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INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE MATERIAL SPECIFICATION

SAE AMS 2774

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Heat Treatment
Wrought Nickel Alloy and Cobalt Alloy Parts

1. SCOPE:

1.1 Purpose:

This specification specifies the engineering requirements for heat treatment, by part fabricators (users) or their vendors or subcontractors, of parts made of wrought 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 8.1. However, this specification also may be used for alloys other than those listed in 8.1 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 8.3.7)
Annealing (See 8.3.8)
Stabilization Annealing (See 8.3.10)
Interstage Annealing (See 8.3.13)
Stabilization (See 8.3.11)
Precipitation (See 8.3.12)
Equalization (See 8.3.14)
Stress Relief (See 8.3.9).

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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 following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 2750	Pyrometry
ARP1820	Chord Method of Evaluating Surface Microstructural Characteristics
ARP1962	Certification of Heat Treating Personnel

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

2.2 ASTM Publications:

Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM E 3	Preparation of Metallographic Specimens
ASTM E 8	Tension Testing of Metallic Materials
ASTM E 8M	Tension Testing of Metallic Materials (Metric)
ASTM E 10	Brinell Hardness of Metallic Materials
ASTM E 18	Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
ASTM E 21	Elevated Temperature Tension Tests for Metallic Materials
ASTM E 139	Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials
ASTM E 292	Conducting Time-for-Rupture Notch Tension Tests of Materials
ASTM E 384	Microhardness of Materials

2.3 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-A-18455	Argon, Technical
MIL-P-27201	Propellant, Hydrogen
MIL-P-27401	Propellant Pressurizing Agent, Nitrogen
MIL-P-27407	Propellant Pressurizing Agent, Helium
MIL-STD-2073-1	DOD Materiel, Procedures for Development and Application of Packaging Requirements
BB-H-1168	Helium, Technical

2.4 CGA Publications:

Available from Compressed Gas Association, Inc., 1725 Jefferson Davis Highway, Suite 1600, Arlington, VA 22202-4102.

CGA G-9.1	Commodity Specification for Helium
CGA G-11.1	Commodity Specification for Argon

3. TECHNICAL REQUIREMENTS:

3.1 Equipment:

3.1.1 Pyrometry: Shall conform to AMS 2750.

3.1.2 Furnaces:

3.1.2.1 Temperature Uniformity: Shall be as shown in Table 1, tested in accordance with AMS 2750.

3.1.2.2 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 8.1 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 8.3.6). Direct fired furnaces shall be controlled so that there is no direct flame impingement on the parts.

3.1.2.2.1 Argon, Helium, and Hydrogen Gases: Shall meet the composition requirements of MIL-A-18455 (argon), CGA G-11.1 (argon), MIL-P-27407 (helium), CGA G-9.1, Grade L, minimum (helium), BB-H-1168, Grade A (helium), or MIL-P-27201 (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.

3.1.2.2.2 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 microns (20 µm) per hour, which shall be determined 15 to 60 minutes after closing the vessel and evacuation to 50 microns (50 µm) or lower, and shall be operated at pressures not higher than 10 microns (10 µm) of mercury 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.

3.1.2.2.2.1 Argon or helium conforming to 3.1.2.2.1, 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.

3.1.2.2.2.2 Cooling may be accelerated by back-filling with argon or helium conforming to 3.1.2.2.1 or nitrogen conforming to MIL-P-27401, Grade C, or combinations thereof, meeting the dew point requirements of 3.1.2.2.1.

3.1.2.2.3 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.

3.1.2.2.4 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 must 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 8.3.15) or rapid air cooling (RAC) (See 8.3.16) 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 Quenching: Quenching baths shall permit complete immersion of parts and free movement of the quenchant adjacent to all surfaces 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, and metal particles produced by machining or forming operations.

3.2.1.2 After Heat Treatment: Parts which have been heat treated in salt or cooled in oil, 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 8.3.5) specified or at the offset temperature (See 8.3.5) 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.

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 8.1 shall be performed in accordance with Table 3. The specified solution, stabilization, precipitation, annealing, and stress relief treatments for age-hardening alloys listed in 8.1 shall be performed in accordance with Table 4. Soaking times from Table5 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 8.1 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.

3.2.5 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 8.3.4) 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 AMS 2750, 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 certified 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, nor 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 E 3. The chord method described in ARP1820 may be used to enhance this examination.

3.5.2 Hardness: Shall be determined in accordance with ASTM E 10, ASTM E 18, or ASTM E 384, 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 E 8, ASTM E 8M, or ASTM E 21, as applicable.

3.5.4 Stress Rupture Properties: Testing, when required by the cognizant engineering organization, shall be in accordance with ASTM E 139 or ASTM E 292, as applicable.

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for Inspection:

Unless otherwise specified by the cognizant engineering or quality assurance organization, the heat treatment processor shall be responsible for performance of all tests and inspections specified herein. The processor may use his 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.

4.1.2 Responsibility for Inspection for Direct U.S. Government Orders: Unless otherwise specified in the contract, the contractor is responsible for the performance of all inspection requirements specified herein. Except as otherwise specified in the contract, the contractor may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the government. The government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to ensure supplies and services conform to prescribed requirements.

4.2 Records:

Shall be kept available to purchaser for not less than five 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 Table 3 or Table 4 specifies 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 10microns (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 as defined by the cognizant engineering organization.

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 Table 3 or Table 4 specifies 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 8.3.3) 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 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 AMS 2750.

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

4.6 Furnace Log and Recorder Chart Entries:

4.6.1 Each entry in a furnace log or equivalent document, such as a shop traveler, shall be signed by approved personnel (See 3.3) and shall include the following:

Load number
Part number
Shop order number(s)
Number of parts
Type of material and alloy designation
Equipment identification and furnace number
Thickness of parts (See 8.3.17)
Solution, precipitation, and other thermal processing step temperatures used
Part time at temperature
Dewpoint or other atmosphere control parameter, as applicable, such as vacuum furnace leak rate
Quench media or cooling method
Hardness requirements and results, if required
Date

4.6.2 Furnace temperature recorder charts shall include the following information for each load:

Load number
Shop order number(s)
Time loaded (with AM or PM noted)
Time soaking commences
Verification of alignment of recorder chart with scale
Approved personnel's identification
Furnace number
Date

4.7 Reports:

The heat treatment processor shall furnish with each shipment a report showing the results of tests to determine conformance to the technical requirements and stating that the parts were processed in accordance with specification requirements. This report shall include the purchase order number, AMS 2774, shop order, part number or product identification, alloy designation, identification of furnace(s) used, load number(s), thermal processing temperatures, times, and cooling cycles used, date(s), and quantity of parts heat treated.

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.

5.2.2 For direct U.S. Military procurement, packaging shall be in accordance with MIL-STD-2073-1, Level C, unless Level A is specified in the request for procurement.

6. ACKNOWLEDGMENT:

The heat treatment processor shall mention this specification number 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 Designation of Alloys:

Detailed heat treating requirements are included in this specification for the alloys shown in Table9. 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, i.e., Table 3 for non-age-hardening alloys and Table 4 for age-hardening alloys.

8.2 Hardness conversion tables for metals are presented in ASTM E 140.

8.3 Definitions of terms used in AMS are presented in ARP1917 and the following:

8.3.1 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.

8.3.2 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.

8.3.3 Lot: Shall be all parts of the same nominal configuration, processed at the same time, and heat treated as a heat treatment batch.

8.3.4 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.

8.3.5 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.

8.3.6 Cognizant: The term applies to the engineering organization responsible for the design of the parts, or its allied quality assurance organization, or a designee of these organizations.

8.3.7 Solution Heat Treatment: A high temperature heat treatment designed to place certain carbides and intermetallic compounds into solid solution.

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

8.3.9 Stress Relieving: A heat treatment used to remove or reduce stresses in work-hardened alloys.

8.3.10 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.

8.3.11 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.

8.3.12 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.

8.3.13 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.

8.3.14 Equalization: An intermediate temperature stress-equalization treatment applied to InconelX-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.

8.3.15 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.

8.3.16 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.

8.3.17 Thickness: The minimum specified dimension of the heaviest section of the part.

8.4 Dimensions:

Fahrenheit temperatures are primary; Celsius temperatures are shown as the approximate equivalents of the primary units and are presented only for information.

8.5 For direct U.S. Military procurement, purchase documents should specify not less than the following:

Title, number, and date of this specification
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
Level A packaging, if required (See 5.2.2).

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	AMS 5553	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	AMS 5665	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	AMS 5665	Annealed	2050 °F (1121 °C) 1 to 2 hours AC	1850 °F (1010 °C) AC	Use Anneal	
Sheet, Strip, Plate, Tubing	AMS 5540 and AMS 5580	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	AMS 5715	Annealed	2050 °F (1121 °C) 1 to 2 hours AC	1850 °F (1010 °C) AC	Use Anneal	
Sheet, Strip, and Plate	AMS 5870	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	AMS 5887 and AMS 5888	Annealed	Use Anneal	2075 to 2200 °F[7] (1135 to 1204 °C) AC	Use Anneal	
Sheet, Strip, and Tubing	AMS 5889	Annealed	Use Anneal	2075 to 2175 °F[7] (1135 to 1191 °C) AC	Use Anneal	

TABLE 3 - (Continued)

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]
INCONEL Alloy 625						
Bar, Rings, and Forgings	AMS 5666	Annealed	2150 °F (1177 °C)[8] WQ or RAC	1900 °F (1038 °C)[9] AC	Use Anneal	
Sheet, Strip, Plate, Tubing	AMS 5599 and AMS 5581	Annealed	2150 °F (1177 °C)[8] WQ or RAC	1900 °F (1038 °C)[9] AC	Use Anneal	
INCOLOY Alloy 800						
All forms	AMS 5766 and AMS 5871	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	AMS 5771	Solution heat treated	Use Anneal	2150 °F (1177 °C) WQ or RAC	Use Anneal	
Sheet, Strip, and Plate	AMS 5607	Solution heat treated	Use Anneal	2150 °F (1177 °C) WQ or RAC	Use Anneal	
HASTELLOY Alloy S						
Bars, Rings, and Forgings	AMS 5711	Solution heat treated	Use Anneal	1950 °F (1066 °C) Cool at any rate	Use Anneal	
Sheet, Strip, and Plate	AMS 5873	Solution heat treated	Use Anneal	1950 °F (1066 °C) Cool at any rate	Use Anneal	

TABLE 3 - (Continued)

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]
HASTELLOY Alloy W						
Bars, Rings, and Forgings	AMS 5755	Solution heat treated	Use Anneal	2150 °F (1177 °C) WQ or RAC	Use Anneal	
HASTELLOY Alloy X						
Bars, Rings, and Forgings	AMS 5754	Solution heat treated	Use Anneal	2150 °F (1177 °C) RAC	Use Anneal	
Sheet, Strip, Plate, and Tubing	AMS 5536, AMS 5587, AMS 5588	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	AMS 5769	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	AMS 5532 and AMS 5585	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	AMS 5537	Solution heat treated	Use Anneal	2150 °F (1177 °C) RAC[15]	Use Anneal	
Sheet over 0.025inch (0.64 mm) thick, and plate	AMS 5537	Solution heat treated	Use Anneal	2200 °F (1204 °C) WQ or RAC[15]	Use Anneal	
Bar and Forgings	AMS 5759	Solution heat treated	Use Anneal	2250 °F (1232 °C) WQ or RAC[15]	Use Anneal	
Rivets	AS 7236	Solution heat treated	2150 °F (1177 °C) 10 to 20 minutes WQ[16]	Use solution treatment	None	

TABLE 3 - (Continued)

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]
HAYNES Alloy 188						
Bar, Rings, and Forgings	AMS 5772	Solution heat treated	Use Anneal	2050 °F (1121 °C) WQ or RAC[17]	Use Anneal	
Sheet, Strip, and Plate	AMS 5608	Solution heat treated	Use Anneal	2050 °F (1121 °C) WQ or RAC[17]	Use Anneal	
HAYNES Alloy 230						
Bar, Rings, and Forgings	AMS 5891	Annealed	Use Anneal	2150 to 2275 °F[18] (1177 to 1246 °C) WQ or RAC	Use Anneal	
HAYNES Alloy 230						
Sheet, Strip, and Plate	AMS 5878	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	AMS 5877	Solution heat treated	Use Anneal	2150 °F (1177 °C[19] WQ or RAC	Use Anneal	
Sheet, Strip, and Plate	AMS 5874	Solution heat treated	Use Anneal	2150 °F (1177 °C[19] WQ or RAC	Use Anneal	
STELLITE 6						
Bar and Sheet	AMS 5894	Solution heat treated	2250 °F (1232 °C) Air Cool[20]	Use Solution treatment	Use Solution treatment	

(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.

TABLE 3 - (Continued)

(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.

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	AMS 5708	Solution heat treated	1975 °F (1079 °C) 4 hours AC	1550 °F (843 °C) 4 hours, except Turbine Blade Forgings Hold 24 hours/AC	1400 °F (760 °C) 16 hours AC	
Bolts and Screws	N/A(2)	AS7471 and 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)	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	AMS 5706 and MAM 5706	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	AMS 5544 and AMS 5586	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 See(4)
RENE' 41							
Sheet, Strip, Plate, Bar, Rings, and Forgings	N/A	AMS 5545 and AMS 5712	Solution heat treated	1975 °F (1079 °C) Hold 1 hour per inch (25 mm) of thickness, but 10 minutes min/AC thicknesses under 0.25 inch (6.4 mm); OQ or WQ thicknesses thickness 0.25 inch (6.4 mm) and over	None	1400 °F (760 °C) 16 hours AC	Stress Relief See (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)	

TABLE 4 - (Continued)

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]
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 & Forgings	N/A	AMS 5886	Solution heat treated	2100 °F (1149 °C) Hold 1 hour per inch (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	
Sheet, Strip, and Plate	N/A	AMS 5872	Solution heat treated	Mill Treatment	None	1475 °F (802 °C)[8] 8 hours AC	Interstage Anneal 1950 °F (1066 °C) Hold 1 hour per inch (25 mm) of thickness but 10 minutes min/AC or WQ
UDIMET Alloy 700							
Bar and Forgings	N/A	AMS 5846	Solutioned, Stabilized, and Precipitation treated	2150 °F (1177 °C) 4 hours/Air Cool to Room Temperature plus 4 to 6 hours/RAC	1550 °F (843 °C) 24 hours AC	1400 °F (760 °C) 16 hours AC	

TABLE 4 - (Continued)

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]
INCONEL Alloy 706							
Sheet, Strip, Plate, Bar, Rings, and Forgings	S1800DP	AMS 5605 and AMS 5701	Solution heat treated	1800 °F (982 °C) Hold 1 hour per inch (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	
Sheet, Strip, Plate, Bar, Rings, and Forgings	S1750DP	AMS 5606 and AMS 5702	Solution heat treated	1750 °F (954 °C) Hold 1 hour per inch (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	
INCONEL Alloy 718							
Sheet, Strip, Plate, Tube, Bar, Rings, and Forgings	S1750SDP	AMS 5589, AMS 5596 and AMS 5662	Solution heat treated	1750 °F (954 °C) Hold 1 hour per inch (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	
Bolts and Screws	N/A	AS7466 and 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]	
Sheet, Strip, Plate, Tube, Bar, Rings, and Forgings	S1950DP	AMS 5590, AMS 5597, and AMS 5664	Solution heat treated	1950 °F (1066 °C) Hold 1 hour per inch (25 mm) of thickness but 10 minutes min and not more than 2 hours AC	None	1400 °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	

TABLE 4 - (Continued)

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]
INCONEL Alloy 722							
Sheet and Strip	N/A	AMS 5541	Annealed	1800 °F (982 °C) Hold 1 hour per inch (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	AMS 5714	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	
INCONEL Alloy X750							
Bar, Rings, and Forgings	A[12]	AMS 5667	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]	AMS 5542 and AMS 5582	Annealed	1925 °F (1052 °C)[15] Hold 1 hour per inch (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]	AMS 5583, AMS 5598, MAM 5598, AMS 5670, AMS 5671, and AMS 5747	Solution heat treated	1800 °F (982 °C)[15] Hold 1 hour per inch (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	
Wire	No. 1 Temper[17]	AMS 5698	Cold drawn	None	None	1350 °F (732 °C) 16 hours AC	
Wire	Spring Temper + Direct Age[18]	AMS 5699	Cold drawn	None	None	1200 °F (649 °C) 4 hours AC	

TABLE 4 - (Continued)

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]
INCONEL Alloy X750							
Wire	Spring Temper + SSP[19]	AMS 5699	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	AMS 5660	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	
INCOLOY Alloy 901 Mod							
Bar, Rings, and Forgings	S1975SP	AMS 5661	Solutioned, Stabilized, and Precipitation treated	Select temperature in range 1950 to 2000 °F (1066 to 1093 °C) Hold 1 hour per inch (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 + Direct Age	AMS 4676	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	AMS 5221, AMS 5223 and AMS 5225	Solution heat treated Solution heat treated + cold rolled	Mill Treatment	None	1300 °F (704 °C)[23] 3 hours Cool in vacuum or protective atmosphere	

TABLE 4 - (Continued)

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]
D 979 Alloy							
Bar & Forgings		AMS 5746	Solutioned, Stabilized, and Precipitation Treated	Select temperature in range 1850 to 1900 °F (1010 to 1038 °C) Hold 1 hour per inch (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]	AMS 5884	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) degrees 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]	AMS 5893	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) degrees 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	

TABLE 4 - (Continued)

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	AMS 5892	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) degrees 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	AMS 5882	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	AMS 5833	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	AMS 5876	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	AMS 5844	Solution heat treated + cold worked	Mill treatment	None	Select temperature in range 1000 to 1200 °F (538 to 649 °C) Hold 4 to 4.5 hours AC	

TABLE 4 - (Continued)

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]
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	AMS 5842	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]	

(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.
(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 one 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.

TABLE 4 - (Continued)

(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 AMS 5667 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 AMS 4676, 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 (10HrDP) 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.

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

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

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	AMS 5708	32 to 42 HRC
WASPALOY Alloy Condition: S1850SP Bar, Rings, and Forgings	AMS 5706 or MAM 5706	321 to 437 HB
WASPALOY Alloy Sheet and Tube	AMS 5544 and AMS 5586	34 to 44 HRC(3)
RENE' 41 Alloy Sheet, Strip, and Plate	AMS 5545	35 HRC min(3)
RENE' 41 Alloy Bar, Rings and Forgings	AMS 5712	311 HB min
UDIMET Alloy 700 Bar and Forgings	AMS 5846	36 HRC min
INCONEL Alloy 702 Sheet and Strip	AMS 5550	21 HRC min(3)
INCONEL Alloy 706 Condition: S1800DP Sheet, Strip, and Plate	AMS 5605	34 HRC min(3)
INCONEL Alloy 706 Condition: S1800DP Bar, Rings, and Forgings	AMS 5701	303 HB min
INCONEL Alloy 706 Condition: S1750SDP Sheet, Strip, and Plate	AMS 5606	30 HRC min(3)
INCONEL Alloy 706 Condition: S1750SDP Bar, Rings, and Forgings	AMS 5702	285 HB min
INCONEL Alloy 718 Condition: S1750DP Tube, Sheet, Strip, and Plate	AMS 5589 and AMS 5596	36 HRC min(3)
INCONEL Alloy 718 Condition: S1750DP Bar, Rings, and Forgings	AMS 5662	331 HB min(3)
INCONEL Alloy 718 Tube Condition: S1950DP	AMS 5590	36 HRC min
INCONEL Alloy 718 Condition: S1950DP Sheet, Strip, and Plate	AMS 5597	38 HRC min(3)
INCONEL Alloy 718 Condition: S1950DP Bar, Rings, and Forgings	AMS 5664	341 HB min(3)

TABLE 7 - (Continued)

Alloy, Form, and HT Condition(1)	Applicable AMS	Hardness Requirement(2)
INCONEL Alloy 722 Sheet and Strip	AMS 5541	23 HRC min(3)
INCONEL Alloy 722 Bars, Rings, and Forgings	AMS 5714	23 HRC min(3)
INCONEL Alloy X750, Condition A Bar, Rings, and Forgings	AMS 5667	302 to 363 HB min(3)
INCONEL Alloy X750, Condition B Strip 0.005 inch (0.13 mm) and over and Plate	AMS 5542	30 HRC min
INCONEL Alloy X750, Condition B Sheet	AMS 5542	32 HRC min
INCONEL Alloy X750, Condition C Strip 0.005 inch (0.13 mm) and over and Plate	AMS 5598 or MAM 5598	30 HRC min(3)
INCONEL Alloy X750, Condition C Sheet	AMS 5598 or MAM 5598	32 HRC min(3)
INCONEL Alloy X750, Condition C Tube	AMS 5583	30 HRC min(3)
INCONEL Alloy X750, Condition C Bar, Rings, and Forgings	AMS 5670 and AMS 5671	302 to 410 HB(3)
INCONEL Alloy X750, Condition C Bar, Rings, and Forgings	AMS 5747	302 to 388 HB(3)
INCOLOY Alloy 901 Condition: S2000SP Bar & Forgings	AMS 5660	302 to 388 HB(3)
INCOLOY Alloy 901 Mod Condition: S1975SP Bar, Rings, and Forgings	AMS 5661	302 to 388 HB(3)
INCOLOY Alloy 909 Condition: 10HrDP Bar, Rings, and Forgings	AMS 5884	331 HB min
INCOLOY Alloy 909 Condition: 18HrDP Bar, Rings, and Forgings	AMS 5893	331 HB min(3)
INCOLOY Alloy 909 Sheet and Strip	AMS 5892	35 HRC min(3)
MONEL Alloy K-500	AMS 4676	262 HB min(3)
NI-SPAN-C Alloy 902 Strip	AMS 5221	27 to 35 HRC(3)

TABLE 7 - (Continued)

Alloy, Form, and HT Condition(1)	Applicable AMS	Hardness Requirement(2)
NI-SPAN-C Alloy 902 Strip	AMS 5223	34 to 41 HRC(3)
NI-SPAN-C Alloy 902 Strip	AMS 5225	39 to 46 HRC(3)
D 979 Alloy Bar and Forgings	AMS 5746	340 to 418 HB
ASTROLOY Alloy M Forgings	AMS 5882	311 to 401 HB (3)
ELGILOY Alloy Wire and Sheet	AMS 5833 and AMS 5876	46 HRC min (3)
MP159 Alloy Bar	AMS 5842	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 on the basis of 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
AMS 5544	AMS 5542	AMS 5596
AMS 5704	AMS 5598	AMS 5597
AMS 5706	MAM 5598	AMS 5662
MAM 5706	AMS 5667	AMS 5663
AMS 5707	AMS 5668	AMS 5664
AMS 5708	AMS 5670	
AMS 5709	AMS 5671	
	AMS 5747	