NOT MEASUREMENT SENSITIVE

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MILITARY SPECIFICATION

HEAT TREATMENT OF ALUMINUM ALLOYS

This specification is approved for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Purpose. This specification covers the requirements and recommendations for the heat treatment of aluminum alloy rolled, extruded, forged, drawn, and cast product (see 6.1 and 6.5.1). It does not cover the requirements for the heat treatment of aluminum alloy parts (see 3.4). Subjects covered are: process establishment and re-establishment (previously called "process qualification" and "process requalification"); periodic process surveys; periodic product monitoring; furnaces and operation controls; pyrometric equipment; quenching equipment, media, and operation controls; parameters and procedures for solution heat treatment, quenching, age hardening, and annealing (of certain product); requirements for inspections and record keeping; test methods; and limits of product acceptability.

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications and standards. The following standards form a part of this specification to the extent specified herein. Unless otherwise specified, the issue of these documents shall be those listed in the issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto, cited in the solicitation.

MILITARY STANDARDS

MIL-STD-1537	-	Electrical Conductivity Test for Measurement of Heat Treatment of Aluminum Alloys, Eddy Current Method
MIL-STD-45662	-	Calibration Systems Requirements.

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Naval Air Engineering Center, Systems Engineering and Standardization Department (Code 5314), Lakehurst, NJ 08733-5100, by using the attached Standardization Document Improvement Proposal (DD Form 1426), or by letter.

AMSC N/A FSC 95GP

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(Unless otherwise indicated, copies of military standards are available from the Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

2.2 Non-government documents. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the issue of the DODISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DODISS are the issues of the documents cited in the solicitation (see 6.2).

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM B557 - Tension Testing Wrought and Cast Aluminum and Magnesium Alloy Products
ASTM E10 - Test Method for Brinell Hardness of Metallic Materials
ASTM E18 - Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
ASTM E103 - Rapid Indentation Hardness Testing of Metallic Materials

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187.)

SOCIETY OF AUTOMOTIVE ENGINEERS, INC. (SAE)

AEROSPACE MATERIAL SPECIFICATIONS (AMS)

AMS 2750 - Pyrometry
AMS 2770 - Heat Treatment of Wrought Aluminum Alloy Parts

(Application for copies should be addressed to SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.)

(Non-Government standards and other publications are normally available from the organizations that prepare or distribute the documents. These documents also may be available in or through libraries or other informational services.)

2.3 Order of precedence. In the event of a conflict between the text of this document and the references cited herein (except for related associated detail specifications, specification sheets, or MS standards), the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. REQUIREMENTS

3.1 Process establishment. Prior to production, fully capable heat-treating equipment and procedures shall be in place and established as specified herein (see Table I). The Government reserves the right of review, verification, and approval of the results of process establishment or re-establishment derived from testing new equipment and equipment which has undergone major work or repair (see 3.1.2).

3.1.1 Notification of authorized government representative. When an authorized government representative (see 6.5.6) finds it necessary to witness the process establishment tests, the representative shall be given at least

7 days notice prior to such tests. All process information shall be considered proprietary to the heat treater, and its confidentiality shall be preserved.

3.1.2 Conditions requiring process re-establishment. Occurrence of one or more of the following events necessitates re-establishment of the equipment or procedures involved:

a. Replacement of, extensive deterioration of, major damage to, or modifications to the previously accepted heat-treat/quench equipment that might result in non-conformance (see 3.5.1 through 3.5.5 as applicable).

b. Failure of existing equipment or standard heat-treating procedures to consistently produce product meeting the quality requirements specified herein (see 4.6.4).

c. Any noncompliance (see 4.1.3 and 4.6.4) detected during periodic process surveys (see 3.2) or periodic product monitoring (See 3.3).

3.2 Periodic process surveys. Heat-treating equipment and procedures shall be surveyed as specified in Table I.

3.3 Periodic product monitoring. Products shall be tested to monitor the operational characteristics of the heat-treating equipment and procedures as specified in Table I.

3.4 Heat treatment of parts. Finished or semi-finished parts made from wrought mill products shall be heat treated in accordance with AMS 2770. Raw castings, finished or rough machined parts made from castings, and deep drawn shells shall be heat treated in accordance with the applicable requirements herein.

3.5 Equipment.

3.5.1 Furnaces. Any type of furnace is acceptable for the heat treating of aluminum alloys, provided the product is not deleteriously affected. Unless otherwise indicated herein, the term "air", with reference to a heating medium, shall apply equally to combusted gases and protective atmospheres. The use of torch-heating equipment is prohibited.

3.5.1.1 Air chamber furnaces. Air chamber furnaces in which the products of combustion come in contact with the metal may be used for the heat treatment of those products which have been demonstrated by test to be free from porosity resulting from solution heat treatment (see 6.3.3.2 and 6.5.5) in the furnace of concern.

3.5.1.2 Salt baths. The salt shall not react with the alloys being treated. Nitrate salt baths shall not be used to heat treat 5XX.X casting alloys (see 6.3.1).

3.5.1.3 Alternate apparatus for age-hardening treatment. Other apparatus for age-hardening heat treatment may be used, provided it meets all the requirements specified herein and the material meets the material specification requirements, and is not damaged.

3.5.1.4 Furnace temperature uniformity surveys. Surveys shall be as specified in AMS 2750.

3.5.1.5 Temperature uniformity.

3.5.1.5.1 Batch furnaces and salt baths. The design and construction of batch furnaces and baths shall be such that, during the heating and soaking period, the temperature of the heating medium at any point in the heating or soaking zone is controlled such that the metal temperature does not exceed the maximum of the soaking temperature range specified in 3.6.1 or the selected age-hardening temperature range (see 3.9) applicable to the alloy being solution heat treated or aged. After all of the furnace charge reaches the minimum of the applicable temperature range specified, the maximum temperature variation of the heating medium and furnace charge within this zone shall be 20° F (or less when Table II or VII requires), with the exception of alloy 6061 for which a variation of 30° F is permissible (see Table II, footnote 5 and Table VII, footnote 4).

3.5.1.5.2 Continuous furnaces. For continuous furnaces, the soaking zone follows the heating zone, and it is in the soaking zone that metal temperatures shall be within the heat-treating temperature ranges specified in 3.6.1 or the selected age-hardening temperature range (see 3.9), as applicable. After all of the furnace charge within the soaking zone reaches the minimum of the applicable temperature range specified, the maximum temperature variation of the heating medium and furnace charge in the soaking zone shall be 20° F (or less when Table II or VII requires) with the exception of alloy 6061 for which a variation of 30° F is permissible (see Table II, footnote 5 and Table VII, footnote 4).

3.5.2 Pyrometric equipment. Properly arranged temperature-control and recording devices shall be provided on all heat-treating equipment to ensure control of temperature to the requirements of this specification and AMS 2750 in all heating and soaking zones.

3.5.2.1 Temperature control and recording equipment. Instruments shall meet the requirements of AMS 2750 except that the recordings of the working instruments required by AMS 2750 may be stored on computerized magnetic storage media. If stored this way, a hard copy of the recordings shall be available upon request. The exact location of sensors shall be governed by furnace or bath configurations and dimensions in accordance with AMS 2750, and they shall be in such locations as to give accurate measurement of the workpiece and heating medium temperatures.

3.5.2.2 Accuracy. The furnace pyrometric system shall be set to control at working temperatures applied in practice and the accuracy of the system shall be monitored according to AMS 2750.

3.5.3 Quenching equipment and media. Suitable equipment for water, air, aqueous polymer solution, liquified gas, or oil quenching shall be provided.

3.5.3.1 Quench baths. Quench baths shall permit complete immersion of material and shall be of sufficient size to extract the heat from the most massive load anticipated to be quenched.

3.5.3.1.1 Circulation. The quench bath shall contain a circulation system (either internal or external) to provide for the flow of quench medium through the heat-treat load. In lieu of bath circulation, product may be agitated if movement is sufficient to ensure that quench uniformity is obtained and all requirements are met. This shall be verified by monitoring in accordance with 4.4.2.

3.5.3.1.2 Air agitation. Air agitation of the quench bath is permitted, if it is demonstrated that quench uniformity is obtained. This shall be verified by monitoring in accordance with 4.4.2.

3.5.3.1.3 Heating and cooling. The quench bath shall be provided with sufficient heating and/or cooling capacity needed to maintain the temperature of the quenching medium within the ranges specified in 3.7, as applicable, and instrumentation necessary to ensure adequate temperature control. The instrumentation shall be capable of reading within ±5° F of true temperature.

3.5.3.1.4 Speed of immersion. The quench system shall have the means to control the speed at which solution heat treated parts enter the quench medium, if such control is part of the required heat-treating procedure. The allowable quench delay (see 3.7.4) shall not be exceeded.

3.5.3.1.5 Inflow and draining. All water baths, except aqueous polymer solutions, employed in quenching products which have been heated in salt bath furnaces shall be maintained such that no visible salt residue is observed on the surface of the products after drying. Water-aqueous polymer solutions shall at all times when in use contain no salt concentrations in excess of 6.0 percent by weight.

3.5.3.2 Spray-quenching equipment. When a spray system is employed for quenching, the discharge of the coolant from the nozzles shall be of sufficient volume, pressure and temperature to ensure that a uniform and satisfactory quench is achieved on all products. For plate and extrusions, this shall be verified by monitoring in accordance with 4.4.1. Calibrated recording instrumentation shall be provided to monitor spray quench variables.

3.5.3.3 Location of quenching equipment. Quenching equipment and handling facilities shall be located such that the delay in quenching does not exceed the maximum delay times specified in Table VI, as applicable.

3.5.4 Rinsing equipment. Rinse tanks, sprays, or other suitable apparatus shall be employed as necessary to ensure that no salt residues or films remain on metal surfaces after drying.

3.5.5 Construction of support racks, fixtures, and other workpiece holders. Support racks shall be so constructed as to minimize shifting or movement of the metal during the heat treatment and quenching operations. The racks, fixtures, trays, or baskets shall be constructed so that no deleterious effect on the products being processed will arise from solution heat treating or quenching.

3.5.6 Testing equipment. The electrical conductivity tester shall be calibrated in accordance with the procedures outlined in 4.5.5.2.

3.5.7 Calibration. Calibration of all equipment shall be in accordance with MIL-STD-45662 and AMS 2750, as applicable.

3.6 Parameters and procedures for solution heat treatment.

3.6.1 Solution heat treatment of mill and foundry products. Aluminum alloy wrought products and castings shall be solution heat treated within the applicable metal temperature ranges specified in Table II.

3.6.2 Re-solution heat treatment. A solution heat treatment of an aluminum alloy workpiece which has previously been solution heat treated shall be considered a re-solution heat treatment. Accordingly, the first solution heat treatment of an alloy following purchase as solution heat treated or solution heat treated and aged shall be considered a re-solution heat treatment. Annealing and age-hardening heat treatments shall not be considered re-solution heat treatments. Alclad products of the 2XXX and 7XXX series alloys shall not be re-solution heat treated more than the number of times specified in Table III (see 6.3.3.5).

3.6.3 Heat-treating operations. Heat-treating operations shall be performed on the whole workpiece, never on a portion only, and shall be applied in a manner that will produce uniform properties within the limitations of material configuration.

3.6.3.1 Heat treating alclad sheet. When solution heat treating alclad sheet, the size and spacing of the load shall permit the entire load to come to the specified temperature range within 30 minutes for thicknesses up to 0.050 inch, 60 minutes for 0.050 or greater but less than 0.102 inch, and 120 minutes for 0.102 or greater. When a furnace charge consists of a group of alclad alloy workpieces of varying thickness, the heat-up time for the charge shall be the limit specified for the thinnest work piece or section of a work piece (see 6.3.3.3).

3.6.4 Cleanliness. Surfaces of metal shall be free from lubricants or other matter deleterious to the aluminum alloy being heat treated. Substances on the surface which, after solution heat treatment, affect appearance only shall not be cause for disapproval of the production procedure nor rejection of the workpieces so affected.

3.6.5 Charge preparation and limitation. Aluminum alloys being heat treated shall be so supported as to permit access of the heating medium to uniformly heat the alloy to the required temperature. Except as noted below, furnaces shall not be charged following a downward temperature setting until all instruments indicate that the furnace has reached the range in Table II encompassing the new lower temperature. If the furnace has automatic controls that ensure that the reduction in furnace temperature is attained prior to any metal in the charge reaching the soak temperature, furnace charging may take place at any time.

3.6.6 Soaking time. After the charge has reached the required solution heat-treating temperature range, it shall be held (soaked) within that temperature range for a period necessary to ensure the maximum possible solution of alloying elements and development of specified properties upon aging. In a continuous furnace, the speed of any product passing through the working zone (see 6.5.3) shall be such that soaking time shall yield product capable of being aged to requirements of the applicable product specification. Recommended soaking times are listed in Tables IV and V. When a charge includes sections of various thicknesses, the recommended soaking time shall be determined by the section having the greatest thickness (see 6.3.3.1).

3.7 Quenching parameters and procedures.

3.7.1 Quenching wrought nonforged product. Parameters and procedures for quenching wrought alloy product (except forgings) of 2XXX and 7XXX series alloys shall be as specified in 3.7.1.1 and 3.7.1.2.

3.7.1.1 Total immersion in water baths or aqueous polymer solutions. When a water bath is used, the volume and circulation of the bath shall be such that its temperature shall be no higher than 100° F at the time of completion of the quench. When an aqueous polymer solution is used, the volume and circulation of solution shall be such that the bath temperature at no time exceeds 130° F. Quenching delays and duration of quenchant contact shall be as specified in 3.7.4 and 3.7.5, respectively. Quenched product shall, after age-hardening to tempers specified in the acquisition documents, satisfy the applicable property requirements and when tested, pass the corrosion test in 4.5.3. Test programs to determine compliance with these requirements shall conform to Table VIII, as applicable.

3.7.1.2 Quenching in liquified gas, airblast, and water spray. Quenching by total immersion in liquified gas or by contact with high-pressure, high-volume jets of water, or air within a suitable chamber, is permissible, provided that quenched product is capable of passing the corrosion test in 4.5.3, and of being age-hardened to mechanical properties and other characteristics conforming to applicable specified requirements. Quenching delays and duration of quenchant contact shall be as specified in 3.7.4 and 3.7.5, respectively. Test programs to determine compliance with these requirements shall conform to Table VIII, as applicable.

3.7.2 Quenching forgings. Except as specified in 3.7.2.1, 3.7.2.2, or 3.7.2.3, forgings may be cold water, hot water, or aqueous polymer quenched, provided that resultant product is capable of passing the applicable tests and satisfying all applicable specified requirements after age-hardening to tempers specified in the acquisition documents. Test programs to determine compliance with these requirements shall conform to Table VIII, as applicable.

3.7.2.1 Quenching 2014 and 2024 forgings. Unless otherwise specified in a drawing or procurement document, forgings of 2014 and 2024 shall be quenched by total immersion in water heated to 140-180° F.

3.7.2.2 Quenching 2XXX and 7XXX forgings other than 2014 and 2024. Unless otherwise specified in a drawing or procurement document, forgings of these alloys shall be quenched by total immersion in water heated to 140-160° F.

3.7.2.3 -T41 and -T61 tempers. Unless otherwise specified in a drawing or procurement document, forgings and impact extrusions for heat treatment to the -T41 and -T61 tempers shall be quenched by total immersion in boiling water.

3.7.3 Quenching castings. Castings may be oil, water (see 3.7.3.2), or aqueous polymer quenched, provided that the resultant product is capable of passing the applicable tests and satisfying all applicable specified requirements after age-hardening to tempers specified in the acquisition documents. Air quenching is satisfactory for continuously quenching thin sections if all specified property requirements are met. Test programs to determine compliance with these requirements shall conform to Table VIII, as applicable.

3.7.3.1 Quenching castings of Alloys 520.0 and 242.0. Unless otherwise specified in a drawing or procurement document, castings of Alloy 520.0 (formerly designated 220) shall be quenched by total immersion in oil heated to 300° F and castings of Alloy 242.0 (formerly designated 142) shall be air-quenched.

3.7.3.2 Water quenched castings. Such castings shall be quenched by total immersion in a water bath heated from 150 to 212° F unless other quenching temperatures are approved by the procuring activity.

3.7.4 Quench delay. Maximum allowable delays before immersion quenching product shall comply with Table VI, as applicable to section thickness. Allowable delays before quenching using an alternative to immersion, shall be determined by corrosion tests (see 4.5.3) and/or mechanical property tests on product age-hardened to tempers within the scope of the applicable material specification and specified in the acquisition documents.

3.7.5 Duration of contact between quenchant and workpiece. Workpieces quenched by immersion shall remain in the quenchant for not less than 2 minutes per inch of thickness, or fraction thereof in the thickest section. Alternatively, workpieces shall be kept immersed in the quenchant for not less than 2 minutes after boiling ceases. Workpieces quenched by spray shall remain in contact with the spray until steam no longer rises from the workpiece surface. Workpieces quenched in an air blast shall remain in contact with that quenchant until surface temperatures of the workpiece are reduced to 212° F.

3.8 Racking and spacing. Product shall be racked or supported and spaced to permit free access of the heating and/or quenching medium to all surfaces of the product in all portions of the load. Adequacy of heating and quenching procedures shall be documented by accumulation of adequate data to demonstrate conformance to applicable material specifications. When immersion quenching, see 4.4.2.1 and 4.4.2.3.

3.8.1 Racking and spacing of forgings and castings. Forgings and castings, except as specified in 3.8.1.2, shall be separated from each other by a distance greater than the thickest section, or as provided by special racking procedures which demonstrate that the specific product receives an adequate heating or quench.

3.8.1.1 Fixtures. Fixtures shall be designed so as to have a minimum effect on the heating rate and the quench rate. Orientation shall be such as to avoid entrapment of steam, allow free circulation of quenchant and to preclude steam from harmfully degrading the quench. The size of the load shall be limited so as to produce no more than a 20°F rise in water temperature, or a 25°F rise in aqueous polymer temperature as a result of quenching. Exceptions to the temperature rise are acceptable, if the product has been demonstrated by testing and documentation to meet the requirements of the applicable material specification.

3.8.1.2 Random racking. Random racking or layering of forgings or castings, 1.0 inch or less in thickness, is permitted to a maximum thickness of 3.0 inches, with a minimum spacing of 3.0 inches between layers, provided that quenching is performed by immersion. Exceptions to this method are acceptable, if the product meets the requirements of the applicable material specification. Records shall be kept of the test results of the product so racked.

3.9 Recommended age-hardening heat treatments. The recommended time-temperature cycles shown in Table VII are typical for various forms, sizes and methods of manufacture, and may not exactly describe the optimum treatments for specific products.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the contractor is responsible for the performance of all inspection requirements (examinations and tests) as specified herein. Except as otherwise specified in the contract or purchase order, the contractor may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in this specification where such inspections are deemed necessary to ensure that supplies and services conform to prescribed requirements.

4.1.1 Responsibility for compliance. All items shall meet all requirements of section 3. The inspection set forth in this specification shall become a part of the contractor's overall inspection system or quality program. The absence of any inspection requirements in the specification shall not relieve the contractor of the responsibility of ensuring that all products or supplies submitted to the Government for acceptance comply with all requirements of the contract. Sampling inspection, as part of manufacturing operations, is an acceptable practice to ascertain conformance to requirements, however, this does not authorize submission of known defective material, either indicated or actual, nor does it commit the Government to accept defective material.

4.1.2 Retention of inspection records. Inspection records, unless otherwise specified herein, shall be on file and available for review for four years after the date of inspection.

4.1.2.1 Process establishment and process re-establishment records. Current records of process establishment and process re-establishment shall be kept on file until superseded, and then kept on file for an additional five years.

4.1.2.2 Test results. Results of all tests required by this specification shall be retained for five years after the dates of testing.

4.1.2.3 Furnace and quench process records. Production processing records required by this specification shall be kept on file and available for review for five years after the inspection date of the product.

4.1.2.4 Furnace and quench facility records. Records shall be maintained for each furnace and quench facility to show compliance with this specification. These records shall include the following: furnace number or description; volume of working zone (see 6.5.3); temperature range of usage; whether used for solution heat treatment, age-hardening heat treatment, or both; and dates and types of major repairs or alterations. These records shall be on file and available for review until process re-establishment occurs and then be retained for five years.

4.1.3 Heat-treat deviations. Any change in heat-treating procedures or equipment that results in product not conforming to this specification shall constitute a deviation. Unless such a deviation is approved in writing by the procuring activity, delivery of the product shall be withheld until the deviation(s) is(are) corrected and satisfactory performance is re-established (see 3.1.2).

4.2 Temperature surveys of heating equipment. Process establishment and re-establishment surveys, as well as periodic process surveys shall be performed in accordance with 3.1, 3.2, and AMS 2750, as applicable.

4.3 Spray-quench equipment.

4.3.1 Process establishment and re-establishment for spray quenching. Values of all parameters governing effective quenching for each spray quenching unit shall be obtained (see 3.5.3.2). Process establishment and re-establishment procedures to obtain these values shall consist of quenching product representative of all product to be quenched by the unit of concern, and, after applicable age-hardening, evaluating mechanical properties in accordance with 4.5.1. Re-establishment of the process shall be performed whenever conditions change as set forth in 3.1.2. Process establishment and re-establishment data shall be available for verification, review, and concurrence by an authorized government representative.

4.3.1.1 Procedure for plate. The quenching procedure shall be a single run each of one 2XXX series alloy and one 7XXX (preferably 7075) series alloy in the W temper in the minimum thickness and the maximum thickness of the plate processed through the spray-quench line. The alloys shall be sufficiently quench-sensitive to provide a good evaluation. The test plate shall be of a size which fully evaluates the effective area of furnace and quench chambers. Temperatures and pressures within the quenchant line during test quenching shall be recorded and the records retained (see 4.1.2.3).

4.3.1.1.1 Procedure to evaluate quench effectiveness. Such effectiveness shall be determined by evaluating the tensile properties of spray-quenched and age-hardened test pieces excised from test plates in accordance with ASTM B557.

4.3.1.1.1.1 Test specimens. The numbers and locations of specimen blanks to be excised shall conform to Figures 1 and 2, as applicable to test plate thickness.

4.3.1.1.1.2 Temper of test pieces. Specimen blanks excised in accordance with Figure 1 shall be so excised from each solution heat-treated and spray-quenched test plate. These specimens shall be age-hardened along with the remainder of the test plate or in a laboratory furnace, to one temper representative of mill product. Following age-hardening, one specimen blank shall be excised from the test plate in accordance with Figure 2.

4.3.1.1.1.3 Test method. Specimens shall be machined from the age-hardened blanks, and tension-tested in accordance with ASTM B557. Dimensions of machined specimens shall comply with those specified therein as standards for sheet-type, rectangular specimens, as blank dimensions allow. Deviations from standard configurations and dimensions may be made, if such deviations are allowed in the acquisition documents.

4.3.1.1.1.4 Pass-fail criteria.

a. Tensile properties of specimens made from plate of 1.0-inch or lesser thickness shall comply with the requirements specified for plate of the same temper and thickness in the applicable material specification.

b. Yield and ultimate tensile strengths of specimens made from plate of thicknesses exceeding 1.0 inch shall meet the yield and tensile strengths specified for plate of the same temper and thickness in the applicable material specification. Such plate shall have no requirements of minimum elongation.

4.3.1.2 Procedure for extrusions. The quenching procedure shall be a single run each of one 2XXX series alloy and one 7XXX series alloy in the W temper in the minimum cross-section and the maximum cross-section of extrusions processed through the spray-quench line. The alloys shall be sufficiently quench-sensitive to provide a good evaluation. The test materials may be extrusions of any width with a sufficient number of testpieces quenched at one time to evaluate adequately the effective area of furnace and quench chambers. Temperatures and pressures within the quenchant line shall be recorded and records retained (see 4.1.2.3).

4.3.1.2.1 Procedure to evaluate quench effectiveness. Such effectiveness shall be determined by evaluating the tensile properties of spray-quenched and age-hardened test pieces excised from test extrusions in accordance with ASTM B557.

4.3.1.2.1.1 Test Specimens. Specimen blanks whose longitudinal axis parallels the direction of ram travel during the extrusion operation shall be excised at 6-inch intervals across the working-quench width at each end of the spray-quenched load. For determination of the capability of the quenching procedure to satisfactorily through-quench a section of maximum thickness, specimen blanks shall be excised from several locations in the width or thickness direction, one of them being the t/2 location, as applicable to cross-sectional configuration and dimensions. The specimen blanks shall be of the sheet type and be capable of being machined into tension-test specimens conforming to ASTM B557, as applicable to configuration and dimensions. The blanks shall be excised to a depth of no more than 0.025 inch above the bottom (during quench) surface of any test extrusion. Deviations from standard configurations and dimensions may be made, if such deviations are allowed in the acquisition documents.

4.3.1.2.1.2 Temper of test pieces. Specimen blanks excised in accordance with 4.3.1.2.1.1 shall be age-hardened together with a full simulated production load to one temper representative of plant product.

4.3.1.2.1.3 Test method. Tension-test specimens shall be machined from the age-hardened blanks and be tension-tested in accordance with ASTM B557.

4.3.1.2.1.4 Pass-fail criteria. Specimens shall demonstrate tensile properties complying with the requirements specified for extrusions of the same temper and cross-sectional dimensions in the applicable material specification.

4.4 Periodic product monitoring.

4.4.1 Monitoring spray quenching of plate and extrusions. Except as otherwise specified or allowed herein (see 4.4.1.4), such monitoring shall comprise eddy current tests in accordance with 4.5.5 of the conductivity of quenched 7075 alloy plate of a minimum 0.250-inch thickness, or extrusions of 0.250-inch minimum thickness which do not have a thickness between cross-sectional elements greater than 0.250 inch.

4.4.1.1 Quenching conditions. The line temperature and pressure of the quenchant throughout a test quench shall be maintained within limits determined during process establishment.

4.4.1.2 Quenching records. When product of 0.250 inch or thicker is processed, temperature and pressure within the quenchant line shall be recorded for each quench load. Such records shall be maintained in accordance with 4.1.2.3.

4.4.1.3 Frequency of product monitoring. When product of 0.250 inch or thicker is being quenched by a system conforming to 3.5.3.2, conductivity of the product shall be measured once during each calendar week. In addition, at least once in every three-month interval, conductivity on product of the maximum thickness that the heat-treat line can successfully process, or on product of the maximum thickness processed in that interval, shall be measured in accordance with 4.5.5.

4.4.1.4 Product for testing. Product of 7075 alloy in the dimensions herein specified shall be the product tested, unless the producing facility does not fabricate such product or if 7075 is not available at the time of the survey. In such absence, product of other alloy in the dimensions specified herein may be tested, provided that the alloy is sufficiently quench-sensitive for evaluation of system performance, and that a definitive conductivity range has been established for such product in a temper specified.

4.4.1.5 Measuring electrical conductivity. Test procedures to determine electrical conductivity shall conform to 4.5.5. Conductivity measurements shall be made on product in the W temper after 10 hours or more have elapsed since quenching, or after electrical conductivity has stabilized, but prior to artificial aging. Conductivity of plate shall be measured at four-inch maximum intervals across the width of the plate and at 24 inch maximum intervals along the length of the plate. Readings shall be taken on both sides (faces) of the plate. Conductivity of test extrusions shall be measured at two-inch maximum intervals around the section perimeter of test extrusions and at 24-inch intervals along an extrusion's length. For extruded shapes (T-, L-sections, etc.), conductivity measurements on that portion of a surface directly opposite the junction of two or more sectional elements shall be excluded. Records shall be maintained in accordance with 4.1.2.

4.4.1.6 Criteria for quench-system acceptance - 7075 plate. When testing 7075 plate, the quenching system shall be suspect if the conductivity readings on one-side of the plate exhibit a range greater than 2.5 percent International Annealed Copper Standard (IACS), or exceed a maximum value of 31.0 percent IACS.

4.4.1.7 Criteria for quench-system acceptance - plate other than 7075. When plate of an alloy other than 7075 is tested, the quenching system shall be suspect if the conductivity readings on one side of the plate exhibit a range greater than 2.5 percent IACS, or exceed a maximum established as satisfactory for that alloy, thickness, and temper.

4.4.1.8 Criteria for quench-system acceptance - 7075 extrusions. When testing 7075 extrusions, the quenching system shall be suspect if the conductivity readings around the section perimeter and at 24-inch intervals along the length exhibit a range greater than 4.0 percent IACS, or if the values from each element (flange, web, etc.) of a shape exhibit a range greater than 3.0 percent IACS, or exceed a maximum of 32.0 percent IACS.

4.4.1.9 Criteria for quench-system acceptance - extrusions other than 7075. When extrusions of an alloy other than 7075 are tested, the quenching system shall be suspect if the conductivity readings around the section perimeter and at 24-inch intervals along the length exhibit a range greater than 4.0 percent IACS, or if the values from each element (flange, web, etc.) of a shape exhibit a range greater than 3.0 percent IACS, or exceed a maximum established as satisfactory for that alloy, temper, and cross-sectional configuration and dimensions.

4.4.1.10 Test procedures when quenching system is suspect. When a quenching system is suspect, additional inspections shall be made of the equipment and test material to determine the cause or causes of aberration. The cause(s) shall be corrected and the equipment, procedures and product shall be handled in accordance with 4.6.4 and 4.6.4.1.

4.4.2 Monitoring immersion quenching of product. A plan for such monitoring shall be implemented for each forging and casting and for sheet and plate in each applicable thickness range shown in Table VI, and for each configuration of other wrought products. As a minimum, the plan shall include the following.

4.4.2.1 Racking or spacing documentation. Documentation such as drawings or other suitable media shall be maintained to ensure proper racking. A record shall be maintained to show that each racking plan has produced material satisfying the requirements of the applicable material specification. When specified in a contract or purchase order, a racking plan shall be examined for approval by the procuring activity. Records shall be maintained in accordance with 4.1.2.

4.4.2.2 Periodic inspection. The plan shall include periodic inspection of mill products by electrical conductivity and hardness testing and routine inspection of castings by mechanical property testing to ensure that the quench continues to be adequate. Inspection frequency shall be agreed upon by the purchaser. Frequency and results of inspection shall be recorded and the records retained in accordance with 4.1.2.

4.4.2.3 Inspection for racking adequacy. Unless otherwise specified adequacy of the racking method shall be established by electrical conductivity measurements on a suitable quantity of mill products (see 4.5.5 for test method).

4.4.2.3.1 Testing of forgings. Electrical conductivity of forgings shall be made on a two-inch grid, unless prevented by testpiece configuration. When so prevented, measurements shall be taken in a sufficient number of locations to reveal the adequacy of the quench. Alternatively, one test piece from each inspection lot may be age-hardened to its specified temper and sectioned into test blanks for testing of mechanical properties in accordance with 4.5.1.

4.4.2.3.2 Testing of extrusions. Electrical conductivity measurements on extrusions shall be made at two-inch maximum intervals around the perimeter of the cross-section of the extrusion and at 24-inch maximum intervals along the length of the extrusion, unless prohibited by the size and configuration of the extrusion. It shall not be necessary to check opposite sides of any solid sections of the extrusion which are less than 3/8-inch thick, or that portion of a surface directly opposite the juncture of two or more elements. Exceptions to the requirements herein shall be subject to the approval of the cognizant engineering activity.

4.4.2.3.3 Testing of plate. Electrical conductivity test measurements on plate shall be on a grid four inches (along width) by 24 inches (along length) on at least one piece from the center of the load or rack and two other pieces selected at random from the load or pack.

4.4.2.3.4 Random-racked or layered forgings and castings. Immersion quenching of random-racked or layered forgings and castings shall be monitored on each heat-treat load by electrical conductivity or hardness measurements made on a two-inch grid spacing on at least one piece from the center of the load, and on at least two other pieces selected at random from the load. When material configuration prevents a two-inch grid spacing, then a suitable number of measurements shall be made to determine adequacy of the quench.

4.4.3 Tests for process control.

4.4.3.1 Material and process tests. Such tests shall be performed in order to demonstrate the capability of the facility to produce product meeting the requirements of the applicable product specifications and other acquisition documents. Tests and testing procedures shall conform to Table VIII and 4.4.3.2, as applicable.

4.4.3.2 Monthly test on furnace load. Tests of furnace load performance shall be made once each month. If more frequent testing is necessary or advisable, a test plan incorporating an increased frequency shall be adopted. Such a plan shall be subject to review and approval by an authorized government representative. If the monthly workload included plate and/or sheet as well as other metal forms, the load to be tested per Table VIII shall be a "plate and sheet" load. If this product form was not heat treated during the month, the test load shall be selected from the available product forms, using that form for which Table VIII requires the maximum number of test categories.

4.5 Test methods.

4.5.1 Mechanical properties. Specimens shall conform to an appropriate type of tensile test specimen in ASTM B557 and shall be tested in accordance with an appropriate method specified therein and shall meet the requirements of 4.6.1.

4.5.1.1 Mechanical properties of wrought products. Unless every heat-treated lot is tested (see applicable material specification for sampling plan), a minimum of nine tension tests, sampled to represent the quantity of the mill product, shall be made on the mill product which was heat treated with the monthly production test load from each heat-treat furnace or bath being operated. An authorized government representative may waive this requirement if other approved testing procedures are used. The tension test specimens shall include specimens taken from the portion of the load receiving the slowest quench, those portions subjected to the highest and lowest solution heat-treating temperatures, and, when nonuniform shapes have been heat treated, from the thickest and thinnest sections of the cross-sectional configuration. The tension test specimen having the lowest yield strength shall be used for the corrosion test specified in 4.5.3.

4.5.1.1.1 Mechanical property tests of mill products where specimen taking is impractical. When taking specimens from a heat-treated mill product is impractical, tension-test specimens shall be taken from samples heat treated with a production load. The thickness and alloy of the samples and their location in the load shall be selected so as to represent items heat treated during the previous month which were considered to have experienced the lowest quench rate and those which were subjected to the highest and lowest solution heat-treating temperatures.

4.5.1.1.2 Testing of heat-treat loads when changes are made in the heat-treat facility. When changes are made in the heat-treat facility as outlined in 3.1.2, the mechanical property sampling and testing as specified in 4.5.1.1 and 4.5.1.1.1 shall be followed.

4.5.1.2 Mechanical properties of casting alloys. The required tests for casting alloys shall be in conformance with the applicable casting product specifications.

4.5.2 Melting and porosity resulting from solution heat treatment. One or more of the heat-treated specimens tested in accordance with 4.5.1.1 shall be examined for evidence of melting and porosity and shall conform to the requirements of 4.6.2. Each specimen shall be prepared for examination by sectioning, and then polishing one surface generated by the sectioning to appropriate fineness. Each polished surface shall be examined under a metallurgical microscope at 500 diameters magnification to detect porosity resulting from solution heat treatment. Following this examination, the polished surfaces shall be etched for approximately two seconds in Keller's reagent or other suitable etching solution and examined for evidence of melting during solution heat treatment.

4.5.3 Intergranular corrosion test. Corrosion tests shall be conducted in accordance with the procedure outlined below and samples shall conform to the requirements of 4.6.3. In the case of alclad alloys, the alclad shall be removed from both sides of the sample by filing or by other suitable means. Prior to the corrosion test, each sample shall be immersed for 1 minute in an etching solution at 200° F to produce a uniform surface condition. The solution shall have the following composition:

a. Nitric acid, concentrated (70 percent) - 50 milliliters.
b. Hydrofluoric acid (48 percent) - 5 milliliters.
c. Distilled or deionized water - 945 milliliters.

After this etching treatment, the sample shall be rinsed in distilled or deionized water, immersed for one minute in concentrated nitric acid (70 percent) at room temperature to remove any metallic copper that may have been plated out on the specimen, and rinsed in distilled or deionized water, then allowed to dry. The sample shall be corroded by immersion in a minimum of 30 milliliters per square inch of surface area in a solution of the following composition, which shall be prepared immediately before use (the temperature during the immersion period shall be 86° ± 9° F):

a. Sodium chloride - 57 grams.
b. Hydrogen peroxide (30 percent) - 10 milliliters.
c. Distilled or deionized water - Dilute to 1 liter.

The immersion period shall be 6 hours. All chemicals shall be reagent grade.

4.5.3.1 Number of specimens in container. More than one specimen of the same alloy and temper may be etched in a container, provided that at least 30 milliliters of solution are used for each square inch of specimen surface, and the specimens are electrically insulated from each other.

4.5.3.2 Microscopic examination. 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 3/4 inch long whenever the size of the sample permits, shall be cut from the sample and mounted for microscopic examination. Microscopic examination shall be made on the specimen both before and after etching at 100 to 500 diameters magnification with a metallurgical microscope. The etching shall be done by immersion for 6 to 20 seconds in a solution of the following composition:

a. Nitric acid, concentrated (70 percent) - 2.5 milliliters.
b. Hydrochloric acid, concentrated - 1.5 milliliters.
c. Hydrofluoric acid (48 percent) - 1.0 milliliter.
d. Distilled or deionized water - 95.0 milliliters.

All chemicals shall be reagent grade.

4.5.4 Test for diffusion in alclad alloys. A microscopic examination of sections of specimens cut from mill products representative of a lot or furnace load shall be made to determine the extent of diffusion of the alloying constituents through the cladding. Examination shall be made with a metallurgical microscope at 100 to 1,000 diameters magnification, after etching as specified in 4.5.3.2 and specimens shall conform to the requirements of 4.6.3. The solution potential measurement method for evaluation of alclad diffusion is acceptable providing documentation which correlates this method to the optical method is available for review.

4.5.5 Eddy-current measurements of electrical conductivity.

4.5.5.1 Procedure requirements. Electrical conductivity inspection shall be performed, as specified herein, in accordance with MIL-STD-1537. The procedure shall be available to the authorized government representative.

4.5.5.2 Equipment calibration. The equipment to measure electrical conductivity shall be calibrated in accordance with MIL-STD-1537 except that the number of standards necessary shall be as recommended by the device's manufacturer.

4.5.5.3 Personnel qualification. Personnel conducting eddy current inspections shall be trained and qualified as specified in MIL-STD-1537.

4.5.6 Hardness measurements. When required, hardness of product shall be tested in accordance with ASTM E10 or ASTM E18, as applicable to the product to be tested. The use of ASTM E103 for "pass-fail" inspections during manufacture is neither mandated nor forbidden. When a question arises about hardness data gathered using the method of ASTM E103, additional hardness data shall be taken using the methods of ASTM E10 or E18, as applicable to the product.

4.6 Limits of acceptability.

4.6.1 Mechanical properties. The heat-treated (or re-solution heat-treated) test samples shall exhibit tensile strength, yield strength, and elongation not less than those specified in applicable product specifications or detail drawings.

4.6.2 Melting and porosity resulting from solution heat treatment. Specimens prepared in accordance with 4.5.2 shall show no evidence of melting resulting from solution heat treatment and the specimens shall be substantially free from porosity caused by hydrogen diffusion during solution heat treatment.

4.6.3 Intergranular corrosion and alclad diffusion. The degree of susceptibility to intergranular corrosion and degree of alclad diffusion shall be no greater than that normally experienced when following the practices recommended in this specification. Practices other than those recommended herein may be employed (see 4.6.3.1), provided it is documented that the resulting degrees of intergranular corrosion and alclad diffusion are no greater than those resulting from applications of the recommended practices, as applicable to product. This objective evidence shall be retained in accordance with 4.1.2.2.

4.6.3.1 Tests for alclad diffusion and susceptibility to intergranular corrosion. Prior to using equipment or procedures which vary from those recommended herein, tests shall be made to determine the alclad diffusion and susceptibility to intergranular corrosion produced by the proposed variation. Decision as to whether the alclad diffusion and the susceptibility to intergranular corrosion is excessive shall be based upon comparison with samples of the same thickness from the same piece of raw stock, heat treated in accordance with the equipment and procedures recommended and specified herein.

4.6.4 Failures. The occurrence of failure(s) during any of the tests specified herein shall give rise to an evaluation of the adequacy of heat treatment(s). If the test failure is attributed to improper heat treatment, the equipment and procedures shall not be used until the deviation(s) is (are) corrected and the applicable part(s) of the equipment and procedures are re-established in accordance with 3.1.2, as specified in 4.2 or 4.3.1. Re-establishment may be waived by the procuring activity if corrective action, to bring the equipment and procedures back into conformance with the requirements herein, is implemented and verified by documentation.

4.6.4.1 Status of product. Product heat treated in the interval between the occurrences of the last satisfactory inspection results and the first unsatisfactory inspection results shall be deemed questionable. Each unit of questionable product shall be inspected, unless the inspection method is a destructive test. Destructive testing shall entail a sampling plan agreed upon between the product vendor and the acquisitioner. Unsatisfactory product may be re-solution heat treated unless the product exhibits eutectic or other localized melting, excessive porosity resulting from solution heat treatment, or in the case of alclad product, shows a harmful degree of diffusion of alloying elements from the core through the cladding. Alclad product which is questionable or fails for reasons other than those enumerated above may be re-solution heat treated up to the limit of the permissible number of times specified in Table III. Inspection results shall be documented.

4.7 Heat-treat lot numbers for forgings. Each heat-treat lot of forgings (see 6.5.2) shall be assigned a lot number. Each forging in the lot shall display its lot number, unless such display is infeasible or would result in nonconformance to the applicable product specification. If such display is not feasible, each lot shall be identified by tags or travellers. Lot numbers shall be entered in records kept by the furnace and quench facilities and in records of tests conducted by the quality control laboratory. The entire history of the heat treatment of each heat-treated forging shall be traceable through the records specified herein.

5. PACKAGING (This section is not applicable to this specification.)

6. NOTES

6.1 Intended use. This specification is intended for use in all phases of the control of processes and equipment applied to the heat treatment of aluminum alloy cast, forged, rolled, drawn, and extruded products. It covers products which are essentially raw materials for subsequent operations. It does not cover "parts" in the meaning of that term used in AMS 2770 which is not intended to be applicable to primary mill products. Assigning a part number to a mill product does not change its status from that of a raw mill product to that of a part.

6.2 Acquisition requirements. Acquisition documents should specify the following:

a. Title, number, and date of this specification.

b. Issue of DODISS to be cited in the solicitation, and if required, the specific issue of individual documents referenced (see 2.2).

c. When Government verification of process establishment is required (see 3.1).

d. Conditions governing heat treatment of parts (see 3.4).

e. Exceptions to provisions of 4.1.

6.3 General information.

6.3.1 Advantages of salt baths. The time required to bring the load to temperature is shorter and uniform temperature is more easily maintained in molten salt baths than in air chamber furnaces. When solution heat treating in molten salt, the danger of generating porosity is greatly diminished. After prolonged use, there is some decomposition of the sodium nitrate to form compounds which, when dissolved in the quenching water, attack the aluminum alloys. The addition to the salt bath of about 1/2 ounce of sodium or potassium dichromate per 100 pounds of nitrate tends to inhibit this attack. Nitrate salt baths may present an explosion safety hazard when heat treating 5XX.X casting alloys.

6.3.2 Advantages of air chamber furnaces. Air chamber furnaces are more flexible and more economical for handling large volumes of work. When solution heat treating certain aluminum alloys it is necessary to control the atmosphere in order to avoid the generation of porosity. Such porosity lowers the mechanical properties of aluminum alloys and may be manifest as large numbers of minute blisters over the surface of the product. In severe cases, the product may even crack when it is quenched. Furnace products of combustion contain water vapor and may contain gaseous compounds of sulfur, both of which tend to promote porosity during solution heat treatment. For this reason, furnaces which permit their products of combustion to come in contact with the load are not recommended for the solution heat treatment of alloys which may become porous during such treatment. Either anodic oxide films or the metal coating of the alclad materials protect the underlying alloy from this effect. Also, certain fluoroborates will protect against or minimize this effect.

6.3.3 Solution heat treatment. Solution heat treatment is a process to heat an alloy to a suitable temperature (see Table II) for sufficient time to allow soluble constituents to enter into solid solution where they are retained in a supersaturated state by rapid cooling in a suitable quenching medium.

6.3.3.1 Soaking time. The soaking time required to bring about the necessary degree of solid solution increases with increasing thickness of the metal. The minimum soaking period is determined by testing samples of the metal to make certain that the required mechanical properties have been developed. The soaking periods recommended in Tables IV and V have been found to be sufficient in commercial practice.

6.3.3.2 Development of hydrogen porosity. When solution heat treating in air chamber furnaces, excessive soaking periods increase the danger of the development of hydrogen porosity, a phenomenon formerly known as "high temperature oxidation". However, with proper control of furnace atmospheres, soaking periods longer than those listed in Tables IV and V may be used safely.

6.3.3.3 Diffusion in clad products. The soaking period for clad products should be the minimum which is necessary to develop the required mechanical properties. Longer soaking may allow the alloying constituents of the base metal to diffuse through the alclad coating. When this occurs, corrosion resistance is adversely affected. Consequently, every effort should be made to avoid diffusion by using the minimum possible soaking periods for clad products.

6.3.3.4 Incorrect solution heat-treating temperature. If the specified maximum temperature is exceeded, there is danger of localized melting, with possible lowering of the mechanical properties of the alloy. Excessive overheating will cause severe blistering in the product. If the temperature is below the minimum specified, solution is incomplete, the maximum mechanical properties are not developed, and corrosion resistance can be adversely affected.

6.3.3.5 Effect of re-solution heat treatment on corrosion resistance of 2017-T4 and 2024-T3 and -T4. If the temperature used for re-solution heat treatment of 2017-T4 or 2024-T3 and -T4 product is less than that applied in the initial heat treatment, a loss of corrosion resistance results. Since the use of a longer soaking period tends to overcome this loss, both a longer-than-average soaking period and a solution heat-treating temperature within 5° F of the applicable maximum tabulated are recommended for re-solution heat treatment of each of these alloys.

6.3.3.6 Thermal treatment of forgings to -01 condition. This is a high temperature anneal given to a forging for a special purpose such as to accentuate ultrasonic response or provide dimensional stability. In order to be so annealed, product is held at approximately the same temperature for approximately the same time period as in solution heat treatment, but in this instance the product is slowly cooled to room temperature. This anneal is applied to products that are to be machined prior to solution heat treating and aging to the desired temper. This application is neither mandatory nor forbidden, provided that all other requirements specified herein, in the applicable product specification, and in other applicable acquisition documents are met. The Government reserves the right to require the use or nonuse of such treatments, if these conditions are not being met.

6.3.4 Quenching for resistance to corrosion. For products in some tempers of 2117 and bare and alclad 2024 and 7075 alloys, a rapid quench is necessary so that the resulting product will have maximum resistance to corrosion. As the quench rate is lowered, these alloys become increasingly susceptible to intergranular attack which causes excessive loss of mechanical properties after exposure to corrosives.

6.3.5 Alloy and temper designation. The alloy and temper designations used herein conform to the American National Standards Institute Publication, ANSI H35.1.

6.3.6 Alclad sheet. Alclad sheet is a product consisting of an aluminum alloy sheet having on one or both surfaces a layer of aluminum or aluminum alloy integrally bonded to the surface of the base metal. In general, alclad sheets have mechanical properties slightly lower than those of the bare alloy sheets of the same thickness. However, the corrosion resistant qualities of the aluminum alloy sheet are improved by the cladding.

6.3.7 Annealing treatments.

6.3.7.1 Annealing of work-hardened wrought alloys. Table XI lists recommended annealing conditions for work-hardened wrought aluminum alloys. For desired results for a specific product, optimum annealing conditions should be determined. In order to avoid excessive oxidation and grain growth, the annealing temperature should not exceed 775° F.

6.3.7.2 Relief of residual stresses in castings. The process of soaking castings for 2 hours at 650-750° F and then cooling them to room temperature, will relieve residual stresses in castings and attain dimensional stability.

6.3.7.3 Partial anneal of heat-treated aluminum alloys. When 2XXX, 6XXX and 7XXX series aluminum alloys in the heat-treated condition are heated at 650° F and cooled, they have been partially annealed and can be moderately (not severely) formed. Each particular application should be optimized for retained strength and formability. When attempting to restore the aluminum alloy to its initial heat-treated condition, a complete re-solution heat treatment will be necessary.

6.3.7.4 Full anneal of heat-treatable wrought alloys. All 2XXX, 6XXX and 7XXX series aluminum alloys when fully annealed according to recommended general conditions presented in Table XI obtain their lowest strength and best formability. However, they will require a complete heat treatment (solution heat treatment, quench and age) to develop their desired properties.

6.3.8 Aging. Aging causes precipitation of alloying elements from solid solution resulting in an increase in strength properties of an alloy. This usually occurs slowly at room temperature (natural aging - see Table II) and more rapidly at elevated temperature (artifical aging - see Table VII). Age-hardening is followed by normal cooling in a room temperature atmosphere. (The term "precipitation" is frequently used in lieu of "age-hardening".) Age-hardening heat treatments needing relatively long times and relatively low temperatures to develop required properties are recommended for products with large cross sections or large masses to promote uniformity of properties. Alternate treatment on other products utilizing shorter times at proportionately higher temperatures may be used if all material requirements are met.

6.3.8.1 Artificial aging.

6.3.8.1.1 Example of artificial aging. Heating of aluminum alloy bare and alclad 2024 at an elevated temperature - but well below the annealing temperature - after solution heat treatment and natural aging (temper -T4), will result in tensile and yield strengths considerably higher than those which would result even with prolonged room temperature aging of this alloy. There is also a decrease in the elongation of the material. This process is called "elevated temperature precipitation heat treatment" or "artificial aging."

6.3.8.1.2 Effect of cold work on artificial aging. The mechanical properties resulting from the aging treatment are dependent on the amount of cold work present in the material at the time of artificial aging. The mechanical properties that can be developed in any design are dependent, therefore, upon the severity of the forming operations used in fabricating the part, and this will govern the selection of the temper of stock material used. For example, if only slight forming is involved, 2024-T36 or 2024-T361 material, which contains a considerable degree of cold work, could be used with resultant higher mechanical properties of the aged part than could be obtained if 2024-0 or 2024-T3 material were used. The amount of cold work put into the part during the forming operation will add to that in the stock metal, and therefore, the formed part will generally have greater ultimate and yield strength and lower elongation after aging than would a piece of stock material given the same aging treatment.

6.3.8.1.2.1 Effect of heat on cold work. Annealing or solution heat treating will remove any cold work present in the material so treated. Subsequent solution heat treatment and artificial aging of the annealed material, will result in -T6 conditions, provided the material is not reworked prior to aging. The higher strength conditions can be obtained only if known amounts of cold working are accomplished prior to natural or artificial aging operations. For example, to obtain -T81, -T84, and -T861 conditions, the material would have to be cold-worked to approximately 1, 4, and 6 percent, respectively, subsequent to solution heat treatment and prior to natural and artificial aging.

6.3.9 Mechanical stress relief of plate, extrusions, and forgings. To provide relief of residual stresses, plate, extrusions, and forgings are stretched or compressed after solution treatment, but prior to aging as follows:

a. Plate. Stretched 1.5 - 3 percent permanent set to produce the TXX51 tempers.

b. Extrusions. Stretched 1 - 3 percent permanent set to produce the TXX51 tempers (1/), or compressed 1 - 5 percent permanent set to produce the TXX52 tempers.

c. Forgings. Stretched 1 - 5 percent permanent set to produce the TXX51 tempers.

d. Forgings. Compressed 1 - 5 percent permanent set to produce the TXX52 tempers.

1/ Modifications to this temper are: TXX510 which applies to products that receive no straightening after stretching, and TXX511 which applies to products that receive minor straightening after stretching so as to comply with straightness tolerances.

6.3.10 Influence of residual tensile stress on stress-corrosion behavior. Heat-treatment features, such as quenching medium and aging treatment (as well as straightening procedure after solution heat treatment), can significantly affect the level of residual tensile stress in a part and influence stress-corrosion behavior. These heat-treatment features should be optimum with regard to minimizing residual tensile stress.

6.3.11 Electrical conductivity, hardness and temper relationships. For information purposes only, Tables IX and X present typical values relating electrical conductivity and hardness with temper for non-clad and alclad aluminum alloys.

6.4 Consideration of data requirements. The following data requirements should be considered when this specification is applied on a contract. The applicable Data Item Descriptions (DID's) should be reviewed in conjunction with the specific acquisition to ensure that only essential data are requested/provided and that the DID's are tailored to reflect the requirements of the specific acquisition. To ensure correct contractual application of the data requirements, a Contract Data Requirements List (DD Form 1423) must be prepared to obtain the data, except where DOD FAR Supplement 27.475-1 exempts the requirement for a DD Form 1423.

Reference Paragraph	DID Number	DID Title
3.5.2.1, 3.8, 3.8.1.2, 4.1.2, 4.1.2.1, 4.1.2.3, 4.1.2.4, 4.3.1, 4.5.6, 4.6.4.1	DI-MISC-80653	Test Reports
4.7	DI-A-3027A	Data Accession List/ Internal Data

The above DID's were those cleared as of the date of this specification. The current issue of DOD 5010.12-L, Acquisition Management Systems and Data Requirements Control List (AMSDL), must be researched to ensure that only current, cleared DID's are cited on the DD Form 1423.

6.5 Definitions. Some of the terms defined in this paragraph are so defined as to be especially pertinent to this specification.

6.5.1 Heat treatment. The phrase "heat treatment" as used in this specification is meant to collectively include all thermal treatments covered by this specification such as: solution heat treatment, age-hardening heat treatment, stabilizing, and annealing.

6.5.2 Heat-treat lot, forgings. A heat-treat lot consists of an identifiable quantity of metal of the same alloy and of the same product form, temper and thickness or section, and of the same process history, all forgings, having been processed at the same time through a heat-treat and quench facility, or as a continuous production run in a continuous heat-treating furnace and quench facility during a maximum of eight hours or as required by the applicable material specification.

6.5.3 Working Zone. Working zone is that portion of the enclosed volume of a piece of thermal processing equipment occupied by parts or raw material during the soaking protion of a thermal treatment. It is usually, but not always, a high percentage of the total enclosed volume.

6.5.4 Contractual requirements and recommendations. Wherever used in this specification, the word "shall" indicates a mandatory requirement, and the word "should" indicates a recommendation.

6.5.5 Blistering and porosity resulting from solution heat treatment. Such occurrences have in the past been called high temperature oxidation. It is now known that hydrogen entering aluminum alloys during solution heat treatment is the cause for development of surface blisters and subsurface patterns of pores.

6.5.6 Authorized representative. Any Government representative specifically authorized to approve equipment, material, or procedures within the scope of this document. They can be, but are not limited to, the following:

a. Contracting Officer
b. Defense Industrial Supply Center (DISC)
c. Defense Contract Management Command (DCMC)
d. Defense Plant Representative Office (DPRO)

6.5.7 Cognizant Engineering Activity. The engineering organization responsible for the design of the item being heat treated.

6.6 Patent notice. The Government does not possess a royalty-free license for heat treatment of 7175 alloy forgings under U.S. Patent Number 3,791,876 which expires 12 February 1994. The Department of Defense has no opinion about the novelty, uniqueness, and effectiveness of the patented procedure, nor does the Department offer any advice concerning the seeking of a license to apply that procedure.

6.7 Subject term (key word) listing.

Age-hardening
Alclad
Aluminum
Alloys, aluminum
Heat-treat
Quench
Representative, authorized government
Solution heat-treat
Time, soak

6.8 Changes from previous issue. Asterisks are not used in this revision to identify changes with respect to the previous issue due to the extensiveness of the changes.

Custodians:
Army - MR
Navy - AS
Air Force - 11

Preparing activity:
Navy - AS

(Project No. 95GP-0192)

Reviewer activities:
Army - AR, AV
Navy - SH
Air Force - 99
DLA - IS
MISC - MS
MISC - NA (MSC)

User activities:
Army - ME
Navy - OS

TABLE I. Inspection requirements

Requirement	Requirement paragraph(s)	Quality Assurance paragraph(s)
Process establishment and re-establishment	3.1, 3.1.2	4.1.2.1, 4.2, 4.3.1
Periodic process surveys	3.2	4.2
Periodic product monitoring	3.3	4.4

TABLE II. Solution heat-treating temperatures.

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Wrought products (EXCLUDING FORGINGS)					
2011	wire, rod, bar	945-995	-W	-T3 6/, -T4	-T451
2014	flat sheet	925-945	-W	-T3 6/, -T42	--
	coiled sheet	925-945	-W	-T4, -T42	--
	plate	925-945	-W	-T4, -T42	-T451
	wire, rod, bar	925-945	-W	-T4	-T451
	extrusions	925-945	-W	-T4, -T42	-T4510, -T4511
	drawn tube	925-945	-W	-T4	--
2017	wire, rod, bar	925-950	-W	-T4	-T451
	rivets	925-950	-W	-T4	--
2024	flat sheet	910-930	-W	-T3 6/, -T361 6/, -T42	--
	coiled sheet	910-930	-W	-T4, -T42, -T3 6/	--
	rivets	910-930	-W	-T4	--
	plate	910-930	-W	-T4, -T42, -T361 6/	-T351
	wire, rod, bar	910-930 7/	-W	-T4, -T36 6/, -T42	-T351

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Wrought products (EXCLUDING FORGINGS)					
2024	extrusions	910-930	-W	-T3 6/, -T42	-T3510, T3511
	drawn tube	910-930	-W	-T3 6/, -T42	--
2048	sheet, plate	910-930	-W	-T4, -T42	-T351
2117	wire, rod, bar	925-950	-W	-T4	--
	rivets	890-950	-W	-T4	--
2124	plate	910-930	-W	-T4 2/, -T42	-T351
2219	sheet	985-1005	-W	-T31 6/, -T37 6/, -T42	--
	plate	985-1005	-W	-T31 6/, -T37 6/, -T42	-T351
	rivets	985-1005	-W	-T4	--
	wire, rod, bar	985-1005	-W	-T31 6/, -T42	-T351
	extrusions	985-1005	-W	-T31 6/, -T42	-T3510, -T3511
6010	sheet	1045-1065	-W	-T4	--
6013	sheet	1045-1065	-W	-T4	--
6061	sheet	960-1075 8/	-W	-T4, -T42	--
	plate	960-1075	-W	-T4, -T42	-T451
	wire, rod, bar	960-1075	-W	-T4, -T42	-T451

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Wrought products (EXCLUDING FORGINGS)					
6061	extrusions	960-1075	-W	-T4, -T42	-T4510, -T4511
	drawn tube	960-1075	-W	-T4, -T42	--
6063	extrusions	960-985	-W	-T4, -T42	-T4510, -T4511
	drawn tube	960-980	-W	-T4, -T42	N/A
6066	extrusions	960-1010	-W	-T4, -T42	-T4510, -T4511
	drawn tube	960-1010	-W	-T4, -T42	--
6262	wire, rod, bar	960-1050	-W	-T4	-T451
	extrusions	960-1050	-W	-T4	-T4510, -T4511
	drawn tube	960-1050	-W	-T4	--
6951	sheet	975-995	-W	-T4, -T42	--
7001	extrusions	860-880	-W	--	-W510 2/ W511 2/
7010	plate	880-900	-W		W51 2/
7039	sheet	840-860 9/	-W	--	--
	plate	840-860 9/	-W	--	-W51 2/
7049/ 7149	extrusions	860-885	-W	--	-W510 2/ -W511 2/
7050	sheet	880-900	-W		
	plate	880-900	-W	--	-W51 2/

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Wrought products (EXCLUDING FORGINGS)					
7050	extrusions	880-900	-W	--	-W510 2/ -W511 2/
	wire, rod, rivets	880-900	-W	--	--
7075	sheet	860-930 10/	-W	--	--
	plate 11/	860-930	-W	--	-W51 2/
	wire, rod, bar 11/	860-930	-W	--	-W51 2/
	extrusions	860-880	-W	--	-W510 2/ -W511 2/
	drawn tube	860-880	-W	--	--
7150	extrusions	880-900	-W		-W510 2/ -W511 2/
	plate	880-895	-W		-W51 2/
7178	sheet 13/	860-930	-W		--
	plate 13/	860-910	-W	--	-W51 2/
	extrusions	860-880	-W	--	-W510 2/ -W511 2/
7475	sheet	880-970	-W	--	--
	plate	880-970	-W	--	--
7475 Alclad	sheet	880-945	-W	--	--

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Forgings 14/					
2014	die forgings	925-945	-W	-T4, -T41	--
	hand forgings	925-945	-W	-T4, -T41	-T452
2018	die forgings	940-970	-W	-T4, -T41	--
2024	die & hand forgings	910-930	-W	-T4	-T352
2025	die forgings	950-970	-W	-T4	--
2218	die forgings	940-960	-W	-T4, -T41	--
2219	die & hand forgings	985-1005	-W	-T4	-T352
2618	die & hand forgings	975-995	-W	-T4, -T41	--
4032	die forgings	940-970	-W	-T4	--
6053	die forgings	960-980	-W	-T4	--
6061	die & hand forgings	960-1075	-W	-T4, -T41	-T452
	rolled rings	960-1025	-W	-T4, -T41	-T452
6066	die forgings	960-1010	-W	-T4	--
6151	die forgings	950-980	-W	-T4	--
	rolled rings	950-980	-W	-T4	-T452

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Forgings 14/					
7049/ 7149	die & hand forgings	860-885	-W	--	-W52 2/
7050	die & hand forgings	880-900	-W	--	-W52 2/
7075	die & hand forgings	860-890 9/	-W	--	-W52 2/
	rolled rings	860-890 9/	-W	--	-W52 2/
7076	die & hand forgings	850-910	-W	--	--
7175	die forgings	15/	-W	--	--
	hand forgings	15/	-W	--	--

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Castings (all mold practices) 16/					
A201.0 18/	--	945 - 965 followed by 970 - 995	--	-T4	--
A206.0 (206) 18/	--	945-965 followed by 970-995	--	-T4	--
222.0 (122)	--	930 - 960	--	-T4	--
242.0 (142)	--	950 - 980	--	-T4, -T41	--
295.0 (195)	--	940 - 970	--	-T4	--
296.0 (B295.0)	--	935 - 965	--	-T4	--
319.0 (319)	--	920 - 950	--	-T4	--
328.0 (Red X-8)	--	950 - 970	--	-T4	--
333.0 (333)	--	930 - 950	--	-T4	--
336.0 (A332.0)	--	950 - 970	--	-T45	--
A336.0 (A332.0)	--	940 - 970	--	-T45	--
354.0 (354)	--	980 - 995	--	-T4	--

TABLE II. Solution heat-treating temperatures. - Continued

Alloy	Products 1/ and limitations	Solution heat-treating (metal) temperature (degrees F) 5/	Temper designation		
			Immediately after quenching 2/	After natural aging 3/	After stress relief 4/
Castings (all mold practices) 16/					
355.0 (355), C355.0	--	960 - 995	--	-T4	--
356.0 (356),	--	980 - 1025 12/	--	-T4	--
A356.0 (A356)	--		--	-T4	--
357.0 (357),	--	980 - 1025 12/	--	-T4	--
A357.0 (A357)	--		--	-T4	--
359.0 (359)	--	980 - 1010	--	-T4	
520.0 (220)	--	800 - 820	--	-T4	--
705.0 17/	--	--	--	T1 T5	-- --
707.0 17/	--	--	--	T1	--
712.0 17/	-- --	990 --	-- --	T4 T1	-- --
713.0 17/	--	--	--	T1	--
850.0 17/	--	--	--	T1	--
851.0 17/	--	--	--	T1	--
852.0 17/	--	--	--	T1	--

1/ The term "wire, rod, and bar" as used herein refers to rolled or cold finished wire, rod, and bar. The term "extrusions" refers to extruded wire, rod, bar, shapes, and tube.

2/ This temper is unstable and generally not available.

3/ Applies only to those alloys which will naturally age to a substantially stable condition. See Table VII for natural aging times.

4/ For rolled or extruded products, metal is stress relieved by stretching after quenching, and for forgings, metal is stress relieved by stretching or compression after quenching.

5/ When a difference between the maximum and minimum temperatures of a range listed herein exceeds 20° F, any 20° F temperature range (or 30° range for 6061) within the entire range may be utilized (see 3.5.1.5), provided that no exclusions or qualifying criteria are cited herein or in the applicable material specification.

6/ Cold working subsequent to solution heat treatment and prior to any precipitation heat treatment is necessary.

7/ Temperatures as low as 900° F may be used, provided that every heat treat lot is tested to show that the requirements of the applicable material specification are met, and analysis of test data to show statistic conformance to the specification limits is available for review.

8/ Maximum temperature for alclad 6061 sheet should not exceed 1000° F.

9/ Other temperatures may be necessary for certain sections, conditions and requirements.

10/ It must be recognized that under some conditions melting can occur when heating 7075 alloy above 900° F and that caution should be exercised to avoid this problem. In order to minimize diffusion between the cladding and the core, alclad 7075 sheet in thicknesses of 0.020 inch or less may be solution heat-treated at 850° to 930° F.

11/ For plate thicknesses over 4 inches and for rod diameters or bar thicknesses over 4 inches, a maximum temperature of 910° F is recommended to avoid melting.

12/ Heat treatment above 1010° F may require an intermediate solution heat treatment of one hour at 1000 - 1010° F to prevent eutectic melting of magnesium rich phases.

13/ Under some conditions melting can occur when heating this alloy above 900 degrees F.

14/ Unless otherwise indicated, hand forgings include rolled rings, and die forgings include impacts.

15/ Heat-treating procedures are at present proprietary among producers. At least one such procedure, is patented (U.S. Patent Number 3,791,876). (See 6.6).

16/ Former commercial designation is shown in parentheses.

17/ Unless otherwise specified solution heat treatment is not required. Castings should be quickly cooled after shake-out or stripping from molds, so as to obtain a fine tin distribution.

18/ In general, product should be soaked for two hours in the range 910-930° F prior to heating into the solution heat-treating range. Other presolution heat-treating temperature ranges may be necessary for some configurations and sizes.

TABLE III. Re-solution heat treatment of alclad alloys.

Thickness (inch)	Maximum number of re-solution heat treatments permissible 1/
Under 0.020	0
0.020 to 0.125 inclusive	1
Over 0.125	2

1/ One additional re-solution heat treatment is permitted if the heating rate is sufficiently rapid to keep product in conformance to 4.7.3.

TABLE IV. Recommended soaking time for solution heat treatment of wrought products.

Thickness (inches) 2/	Soaking time (minutes) 1/			
	Salt bath 3/		Air furnace 4/	
	(min)	(max) (alclad only) 5/	(min)	(max) (alclad only) 5/
0.016 and under	10	15	20	25
0.017 to 0.020 incl.	10	20	20	30
0.021 to 0.032 incl.	15	25	25	35
0.033 to 0.063 incl.	20	30	30	40
0.064 to 0.090 incl.	25	35	35	45
0.091 to 0.124 incl.	30	40	40	50
0.125 to 0.250 incl.	35	45	50	60
0.251 to 0.500 incl.	45	55	60	70
0.501 to 1.000 incl.	60	70	90	100
1.001 to 1.500 incl.	90	100	120	130
1.501 to 2.000 incl.	105	115	150	160
2.001 to 2.500 incl.	120	130	180	190
2.501 to 3.000 incl.	135	160	210	220
3.001 to 3.500 incl.	150	175	240	250
3.501 to 4.000 incl.	165	190	270	280

1/ 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.

2/ The thickness is the minimum dimension of the heaviest section.

3/ Soaking time in salt-bath furnaces begins at time of immersion, except when, owing to a heavy charge, the temperature of the bath drops below the specified minimum; in such cases, soaking time begins when the bath reaches the specified minimum.

4/ Soaking time in air furnaces begins when all furnace control instruments indicate recovery to the minimum of the process range.

5/ For alclad metals, the maximum recovery time (time between charging furnace and recovery of furnace instruments) should not exceed 30 minutes for thicknesses up to 0.050 inch, 60 minutes for 0.050 or greater but less than 0.102 inch, and 120 minutes for 0.102 or greater.

TABLE V. Recommended soaking time for solution treatment of cast alloys.

Alloy	Soaking Time (hours)
A201.0 (201) and A206.0 (206)	2 at 910 - 930°F followed by 2-8 at 945-965 followed by 8-24 at 970-995
222.0 (122)	6 to 18 incl.
242.0 (142)	2 to 10 incl.
295.0 (195)	6 to 18 incl.
296.0 (13295.0)	4 to 12 incl.
319.0 (319)	6 to 18 incl.
328.0	12
336.0, A336.0	8 hr. then water quench to 150-212° F
354.0 (354)	10 to 12 incl.
355.0 (355) and C355.0 (C355)	6 to 24 incl.
356.0 (356) and A356.0 (A356)	6 to 24 incl.
357.0 (357) and A357.0 (A357)	8 to 24 incl.
359.0 (359)	10 to 14 incl.
520.0 (220)	18

TABLE VI. Maximum quench delay, (for immersion quenching). 1/

Nominal thickness (inches)	Maximum time (seconds) 2/
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

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 alloy 2219, the maximum quench delay times may be exceeded (for examples, with extremely large loads or long lengths) if performance tests indicate that all portions of the load will be above 775° F when quenched. For alloy 2219, the maximum quench delay times may be exceeded if performance tests indicate all parts will be above 900° F when quenched.

2/ Shorter times than shown may be necessary to ensure that the minimum temperature of 7178 alloy is above 775° F when quenched.

TABLE VII. Recommended age-hardening heat-treating condition.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Wrought products (excluding forgings):					
2011	-W		Room temp.	96 Minimum	-T4, -T42
	-T3		310-330	14	-T8
	-T4		--	--	--
	-T451		--	--	--
2014	-W		Room temp.	96 Minimum	-T4, -T42
	-T3	flat sheet	310-330	18	-T6
	-T4, -T42 3/		340-360	10	-T6, -T62
	-T451 3/		340-360	10	-T651
	-T4510	extrusions	340-360	10	-T6510
	-T4511	extrusions	340-360	10	-T6511
2017	-W		Room temp.	96 Minimum	-T4
	-T4		--	--	--
	-T451		--	--	--
2024	-W		Room temp.	96 Minimum	-T4, -T42
	-T3	sheet and drawn tube	365-385	12	-T81
	-T4	wire, rod, bar	365-385	12	-T6
	-T3	extrusions	365-385	12	-T81
	-T36	wire	365-385	8	-T86
	-T42	sheet and plate	365-385	9	-T62
	-T42	sheet only	365-385	16	-T72
	-T42	other than sheet and plate	365-385	16	-T62
	-T351	sheet and plate	365-385	12	-T851
	-T361		365-385	8	-T861
	-T3510	extrusions	365-385	12	-T8510
	-T3511		365-385	12	-T8511
2048	-W		Room temp.	96 Minimum	-T4, -T42
	-T42	sheet and plate	365-385	9	-T62
	-T351		365-385	12	-T851
2117	-W	wire, rod, bar and rivets	Room temp.	96 Minimum	-T4
2124	-W	plate	Room temp.	96 Minimum	-T4, -T42
	-T4		365-385	9	-T6
	-T42		365-385	9	-T62
	-T351		365-385	12	-T851

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Wrought products (excluding forgings):					
2219	-W		Room temp.	96 Minimum	-T4, -T42
	-T31	sheet	340-360	18	-T81
	-T31	extrusions	365-385	18	-T81
	-T31	rivets	340-360	18	-T81
	-T37	sheet	315-335	24	-T87
	-T37	plate	340-360	18	-T87
	-T42		365-385	36	-T62
	-T351		340-360	18	-T851
	-T351	rod and bar	365-385	18	-T851
	-T3510	extrusions	365-385	18	-T8510
	-T3511		365-385	18	-T8511
6010	-W	sheet	340-360	8	-T6
6013	-W	sheet	Room temp.	336	-T4
	-T4 22/		365-385	4	-T6
6061	-W		Room temp.	96 Minimum	-T4, -T42
	-T1	rods, bar, shapes and tube, extruded	340-360	8	-T5
	-T4 14/	except extrusions	310-330	18	-T6
	-T451		310-330	18	-T651
	-T42		310-330	18	-T62
	-T4	extrusions	340-360	8	-T6
	-T42		340-360	8	-T62
	-T4510		340-360	8	-T6510
	-T4511		340-360	8	-T6511
6063	-W	extrusions	Room temp.	96 Minimum	-T4, -T42
	-T1		350-370	3	-T5, -T52
	-T1		415-435	1-2	-T5, -T52
	-T4		340-360	8	-T6
	-T4		350-370	6	-T6
	-T42		340-360	8	-T62
	-T42		350-370	6	-T62
	-T4510		340-360	8	-T6510
	-T4511		340-360	8	-T6511
6066	-W	extrusions	Room temp.	96 Minimum	-T4, -T42
	-T4		340-360	8	-T6
	-T42		340-360	8	-T62
	-T4510		340-360	8	-T6510
	-T4511		340-360	8	-T6511

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Wrought products (excluding forgings):					
6262	-W		Room temp.	96 Minimum	-T4
	-T4	wire, rod, bar, drawn tube	330-350	8	-T6
	-T451		330-350	8	-T651
	-T4	extrusions	340-360	12	-T6
	-T4510		340-360	12	-T6510
	-T4511		340-360	12	-T6511
6951	-W		Room temp.	96 Minimum	-T4, -T42
	-T4	sheet	310-330	18	-T6
	-T42		310-330	18	-T62
7001	-W	extrusions	240-260	24	-T6
	-W510		240-260	24	-T6510
	-W511		240-260	24	-T6511
7010	-W51 21/	plate	240-260 plus 330-350	6-24 6-15	-- T7651
			240-260 plus 330-350	6-24 9-18	T7451 17/
			240-260 plus 330-350	6-24 15-24	T7351
7039	-W 15/	sheet	165-185 plus 310-330	16 14	-T61
	-W51 15/	plate	165-185 plus 310-330	16 14	-T64
7049, 7149	-W511	extrusions	Room temp. followed by 240-260 followed by 320-330	48 24 12-14	-T76510, -T76511
			Room temp. followed by 240-260 followed by 325-335	48 24-25 12-21	-T73510, -T73511 19/

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/ Metal temperature (degrees F) 4/	Age-hardening heat treatment 1/ Aging time 2/ 13/ (hours)	Temper designation after indicated treatment
Wrought products (excluding forgings):					
7050	-W51 8/	plate	240-260 plus 315-335	3-6 12-15	-T7651
			240-260 plus 315-335	3-6 24-30	-T7451 17/
	-W510 8/	extrusions	240-260 plus 315-335	3-8 15-18	-T76510
	-W511 8/		240-260 plus 315-335	3-8 15-18	-T76511
	-W 8/	wire, rod, rivets	245-255 plus 350-360	4 min. 8 min.	-T73
7075	-W 7/		240-260	24	-T6, -T62
	-W 5/ 8/ 11/	sheet and plate	215-235 plus 315-335	6-8 24-30	-T73
	-W 8/ 11/		240-260 plus 315-335	3-5 15-18	-T76
	-W 6/ 8/ 11/	wire, rod, bar	215-235 plus 340-360	6-8 8-10	-T73
	-W 5/ 8/ 11/	extrusions	215-235 plus 340-360	6-8 6-8	-T73
	-W 8/ 11/		240-260 plus 310-330	3-5 18-21	-T76
	-W51 5/ 8/, 11/	plate	215-235 plus 315-335	6-8 24-30	-T7351

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Wrought products (excluding forgings):					
7075	W51 8/ 11/	plate	240-260 plus 315-335	3-5 15-18	-T7651
	-W51 10/		240-260	24	-T651
	-W51 6/ 8/ 11/	wire, rod, bar	215-235 plus 340-360	6-8 8-10	-T7351
	-W510 7/	extrusions	240-260	24	-T6510
	-W511 7/		240-260	24	-T6511
	-W510 5/ 8/ 11/		215-235 plus 340-360	6-8 6-8	-T73510
	-W511 5/ 8/ 11/		215-235 plus 340-360	6-8 6-8	-T73511
	-W510 5/ 8/ 11/		240-260 plus 310-330	3-5 18-21	-T76510
	-W511 8/ 11/		240-260 plus 310-330	3-5 18-21	-T76511
	-T6 8/	sheet	315-335	24-30	-T73
	-T6 8/	wire, rod, bar	340-360	8-10	-T73
	-T6 8/	extrusions	340-360	6-8	-T73
			310-330	18-21	-T76
	-T651 8/	plate	315-335	24-30	-T7351
			315-335	15-18	-T7651

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F 4/	Aging time 2/ 13/ (hours)	
Wrought products (excluding forgings):					
	-T651 8/	wire, rod, bar	340-360	8-10	-T7351
	-T6510 8/	extrusions	340-360	6-8	-T73510
			310-330	18-21	-T76510
	-T6511 8/		340-360	6-8	-T73511
			310-330	18-21	-T76511
7150	W510, W511	extrusions	240-260 plus 310-330	8 4-6 20/	-T6510, -T6511
	W51	plate	240-260 plus 300-320	24 12	T651
7178	-W		240-260	24	-T6, -T62
	-W 8/ 11/	sheet	240-260 plus 315-335	3-5 15-18	-T76
	-W 8/ 11/	extrusions	240-260 plus 310-330	3-5 18-21	-T76
	-W51	plate	240-260	24	-T651
	-W51 8/ 11/		240-260 plus 315-335	3-5 15-18	-T7651
	-W510	extrusions	240-260	24	-T6510
	-W510 8/ 11/		240-260 plus 310-330	3-5 18-21	-T76510

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Wrought products (excluding forgings):					
7178	-W511	extrusions	240-260	24	-T6511
	-W511 8/ 11/		240-260 followed by 310-330	3-5 18-21	-T76511
7475	-W	sheet	240-260 followed by 315-325	3 8-10	-T761
	-W51	plate	240-260	24	-T651
7475 Alclad	-W	sheet	250-315	3	-T61

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/ Metal temperature (degrees F) 4/	Age-hardening heat treatment 1/ Aging time 2/ 13/ (hours)	Temper designation after indicated treatment
Forgings:					
2014	-W		Room temp.	96 Minimum	-T4
	-T4		330-350	10	-T6
	-T41		340-360	5-14	-T61
	-T452	hand forgings	330-350	10	-T652
2018	-W	die forgings	Room temp.	96 Minimum	-T4
	-T41	die forgings	330-350	10	-T61
2024	-W	die & hand forgings	Room temp.	96 Minimum	-T4
	-W52	hand forgings	Room temp.	96 Minimum	-T352
	-T4	die & hand forgings	365-385	12	-T6
	-T352	hand forgings	365-385	12	-T852
2025	-W	die forgings	Room temp.	96 Minimum	-T4
	-T4	die forgings	330-350	10	-T6
2218	-W	die forgings	Room temp.	96 Minimum	-T4, -T41
	-T4	die forgings	330-350	10	-T61
	-T41	die forgings	450-470	6	-T72
2219	-W		Room temp.	96 Minimum	-T4
	-T4		365-385	26	-T6
	-T352	hand forgings	340-360	18	-T852

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Forgings:					
2618	-W		Room temp.	96 Minimum	-T4
	-T41	die forgings	380-400	20	-T61
4032	-W	die forgings	Room temp.	96 Minimum	-T4
	-T4	die forgings	330-350	10	-T6
6053	-W	die forgings	Room temp.	96 Minimum	-T4
	-T4	die forgings	330-350	10	-T6
6061	-W	die & hand forgings	Room temp.	96 Minimum	-T4
	-T41	die & hand forgings	340-360	8	-T61
	-T452	rolled rings & hand forgings	340-360	8	-T652
6066	-W	die forgings	Room temp.	96 Minimum	-T4
	-T4	die forgings	340-360	8	-T6
6151	-W	die forgings	Room temp.	96 Minimum	-T4
	-T4	die forgings	330-350	10	-T6
	-T452	rolled rings	330-350	10	-T652
7049	-W -W52	die & hand forgings	Room temp. followed by 240-260 followed by 320-330	48 24 10-16	-T73, -T7352

TABLE VII. Recommended age-hardening heat-treating condition – Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/ Metal temperature (degrees F) 4/	Age-hardening heat treatment 1/ Aging time 2/ 13/ (hours)	Temper designation after indicated treatment
Forgings:					
7050	-W	die forgings	240-260 plus 340-360	3-6 6-12	-T74 16/
	-W52	hand forgings	240-260 plus 340-360	3-6 6-8	-T7452 18/
7075	-W		240-260	24	-T6
	-W 8/ 11/		215-235 plus 340-360	6-8 8-10	-T73
	-W52	hand forgings	240-260	24	-T652
	-W52 8/ 11/		215-235 plus 340-360	6-8 6-8	-T7352
	-W51	rolled rings	215-235 plus 340-360	6-8 6-8	-T7351
	-W	die & hand forgings	215-235 plus 340-360	6-8 6-8	-T74 16/
7076	-W	die & hand forgings	265-285	14	-T6
7149	-W	die & hand forgings	Room temp.	48	
	-W52		240-260 plus 320-340	24 10-16	-T73, -T7352
7175	-W52	hand forgings	240-260	24	-T652
	-W	die & hand forgings	215-235 plus 340-360	6-8 6-8	-T74 16/

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Castings (all mold practices)					
201.0	-T4		300-320	10-24	-T6
A201.0 (201)	-T4		360-380	5 minimum	-T7
A206.0 (206)	-T4		380-400	5 minimum	-T7
222.0 (122)	-F		330-350	16-22	-T551
	-T4		380-400	10-12	-T61
	-T4		330-350	7-9	-T65
242.0 (142)	-F		320-350	22-26	-T571
	-T41		400-450	1-3	-T61
295.0 (195)	-T4		300-320	12-20	-T62
296.0 (B295.0)	-T4		300-320	1-8	-T6
	-T4		490-510	4-6	-T7
319.0 (319)	-T4		300-320	1-6	-T6
328.0 (Red X-8)	-T4		300-320	2-5	-T6
333.0 (333)	-F		390-410	7-9	-T5
	-T4		300-320	2-5	-T6
	-T4		490--510	4-6	-T7
336.0 (A332.0)	-T45		300-350	14-18	-T65

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/ Metal temperature (degrees F) 4/	Age-hardening heat treatment 1/ Aging time 2/ 13/ (hours)	Temper designation after indicated treatment
Castings (all mold practices)					
354.0 (354)	-T41		300-320	10-12	-T61
	-T41		330-350	6-10	-T62
355.0 (355) and C355.0 (C355)	-F		430-450	7-9	-T51
	-T4		300-320	1-6	-T6
	-T4		300-320	10-12	-T61
	-T4		330-350	14-18	-T62
	-T4		430-450	3-5	-T7
	-T4		465-485	4-6	-T71
356.0 (356) and A356.0 (A356)	-T4				
	-F		430-450	6-12	-T51
	-T4		300-320	1-6	-T6
	-T4		300-320	6-10	-T61
357.0 (357) and A357.0 (357)	-T4		300-340	2-12	-T6
359.0 (359)	-T4		300-320	8-12	-T61
	-T41		330-350	6-10	-T62
520.0 (220)	-T4		300-320	20-12	-T61
	-T41		330-350	6-10	-T62
705.0 (603)	-W		200-220 or Room temp.	10 21 days	-T5
707.0 (607)	-F		300-320 or Room temp.	3-5 21 days	-T5

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

Alloy	Temper before aging	Limitations	Age-hardening heat treatment 1/		Temper designation after indicated treatment
			Metal temperature (degrees F) 4/	Aging time 2/ 13/ (hours)	
Castings (all mold practices)					
712.0 (D712.0)	-F		345-365 or Room temp.	9-11 21 days	-T5
	-F		Room temp.	96 Minimum	-T1
713.0 (613)	-F		240-260 or Room temp.	16 21 days	-T5
850.0 (750)	-F		420-440	7-9	-T5
851.0 (A850.0)	-F		420-440	7-9	-T5
852.0 (B850.0)	-F		420-440	7-9	-T5

1/ To produce the stress-relieved tempers, metal which has been solution heat-treated in accordance with Table II (-W temper) must be stretched or compressed as required before aging. In instances where a multiple stage aging treatment is used, the metal may be, but need not be, removed from the furnace and cooled between aging steps.

2/ The time at temperature will depend on time required for load to reach temperature. The times shown are based on rapid heating with soaking time measured from the time the load reached the minimum temperature shown.

3/ Alternate treatment of 18 hours at 305° - 330 F may be used for sheet and plate.

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

4/ When the interval of the specified temperature range exceeds 20° F, any 20° temperature range (or 30° range for 6061) within the entire range may be utilized provided that no exclusions or qualifying criteria are cited herein or in the applicable material specification.

5/ Alternate treatment of 6 to 8 hours at 215° to 235° F followed by a second stage of 14 to 18 hours at 325° to 345° F may be used providing a heating-up rate of 25° F per hour is used.

6/ Alternate treatment of 10 to 14 hours at 340° to 360° F may be used providing a heating-up rate of 25° F per hour is used.

7/ For extrusions an alternate three-stage treatment comprised of 5 hours at 200° to 220° F followed by 4 hours at 240° to 260° F followed by 4 hours at 290° to 310° F may be used.

8/ The aging of aluminum alloys 7049, 7050, 7075 and 7178 from any temper to the T7 type tempers requires closer control on aging practice variables such as time, temperature, heating-up rates, etc., for any given item. In addition to the above, when re-aging material in the T6 temper series to the T7 type temper series, the specific condition of the T6 temper material (such as its property level and other effects 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 T7 type tempers.

9/ Old or former commercial designation is shown in parentheses.

10/ For plate, an alternate treatment of 4 hours at 195° - 215 degrees F followed by a second stage of 8 hours at 305° - 325° F may be used.

11/ With respect to -T73, -T7351, -T73510, -T73511, -T7352, -T76, -T76510 and -T76511 tempers, a license has been granted to the public under U.S. Patent 3,198,676 and these times and temperatures are those generally recommended by the patent holder. Counterpart patents exist in several countries other than the United States. Licenses to operate under these counterpart patents should be obtained from the patent holder.

12/ A heating-up rate of 50° - 75° F per hour is recommended.

13/ The 96 hour minimum aging time required for each alloy listed with temper designation W is not necessary if artificial aging is to be employed to obtain tempers other than that derived from room temperature aging. (For example, natural aging (96 hours) to achieve the -T4 or -T42 temper for 2014 alloy is not necessary prior to artificial aging to obtain a -T6 or -T62 temper.)

TABLE VII. Recommended age-hardening heat-treating condition - Continued.

14/ An alternate treatment comprised of 8 hours at 350° F also may be used.

15/ A heating-up rate of 35° F per hour from 135° F is recommended.

16/ Formerly designated as T736 temper.

17/ Formerly designated as T73651 temper.

18/ Formerly designated as T73652 temper.

19/ Longer times are to be used with section thicknesses less than 2 inches.

20/ Soak time of 4 hours for extrusions with leg thickness less than 0.8 inch and 6 hours for extrusions having thicker legs.

21/ An alternative treatment is to omit the first stage and heat at a rate no greater than 36° F/hr.

22/ Doesn't require the 14-day room temperature age.

TABLE VIII. Test requirements for periodic monitoring.

Material	Mechanical properties 1/	Inter-granular corrosion 2/	Tests Diffusion (alclad only)	Melting and hydrogen porosity 5/
Plate, sheet and extrusions	X	X 3/	X 4/	X
Castings	X	--	--	--
Bar, rod and wire	X	X 3/	--	X
Forgings	X	--	--	X
Tubing	X	--	X	X
Rivets & fastener components	X	X	--	X

1/ Those specified in the applicable material specification.

2/ Applicable only to bare or alclad 2XXX series (unaged) and 7XXX alloy series.

3/ Required only for metal under 0.250 inch thick.

4/ Not required for metal under 0.020 inch thick.

5/ Melting and hydrogen porosity resulting from solution heat treatment.

TABLE IX. Aluminum alloys (non-clad), typical values, hardness and electrical conductivity vs. temper. 1/

Alloy	Temper 2/	Brinell, 3/ typical minimum	Rockwell, typical minimum 4/,6/ B	E	H	15T	Typical conductivity 5/
1100	0	-	-	-	50 tmx	-	57.0 - 62.0
2014	0	-	22 tmx 6/	70 tmx	95 tmx	-	43.5 - 51.5
	T3	100	65	95	-	82	31.5 - 35.0
	T4	100	65	95	-	82	31.5 - 35.0
	T6	125	78	102	-	86	35.0 - 41.5
2024	0	-	22 tmx	70 tmx	95 tmx	-	46.0 - 51.0
	T3	110	69	94	-	82	27.5 - 32.5
	T4	100	63	94	-	82	27.5 - 34.0
	T6	125	72	98	-	84	34.0 - 44.0
	T8	120	74	99	-	85	35.0 - 42.5
2048	T8	120	72	98	-	-	35.0 - 42.5
2124	T3	110	69	97	-	-	27.5 - 32.5
	T8	120	74	99	-	-	35.0 - 42.5
2219 7/	0	-	22 tmx	70 tmx	95 tmx	-	44.0 - 49.0
	T3	98	60	92	-	79	26.0 - 31.0
	T37	100	62	93	-	81	27.0 - 31.0
	T4	100	58	90	-	78	28.0 - 32.0
	T6	110	62	93	-	81	32.0 - 36.0
	T8	115	71	98	-	83	31.0 - 35.0
	T87	125	75	100	-	84	31.0 - 35.0
3003	0	-	-	-	65 tmx	-	44.5 - 50.5
5052	0	-	-	70 tmx 6/	95 tmx	-	34.0 - 37.0
6013	0	-	-	90 tmx	-	-	-
	T4	-	40	-	-	-	37.0 - 39.0
	T6	-	61	96	-	-	40.0 - 43.0
6061	0	40 tmx 6/	-	-	75 tmx	-	42.0 - 50.0
	T4	50	-	60	-	64	35.5 - 43.0
	T6	80	42	85	-	78	40.0 - 50.0
6063	0	-	-	-	70 tmx	-	57.0 - 65.0
	T1	-	-	37	-	53	48.0 - 58.0
	T4	-	-	40	-	54	48.0 - 58.0
	T5	-	-	44	-	57	50.0 - 60.0
	T6	60	-	70	-	68	50.0 - 60.0

TABLE IX. Aluminum alloys (non-clad), typical values, hardness and electrical conductivity vs. temper. 1/

Alloy	Temper 2/	Brinell, 3/ typical minimum	Rockwell, typical minimum 4/				Typical conductivity 5/
			B	E	H	15T	
6066	O T4 T6	- - 100	- - 65	40 tmx 85 95	- - -	- 76 82	42.0 - 47.0 34.0 - 41.0 38.0 - 50.0
7010	O T3 T4 T6	- 134 140 142	22 tmx 85 82 84	70 tmx 104 105 106	95 tmx - - -	- 85 86 87	44.0 - 50.0 40.0 - 44.0 40.0 - 44.0 39.0 - 44.0
7049/	O T73	- 135	22 tmx 6/ 81	70 tmx 6/ 104	95 tmx 6/ -	- 85	44.0 - 50.0 40.0 - 44.0
7050	O T73 T74 10/ T76	- 135 135 140	22 tmx 6/ 81 82 84	70 tmx 6/ 104 105 106	95 tmx 6/ - - -	- 85 86 87	44.0 - 50.0 41.0 - 44.0 40.0 - 44.0 39.0 - 44.0
7075	O T6 T73 T76	- 135 125 130	22 tmx 6/ 84 78 82	70 tmx 6/ 106 102 104	95 tmx 6/ - - -	- 87 85 86	44.0 - 48.0 30.5 - 36.0 40.0 - 43.0 38.0 - 42.0
7149	T76	140	84	106	-	87	38.0 - 44.0
7150	O T61 T73 T74 T76	- 145 135 135 140	22 tmx 87 81 82 84	70 tmx 108 104 105 106	95 tmx - - - -	- - 85 86 87	44.0 - 50.0 29.0 - 33.5 41.0 - 44.0 40.0 - 44.0 39.0 - 44.0
7178	O T6 T76	- 145 140	- 87 84	- 108 106	95 tmx 6/ - -	- 88 87	43.0 - 47.0 29.0 - 34.0 38.0 - 42.0
7475	T73 T76	- -	- -	103 105	- -	- -	40.0 - 44.5 38.0 - 42.0

NOTE: Refer to notes at end of Table X.

TABLE X. Aluminum alloys (alclad), heat-treated, typical values, electrical conductivity vs. temper 1/

Alloy	Temper 2/	Sheet thickness (inches) 9/	Rockwell, typical minimum 4/ B	E	15T	Typical conductivity 5/
2014	T6	.062 & Under	76	102	85	35.5 - 44.0
		.063 & Over	75	101	-	35.5 - 44.0
2024	T3	.062 & Under	57	91	79	28.5 - 35.0
		.063 & Over	60	93	-	28.5 - 35.0
	T4	.062 & Under	57	91	79	28.5 - 35.0
		.063 & Over	60	93	-	28.5 - 35.0
	T6	.062 & Under	60	93	82	35.0 - 45.0
		.063 & Over	62	94	-	35.0 - 45.0
	T8	All	65	97	82	35.0 - 45.0
2219 7/	T6	.062 & Under	61	92	80	32.0 - 37.0
		.063 & Over	60	91	-	32.0 - 37.0
	T8	.062 & Under	64	96	82	31.0 - 37.0
		.063 & Over	63	95	-	31.0 - 37.0
6061	T6	All	-	84	74	40.0 - 47.0
7075	T6	.032 & Under	78	103	86	30.5 - 36.0
		.033 - .062	76	102	-	30.5 - 36.0
		.063 & Over	75	101	-	30.5 - 36.0
	T76	.032 & Under	76	102	84	38.0 - 42.0
		.033 - 0.62	75	101	-	38.0 - 42.0
		.063 & Over	74	100	-	38.0 - 42.0
7178	T6	.036 & Under	79	104	86	29.0 - 34.0
		.037 - .062	78	103	-	29.0 - 37.0
		.063 & Over	76	102	-	29.0 - 37.0

1/ This table is for information purposes only. Electrical conductivity measurements may be influenced by the operating characteristics of the instrument probe used.

2/ Only the basic temper, TX(X), is shown. Hardness values also apply to the stress relieved TX51, TX52, TX54, TX510 or TX511 conditions and the user heat treated T42 and T62 conditions.

3/ BHN, 500 Kg load, 10 mm ball.

4/ Hardness values for the annealed (O) conditions are typical maximum, all other hardness values are typical minimum. The 15T values are for material 0.032 inch or less in thickness and may be used for the thinnest material that does not show anvil effect.

5/ Typical conductivity as expressed by percentage of conductivity of the International Annealed Copper Standard (IACS).

6/ Tmx is the abbreviation for typical maximum.

7/ Electrical conductivity is not as sensitive an indicator as hardness testing for metallurgical conditions that affect strength in alloy 2219.

8/ For the annealed (O temper), the non-clad values are applicable.

9/ Values are for sheet with clad intact. For alclad sheet over 0.091 inch thick, incorrect hardness readings can result from the cladding thicknesses. Partial removal of the cladding thickness in local areas is permitted to obtain valid hardness readings.

10/ Formerly designated as T736 temper.

TABLE XI. Recommended annealing conditions for wrought aluminum and aluminum alloys. 1/

	O Temper is obtained after these annealing conditions				
Alloy	Metal temper-ature degrees F 3/	Approximate time at temperature, hours	Alloy	Metal temper-ature degrees F 3/	Approximate time at temperature, hours
1060	650	2/	5086	650	2/
1100	650	2/	5154	650	2/
1350	650	2/	5254	650	2/
2014	760 4/	2 - 3	5454	650	2/
2017	760 4/	2 - 3	5456	650	2/
2024	760 4/	2 - 3	5457	650	2/
2036	725 4/	2 - 3	5652	650	2/
2117	760 4/	2 - 3	6005	760 4/	2 - 3
2219	760 4/	2 - 3	6013	775 4/	2 - 3
3003	775	2/	6053	760 4/	2 - 3
3004	650	2/	6061	760 4/	2 - 3
3105	650	2/	6063	760 4/	2 - 3
5005	650	2/	6066	760 4/	2 - 3
5050	650	2/	7001	760 5/	2 - 3
5052	650	2/	7075	760 5/	2 - 3
5056	650	2/	7175	760 5/	2 - 3
5083	650	2/	7178	760 5/	2 - 3

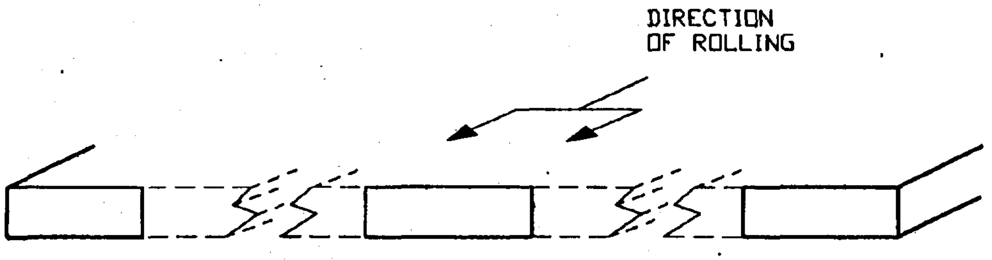
1/ This table is for information purposes only.

2/ Time in furnace should be no longer than necessary to get center of load to the desired temperature, taking into consideration the thickness or diameter of metal. Rate of cooling is unimportant.

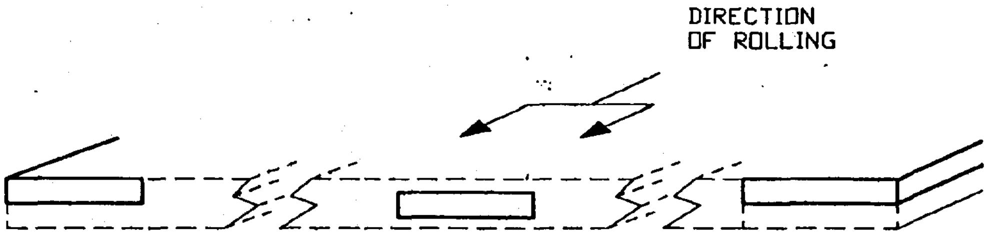
3/ Metal temperature variation in the annealing furnace should be not greater than +10° F, -15° F.

4/ This annealing removes the effects of the solution heat treatment. Cooling rate must be 50° F per hour from annealing temperature to 500° F. The rate of subsequent cooling is unimportant.

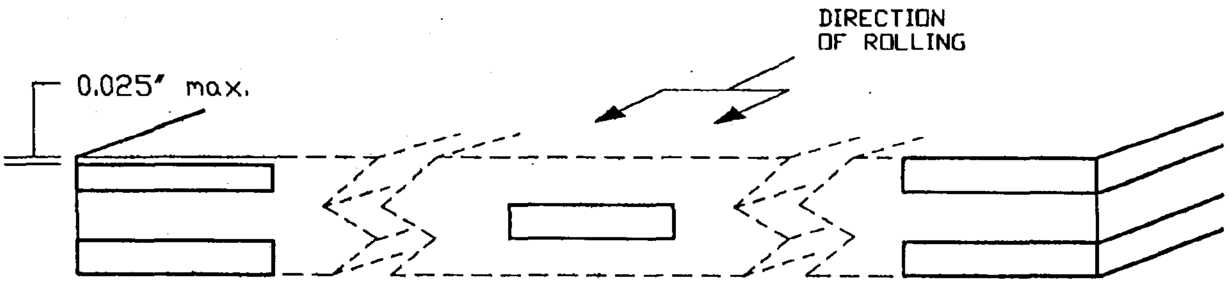
5/ This annealing removes the effects of the solution heat treatment by cooling at an uncontrolled rate in the air to 400° F or less followed by a reheating to 450° F for 4 hours and cooling at room atmosphere conditions.



A. For plate thicknesses 0.250 to 0.500 inch, inclusive. Total number of samples from plate = 7 (3 per end plus one from center as shown in figure 2).



B. For plate thicknesses over 0.500 to 1.0 inches, inclusive. Total number of samples from plate = 11 (5 per end plus one from center as shown in figure 2).



C. For plate thicknesses over 1.0 inches, total number of samples from plate = 11 (5 per end plus one from center as shown in figure 2).

NOTE: Directions of rolling is perpendicular to the above plate sections. Finish rolling widths of plates are shown.

FIGURE 1. Tension test sample location for spray quench equipment verification.

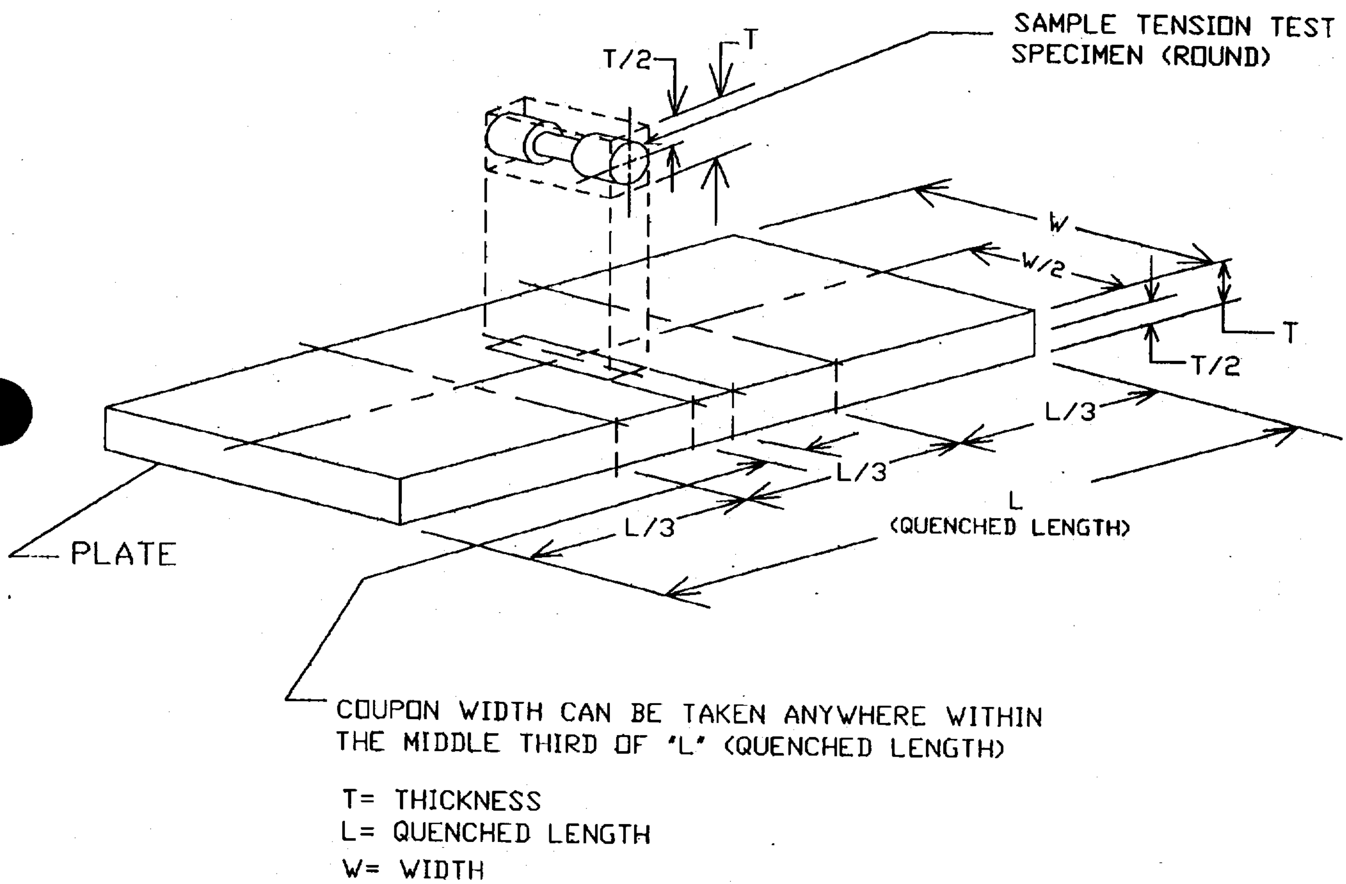


FIGURE 2. Allowable location to sample tension specimen from approximate location of center of plate.

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HEAT TREATMENT OF ALUMINUM ALLOYS

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5. REASON FOR RECOMMENDATION

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