SAE Aerospace
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AEROSPACE MATERIAL SPECIFICATION

SAE AMS2771 REV. D

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Superseding AMS2771C

Heat Treatment of Aluminum Alloy Castings

RATIONALE

AMS2771D clarifies the use of AMS2750 for temperature surveys and furnace classification (3.1.2.2), revises Cleaning (3.1.4, 3.2.8), introduces requirements for batch furnace unloading procedures (3.2.4), removes reference to AQ temper (3.2.9.5, Table 2), adds requirements for a chart recorder when retention of W temper is required (3.2.10), revises Straightening After Heat Treatment (3.2.13) and Records (4.3), and is a Five Year Review and update of this specification.

1. SCOPE

1.1 Purpose

This specification covers the engineering requirements for heat treatment of aluminum alloy castings and for parts machined from castings.

1.2 Application

This specification is applicable to castings of the following aluminum alloys and modifications (See 8.2.8):

201.0	328.0	520.0
203.0	333.0	705.0
206.0	336.0	707.0
222.0	354.0	712.0
242.0	355.0	713.0
243.0	356.0	850.0
295.0	357.0	851.0
296.0	358.0	852.0
319.0	359.0	

1.3 When AMS2771 is specified and specific heat treat processing instructions are included in the material specification, the equipment and control requirements of AMS2771 shall apply. For alloys not specifically covered, the provisions of this specification shall be applicable, but temperatures, times, and quenching procedures shall be as specified by the purchaser.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: **http://www.sae.org**

SAE values your input. To provide feedback on this Technical Report, please visit
http://www.sae.org/technical/standards/AMS2771D

2. APPLICABLE DOCUMENTS

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

2.1 SAE Publications

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

AMS2750 Pyrometry

AMS3025 Polyalkylene Glycol Heat Treat Quenchant

ARP1962 Training and Approval of Heat-Treating Personnel

3. TECHNICAL REQUIREMENTS

3.1 Equipment

Equipment used for thermal processing shall conform to the requirements of this specification and AMS2750, except (1) requirements for working zone controls, instruments and sensors shall apply to all heating zones of continuous and semi-continuous furnaces and (2) recordings from instruments may be stored on magnetic or optical media providing a hard copy is available on request.

3.1.1 Pyrometry

Shall meet the requirements of AMS2750.

3.1.2 Furnaces

3.1.2.1 Heating Media

Shall be air, protective atmosphere, combusted gases, molten salt bath, oil bath, or fluidized bed. Electrical heating elements and radiant tubes shall be shielded to prevent direct radiation from striking any part. The products of combustion in the furnace, and the composition and maintenance of salt baths and fluidized beds shall be such as to prevent attack or contamination of the castings. Ammonium fluoroborate, or equivalent, may be used in air furnaces as necessary. Nitrate salt baths shall not be used to heat treat 520.0 alloy due to a potential explosion safety hazard.

3.1.2.1.1 Salt Entrapment

Castings that will entrap salt shall not be heated in a molten salt bath.

3.1.2.2 Temperature Uniformity Survey Requirements

Temperature uniformity surveys shall be performed as defined in AMS2750 .

3.1.2.2.1 Solution Heat Treating and Aging Furnaces shall be class 2 minimum as defined in AMS2750.

3.1.2.2.2 Annealing Furnaces shall be class 5 minimum as defined in AMS2750.

3.1.3 Quenching

Unless otherwise approved by the cognizant engineering organization, the following provisions apply. Equipment shall be provided for quenching in water, air blast, oil, or in polymer quenchants and for measuring quenchant temperature. Provisions shall be made for mechanical, hydraulic, or air agitation of the quenching medium or agitation of the castings or both and for heating and cooling of the quenchant, as required. Air agitation shall be allowed provided the air doesn't come in contact with the castings being quenched. The volume of quenching medium for immersion quenching shall be sufficient so that its temperature rise due to quenching meets the requirements of 3.2.9.4.1.

3.1.3.1 Polymer Quenchants

Polyalkalene glycol shall meet the requirements of AMS3025. Other synthetics may be used provided that they are not detrimental to the material and that the parts meet the required specified properties in the final heat treated condition. Polymer concentration shall be established for the particular casting configuration prior to use.

3.1.3.2 Salt Contamination of Polymer Quenchants

Shall not exceed 6% by weight.

3.1.4 Cleaning

Equipment shall be provided to clean castings, as necessary for heat treatment, and to remove residual quenchant after solution heat treatment. Examples include: water rinse to remove polymer quenchant residue, detergent and rinse to remove oil quenchant residue, and fresh water overflow to remove salt quenchant residue.

3.1.5 Refrigeration

Refrigeration or liquid baths shall be provided for cold storage of castings when prevention of natural aging is necessary.

3.2 Procedures

3.2.1 General

Cast parts that require heat treatment to a T4X, T6X, or T7X temper shall be solution heat treated (including quenching), refrigerated after quenching, when necessary, and aged, when required, as specified herein. Castings in the T5X condition shall be refrigerated after casting, when necessary, and aged as specified herein. Heat treatment shall be performed only on entire castings, never on a portion of a part.

3.2.2 Racking and Spacing

Product shall be supported or hung and spaced to permit flow of the heating and cooling media over all surfaces to ensure that the castings will meet the specified requirements. Alternate racking methods are acceptable if tests have been performed to demonstrate that all castings so racked will meet specified requirements. Written instructions, drawings, photographs, etc. shall be used to ensure proper spacing.

3.2.2.1 Small castings as defined in 8.2.4 may be heated and soaked in baskets or continuous furnaces. Care must be used to provide access for heating and quench media and to prevent damage during loading and quenching. Arrangement in baskets may be either orderly or random provided that the castings meet the required specified properties in the final heat treated condition.

3.2.2.2 Water Entrapment

Racks and fixtures used for solution heat treatment shall be constructed to preclude entrapment of water.

3.2.3 Loading

The temperature of the furnace during part loading shall not exceed the solution treating temperature of the castings being heat treated.

3.2.4 Post quench reload to furnace

Batch type furnaces that momentarily reload the freshly quenched material back into the furnace work zone as part of the unloading/quench tank transfer sequence is allowed provided objective evidence is available to qualify this process. The evidence shall demonstrate the thinnest material processed is not heated above 212 °F (100 °C) by this post quench process using radiation survey process in AMS2750. The castings shall not be held in the furnace for more than 5 minutes during this post-quench sequence. The process used to provide the objective evidence shall be perfomed at the minimum furnace open time established by the heat treater's documented process after quenching the castings. The documented process shall include the maximum temperature of the furnace as measured by the control thermocouple or a specificed minimum furnace cooling time prior to raising the load into the furnace.

3.2.5 Set Temperature

Control instrument(s) shall be set at the temperature specified in 3.2.9 for solution treating and 3.2.11 for aging, and should be set at the recommended annealing temperature specified in 3.2.12. Sensor/control offsets, if used, shall comply with AMS2750.

3.2.6 Soaking

Soaking time starts when all temperature control sensing elements and load thermocouples (if used) are within 10 °F (6 °C) of the set or offset temperature.

3.2.6.1 Batch Furnaces

Interruptions during solution treatment are permitted provided the minimum soak time is met and at least a 2-hour soak time occurs after the interruption. During aging and annealing treatments a maximum of four interruptions are permitted for removal or loading of castings. The time between door opening and furnace or load thermocouple recovery is not to be counted as part of the total aging time.

3.2.6.2 Continuous and Semi-Continuous Furnaces

During soaking, a drop in temperature indicated by furnace instrument(s) is permissible provided (1) that temperature does not drop more than 20 °F (11 °C) below the minimum of the specified range, (2) time below the minimum of the specified range does not exceed 5 minutes, and (3) soaking is continued for not less than 10 minutes after recovery before quenching.

3.2.6.2.1 If furnace temperature does not drop more than 20 °F (11 °C) below the minimum of the specified range, but does not recover to the minimum of the specified range within 5 minutes, the total soaking time, if not less than 1 hour was required, shall be increased by 1/2 hour. If 1 hour or more was required, the total soaking time shall be increased by 1 hour.

3.2.6.3 Load thermocouples shall be used, when needed, to determine and control metal temperature and heating time or when required by the cognizant engineering organization (See 8.2.7).

3.2.7 Logs

A record (written or electronic storage media), traceable to temperature recording information (chart(s) or electronic storage media) and to shop travelers or other documentation, shall be kept for each furnace and load. The information on the combination of documents shall include: equipment identification, approved personnel's identification, date, part number or product identification, number of castings, alloy, lot identification, AMS2771 or other applicable specification, actual thermal processing times and temperatures used. When applicable, atmosphere control parameters, quench delay, quenchant type, polymer concentration and quenchant temperature shall also be recorded. The maximum thickness, when process parameters are based on thickness, shall be recorded and shall be taken as the minimum dimension of the heaviest section of the part. The log data shall be recorded in accordance with the heat treater's documented procedures.

3.2.8 Cleaning

Castings shall be clean of contaminants that will react during heat treatment or cause adverse effects. Residue from heating and quenching media shall be removed from castings after solution heat treatment.

3.2.9 Solution Heat Treating

3.2.9.1 Temperature

Castings that require solution heat treatment shall be soaked at the temperature specified in Table 1, except as permitted in 3.2.9.3.

3.2.9.2 Soaking Time

Shall conform to Table 1 (See 8.2.5).

3.2.9.3 Variations

Solution treating set temperatures may vary from the requirements of Table 1 to obtain required properties for a specific casting configuration. Departure from the required set temperature of more than 10 °F (6 °C) shall require approval of the cognizant engineering organization (See 8.2.6).

3.2.9.4 Quenching

Castings, after being soaked at the solution heat treating temperature for the required time, shall be quenched.

3.2.9.4.1 Quenchant Temperature

During the quench, the quenchant temperature shall not rise more than 25 °F (14 °C). To prevent excessive warpage and possible cracking, castings may be quenched in oil or water with temperature varying from cold to hot (212 °F (100 °C)) or in a polymer quenchant at room temperature providing it is substantiated that the combination of quench and solution temperature will produce mechanical properties meeting the material specification. Exceptions to the temperature rise are permitted provided that it has been demonstrated by testing and documentation that the castings meet the required specified properties in the final heat treated condition. Unless otherwise specified in a drawing or procurement document, castings of Alloy 520.0 shall be quenched by total immersion in oil heated to 300 °F (149 °C) and castings of Alloy 242.0 shall be air-quenched.

3.2.9.4.2 Quench Delay Time

The quench delay time shall not exceed 15 seconds. The delay shall be measured from the time the furnace door of an air furnace starts to open, or the first portion of the load emerges from a fluidized bed or salt bath, to complete immersion of the load in the quenchant. This delay time may be exceeded providing that the cooling rate does not result in a loss of any mechanical property typically obtained by the established process for that casting configuration.

3.2.9.4.3 Agitation

Castings, quenchant, or both shall be agitated during quenching. Small parts heated and soaked in baskets may be quenched by dumping when basket loads are too heavy to allow adequate quenching by immersion of the full basket and provided that the castings are not damaged by dumping. Exceptions to the use of agitation is permitted provided that it has been demonstrated that the castings meet the required specified properties in the final heat treated condition.

3.2.9.4.4 Quenchant Contact Time

Castings which are quenched by immersion shall be kept immersed in the quenchant for not less than 2 minutes per inch of thickness, or fraction thereof in the thickest section. Alternatively, castings shall be kept immersed in the quenchant for not less than 2 minutes after boiling ceases. Castings quenched in boiling water shall remain immersed for not less than 2 minutes. Castings quenched in an air blast shall remain in contact with the air blast until surface temperatures are reduced to 212 °F (100 °C).

3.2.9.5 Temper After Treatment

All alloys are in the AQ ($W_{t=0}$) temper immediately after quenching. After 45 minutes at room temperature or after the maximum refrigerated storage time has elapsed, they are in the W temper which is unstable, i.e., their properties are continuously changing. After an appropriate delay at room temperature, unless otherwise noted herein, the tempers shall be as shown in Table 1.

3.2.10 Refrigeration

When retention of the AQ condition is necessary to attain the required mechanical properties, castings shall be refrigerated within 45 minutes after quenching (See 8.3) and storage conditions shall be documented by a temperature recorder with record of casting traceability. Castings may be refrigerated as necessary to facilitate straightening; there is no requirement for traceability records or a temperature recorder. See 8.4 for additional recommendations.

3.2.11 Aging

Castings requiring aging shall be aged as specified in Table 2 to obtain the final temper and required mechanical properties except as permitted in 3.2.11.1.

3.2.11.1 Variations

Aging set temperature and/or soak time may vary from the requirements of Table 2 to obtain required properties for a specific casting configuration; however, alloys 201 and A201 shall not be aged below a minimum temperature of 360 °F (182 °C) unless the T6 condition is specifically called for in the procurement documents. Departure of more than 30 °F (17 °C) from the required set temperature shall require approval of the cognizant engineering organization.

3.2.12 Annealing

Heating, soaking, and cooling parameters in Table 3 are recommended for annealing of castings. If a partial anneal (stress relief) is required, it shall be as specified by the cognizant engineering organization.

3.2.13 Straightening After Final Heat Treatment

Shall not be performed unless authorized by the cognizant engineering organization.

3.3 Qualification

3.3.1 Suppliers

Facilities performing heat treatment in accordance with this specification shall be approved by the cognizant quality assurance organization (See 8.2.7).

3.3.2 Personnel

All responsible heat treating personnel performing heat treatment in accordance with this specification shall be qualified as specified in 4.5.

3.4 Acceptance

3.4.1 Castings shall meet the hardness and tensile property requirements of the applicable material specification. When hardness or tensile properties are not specified, the test method, test specimens (i.e., separately cast specimens, integrally attached specimens, specimens machined from prolongations, or specimens machined from casting sections), and acceptance criteria shall be agreed upon by purchaser and vendor.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The supplier shall be responsible for the performance of all tests and inspections specified herein. The procuring activity reserves the right to sample and to perform any tests or inspections to confirm that castings have been heat treated properly.

4.2 Inspection

The cognizant quality assurance organization shall review heat treating records and the results of tests and inspections to verify that heat treatment conformed to specified requirements .

4.3 Records

Records shall be kept available to purchaser for not less than five years after performance of heat treatment. The records shall contain all data necessary to verify conformance to the requirements of this specfication.

4.3.1 If the heat treating procedure is considered proprietary, the vendor may certify that the information is proprietary and is on file. The procedures shall be available for review by personnel representing the cognizant engineering organization.

4.4 Process Control

The cognizant quality assurance organization may perform any inspections, surveillances, tests, and statistical process control analyses necessary to ensure that castings are heat treated in accordance with this specification.

4.5 Personnel Qualification

All personnel performing heat treating operations shall be trained and approved. ARP1962 provides an example of a program for training and approval and lists the associated operations.

4.6 Reports

The vendor shall furnish with each shipment a report referencing the heat treatment log number, the results of tests to determine conformance to this specification, and a statement that the castings were processed in accordance with the requirements of this specification. This report shall include the purchase order number, AMS2771D, alloy designation and material specification number, casting number, and quantity.

5. PREPARATION FOR DELIVERY

All castings shall be wrapped or packaged to ensure protection from corrosion and damage during handling, transportation, and storage.

6. ACKNOWLEDGMENT

A vendor shall mention this specification number and its revision letter in all quotations and when acknowledging purchase orders.

7. REJECTIONS

Castings not heat treated in accordance with this specification, or to modifications authorized by purchaser, will be subject to rejection.

8. NOTES

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

8.2 Terms used in AMS are clarified in ARP1917 and the following:

8.2.1 Solution Heat Treatment

Soaking castings at an elevated temperature for a sufficient time to put alloying constituents into solid solution followed by quenching to retain the condition until the castings are aged.

8.2.2 Aging (Precipitation Heat Treatment)

Soaking solution heat treated castings at a moderately elevated temperature or, for some alloys and tempers, at room temperature to precipitate alloying constituents from solid solution to develop strength and corrosion resistance properties.

8.2.3 Polymer Quenchant

A water solution of polyalkylene glycol or other synthetic material used when minimum distortion or low residual stresses are desired.

8.2.4 Parts

The words “parts”, “casting”, and “cast parts” as used in this specification have the same meaning and are used interchangeably. Small parts are those that are under 0.250 inch (6.4 mm) in nominal thickness and weigh 2 pounds or less.

8.2.5 Recovery and Soaking Time

Recovery time is elapsed time between insertion of parts in a heating medium and start of soaking time. Soaking time starts when all temperature control sensing elements and load thermocouples (if used) are within 10 °F (6 °C) of the set or offset temperature.

8.2.6 Cognizant Engineering Organization

A term applied to the engineering organization responsible for the design of the parts or a designee of that organization.

8.2.7 Cognizant Quality Assurance Organization

A term applied to the quality assurance organization that is allied to the cognizant engineering organization or its designee.

8.2.8 Alloy Modifications

A term that refers to variations within a single alloy designation. The variations normally only amount to closer control on certain elements in the composition or tighter tolerances on allowable interstitials while maintaining the basic chemistry. An example being 357.0 with variations designated A357.0, B357.0, D357.0, etc. Different heat treat procedures may be necessary due to composition variations as noted in Table 1 and Table 2.

8.3 Prechilling

Prior to refrigeration, casting may be prechilled in a suitably cooled bath if necessary to accelerate cooling for compliance with requirements of 3.2.10.

8.4 To facilitate straightening, castings should be refrigerated within 45 minutes after quenching and the maximum refrigeration storage time should not exceed seven days at 10 °F (-12 °C), 30 days at 0 °F (-18 °C), or 90 days at -10 °F (-23 °C) maximum temperatures.

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

PREPARED BY AMS COMMITTEE “D” AND “AMEC”

TABLE 1 - SOLUTION HEAT TREATMENT TEMPERATURE, SOAK TIME, AND NATURAL AGED TEMPER

Alloy	Set Temperature, °F [1]	Set Temperature, °C [1]	Minimum Soak Time, Hours [5]	Temper After Solution Treatment and Delay at RT
201.0	980 [2]	527 [2]	14	T4
A201.0	985 [2]	529 [2]	14	T4
203.0	1010 [2]	543 [2]	5	T4
A206.0	980 [2]	527 [2]	12	T4
222.0	945	507	6	T4
242.0	970	521	2	T41
243.0	965	518	2	T41
295.0	955	513	6	T4
296.0	950	510	4	T4
319.0	935	502	6	T4
328.0	960	516	12	T4
333.0	940	504	2	T4
336.0	955	513	6	T45
354.0 [3]	980	527	10	T41
355.0	980	527	6	T4
C355.0	985	529	6	T4
356.0	1000 [4]	538 [4]	6	T4
A356.0	1000 [4]	538 [4]	6	T4
A357.0	1010 [4]	543 [4]	8	T4
D357.0	1010 [4]	543 [4]	8	T4
358.0 [3]	1005	541	20	T4
359.0	1000	538	10	T4
520.0	810	432	12	T4
712.0	990	532	2	T4

NOTES:

1. Unless otherwise noted, the same temperature and time apply to the other alloy modifications (See 8.2.8). Temperature variations are governed by 3.2.9.3.
2. A step solution treatment at 955 °F (513 °C), for not less than 2 hours prior to the noted solution treatment, is recommended.
3. For a final temper of T60 (See Table 2) the delay after solution treatment and aging shall be 4 to 6 hours.
4. Final solution heat treatment above 1010 °F (543 °C) may require an intermediate solution heat treatment of 1-hour minimum at 1000 to 1010 °F (538 to 543 °C) to prevent eutectic melting of magnesium-rich phases during final solution heat treatment.
5. Once castings have been solution treated for the required time, re-solution treatment time may be shortened to 3 hours minimum unless a shorter solution heat treat time is specified above.