

Properties of Wrought Aluminum and Aluminum Alloys

1050 99.5 Al min

Specifications

ASTM. B 491

UNS number. A91050

Foreign. Canada: CSA 9950. France: NF A5. United Kingdom: BS 1B. West Germany: DIN A199.5

Chemical Composition

Composition limits. 99.50 Al min, 0.25 Si max, 0.40 Fe max, 0.05 Cu max, 0.05 Mn max, 0.05 Mg max, 0.05 V max, 0.03 max other (each)

Applications

Typical uses. Extruded coiled tube for equipment and containers for food, chemical, and brewing industries; collapsible tubes; pyrotechnic powder

Mechanical Properties

Tensile properties. See Table 1.

Mass Characteristics

Density. 2.705 g/cm³ (0.0977 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 657 °C (1215 °F)

Solidus temperature. 646 °C (1195 °F)

Coefficient of thermal expansion. Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.8	12.1
20 to 100	68 to 212	23.6	13.1
20 to 200	68 to 392	24.5	13.6
20 to 300	68 to 572	25.5	14.2

Volumetric: 68.1 × 10⁻⁶ m³/m³ · K (3.78 ×

Table 1 Typical mechanical properties of 1050 aluminum

Temper	Tensile strength		Yield strength		Elongation, %	Shear strength	
	MPa	ksi	MPa	ksi		MPa	ksi
O	76	11	28	4	39	62	9
H14	110	16	103	15	10	69	10
H16	131	19	124	18	8	76	11
H18	159	23	145	21	7	83	12

10⁻⁵ in.³/in.³ · °F)

Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. O temper, 231 W/m · K (133 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric. O temper, 61.3% IACS at 20 °C (68 °F)

Electrical resistivity. O temper: 28.1 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

1060 99.60 Al min

Specifications

AMS. Sheet and plate: 4000

ASME. See Table 2.

ASTM. See Table 2.

SAE. J454

UNS number. A91060

Chemical Composition

Composition limits. 99.60 Al min, 0.25 Si max, 0.35 Fe max, 0.05 Cu max, 0.03 Mn max, 0.03 Mg max, 0.05 Zn max, 0.05 V max, 0.03 Ti max, 0.03 max other (each)

Applications

Typical uses. Applications requiring very good resistance to corrosion and good formability, but tolerate low strength. Chemical process equipment is typical.

Mechanical Properties

Tensile properties. See Tables 3 and 4.

Hardness. See Table 3.

Poisson's ratio. 0.33 at 20 °C (68 °F)

Elastic modulus. Tension, 69 GPa (10 × 10⁶ psi)

Fatigue strength. See Table 3.

Mass Characteristics

Density. 2.705 g/cm³ (0.0977 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 657 °C (1215 °F)

Solidus temperature. 646 °C (1195 °F)

Coefficient of thermal expansion. Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.8	12.1
20 to 100	68 to 212	23.6	13.1
20 to 200	68 to 392	24.5	13.6
20 to 300	68 to 572	25.5	14.1

Volumetric: 68 × 10⁻⁶ m³/m³ · K (3.8 × 10⁻⁵ in.³/in.³ · °F)

Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. 234 W/m · K (135 Btu/ft · h · °F) at 25 °C (77 °F)

Electrical Properties

Electrical conductivity. Volumetric at 20 °C (68 °F): O temper, 62% IACS; H18 temper, 61% IACS

Electrical resistivity. At 20 °C (68 °F): O temper, 27.8 nΩ · m; H18 temper, 28.3 nΩ · m. Temperature coefficient, O and H18 tempers, 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. -0.84 V versus 0.1 N calomel electrode in aqueous

Table 2 ASME and ASTM specifications for 1060 aluminum

Mill form and condition	Specification number	
	ASME	ASTM
Sheet and plate	SB209	B 209
Wire, rod, and bar (rolled or cold finished)		B 211
Wire, rod, bar, shapes, and tube (extruded)	SB221	B 221
Pipe (gas and oil transmission)		B 345
Tube (condenser)	SB234	B 234
Tube (condenser with integral fins)		B 404
Tube (drawn)		B 483
Tube (drawn, seamless)	SB210	B 210
Tube (extruded, seamless)	SB241	B 241

Table 3 Typical mechanical properties of 1060 aluminum

Temper	Tensile strength		Yield strength		Elongation(a), %	Hardness, HB(b)	Shear strength		Fatigue limit(c)	
	MPa	ksi	MPa	ksi			MPa	ksi	MPa	ksi
O	69	10	28	4	43	19	48	7	21	3
H12	83	12	76	11	16	23	55	8	28	4
H14	97	14	90	13	12	26	62	9	34	5
H16	110	16	103	15	8	30	69	10	45	6.5
H18	131	19	124	18	6	35	76	11	45	6.5

(a) 1.6 mm (1/16 in.) thick specimens. (b) 500 kg load; 10 mm diam ball. (c) At 5×10^8 cycles; R.R. Moore type test

Table 4 Tensile-property limits for 1060 aluminum

Temper	Tensile strength				Yield strength		Elongation (min), % (a)
	Minimum		Maximum		(min)		
	MPa	ksi	MPa	ksi	MPa	ksi	
Sheet and plate							
O	55	8.0	95	14.0	17	2.5	15-25
H12	75	11.0	110	16.0	62	9.0	6-12
H14	83	12.0	115	17.0	70	10.0	1-10
H16	110	16.0	...	...	83	12.0	1-4
H112							
0.250-0.499 in. thick	75	11.0	...	...	...	...	10
0.500-1.000 in. thick	70	10.0	...	...	...	...	20
1.001-3.000 in. thick	62	9.0	...	...	...	...	25
Drawn tube (0.010-0.500 in. wall thickness)							
O	58	8.5	...	...	17	2.5	...
H12	70	10.0	...	...	28	4.0	...
H14	83	12.0	...	...	70	10.0	...
H18	110	16.0	...	...	90	13.0	...
H112	58	8.5	...	...	17	2.5	...
Extruded tube							
O	58	8.5	95	14.0	17	2.5	...
H112	58	8.5	95(b)	14.0(b)	17	2.5	30(b)
Heat-exchanger tube (0.010-0.200 in. wall thickness)							
H14	83	12.0	...	...	70	10.0	...

(a) In 50 mm (2 in.) or $4d$, where d is diameter of reduced section of tensile test specimen. Where a range of values appears in this column, specified minimum elongation varies with thickness of the mill product. (b) Applicable only to tube 25.4 to 114.3 mm (1.000 to 4.500 in.) diam by 1.27 to 4.29 mm (0.050 to 0.169 in.) wall thickness

Table 5 Standard specifications for 1100 aluminum

Mill form and condition	Specification number			
	AMS	ASME	ASTM	Government
Sheet and plate	4001, 4003	SB209	B 209	QQ-A-250/1
Wire, rod, and bar (rolled or cold finished)	4102	...	B 211	QQ-A-225/1
Wire, rod, bar, shapes, and tube (extruded)	...	SB221	B 221	...
Tube (extruded, seamless)	...	SB241	B 241	...
Tube (extruded, coiled)	...	...	B 491	...
Tube (drawn)	...	...	B 483	...
Tube (drawn, seamless)	4062	...	B 210	WW-T-700/1
Tube (welded)	...	...	B 313, B 547	...
Rivet wire and rod	...	...	B 316	QQ-A-430
Spray gun wire	4180	...	...	MIL-W-6712
Forgings and forging stock	...	...	B 247	...
Welding rod and electrodes (bare)	...	...	...	QQ-R-566, MIL-E-16053
Impacts	...	...	...	MIL-A-12545
Foil	...	...	...	QQ-A-1876

Table 6 Typical room-temperature mechanical properties of 1100 aluminum

Temper	Tensile strength		Yield strength		Elongation, %		Hardness, HB(a)	Shear strength		Fatigue limit(b)	
	MPa	ksi	MPa	ksi	1/16 in. thick specimens	1/2 in. thick specimens		MPa	ksi	MPa	ksi
O	90	13	34	5	35	45	23	62	9	34	5
H12	110	16	103	15	12	25	28	69	10	41	6
H14	124	18	117	17	9	20	32	76	11	48	7
H16	145	21	138	20	6	17	38	83	12	62	9
H18	165	24	152	22	5	15	44	90	13	62	9

(a) 500 kg load; 10 mm ball. (b) At 5×10^8 cycles; R.R. Moore type test

solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F)

1100 99.00Al (min)-0.12Cu

Commercial Names

Common name. Aluminum

Specifications

AMS. See Table 5.

ASME. See Table 5.

ASTM. See Table 5.

SAE. J454

UNS number. A91100

Government. See Table 5.

Foreign. Canada: CSA 990C. France: NF

A45. ISO: A199.0Cu

Chemical Composition

Composition limits. 99.00 Al min, 1.0 Si max + Fe, 0.05 to 0.20 Cu, 0.05 Mn max, 0.10 Zn max, 0.05 max other (each), 0.15 max others (total), 0.0008 Be max (welding electrode and filler wire only)

Applications

Typical uses. Applications requiring good formability and high resistance to corrosion where high strength is not necessary. Food and chemical handling and storage equipment, sheet metal work, drawn or spun hollowware, welded assemblies, heat exchangers, litho plate, nameplates, light reflectors

Mechanical Properties

Tensile properties. See Tables 6, 7, and 8.

Hardness. See Table 6.

Poisson's ratio. 0.33 at 20 °C (68 °F)

Elastic modulus. Tension, 69 GPa (10 × 10⁶ psi); shear, 26 GPa (3.75 × 10⁶ psi)

Mass Characteristics

Density. 2.71 g/cm³ (0.098 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 657 °C (1215 °F)

Solidus temperature. 643 °C (1190 °F)

Coefficient of thermal expansion.

Linear:

Temperature range °C	Temperature range °F	Average coefficient μm/m · K	Average coefficient μin./in. · °F
-50 to 20	-58 to 68	21.8	12.1
20 to 100	68 to 212	23.6	13.1
20 to 200	68 to 392	24.5	13.6
20 to 300	68 to 572	25.5	14.1

Volumetric: 68 × 10⁻⁶ m³/m³ · K (3.8 × 10⁻⁵ in.³/in.³ · °F)

Specific heat. 904 J/kg · K (0.216 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. O temper, 222 W/m ·

Table 7 Tensile-property limits for 1100 aluminum

Temper	Tensile strength				Yield strength (min)		Elongation (min), % (a)
	Minimum MPa	ksi	Maximum MPa	ksi	MPa	ksi	
Sheet and plate							
O	75	11.0	105	15.5	25	3.5	15-28
H12	95	14.0	130	19.0	75	11.0	3-12
H14	110	16.0	145	21.0	95	14.0	1-10
H16	130	19.0	165	24.0	115	17.0	1-4
H18	150	22.0	...	...	...	...	1-4
H112							
0.250-0.499 in. thick	90	13.0	...	...	50	7.0	9
0.500-2.000 in. thick	83	12.0	...	...	35	5.0	14
2.001-3.000 in. thick	80	11.5	...	...	30	4.0	20
Wire, rod, and bar (rolled or cold finished)							
O	75	11.0	105	15.5	20	3.0	25
H112	75	11.0	...	...	20	3.0	...
H12(b)	95	14.0	...	...	...	...	...
H14(b)	110	16.0	...	...	...	...	...
H16(b)	130	19.0	...	...	...	...	...
H18(b)	150	22.0	...	...	...	...	...
Wire, rod, bar, and shapes (extruded)							
O	75	11.0	105	15.5	20	3.0	25
H112	75	11.0	...	...	20	3.0	...
Wire and rod (rivet and cold heading grade)							
O(c)	...	...	105	15.5	...	...	...
H14(c)	110	16.0	145	21.0	...	...	...
Drawn tube (0.014 to 0.500 in. wall thickness)							
O	...	...	105	15.5	...	...	...
H12	95	14.0	...	...	...	...	...
H14	110	16.0	...	...	...	...	...
H16	130	19.0	...	...	...	...	...
H18	150	22.0	...	...	...	...	...
Extruded tube							
O	75	11.0	105	15.5	20	3.0	25
H112	75	11.0	...	...	20	3.0	25

(a) In 50 mm (2 in.) or 4d, where d is diameter of reduced section of tensile test specimen. Where a range of values appears in this column, the specified minimum elongation varies with thickness of the mill product. (b) Nominal thickness up through 9.5 mm (0.374 in.). (c) Nominal diameter up through 25.4 mm (1.000 in.)

K (128 Btu/ft · h · °F); H18 temper, 218 W/m · K (126 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric at 20 °C (68 °F): O temper, 59% IACS; H18 temper, 57% IACS

Electrical resistivity. At 20 °C (68 °F): O temper, 29.2 nΩ · m; H18 temper, 30.2 nΩ · m. Temperature coefficient at 20 °C (68 °F): O and H18 tempers, 0.1 nΩ · m per K

Electrolytic solution potential. All tempers, -0.83 V versus 0.1 N calomel electrode in aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter at 25 °C (77 °F)

Optical Properties

Reflectance. Brightly polished or diffusely etched reflector: 86% for light from tungsten filament; 84% for light having a wavelength of 250 nm. See also Fig. 1.

Emittance. See Fig. 2.

Fabrication Characteristics

Annealing temperature. 343 °C (650 °F)

**1145
99.45 Al min
Specifications**

AMS. 4011
ASTM. B 373
Government. QQ-A-1876

Chemical Composition

Composition limits. 99.45 Al min, 0.55 Si max + Fe, 0.05 Cu max, 0.05 Mn max, 0.05 Mg max, 0.05 Zn max, 0.05 V max, 0.03 Ti max, 0.03 max other (each)

Applications

Typical uses. Foil for packaging, insulating, and heat exchangers

Mechanical Properties

Tensile properties. See Table 9.

Mass Characteristics

Density. 2.705 g/cm³ (0.0977 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 657 °C (1215 °F)
Solidus temperature. 646 °C (1195 °F)

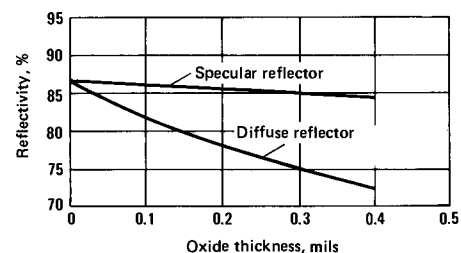


Fig. 1 Reflectivity of 1100 aluminum as a function of aluminum oxide coating thickness

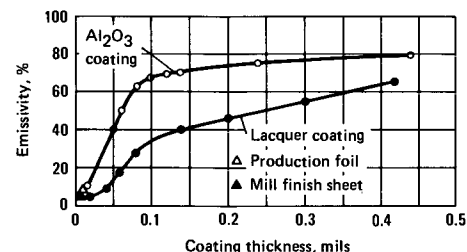


Fig. 2 Emissivity of 1100 aluminum foil as a function of coating thickness

Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.8	12.1
20 to 100	68 to 212	23.6	13.1
20 to 200	68 to 392	24.5	13.6
20 to 300	68 to 572	25.5	14.1

Volumetric: 68 × 10⁻⁶ m³/m³ · K (3.8 × 10⁻⁵ in.³/in.³ · °F)

Specific heat. 904 J/kg · K (0.216 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F): O temper, 230 W/m · K (133 Btu/ft · h · °F); H18 temper, 227 W/m · K (131 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric at 20 °C (68 °F): O temper, 61% IACS; H18 temper, 60% IACS

Electrical resistivity. At 20 °C (68 °F): O temper, 28.3 nΩ · m; H18 temper, 28.7 nΩ · m. Temperature coefficient at 20 °C: O and H18 tempers, 0.1 nΩ · m per K

Optical Properties

Reflectance. 95 to 97% for λ = 0.3 to 10 μm
Emittance. 3 to 5% for λ = 9.3 μm at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F)

**1199
99.99 Al min**

Commercial Names

Trade name. Super-purity aluminum, Raffinal

Table 8 Typical tensile properties of 1100 aluminum at various temperatures

Temperature		Tensile strength		Yield strength		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
O temper						
-195	-320	170	25	41	6	50
-80	-112	105	15	38	5.5	43
-28	-18	97	14	34	5	40
24	75	90	13	34	5	40
100	212	69	10	32	4.6	45
149	300	55	8	29	4.2	55
204	400	41	6	24	3.5	65
260	500	28	4	18	2.6	75
316	600	20	2.9	14	2.0	80
371	700	14	2.1	11	1.6	85
H14 temper						
-196	-320	205	30	140	20	45
-80	-112	140	20	125	18	24
-28	-18	130	19	115	17	20
24	75	125	18	115	17	20
100	212	110	16	105	15	20
149	300	97	14	83	12	23
204	400	69	10	52	7.5	26
260	500	28	4	18	2.6	75
316	600	20	2.9	14	2.0	80
371	700	14	2.1	11	1.6	85
H18 temper						
-196	-320	235	34	180	26	30
-80	-112	180	26	160	23	16
-28	-18	170	25	160	23	16
24	75	165	24	150	22	15
100	212	145	21	130	19	15
149	300	125	18	97	14	20
204	400	41	6	24	3.5	65
260	500	28	4	18	2.6	75
316	600	20	2.9	14	2.0	80
371	700	14	2.1	11	1.6	85

Table 9 Tensile properties of 1145 aluminum foil

Temper	Tensile strength		Yield strength		Elongation, %
	MPa	ksi	MPa	ksi	
Typical properties					
O	75	11	34	5	40
H18	145	21	117	17	5
Tensile strength limits(a)					
O	95 max	14 max	...	...	...
H19	140 min	20 min	...	...	...

(a) Unmounted foil 0.02 to 0.15 mm (0.0007 to 0.0059 in.) thick

Table 10 Typical tensile properties of 1199 aluminum

Reduction by cold rolling, %	Tensile strength		Yield strength		Elongation, %
	MPa	ksi	MPa	ksi	
0 (annealed)	45	6.5	10	1.5	50
10	59	8.6	57	8.2	40
20	77	11.1	75	10.8	15
40	96	13.9	91	13.2	11
60	110	15.9	105	15.1	6
75	120	17.5	113	16.4	5

Common name. Super-purity aluminum, refined aluminum

Chemical Composition

Composition limits. 99.99 Al min, 0.006 Si max, 0.006 Fe max, 0.006 Cu max, 0.002 Mn max, 0.006 Mg max, 0.006 Zn max, 0.002 Ti max, 0.005 V max, 0.005 Ga max, 0.002 max other (each)

Consequence of exceeding impurity limits.

See Fig. 3.

Applications

Typical uses. Electrolytic capacitor foil, vapor deposited coatings for optically reflecting surfaces

Mechanical Properties

Tensile properties. See Table 10 and Fig. 3.
Hardness. O temper, 15 HB; H18 temper,

27 HB. (500 kg load; 10 mm diam ball). See also Fig. 3.

Elastic modulus. Tension, 62 GPa (9.0×10^6 psi); shear, 25.0 GPa (3.62×10^6 psi)

Mass Characteristics

Density. 2.70 g/cm³ (0.0975 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Melting point. 660 °C (1220 °F)

Coefficient of thermal expansion.

Linear:

Temperature range °C	Temperature range °F	Average coefficient	
		μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.8	12.1
20 to 100	68 to 212	23.6	13.1
20 to 200	68 to 392	24.5	13.6
20 to 300	68 to 572	25.5	14.2

Specific heat. 900 J/kg · K at 25 °C (77 °F)

Heat of fusion. 390 kJ/kg · K

Thermal conductivity. O temper, 243 W/m · K (140 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, O temper: 64.5% IACS at 20 °C (68 °F)

Electrical resistivity. O temper: 26.7 nΩ · m at 20 °C (68 °F); temperature coefficient, O temper: 0.1 nΩ · m per K at 20 °C (68 °F)

Optical Properties

Reflectivity. 85 to 90% to visible light for an electrolytically brightened surface

1350

99.50 Al min

Commercial Names

Common name. Electrical conductor grade (EC)

Specifications

ASTM. Aluminum conductor steel reinforced B 232, B 401. Bus conductors: B 236. Communication wire: B 314. Rolled redraw rod: B 233. Round wire: B 230, B 609. Wire, rectangular and square: B 324. Round solid conductors: B 544. Stranded conductors: B 231, B 400

Foreign. France: NF A5/L. Spain: UNE AL99.5E. United Kingdom: BS1E. West Germany: DIN E-A199.5

Chemical Composition

Composition limits. 99.50 Al min, 0.10 Si max, 0.40 Fe max, 0.05 Cu max, 0.01 Mn max, 0.01 Cr max, 0.05 Zn max, 0.03 Ga max, 0.02 V max + Ti, 0.05 B max, 0.03 max other (each), 0.10 max others (total)

Consequence of exceeding impurity limits. Impurity elements in excess of limits degrade electrical conductivity.

Applications

Typical uses. Wire, stranded conductors, bus conductors, transformer strip

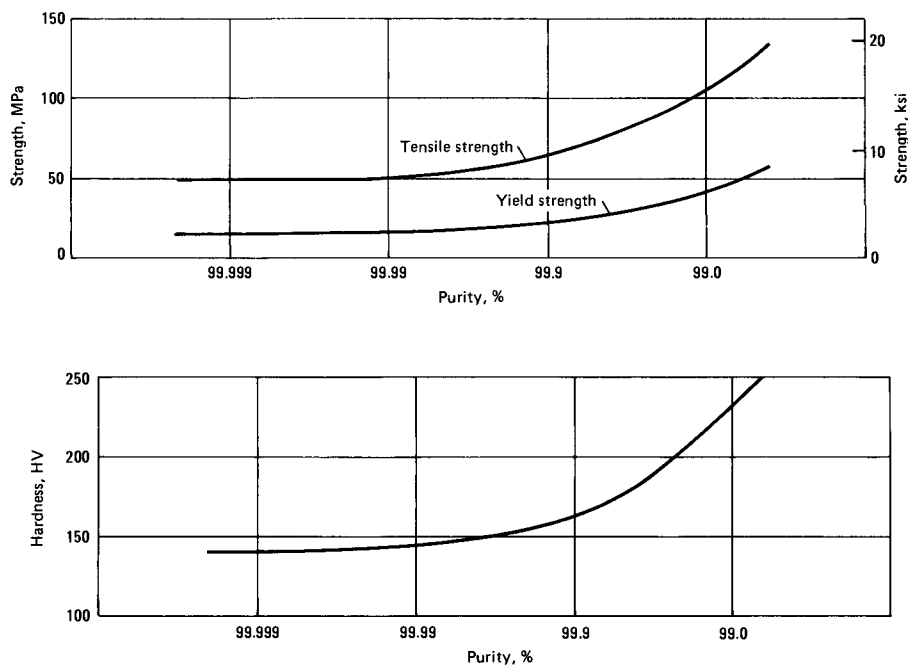


Fig. 3 Effect of purity on strength and hardness of unalloyed aluminum

Table 11 Typical mechanical properties of 1350 aluminum

Temper	Tensile strength		Yield strength		Elongation(a), %	Shear strength	
	MPa	ksi	MPa	ksi		MPa	ksi
O	83	12	28	4	23	55	8
H12	97	14	83	12	...	62	9
H14	110	16	97	14	...	69	10
H16	124	18	110	16	...	76	11
H19	186	27	165	24	1.5	103	15

(a) In 250 mm (10 in.), value applicable to wire only

Table 12 Tensile-property limits for 1350 aluminum

Temper	Tensile strength				Yield strength (min)		Elongation (min), % (a)
	Minimum MPa	ksi	Maximum MPa	ksi	MPa	ksi	
Sheet and plate							
O	55	8.0	95	14.0	...	...	15-28
H12	83	12.0	115	17.0	...	...	3-12
H14	95	14.0	130	19.0	...	...	1-10
H16	110	16.0	145	21.0	...	...	1-4
H18	125	18.0	...	...	...	...	1-4
H112							
0.250-0.499 in.	75	11.0	...	...	...	...	10
0.500-1.000 in.	70	10.0	...	...	...	...	16
1.001-1.500 in.	62	9.0	...	...	...	...	22
Wire(b) and redraw rod(c)							
O	58	8.5	95	14.0	...	...	...
H12 and H22	83	12.0	115	17.0	...	...	...
H14 and H24	105	15.0	140	20.0	...	...	...
H16 and H26	115	17.0	150	22.0	...	...	...
Extrusions(d)							
H111	58	8.5	...	...	25	3.5	...
Rolled bar(e)							
H12	83	12.0	...	...	55	8.0	...
Sawed-plate bar							
H112							
0.125-0.499 in.	75	11.0	...	...	40	6.0	...
0.500-1.000 in.	70	10.0	...	...	28	4.0	...
1.001-1.500 in.	62	9.0	...	...	25	3.5	...

(a) In 50 mm (2 in.) or 4d, where d is diameter of reduced section of test specimen. Where a range of values appears in this column, specified minimum elongation varies with thickness of the mill product. (b) Up through 9.50 mm (0.374 in.) diam. (c) 9.52 mm (0.375 in.) diam. (d) Bar, rod, tubular products, and structural shapes. (e) 3 to 25 mm (0.125 to 1.0 in.) thick

Mechanical Properties

Tensile properties. Typical, see Table 11; property limits, see Tables 12 and 13.

Shear strength. See Table 11.

Poisson's ratio. 0.33 at 20 °C (68 °F)

Elastic modulus. Tension, 69 GPa (10 × 10⁶ psi)

Fatigue strength. H19 temper, 48 MPa (7 ksi) at 5 × 10⁸ cycles in an R.R. Moore type test

Mass Characteristics

Density. 2.705 g/cm³ (0.0977 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 657 °C (1215 °F)

Solidus temperature. 646 °C (1195 °F)

Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.8	12.1
20 to 100	68 to 212	23.6	13.1
20 to 200	68 to 392	24.5	13.6
20 to 300	68 to 572	25.5	14.2

Volumetric: 68 × 10⁻⁶ m³/m³ · K (3.8 × 10⁻⁵ in.³/in.³ · °F)

Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. O temper, 234 W/m · K (135 Btu/ft · h · °F); H19 temper, 230 W/m · K (133 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F). O temper, 61.8% IACS min; H1x tempers, 61.0% IACS min

Electrical resistivity. O temper, 27.9 nΩ · m max at 20 °C (68 °F); H1x tempers, 28.2 nΩ · m max at 20 °C. Temperature coefficient, all tempers: 0.1 nΩ · m per K at 20 °C

Electrolytic solution potential. -0.84 V versus 0.1 N calomel electrode in aqueous solution of 53 g NaCl plus 3 g H₂O₂ per liter at 25 °C (77 °F)

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F)

2011

5.5Cu-0.4Pb-0.4Bi

Specifications

ASTM. Drawn, seamless tube: B 210. Rolled or cold finished wire, rod, and bar: B 211

SAE. J454

UNS number. A92011

Government. Rolled or cold finished wire, rod, and bar: QQ-A-225/3

Foreign. Canada: CSA CB60. France: NF A-U4Pb. United Kingdom: BS FC1. Germany: DINAL CuBiPb

Table 13 Tensile-property limits for 1350 aluminum wire, H19 temper

Wire diameter, in.	Minimum tensile strength				Minimum elongation(c), %	
	Individual(a)		Average(b)		Individual(a)	Average(b)
	MPa	ksi	MPa	ksi		
0.0105–0.0500	160	23.0	172	25.0	...	...
0.0501–0.0600	185	27.0	200	29.0	1.2	1.4
0.0601–0.0700	185	27.0	195	28.5	1.3	1.5
0.0701–0.0800	183	26.5	193	28.0	1.4	1.6
0.0801–0.0900	180	26.0	190	27.5	1.5	1.6
0.0901–0.1000	175	25.5	185	27.0	1.5	1.6
0.1001–0.1100	170	24.5	180	26.0	1.5	1.6
0.1101–0.1200	165	24.0	175	25.5	1.6	1.7
0.1201–0.1400	162	23.5	172	25.0	1.7	1.8
0.1401–0.1500	162	23.5	170	24.5	1.8	1.9
0.1501–0.1800	160	23.0	165	24.0	1.9	2.0
0.1801–0.2100	160	23.0	165	24.0	2.0	2.1
0.2101–0.2600	155	22.5	162	23.5	2.2	2.3

(a) Minimum value for any test in a given lot. (b) Minimum value for average of all tests for a given lot. (c) In 250 mm (10 in.)

Chemical Composition

Composition limits. 0.40 Si max, 0.7 Fe max, 5.0 to 6.0 Cu, 0.30 Zn max, 0.20 to 0.6 Pb, 0.05 max other (each), 0.15 others (total), bal Al

Applications

Typical uses. Wire, rod, and bar for screw machine products. Applications where good machinability and good strength are required

Mechanical Properties

Tensile properties. See Tables 14 and 15.
Compressive yield strength. Approximately equal to tensile yield strength

Hardness. See Table 14.

Poisson's ratio. 0.33 at 20 °C (68 °F)
Elastic modulus. Tension, 70 GPa (10.2 × 10⁶ psi); shear, 26 GPa (3.8 × 10⁶ psi)
Fatigue strength. At 5 × 10⁸ cycles, R.R. Moore type test: T3 and T8 tempers, 124 MPa (18 ksi)

Mass Characteristics

Density. 2.82 g/cm³ (0.102 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 638 °C (1180 °F)
Solidus temperature. 541 °C (1005 °F)
Incipient melting temperature. 535 °C (995 °F)

Coefficient of thermal expansion.
Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.4	11.9
20 to 100	68 to 212	23.1	12.8
20 to 200	68 to 392	24.0	13.3
20 to 300	68 to 572	25.0	13.9

Volumetric: 67 × 10⁻⁶ m³/m³ · K (3.72 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 864 J/kg · K (0.206 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F): T3 and T4 tempers, 152 W/m · K (87.8 Btu/ft · h · °F); T8 temper, 173 W/m · K (99.9 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): T3 and T4 tempers, 39% IACS; T8 temper, 45% IACS

Electrical resistivity. At 20 °C (68 °F): T3 and T4 tempers, 44 nΩ · m; T8 temper, 38 nΩ · m; temperature coefficient. T3, T4, and T8 tempers, 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. At 25 °C (77 °F): -0.69 V (T3 and T4 tempers), -0.83 V (T8 temper) versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 413 °C (775 °F)
Solution temperature. 524 °C (975 °F)
Aging temperature. T8 temper, 160 °C (320 °F); 14 h at temperature

Table 14 Room-temperature mechanical properties of alloy 2011

Temper	Tensile strength		Yield strength(a)		Elongation, %	Hardness(b), HB	Shear strength	
	MPa	ksi	MPa	ksi			MPa	ksi
Typical properties								
T3(c)	379	55	296	43	15(d)	95	221	32
T8(c)	407	59	310	45	12(d)	100	241	35
Property limits (minimum values for rolled or cold finished wire, rod, and bar)								
T3								
0.125 to 1.500 in. thick	310	45	260	38	10(a)(e)	...	...	...
1.501 to 2.000 in. thick	295	43	235	34	12(a)(e)	...	...	...
2.001 to 3.250 in. thick	290	42	205	30	14(a)(e)	...	...	...
T4, T451								
0.375 to 8.000 in. thick	275	40	125	18	16	...	...	...
T8								
0.125 to 3.250 in. thick	370	54	275	40	10	...	...	...

(a) Yield strength and elongation limits not applicable to wire less than 3.2 mm (0.125 in.) in thickness or diameter. (b) 500 kg (1100 lb) load; 10 mm diam ball. (c) Strengths and elongations generally unchanged or improved at low temperatures. (d) 13 mm (½ in.) diam specimen. (e) In 2 in. or 4d, where d is diameter of reduced section of tensile test specimen

Table 15 Typical tensile properties of alloy 2011-T3

Temperature		Tensile strength		Yield strength (0.2% offset)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
24	75	379	55	296	43	15
100	212	324	47	234	34	16
149	300	193	28	131	19	25
204	400	110	16	76	11	35
260	500	45	6.5	26	3.8	45
316	600	21	3.1	12	1.8	90
371	700	16	2.3	10	1.4	125

(a) Lowest strength for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (6 ksi/min) to yield strength and then at strain rate of 5%/min to fracture

2014, Alclad 2014

4.4Cu-0.8Si-0.8Mn-0.5Mg

Specifications

AMS. See Table 16.
ASME. Rolled or cold finished wire, rod, and bar: SB211. Forgings: SB247
ASTM. See Table 16.
SAE. J454
UNS number. A92014
Government. See Table 16.
Foreign. Canada: CSA CS41N. France: NF A-U4SG. Germany: DIN AlCuSiMn. ISO: AlCu4SiMg. United Kingdom: BS H15

Chemical Composition

Composition limits of 2014. 3.9 to 5.0 Cu, 0.50 to 1.2 Si, 0.7 Fe max, 0.40 to 1.2 Mn, 0.20 to 0.8 Mg, 0.25 Zn max, 0.10 Cr max, 0.15 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Composition limits of Alclad 2014. 6006 cladding—0.20 to 0.6 Si, 0.35 Fe max, 0.15 to 0.30 Cu, 0.05 to 0.20 Mn, 0.45 to 0.9 Mg, 0.10 Cr max, 0.10 Zn max, 0.10 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Table 16 Standard specifications for alloy 2014

Mill form	Specification number		
	AMS	ASTM	Government
Sheet and plate	4014 4028 4029	B 209......	.........
Rolled or cold finished wire, rod, and bar	4121	B 211	QQ-A-225/4
Extruded wire, rod, bar, shapes, and tube	4153	B 221	QQ-A-200/2
Extruded seamless tube	...	B 241	...
Drawn, seamless tube	...	B 210	...
Forgings	4133 4134 4135	B 247	QQ-A-367 MIL-A-22771
Forging stock	4134 4133 4135	...	QQ-A-367
Impacts	...	...	MIL-A-12545
Sheet and plate (Alclad)	...	B 209	QQ-A-250/3

Applications

Typical uses. Heavy-duty forgings, plate, and extrusions for aircraft fittings, wheels, and major structural components, space booster tankage and structure, truck frame and suspension components. Applications requiring high strength and hardness including service at elevated temperatures

Mechanical Properties

Tensile properties. See Tables 17 to 19.

Compressive yield strength. Approximately the same as tensile yield strength

Hardness. O temper: 87 to 98 HRH; 45 HB. T4 temper: 65 to 73 HRB; 105 HB. T6 temper: 80 to 86 HRB; 135 HB. HB values obtained using 500 kg load and 10 mm diam ball

Poisson's ratio. 0.33 at 20 °C (68 °F)

Elastic modulus. Tension: 2014, 72.4 GPa (10.5×10^6 psi); Alclad 2014, 71.7 GPa (10.4×10^6 psi). Shear: 2014 and Alclad 2014, 28 GPa (4.0×10^6 psi). Compression: 2014, 73.8 GPa (10.7×10^6 psi); Alclad 2014, 73.1 GPa (10.6×10^6 psi)

Fatigue strength. O temper, 90 MPa (13 ksi); T4 temper, 140 MPa (20 ksi); T6 temper, 125 MPa (18 ksi); all at 5×10^8 cycles in an R.R. Moore type test

Mass Characteristics

Density. 2.80 g/cm³ (0.101 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 638 °C (1180 °F)

Solidus temperature. 507 °C (945 °F)

Coefficient of thermal expansion.

Table 17 Typical tensile properties of alloy 2014

Temper	Tensile strength		Yield strength		Elongation, %	Hardness, HB	Shear strength		Fatigue strength	
	MPa	ksi	MPa	ksi			MPa	ksi	MPa	ksi
Bare 2014										
O	186	27	97	14	18(a)	45	125	18	90	13
T4	427	62	290(b)	42(a)	20(a)	105	260	38	140	20
T6(c)	483	70	414	60	13(a)	135	240	42	125	18
Alclad 2014										
O	172	25	69	10	21(e)	...	125	18	...	...
T3(d)	434	63	276	40	20(e)	...	255	37	...	...
T4(d)	421	61	255	37	22(e)	...	255	37	...	...
T6(d)	469	68	414	60	10(e)	...	285	41	...	...

(a) Round bar 13 mm (½ in.) diam. (b) Die forgings have about 20% lower yield strength. (c) Extruded products more than 19 mm (¾ in.) thick have 15 to 20% higher strengths. (d) Sheet less than 1 mm (0.04 in.) thick has slightly lower strength. (e) Sheet 1.6 mm (⅙ in.) thick

Table 18 Typical tensile properties of alloy 2014-T6 or 2014-T651 at various temperatures

Lowest strength for exposures up to 10 000 h at temperature under no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture

Temperature °C	Temperature °F	Tensile strength		Yield strength(a)		Elongation, %
		MPa	ksi	MPa	ksi	
-196	-320	579	84	496	72	14
-80	-112	510	74	448	65	13
-28	-18	496	72	427	62	13
24	75	483	70	414	60	13
100	212	439	63	393	57	15
149	300	276	40	241	35	20
204	400	110	16	90	13	38
260	500	66	9.5	52	7.5	52
316	600	45	6.5	34	5	65
371	700	30	4.3	24	3.5	72

(a) 0.2% offset

Linear:

Temperature range °C		Average coefficient μm/m · K	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	20.8	11.5
20 to 100	68 to 212	22.5	12.5
20 to 200	68 to 392	23.4	13.0
20 to 300	68 to 572	24.4	13.6

Volumetric: $65.1 \times 10^{-6} \text{ m}^3/\text{m}^3 \cdot \text{K}$ ($3.62 \times 10^{-5} \text{ in.}^3/\text{in.}^3 \cdot \text{°F}$)

Thermal conductivity. At 20 °C (68 °F): O temper, 192 W/m · K (111 Btu/ft · h · °F); T3, T4, T451 tempers, 134 W/m · K (77.4 Btu/ft · h · °F); T6, T651, T652 tempers, 155 W/m · K (89.5 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. At 20 °C (68 °F): O temper, 50% IACS; T3, T4, T451 tempers, 34% IACS; T6, T651, T652 tempers, 40% IACS

Electrical resistivity. At 20 °C (68 °F): O temper, 34 nΩ · m; T3, T4, T451 tempers, 51 nΩ · m; T6, T651, T652 tempers, 43 nΩ · m. Temperature coefficient: O, T3, T4, T451, T6, T651, T652 tempers, 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. At 25 °C (77 °F): -0.68 V (T3, T4, T451 tempers) or -0.78 V (T6, T651, T652 tempers) versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 413 °C (775 °F)

Solution temperature. 502 °C (935 °F)

Aging temperature. T6 temper. Sheet, plate, wire, rod, bar, shapes, and tube: 160 °C (320 °F) for 18 h at temperature. Forgings: 171 °C (340 °F) for 10 h at temperature

2017

4.0Cu-0.6Mg-0.7Mn-0.5Si

Specifications

ASTM. B 211 and B 316

SAE. J454

ANSI. H38.4 and H38.12

UNS number. A92017

Government. QQ-A-222/5, QQ-A-430, MIL-R-430

Foreign. France: A-U46. Germany: AlCuMg1 and 3.1325. Great Britain: L18 and 150A. Canada: CM41. Austria: AlCuMg1. ISO: AlCuMgSi

Chemical Composition

Composition limits. 0.20 to 0.80 Si, 0.7 max Fe, 3.5 to 4.5 Cu, 0.4 to 0.80 Mg, 0.40 to 1.0 Mn, 0.10 max Cr, 0.15 max Ti, 0.25 max Zn, 0.05 other (each), 0.15 others (total); bal Al

Applications

Typical uses. Alloy 2017, which was the first alloy developed in the Al-Cu-Mg series, is now in rather limited use, chiefly for

Table 19 Tensile-property limits for alloy 2014

Temper	Tensile strength				Yield strength (min)		Elongation(a), %	Temper	Tensile strength				Yield strength (min)		Elongation(a), %
	Minimum MPa	ksi	Maximum MPa	ksi	MPa	ksi			Minimum MPa	ksi	Maximum MPa	ksi	MPa	ksi	
Flat products (bare)								Extruded tube (continued)							
Sheet and plate, O								T6, T6510, T6511							
0.020–0.499 in. thick								≤0.499 in. thick							
0.500–1.000 in. thick								0.500–0.749 in. thick							
0.020–0.039 in. thick								≥0.750 in. thick							
0.040–0.249 in. thick								T62							
Coiled sheet, T4								Drawn tube							
0.020–0.249 in. thick								O, 0.18–0.500 in. thick							
Plate, T451(b)								T4, T42							
0.250–2.000 in. thick								0.018–0.500 in. thick							
2.001–3.000 in. thick								Die forgings: axis parallel to direction of grain flow							
Sheet and plate, T42								T4, ≤4 in. thick							
0.020–1.000 in. thick								T6							
Sheet, T6, T62								≤2 in. thick							
0.020–0.039 in. thick								>2–3 in. thick							
0.040–0.249 in. thick								≤3–4 in. thick							
Plate, T62, T651								Die forgings: axis not parallel to direction of grain flow							
0.250–2.000 in. thick								T6, ≤2 in. thick							
2.001–2.500 in. thick								>2–4 in. thick							
2.501–3.000 in. thick								Hand forgings							
3.001–4.000 in. thick								T6							
Flat products (Alclad)								≤2.000 in. thick longitudinal,							
Sheet and plate, O								long transverse							
0.020–0.499 in. thick								2.001–3.000 in. thick							
0.500–1.000 in. thick								Longitudinal							
Flat sheet, T3								Long transverse							
0.020–0.024 in. thick								Short transverse							
0.025–0.039 in. thick								3.001–4.000 in. thick							
0.040–0.249 in. thick								Longitudinal, long transverse							
Coiled sheet, T4								Short transverse							
0.020–0.024 in. thick								4.001–5.000 in. thick							
0.025–0.039 in. thick								Longitudinal, long transverse							
0.040–0.249 in. thick								Short transverse							
Plate, T451(b)								5.001–6.000 in. thick							
0.500–2.000 in. thick								Longitudinal, long transverse							
0.250–0.499 in. thick								Short transverse							
0.500–2.000 in. thick								6.001–7.000 in. thick							
2.001–3.000 in. thick								Longitudinal							
Sheet and plate, T4								Long transverse							
0.020–0.024 in. thick								Short transverse							
0.025–0.039 in. thick								7.001–8.000 in. thick							
0.040–0.499 in. thick								Longitudinal, long transverse							
0.500–1.000 in. thick								Short transverse							
Sheet, T6								T652							
0.020–0.024 in. thick								≤2.000 in. thick							
0.025–0.039 in. thick								Longitudinal, long transverse							
0.040–0.249 in. thick								2.001–3.000 in. thick							
Plate, T62, T651								Longitudinal							
0.250–0.499 in. thick								Long transverse							
0.500–2.000 in. thick								Short transverse							
2.001–2.500 in. thick								3.001–4.000 in. thick							
2.501–3.000 in. thick								Longitudinal, long transverse							
3.001–4.000 in. thick								Short transverse							
Rolled or cold finished wire (rod and bar)								4.001–5.000 in. thick							
T4, T42, T451(b)								Longitudinal, long transverse							
T6, T62, T651								Short transverse							
Extruded wire, rod, bar, and shapes								5.001–6.000 in. thick							
O								Longitudinal, long transverse							
T4, T4510, T4511								Short transverse							
T42								6.001–7.000 in. thick							
T6, T6510, T6511								Longitudinal, long transverse							
≤0.499 in. thick								Short transverse							
0.500–0.749 in. thick								7.001–8.000 in. thick							
0.750 in. thick								Longitudinal, long transverse							
T62								Short transverse							
Extruded tube								Rolled rings, T6, T652							
O								≤2.500 in. thick							
T4, T4510, and T4511								Tangential							
T42								Axial							
								Radial							
								2.501–3.000 in. thick							
								Tangential							
								Axial							

(a) In 50 mm (2 in.) or 4d, where d is diameter of reduced section of tensile test specimen. Where a range of values appears in this column, specified minimum elongation varies with thickness of the mill product. (b) Upon artificial aging. T451 temper material develops properties applicable to T651 temper. (c) 6% elongation for products over 19 mm (0.750 in.) in diameter or thickness and over 160 through 205 cm² (25 through 32 in.²) in cross-sectional area. (d) Value slightly lower for material over 160 through 205 cm² (25 through 32 in.²) in cross-sectional area. (e) Test bar machined from sample forging. (f) 16% for test bar taken from separately forged coupon. (g) 8% for test bar taken from separately forged coupon. (h) 2% for forgings over 25 through 50 mm (1 through 2 in.) thick

Table 20 Typical room-temperature mechanical properties of 2017

Property	Temper condition	
	O	T4, T451
Tensile strength, MPa (ksi)	180 (26)	427 (62)
Yield strength (0.2% offset), MPa (ksi)	70 (10)	275 (40)
Elongation in 50 mm (2 in.)(a), %	22	22
Hardness, HB(b)	45	105
Shear strength, MPa (ksi)	125 (18)	262 (38)
Fatigue strength (5 × 10 ⁸ cycles), MPa (ksi)	90 (13)	125 (18)

(a) Specimens 13 mm (½ in.) diameter. (b) 500 kg load, 10 mm ball

rivets. Used in components for general engineering purposes, structural applications in construction and transportation, screw machine products, and fittings

General characteristics. Age-hardenable wrought aluminum alloy with medium strength and ductility, good machinability, good formability, and fair resistance to atmospheric corrosion. Welding is not recommended unless heat treatment after welding is practicable. Its service temperature is below 100 °C (212 °F).

Forms available. Forgings, extrusions, bars, rods, wire, shapes, and rivets

Mechanical Properties

Tensile properties. See Tables 20 and 21.

Hardness. See Table 20.

Shear strength. See Table 20.

Modulus of elasticity. 72.4 GPa (10.5 × 10⁶ psi) average of tension and compression; modulus is about 2% greater for compression than tension

Modulus of rigidity. 27.5 GPa (4 × 10⁶ psi)

Fatigue strength. See Table 20.

Mass Characteristics

Density. 2.80 g/cm³ (0.101 lb/in.³)

Thermal Properties

Liquidus temperature. 640 °C (1185 °F)

Solidus temperature. 513 °C (955 °F)

Thermal conductivity. At 25 °C (77 °F): 193 W/m · °C (1340 Btu · in./ft² · h · °F) with an O temper and 134 W/m · °C (930 Btu · in./ft² · h · °F) with a T4 temper

Coefficient of thermal expansion. From 20 to 100 °C (68 to 212 °F): 23.6 μm/m · °C (13.1 μin./in. · °F)

Electrical Properties

Electrical conductivity. At 20 °C (68 °F): 50% IACS on a volume basis (159% IACS on weight basis) with an O temper; 34% IACS on a volume basis (108% IACS on a weight basis) with a T4 temper

Electrical resistivity. At 20 °C (68 °F): 0.035 Ω · mm²/m (21 Ω · circ mil/ft) with an O temper and 0.05 Ω · mm²/m (30 Ω · circ mil/ft) with a T4 temper

Fabrication Characteristics

Annealing temperature. 415 °C (775 °F) for a heat-treated anneal and 340 to 350 °C (640

Table 21 Typical tensile properties of 2017 (T4 and T451 tempers) at various temperatures

Test temperature(a)		Tensile strength		Yield strength (0.2% offset)		Elongation in 50 mm (2 in.), %
°C	°F	MPa	ksi	MPa	ksi	
-196	-320	550	80	365	53	28
-80	-112	448	65	290	42	24
-28	-18	440	64	283	41	23
24	75	427	62	275	40	22
100	212	393	57	270	39	18
149	300	275	40	207	30	15
204	400	110	16	90	13	35
260	500	62	9	52	7.5	45
316	600	40	6	35	5	65
371	700	30	4.3	24	3.5	70

(a) Tested after holding 10 000 h at temperature

to 660 °F) for cold-work anneal

Solution temperature. 500 to 510 °C (930 to 950 °F)

Aging temperature. Room temperature

Machinability. Fair to good in the annealed condition and excellent in the solution treated and naturally aged condition (T4 temper)

Workability. Has good formability. In the annealed condition (O temper) its formability is equal to or superior to 2024-O. In the T4 temper condition, it forms as readily as 2024-T3 or 2024-T4.

Weldability. Because of the effect of heating on corrosion resistance, welding is rarely recommended except where heat treatment after welding is practicable. The inert gas method and resistance welding have given satisfactory results. Gas welding, brazing, and soldering are not successful. This alloy is so sensitive to cracking during welding that other aluminum alloys, joint design, fixtures, and so on must be arranged so as to put a minimum stress on the joint during cooling. The best filler material is parent metal.

Corrosion Resistance

2017 has a fair resistance to atmospheric corrosion, depending on its thermal treatment. Quenching slowly from the solution-treatment temperature lowers the resistance to corrosion and makes this alloy susceptible to intergranular attack. The same result is obtained by heating the alloy after solution treatment. If, however, the alloy has been slowly quenched, artificial aging tends to restore the normal resistance to attack; in fact, for material that is to be artificially aged, a mild quench may be preferable. For thicker sections, the rate of cooling even by immersion in cold water is not great enough to produce complete freedom from susceptibility to intergranular attack. In thin sections the solution treated material, being aged at room temperature, is more resistant to corrosion than the fully aged material, while in heavy sections the latter is more resistant because of the beneficial effect of artificial aging on more slowly cooled material.

2024, Alclad 2024 4.4Cu-1.5Mg-0.6Mn

Specifications

AMS. See Table 22.

ASME. Rolled or drawn wire, rod, and bar: SB211. Extrusions: SB221

ASTM. See Table 22.

SAE. J454

UNS number. A92024

Government. See Table 22.

Foreign. Austria: Önorm AlCuMg2. Canada: CSA CG42. France: NF A-U4G1. Italy: UNI P-AlCu4.5MgMn; Alclad 2024, P-AlCu4.5MgMn placc. Spain: UNE L-314. Germany: DIN AlCuMg2

Chemical Composition

Composition limits. 0.5 Si max, 0.50 Fe max, 3.8 to 4.9 Cu, 0.30 to 0.9 Mn, 1.2 to 1.8 Mg, 0.10 Cr max, 0.25 Zn max, 0.15 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Composition limits of Alclad 2024. 1230 cladding—99.30 Al min, 0.7 Si max + Fe, 0.10 Cu max, 0.05 Mn max, 0.05 Mg max, 0.10 Zn max, 0.05 V max, 0.03 Ti max, 0.03 max other (each)

Applications

Typical uses. Aircraft structures, rivets, hardware, truck wheels, screw machine products, and other miscellaneous structural applications

Mechanical Properties

Tensile properties. See Tables 23, 24, and 25.

Shear strength. See Table 24.

Hardness. See Table 24.

Poisson's ratio. 0.33 at 20 °C (68 °F)

Elastic modulus. Tension, 72.4 GPa (10.5 × 10⁶ psi); shear, 28.0 GPa (4.0 × 10⁶ psi); compression, 73.8 GPa (10.7 × 10⁶ psi)

Fatigue strength. See Table 24.

Elevated-temperature strengths. See Fig. 4.

Mass Characteristics

Density. 2.77 g/cm³ (0.100 lb/in.³) at 20 °C (68 °F)

Table 22 Standard specifications for alloy 2024

Mill form and condition	Specification number		
	AMS	ASTM	Government
Bare 2024			
Sheet and plate	4033	B 209	QQ-A-250/4
	4035	...	...
	4037	...	...
	4097	...	...
	4098	...	...
	4099	...	...
	4103	...	...
	4104	...	...
	4105	...	...
	4106	...	...
	4192	...	...
	4193	...	...
Wire, rod, and bar (rolled or cold finished)	4112	B 211	QQ-A-225/6
	4119	...	...
	4120	...	...
Wire, rod, bar, shapes, and tube (extruded)	4152	B 221	QQ-A-200/3
	4164	...	...
	4165	...	...
Tube (extruded, seamless)	...	B 241	...
Tube (drawn, seamless)	4087	B 210	WW-T-700/3
	4088	...	MIL-T-50777

Tube (hydraulic)	4086	...	...
Rivet wire and rod	...	B 316	QQ-A-430
Foil	4007	...	MIL-A-81596
Alclad 2024			
Sheet and plate	4034	B 209	QQ-A-250/5
	4040	...	...
	4041	...	...
	4042	...	...
	4060	...	...
	4061	...	...
	4072	...	...
	4073	...	...
	4074	...	...
	4075	...	...
	4194	...	...
	4195	...	...

Thermal Properties

Liquidus temperature. 638 °C (1180 °F)
 Solidus temperature. 502 °C (935 °F)
 Incipient melting temperature. 502 °C (935 °F)
 Coefficient of thermal expansion.
 Linear:

Temperature range		Average coefficient	
°C	°F	µm/m · K	µin./in. · °F
-50 to 20	-58 to 68	21.1	11.7
20 to 100	68 to 212	22.9	12.7
20 to 200	68 to 392	23.8	13.2
20 to 300	68 to 572	24.7	13.7

Volumetric: 66.0 × 10⁻⁶ m³/m³ · K (3.67 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)
 Specific heat. 875 J/kg · K (0.209 Btu/lb · °F) at 20 °C (68 °F)
 Thermal conductivity:

Temper	Conductivity	
	W/m · K	Btu/ft · h · °F
O	190	110
T3, T36, T351, T361, T4	120	69
T6, T81, T851, T861	151	88

Table 23 Typical tensile properties of alloy 2024

Temper	Temperature		Tensile strength		Yield strength (0.2% offset)		Elongation, %	
	°C	°F	MPa	ksi	MPa	ksi		
T3 (sheet)	-196	-320	586	85	427	62	18	
	-80	-112	503	73	359	52	17	
	-28	-18	496	72	352	51	17	
	24	75	483	70	345	50	17	
	100	212	455	66	331	48	16	
	149	300	379	55	310	45	11	
	204	400	186	27	138	20	23	
	260	500	76	11	62	9	55	
	316	600	52	7.5	41	6	75	
	371	700	34	5	28	4	100	
	T4, T351 (plate)	-196	-320	579	84	421	61	19
		-80	-112	490	71	338	49	19
		-28	-18	476	69	324	47	19
24		75	469	68	324	47	19	
100		212	434	63	310	45	19	
149		300	310	45	248	36	17	
204		400	179	26	131	19	27	
260		500	76	11	62	9	55	
316		600	52	7.5	41	6	75	
371		700	34	5	28	4	100	
T6, T651		-196	-320	579	84	469	68	11
		-80	-112	496	72	407	59	10
		-28	-18	483	70	400	58	10
	24	75	476	69	393	57	10	
	100	212	448	65	372	54	10	
	149	300	310	45	248	36	17	
	204	400	179	26	131	19	27	
	260	500	76	11	62	9	55	
	316	600	52	7.5	41	6	75	
	371	700	34	5	28	4	100	
	T81, T851	-196	-320	586	85	538	78	8
		-80	-112	510	74	476	69	7
		-28	-18	503	73	469	68	7
24		75	483	70	448	65	7	
100		212	455	66	427	62	8	
149		300	379	55	338	49	11	
204		400	186	27	138	20	23	
260		500	76	11	62	9	55	
316		600	52	7.5	41	6	75	
371		700	34	5	28	4	100	
T861		-196	-320	634	92	586	85	5
		-80	-112	558	81	531	77	5
		-28	-18	538	78	510	74	5
	24	75	517	75	490	71	5	
	100	212	483	70	462	67	6	
	149	300	372	54	331	48	11	
	204	400	145	21	117	17	28	
	260	500	76	11	62	9	55	
	316	600	52	7.5	41	6	75	
	371	700	34	5	28	4	100	

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F):

Temper	Conductivity, %IACS
O	50
T3, T36, T351, T361, T4	30
T6, T81, T851, T861	38

Electrical resistivity:

Temper	Resistivity, nΩ · m
O	34
T3, T36, T351, T361, T4	57
T6, T81, T851, T861	45

Temperature coefficient. 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. At 25 °C (77

°F) and versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter:

Temper	Volts
T3, T4, T361	-0.68
T6, T81, T861	-0.80
Alclad 2024	-0.83

Fabrication Characteristics

Annealing temperature. 413 °C (775 °F)
 Solution temperature. 493 °C (920 °F)
 Aging temperature. T6 and T8 tempers: 191 °C (375 °F) for 8 to 16 h at temperature

2036

2.6Cu-0.45Mg-0.25Mn

Specifications

UNS number. A92036

Chemical Composition

Composition limits. 0.50 Si max, 0.50 Fe max, 2.2 Cu max, 0.10 to 0.40 Mn, 0.30 to 0.6 Mg, 0.10 Cr max, 0.25 Zn max, 0.15 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Sheet for auto body panels

Mechanical Properties

Tensile properties. Typical, for 0.64 to 3.18 mm (0.025 to 0.125 in.) flat sheet, T4 temper: tensile strength, 340 MPa (49 ksi); yield strength, 195 MPa (28 ksi); elongation, 24% in 50 mm (2 in.). Minimum, for 0.64 to 3.18 mm flat sheet, T4 temper: tensile strength, 290 MPa (42 ksi); yield strength, 160 MPa (23 ksi); elongation, 20% in 50 mm (2 in.)

Hardness. Typical, T4 temper: 80 HR15T

Strain-hardening exponent. 0.23
Elastic modulus. Tension, 70.3 GPa (10.2×10^6 ksi); compression, 71.7 GPa (10.4×10^6 ksi)

Fatigue strength. Typical, T4 temper: 124 MPa (18 ksi) at 10^7 cycles for flat sheet tested in reversed flexure

Mass Characteristics

Density. 2.75 g/cm³ (0.099 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 650 °C (1200 °F)
Solidus temperature. 554 °C (1030 °F)
Incipient melting temperature. 510 °C (950 °F)
Coefficient of thermal expansion. Linear:

Temperature range °C	Temperature range °F	Average coefficient $\mu\text{m}/\text{m} \cdot \text{K}$	Average coefficient $\mu\text{in.}/\text{in.} \cdot \text{°F}$
-50 to 20	-58 to 68	21.6	12.0
20 to 100	68 to 212	23.4	13.0
20 to 200	68 to 392	24.3	13.5
20 to 300	68 to 572	25.2	14.0

Volumetric: $67.5 \times 10^{-6} \text{ m}^3/\text{m}^3 \cdot \text{K}$ ($3.75 \times 10^{-5} \text{ in.}^3/\text{in.}^3 \cdot \text{°F}$) at 20 °C (68 °F)

Specific heat. 882 J/kg · K (0.211 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F): O temper, 198 W/m · K (114 Btu/ft · h · °F); T4 temper, 159 W/m · K (91.8 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 33.2 nΩ · m; T4 temper, 42.1 nΩ · m. Temperature coefficient, at 20 °C (68 °F): O and T4 tempers, 0.1 nΩ · m per K

Electrolytic solution potential. At 25 °C (77 °F): -0.75 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Table 24 Typical mechanical properties of alloy 2024

Temper	Tensile strength		Yield strength		Elongation(a), %	Hardness(b), HB	Shear strength		Fatigue strength(c)	
	MPa	ksi	MPa	ksi			MPa	ksi	MPa	ksi
Bare 2024										
O.....	185	27	75	11	20	47	125	18	90	13
T3.....	485	70	345	50	18	120	285	41	140	20
T4, T351.....	470	68	325	47	20	120	285	41	140	20
T361.....	495	72	395	57	13	130	290	42	125	18
Alclad 2024										
O.....	180	26	75	11	20	...	125	18	...	...
T3.....	450	65	310	45	18	...	275	40	...	...
T4, T351.....	440	64	290	42	19	...	275	40	...	...
T361.....	460	67	365	53	11	...	285	41	...	...
T81, T851.....	450	65	415	60	6	...	275	40	...	...
T861.....	485	70	455	66	6	...	290	42	...	...

(a) 1.6 mm (1/16 in.) thick specimen. (b) 500 kg load; 10 mm ball. (c) At 5×10^8 cycles of completely reversed stress; R.R. Moore type test

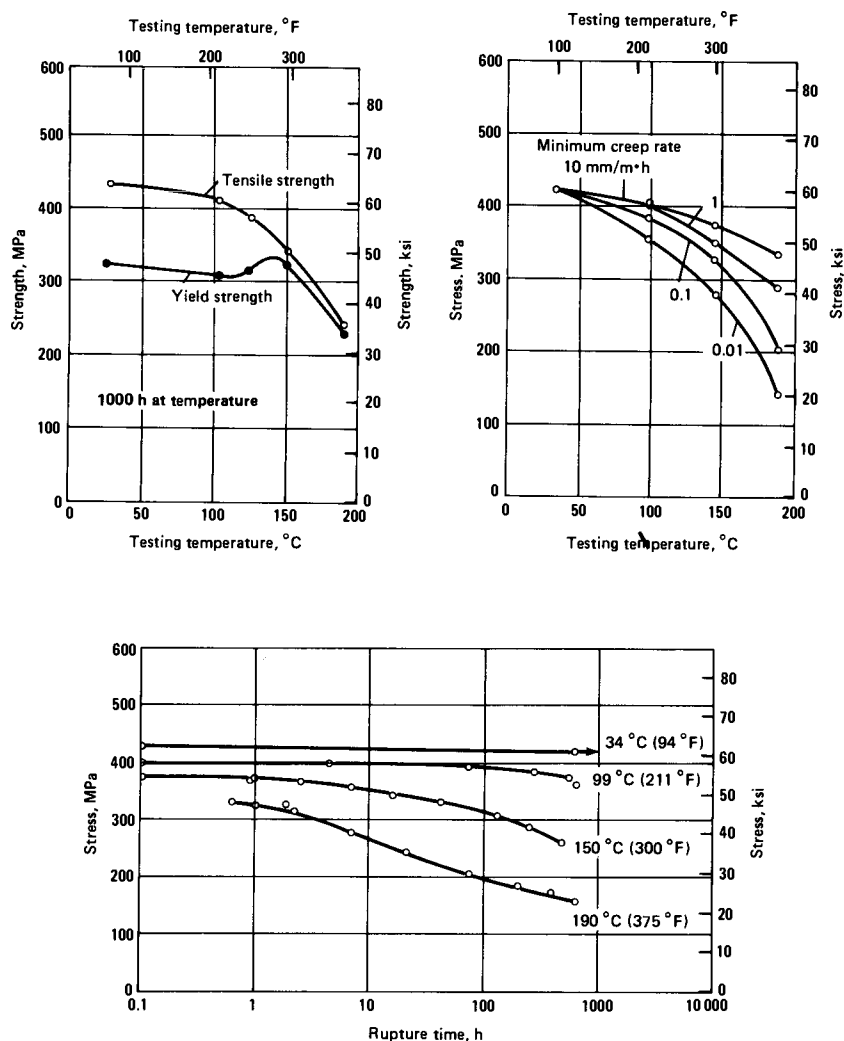


Fig. 4 Effect of temperature on tensile properties of Alclad 2024-T3. Sheet was 1.0 mm (0.04 in.) thick.

Fabrication Characteristics

Weldability. Arc welding with inert gas limited due to crack sensitivity, loss of mechanical properties, and/or loss in resistance to corrosion. When used for

automotive parts, can be resistance welded with very good results
Annealing temperature. 385 °C (725 °F); hold 2 to 3 h at temperature for sheet
Solution temperature. 500 °C (930 °F)

Table 25 Tensile property limits for alloy 2024

Temper	Tensile strength (min)		Yield strength (min)		Elongation (min)(a), %	Temper	Tensile strength (min)		Yield strength (min)		Elongation (min)(a), %
	MPa	ksi	MPa	ksi			MPa	ksi	MPa	ksi	
Sheet and plate						Plate (continued)					
O.....	220 (max)	32 (max)	95 (max)	14 (max)	12	0.500-1.000 in. thick.....	455	66	400	58	5
T42						1.001-1.499 in. thick.....	455	66	395	57	5
0.010-0.499 in. thick.....	425	62	260	38	12-15	Alclad T351					
0.500-1.000 in. thick.....	420	61	260	38	8	0.250-0.499 in. thick.....	425	62	275	40	12
1.001-2.000 in. thick.....	415	60	260	38	6-7	0.500-1.000 in. thick(b) ..	435	63	290	42	8
2.001-3.000 in. thick.....	400	58	260	38	4	1.001-2.000 in. thick(b) ..	425	62	290	42	6-7
T62						2.001-3.000 in. thick(b) ..	415	60	290	42	4
0.010-0.499 in. thick.....	440	64	345	50	5	3.001-4.000 in. thick(b) ..	395	57	285	41	4
0.500-3.000 in. thick.....	435	63	345	50	5	Alclad T851					
T361						0.250-0.499 in. thick.....	450	65	385	56	5
0.020-0.062 in. thick.....	460	67	345	50	8	0.500-1.000 in. thick(b) ..	455	66	400	58	5
0.063-0.249 in. thick.....	470	68	350	51	9	Wire, rod, and bar (rolled or cold finished)					
0.250-0.500 in. thick.....	455	66	340	49	9-10	O.....	240 (max)	35 (max)	...	...	16
T861						T36.....	475	69	360	52	10
0.020-0.062 in. thick.....	485	70	425	62	3	T4.....					
0.063-0.249 in. thick.....	490	71	455	66	4	≤0.499 in. thick or in					
0.250-0.499 in. thick.....	485	70	440	64	4	diam.....	425	62	310(c)	45(c)	10
Alclad O						0.500-4.500 in. thick or in					
0.008-0.062 in. thick.....	205 (max)	30 (max)	95 (max)	14 (max)	10-12	diam.....	425	62	290(c)	42(c)	10
0.063-1.750 in. thick(b) ..	220 (max)	32 (max)	95 (max)	14 (max)	12	4.501-6.500 in. thick or in					
Alclad T42						diam.....	425	62	275(c)	40(c)	10
0.008-0.009 in. thick.....	380	55	235	34	10	6.501-8.00 in. in diam.....	400	58	260	38	10
0.010-0.062 in. thick.....	395	57	235	34	12-15	T42.....	425	62	275	40	10
0.063-0.499 in. thick.....	415	60	250	36	12-15	T351.....	425	62	310	45	10
0.500-1.000 in. thick(b) ..	420	61	260	38	8	T6.....	425	62	345	50	5
1.001-2.000 in. thick(b) ..	415	60	260	38	6-7	T62.....	415	60	315	46	5
2.001-3.000 in. thick(b) ..	400	58	260	38	4	T851.....	455	66	400	58	5
Alclad T62						Wire, rod, bar and shapes (extruded)					
0.010-0.062 in. thick.....	415	60	325	47	5	O.....	240 (max)	35 (max)	130 (max)	19 (max)	12
0.063-0.499 in. thick.....	425	62	340	49	5	T3, T3510, T3511:					
Alclad T361						≤0.249 in. thick or in					
0.020-0.062 in. thick.....	420	61	325	47	8	diam.....	395	57	290	42	12
0.063-0.499 in. thick.....	440	64	330	48	9	0.250-0.749 in. thick or in					
0.500 in. thick(b).....	445	66	340	49	10	diam.....	415	60	305	44	12
Alclad T861						0.750-1.499 in. thick or in					
0.020-0.062 in. thick.....	440	64	400	58	3	diam.....	450	65	315	46	10
0.063-0.249 in. thick.....	475	69	440	64	4	≥1.500 in. thick or in					
0.250-0.499 in. thick.....	470	68	425	62	4	diam:					
0.500 in. thick(b).....	485	70	440	64	4	≤25 in. ² area.....	485	70	360	52	10
Flat sheet						>25-32 in. ² area.....	470	68	330	48	8
T3						T42.....	395	57	260	38	8-12
0.008-0.128 in. thick.....	435	63	290	42	10-15	T81, T851, T8510, T8511					
0.129-0.249 in. thick.....	440	64	290	42	15	0.050-0.249 in. thick or in					
T81.....	460	67	400	58	5	diam.....	440	64	385	56	4
Alclad T3						0.250-≥1.500 in. thick or					
0.008-0.009 in. thick.....	400	58	270	39	10	in diam: area					
0.010-0.062 in. thick.....	405	59	270	39	12-15	≤32 in. ²	455	66	400	58	5
0.063-0.128 in. thick.....	420	61	275	40	15	Extruded tube					
0.129-0.249 in. thick.....	425	62	275	40	15	O.....	240 (max)	35 (max)	130 (max)	19 (max)	12
Alclad T81						T3, T3510, T3511					
0.010-0.062 in. thick.....	425	62	370	54	5	≤0.249 in. thick.....	395	57	290	42	10
0.063-0.249 in. thick.....	450	65	385	56	5	0.250-0.749 in. thick.....	415	60	305	44	10
Sheet						0.750-1.499 in. thick.....	450	65	315	46	10
T72.....	415	60	315	46	5	≥1.500 and over in. thick					
Alclad T72						Area ≤25 in. ²	485	70	330	48	10
0.010-0.062 in. thick.....	385	56	295	43	5	Area >25-32 in. ²	470	68	315	46	8
0.063-0.249 in. thick.....	400	58	310	45	5	T42.....	395	57	260	38	12-8
Coiled sheet						T81, T8510, T8511.....					
T4.....	425	62	275	40	12-15	0.050-0.249 in. thick.....	440	64	385	56	4
Alclad T4						0.250-≥1.500; area ≤32					
0.010-0.060 in. thick.....	400	58	250	36	12-15	in. ²	455	66	400	58	5
0.063-0.128 in. thick.....	420	61	260	38	15	Drawn tube					
Plate						O.....	220 (max)	32 (max)	105 (max)	15 (max)	...
T351						T3.....	440	64	290	42	10-16(e)
0.250-0.499 in. thick.....	440	64	290	42	12	T42.....	440	64	275	40	10-16(e)
0.500-1.000 in. thick.....	435	63	290	42	8	Rivet and cold-heading wire and rod					
1.001-2.000 in. thick.....	425	62	290	42	6-7	O.....	240 (max)	35 (max)	...	...	...
2.001-3.000 in. thick.....	415	60	290	42	4	H13.....	220	32	...	...	...
3.001-4.000 in. thick.....	395	57	285	41	4		290 (max)	42 (max)	...	...	...
T851						T4.....	425	62	275	40	10
0.250-0.499 in. thick.....	460	67	400	58	5						

(a) In 50 mm (2 in.) or 4d, where d is diameter of reduced section of tension-test specimen. Where a range of values appears in this column, the specified minimum elongation varies with thickness of the mill product. (b) For plate 12.7 mm (0.500 in.) or over in thickness, listed properties apply to core material only. Tensile and yield strengths of composite plate are slightly lower than the listed value, depending on thickness of the cladding. (c) Minimum yield strength of coiled wire and rod, 276 MPa (40 ksi). (d) Applicable to rod only. (e) Full section specimen; minimum elongation is 10 to 12% for cut-out specimen

Table 26 Typical mechanical properties of alloy 2048 plate, 75 mm (3 in.) thick

	At room temperature	At 120 °C (250 °F)	At 175 °C (350 °F)	At 260 °C (500 °F)
Tensile strength, MPa (ksi)				
Longitudinal	457 (66)	414 (60)	350 (51)	234 (34)
Transverse	465 (67)	414 (60)	345 (50)	230 (33)
Short transverse	463 (67)	...	...	...
Yield strength, MPa (ksi)				
Longitudinal	416 (60)	392 (57)	338 (49)	220 (32)
Transverse	420 (61)	388 (56)	338 (49)	220 (32)
Short transverse	406 (59)	...	...	...
Elongation, %				
Longitudinal	8	13	14	10
Transverse	7	13	...	8
Short transverse	6	...	...	...
Reduction in area, %				
Longitudinal	16	32	37	23
Transverse	12	28	34	15
Short transverse	9	...	...	...
Compressive yield strength, MPa (ksi)				
Longitudinal	420 (61)	391 (57)	350 (51)	243 (35)
Transverse	420 (61)	386 (56)	350 (51)	227 (33)
Elastic moduli, GPa (10⁶ psi)				
In tension				
Longitudinal	70 (10)	68 (9.9)	64 (9.3)	57 (8.3)
Transverse	72 (10.4)	68 (9.9)	64 (9.3)	53 (8.7)
Short transverse	77 (11.1)	...	...	...
In compression				
Longitudinal	78 (11.3)	70 (10)	66 (9.6)	65 (9.4)
Transverse	77 (11.1)	71 (10.3)	67 (9.7)	66 (9.6)
Axial fatigue (longitudinal), MPa (ksi)				
Unnotched, $R = 0.1$				
10 ³ cycles	469 (68)	469 (68)	469 (68)	...
10 ⁵ cycles	262 (38)	255 (37)	241 (35)	...
10 ⁷ cycles	221 (32)	193 (28)	172 (25)	...
Notched, $K_t = 3.0, R = 0.1$				
10 ³ cycles	372 (54)	372 (54)	344 (50)	...
10 ⁵ cycles	152 (22)	145 (21)	131 (19)	...
10 ⁷ cycles	110 (16)	97 (14)	82 (12)	...
Creep strength (longitudinal)(a), MPa (ksi)				
100 h	...	303 (44)	241 (35)	60 (9)
1000 h	...	283 (41)	131 (19)	31 (5)
Rupture strength (longitudinal), MPa (ksi)				
100 h	...	345 (50)	269 (39)	90 (13)
1000 h	...	324 (47)	221 (32)	60 (9)

(a) Stress to produce 0.2% plastic extension in the indicated time

2048 3.3Cu-1.5Mg-0.40Mn

Specifications

UNS number. A92048

Chemical Composition

Composition limits. 0.15 Si max, 0.20 Fe max, 2.8 to 3.8 Cu, 0.20 to 0.6 Mn, 1.2 to 1.8 Mg, 0.25 Zn max, 0.10 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Sheet and plate in structural components for aerospace application and military equipment

Mechanical Properties

Tensile properties. See Table 26 and Fig. 5.
Shear strength. Longitudinal, 271 MPa

(39.3 ksi); transverse, 270 MPa (39.2 ksi)
Compressive properties. See Table 26 and Fig. 6.

Elastic modulus. See Fig. 5 and 6.

Impact strength. Charpy V-notch: longitudinal, 10.3 J (7.6 ft · lbf); transverse, 6.1 J (4.5 ft · lbf)

Fatigue strength. See Table 26 and Fig. 7 to 10.

Plane-strain fracture toughness. L-T crack orientation, 35.2 MPa√m (32.0 ksi√in.); T-L crack orientation, 31.9 MPa√m (29.1 ksi√in.)

Creep-rupture characteristics. See Table 26 and Fig. 11.

Mass Characteristics

Density. 2.75 g/cm³ (0.099 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Coefficient of thermal expansion. Linear, 23.5 μm/m · K (13.0 μin./in. · °F) at 21 to 104 °C (70 to 220 °F)

Specific heat. 926 J/kg · K (0.221 Btu/lb · °F) at 100 °C (212 °F)

Thermal conductivity. T851 temper, 159 W/m · K (92 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, T851 temper: 42% IACS at 20 °C (68 °F)

Electrical resistivity. T851 temper, 40 nΩ · m at 20 °C (68 °F)

2124

4.4Cu-1.5Mg-0.6Mn

Specifications

AMS. 4101

ASTM. B 209

UNS number. A92124

Government. QQ-A-250/29

Chemical Composition

Composition limits. 0.20 Si max, 0.30 Fe max, 3.8 to 4.9 Cu, 0.30 to 0.9 Mn, 1.2 to 1.8 Mg, 0.10 Cr max, 0.25 Zn max, 0.15 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Consequence of exceeding impurity limits. Degrades fracture toughness

Applications

Typical uses. Plate in thicknesses of 40 to 150 mm (1.5 to 6.0 in.) for aircraft structures

Mechanical Properties

Tensile properties. See Tables 27 and 28.

Poisson's ratio. 0.33 at 20 °C (68 °F)

Elastic modulus. See Table 28.

Plane-strain fracture toughness. T851 temper, plate: L-T, 31.9 MPa√m (29.0 ksi√in.); T-L, 27.5 MPa√m (25.0 ksi√in.); S-L, 24.2 MPa√m (22.0 ksi√in.)

Creep-rupture characteristics. See Table 29.

Mass Characteristics

Density. 2.77 g/cm³ (0.100 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 638 °C (1180 °F)

Solidus temperature. 502 °C (935 °F)

Incipient melting temperature. 502 °C (935 °F)

Coefficient of thermal expansion.

Linear:

Temperature range °C	Temperature range °F	Average coefficient	
		μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.1	11.7
20 to 100	68 to 212	22.9	12.7
20 to 200	68 to 392	23.8	13.2
20 to 300	68 to 572	24.7	13.7

Volumetric: 66.0 × 10⁻⁶ m³/m³ · K (3.6 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

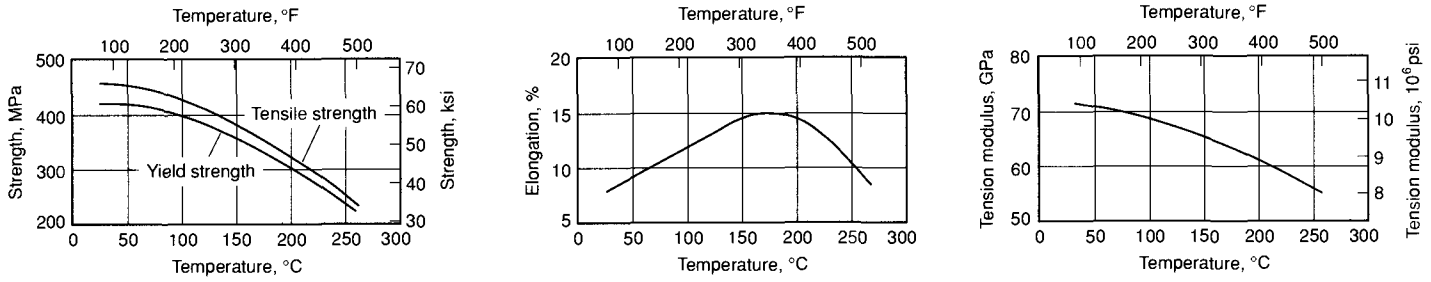


Fig. 5 Typical tensile properties of alloy 2048-T851 plate

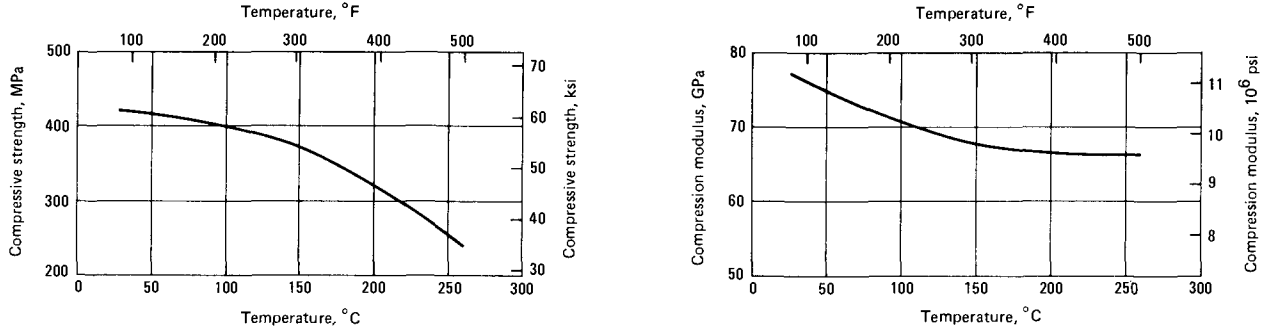


Fig. 6 Typical compressive properties of alloy 2048-T851 plate

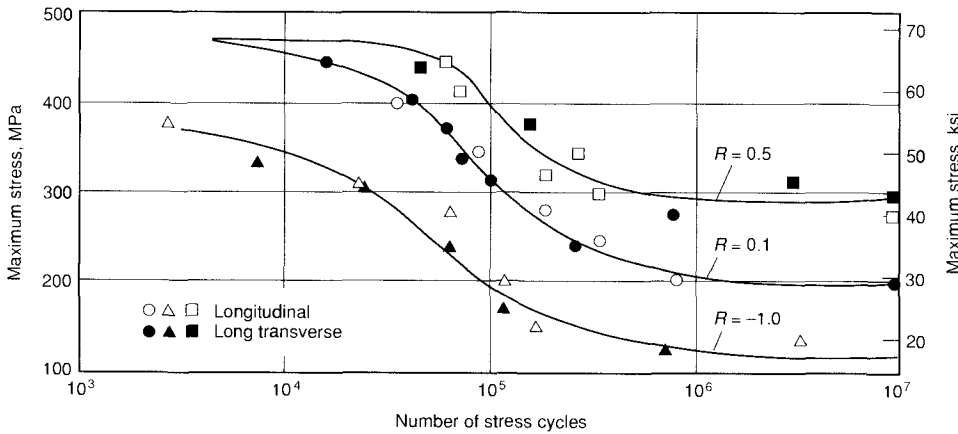


Fig. 7 Axial fatigue curves for unnotched specimens of alloy 2048-T851 plate

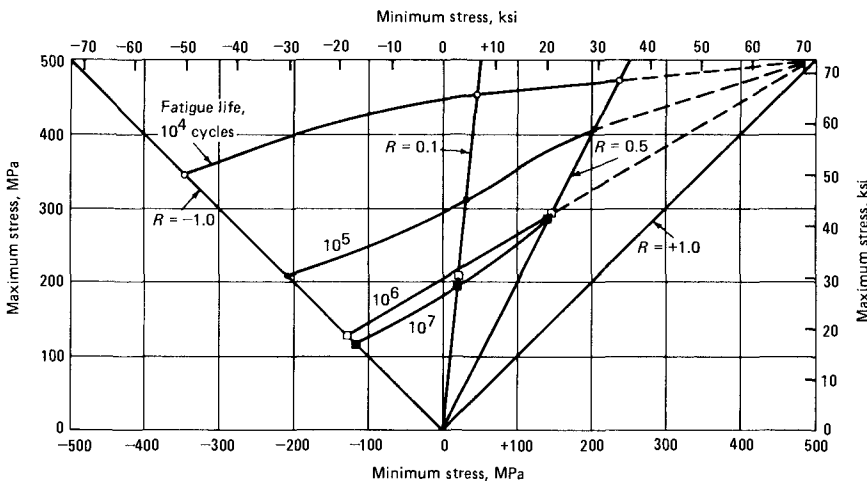


Fig. 8 Modified Goodman diagram for axial fatigue of unnotched specimens of alloy 2048-T851 plate

Specific heat. 882 J/kg · K (0.210 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F): O temper, 191 W/m · K (110 Btu/ft · h · °F); T851, 152 W/m · K (87.8 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 50% IACS; T851, 39% IACS

Electrical resistivity. At 20 °C (68 °F): O temper, 34.5 nΩ · m. Temperature coefficient, O and T851 tempers: 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. T851 temper, -0.80 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter at 25 °C (77 °F)

Fabrication Characteristics

Annealing temperature. 413 °C (775 °F)

Solution temperature. 493 °C (920 °F)

Aging temperature. 191 °C (375 °F)

**2218
4.0Cu-2.0Ni-1.5Mg**

Specifications

AMS. Forgings and forging stock: 4142

SAE. J454

UNS. A92218

Government. Forgings and forging stock: QQ-A-367

Foreign. France: NF A-U4N. Spain: UNE L-315. Switzerland: VSM Al-Cu-Ni

Chemical Composition

Composition limits. 0.9 Si max, 1.0 Fe max, 3.5 to 4.5 Cu, 0.20 Mn max, 1.2 to 1.8 Mg,

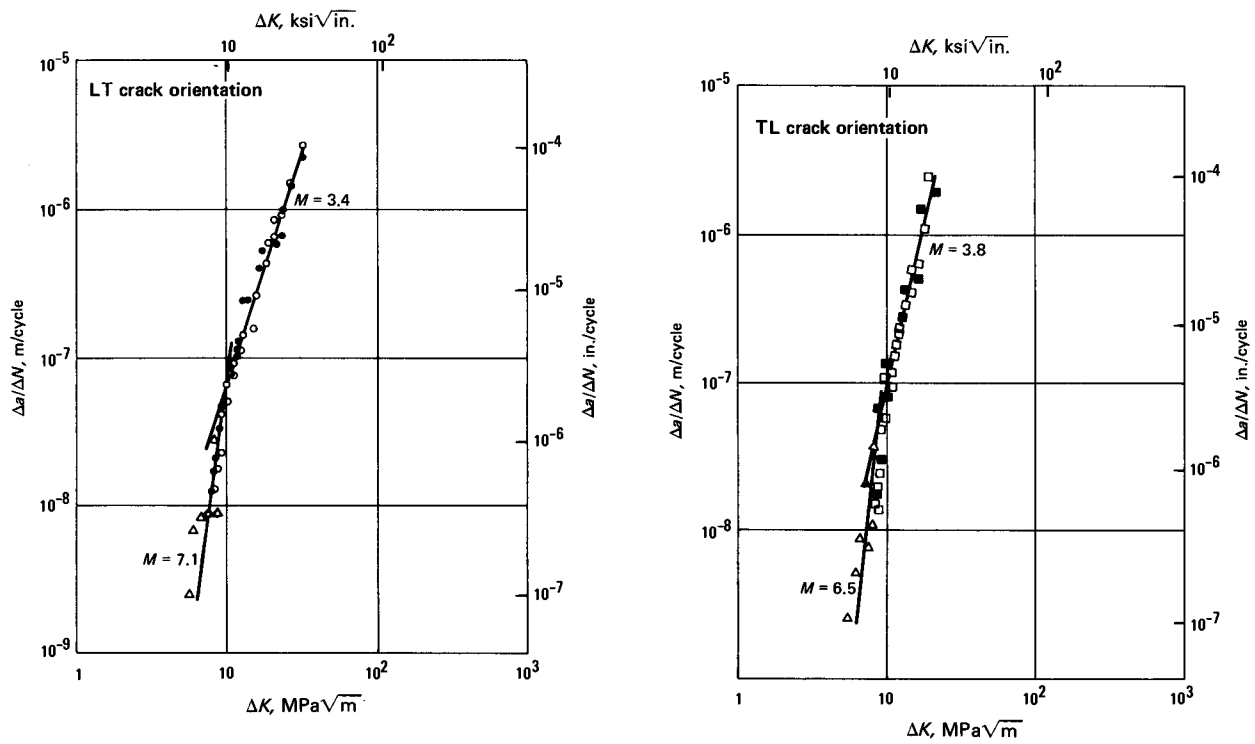


Fig. 9 Fatigue-crack propagation in alloy 2048-T851 plate

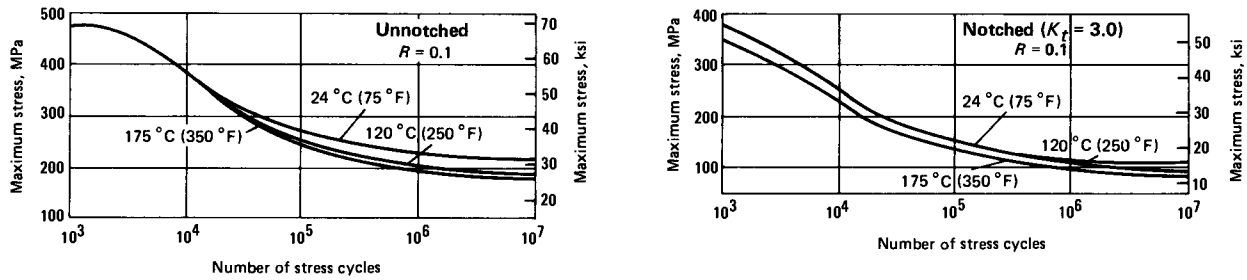


Fig. 10 Axial fatigue of alloy 2048-T851 plate

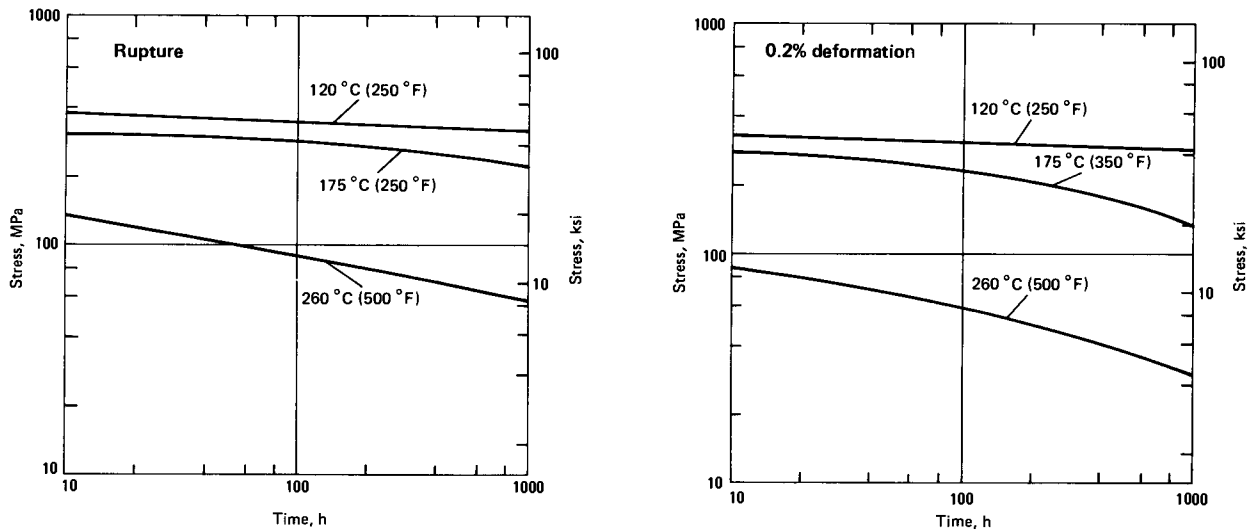


Fig. 11 Creep-rupture curves for alloy 2048-T851 plate, longitudinal orientation

Table 27 Typical tensile properties of alloy 2124-T851

Specimen orientation	Tensile strength		Yield strength		Elongation, %
	MPa	ksi	MPa	ksi	
1.500–2.000 in. thick					
Longitudinal.....	490	71	440	64	9
Long transverse.....	490	71	435	63	9
Short transverse.....	470	68	420	61	5
2.000–3.000 in. thick					
Longitudinal.....	480	70	440	64	9
Long transverse.....	470	68	435	63	8
Short transverse.....	465	67	420	61	4

0.10 Cr max, 1.7 to 2.3 Ni, 0.25 Zn max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Forgings; aircraft and diesel engine pistons; aircraft engine cylinder heads; jet engine impellers and compressor rings

Mechanical Properties

Tensile properties. See Tables 30 and 31.
Shear strength. T72 temper, 205 MPa (30 ksi)
Compressive yield strength. Approximately the same as tensile yield strength
Hardness. See Table 30.

Table 28 Mechanical properties of alloy 2124-T851 plate, 70 mm (2.75 in.) thick

Temperature °C °F		Time at temperature, h	At indicated temperature						At room temperature after heating							
			Tensile strength		Yield strength		Elongation, %	Modulus of elasticity		Tensile strength		Yield strength		Elongation, %		
MPa	ksi	MPa	ksi	MPa	ksi	GPa		10 ⁶ psi	MPa	ksi	MPa	ksi				
-269	-452	...	705	102	620	90	10	...	...	...	...	...	...
-195	-320	...	595	86	545	79	9	81	11.8	...	...	...	...
-80	-112	...	525	76	490	71	8	76	11.0	...	...	...	...
-28	-18	...	505	73	470	68	8	74	10.7	...	...	...	...
24	75	...	485	70	450	65	8	72	10.5	485	70	450	65	8		
100	212	0.1–10 000	455	66	420	61	9	71	10.3	485	70	450	65	8		
		100 000	450	65	415	60	9	71	10.3	...	...	...	...	71
150	300	0.1–10	415	60	395	57	10	68	9.9	485	70	450	65	8		
		100	405	59	395	57	10	68	9.9	485	70	440	64	8		
		1 000	400	58	380	55	11	68	9.9	475	69	435	63	8		
		10 000	370	54	330	48	13	68	9.9	460	67	405	59	8		
		100 000	345	50	295	43	15	68	9.9	...	...	...	...	...
175	350	0.1	397	57	370	54	12	66	9.6	485	70	450	65	8		
		0.5	385	56	365	53	12	66	9.6	485	70	450	65	8		
		10	380	55	360	52	12	66	9.6	485	70	435	63	8		
		100	360	52	340	49	12	66	9.6	470	68	420	61	8		
		1 000	330	48	305	44	14	66	9.6	455	66	400	58	8		
		10 000	295	43	250	36	16	66	9.6	405	59	305	44	10		
		100 000	220	32	180	26	23	66	9.6	...	...	...	...	...
		205	400	0.1	365	53	340	49	13	63	9.2
				0.5	360	52	330	48	13	63	9.2	475	69	435	63	8
				10	330	48	310	45	14	63	9.2	460	67	405	59	8
100	305			44	270	39	15	63	9.2	435	63	370	54	8		
1 000	260			38	220	32	19	63	9.2	395	57	305	44	9		
230	450	10 000	185	27	140	20	28	63	9.2	290	42	165	24	12		
		100 000	125	18	90	13	40	63	9.2	...	...	...	...	...
		0.1	325	47	295	43	15	61	8.9	...	...	...	...	...
		0.5	310	45	285	41	15	61	8.9	470	68	425	62	8		
		10	275	40	250	36	17	61	8.9	425	62	360	52	8		
		100	235	34	200	29	20	61	8.9	370	54	275	40	10		
		1 000	170	25	125	18	30	61	8.9	290	42	170	25	12		
		10 000	110	16	76	11	45	61	8.9	215	31	90	13	18		
		100 000	83	12	59	8.5	55	61	8.9	...	...	...	...	...
		260	500	0.1	270	39	240	35	17	59	8.5
0.5	255			37	230	33	17	59	8.5	455	66	400	58	9		
10	205			30	185	27	20	59	8.5	385	56	295	43	10		
100	150			22	125	18	29	59	8.5	290	42	170	25	12		
1 000	105			15	76	11	45	59	8.5	235	34	110	16	17		
10 000	76			11	55	8	60	59	8.5	195	28	83	12	22		
100 000	62			9	45	6.5	65	59	8.5	...	...	...	...	...
315	600			0.1	160	23	145	21	23	53	7.7
				0.5	140	20	115	17	26	53	7.7	340	49	230	33	10
				10	83	12	69	10	40	53	7.7	270	39	130	19	13
		100	69	10	55	8	50	53	7.7	240	35	105	15	17		
		1 000	62	9	45	6.5	65	53	7.7	215	31	83	12	22		
370	700	10 000	52	7.5	41	6	75	53	7.7	185	27	76	11	22		
		100 000	45	6.5	38	5.5	80	53	7.7	...	...	...	...	...
		0.1	76	11	69	10	35	45	6.5	...	...	...	...	...
		0.5	59	8.5	45	6.5	50	45	6.5	275	40	130	19	13		
		10	48	7	34	5	75	45	6.5	255	37	105	15	18		
		100	41	6	31	4.5	85	45	6.5	235	34	90	13	22		
		1 000	38	5.5	28	4.1	90	45	6.5	205	30	83	12	22		
		10 000	34	5	28	4.1	95	45	6.5	185	27	76	11	22		
		100 000	34	5	28	4.1	100	45	6.5	...	...	...	...	...
		425	800	0.1	34	5	28	4.1	65	
0.5	30			4.4	24	3.5	85	...	...	...	...	...	...
480	900	...	16	2.3	12	1.8	65	...	...	...	...	...	...
				
535	1000	...	2	0.3	2	0.3	2	...	...	...	...	...	...

Table 29 Creep-rupture properties of alloy 2124-T851 plate, 70 mm thick

Temperature		Time under stress, h	Rupture stress		Stress for creep of							
°C	°F		MPa	ksi	1.0%		0.5%		0.2%		0.1%	
			MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
24	75	0.1	485	70	470	68	455	66	...	...	...	...
		1	475	69	460	67	450	65	...	...	...	...
		10	475	69	455	66	...	...	...	...	...	...
		100	470	68	...	...	...	...	...	...	...	...
100	212	0.1	455	66	435	63	425	62	420	61	415	60
		1	435	63	420	61	415	60	405	59	395	57
		10	420	61	405	59	395	57	380	55	370	54
		100	400	58	385	56	380	55	360	52	345	50
150	300	0.1	380	55	370	54	360	52	340	49	325	47
		1	400	58	380	55	370	54	360	52	345	50
		10	370	54	360	52	345	50	330	48	310	45
		100	345	50	340	49	325	47	310	45	285	41
175	350	0.1	315	46	310	45	305	44	290	42	250	36
		1	290	42	285	41	270	39	235	34	205	30
		10	235	34	...	...	...	...	...	...	...	...
		100 000	170	25	...	...	...	...	...	...	...	...
205	400	0.1	365	53	345	50	340	49	325	47	305	44
		1	340	49	325	47	310	45	290	42	260	38
		10	305	44	290	42	275	40	255	37	230	33
		100	270	39	255	37	240	35	205	30	170	25
230	450	0.1	205	30	195	28	170	25	140	20	105	15
		1	145	21	...	...	...	...	...	...	...	...
		10	90	13	...	...	...	...	...	...	...	...
		100 000	205	30	195	28	170	25	140	20	105	15
260	500	0.1	205	30	195	28	170	25	140	20	105	15
		1	290	42	275	40	270	39	250	36	220	32
		10	255	37	240	35	235	34	205	30	170	25
		100	200	29	185	27	180	26	150	22	115	17
260	500	1 000	130	19	125	18	115	17	90	13	52	7.5
		10 000	83	12	69	10	59	8.5	...	...	...	...
		100 000	52	7.5	...	...	...	...	...	...	...	...
		100 000	275	40	260	38	250	36	235	34	215	31
260	500	1	240	35	235	34	220	32	205	30	170	25
		10	195	28	185	27	180	26	150	22	115	17
		100	130	19	125	18	115	17	...	...	...	...
		1 000	76	11	...	...	...	...	...	...	...	...
315	600	0.1	48	7	...	...	...	...	...	...	...	...
		1	34	4.9	...	...	...	...	...	...	...	...
		10	215	31	205	30	200	29	180	26	170	25
		100	185	27	180	26	170	25	150	22	130	19
315	600	10	140	20	130	19	125	18	97	14	76	11
		100	83	12	76	11	69	10	...	...	...	...
		1 000	48	7	...	...	...	...	...	...	...	...
		10 000	32	4.7	...	...	...	...	...	...	...	...
315	600	100 000	23	3.4	...	...	...	...	...	...	...	...
		0.1	110	16	110	16	105	15	97	14	90	13
		1	97	14	90	13	83	12	69	10	59	8.5
		10	59	8.5	55	8	52	7.5	45	6.5	38	5.5
315	600	100	34	5	34	5	30	4.4	25	3.6	21	3
		1 000	21	3	20	2.9	18	2.6	...	...	...	...

Poisson's ratio. 0.33 at 20 °C (68 °F)
 Elastic modulus. Tension, 74.4 GPa (10.8 × 10⁶ psi); shear, 27.5 GPa (4.0 × 10⁶ psi)
 Fatigue strength. See Table 32.
 Creep-rupture characteristics. See Table 33.

Mass Characteristics

Density. 2.80 g/cm³ (0.101 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 635 °C (1175 °F)

Solidus temperature. 532 °C (990 °F)
 Incipient melting temperature. 504 °C (940 °F)
 Coefficient of thermal expansion.
 Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	20.7	11.5
20 to 100	68 to 212	22.4	12.4
20 to 200	68 to 392	23.3	12.9
20 to 300	68 to 572	24.2	13.4

Volumetric. 6.5 × 10⁻⁵ m³/m³ · K (3.6 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)
 Specific heat. 871 J/kg · K (0.208 Btu/lb · °F) at 20 °C (68 °F)
 Thermal conductivity. At 20 °C (68 °F): T61 temper, 148 W/m · K (85.5 Btu/ft · h · °F); T72 temper, 155 W/m · K (89.6 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric: T61 temper, 38% IACS; T72 temper, 40% IACS
 Electrical resistivity. T61 temper, 45.0 nΩ · m; T72 temper, 43.0 nΩ · m. Temperature coefficient, T61 and T72 tempers: 0.1 nΩ · m per K at 20 °C (68 °F)

Fabrication Characteristics

Solution temperature. 510 °C (950 °F)
 Aging temperature. T61 temper, 170 °C (340 °F) for 10 h at temperature; T72 temper, 240

Table 30 Typical mechanical properties of alloy 2218

Temper	Tensile strength		Yield strength		Elongation, %	Hardness(a), HB
	MPa	ksi	MPa	ksi		
T61	407	59	303	44	13	115
T71	345	50	276	40	11	105
T72	331	48	255	37	11	95

(a) 500 kg load; 10 mm diam ball

Table 31 Tensile properties of alloy 2218-T61

Temperature		Tensile strength(a)		Yield strength(a)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
-195	-320	495	72.0	360	52.0	15
-80	-112	420	61.0	310	45.0	14
-30	-18	405	59.0	305	44.0	13
25	75	405	59.0	305	44.0	13
100	212	385	56.0	290	42.0	15
150	300	285	41.0	240	35.0	17
205	400	150	22.0	110	16.0	30
260	500	70	10.0	40	6.0	70
315	600	40	5.5	20	3.0	85
370	700	30	4.0	17	2.5	100

(a) Lowest strength determined for representative lot during 10 000 h exposure at temperature under no load

Table 32 Fatigue strength of alloy 2218-T61

Temperature °C	Temperature °F	No. of cycles	Fatigue strength(a)	
			MPa	ksi
23	75	10 ⁵	270	39.0
		10 ⁶	215	31.0
		10 ⁷	170	25.0
		10 ⁸	135	20.0
		5 × 10 ⁸	125	18.0
150	300	10 ⁵	...	...
		10 ⁶	170	25.0
		10 ⁷	130	19.0
		10 ⁸	105	15.0
		5 × 10 ⁸	100	14.0
205	400	10 ⁵	...	...
		10 ⁶	150	22.0
		10 ⁷	105	15.0
		10 ⁸	69	10.0
		5 × 10 ⁸	59	8.5
260	500	10 ⁵	145	21.0
		10 ⁶	105	15.0
		10 ⁷	72	10.0
		10 ⁸	48	7.0
		5 × 10 ⁸	41	6.0
315	600	10 ⁵	90	13.0
		10 ⁶	69	10.0
		10 ⁷	48	7.0
		10 ⁸	34	5.0
		5 × 10 ⁸	31	4.5

(a) R. R. Moore type test

°C (460 °F) for 6 h at temperature

2219, Alclad 2219

6.3Cu-0.3Mn-0.18Zr-0.10V-0.06Ti

Specifications

AMS. Sheet and plate: 4031. Extruded wire, rod, bar, shapes, and tube: 4162, 4163. Forgings: 4143, 4144. Alclad 2219, sheet and plate: 4094, 4095, 4096

ASTM. Sheet and plate: B 209. Rolled or cold finished wire, rod, and bar: B 211. Extruded wire, rod, bar, shapes, and tube: B 221. Extruded, seamless tube: B 241. Forgings: B 247. Alclad 2219, sheet and plate: B 209

SAE. J454

UNS. A92219

Government. Sheet and plate: QQ-A-250/30. Forgings: QQ-A-367, MIL-A-22771. Armor plate: MIL-A-46118. Rivet wire and rod: QQ-A-430

Foreign. France: NF A-U6MT. United Kingdom: DTD 5004

Chemical Composition

Composition limits for 2219. 0.20 Si max, 0.30 Fe max, 5.8 to 6.8 Cu, 0.20 to 0.40 Mn, 0.02 Mg max, 0.10 Zn max, 0.05 to 0.15 V, 0.02 to 0.10 Ti, 0.10 to 0.25 Zr, 0.05 max other (each), 0.15 max others (total), bal Al
Composition limits for Alclad 2219. 7072 cladding—0.10 Cu max, 0.10 Mn max, 0.70

Si max + Fe, 0.80 to 1.3 Zn, 0.10 Mg max, 0.05 max other (each), 0.15 max others (total)

Applications

Typical uses. Welded space booster oxidizer and fuel tanks, supersonic aircraft skin and structure components. Readily weldable and useful for applications over temperature range of -270 to 300 °C (-450 to 600 °F). Has high fracture toughness, and the T8 temper is highly resistant to stress-corrosion cracking

Mechanical Properties

Tensile properties. See Tables 34 to 36.

Poisson's ratio. 0.33 at 20 °C (68 °F)

Elastic modulus. Tension, 73.8 GPa (10.7 × 10⁶ psi); compression, 75.2 GPa (10.9 × 10⁶ psi)

Fatigue strength. 103 MPa (15 ksi) at 5 × 10⁸ cycles, R.R. Moore type test

Creep-rupture characteristics. See Tables 37 and 38.

Mass Characteristics

Density. 2.84 g/cm³ (0.103 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 643 °C (1190 °F)

Incipient melting temperature. 543 °C (1010 °F)

Coefficient of thermal expansion. Linear:

Temperature range °C	Temperature range °F	Average coefficient	
		μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	20.8	11.5
20 to 100	68 to 212	22.5	12.5
20 to 200	68 to 392	23.4	13.0
20 to 300	68 to 572	24.4	13.6

Volumetric. 6.5 × 10⁻⁵ m³/m³ · K (3.62 × 10⁻⁵ in.³/in.³ · °F)

Specific heat. 864 J/kg · K (0.206 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. O temper, 170 W/m · K (98.2 Btu/ft · h · °F); T31, T37 tempers, 116 W/m · K (67.0 Btu/ft · h · °F); T62, T81, T87 tempers, 130 W/m · K (75.1 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 44% IACS; T31, T37,

Table 33 Creep-rupture properties of alloy 2218-T61

Temperature °C	Temperature °F	Time under stress, h	Rupture stress		Stress for creep of:								
			MPa	ksi	1%		0.5%		0.2%		0.1%		
					MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	
100	212	Up to 1000	385	56.0
150	300	0.1	360	52.0	350	51.0	330	48.0	315	46.0	290	42.0	
		1	350	51.0	345	50.0	325	47.0	310	45.0	285	41.0	
		10	350	51.0	340	49.0	315	46.0	305	44.0	275	40.0	
		100	330	48.0	325	47.0	310	45.0	295	43.0	230	33.0	
		1000	290	42.0	290	42.0	290	42.0	270	39.0	140	20.0	
205	400	0.1	325	47.0	315	46.0	290	42.0	275	40.0	255	37.0	
		1	310	45.0	305	44.0	275	40.0	260	38.0	235	34.0	
		10	255	37.0	250	36.0	240	35.0	220	32.0	160	23.0	
		100	185	27.0	180	26.0	170	25.0	140	20.0	105	15.0	
		1000	115	17.0	110	16.0	105	15.0	105	15.0	...	...
315	600	0.1	55	8.0	52	7.5	48	7.0	45	6.5	41	6	
		1	48	7.0	48	7.0	45	6.5	41	6.0	38	5.5	
		10	45	6.5	41	6.0	47	6.9	34	5.0	21	3.0	
		100	27	3.9	23	3.4	21	3.0	14	2.1	...	...

Table 34 Typical tensile properties of alloy 2219

Temper	Tensile strength		Yield strength		Elongation, %
	MPa	ksi	MPa	ksi	
O	172	25	76	11	18
T42	359	52	186	27	20
T31, T351	359	52	248	36	17
T37	393	57	317	46	11
T62	414	60	290	42	10
T81, T851	455	66	352	51	10
T87	476	69	393	57	10

T351 tempers, 28% IACS; T62, T81, T87, T851 tempers, 30% IACS
Electrical resistivity. At 20 °C (68 °F); O temper, 39 nΩ · m; T31, T37, T351 tempers,

62 nΩ · m; T62, T81, T87, T851 tempers, 57 nΩ · m. Temperature coefficient, all tempers: 0.1 nΩ · m per K at 20 °C (68 °F)
Electrolytic solution potential. T31, T37, T351 tempers, -0.64 V and T62, T81, T87, T851 tempers, -0.80 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter at 25 °C (77 °F)

Fabrication Characteristics

Annealing temperature. 415 °C (775 °F)
Solution temperature. 535 °C (995 °F)
Aging temperature. 165 to 190 °C (325 to 375 °F) from 18 to 36 h at temperature. Appropriate combination of aging time and temperature is different for different tempers.

2319 5.3Cu-0.3Mn-0.18Zr-0.15Ti-0.10V

Specifications

UNS. A92319
Government. QQ-R-566, MIL-E-16053

Chemical Composition

Composition limits. 5.8 to 6.8 Cu, 0.20 to 0.40 Mn, 0.10 to 0.25 Zr, 0.10 to 0.20 Ti, 0.05 to 0.15 V, 0.20 Si max, 0.30 Fe max, 0.02 Mg max, 0.10 Zn max, 0.0008 Be max, 0.05 max other (each), 0.15 max others (total)

Applications

Typical uses. Electrodes and filler wire for welding 2219

Table 35 Tensile-property limits for alloy 2219

Temper	Tensile strength (min)		Yield strength (min)		Elongation(a), %	Temper	Tensile strength (min)		Yield strength (min)		Elongation(a), %
	MPa	ksi	MPa	ksi			MPa	ksi	MPa	ksi	
Sheet and plate						Wire, rod, and bar (rolled or cold finished)					
O	220 (max)	32 (max)	110 (max)	16 (max)	12	T851					
Alclad O	220 (max)	32 (max)	110 (max)	16 (max)	12	0.500–2.000 in. thick or in diam.	400	58	275	40	4
T31(b)						2.001–4.000 in. thick or in diam.	395	57	270	39	4
0.020–0.039 in. thick	315	46	200	29	8	Wire, rod, bar, and shapes (extruded)					
0.040–0.249 in. thick	315	46	195	28	10	O	221 (max)	32 (max)	125 (max)	18 (max)	12
Alclad T31(b)						T31, T3510, T3511					
0.040–0.099 in. thick	290	42	170	25	10	Up thru 0.499 in. thick or in diam.	290	42	180	26	14
0.100–0.249 in. thick	305	44	180	26	10	0.500–2.999 in. thick or in diam.	310	45	185	27	14
T351(c)						T62	370	54	250	36	6
0.250–2.000 in. thick	315	46	195	28	10	T81, T8510, T8511	400	58	290	42	6
2.100–3.000 in. thick	305	44	195	28	10	Extruded tube					
3.100–4.000 in. thick	290	42	185	27	9	O	220 (max)	32 (max)	125 (max)	18 (max)	12
4.100–5.000 in. thick	275	40	180	26	9	T31, T3510, T3511					
5.001–6.000 in. thick	270	39	170	25	8	Up thru 0.499 in. thick or in diam.	290	42	180	26	14
Alclad T351(c)	305	44	180	26	10	0.500–2.999 in. thick or in diam.	310	45	185	27	14
T37						T62	370	54	250	36	6
0.020–0.039 in. thick	340	49	260	38	6	T81, T8510, T8511	400	58	290	42	6
0.040–2.500 in. thick	340	49	255	37	6	Die forgings					
2.501–3.000 in. thick	325	47	250	36	6	T6					
3.001–4.000 in. thick	310	45	240	35	5	Specimen axis parallel to grain flow	400	58	260	38	8(e)(f)
4.001–5.000 in. thick	295	43	235	34	4	Specimen axis not parallel to grain flow	385	56	250	36	4(e)
Alclad T37						Hand forgings(g)					
0.040–0.099 in. thick	310	45	235	34	6	T6					
0.100–0.499 in. thick	325	47	240	35	6	Longitudinal axis	400	58	275	40	6
T62	370	54	250	36	6–8	Long transverse axis	380	55	255	37	4
Alclad T62						Short transverse axis	365	53	240	35	2
0.020–0.039 in. thick	305	44	200	29	6	Mechanical property limits					
0.040–0.099 in. thick	340	49	220	32	7	T852					
0.100–0.499 in. thick	350	51	235	34	7–8	Longitudinal axis	425	62	345	50	6
0.500–2.000 in. thick(c)	370	54	250	36	7–8	Long transverse axis	425	62	340	49	4
T81(b)	425	62	315	46	6–7	Short transverse axis	415	60	315	46	3
Alclad T81(b)						Rolled rings(h)					
0.020–0.039 in. thick	340	49	255	37	6	T6					
0.040–0.099 in. thick	380	55	285	41	7	Tangential axis	385	56	275	40	6
0.100–0.249 in. thick	400	58	295	43	7	Axial axis	380	55	255	37	4
T851(d)						Radial axis	365	53	240	35	2
0.250–2.000 in. thick	425	62	315	46	7–8						
2.001–3.000 in. thick	425	62	310	45	6						
3.001–4.000 in. thick	415	60	305	44	5						
4.001–5.000 in. thick	405	59	295	43	5						
5.001–6.000 in. thick	395	57	290	42	4						
Alclad T851(d)	400	58	290	42	8						
T87											
0.020–0.249 in. thick	440	64	360	52	5–6						
0.250–3.000 in. thick	440	64	350	51	6–7						
3.001–4.000 in. thick	425	62	345	50	4						
4.001–5.000 in. thick	420	61	340	49	3						
Alclad T87											
0.040–0.099 in. thick	395	57	315	46	6						
0.100–0.499 in. thick	415	60	330	48	6–7						

(a) In 50 mm (2 in.) or 4d, where d is diameter of reduced section of tensile test specimen. Where a range of values appears in this column, specified minimum elongation varies with thickness of the mill product. (b) Sheet only. (c) For plate 12.7 mm (0.500 in.) or greater in thickness, property limits apply to core material only. Tensile and yield strengths of composite plate slightly lower depending on thickness of cladding. (d) Plate only. (e) Specimen taken from forging. (f) 10% for specimen taken from separately forged coupon. (g) Maximum cross-sectional area 1650 cm² (256 in.²). These properties not applicable to upset biscuit forgings or rolled rings. (h) Only applicable to rings having ratio of outside diameter to wall thickness equal to or greater than 10

Table 36 Typical tensile properties of alloy 2219 at various temperatures

Temper	Temperature		Tensile strength(a)		Yield strength (0.2% offset)(a)		Elongation, %
	°C	°F	MPa	ksi	MPa	ksi	
762	-196	-320	503	73	338	49	16
	-80	-112	434	63	303	44	13
	-28	-18	414	60	290	42	12
	24	75	400	58	276	40	12
	100	212	372	54	255	37	14
	149	300	310	45	227	33	17
	204	400	234	34	172	25	20
T81, T851	260	500	186	27	133	20	21
	316	600	69	10	55	8	40
	371	700	30	4.4	26	3.7	75
	-196	-320	572	83	421	61	15
	-80	-112	490	71	372	54	13
	-28	-18	476	69	359	52	12
	24	75	455	66	345	50	12
100	212	414	60	324	47	15	
149	300	338	49	276	40	17	
204	400	248	36	200	29	20	
260	500	200	29	159	23	21	
316	600	48	7	41	6	55	
371	700	30	4.4	26	3.7	75	

(a) Lowest strength for exposures up to 10 000 h at temperature under no load; test load applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture

Mass Characteristics

Density. 2.83 g/cm³ (0.103 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 643 °C (1190 °F)
Incipient melting temperature. 543 °C (1010 °F)
Coefficient of thermal expansion.
 Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	20.8	11.5
20 to 100	68 to 212	22.5	12.5
20 to 200	68 to 392	23.4	13.0
20 to 300	68 to 572	24.4	13.6

Volumetric: 6.5 × 10⁻⁵ m³/m³ · K (3.62 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)
Specific heat. 864 J/kg · K (0.206 Btu/lb · °F)
Thermal conductivity. O temper: 170 W/m · K (98.2 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric: O temper, 44% IACS at 20 °C (68 °F)
Electrical resistivity. O temper, 39 nΩ · m at 20 °C (68 °F)
Temperature coefficient. 2.94 × 10⁻³/K

Fabrication Characteristics

Annealing temperature. 413 °C (775 °F)

2618
2.3Cu-1.6Mg-1.1Fe-1.0Ni-0.18Si-0.07Ti

Specifications

AMS. Forgings and forging stock: 4132
ASTM. Forgings: B 247
SAE. J454

Government. Forgings: QQ-A-367; MIL-A-22771

Foreign. France: NF A-U2GN. United Kingdom: BS H12

Chemical Composition

Composition limits. 0.10 to 0.25 Si, 0.9 to 1.3 Fe, 1.9 to 2.7 Cu, 1.3 to 1.8 Mg, 0.9 to 1.2 Ni, 0.10 Zn max, 0.04 to 0.10 Ti, 0.05 max other (each), 0.15 others (total), bal Al

Applications

Typical uses. Die and hand forgings. Pistons and rotating aircraft engine parts for operation at elevated temperatures. Tire molds

Mechanical Properties

Tensile properties. See Tables 39 and 40 and Fig. 12.

Shear strength. T61 temper, 260 MPa (38 ksi)

Compressive yield strength. Approximately the same as the tensile yield strength. See also Fig. 13.

Hardness. Die forgings, T61 temper: 115 HB min

Poisson's ratio. 0.33 at 20 °C (68 °F)
Elastic modulus. Tension, 74.4 GPa (10.8 × 10⁶ psi); shear, 28.0 GPa (4.0 × 10⁶ psi)

Fatigue strength. T61 temper, 125 MPa (18 ksi) at 5 × 10⁸ cycles; R.R. Moore type test
Creep-rupture characteristics. See Table 41.

Mass Characteristics

Density. 2.76 g/cm³ (0.100 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 638 °C (1180 °F)
Solidus temperature. 549 °C (1020 °F)
Incipient melting temperature. 502 °C (935 °F)

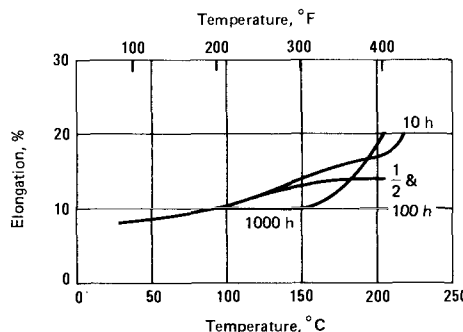
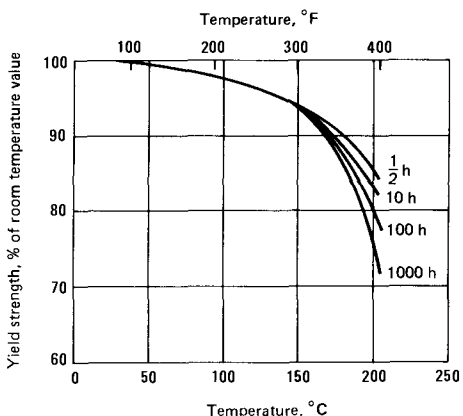
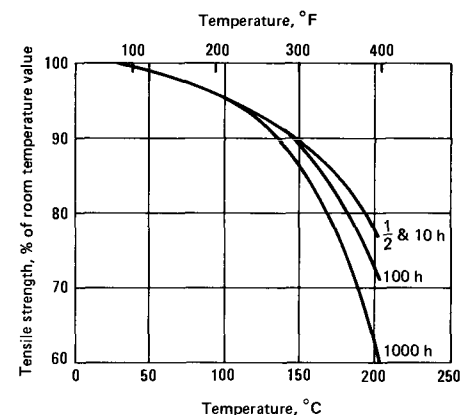


Fig. 12 Influence of prolonged holding at elevated temperature on tensile properties of alloy 2618-T61 hand-forged billets. Properties determined at temperature after holding for the indicated time under no load. Tensile and yield strengths plotted as percentage of corresponding room-temperature value. Elongation plotted as value determined at temperature

Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	20.6	11.4
20 to 100	68 to 212	22.3	12.4
20 to 200	68 to 392	23.2	12.9
20 to 300	68 to 572	24.1	13.4

Volumetric: 6.45 × 10⁻⁵ m³/m³ · K (3.6 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)
Specific heat. 875 J/kg · K at 20 °C (68 °F)

Table 37 Creep-rupture properties of alloy 2219-T851 plate

Temperature °C	Temperature °F	Time under stress, h	Rupture stress		Stress for creep of							
			MPa	ksi	1.0%		0.5%		0.2%		0.1%	
			MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
24	75	0.1	455	66	435	63	415	60	365	53	350	51
		1	450	65	420	61	385	56	360	52	345	50
		10	435	63	400	58	365	53	345	50	330	48
		100	425	62	380	55	360	52	340	49	325	47
100	212	1 000	420	61	365	53	350	51	330	48	315	46
		0.1	395	57	360	52	340	49	315	46	305	44
		1	370	54	340	49	325	47	305	44	285	41
		10	350	51	325	47	310	45	290	42	275	40
150	300	100	330	48	310	45	295	43	275	40	270	39
		1 000	315	46	295	43	285	41	270	39	260	38
		0.1	340	49	305	44	295	43	275	40	260	38
		1	315	46	290	42	275	40	255	37	235	34
175	350	10	290	42	270	39	255	37	235	34	205	30
		100	260	38	250	36	235	34	200	29	170	25
		1 000	235	34	220	32	200	29	165	24	150	22
		10 000	205	30	...	...	...	...	...	...	...	...
205	400	100 000	170	25	...	...	...	...	...	...	...	...
		0.1	305	44	275	40	260	38	250	36	230	33
		1	275	40	255	37	240	35	220	32	200	29
		10	250	36	230	33	215	31	195	28	165	24
230	450	100	220	32	200	29	185	27	160	23	130	19
		1 000	185	27	170	25	160	23	140	20	105	15
		10 000	160	23	...	...	...	...	...	...	...	...
		100 000	130	19	...	...	...	...	...	...	...	...
260	500	0.1	270	39	240	35	235	34	215	31	195	28
		1	235	34	220	32	205	30	180	26	160	23
		10	205	30	195	28	180	26	150	22	130	19
		100	180	26	165	24	150	22	130	19	110	16
230	450	1 000	150	22	140	20	125	18	115	17	90	13
		10 000	125	18	125	18	...	...	...	...	...	...
		100 000	97	14	...	...	...	...	...	...	...	...
		0.1	230	33	205	30	200	29	180	26	165	24
260	500	1	200	29	185	27	170	25	150	22	140	20
		10	170	25	160	23	150	22	130	19	110	16
		100	150	22	140	20	130	19	110	16	90	13
		1 000	125	18	115	17	110	16	90	13	69	10
315	600	10 000	97	14	97	14	97	14	...	...	...	...
		100 000	66	9.5	...	...	...	...	...	...	...	...
		0.1	180	26	170	25	165	24	160	23	145	21
		1	165	24	160	23	150	22	140	20	115	17
370	700	10	150	22	140	20	130	19	110	16	90	13
		100	130	19	125	18	110	16	90	13	69	10
		1 000	105	15	97	14	83	12	69	10	59	8.5
		10 000	69	10	69	10	...	...	...	...	...	...
315	600	100 000	45	6.5	...	...	...	...	...	...	...	...
		0.1	130	19	125	18	125	18	115	17	110	16
		1	115	17	115	17	110	16	105	15	90	13
		10	105	15	97	14	90	13	76	11	62	9
370	700	100	69	10	69	10	62	9	52	7.5	38	5.5
		1 000	41	6	41	6	38	5.5	28	4.1	23	3.4
		10 000	22	3.2	...	...	...	...	...	...	...	...
		0.1	69	10	69	10	69	10	66	9.5	66	9.5
370	700	1	62	9	62	9	59	8.5	45	6.5	32	4.7
		10	32	4.7	30	4.3	27	3.9	23	3.3	18	2.6
		100	22	3.2	20	2.9	18	2.6	13	1.9	...	...
		1 000	14	2.1	13	1.9	11	1.6	...	...	...	...

Thermal conductivity. T61 temper, 146 W/m · K (84 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, T61 temper, 37% IACS at 20 °C (68 °F)

Electrical resistivity. T61 temper, 47 nΩ · m at 20 °C (68 °F); temperature coefficient, T61 temper: 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. At 25 °C (77 °F): T61 temper, -0.80 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Solution temperature. 530 °C (985 °F)

Aging temperature. T61, 200 °C (390 °F) for 20 h at temperature

3003, Alclad 3003 1.2Mn-0.12Cu

Specifications

AMS. See Table 42.

ASME. See Table 42.

ASTM. See Table 42.

SAE. J454

UNS number. 3003: A93003

Government. See Table 42.

Foreign. Canada: CSA MC10. France: NF A-M1. United Kingdom: BS N3. West Germany: DIN AlMn. ISO: AlMn1Cu

Chemical Composition

Composition limits of 3003: 0.6 Si max, 0.7 Fe max, 0.05 to 0.20 Cu, 1.0 to 1.5 Mn, 0.10 Zn max, 0.05 max other (each), 0.15 max others (total), bal Al

Composition limits of Alclad 3003. 7072 cladding—0.10 Cu max, 0.10 Mg max, 0.10 Mn max, 0.7 Fe max + Si, 0.8 to 1.3 Zn, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses of 3003. Applications where good formability, very good resistance to corrosion or good weldability, or all three, are required, and where more strength is

Table 38 Creep-rupture properties of alloy 2219-T87 plate

Temperature °C	Temperature °F	Time under stress, h	Rupture stress		Stress for creep of							
			MPa	ksi	1.0%		0.5%		0.2%		0.1%	
			MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
24	75	0.1	460	67	450	65	420	61	385	56	370	54
		1	455	66	425	62	400	58	380	55	365	53
		10	450	65	405	59	385	56	370	54	360	52
		100	435	63	395	57	380	55	365	53	350	51
		1 000	420	61	380	55	370	54	360	52	345	50
100	212	0.1	400	58	365	53	350	51	340	49	325	47
		1	380	55	345	50	340	49	325	47	310	45
		10	350	51	330	48	325	47	305	44	290	42
		100	330	48	315	46	310	45	290	42	260	38
		1 000	315	46	305	44	295	43	260	38	240	35
150	300	0.1	345	50	315	46	310	45	290	42	270	39
		1	315	46	295	43	290	42	260	38	240	35
		10	290	42	275	40	260	38	235	34	205	30
		100	260	38	250	36	235	34	200	29	165	24
		1 000	235	34	230	33	205	30	165	24	140	20
205	400	0.1	255	37	240	35	230	33	200	29	165	24
		1	230	33	215	31	200	29	165	24	140	20
		10	205	30	185	27	170	25	140	20	110	16
		100	180	26	165	24	145	21	115	17	97	14
		1 000	150	22	145	21	130	19	97	14	83	12
230	450	0.1	206	30	195	28	180	26	165	24	140	20
		1	185	27	170	25	165	24	140	20	115	17
		10	170	25	160	23	145	21	115	17	97	14
		100	150	22	140	20	125	18	105	15	83	12
		1 000	130	19	125	18	115	17	83	12	69	10
260	500	0.1	170	25	160	23	150	22	140	20	125	18
		1	160	23	145	21	140	20	125	18	105	15
		10	145	21	130	19	125	18	105	15	83	12
		100	125	18	115	17	110	16	90	13	69	10
		1 000	105	15	105	15	97	14	69	10	59	8.5
315	600	0.1	115	17	110	16	105	15	97	14	83	12
		1	105	15	105	15	97	14	83	12	66	9.5
		10	90	13	83	12	76	11	62	9	52	7.5
		100	62	9	55	8	52	7.5	45	6.5	34	5
		1 000	34	5	31	4.5	28	4	26	3.8	23	3.3
370	700	0.1	59	8.5	55	8	52	7.5	48	7	34	5
		1	48	7	45	6.5	41	6	32	4.7	18	2.6
		10	34	5	30	4.4	26	3.8	17	2.4	12	1.7
		100	23	3.4	20	2.9	17	2.5	11	1.6	8	1.2
		1 000	17	2.4	13	1.9	11	1.6	8	1.2	6	0.9

desired than is provided by unalloyed aluminum. Cooking utensils, food and chemical handling and storage equipment, tanks, trim in transportation equipment, lithographic sheet pressure vessels and piping

Typical uses of Alclad 3003. Farm roofing and siding

Mechanical Properties

Tensile properties. See Tables 43 and 44. Directional characteristics: tensile strength and elongation of sheet in any of the H tempers are slightly lower in transverse direction

Compressive yield strength. Approximately the same as tensile yield strength

Shear yield strength. Approximately 55% of the tensile strength

Hardness. See Table 43.

Poisson's ratio. 0.33 at 20 °C (68 °F)

Elastic modulus. Tension, 70 GPa (10.2 × 10⁶ psi); shear, 25 GPa (3.6 × 10⁶ psi)

Fatigue strength. See Table 43.

Mass Characteristics

Density. 2.73 g/cm³ (0.099 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 654 °C (1210 °F)

Solidus temperature. 643 °C (1190 °F)

Coefficient of thermal expansion.

Linear:

Temperature range °C	Temperature range °F	Average coefficient	
		μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.5	11.9
20 to 100	68 to 212	23.2	12.9
20 to 200	68 to 392	24.1	13.4
20 to 300	68 to 572	25.1	13.9

Volumetric: 67 × 10⁻⁶ m³/m³ · K (3.72 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 893 J/kg · K (0.213 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F):

Temper	Conductivity	
	W/m · K	Btu/ft · h · °F
O	193	112
H12	163	94.1
H14	159	91.9
H18	155	89.6

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F):

Temper	Conductivity, % IACS
O	50
H12	42
H14	41
H18	40

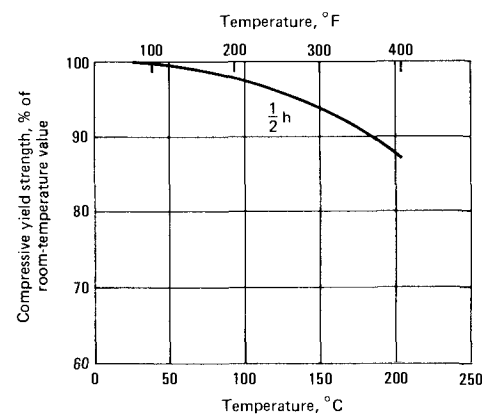


Fig. 13 Influence of temperature on compressive yield strength of alloy 2618-T61 hand-forged billets. Compressive yield strength determined at temperature after holding 1/2 h under no load. Value plotted as percentage of corresponding room-temperature value

Table 39 Tensile properties of alloy 2618-T61

Product and orientation	Tensile strength		Yield strength		Elongation(a), %
	MPa	ksi	MPa	ksi	
Typical					
All products	440	64	372	54	10(b)
Property limits					
Die forgings, thickness ≤4 in.(c)					
Axis parallel to grain flow	400	58	310	45	4(d)(e)
Axis not parallel to grain flow	380	55	290	42	4(d)
Hand forgings					
Thickness ≤2.000 in.(c)(f)					
Longitudinal	400	58	325	47	7
Long transverse	380	55	290	42	5
Short transverse	360	52	290	42	4
2.001-3.000 in.					
Longitudinal	395	57	315	46	7
Long transverse	380	55	290	42	5
Short transverse	360	52	290	42	4
3.001-4.000 in.					
Longitudinal	385	56	310	45	7
Long transverse	365	53	275	40	5
Short transverse	350	51	270	39	4
Rolled rings, thickness ≤2.500 in.(g)					
Tangential	380	55	285	41	6
Axial	380	55	285	41	5

(a) In 50 mm (2 in.) or 4 d, where d is diameter of reduced section of tensile test specimen. (b) 12.5 mm (½ in.) diameter specimen. (c) Properties also apply to forgings machined prior to heat treatment, provided machined thickness is not less than ½ original (as-forged) thickness. (d) Specimen taken from forgings. (e) Elongation 6% min for specimen taken from separately forged coupon. (f) Maximum cross-sectional area 930 cm² (1 ft²). Not applicable to upset biscuit forgings or to rolled rings. (g) Applicable only to rings having ratio of outside diameter to wall thickness equal to or greater than 10

Electrical resistivity. At 20 °C (68 °F):

Temper	Resistivity, nΩ · m
O	34
H12	41
H14	42
H18	43

Temperature coefficient, all temps: 0.1 nΩ · m per K at 20 °C (68 °F)
 Electrolytic solution potential. 3003 and core of Alclad 3003, -0.83 V; 7072 cladding, -0.96 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Magnetic Properties

Magnetic susceptibility. Mass: 0.8 × 10⁻⁶ (cgs/g) at 25 °C (77 °F)

Fabrication Characteristics

Annealing temperature. 415 °C (775 °F). Commercial practice: 400 to 600 °C (750 to 1100 °F); higher temperatures used only for flash annealing

3004, Alclad 3004 1.2Mn-1.0Mg

Specifications

ASTM. 3004: sheet and plate, B 209; extruded tube, B 221; welded tube, B 313, B 547. Alclad 3004: sheet and plate, B 209; welded tube, B 313; culvert pipe, B 547
 SAE. J454
 UNS number. A93004
 Government. Culvert pipe: WW-P-402
 Foreign. Australia: A3004. France: NF A-M1G. West Germany: DIN AlMn1MgI

Table 40 Typical tensile properties of alloy 2618-T61 at various temperatures

Temperature		Tensile strength		Yield strength (0.2% offset)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
-196	-320	538	78.0	421	61.0	12
-80	-112	462	67.0	379	55.0	11
-28	-18	441	64.0	372	54.0	10
24	75	441	64.0	372	54.0	10
100	212	427	62.0	372	54.0	10
149	300	345	50.0	303	44.0	14
204	400	221	32.0	179	26.0	24
260	500	90	13.0	62	9.0	50
316	600	52	7.5	31	4.5	80
371	700	34	5.0	24	3.5	120

Table 41 Creep-rupture properties of alloy 2618

Temperature °C	Temperature °F	Time under stress, h	Rupture stress		Stress for creep of							
			MPa	ksi	1.0%		0.5%		0.2%		0.1%	
150	300	0.1	380	55	345	50	345	50	330	48	315	46
		1	360	52	340	49	330	48	315	46	290	42
		10	340	49	325	47	315	46	295	43	270	39
		100	305	44	305	44	290	42	270	39	240	35
		1000	255	37	255	37	250	36	240	35	205	30
177	350	0.1	340	49	325	47	315	46	295	43	285	41
		1	310	45	305	44	295	43	275	40	255	37
		10	285	41	275	40	260	38	250	36	220	32
		100	250	36	240	35	235	34	220	32	185	27
		1000	205	30	200	29	195	28	185	27	150	22
205	400	0.1	290	42	285	41	270	39	255	37	240	35
		1	260	38	255	37	250	36	235	34	205	30
		10	230	33	220	32	215	31	200	29	170	25
		100	195	28	185	27	180	26	165	24	140	20
		1000	160	23	150	22	145	21	130	19	90	13
260	500	0.1	185	27	170	25	165	24	160	23	145	21
		1	165	24	150	22	145	21	140	20	115	17
		10	140	20	130	19	125	18	110	16	83	12
		100	105	15	97	14	90	13	69	10	52	7.5
		1000	62	9	62	9	55	8	48	7	...	...
315	600	0.1	97	14	83	12	69	10	55	8	48	7
		1	69	10	62	9	55	8	45	6.5	41	6
		10	52	7.5	45	6.5	41	6	38	5.5	26	3.8
		100	32	4.6	28	4.1	26	3.7	19	2.8	15	2.2
		1000	20	2.9	17	2.5	14	2.1	...	...	...	...

Table 42 Standard specifications for alloy 3003

Mill form and condition	Specification number			
	AMS	ASME	ASTM	Government
Bare 3003				
Sheet and plate	4006 4008	SB209 ...	B 209 ...	QQ-A-250/2 ...
Wire, rod, and bar (rolled or cold finished)	B 211	QQ-A-225/2
Wire, rod, bar, shapes, and tube (extruded)	...	SB221	B 221	QQ-A-200/1
Tube				
Extruded, seamless	...	SB241	B 241	...
Extruded, coiled	B 491	...
Drawn	B 483	...
Drawn, seamless	4065 4067	SB210	B 210	WW-T-700/2
Condenser	...	SB234	B 234	...
Condenser with integral fins	B 404	...
Welded	B 313 B 547	...
Pipe: seamless	B 241	MIL-P-25995
Gas and oil transmission	B 345	...
Rivet wire and rod	B 316	QQ-A-430
Forgings	...	SB247	B 247	...
Foil	4010	...	...	MIL-A-81596
Alclad 3003				
Sheet and plate	B 209	...
Tube				
Drawn, seamless	B 210	...
Extruded	B 221	...
Extruded, seamless	B 241	...
Condenser	B 234	...
Condenser with integral fins	B 404	...
Welded	B 547	...
Pipe (gas and oil transmission)	B 345	...

Chemical Composition

Composition limits of 3004. 0.25 Cu max, 0.30 Si max, 0.70 Fe max, 1.0 to 1.5 Mn, 0.8 to 1.3 Mg, 0.25 Zn max, 0.05 max other (each), 0.15 max others (total), bal Al

Composition limits of Alclad 3004. 7072 cladding—0.10 Cu max, 0.10 Mg max, 0.10 Mn max, 0.7 Fe max + Si, 0.8 to 1.3 Zn, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses of 3004. Drawn and ironed rigid containers (cans), chemical handling and storage equipment, sheet metal work, builders' hardware, incandescent and fluorescent lamp bases and similar applications requiring good formability and higher strength than provided by 3003

Typical uses of Alclad 3004. Siding, culvert pipe, industrial roofing

Mechanical Properties

Tensile properties. See Tables 45 and 46.

Compressive yield strength. Approximately the same as tensile yield strength

Shear yield strength. Approximately 55% of tensile strength

Hardness. See Table 45.

Poisson's ratio. 0.35 at 20 °C (68 °F)

Table 43 Mechanical properties of alloy 3003

Temper	Tensile strength				Yield strength		Elongation, %	Hardness		Shear strength		Fatigue strength(b)	
	MPa	ksi	MPa	ksi	MPa	ksi		HB(a)	HRH	MPa	ksi	MPa	ksi
Typical properties													
O	110	16	...	...	42	6	30-40	28	45-65	76	11	48	7
H12	130	19	...	...	125	18	10-20	35	55-75	83	12	55	8
H14	150	22	...	...	145	21	8-16	40	70-90	97	14	62	9
H16	175	25	...	...	175	25	5-14	47	75-92	105	15	69	10
H18	200	29	...	...	185	27	4-10	55	84-95	110	16	69	10
Property limits													
	Minimum		Maximum		Minimum								
O (0.006-3.000 in. thick)	97	14	130	19	34	5	14-25	...	...	...	...	...	...
H12 (0.017-2.000 in. thick)	115	17	160	23	83	12	3-10	...	...	...	...	...	...
H14 (0.009-1.000 in. thick)	140	20	180	26	115	17	1-10	...	...	...	...	...	...
H16 (0.006-0.162 in. thick)	165	24	205	30	145	21	1-4	...	...	...	...	...	...
H18 (0.006-0.128 in. thick)	185	27	...	...	165	24	1-4	...	...	...	...	...	...
H112													
(0.250-0.499 in. thick)	115	17	...	...	69	10	8	...	...	...	...	...	...
(0.500-2.000 in. thick)	105	15	...	...	41	6	12	...	...	...	...	...	...
(2.000-3.000 in. thick)	100	14.5	...	...	41	6	18	...	...	...	...	...	...
Property limits, Alclad 3003(c)													
O (0.006-0.499 in. thick)	90	13	125	18	31	4.5	14-25	...	...	...	...	...	...
(0.500-3.000 in. thick)	97	14	130	19	34	5.0	23	...	...	...	...	...	...
H12													
(0.017-0.499 in. thick)	110	16	150	22	77	11	4-9	...	...	...	...	...	...
(0.500-2.000 in. thick)	115	17	160	23	83	12	10	...	...	...	...	...	...
H14													
(0.009-0.499 in. thick)	130	19	170	25	110	16	1-8	...	...	...	...	...	...
(0.500-2.000 in. thick)	140	20	180	26	115	17	10	...	...	...	...	...	...
H16 (0.006-0.162 in. thick)	160	23	200	29	140	20	1-4	...	...	...	...	...	...
H18 (0.006-0.128 in. thick)	180	26	...	...	...	...	1-4	...	...	...	...	...	...
H112													
(0.250-0.499 in. thick)	110	16	...	...	62	9	8	...	...	...	...	...	...
(0.500-2.000 in. thick)	105	15	...	...	41	6	12	...	...	...	...	...	...
(2.000-3.000 in. thick)	100	14.5	...	...	41	6	18	...	...	...	...	...	...

(a) 500 kg load, 10 mm ball, 30 s duration of loading. (b) At 5×10^8 cycles. R.R. Moore type test. (c) Mechanical properties of 3003 clad with 7072 are practically the same as for bare material, except that hardness and fatigue resistance tend to be slightly lower for the clad product.

Table 44 Typical mechanical properties of alloy 3003 at various temperatures

Temperature		Tensile strength(a)		Yield strength(a)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
O temper						
-200	-328	230	33	60	8.6	46
-100	-148	150	22	52	7.5	43
-30	-22	115	17	45	6.5	41
25	77	110	16	41	6	40
100	212	90	13	38	5.5	43
200	392	60	8.6	30	4.3	60
300	572	29	4.2	17	2.5	70
400	752	18	2.6	12	1.7	75
H14 temper						
-200	-328	250	36	170	25	30
-100	-148	175	25	155	22.5	19
-30	-22	150	22	145	21	16
25	77	150	22	145	21	16
100	212	145	21	130	19	16
200	392	96	14	62	9	20
300	572	29	4.2	17	2.5	70
400	752	18	2.6	12	1.7	75
H18 temper						
-200	-328	290	42	230	33	23
-100	-148	230	33	210	30	12
-30	-22	210	30	190	38	10
25	77	200	29	185	27	10
100	212	180	26	145	21	10
200	392	96	14	62	9	18
300	572	29	4.2	17	2.5	70
400	752	18	2.6	12	1.7	75

(a) Lowest strengths for exposures up to 10 000 h at temperature, no load; test load applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture

Elastic modulus. Tension, 70 GPa (10.2 × 10⁶ psi); shear, 25 GPa (3.6 × 10⁶ psi)
Fatigue strength. See Table 45.

Mass Characteristics

Density. 2.72 g/cm³ (0.098 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 654 °C (1210 °F)
Solidus temperature. 629 °C (1165 °F)
Coefficient of thermal expansion.
 Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.5	11.9
20 to 100	68 to 212	23.2	12.9
20 to 200	68 to 392	24.1	13.4
20 to 300	68 to 572	25.1	13.9

Volumetric: 67 × 10⁻⁶ m³/m³ · K (3.72 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)
Specific heat. 893 J/kg · K (0.213 Btu/lb · °F) at 20 °C (68 °F)
Thermal conductivity. O temper: 162 W/m · K (93.6 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, O temper: 42% IACS at 20 °C (68 °F)
Electrical resistivity. O temper: 41.0 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)
Electrolytic solution potential. -0.84 V; 3004 and core of Alclad 3004, 7072 cladding, -0.96 V (cladding) versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Magnetic Properties

Magnetic susceptibility. Mass: 0.8 × 10⁻⁶ (cg/g) at 25 °C (68 °F)

Table 45 Mechanical properties of alloy 3004

Temper	Tensile strength				Yield strength		Elongation, %	Hardness, HB(a)	Shear strength		Fatigue strength(b)	
	MPa	ksi	MPa	ksi	MPa	ksi			MPa	ksi	MPa	ksi
Typical properties												
O	180	26	...	...	69	10	20-25	45	110	16	97	14
H32	215	31	...	...	170	25	10-17	52	115	17	105	15
H34	240	35	...	...	200	29	9-12	63	125	18	105	15
H36	260	38	...	...	230	33	5-9	70	140	20	110	16
H38	285	41	...	...	250	36	4-6	77	145	21	110	16
Property limits												
	Minimum		Maximum		Minimum							
O (0.006-3.000 in. thick)	150	22	200	29	59	8.5	10-18	...	...	...	...	...
H32 (0.017-2.000 in. thick)	195	28	240	35	145	21	1-6	...	...	...	...	...
H34 (0.009-1.000 in. thick)	220	32	260	38	170	25	1-5	...	...	...	...	...
H36 (0.006-0.162 in. thick)	240	35	285	41	195	28	1-4	...	...	...	...	...
H38 (0.006-0.128 in. thick)	260	38	...	...	215	31	1-4	...	...	...	...	...
H112 (0.250-3.000 in. thick)	160	23	...	...	62	9	7	...	...	...	...	...
Property limits, Alclad 3004(c)												
O												
(0.006-0.499 in. thick)	145	21	195	28	55	8	10-18	...	...	...	...	...
(0.500-3.000 in. thick)	150	22	200	29	59	8.5	16	...	...	...	...	...
H32												
(0.017-0.499 in. thick)	185	27	235	34	140	20	1-6	...	...	...	...	...
(0.500-2.000 in. thick)	195	28	240	35	145	21	6	...	...	...	...	...
H34												
(0.009-0.499 in. thick)	215	31	255	37	165	24	1-5	...	...	...	...	...
(0.500-1.000 in. thick)	220	32	260	38	170	25	5	...	...	...	...	...
H36 (0.006-0.162 in. thick)	235	34	275	40	185	27	1-4	...	...	...	...	...
H38 (0.006-0.128 in. thick)	255	37	...	...	...	...	1-4	...	...	...	...	...
H112												
(0.250-0.499 in. thick)	150	22	...	...	59	8.5	7	...	...	...	...	...
(0.500-3.000 in. thick)	160	23	...	...	62	9	7	...	...	...	...	...

(a) 500 kg load, 10 mm ball, 30 s duration of loading. (b) At 5 × 10⁸ cycles, R.R. Moore type test. (c) Mechanical properties of 3004 clad with 7072 are practically the same as for bare material, except that hardness and fatigue resistance tend to be slightly lower for the clad product.

Table 46 Typical mechanical properties of alloy 3004 at various temperatures

Temperature		Tensile strength(a)		Yield strength(a)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
O temper						
-200	-328	290	42.5	90	13.2	38
-100	-148	200	29	80	11.5	31
-30	-22	180	26	69	10	26
25	77	180	26	69	10	25
100	212	180	26	69	10	25
200	392	96	14	65	9.5	55
300	572	50	7.2	34	4.9	80
400	752	30	4.4	9	2.8	90
H34 temper						
-200	-328	360	52	235	34	26
-100	-148	270	39	212	31	17
-30	-22	245	36	200	29	13
25	77	240	35	200	29	12
100	212	240	35	200	29	12
200	392	145	21	105	15	35
300	572	50	7.2	34	4.9	80
400	752	30	4.4	19	2.8	90
H38 temper						
-200	-328	400	58	295	43	20
-100	-148	310	45	267	39	10
-30	-22	290	42	245	36	7
25	77	280	41	245	36	6
100	212	275	40	245	36	7
200	392	150	22	105	15	30
300	572	50	7.2	34	4.9	80
400	752	30	4.4	19	2.8	90

(a) Lowest strength for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture

Fabrication Characteristics

Annealing temperature. 415 °C (775 °F)

3105

0.55Mn-0.50Mg

Specifications

ASTM. B 209
SAE. J454

Chemical Composition

Composition limits. 0.6 Si max, 0.7 Fe max, 0.30 Cu max, 0.20 to 0.80 Mn, 0.20 to 0.80 Mg, 0.20 Cr max, 0.40 Zn max, 0.10 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Residential siding, mobile home sheet, gutters and downspouts, sheet metal work, bottle caps and closures

Mechanical Properties

Tensile properties. See Table 47.

Poisson's ratio. 0.33

Elastic modulus. Tension, 69 GPa (10 × 10⁶ psi); shear, 25 GPa (3.6 × 10⁶ psi)

Mass Characteristics

Density. 2.71 g/cm³ (0.098 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 657 °C (1215 °F)

Solidus temperature. 638 °C (1180 °F)

Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	µm/m · K	µin./in. · °F
-50 to 20	-58 to 68	21.8	12.1
20 to 100	68 to 212	23.6	13.1
20 to 200	68 to 392	24.5	13.6
20 to 300	68 to 572	25.5	14.2

Volumetric: 68 × 10⁻⁶ m³/m³ · K (3.77 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 897 J/kg · K (0.214 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. 173 W/m · K (99.9 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, O temper: 45% IACS at 20 °C (68 °F)

Electrical resistivity. O temper: 38.3 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. -0.84 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Magnetic Properties

Magnetic susceptibility. Mass: 0.7 × 10⁻⁶ (cgs/g) at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F)

4032

12.2Si-1.0Mg-0.9Cu-0.9Ni

Specifications

AMS. Forgings and forging stock: 4145
ASTM. Forgings: B 247

SAE. J454

UNS number. A94032

Government. Forgings: QQ-A-367

Foreign. Canada: CSA SG121. France: NF A-S12UN. Italy: UNI P-AISI12MgCuNi

Table 47 Mechanical properties of alloy 3105 sheet

Temper	Tensile strength				Yield strength		Elongation, %	Shear strength	
	MPa	ksi	MPa	ksi	MPa	ksi		MPa	ksi
Typical properties									
O	115	17	...	...	55	8	24	83	12
H12	150	22	...	...	130	19	7	97	14
H14	170	25	...	...	150	22	5	105	15
H16	195	28	...	...	170	25	4	110	16
H18	215	31	...	...	195	28	3	115	17
H25	180	26	...	...	160	23	8	105	15
Property limits									
	Minimum		Maximum		Minimum				
O (0.013-0.080 in. thick)	97	14	145	21	34	5	16-20	...	...
H12 (0.017-0.080 in. thick)	130	19	180	26	105	15	1-3	...	...
H14 (0.013-0.080 in. thick)	150	22	200	29	125	18	1-2	...	...
H16 (0.013-0.080 in. thick)	170	25	220	32	145	21	1-2	...	...
H18 (0.013-0.080 in. thick)	195	28	...	...	165	24	1-2	...	...
H25 (0.013-0.080 in. thick)	160	23	...	...	130	19	2-6	...	...

Table 48 Typical mechanical properties of alloy 4032-T6 at various temperatures

Temperature		Tensile strength		Yield strength		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
-200	-328	460	67	337	49	11
-100	-148	415	60	325	47	10
-30	-22	385	56	315	46	9
25	77	380	55	315	46	9
100	212	345	50	300	44	9
200	392	90	13	62	9	30
300	572	38	5.5	24	3.5	70
400	752	21	3.1	12	1.8	90

Chemical Composition

Composition limits. 11.0 to 13.5 Si, 1.0 Fe max, 0.50 to 1.30 Cu, 0.8 to 1.3 Mg, 0.10 Cr max, 0.50 to 1.3 Ni, 0.25 Zn max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Pistons and other high-temperature service parts

Mechanical Properties

Tensile properties. T6 temper: tensile strength, 380 MPa (55 ksi); yield strength, 315 MPa (46 ksi); elongation, 9% in 50 mm (2 in.). For typical properties at various temperatures, see Table 48.

Hardness. T6 temper: 120 HB at 500 kg load, 10 mm ball

Poisson's ratio. 0.33

Elastic modulus. Tension, 79 GPa (11.4 × 10⁶ psi). Shear, 26 GPa (3.8 × 10⁶ psi)

Fatigue strength. T6 temper: 110 MPa (16 ksi) at 5 × 10⁸ cycles, R.R. Moore type test. At various temperatures, see Table 49.

Creep-rupture characteristics. See Table 50.

Mass Characteristics

Density. 2.68 g/cm³ (0.097 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 571 °C (1060 °F)

Eutectic temperature. 532 °C (990 °F)

Incipient melting temperature. 532 °C (990 °F)

Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	18.0	10.0
20 to 100	68 to 212	19.5	10.8
20 to 200	68 to 392	20.2	11.2
20 to 300	68 to 572	21.0	11.7

Volumetric: 56 × 10⁻⁶ m³/m³ · K (3.11 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 864 J/kg · K (0.206 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F): O temper, 155 W/m · K (89.6 Btu/ft · h · °F); T6 temper, 141 W/m · K (81.5 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 40% IACS; T6 temper, 36% IACS

Electrical resistivity. At 20 °C (68 °F): O temper, 43.1 nΩ · m; T6 temper, 47.9 nΩ · m. Temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 415 °C (775 °F); 2 to 3 h at temperature then furnace cooled to 260 °C (500 °F) at 25 °C (50 °F) per h max

Solution temperature. 505 to 515 °C (940 to 960 °F). Hold 4 min at temperature then quench in cold water; for heavy or complicated forgings, quench in water at 65 to 100 °C (150 to 212 °F)

Aging temperature. 170 to 175 °C (335 to 345 °F); 8 to 12 h at temperature

Table 49 Fatigue strength of alloy 4032-T6 at various temperatures

Temperature		No. of cycles	Stress(a)	
°C	°F		MPa	ksi
24	75	10 ⁴	359	52
		10 ⁵	262	38
		10 ⁶	207	30
		10 ⁷	165	24
		10 ⁸	124	18
149	300	5 × 10 ⁸	114	16.5
		10 ⁵	207	30
		10 ⁶	165	24
		10 ⁷	124	18
		10 ⁸	90	13
204	400	5 × 10 ⁸	79	11.5
		10 ⁵	186	27
		10 ⁶	138	20
		10 ⁷	90	13
		10 ⁸	55	8
260	500	5 × 10 ⁸	48	7
		10 ⁵	131	19
		10 ⁶	83	12
		10 ⁷	55	8
		10 ⁸	34	5
		5 × 10 ⁸	34	5

(a) Based on rotating beam tests at room temperature and cantilever beam tests at elevated temperatures

Hot-working temperature. 315 to 480 °C (600 to 900 °F)

4043

5.2Si

Specifications

AMS. Bare welding rod and electrodes: 4190

SAE. J454

Government. Bare welding rod and electrodes: QQ-R-566, MIL-E-16053; spray gun wire: MIL-W-6712

Foreign. Australia: B4043. Canada: CSA S5. France: NF A-S5. United Kingdom: BS N21. Germany: DIN AlSi5, Werstoff-Nr. 3.2245

Chemical Composition

Composition limits. 4.5 to 6.0 Si, 0.8 Fe max, 0.30 Cu max, 0.05 Mn max, 0.05 Mg max, 0.10 Zn max, 0.20 Ti max, 0.05 max other (each), 0.15 max others (total), 0.0008 Be max for welding electrode only, bal Al

Applications

Typical uses. General purpose weld filler alloy (rod or wire) for welding all wrought and foundry alloys except those rich in magnesium

Mechanical Properties

Tensile properties. See Table 51.

Mass Characteristics

Density. 2.68 g/cm³ (0.097 lb/in.³)

Thermal Properties

Liquidus temperature. 630 °C (1170 °F)

Solidus temperature. 575 °C (1065 °F)

Coefficient of thermal expansion. Linear, 22.0 μm/m · K (12.2 μin./in. · °F) at 20 to 100 °C (68 to 212 °F)

Table 50 Creep-rupture properties of alloy 4032

Temperature		Time under stress, h	Rupture stress		Stress for creep of:					
°C	°F		MPa	ksi	1.0%		0.5%		0.2%	
					MPa	ksi	MPa	ksi	MPa	ksi
100	212	0.1	331	48	283	41	269	39	...	...
		1	317	46	283	41	262	38	...	...
		10	303	44	283	41	262	38	...	...
		100	296	43	276	40	262	38	...	...
		1000	296	43	276	40	255	37	...	...
149	300	0.1	290	42	276	40	248	36	...	...
		1	276	40	269	39	241	35	...	...
		10	269	39	255	37	234	34	...	...
		100	248	36	241	35	221	32	...	...
		1000	207	30	200	29	186	27	...	...
204	400	0.1	234	34	228	33	221	32	138	20
		1	214	31	207	30	200	29	131	19
		10	186	27	179	26	165	24	103	15
		100	138	20	131	19	124	18	59	8.5
		1000	83	12	76	11	69	10	...	...

Table 51 Typical tensile properties of alloy 4043 welding wire

Wire diameter		Temper	Tensile strength		Yield strength (0.2% offset)		Elongation, %
mm	in.		MPa	ksi	MPa	ksi	
5.0	0.20	H16.....	205	30	180	26	1.7
3.2	0.12	H14.....	170	25	165	24	1.3
1.6	0.06	H18.....	285	41	270	39	0.5
1.2	0.05	H16.....	200	29	185	27	0.4
5.0	0.20	O.....	130	19	50	7	25
3.2	0.12	O.....	115	17	55	8	31
1.6	0.06	O.....	145	21	65	10	22
1.2	0.05	O.....	110	16	55	8	29

Electrical Properties

Electrical conductivity. Volumetric, O temper: 42% IACS at 20 °C (68 °F)

Electrical resistivity. O temper: 41 nΩ · m at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 350 °C (660 °F)

5005

0.8Mg

Specifications

ASTM. Sheet and plate: B 209. Wire, H19 temper: B 396. Stranded conductor: B 397. Rivet wire and rod: B 316. Rolled rod: B 531. Drawn tube: B 210, B 483

SAE. J454

UNS number. A95005

Government. Rivet wire and rod: QQ-A-430

Foreign. France: NF A-G0.6. United Kingdom: BS N41. Germany: DIN AlMg1. ISO: AlMg1

Chemical Composition

Composition limits. 0.30 Si max, 0.7 Fe max, 0.20 Cu max, 0.20 Mn max, 0.50 to 1.1 Mg, 0.10 Cr max, 0.25 Zn max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Electrical conductor wire, cooking utensils, appliances, and architectural applications. Medium strength and good resistance to corrosion are two characteristics of 5005 similar to those of 3003. When anodized, film on 5005 is clearer and lighter than on 3003 and gives better color match with 6063 architectural extrusions.

Mechanical Properties

Tensile properties. See Tables 52 and 53. Tensile strength and elongation are slightly lower in transverse direction than in longitudinal direction.

Shear yield strength. Approximately 55% of tensile yield strength

Compressive yield strength. Approximately the same as tensile yield strength

Hardness. See Table 52.

Poisson's ratio. 0.33

Elastic modulus. Tension, 68.2 GPa (9.90 × 10⁶ psi); shear, 25.9 GPa (3.75 × 10⁶ psi); compression, 69.5 GPa (10.1 × 10⁶ psi)

Mass Characteristics

Density. 2.70 g/cm³ (0.097 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 652 °C (1205 °F)

Solidus temperature. 632 °C (1170 °F)

Coefficient of thermal expansion.

Linear:

Temperature range °C	Temperature range °F	Average coefficient	
		μm/m · K	μin./in. · °F
-50 to 20	-58 to 68.....	21.9	12.2
20 to 100	68 to 212.....	23.7	13.2
20 to 200	68 to 392.....	24.6	13.7
20 to 300	68 to 572.....	25.6	14.2

Volumetric: 68 × 10⁻⁶ m³/m³ · K (3.77 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. 205 W/m · K (118 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, O and H38 tempers: 52% IACS at 20 °C (68 °F)

Electrical resistivity. O and H38 tempers: 33.2 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. -0.83 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F); holding at temperature not required

Hot-working temperature. 260 to 510 °C (500 to 950 °F)

5050

1.4Mg

Specifications

ASTM. Sheet and plate: B 209. Drawn, seamless tube: B 210. Drawn tube: B 483. Welded tube: B 313, B 547

SAE. J454

UNS number. A95050

Foreign. France: NF A-G1. Italy: P-AlMg 1.5. Switzerland: A11.5Mg. United Kingdom: BS 3L44. ISO: AlMg1.5

Table 52 Typical mechanical properties of alloy 5005

Temper	Tensile strength(a)		Yield strength(a)		Elongation(a)(b), %	Hardness(c), HB	Shear strength	
	MPa	ksi	MPa	ksi			MPa	ksi
O.....	124	18	41	6	25	28	76	11
H12.....	138	20	131	19	10	...	97	14
H14.....	159	23	152	22	6	...	97	14
H16.....	179	26	172	25	5	...	103	15
H18.....	200	29	193	28	4	...	110	16
H32.....	138	20	117	17	11	36	97	14
H34.....	159	23	138	20	8	41	97	14
H36.....	179	26	165	24	6	46	103	15
H38.....	200	29	186	27	5	51	110	16

(a) Strengths and elongations unchanged or improved at low temperatures. (b) 1.6 mm (1/16 in.) thick specimen. (c) 500 kg load; 10 mm diam ball

Table 53 Mechanical property limits for alloy 5005 sheet and plate

Temper	Tensile strength				Yield strength (min)		Elongation (min), % (a)
	Minimum MPa	ksi	Maximum MPa	ksi	MPa	ksi	
O.....	105	15	145	21	35	5	12-22
H12.....	125	18	165	24	95	14	2-9
H14.....	145	21	185	27	115	17	1-8
H16.....	165	24	205	30	135	18	1-3
H18.....	185	27	...	...	...	...	1-3
H32.....	120	17	160	23	85	12	3-10
H34.....	140	20	180	26	105	15	2-8
H36.....	160	23	200	29	125	18	1-4
H38.....	180	26	...	...	...	...	1-4
H112							
0.250-0.492 in. thick.....	115	17	...	...	...	...	8
0.492-1.60 in. thick.....	105	15	...	...	...	...	10
1.60-3.20 in. thick.....	100	15	...	...	...	...	16

(a) In 50 mm (2 in.) or 5d, where d is diameter or reduced section of tensile test specimen. Where a range of values appears in this column, the specified minimum elongation varies with thickness of the mill product.

Table 54 Typical mechanical properties of alloy 5050

Temper	Tensile strength(a)		Yield strength(a)		Elongation(a)(b), %	Hardness(c), HB	Shear strength		Fatigue strength(d)	
	MPa	ksi	MPa	ksi			MPa	ksi	MPa	ksi
O	145	21	55	8	24	36	105	15	83	12
H32	170	25	145	21	9	46	115	17	90	13
H34	190	28	165	24	8	53	123	18	90	13
H36	205	30	180	26	7	58	130	19	97	14
H38	220	32	200	29	6	63	138	20	97	14

(a) Strengths and elongation generally unchanged or improved at low temperatures. (b) 1.6 mm (1/16 in.) thick sheet specimen. (c) 500 kg load; 10 mm diam ball. (d) At 5×10^6 cycles; R.R. Moore type test

Chemical Composition

Composition limits. 0.40 Si max, 0.7 Fe max, 0.20 Cu max, 0.10 Mn max, 1.1 to 1.8 Mg, 0.10 Cr max, 0.25 Zn max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Sheet used as trim in refrigerator applications; tube for automotive gas and oil lines; welded irrigation pipe; also available as plate, tube, rod, bar, and wire

Mechanical Properties

Tensile properties. See Tables 54 to 56. Tensile strength and yield strength are approximately the same in both the transverse and longitudinal directions; however, elongation is slightly lower in the transverse direction than in the longitudinal direction.

Shear yield strength. Approximately 55% of the tensile yield strength

Compressive yield strength. Approximately the same as tensile yield strength

Hardness. See Table 54.

Poisson's ratio. 0.33

Elastic modulus. Tension, 68.9 GPa (10.0×10^6 psi); shear, 25.9 GPa (3.75×10^6 psi)

Mass Characteristics

Density. 2.69 g/cm³ (0.097 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 652 °C (1205 °F)

Solidus temperature. 627 °C (1160 °F)

Coefficient of thermal expansion.

Linear:

Temperature range °C		Average coefficient $\mu\text{m}/\text{m} \cdot \text{K}$	
-50 to 20	-58 to 68	21.8	12.1
20 to 100	68 to 212	23.8	13.2
20 to 200	68 to 392	24.7	13.7
20 to 300	68 to 572	25.6	14.2

Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. 191 W/m · K (110 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, O and H38 tempers: 50% IACS at 20 °C (68 °F)

Electrical resistivity. O and H38 tempers: 34 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. -0.83 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F); holding at temperature not required

Hot-working temperature. 260 to 510 °C (500 to 950 °F)

5052

2.5Mg-0.25Cr

Specifications

AMS. See Table 57.

ASTM. See Table 57.

SAE. J454

UNS number. A95052

Government. Sheet and plate: QQ-A-250/8

Foil: MIL-A-81596. Rolled or cold finished

wire, rod, and bar: QQ-A-225/7. Drawn,

seamless tube: WW-T-700/4. Rivet wire and

rod: QQ-A430. Rivets: MIL-R-24243

Foreign. Canada: CSA GR20. France: NF

A-G2.5C. Italy: UNI P-AlMg2.5. Germany:

DIN AlMg2.5. ISO: AlMg2.5

Chemical Composition

Composition limits. 0.25 Si max, 0.40 Fe max, 0.10 Cu max, 0.10 Mn max, 2.2 to 2.8 Mg, 0.15 to 0.35 Cr, 0.10 Zn max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Aircraft fuel and oil lines, fuel tanks, miscellaneous marine and transport

Table 55 Typical tensile properties of alloy 5050

Temperature °C	Temperature °F	Tensile strength(a)		Yield strength (0.2% offset)(a)	
		MPa	ksi	MPa	ksi
-196	-320	255	37	70	10
-80	-112	150	22	60	8.5
-28	-18	145	21	55	8
24	75	145	21	55	8
100	212	145	21	55	8
149	300	130	19	55	8
204	400	95	14	50	7.5
260	500	60	9	41	6
316	600	41	6	29	4.2
371	700	27	3.9	18	2.6
-196	-320	305	44	205	30
-80	-112	205	30	170	25
-28	-18	195	28	165	24
24	75	195	28	165	24
100	212	195	28	165	24
149	300	170	25	150	22
204	400	95	14	50	7.5
260	500	60	9	41	6
316	600	41	6	29	4.2
371	700	27	3.9	18	2.6
-196	-320	315	46	250	36
-80	-112	235	34	205	30
-28	-18	220	32	200	29
24	75	220	32	200	29
100	212	215	31	200	29
219	300	185	27	170	25
204	400	95	14	50	7.5
260	500	60	9	41	6
316	600	41	6	29	4.2
371	700	27	3.9	18	2.6

(a) Lowest strengths for exposures up to 10 000 h at temperature; no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture

Table 56 Tensile-property limits for alloy 5050

Temper	Tensile strength (min)		Yield strength (min)		Elongation (min), %(a)
	MPa	ksi	MPa	ksi	
O	125	18	41	6	16-20
H32	150	22	110	16	4-6
H34	170	25	138	20	3-5
H36	185	27	151	22	2-4
H38	200	29	...	...	2-4

(a) Where a range of values appears in this column, specified minimum elongation varies with thickness of the mill product.

Table 57 Standard specifications for alloy 5052

Mill form	Specification No.	
	AMS	ASTM
Sheet and plate	4015	B 209
Sheet, plate, bar, and shapes (extruded)	4016, 4017	B 221
Wire, rod, and bar (rolled or cold finished)	4114	B 221
Tube		
Drawn	4069	B 483
Drawn, seamless	4070	B 210
Hydraulic	4071	
Extruded		B 221
Extruded, seamless		B 241
Condenser		B 234
Condenser with integral fins		B 404
Welded		B 313, B 547
Rivet wire and rod		B 316
Foil	4004	

applications, sheet metal work, appliances, street light standards, rivets, and wire. Applications where good workability, very good resistance to corrosion, high fatigue strength, weldability, and moderate static strength are desired

Mechanical Properties

Tensile properties. See Tables 58 and 59.
Shear yield strength. Approximately 55% of tensile yield strength
Compressive yield strength. Approximately the same as tensile yield strength
Hardness. See Table 58.
Poisson's ratio. 0.33
Elastic modulus. Tension, 69.3 GPa (10.1 × 10⁶ psi); shear, 25.9 GPa (3.75 × 10⁶ psi); compression, 70.7 GPa (10.3 × 10⁶ psi)

Table 58 Typical mechanical properties of alloy 5052

Temper	Tensile strength(a)		Yield strength(a)		Elongation, % (a)		Hardness, HB(b)	Shear strength		Fatigue strength(c)
	MPa	ksi	MPa	ksi	1.6 mm (1/16 in.) thick	12.5 mm (1/2 in.) diam		MPa	ksi	
	O	195	28	90	13	25		27	47		125	18	110
H32	230	33	195	28	12	16	60	140	20	115
H34	260	38	215	31	10	12	68	145	21	125
H36	275	40	240	35	8	9	73	160	23	130
H38	290	42	255	37	7	7	77	165	24	140

(a) Strengths and elongations unchanged or improved at low temperatures. (b) 500 kg load; 10 mm diam ball. (c) At 5 × 10⁸ cycles; R.R. Moore type test

Mass Characteristics

Density. 2.68 g/cm³ (0.097 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 649 °C (1200 °F)
Solidus temperature. 607 °C (1125 °F)
Coefficient of thermal expansion. Linear:

Temperature range °C	Temperature range °F	Average coefficient	
		µm/m · K	µin./in. · °F
-50 to 20	-58 to 68	22.1	12.3
20 to 100	68 to 212	23.8	13.2
20 to 200	68 to 392	24.8	13.8
20 to 300	68 to 572	25.7	14.3

Volumetric: 69 × 10⁻⁶ m³/m³ · K (3.83 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, O and H38 tempers: 35% IACS at 20 °C (68 °F)
Electrical resistivity. O and H38 tempers: 49.3 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)
Electrolytic solution potential. -0.85 V ver-

sus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F); holding at temperature not required
Hot-working temperature. 260 to 510 °C (500 to 950 °F)

5056, Alclad 5056 5.0Mg-0.1Mn-0.1Cr

Specifications

AMS. Rolled or cold finished wire, rod, and bar: 4182. Foil: 4005
ASTM. Rivet wire and rod: B 316. Rolled or cold finished wire, rod, and bar: B 211. Alclad, rolled or cold finished wire, rod, and bar: B 211
SAE. J454
UNS number. A95056
Government. Rivet wire and rod: QQ-A430. Foil: MIL-A-81596
Foreign. Austria: AlMg5. Canada: CSA-GM50R. United Kingdom: BS N6 2L.58. Germany: DIN AlMg5. ISO: AlMg5

Chemical Composition

Composition limits of 5056. 0.30 Si max, 0.40 Fe max, 0.10 Cu max, 0.05 to 0.20 Mn, 4.5 to 5.6 Mg, 0.20 Cr max, 0.10 Zn max, 0.05 max other (each), 0.15 max others (total), bal Al
Composition limits of Alclad 5056. 6253 cladding—Si, 45 to 65% of Mg content, 0.50 Fe max, 0.10 Cu max, 1.0 to 1.5 Mg, 0.15 to 0.35 Cr, 1.6 to 2.4 Zn, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Rivets for use with magnesium alloy and cable sheathing; zipper stock, nails; also Alclad wire is extensively used in fabrication of insect screens and other applications where wire products with good resistance to corrosion are required

Mechanical Properties

Tensile properties. See Tables 60, 61, and 62. Elongation, O temper: 20% in 50 mm (2 in.) or 4d, where d is diameter of reduced section of tension test specimen
Shear yield strength. Approximately 55% of tensile yield strength

Table 59 Typical tensile properties of alloy 5052 at various temperatures

Temper	Temperature		Tensile strength		Yield strength (0.2% offset)		Elongation, %
	°C	°F	MPa	ksi	MPa	ksi	
O	-196	-320	303	44	110	16	46
	-80	-112	200	29	90	13	35
	-28	-18	193	28	90	13	32
	24	75	193	28	90	13	30
	100	212	193	28	90	13	36
	149	300	159	23	90	13	50
	204	400	117	17	76	11	60
	260	500	83	12	52	7.5	80
	316	600	52	7.5	38	5.5	110
	371	700	34	5	21	3	130
	H34	-196	-320	379	55	248	36	28
-80		-112	276	40	221	32	21
-28		-18	262	38	214	31	18
24		75	262	38	214	31	16
100		212	262	38	214	31	18
149		300	207	30	186	27	27
204		400	165	24	103	15	45
260		500	83	12	52	7.5	80
316		600	52	7.5	38	5.5	110
371		700	34	5	21	3	130
H38		-196	-320	414	60	303	44	25
	-80	-112	303	44	262	38	18
	-28	-18	290	42	255	37	15
	24	75	290	42	255	37	14
	100	212	276	40	248	36	16
	149	300	234	34	193	28	24

Table 60 Typical mechanical properties of alloy 5056

Temper	Tensile strength(a)		Yield strength(a)		Elongation(a)(b), %	Hardness(c), HB	Shear strength		Fatigue strength(d)	
	MPa	ksi	MPa	ksi			MPa	ksi	MPa	ksi
O	290	42	152	22	35	65	179	26	138	20
H18	434	63	407	59	10	105	234	34	152	22
H38	414	60	345	50	15	100	221	32	152	22

(a) Strengths and elongations are unchanged or improved at low temperatures. (b) 12.5 mm (½ in.) diam; round specimen. (c) 500 kg load; 10 mm diam ball. (d) At 5 × 10⁸ cycles, R.R. Moore type test

Compressive yield strength. Approximately the same as the tensile yield strength

Hardness. See Table 60.

Poisson's ratio. 0.33

Elastic modulus. Tension, 71.7 GPa (10.4 × 10⁶ psi); shear, 25.9 GPa (3.75 × 10⁶ psi); compression, 73.1 GPa (10.6 × 10⁶ psi)

Mass Characteristics

Density. 2.64 g/cm³ (0.095 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 638 °C (1180 °F)

Solidus temperature. 568 °C (1055 °F)

Coefficient of thermal expansion.

Linear, O temper:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	22.5	12.5
20 to 100	68 to 212	24.1	13.7
20 to 200	68 to 392	25.2	14.0
20 to 300	68 to 572	26.1	14.5

Volumetric: 70 × 10⁻⁶ m³/m³ · K (3.89 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 904 J/kg · K (0.216 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F): O temper, 120 W/m · K (69.3 Btu/ft · h · °F); H38 temper, 112 W/m · K (64.7 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 29% IACS; H38 temper, 27% IACS

Electrical resistivity. At 20 °C (68 °F): O temper, 59 nΩ · m, H38 temper, 64 nΩ · m. Temperature coefficient, O and H38 tempers: 0.1 nΩ · m per K at 20 °C (68 °F)

Table 61 Typical tensile properties of alloy 5056

Temper	Temperature		Tensile strength(a)		Yield strength(a)		Elongation, %
	°C	°F	MPa	ksi	MPa	ksi	
O	24	75	290	42	150	22	35
	149	300	214	31	117	17	55
	204	400	152	22	90	13	65
	260	500	110	16	69	10	80
	316	600	76	11	48	7	100
H38	371	700	41	6	28	4	130
	24	75	414	60	345	50	15
	149	300	262	38	214	31	30
	204	400	179	26	124	18	50
	260	500	110	16	69	10	80
316	600	76	11	48	7	100	
371	700	41	6	28	4	130	

(a) Lowest strengths for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture

Electrolytic solution potential. -0.87 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 415 °C (775 °F); holding at temperature not required

Hot-working temperature. 315 to 480 °C (600 to 900 °F)

**5083
4.4Mg-0.7Mn-0.15Cr**

Specifications

AMS. Sheet and plate: 4056, 4057, 4058, 4059
ASTM. Sheet and plate: B 209. Extruded wire, rod, bar, shapes, and tube: B 221. Extruded seamless tube: B 241. Drawn seamless tube: B 210. Welded tube: B 547. Forgings: B 247. Gas and oil transmission pipe: B 345

SAE. J454

UNS number. A95083

Government. Sheet and plate: QQ-A-250/6. Extruded wire, rod, bar, shapes, and tube: QQ-A-200/4. Forgings: QQ-A-367. Armor plate: MIL-A-46027. Extruded armor: MIL-A-46083. Forged armor: MIL-A-45225
Foreign. Canada: CSA GM41. United Kingdom: BS N8. Germany: DIN AlMg4.5Mn; Werstoff-Nr. 3.3547. ISO: AlMg4.5Mn

Chemical Composition

Composition limits. 0.40 Si max, 0.40 Fe max, 0.10 Cu max, 0.40 to 1.0 Mn, 4.0 to 4.9 Mg, 0.05 to 0.25 Cr, 0.25 Zn max, 0.15 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Marine, auto, and aircraft

applications, unfired welded pressure vessels, cryogenics, TV towers, drilling rigs, transportation equipment, missile components, armor plate. Applications requiring a weldable moderate-strength alloy having good corrosion resistance

Mechanical Properties

Tensile properties. See Tables 63, 64, and 65.
Shear properties. O temper: shear strength, 172 MPa (25 ksi); shear yield strength, approximately 55% of tensile yield strength
Compressive yield strength. Approximately the same as tensile yield strength

Elastic modulus. Tension, 70.3 GPa (10.2 × 10⁶ psi); shear, 26.4 GPa (3.83 × 10⁶ psi); compression, 71.7 GPa (10.4 × 10⁶ psi)

Fatigue strength. H321 and H116 tempers: 160 MPa (23 ksi) at 5 × 10⁸ cycles; R.R. Moore type test

Mass Characteristics

Density. 2.66 g/cm³ (0.096 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 638 °C (1180 °F)

Solidus temperature. 574 °C (1065 °F)

Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	22.3	12.4
20 to 100	68 to 212	24.2	13.4
20 to 200	68 to 392	25.0	13.9
20 to 300	68 to 572	26.0	14.4

Table 62 Mechanical-property limits for alloy 5056—rolled or cold finished wire, rod, and bar

Temper	Tensile strength (min)	
	MPa	ksi
Bare 5056		
O	315 (max)	46 (max)
H111	305	44
H12	315	46
H32	305	44
H14	360	52
H34	345	50
H18	400	58
H38	380	55
H192	415	60
H392	400	58
Alclad 5056		
H192	360	52
H392	345	50
H393	370(a)	54

(a) Yield strength (min), 325 MPa (47 ksi)

Table 63 Typical tensile properties of alloy 5083

Temper	Tensile strength(a)		Yield strength		Elongation(a)(b), %
	MPa	ksi	MPa	ksi	
O	290	42	145	21	22
H112	303	44	193	28	16
H116	317	46	228	33	16
H321	317	46	228	33	16
H323, H32	324	47	248	36	10
H343, H34	345	50	283	41	9

(a) Strengths and elongations are unchanged or improved at low temperatures. (b) 1.6 mm (1/16 in.) thick specimen

Volumetric: $70 \times 10^{-6} \text{ m}^3/\text{m}^3 \cdot \text{K}$ ($3.89 \times 10^{-5} \text{ in.}^3/\text{in.}^3 \cdot \text{°F}$) at 20 °C (68 °F)
Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)
Thermal conductivity. 120 W/m · K (69.3 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, average of all tempers: 29% IACS at 20 °C (68 °F)
Electrical resistivity. 59.5 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)
Electrolytic solution potential. -0.91 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 415 °C (775 °F); holding at temperature not required
Hot-working temperature. 315 to 480 °C (600 to 900 °F)

**5086, Alclad 5086
4.0Mg-0.4Mn-0.15Cr**

Specifications

ASTM. Sheet and plate; B 209. Extruded wire, rod, bar, shapes, and tube: B 221. Extruded seamless tube: B 241. Drawn, seamless tube: B 210. Welded tube: B 313, B 547. Gas and oil transmission pipe: B 345. Alclad 5086, sheet and plate: B 209
SAE. J454
UNS number. A95086

Table 64 Mechanical-property limits for alloy 5083

Temper	Tensile strength				Yield strength				Elongation (min), % (a)
	Minimum MPa	ksi	Maximum MPa	ksi	Minimum MPa	ksi	Maximum MPa	ksi	
O									
0.051-1.5000 in. thick	275	40	350	51	125	18	200	29	16
1.501-3.000 in. thick	270	39	345	50	115	17	200	29	16
3.001-5.000 in. thick	260	38	...	...	110	16	...	...	14-16
5.001-7.000 in. thick	255	37	...	...	105	15	...	...	14
7.001-8.000 in. thick	250	36	...	...	95	14	...	...	12
H112									
0.250-1.500 in. thick	275	40	...	...	125	18	...	...	12
1.501-3.000 in. thick	270	39	...	...	115	17	...	...	12
H116									
0.063-1.500 in. thick	305	44	...	...	215	31	...	...	12
1.501-3.000 in. thick	285	41	...	...	200	29	...	...	12
H321									
0.188-1.500 in. thick	305	44	385	56	215	31	295	43	12
1.501-3.000 in. thick	285	41	385	56	200	29	295	43	12
H323	310	45	370	54	235	34	305	44	8-10
H343	345	50	405	59	270	39	340	49	6-8

(a) In 50 mm (2 in.) or 4d, where d is diameter of reduced section of tensile test specimen. Where a range of values appears in this column, the specified minimum elongation varies with thickness of the mill product.

Table 65 Typical tensile properties of alloy 5083-O at various temperatures

Temperature		Tensile strength(a)		Yield strength (0.2% offset)(a)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
-195	-315	405	59	165	24	36
-80	-112	295	43	145	21	30
-30	-22	290	42	145	21	27
25	80	290	42	145	21	25
100	212	275	40	145	21	36
150	302	215	31	130	19	50
205	400	150	22	115	17	60
260	500	115	17	75	11	80
315	600	75	11	50	7.5	110
370	698	41	6	29	4.2	130

(a) Lowest strength for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 10%/min to fracture

Government. Sheet and plate: QQ-A-250/7, QQ-A-250/19. Extruded wire, rod, bar, shapes, and tube: QQ-A-200/5. Drawn, seamless tube: WW-T-700/5
Foreign. France: NF A-G4MC. Germany: DIN AlMg4. ISO: AlMg4

Chemical Composition

Composition limits. 0.40 Si max, 0.50 Fe max, 0.20 to 0.7 Mn, 3.5 to 4.5 Mg, 0.25 Zn max, 0.15 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Marine, automotive, and aircraft parts, cryogenics, TV towers, drilling rigs, transportation equipment, missile components, armor plate. Applications requiring weldable moderate-strength alloy having comparatively good corrosion resistance

Mechanical Properties

Tensile properties. See Tables 66 and 67. Tensile strength and elongation are approximately equal in the longitudinal and transverse directions.
Shear properties. Shear strength: O temper, 160 MPa (23 ksi); H34 temper, 185 MPa (27 ksi). Shear yield strength: approximately 55% of tensile yield strength
Compressive yield strength. Approximately the same as tensile yield strength
Poisson's ratio. 0.33
Elastic modulus. Tension, 71.0 GPa (10.3 × 10⁶ psi); shear, 26.4 GPa (3.83 × 10⁶ psi); compression, 72.4 GPa (10.5 × 10⁶ psi)

Mass Characteristics

Density. 2.66 g/cm³ (0.096 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 640 °C (1184 °F)
Solidus temperature. 585 °C (1085 °F)
Coefficient of thermal expansion. Linear:

Temperature range °C	Temperature range °F	Average coefficient	
		μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	22.0	12.2
20 to 100	68 to 212	23.8	13.2
20 to 200	68 to 392	24.7	13.7
20 to 300	68 to 572	25.8	14.3

Volumetric: $69 \times 10^{-6} \text{ m}^3/\text{m}^3 \cdot \text{K}$ ($3.83 \times 10^{-5} \text{ in.}^3/\text{in.}^3 \cdot \text{°F}$)
Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)
Thermal conductivity. 127 W/m · K (73.4 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, average of all tempers: 31% IACS at 20 °C (68 °F)
Electrical resistivity. Average of all tempers: 56 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)
Electrolytic solution potential. -0.88 V ver-

Table 66 Tensile properties of alloy 5086

Temper	Tensile strength				Yield strength		Elongation(a), %
	MPa	ksi	MPa	ksi	MPa	ksi	
Typical properties							
O	260	38	...	...	115	17	22
H32, H116	290	42	...	...	205	30	12
H34	325	47	...	...	255	37	10
H112	270	39	...	...	130	19	14
Property limits							
	Minimum		Maximum		Minimum		Minimum
O (0.020–2.000 in. thick)	240	35	305	44	95	14	15–18
H32 (0.020–2.000 in. thick)	275	40	325	47	195	28	6–12
H34 (0.009–1.000 in. thick)	305	44	350	51	235	34	4–10
H36 (0.006–0.162 in. thick)	325	47	370	54	260	38	3–6
H38 (0.006–0.020 in. thick)	345	50	...	...	285	41	3
H112							
(0.188–0.499 in. thick)	250	36	...	...	125	18	8
(0.500–1.000 in. thick)	240	35	...	...	110	16	10
(1.001–3.000 in. thick)	240	35	...	...	95	14	14
(2.001–3.000 in. thick)	235	34	...	...	95	14	14
H116 (0.063–2.000 in. thick)	275	40	...	...	195	28	8–10

(a) In 50 mm (2 in.) or 4d, where d is diameter of reduced section of tensile test specimen. Where a range of values appears in this column, specified minimum elongation varies with thickness of the mill product.

Table 67 Typical tensile properties of alloy 5086-O at various temperatures

Temperature		Tensile strength(a)		Yield strength (0.2% offset)(a)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
-196	-320	379	55	131	19	46
-80	-112	269	39	117	17	35
-28	-18	262	38	117	17	32
24	75	262	38	117	17	30
100	212	262	38	117	17	36
149	300	200	29	110	16	50
204	400	152	22	103	15	60
260	500	117	17	76	11	80
316	600	76	11	52	7.5	110
371	700	41	6	29	4.2	130

(a) Lowest strengths for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture

sus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter (600 to 900 °F)

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F); holding at temperature not required
Hot-working temperature. 315 to 480 °C

**5154
3.5Mg-0.25Cr**

Specifications

AMS. Sheet and plate: 4018, 4019
ASTM. Sheet and plate: B 209. Rolled or

Table 68 Mechanical properties of alloy 5154

Temper	Tensile strength				Yield strength		Elongation(a), %	Hardness(b), HB	Shear strength		Fatigue strength(c)	
	MPa	ksi	MPa	ksi	MPa	ksi			MPa	ksi	MPa	ksi
Typical properties												
O	240	35	...	...	117	17	27	58	152	22	117	17
H32	270	39	...	...	207	30	15	67	152	22	124	18
H34	290	42	...	...	228	33	13	73	165	24	131	19
H36	310	45	...	...	248	36	12	78	179	26	138	20
H38	330	48	...	...	269	39	10	80	193	28	145	21
H112	240	35	...	...	117	17	25	63	...	...	117	17
Property limits												
	Minimum		Maximum		Minimum							
O (0.020–3.000 in. thick)	205	30	285	41	75	11	12 to 18	...	...	...	...	...
H32 (0.020–2.000 in. thick)	250	36	295	43	180	26	5 to 12	...	...	...	...	...
H34 (0.009–1.000 in. thick)	270	39	315	46	200	29	4 to 10	...	...	...	...	...
H36 (0.006–0.162 in. thick)	290	42	340	49	220	32	3 to 5	...	...	...	...	...
H38 (0.006–0.128 in. thick)	310	45	...	...	240	35	3 to 5	...	...	...	...	...
H112												
(0.250–0.499 in. thick)	220	32	...	...	125	18	8	...	...	...	...	...
(0.0500–3.000 in. thick)	205	30	...	...	75	11	11 to 15	...	...	...	...	...

(a) In 50 mm (2 in.) or 4d, where d is diameter of tensile test specimen. Where a range of values appears in this column, specified minimum elongation varies with thickness of the mill product. (b) 500 kg load; 10 mm ball. (c) At 5 × 10⁸ cycles of completely reversed stress; R.R. Moore type test

cold finished wire, rod, and bar: B 211. Extruded wire, rod, bar, shapes, and tube: B 221. Drawn, seamless tube: B 210. Welded tube: B 313, B 547
SAE. J454
UNS number. A95154
Foreign. Canada: CSA GR40. France: NF A-G3C. United Kingdom: BS N5. ISO: AlMg3.5

Chemical Composition

Composition limits. 0.25 Si max, 0.40 Fe max, 0.10 Cu max, 0.10 Mn max, 3.1 to 3.9 Mg, 0.15 to 0.35 Cr, 0.20 Zn max, 0.20 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Welded structures, storage tanks, pressure vessels, marine structures, transportation trailer tanks

Mechanical Properties

Tensile properties. See Tables 68 and 69. Tensile strength and elongation are approximately equal in the longitudinal and transverse directions.

Shear properties. Shear strength: see Table 68. Shear yield strength: approximately 55% of tensile yield strength

Compressive yield strength. Approximately the same as tensile yield strength

Hardness. See Table 68.

Poisson's ratio. 0.33

Elastic modulus. Tension, 69.3 GPa (10.1 × 10⁶ psi); shear, 25.9 GPa (3.75 × 10⁶ psi); compression, 70.7 GPa (10.3 × 10⁶ psi)

Fatigue strength. See Table 68.

Mass Characteristics

Density. 2.66 g/cm³ (0.096 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 643 °C (1190 °F)

Solidus temperature. 593 °C (1100 °F)

Table 69 Typical tensile properties of alloy 5154-O at various temperatures

Temperature		Tensile strength		Yield strength (0.2% offset)		Elongation(a), %
°C	°F	MPa	ksi	MPa	ksi	
-196	-320	360	52	130	19	46
-80	-112	250	36	115	17	35
-28	-18	240	35	115	17	32
24	75	240	35	115	17	30
100	212	240	35	115	17	30
149	300	200	29	110	16	50
204	400	150	22	105	15	60
260	500	115	17	75	11	80
316	600	75	11	50	7.5	110
371	700	41	6	29	4.2	130

(a) In 50 mm (2 in.) or 4d, where d is diameter of reduced section of tensile test specimen

Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	22.1	12.3
20 to 100	68 to 212	23.9	13.3
20 to 200	68 to 392	24.9	13.8
20 to 300	68 to 572	25.9	14.4

Volumetric: $69 \times 10^{-6} \text{ m}^3/\text{m}^3 \cdot \text{K}$ ($3.83 \times 10^{-5} \text{ in.}^3/\text{in.}^3 \cdot \text{°F}$) at 20 °C (68 °F)

Specific heat: $900 \text{ J/kg} \cdot \text{K}$ ($0.215 \text{ Btu/lb} \cdot \text{°F}$) at 20 °C (68 °F)

Thermal conductivity: $127 \text{ W/m} \cdot \text{K}$ ($73.3 \text{ Btu/ft} \cdot \text{h} \cdot \text{°F}$) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, average of all tempers: 32% IACS at 20 °C (68 °F)

Electrical resistivity. Average of all tempers: $53.9 \text{ n}\Omega \cdot \text{m}$ at 20 °C (68 °F); temperature coefficient, $0.1 \text{ n}\Omega \cdot \text{m per K}$ at 20 °C (68 °F)

Electrolytic solution potential. -0.86 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H_2O_2 per liter

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F); holding at temperature not required

Hot-working temperature. 260 to 510 °C (500 to 950 °F)

Table 71 Tensile properties of alloy 5252

Temper	Tensile strength		Yield strength		Elongation, %
	MPa	ksi	MPa	ksi	
Typical properties					
H25	235	34	...	...	11(a)
H28, H38	283	41	...	...	5(a)
Property limits for 0.75–2.3 mm (0.030–0.090 in.) thick sheet					
	Minimum		Maximum		Minimum
H24	205	30	260	38	10
H25	215	31	270	39	9
H28	260	38	...	...	3

(a) 1.6 mm (1/16 in.) thick specimen

Table 70 Typical tensile properties of alloy 5182

Temper	Tensile strength(a)		Yield strength(a)		Elongation(a)(b), %
	MPa	ksi	MPa	ksi	
O	276	40	138	19	25
H32	317	46	234	34	12
H34	338	49	283	41	10
H19(c)	421	61	393	57	4

(a) Strengths and elongations are unchanged or increased at low temperatures. (b) 1.6 mm (1/16 in.) thick specimen. (c) Properties of this temper are for container end stock 0.25 to 0.38 mm (0.010 to 0.015 in.) thick.

Mass Characteristics

Density. 2.65 g/cm^3 (0.096 lb/in.^3) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 638 °C (1180 °F)

Solidus temperature. 577 °C (1070 °F)

Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	22.2	12.3
20 to 100	68 to 212	24.1	13.4
20 to 200	68 to 392	25.0	13.9
20 to 300	68 to 572	26.0	14.4

Volumetric: $70 \times 10^{-6} \text{ m}^3/\text{m}^3 \cdot \text{K}$ ($3.89 \times 10^{-5} \text{ in.}^3/\text{in.}^3 \cdot \text{°F}$) at 20 °C (68 °F)

Specific heat: $904 \text{ J/kg} \cdot \text{K}$ ($0.216 \text{ Btu/lb} \cdot \text{°F}$) at 20 °C (68 °F)

Thermal conductivity: $123 \text{ W/m} \cdot \text{K}$ ($71.1 \text{ Btu/ft} \cdot \text{h} \cdot \text{°F}$) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, 31% IACS at 20 °C (68 °F)

Electrical resistivity. $55.6 \text{ n}\Omega \cdot \text{m}$ at 20 °C (68 °F); temperature coefficient, $0.1 \text{ n}\Omega \cdot \text{m per K}$ at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F)

Hot-working temperature. 260 to 510 °C (500 to 950 °F)

5252

2.5Mg

Specifications

ASTM. Sheet: B 209

SAE. J454

UNS number. A95252

Chemical Composition

Composition limits. 0.08 Si max, 0.10 Fe max, 0.10 Cu max, 0.10 Mn max, 2.2 to 2.8 Mg, 0.05 Zn max, 0.05 V max, 0.03 max other (each), 0.10 max others (total), bal Al

Applications

Typical uses. Automotive and appliance trim where greater strength is required than in other trim alloys. Can be bright dipped or anodized to give a bright, clear finish

Table 72 Mechanical properties of alloy 5254

Temper	Tensile strength				Yield strength		Elongation, %	Hardness(a), HB	Shear strength		Fatigue strength(b)	
	MPa	ksi	MPa	ksi	MPa	ksi			MPa	ksi	MPa	ksi
Typical properties(c)												
O	240	35	...	...	115	17	27	58	150	22	115	17
H32	270	39	...	...	205	30	15	67	150	22	125	18
H34	290	42	...	...	230	33	13	73	165	24	130	19
H36	310	45	...	...	250	36	12	78	180	26	140	20
H38	330	48	...	...	270	39	10	80	195	28	145	21
H112	240	35	...	...	115	17	25	63	...	...	115	17
Property limits												
	Minimum		Maximum		Minimum		Minimum(d)					
O	205	30	285	41	75	11	12-18					
H32	250	36	295	43	180	26	5-12					
H34	270	39	315	46	200	29	4-10					
H36	290	42	340	49	220	32	3-5					
H38	310	45	...	...	240	35	3-5					
H112												
6-12.5 mm (0.250-0.499 in.) thick	220	32	...	...	125	18	8					
13-75 mm (0.500-3.000 in.) thick	205	30	...	...	75	11	11-15					

(a) 500 kg load; 10 mm ball. (b) At 5×10^8 cycles; R.R. Moore type test. (c) Strengths and elongations are unchanged or increased at low temperatures. (d) In 50 mm (2 in.) or $4d$, where d is diameter of reduced section of test specimen. Where a range of values appears in this column, specified minimum elongation varies with thickness of the mill product.

Mechanical Properties

Tensile properties. See Table 71.
Shear strength. H25 temper: 145 MPa (21 ksi); H28, H38 tempers: 160 MPa (23 ksi)
Compressive yield strength. Approximately the same as tensile yield strength
Hardness. H25 temper: 68 HB. H28, H38 tempers: 75 HB. Brinell hardness determined using 500 kg load, 10 mm ball, 30 s duration of loading
Elastic modulus. Tension, 68.3 GPa (9.90×10^6 psi); compression, 69.7 GPa (10.1×10^6 psi)

Mass Characteristics

Density. 2.67 g/cm³ (0.097 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 649 °C (1200 °F)
Solidus temperature. 607 °C (1125 °F)
Coefficient of thermal expansion.
 Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	23.0	12.2
20 to 100	68 to 212	23.8	13.2
20 to 200	68 to 392	24.7	13.7
20 to 300	68 to 572	25.8	14.3

Table 73 Typical tensile properties of alloy 5254-O at various temperatures

Temperature		Tensile strength(a)		Yield strength(a)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
-196	-320	360	52	130	19	46
-80	-112	250	36	115	17	35
-28	-18	240	35	115	17	32
24	75	240	35	115	17	30
100	212	240	35	115	17	36
149	300	200	29	110	16	50
204	400	150	22	105	15	60
260	500	115	17	75	11	80
316	600	75	11	50	7.5	110
371	700	41	6	29	4.2	130

(a) Lowest strengths for exposure up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture

Volumetric: $69 \times 10^{-6} \text{ m}^3/\text{m}^3 \cdot \text{K}$ ($3.83 \times 10^{-5} \text{ in.}^3/\text{in.}^3 \cdot \text{°F}$)
Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)
Thermal conductivity. 138 W/m · K (80 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, average of all tempers: 35% IACS at 20 °C (68 °F)
Electrical resistivity. Average of all tempers: 49 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F); holding at temperature not required
Hot-working temperature. 260 to 510 °C (500 to 950 °F)

**5254
3.5Mg-0.25Cr**

Specifications

ASTM. Sheet and plate: B 209. Extruded, seamless tube: B 241
SAE. J454
UNS number. A95254
Foreign. Canada: CSA GR40

Chemical Composition

Composition limits. 0.45 Si max + Fe, 0.05 Cu max, 0.01 Mn max, 3.1 to 3.9 Mg, 0.15 to 0.35 Cr, 0.20 Zn max, 0.05 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Storage vessels for hydrogen peroxide and other chemicals

Mechanical Properties

Tensile properties. See Tables 72 and 73.
Shear yield strength. Approximately 55% of tensile yield strength
Compressive yield strength. Approximately the same as tensile yield strength
Hardness. See Table 72.
Elastic modulus. 70.3 GPa (10.2×10^6 psi); compression, 70.9 GPa (10.3×10^6 psi)
Fatigue strength. See Table 72.

Mass Characteristics

Density. 2.66 g/cm³ (0.096 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 643 °C (1190 °F)
Solidus temperature. 593 °C (1100 °F)
Coefficient of thermal expansion.
 Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	22.1	12.3
20 to 100	68 to 212	24.0	13.3
20 to 200	68 to 392	24.9	13.8
20 to 300	68 to 572	25.9	14.4

Volumetric: $69 \times 10^{-6} \text{ m}^3/\text{m}^3 \cdot \text{K}$ ($3.83 \times 10^{-5} \text{ in.}^3/\text{in.}^3 \cdot \text{°F}$) at 20 °C (68 °F)
Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)
Thermal conductivity. 127 W/m · K (73.4 Btu/ft · h · °F) at 20 °C (68 °F)

Table 74 Mechanical properties of alloy 5454

Temper	Tensile strength				Yield strength		Elongation, %	Hardness(a), HB	Shear strength	
	MPa	ksi	MPa	ksi	MPa	ksi			MPa	ksi
Typical properties										
O	250	36	...	...	117	17	22	62	159	23
H32	275	40	...	...	207	30	10	73	165	24
H34	305	44	...	...	241	35	10	81	179	26
H36	340	49	...	...	276	40	8	...	...	...
H38	370	54	...	...	310	45	8	...	...	...
H111	260	38	...	...	179	26	14	70	159	23
H112	250	36	...	...	124	18	18	62	159	23
H311	260	38	...	...	179	26	18	70	159	23
Property limits										
	Minimum		Maximum		Minimum					
O	215	31	285	41	85	12	12-18(b)	...	...	...
H32	250	36	305	44	180	26	5-12(b)	...	...	...
H34	270	39	325	47	200	29	4-10(b)	...	...	...
H112										
	6-12.5 mm (0.250-0.499 in.) thick		...		125	18	8	...	...	...
	13-75 mm (0.500-3.00 in.) thick		...		85	12	11-15(b)	...	...	...

(a) 500 kg load; 10 mm ball. (b) Range of values indicates that specified minimum elongation varies with thickness of mill product.

Electrical Properties

Electrical conductivity. Volumetric, 32% IACS at 20 °C (68 °F)

Electrical resistivity. 54 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. -0.86 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F); holding at temperature not required

Hot-working temperature. 260 to 510 °C (500 to 950 °F)

5356

5.0Mg-0.12Mn-0.12Cr

Specifications

UNS number. A95356

Government. QQ-R-566, MIL-E-16053

Foreign. Canada: CSA GM50P. France: NF A-G5

Chemical Composition

Composition limits. 0.25 Si max, 0.40 Fe max, 0.10 Cu max, 0.05 to 0.20 Mn, 4.5 to 5.5 Mg, 0.05 to 0.20 Cr, 0.10 Zn max, 0.06 to 0.20 Ti, 0.05 max other (each), 0.15 max others (total), 0.0008 Be max, bal Al

Applications

Typical uses. Welding electrodes and filler wire for base metals with high magnesium content (>3% Mg)

Mass Characteristics

Density. 2.64 g/cm³ (0.0954 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 638 °C (1180 °F)

Solidus temperature. 574 °C (1065 °F)

Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	22.3	12.3
20 to 100	68 to 212	24.2	13.4
20 to 200	68 to 392	25.1	13.9
20 to 300	68 to 572	26.1	14.5

Volumetric: 70 × 10⁻⁶ m³/m³ · K (3.89 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 904 J/kg · K (0.216 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. 116 W/m · K (67 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, O temper: 29% IACS at 20 °C (68 °F)

Electrical resistivity. O temper: 59.4 nΩ · m at 20 °C (68 °F). Temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. -0.87 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F); holding at temperature not required

Hot-working temperature. 260 to 510 °C (500 to 950 °F)

5454

2.7Mg-0.8Mn-0.12Cr

Specifications

ASTM. Sheet and plate: B 209. Extruded wire, rod, bar, shapes, and tube: B 221. Extruded seamless tube: B 241. Condenser tube: B 234. Condenser tube with integral fins: B 404. Welded tube: B 547

SAE. J454

UNS number. A95454

Government. Sheet and plate: QQ-A-250/10. Extruded wire, rod, bar, shapes, and

tube: QQ-A-200/6

Foreign. Canada: CSA GM31N. France: NF A-G2.5MC. United Kingdom: BS N51. Germany: DIN AlMg2.7Mn. ISO: AlMg3Mn

Chemical Composition

Composition limits. 0.25 Si max, 0.40 Fe max, 0.10 Cu max, 0.50 to 1.0 Mn, 2.4 to 3.0 Mg, 0.05 to 0.20 Cr, 0.25 Zn max, 0.20 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Welded structures, pressure vessels, tube for marine service

Mechanical Properties

Tensile properties. See Tables 74 and 75.

Shear yield strength. Approximately 55% of tensile yield strength

Compressive yield strength. Approximately the same as tensile yield strength

Hardness. See Table 74.

Elastic modulus. Tension, 69.6 GPa (10.1 × 10⁶ psi); compression, 71.0 GPa (10.3 × 10⁶ psi)

Mass Characteristics

Density. 2.68 g/cm³ (0.097 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 646 °C (1195 °F)

Solidus temperature. 602 °C (1115 °F)

Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.9	12.2
20 to 100	68 to 212	23.7	13.2
20 to 200	68 to 392	24.6	13.7
20 to 300	68 to 572	25.6	14.2

Volumetric: 68 × 10⁻⁶ m³/m³ · K (3.77 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. 134 W/m · K (77.4 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, average of all tempers: 34% IACS at 20 °C (68 °F)

Electrical resistivity. Average of all tempers: 51 nΩ · m at 20 °C (68 °F). Temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. -0.86 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F); holding at temperature not required

Table 75 Typical tensile properties of alloy 5454 at various temperatures

Temperature		Tensile strength(a)		Yield strength(a)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
O temper						
-196	-320	370	54	130	19	39
-80	-112	255	37	115	17	30
-28	-18	250	36	115	17	27
24	75	250	36	115	17	25
100	212	250	36	115	17	31
149	300	200	29	110	16	50
204	400	150	22	105	15	60
260	500	115	17	75	11	80
316	600	75	11	50	7.5	110
371	700	41	6	29	4.2	130
H32 temper						
-196	-320	405	59	250	36	32
-80	-112	290	42	215	31	23
-28	-18	285	41	205	30	20
24	75	275	40	205	30	18
100	212	270	39	200	29	20
149	300	220	32	180	26	37
204	400	170	25	130	19	45
260	500	115	17	75	11	80
316	600	75	11	50	7.5	110
371	700	41	6	29	4.2	130
H34 temper						
-196	-320	435	63	285	41	30
-80	-112	315	46	250	36	21
-28	-18	305	44	240	35	18
24	75	305	44	240	35	16
100	212	295	43	235	34	18
149	300	235	34	195	28	32
204	400	180	26	130	19	45
260	500	115	17	75	11	80
316	600	75	11	50	7.5	110
371	700	41	6	29	4.2	130

(a) Lowest strengths for exposures up to 10 000 h at temperature, no load, test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture

Hot-working temperature. 260 to 510 °C (500 to 950 °F)

5456
5.1Mg-0.8Mn-0.12Cr

Specifications

ASTM. Sheet and plate: B 209. Extruded wire, rod, bar, shapes, and tube: B 221. Extruded, seamless tube: B 241. Drawn, seamless tube: B 210

SAE. J454

UNS number. A95456

Government. Sheet and plate: QQ-A-250/9, QQ-A-250/20. Extruded wire, rod, bar, shapes, and tube: QQ-A-200/7. Armor plate: MIL-A-46027. Extruded armor: MIL-A-46083. Forged armor: MIL-A-45225

Chemical Composition

Composition limits. 0.25 Si max, 0.40 Fe max, 0.10 Cu max, 0.50 to 1.0 Mn, 4.7 to 5.5 Mg, 0.05 to 0.20 Cr, 0.25 Zn max, 0.20 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Armor plate, high strength welded structures, storage tanks, pressure vessels, marine service

Mechanical Properties

Tensile properties. See Table 76.

Shear strength. H321, H116 tempers: 207 MPa (30 ksi)

Table 76 Tensile properties of alloy 5456

Temper	Tensile strength				Yield strength				Elongation, %	
	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi		
Typical properties										
O	310	45	...	...	159	23	...	...	24(a)	
H111	324	47	...	...	228	33	...	...	18(a)	
H112	310	45	...	...	165	24	...	...	22(a)	
H321(b), H116(c)	352	51	...	...	255	37	...	...	16(a)	
Property limits										
	Minimum		Maximum		Minimum		Maximum		Minimum(d) In 50 mm	In 5d(5.65 √A)
O	290	42	365	53	130	19	205	30	16	...
1.20-6.30 mm thick	285	41	360	52	125	18	205	30	16	14
6.30-80.00 mm thick	275	40	...	...	120	17	...	...	...	12
80.00-120.00 mm thick	270	39	...	...	115	17	...	...	...	12
120.00-160.00 mm thick	265	38	...	...	105	15	...	...	...	10
160.00-200.00 mm thick	H112									
6.30-40.00 mm thick	290	42	...	...	130	19	...	...	12	10
40.00-80.00 mm thick	285	41	...	...	125	18	...	...	...	10
H116(c)(e)										
1.60-30.00 mm thick	315	46	...	...	230	33	...	...	10	10
30.00-40.00 mm thick	305	44	...	...	215	31	...	...	...	10
40.00-80.00 mm thick	285	41	...	...	200	29	...	...	...	10
80.00-110.00 mm thick	275	40	...	...	170	25	...	...	...	10
H321										
4.00-12.50 mm thick	315	46	405	59	230	33	315	46	12	...
12.50-40.00 mm thick	305	44	385	56	215	31	305	44	...	10
40.00-80.00 mm thick	285	41	385	56	200	29	295	43	...	10
H323										
1.20-6.30 mm thick	330	48	400	58	250	36	315	46	6 to 8	...
H343										
1.20-6.30 mm thick	365	53	435	63	285	41	350	51	6 to 8	...

(a) 12.5 mm (½ in.) diam specimen. (b) Material in this temper not recommended for applications requiring exposure to seawater. (c) H116 designation also applies to the condition previously designated H117. (d) Elongations in 50 mm (2 in.) apply to thicknesses through 12.5 mm (½ in.); elongation in 5d (5.65 √A), where d is diameter and A is cross-sectional area of tensile test specimen, apply to material over 12.5 mm (½ in.) thick. (e) Material in this temper required to pass an exfoliation corrosion test administered by the purchaser

Table 77 Typical mechanical properties of alloy 5457

Temper	Tensile strength(a)		Yield strength(a)		Elongation(a)(b), %	Hardness(c), HB	Shear strength	
	MPa	ksi	MPa	ksi			MPa	ksi
O	130	19	50	7	22	32	85	12
H25	180	26	160	23	12	48	110	16
H38, H28	205	30	185	27	6	55	125	18

(a) Strengths and elongations are unchanged or improved at lower temperatures. (b) 1.6 mm (1/16 in.) thick specimen. (c) 500 kg load; 10 mm ball

Hardness. H321, H116 tempers: 90 HB
Elastic modulus. Tension, 70.3 GPa (10.2 × 10⁶ psi); compression, 71.7 GPa (10.4 × 10⁶ psi)

Mass Characteristics

Density. 2.66 g/cm³ (0.096 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 638 °C (1180 °F)
Solidus temperature. 570 °C (1055 °F)
Coefficient of thermal expansion.
 Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	22.1	12.3
20 to 100	68 to 212	23.9	13.3
20 to 200	68 to 392	24.8	13.8
20 to 300	68 to 572	25.9	14.4

Volumetric: 69 × 10⁻⁶ m³/m³ · K (3.83 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)
Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)
Thermal conductivity. 116 W/m · K (67 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, average of all tempers: 29% IACS at 20 °C (68 °F)
Electrical resistivity. Average of all tempers: 59.5 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. -0.87 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 343 °C (650 °F); holding at temperature not required
Hot-working temperature. 260 to 510 °C (500 to 950 °F)

**5457
1.0Mg-0.30Mn**

Specifications

ASTM. Sheet: B 209
UNS number. A95457

Chemical Composition

Composition limits. 0.08 Si max, 0.10 Fe max, 0.20 Cu max, 0.15 to 0.45 Mn, 0.08 to 1.2 Mg, 0.05 Zn max, 0.05 V max, 0.03 max other (each), 0.10 max others (total), bal Al

Applications

Typical uses. Brightened and anodized automotive and appliance trim
Precautions in use. Fine grain size required for most applications of this alloy

Mechanical Properties

Tensile properties. Tensile strength: min, 110 MPa (16 ksi); max, 150 MPa (22 ksi). Elongation, 20% in 50 mm (2 in.). See also Table 77.

Shear strength. See Table 77.

Compressive yield strength. Approximately the same as tensile yield strength

Hardness. See Table 77.

Poisson's ratio. 0.33 at 20 °C (68 °F)

Elastic modulus. Tension, 68.2 GPa (10.0 × 10⁶ psi); shear, 25.9 GPa (3.75 × 10⁶ psi); compression, 69.6 GPa (10.1 × 10⁶ psi)

Mass Characteristics

Density. 2.69 g/cm³ (0.0972 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 654 °C (1210 °F)
Solidus temperature. 629 °C (1165 °F)
Coefficient of thermal expansion.
 Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.9	12.2
20 to 100	68 to 212	23.7	13.2
20 to 200	68 to 392	24.6	13.7
20 to 300	68 to 572	25.6	14.2

Volumetric: 68 × 10⁻⁶ m³/m³ · K (3.77 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)
Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)
Thermal conductivity. 177 W/m · K (102 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, average of all tempers: 46% IACS at 20 °C (68 °F)
Electrical resistivity. 37.5 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)
Electrolytic solution potential. -0.84 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Formability. Readily formed in both annealed and H25 tempers

Table 78 Mechanical properties of alloy 5652

Temper	Tensile strength				Yield strength		Elongation(a), %	Hardness(b), HB	Shear strength		Fatigue strength(c)	
	MPa	ksi	MPa	ksi	MPa	ksi			MPa	ksi	MPa	ksi
Typical properties												
O	195	28	...	...	90	13	25	47	124	18	110	16
H32	230	33	...	...	195	28	12	60	138	20	117	17
H34	260	38	...	...	215	31	10	68	145	21	124	18
H36	275	40	...	...	240	35	8	73	158	23	131	19
H38	290	42	...	...	255	37	7	77	165	24	138	20
Property limits												
	Minimum		Maximum		Minimum		Minimum					
O	170	25	215	31	65	9.5	14-18	...	...	...	...	...
H32	215	31	260	38	160	23	4-12	...	...	...	...	...
H34	235	34	285	41	180	26	3-10	...	...	...	...	...
H36	255	37	305	44	200	29	2-4	...	...	...	...	...
H38	270	39	...	...	220	32	2-4	...	...	...	...	...
H112												
(0.250-0.499 in. thick)	195	28	...	...	110	16	7	...	...	...	...	...
(0.500-3.000 in. thick)	170	25	...	...	65	9.5	12-16	...	...	...	...	...

(a) In 50 mm (2 in.) or 4d, where d is diameter of reduced section of tension-test specimen. Where a range of values appears in this column, the specified minimum elongation varies with thickness of the mill product. (b) 500 kg load; 10 mm ball. (c) At 5 × 10⁸ cycles; R.R. Moore type test

Table 79 Tensile properties of alloy 5657

Temper	Tensile strength				Yield strength		Elongation(a), %
	MPa	ksi	MPa	ksi	MPa	ksi	
Typical properties(b)							
H25	160	23	...	...	140	20	12
H28, H38	195	28	...	...	165	24	7
Property limits							
	Minimum		Maximum				Minimum
H241(c)	125	18	180	26	...	...	13
H25	140	20	195	28	...	...	8
H26	150	22	205	30	...	...	7
H28	170	25	...	...	...	...	5

(a) In 50 mm (2 in.) or $4d$, where d is diameter of reduced section of tension-test specimen. (b) Strengths and elongations are unchanged or increased at low temperatures. (c) Material in this temper subject to some recrystallization and attendant loss of brightness

Annealing temperature. 343 °C (650 °F); holding temperature not required
Hot-working temperature. 260 to 510 °C (500 to 950 °F)

5652 2.5Mg-0.25Cr

Specifications

ASTM. Sheet and plate: B 209. Extruded, seamless tube: B 241
SAE. J454
UNS number. A95652

Chemical Composition

Composition limits. 0.40 Si max + Fe, 0.04 Cu max, 0.01 Mn max, 2.2 to 2.8 Mg, 0.15 to 0.35 Cr, 0.10 Zn max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Storage vessels for hydrogen peroxide and other chemicals

Mechanical Properties

Tensile properties. See Table 78.
Shear strength. See Table 78.
Compressive yield strength. Approximately the same as tensile yield strength
Hardness. See Table 78.
Poisson's ratio. 0.33
Elastic modulus. Tension, 68.2 GPa (9.89×10^6 psi); shear, 25.9 GPa (3.75×10^6 psi); compression, 69.6 GPa (10.1×10^6 psi)
Fatigue strength. See Table 78.

Mass Characteristics

Density. 2.68 g/cm³ (0.097 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 649 °C (1200 °F)
Solidus temperature. 607 °C (1125 °F)
Coefficient of thermal expansion.
 Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	22.0	12.2
20 to 100	68 to 212	23.8	13.2
20 to 200	68 to 392	24.7	13.7
20 to 300	68 to 572	25.8	14.3

Volumetric: $69 \times 10^{-6} \text{ m}^3/\text{m}^3 \cdot \text{K}$ ($3.83 \times 10^{-5} \text{ in.}^3/\text{in.}^3 \cdot \text{°F}$) at 20 °C (68 °F)
Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)
Thermal conductivity. 137 W/m · K (79.1 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, average of all tempers: 35% IACS at 20 °C (68 °F)
Electrical resistivity. 49 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)
Electrolytic solution potential. -0.85 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F); holding at temperature not required
Hot-working temperature. 260 to 510 °C (500 to 950 °F)

5657 0.8Mg

Specifications

ASTM. B 209
UNS number. A95657
Foreign. Italy: P-ALMg0.9

Chemical Composition

Composition limits. 0.08 Si max, 0.10 Fe max, 0.10 Cu max, 0.03 Mn max, 0.6 to 1.0 Mg, 0.05 Zn max, 0.03 Ga max, 0.05 V max, 0.02 max other (each), 0.05 max others (total), bal Al

Applications

Typical uses. Brightened and anodized automotive and appliance trim
Precautions in use. Fine grain size essential for almost all applications of this alloy

Mechanical Properties

Tensile properties. See Table 79.
Shear strength. H25 temper: 95 MPa (14 ksi); H28, H38 tempers: 105 MPa (15 ksi)
Compressive yield strength. Approximately the same as tensile yield strength
Hardness. H25 temper: 40 HB. H28 and

H38 tempers: 50 HB. All hardness values obtained with 500 kg load, 10 mm diam ball, and 30 s duration of loading

Poisson's ratio. 0.33

Elastic modulus. Tension, 68.2 GPa (9.89×10^6 psi); shear, 25.9 GPa (3.75×10^6 psi); compression, 69.6 GPa (10.1×10^6 psi)

Mass Characteristics

Density. 2.69 g/cm³ (0.097 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 657 °C (1215 °F)

Solidus temperature. 638 °C (1180 °F)

Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.9	12.2
20 to 100	68 to 212	23.7	13.2
20 to 200	68 to 392	24.6	13.7
20 to 300	68 to 572	25.6	14.2

Volumetric: $68 \times 10^{-6} \text{ m}^3/\text{m}^3 \cdot \text{K}$ ($3.77 \times 10^{-5} \text{ in.}^3/\text{in.}^3 \cdot \text{°F}$) at 20 °C (68 °F)

Specific heat. 900 J/kg · K (0.215 Btu/lb · °F)

Electrical Properties

Electrical conductivity. Volumetric, 54% IACS at 20 °C (68 °F)
Electrical resistivity. 32 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F); holding at temperature not required
Hot-working temperature. 260 to 510 °C (500 to 950 °F)

6005

0.8Si-0.5Mg

Specifications

ASTM. Extruded wire, rod, bar, shapes, and tube: B 221
SAE. J454
UNS. A96005

Chemical Composition

Composition limits. 0.6 to 0.9 Si, 0.35 Fe max, 0.10 Cu max, 0.10 Mn max, 0.40 to 0.6 Mg, 0.10 Cr max, 0.10 Zn max, 0.10 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Extruded shapes and tubing for commercial applications requiring strength greater than that of 6063; ladders and TV antennas are among the more common products

Precautions in use. Not recommended for applications requiring resistance to impact loading

Table 80 Typical tensile properties of alloy 6009 automobile body sheet

Orientation	Tensile strength		Yield strength		Elongation, %
	MPa	ksi	MPa	ksi	
T4 temper					
Longitudinal.....	234	34	131	19	24
Transverse and 45°.....	228	33	124	18	25
T6 temper					
Longitudinal.....	345	50	324	47	12
Transverse and 45°.....	338	49	296	43	13

Table 81 Typical tensile properties of alloy 6010 automobile body sheet

Orientation	Tensile strength		Yield strength		Elongation, %
	MPa	ksi	MPa	ksi	
T4 temper					
Longitudinal.....	296	43	186	27	23
Transverse and 45°.....	290	42	172	25	24
T6 temper					
Longitudinal.....	386	56	372	54	11
Transverse and 45°.....	379	55	352	51	12

Mechanical Properties

Tensile properties. Tensile strength (minimum): T1 temper, 172 MPa (25 ksi); T5 temper, 262 MPa (38 ksi). Yield strength (minimum): T1 temper, 103 MPa (15 ksi); T5 temper: 241 MPa (35 ksi). Elongation (minimum): T1 temper, 16%; T5 temper, 8 to 10%, specific value varies with thickness of mill product

Shear strength. T5 temper: 205 MPa (30 ksi)

Hardness. T5 temper: 95 HB

Elastic modulus. Tension, 69 GPa (10 × 10⁶ psi)

Fatigue strength. (minimum). 97 MPa (14 ksi) at 5 × 10⁸ cycles; R.R. Moore type test

Mass Characteristics

Density. 2.7 g/cm³ (0.098 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 654 °C (1210 °F)

Solidus temperature. 607 °C (1125 °F)

Coefficient of thermal expansion. Linear, 23.4 μm/m · K (13.0 μin./in. · °F) at 20 to 100 °C (68 to 212 °F)

Thermal conductivity. T5 temper: 167 W/m · K (97 Btu/ft · h · °F) at 25 °C (77 °F)

Electrical Properties

Electrical conductivity. Volumetric, T5 temper: 49% IACS at 20 °C (68 °F)

Electrical resistivity. T5 temper: 35 nΩ · m at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 415 °C (778 °F); hold at temperature for 2 to 3 h

Solution temperature. 547 °C (1015 °F)

Aging temperature. 175 °C (346 °F), hold at temperature for 8 h

6009

0.80Si-0.60Mg-0.50Mn-0.35Cu

Specifications

UNS. A96009

Chemical Composition

Composition limits. 0.6 to 1.0 Si, 0.50 Fe max, 0.15 to 0.6 Cu, 0.20 to 0.8 Mn, 0.40 to 0.8 Mg, 0.10 Cr max, 0.25 Zn max, 0.10 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Automobile body sheet

Mechanical Properties

Tensile properties. See Table 80.

Yield stretch. Following simulated forming and a paint bake cycle consisting of 1 h at 175 °C (350 °F). T4 temper: no stretch, 228 MPa (33 ksi); 5% stretch, 262 MPa (38 ksi); 10% stretch, 290 MPa (42 ksi)

Shear strength. Auto body sheet, T4 temper: 152 MPa (22 ksi)

Hardness. T4 temper, auto body sheet: 70 HR15T

Poisson's ratio. 0.33

Elastic modulus. Tension, 69 GPa (10 × 10⁶ psi); shear, 25.4 GPa (3.75 × 10⁶ psi)

Fatigue strength. T4 temper: 117 MPa (17 ksi) at 10 × 10⁶ cycles; sheet flexural specimens

Mass Characteristics

Density. 2.71 g/cm³ (0.098 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 650 °C (1202 °F)

Solidus temperature. 560 °C (1040 °F)

Coefficient of thermal expansion.

Linear:

Temperature range °C		Average coefficient μm/m · K	
-50 to 20	-58 to 68.....	21.6	12.0
20 to 100	68 to 212.....	23.4	13.0
20 to 200	68 to 392.....	24.3	13.5
20 to 300	68 to 572.....	25.2	14.0

Volumetric: 67 × 10⁻⁶ m³/m³ · K (3.72 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 897 J/kg · K (0.214 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F): O temper, 205 W/m · K (118 Btu/ft · h · °F); T4 temper, 172 W/m · K (99 Btu/ft · h · °F); T6 temper, 180 W/m · K (104 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 54% IACS; T4 temper, 44% IACS; T6 temper: 47% IACS

Electrical resistivity. At 20 °C (68 °F): O temper, 31.9 nΩ · m; T4 temper, 39.2 nΩ · m; T6 temper, 36.7 nΩ · m. Temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

Fabrication Characteristics

Formability. Auto body sheet, T4 temper. ½t radius required for 90° bending or for flanging material 0.80 to 1.30 mm (0.032 to 0.050 in.) thick. Standard hems, which are made by bending 180° over 1t interface thickness, also can be made in auto body sheet 0.80 to 1.30 mm thick. Olsen cup height, typically 0.38 in. when tested using a 25 mm (1 in.) diam top die, 15 MPa (2.2 ksi) hold-down pressure and polyethylene film as a lubricant. Strain-hardening exponent (n) typically 0.23; plastic strain ratio (r) typically 0.70

Annealing temperature. 415 °C (775 °F)

Solution temperature. 555 °C (1030 °F)

Aging temperature. 175 °C (350 °F)

6010

1.0Si-0.8Mg-0.5Mn-0.35Cu

Specifications

UNS. A96010

Chemical Composition

Composition limits. 0.8 to 1.2 Si, 0.50 Fe max, 0.15 to 0.6 Cu, 0.20 to 0.8 Mn, 0.60 to 1.0 Mg, 0.10 Cr max, 0.25 Zn max, 0.10 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Automobile body sheet

Mechanical Properties

Tensile properties. Typical. T4 temper: tensile strength, 290 MPa (42 ksi); yield strength, 172 MPa (25 ksi); elongation, 24% in 50 mm (2 in.). See also Table 81.

Yield stretch. Following simulated forming and a paint bake cycle consisting of 1 h at

Table 82 Standard specifications for alloy 6061

Mill form and condition	Specification No.		
	AMS	ASTM	Government
Bare 6061			
Sheet and plate	4025	B 209	QQ-A-250/11
	4026	...	...
	4027	...	...
	4043	...	...
	4053	...	...
Tread plate .....	...	B 632	MIL-F-17132
Wire, rod, and bar (rolled or cold finished)	4115	B 211	QQ-A-225/8
	4116	...	...
	4117	...	...
	4128	...	...
	4129	...	...
Rod, bar, shapes, and tube (extruded)	4150	B 221	QQ-A-200/8
	4160	...	...
	4161	...	...
	4172	...	...
	4173	...	...
Structural shapes	4113	B 808	QQ-A-200/8
Tube (extruded, seamless) .....	...	B 241	...
Tube (drawn) .....	...	B 483	...
Tube (seamless)	4079	B 210	WW-T-700/6
Tube (hydraulic)	4080	...	...
	4082	...	...
	4081	...	MIL-T-7081
Tube (condenser)	4083	...	...
	...	B 234	...
Tube (condenser with integral fins) .....	...	B 404	...
Tube (welded) .....	...	B 313	...
	...	B 549	...
Tube (wave guide) .....	...	...	MIL-W-85
	...	...	MIL-W-23068
Pipe .....	...	...	MIL-W-23351
	...	B 241	MIL-P-25995
Pipe (gas and oil transmission) .....	...	B 345	...
Forgings	4127	B 247	QQ-A-367,
	4146	...	MIL-A-22771
	4127	...	QQ-A-367
Forging stock	4146	...	...

Rivet wire .....	...	B 316	QQ-A-430
Impacts .....	...	...	MIL-A-12545
	...	B 429	MIL-P-25995
Alclad 6061			
Sheet and plate	4020	B 209	...
	4021	...	...
	4022	...	...
	4023	...	...

Table 83 Typical mechanical properties of alloy 6061

Temper	Tensile strength		Yield strength		Elongation, %		Shear strength	
	MPa	ksi	MPa	ksi	1.6 mm (1/16 in.) thick specimen	13 mm (1/2 in.) diam specimen	MPa	ksi
Bare 6061								
O.....	124	18	55	8	25	30	83	12
T4, T451	241	35	145	21	22	25	165	24
T6, T651	310	45	276	40	12	17	207	30
Alclad 6061								
O.....	117	17	48	7	25	...	76	11
T4, T451	228	33	131	19	22	...	152	22
T6, T651	290	42	255	37	12	...	186	27

175 °C (350 °F). T4 temper: no stretch, 255 MPa (37 ksi); 5% stretch, 295 MPa (43 ksi); 10% stretch, 324 MPa (47 ksi)
Hardness. T4 temper: 76 HR15T
Poisson's ratio. 0.33
Elastic modulus. Tension, 69 GPa (10 × 10⁶ psi); shear, 25.4 GPa (3.75 × 10⁶ psi)
Fatigue strength. T4 temper: 117 MPa (17 ksi) at 10 × 10⁶ cycles; sheet flexural specimens

Mass Characteristics

Density. 2.70 g/cm³ (0.098 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 650 °C (1200 °F)
Solidus temperature. 585 °C (1085 °F)
Incipient melting temperature. 577 °C (1070 °F)
Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68.....	21.5	11.9
20 to 100	68 to 212.....	23.2	12.9
20 to 200	68 to 392.....	24.1	13.4
20 to 300	68 to 572.....	25.1	13.9

Volumetric: 67 × 10⁻⁶ m³/m³ · K (3.72 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)
Specific heat. 897 J/kg · K (0.214 Btu/lb · °F) at 20 °C (68 °F)
Thermal conductivity. At 20 °C (68 °F): O temper, 202 W/m · K (117 Btu/ft · h · °F); T4 temper, 151 W/m · K (87.3 Btu/ft · h · °F); T6 temper, 180 W/m · K (104 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 53% IACS; T4 temper, 39% IACS; T6 temper, 44% IACS
Electrical resistivity. At 20 °C (68 °F): O temper, 32.5 nΩ · m; T4 temper, 44.2 nΩ · m; T6 temper, 39.2 nΩ · m. Temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)

Fabrication Characteristics

Formability. Auto body sheet, T4 temper. 1t radius required for 90° bending, 1t for flanging material 0.80 to 1.30 mm (0.032 to 0.050 in.) thick. Only roped hems, which are made by bending 180° over 2t interface thickness, can be made in auto body sheet 0.80 to 1.30 mm (0.0315 to 0.05 in.) thick. Olsen cup height, typically 9.1 mm (0.36 in.) when tested using a 25 mm (1 in.) diam top die, 15 MPa (2200 psi) hold-down pressure and polyethylene film as a lubricant. Strain-hardening exponent (n) typically 0.22; plastic strain ratio (r) typically 0.70
Annealing temperature. 415 °C (775 °F)
Solution temperature. 565 °C (1050 °F)
Aging temperature. 175 °C (350 °F)

6061 Alclad 6061
1.0Mg-0.6Si-0.30Cu-0.20Cr

Specifications

AMS. See Table 82.
ASTM. See Table 82.
UNS. A96061
Government. See Table 82.
Foreign. Canada: CSA GS11N. France: NF A-G5UC. United Kingdom: BS H20. ISO: AlMg1SiCu

Chemical Composition

Composition limits of 6061. 0.40 to 0.8 Si, 0.7 Fe max, 0.15 to 0.40 Cu, 0.15 Mn max, 0.8 to 1.2 Mg, 0.04 to 0.35 Cr, 0.25 Zn max, 0.15 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al
Composition limits of Alclad 6061. 7072 cladding—0.7 Si max + Fe, 0.10 Cu max, 0.10 Mn max, 0.10 Mg max, 0.8 to 1.3 Zn, 0.05 max other (each), 0.15 max others (total), bal Al

Table 84 Typical tensile properties of alloy 6061-T6 or T651 at various temperatures

Temperature		Tensile strength(a)		Yield strength (0.2% offset)(a)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
-196	-320	414	60	324	47	22
-80	-112	338	49	290	42	18
-28	-18	324	47	283	41	17
24	75	310	45	276	40	17
100	212	290	42	262	38	18
149	300	234	34	214	31	20
204	400	131	19	103	15	28
260	500	51	7.5	34	5	60
316	600	32	4.6	19	2.7	85
371	700	24	3	12	1.8	95

(a) Lowest strength for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture

Applications

Typical uses. Trucks, towers, canoes, railroad cars, furniture, pipelines, and other structural applications where strength, weldability, and corrosion resistance are needed

Mechanical Properties

Tensile properties. See Tables 83 and 84.
Shear strength. See Table 83.
Hardness. O temper: 30 HB; T4, T451 tempers: 65 HB; T6, T651 tempers: 95 HB. Data obtained using 500 kg load, 10 mm diam ball, and 30 s duration of loading
Elastic modulus. Tension, 68.9 GPa (10.0 × 10⁶ psi); compression, 69.7 GPa (10.1 × 10⁶ psi)
Fatigue strength. O temper: 62 MPa (9 ksi). T4, T451, T6, and T651 tempers: 97 MPa (14 ksi). Data correspond to 5 × 10⁸ cycles of completely reversed stress in R.R. Moore type tests.

Mass Characteristics

Density. 2.70 g/cm³ (0.098 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 652 °C (1206 °F)
Solidus temperature. 582 °C (1080 °F)
Coefficient of thermal expansion. Linear, 23.6 μm/m · K (13.1 μin./in. · °F) at 20 to 100 °C (68 to 212 °F)
Specific heat. 896 J/kg · K (0.214 Btu/lb · °F) at 20 °C (68 °F)
Thermal conductivity. At 25 °C (77 °F): O temper, 180 W/m · K (104 Btu/ft · h · °F); T4

temper, 154 W/m · K (89.0 Btu/ft · h · °F); T6 temper, 167 W/m · K (96.5 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric at 20 °C (68 °F): O temper, 47% IACS; T4 temper, 40% IACS; T6 temper: 43% IACS
Electrical resistivity. At 20 °C (68 °F): O temper, 37 nΩ · m; T4 temper, 43 nΩ · m; T6 temper, 40 nΩ · m

Fabrication Characteristics

Solution temperature. 530 °C (985 °F)
Aging temperature. Rolled or drawn products: 160 °C (320 °F); hold at temperature for 18 h. Extrusions or forgings: 175 °C (350 °F); hold at temperature for 8 h

**6063
0.7Mg-0.4Si**

Specifications

AMS. Extruded wire, rod, bar, shapes, and tube: 4156
ASME. Extruded wire, rod, bar, shapes, and tube: SB221. Pipe: SB241
ASTM. See Table 85.
SAE. J454
UNS. A96063
Government. QQ-A-200/9, MIL-P-25995
Foreign. Austria: Önorm AlMgSi0,5. Canada: CSA GS10. France: NF A-GS. Italy: UNI P-AlSi0.4Mg. United Kingdom: BS H19; DTD 372B. Germany: DIN AlMgSi0.5; Werkstoff-Nr. 3.3206. ISO: AlMgSi

Table 86 Typical mechanical properties of alloy 6063

Temper	Tensile strength		Yield strength		Elongation, %	Hardness(a), HB	Shear strength		Fatigue strength	
	MPa	ksi	MPa	ksi			MPa	ksi	MPa	ksi
O	90	13	48	7	...	25	69	10	55	8
T1(c)	152	22	90	13	20	42	97	14	62	9
T4	172	25	90	13	22	...	...	...	...	...
T5	186	27	145	21	12	60	117	17	69	10
T6	241	35	214	31	12	73	152	22	69	10
T83	255	37	241	35	9	82	152	22	...	...
T831	207	30	186	27	10	70	124	18	...	...
T832	290	42	269	39	12	95	186	27	...	...

(a) 500 kg load; 10 mm diam ball. (b) At 5 × 10⁸ cycles; R.R. Moore type test. (c) Formerly T42 temper

Table 85 ASTM specifications for alloy 6063

Mill form and condition	ASTM No.
Wire, rod, bar, shapes, and tube (extruded)...	B 221
Tube (extruded, seamless); pipe.....	B 241
Tube (extruded, coiled)	B 491
Tube (drawn)	B 483
Tube (drawn, seamless)	B 210
Pipe (gas and oil transmission)	B 345
Structural pipe and tube (extruded).....	B 429

Chemical Composition

Composition limits. 0.20 to 0.6 Si, 0.35 Fe max, 0.10 Cu max, 0.10 Mn max, 0.45 to 0.9 Mg, 0.10 Cr max, 0.10 Zn max, 0.10 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Pipe, railings, furniture, architectural extrusions, truck and trailer flooring, doors, windows, irrigation pipes

Mechanical Properties

Tensile properties. See Tables 86 and 87.
Hardness. See Table 86.
Poisson's ratio. 0.33
Elastic modulus. Tension, 68.3 GPa (9.91 × 10⁶ psi); shear, 25.8 GPa (3.75 × 10⁶ psi); compression, 69.7 GPa (10.1 × 10⁶ psi)

Mass Characteristics

Density. 2.69 g/cm³ (0.097 lb/in.³)

Thermal Properties

Liquidus temperature. 655 °C (1211 °F)
Solidus temperature. 615 °C (1139 °F)
Coefficient of thermal expansion. Linear:

Temperature range	Average coefficient		
	°C	°F	
-50 to 20	-58 to 68	21.8	12.1
20 to 100	68 to 212	23.4	13.0
20 to 200	68 to 392	24.5	13.6
20 to 300	68 to 572	25.6	14.2

Specific heat. 900 J/kg · K (0.215 Btu/lb · °F) at 20 °C (68 °F)
Thermal conductivity. At 25 °C (77 °F):

Temper	Conductivity	
	W/m · K	Btu/ft · h · °F
O	218	126
T1 (formerly T42)	193	112
T5	209	121
T6	201	116

Electrical Properties

Electrical conductivity. At 20 °C (68 °F):

Temper	Conductivity, %IACS	
	Equal volume	Equal weight
O	58	191
T1 (formerly T42)	50	165
T5	55	181
T6, T83	53	175

Table 87 Typical tensile properties of alloy 6063 at various temperatures

Temperature		Tensile strength(a)		Yield strength (0.2% offset)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
T1 temper(b)						
-196	-320	234	34	110	16	44
-80	-112	179	26	103	15	36
-28	-18	165	24	97	14	34
24	75	152	22	90	13	33
100	212	152	22	97	14	18
149	300	145	21	103	15	20
204	400	62	9	45	6.5	40
260	500	31	4.5	24	3.5	75
316	600	23	3.2	17	2.5	80
371	700	16	2.3	14	2	105
T5 temper						
-196	-320	255	37	165	24	28
-80	-112	200	29	152	22	24
-28	-18	193	28	152	22	23
24	75	186	27	145	21	22
100	212	165	24	138	20	18
149	300	138	20	124	18	20
204	400	62	9	45	6.5	40
260	500	31	4.5	24	3.5	75
316	600	23	3.2	17	2.5	80
371	700	16	2.3	14	2	105
T6 temper						
-196	-320	324	47	248	36	24
-80	-121	262	38	228	33	20
-28	-18	248	36	221	32	19
24	75	241	35	214	31	18
100	212	214	31	193	28	15
149	300	145	21	133	20	20
204	400	62	9	45	6.5	40
260	500	31	4.5	24	3.5	75
316	600	23	3.3	17	2.5	80
371	700	16	2.3	14	2	105

(a) Lowest strength for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture. (b) T1 temper formerly T42

Table 88 Tensile properties of alloy 6066

Temper	Tensile strength		Yield strength (0.2% offset)		Elongation(a), %
	MPa	ksi	MPa	ksi	
Typical properties					
O	150	22	83	12	18
T4, T451	360	52	207	30	18
T6, T651	395	57	359	52	12
Property limits (extrusions)					
O	200 max	29 max	125 max	18 max	16 min
T4, T4510, T4511	275 min	40 min	170 min	25 min	14 min
T42	275 min	40 min	165 min	24 min	14 min
T6, T6510, T6511	345 min	50 min	310 min	45 min	8 min
T62	345 min	50 min	290 min	42 min	8 min
Property limits (die forgings)					
T6	345 min	50 min	310 min	45 min	...

(a) In 50 mm (2 in.) or 4d, where d is diameter of reduced section of tensile test specimen

Electrical resistivity. At 20 °C (68 °F):

Temper	Resistivity, nΩ · m
O	30
T1 (formerly T42)	35
T5	32
T6, T83	33

Chemical Properties

General corrosion resistance. Highly resistant to all types of corrosion

Fabrication Characteristics

Machinability. Fair, depending on temper
Weldability. For all commercial processes, excellent weldability and brazability

Annealing temperature. 415 °C (775 °F); hold at temperature 2 to 3 h; cool at 28 °C (50 °F) per h from 415 °C (775 °F) to 260 °C (500 °F)

Solution temperature. 520 °C (970 °F)

Aging temperature. T5 temper: 205 °C (400 °F), hold at temperature for 1 h; or 182 °C (360 °F), hold at temperature for 1 h. All

other artificially aged tempers: 175 °C (350 °F), hold at temperature for 8 h

6066

1.4Si-1.1Mg-1.0Cu-0.8Mn

Specifications

ASTM. Extruded wire, rod, bar, shapes, and tube: B 221

SAE. J454

UNS number. A96066

Government. Extruded wire, rod, bar, shapes, and tube: QQ-A-200/10. Forgings: QQ-A-367

Foreign. United Kingdom: BS H11

Chemical Composition

Composition limits. 0.9 to 1.8 Si, 0.50 Fe max, 0.7 to 1.2 Cu, 0.6 to 1.1 Mn, 0.8 to 1.4 Mg, 0.40 Cr max, 0.25 Zn max, 0.20 Ti max, 0.50 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Forgings and extrusions for welded structures

Mechanical Properties

Tensile properties. See Table 88.

Shear strength. Typical. O temper: 97 MPa (14 ksi); T4 and T451 tempers: 200 MPa (29 ksi); T6 and T651 tempers: 234 MPa (34 ksi)

Hardness. O temper: 43 HB; T4 and T451 tempers: 90 HB; T6 and T651 tempers: 120 HB

Elastic modulus. Tension, 69 GPa (10 × 10⁶ psi)

Fatigue strength. T6 and T651 tempers, 110 MPa (16 ksi). Data correspond to 5 × 10⁸ cycles in R.R. Moore type test.

Mass Characteristics

Density. 2.71 g/cm³ (0.098 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 645 °C (1195 °F)

Solidus temperature. 563 °C (1045 °F)

Coefficient of thermal expansion. Linear, 23.2 μm/m · K (12.9 μin./in. · °F) at 20 to 100 °C (68 to 212 °F)

Specific heat. 887 J/kg · K (0.212 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. T6 temper, 147 W/m · K (85 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 40% IACS; T6 temper, 37% IACS

Electrical resistivity. At 20 °C (68 °F): O temper, 43 nΩ · m; T6 temper, 47 nΩ · m

Fabrication Characteristics

Annealing temperature. 415 °C (778 °F);

hold at temperature 2 to 3 h

Solution temperature. 530 °C (990 °F); followed by quenching

Table 89 Typical tensile properties of alloy 6101-T6 at various temperatures

Temperature		Tensile strength(a)		Yield strength (0.2% offset)(a)		Elongation(b), %
°C	°F	MPa	ksi	MPa	ksi	
-196	-320	296	43	228	33	24
-80	-112	248	36	207	30	20
-28	-18	234	34	200	29	19
24	75	221	32	193	28	19
100	212	193	28	172	25	20
149	300	145	21	131	19	20
204	400	69	10	48	7	40
260	500	33	4.8	23	3.3	80
316	600	24	3	16	2.3	100
371	700	17	2.5	12	1.8	105

(a) Lowest strength for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture. (b) In 50 mm (2 in.)

Table 90 Property limits for alloy 6101 extrusions

Temper	Tensile strength(a)		Yield strength(a)		Electrical conductivity(a), %IACS
	MPa	ksi	MPa	ksi	
H111	83	12	55	8	59
T6	200	29	172	25	55
T61					
0.125-0.749 in. thick	138	20	103	15	57
0.750-1.499 in. thick	124	18	76	11	57
1.500-2.000 in. thick	103	15	55	8	57
T63	186	27	152	22	56
T64	103	15	55	8	59.5
T65	172-221	25-32	138-186	20-27	56.5

(a) Single entries are minimum values.

Aging temperature. 175 °C (350 °F); hold at temperature 8 h

6070
1.4Si-0.8Mg-0.7Mn-0.3Cu

Specifications

ASTM. Gas and oil transmission pipe: B 345
SAE. J454

Government. Extruded rod, bar, shapes, and tube: MIL-A-46104. Impacts: MIL-A-12545

Chemical Composition

Composition limits. 1.0 to 1.7 Si, 0.50 Fe max, 0.15 to 0.40 Cu, 0.40 to 1.0 Mn, 0.50 to 1.2 Mg, 0.10 Cr max, 0.25 Zn max, 0.15 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Heavy duty welded structures, pipelines, extruded structural components for automobiles

Mechanical Properties

Tensile properties. Typical. Tensile strength: O temper, 145 MPa (21 ksi); T4 temper, 317 MPa (46 ksi); T6 temper, 379 MPa (55 ksi). Yield strength: O temper, 69 MPa (10 ksi); T4 temper, 172 MPa (25 ksi); T6 temper, 352 MPa (51 ksi). Elongation: O and T4 tempers, 20%; T6 temper, 10%

Shear strength. Typical. O temper: 97 MPa (14 ksi); T4 temper: 206 MPa (30 ksi); T6 temper: 234 MPa (34 ksi)

Hardness. O temper: 35 HB; T4 temper: 90

HB; T6 temper: 120 HB. Data obtained using 500 kg load, 10 mm diam ball, and 30 s duration of loading.

Elastic modulus. Tension, 68 GPa (9.9 × 10⁶ psi)

Fatigue strength. O temper: 62 MPa (9 ksi); T4 temper: 90 MPa (13 ksi); T6 temper: 97 MPa (14 ksi). Data correspond to 5 × 10⁸ cycles of completely reversed stress in an R.R. Moore type test

Mass Characteristics

Density. 2.71 g/cm³ (0.098 lb/in.³)

Thermal Properties

Liquidus temperature. 649 °C (1200 °F)

Solidus temperature. 566 °C (1050 °F)

Specific heat. 891 J/kg · K (0.213 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. T6 temper: 172 W/m · K (99.1 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, T6 temper: 44% IACS at 20 °C (68 °F)

Electrical resistivity. 39 nΩ · m at 20 °C (68 °F)

Fabrication Characteristics

Solution temperature. 545 °C (1015 °F); followed by quenching

Annealing temperature. T4 temper: 545 °C (1015 °F)

Aging temperature. 160 °C (320 °F); hold at temperature for 18 h

6101
0.6Mg-0.5Si

Specifications

ASTM. Bus conductor: B 317

SAE. J454

UNS number. A96101

Foreign. Austria: Önorm E-AlMgSi.

France: NF A-GS/L. Italy: UNI P-

AlSi0.5Mg. Switzerland: VSM Al-Mg-Si.

United Kingdom: BS 91E. Germany: E-AlMgSi0.5; Werkstoff-Nr. 3.3207

Chemical Composition

Composition limits. 0.30 to 0.7 Si, 0.50 Fe max, 0.10 Cu max, 0.03 Mn max, 0.35 to 0.8 Mg, 0.03 Cr max, 0.10 Zn max, 0.06 B max, 0.03 max other (each), 0.10 max others (total), bal Al

Applications

Typical uses. High strength bus bars, electrical conductors, heat sinks

Mechanical Properties

Tensile properties. Typical. Tensile strength, 221 MPa (32 ksi); yield strength, 193 MPa (28 ksi); elongation, 15%. See also Tables 89 and 90.

Shear strength. 138 MPa (20 ksi)

Hardness. 71 HB with 500 kg load, 10 mm diam ball

Elastic modulus. Tension, 68.9 GPa (10.0 × 10⁶ psi); compression, 70.3 GPa (10.2 × 10⁶ psi)

Mass Characteristics

Density. 2.69 g/cm³ (0.097 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 654 °C (1210 °F)

Solidus temperature. 621 °C (1150 °F)

Coefficient of thermal expansion.

Linear:

Temperature range °C	Temperature range °F	Average coefficient	
		μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.7	12.0
20 to 100	68 to 212	23.5	13.0
20 to 200	68 to 392	24.4	13.5
20 to 300	68 to 572	25.4	14.1

Specific heat. 895 J/kg · K (0.214 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. 218 W/m · K (126 Btu/ft · h · °F) at 25 °C (77 °F)

Electrical Properties

Electrical conductivity and resistivity at 20 °C (68 °F):

Temper	Electrical conductivity, %IACS	Electrical resistivity, nΩ · m
T6	57	30.2
T61	59	29.2
T63	58	29.7
T64	60	28.7
T65	58	29.7

Table 91 Tensile-property limits for alloy 6151

Temper	Tensile strength		Yield strength		Elongation(a), %
	MPa	ksi	MPa	ksi	
Die forgings, T6					
Axis parallel to grain flow	303	44	255	37	14 (coupon) 10 (forging)
Axis not parallel to grain flow	303	44	255	37	6 (forging)
Rolled rings, T6 and T652					
Tangential	303	44	255	37	5
Axial	303	44	241	35	4
Radial	290	42	241	35	2

(a) In 50 mm (2 in.) or 4d, where d is diameter of reduced section of tensile test specimen

Table 92 Typical tensile properties of alloy 6151

Temperature		Tensile strength(a)		Yield strength (0.2% offset)(a)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
-196	-321	395	57	345	50	20
-80	-112	345	50	315	46	17
-28	-18	340	49	310	45	17
24	76	330	48	298	43	17
100	212	295	43	275	40	17
149	300	195	28	185	27	20
204	400	95	14	85	12	30
260	500	45	6.5	34	5	50
316	600	34	5	27	3.9	43
371	700	28	4	22	3.2	35

(a) Lowest strength for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture

Fabrication Characteristics

Solution temperature. 510 °C (950 °F); hold for 1 h at temperature
Aging temperature. 175 °C (350 °F); hold for 6 to 8 h at temperature
Hot-working temperature. 260 to 510 °C (500 to 950 °F)

**6151
0.9Si-0.6Mg-0.25Cr**

Specifications

AMS. Forgings: 4125
 SAE. J454

UNS number. A96151

Government. Forgings and forging stock: QQ-A-367; MIL-A-22771

Foreign. Canada: CSA SG11P

Chemical Composition

Composition limits. 0.6 to 1.2 Si, 1.0 Fe max, 0.35 Cu max, 0.20 Mn max, 0.45 to 0.8 Mg, 0.15 to 0.35 Cr, 0.25 Zn max, 0.15 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Die forgings and rolled rings for crank cases, fuses, and machine parts. Applications requiring good forgeability, good strength, and resistance to corrosion

Mechanical Properties

Tensile properties. See Tables 91 and 92.
Hardness. T6 temper: 90 HB with 500 kg load, 10 mm diam ball

Mass Characteristics

Density. 2.70 g/cm³ (0.098 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 650 °C (1200 °F)
Solidus temperature. 588 °C (1090 °F)
Coefficient of thermal expansion. Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.8	12.1
20 to 100	68 to 212	23.0	12.8
20 to 200	68 to 392	24.1	13.4
20 to 300	68 to 572	25.0	13.9

Specific heat. 895 J/kg · K (0.214 Btu/lb · °F)
Thermal conductivity. At 20 °C (68 °F): O temper, 205 W/m · K (118 Btu/ft · h · °F); T4 temper, 163 W/m · K (94 Btu/ft · h · °F); T6 temper, 175 W/m · K (101 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 54% IACS; T4 temper, 42% IACS; T6 temper, 45% IACS
Electrical resistivity. At 20 °C (68 °F): O temper, 32 nΩ · m; T4 temper, 41 nΩ · m; T6 temper, 38 nΩ · m
Electrolytic solution potential. -0.83 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 413 °C (775 °F); hold at temperature 2 to 3 h; furnace cool to

260 °C (500 °F) at 27 °C (50 °F) per h max
Solution temperature. 510 to 525 °C (950 to 975 °F); hold at temperature 4 min, quench in cold water; heavy or complicated forgings, quench in water at 65 to 100 °C (150 to 212 °F)

Aging temperature. 165 to 175 °C (300 to 345 °F); hold at temperature 8 to 12 h

Hot-working temperature. 260 to 480 °C (500 to 900 °F)

**6201
0.7Si-0.8Mg**

Specifications

ASTM. Wire, B 398. Stranded conductor, T81 temper: B 399

SAE. J454

UNS. A96201

Chemical Composition

Composition limits. 0.50 to 0.95 Si, 0.50 Fe max, 0.10 Cu max, 0.03 Mn max, 0.6 to 0.9 Mg, 0.03 Cr max, 0.10 Zn max, 0.06 B max, 0.03 max other (each), 0.10 max others (total), bal Al

Applications

Typical uses. Rod and wire for high strength electrical conductors

Mechanical Properties

Tensile properties. Typical. T81 temper: tensile strength, 331 MPa (48 ksi); yield strength, 310 MPa (45 ksi); elongation, 6% in 250 mm (10 in.)

Property limits for T81 temper wire with 1.6 to 3.2 mm (1/16 to 1/8 in.) diameter. Min tensile strength (individual), 315 MPa (46 ksi); min tensile strength (average), 330 MPa (48 ksi)

Property limits for T81 temper wire with 3.2 to 4.8 mm (1/8 to 3/16 in.) diameter. Min tensile strength (individual), 305 MPa (44 ksi); min tensile strength (average), 315 MPa (46 ksi). Min elongation, 3% in 250 mm (10 in.) for all diameters

Mass Characteristics

Density. 2.69 g/cm³ (0.097 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 654 °C (1210 °F)
Solidus temperature. 607 °C (1125 °F)
Coefficient of thermal expansion:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.6	12.0
20 to 100	68 to 212	23.4	13.0
20 to 200	68 to 392	24.3	13.5
20 to 300	68 to 572	25.2	14.0

Specific heat. 895 J/kg · K (0.214 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. T8 temper: 205 W/m · K (118 Btu/ft · h · °F) at 25 °C (77 °F)

Table 93 Typical tensile properties of alloy 6262 at various temperatures

Temperature		Tensile strength(a)		Yield strength (0.2% offset)(a)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
T651 temper						
-196	-320	414	60	324	47	22
-80	-112	338	49	290	42	18
-28	-18	324	47	283	41	17
24	75	310	45	276	40	17
100	212	290	42	262	38	18
149	300	234	34	214	31	20
T9 temper						
-196	-320	510	74	462	67	14
-80	-112	427	62	400	58	10
-28	-18	414	60	386	56	10
24	75	400	58	379	55	10
100	212	365	53	359	52	10
149	300	262	38	255	37	14
204	400	103	15	90	13	34
260	500	59	8.5	41	6	48
316	600	32	4.6	19	2.7	85
371	700	24	3	12	1.8	95

(a) Lowest strength for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 3%/min to fracture

Electrical Properties

Electrical conductivity. Volumetric, T81 temper: 54% IACS at 20 °C (68 °F)
Electrical resistivity. T81 temper: 32 nΩ · m at 20 °C (68 °F)

Fabrication Characteristics

Solution temperature. 510 °C (950 °F)
Aging temperature. 150 °C (300 °F); hold at temperature approximately 4 h

**6205
0.8Si-0.5Mg-0.10Mn-0.10Cr-0.10Zr**

Specifications
 UNS. A96205

Chemical Composition

Composition limits. 0.6 to 0.9 Si, 0.7 Fe max, 0.20 Cu max, 0.05 to 0.15 Mn, 0.40 to 0.6 Mg, 0.05 to 0.15 Cr, 0.25 Zn max, 0.05 to 0.15 Zr, 0.15 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Plate, tread plate, and extrusions for applications requiring high impact strength

Mechanical Properties

Tensile properties. Typical. T1 temper: tensile strength, 262 MPa (38 ksi); yield strength, 138 MPa (20 ksi); elongation, 19%. T5 temper: tensile strength, 310 MPa (45 ksi); yield strength, 290 MPa (42 ksi); elongation, 11%
Shear strength. T5 temper: 207 MPa (30 ksi)
Hardness. T1 temper: 65 HB; T5 temper: 95 HB
Fatigue strength. T5 temper: 103 MPa (15 ksi) at 5 × 10⁸ cycles in R.R. Moore type test

Mass Characteristics

Density. 2.70 g/cm³ (0.098 lb/in.³)

Thermal Properties

Liquidus temperature. 645 °C (1210 °F)
Solidus temperature. 613 °C (1135 °F)
Coefficient of thermal expansion. Linear, 23.0 μm/m · K (12.8 μin./in. · °F)
Thermal conductivity. At 25 °C (77 °F): T1 temper, 172 W/m · K (99.1 Btu/ft · h · °F); T5 temper, 188 W/m · K (109 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): T1 temper, 45% IACS; T5 temper, 49% IACS
Electrical resistivity. At 20 °C (68 °F): T1 temper, 37 nΩ · m per K; T5 temper, 35 nΩ · m

Fabrication Characteristics

Solution temperature. 525 °C (980 °F)
Aging temperature. 175 °C (350 °F); hold at temperature approximately 6 h

**6262
1.0Mg-0.6Si-0.3Cu-0.09Cr-0.6Pb-0.6Bi**

Specifications

ASTM. Rolled or cold finished wire, rod, and bar: B 211. Extruded wire, rod, bar, shapes, and tube: B 221. Drawn, seamless tube: B 210. Drawn tube: B 483
SAE J454
UNS. A96262
Government. Rolled or cold finished wire, rod, and bar: QQ-A-225/10

Chemical Composition

Composition limits. 0.40 to 0.8 Si, 0.7 Fe max, 0.15 to 0.40 Cu, 0.15 Mn max, 0.8 to 1.2 Mg, 0.04 to 0.14 Cr, 0.25 Zn max, 0.15 Ti max, 0.40 to 0.7 Bi, 0.40 to 0.7 Pb, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. High-stress screw machine products requiring corrosion resistance superior to 2011 and 2017

Mechanical Properties

Tensile properties. Typical, T9 temper: tensile strength, 400 MPa (58 ksi); 0.2% yield strength, 379 MPa (55 ksi); see also Table 93.

Shear strength. Typical, T9 temper: 241 MPa (35 ksi)

Hardness. Typical, T9 temper: 120 HB with 500 kg load, 10 mm diam ball

Fatigue strength. Typical, T9 temper: 90 MPa (13 ksi) at 5 × 10⁸ cycles; R.R. Moore type test

Mass Characteristics

Density. 2.71 g/cm³ (0.098 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 650 °C (1205 °F)
Solidus temperature. 585 °C (1080 °F)
Coefficient of thermal expansion. Linear, 23.4 μm/m · K (13.0 μin./in. · °F) at 20 to 100 °C (68 to 212 °F)
Thermal conductivity. T9 temper: 172 W/m · K (99.1 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, T9 temper: 44% IACS at 20 °C (68 °F)
Electrical resistivity. T9 temper: 39 nΩ · m at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 415 °C (780 °F); hold at temperature 2 to 3 h
Solution temperature. 540 °C (1000 °F); hold at temperature 8 to 12 h
Aging temperature. 170 °C (340 °F); hold at temperature 8 to 12 h

**6351
1.0Si-0.6Mg-0.6Mn**

Specifications

ASTM. Gas and oil transmission pipe: B 345. Extruded wire, rod, bar, shapes, and tube: B 221
UNS. A96351

Chemical Composition

Composition limits. 0.7 to 1.3 Si, 0.50 Fe max, 0.10 Cu max, 0.40 to 0.8 Mn, 0.40 to 0.8 Mg, 0.20 Zn max, 0.20 Ti max, 0.05 max other (each), 0.15 others (total), bal Al

Applications

Typical uses. Extruded structures used in road vehicles and railroad stock; tubing and pipe for carrying water, oil, or gasoline

Mechanical Properties

Tensile properties. Typical. T4 temper: tensile strength, 248 MPa (36 ksi); 0.2% yield

Table 94 Minimum mechanical properties of alloy 7005

Temper	Tensile strength		Yield strength		Elongation(a), %	Compressive yield strength		Shear strength		Shear yield strength		Bearing strength		Bearing yield strength	
	MPa	ksi	MPa	ksi		MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
Extrusions															
T53															
L direction	345	50	303	44	10	296	43	193	28	172	25	655(b)	95(b)	503(b)	73(b)
L-T direction	331	48	290	42	...	303	44	...	...	...	...	496(c)	72(c)	407(c)	59(c)
Sheet and plate															
T6(d), T63(e), T6351(e)	324	47	262	38	...	269	39	186	27	152	22	634(b)	92(b)	448(b)	65(b)
												483(c)	70(c)	365(c)	53(c)

(a) In 50 mm (2 in.) or $4d$, where d is diameter of reduced section of tensile test specimen. (b) $e/d = 2.0$, where e is edge distance and d is pin diameter. (c) $e/d = 1.5$. (d) Up to 6.35 mm (0.250 in.) thick. (e) 6.35 to 75 mm (0.250 to 3.00 in.) thick

strength, 152 MPa (22 ksi); elongation, 20%. T6 temper: tensile strength, 310 MPa (45 ksi); 0.2% yield strength, 283 MPa (41 ksi); elongation, 14%. Property limits for extrusions, T54 temper: tensile strength (min), 207 MPa (30 ksi); 0.2% yield strength (min), 138 MPa (20 ksi); elongation (min), 10% *Shear strength*. T6 temper, 200 MPa (29 ksi) *Hardness*. T6 temper, 95 HB with 500 kg load, 10 mm diam ball *Fatigue strength*. Typical, T6 temper: 90 MPa (13 ksi) at 5×10^8 cycles in R.R. Moore type test

Mass Characteristics

Density. 2.71 g/cm³ (0.098 lb/in.³)

Thermal Properties

Liquidus temperature. 650 °C (1202 °F)

Solidus temperature. 555 °C (1030 °F)

Coefficient of thermal expansion. Linear, 23.4 μm/m · K (13.0 μin./in. · °F) at 20 to 80 °C (68 to 176 °F)

Thermal conductivity. 176 W/m · K (102 Btu/ft · h · °F) at 25 °C (77 °F)

Electrical Properties

Electrical conductivity. Volumetric, T6 temper: 46% IACS at 20 °C (68 °F)

Electrical resistivity. 38 nΩ · m at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 350 °C (660 °F); hold at temperature for about 4 h

Solution temperature. 505 °C (940 °F)

Aging temperature. 170 °C (338 °F); hold at temperature 6 h

6463

0.40Si-0.7Mg

Specifications

ASTM. Extruded wire, rod, bar, shapes, and tube: B 221

SAE. J454

UNS number. A96463

Foreign. United Kingdom: BS E6

Chemical Composition

Composition limits. 0.20 to 0.6 Si, 0.15 Fe max, 0.20 Cu max, 0.05 Mn max, 0.45 to 0.9

Mg, 0.05 Zn max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Architectural, appliance, and bright anodized automotive extrusions

Mechanical Properties

Tensile properties. Typical. Tensile strength: T1 temper, 152 MPa (22 ksi); T5 temper, 186 MPa (27 ksi); T6 temper, 241 MPa (35 ksi). 0.2% yield strength: T1 temper, 90 MPa (13 ksi); T5 temper, 145 MPa (21 ksi); T6 temper: 214 MPa (31 ksi). *Elongation*: T1 temper, 20%; T5 and T6 tempers: 12%

Shear strength. T1 temper, 97 MPa (14 ksi); T5 temper, 117 MPa (17 ksi); T6 temper, 152 MPa (22 ksi)

Hardness. T1 temper, 42 HB; T5 temper, 60 HB; T6 temper, 74 HB. Values obtained with 500 kg load and 10 mm diam ball

Fatigue strength. All tempers: 69 MPa (10 ksi) at 5×10^8 cycles; R.R. Moore type test

Mass Characteristics

Density. 2.69 g/cm³ (0.097 lb/in.³)

Thermal Properties

Liquidus temperature. 654 °C (1210 °F)

Solidus temperature. 621 °C (1150 °F)

Coefficient of thermal expansion. Linear, 23.4 μm/m · K (13.0 μin./in. · °F) at 20 to 100 °C (68 to 212 °F)

Thermal conductivity. At 25 °C (77 °F): T1 temper, 192 W/m · K (111 Btu/ft · h · °F); T5 temper, 209 W/m · K (121 Btu/ft · h · °F); T6 temper, 201 W/m · K (116 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): T1 temper, 50% IACS; T5 temper, 55% IACS; T6 temper, 53% IACS

Electrical resistivity. At 20 °C (68 °F): T1 temper, 34 nΩ · m; T5 temper, 31 nΩ · m; T6 temper, 33 nΩ · m

Fabrication Characteristics

Annealing temperature. 415 °C (780 °F)

Solution temperature. 520 °C (968 °F)

Aging temperature. To produce T6 temper:

175 °C (350 °F), hold at temperature 8 h; can also use 180 °C (360 °F), hold at temperature 6 h. To produce T5 temper: 205 °C (400 °F), hold at temperature 1 h; can also use 180 °C (360 °F), hold at temperature 3 h

7005

4.6Zn-1.4Mg-0.5Mn-0.1Cr-0.1Zr-0.03Ti

Specifications

ASTM. Extruded wire, rod, bar, shapes, and tube: B 221

UNS number. A97005

Chemical Composition

Composition limits. 0.10 Cu max, 1.0 to 1.8 Mg, 0.20 to 0.70 Mn, 0.35 Si max, 0.40 Fe max, 0.06 to 0.20 Cr, 0.01 to 0.06 Ti, 4.0 to 5.0 Zn, 0.08 to 0.20 Zr, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Extruded structural members such as frame rails, cross members, corner posts, side posts, and stiffeners for trucks, trailers, cargo containers, and rapid transit cars. Welded or brazed assemblies requiring moderately high strength and high fracture toughness, such as large heat exchangers, especially where solution heat treatment after joining is impractical. Sports equipment such as tennis racquets and softball bats

Precautions in use. To avoid stress-corrosion cracking, stresses in the transverse direction should be avoided at exposed machined or sawed surfaces. Parts should be cold formed in O temper, then heat treated; alternatively, parts may be cold formed in W temper, followed by artificial aging. In parts intended for service in aggressive electrolytes such as seawater, selective attack along the heat-affected zone in a weldment or torch-brazed assembly can be avoided by postweld aging. When the service environment is conducive to galvanic corrosion, 7005 should be coupled or joined only to aluminum alloy components having similar electrolytic solution potentials;

Table 95 Typical tensile properties at various temperatures for alloy 7005-T53 extrusions

Temperature		Tensile strength(a)		Yield strength(a)		Elongation, %
°C	°F	MPa	ksi	MPa	ksi	
-269	-452	641	93	483	70	16
-196	-320	538	78	421	61	16
-80	-112	441	64	379	55	13
-28	-18	421	61	359	52	14
24	75	392	57	345	50	15
100	212	303	44	283	41	20
149	300	165	24	145	21	35
204	400	97	14	83	12	60
260	500	76	11	66	9.5	80

(a) Lowest strength for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 3%/min to fracture

alternatively, joint surfaces should be protected or insulated.

Mechanical Properties

Tensile properties. Typical. Tensile strength: O temper, 193 MPa (28 ksi); T53 temper, 393 MPa (57 ksi); T6, T63, T6351 tempers, 372 MPa (54 ksi). Yield strength: O temper, 83 MPa (12 ksi); T53 temper, 345 MPa (50 ksi); T6, T63, T6351 tempers, 317 MPa (46 ksi). Elongation in 50 mm (2 in.) or 4d where d is diameter of tensile test specimen: O temper, 20%; T53 temper, 15%; T6, T63, T6351 tempers, 12%. See also Tables 94 and 95.

Shear strength. Typical. O temper: 117 MPa (17 ksi); T53 temper: 221 MPa (32 ksi); T6, T63, T6351 tempers: 214 MPa (31 ksi); see also Table 94.

Compressive strength. See Table 94.
Elastic modulus. Tension, 71 GPa (10.3 × 10⁶ psi); shear, 26.9 GPa (3.9 × 10⁶ psi); compression, 72.4 GPa (10.5 × 10⁶ psi)
Fatigue strength. Rotating beam at 10⁸ cycles. T6351 plate: smooth specimens, 115 to 130 MPa (17 to 19 ksi); 60° notched specimens, 20 to 50 MPa (3 to 7 ksi). T53 extrusions: smooth specimens, 130 to 150 MPa (19 to 22 ksi); 60° notched specimens, 24 to 40 MPa (3.5 to 6 ksi). Axial (R = 0) at 10⁸ cycles, smooth specimens. T6351 plate: 195 MPa (28 ksi). T53 extrusions: 231 MPa (33.5 ksi)
Plane-strain fracture toughness. Typical, T6351 temper. L-T orientation: 51.3 MPa√m (46.7 ksi√in.); data from 75 mm (3 in.) thick notch bend specimens. T-L orientation: 44 MPa√m (40 ksi√in.); data from

Table 96 Typical mechanical properties of 7039

Property	Property value(a) at temper:		
	T64	T61	O
Tensile strength, MPa (ksi)			
Longitudinal	450 (65)	400 (58)	227 (33)
Transverse	450 (65)	400 (58)	227 (33)
0.2% tensile yield strength, MPa (ksi)			
Longitudinal	380 (55)	330 (48)	103 (15)
Transverse	380 (55)	330 (48)	103 (15)
Elongation in 50 mm (2 in.), %			
Longitudinal	13	14	22
Transverse	13	14	22
0.2% compressive yield strength, MPa (ksi)			
Longitudinal	400 (58)	380 (55)	...
Transverse	415 (60)	407 (59)	...
Shear strength, MPa (ksi)			
Longitudinal	270 (39)	...	...
Transverse	255 (37)	235 (34)	...
Bearing strength(b), MPa (ksi)			
Longitudinal	910 (132)	...	...
Transverse	910 (132)	827 (120)	...
Brinell hardness (1500 kg), HB	133	123	61

(a) Property values for 6 to 75 mm (0.25 to 3.0 in.) thick plate. (b) e/d = 2, where e is the edge distance and d is the pin diameter

Table 97 Transverse impact toughness of 7039-T64 plate

Plate thickness mm	in.	Test temperature		Elongation in 50 mm (2 in.), %	Unnotched impact toughness		Notched impact toughness	
		°C	°F		J	ft · lbf	J	ft · lbf
45	1.75	24	75	12	66.2	48.8	7.6	5.6
		-195	-320	12	87.5	64.5	6.5	4.8
38	1.50	24	75	11	75.3	55.5	7.5	5.5
		-195	-320	11	96.7	71.3	8.3	6.1

75 mm (3 in.) thick notch bend specimens. S-L orientation: 30.3 MPa√m (27.6 ksi√in.); data from 25 to 32 mm (1 to 1¼ in.) thick compact tensile specimens

Mass Characteristics

Density. 2.78 g/cm³ (0.100 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 643 °C (1190 °F)

Solidus temperature. 604 °C (1120 °F)

Coefficient of thermal expansion. Linear:

Temperature range °C	°F	Average coefficient	
		μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.4	11.9
20 to 100	68 to 212	23.1	12.8
20 to 200	68 to 392	24.0	13.3
20 to 300	68 to 572	25.0	13.9

Volumetric: 67.0 × 10⁻⁶ m³/m³ · K (3.72 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 875 J/kg · K (0.209 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F); O temper, 166 W/m · K (96 Btu/ft · h · °F); T53, T5351, T63, T6351, T63, T6351 tempers, 148 W/m · K (86 Btu/ft · h · °F); T6 temper, 137 W/m · K (79 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 43% IACS; T53, T5351, T63, T6351 tempers, 38% IACS; T6 temper, 35% IACS

Electrical resistivity. At 20 °C (68 °F): O temper, 40.1 nΩ · m; T53, T5351, T63, T6351 tempers, 45.4 nΩ · m; T6 temper, 49.3 nΩ · m. Temperature coefficient, all tempers: 0.1 nΩ · m per K at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F)

Solution temperature. 400 °C (750 °F)

Heat treatment. T53: Press quench from hot working temperature, naturally age 72 h at room temperature, then two-stage artificially age 8 h at 100 to 110 °C (212 to 230 °F) plus 16 h at 145 to 155 °C (290 to 310 °F)

**7039
4Zn-2.8Mg-0.25Mn-0.20Cr**

Specifications

Military. MIL-A-22771, MIL-A-45225, MIL-A-46063

UNS number. A97039

Chemical Composition

Composition limits. 2.3 to 3.3 Mg, 3.5 to 4.5 Zn, 0.10 to 0.40 Mn, 0.15 to 0.25 Cr, 0.30 max Si, 0.10 max Cu, 0.40 max Fe, 0.10 max Ti, 0.50 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Cryogenic storage tanks, unfired pressure vessels, ordnance tanks, armor

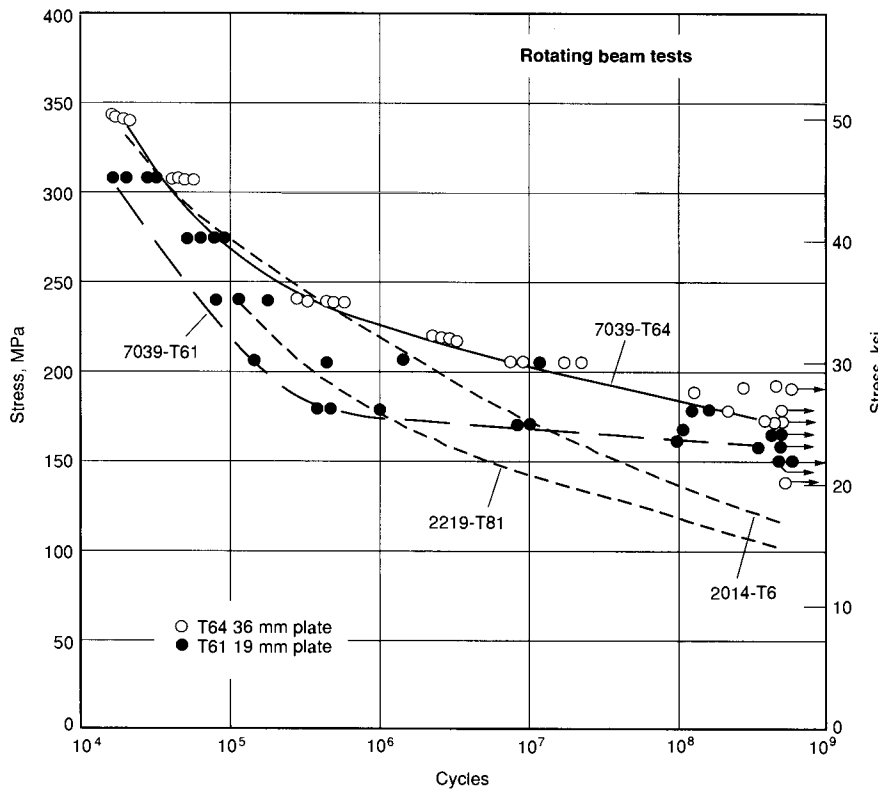


Fig. 14 Rotating beam fatigue data of 7039 plate compared with fatigue characteristics of 2014 and 2219. Data for 7039 are based on least-of-four results in the longitudinal direction with a 7.5 mm (0.3 in.) diam smooth specimen. Curves for 2014 and 2219 are mean values from published literature.

plate, missile structures, low-temperature processing equipment, and storage tanks.
Forms available. Plates, forgings, extrusions, and sometimes sheet

Mechanical Properties

Tensile properties. See Table 96.
Hardness. See Table 96.
Compressive yield strength. See Table 96.

Shear strength. See Table 96.
Elastic modulus. 69.6 GPa (10.1 × 10⁶ psi)
Fatigue strength. See Fig. 14.
Impact toughness. See Table 97.

Mass Characteristics

Density. 2.73 g/cm³ (0.0988 lb/in.³)

Thermal Properties

Liquidus temperature. 638 °C (1180 °F)
Solidus temperature. 482 °C (900 °F)
Coefficient of thermal expansion. From 20 to 100 °C (68 to 212 °F): 23.4 μm/m · °C (13 μin./in. · °F)
Thermal conductivity. 125 to 155 W/m · °C (0.30 to 0.37 cal/cm · s · °C)

Electrical Properties

Electrical conductivity. 32 to 40% IACS (volumetric)

Fabrication Characteristics

Solution treatment. Heat to 460 to 500 °C (860 to 930 °F), soak 2 h, quench in cold water. Sheet stock should be quenched from 490 to 500 °C (910 to 930 °F), while extruded stock should be quenched from 460 to 470 °C (860 to 880 °F).
Aging treatment. T6 temper: reheat to 120 °C (250 °F), hold at temperature for 20 to 24 h, air cool
Annealing treatment. O temper: heat to 415 to 455 °C (775 to 850 °F), soak for 2-3 h, air cool, reheat at 230 °C (450 °F), hold at temperature for 4 h, air cool. Or heat to 355 to 370 °C (670 to 700 °F), air cool
Stress-relief anneal. Heat to 355 to 370 °C (670 to 700 °F), soak for 2 h, air cool to room

Table 98 Mechanical properties of alloy 7049

Size and direction	Tensile strength(a)		Yield strength (0.2% offset)(a)		Elongation(a)(b), %	Compressive yield strength		Shear strength		Bearing strength(c)		Bearing yield strength(a)	
	MPa	ksi	MPa	ksi		MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
Die forgings (AMS 4111), T73 temper													
Parallel to grain flow													
Up to 2 in., incl	496	72	427	62	7	441	64	283	41	917	133	662	96
Over 2-4 in., incl	490	71	421	61	7	434	63	276	40	903	131	655	95
Over 4-5 in., incl	483	70	414	60	7	427	62	269	39	890	129	641	93
Across grain flow													
Up to 1 in., incl	490	71	421	61	3	434	63	283	41	917	133	662	96
Over 1-4 in., incl	483	70	414	60	3-2	427	62	276	40	903	131	655	95
Over 4-5 in., incl	469	68	400	58	2	414	60	269	39	890	129	641	93
Extrusions (AMS 4157), T73511 temper													
Up to 2.999 in., incl													
Longitudinal	510	74	441	64	7	448	65	276	40	758	110	...	...
Long transverse	483	70	414	60	5	420	61	276	40	993	144	...	...
Over 2.999-5,000 in., incl													
Longitudinal	496	72	427	62	7	435	63	269	39	738	107	...	...
Long transverse	469	68	400	58	5	407	59	269	39	965	140	...	...
Extrusions (AMS 4159), T75511 temper													
Up to 2.999 in., incl													
Longitudinal	538	78	483	70	7	490	71	290	42	...	...	586	85
Long transverse	524	76	469	68	5	475	69	290	42	...	...	724	105
Over 2.999-5,000 in., incl													
Longitudinal	524	76	469	68	7	475	69	283	41	...	...	572	83
Long transverse	510	74	455	66	5	462	67	283	41	...	...	696	101

(a) Single values are minimum values. (b) In 50 mm (2 in.) or 4d, where d is diameter of reduced section of tensile test specimen. Where a range appears in this column, the specified minimum elongation varies with thickness of mill product. (c) e/d = 2.0, where e is edge distance and d is pin diameter

Table 99 Minimum mechanical properties of alloy 7050-T736 (or -T74) die forgings

Property	Thickness, in.			
	Up to 2.000	2.001-4.000	4.001-5.000	5.001-6.000
Tensile strength, MPa (ksi)				
Longitudinal direction	496 (72)	490 (71)	483 (70)	483 (70)
Transverse direction	469 (68)	462 (67)	455 (66)	455 (66)
Yield strength, MPa (ksi)				
Longitudinal direction	427 (62)	421 (61)	414 (60)	405 (59)
Transverse direction	386 (56)	379 (55)	372 (54)	372 (54)
Compressive yield strength, MPa (ksi)				
Longitudinal direction	434 (63)	434 (63)	434 (63)	427 (62)
Transverse direction	400 (58)	393 (57)(a)	379 (55)	372 (54)
Shear strength	290 (42)	283 (41)	283 (41)	283 (41)
Bearing strength, MPa (ksi)				
$eld = 1.5$	683 (99)	676 (98)	669 (97)	669 (97)
$eld = 2.0$	903 (131)	889 (129)	876 (127)	876 (127)
Bearing yield strength, MPa (ksi)				
$eld = 1.5$	565 (82)	558 (81)	545 (79)	538 (78)
$eld = 2.0$	662 (96)	655 (95)	641 (93)	634 (92)
Elongation(b), %				
Longitudinal direction	7	7	7	7
Transverse direction	5	4	3	3

(a) For material 3.001 to 4.000 in. thick, 386 MPa (56 ksi). (b) In 50 mm (2 in.)

temperature

Weldability. Readily weldable by the direct-current inert-gas tungsten-arc (TIG) and by the metal-arc-inert-gas (MIG) process, using a weld-filler alloy of aluminum X5039 or 5183 rod. Has considerably better weld strength and ductility than 5083. Readily welded over a wide range of thicknesses with no decrease in weld ductility. Shows very good crack resistance in restrained plate weldments when joined with X5039 filler wire. Room temperature weld strength averages 360 MPa (52 ksi) and increases to 448 MPa (65 ksi) at -195°C (-320°F).

No special pre-weld or post-weld heat treatment is required.

Machinability. Good machinability in the annealed state. Soluble oil emulsions, kerosene, and kerosene-lard oil mixtures are recommended for most machining opera-

tions, but high viscosity lubricants are recommended for tapping operations.

Workability. Best formed in its freshly quenched condition. In the soft temper, the alloy can be successfully formed on all types of equipment. Because of its higher strength, a greater allowance for springback will have to be made than when working with other aluminum alloys. Use of heat up to 120°C (250°F) during forming in the annealed condition is beneficial in certain swaging, spinning, and drop hammer operations. In the solution treated condition the properties are intermediate between those of O and T6 temper, but definitely higher than O temper condition during the first few hours after quenching. Then formability gradually lessens as age-hardening increases. In the solution treated and aged T6 temper condition, the material exhibits very

poor forming qualities. Due to the elaborate annealing and stabilizing treatment required, severe forming in its annealed O temper condition would be impractical. Rubber forming or streaking is usually conducted at 120 to 230°C (250 to 450°F).

Corrosion Resistance

The general corrosion resistance characteristics of 7039-T64 are comparable to such highly resistant aluminum-magnesium alloys as 5052, 5086, and 5083. Resistance to general corrosion is very much superior to that of most heat-treatable alloys. Under standard 6% NaCl immersion test for 6 mo or 5% NaCl salt fog, the alloy evidenced a slight superficial staining and a mild and shallow pitting attack with no measurable loss in strength. In a sodium chloride-hydrogen peroxide test, no evidence of intergranular corrosion was observed.

7049

7.6Zn-2.5Mg-1.5Cu-0.15Cr

Specifications

AMS. Extrusions: 4157, 4159. Forgings: 4111 UNS number. A97049

Government. Forgings: QQ-A-367, MIL-H-6088

Chemical Composition

Composition limits. 1.2 to 1.9 Cu, 2.0 to 2.9 Mg, 0.20 Mn max, 0.25 Si max, 0.35 Fe max, 0.10 to 0.22 Cr, 7.2 to 8.2 Zn, 0.10 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Forged aircraft and missile fittings, landing gear cylinders, and extruded sections. Used where static strengths approximately the same as forged 7079-T6

Table 100 Minimum mechanical properties of alloy 7050-T73652 hand forgings

Property	Thickness, in.						
	Up to 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
Tensile strength, MPa (ksi)							
Longitudinal direction	496 (72)	496 (72)	490 (71)	483 (70)	476 (69)	469 (68)	462 (67)
L-T direction	490 (71)	483 (70)	483 (70)	476 (69)	469 (68)	462 (67)	455 (66)
S-T direction		462 (67)	462 (67)	455 (66)	455 (66)	448 (65)	441 (64)
Yield strength, MPa (ksi)							
Longitudinal direction	434 (63)	427 (62)	421 (61)	414 (60)	407 (59)	400 (58)	393 (57)
L-T direction	421 (61)	414 (60)	407 (69)	400 (58)	386 (56)	372 (54)	359 (52)
S-T direction		379 (55)	379 (55)	372 (54)	365 (53)	352 (51)	345 (50)
Compressive yield strength, MPa (ksi)							
Longitudinal direction	441 (64)	434 (63)	427 (62)	421 (61)	414 (60)	407 (59)	400 (58)
L-T direction	448 (65)	441 (64)	434 (63)	427 (62)	414 (60)	400 (58)	386 (56)
S-T direction		421 (61)	421 (61)	414 (60)	407 (59)	393 (57)	379 (55)
Shear strength, MPa (ksi)	290 (42)	283 (41)	283 (41)	283 (41)	276 (40)	269 (39)	269 (39)
Bearing strength, MPa (ksi)							
$eld = 1.5$	689 (100)	683 (99)	683 (99)	669 (97)	662 (96)	655 (95)	641 (93)
$eld = 2.0$	903 (131)	896 (130)	896 (130)	883 (128)	869 (126)	855 (124)	841 (122)
Bearing yield strength, MPa (ksi)							
$eld = 1.5$	593 (86)	586 (85)	572 (83)	565 (82)	545 (79)	524 (76)	503 (73)
$eld = 2.0$	696 (10)	689 (100)	676 (98)	662 (96)	641 (93)	621 (90)	593 (86)
Elongation, %							
Longitudinal direction	9	9	9	9	9	9	9
L-T direction	5	5	5	4	4	4	4
S-T direction		4	4	3	3	3	3

Table 101 Typical mechanical properties of alloy 7050

Temperature		Time at temp, h	At indicated temperature				At room temperature after heating					
°C	°F		Tensile strength MPa	Yield strength ksi	Tensile strength MPa	Yield strength ksi	Elongation(a), %	Tensile strength MPa	Yield strength ksi	Tensile strength MPa	Yield strength ksi	Elongation(a), %
T73651 plate												
24	75	...	510	74	455	66	11	510	74	455	66	11
100	212	0.1-10	441	64	427	62	13	510	74	455	66	11
		100	448	65	434	63	13	510	74	462	67	12
		1 000	441	64	427	62	14	510	74	455	66	12
		10 000	441	64	421	61	15	510	74	441	64	12
		10 000	393	57	386	56	16	510	74	455	66	11
149	300	0.1	393	57	386	56	16	510	74	441	64	12
		0.5	393	57	386	56	17	510	74	448	65	12
		10	393	57	386	56	18	503	74	441	64	12
		100	359	52	332	51	19	483	70	407	59	13
		1 000	290	42	276	40	21	407	59	317	46	13
177	350	0.1	221	32	193	28	29	331	48	228	33	14
		0.5	359	52	345	50	19	510	74	448	65	12
		10	352	51	345	50	20	496	72	441	64	12
		100	324	47	310	45	22	469	68	400	58	13
		1 000	248	36	234	34	25	386	56	296	43	13
204	400	0.1	193	28	172	25	31	317	46	214	31	14
		0.5	159	23	124	18	40	248	36	152	22	15
		10	303	44	290	42	22	490	71	434	63	12
		100	290	42	276	40	23	469	68	421	61	12
		1 000	221	32	207	30	27	386	56	283	41	13
		100	165	24	152	22	32	317	46	200	29	14
		1 000	131	19	110	16	45	262	38	138	20	16
		10 000	117	17	90	13	54	234	34	117	17	19
		10 000	117	17	90	13	54	234	34	117	17	19
		10 000	117	17	90	13	54	234	34	117	17	19
T73652 forgings												
-196	-320	...	662	96	572	83	13	...	...	...	...	...
-80	-112	...	586	85	503	73	14	...	...	...	...	...
-28	-18	...	552	80	476	69	15	...	...	...	...	...
24	75	...	524	76	455	66	15	524	76	455	66	15
100	212	0.1-10	462	67	427	62	16	524	76	462	67	15
		100	469	68	434	63	16	524	76	462	67	15
		1 000	462	67	427	62	17	524	76	524	76	16
		10 000	462	67	421	61	17	517	75	517	75	16
		10 000	414	60	386	56	17	517	75	455	66	15
149	300	0.1	414	60	386	56	17	517	75	448	65	15
		0.5	414	60	386	56	17	510	74	448	65	15
		10	407	59	386	56	18	503	73	441	64	16
		100	365	53	352	51	20	483	70	407	59	16
		1 000	290	42	276	40	23	407	59	317	46	17
177	350	0.1	221	32	193	28	29	331	48	228	33	17
		0.5	379	55	345	50	19	510	74	448	65	15
		10	365	53	345	50	20	496	72	441	64	15
		100	324	47	310	45	22	469	68	400	58	16
		1 000	248	36	234	34	25	386	56	296	43	17
204	400	0.1	193	28	172	25	31	317	46	214	31	17
		0.5	159	23	124	18	40	248	36	152	22	18
		10	324	47	290	42	22	503	73	434	63	15
		100	296	43	276	40	23	483	70	421	61	15
		1 000	221	32	207	30	27	386	56	283	41	16
		100	165	24	152	22	32	317	46	200	29	17
		1 000	131	19	110	16	45	262	38	138	20	19
		10 000	117	17	90	13	54	234	34	117	17	22
		10 000	117	17	90	13	54	234	34	117	17	22
		10 000	117	17	90	13	54	234	34	117	17	22

(a) In 50 mm (2 in.)

and high resistance to stress-corrosion cracking are required. Fatigue characteristics about equal to those of 7075-T6 products, toughness somewhat higher

Precautions in use. Poor general corrosion resistance

Mechanical Properties

Tensile property limits. See Table 98.

Shear strength. See Table 98.

Compressive strength. See Table 98.

Bearing strength. See Table 98.

Hardness. 135 HB min with 500 kg load, 10 mm diam ball

Poisson's ratio. 0.33

Elastic modulus. Forgings, typical: tension, 70 GPa (10.2×10^6 psi). Extrusions,

typical: tension, 72.5 GPa (10.5 ksi); shear, 27.6 GPa (4.0 ksi); compression, 76 GPa (11 ksi)

Fatigue strength. Axial fatigue at stress ratio R of 1.0 for material in the T73 temper. Smooth specimens from 125 mm (5 in.) thick forgings: 275 to 315 MPa (40 to 46 ksi) at 10^7 cycles for temperatures from room temperature to 175 °C (350 °F). Notched specimens from 75 mm (3 in.) thick forgings: 390 MPa (56 ksi) for K_t of 1.0; 115 MPa (17 ksi) for K_t of 3.0; both at 10^7 cycles

Plane-strain fracture toughness. K_{Ic} values from compact tension tests of 7049-T73 die forgings: L-S orientation, 32 to 36 MPa \sqrt{m} (29 to 33 ksi $\sqrt{in.}$); L-T orientation, 31 to 40 MPa \sqrt{m} (28 to 37 ksi $\sqrt{in.}$);

S-L orientation, 21 to 27 MPa \sqrt{m} (19 to 25 ksi $\sqrt{in.}$)

Mass Characteristics

Density. 2.82 g/cm³ (0.102 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 627 °C (1160 °F)

Solidus temperature. 477 °C (890 °F)

Coefficient of thermal expansion. Linear, 23.4 $\mu\text{m}/\text{m} \cdot \text{K}$ (13.0 $\mu\text{in.}/\text{in.} \cdot \text{°F}$) at 20 to 100 °C (68 to 212 °F)

Specific heat. 960 J/kg \cdot K (0.23 Btu/lb \cdot °F) at 100 °C (212 °F)

Thermal conductivity. 154 W/m \cdot K (89 Btu/ft \cdot h \cdot °F) at 25 °C (77 °F)

Table 102 Typical axial fatigue strength at 10⁷ cycles for alloy 7050

Product and temper	Stress ratio, R	Fatigue strength (max stress)			
		Smooth specimens		Notched specimens(a)	
		MPa	ksi	MPa	ksi
Plate, 25–150 mm (1 to 6 in.) thick					
T6 type tempers.....	0.0	190–290	28–42	...	...
T73xxx tempers.....	0.0	170–300	24–44	50–90	7.5–13
Extrusions, 29.5 mm (1.16 in.) thick					
T76511 temper.....	0.5	320–340	46–50	110–125	16–18
	0.0	180–210	26–30	70–80	10–12
	-1.0	130–150	19–22	35–50	5–7
Die forgings, 25–150 mm (1 to 6 in.) thick					
T736 temper.....	0.0	210–275	30–40	75–115	11–17
Hand forgings, 144 × 559 × 2130 mm (4½ × 22 × 84 in.)					
T73652 temper					
Longitudinal.....	0.5	325	47	145	21
	0.0	225	33	90	13
	-1.0	145	21	50	7
Long transverse.....	0.5	275	40	115	17
	0.0	170	25	90	13
	-1.0	125	18	50	7
Short transverse.....	0.5	260	38	115	17
	0.0	170	25	60	9
	-1.0	115	17	50	7

(a) Notch fatigue factor, K_t, of 3.0

Electrical Properties

Electrical conductivity. Volumetric, 40% IACS min at 20 °C (68 °F)
Electrical resistivity. 43 nΩ · m

**7050
6.2Zn-2.3Mg-2.3Cu-0.12Zr**

Specifications

AMS. 4050, 4107, 4108

UNS number. A97050

Chemical Composition

Composition limits. 2.0 to 2.6 Cu, 1.9 to 2.6 Mg, 0.10 Mn max, 0.12 Si max, 0.15 Fe max, 0.04 Cr max, 0.08 to 0.15 Zr, 5.7 to 6.7 Zn, 0.06 Ti max, 0.05 max other (each), 0.15 max others (total)

Consequence of exceeding impurity limits. Excess Fe and Si degrade fracture toughness.

Table 104 Creep and rupture properties of alloy 7050-T3651 plate

Temperature °C	Temperature °F	Time under stress h	Rupture stress		Stress for creep of:							
			MPa	ksi	1.0%		0.5%		0.2%		0.1%	
			MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
24	75	0.1	510	74	496	72	476	69	455	66	448	65
		1	503	73	483	70	462	67	448	65	441	64
		10	490	71	469	68	455	66	441	64	441	64
		100	476	69	455	66	448	65	441	64	434	63
100	212	0.1	469	68	448	65	441	64	...	...	...	...
		1	441	64	434	63	427	62	421	61	414	60
		10	427	62	414	60	407	59	400	58	386	56
		100	407	59	393	57	386	56	372	54	359	52
149	300	0.1	379	55	372	54	365	53	345	50	331	48
		1	359	52	352	51	345	50	317	46	...	...
		10	372	54	365	53	359	52	345	50	324	47
		100	345	50	338	49	324	47	303	44	290	42
		1000	310	45	303	44	290	42	269	39	228	33
		100	262	38	255	37	241	35	193	28	152	22
		1000	179	26	179	26	165	24	145	21	124	18

Table 105 Mechanical-property limits for alloy 7072 fin stock

Temper	Tensile strength				Yield strength (min)		Elongation (min), % (a)
	Minimum MPa	ksi	Maximum MPa	ksi	MPa	ksi	
O.....	55	8.0	90	13.0	21	3	15–20
H14.....	97	14.0	131	19.0	83	12	1–3
H18.....	131	19.0	...	...	...	...	1–2
H19.....	145	21.0	...	...	...	...	1
H25.....	107	15.5	148	21.5	83	12	2–3
H111, H211.....	62	9.0	97	14.0	41	6.0	12

(a) In 50 mm (2 in.). Where a range of values appears in this column, specified minimum elongation varies with thickness of the mill product.

Table 103 Plane-strain fracture toughness of alloy 7050

Temper and orientation	Minimum		Average	
	MPa√m	ksi√in.	MPa√m	ksi√in.
Plate				
T73651				
L-T.....	26.4	24	35.2	32
T-L.....	24.2	22	29.7	27
S-L.....	22.0	20	28.6	26
Extrusions				
T7651X				
L-T.....	...	...	30.8	28
T-L.....	...	...	26.4	24
S-L.....	...	...	20.9	19
T7351X				
L-T.....	...	...	45.1	41
T-L.....	...	...	31.9	29
S-L.....	...	...	26.4	24
Die forgings				
T736				
L-T.....	27.5	25	36.3	33
T-L, S-L.....	20.9	19	25.3	23
Hand forgings				
T73652				
L-T.....	29.7	27	36.3	33
T-L.....	18.7	17	23.1	21
S-L.....	17.6	16	22.0	20

ness. Increased sensitivity to quenching rate due to excess Mn and Cr results in low strength in thick sections.

Applications

Typical uses. Plate, extrusions, hand and die forgings in aircraft structural parts. Other applications requiring very high strength coupled with high resistance to exfoliation corrosion and stress-corrosion cracking, high fracture toughness and fatigue resistance

Mechanical Properties

Tensile properties. See Tables 99 to 101.
Shear properties. See Tables 99 and 100.
Compressive properties. See Tables 99 and 100.
Bearing properties. See Tables 99 and 100.
Poisson's ratio. 0.33
Elastic modulus. Tension, 70.3 GPa (10.2 × 10⁶ psi); shear, 26.9 GPa (3.9 × 10⁶ psi); compression, 73.8 GPa (10.7 × 10⁶ psi)
Fatigue strength. See Table 102.
Plane-strain fracture toughness. See Table 103.
Creep-rupture characteristics. See Table 104.

Mass Characteristics

Density. 2.83 g/cm³ (0.102 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 635 °C (1175 °F)
Solidus temperature. 465 °C (870 °F)
Incipient melting temperature. 488 °C (910 °F) for homogenized (solution treated) wrought material
Eutectic temperature. 465 °C (870 °F) for

Table 106 Standard specifications for alloy 7075

Mill form and condition	AMS	ASTM	Government
Bare products			
Sheet and plate.....	4038	B 209	QQ-A-250/2
	4044	...	...
	4045	...	...
	4078	...	...
Wire, rod, and bar (rolled or cold finished).....	4122	B 211	QQ-A-225/9
	4123	...	...
	4124	...	...
Rod, bar, shapes, and tube (extruded).....	4154	B 221	QQ-A-200/11
	4167	...	...
	4168	...	...
	4169	...	...
Tube (extruded, seamless).....	...	B 241	...
Tube (drawn, seamless).....	...	B 210	...
Forgings and forging stock.....	4139	B 247	QQ-A-367
	...	...	MIL-A-22771
	...	...	MIL-A-12545
Impacts.....	4170	...	...
Rivets.....	...	B 316	QQ-A-430
Alclad products			
Sheet and plate.....	4039	B 209	QQ-A-250/13
	4048	...	...
	4049	...	...
Tapered sheet and plate.....	4047	...	...
Alclad one side products			
Sheet and plate.....	4046	B 209	QQ-A-250/18

Table 107 Typical tensile properties for alloy 7075 at various temperatures

Temperature		Tensile strength(a)		Yield strength (0.2% offset)(a)		Elongation(b),
°C	°F	MPa	ksi	MPa	ksi	%
T6, T651 tempers						
-196	-320	703	102	634	92	9
-80	-112	621	90	545	79	11
-28	-18	593	86	517	75	11
24	75	572	83	503	73	11
100	212	483	70	448	65	14
149	300	214	31	186	27	30
204	400	110	16	87	13	55
260	500	76	11	62	9	65
316	600	55	8	45	6.5	70
271	700	41	6	32	4.6	70
T73, T7351 tempers						
-196	-320	634	92	496	72	14
-80	-112	545	79	462	67	14
-28	-18	524	76	448	65	13
24	75	503	73	434	63	13
100	212	434	63	400	58	15
149	300	214	31	186	27	30
204	400	110	16	90	13	55
260	500	76	11	62	9	65
316	600	55	8	45	6.5	70
371	700	41	6	32	4.6	70

(a) Lowest strength for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 3%/min to fracture. (b) In 50 mm (2 in.)

unhomogenized wrought or as-cast material
Coefficient of thermal expansion. Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.7	12.1
20 to 100	68 to 212	23.5	13.1
20 to 200	68 to 392	24.4	13.6
20 to 300	68 to 572	25.4	14.1

Volumetric: 68.0 × 10⁻⁶ m³/m³ · K (3.78 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)
Specific heat. 860 J/kg · K (0.206 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F): O temper, 180 W/m · K (104 Btu/ft · h · °F); T76, T7651 tempers, 154 W/m · K (89 Btu/ft · h · °F); T736, T73651 tempers, 157 W/m · K (91 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 47% IACS; T76, T7651 tempers, 39.5% IACS; T736, T73651 tempers, 40.5% IACS
Electrical resistivity. At 20 °C (68 °F): O temper, 36.7 nΩ · m; T76, T7651 tempers, 43.6 nΩ · m; T736, T73651 tempers, 42.6 nΩ

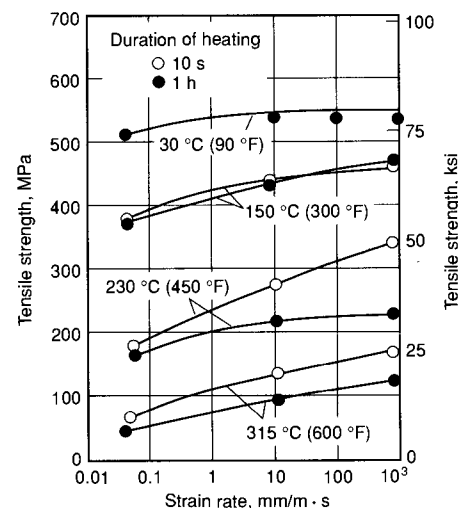


Fig. 15 Effect of strain rate and temperature on tensile strength of alloy 7075-T6

· m. Temperature coefficient, all tempers: 0.1 nΩ · m per K at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 415 °C (775 °F)
Solution temperature. 475 °C (890 °F)
Aging temperature. 120 to 175 °C (250 to 350 °F)

7072

1.0Zn

Specifications

ASTM. B 209
SAE. J454
UNS number. A97072

Chemical Composition

Composition limits. 0.10 Cu max, 0.10 Mg max, 0.10 Mn max, 0.7 Si max + Fe, 0.8 to 1.3 Zn, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Fin stock. Cladding alloy for Alclad sheet, plate, and tube products with the following core alloys: 2219, 3003, 3004, 5050, 5052, 5154, 6061, 7075, 7475, 7178

Mechanical Properties

Tensile properties. See Table 105.
Shear strength. O temper, 55 MPa (8 ksi); H12 temper, 62 MPa (9 ksi); H14 temper, 69 MPa (10 ksi)
Hardness. O temper, 20 HB; H12 temper, 28 HB; H14 temper, 32 HB; all values obtained with 500 kg load, 10 mm diam ball, and 30 s duration of loading
Poisson's ratio. 0.33
Elastic modulus. Tension, 68 GPa (9.9 × 10⁶ psi); compression, 70 GPa (10.1 × 10⁶ psi)

Mass Characteristics

Density. 2.72 g/cm³ (0.098 lb/in.³) at 20 °C (68 °F)

Table 108 Tensile properties of alloy 7075

Temper	Tensile strength		Yield strength		Elongation(a), %
	MPa	ksi	MPa	ksi	
Typical properties					
O	228	33	103	15	17
T6, T651	572	83	503	73	11
T73	503	73	434	63	...
Alclad O	221	32	97	14	17
T6, T651	524	76	462	67	11
Property Limits					
	Minimum		Minimum		Minimum
Sheet and plate					
O	276 (max)	40 (max)	145 (max)	21 (max)	10
Sheet					
T6, T62					
0.008-0.011 in. thick	510	74	434	63	5
0.012-0.039 in. thick	524	76	462	67	7
0.040-0.125 in. thick	538	78	469	68	8
0.126-0.249 in. thick	538	78	476	69	8
T73	462	67	386	56	8
T76	503	73	427	62	8
Plate					
T62, T651					
0.250-0.499 in. thick	538	78	462	67	9
0.500-1.000 in. thick	538	78	469	68	7
1.001-2.000 in. thick	531	77	462	67	6
2.001-2.500 in. thick	524	76	441	64	5
2.501-3.000 in. thick	496	72	421	61	5
3.001-3.500 in. thick	490	71	400	58	5
3.501-4.000 in. thick	462	67	372	54	3
T7351					
0.250-2.000 in. thick	476	69	393	57	6-7
2.001-2.500 in. thick	455	66	359	52	6
2.501-3.000 in. thick	441	64	338	49	6
T7651					
0.250-0.499 in. thick	496	72	421	61	8
0.500-1.000 in. thick	490	71	414	60	6
Alclad sheet and plate					
O					
0.008-0.062 in. thick	248 (max)	36 (max)	138 (max)	20 (max)	9-10
0.063-0.187 in. thick	262 (max)	38 (max)	138 (max)	20 (max)	10
0.188-0.499 in. thick	269 (max)	39 (max)	145 (max)	21 (max)	10
0.500-1.000 in. thick	276 (max)	40 (max)	...	...	10
Alclad sheet					
T6, T62					
0.008-0.011 in. thick	469	68	400	58	5
0.012-0.039 in. thick	483	70	414	60	7
0.040-0.062 in. thick	496	72	427	62	8
0.063-0.187 in. thick	503	73	434	63	8
0.188-0.249 in. thick	517	75	441	64	8
T73					
0.040-0.062 in. thick	434	63	352	51	8
0.063-0.187 in. thick	441	64	359	52	8
0.188-0.249 in. thick	455	66	372	54	8
T76					
0.125-0.187 in. thick	469	68	393	57	8
0.188-0.249 in. thick	483	70	407	59	8
Alclad plate					
T62, T651					
0.250-0.499 in. thick	517	75	448	65	9
0.500-1.000 in. thick	538(b)	78(b)	469(b)	68(b)	7
1.001-2.000 in. thick	531(b)	77(b)	462(b)	67(b)	6
2.001-2.500 in. thick	524(b)	76(b)	441(b)	64(b)	5
2.501-3.000 in. thick	496(b)	72(b)	421(b)	61(b)	5
3.001-3.500 in. thick	490(b)	71(b)	400(b)	58(b)	5
3.501-4.000 in. thick	462(b)	67(b)	372(b)	54(b)	3
T7351					
0.250-0.499 in. thick	455	66	372	54	8
0.500-1.000 in. thick	476	69	393	57	7
T7651					
0.250-0.499 in. thick	476	69	400	58	8
0.500-1.000 in. thick	490(b)	71(b)	414(b)	60(b)	6

(a) In 50 mm (2 in.) or 4*d*, where *d* is diameter of reduced section of tensile test specimen. Where a range appears in this column, the specified minimum elongation varies with thickness of the mill product. (b) For plate 13 mm (0.500 in.) or over in thickness, listed properties apply to core material only. Tensile and yield strengths of composite plate are slightly lower than listed value, depending on thickness of cladding.

Thermal Properties

Liquidus temperature. 657 °C (1215 °F)
 Solidus temperature. 641 °C (1185 °F)
 Coefficient of thermal expansion. Linear:

Temperature range		Average coefficient	
°C	°F	µm/m · K	µin./in. · °F
-50 to 20	-58 to 68	21.8	12.1
20 to 100	68 to 212	23.6	13.1
20 to 200	68 to 392	24.5	13.6
20 to 300	68 to 572	25.5	14.2

Volumetric: 68 × 10⁻³ m³/m³ · K (3.78 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)
 Specific heat. 893 J/kg · K (0.213 Btu/lb · °F) at 20 °C (68 °F)
 Thermal conductivity. O temper: 227 W/m · K (131 Btu/ft · h · °F) at 20 °C (68 °F)

Electrical Properties

Electrical conductivity. Volumetric, O temper: 60% IACS at 20 °C (68 °F)
 Electrical resistivity. 28.7 nΩ · m at 20 °C (68 °F); temperature coefficient, 0.1 nΩ · m per K at 20 °C (68 °F)
 Electrolytic solution potential. -0.96 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter at 25 °C (77 °F)

Chemical Properties

General corrosion behavior. High resistance to general corrosion. Provides galvanic protection when used as cladding on several different alloys

Fabrication Characteristics

Annealing temperature. 345 °C (650 °F)

**7075, Alclad 7075
5.6Zn-2.5Mg-1.6Cu-0.23Cr**

Specifications

AMS. See Table 106.
 ASTM. See Table 106.
 SAE. J454
 UNS number. A97075
 Government. See Table 106.
 Foreign. Austria: Önorm AlZnMg-Cu1.5.
 Canada: CSA ZG62, ZG62Alclad. France: NF A-Z5GU. Spain: UNE L-371. Switzerland: VSM Al-Zn-Mg-Cu; Alclad, Al-Zn-Mg-Cu-pl. United Kingdom: BS L.95, L.96. Germany: DIN AlZnMgCu1.5; Werkstoff-Nr. 3.4365. ISO: AlZn6MgCu

Chemical Composition

Composition limits of 7075. 1.20 to 2.0 Cu, 2.1 to 2.9 Mg, 0.30 Mn max, 0.40 Si max, 0.50 Fe max, 0.18 to 0.28 Cr, 5.1 to 6.1 Zn, 0.20 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al
 Composition limits of Alclad 7075. 7072 cladding—0.10 Cu max, 0.10 Mg max, 0.10 Mn max, 0.7 Si max + Fe, 0.8 to 1.3 Zn, 0.05 max other (each), 0.15 max others (total), bal Al

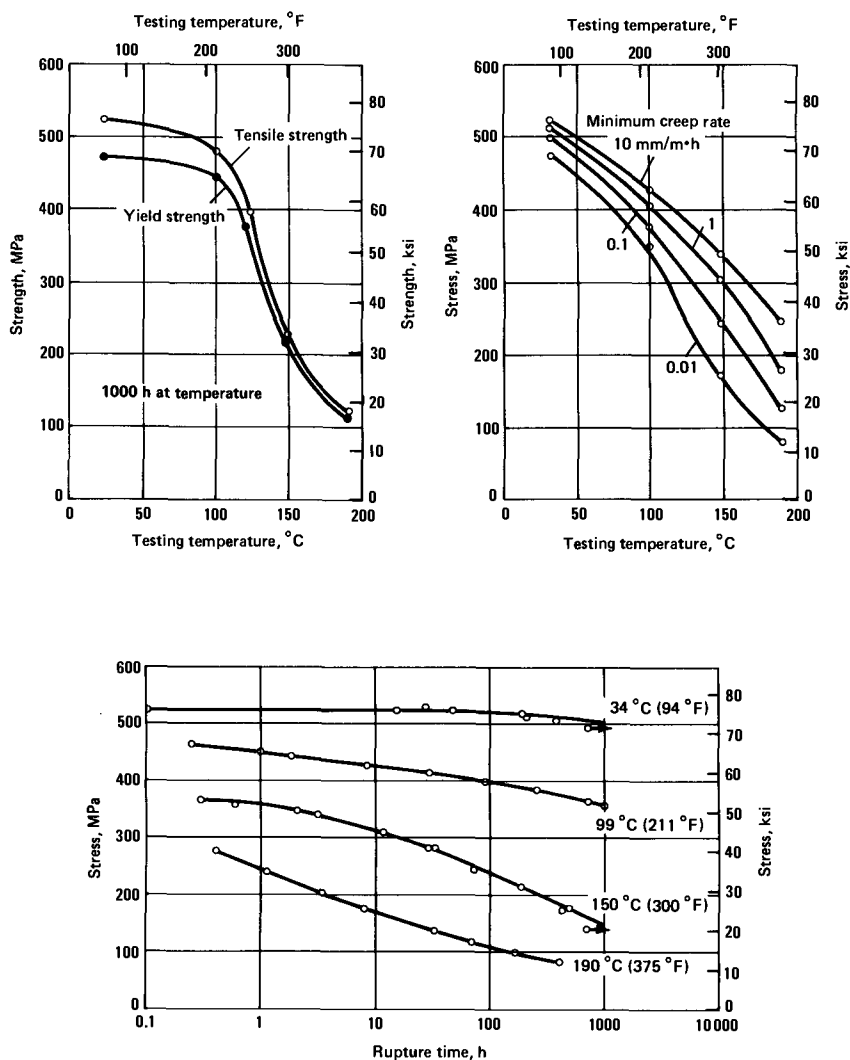


Fig. 16 Effect of temperature on tensile properties of Alclad 7075-T6

Applications

Typical uses. Aircraft structural parts and other highly stressed structural applications where very high strength and good resistance to corrosion are required

Precautions in use. Caution should be exercised in T6 temper applications where sustained tensile stresses are encountered, either residual or applied, particularly in the transverse grain direction. In such instances, the T73 temper should be considered, at some sacrifice in tensile strength.

Mechanical Properties

Tensile properties. See Tables 107 and 108.

Shear strength. Bare and Alclad products, O temper: 152 MPa (22 ksi). Bare products—T6, T651 tempers: 331 MPa (48 ksi); Alclad T6, T651: 317 MPa (46 ksi)

Hardness. O temper, 60 HB; T6, T651 temper, 150 HB; data obtained using 500 kg load, 10 mm diam ball, and 30 s duration of loading

Poisson's ratio. 0.33

Elevated-temperature effects. See Fig. 15 and 16.

Elastic modulus. Tension, 71.0 GPa (10.3×10^6 psi); shear, 26.9 GPa (3.9×10^6 psi); compression, 72.4 GPa (10.5×10^6 psi)

Fatigue strength. T6, T651, T73 tempers: 159 MPa (23 ksi) at 5×10^8 cycles in R.R. Moore type test of smooth (unnotched) specimens

Plane-strain fracture toughness. See Table 109.

Directional properties. Transverse mechanical properties of many products, particularly tensile strength and ductility in the short transverse direction, are less than those in the longitudinal direction.

Mass Characteristics

Density. 2.80 g/cm³ (0.101 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 635 °C (1175 °F)

Solidus temperature. 477 °C (890 °F); eutectic temperature for nonhomogeneous as-cast or wrought material that has not been solution heat treated

Incipient melting temperature. 532 °C (990 °F) for homogenized (solution heat treated) wrought material

Coefficient of thermal expansion. Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68.....	21.6	12.0
20 to 100	68 to 212.....	23.4	13.0
20 to 200	68 to 392.....	24.3	13.5
20 to 300	68 to 572.....	25.2	14.0

Volumetric: 68×10^{-6} m³/m³ · K (3.78×10^{-5} in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 960 J/kg · K (0.23 Btu/lb · °F) at 100 °C (212 °F)

Thermal conductivity. At 20 °C (68 °F). T6, T62, T651, T652 tempers: 130 W/m · K (75 Btu/ft · h · °F). T76, T7651 tempers: 150 W/m · K (87 Btu/ft · h · °F). T73, T7351, T7352 tempers: 155 W/m · K (90 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F). T6, T62, T651, T652 tempers: 33% IACS. T76, T7651 tempers: 38.5% IACS. T73, T7351, T7352 tempers: 40% IACS

Electrical resistivity. At 20 °C (68 °F). T6, T62, T651, T652 tempers: 52.2 nΩ · m. T76, T7651 tempers: 44.8 nΩ · m. T73, T7351, T7352 tempers: 43.1 nΩ · m. Temperature coefficient, all tempers: 0.1 nΩ · m per K at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 415 °C (775 °F)

Solution temperature. 465 to 480 °C (870 to 900 °F), depending on product

Aging temperature. T6 temper: 120 °C (250 °F); T7 temper: two-stage treatment—107 °C (225 °F) followed by 163 to 177 °C (325 to 350 °F), depending on product

7076

7.5Zn-1.6Mg-0.55Mn-0.65Cu

Specifications

AMS. 4137

ASTM. B 247

Government. QQ-A-367, MIL-A-8097

Chemical Composition

Composition limits. 7.0 to 8.0 Zn, 1.2 to 2.0 Mg, 0.30 to 0.80 Mn, 0.3 to 1.0 Cu, 0.40 Si max, 0.60 Fe max, 0.20 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Aircraft propellers

Available forms. Forgings

Table 109 Typical plane-strain fracture toughness of alloy 7075

Product and temper	Minimum		Average		Maximum	
	MPa√m	ksi√in.	MPa√m	ksi√in.	MPa√m	ksi√in.
L-T orientation						
Plate						
T651	27.5	25	28.6	26	29.7	27
T7351	...	...	33.0	30	...	...
Extruded shapes						
T6510,1	28.6	26	30.8	28	35.2	32
T7310,1	34.1	31	36.3	33	37.4	34
Forgings						
T652	26.4	24	28.6	26	30.8	28
T7352	29.7	27	34.1	31	38.5	35
T-L orientation						
Plate						
T651	22.0	20	24.2	22	25.3	23
T7351	27.5	25	31.9	29	36.3	33
Extruded shapes						
T6510,1	20.9	19	24.2	22	28.6	26
T7310,1	24.2	22	26.4	24	30.8	28
Forgings						
T652	...	...	25.3	23	...	...
T7352	25.3	23	27.5	25	28.6	26
S-L orientation						
Plate						
T651	16.5	15	17.6	16	19.8	18
T7351	20.9	19	22.0	20	23.1	21
Extruded shapes						
T6510,1	19.8	18	20.9	19	24.2	22
T7310,1	...	...	22.0	20	...	...
Forgings						
T651	...	...	18.7	17	...	...
T7351	20.9	19	23.1	21	27.5	25

Mechanical Properties

Tensile properties. T61 temper: tensile strength of 485 MPa (70 ksi), yield strength (0.2% offset) of 415 MPa (60 ksi), and elongation of 14% in 50 mm (2 in.)

Hardness. T61 temper: 140 HB (500 kg load).

Modulus of elasticity. 67 GPa (9.7 × 10⁶ psi)

Physical Properties

Density. 2.82 g/cm³ (0.102 lb/in.³)

Coefficient of thermal expansion. 21.6 μm/m · °C (12 μin./in. · °F) from 21 to 100 °C (70 to 212 °F)

Electrical conductivity. 35% IACS (volumetric)

Fabrication Characteristics

Solution anneal. T4 temper: heat to 493 °C (920 °F), quench in water.

Precipitation treatment. T6 temper: after solution anneal, heat at 120 °C (250 °F) for 24 h, air cool

Annealing treatment. O temper; heat to 415 to 455 °C (775 to 850 °F), soak for 2 h, air cool, reheat at 232 °C (450 °F), hold at temperature for 4 h, air cool. Or heat to 355 to 370 °C (670 to 700 °F), soak for 2 h, air cool to 232 °C (450 °F), soak 4 h at 232 °C (450 °F), air cool

Table 110 Typical mechanical properties of alloy 7175-T736 die forgings up to 75 mm (3 in.) thick

Temperature		Time at temperature, h	At indicated temperature			At room temperature after heating				
°C	°F		Tensile strength MPa	Tensile strength ksi	Yield strength MPa	Yield strength ksi	Elongation(a), %	Tensile strength MPa	Yield strength MPa	Elongation(a), %
-253	-423	...	876	127	745	108	12	...	...	...
-196	-320	...	731	106	676	98	13	...	...	...
-80	-112	...	621	90	572	83	14	...	...	...
-28	-18	...	600	87	552	80	16	...	...	...
24	75	...	552	80	503	73	14	552	80	503
100	212	0.1	490	71	476	69	14	552	80	503
		0.5	490	71	462	67	15	552	80	503
		10	496	72	476	69	16	552	80	510
		100	503	73	483	70	16	558	81	510
		1 000	503	73	483	70	17	565	82	517
		10 000	496	72	476	69	17	558	81	503
149	300	0.1	427	62	414	60	20	552	80	503
		0.5	427	62	414	60	18	552	80	503
		10	427	62	414	60	20	552	80	496
		100	393	57	372	54	25	524	76	462
		1 000	310	45	296	43	30	441	64	359
		10 000	241	35	214	31	30	352	51	248
176	350	0.1	365	53	345	50	20	538	78	490
		0.5	379	55	345	50	25	538	78	483
		10	338	49	324	47	25	496	72	427
		100	262	38	241	35	25	421	61	331
		1 000	200	29	179	26	35	331	48	228
		10 000	165	24	131	19	55	262	38	152
204	400	0.1	324	47	303	44	20	524	76	469
		0.5	310	45	283	41	30	503	73	427
		10	228	33	214	31	35	393	57	296
		100	165	24	221	32	35	317	46	207
		1 000	124	18	103	15	45	255	37	138
		10 000	124	18	90	13	65	234	34	110
232	450	0.1	262	38	241	35	20	510	74	441
		0.5	228	33	214	31	25	448	65	359
		10	159	23	145	21	35	338	49	228
		100	117	17	103	15	40	269	39	145
		1 000	97	14	83	12	45	234	34	103
		10 000	90	13	76	11	50	221	32	97

(a) In 50 mm (2 in.)

Table 111 Plane-strain fracture toughness of alloy 7175-T736 forgings

Temper and orientation	Plane-strain fracture toughness			
	Minimum		Average	
	MPa√m	ksi√in.	MPa√m	ksi√in.
Die forgings				
T736				
L-T.....	29.7	27	33.0	30
T-L, S-L.....	23.1	21	28.6	26
Hand forgings				
T736				
L-T.....	33.0	30	37.4	34
T-L.....	27.5	25	29.7	27
S-L.....	23.1	21	26.4	24

Stress-relief anneal. Heat to 355 to 370 °C (670 to 700 °F), soak for 2 h, air cool to room temperature

**7175
5.6Zn-2.5Mg-1.6Cu-0.23Cr**

Commercial Names

Trade name. AA7175

Specifications

AMS. 4109, 4148, 4149, 4179

UNS number. A97175

Chemical Composition

Composition limits. 1.2 to 2.0 Cu, 2.1 to 2.9 Mg, 0.10 Mn max, 0.15 Si max, 0.20 Fe max, 0.18 to 0.28 Cr, 5.1 to 6.1 Zn, 0.10 Ti max, 0.05 max other (each), 0.15 max others (total)

Consequence of exceeding impurity limits. Degraded fracture toughness

Applications

Typical uses. Die and hand forgings for

structural parts requiring very high strength, such as aircraft components. T736 tempers supply high strength, resistance to exfoliation corrosion and stress-corrosion cracking, high fracture toughness, and good fatigue resistance.

Mechanical Properties

Tensile properties. Typical. Tensile strength: T66 temper, 593 MPa (86 ksi); T736 temper, 524 MPa (76 ksi). Yield strength: T66 temper, 524 MPa (76 ksi); T736 temper, 455 MPa (66 ksi). Elongation: 11% in 50 mm (2 in.). See also Table 110.

Shear strength. Typical. T66 temper: 324 MPa (47 ksi); T736 temper: 290 MPa (42 ksi)

Hardness. Typical. T66 temper, 150 HB; T736 temper, 145 HB; data obtained with 500 kg load, 10 mm diam ball, and 30 s duration of loading

Poisson's ratio. 0.33

Elastic modulus. Tension, 72 GPa (10.4 × 10⁶ psi)

Fatigue strength. Typical. T66 and T736 tempers: 159 MPa (23 ksi)

Table 112 Standard specifications for alloy 7178

Mill form and condition	Specification number	
	ASTM	Government
Sheet and plate	B 209	QQ-A-250/14
	...	QQ-A-250/21
Wire, rod, bar, shapes, and tube (extruded).....	B 221	QQ-A-200/13
	...	QQ-A-200/14
Rivet wire	B 316	...
Tube (extruded, seamless) ..	B 241	...
Alclad sheet and plate	B 209	QQ-A-250/15
	...	QQ-A-250/22
	...	QQ-A-250/28

Plane-strain fracture toughness. See Table 111.

Mass Characteristics

Density. 2.80 g/cm³ (0.101 lb/in.³)

Thermal Properties

Liquidus temperature. 635 °C (1175 °F)

Incipient melting temperature. 532 °C (990 °F) for homogenized (solution heat treated) wrought material

Eutectic temperature. 477 °C (890 °F) for nonhomogeneous as cast or wrought material that has not been solution heat treated

Coefficient of thermal expansion. Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68.....	21.6	12.0
20 to 100	68 to 212.....	23.4	13.0
20 to 200	68 to 392.....	24.3	13.5
20 to 300	68 to 572.....	25.2	14.0

Volumetric: 68 × 10⁻⁶ m³/m³ · K (3.78 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 864 J/kg · K (0.206 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F): O temper, 177 W/m · K (102 Btu/ft · h · °F); T66 temper, 142 W/m · K (82 Btu/ft · h · °F) T736, T73652 tempers, 155 W/m · K (90 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 46% IACS; T66 temper, 36% IACS; T736, T73652 tempers, 40% IACS

Electrical resistivity. At 20 °C (68 °F): O temper, 37.5 nΩ · m; T66 temper, 47.9 nΩ · m; T736, T73652 tempers, 43.1 nΩ · m. Temperature coefficient, all tempers: 0.1 nΩ · m per K at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 415 °C (775 °F)

Solution temperature. 515 °C (960 °F); must be preceded by soak at 477 to 485 °C (890 to 905 °F). Quench from lower temperature.

Aging temperature. 120 to 175 °C (250 to 350 °F)

Table 113 Typical tensile properties of alloy 7178

Temperature		Tensile strength(a)		Yield strength (0.2% offset)(a)		Elongation(b), %
°C	°F	MPa	ksi	MPa	ksi	
T6, T651 tempers						
-196	-320	730	106	650	94	5
-80	-112	650	94	580	84	8
-28	-18	625	91	560	81	9
24	75	605	88	540	78	11
100	212	505	73	470	68	14
149	300	215	31	185	27	40
204	400	105	15	83	12	70
260	500	76	11	62	9	76
316	600	59	8.5	48	7	80
371	700	45	6.5	38	5.5	80
T76, T7651 tempers						
-196	-320	730	106	615	89	10
-80	-112	625	91	540	78	10
-28	-18	605	88	525	76	10
24	75	570	83	505	73	11
100	212	475	69	440	64	17
149	300	215	31	185	27	40
204	400	105	15	83	12	70
260	500	76	11	62	9	76
316	600	59	8.5	48	7	80
371	700	45	6.5	38	5.5	80

(a) Lowest strength for exposures up to 10 000 h at temperature, no load; test loading applied at 35 MPa/min (5 ksi/min) to yield strength and then at strain rate of 5%/min to fracture. (b) In 50 mm (2 in.)

Table 114 Creep-rupture properties of alloy 7178-T6

Temperature °C	Temperature °F	Time under stress, h	Rupture stress		Stress for creep of:									
			MPa	ksi	1.0%		0.5%		0.2%		0.1%			
			MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
150	300	0.1	440	64	420	61	415	60	395	57	365	53	365	53
		1	415	60	395	57	380	55	360	52	315	46	315	46
		10	370	54	345	50	340	49	310	45	250	36	250	36
		100	285	41	270	39	255	37	235	34	185	27	185	27
205	400	1000	180	26	180	26	170	25	150	22	130	19	130	19
		0.1	275	40	260	38	255	37	235	34	205	30	205	30
		1	215	31	205	30	200	29	180	26	145	21	145	21
		10	150	22	145	21	145	21	130	19	97	14	97	14
260	500	100	105	15	97	14	97	14	83	12	76	11	76	11
		1000	69	10	69	10	69	10	59	8.5	55	8	55	8
		1	110	16	110	16	110	16	105	15	97	14	97	14
		10	97	14	97	14	90	13	83	12	66	9.5	66	9.5
315	600	10	69	10	69	10	66	9.5	55	8	41	6	41	6
		100	55	8	52	7.5	45	6.5	34	5	...	...	...	...
		1000	41	6	34	5	29	4.2	...	...	...	...	...	...
		0.1	62	9	52	7.5	48	7	45	6.5	38	5.5	38	5.5
315	600	1	52	7.5	45	6.5	41	6	34	5	26	3.7	26	3.7
		10	41	6	38	5.5	34	4.9	26	3.8	...	...	...	...
		100	34	5	30	4.3	26	3.8	...	...	...	...	...	...
		1000	28	4	23	3.4	...	...	...	...	...	...	...	...

7178, Alclad 7178 6.8Zn-2.7Mg-2.0Cu-0.3Cr

Specifications

AMS. Extruded wire, rod, bar, shapes, and tube; 4158. Alclad 7178, sheet and plate: 4051, 4052

ASTM. See Table 112.

SAE. J454

UNS number. A97178

Government. See Table 112.

Chemical Composition

Composition limits of 7178. 1.6 to 2.4 Cu, 2.4 to 3.1 Mg, 0.30 Mn max, 0.40 Si max, 0.50 Fe max, 0.18 to 0.35 Cr, 6.3 to 7.3 Zn, 0.20 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Composition limits of Alclad 7178. 7011 cladding—0.05 Cu max, 1.0 to 1.6 Mg, 0.10 to 0.30 Mn, 0.15 Si max, 0.20 Fe max, 0.08 to 0.20 Cr, 4.0 to 5.5 Zn, 0.05 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al. 7072 cladding—0.10 max Cu, 0.10 Mg max, 0.10 Mn max, 0.70 Si max + Fe, 0.8 to 1.3 Zn, 0.05 max other (each), 0.15 max others (total), bal Al

Applications

Typical uses. Aircraft and aerospace applications where high compressive yield is design criteria

Precautions in use. T6 temper is highly susceptible to exfoliation corrosion. T76 temper has mechanical properties comparable to 7075-T6 and provides improved resistance to exfoliation corrosion.

Mechanical Properties

Tensile properties. See Table 113.

Shear strength. T6, T6510, T6511 tempers: 305 MPa (44 ksi). T76, T76510, T76511 tempers: 295 MPa (43 ksi)

Compressive strength. T6, T6510, T6511 tempers: 530 MPa (77 ksi) at 0.1% perma-

nent set. T76, T76510, T76511 tempers: 460 MPa (67 ksi) at 0.1% permanent set

Bearing properties. T6, T6510, T6511 tempers: bearing strength, 1035 to 1100 MPa (150 to 160 ksi); bearing yield strength, 680 to 730 MPa (99 to 106 ksi). T76, T76510, T76511 tempers: bearing strength, 965 MPa (140 ksi); bearing yield strength, 740 MPa (107 ksi). All data for e/d ratio of 2.0, where e is edge distance and d is pin diameter

Poisson's ratio. 0.33

Elastic modulus. Tension, 71.7 GPa (10.4×10^6 psi); shear, 27.5 GPa (4.0×10^6 psi); compression, 73.7 GPa (10.7×10^6 psi)

Fatigue strength. T76 type tempers: 200 to 290 MPa (29 to 42 ksi) at 10^7 cycles in axial fatigue tests ($R = 0.0$) of smooth specimens; 130 to 195 MPa (19 to 28 ksi) at 10^8 cycles in rotating beam tests ($R = -1.0$) of polished specimens; 28 to 55 MPa (4 to 8 ksi) at 10^8 cycles in rotating beam tests ($R = -1.0$) of 60° V-notched specimens ($K_t = 3.0$)

Creep-rupture characteristics. See Table 114.

Mass Characteristics

Density. 2.83 g/cm³ (0.102 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 629 °C (1165 °F)

Eutectic temperature. 477 °C (890 °F)

Coefficient of thermal expansion. Linear:

Temperature range °C	Temperature range °F	Average coefficient μm/m · K	Average coefficient μin./in. · °F
-50 to 20	-58 to 68	21.7	12.1
20 to 100	68 to 212	23.5	13.1
20 to 200	68 to 392	24.4	13.6
20 to 300	68 to 572	25.4	14.1

Volumetric. $68 \times 10^{-6} \text{ m}^3/\text{m}^3 \cdot \text{K}$ ($3.78 \times 10^{-5} \text{ in.}^3/\text{in.}^3 \cdot \text{°F}$)

Specific heat. 856 J/kg · K (0.205 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F): O temper, 180 W/m · K (104 Btu/ft · h · °F); T6, T651 tempers, 127 W/m · K (73 Btu/ft · h · °F); T76, T7651 tempers, 152 W/m · K (88 Btu/ft · h · °F)

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F): O temper, 46% IACS; T6, T651 tempers, 32% IACS; T76, T7651 tempers, 39% IACS

Electrical resistivity. At 20 °C (68 °F): O temper, 37.5 nΩ · m; T6, T651 tempers, 53.9 nΩ · m; T76, T7651 tempers, 44.2 nΩ · m. Temperature coefficient, all tempers: 0.1 nΩ · m per K at 20 °C (68 °F)

Electrolytic solution potential. T6 temper: -0.81 V versus 0.1 N calomel electrode in an aqueous solution containing 53 g NaCl plus 3 g H₂O₂ per liter

Fabrication Characteristics

Annealing temperature. 415 °C (775 °F)

Solution temperature. 468 °C (875 °F)

Aging temperature. T6 and T7 tempers, 121 °C (250 °F) for 24 h

7475

5.7Zn-2.3Mg-1.5Cu-0.22Cr

Specifications

AMS. 4084, 4085, 4089, 4090

UNS number. A94475

Chemical Composition

Composition limits. 1.2 to 1.9 Cu, 1.9 to 2.6 Mg, 0.06 Mn max, 0.18 to 0.25 Cr, 0.12 Fe max, 0.10 Si max, 5.2 to 6.2 Zn, 0.06 Ti max, 0.05 max other (each), 0.15 max others (total), bal Al

Consequence of exceeding impurity limits. Degrades fracture toughness

Applications

Typical uses. Bare and Alclad sheet and plate for aircraft fuselage and wing skins,

Table 115 Typical tensile properties of alloy 7475 at various temperatures

Temperature °C	Temperature °F	Time at temperature, h	At indicated temperature				At room temperature after heating					
			Tensile strength		Yield strength		Elongation(a), %	Tensile strength		Yield strength		Elongation(a), %
			MPa	ksi	MPa	ksi		MPa	ksi	MPa	ksi	
T61 sheet, to 6.35 mm (0.040–0.249 in.) thick												
-196	-320		683	99	600	87						
-80	-112		607	88	545	79						
-28	-18		579	84	517	75						
24	75		552	80	496	72						
100	212	0.1–0.5	496	72	462	67	14	552	80	496	72	12
		10	496	72	462	67	14	558	81	496	72	12
		100	503	73	469	68	13	558	81	503	73	12
		1 000	503	73	476	69	13	565	82	510	74	12
		10 000	483	70	448	65	14	552	80	490	71	13
149	300	0.1–0.5	434	63	414	60	18	552	80	496	72	12
		10	434	63	414	60	17	545	79	490	71	12
		100	379	55	372	54	19	510	74	434	63	12
		1 000	262	38	255	37	23	400	58	310	45	13
		10 000	207	30	179	26	28	310	45	207	30	14
177	350	0.1	386	56	365	53	19	545	79	490	71	12
		0.5	379	55	365	53	19	538	78	483	70	12
		10	324	47	310	45	21	490	71	414	60	12
		100	228	33	221	32	23	386	56	290	42	12
		1 000	172	25	159	23	30	303	44	193	28	14
204	400	0.1	131	19	110	16	40	234	34	124	18	15
		0.5	331	48	317	46	17	531	77	469	68	12
		10	296	43	283	41	19	496	72	427	62	12
		100	200	29	193	28	26	372	54	276	40	12
		1 000	145	21	138	20	35	296	43	186	27	13
232	450	0.1	110	16	97	14	45	234	34	117	17	15
		0.5	97	14	76	11	55	207	30	97	14	18
		10	234	34	221	32	19	490	71	414	60	12
		100	200	29	186	27	21	421	61	331	48	12
		1 000	138	20	131	19	30	303	44	193	28	13
260	500	0.1	97	14	90	13	45	241	35	124	18	14
		0.5	83	12	76	11	60	214	31	97	14	18
		10	193	28	186	27	21	421	61	331	48	12
		100	159	23	152	22	20	407	59	310	45	12
		1 000	131	19	124	18	25	338	49	221	32	12
316	600	0.1	90	13	83	12	45	255	37	131	19	15
		0.5	76	11	69	10	60	228	33	97	14	19
		10	69	10	59	8.5	70	207	30	83	12	21
		1 000	66	9.5	48	7	70	186	27	69	10	22
		10 000	76	11	69	10	35	317	46	193	28	13
371	700	0.1	69	10	62	9	45	269	39	131	19	15
		0.5	48	7	41	6	65	241	35	90	13	19
		10	45	6.5	38	5.5	75	221	32	83	12	20
		1 000	45	6.5	38	5.5	80	207	30	76	11	21
		10 000	45	6.5	38	5.5	80	186	27	69	10	...
427	800	0.1	41	6	34	5	70	276	40	117	17	17
		0.5	38	5.5	32	4.7	70	...	...	...	...	...
		10–10 000	34	5	27	3.8	85	...	...	...	...	...
482	900	0.1	24	3.5	20	2.8	85	...	...	...	...	...
		0.5	23	3.3	19	2.7	85	...	...	...	...	...
538	1000		18	2.6	15	2.2	50	...	...	...	...
			11	1.6	9	1.3	3	...	...	...	...
T761 sheet, 1 to 6.35 mm (0.040 to 0.249 in.) thick												
-196	-320		655	95	565	82						
-80	-112		579	84	503	73						
-28	-18		552	80	483	70						
24	75		524	76	462	67						
100	212	0.1–10	455	66	434	63	14	524	76	462	67	12
		100–1 000	455	66	434	63	13	531	77	469	68	12
		10 000	441	64	421	61	14	524	76	462	67	13
149	300	0.1–0.5	400	58	386	56	18	524	76	462	67	12
		10	393	57	379	55	17	524	76	455	66	12
		100	359	52	345	50	19	490	71	421	61	12
		1 000	362	38	255	37	23	400	58	303	44	13
		10 000	207	30	179	26	28	310	45	207	30	14
177	350	0.1	352	51	338	49	19	517	75	455	66	12
		0.5	352	51	331	48	19	517	75	455	66	12
		10	303	44	290	42	21	469	68	393	57	12
		100	228	33	221	32	23	379	55	283	41	12
		1 000	172	25	159	23	30	303	44	193	28	14
204	400	0.1	131	19	110	16	40	234	34	124	18	15
		0.5	290	42	269	39	17	503	73	434	63	12
		10	276	40	262	38	19	483	70	414	60	12
		100	200	29	193	28	26	372	54	276	40	12
		1 000	200	29	193	28	26	372	54	276	40	12

(continued)

(a) In 50 mm (2 in.)

Table 115 (continued)

Temperature °C	Temperature °F	Time at temperature, h	At indicated temperature					At room temperature after heating				
			Tensile strength		Yield strength		Elongation(a), %	Tensile strength		Yield strength		Elongation(a), %
			MPa	ksi	MPa	ksi		MPa	ksi	MPa	ksi	
T761 sheet, 1 to 6.35 mm (0.040 to 0.249 in.) thick (continued)												
		100	145	21	138	20	35	296	43	186	27	13
		1 000	110	16	97	14	45	234	34	117	17	15
		10 000	97	14	76	11	55	207	30	97	14	18
232	450	0.1	221	32	207	30	19	462	67	386	56	12
		0.5	193	28	179	26	21	414	60	324	47	12
		10	138	20	131	19	30	303	44	193	28	13
		100	97	14	90	13	45	241	35	124	18	14
		1 000	83	12	76	11	60	214	31	97	14	18
		10 000	83	12	62	9	65	193	28	76	11	22
260	500	0.1	159	23	152	22	20	386	56	283	41	12
		0.5	131	19	124	18	25	338	49	221	32	12
		10	90	13	83	12	45	255	37	131	19	15
		100	76	11	69	10	60	228	33	97	14	19
		1 000	69	10	59	8.5	70	207	30	83	12	21
		10 000	66	9.5	48	7	70	186	27	69	10	22
316	600	0.1	76	11	69	10	35	310	45	186	27	13
		0.5	69	10	62	9	45	269	39	131	19	15
		10	48	7	41	6	65	241	35	90	13	19
		100	45	6.5	38	5.5	75	221	32	83	12	20
		1 000	45	6.5	38	5.5	80	207	30	76	11	21
		10 000	45	6.5	38	5.5	80	186	27	69	10	...
371	700	0.1	41	6	34	5	70	276	40	117	17	17
		0.5	38	5.5	32	4.7	70	...	...	...	...	...
		10	34	5	27	3.9	80	...	...	...	...	...
		100-10 000	34	5	27	3.8	85	...	...	...	...	...

(a) In 50 mm (2 in.)

Table 116 Typical fracture-toughness values for alloy 7475

Temper	L-T		T-L		S-L	
	MPa√m	ksi√in.	MPa√m	ksi√in.	MPa√m	ksi√in.
High-strength plate (K_{Ic})(a)						
T651	42.9	39	37.4	34	29.7	27
T7651	47.3	43	38.5	35	30.8	28
T7351	52.7	48	41.8	38	35.2	32
High-strength sheet (K_{Ic})(b)						
T761						
1.2 mm (0.047 in.) thick, room temperature	143		130		...	...
-54 °C (-65 °F)	90		82		...	...
1.4 mm (0.055 in.) thick, room temperature	136		123		...	...
-54 °C (-65 °F)	87		79		...	...
1.6 mm (0.063 in.) thick, room temperature	122		112		...	...
-54 °C (-65 °F)	102		93		...	...
1.6 mm (0.063 in.) thick, room temperature	150		137		...	...
-54 °C (-65 °F)	111		101		...	...
1.6 mm (0.063 in.) thick, room temperature	147		134		...	...
-54 °C (-65 °F)	109		99		...	...
1.8 mm (0.071 in.) thick, room temperature	149		136		...	...
-54 °C (-65 °F)	125		114		...	...

(a) Determined using standard compact tension specimen. (b) Determined using 400 × 1120 mm (16 × 44 in.) center cracked panel with antibuckling guides

spars, and bulkheads. Other structural applications requiring a combination of high strength and high fracture toughness

Mechanical Properties

Tensile properties. See Table 115.

Shear strength. Plate: T651 temper, 296 MPa (43 ksi); T7351, T7651 tempers, 269 MPa (39 ksi)

Compressive strength. At 0.1% permanent set. Plate: T651 temper, 476 MPa (69 ksi); T7351 temper, 379 MPa (55 ksi); T7651 temper, 414 MPa (60 ksi)

Bearing properties. Plate, all data for e/d ratio of 2.0, where e is edge distance and d is pin diameter. T761 temper: bearing

strength, 990 MPa (144 ksi); bearing yield strength, 730 MPa (106 ksi). T7351 temper: bearing strength, 875 MPa (127 ksi); bearing yield strength, 640 MPa (93 ksi). T7651 temper: bearing strength, 925 MPa (134 ksi); bearing yield strength, 655 MPa (95 ksi)

Poisson's ratio. 0.33

Elastic modulus. Tension, 70 GPa (10.2 × 10⁶ psi); shear, 27 GPa (3.9 × 10⁶ psi); compression, 73 GPa (10.6 × 10⁶ psi)

Fatigue strength. At 10⁷ cycles in axial fatigue tests of smooth specimens from T7351 plate. Longitudinal or transverse orientation: 205 to 235 MPa (30 to 34 ksi) for $R = 0.0$. Transverse orientation: 315 MPa (46 ksi) for $R = +0.5$; 165 MPa for $R = -1.0$

Plane-strain fracture toughness. See Table 116.

Creep-rupture characteristics. See Table 117.

Mass Characteristics

Density. 2.80 g/cm³ (0.101 lb/in.³) at 20 °C (68 °F)

Thermal Properties

Liquidus temperature. 635 °C (1175 °F)

Incipient melting temperature. 538 °C (1000 °F) for homogenized (solution heat treated) wrought material

Eutectic temperature. 477 °C (890 °F) for as-cast or inhomogeneous wrought material that has not been solution heat treated

Coefficient of thermal expansion.

Linear:

Temperature range		Average coefficient	
°C	°F	μm/m · K	μin./in. · °F
-50 to 20	-58 to 68	21.6	12.0
20 to 100	68 to 212	23.4	13.0
20 to 200	68 to 392	24.3	13.5
20 to 300	68 to 572	25.2	14.2

Volumetric: 68 × 10⁻⁶ m³/m³ · K (3.78 × 10⁻⁵ in.³/in.³ · °F) at 20 °C (68 °F)

Specific heat. 865 J/kg · K (0.207 Btu/lb · °F) at 20 °C (68 °F)

Thermal conductivity. At 20 °C (68 °F):

Temper	Conductivity	
	W/m · K	Btu/ft · h · °F
O	177	102
T61, T651	142	82
T761, T7651	155	90
T7351	163	94

Table 117 Creep-rupture properties of alloy 7475 sheet 1 to 6.35 mm (0.040 to 0.25 in.) thick

Temperature °C	°F	Time under stress, h	Rupture stress		Stress for creep of:							
			MPa	ksi	1.0%		0.5%		0.2%		0.1%	
			MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi
T61 sheet												
24	75	0.1	552	80	538	78	524	76	517	75	510	74
		1	545	79	531	77	517	75	510	74	503	73
		10	545	79	517	75	510	74	503	73	496	72
		100	538	78	510	74	503	73	496	72	...	...
		1000	524	76	503	73	496	72	...	...	...	...
100	212	0.1	490	71	476	69	455	68	455	66	448	65
		1	476	69	455	66	448	65	434	63	421	61
		10	455	66	434	63	427	62	414	60	393	57
		100	427	62	414	60	400	58	386	56	365	53
		1000	386	56	379	55	365	53	352	51	...	...
149	300	0.1	414	60	400	58	393	57	379	55	365	53
		1	386	56	372	54	365	53	345	50	310	45
		10	352	51	338	49	317	46	283	41	241	35
		100	262	38	248	39	241	35	214	31	193	28
		1000	186	27	179	26	179	26	165	24	159	23
T761 sheet												
24	75	0.1	524	76	503	73	483	70	476	69	469	68
		1	517	75	490	71	476	69	469	68	462	67
		10	510	74	483	70	469	68	462	67	462	67
		100	496	72	476	69	469	68	462	67	455	66
		1000	490	71	462	67	462	67	455	66	448	65
100	212	0.1	441	64	421	61	414	60	414	60	400	58
		1	421	61	407	59	400	58	393	57	379	55
		10	400	58	386	56	386	56	372	54	359	52
		100	379	55	372	54	365	53	352	51	324	47
		1000	359	52	352	51	345	50	324	47	...	...
149	300	0.1	372	54	365	53	365	53	352	51	324	47
		1	345	50	338	49	331	48	310	45	276	40
		10	310	45	303	44	290	42	255	37	234	34
		100	248	36	234	34	228	33	207	30	193	28
		1000	186	27	179	26	179	26	165	24	159	23

Electrical Properties

Electrical conductivity. Volumetric, at 20 °C (68 °F):

Temper	Conductivity, %IACS
O	46
T61, T651	36
T761, T7651	40
T7351	42

Electrical resistivity. At 20 °C (68 °F):

Temper	Resistivity, nΩ · m
O	37.5
T61, T651	47.9
T761, T7651	43.1
T7351	41.1

nΩ · m per K at 20 °C (68 °F)

Fabrication Characteristics

Annealing temperature. 415 °C (775 °F)
Solution temperature. 515 °C (960 °F); must be preceded by soak at 465 to 477 °C (870 to 890 °F)
Aging temperature. 120 to 175 °C (250 to 350 °F)

Temperature coefficient. All temps: 0.1