SAE Aerospace
An SAE International Group

AEROSPACE MATERIAL SPECIFICATION

AMS 2772D

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Superseding AMS 2772C

Heat Treatment of Aluminum Alloy Raw Materials

RATIONALE

AMS 2272D adds heat treating parameters for alloys 2013, 2027, 2056, 2099, 7036, 7040, 7055, 7136, 7249, 7349, and 7449, eliminates the 18-month moratorium on mandatory response to aging practices (previously 4.5.1), and in Table 1 adds footnote 9 which specifically excludes rolling mill quenched and extrusion press quenched products from the applicability of this specification.

1. SCOPE

1.1 Purpose

This specification covers requirements and recommendations for the heat treatment of wrought aluminum alloy raw materials (See 8.2.1) by producers. It supersedes AMS-H-6088 and replaces MIL-H-6088.

1.1.1 Tempers

Aluminum alloy tempers are described in SAE AS1990 and ANSI H35.1.

1.1.2 Other Alloys

This specification may be used for alloys other than those specified herein providing temperatures, times, and quenchant are specified.

1.1.3 Other Heat Treatment

1.1.3.1 Parts (See 8.2.2)

Made from wrought raw material shall be heat treated in accordance with AMS 2770.

1.1.3.2 Castings and Parts Made from Castings

Are not covered by this specification; heat treatment of aluminum castings and parts made from such castings is covered by AMS 2771.

1.1.3.3 Temper Conversion

Warehouses, distributors etc. shall conform to 3.8.

1.1.3.4 Procedure for Response-to-Heat-Treatment Tests

Shall conform to 3.9.

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2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AMS 2750	Pyrometry
AMS 2770	Heat Treatment of Wrought Aluminum Alloy Parts
AMS 2771	Heat Treatment of Aluminum Alloy Castings
AMS-H-6088	Heat Treatment of Aluminum Alloys
ARP1962	Training and Approval of Heat Treating Personnel
AS1990	Aluminum Alloy Tempers

2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM STP 15D	Manual on Presentation of Data and Control Chart Analysis
ASTM B 557	Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products
ASTM B 557M	Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products (Metric)
ASTM B 666/B 666M	Identification Marking of Aluminum and Magnesium Products
ASTM G 110	Evaluating Intergranular Corrosion Resistance of Heat Treatable Aluminum Alloys by Immersion in Sodium Chloride + Hydrogen Peroxide Solution

2.3 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

MIL-H-6088	Heat Treatment of Aluminum Alloys
MIL-STD-1537	Electrical Conductivity Test for Verification of Heat Treatment of Aluminum Alloys, Eddy Current Method

2.4 ANSI Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036, Tel: 212-642-4900, www.ansi.org.

ANSI H35.1	American National Standard Alloy and Temper Designation Systems for Aluminum

2.5 Battelle Publications

Available from Battelle, 505 King Ave, Columbus, OH 43201 or www.mmpds.org.

MMPDS	Metallic Materials Properties Development and Standardization (MMPDS)

3. TECHNICAL REQUIREMENTS

3.1 Equipment Qualification

Before production heat treatment, each solution heat treating furnace/quench facility and each aging furnace shall be qualified by tensile and metallurgical testing (See 4.4) of heat treated samples representative of the most quench-sensitive (See 4.3.2.5.1) product to be heat treated. In addition, qualification of quench facilities shall include conformance to 4.3.

3.1.1 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 heat treatment. Thickness for metallurgical tests shall conform to 4.4.

3.1.2 Sample Locations

Samples shall be randomly positioned in simulated production loads except at least one of the tensile test samples shall be positioned at a location which exhibited a conductivity within 0.3% of the highest conductivity in a quench uniformity test.

3.1.3 Equipment Re-Qualification

Whenever any qualified equipment is changed or reworked, it shall be re-qualified unless it is known that the change or rework will not have a detrimental effect upon the properties of products. Re-qualification of quench facilities shall include conformance to 4.3.

3.2 Pyrometry

Shall conform to AMS 2750 except (1) it is not applicable to furnaces used only for stress relieving or full annealing below 825 °F (441 °C), (2) recordings from instruments may be stored on magnetic or optical media providing a hard copy is producible on request, and (3) in continuous and semi- continuous furnaces, the requirements applicable to controls, instruments, and sensors in the working (soaking) zone shall also be applicable to the heating (heat-up) zone.

3.2.1 The temperature uniformity test requirements of AMS 2750 shall be modified as follows:

3.2.1.1 Load Condition

Initial tests shall be performed with a typical load. Subsequent tests may be performed with any load or no load. Furnaces which have only been tested with a heavy load (in anticipation of only heat treating heavy loads) (See 8.2.9) shall not be used to heat treat light loads unless load sensors and recording instruments are employed to (1) preclude any portion of the load exceeding the maximum specified temperature on heat-up and (2) ensure soaking within the specified range for the required time.

3.2.1.2 Load Sensors

When all production loads are heavy (See 8.2.9) and a temperature uniformity test load is heavy, load sensors may be used in lieu of uniformity test sensors.

3.2.1.3 Loaded Furnaces

During the heat-up portion of uniformity tests performed on a loaded batch furnace and during the period that a load is in the heating (heat-up) zone(s) of continuous and semi-continuous furnaces, the temperature of the heating medium may exceed the maximum of the range being tested providing that the metal temperature does not exceed that maximum.

3.2.1.4 Uniformity Requirements

During the test period, the temperature of all working and test sensors in the working (soaking) zone shall be within the following allowable ranges (these ranges supersede the ± temperature tolerances specified in AMS 2750):

3.2.1.4.1 50 °F (28 °C) range for furnaces used only for full annealing at 825 °F (441 °C) and higher. Annealing temperatures shall be controlled so as to preclude any material exceeding the lowest solution heat treating temperature for the alloy being annealed.

3.2.1.4.1.1 For furnaces used only for full annealing below 825 °F (441 °C) and for stress relieving, there are no temperature uniformity requirements.

3.2.1.4.2 30 °F (17 °C) range for furnaces used only for solution heat treatment of those 6xxx alloys for which Table 1 specifies a range of 30 °F (17 °C) degrees or more.

3.2.1.4.3 20°F (11°C) range for furnaces used for solution heat treatment of 6xxx alloys for which Table 1 specifies a range of less than 30°F (17°C).

3.2.1.4.4 20 °F (11 °C) range for furnaces used for solution heat treatment of other alloys except 10 °F (6 °C) range for furnaces used for solution heat treatment of 8090 sheet.

3.2.1.4.5 20 °F (11 °C) range for furnaces used for aging treatments.

3.2.1.4.6 20 °F (11 °C) range for furnaces used for processing to the -O1 temper.

3.3 Heating Media for Solution Heat Treatment

Shall be air, protective atmosphere, combusted gases, molten salt bath, or fluidized bed. However, no protective atmosphere, combusted gas or fluidized bed environment shall be used unless it has been shown by test (in accordance with 4.4.1.1), on the alloy/form to be heat treated, to yield product which is free from heat treat induced porosity. Composition of salt baths and fluidized beds shall be maintained to prevent attack of the product.

3.4 Preparation for Heat Treatment

3.4.1 Cleanliness

Prior to heat treating, product shall be free from surface contaminants which could have a detrimental effect on the material.

3.4.2 Racking and Spacing

During solution heat treatment, product shall be supported or hung and spaced to permit flow of the heating and cooling media over all surfaces to ensure that all product will meet the specified requirements. During aging, product shall be supported or hung and spaced so that it will be heated and soaked as required to meet the specified requirements.

3.4.2.1 Load arrangement shall be validated by heat treatment of a similarly arranged load (See 8.2.10) containing one or more appropriately placed load sensors which show that all product will be soaked within the specified temperature range for a time which has been previously shown, by tensile tests, to produce the specified properties (not required for load arrangements which have been previously validated in accordance with MIL-H-6088, AMS-H-6088 or a previous issue of AMS 2772). Written instructions, drawings, photographs, or other illustrations shall be used to ensure proper load arrangements.

3.4.2.2 Thin Forgings

Random racking (not nested) or layering of forgings, 1-inch (25-mm) and under in thickness is permissible for (1) solution heat treating (providing quenching is by immersion), (2) aging, and (3) annealing, providing product so racked has been demonstrated by test to meet the specified requirements. Layer thickness shall not exceed three inches (76 mm) and distance between layers shall be at least three inches (76 mm) (not required for load arrangements which have been previously validated in accordance with MIL-H-6088, AMS-H-6088, or a previous issue of AMS 2772).

3.5 Temperatures

3.5.1 Furnace temperatures shall be controlled so as to ensure that the metal temperature does not exceed the maximum of the range.

3.5.1.1 When a load is charged into a batch furnace whose indicated temperature is higher than the maximum of the specified range, a recording load sensor, in contact with the thinnest material on the outside of the load, shall be used to verify that the metal temperature did not exceed the maximum of the range.

3.6 Solution Heat Treatment

3.6.1 Product shall be soaked, in accordance with 3.6.2, within the temperature range specified in Table 1 and quenched as specified in 3.6.3. Quenching directly from a furnace or salt bath is required. Extrusion press quenching (see 8.2.6) and rolling mill quenching (see 8.2.7) are not permitted by AMS 2772.

3.6.2 Soaking

3.6.2.1 Start

Soaking time shall start when the readings of all load sensors indicate that the temperature of the load has reached the minimum of the required temperature range. Alternatively, determination that the temperature of the load has reached the minimum of the required temperature range (start of soaking time) may be based on readings of furnace instruments providing the lag between their readings and load temperature has been determined in a similarly arranged load.

3.6.2.2 Duration

The load shall be maintained within the required temperature range for a time which has been previously shown, by tensile tests, to produce the specified properties (not required for soaking times which have been previously validated in accordance with MIL-H-6088, AMS-H-6088 or a previous issue of AMS 2772). Recommended soaking times are listed in Table 2.

3.6.2.3 During soaking in a semi-continuous air furnace, a drop in temperature indicated by furnace instrument(s) is permissible providing that:

3.6.2.3.1 The temperature indicated by any instrument does not drop more than 20 °F (11 °C) below the minimum of the specified range.

3.6.2.3.2 Time below the minimum of the specified range does not exceed five minutes.

3.6.2.3.3 Soaking is continued for not less than 10 minutes after recovery to the minimum of the solution heat treatment temperature range before quenching.

3.6.2.3.4 If furnace temperature does not drop more than 20 °F (11 °C) below the minimum of the specified range, but does not recover to the minimum of the specified temperature range within five minutes, the total soaking time within the specified range shall be increased; if less than one hour was required, it shall be increased by one-half hour; if one hour or more was required, it shall be increased by one hour.

3.6.3 Quenching (See 4.3, 8.2.6, and 8.2.7)

2xxx and 7xxx alloy forgings shall be quenched by immersion. Quenching of other forms of 2xxx and 7xxx alloys and all forms of other alloys shall be by immersion, spray or, in a suitable chamber, by air blast.

3.6.3.1 Quenchant

For immersion and spray quenching shall be water or an aqueous solution of a residual stress/distortion reducing additive such as polymer.

3.6.3.2 Quench Conditions

Quenchant volume, velocity, distribution and agitation (of quenchant and/or product) shall be sufficient to ensure that all products will meet specified requirements after aging. Quenchant temperature shall conform to 3.6.3.5. The additive, concentration and specific temperature used for each load shall be supported by analysis of data verifying that the specified properties are achieved after aging (not required for additives/concentrations/temperatures previously valid in accordance with AMS-H-6088, MIL-H-6088, AMS 2770 or a previous issue of AMS 2772).

3.6.3.3 Quench Delay

For immersion quenching shall conform to Table 3. For air blast and spray quenching, maximum allowable quench delays shall be established based on tests of tensile properties and, for 2xxx and 7xxx sheet, wire and extrusion under 0.250 inches (6.35 mm) thick, tests for susceptibility to inter-granular corrosion (See 4.4.1.2).

3.6.3.4 Rinsing

Product heat treated in salt bath furnaces and product quenched in an aqueous solution of polymer shall be rinsed as necessary to ensure that it will be free from corrosion and detrimental foreign materials

3.6.3.5 Quenchant Temperature

3.6.3.5.1 Forgings and Impact Extrusions

3.6.3.5.1.1 Quenchant - Water, with or without a Non-Polymer Additive

Recommended quenchant temperature ranges are 140 to 180 °F (60 to 82 °C) for 2014 and 2024 alloys and 140 to 160 °F (60 to 71 °C) for other alloys except, when final temper of T41 or T61 temper is specified, immersion quenching in boiling water is required.

3.6.3.5.1.2 Quenchant - Water with a Polymer Additive

Quenchant temperature shall not exceed 130 °F (54 °C) at the completion of the quench.

3.6.3.5.2 Immersion Quenching of Other Forms of 2xxx and 7xxx Alloys

If the quenchant is water or an aqueous solution of a non-polymer additive, quenchant temperature shall not exceed 100 °F (38 °C) at the start of quench and 110 °F (43 °C) at the completion of the quench (See 3.6.3.7). If the quenchant is an aqueous solution of polymer, quenchant temperature shall not exceed 130 °F (54 °C) at the completion of the quench.

3.6.3.5.3 Spray Quenching of Other Forms of 2xxx and 7xxx Alloys

The quenchant temperature is not restricted but the quenchant temperature used shall be supported by analysis of data in accordance with 3.6.3.2.

3.6.3.6 Salt Contamination in Aqueous Solutions of Additives

When an aqueous solution of additive is used for quenching product heat treated in a salt bath furnace, salt contamination in the quenchant shall not exceed 6% by weight.

3.6.3.7 Immersion Quench Completion

Product under 0.250 inch (6.35 mm) in thickness shall remain in the quenchant at least until boiling emanating from the product (not the rack) ceases. Product 0.250 inch (6.35 mm) and over in thickness shall remain in the quenchant for not less than two minutes per inch (25 mm) of thickness, or fraction thereof, or for not less than two minutes after boiling ceases.

3.6.3.8 Other Quench Completion

Product quenched by spray or air blast shall remain in contact with the quenchant until the temperature of the product is below the boiling point of water.

3.6.4 Restrictions on Alclad Products

3.6.4.1 Heat-Up Time

The time required for sheet material to reach the minimum of the specified temperature range shall not exceed 30 minutes for thicknesses up to 0.049 inch (1.24 mm), 60 minutes for thicknesses from 0.050 to 0.101 inch (1.27 to 2.57 mm) and 120 minutes for thicker sheet or for plate.

3.6.4.2 Soaking Time

To ensure all lots will develop specified properties after aging, soaking time shall be established in accordance with 3.6.2. However, the total soaking time used for any lot (single or multiple solution heat treatments) should be limited to the minimum necessary to ensure that the product will meet the specified requirements.

3.6.4.3 Re-Solution Heat Treatment of Alclad 2xxx and 7xxx Sheet and Plate

Product thinner than 0.020 inch (0.51 mm) shall not be re-solution heat treated. Sheet thicknesses from 0.020 to 0.125 inch (0.51 to 3.18 mm) inclusive shall not be re-solution heat treated more than once. Product thicker than 0.125 inch (3.18 mm) shall not be re-solution heat treated more than twice.

3.6.4.4 The restrictions of 3.6.4.1 and 3.6.4.3 are not applicable to any lot of product which is tested to ensure conformance to the alclad thickness requirement of the material specification.

3.7 Aging

3.7.1 Recommended aging temperatures and times are shown in Table 4. Alternate temperatures and times may be used provided the aged material meets the specified requirements.

3.8 Temper Conversion

3.8.1 When a warehouse, distributor or similar organization, or its vendor, converts raw material to a different temper in accordance with this specification or AMS-H-6088 or MIL-H-6088, the following provisions shall apply:

3.8.1.1 The heat treatment of the raw material and any heat treatment of samples for heat-treatment- response tests shall conform to the technical requirements and quality assurance provisions of AMS 2770. For products not included in the Tables in AMS 2770, the temperatures and times of Tables 5 or 6 shall be used.

3.8.1.2 The converted product shall be tested in accordance with the requirements of the applicable material specification.

3.8.1.3 Any original mill marks shall be removed and the product shall be re-identified in accordance with ASTM B 666/B 666M; the new identification shall ensure traceability to the warehouse/ distributor's records showing the original producer, the lot number and the converting organization.

3.8.1.4 The report to the purchaser shall include certification of conversion to the new temper, the conversion heat treatment procedure, the test results for the converted product and the original mill certification.

3.9 Procedure for Response-to-Heat-Treatment Tests

When a material specification or other procurement document requires heat treatment of samples to demonstrate response to user heat treatment (e.g., heat treatment of -O or -F temper material to -T42 or -T62 temper), the procedure used by producers, forge shops or warehouses/distributors and their vendors shall include conformance to the mandatory set temperatures and times in Tables 5 and 6 (See 4.5.1).

3.10 Recommended Annealing Times, Temperatures and Cooling Rates

3.10.1 1xxx, 3xxx, and 5xxx Series Alloys Except 3003

Heat to 650 °F (343 °C); cooling rate optional.

3.10.2 3003 Alloy

Heat to 775 °F (413 °C); cooling rate optional.

3.10.3 2xxx and 6xxx Series Alloys Except 6013

Soak for two to three hours at 760 °F (404 °C); cool at rate of 50°F (28°C) per hour or slower to 500 °F (260 °C); further cooling rate optional.

3.10.4 6013 Alloy

Soak for two to three hours at 775 °F (413 °C); cool at rate of 50 °F (28 °C) per hour or slower to 500 °F (260 °C); further cooling rate optional.

3.10.5 7xxx Series Alloys

Soak for two to three hours at 760 °F (404 °C); cool to 400 °F (204 °C) or lower, reheat to 450 °F (232 °C), and soak for four hours; cooling rate optional.

3.11 Processing to -O1 Temper

Shall consist of heating product to the temperature range shown in Table 1 followed by an air cool.

3.12 Personnel Training

A company performing heat treating shall have a verifiable program (either company-created or conforming to ARP1962) of initial and periodic training and evaluation of its personnel. The training program shall consist of one or more of the following: on-the-job training, classroom instruction, academic instruction. The evaluation shall be based on education, experience and training results.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

4.1.1 The supplier (producer or other agency defined in 3.8.1) or its designee is responsible for the performance of all inspections and specified tests.

4.2 Records

4.2.1 Retention

Records of all inspections and tests shall be kept available for review for five years after the inspection or test. Records of all applicable production parameters, e.g., racking, time, temperature, quenchant temperature and pressure, and quench delay shall be kept available for review for five years after heat treatment.

4.3 Equipment Used for Air Blast, Spray and Immersion Quenching of 2xxx and 7xxx Series Alloys

4.3.1 Effectiveness of Quench (See 4.3.3)

Shall be demonstrated by tensile tests upon initial installation (not required for equipment previously qualified in accordance with AMS-H-6088, MIL-H-6088 or a previous issue of AMS 2772). The effectiveness of quench shall also be demonstrated by tensile tests after any modification which could reduce the quenching effectiveness. Some examples of modifications for which the need for testing should be evaluated are nozzle size change or arrangement, reduction of spacing between pieces, manifold size change, pump size change, and change of quenchant type or manufacturer. Tensile properties shall meet the requirements of the material specification or the drawing.

4.3.1.1 Load Selection and Configuration

A load of sheet(s), plate(s), forgings, extrusions, rods, or bars (See 4.3.3), sufficiently large to evaluate the entire quench facility and conforming to the following, shall be selected and quenched in the equipment:

4.3.1.1.1 Alloy Selection

Shall be in accordance with the following order of preference: (1) 7x75, (2) 7xxx, (3) 2xxx.

4.3.1.1.2 Thickness

Shall be representative of the maximum thickness of product (of the alloy selected) to be heat treated.

4.3.1.2 Procedure

Tensile specimens shall be full thickness or located and oriented as required by the material specification or the forging/extrusion drawing. They shall be excised from the product or sample (See 4.3.3) before or after aging to the final temper and shall be tested in accordance with ASTM B 557 or ASTM B 557M. The number of specimens and locations shall be as follows:

4.3.1.2.1 Immersion Quenched Loads

Specimens shall be taken from one piece, or 10% of the pieces, whichever is greater, from random locations in the load.

4.3.1.2.1.1 Sheet(s) or Plate(s)

Specimens shall be taken at both ends and the mid-length, from four locations across the width of the load. The centers of the outer specimens shall be between 6 inches (152 mm) and 9 inches (229 mm) from the edge of the load and the spaces between the specimens shall be approximately equal.

4.3.1.2.1.2 Extrusions, Rods or Bars

Specimens shall be taken at both ends of the pieces selected.

4.3.1.2.1.3 Forgings

Specimens shall be taken from each of the pieces selected.

4.3.1.2.1.4 Additional Specimen

At least one of the above specimens shall represent a location which exhibited a conductivity within 0.3% of the highest conductivity in the most recent quench uniformity test or an additional specimen shall be taken to represent such a location.

4.3.1.2.2 Air Blast and Spray Quenched Loads

4.3.1.2.2.1 Continuously Quenched Sheet or Plate (See 8.5)

Specimens shall be taken at both ends from four locations across the width of the load. The centers of the outer specimens shall be between 6 inches (152 mm) and 9 inches (229 mm) from the edge of the load and the spaces between the specimens shall be approximately equal.

4.3.1.2.2.2 Non-Continuously Quenched Sheet or Plate (See 8.5)

Specimens shall be taken at both ends and the mid-length, from four locations across the width of the load. The centers of the outer specimens shall be between 6 inches (152 mm) and 9 inches (229 mm) from the edge of the load and the spaces between the specimens shall be approximately equal.

4.3.1.2.2.3 Extrusions, Rod or Bar

Specimens shall be taken from product located at both ends of the load, at 6 to 12-inch (152 to 305-mm) intervals across the width of the load.

4.3.2 Uniformity of quench of product shall be demonstrated by conductivity tests upon initial installation (not required for equipment previously qualified in accordance with MIL-H-6088, AMS-H-6088 or a previous issue of AMS 2772). The uniformity of quench shall also be demonstrated by conductivity tests after any modification, which could reduce the quenching uniformity. Some examples of modifications for which the need for testing should be evaluated are nozzle size change or arrangement, reduction of spacing between pieces, manifold size change, pump size change, and quenchant change.

4.3.2.1 In addition, the uniformity of quench shall be tested (1) weekly for spray and air blast quenching and (2) monthly for immersion quenching.

4.3.2.2 Uniformity of quench tests are not required for equipment used exclusively for quenching of (1) sheet, (2) wire, rod and round tube under 0.750 inch (19 mm) diameter or (3) all forms of 6xxx alloys.

4.3.2.3 Pressure or Flow

Shall be inspected and recorded daily during production to ensure proper operation.

4.3.2.4 Alternate Inspection

In lieu of the periodic uniformity of quench test (4.3.2.1) and the daily pressure or flow inspection (4.3.2.3), it is permissible to substitute the following:

4.3.2.4.1 Daily Inspection

During production, quenchant flow rate, plus flow direction if variable, shall be inspected daily to ensure that they remain consistent with those conditions at the time of a previous uniformity of quench test. A daily record of the observed values shall be maintained. Flow rate for air blast quenching shall be measured by fan rpm or equivalent; flow rate for spray quenching shall be accomplished by direct or remote visual inspection of nozzle spray or by measurement of nozzle output pressure or equivalent; flow rate for immersion quenching shall be measured by flow meters, pump or propeller rpm or equivalent. Flow direction shall be inspected visually.

4.3.2.5 Load Selection and Configuration

A load of sheet(s), plate(s), forgings, extrusions, rods, or bars (See 4.3.3), sufficiently large to evaluate the entire quench facility and conforming to the following, shall be selected and quenched in the equipment:

4.3.2.5.1 Alloy Selection

Order of preference shall be in accordance with the order of quench sensitivity as follows: (1) 7x75 or 2x24, (2) other 7xxx, (3) other 2xxx, (4) other.

4.3.2.5.2 Thickness

Shall be the maximum (of the alloy selected) available within 24 hours of the time of selection for test, except that testing during each calendar quarter shall include the thickest material of the most quench-sensitive alloy (See 4.3.2.5.1) of each form solution heat treated during that quarter.

4.3.2.6 Procedure

The electrical conductivity of the product or sample (See 4.3.3) in the -W, -T3, or -T4 temper shall be tested (before or after stretching, compressing, forming or straightening) using equipment calibrated in accordance with MIL-STD-1537. Tests of 7075 product shall not be started until a minimum of 10 hours of room temperature aging have elapsed.

4.3.2.6.1 Sampling (See 4.3.3)

4.3.2.6.1.1 Immersion Quenched Loads

The sample shall consist of one piece, or 10% of the pieces, selected at random, whichever is greater.

4.3.2.6.1.2 Air Blast and Spray Quenched Loads

The sample shall consist of all pieces in the load. For extrusion, rod, and bar; the sample pieces shall be arranged in a single plane.

4.3.2.6.2 Test Location Spacing

4.3.2.6.2.1 Plate

Maximum distance between test locations shall be four inches (102-mm) on a line across the width; maximum distance between the lines shall be 24 inches (610-mm) along the length.

4.3.2.6.2.2 Extrusion, Rod and Bar

Maximum distance between test locations shall be 12 inches (102 mm) on a line across the width and two inches (51 mm) around the product section perimeter; maximum distance between the lines shall be 24 inches (610 mm) if air blast or spray quenched and 48 inches (1219 mm) if immersion quenched.

4.3.2.6.2.3 Forgings

When possible, distance between test locations on surfaces of forgings shall be 2 inches (51 mm) or less; when 2-inch (51-mm) spacing is precluded by the forging configuration, spacing shall be the minimum possible.

4.3.2.6.3 Minimum Length/Quantity of Product to be Tested

4.3.2.6.3.1 Immersion and Continuously Quenched (See 8.5) Loads

For initial and equipment modification tests (See 4.3.2), the entire load shall be tested. For periodic tests, if the load is longer than 24 feet (7.4 m), a minimum of 12 feet (3.7 m) shall be tested at each end; if the load is 24 feet (7.4 m) long or less, the entire load shall be tested.

4.3.2.6.3.2 Non-Continuously Quenched (See 8.5) Loads

The entire load shall be tested.

4.3.2.7 Acceptance Criteria

4.3.2.7.1 Plate

The range of the conductivity on one side (face) of any plate shall not exceed 2.5% International Annealed Copper Standard (1.45 MS/m IACS).

4.3.2.7.2 Forging, Extrusion, Rod and Bar

The range of conductivity of any forging, extrusion, rod, or bar shall not exceed 4% IACS (2.32 MS/m IACS) overall, but shall not exceed 3% IACS (1.74 MS/m IACS) on any one element (flange, web, etc).

4.3.2.7.3 In addition to the requirements of 4.3.2.7.1 or 4.3.2.7.2, the conductivity of any 4-inch (102- mm) thick or thinner 7075 alloy non-alclad product shall not exceed the following: 31% IACS (17.98 MS/m IACS) for plate; 32% IACS (18.56 MS/m IACS) for forgings, extrusion, rod, or bar.

4.3.3 Sample Material

It is permissible to perform quench effectiveness tensile tests and quench uniformity conductivity tests on sample material, of the same alloy/form/thickness, inserted in the load at the appropriate locations. When samples are used for quench effectiveness tests, their length and width shall be at least 3 times their thickness.

4.4 Metallurgical Testing

4.4.1 The tests in 4.4.1.1 and 4.4.1.2 shall be performed on production material from each solution heat treating furnace initially and periodically thereafter. The frequency of testing shall be (1) monthly until a total of 6 successful tests have been performed, then the frequency may be reduced to quarterly. However, if a failure occurs, the frequency shall revert to monthly and shall not be reduced again until a total of 6 successive successful tests have been performed. The above initial and periodic test requirements shall be applied after any modification of the equipment which could affect the metallurgical properties of the product.

4.4.1.1 Heat Treat Induced Porosity and Eutectic Melting

A sample of 2xxx or 7xxx sheet (non-alclad shall be used for heat treat induced porosity testing) heat treated during the previous calendar month (See 8.2.4) shall be tested in accordance with 4.4.2.1. If sheet was not heat treated, a sample of product of an alternate form (order of preference: tube, extrusion, wire, rod, bar, plate, forging) shall be tested. The thickness of the sample shall be not more than twice the thickness of the thinnest product heat treated during the previous month.

4.4.1.2 Intergranular Corrosion Susceptibility of Sheet, Wire, or Extrusion

A sample representative of the thickest (under 0.250 inch (6.35 mm)) product solution heat treated during the previous calendar month (See 8.2.4) shall be tested in accordance with 4.4.2.2. Primary order of preference shall be based on alloy/temper as follows: (1) 2xxx in -T3 or -T4 temper, (2) 7xxx in -T6 temper. Secondary order of preference shall be based on form as follows: (1) sheet, (2) extrusion, (3) wire. No test is required if 2xxx-T3 or -T4 or 7xxx-T6 in the above categories was not solution heat treated.

4.4.2 Test Methods and Acceptance Criteria

4.4.2.1 Heat Treat Induced Porosity and Eutectic Melting

One or more specimens taken from the solution heat treated sample(s) shall be sectioned, polished, and examined at 500X magnification before and after etching. The specimen(s) shall be free from (1) heat treat 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.

4.4.2.2 Intergranular Corrosion Susceptibility

The sample shall be prepared and tested in accordance with ASTM G 110 modified as follows:

4.4.2.2.1 Specimen surface area shall be not less than 4 square inches (25.8 sq cm) (sum of both sides) except, for wire, a minimum length of 4 inches (102 mm) shall suffice.

4.4.2.2.2 Removal of cladding may be confirmed by either examination of specimen surfaces or microscopic examination of metallographic cross sections.

4.4.2.2.3 After immersion in the etching cleaner and nitric acid, the specimen shall be rinsed in water and either (1) air dried or (2) immersed in the test solution.

4.4.2.2.4 The immersion period in the test solution shall be six to seven hours.

4.4.2.2.5 After exposure in the test solution, corrosion products shall be removed by simultaneously rinsing in running water and brushing with a soft bristle brush.

4.4.2.2.6 Metallographic examination shall be between 200 and 500X magnification.

4.4.2.2.7 The severity of inter-granular corrosion exhibited by the major surfaces of the sample (end-grain attack shall be disregarded) shall be no greater than that normally experienced by producers when heat treating under production conditions in accordance with the requirements and recommendations of this specification. Intentional or inadvertent process changes shall not cause increased severity.

4.5 Test Failures

4.5.1 Equipment Deficiency

If any valid test fails to meet any requirement specified herein, or if any valid test (after retesting, if permitted) fails to meet a requirement of the material specification or the drawing, and the cause of the failure was a deficiency of the heat treating equipment (not the test procedure or test apparatus), the following measures shall be taken:

4.5.1.1 The equipment shall not be used for production until the cause of the failure has been corrected and the test has been performed successfully.

4.5.1.2 The quality assurance organization responsible for the equipment shall evaluate possible effects of the failure on product processed since the last successful test. The evaluation shall be documented and, where necessary, shall include consultation with metallurgists, engineers, and purchasers. Appropriate corrective action shall be taken and documented.

5. PREPARATION FOR DELIVERY

Not applicable.

6. ACKNOWLEDGMENT

Not applicable.

7. REJECTIONS

Not applicable.

8. NOTES

8.1 A change bar (|) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of a specification. An (R) symbol to the left of the document title indicates a complete revision of the specification. Change bars and (R) are not used in original publications, nor in specifications that contain editorial changes only.

8.2 Terms used in AMS are clarified in ARP1917 and as follows:

8.2.1 Raw Material (e.g., Sheet, Plate, Wire, Rod and Bar, Tubing, Forging, Extrusion)

Usually is identified by a heat or lot number and is usually tested destructively for acceptance. It is heat treated, by or for a material producer, in accordance with a material specification which may require, by reference, conformance to a heat treating specification.

8.2.2 Parts

Usually are identified by a part number and are produced from raw material in accordance with requirements of a drawing, and are usually tested by nondestructive techniques only. They are heat treated by or for a fabricator, in accordance with a drawing, purchase order, fabrication order, or heat treatment specification. At the time of heat treatment, they may resemble raw material.

8.2.3 Thickness

For forgings and extrusions, thickness is the minimum dimension of the heaviest section.

8.2.4 Samples for Metallurgical Tests

May be taken from remnants of samples taken in accordance with material specification requirements.

8.2.5 Mandatory and Non-Mandatory Provisions

The word “shall” identifies mandatory provisions; “should”, “may”, and “recommended” identify non-mandatory provisions.

8.2.6 Extrusion Press Quenching (Extrusion Press Solution Heat Treating)

Directly quenching from the extrusion press without a subsequent furnace solution heat treating operation. As a substitute for the furnace heating and quenching specified herein, extrusion press quenching is not covered by this specification.

8.2.7 Rolling Mill Quenching (Rolling Mill Solution Heat Treating)

Directly quenching from the rolling mill without a subsequent furnace solution heat treating operation. As a substitute for the furnace heating and quenching specified herein, rolling mill quenching is not covered by this specification.

8.2.8 Forms

“Forging” includes die and hand forgings and rolled or forged rings. “Extrusion” includes wire, rod, bar, profiles (shapes), and tube. When “Wire”, “Bar” and “Rod” are specified, they refer to cold finished or rolled products.

8.2.9 Heavy Load

A load is heavy if the volume of the metal in the load is more than 10% of the volume of the working (soaking) zones.

8.2.10 Similar Load Arrangement

A load arrangement in which all pieces will have heating and cooling rates similar to, or faster than, the pieces in the previously validated load arrangement may be considered similar. An example of a similar load arrangement is one in which the thickness of the pieces is similar to or less than, and the space between the pieces is similar to or greater than, the pieces in the previously validated load.

8.3 Dimensions and properties in inch/pound units and the Fahrenheit temperatures are primary; dimensions and properties in SI units and the Celsius temperatures are shown as the approximate equivalents of the primary units and are presented only for information.

8.4 Most of the mandatory set temperatures and aging times specified for response-to-heat-treatment tests (in Tables 5 and 6) are based on those of AMS 2770. For alloys/tempers not covered by AMS 2770, Tables 5 and 6 temperatures/times are based on Tables 1 and 4 herein. These tests are intended to demonstrate that the material, in the as-produced condition (prior to any additional processing) has the capability to respond to a heat treatment which duplicates, as closely as possible, user's test and production heat treating conditions.

8.5 Continuously quenched product traverses through a quench chamber without a pause or change of direction. Non-continuously quenched product pauses or changes direction during its traverse through a quench chamber.

TABLE 1 - SOLUTION HEAT TREATING TEMPERATURES [9]

Alloy	Product Form (See 8.2.8)	Temperature [1][2][3] °F	Temperature [1][2][3] °C	Alloy	Product Form (See 8.2.8)	Temperature [1][2][3] °F	Temperature [1][2][3] °C
2011	Wire, Rod, Bar	945-995	507-535	6156	Sheet	1010-1025	543-552
2013	Extrusion	1003-1023	539-551	6262	All	960-1050	516-566
2014	All	925-945	496-507	6951	Sheet	975-995	524-535
2017	Wire, Rod, Bar	925-950	496-510	7001	Extrusion	860-880	460-471
2018	Forging	940-970	504-521	7010	Plate, Forging	880-900	471-482
2024	All[4]	910-930	488-499	7036	Extrusion	870-890	466-477
2025	Forgings	950-970	510-521	7136	Extrusion	870-890	466-477
2026	Extrusion	910-930	488-499	7039	Plate	700-880	371-471
2027	Plate, Extrusion	915-935	491-502	7039	Other	840-860	449-460
2048	Sheet, Plate	910-930	488-499	7040	Plate	880-910	471-488
2056	Sheet	915-935	491-502	7140	Plate	880-900	471-482
2090	Extrusion	990-1010	532-543	7049	All	860-900	460-482
2090	Sheet	975-1000	524-538	7050	All	880-900	471-482
2098	All	960-980	516-527	7055	Extrusion	870-890	466-477
2099	Extrusion	990-1030	532-554	7055	Plate	860-900	460-482
2117	Wire, Rod, Bar	925-950	488-499	7056	Plate	860-890	460-477
2124	Plate	910-930	488-499	7068	Extrusion	860-885	460-474
2218	Forging	940-960	504-516	7075	Forging	860-900	460-482
2219	All	985-1005	529-541	7075	Other	860-930[5][6]	460-499
2297	Plate	980-1000	527-538	7076	Forging	850-910	454-488
2397	Plate	960-980	516-527	7149	All	860-900	460-482
2524	Sheet, Plate	910-930	488-499	7150	Plate, Extrusion	880-900	471-482
2618	Forging	975-995	524-535	7175[7]	Plate, Extrusion	880-910	471-488
4032	Forging	940-970	504-521	7178	Sheet	860-930	460-499
6013	Sheet	1045-1065	563-574	7249	Extrusion	865-895	463-479
6013	Rod, Bar	1040-1060	560-571	7349	Extrusion	870-890	466-477
6053	Forging	960-980	516-527	7449	Plate	860-890	460-477
6061	All	960-1075	516-579	7449	Extrusion	860-890	460-477
6063	Extrusion	960-1010	516-529	7475	Sheet[8], Plate	880-970	471-521
6066	All	960-1010	516-543	8090	Sheet	990-1000	532-538
6151	Forging	950-980	510-527	8090	Plate	990-1025	532-552

(1) Set temperature shall be selected so as to ensure, based on temperature uniformity tests and/or load sensors, the product is soaked within the selected range.

(2) During heating of a load, until it reaches the selected range, the temperature of the heating medium may exceed maximum temperature providing that the temperature of the metal in the load does not exceed the maximum.

(3) Solution heat treatment set temperatures for response-to-heat-treatment tests are mandatory and shall conform to Table 5A or 6A (See 8.4).

(4) For wire, rod, and bar, minimum temperature of 900 °F (482 °C) is permissible provided that statistical analysis of the test results, in accordance with MMPDS or ASTM STP 15D, shows, with a 95% confidence level, that 99% of the material meets specification requirements.

(5) For alclad sheet, 0.020 inch (0.51 mm) and under in thickness, minimum temperature of 850 °F (454 °C) is permissible; for alclad sheet over 0.020 inch (0.51 mm) in thickness, temperature should not exceed 900 °F (482 °C).

(6) Temperatures higher than 900 °F (482 °C) should not be used unless manufacturing controls, production experience and/or tests ensure freedom from eutectic melting. For products thicker than 4 in (102 mm), temperatures higher than 910 °F (488 °C) are not recommended.

(7) Procedures for solution heat treatment of forgings are proprietary.

(8) Alclad sheet, maximum temperature shall be 945 °F (507 °C).

(9) AMS 2772 is not applicable to extrusion press quenched nor rolling mill quenched products. Refer to 8.2.6 and 8.2.7.

TABLE 2 - RECOMMENDED MINIMUM SOAKING TIME FOR SOLUTION HEAT TREATMENT OF WROUGHT PRODUCTS

Thickness (See 8.2.3) Inches	Thickness (See 8.1.4) Millimeters[1]	Minimum Soaking Time Minutes[1] Salt Bath or Fluidized Bed	Minimum Soaking Time Minutes[1] Air Furnace
Up to 0.020, incl	Up to 0.51, incl	10	20
Over 0.020 to 0.032, incl	Over 0.51 to 0.81, incl	15	25
Over 0.032 to 0.063, incl	Over 0.81 to 1.60, incl	20	30
Over 0.063 to 0.090, incl	Over 1.60 to 2.29, incl	25	35
Over 0.090 to 0.124, incl	Over 2.29 to 3.15, incl	30	40
Over 0.124 to 0.250, incl	Over 3.15 to 6.35, incl	35	50
Over 0.250 to 0.500, incl	Over 6.35 to 12.70, incl	45	60
Over 0.500 to 1.000, incl	Over 12.70 to 25.40, incl	60	90
Over 1.000 to 1.500, incl	Over 25.40 to 38.10, incl	90	120
Over 1.500 to 2.000, incl	Over 38.10 to 50.80, incl	105	150
Over 2.000 to 2.500, incl	Over 50.80 to 63.50, incl	120	180
Over 2.500 to 3.000, incl	Over 63.50 to 76.20, incl	135	210
Over 3.000 to 3.500, incl	Over 76.20 to 88.90, incl	150	240
Over 3.500 to 4.000, incl	Over 88.90 to 101.60, incl	165	270
Over 4.000	Over 101.60	add 15 per 0.500 inch (12.70 mm)	add 30 per 0.500 inch (12.70 mm)

1. Soaking time for alclad products should be minimized to preclude reduction of alclad thickness below the minimum thickness requirement of the material specification (See 3.6.4).

TABLE 3 - MAXIMUM QUENCH DELAY (FOR IMMERSION QUENCHING)[1]

Nominal Thickness Inch	Nominal Thickness Millimeters	Maximum Time (Seconds)
Up to 0.016, incl	Up to 0.41, incl	5
Over 0.016 to 0.031, incl	Over 0.41 to 0.79, incl	7
Over 0.031 to 0.090, incl	Over 0.79 to 2.29, incl	10
Over 0.090	Over 2.29	15

1. Quench delay time begins when the furnace door starts to open or when the first corner of the load emerges from a salt bath and ends when the last corner of the load is immersed in the quenchant. With the exception of 2219 alloy, the maximum quench delay times may be exceeded if results of tests prove that all product in the load will be above 775 °F (413 °C) when quenched. For 2219 alloy, the maximum quench delay times may be exceeded if results of tests prove that all product in the load will be above 900 °F (482 °C) when quenched.

TABLE 4 - RECOMMENDED[5][6] AGING TREATMENTS

Alloy	Product Form (See 8.2.8)	Temper[1] Before Aging[2]	Temper[1] After Aging[2]	Aging[3] Temperature[4] (°F)	(°C)	Aging[3] Time (Hours)
2011	All	T3	T8	320	160	14
2013	Extrusion	T3511	T6511	374	190	7 - 9
2014	Sheet	T4	T6	320	160	18
2014	All	T4	T6	350	177	9
2018	Forging	T41	T61	340	171	10
2024	Forging	T3	T8	375	191	11
2024	All other	T3	T81	375	191	12
2024	Sheet, Wire	T36	T86	375	191	8
2024	Forging	T4	T6	375	191	17
2024	Wire, Rod, Bar	T4	T6	375	191	12
2025	Forging	T4	T6	350	177	9
2048	All	T3	T8	375	191	12
2090	Extrusion	T3	T86	305	151	30
2090	Sheet	T3	T83	325	163	20 - 26
2098	All	T32P	T82P	320	160	17 - 19
2099	Extrusion	T33	T83	250 Followed by 305	121 151	10 - 14 42 - 54
2124	Plate	T3	T8	375	191	12
2124	Plate	T31	T8151	370	188	9 - 12
2124	Plate	T4	T6	375	191	9
2218	Forging	T4	T6	340	171	10
2218	Forging	T4	T7	460	238	6
2219	Rod, Bar, Extrusion	T3	T8	375	191	18
2219	Sheet, Plate	T37	T87	325	163	24
2219	Forging	T4	T6	375	191	26
2219	All other	T3	T8	350	177	18
2297	Plate	T37	T87	320	160	20 - 48
2397	Plate	T37	T87	320	160	59 - 61
2618	Forging	T4	T6	390	199	20
4032	Forging	T4	T6	340	171	10
6013	All	T4	T6	375	191	4
6013	Sheet, Alternate	T4	T6	345	174	8
6053	Forging	T4	T6	340	171	10
6061	Forging, Extrusion	T4	T6	350	177	8
6061	All other	T4	T6	320	160	18
6063	All	T4	T6	350	177	8
6063	All, Alternate	T4	T6	360	182	6
6066	All	T4	T6	350	177	8
6151	All	T4	T6	340	171	10
6156	Sheet	T4	T62	375	190	4 - 6
6262	Extrusion	T4	T6	350	177	12
6262	All other	T4	T6	340	171	8
6951	Sheet	T4	T6	320	160	18
7001	Extrusion	W	T6	250	121	24
7010	Plate, Forging	W	T73	250 Followed by 340	121 171	6 - 24 20
7010	Plate, Forging	W	T74	250 Followed by 340	121 171	6 - 24 14
7010	Plate, Forging	W	T76	250 Followed by 340	121 171	6 - 24 11
7039	Plate	W	T64	room Followed by 225 Followed by 300	room 107 149	72 8 16

TABLE 4 - RECOMMENDED[5][6] AGING TREATMENTS (CON'T.)

Alloy	Product Form (See 8.2.8)	Temper[1] Before Aging[2]	Temper[1] After Aging[2]	Aging[3] Temperature[4] (°F)	(°C)	Aging[3] Time (Hours)
7040	Plate	W	T7451	250	121	4 - 28
				Followed by 329	165	10 - 16
7039	Forgings	W	T73	room	room	48
				Followed by 250	121	24
				Followed by 325	163	12
7140	Plate	W	T7451	250	121	6 - 12
				Followed by 310	154	20 - 30
7049 & 7149	Extrusion	W	T73	room	room	48
				Followed by 250	121	24
				Followed by 330	166	17
7049 & 7149	Extrusion	W	T76	room	room	48
				Followed by 250	121	24
				Followed by 375	163	13
7049 & 7149	Forging	W	T73	room	room	48
				Followed by 250	121	8 - 24
				Followed by 340	171	6 - 16
7049 & 7149	Forging	W52	T7352	room	room	24
				Followed by 250	121	8 - 24
				Followed by 335	168	6 - 16
7049	Forging	W51	T7351	room	room	8 - 16
				Followed by 250	121	8 - 24
				Followed by 335	168	6 - 16
7050	Forging	W	T6	room	room	72
				Followed by 250	121	48
7050	Wire, Rod, Bar	W	T73	250	121	4 - 24
				Followed by 350	177	6 - 12
7050	Plate	W	T73	250	121	4 - 24
				Followed by 350	177	8 - 16
7050	Plate	W	T74	250	121	3 - 6
				Followed by 325	163	24 - 30
7050	Forging	W	T74	250	121	3 - 6
				Followed by 350	177	6 - 12
7050	Forging	W51, 52	T7451, 52	250	121	3 - 6
				Followed by 350	177	6 - 10
7050	Plate	W	T76	250	121	3 - 6
				Followed by 325	163	12 - 15
7050	Extrusion	W	T76	250	121	3 - 8
				Followed by 325	163	15 - 18
7050	Extrusion	W	T6	250	121	23 - 25
7055	Extrusion	W	T74511	250	121	4 - 6
				Followed by 320	160	11 - 12
7055	Extrusion	W	T76511	250	121	4 - 6
				Followed by 320	160	6.5 - 7.5
7056	Plate	W	T7651	250	121	19 - 29
				Followed by 300	149	11 - 21
7068	Extrusion	W	T6	250	121	23 - 25
7075	All	W	T6	250	121	24
7075	Sheet, Plate	W	T73	225	107	6 - 8
				Followed by 325	163	24 - 30
7075	Forgings, Wire, Rod, Bar	W	T73	225	107	6 - 8
				Followed by 350	177	8 - 10
7075	Forging	W51, 52	T7351, 52	225	107	6 - 8
				Followed by 350	177	6 - 8