AEROSPACE MATERIAL SPECIFICATION

AMS2774™	REV. G

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Reaffirmed 2001-11
Revised 2020-12

Superseding AMS2774F

Heat Treatment
Nickel Alloy and Cobalt Alloy Parts

RATIONALE

AMS2774G corrects an error in Table 3.

1. SCOPE

1.1 Purpose

This specification specifies the engineering requirements for heat treatment, by part fabricators (users) or subcontractors, of parts made of wrought or additively manufactured nickel or cobalt alloys, of raw materials during fabrication, and of fabricated assemblies in which wrought nickel or cobalt alloys are the primary structural components.

1.2 Application

1.2.1 Alloys

Detailed heat treating instructions are specified for the age-hardenable (precipitation-hardenable) and non-age-hardenable alloys listed in 8.2. However, this specification also may be used for alloys other than those listed in 8.2, provided that temperatures, soaking times, and cooling requirements are specified by the cognizant engineering organization.

1.2.2 Heat Treatments

Heat treatments covered by this specification are as follows:

Solution Treating (see 8.4.7)
Annealing (see 8.4.8)
Stabilization Annealing (see 8.4.10)
Interstage Annealing (see 8.4.13)
Stabilization (see 8.4.11)
Precipitation (see 8.4.12)
Equalization (see 8.4.14)
Stress Relief (see 8.4.9)

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1.3 Safety - Hazardous Materials

While the materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials, this specification does not address the hazards which may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

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 +1 724-776-4970 (outside USA), www.sae.org.

AMS2750 Pyrometry

AMS2769 Heat Treatment of Parts in a Vacuum

ARP1820 Chord Method of Evaluating Surface Microstructural Characteristics

ARP1917 Clarification of Terms Used in Aerospace Metals Specifications

ARP1962 Training and Approval of Heat-Treating Personnel

HS-1086 Metals & Alloys in the Unified Numbering System

2.1.1 Titles of SAE publications listed in Tables 3, 4, 7, and 8 are presented in Appendix A.

2.2 ASTM Publications

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

ASTM E3 Preparation of Metallographic Specimens

ASTM E8/E8M Tension Testing of Metallic Materials

ASTM E10 Brinell Hardness of Metallic Materials

ASTM E18 Rockwell Hardness of Metallic Materials

ASTM E21 Elevated Temperature Tension Tests for Metallic Materials

ASTM E139 Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials

ASTM E292 Conducting Time-for-Rupture Notch Tension Tests of Materials

ASTM E384 Microindentation Hardness of Materials

2.3 U.S. Government Publications

Copies of these documents are available online at https://quicksearch.dla.mil.

BB-H-1168 Helium, Technical

MIL-A-18455 Argon, Technical

MIL-PRF-27201 Propellant, Hydrogen

MIL-PRF-27401 Propellant Pressurizing Agent, Nitrogen

MIL-PRF-27407 Propellant Pressurizing Agent, Helium

2.4 CGA Publications (Compressed Gas Association)

Available from CGA, 14501 George Carter Way, Suite 103, Chantilly, VA 20151 Tel: 703-788-2700, www.cganet.com.

CGA G-5.3 Commodity Specification for Hydrogen

CGA G-9.1 Commodity Specification for Helium

CGA G-10.1 Commodity Specification for Nitrogen

CGA G-11.1 Commodity Specification for Argon

3. TECHNICAL REQUIREMENTS

3.1 Equipment

3.1.1 Pyrometry

Shall conform to AMS2750.

3.1.2 Furnaces

3.1.2.1 Temperature Uniformity

Shall be as shown in Table 1 tested in accordance with AMS2750.

3.1.2.2 Vacuum furnaces and processing shall meet the requirements of AMS2769.

3.1.2.3 Heating Media

Protective atmospheres shall be used whenever heat treating temperature is above 1550 °F (843 °C), unless parts will have sufficient surface material removed after heat treatment to eliminate high temperature atmospheric effects, such as oxidation, alloy depletion, and carburization. Certain of the alloys listed in 8.2 require protective atmospheres for heat treatments under 1550 °F (843 °C), and these requirements are noted with the detailed heat treating instructions for these alloys. Acceptable protective atmospheres include argon, helium, hydrogen, vacuum, and vacuum with partial pressure of any of these three gases. In addition, for non-age-hardening alloys, neutral salt baths and exothermic gas atmospheres are acceptable protective atmospheres when approved by the cognizant engineering organization (see 8.4.6). Direct fired furnaces shall be controlled so that there is no direct flame impingement on the parts.

3.1.2.3.1 Argon, Helium, and Hydrogen Gases

Shall meet the composition requirements of MIL-A-18455 (argon), CGA G-11.1, Grade C (argon), MIL-PRF-27407 (helium), CGA G-9.1, Grade L, minimum (helium), BB-H-1168, Grade A (helium), or MIL-PRF-27201 or CGA G-5.3, Grade B (hydrogen), as applicable. The dew point of the gas shall be -60 °F (-51 °C) or lower as the gas enters the furnace. Atmospheres of any of these gases in the furnace work zone shall have sufficient purity to avoid contamination or degradation of any part surfaces which will not have surface material removed after heat treatment.

3.1.2.3.2 Vacuum and Partial Pressure Atmospheres

Shall be sufficient to avoid contamination or degradation of any part surface which will not have surface material removed after heat treatment. Unless otherwise specified by the cognizant engineering organization, as a minimum, vacuum furnaces shall have a cold leak rate of a maximum of 20 µm/h, which shall be determined 15 to 60 minutes after closing the vessel and evacuation to 50 µm or lower, and shall be operated at pressures not higher than 10 µm Hg, unless argon, helium, hydrogen, or a mixture of argon and helium gas conforming to 3.1.2.2.1 is used to provide a partial pressure.

3.1.2.3.2.1 Argon or helium conforming to 3.1.2.3.1, or a mixture of the two, may be used to achieve partial pressures whenever necessary to avoid surface alloy depletion by sublimation of high vapor pressure elements, such as aluminum and chromium.

3.1.2.3.3 Salt Baths

Acceptable only for non-age-hardening alloys, and, when approved by the cognizant engineering organization, shall be neutral with respect to the alloy being treated so as to avoid contamination or degradation of any part surfaces which will not be machined after heat treatment.

3.1.2.3.4 Exothermic Atmospheres

Acceptable only for non-age-hardening alloys, and, when approved by the cognizant engineering organization, shall be produced by the combustion of fuel gas in air, shall be neutral to slightly reducing with respect to the parts being treated, and shall be sufficiently low in sulfur content to avoid contamination or degradation of any part surfaces which will not have surface material removed after heat treatment.

3.1.3 Auxiliary Equipment

Fixtures, jigs, hangers, trays, racks, etc., shall not cause contamination of the surface of parts and shall not reduce the heating, cooling, or quenching rates below those required for proper heat treatment.

3.1.4 Cooling

Shall be provided to cool parts according to the heat treatment requirements specified for each alloy. Acceptable cooling media may include air, oil, water, water-polymer solutions, salt, brine (nominally 10% by weight NaCl), argon, helium, hydrogen, nitrogen, and vacuum. The medium selected shall not contaminate or degrade any part surface which will not be machined after heat treatment. When air cooling (AC) (see 8.4.15) or rapid air cooling (RAC) (see 8.4.16) is specified, cooling media shall be used which will provide protection, if required, to avoid contamination or degradation of finished surfaces; cooling rates shall be achieved that will be equivalent to, or faster than, rates that would be achieved by AC or RAC, as specified.

3.1.4.1 Cooling may be accelerated by back-filling to partial or positive pressure atmospheres with argon or helium conforming to 3.1.2.3.1, or nitrogen conforming to either MIL-PRF-27401, Grade C, or CGA G-10.1, Grade L, or combinations thereof, meeting the dew point requirements of 3.1.2.3.1.

3.1.4.2 Quenching

Quenching baths shall permit complete immersion of parts and free movement of the quenchant adjacent to all surfaces of parts. Equipment shall agitate or circulate the quenchant and/or the parts. The volume of the quenchant and the capabilities of auxiliary equipment shall be sufficient to maintain the quenchant temperature shown in Table 2.

3.2 Procedures

3.2.1 Cleaning

3.2.1.1 Prior to Heat Treatment

Parts shall be thoroughly cleaned to remove all foreign material, including greases, oils, inks, pencil marks, metal particles produced by machining or forming operations, and residual powder from the additive manufacturing process.

3.2.1.2 After Heat Treatment

Parts which have been heat treated in molten salt or cooled in oil, molten salt, brine, or water-polymer solution shall be thoroughly cleaned to remove all residues of these materials.

3.2.2 Racking

3.2.2.1 Except as permitted in 3.2.2.2, parts shall be racked to ensure uniform heating and cooling throughout the load. Parts shall not be nested unless tests with load thermocouples have demonstrated that the arrangement will not affect uniformity of heating and cooling and will not reduce cooling rate below minimum requirements.

3.2.2.2 Rivets, bolts, nuts, and other small parts may be racked or heated and soaked in baskets or in a continuous furnace. Parts shall not be nested. Maximum thickness of layers, and minimum space between layers, shall be 1 inch (25 mm).

3.2.3 Control Instruments

Shall be set either at the set temperature (see 8.4.5) specified, or at the offset temperature (see 8.4.5) based on the last temperature uniformity determination. The offset temperature shall be within 5 °F (3 °C) for precipitation treatments, and 10 °F (6 °C) for other treatments, of the specified set temperature, and shall be posted on the instrument. The offset temperature shall be selected to optimize the temperature distribution within the furnace so that the highest and lowest temperatures are equidistant from the set temperature in addition to the tolerance requirements of AMS2750 or AMS2769 as applicable.

3.2.3.1 The posting of the offset temperature shall include, or consist of, a statement of both the “desired” temperature and the corresponding “set” temperature, e.g., “When 1000 °F is desired, set at 1004 °F.”

3.2.4 Heat Treatment

Shall be performed as follows unless an alternate treatment has been specified by the purchase order or by the cognizant engineering organization.

3.2.4.1 The specified solution, annealing, stress-relief, and stabilization treatment for the non-age-hardening alloys listed in 8.2 shall be performed in accordance with Table 3. The specified solution, stabilization, precipitation, annealing, and stress relief treatments for age-hardening alloys listed in 8.2 shall be performed in accordance with Table 4. Soaking times from Table 5 shall be used when soaking times are not specified in Table 3. Tolerances for the soaking times for both age-hardening and non-age-hardening alloys shall be as shown in Table 6.

3.2.4.1.1 Parts made of age-hardening alloys shall be heat treated to the precipitation hardened condition. When a stabilization heat treatment is also shown for the alloy in Table 4, stabilization shall be applied to solution treated parts before precipitation treatment.

3.2.4.1.2 Where temperature ranges are specified in Tables 3 and 4, it is the responsibility of the heat treatment processor to select, for each lot of material, the specific temperature and time, within the ranges specified, which will produce heat treated parts meeting all technical requirements of the drawing and applicable material specification.

3.2.4.2 Other Alloys Not Listed in 8.2 and Fabricated Assemblies of Cast and Wrought Alloys

Heat treatments for alloys not covered herein and for assemblies of cast alloys fabricated with wrought forms of the nickel or cobalt alloys in which the cast material is the primary structural component shall be as specified by the purchase order or by the cognizant engineering organization. This information shall include the heat treatment name (e.g., annealing, precipitation), the set temperature, the soaking time, and quenchant or cooling medium.

3.2.4.3 Assemblies of Castings and Wrought Alloys

If wrought alloys covered by this specification are fabricated with castings into a single assembly in which the wrought material is the primary structural component, the heat treatment designated for the wrought material shall be used for the assembly.

3.2.4.4 Cycle Interruptions

If the precipitation, stabilization, or stress relief cycle is interrupted due to power loss or furnace malfunction that causes the furnace temperature to drop below the required setpoint tolerance, the cycle can be continued to complete the required soak time. For example, if power is lost 1 hour and 20 minutes into an 8 hour precipitation cycle, the parts can be re-heated to the precipitation temperature and continued for 6 hours and 40 minutes in order to complete the 8 hour cycle. In no cases can the cumulative precipitation time exceed the maximum time tolerance (for example, 8 hour cycle allow +30 minutes, the cumulative precipitation time cannot exceed 8 hours and 30 minutes). Only one such interruption is allowed per cycle. Further interruptions or exceeding the time tolerance requires reworking via re-solution treatment (see 3.2.4.5).

3.2.4.5 Rework

Parts may be resolution treated, and reprecipitation heat treated when applicable, one time without cognizant engineering organization approval.

3.2.5 Start of Soaking Time

3.2.5.1 Batch Furnaces

Soaking time starts when all temperature sensors reach the specified set or offset temperature, or, if load thermocouples (see 8.4.4) are used, when the part temperature reaches the temperature described by the set or offset temperature minus the appropriate tolerance (3.1.2.1).

3.2.5.1.1 Vacuum Furnaces

Unless otherwise specified by the cognizant engineering organization, load thermocouples shall be used to determine the start of soaking time except when this is impracticable, such as with two- or three-chamber oil or gas quench furnaces, in which case tests shall be conducted to establish the correct heat-up time for the load. Once a load has been qualified with load thermocouples, subsequent loads may be run without load thermocouples, provided records detailing the number of parts in the first qualified load are kept on file, and provided that subsequent loads have an equal or fewer number of similar parts in the load, and the distribution of the parts is the same as the distribution in the first load.

3.2.5.2 Continuous Furnaces

Shall be operated so that all part temperatures are within the allowed range (the range described by the specified set temperature and the tolerance specified in 3.1.2.1) for the specified time. Conformance to this requirement shall be verified by temperature uniformity tests, performed at the frequency specified in AMS2750, using load thermocouples, in a load representative of the weight and traverse speed of the parts to be heat treated.

3.2.6 Straightening After Heat Treatment

Shall be performed only when the straightening procedure and any subsequent stress-relief are approved by the cognizant engineering organization.

3.3 Qualification

Facilities performing heat treatment in accordance with this specification shall be approved by the cognizant engineering or quality assurance organization (see 4.5). Personnel performing or directing the performance of heat treatment in accordance with this specification shall be approved in accordance with ARP1962 or other established procedures acceptable to the cognizant engineering organization.

3.4 Properties After Heat Treatment

3.4.1 Surface Contamination

3.4.1.1 The heat treatment processor shall assume surfaces will not be machined after heat treatment unless the minimum amount of surface material to be removed after heat treatment is determined.

3.4.1.2 Surfaces of parts which are not to have surface material removed after heat treatment shall have no carburization, sulfidation, nitriding, or intergranular oxidation resulting from the heat treating operations; evidence of such contamination shall be a continuous or general condition in the microstructure at the surface determined by the metallurgical examination in accordance with 3.5.1. On surfaces which are to have material removed after heat treatment, the depth of any of these conditions shall not exceed the depth of surface material to be removed in finishing the part.

3.4.2 Hardness

Parts shall conform to hardness requirements specified on the engineering drawing or purchase order.

3.4.2.1 If hardness requirements are not specified on the engineering drawing or purchase order, age-hardening alloys conforming to one of the AMS listed in Table 7 shall meet the hardness specified in Table 7 following precipitation treatment.

3.4.2.2 If hardness is not specified on the engineering drawing or purchase order or in Table 7, parts shall conform to the hardness requirements of the applicable material specification when the material specification contains hardness requirements for the heat treatment condition represented by the parts.

3.4.3 Tensile and Stress Rupture

When required by the cognizant engineering organization, parts shall conform to tensile property and stress rupture requirements of the applicable material specification when the material specification contains requirements for the heat treatment condition represented by the parts.

3.5 Test Methods

The following test methods shall be used when applicable, unless otherwise specified by the cognizant engineering organization:

3.5.1 Surface Contamination

Testing shall be by metallurgical examination, at approximately 500X magnification, of etched specimens prepared in accordance with ASTM E3. The chord method described in ARP1820 may be used to enhance this examination.

3.5.2 Hardness

Shall be determined in accordance with ASTM E10, ASTM E18, or ASTM E384, as applicable. Unless otherwise specified by the cognizant quality assurance organization, hardness tests shall be performed on the thickest section of the part which is practical to test and where the test will not be detrimental to the function of the part.

3.5.3 Tensile Properties

Testing, when required by the cognizant engineering organization, shall be in accordance with ASTM E8/E8M, or ASTM E21, as applicable.

3.5.4 Stress Rupture Properties

Testing, when required by the cognizant engineering organization, shall be in accordance with ASTM E139 or ASTM E292, as applicable.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

Unless otherwise specified by the cognizant engineering or quality assurance organization (see 8.4.6), the heat treatment processor shall be responsible for performance of all tests and inspections specified herein. The processor may use its own facilities or any commercial laboratory acceptable to the cognizant engineering or quality assurance organization.

4.1.1 The procuring activity reserves the right to perform any surveillance, tests, or inspection of parts, and to review heat treatment records and results of processor's tests and inspections to verify that the heat treatment conformed to specified requirements.

4.2 Records

Shall be kept available to purchaser for not less than 5 years after heat treatment. The records shall contain all data necessary to verify conformance to requirements of this specification.

4.3 Classification of Tests

4.3.1 Acceptance Tests

For age-hardenable alloys as included in Table 4, hardness (3.4.2) is an acceptance test and shall be performed on each lot according to a sampling plan which conforms to the heat treatment processor's shop procedures, unless otherwise specified by the cognizant engineering or quality assurance organization.

4.3.2 Periodic Tests

Surface contamination is a periodic test and shall be performed monthly on each furnace, except as provided in 4.3.2.1, for each type of atmosphere used in each furnace when (a) heat treating temperature is above 1550 °F (843 °C) and parts have less than 0.008 inch (0.20 mm) finishing stock on any surface, or (b) parts are made of an alloy which Tables 3 or 4 specify shall require a protective atmosphere for heat treatments at lower temperatures and parts have any surface which will not have surface material removed after heat treatment.

4.3.2.1 Periodic surface contamination tests are not required on vacuum furnaces operating under 10 µm pressure, except as provided in 4.3.2.2.

4.3.2.2 Surface contamination tests shall also be performed whenever parts which have less than 0.008 inch (0.20 mm) finishing stock on any surface, and which have been heat treated at a temperature above 1550 °F (843 °C), show abnormal surface discoloration after heat treatment. The cognizant engineering organization is responsible for defining "abnormal surface discoloration."

4.3.3 Preproduction Tests

Surface contamination (3.4.1) is a preproduction test when (a) heat treating temperature is above 1550 °F (843 °C) and parts have less than 0.008 inch (0.20 mm) finishing stock on any surface, or (b) parts are made of alloys which Tables 3 or 4 specify shall require a protective atmosphere for heat treatments at temperatures below 1550 °F (843 °C) and parts have any surface which will not have surface material removed after heat treatment. Preproduction tests shall be performed prior to, or on, the first production lot (see 8.4.3) heat treated in each type of furnace equipment, and for each type of atmosphere to be used in each furnace type.

4.3.3.1 When specified by the cognizant engineering or quality assurance organization, hardness (3.4.2), tensile (3.4.3), and stress-rupture (3.4.3) shall also be preproduction tests and shall be performed prior to, or on, the first production lot heat treated in each type of furnace equipment, and for each type of atmosphere used in each furnace type.

4.4 Test Samples

4.4.1 Surface Contamination Tests (3.5.1)

4.4.1.1 For preproduction surface contamination tests (4.3.3), sample material of the same alloy representing the parts shall be supplied to the heat treatment processor by purchaser, or destructive testing of a part shall be authorized by purchaser.

4.4.1.2 For periodic surface contamination tests (4.3.2), sample material shall be prepared in accordance with 4.4.1.2.1 and be either the same alloy as the production parts to be heat treated or shall be an alloy selected from Table 8.

4.4.1.2.1 Prior to furnace exposure, at least one surface shall be machined or ground. The test samples shall be exposed to the heat treating atmosphere at the maximum temperature, or higher, and for the maximum time, or longer, required for heat treating the production parts.

4.4.2 When tensile (3.5.3) or stress rupture (3.5.4) properties are required, sample material which represents the parts to be heat treated and is a size suitable for obtaining the test specimens required shall be supplied to the heat treatment processor by purchaser, or destructive testing of a part shall be authorized by purchaser.

4.4.3 Hardness tests (3.5.2) shall be performed nondestructively on parts except when the parts are not of suitable size or shape, or when the test will be detrimental to the function of the part; in these cases, suitable sample material which represents the parts shall be supplied to the heat treatment processor by purchaser for hardness tests.

4.5 Approval of Heat Treatment Processors

Shall be accomplished by the cognizant engineering or quality assurance organization (see 8.4.6) and will normally be based on the following:

4.5.1 Approval of the heat treatment processor's shop procedure document, which shall include a full description of all equipment and procedures that will be used to meet requirements of this specification and AMS2750.

4.5.2 Competence of heat treatment processor's personnel (see 3.3).

4.6 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 parts, alloy, lot identification, AMS2774G 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.

4.7 Report/Certification

The heat treating processor shall furnish, with each shipment of parts, a certified quality assurance report, traceable to the heat treat control number(s), stating that the parts were processed in accordance with the requirements of AMS2774G (or other applicable specification). The report shall include purchase order number, part number or product identification, alloy, temper/strength designation, quantity of parts in the shipment, identification of furnace(s) used, actual thermal processing times, and temperatures used. When applicable, the report shall also include atmosphere type, quenchant (including polymer concentration range), hot straightening temperature and method of straightening (e.g., press, fixtures), actual test results (e.g., hardness, conductivity, tensile, shear, etc.), and a statement of their conformance/nonconformance to requirements. This data shall be reported in accordance with the heat treater's documented procedures.

5. PREPARATION FOR DELIVERY

5.1 Identification

Identification of parts provided to the heat treatment processor shall be maintained on the parts at delivery.

5.2 Packaging

Parts shall be packaged to ensure protection from damage during shipment and storage.

5.2.1 Packages of parts shall be prepared for shipment in accordance with commercial practice and in compliance with applicable rules and regulations pertaining to the handling, packaging, and transportation of the parts to ensure carrier acceptance and safe delivery.

6. ACKNOWLEDGMENT

The heat treatment processor shall mention this specification number and its revision letter in all quotations and when acknowledging purchase orders.

7. REJECTIONS

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

8. NOTES

8.1 Revision Indicator

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 Designation of Alloys

Detailed heat treating requirements are included in this specification for the alloys shown in Table 9. They are listed in order of their Unified Numbering System designation, from SAE HS-1086, and by their most common trademark or other trade name; AMS numbers are shown for reference, wherever applicable, and the proper table of this specification is referenced where the heat treating requirements for each alloy are specified (e.g., Table 3 for non-age-hardening alloys and Table 4 for age-hardening alloys).

8.3 Hardness conversion tables for metals are presented in ASTM E140.

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

8.4.1 Parts

Usually identified by a part number, parts are produced from raw material in accordance with requirements of a drawing, and, except for those parts produced in large quantities (e.g., rivets), are usually tested by nondestructive techniques only. They are heat treated by a fabricator/user, or his designee, to meet requirements of a drawing. The requirements are usually conveyed by a purchase order, fabrication outline, and/or heat treating specification. Parts, at the time of heat treatment, may resemble raw material.

8.4.2 Raw Material

Consists of sheet, strip, foil, plate, tube, wire, rod, bar, rings, extrusions, and forgings, and is usually identified by a heat or lot number; in the form of rings, extrusions, and forgings, is usually also identified with a part number; in addition, is usually tested destructively for acceptance. It is heat treated, usually by or for a material producer, in accordance with a material specification which may require, by reference, conformance to a heat treating specification.

8.4.3 Lot

Shall be all parts of the same nominal configuration, of the same alloy, processed at the same time, and heat treated as a heat treatment batch or, in the case of continuous furnaces, have been heat treated continuously during a single shift, not to exceed a 12 hour period.

8.4.4 Load Thermocouple

A thermocouple attached to and in direct contact with the heaviest section of a part or representative sample. There should be no gap between the thermocouple and the part. It should be shielded against furnace radiation and protected against contamination from the furnace atmosphere or heating medium.

8.4.5 Set or Offset Temperature

The temperature at which controlling instruments are set to cause the working zone of the furnace to operate within required temperature tolerance.

8.4.6 Cognizant Organization

The engineering organization responsible for the design of the parts, or the quality assurance organization, or a designee of these organizations.

8.4.7 Solution Heat Treatment

A high-temperature heat treatment designed to place certain carbides and intermetallic compounds into solid solution.

8.4.8 Annealing

A high-temperature heat treatment designed to produce a recrystallized grain structure and softening in a work-hardened alloy.

8.4.9 Stress Relieving

A heat treatment used to remove or reduce stresses in work-hardened alloys.

8.4.10 Stabilization Annealing

A heat treatment used with some non-age-hardening alloys to cause a precipitation of carbides of a form and composition that do not sensitize the alloy to intergranular corrosion, and which stabilize the alloy against becoming sensitized during subsequent elevated temperature exposures.

8.4.11 Stabilization Heat Treatment

An intermediate temperature precipitation heat treatment used with many age-hardening nickel alloys to cause a precipitation of discontinuous chromium carbides at grain boundaries prior to a lower temperature aging heat treatment which will cause a fine gamma-prime precipitation within the grains. This two-step precipitation results in an optimization of tensile and creep-rupture properties.

8.4.12 Precipitation Heat Treatment

An intermediate temperature heat treatment causing hardening and strengthening of the alloy by the precipitation of intermetallic compounds, and, in some instances, of carbides from supersaturated solid solutions.

8.4.13 Interstage Annealing

An annealing treatment performed between stages of forming or other fabricating operations in the process of manufacturing a part, for the purpose of softening or restoring optimum workability properties to the alloy.

8.4.14 Equalization

An intermediate temperature stress-equalization treatment applied to Inconel X-750 rods, bars, and forgings by the producing mill or forge shop which, when followed by precipitation treatment, provides optimum balance in strength and notch-rupture ductility properties at service temperatures under 1100 °F (593 °C). This treatment is referred to as Condition A in Table 4.

8.4.15 Air Cooling

The rate at which the parts, separated from one another sufficiently to allow free movement of air between them, would cool to room temperature after being removed from the furnace and placed in ambient air without forced motion of the air.

8.4.16 Rapid Air Cooling

The rate at which the parts, separated from one another sufficiently to allow free movement of air between them, would cool to room temperature after being removed from the furnace and placed in shop air with rapid motion of the air forced over the parts by a fan or blower.

8.4.17 Thickness

The minimum specified dimension of the heaviest section of the part.

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.

8.6 Purchase documents should specify not less than the following:

AMS2774G
Size of parts
Quantity of parts
Part number or product identity
Material alloy designation of parts or the material specification number applicable to the parts
Heat treatment operations desired
Condition to which parts are to be heat treated

Table 1 - Temperature tolerance

Heat Treatment	Tolerance °F	Tolerance °C
Stress relief of age hardening alloys at 1550 °F (843 °C) and under	±15	±8
Stress relief of age hardening alloys over 1550 °F (843 °C)	±25	±14
Stabilization of age hardening alloys	±15	±8
Precipitation	±15	±8
All other treatments	±25	±14

Table 2 - Quenchant temperature

Quenchant	Quenchant Temperature
Water	Under 200 °F (93 °C)
Brine	60 to 100 °F (16 to 38 °C)
Salt	350 to 400 °F (177 to 204 °C)
Oil	Within ranges recommended by the oil supplier
Water-polymer solution	Within ranges recommended by the polymer supplier

Table 3 - Heat treatment of non-age-hardenable nickel alloy and cobalt alloy parts

Alloy and Form	Applicable AMS	Purchased Condition	Solution Set Temperature[1]	Anneal Set Temperature[1]	Stress Relief Set Temperature[1]	Other Treatments Set Temperature[1]
NICKEL 201						
Sheet and Strip	AMS5553	Annealed	N/A	1350 °F (732 °C)[2]	1300 °F (704 °C) 30 minutes[2]	
NIMONIC Alloy 75						
All Forms	None	Annealed	Use anneal	1920 °F (1049 °C); Air Cool	Use anneal	
INCONEL Alloy 600						
Bars	AMS5665	Hot or cold finished	2050 °F (1121 °C)[3] 1 to 2 hours; AC[4]	1850 °F (1010 °C)[5]; AC[3]	Use anneal	
Forgings	AMS5665	Annealed	2050 °F (1121 °C) 1 to 2 hours; AC	1850 °F (1010 °C); AC	Use anneal	
Sheet, Strip, Plate, Tubing	AMS5540 AMS5580	Annealed	2050 °F (1121 °C) 1 to 2 hours; AC	1850 °F (1010 °C); AC	Use anneal	
Rivets	AS7232	Cold drawn	None	1950 °F (1066 °C) 5 to 10 minutes; AC[6]		
INCONEL Alloy 601						
Bar, Rings, and Forgings	AMS5715	Annealed	2050 °F (1121 °C) 1 to 2 hours; AC	1850 °F (1010 °C); AC	Use anneal	
Sheet, Strip, and Plate	AMS5870	Solution heat treated	2050 °F (1121 °C) 1 to 2 hours; AC	1850 °F (1010 °C); AC	Use anneal	
INCONEL Alloy 617						
Rod, Bar, Forgings, and Plate	AMS5887 AMS5888	Annealed	Use anneal	2075 to 2200 °F[7] (1135 to 1204 °C); AC	Use anneal	
Sheet, Strip, and Tubing	AMS5889	Annealed	Use anneal	2075 to 2175 °F[7] (1135 to 1191 °C); AC	Use anneal	
INCONEL Alloy 625						
Bar, Rings, and Forgings	AMS5666	Annealed	2150 °F (1177 °C)[8]; WQ or RAC	1900 °F (1038 °C)[9]; AC[21]	Use anneal	
Sheet, Strip, Plate, Tubing	AMS5599 AMS5581	Annealed	2150 °F (1177 °C)[8]; WQ or RAC	1900 °F (1038 °C)[9]; AC[21]	Use anneal	
Additively Manufactured	AMS7000	Solution heat treated	1900 °F (1038 °C)		Use solution heat treatment	
INCOLOY Alloy 800						
All forms	AMS5766 AMS5871	Solution heat treated	N/A	1800 °F (982 °C); AC	1650 °F (899 °C); AC	
INCOLOY Alloy 800HT						
All Forms	None	Solution heat treated	N/A	2100 °F (1149 °C); AC	Use anneal	
INCOLOY Alloy 825						
All Forms	None	Annealed	N/A	1800 °F (982 °C); AC[10]	Use anneal	Stabilization anneal[11] 1725 °F (941 °C); AC
HASTELLOY Alloy B-2						
All Forms	None	Annealed	N/A	1950 °F (1066 °C); WQ or RAC	Use anneal	
HASTELLOY Alloy C-276						
All Forms	None	Annealed	Use anneal	2050 °F (1121 °C); WQ or RAC	Use anneal	
HASTELLOY Alloy N						
Bar, Rings, and Forgings	AMS5771	Solution heat treated	Use anneal	2150 °F (1177 °C); WQ or RAC	Use anneal	

Alloy and Form	Applicable AMS	Purchased Condition	Solution Set Temperature[1]	Anneal Set Temperature[1]	Stress Relief Set Temperature[1]	Other Treatments Set Temperature[1]
Sheet, Strip, and Plate	AMS5607	Solution heat treated	Use anneal	2150 °F (1177 °C); WQ or RAC	Use anneal	
HASTELLOY Alloy S						
Bars, Rings, and Forgings	AMS5711	Solution heat treated	Use anneal	1950 °F (1066 °C); Cool at any rate	Use anneal	
Sheet, Strip, and Plate	AMS5873	Solution heat treated	Use anneal	1950 °F (1066 °C); Cool at any rate	Use anneal	
HASTELLOY Alloy W						
Bars, Rings, and Forgings	AMS5755	Solution heat treated	Use anneal	2150 °F (1177 °C); WQ or RAC	Use anneal	
HASTELLOY Alloy X						
Bars, Rings, and Forgings	AMS5754	Solution heat treated	Use anneal	2150 °F (1177 °C); RAC	Use anneal	
Sheet, Strip, Plate, and Tubing	AMS5536, AMS5587, AMS5588	Solution heat treated	Use anneal	Select temperature in the range 2100 to 2150 °F (1149 to 1177 °C); RAC	Use anneal	
HASTELLOY Alloy X						
Rivets	AS7237	Solution heat treated	2150 °F (1177 °C) 7 to 10 minutes; AC[12]	Use solution treatment	None	
N-155 Alloy						
Bar, Rings, and Forgings	AMS5769	Solution heat treated	2150 °F (1177 °C); WQ or RAC[13]	Use solution treatment	See[14] Max service temperature 2 to 4 hours; AC	
Sheet, Strip, Plate, and Tubing	AMS5532 AMS5585	Solution heat treated	2150 °F (1177 °C); WQ or RAC	Use solution treatment	See[14] Max service temperature 2 to 4 hours; AC	
L-605 Alloy						
Sheet 0.025 Inch (0.64 mm) or Under Thick	AMS5537	Solution heat treated	Use anneal	2150 °F (1177 °C); RAC[15]	Use anneal	
Sheet Over 0.025 Inch (0.64 mm) Thick, and Plate	AMS5537	Solution heat treated	Use anneal	2200 °F (1204 °C); WQ or RAC[15]	Use anneal	
Bar and Forgings	AMS5759	Solution heat treated	Use anneal	2250 °F (1232 °C); WQ or RAC[15]	Use anneal	
Rivets	AS7236	Solution heat treated	2150 °F (1177 °C) 10 to 20 minutes; WQ[16]	Use solution treatment	None	
HAYNES Alloy 188						
Bar, Rings, and Forgings	AMS5772	Solution heat treated	2150 °F (1177 °C)	2050 °F (1121 °C); WQ or RAC[17]	Use anneal	
Sheet, Strip, and Plate	AMS5608	Solution heat treated	2125 °F-2250 °F (1163 °C-1232 °C)	2050 °F (1121 °C); WQ or RAC[17]	Use anneal	
HAYNES Alloy 230						
Bar, Rings, and Forgings	AMS5891	Annealed	Use anneal	2150 to 2275 °F[18] (1177 to 1246 °C); WQ or RAC	Use anneal	
HAYNES Alloy 230						
Sheet, Strip, and Plate	AMS5878	Solution heat treated	Use anneal	Select temperature in the range 2150 to 2275 °F[18] (1177 to 1246 °C); WQ or RAC	Use anneal	
HAYNES Alloy 556						
Bar, Rings, and Forgings	AMS5877	Solution heat treated	Use anneal	2150 °F (1177 °C)[19]; WQ or RAC	Use anneal	
Sheet, Strip, and Plate	AMS5874	Solution heat treated	Use anneal	2150 °F (1177 °C)[19]; WQ or RAC	Use anneal	

Alloy and Form	Applicable AMS	Purchased Condition	Solution Set Temperature(1)	Anneal Set Temperature(1)	Stress Relief Set Temperature(1)	Other Treatments Set Temperature(1)
STELLITE 6						
Bar and Sheet	AMS5894	Solution heat treated	2250 °F (1232 °C); Air Cool(20)	Use solution treatment	Use solution treatment	

NOTES:
(1) Abbreviations: WQ = Water Quench or equivalent rate; AC = Air Cool or equivalent rate; RAC = Rapid Air Cool or equivalent rate; N/A = Not Applicable. All soaking times shall be as shown in Table 5 unless otherwise stated.
(2) Soak time shall be established empirically and selected between 15 minutes minimum and 3 hours maximum so that the anneal of the fabricated part shall provide grain size which is not substantially coarser than the mill annealed raw material. Cooling rate is not critical. Cooling may be accomplished by quenching in water containing 2% alcohol; a soft oxide will remain which can be easily removed in standard pickling solutions. Annealing and stress relieving require heating in a vacuum, argon, or reducing atmosphere.
(3) Solution treatment of Inconel Alloys 600 and 601 produces a coarse grain structure and is normally not used on these alloys, except to obtain maximum creep and rupture strengths, but with lower corrosion-resistance, and lower tensile, fatigue, and impact strengths, than the finer grain structures produced using the 1850 °F (1010 °C) anneal.
(4) Rapidly cool through the 1000 to 1400 °F (538 to 760 °C) range; if parts are to be pickled or used in an environment requiring freedom from sensitization, sections of 0.10 inch (2.5 mm) thickness and over require water quenching or equivalent cooling rates.
(5) When specified, annealing Inconel Alloys 600 and 601 prior to high-temperature brazing, as required for nickel brazing alloys, shall be done at 2100 °F (1149 °C), soaking for 15 minutes, and cooling at a rate equivalent to an air cool.
(6) AS7232 rivets shall be annealed after the head-forming operation.
(7) In cases where small amounts (under 10%) of strain are present in the fabrication of Inconel Alloy 617 parts, select temperature at the low end of the range to minimize grain growth.
(8) Solution treatment is normally not used with Inconel 625 except to obtain maximum ductility, i.e., higher ductility than with the normal 1900 °F (1038 °C) anneal treatment, but also with a lower tensile strength than the anneal treatment.
(9) When specified, annealing Inconel 625 prior to high-temperature brazing, e.g., with nickel brazing alloys, shall be done at 2050 °F (1121 °C), soaking for 15 minutes, and cooling at a rate equivalent to an air cool.
(10) Rapidly cool through the 1000 to 1400 °F (538 to 760 °C) range; if parts are to be pickled or used in an environment requiring freedom from sensitization, sections over 0.25 inch (6.4 mm) thickness require water quenching or equivalent cooling rates.
(11) The 1725 °F (941 °C) treatment stabilizes the Inconel 825 alloy against sensitization; it is recommended when parts are to be exposed to service temperatures above 1200 °F (650 °C) and resistance to sensitization is also desired.
(12) AS7237 rivets shall be solution treated after the head-forming operation.
(13) Rapid air cool sections under 0.25 inch (6.4 mm) thick; heavier sections require water quenching or equivalent rates.
(14) Engineering or procurement documents from purchaser shall specify the stress relief temperature; maximum expected service temperature is recommended for the stress relief temperature.
(15) Parts of this alloy fabricated of any combination sheet, plate, bar, or forgings shall be annealed according to the temperature and cooling requirements for the thinnest sheet or plate in the assembly and soaked according to the Table 5 requirements for the heaviest section of the assembly.
(16) AS7236 rivets shall be solution treated after the head-forming operation; they may be rapidly cooled in media other than water, provided cooling rate is sufficient to meet hardness and formability requirements.
(17) Annealed products of this alloy may be cooled in hydrogen.
(18) In cases where small amounts (under 10%) of strain are present in the part fabrication, select temperature at the low end of the range to minimize grain growth.
(19) In cases where small amounts (less than 10%) of strain are present in the part fabrication, to minimize grain growth, heat parts to 2050 °F (1121 °C), soak according to Table 5, and then raise the temperature to the anneal temperature shown, and soak according to Table 5, followed by rapid air cool or water quench.
(20) Soak time shall be according to Table 5 except not less than 15 minutes.
(21) In-process anneal of 1600 to 1900 °F (871 to 1038 °C) permitted.

Table 4 - Heat treatment of age-hardenable nickel alloy and cobalt alloy parts

Alloy and Form	Heat Treatment Condition[1]	Applicable AMS	Purchased Condition	Solution Set Temperature[2]	Stabilization Set Temperature[2]	Precipitation Set Temperature[2]	Other Treatments Set Temperature[2]
WASPALOY							
Bar, Rings, and Forgings	S1975SP	AMS5708	Solution heat treated	1975 °F (1079 °C) 4 hours; AC	1550 °F (843 °C) 4 hours, except turbine blade forgings Hold 24 hours; AC or WQ	1400 °F (760 °C) 16 hours; AC	
Bolts and Screws	N/A[2]	AS7471 MA3378	N/A	Select temperature in range 1900 to 1975 °F (1038 to 1079 °C) Hold 1 to 4 hours; AC[3]	1550 °F (843 °C) 4 hours; AC[3] or WQ	1400 °F (760 °C) 16 hours; AC	
Nuts, Self-Locking	S1975SP	AS7253	N/A	1975 °F (1079 °C) 4 hours; AC	1550 °F (843 °C) 4 hours; AC	1400 °F (760 °C) 16 hours; AC	
Bar, Rings, and Forgings	S1850SP	AMS5706 MAM5706	Solution heat treated	Select temperature in range 1825 to 1900 °F (996 to 1038 °C) Hold 1 to 4 hours; OQ or WQ	1550 °F (843 °C) 4 hours; AC	1400 °F (760 °C) 16 hours; AC	
Sheet and Tube	N/A	AMS5544 AMS5586	Solution heat treated	1825 °F (996 °C) 2 hours; AC	1550 °F (843 °C) 4 hours; AC	1400 °F (760 °C) 16 hours; AC	Anneal 1975 °F (1079 °C) 10 to 30 minutes; AC; Stress Relief[4]
RENE' 41							
Sheet, Strip, Plate, Bar, Rings, and Forgings	N/A	AMS5545 AMS5712	Solution heat treated	1975 °F (1079 °C) Hold 1 h/in (25 mm) of thickness, but 10 minutes min; AC thicknesses under 0.25 inch (6.4 mm); OQ or WQ thicknesses 0.25 inch (6.4 mm) and over	None	1400 °F (760 °C) 16 hours; AC	Stress Relief[4]
Bolts and Screws	N/A	AS7469	N/A	2050 °F (1121 °C) 30 minutes; AC	None	1650 °F (899 °C) 4 hours; AC[5]	
NIMONIC ALLOYS 80A and 90							
Bar and Forgings	S1975P(6)	None	Solution heat treated	1975 °F (1079 °C) 8 hours; AC	None	1300 °F (704 °C) 16 hours; AC	
Bar	CSSSP(6)	None	Cold stretched and solution heat treated	1975 °F (1079 °C) 8 hours; AC	1560 °F (849 °C) 24 hours; AC	1300 °F (704 °C) 16 hours; AC	
Sheet	N/A	None	Solution heat treated	Mill treatment	None	1380 °F (749 °C)[7] 4 hours; AC	Interstage anneal 1905 °F (1041 °C) 20 minutes; AC; Post–weld stress relief 1700 °F (927 °C) 1 hour; AC
NIMONIC Alloy 263							
Bar and Forgings	N/A	AMS5886	Solution heat treated	2100 °F (1149 °C) Hold 1 h/in (25 mm) of thickness but 30 minutes min and not more than than 90 minutes; OQ or WQ	None	1475 °F (802 °C) 8 hours; AC	

Alloy and Form	Heat Treatment Condition[1]	Applicable AMS	Purchased Condition	Solution Set Temperature[2]	Stabilization Set Temperature[2]	Precipitation Set Temperature[2]	Other Treatments Set Temperature[2]
Sheet, Strip, and Plate	N/A	AMS5872	Solution heat treated	Mill treatment	None	1475 °F (802 °C)[8] 8 hours; AC	Interstage anneal 1950 °F (1066 °C) Hold 1 h/in (25 mm) of thickness but 10 minutes min; AC or WQ
UDIMET Alloy 700							
Bar and Forgings	N/A	AMS5846	Solutioned, stabilized, and precipitation treated	2150 °F (1177 °C) 4 hours; AC to room temperature plus 4 to 6 hours; RAC	1550 °F (843 °C) 24 hours; AC	1400 °F (760 °C) 16 hours; AC	
INCONEL Alloy 706							
Sheet, Strip, Plate, Bar, Rings, and Forgings	S1800DP	AMS5605 AMS5701	Solution heat treated	1800 °F (982 °C) Hold 1 h/in (25 mm) of thickness, but 5 minutes min for sheet and strip and 30 minutes min for bar, rings, and forgings; AC	None	1350 °F (732 °C) 8 hours; Furnace cool to 1150 °F (621 °C) and hold at 1150 °F (621 °C) for total precipitation time of 18 hours; AC[27]	
Sheet, Strip, Plate, Bar, Rings, and Forgings	S1750SDP	AMS5606 AMS5702	Solution heat treated	1750 °F (954 °C) Hold 1 h/in (25 mm) of thickness, but 5 minutes min for sheet and 30 minutes min for bar and forgings; AC	1550 °F (843 °C) 3 hours; AC	1325 °F (718 °C) 8 hours; Furnace cool to 1150 °F (621 °C) and hold at 1150 °F (621 °C) for total precipitation time of 18 hours; AC[27]	
INCONEL Alloy 718							
Sheet, Strip, Plate, Tube, Bar, Rings, and Forgings	S1750DP	AMS5589, AMS5596, AMS5662	Solution heat treated	1750 °F (954 °C) Hold 1 h/in (25 mm) of thickness but 10 minutes min; AC	None	1325 °F (718 °C) 8 hours; Furnace cool to 1150 °F (621 °C) and hold at 1150 °F (621 °C) for total precipitation time of 18 hours; AC[27]	
Bolts and Screws	N/A	AS7466 AS7467	N/A	Select temperature in range 1700 to 1850 °F (927 to 1010 °C) Hold 1 hour; OQ or WQ[9][10]	None	1325 °F (718 °C) 8 hours; Furnace cool to 1150 °F (621 °C) and hold at 1150 °F (621 °C) for total precipitation time of 18 hours; AC[9][10][27]	
Sheet, Strip, Plate, Tube, Bar, Rings, and Forgings	S1950DP	AMS5590, AMS5597, AMS5664	Solution heat treated	1950 °F (1066 °C) Hold 1 h/in (25 mm) of thickness but 10 minutes min and not more than 2 hours; AC	None	1,400 °F (760 °C) 10 hours; Furnace cool to 1200 °F (649 °C) and hold at 1200 °F (649 °C) for total precipitation time of 20 hours; AC[27]	

Alloy and Form	Heat Treatment Condition[1]	Applicable AMS	Purchased Condition	Solution Set Temperature[2]	Stabilization Set Temperature[2]	Precipitation Set Temperature[2]	Other Treatments Set Temperature[2]
ATI 718Plus Alloy							
Bars, Rings, and Forgings		AMS5441	Solution heat treated	1775 °F (968 °C) Hold 1 h/in (25 mm) of thickness but 30 minutes min; AC	None	1450 °F (788 °C) 8 hours; Furnace cool to 1300 °F (704 °C) and hold at 1300 °F (704 °C) for total precipitation time of 18 hours; AC[27]	
INCONEL Alloy 722							
Sheet and Strip	N/A	AMS5541	Annealed	1800 °F (982 °C) Hold 1 h/in (25 mm) of thickness but 10 minutes min; AC	None	1300 °F (704 °C)[11] 16 hour min; AC	
Bar, Rings, and Forgings	N/A	AMS5714	Solution heat treated	1800 °F (982 °C) 1 hour; AC	None	1325 °F (718 °C) 8 hours; Furnace cool to 1150 °F (621 °C) and hold at 1150 °F (621 °C) for total precipitation time of 16 hours; AC[27]	
INCONEL Alloy X750							
Bar, Rings, and Forgings	A[12]	AMS5667	Equalization heat treated	None	None	1300 °F (704 °C) 20 hours; AC	Equalization[13] 1625 °F (885 °C) 24 hours; AC
Sheet, Strip, Plate, and Tube	B[14]	AMS5542 AMS5582	Annealed	1925 °F (1052 °C)[15] Hold 1 h/in (25 mm) of thickness but 10 minutes min; AC	None	1300 °F (704 °C) 20 hours; AC	
Sheet, Strip, Plate, Tube, Bar, Rings, and Forgings	C[16]	AMS5583, AMS5598, MAM5598, AMS5670, AMS5671, AMS5747	Solution heat treated	1800 °F (982 °C)[15] Hold 1 h/in (25 mm) of thickness but 10 minutes min; AC	None	1350 °F (732 °C) 8 hours; Furnace cool to 1150 °F (621 °C) and hold at 1150 °F (621 °C) for total precipitation time of 18 hours; AC[27]	
Wire	No. 1 Temper[17]	AMS5698	Cold drawn	None	None	1350 °F (732 °C) 16 hours; AC	
Wire	Spring Temper and Direct Age[18]	AMS5699	Cold drawn	None	None	1200 °F (649 °C) 4 hours; AC	
INCONEL Alloy X750							
Wire	Spring Temper and SSP[19]	AMS5699	Cold drawn	2100 °F (1149 °C) 2 hours; AC	1550 °F (843 °C) 24 hours; AC	1300 °F (704 °C) 20 hours; AC	
Thread Form Inserts	N/A	AS7246	Cold drawn and shaped wire	N/A	N/A	1300 °F (704 °C)[20] 4 hours min; AC	
INCOLOY Alloy 901							
Bar and Forgings	S2000SP	AMS5660	Solutioned, stabilized, and precipitation treated	Select temperature in range 1975 to 2025 °F (1079 to 1107 °C) Hold 2 hours; Quench[21]	Select temperature in range 1425 to 1475 °F (774 to 802 °C) Hold 2 to 4 hours; RAC	Select temperature in range 1325 to 1375 °F (718 to 746 °C) Hold 24 hours; AC	

Alloy and Form	Heat Treatment Condition[1]	Applicable AMS	Purchased Condition	Solution Set Temperature[2]	Stabilization Set Temperature[2]	Precipitation Set Temperature[2]	Other Treatments Set Temperature[2]
INCOLOY Alloy 901 Mod							
Bar, Rings, and Forgings	S1975SP	AMS5661	Solutioned, stabilized, and precipitation treated	Select temperature in range 1950 to 2000 °F (1066 to 1093 °C) Hold 1 h/in (25 mm) of thickness but 1 hour min; Quench[21]	Select temperature in range 1425 to 1475 °F (774 to 802 °C) Hold 2 to 4 hours; RAC	Select temperature in range of 1300 to 1375 °F (704 to 746 °C) Hold 24 hours; AC	
MONEL Alloy K-500							
Bar and Forgings	Hot Finished and Direct Age	AMS4676	As hot finished	See(22) 1800 °F (982 °C) 1 hour; Quench in solution of water - 2% alcohol	None	1113 °F (601 °C) 16 hours; Furnace cool 15 to 25 °F (8 to 14 °C) per hour to 900 °F (482 °C); AC[22]	Post-weld stress relief 1725 °F (941 °C) 20 minutes; RAC to below 900 °F (482 °C)
NI-SPAN-C Alloy 902							
Strip	N/A	AMS5221 AMS5223 AMS5225	Solution heat treated, solution heat treated plus cold rolled	Mill treatment	None	1300 °F (704 °C)[23] 3 hours; Cool in vacuum or protective atmosphere	
D 979 Alloy							
Bar and Forgings		AMS5746	Solutioned, stabilized, and precipitation treated	Select temperature in range 1850 to 1900 °F (1010 to 1038 °C) Hold 1 h/in (25 mm) thickness but 1 hour min; OQ or WQ	1550 °F (843 °C) 6 to 12 hours; AC	1300 °F (704 °C) 16 hours; AC	
INCOLOY Alloy 909							
Bar, Rings, and Forgings	18 HrDP[24]	AMS5884	Solution heat treated	1800 °F (982 °C) For thickness of 1 inch (25 mm) and under hold 1 hour and an additional 15 minutes for each additional 0.25 inch (6.4 mm) of thickness; AC	None	1325 °F (718 °C)[25] 8 hours; Furnace cool at 100 °F (56 °C) per hour max to 1150 °F (621 °C) and hold at 1150 °F (621 °C) 8 hours; Use protective atmosphere unless parts will have surface material removed all over; AC	
Bar, Rings, and Forgings	10 HrDP[24]	AMS5893	Solution heat treated	1800 °F (982 °C) For thickness of 1 inch (25 mm) and under hold 1 hour and an additional 15 minutes for each additional 0.25 inch (6.4 mm) of thickness; AC	None	1375 °F (746 °C)[25] 4 hours; Furnace cool at 100 °F (56 °C) per hour max to 1150 °F (621 °C) and hold at 1150 °F (621 °C) 4 hours; Use protective atmosphere unless parts will have surface material removed all over; AC	

Alloy and Form	Heat Treatment Condition[1]	Applicable AMS	Purchased Condition	Solution Set Temperature[2]	Stabilization Set Temperature[2]	Precipitation Set Temperature[2]	Other Treatments Set Temperature[2]
INCOLOY Alloy 909							
Sheet and Strip	N/A	AMS5892	Solution heat treated	1800 °F (982 °C) 1 hour; AC	None	1375 °F (746 °C)[25] 4 hours; Furnace cool at 100 °F (56 °C) per hour max to 1150 °F (621 °C) and hold at 1150 °F (621 °C) 4 hours; Use protective atmosphere unless parts will have surface material removed all over; AC	
ASTROLOY Alloy M							
Forgings	N/A	AMS5882	Solutioned, stabilized, and precipitation treated	Select temperature in range 1975 to 2075 °F (1079 to 1135 °C) Hold 4 hours; AC	1600 °F (871 °C) 8 hours; AC; Plus 1800 °F (982 °C) 4 hours; AC	1200 °F (649 °C) 24 hours; AC; Plus 1400 °F (760 °C) 8 hours; AC	
ELGILOY							
Wire	N/A	AMS5833	Cold drawn	Mill treatment	None	Select temperature in range 900 to 1000 °F (482 to 538 °C) Hold 5 to 5.5 hours; AC	
Sheet	N/A	AMS5876	Cold rolled	Mill treatment	None	Select temperature in range 850 to 950 °F (454 to 510 °C) Hold 5 to 5.5 hours; AC	
MP-35N							
Bar	N/A	AMS5844	Solution heat treated plus cold worked	Mill treatment	None	Select temperature in range 1000 to 1200 °F (538 to 649 °C) Hold 4 to 4.5 hours; AC	
MP-35N							
Bolts and Screws	N/A	AS7468	N/A	None	None	Select temperature in range 1000 to 1200 °F (538 to 649 °C) Hold 4 to 4.5 hours; AC[26]	
MP159							
Bar	N/A	AMS5842	Solution heat treated + cold worked	Mill treatment	None	Select temperature in range 1200 to 1250 °F (649 to 677 °C) Hold 4 to 4.5 hours; AC	
Bolts and Screws	N/A	AS7475	N/A	None	None	Select temperature in range 1200 to 1250 °F (649 to 677 °C) Hold 4 to 4.5 hours; AC[26]	

NOTES:

(1) Heat Treatment Condition: A designation for the heat treat condition (e.g., for Waspaloy, “S1975SP” or “S1850SP”) is used in this table to distinguish a specific heat treatment when more than one heat treatment is used for the same form (i.e., bar, sheet, etc.) of a single alloy. Proper interpretation of the various designations is as follows:
CSSSP = Cold stretched, solution heat treated, stabilized, precipitation heat treated
STTTTP = Solution heat treated at TTTT temperature, precipitation heat treated
STTTTSP = Solution heat treated at TTTT, stabilized, precipitation heat treated
STTTTDP = Solution heat treated at TTTT, double (i.e., two temperature steps) precipitation heat treated
STTTTSDP = Solution heat treated at TTTT, stabilized, double (i.e., two temperature steps) precipitation heat treated

(2) Abbreviations: AC = Air Cool; OQ = Oil Quench; WQ = Water Quench; RAC = Rapid Air Cool; N/A = Not Applicable.

(3) For AS7471 and MA3378 bolt and screw blanks, solution and stabilization treatments shall be applied to headed blanks before finishing the shank and the bearing surface of the head, cold-working the head-to-shank radius and rolling the threads. Precipitation shall follow cold-working of the fillet radius and rolling the threads.

(4) When stress relief is required prior to stabilization and precipitation treatments, use solution treatment, except soaking time shall be selected in the range 10 to 30 minutes. When stress relief is required after precipitation treatment, heat to 1400 °F (760 °C), hold at heat for 1 hour, and air cool.

(5) For AS7469 bolts and screws, solution heat treatment shall be applied to headed blanks before finishing the shank and the bearing surface of the head, cold-working of the fillet radius, and rolling the threads. Precipitation heat treatment shall follow cold working of the fillet radius and rolling the threads. The heating atmosphere shall be maintained at a total sulfur content under 5 grains per 100 cubic feet; heating shall be performed rapidly through the 1200 to 1400 °F (649 to 760 °C) temperature range.

(6) Two-step solution + precipitation treatment, designated “S1975P,” is usually employed for components, e.g., turbine blades, where good high-temperature properties are required. The three-step solution + stabilization + precipitation treatment, designated “CSSSP,” is employed on cold-stretched bar to promote long time, elevated temperature carbide stability, and notch-rupture ductility.

(7) Precipitation treatment should be applied to welded components after the post-weld stress relief; it should be applied to cold-formed parts after the interstage anneal.

(8) Precipitation treatment of Nimonic 263 should be applied to welded components after welding operations are complete; it should be applied to cold formed parts after the interstage anneal.

(9) For AS7466 bolts and screws, solution and precipitation heat treatments shall be applied to headed blanks before finishing the shank and the bearing surface of the head.

(10) For AS7467 bolts and screws, solution heat treatment shall be applied to headed blanks before finishing the shank and the bearing surface of the head, cold working the head-to-shank fillet radius and rolling the threads. Precipitation heat treatment shall follow cold working of the fillet radius and rolling the threads.

(11) If bars, forgings, or rings are fabricated with sheet or strip into a single assembly before precipitation treatment, the precipitation treatment designated for bar, forgings, and rings shall be used for the assembly.

(12) Heat treat condition “A” for Alloy X750 provides high strength and notch-rupture ductility up to 1100 °F (593 °C).

(13) Equalization treatment is applied by the mill or forging supplier for AMS5667 products; it shall precede the precipitation treatment.

(14) Heat treat condition “B” for Alloy X750 provides high strength to 1300 °F (704 °C).

(15) Solution treatment should be applied to weldments of Alloy X750 prior to precipitation heat treatment. Rate of heating shall be fast and uniform; charging the fabricated part into a preheated furnace is recommended. Cooling shall be air cool or equivalent rate; liquid quenching should not be used.

(16) Heat treat condition “C” provides high strength to 1300 °F (704 °C) with increased tensile properties to about 1100 °F (593 °C).

(17) “No. 1 Temper” wire provides springs with optimum resistance to relaxation from about 700 to 850 °F (371 to 454 °C) and at low or moderate stresses up to 1000 °F (538 °C).

(18) “Spring Temper + Direct Age” provides springs with high strength up to about 700 °F (371 °C).

(19) “Spring Temper + SSP” (solution, stabilization, and precipitation treatment) provides springs with maximum resistance to relaxation in the 850 to 1200 °F (454 to 649 °C) temperature range.

(20) AS7246 screw thread inserts shall be precipitation heat treated after coiling the cold drawn and shaped wire.

(21) Rapid air cool Alloy 901 and Alloy 901 Mod parts of 0.080 inch (2.03 mm) nominal thickness and under; liquid quench parts of thicknesses greater than 0.080 inch (2.03 mm).

(22) Solution treatment is not applicable per AMS4676 but may be required for other conditions of Alloy K-500; water may be used in place of the water-alcohol solution as the quenchant when approved by the cognizant engineering organization. Post-weld stress relieve welded components prior to precipitation treatment. During precipitation heat treatment, an acceptable alternate method of cooling from 1113 to 900 °F (601 to 482 °C) is cooling in steps to 1000 °F (538 °C) and then to 900 °F (482 °C), holding 4 to 6 hours at each step.

(23) Perform precipitation treatment in vacuum or protective atmosphere. Unless otherwise specified by the purchase documents or by the cognizant engineering organization, bright hardening is required. Absolute pressure of 0.1 µm or less is required for bright work in vacuum furnaces; very pure hydrogen produced by palladium diffusion cells will also maintain bright surfaces.

(24) The 18 hour double precipitation treatment (18 HrDP) provides optimum properties in this alloy, and is normally used on parts made from bar, forgings, and rings where the highest mechanical properties are required. The 10 hour double precipitation treatment (10 HrDP) is used on parts where slightly lower mechanical properties are acceptable and on parts fabricated of sheet and strip.

(25) Plastic strain introduced to the part after mill solution heat treatment must be removed by resolution heat treatment prior to precipitation treatment.

(26) AS7468 and AS7475 bolt and screw blanks shall be precipitation heat treated before cold working of fillet radius and thread rolling operations.

(27) Total precipitation time includes the cooling time from the higher temperature to the lower temperature.

Table 5A - Soaking time for non-age-hardenable nickel alloy and cobalt alloy parts, inch/pound units

Diameter or Thickness of Maximum Section Inches	Soaking Time (see 3.2.5)
Up to 0.025, incl	10 minutes
Over 0.025 to 0.050, incl	15 minutes
Over 0.050 to 0.100, incl	20 minutes
Over 0.100 to 0.250, incl	25 minutes
Over 0.250 to 0.500, incl	45 minutes
Over 0.500 to 1.00, incl	1 hour
Over 1.00 to 1.50, incl	1 hour, 15 minutes
Over 1.50 to 2.00, incl	1 hour, 30 minutes
Over 2.00 to 2.50, incl	1 hour, 45 minutes
Over 2.50 to 3.00, incl	2 hours

Table 5B - Soaking time for non-age-hardenable nickel alloy and cobalt alloy parts, SI units

Diameter or Thickness of Maximum Section Millimeters	Soaking Time (see 3.2.5)
Up to 0.64, incl	10 minutes
Over 0.64 to 1.27, incl	15 minutes
Over 1.27 to 2.54, incl	20 minutes
Over 2.54 to 6.35, incl	25 minutes
Over 6.35 to 12.70, incl	45 minutes
Over 12.70 to 25.4, incl	1 hour
Over 25.4 to 38.1, incl	1 hour, 15 minutes
Over 38.1 to 50.8, incl	1 hour, 30 minutes
Over 50.8 to 63.5, incl	1 hour, 45 minutes
Over 63.5 to 76.2, incl	2 hours

Table 6 - Tolerance for the soaking times specified in Tables 3, 4, and 5 for heat treatment of nickel alloy and cobalt alloy parts (1)

Soaking Time Specified	Tolerance
Up to 1 hour, incl	Plus or minus 10%
Over 1 hour to 3 hours, incl	Plus or minus 6 minutes
Over 3 hours to 4 hours, incl	Plus or minus 15 minutes
Over 4 hours	Plus or minus 30 minutes

(1) Tolerances apply to each segment of multi-step cycles and to total cycle times.

Table 7 - Hardness requirements for age-hardenable nickel alloy and cobalt alloy parts in the precipitation heat treated condition

Alloy, Form, and HT Condition(1)	Applicable AMS	Hardness Requirement(2)
WASPALOY Alloy Condition: S1975SP Bar, Rings, and Forgings	AMS5708	32 to 42 HRC
WASPALOY Alloy Condition: S1850SP Bar, Rings, and Forgings	AMS5706	321 to 437 HB
WASPALOY Alloy Sheet and Tube	AMS5544 AMS5586	34 to 44 HRC(3)
RENE' 41 Alloy Sheet, Strip, and Plate	AMS5545	35 HRC min(3)
RENE' 41 Alloy Bar, Rings, and Forgings	AMS5712	311 HB min
UDIMET Alloy 700 Bar and Forgings	AMS5846	36 HRC min
INCONEL Alloy 702 Sheet and Strip	AMS5550	21 HRC min(3)
INCONEL Alloy 706 Condition: S1800DP Sheet, Strip, and Plate	AMS5605	34 HRC min(3)
INCONEL Alloy 706 Condition: S1800DP Bar, Rings, and Forgings	AMS5701	303 HB min
INCONEL Alloy 706 Condition: S1750SDP Sheet, Strip, and Plate	AMS5606	30 HRC min(3)
INCONEL Alloy 706 Condition: S1750SDP Bar, Rings, and Forgings	AMS5702	285 HB min
INCONEL Alloy 718 Condition: S1750DP Tube, Sheet, Strip, and Plate	AMS5589 AMS5596	36 HRC min(3)
INCONEL Alloy 718 Condition: S1750DP Bar, Rings, and Forgings	AMS5662	331 HB min(3)
INCONEL Alloy 718 Tube Condition: S1950DP	AMS5590	36 HRC min
INCONEL Alloy 718 Condition: S1950DP Sheet, Strip, and Plate	AMS5597	38 HRC min(3)
INCONEL Alloy 718 Condition: S1950DP Bar, Rings, and Forgings	AMS5664	341 HB min(3)
INCONEL Alloy 722 Sheet and Strip	AMS5541	23 HRC min(3)
INCONEL Alloy 722 Bars, Rings, and Forgings	AMS5714	23 HRC min(3)
INCONEL Alloy X750, Condition A Bar, Rings, and Forgings	AMS5667	302 to 363 HB min(3)
INCONEL Alloy X750, Condition B Strip 0.005 inch (0.13 mm) and Over and Plate	AMS5542	30 HRC min
INCONEL Alloy X750, Condition B Sheet	AMS5542	32 HRC min
INCONEL Alloy X750, Condition C Strip 0.005 inch (0.13 mm) and Over and Plate	AMS5598	30 HRC min(3)
INCONEL Alloy X750, Condition C Sheet	AMS5598	32 HRC min(3)

Alloy, Form, and HT Condition(1)	Applicable AMS	Hardness Requirement(2)
INCONEL Alloy X750, Condition C Tube	AMS5583	30 HRC min(3)
INCONEL Alloy X750, Condition C Bar, Rings, and Forgings	AMS5670 AMS5671	302 to 410 HB(3)
INCONEL Alloy X750, Condition C Bar, Rings, and Forgings	AMS5747	302 to 388 HB(3)
INCOLOY Alloy 901 Condition: S2000SP Bar and Forgings	AMS5660	302 to 388 HB(3)
INCOLOY Alloy 901 Mod Condition: S1975SP Bar, Rings, and Forgings	AMS5661	302 to 388 HB(3)
INCOLOY Alloy 909 Condition: 10 HrDP Bar, Rings, and Forgings	AMS5884	331 HB min
INCOLOY Alloy 909 Condition: 18 HrDP Bar, Rings, and Forgings	AMS5893	331 HB min(3)
INCOLOY Alloy 909 Sheet and Strip	AMS5892	35 HRC min(3)
MONEL Alloy K-500	AMS4676	262 HB min(3)
NI-SPAN-C Alloy 902 Strip	AMS5221	27 to 35 HRC(3)
NI-SPAN-C Alloy 902 Strip	AMS5223	34 to 41 HRC(3)
NI-SPAN-C Alloy 902 Strip	AMS5225	39 to 46 HRC(3)
D 979 Alloy Bar and Forgings	AMS5746	340 to 418 HB
ASTROLOY Alloy M Forgings	AMS5882	311 to 401 HB(3)
ELGILOY Alloy Wire and Sheet	AMS5833 AMS5876	46 HRC min(3)
MP159 Alloy Bar	AMS5842	44 HRC min(3)

(1) HT = Heat Treatment. A heat treatment designation, e.g., “Condition S1975SP,” is used to distinguish a specific heat treatment when more than one heat treatment is in common use for the same form (i.e., bar, sheet, etc.) of a single alloy. See the footnotes to Table 3 for descriptions of the general properties achieved in the different designated heat treat conditions.

(2) Hardness requirements are shown as HRC or HB, the same as used in the specified AMS material specification. Equivalent hardness (see 8.2) determined by another type of hardness testing is satisfactory, providing the alternate testing conforms to 3.4.2, 3.5.2, and 4.4.3 of this specification.

(3) The heat treated parts shall not be rejected based on hardness if the room temperature tensile property requirements are met. Tensile testing to qualify parts, which do not conform to the specified hardness, shall be conducted in accordance with 3.4.3, 3.5.3, and 4.4.2 of this specification.

Table 8 - Periodic surface contamination test alloys

Waspaloy	Alloy X-750	Alloy 718
AMS5544	AMS5542	AMS5596
AMS5704	AMS5598	AMS5597
AMS5706	AMS5667	AMS5662
AMS5707	AMS5668	AMS5663
AMS5708	AMS5670	AMS5664
AMS5709	AMS5671	
	AMS5747	