Designation: B 918 – 01

Standard Practice for Heat Treatment of Wrought Aluminum Alloys[1]

This standard is issued under the fixed designation B 918; 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.

1. Scope *

1.1 This practice is intended for use in the heat treatment of wrought aluminum alloys for general purpose applications.

1.1.1 The heat treatment of wrought aluminum alloys used in specific aerospace applications is covered in AMS 2772.[2]

1.1.2 Heat treatment of aluminum alloy castings for general purpose applications is covered in Practice B 917/B 917M.

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 in Table 2, by Footnote *L*, for heat treatment of wrought aluminum alloys. However, this practice does not cover the requirements for a controlled press heat treatment. (Refer to Practice B 807 for press heat treatment of aluminum alloys.)

1.4 This practice is in inch-pound units.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

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 557 Test Methods of Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products[3]

B 881 Terminology Relating to Aluminum- and Magnesium-Alloy Products[3]

B 917/B 917M Practice for Heat Treatment of Aluminum-Alloy Castings from All Processes[3]

2.3 *American National Standard:*

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

3. Terminology

3.1 *Definitions*—Refer to Terminology B 881 for definitions of product terms used in this practice.

3.2 *Definition of Pyrometry Terms Specific to This Standard:*

3.2.1 *control sensor*—temperature measurement sensor tied to the PID (proportional, integral, and derivative) furnace control for controlling heat input to the working (soaking) zone of the furnace.

3.2.2 *monitoring sensor*—a sensor which does not control the furnace temperature is designated as a monitoring sensor, and includes additional furnace temperature sensor(s) and load monitoring sensor(s).

3.2.3 *test sensor*—temperature measurement sensor(s) used in furnace temperature uniformity surveys.

4. Equipment

4.1 *Heating Media*—Aluminum alloys are typically heat-treated in air chamber furnaces or molten salt baths; however, lead baths, oil baths, or fluidized beds, may be used. 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 Air chamber furnaces may be oil- or gas-fired or may be electrically heated. 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 atmosphere in air chamber furnaces must be controlled to prevent potential porosity resulting from solution heat treatment (see Note 1). The suitability of the atmosphere in an air-chamber furnace can be demonstrated by testing, in accordance with 7.4.2.1, that products processed in that furnace are free from heat-treat induced porosity.

NOTE 1—Heat-treat induced porosity may lower mechanical properties and commonly causes blistering of the surface of the material. The condition is most likely to occur in furnaces in which the products of combustion contact the work, particularly if the gases are high in water

[1] This practice is under the jurisdiction of ASTM Committee B07 on Light Metals and Alloys and is the direct responsibility of Subcommittee B07.03 on Aluminum Alloy Wrought Products.

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[2] Available from SAE-AEROSPACE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

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

[4] Available from American National Standards Institute, 25 West 43rd St., 4th Floor, New York, NY 10036.

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

vapor or contain compounds of sulfur. In general, the high-strength wrought alloys of the 2xxx and 7xxx series are most susceptible. Low-strength and Alclad (two sides) products 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 heat-treat induced porosity (see 7.4.2.1).

4.1.2 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. High-temperature oxidation of aluminum is not a problem in salt baths.

4.2 *Furnace Temperature Uniformity and Calibration Requirements*:

4.2.1 After establishment of thermal equilibrium or a recurrent temperature pattern, the temperature in the working (soaking) zone, for all furnace control and test sensors, shall maintain temperature in the working (soaking) zone within the following allowable ranges:

4.2.1.1 50°F range for furnaces used only for full annealing at 825°F and higher, except 20°F range if the annealing temperature is within 15°F of the middle of the solution heat treating temperature range specified in Table 2.

4.2.1.2 30°F range for furnaces used only for solution heat treatment of those 6xxx alloys for which Table 2 specifies a range from 30°F or more.

4.2.1.3 20°F range for furnaces used for other solution heat treatment specified in Table 2 and any aging heat treatment.

4.2.2 *Temperature-Measuring System Accuracy Test*—The accuracy of temperature-measuring system shall be checked weekly under operating conditions. This check should be made by inserting a calibrated test temperature-sensing element adjacent to the furnace temperature-sensing element and reading the test temperature-sensing element with a calibrated test potentiometer. When the furnace is equipped with dual potentiometer measuring systems which are checked daily against each other, the preceding checks may be conducted every 3 months rather than every week. The test temperature-sensing element, potentiometer, and cold junction compensation combination shall have been calibrated against National Institute of Standards and Technology (NIST) primary or secondary certified temperature-sensing elements, within the previous 3 months, to an accuracy of ±2°F.

4.3 *Furnaces and Salt Baths Temperature Uniformity Surveys*—A temperature uniformity survey shall be performed for each furnace and salt bath to ensure compliance with temperature uniformity requirements (see 4.2) and the requirements presented herein.

4.3.1 A new temperature uniformity survey shall be made after any modification, repair, adjustment (for example, to power controls, or baffles), or re-build which alters the temperature uniformity characteristics of the furnace or salt bath and reduce the effectiveness of the heat treatment.

4.3.2 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.

4.3.3 After the initial survey, each furnace shall be surveyed monthly thereafter, except as provided in 4.3.8 and 4.3.9. The monthly survey shall be at one operating temperature for solution heat treatment and one operating temperature for precipitation heat treatment.

4.3.4 During furnace temperature uniformity surveys, separate test sensors shall be used to determine actual temperature distribution and uniformity. The furnace control sensor(s), in the working (soaking) zone(s), shall not be used to determine the temperature of the test. There shall be at least one test sensor for each 40 ft^3 of load volume, with a minimum of nine test sensors, one in each corner and one in the center. For furnaces of 10 ft^3 or less, the temperature uniformity survey may be made with a minimum of three test sensors, one each in the front, center, and rear, or one each at the top, center, and bottom of the furnace.

4.3.5 *Batch Furnace Temperature Uniformity Surveys*—The temperature uniformity 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 test sensors shall be similarly charged. If the furnace is normally charged cold, the test sensors shall be charged cold. After insertion of the test sensors, 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 equilibrium is reached, the temperature of all test locations should be determined at 2-min intervals in order to detect any overshooting. After thermal equilibrium is reached, readings should be taken at 5-min intervals, for not less than 30 min, to determine the recurrent temperature pattern. The results of these surveys shall demonstrate that: (*1*) the maximum temperature variation (from the coldest to the hottest reading) between all test sensors and furnace control sensor(s), is within the applicable temperature uniformity range defined in 4.2; and, (*2*) all test sensor readings are within the specified heat-treating temperature range being surveyed.

4.3.6 *Continuous Furnace Temperature Uniformity Surveys*—The type of survey and the procedures for performing surveys on continuous furnaces shall be established for each particular furnace involved. The types of continuous heat-treating furnaces vary considerably, depending upon the product form and sizes involved. For some types and sizes of furnaces, the only practical way to survey the furnace is to perform an extensive mechanical property survey of the limiting product sizes to verify conformance with the specified mechanical properties for such sizes and to verify conformance with Table 1. Monthly furnace temperature uniformity surveys should be performed, when physically practical, using a minimum of two test sensors attached to the material being heat treated. The surveys should reflect the normal operating characteristics of the furnace. The results of these surveys shall demonstrate that: (*1*) the maximum temperature variation (from the coldest to the hottest reading) between all test sensors and furnace control sensor(s) is within the applicable temperature uniformity range defined in 4.2; and (*2*) all test sensor readings are within the specified heat treating temperature range being surveyed.

4.3.7 *Salt Bath Temperature Uniformity Surveys*—The temperature uniformity in salt bath may be determined by using a test sensor enclosed in a suitable protection tube. The test sensor should be held in one position until thermal equilibrium has been reached and a reading made. The test sensor should then be placed in a new location and the procedure repeated. These operations should be repeated until the temperature distribution in all parts of the bath has been determined. The results of these surveys shall demonstrate that: (*1*) the maximum temperature variation (from the coldest to the hottest reading) is within the applicable temperature uniformity range defined in 4.2; and (*2*) all test sensor readings within the bath are within the specified heat treating temperature range being surveyed.

4.3.8 *Extended Survey Time Intervals for Solution Heat-Treating Furnaces*—Time between surveys may be extended to six months after the successful completion of six consecutive monthly surveys (including the initial survey, as outlined in 4.3.2, provided that all the following conditions are met:

4.3.8.1 The previous furnace temperature uniformity surveys have shown a history of satisfactory performance for a period of at least 6 consecutive months, and

4.3.8.2 In addition to each furnace zone's control sensor, the furnace or bath is equipped with a permanent multipoint recording instrument, with at least one additional furnace temperature monitoring sensor in each zone, or with one or more load monitoring sensors to measure actual metal temperature in each zone, and

4.3.8.3 Each zone's control sensor and load monitoring sensor(s) shall be installed so as to record the temperature of the heated media (air, salt, lead, and so forth) and actual metal temperature(s).

4.3.9 *Extended Survey Time Interval for Precipitation (Aging) Furnaces*—Survey frequency, for furnaces used only for precipitation treatment, may be reduced to six months after the successful completion of six consecutive monthly surveys (including the initial survey as outlined in 4.3.2), provided that either of the following conditions are met:

4.3.9.1 The furnace utilizes a multipoint recorder for continuous recording of furnace temperature data; or,

4.3.9.2 One or more load monitoring sensor(s) are employed to measure and record actual metal temperature(s).

5. Preparation for Heat Treatment

5.1 *Racking and Spacing*—Product shall be supported or hung and spaced to permit free flow and circulation of the quenchant over all surfaces to ensure that the entire product receives an adequate quench and will meet the requirements of the material specification.

5.1.1 *Small Sized Product Heat Treated in Baskets*—Product load arrangement shall ensure that quenching media has access to all surfaces for each piece of product. Batch furnace loading of baskets containing small sized product, such as rivets or forgings, shall be controlled by limiting the depth of product in each layer and by maintaining minimum spacing between layers to preclude steam generated in any portion of the load from degrading the quench in another part of the load. Periodic product testing (see Table 1) shall be performed to ensure that small-sized product, immersion quenched in baskets, exhibits no greater susceptibility to intergranular corrosion than product separately and individually quenched without baskets.

5.2 *Cleanliness*—Prior to heat treating, product shall be free from surface contaminants which might have a detrimental effect.

6. Heat Treatment Procedures

6.1 *Solution Heat Treatment*—Recommended temperature ranges, for various heat-treatable wrought aluminum alloys, are defined in Table 2.

6.2 *Soak Time*—Recommended soaking times are indicated in Table 3 and reflect the minimum time periods generally required to achieve proper solution of alloying constituents for the respective thicknesses of wrought alloy product.

6.3 *Quenching* is typically performed by immersion of wrought products in a cold-water bath, although some forgings are quenched in hot-water. Immersion in an aqueous polymer solution may also be used (see Note 2). Quench delay shall be minimized and maximum quench delays are defined in Table 4 (see Note 3). 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. For immersion quenching in water, the quenchant temperature shall not exceed 100°F at the start of quench and 110°F at the completion of quench. If the quenchant is an aqueous solution of polymer, the quenchant temperature shall not exceed 130°F at the completion of quench. For hot-water quenching of forgings, the quenchant temperature shall not exceed 170°F at the completion of quench. 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 2—Quenching may be performed by alternative means such as total immersion in an aqueous polymer 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: (*1*) the mechanical properties; (*2*) other requirements of the applicable material specification; and (*3*) not exhibit greater 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, and so forth).

NOTE 3—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 4. Although other alloys are not as sensitive, in general, quench delay time should not exceed 45 s.

6.4 *Restrictions on Heat Treating*—Alclad products shall not be re-solution heat-treated more than the number of times specified in Table 5.

NOTE 4—*Heat-treating Restrictions Applicable to 6xxx Alloys*: 6061 and Alclad 6061 (and other 6xxx alloys) may be incapable of achieving T42 mechanical properties after re-solution heat treatment due to recrystallization and grain growth associated with small amounts of cold work introduced during flattening or straightening following to the original solution heat treatment.

6.5 *Precipitation Heat Treating (Artificial Aging)*:

6.5.1 Recommended times and temperatures for precipitation heat-treating various heat-treatable wrought aluminum alloys appear in Table 2.

6.5.2 At completion of precipitation time-at-temperature, the product shall be removed from the furnace and cooled to room temperature.

6.6 *Annealing*—Recommended times and temperatures for annealing of wrought alloys appear in Table 6.

NOTE 5—Heat-treated wrought alloys may be partially annealed to facilitate moderate forming by heating to 650 to 750°F (never exceed 775°F) and holding at temperature until a uniform temperature is achieved, followed by either ambient air cooling or furnace cooling. If severe forming is to be performed, a full anneal in accordance with Table 6 should be used.

7. Quality Assurance

7.1 *Responsibility for Inspection and Tests*—The heat treater is responsible for the performance of all inspections and test requirements, unless otherwise specified in the contract.

7.1.1 The heat treater may use any suitable facilities for the performance of specified inspection and test requirements.

7.2 *Records* shall be maintained for a minimum of three years after the inspection or test.

7.2.1 Furnace records shall include all applicable production parameters including the following: furnace number or description; size; temperature range of usage; whether used for solution heat treatment or precipitation heat treatment, or both; temperature(s) at which uniformity was surveyed; dates of each survey, number and locations of thermocouples used; and dates of major repairs or alterations.

7.3 *Qualification, Testing, and Periodic Verification of Equipment and Process*:

7.3.1 *Effectiveness of Quench*—A monitoring plan shall be developed and utilized for all modes of quenching for all products covered by this practice. The plan should include monitoring of process (for example, quench delay time; agitation of quenchant or product, or both; quenchant temperature, velocity, and distribution). The plan should also incorporate surveying the uniformity of product conductivity or hardness to determine the uniformity of the quench, or both. Areas having substantially higher conductivity or lower hardness than other areas of similar thickness in the lot shall be investigated to ensure that the requirements of the material specification are met.

7.3.2 *Testing Requirements*—Heat-treating equipment, operated in accordance with documented procedures, shall have a demonstrated capability of producing material and components meeting the tensile and physical properties specified for each alloy heat-treated.

7.3.3 *Periodic Tests*—Required periodic tests are shown in Table 1 and are required for each product to verify the continued acceptability of the heat treatment.

7.3.3.1 *Frequency of Tests*—Tests shall be made once each month or more frequently as may be required (for example, determination of tensile properties is typically a lot release test). Testing one load per furnace per month shall constitute conformance with the requirements of this paragraph. If the monthly workload includes plate and sheet as well as other material forms, the load to be tested in accordance with Table 1 shall be a plate and sheet load. If this product form was not heat treated during the month, the test load shall be that for which Table 1 requires the maximum number of tests.

7.3.3.2 *Use of Production Test Results*—Results of tests made to determine conformance of heat-treated material to the requirements of the respective material specifications are acceptable as evidence of the properties being obtained with the equipment and procedure employed.

7.4 *Testing Requirements*:

7.4.1 *Tensile Properties*—Representative test samples from each lot of production material shall exhibit tensile strength, yield strength, and elongation properties not less than those specified in applicable procurement specifications or detail drawings.

7.4.1.1 The effectiveness of heat treatment shall also be demonstrated by tensile tests after any modification, repair, adjustment (for example, to power controls, or baffles), or re-build which might alter the temperature uniformity characteristics of the furnace or salt bath and reduce the effectiveness of the heat treatment. Some examples of modifications for which the need for testing should be evaluated include: furnace baffling; furnace fans; reduction of spacing between pieces; nozzle size change; manifold size change; pump size change; and quenchant change. After any repair or alteration which could reduce the effectiveness of the heat treatment, or re-build of the furnace, or change to the heat-treat practice, a minimum of nine suitably distributed samples shall be tensile tested. This requirement may be waived if other approved testing procedures are used. Tensile specimens shall be taken from production material. They should be selected from the largest and smallest sections of the piece so as to represent the portions of the load receiving the least drastic quench and subjected to the highest and lowest temperatures. The test specimen with the lowest yield strength shall be used for the intergranular corrosion test specified in 7.4.2.2. When taking specimens from production material is impractical, tensile specimens shall be taken from samples heat-treated with a production load. The thickness and alloy of such samples and their location in the load shall be selected so as to represent material heat-treated during the previous month which received the least drastic quench and to represent material which was subjected to the highest and lowest solution heat-treating temperatures.

7.4.2 *Metallurgical Properties*—The following tests shall be performed on production product from each solution heat-treating furnace initially and monthly thereafter and after any modification of the equipment which could affect the metallurgical properties of the product.

7.4.2.1 *Eutectic Melting (*see Note 6*) and Heat-Treat-Induced Porosity*—Specimens shall be free from: (*1*) heat-treated-induced porosity, evidenced by multiple voids in grain boundaries near the surface which are visible in more than two fields of view; and (*2*) eutectic melting, evidenced by rosettes or eutectic structure at grain boundary triple points.

NOTE 6—Micrographs illustrating typical eutectic melting (in alloys 2014 and 7075) may be found in *Metals Handbook*, 8th Ed., Vol 7 (Micrograph Numbers 2018 and 2073), published by the ASM International.[5]

7.4.2.2 *Intergranular Corrosion (*see Note 7*) and Alclad Diffusion*—There shall be no evidence of excessive intergranular corrosion or Alclad diffusion. Consideration shall be given to size and thickness of the material in deciding whether the intergranular corrosion is excessive as compared to typical product. Alclad sheet in all alloys and thicknesses less than 0.020 in. generally contain areas of diffusion into the cladding, even though heat-treated in accordance with 6.4 and all other requirements of this practice. Degree of susceptibility to intergranular corrosion and degree of Alclad diffusion shall be not greater than normally experienced when following this practice.

NOTE 7—Micrographs illustrating typical pitting type, intergranular, and branched-type intergranular stress-corrosion cracks may be found in *Metals Handbook*, 8th Ed., Vol 7 (Micrograph Numbers 2092, 2093, and 2098), published by the ASM International.[5]

7.4.3 *Test Reports*—Test reports shall be identified to the equipment and heat-treated lots of material associated with the tests and shall be retained and readily retrievable for a minimum of three years.

7.4.4 *Rejection and Reheat Treatment*—Materials heat-treated in the furnace since the time of the previous satisfactory tests and determined as unsatisfactory shall be rejected or reheat-treated (beginning with the solution heat treatment) in an acceptable furnace. Materials in which eutectic melting, heat treat induced porosity, or excessive diffusion of alloying elements from the core material into the Alclad is found, shall be rejected and no reheat-treatment permitted. Materials that fail for reasons other than those enumerated above may be reheat-treated up to the limit of the permissible number of times specified in Table 5.

7.5 *Testing Methods and Procedures*:

7.5.1 Tensile properties shall be determined by tensile testing in accordance with Test Methods B 557 and shall meet specified requirements.

7.5.2 *Metallurgical Testing*:

7.5.2.1 *Eutectic Melting and Heat-Treat-Induced Porosity*—After sectioning and polishing to appropriate fineness, the un-etched surface shall be examined at 500× magnification, with a metallurgical microscope, to detect evidence of heat treat induced porosity (7.4.2.1). The sections may then be mildly etched (approximately 2 s in an etchant) to reveal evidence of eutectic melting. Keller's Etch has been found satisfactory for this purpose.

7.5.2.2 *Intergranular Corrosion Test*—Corrosion tests shall be conducted in accordance with the following procedure. For Alclad alloys, the cladding shall be removed from both sides of the sample by filing or by other suitable means. Prior to the corrosion test, each sample (see Note 8) shall be immersed for 1 min in an etching solution at 200°F to produce a uniform surface condition. The solution shall have the following composition:

Nitric acid, concentrated (70 %) 50 mL
Hydrofluoric acid, (48 %) 5 mL
Distilled or deionized water 945 mL

After this etching treatment, the sample shall be rinsed in distilled or deionized water, immersed for 1 min in concentrated nitric acid (70 %) at room temperature to remove any metallic copper that may have been plated out on the specimen, rinsed in distilled or deionized water, and allowed to dry. The sample shall be corroded by immersion in a solution of the following composition for 6 h at 86 ± 9°F.

Sodium chloride, 57 g
Hydrogen peroxide, (30 %) 10 mL
Dilute to 1 l with distilled or deionized water.

All chemicals shall be reagent grade and the solution shall be prepared immediately before use. A minimum of 30 mL of solution per in.^{2} of surface area shall be used for the test.

NOTE 8—More than one sample of the same alloy may be corroded in a container, provided that at least 30 mL of solution are used for each 1 in.^{2} of specimen surface and provided that the specimens are electrically insulated from each other.

Nitric acid, concentrated (70 %) 2.5 mL
Hydrochloric acid, concentrated 1.5 mL
Hydrofluoric acid, (48 %) 1.0 mL
Distilled or deionized water 95.0 mL

7.5.2.3 *Examination with a Metallurgical Microscope*—At the end of the immersion period, the sample shall be removed from the solution, washed, and dried. A cross-section specimen, which shall be at least ¾ in. long (whenever the size of the sample permits), shall be cut from the sample and mounted for examination between 200 and 500× magnification with a metallurgical microscope. Examination shall be made of the specimen both before and after etching. The etching shall be done by immersion for 6 to 20 s in a solution of the following composition; all chemicals shall be reagent grade:

7.5.2.4 *Alclad Diffusion Test*—Diffusion in Alclad products shall be evaluated by microscopic examination of sections through specimens cut from Alclad products or parts representative of a lot or furnace charge. This examination shall establish the extent of diffusion of the alloying constituents into the cladding. For material thicknesses under 0.020 in., this test will not apply. Examination shall be made at 100× magnification, with a metallurgical microscope, after etching, as specified in 7.5.2.3. An approved method for solution potential evaluation for Alclad diffusion is an acceptable alternative.

7.5.3 *Interpretation of Results and Acceptance Criteria*—Test specimens prepared in accordance with 7.5.1 and 7.5.2, as representative of material, heat-treated in accordance with the applicable parts of Section 6, shall meet the requirements specified in Section 7. Failure to meet the specified tensile or metallurgical requirements is reason to disqualify the heat-treating equipment and associated process until the reason for the failure is determined and appropriate corrective action completed and documented.

8. Precision and Bias

8.1 No information is presented about either precision or bias of metallurgical testing for evaluation of eutectic melting

[5] Available from ASM International, Materials Park, OH 44073-0002.

and heat-treat-induced porosity (7.5.2.1), intergranular corrosion (7.5.2.2), or alclad diffusion (7.5.2.4), since the test results are nonquantitative.

9. Keywords

9.1 aluminum alloys; annealing; precipitation heat treatment; solution heat treatment

SUMMARY OF CHANGES

This is a new specification based on the wrought heat-treating provisions of Practice B 597; however, organization and content have been significantly revised to reflect current industry practices and material requirements. The large number of differences precludes a listing of each change.

TABLE 1 Tests Required

Product Form	Tensile Properties[A]	Heat-Treat-Induced Porosity[B] [Periodic Test]	Intergranular Corrosion[C] [Periodic Test]	Diffusion (Alclad Only)[D] [Periodic Test]	Eutectic Melting [Periodic Test]
Plate and sheet	X	X	X[E]	X	X
Wire, rod, bar, and profiles	X	X	X	. . .	X
Forgings	X	X	X	. . .	X
Tubing	X	X	. . .	X	X
Rivets, fastener components	X	X	X	. . .	X

[A] Those specified in the applicable procurement material specification for lot release.
[B] Applicable only to material solution heat-treated in air furnaces.
[C] Applicable to the most quench-sensitive alloys-tempers in the following order of preference: (*1*) 2xxx in -T3 or -T4 and (*2*) 7xxx in -T6 temper. No test is required if 2xxx-T3 or -T4 or 7xxx-T6, was not solution heat-treated during the period since the prior verification test.
[D] Not applicable for thicknesses less than 0.020 in.
[E] Applicable to periodic testing of sheet product only.

TABLE 2 Recommended Heat Treatment for Wrought Aluminum Alloys[A]

	Solution Heat Treatment			Precipitation Heat Treatment[B]		
Product	Metal Temperature, ±10°F[C,D]	Quench Temperature, °F[E]	Temper	Metal Temperature, ±10°F	Time at Temperature, h	Temper
2011 Alloy[A]						
Cold-finished wire, rod, and bar	945-995	110 max	T3[F]	320	14	T8[F]
			T4	. . .	. . .	. . .
			T451[G]	. . .	. . .	. . .
Drawn tube	975	110 max	T3[F]	. . .	. . .	. . .
			T4511[G]			
2014 Alloy[A]						
Flat sheet, bare or Alclad	935	110 max	T3[F]	. . .	. . .	. . .
			T42	320	18	T62
Coiled sheet, bare or Alclad	935	110 max	T4	320	18	T6
			T42	320	18	T62
Plate, bare or Alclad	935	110 max	T451[G]	320	18	T651[G]
			T42	. . .	. . .	. . .
Cold-finished wire, rod, and bar	935	110 max	T4	320	18	T6
				or 350	8	
			T451[H]	320	18	T651[H]
				or 350	8	
			T42	320	18	T62
				or 350	8	
Extruded wire, rod, bar, profiles, and tube	935	110 max	T4	320	18	T6
				or 350	8	
			T4510[H]	320	18	T6510[H]
				or 350	8	
			T4511[H]	320	18	T6511[H]
				or 350	8	
			T42	320	18	T62
				or 350	8	
Drawn tube	935	110 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[I]	340	10	T652[I]
			T4	340	10	T6
2017 Alloy[A]						
Cold-finished wire, rod, and bar	925–950	110 max	T4	. . .	. . .	. . .
			T451[H]	. . .	. . .	. . .
			T42	. . .	. . .	. . .
2018 Alloy[A]						
Die forgings	940–970	212	T4	340	10	T61
2024 Alloy[A]						
Flat sheet, bare or Alclad	920	110 max	T3[F]	375	12	T81[F]
			T361[J]	375	8	T861[J]
			T42	375	9	T62
			T42	375	16	T72
Coiled sheet, bare or Alclad	920	110 max	T4	. . .	. . .	. . .
			T42	375	9	T62
Plate, bare or Alclad	920	110 max	T351[G]	375	12	T851[G]
			T361[J]	375	8	T861[J]
			T42	375	9	T62
Cold-finished wire, rod, and bar	920	110 max	T351[H]	375	12	T851[H]
			T36[J]	. . .	. . .	. . .
			T4	375	12	T6
			T42	375	16	T62
Extruded wire, rod, bar, profiles, and tube	920	110 max	T3[F]	375	12	T81[F]
			T3510[H]	375	12	T8510[H]
			T3511[H]	375	12	T8511[H]
			T42	. . .	. . .	. . .
Drawn tube	920	110 max	T3[F]	. . .	. . .	. . .
			T42	. . .	. . .	. . .
2025 Alloy[A]						
Die forgings	960	140–160	T4	340	10	T6
2117 Alloy[A]						
Cold-finished, wire or rod	925–950	110 max	T4	. . .	. . .	. . .
2124 Alloy[A]						
Plate	920	110 max	T351[G]	350	12	T851[G]

TABLE 2 *Continued*

Product	Solution Heat Treatment: Metal Temperature, ±10°F[C,D]	Solution Heat Treatment: Quench Temperature, °F[E]	Solution Heat Treatment: Temper	Precipitation Heat Treatment[B]: Metal Temperature, ±10°F	Precipitation Heat Treatment[B]: Time at Temperature, h	Precipitation Heat Treatment[B]: Temper
2218 Alloy[A]						
Die forgings	950	212	T4	340	10	T61
2219 Alloy[A]						
Flat sheet, bare or Alclad	995	110 max	T31[F]	350	18	T81[F]
			T37[K]	325	24	T87[K]
			T42	375	36	T62
Plate	995	110 max	T37[K]	350	18	T87[K]
			T351[G]	350	18	T851[G]
			T42	375	36	T62
Cold-finished wire, rod, and bar	995	110 max	T4	375	18	T6
			T351[H]	375	18	T851[H]
Extruded wire, rod, bar, profiles, and tube	995	110 max	T31[F]	375	18	T81[F]
			T3510[H]	375	18	T8510[H]
			T3511[H]	375	18	T8511[H]
			T42	375	36	T62
Die forgings and rolled rings	995	110 max	T4	375	26	T6
Hand forgings	995	110 max	T4	375	26	T6
			T352[I]	350	18	T852[I]
2618 Alloy[A]						
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 Alloy						
Extruded rod, bar, profiles, and tube	. . .[L]	. . .	T1	350	8	T5
6005A Alloy						
Extruded rod, bar, profiles, and tube	. . .[L]	. . .	T1	350	8	T5
6013 Alloy[A]						
Sheet, bare	1055	110 max	T4	375	4	T6
				or 345	8	
Plate, bare	1020–1050	110 max	. . .	345	8–16	T651[G]
Cold-finished wire, rod, and bar	1050	110 max	. . .	375	4	T651[H]
			. . .	375	4	T8[F]
6053 Alloy						
Cold-finished wire and rod	970	110 max	T4	355	8	T61
Die forgings	970	110 max	T4	340	10	T6
6061 Alloy[A]						
Sheet, bare or Alclad	960–1075[M]	110 max	T4	320	18	T6
			T42	320	18	T62
Plate	960–1075	110 max	T451[G]	320	18	T651[G]
			T42	320	18	T62
Tread Sheet and Plate[N,O]	960–1075	110 max	T4	320	18	T6
Cold-finished wire, rod, and bar	960–1075	110 max[P]	T4	340	8	T6
				or 320	18	
			T3[F]	340	8	T89[Q,R]
				or 320	18	
			T4	340	8	T94[S]
				or 320	18	
			T451[H]	340	8	T651[H]
				or 320	18	
			T42	340	8	T62
				or 320	18	
Extruded rod, bar, profiles, and tube	. . .[L]	. . .	T1	350	8	T51
	960–1075[L]	110 max[P]	T4	350	8	T6
			T4510[H]	350	8	T6510[H]
			T4511[H]	350	8	T6511[H]
			T42	350	8	T62
Structural profiles	960–1075[L]	110 max[P]	T4	350	8	T6
Pipe	960–1075[L]	110 max[P]	T4	350	8	T6
Drawn tube	960–1075	110 max	T4	340	8	T6
				or 320	18	
			T42	340	8	T62
				or 320	18	

TABLE 2 *Continued*

Product	Solution Heat Treatment: Metal Temperature, ±10°F[C,D]	Solution Heat Treatment: Quench Temperature, °F[E]	Solution Heat Treatment: Temper	Precipitation Heat Treatment[B]: Metal Temperature, ±10°F	Precipitation Heat Treatment[B]: Time at Temperature, h	Precipitation Heat Treatment[B]: Temper
Die and hand forgings	960–1075	110 max	T4	340	8	T6
				or 320	18	
Rolled rings	960–1075	110 max	T4	350	8	T6
			T452[T]	350	8	T652[T]
			6063 Alloy			
Extruded rod, bar, tube, and profiles	. . .[L]	. . .	T1	400	1 to 2	T5
				or 360	3	
			T1	400	1 to 2	T52
				or 360	3	
	970[L]	110 max[P]	T4	360	6	T6
				or 350	8	
			T42	360	6	T62
				or 350	8	
Drawn tube	970	110 max	T4	350	8	T6
			T3[F]	350	8	T83[R]
			T3[F]	350	8	T831[R]
			T3[F]	350	8	T832[R]
			T31[F]	. . .	. . .	. . .
			T42	350	8	T62
Pipe	970[L]	110 max[P]	T4	360	6	T6
				or 350	8	
			6066 Alloy			
Extruded rod, bar, profiles, and tube	960–1010	110 max	T4	350	8	T6
			T4510[H]	350	8	T6510[H]
			T4511[H]	350	8	T6511[H]
			T42	350	8	T62
Die forgings	960–1010	110 max	T4	350	8	T6
			6070 Alloy			
Extruded rod, bar, profiles, and tube	1015	110 max	T4	320	18	T6
			T42	320	18	T62
			6101 Alloy			
Extruded rod, bare tube, pipe and structural profiles	970[L]	110 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, profiles, and tube	. . .[L]	. . .	T1	350	8	T5
			6110 Alloy			
Cold-finished wire, rod, and bar	980–1050	110 max	T4	380	8	T9[S]
			6151 Alloy			
Die forgings	950–980	110 max	T4	340	10	T6
Rolled rings	960	110 max	T4	340	10	T6
			T452[I]	340	10	T652[I]
			6201 Alloy			
Wire	950	110 max	T3	320	4	T81[R]
			6262 Alloy			
Cold-finished wire, rod, and bar	960–1050	110 max	T4	340	8	T6
			T4	340	8	T9[S]
			T451[H]	340	8	T651[H]
Extruded rod, bar, profiles, and tube	960–1050[L]	110 max	T4	350	12	T6
			T4510[H]	350	12	T6510[H]
			T4511[H]	350	12	T6511[H]
			T42	350	12	T62
Drawn tube	960–1050	110 max	T4	340	8	T6
			T4	340	8	T9[S]
			T42	340	8	T62

TABLE 2 *Continued*

Product	Solution Heat Treatment			Precipitation Heat Treatment[B]		
	Metal Temperature, ±10°F[C,D]	Quench Temperature, °F[E]	Temper	Metal Temperature, ±10°F	Time at Temperature, h	Temper
			6351 Alloy			
Extruded rod, bar, profiles, and tube	. . .[L]	. . .	T1	350	8	T5
				350	8	T51
				250	10	T54
				or 350	8	
	. . .[L]	. . .	T11	. . .	. . .	. . .
	960–1010[L]	110 max[P]	T4	350	8	T6
			6463 Alloy			
Extruded rod, bar, profiles, and tube	. . .[L]	. . .	T1	400	1	T5
				or 360	3	
	970[L]	110 max[P]	T4	350	8	T6
				or 360	6	
			7001 Alloy			
Extruded rod, bar, profiles, and tube	870	110 max	W[U]	250	24	T6
			W510[H,U]	250	24	T6510[H]
			W511[H,U]	250	24	T6511[H]
			W[U]	250	24	T62
			7005 Alloy			
Extruded rod, bar, and profiles	. . .[L]	. . .	T1	room temperature	72 plus	T53
				225	8 plus	
				300	16	
			7049 Alloy			
Extruded rod, bar, and profiles	875	110 max	W511[H,U]	room temperature	48 plus	T76511[H]
				250	24 plus	
				325	12 to 14	
			W511[H,U]	room temperature	48 plus	T73511[H]
				250	24 plus	
				300	12 to 21	
Die and hand forgings	875	140–160	W[U]	room temperature	48 plus	T73
				250	24 plus	
				330	10 to 16	
			W52[I,U]	room temperature	48 plus	T7352[I]
				250	24 plus	
				330	10 to 16	
			7050 Alloy			
Plate	890	110 max	W51[G,U]	250	3 to 6 plus	T7451[G]
				330	24 to 30	
			W51[G,U]	250	3 to 6 plus	T7651[G]
				330	12 to 15	
Cold-finished wire, rod	890	110 max	W[U]	250	4 plus	T7
				355	8 to 12	
Extruded rod, bar, and profiles	890	110 max	W510[H,U]	250	24 plus	T73510[H]
				350	12 to 15	
			W510[H,U]	250	24 plus	T74510[H]
				340	8 to 12	
			W510[H,U]	250	3 to 6 plus	T76510[H]
				315	15 to 18	
			W511[H,U]	250	24 plus	T73511[H]
				350	12 to 15	
			W511[H,U]	250	24 plus	T74511[H]
				340	8 to 12	
			W511[H,U]	250	3 to 6 plus	T76511[H]
				315	15 to 18	
Die forgings	890	140–160	W[U]	250	1 to 6 plus	T74
				350	4 to 12	
Hand forgings	890	140–160	W52[I,U]	250	1 to 6 plus	T7452
				350	4 to 8	

TABLE 2 *Continued*

Product	Solution Heat Treatment			Precipitation Heat Treatment[B]		
	Metal Temperature, ±10°F[C,D]	Quench Temperature, °F[E]	Temper	Metal Temperature, ±10°F	Time at Temperature, h	Temper
			7075 Alloy[A]			
Sheet, bare or Alclad	860–930[V]	110 max	W[U]	250	24	T6
				or 205	4 plus	
				315	8	
			W[U]	225	6 to 8 plus	T73[X]
				325	24 to 30	
				or 225	6 to 8 plus	
				335[W]	14 to 18	
			W[U]	250	3 to 5 plus	T76[X]
				325	15 to 18	
				250	24	T62
			W[U]	or 205	4 plus	
				315	8	
Plate, bare or Alclad	860–930[V,Y]	110 max	W51[G,U]	250	24	T651[G]
				or 205	4 plus	
				315	8	
			W51[G,U]	225	6 to 8 plus	T7351[G,X]
				325	24 to 30	
				or 225	6 to 8 plus	
				335[W]	14 to 18	
			W51[G,U]	250	3 to 5 plus	T7651[G,X]
				325	15 to 18	
			W[U]	250	24	T62
				or 205	4 plus	
				315	8	
Cold-finished wire, rod, and bar	860–930[V,Y]	110 max	W[U]	250	24	T6
			W[U]	225	6 to 8 plus	T73[X]
				350	8 to 10	
			W[U]	250	24	T62
			W51[G,U]	250	24	T651[H]
			W51[G,U]	225	6 to 8 plus	T7351[H,X]
				350	8 to 10	
Extruded rod, bar, profiles, and tube	860–930[V,Y]	110 max	W[U]	250	24	T6
				or 210	5 plus	
				250	4 plus	
				300	4	
			W[U]	225	6 to 8 plus	T73[X]
				350	6 to 8	
				or 225	6 to 8 plus	
				335	14 to 18	
Extruded rod, bar, profiles, and tube			W[U]	250	3 to 5 plus	T76[X]
				325	15 to 18	
			W[U]	250	24	T62
				or 210	5 plus	
				250	4 plus	
				300	4	
			W510[H,U]	250	24	T6510[H]
				or 210	5 plus	
				250	4 plus	
				300	4	
			W510[H,U]	225	6 to 8 plus	T73510[H,X]
				350	6 to 8	
				or 225	6 to 8 plus	
				335[W]	14 to 18	
			W510[H,U]	250	3 to 5 plus	T76510[H,X]
				325	15 to 18	
			W511[H,U]	250	24	T6511[H]
				or 210	5 plus	
				250	4 plus	
				300	4	
			W511[H,U]	225	6 to 8 plus	T73511[H,X]
				350	6 to 8	
				or 225	6 to 8 plus	
				335[W]	14 to 18	
			W511[H,U]	250	3 to 5	T76511[H,X]
				325	15 to 18	

TABLE 2 *Continued*

Product	Solution Heat Treatment: Metal Temperature, ±10°F[C,D]	Solution Heat Treatment: Quench Temperature, °F[E]	Solution Heat Treatment: Temper	Precipitation Heat Treatment[B]: Metal Temperature, ±10°F	Precipitation Heat Treatment[B]: Time at Temperature, h	Precipitation Heat Treatment[B]: Temper
Drawn tube	870	110 max	W[U]	250	24	T6
			W[U]	225	6 to 8 plus	T73[X]
				350	6 to 8	
				or 225	6 to 8 plus	
				335	14 to 18	
			W[U]	250	24	T62
Die forgings	860–900	140–160	W[U]	250	24	T6
			W[U]	225	6 to 8 plus	T73[X]
				350	8 to 10	
			W52[I,U]	225	6 to 8 plus	T7352[I,X]
				350	6 to 8	
			W[U]	225	6 to 8 plus	T74
				350	6 to 8	
Hand forgings	860–900	140 to 160	W[U]	250	24	T6
			W[U]	225	6 to 8 plus	T73[X]
				350	8 to 10	
			W52[I,U]	225	6 to 8 plus	T7352[I,X]
				350	6 to 8	
			W[U]	225	6 to 8 plus	T74
				350	6 to 8	
			W52[I,U]	250	24	T652[I]
Rolled rings	860–900	110 max	W[U]	250	24	T6
			W52[I,U]	250	24	T652[I]
7076 Alloy[A]						
Die and hand forgings	850–910	212	W[U]	275	14	T61
7116 Alloy[A]						
Extruded rod, bar, profiles, and tube	. . . [L]	. . .	W[U]	215	5 plus	T5
				330	5	
7129 Alloy[A]						
Extruded rod, bar, profiles, and tube	. . . [L]	. . .	W[U]	215	5 plus	T5
				320	5	
	900[L]	110 max	W[U]	215	5 plus	T6
				320	5	
7175 Alloy[A]						
Die and hand forgings	880	180	W[U]	225	6 to 8 plus	T74
				350	6 to 8	
			W52[I,U]	225	6 to 8 plus	T7452[I]
				350	6 to 8	
7178 Alloy[A]						
Bare and Alclad sheet	860–900	110 max	W[U]	250	24	T6
			W[U]	250	3 to 5 plus	T76[X]
				325	15 to 18	
			W[U]	250	24	T62
Plate, bare and Alclad	860–900	110 max	W51[G,U]	250	24	T651[G]
			W51[G,U]	250	3 to 5 plus	T7651[G,X]
				325	15 to 18	
			W[U]	250	24	T62
Cold-finished wire and rod	870	110 max	W[U]	250	24	T6
Extruded rod, bar, profiles, and tube	870	110 max	W[U]	250	24	T6
			W[U]	250	3 to 5 plus	T76[X]
				320	18 to 21	
			W[U]	250	24	T62
			W510[H,U]	250	24	T6510[H]
			W510[H,U]	250	3 to 5 plus	T76510[H,X]
				320	18 to 21	
			W511[H,U]	250	24	T6511[H]
			W511[H,U]	250	3 to 5 plus	T76511[H,X]
				320	18 to 21	

[A] For specific aerospace applications, refer to SAE-AMS heat-treating and material specifications.[2]
[B] Typical or nominal time at temperature. Actual practice may vary depending on material requirements.
[C] Recommended soaking times to achieve specified metal temperature appear in Table 3.
[D] Where a temperature range exceeding 20°F is shown, a temperature within that range shall be selected and adhered to within the ±10°F limits. Limits thus derived must lie totally within the range specified.
[E] Unless otherwise indicated, when material is quenched by total immersion in water, the water should be at room temperature and suitably cooled to remain below 110°F during the quenching cycle.
[F] Cold-worked in the solution heat-treated condition, prior to precipitation heat treatment to obtain specified mechanical properties.
[G] Stress-relieved by cold stretching to a permanent set of 1½ to 3 % in the solution heat-treated condition.

H Stress-relieved by cold stretching to a permanent set of 1 to 3 % in the solution heat-treated condition for wire, rod, bar, profiles, and extruded tube, and ½ to 3 % for drawn tubular products.
I Stress relieved by cold compressing 1 to 3 % after solution heat treatment.
J Approximately 6 % cold-worked in the solution heat-treated condition.
K Approximately 7 % cold-worked in the solution heat-treated condition.
L With suitable control of extruding temperature and quench rate, product may be quenched upon emerging from an extrusion press instead of being furnace heat treated.
M For Alclad sheet the maximum temperature is 1000°F.
N "Tread Plate" is a generic term and includes thicknesses below 0.250 in.
O Unused to avoid confusion.
P Upon exiting the solution heat treating furnace, spray quenching may be used on thin sections where substantiated by test results.
Q Unused to avoid confusion.
R Cold-worked in the solution heat-treated condition sufficient to produce the properties specified for this temper upon subsequent precipitation heat treatment.
S Cold-worked after precipitation heat treatment sufficient to produce the properties specified for this temper.
T Stress-relieved by 1 to 5 % cold reduction in the solution heat-treated condition.
U The "W" (as-quenched) condition is an unstable temper and at room temperature will change due to precipitation hardening.
V Under some conditions melting can occur when heating 7075 alloy above 900°F and caution should be exercised to avoid this potential.
W A heat-up rate to 335°F should be 25°F/h.
X The aging of aluminum alloys 7075 and 7178 from any temper to the T73 (applicable to alloy 7075 only) or T76 temper series requires closer than normal controls on aging practice variables such as time, temperature, heating-up rates, and so forth, for any given item. In addition to the preceding, when aging material in the T6 temper series to the T73 or T76 temper series, the specific condition of the T6 temper material (such as its property level and other effect of processing variables) is extremely important and will affect the capability of the re-aged material to conform to the requirements specified for the applicable T73 or T76 temper series.
Y For plate, rod, or bar over 4 in. in thickness or diameter, heat-treat 860 to 910°F.

TABLE 3 Recommended Soaking Time for Solution Heat-Treatment of Wrought Aluminum Alloys

	Soaking Time in Minutes[A]			
	Salt Bath[B]		Air Furnace[C]	
Thickness, in.[D]	Minimum	Maximum[E] (Clad Only)	Minimum	Maximum[E] (Clad Only)
0.016 and under	10	15	20	25
0.017 to 0.020	10	20	20	30
0.021 to 0.032	15	25	25	35
0.033 to 0.063	20	30	30	40
0.064 to 0.090	25	35	35	45
0.091 to 0.124	30	40	40	50
0.125 to 0.250	35	45	50	60
0.251 to 0.500	45	55	60	70
0.501 to 1.000	60	70	90	100
1.001 to 1.500	90	100	120	130
1.501 to 2.000	105	115	150	160
2.001 to 2.500	120	130	180	190
2.501 to 3.000	135	155	210	220
3.001 to 3.500	150	160	240	250
3.501 to 4.000	165	175	270	280
over 4.000	add 15 min/ 0.500 in.		add 30 min/ 0.500 in.	

A Longer soaking times may be necessary for specific forgings. Shorter soaking times are satisfactory when the soak time is accurately determined by thermocouples attached to the load or when other metal temperature-measuring devices are used.
B Soaking time in salt-bath furnaces should be measured from the time of immersion, except when, owing to a large charge, the temperature of the bath drops below the specified minimum; in such cases, soaking time should be measured from the time the bath reaches the specified minimum.
C Soaking time in air furnaces should be measured from the time all furnace control instruments indicate recovery to the minimum of the process range.
D The thickness is the minimum dimension of the thickest section.
E For Alclad materials, the maximum recovery time (time between charging furnace and recovery of furnace instruments) should not exceed 30 min for thicknesses through 0.102 in., 1 h for thicknesses over 0.102 through 1.000 in., and 1.5 h for thicknesses over 1.000 through 2.000 in. Somewhat longer periods may be required for thicker sections.

TABLE 4 Maximum Quench Delay (for Immersion Quenching of All Alloys)

NOTE—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 shall end when the last corner of the load is immersed in the quenchant. 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 Quench Delay 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

TABLE 5 Restrictions for Reheat Treatment of Alclad Products

Thickness, in.	Maximum Number of Reheat Treatments Permissible
Under 0.020	0
0.020 to 0.125	1[A]
Over 0.125	2[A]

[A] One additional reheat treatment is permitted if the heat-up rate is fast enough, such as is achieved in a salt bath or continuous air furnace.

TABLE 6 Recommended Annealing Treatments for Wrought Aluminum Alloys[A]

Alloy	Metal Temperature, ±10°F	Time at Temperature, h	Temper Designation
1060	650	[B]	-O
1100[A]	650	[B]	-O
1350	650	[B]	-O
2014[A]	760[C]	2 to 3	-O
2017[A]	760[C]	2 to 3	-O
2024[A]	760[C]	2 to 3	-O
2117[A]	760[C]	2 to 3	-O
2219[A]	760[C]	2 to 3	-O
3003[A]	775	[B]	-O
3004	650	[B]	-O
3105	650	[B]	-O
5005	650	[B]	-O
5050	650	[B]	-O
5052[A]	650	[B]	-O
5056[A]	650	[B]	-O
5083[A]	650	[B]	-O
5086	650	[B]	-O
5154	650	[B]	-O
5254	650	[B]	-O
5454	650	[B]	-O
5456	650	[B]	-O
5457	650	[B]	-O
5652	650	[B]	-O
6053	765[C]	2 to 3	-O
6061[A]	765[C]	2 to 3	-O
6063	765[C]	2 to 3	-O
6066	765[C]	2 to 3	-O
7001	765[D]	2 to 3	-O
7050[A]	765[D]	2 to 3	-O
7075[A]	765[D]	2 to 3	-O
7178[A]	765[D]	2 to 3	-O

[A] For specific aerospace applications, refer to SAE-AMS heat treating and material specifications.[2]

[B] Time in the furnace need not be longer than necessary to bring the entire load to the prescribed temperature. Rate of cooling is unimportant.

[C] Intended for removal of solution heat treatment (full annealing). Cooling must be performed at a rate of 50°F/h to 500°F. Partial annealing of heat-treated material or removal of effects of cold work may be accomplished by heating to 650°F and cooling in air at an uncontrolled rate.

[D] Intended for full annealing to remove the effects of solution heat treatment. Treatment requires cooling in still air to 400°F or less followed by reheating to 450°F for 4 h and cooling in still air. Partial annealing of heat-treatment material or removal of effects of cold work may be accomplished by heating to 650°F and cooling in air at an uncontrolled rate.