Designation: B947 – 14

Standard Practice for Hot Rolling Mill Solution Heat Treatment for Aluminum Alloy Plate[1]

This standard is issued under the fixed designation B947; 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 establishes the controls required for hot rolling mill solution heat treatment of the 6xxx series aluminum alloy plate in Table 1 when ASTM material specifications allow use of this process instead of furnace solution heat treatment. For the alloys listed in Table 1, this practice is an alternate process to solution heat treatment in a furnace, such as specified in Practice B918 as the preliminary step for the attainment of T651-type tempers (see ANSI H35.1/H35.1M).

1.2 This practice applies only to hot rolling mill solution heat treatment of plate for the listed aluminum alloys. Precipitation hardening (aging), processing, and equipment calibration for aging shall meet the practice and requirements of Practice B918.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.4 *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:*[2]

B209 Specification for Aluminum and Aluminum-Alloy Sheet and Plate

B209M Specification for Aluminum and Aluminum-Alloy Sheet and Plate (Metric)

B557 Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products

B557M Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products (Metric)

B881 Terminology Relating to Aluminum- and Magnesium-Alloy Products

B918 Practice for Heat Treatment of Wrought Aluminum Alloys

E2281 Practice for Process and Measurement Capability Indices

ASTM MNL7 Manual on Presentation of Data and Control Chart Analysis

2.3 *ANSI Standard:*

H35.1/H35.1M Alloy and Temper Designation Systems for Aluminum[3]

2.4 *European Standard:*

EN 485-2 Aluminium and Aluminium Alloys—Sheet, Strip And Plate—Part 2: Mechanical Properties[4]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology B881.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *rolling slab, n*—semi-finished or intermediate product produced by hot rolling which is between ingot and plate form.

3.2.2 *load sensor or load thermocouple, n*—sensors that are attached to the production material or a representation of production material, that supply temperature data of the production material to process or test instrumentation.

4. Equipment

4.1 Aluminum alloy ingots or rolling slabs are preheated prior to being hot rolled as prescribed in 6.2. Controls shall be

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from the Aluminum Association, Inc., 1525 Wilson Blvd. Suite 600, Arlington, VA 22209, www.aluminum.org.

[4] Available from European Committee for Standardization (CEN), 36 rue de Stassart, B-1050, Brussels, Belgium.

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

TABLE 1 Ingot High Limit Temperature[A]

Alloy	Ingot Upper Limit Temperature °F [°C]
6061	1067 [575]

[A] These upper limit temperatures avoid the possibility of eutectic melting due to overheating, and include a safety margin of approximately 13°F [7°C].

adequate to ensure that the equipment is operated in a manner which precludes overheating of the ingot or rolling slab or deleterious contamination by the furnace environment. Metal temperature shall be monitored and controlled to not exceed the maximum temperature shown in Table 1 prior to hot rolling.

NOTE 1—Some aspects of the metallurgical structure of the alloy after solution heat treatment are influenced by the thermal characteristics of the heating equipment used, and the starting microstructure of the ingot. Some heating equipment achieves very rapid temperature rise and may require the metal to be soaked for a period to ensure that sufficient applicable alloying elements are taken into solid solution. This soaking stage may be minimized if the alloying elements are substantially in solid solution prior to charging the metal to the heating equipment (this being accomplished by sufficient prior homogenization/cooling practices).

4.1.1 Automatic or manual control and recording devices used to measure temperature at pertinent points in the heating equipment shall be calibrated as specified in 5.1 and 5.2. Table 2 shows preheat/homogenizing furnace temperature tolerance.

4.2 The hot rolling and quench equipment and controls shall be adequate to ensure that ingots are capable of being hot rolled in accordance with the process requirements for the products being produced, as prescribed in 6.3 and 6.4.

4.3 Equipment for quenching the hot rolled slab may consist of, but is not limited to, water or water/glycol mixture in a standing wave, quench tank, spray, or pressurized water device. Controls shall be adequate to assure that the equipment is operated in a manner which achieves the required quench conditions in Table 3.

5. Equipment Calibration and System Accuracy Tests (SAT)

5.1 *Non-Contact Sensor System (Remote Sensing System) Calibration and SAT:*

5.1.1 *Initial Calibration*—Non-contact sensors shall be calibrated prior to initial use by an ISO 17025 or A2LA (American Association for Laboratory Accreditation) certified laboratory. It may also be certified by the manufacturer if their calibration process is traceable to NIST or national equivalent. Initial calibration shall be within ±6°F [±3°C].

5.1.2 *SAT*—Noncontact sensors must be compared weekly under operating conditions and temperature to the SAT test instrument/sensor (5.3); test sensor must be in contact with the ingot, hot rolled slab, or plate within 3 in. [75 mm] of the focus point of the noncontact sensor (see Note 2). The noncontact sensor must read within ±2°F [±1°C] of the contact pyrometry system; if not, the noncontact sensor system must be adjusted to read within the stated tolerance or an offset in operation must be used to account for the variation and may then be used for production.

TABLE 2 Homogenization and Pre-heat Furnace Temperature Tolerance

Alloy	Pre-heat Oven Temperature Range °F [°C]
6061	±15 [±8]

TABLE 3 Minimum Temperature Entering Quench and Cooling Rate in Quench Zone[A,B]

Alloy	Min Temp Entering Quench °F [°C]	Min Cooling Rate °F/min [°C/min]
6061	870 [466]	600 [316]

[A] The cooling rate is defined as the average temperature drop per unit of time when subjected to a constant cooling system from initial slab temperature, down to 400°F [205°C], forced cooling allowed at a reduced rate down to 350°F [175°C], and cooling continuing to ambient.
[B] These minimum temperatures and cooling rates may be altered when statistical analysis of mechanical property test data substantiates that the material will meet the tensile property requirements of 7.1 and other required material characteristics such as corrosion resistance.

5.2 *Temperature Measuring System Accuracy Test (SAT) for Contact Systems:*

5.2.1 *SAT*—The accuracy of temperature measuring system(s) shall be tested under operating conditions at least once during each week that the facility is used. The test should be made by placing a calibrated test temperature sensing element (5.3) to make contact with the surface (ingot, hot rolled slab, or plate) being measured within 3 in. [75 mm] of the system's sensing element and reading the test temperature sensing element with a calibrated test potentiometer (see Note 2). The contact system must read within ±2°F [±1°C] of the test instrument. If not, the contact system shall be calibrated to read within the stated tolerance or an offset in operation shall be used to account for the variation. Once the adjustment or offset is in use, the system may then be used for production. When the system is equipped with dual potentiometer measuring systems which are checked daily against each other and agree within ±2°F [±1°C], the above checks and corrections shall be conducted at least once every three months.

5.3 *Test Instrument/Sensor for SAT*—The contact pyrometer thermocouple (sensor) and test instrument must be calibrated to a NIST (or equivalent national standard) traceable source before first use and calibrated within three months of use and recalibrated every three months thereafter when used. Calibration error of the instrument shall be no more than ±1°F [±0.6°C] and the sensor shall be within ±2°F [±1°C] or 0.4 % of true temperature (whichever is greater).

NOTE 2—**Warning:** Advice should be sought from the equipment manufacturer to determine precautions necessary when inserting sensing elements to avoid incurring any safety hazards.

5.4 *Preheat/Slab Reheat Furnace Calibration and Temperature Uniformity Survey*—For continuous or batch furnaces, the type of survey and procedures for performing the survey shall be established and documented for each particular furnace or furnace type involved.

5.4.1 A temperature uniformity survey shall be performed before first use and at least each six months thereafter using load thermocouples in each corner that represent the ends and corners as well as the remainder of the ingot or slab. Variation

within and across zones of the furnace should be tested. This shall be done for both the thickest and thinnest ingot or slab being heated. These load thermocouple tests shall be performed at normal production settings; ingot temperature shall meet requirements of Table 2 for the alloy specified.

5.4.2 Test instrument and thermocouples for the temperature uniformity survey must be calibrated to a NIST (or equivalent national standard) traceable source before first use, within one year of use, and annually thereafter. Calibration error of the instrument shall be no more than ±1°F [±0.6°C] and the thermocouple shall be within ±2°F [±1°C] or 0.4 % of true temperature (whichever is greater).

5.5 Control instruments for the furnace shall be calibrated at least annually to a NIST (or equivalent national standard) traceable source. Instruments shall be calibrated to limits of ±2°F [±1°C].

6. Hot Rolling Mill Solution Heat Treat Procedure

6.1 Pertinent control points requiring defined written operating practices, data collection, and record keeping include, but are not limited to:

6.1.1 Ingot homogenization and/or preheat processing time, temperature, and cooling,

6.1.2 Ingot temperature in the heating equipment (6.2),

6.1.3 Ingot temperature upon being charged onto the hot rolling mill (6.2),

6.1.4 Time from ingot discharge from heating furnace to charging of ingot onto the hot mill,

6.1.5 Reduction pass schedule,

6.1.6 Roll speed,

6.1.7 Roll force,

6.1.8 Lubricant spray practices,

6.1.9 Reaction plan for delays on the hot line which deviate from hot mill practice (shall include time allowed between passes in the mill, allowable slab temperature range between passes, or both),

6.1.10 Material temperature at quench entry (6.3),

6.1.11 Material temperature at completion of quench,

6.1.12 Quench media temperature,

6.1.13 Quench rate (6.4), and

6.1.14 System reaction to unplanned interruptions (warning lights/audible alarms, system interlocks, records).

NOTE 3—Some of these time or temperature measurements (other than items in 6.1.3, 6.1.10, 6.1.11, 6.1.13, and 6.1.14) may be omitted if it has been demonstrated (and documented) that they are not essential to achieving an appropriate degree of process control.

6.2 Ingot shall be heated to a temperature appropriate for the alloy and shall not exceed the maximum temperatures listed in Table 1 (see Note 4). Table 2 shows the maximum allowable preheat/homogenizing furnace temperature tolerance. If a remote temperature sensing system is used and has a known error which exceeds ±2°F [±1°C], then the permitted upper bound shown in Table 1 shall be adjusted by an amount to ensure that the true metal temperature does not exceed the upper limit shown, or the instrument shall be recalibrated in accordance with 5.1.

NOTE 4—The surface temperature of a ingot may differ significantly from its interior temperature. Temperature sensing devices may give instantaneous values at a specific point, or give average values over time or over an area. Note that gradients may differ between various heating equipment.

NOTE 5—The minimum starting ingot temperature is at the producer's option. This is due to state of the art in roll speed control and reduction capabilities. Documented Work Instructions shall be developed for each product thickness/alloy group (as established by the producer).

6.3 *Minimum Temperatures:*

6.3.1 The minimum slab temperature upon entering the quench zone or chamber shall not be less than the temperature shown for the alloy in Table 3.

6.3.2 Any rolled product that does not meet temperature requirements of 6.3.1 shall be either furnace solution re-heat treated in accordance with Practice B918, or scrapped. Material from the same slab shall not be sorted by testing individual sections of the slab. Where practices exist for cropping material at start or end of slab, these portions shall be excluded from testing requirements.

6.4 The minimum cooling or quench rate of the slab in the quench zone or chamber shall conform to Table 3. The cooling equipment shall be operated in a manner to preclude reheating of the slab.

6.5 For precipitation hardening (aging) and equipment calibration thereof, the requirements of Practice B918 shall be met.

7. Process Capability and Quality Assurance

7.1 *Demonstration of Process Capability*—Before production of product for buyers, each product range shall be qualified by tensile and metallurgical testing of hot rolling mill solution heat treated samples (after subsequent processing; in other words, aging) to clarify the alloy to be qualified. The producer's process shall have been proven, with documented evidence of statistically verified capability, to produce product in various product thicknesses which conform to required mechanical property minimums or limits. Methods to demonstrate statistical capability are defined in Practice E2281. Appropriate models shall be used for representation of the data as well as the generation of control charts. For further information see Manual ASTM MNL7A. Use of MMPDS methods for establishing capability is also acceptable.

7.1.1 Mechanical Properties shall be determined in accordance with Test Method B557 or B557M.

7.1.1.1 During initial qualification, tensile samples shall be excised from both ends and from both sides from at least three lots of the as rolled product after quenching and subsequent aging and stretching, if applicable, to qualify the process. A minimum of ten samples shall be extracted from each lot, three samples from each end (both sides and the center), and two samples from each side of the plate, approximately ⅓ the distance from each end. The intent is to get a full spectrum of samples from the process to insure the material is uniform in mechanical properties. Sample type, thickness location and orientation shall be as specified in Test Method B557 or B557M.

7.1.1.2 *Sample Thickness*—Tensile tests shall be representative of the thinnest and the thickest material to be heat treated; intermediate thickness samples shall be included when necessary to ensure proper production hot rolling mill solution heat treatment.

7.1.1.3 *Equipment Requalification*—Whenever any qualified equipment is changed or reworked, it shall be requalified unless it is known that the change or rework will not have a detrimental effect upon the properties of products.

Examples of changes requiring requalification are:

(1) Change in quench nozzle type, design, or orientation,

(2) Change in quench flow rates of greater than ±5 % of rate previously qualified,

(3) Change in documented process minimum temperature allowed for material entering quench,

(4) Change in quenchant material or specified solution range, and

(5) Change in length of roll-out table.

7.1.2 Cross sections of the produced plate shall be made and prepared for micro- and macro-scopic examination during qualification. Size, distribution, and uniformity of precipitate should be indicative of properly solution heat treated and quenched structure. These cross sections shall be stored for comparison in the event of problems or periodic surveillance testing in the future. Accurate photographic images or digital images may be stored in lieu of retaining the material sections.

7.2 *Quality Assurance*—Heating, hot rolling, and quenching facilities operated in accordance with documented procedures shall have a demonstrated ongoing capability for producing material meeting applicable material specification requirements for each product type and alloy and temper produced.

7.2.1 *Mechanical Properties*—Mechanical Properties, once all subsequent thermal processing is complete, shall conform to the mechanical property requirements of the applicable material specifications for the alloy-temper-thickness combination (for example, 6061 values can be found in Table 3 of Specification B209 or Table 33 of EN 485-2). Tensile test specimens shall be excised from the center of both the leading and trailing edges of the product as it was processed through the quench. Material may be removed to obtain a clean edge before samples are taken.

7.2.2 *Nondestructive Testing*—For documentation of process capability, and as part of process qualification, hardness test values and/or eddy current/conductivity test values may be used as supplemental indicators of mechanical properties. These checks may be used as nondestructive screening methods in process surveillance checks, and may be complimentary to, but shall not be substituted for tensile test minimum requirements. Such nondestructive testing may be included in lot release criteria, but must be in conjunction with tensile property testing.

7.2.3 *Statistical Significance of Material Property Data*—Though different statistical techniques may be found useful in the analysis of mechanical property data, sufficient mechanical property test data should be accumulated to adequately determine the statistical characteristics of the process using accepted conventions.

7.2.4 *Use of Production Test Results*—The results of tests to determine conformance of heat-treated material to the requirements of the respective material specification are acceptable as evidence of process surveillance of the equipment and procedure employed.

7.2.5 *Process Disqualification*—Inability to conform to 7.2.1 shall result in process disqualification. The process shall remain disqualified until corrective action is taken and its effectiveness is substantiated through conformance to those sections.

7.2.6 *Records*—Records and material test reports shall be maintained for each hot rolling mill and quenching facility involved in the production of hot rolling mill solution heat treated material to show compliance with this practice. The records shall include identification of the specific hot rolling mill and associated equipment involved, which includes metal heating and quenching equipment, the frequency and results of each calibration of measurement equipment or instrument used for control, and the dates and description of equipment repairs or alteration. Records and material test reports shall be maintained for a minimum of three years after the inspection or test.

8. Keywords

8.1 aluminum alloys; hot rolling; hot rolling mill solution heat treatment; slab; solution heat treatment

SUMMARY OF CHANGES

Committee B07 has identified the location of selected changes to this standard since the last issue (B947 – 06 (2013)) that may impact the use of this standard. (Approved Dec. 1, 2014.)

(1) The temperature limit in Table 1 has been increased and the footnote has been revised.

(2) In 5.5, the temperature of 1.1°C has been changed to 1°C in order to be consistent with other conversions of 2°F in the standard.

(3) The Celsius temperatures in Table 3 for both the min temper entering quench and min cooling rate have been corrected.

(4) In Section 6, Note 3, the reference to the non-existent subsection 6.1.15 has been removed.

(5) In the footnote of Table 1, “safety factor” has been replaced by “safety margin.”

(6) References to H35.1 have been changed to H35.1/H35.1M with availability from the Aluminum Association.

(7) Table 2 and Table 3 have been renumbered to be aligned with the order that they are referred to in the text.