum Specified Tension Stress at Which Test Specimens Will Not Fail in 3½% NaCl Alternate Immersion Test[a] for Various Stress Corrosion Resistant Aluminum Alloy Plate

Alloy and Temper	Test Direction	Thickness, inches	Stress, ksi	Referenced Specifications
2024-T851	ST	1.001-4.000	28[b]	Company specification
		4.001-6.000	27[b]	
2090-T81[c]	ST	0.750-1.500	20	AMS 4303
2098-T82P	LT	0.125	35	AMS 4327
2124-T851	ST	1.500-1.999	28[b]	AMS 4101
		2.000-4.000	28[b]	AMS-QQ-A-250/29, ASTM B 209, AMS 4101
		4.001-6.000	27[b]	
2124-T8151[c]	ST	1.500-3.000	30[b]	AMS 4221
		3.001-5.000	29[b]	
		5.001-6.000	28[b]	
2219-T851	ST	0.750-2.000	34[d]	AMS-QQ-A-250/30
		2.001-4.000	33[d]	
		4.001-5.000	32[d]	
		5.001-6.000	31[d]	
2219-T87	ST	0.750-3.000	38[d]	AMS-QQ-A-250/30
		3.001-4.000	37[d]	
		4.001-5.000	36[d]	
2519-T87	ST	0.750-4.000	43[d]	MIL-DTL-46192
7010-T7351[c]	ST	0.750-3.000	41[d]	AMS 4203
		3.001-5.000	40[d]	
		5.001-5.500	39[d]	
7010-T7451	ST	0.750-3.000	31[b]	AMS 4205
		3.001-5.500	35	
7010-T7651	ST	0.750-5.500	25	AMS 4204
7049-T7351	ST	0.750-5.000	45	AMS 4200
7050-T7451	ST	0.750-6.000	35	AMS 4050
7050-T7651	ST	0.750-3.000	25	AMS 4201
7075-T7351	ST	0.750-2.000	42[d]	AMS-QQ-A-250/12, AMS 4078, ASTM B 209
		2.001-2.500	39[d]	
		2.501-4.000	36[d]	
7075-T7651	ST	0.750-1.000	25	AMS-QQ-A-250/24, ASTM B 209
Clad 7075-T7651	ST	0.750-1.000	25	AMS-QQ-A-250/25, ASTM B 209
7085-T7651	ST	4.000-7.000	26	AMS 4329
7150-T7751	ST	0.750-3.000	25	AMS 4252
7475-T7351	ST	0.750-4.000	40	AMS 4202
7475-T7651	ST	0.750-1.500	25	AMS 4089

a Most specifications reference ASTM G 47, which requires exposures of 10 days for 2XXX alloys and 20 days for 7XXX alloys in ST test direction.
b 50% of specified minimum long transverse yield strength.
c Design values are not included in MMPDS.
d 75% of specified minimum long transverse yield strength.

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Table 3.1.2.3.1(c). Maximum Specified Tension Stress at Which Test Specimens Will Not Fail in 3½% NaCl Alternate Immersion Test[a] for Various Stress Corrosion Resistant Aluminum Alloy Rolled Bars, Rods, and Extrusions

Alloy and Temper	Product Form	Test Direction	Thickness, inches	Stress, ksi	Referenced Specifications
7075-T73, T7351	Rolled Bar and Rod	ST	0.750-3.000	42[b]	AMS-QQ-A-225/9, AMS 4124, ASTM B 211
2013-T6511	Extrusion	LT	< 0.200	42	AMS 4326
2219-T8511	Extrusion	ST	0.750-3.000	30	AMS 4162, AMS 4163
7049-T73511	Extrusion	ST	0.750-2.999	41[c]	AMS 4157
			3.000-5.000	40[c]	
7049-T76511[d]	Extrusion	ST	0.750-5.000	20	AMS 4159
7050-T73511	Extrusion	ST	0.750-5.000	45	AMS 4341
7050-T74511	Extrusion	ST	0.750-5.000	35	AMS 4342
7050-T76511	Extrusion	ST	0.750-5.000	17	AMS 4340
7075-T73, T73510, T73511	Extrusion	ST	0.750-1.499	45[b]	AMS-QQ-A-200/11, AMS 4166, AMS 4167, ASTM B 211
			1.500-2.999	44[b]	
			3.000-4.999	42[b]	
			3.000-4.999	41[b,e]	
7075-T76, T76510, T76511	Extrusion	ST	0.750-1.000	25	AMS-QQ-A-200/15, ASTM B 221
7149-T73511[d]	Extrusion	ST	0.750-2.999	41[c]	AMS 4543
			3.000-5.000	40[c]	
7150-T77511	Extrusion	ST	0.750-2.000	25	AMS 4345
7175-T73511	Extrusion	ST	0.750-2.000	44	AMS 4344
7249-T76511	Extrusion	ST	0.760	25	AMS 4293
7449-T79511	Extrusion	LT[f]	0.500-1.750	45	AMS 4305

a Most specifications reference ASTM G 47, which requires exposures of 10 days for 2XXX alloys and 20 days for 7XXX alloys in ST test direction.
b 75% of specified minimum longitudinal yield strength.
c 65% of specified minimum longitudinal yield strength.
d Design values are not included in MMPDS-01.
e Over 20 square inches cross-sectional area.
f Test duration exceeded 40 days as specified in ASTM G47 for testing in the LT direction.

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Table 3.1.2.3.1(d). Maximum Specified Tension Stress at Which Test Specimens Will Not Fail in 3½% NaCl Alternate Immersion Test[a] for Various Stress Corrosion-Resistant Aluminum Die Forgings

Alloy and Temper	Test Direction	Thickness, inches	Stress, ksi	Referenced Specifications
7049-T73	ST	0.750-2.000	46[b]	AMS-QQ-A-367, AMS 4111, ASTM B 247
		2.001-5.000	45[b]	
7050-T74	ST	0.750-6.000	35	AMS 4107
7050-T7452	ST	0.750-4.000	35	AMS 4333
7075-T73	ST	0.750-3.000	42[b]	AMS-A-22771, AMS-QQ-A-367
		3.001-4.000	41[b]	AMS 4241, ASTM B 247
		4.001-5.000	39[b]	AMS 4141
		5.001-6.000	38[b]	
7075-T7352	ST	0.750-3.000	42[b]	AMS-A-22771, AMS-QQ-A-367, AMS 4147, ASTM B 247
		3.001-4.000	39[b]	
7075-T7354[c]	ST	0.750-3.000	42	Company Specification
7075-T74[c]	ST	0.750-3.000	35	AMS 4131
		3.001-4.000	31[d]	
		4.001-5.000	30[d]	
		5.001-6.000	29[d]	
7149-T73	ST	0.750-2.000	46[b]	AMS 4320
		2.001-5.000	45[b]	
7175-T74	ST	0.750-3.000	35	AMS 4149, ASTM B 247
		3.001-4.000	31[d]	AMS 4149
		4.001-5.000	30[d]	
		5.001-6.000	29[d]	
7175-T7452[c]	ST	0.750-3.000	35	AMS 4179

a Most specifications Reference ASTM G 47, which requires 20 days of exposure for 7XXX alloys in ST test direction.
b 75% of specified minimum longitudinal yield strength.
c Design values are not included in MMPDS.
d 50% of specified minimum longitudinal yield strength.

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Table 3.1.2.3.1(e). Maximum Specified Tension Stress at Which Test Specimens Will Not Fail in 3½% NaCl Alternate Immersion Test[a] for Various Stress Corrosion-Resistant Aluminum Hand Forgings

Alloy and Temper	Test Direction	Thickness, inches	Stress, ksi	Referenced Specifications
7049-T73	ST	2.001-3.000	45[b]	AMS-QQ-A-367, AMS 4111, ASTM B 247
		3.001-4.000	44[b]	
		4.001-5.000	42[b]	
7049-T7352[c]	ST	0.750-3.000	44[b]	AMS 4247
		3.001-4.000	43[b]	
		4.001-5.000	40[b]	
7050-T7452	ST	0.750-8.000	35	AMS 4108
7075-T73	ST	0.750-3.000	42[b]	AMS-A-22771, AMS-QQ-A-367,
		3.001-4.000	41[b]	ASTM B 247
		4.001-5.000	39[b]	
		5.001-6.000	38[b]	
7075-T7352	ST	0.750-3.000	39[d]	AMS 4147
		3.001-4.000	37[d]	
		4.001-5.000	36[d]	
		5.001-6.000	34[d]	
7075-T74[c]	ST	0.750-3.000	35	AMS 4131
		3.001-4.000	30[e]	
		4.001-5.000	28[e]	
		5.001-6.000	27[e]	
7075-T7452[c]	ST	0.750-2.000	35	AMS 4323
		2.001-3.000	29[f]	
		3.001-4.000	28[f]	
		4.001-5.000	26[f]	
		5.001-6.000	24[f]	
7149-T73	ST	2.000-3.000	44[d]	AMS 4320
		3.001-4.000	43[d]	
		4.001-5.000	42[d]	
7175-T74	ST	0.750-3.000	35	AMS 4149
		3.001-4.000	29[f]	
		4.001-5.000	28[f]	
		4.001-6.000	26[f]	
7175-T7452	ST	0.750-3.000	35	AMS 4179
		3.001-4.000	27[f]	
		4.001-5.000	26[f]	
		5.001-6.000	24[f]	

a Most specifications Reference ASTM G 47, which requires 20 days of exposure for 7XXX alloys in ST test direction.
b 75% of specified minimum longitudinal yield strength.
c Design values are not included in MMPDS.
d 75% of specified minimum long-transverse yield strength.
e 50% of specified minimum longitudinal yield strength.
f 50% of specified minimum long-transverse yield strength.

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3.1.2.3.2 *Resistance to Exfoliation* — The high-strength wrought aluminum alloys in certain tempers are susceptible to exfoliation corrosion, dependent upon product and section size. Generally those alloys and tempers that have the lowest resistance to stress corrosion cracking also have the lowest resistance to exfoliation [Reference 3.1.2.3.2]. The tempers that provide improved resistance to stress corrosion cracking also provide improved resistance or immunity to exfoliation. For example, the T76 temper of 7075, 7049, 7050, and 7475 provides a very high resistance to exfoliation, i.e., decidedly superior to the T6 temper, and almost the immunity provided by the T73 temper of 7075 alloy [Reference 3.1.2.3.2].

3.1.3 MANUFACTURING CONSIDERATIONS

3.1.3.1 *Avoiding Stress Corrosion Cracking* — In order to avoid stress corrosion cracking (see Section 3.1.2.3), practices, such as the use of press or shrink fits, taper pins, clevis joints in which tightening of the bolt imposes a bending load on female lugs; and straightening or assembly operations, which result in sustained surface tensile stresses (especially when acting in the short-transverse grain orientation) should be avoided in these high-strength alloys: 2014-T451, T4, T6, T651, T652; 2024-T3, T351, T4; 7075-T6, T651, T652; 7150-T6151, T61511; and 7475-T6, T651.

Where straightening or forming is necessary, it should be performed when the material is in the freshly quenched condition or at an elevated temperature to minimize the residual stress induced. Where elevated temperature forming is performed on 2014-T4 T451 or 2024-T3 T351, a subsequent precipitation heat treatment to produce the T6 or T651, T81 or T851 temper is recommended.

It is good engineering practice to control sustained short-transverse tensile stress at the surface of structural parts at the lowest practicable level. Thus, careful attention should be given in all stages of manufacturing, starting with the design of the part configuration, to choose practices in the heat treatment, fabrication, and assembly to avoid unfavorable combinations of end grain microstructure and sustained tensile stress. The greatest danger arises when residual, assembly, and service stress combine to produce high-sustained tensile stress at the metal surface. Sources of residual and assembly stress have been the most contributory to stress corrosion cracking problems because their presence and magnitude were not recognized. In most cases, the design stresses (developed by functional loads) are not continuous and would not be involved in the summation of sustained tensile stress. It is imperative that, for materials with low resistance to stress corrosion cracking in the short-transverse grain orientation, every effort be taken to keep the level of sustained tensile stress close to zero.

3.1.3.2 *Cold-Formed, Heat-Treatable Aluminum Alloys* — Cold working such as stretch forming of aluminum alloy prior to solution heat treatment may result in recrystallization or grain growth during heat treatment. The resulting strength, particularly yield strength, may be significantly below the specified minimum values. For critical applications, the strength should be determined on the part after forming and heat treating, including straightening operations. To minimize recrystallization during heat treatment, it is recommended that forming be done after solution heat treatment in the as-quenched condition whenever possible, but this may result in compressive yield strength in the direction of stretching being lower than MMPDS design allowables for user heat treat tempers.

3.1.3.3 *Dimensional Changes* — The dimensional changes that occur in aluminum alloy during thermal treatment generally are negligible, but in a few instances these changes may have to be considered in manufacturing. Because of many variables involved, there are no tabulated values for these dimensional changes. In the artificial aging of alloy 2219 from the T42, T351, and T37 tempers to the T62, T851, and T87 tempers, respectively, a net dimensional growth of 0.00010 to 0.0015 in./in. may be anticipated. Additional growth of as much as 0.0010 in./in. may occur during subsequent service of a year or more at 300°F or equivalent shorter exposures at higher temperatures. The dimensional changes that occur during the artificial aging of other wrought heat-treatable alloys are less than one-half that for alloy 2219 under the same conditions.

3.1.3.4 *Welding* — The ease with which aluminum alloys may be welded is dependent principally upon composition, but the ease is also influenced by the temper of the alloy, the welding process, and the filler metal used. Also, the weldability of wrought and cast alloys is generally considered separately.

Several weldability rating systems are established and may be found in publications by the Aluminum Association, American Welding Society, Society for Automotive Engineers, and the American Society for Metals. Handbooks from these groups can be consulted for more detailed information. For example, Specification AWS D17.1, Specification for Fusion Welding for Aerospace Applications, and "Welding Aluminum: Theory and Practice" [Reference 3.1.3.4] contains useful information. This document follows most of these references in adopting a four-level rating system. An "A" level, or readily weldable, means that the alloy (and temper) is routinely welded by the indicated process using commercial procedures. A "B" level means that welding is accomplished for many applications, but special techniques are required, and the application may require preliminary trials to develop procedures and tests to demonstrate weld performance. A "C" level refers to limited weldability because crack sensitivity, loss of corrosion resistance, and/or loss of mechanical properties may occur. An "X" level indicates welding is not recommended.

The weldability of aluminum alloys is rated by alloy, temper, and welding process (arc or resistance). Tables 3.1.3.4(a) and 3.1.3.4(b) list the ratings in the alloy section number order in which they appear in Chapter 3.

When heat-treated or work-hardened materials of most systems are welded, a loss of mechanical properties generally occurs. The extent of the loss (if not reheat treated) over the table strength allowables will have to be established for each specific situation.

Table 3.1.3.4(a). Fabrication Weldability of Wrought Aluminum Alloys

MMPDS Section No.	Alloy	Tempers	Weldability[a,b] Inert Gas Metal or Tungsten Arc	Resistance Spot[c]
3.2.1	2013	...	...	...
3.2.2	2014	O	C	D
		T6, T62, T651, T652, T6510, T6511	B	B
3.2.3	2017	T4, T42, T451	C	B
3.2.4	2024	O	D	D
		T3, T351, T361, T4, T42	C	B
		T6, T62, T81, T851, T861	C	B
		T8510, T8511, T3510, T3511	C	B
3.2.5	2025	T6	C	B
3.2.6	2026	...	...	...
3.2.7	2027	...	...	...
3.2.8	2056	...	...	...
3.2.9	2090	T83	B	B
3.2.10	2098	...	...	...
3.2.11	2099	...	...	...
3.2.12	2124	T851	C	B
3.2.13	2219	O	A	B-D
		T62, T81, T851, T87, T8510, T8511	A	A
3.2.14	2297	...	...	...
3.2.15	2397	...	...	...
3.2.16	2424	...	...	...
3.2.17	2519	T87	A	...
3.2.18	2524	...	...	...
3.2.19	2618	T61	C	B
3.5.1	5052	O	A	B
		H32, H34, H36, H38	A	A
3.5.2	5083	O	A	B
		H321, H323, H343, H111, H112	A	A
3.5.3	5086	O	A	B
		H32, H34, H36, H38, H111, H112	A	A
3.5.4	5454	O	A	B
		H32, H34, H111, H112	A	A
3.5.5	5456	O	A	B
		H111, H321, H112	A	A
3.6.1	6013	T6	A	A
3.6.2	6061	O	A	B
		T4, T42, T451, T4510, T4511, T6	A	A
		T62, T651, T652, T6510, T6511	A	A
3.6.3	6151	T6	A	A

Continued

Table 3.1.3.4(a). Fabrication Weldability of Wrought Aluminum Alloys (Continued)

MMPDS Section No.	Alloy	Tempers	Weldability[a,b]	
			Inert Gas Metal or Tungsten Arc	Resistance Spot[c]
3.7.1	7010	All	C	B
3.7.2	7040	All	C	B
3.7.3	7049/	All	C	B
	7149	...	...	...
3.7.4	7050	All	C	B
3.7.5	7055	...	...	...
3.7.6	7068	...	...	...
3.7.7	7075	All	C	B
3.7.8	7085	...	...	...
3.7.9	7140	...	...	...
3.7.10	7150	All	C	B
3.7.11	7175	All	C	B
3.7.12	7249	...	...	...
3.7.13	7349	...	...	...
3.7.14	7449	...	...	...
3.7.15	7475	All	C	B

a Ratings A, B, C and X are relative ratings defined as follows:
A - Generally weldable by all commercial procedures and methods.
B - Weldable with special techniques or for specific applications which justify preliminary trials or testing to develop welding procedures and weld performance.
C - Limited weldability because of crack sensitivity or loss in resistance to corrosion and mechanical properties.
X - Welding is not recommended

b When using filler wire, the wire should contain less than 0.0008 percent beryllium to avoid toxic fumes.

c See AMS-W-6858 for permissible combinations.

Table 3.1.3.4(b). Fabrication Weldability[a] of Cast Aluminum Alloys

MMPDS Section No.	Alloy	Weldability[b,c]	
		Inert Gas Metal or Tungsten Arc	Resistance Spot
3.8.1	A201.0	C	C
3.9.1	354.0	B	B
3.9.2	355.0	B	B
3.9.3	C355.0	B	B
3.9.4	356.0	A	A
3.9.5	A356.0	A	A
3.9.6	A357.0	A	B
3.9.7	D357.0	A	A
3.9.8	359.0	A	B

a Weldability related to joining a casting to another part of the same composition. The weldability ratings are not applicable to minor weld repairs. Such repairs shall be governed by the contractors procedure for in-process welding of castings, after approval by the procuring agency.

b Ratings A, B, C and X are relative ratings defined as follows:
- A - Generally weldable by all commercial procedures and methods.
- B - Weldable with special techniques or for specific applications that justify preliminary trials or testing to develop welding procedure and weld performance.
- C - Limited weldability because of crack sensitivity or loss in resistance to corrosion and mechanical properties.
- X - Welding is not recommended.

c When using filler wire, the wire should contain less than 0.0008 percent beryllium to avoid toxic fumes.

3.1.4 Obsolete Alloys, Tempers, and Product Forms – Table 3.1.4 includes a summary of the aluminum alloys, tempers, and product forms that have been removed from the Handbook, along with information regarding why and when they were removed.

Table 3.1.4 Obsolete Aluminum Alloys, Tempers, and Product Forms

Alloy	Heat Treatment(s)	Product Form	Specification	Basis for Removal	Removal Approved Item No.	Removal Approved Meeting	Last Shown Edition	Last Shown Date
224	Overaged	Casting	AMS 4226	Obsolete alloy	81-31	62	MIL-HDBK-5C, CN3	June 81
295	T4	Casting	AMS 4283	Cancelled specification	81-31	62	MIL-HDBK-5C, CN3	June 81
2021	T81	Sheet and Plate	-	-	72-17	46	Dropped - not covered by AMS spec	
355	T6	Permanent Mold Casting	QQ-A-596	Spec. Properties based on separately cast test bars	87-15	74	MIL-HDBK-5E	June 87
356	T6	Sand Casting	QQ-A-601					
		Investment Casting	AMS 4260					
520	T4	Sand Casting	QQ-A-601					
			AMS 4240	Cancelled specification	91-17	81	MIL-HDBK-5F	Dec 90
535	F	Casting	AMS 4238	Cancelled specification	81-31	62	MIL-HDBK-5C, CN3	June 81
	T2		AMS 4239	Cancelled specification				
6061	T6	Pipe	MIL-P-25995	Cancelled specification	02-21	02	MIL-HDBK-5J	Feb 03

Table 3.1.4 Obsolete Aluminum Alloys, Tempers, and Product Forms

Alloy	Heat Treatment(s)	Product Form	Specification	Basis for Removal	Removal Approved		Last Shown	
					Item No.	Meeting	Edition	Date
712	T5	Sand Casting	QQ-A-601	Spec. properties based on separately cast test bars	87-15	74	MIL-HDBK-5E	June 87
7001	T6 and T75	Plate	-	Highly susceptible to SCC	64-18	33	Dropped without inclusion	
7079	T6 and T62	One-side clad sheet	QQ-A-250/23	Obsolete alloy; highly susceptible to SCC	84-16	67	MIL-HDBK-5D, CN1	Jan 84
	T6 and T62	Clad sheet and plate	MIL-A-8923					
	T6 and T652	Forging	MIL-A-22771					
7178	T6, T62, T651, T76, and T7651	Bare sheet and plate	QQ-A-250/14, 21	Obsolete alloy; highly susceptible to SCC	86-32	72	MIL-HDBK-5D, CN3	May 86
	T6, T62, T651, T76 and T7651	Clad sheet and plate	QQ-A-250/15, 22					
	T6, T62, T6510, and T6511	Extrusion	QQ-A-250/13, 14					
	T6, T62, T651, T76, and T7651	7011 clad sheet and plate	QQ-A-250/28					