Designation: B 597 – 92 (Reapproved 1998)

AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428
Reprinted from the Annual Book of ASTM Standards. Copyright ASTM

Standard Practice for Heat Treatment of Aluminum Alloys[1]

This standard is issued under the fixed designation B 597; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 This practice is intended as an aid in establishing a suitable procedure for the heat treatment of aluminum alloys.

1.2 Times and temperatures appearing in the heat treatment tables are typical for various forms, sizes, and manufacturing methods and may not provide the optimum heat treatment for a specific item.

1.3 Some alloys in the 6XXX series may achieve the T4 temper by quenching from within the solution temperature range during or immediately following a hot working process, such as upon emerging from an extrusion die. Such alternatives to furnace heating and immersion quenching are indicated by footnote K of the table for heat treatment of wrought aluminum alloys. However, this practice does not cover the requirements for a controlled press heat treatment. (A practice for press solution heat treatment of aluminum alloys is being developed.)

2. Referenced Documents

2.1 The following documents of the issue in effect on the date of material purchase form a part of this specification to the extent referenced herein:

2.2 *ASTM Standards:*

B 275 Practice for Codification of Certain Nonferrous Metals and Alloys, Cast and Wrought[2]

B 557 Test Methods of Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products[2]

E 44 Definitions of Terms Relating to Heat Treatment of Metals[3]

2.3 *American National Standard:*

H35.1 Alloy and Temper Designation Systems for Aluminum[4]

3. Terminology

3.1 *Definitions:*

3.1.1 The definitions relating to heat treatment of metals appearing in Definitions E 44 are considered as applying to this practice.

4. Apparatus

4.1 Aluminum alloys are usually heat treated in molten salt baths or air chamber furnaces; however, lead baths, oil baths, fluidized beds, or even superheated steam may be used in specific applications. However the use of uncontrolled heating is not permitted. Whichever heating means are employed, careful evaluation is required to ensure that the alloy being heat treated responds properly to heat treatment and is not damaged by overheating or by the heat treatment environment.

4.1.1 *Salt Baths* heat the work rapidly and uniformly. The temperature of the bath can be closely controlled, an important consideration in solution heat treatment of wrought-aluminum alloys. Salt baths are not recommended for heat treatment of casting alloys. High-temperature oxidation of aluminum is not a problem in salt baths.

NOTE 1—**Warning:** Nitrate baths must not be used in the heat treatment of 5xx.x series casting alloys because of a possible explosion.

4.1.2 *Air-Chamber Furnaces* may be oil- or gas-fired or may be electrically heated. The atmosphere in air chamber furnaces must be controlled to prevent porosity resulting from solution heat treatment. Furnace components that are significantly hotter than the metal should be suitably shielded for metal less than 0.250 in. thick to prevent adverse radiation effects. The suitability of the atmosphere in an air-chamber furnace can be demonstrated by determining by test that products processed in that furnace are substantially free of porosity resulting from solution heat treatment.

NOTE 2—Porosity resulting from solution heat treatment may lower mechanical properties and commonly causes blistering of the surface of the material. The condition is most likely in furnaces in which the products of combustion contact the work, particularly if the gases are high in water vapor or contain compounds of sulfur. In general, the high-strength wrought alloys of the 2000 and 7000 series are most susceptible, particularly in the extruded form or as forgings, and casting alloys in the 300 series. Low-strength and alclad (two sides) alloys are practically immune to this type of damage. Anodic films and proprietary heat-treat coatings are also useful in protecting against porosity resulting from solution heat treatment. Surface discoloration is a normal result of solution heat treatment of aluminum alloys and should not be interpreted as evidence of damage from overheating or as porosity resulting from solution heat treatment.

[1] This recommended practice is under the jurisdiction of ASTM Committee B-7 on Light Metals and Alloys and is the direct responsibility of Subcommittee B07.03 on Aluminum Alloy Wrought Products and Subcommittee B07.01 on Aluminum Alloy Ingots and Castings.

Current edition approved January 15, 1992. Published March 1992. Originally published as B 597 – 74. Last previous edition B 597 – 90.

[2] *Annual Book of ASTM Standards*, Vol 02.02.

[3] *Annual Book of ASTM Standards*, Vol 01.02.

[4] Available from American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

***A Summary of Changes section appears at the end of this standard.**

4.1.3 *Automatic Recording and Control Equipment* to control temperature of either salt baths or air furnaces shall be capable of maintaining temperature in the working zone to within ±10°F of the specified temperature.

4.1.4 *Quench Baths*:

4.1.4.1 Quenching is normally performed by immersion of wrought products in a cold-water bath and immersion of castings and some forgings in a hot-water bath. The water baths must be located close enough to solution heat-treating facilities to minimize delay in quenching. Tanks must be of adequate size for the expected work load and must have the means of providing adequate circulation of the quenching media about the work load. Means for heating or cooling the quench water should be available when needed. Quench baths for salt bath facilities require drain and fresh water inlets to prevent the accumulation of dissolved heat-treat salts. An additional rinse tank is desirable as a means of removing any salt bath residue carried from the quench tank.

NOTE 3—Quenching may be performed by alternative means such as total immersion in a glycol water solution, liquefied gas, cold water, hot water, or boiling water, or by air blast or fog to minimize distortion provided samples from the material so quenched will conform to the (*a*) mechanical properties, (*b*) other requirements of the applicable material specification and (*c*) not exhibit more intergranular corrosion susceptibility than if the metal was immersion quenched in cold water. The use of a water spray or high-velocity, high-volume jets of water in which the material is thoroughly and effectively flushed is satisfactory for quenching wrought alloys. Alternative quenching means are frequently contingent on the type of product (sheet parts, forgings, castings, etc.).

4.1.4.2 During quenching it is important that cooling proceeds rapidly through the 750 to 500°F range in order to avoid the type of precipitation detrimental to tensile properties and corrosion resistance. Maximum quench delay times for wrought alloys sensitive to quench delay appear in Table 1. For casting alloys a maximum quench delay of 10 s may be necessary to attain the tensile requirements in the product specifications for Alloys C355.0 and A356.0 in the heat treatment table for sand-cast and investment-cast aluminum alloys and Alloys 354.0, C355.0, A356.0, A357.0, 359.0, and A444.0 in the heat treatment table for permanent mold aluminum alloys. Although other alloys are not as sensitive, in general, quench delay time should not exceed 45 s.

TABLE 1 Maximum Quench Delay for Wrought Alloys (for Immersion Quenching)

NOTE 1—Quench delay time shall begin when the furnace door begins to open or when the first corner of a load emerges from a salt bath, and end when the last corner of the load is immersed in the water, water-solution; liquefied gas; or oil quench tank. The maximum quench delay times may be exceeded (for example, with extremely large loads or long lengths) provided samples of the material so quenched conform to the expected mechanical properties and other characteristics of satisfactorily heat-treated material. For 2219 alloy the metal temperature should be above 900°F at the time of quenching. For other alloys the metal temperature should be above 775°F.

Nominal Thickness, in.	Maximum Time, s
Up to 0.016 incl	5
0.017 to 0.031 incl	7
0.032 to 0.090 incl	10
0.091 and over	15

4.1.5 *Batch Furnace Loading*:

4.1.5.1 Aluminum alloy mill products and parts shall be supported and spaced in the furnace racks to permit heating to heat-treat temperature uniformly.

4.1.5.2 Raking and spacing procedures shall allow free circulation of the quenchant to all mill products surfaces so that the specific product receives an adequate quench to meet the requirements of the material specification.

4.1.5.3 Batch furnace loading of rivets and similar small parts in baskets to be water quenched shall be controlled by limiting the depth of parts in each layer and the minimum spacing between layers to preclude steam generated in any portion of the load from degrading the quench in another part of the load.

4.1.5.3.1 For material 1 in. or less in thickness or diameter that is cold water immersion quenched, random packing should be limited to a maximum thickness of three inches with a minimum spacing of three inches between layers provided the material does not exhibit more intergranular corrosion susceptibility than when quenched by dumping into cold water.

NOTE 4—Quenching by dumping small parts into water ensures access of the quenching media to all surfaces of each part.

5. Calibration and Standardization

5.1 *Calibration of Equipment*:

5.1.1 *Furnace and Salt Bath Temperature Survey*:

5.1.1.1 A temperature survey, to ensure compliance with the applicable recommendations presented herein, shall be performed for each furnace or salt bath.

5.1.1.2 A new temperature survey shall be made after any changes are made in the furnace or salt bath that may affect operational characteristics.

5.1.2 *Batch Furnace Calibration*:

5.1.2.1 The initial temperature survey shall be made at the maximum and minimum temperature of solution heat treatments and precipitation heat treatments for which each furnace is to be used. There shall be at least one test location for each 25 ft^3 of air furnace volume up to a maximum of 40 test locations, with a minimum of nine test locations, one in each corner and one in the center. For salt-bath furnaces, one test location is required for each 40 ft^3 of volume.

5.1.2.2 After the initial survey, each furnace shall be surveyed monthly, except as provided in 5.1.2.7. The monthly survey shall be at one operating temperature for solution heat treatment and one for precipitation heat treatment.

5.1.2.3 There shall be at least one test location for each 40 ft^3 of load volume, with a minimum of nine test locations, one in each corner and one in the center.

5.1.2.4 The surveys shall reflect the normal operating characteristics of the furnace. If the furnace is normally charged after being stabilized at the correct operating temperature, the temperature-sensing elements shall be similarly charged. If the furnace is normally charged cold, the temperature-sensing elements shall be charged cold. After insertion of the temperature-sensing elements, readings should be taken frequently enough to determine when the temperature of the hottest region of the furnace approaches the bottom of the temperature range being surveyed. From that time until thermal

TABLE 2 Tests Required

Material	Tests				
	Tensile Properties[A]	Porosity Resulting from Solution Heat Treatment[B]	Intergranular Corrosion[C]	Diffusion (Alclad Only)[D]	Eutectic Melting
Plate and sheet	x	x	X[E]	x	x
Castings	x	...	...	...	...
Bar, rod, wire, and shapes	x	x	x	...	x
Forgings	x	x	x	...	x
Tubing	x	x	...	x	x
Rivets and fastener components	x	x	x	...	x

[A] Those specified in the applicable procurement specification.
[B] Applicable only to material solution heat treated in air furnaces.
[C] Applicable only to bare or alclad 2014, 2017, 2024, 2117, 7075, and 7178 alloys.
[D] Not applicable for thicknesses less than 0.020 in.
[E] Required only for sheet thicknesses.

equilibrium is reached, the temperature of all test locations should be determined at 2-min intervals in order to detect any over-shooting. After thermal equilibrium is reached, readings should be taken at 5-min intervals for sufficient time to determine the recurrent temperature pattern, but for not less than 30 min. Before thermal equilibrium is reached, none of the temperature readings should exceed the maximum temperature of the range being surveyed. After thermal equilibrium is reached, the maximum temperature variation of all elements (both load and furnace thermocouples) shall not exceed 20°F and shall not vary outside the range being surveyed.

5.1.2.5 For furnaces of 10 ft^3 or less the temperature survey may be made with a minimum of three thermocouples located at front, center, and rear or at top, center, and bottom of the furnace.

5.1.2.6 For furnaces used only for precipitation treatment, after the initial temperature-uniformity survey, as outlined in 5.1.2.7, surveys need not be made more often than at each 6-month interval provided that (*a*) test specimens from each lot are tested and meet applicable material specifications requirements, (*b*) the furnace is equipped with a multipoint recorder, or (*c*) one or more separate load thermocouples are employed to measure and record actual metal temperatures.

5.1.2.7 Monthly surveys for batch furnaces are not necessary when the furnace or bath is equipped with a permanent multipoint recording system with at least two sensing thermocouples in each zone or when one or more separate load thermocouples are employed to measure actual metal temperature, providing that uniformity surveys show a history of satisfactory performance for a period of at least 6 months. The sensing thermocouples shall be installed so as to record the temperature of the heated media (air, salt, lead, etc.) or actual metal temperatures. However, periodic surveys should also be made at 6-month intervals in accordance with the procedures outlined for the monthly survey.

TABLE 3 Recommended Heat Treatment for Wrought Aluminum Alloys

Product	Solution Heat Treatment			Precipitation Heat Treatment[A]		
	Metal Temperature, ±10°F[B,C]	Quench Temperature, °F[D]	Temper	Metal Temperature, ±10°F	Time at Temperature, h	Temper
2011 Alloy						
Cold finished wire, rod, bar,	945–985	100 max	T3[E]	320	14	T8[E]
			T4	...	...	...
			T451[F]	...	...	...
Drawn tube	975	100 max	T3[E]	...	...	...
			T4511[F]			
2014 Alloy						
Flat sheet, bare or alclad	935	100 max	T3[E]	...	...	...
			T42	320	18	T62
Coiled sheet, bare or alclad	935	100 max	T4	320	18	T6
			T42	320	18	T62
Plate, bare or alclad	935	100 max	T451[F]	320	18	T651[F]
			T42			
Cold finished rod, bar or wire	935	100 max	T4	320	18	T6
				or 350	8	
			T451[G]	320	18	T651[G]
				or 350	8	
			T42	320	18	T62
				or 350	8	
Extruded rod, bar, wire, shapes, tube	935	100 max	T4	320	18	T6
				or 350	8	
			T4510[G]	320	18	T6510[G]

TABLE 3 *Continued*

Product	Solution Heat Treatment			Precipitation Heat Treatment[A]		
	Metal Temperature, ±10°F[B,C]	Quench Temperature, °F[D]	Temper	Metal Temperature, ±10°F	Time at Temperature, h	Temper
				or 350	8	
			T4511[G]	320	18	T6511[G]
				or 350	8	
			T42	320	18	T62
				or 350	8	
Drawn Tube	935	100 max	T4	320	18	T6
			T42	320	18	T62
Die forgings	935	140–180	T4	340	10	T6
Hand forgings and rolled rings	935	140–180	T452[H]	340	10	T652[H]
			T4	340	10	T6
			2017 Alloy			
Cold finished wire, rod or bar	925–950	100 max	T4	...	...	...
			T451[G]	...	...	...
			T42	...	...	...
			2018 Alloy			
Die forgings	940–970	212	T4	340	10	T61
			2024 Alloy			
Flat sheet bare or alclad	920	100 max	T3[E]	375	12	T81[E]
			T361[I]	375	8	T861[I]
			T42	375	9	T62
			T42	375	16	T72
Coiled sheet bare or alclad	920	100 max	T4	375	...	...
			T42	375	9	T62
Plate, bare or alclad	920	100 max	T351[F]	375	12	T851[F]
			T361[I]	375	8	T861[I]
			T42	375	9	T62
Cold finished wire, rod, bar	920	100 max	T351[G]	375	12	T851[G]
			T36[I]	...	...	...
			T4	375	12	T6
			T42	375	16	T62
Extruded wire, rod, bar, shapes, tube	920	100 max	T3[E]	375	12	T81[E]
			T3510[G]	375	12	T8510[G]
			T3511[G]	375	12	T8511[G]
			T42	...	...	...
Drawn tube	920	100 max	T3[E]	...	...	...
			T42	...	...	...
			2025 Alloy			
Die forgings	960	140–160	T4	340	10	T6
			2117 Alloy			
Cold finished, wire or rod	925–950	100 max	T4	...	...	...
			2124 Alloy			
Plate	920	100 max	T351[F]	3'5	12	T851[F]
			2218 Alloy			
Die forging	950	212	T4	340	10	T61
			2219 Alloy			
Flat sheet bare or alclad	995	100 max	T31[E]	350	18	T81[F]
			T37[J]	325	24	T87[J]
			T42	375	36	T62
Plate	995	100 max	T37[J]	350	18	T87[J]
			T351[F]	350	18	T851[F]
			T42	375	36	T62
Cold finished wire, rod, bar	995	100 max	T4	375	36	T6
			T351[G]	375	18	T851[G]
Extruded rod, bar, shape, wire, tube	995	100 max	T31[E]	375	18	T81[E]
			T3510[G]	375	18	T8510[G]
			T42	375	18	T851[G]
				375	36	T62
Die forging and rolled ring	995	100 max	T4	375	26	T6
Hand forging	995	100 max	T4	375	26	T6
			T352[H]	350	18	T852[H]
			2618 Alloy			

TABLE 3 *Continued*

Product	Solution Heat Treatment			Precipitation Heat Treatment[A]		
	Metal Temperature, ±10°F[B,C]	Quench Temperature, °F[D]	Temper	Metal Temperature, ±10°F	Time at Temperature, h	Temper
Die, hand, and rolled ring forgings	985	212	T4	390	20	T61
			4032 Alloy			
Die forgings	940–970	140–180	T4	340	10	T6
			6005 and 6005A Alloy			
Extruded rod, bar, shape, and tube	...[K]	...	T1	350	8	T5
			6053 Alloy			
Cold-finished rod and wire	970	100 max	T4	355	8	T61
Die forgings	970	100 max	T4	340	10	T6
			6061 Alloy			
Sheet, bare or alclad	960–1075[L]	100 max	T4	320	18	T6
			T42	320	18	T62
Plate	960–1075	100 max	T451[F]	320	18	T651[F]
			T42	320	18	T62
Tread plate[M]	960–1075	100 max	T4	320	18	T6
Cold finished rod, bar or wire	960 to 1025	100 max[I]	T4	340	8	T6
				or 320	18	
			T3	340	8	T89[M]
				or 320	18	
			T4	340	8	T94[N]
				or 320	18	
			T451[G]	340	8	T651[G]
				or 320	18	
			T42	340	8	T62
				or 320	18	
Extruded tube rod, bar, shapes	...	...	T1	350	8	T51
	960–1025	100[I]	T4	350	8	T6
			T4510[G]	350	8	T6510[G]
			T4511[G]	350	8	T6511[G]
			T42	350	8	T62
Structural shapes	960–1025	100[I]	T4	350	8	T6
Pipe	960–1025	100[I]	T4	350	8	T6
Drawn tube	960–1075	100 max	T4	340	8	T6
				or 320	18	
			T42	340	8	T62
				or 320	18	
Die and hand forgings	960–1075	100 max	T4	340	8	T6
				or 320	18	
Rolled rings	960–1075	100 max	T4	350	8	T6
			T452[O]	350	8	T652[O]
			6063 Alloy			
Extruded rod, bar, tube, shapes	...[K]	...	T1	400	1 to 2	T5
				or 360	3	
			T1	400	1 to 2	T52
				or 360	3	
Extruded rod, bar, tube, shapes (cont'd)	970[K]	100 max[P]	T4	360	6	T6
				or 350	8	
			T42	360	6	T62
				or 350	8	
Drawn tube	970	100 max	T4	350	8	T6
			T3	350	8	T83[M]
			T3	350	8	T831[M]
			T3	350	8	T832[M]
			T31	...	...	...
			T42	350	8	T62
Pipe	970[K]	100 max[P]	T4	360	6	T6
				or 350	8	
			6066 Alloy			
Extruded rod, bar, shapes, tube	960–1010	100 max	T4	350	8	T6
			T4510[G]	350	8	T6510[G]
			T4511[G]	350	8	T6511[G]
			T42	350	8	T62
Die forgings	960–1010	100 max	T4	350	8	T6
			6070 Alloy			

TABLE 3 *Continued*

Product	Solution Heat Treatment			Precipitation Heat Treatment[A]		
	Metal Temperature, ±10°F[B,C]	Quench Temperature, °F[D]	Temper	Metal Temperature, ±10°F	Time at Temperature, h	Temper
Extruded rod, bar, shapes, tube	1015	100 max	T4	320	18	T6
			T42	320	18	T62
6101 Alloy						
Extruded rod, bare tube, pipe, and structural shapes	970[K]	100 max[P]	T4	390	10	T6
			T4	440	5	T61
			T4	410	9	T63
			T4	535	7	T64
			T4	430	3	T65
6105 Alloy						
Extruded rod, bar, shape, tube	...[K]	...	T1	350	8	T5
6110 Alloy						
Rod, bar, wire, cold finished	980–1050	100 max	T4	380	8	T9[P]
6151 Alloy						
Die forgings	950–980	100 max	T4	340	10	T6
Rolled rings	960	100 max	T4	340	10	T6
			T452[H]	340	10	T652[H]
6201 Alloy						
Wire	950	100 max	T3	320	4	T81[M]
6262 Alloy						
Cold finished wire, rod, bar	960–1050	100 max	T4	340	8	T6
			T4	340	8	T9[P]
			T451[G]	340	8	T651[G]
Extruded rod, bar, shapes, tube	960–1050	100 max	T4	350	12	T6
			T4510[G]	350	12	T6510[G]
			T4511[G]	350	12	T6511[G]
			T42	350	12	T62
Drawn tube	960–1050	100 max	T4	340	8	T6
			T4	340	8	T9[P]
			T42	340	8	T62
6351 Alloy						
Extruded rod, bar, shapes and tube	...[K]	...	T1	350	8	T5
				350	8	T51
				350	8	T52
				350	8	T53
				250	10	T54
				or 350	8	
	...[K]	...	T11			
	960 to 1010[K]	100[P]	T4	350	8	T6
6463 Alloy						
Extruded rod, bar, shapes, and tube	...[K]	...	T1	400	1	T5
				or 360	3	
	970[K]	100 max[P]	T4	350	8	T6
				or 360	6	
7001 Alloy						
Extruded rod, bar, shape, and tube	870	100 max	W[Q]	250	24	T6
			W510[G,Q]	250	24	T6510[G]
			W511[G,Q]	250	24	T6511[G]
			W[Q]	250	24	T62
7005 Alloy						
Extruded rod, bar, shape	...[K]		T1	room temperature	72 plus	
				225	8 plus	T53
				300	16	
7049 Alloy						
Extruded rod, bar, shape	875	100 max	W511[G,Q]	room temperature	48 plus	
				250	24 plus	T76511[G]
				325	12 to 14	
			W511[G,Q]	room temperature	48 plus	