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AEROSPACE MATERIAL SPECIFICATION

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Heat Treatment of Steel Raw Materials

NOTICE

This document has been taken directly from U.S. Military Specification MIL-H-6875H, Amendment 2 and contains only minor editorial and format changes required to bring it into conformance with the publishing requirements of SAE technical standards. The initial release of this document is intended to replace MIL-H-6875H, Amendment 2. Any part numbers established by the original specification remain unchanged.

The original Military Specification was adopted as an SAE standard under the provisions of the SAE Technical Standards Board (TSB) Rules and Regulations (TSB 001) pertaining to accelerated adoption of government specifications and standards. TSB rules provide for (a) the publication of portions of unrevised government specifications and standards without consensus voting at the SAE Committee level, and (b) the use of the existing government specification or standard format.

Under Department of Defense policies and procedures, any qualification requirements and associated qualified products lists are mandatory for DOD contracts. Any requirement relating to qualified products lists (QPL's) has not been adopted by SAE and is not part of this technical report.

1. SCOPE:

1.1 Scope:

This specification covers the requirements for heat-treatment of four classes of steel (see 1.2) and the requirements for furnace equipment, test procedures and information for heat-treating procedures, heat-treating temperatures and material (see 6.11) test procedures. This specification is applicable only to the heat treatment of raw material (see 6.1.1); it does not cover the requirements for the heat treatment of steel parts (see 3.4 and 6.1.2). This specification also describes procedures which, when followed, will produce the desired properties and material qualities within the limitations of the respective alloys tabulated in Tables IA, IB, IC and ID. Alloys other than those specifically covered herein may be heat treated using all applicable requirements of this specification.

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1.1.1 Limitations: Unless otherwise specified, this specification is not applicable to heating or to intermediate (non-final) heat treatment, of raw material, e.g. for hot working. Processes not covered include deliberate surface heat-treating and specialized heat-treating, such as induction hardening, flame hardening, carburizing, nitriding; however, this specification may be referenced for equipment and controls. Austempering, ausbay quenching and martempering may be used when specified by the cognizant engineering organization.

1.2 Classification:

Steels covered by this specification are classified into the following four classes. Unless otherwise specified, the process and equipment requirements in this specification refer to all classes of steel tabulated in Tables IA, IB, IC and ID, respectively.

Class A - Carbon and low alloy steel
Class B - Martensitic corrosion-resistant steel
Class C - Austenitic corrosion-resistant steel
Class D - Precipitation-hardening and maraging steel

2. APPLICABLE DOCUMENTS:

The following publications, of the issues in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

2.1 SAE Publications:

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

AMS 2418	Copper Plating
AMS 2424	Nickel Plating, Low Stressed Deposit
AMS 2750	Pyrometry
AMS 2759	Heat Treatment of Steel Parts, General Requirements
AMS 2759/3	Heat Treatment of Precipitation Hardening Corrosion Resistant and Maraging Steel Parts

2.2 ASTM Publications:

Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM A 262	Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
ASTM A 370	Mechanical Testing of Steel Products, Methods and Definitions for
ASTM C 848	Young's Modulus, Shear Modulus, and Poisson's Ratio for Ceramic Whitewares by Resonance, Test Method for
ASTM D 3520	Test Method for Quenching Time of Heat Treating Fluids (Magnetic Quenchometer Test)
ASTM E 3	Metallographic Specimens, Preparation of
ASTM E 8	Tension Testing of Metallic Materials

2.2 (Continued):

ASTM E 10 Brinell Hardness of Metallic Materials
ASTM E 18 Rockwell Hardness and Rockwell Superficial Hardness of Metallic 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.

QQ-N-290 Nickel Plating (Electroplated)

MIL-C-14550 Copper Plating, (Electrodeposited)

3. REQUIREMENTS:

3.1 Equipment:

3.1.1 Furnace media and protective coatings:

3.1.1.1 Atmosphere for Classes A, B, C and D steel parts: The gaseous medium for heat treating Classes A, B, C and D steel parts above 1250 °F shall be air/products of combustion, argon, helium, hydrogen, nitrogen, or blends of these gases, vacuum, exothermic, endothermic, nitrogen based, or dissociated ammonia conforming to the requirements below. Supplementary protective coatings, in accordance with 3.3.1.3, may be used where necessary.

Atmosphere	Class A 1/	Class B 1/	Class C 1/	Class D 1/
Air/Products of Combustion	X 2/	X 2/	X	X
Argon 3/	X	X	X	X
Helium 3/	X	X	X	X
Hydrogen 3/	X	X 7/	X	X 5/
Nitrogen 3/ 6/	X 8/	X	X	X10/
Vacuum	X	X	X	X11/
Exothermic 4/	X	X	X	No
Nitrogen based or endothermic 4/	X 8/	X	No	No
Dissociated Ammonia 3/ 9/	No	No	X	No

1/ X - Denotes atmosphere acceptable for use on that designated class of steel with or without limitations.

2/ Unless otherwise specified, an air/product of combustion atmosphere shall be limited to precipitation hardening, tempering, stress relieving and 1400 °F transformation treatments. An air/product of combustion atmosphere may be used for treatment above 1400 °F for Classes A and B material which will have a minimum of 0.020 inch metal removed from all surfaces after heat treatment or which have been protected by electroplates.

3/ Dew point shall be not higher than -40 °F at the exit of the working zone.

4/ Atmosphere shall be refined or blended to avoid a change in carbon content at the surface of the material as specified in 3.3.3. A product of combustion at -40 °F maximum dew point (e.g. endothermic) may be used for class A material which allows 0.003 inch maximum partial decarburization at the surface. Exothermic atmosphere permissible only for heat treatment of class A mill products.

5/ Acceptable up to 1950 °F.

6/ Nitrogen atmosphere does not include nitrogen from dissociated ammonia

7/ Only acceptable when tempered at 1000 °F or above. Acceptable for annealing.

8/ Class A steels may be fine grain copper plated 0.002 to 0.005 inch thick in accordance with MIL-C-14550 or AMS 2418 or nickel plated per AMS 2424 or QQ-N-290 or equivalent as a supplementary surface protection. Other supplementary protective coatings may be used if approved by the cognizant engineering organization.

9/ Permissible only for annealing of mill products providing residual ammonia at the outlet of the generator does not exceed 15 ppm.

10/ The use of a nitrogen atmosphere shall be limited to heat treating temperatures of 1400 °F and below. A nitrogen atmosphere may be used for heat treatment above 1400 °F provided a minimum of 0.020 inches of metal is subsequently removed from all surfaces of heat treated material.

11/ Nitrogen is not permitted as a partial pressure above 1400 °F. Nitrogen may be used as a backfill quench for vacuum heat treatments performed at or below 1925 °F.

3.1.1.2 Atmospheres for mill products: Furnaces for mill products shall be supplied with gases of a consistent analysis such that the product meets the requirements of the appropriate material specification. Furnaces, gases, and gas generators shall be controlled. Ducts and working zones shall be sealed to prevent contamination by outside gases. Vacuum furnaces shall have a calibrated recording instrument for sensing the vacuum in the vacuum chamber. All atmosphere furnaces and gas supply lines shall be purged with the designated and approved atmosphere gas for the specific steel to be heat treated.

3.1.1.3 Salt baths: Salt baths may be used for the heat treatment of Classes A and B steels. Salt baths shall be tested initially and at least once each week and shall be adjusted to assure that part surfaces shall be free from general corrosion, carburization and decarburization or intergranular attack in excess of limits specified in 3.3.3. Additives used for adjustments shall be limited to salts in bath and rectifiers recommended by the salt manufacturer.

3.1.1.4 Temperature uniformity: The design and construction of heating equipment shall be such that the temperature at any point in the furnace working zone or work load shall comply with AMS 2750.

3.1.1.5 Temperature range and set temperature: The set temperature on the furnace control instrument shall be such that the load temperature falls within the specified range, taking into account the temperature uniformity of the furnace. In continuous furnaces used to anneal and normalize mill products, a thermal head may be used. The temperature of the mill product shall not exceed the maximum processing temperature.

3.1.2 Pyrometry and furnace temperature control: The requirements and procedures for control and testing of furnaces, ovens, salt baths, vacuum furnaces, refrigeration equipment and allied pyrometric equipment used for heat treatment shall be in accordance with AMS 2750 and the appendix thereto (see 4.2.1 and 4.2.2). Equipment which cannot be controlled and tested in accordance with AMS 2750 shall be controlled and tested as directed by the cognizant engineering organization.

3.1.3 Quenching equipment:

3.1.3.1 Quench baths: Quench baths shall permit complete immersion of material, provide for adequate circulation of the media or agitation of material, provide a means for indicating the temperature of the media and for cooling and heating, as applicable. Baths shall be adequate to produce the required properties in the most massive material to be quenched.

3.1.3.1.1 Oil-quenching baths: The oil-quenching medium shall be between 60 °F and 160 °F at the beginning of the quenching operation and shall not exceed 200 °F at any time during the quenching operation, unless otherwise approved by the cognizant engineering organization. The temperature of the oil quenching media shall not exceed the manufacturers recommended operating range. Quench oil used in integral quench vacuum furnace systems, where the quench chamber is below atmospheric pressure, shall be vacuum degassed at approximately the maximum recommended temperature for the quenchant initially and after each major addition of oil.

3.1.3.1.2 Aqueous polymer quenchants: Aqueous polymer quenchants may be used as permitted in Tables IA through ID. The temperature of the aqueous polymer quenchant baths shall not exceed the manufacturers recommended operating range. These baths shall also be adequately circulated to assure homogeneity of the aqueous polymer quenchant media.

3.1.3.1.3 Quenching from salt bath furnaces: Water-quenching baths employed in cooling steel parts which have been heated in salt-bath furnaces should be provided with an inflow of fresh water to prevent a concentration of dissolved salts in the tanks. Polymer quenching baths when used in conjunction with salt bath furnaces shall be monitored weekly so that the salt content of the bath shall not exceed 6% by weight of the bath. All salt residues shall be removed from parts processed in salt-bath furnaces or quenched in brine, during or immediately following quenching.

3.1.3.1.4 Alternative Quenchants: In lieu of the stated methods in Tables IA through ID, steam, air, water sprays, inert gases, polymers, molten salts or other commercial quenching media or processes may be used when approved by the cognizant engineering organization, providing equivalence with respect to mechanical properties and corrosion resistance, as applicable to the material and its application, can be substantiated. Equivalence tests shall be as specified by the cognizant engineering organization. Where air quenching is permitted in the Tables IA-ID, argon and helium may be used; other inert gases may be substituted when approved by the cognizant engineering organization.

3.1.3.2 Location of quenching equipment: Quenching equipment shall be located in such a manner and handling facilities shall function with sufficient speed to prevent the initiation of transformation or sensitization prior to quenching.

3.1.4 Miscellaneous equipment: Suitable jigs, fixtures, trays, hangers, racks, ventilators, and so on, shall be employed as necessary for the proper handling of the work and for maintenance of the major items of equipment. The use of heat-treating fixtures or fixture materials where the contact with or proximity to the material could contaminate the material or reduce the heating, cooling or quenching rates to less than required for complete transformation or through-hardening of the material shall not be permitted.

3.1.5 Cleaning Equipment: Equipment shall be provided to clean material in accordance with 3.3.1.1. Where toxic or harmful cleaners are employed, they shall be used in compliance with the applicable health and safety regulations.

3.2 Thermal treatment:

3.2.1 Rate of heating: Heating rates shall be controlled to prevent damage to the material (see 6.2). Pre-heating at 1000 °F-1200 °F is recommended before heating material above 1300 °F if the material:

(a) Has been previously hardened above Rc 35, or is made of steel of 0.50 (nominal) percent carbon or over, or
(b) Has abrupt changes of section, or sharp re-entrant angles, or
(c) Has been finish machined.

3.2.2 Hardening of Classes A and B material: Classes A and B material shall be hardened by austenitizing, quenching and tempering.

3.2.2.1 Prior condition of Class A steel parts:

3.2.2.1.1 H-11 material: H-11 parts shall be in the annealed condition, prior to hardening, unless it has been hot headed. Hot headed H-11 material shall be annealed, prior to hardening, by furnace cooling from 1625 °F ± 25 °F to at least 1000 °F, at a maximum rate of 50 °F per hour.

3.2.2.1.2 52100 or 1095 material: Parts made of 52100 or 1095 steel should be hardened from the spheroidize annealed condition.

3.2.2.1.3 Other Class A parts: Parts made from other Class A steels to be hardened and tempered to 220 ksi and above shall be either normalized, normalized and tempered, or normalized and sub-critical annealed, prior to initial austenitizing. Parts that have been welded shall be normalized, prior to hardening. Parts identified as damage tolerant, maintenance critical or fracture critical shall be normalized, normalized and tempered or normalized and subcritical annealed, regardless of the strength to which they are subsequently to be heat-treated.

3.2.2.2 Austenitizing: The austenitizing temperature shall conform to Tables IA and IB, as applicable. Parts shall be held within the specified temperature range for sufficient time for the necessary transformation and diffusion to take place. The recommended holding times at temperature are listed in Table IIA.

3.2.2.3 Quenching: Material shall be quenched from the austenitizing temperature in the quenchant specified in Tables IA or IB, as applicable. Material shall be cooled to or below the quenchant temperature before tempering. Material should be tempered within two hours after quench or within two hours after reaching room temperature after cold treatment. If hardened parts cannot be tempered within 2 hrs. of quenching, they can be snap tempered for one hour at 400 °F ± 25 °F or as appropriate to prevent cracking. Mill products shall be quenched in a manner consistent with commercial practice where Tables IA & IB are not applicable. They shall be cooled sufficiently and tempered within a period of time adequate to prevent quench cracking or conditions deleterious to end product mechanical properties and corrosion resistance.

3.2.2.4 Tempering: Material shall be tempered in accordance with Table III. When multiple tempering is used, material shall be cooled to room temperature between tempering treatments. The tempering temperatures listed in Tables IA or IB are recommended, unless indicated as mandatory by the footnotes.

3.2.3 Hardening Class D steel: Class D steel parts shall be hardened by precipitation heat-treatment of material which has been either solution-treated, austenite conditioned, or cold worked. Class D material is normally acquired in the solution treated or solution treated and cold worked (i.e. spring temper) condition. Thermal treatment for Class D material shall conform to Table ID. The aging temperature in Table ID may be adjusted higher to meet the specified tensile strength.

3.2.4 Other thermal treatment:

3.2.4.1 Normalizing (applicable to Class A steel only): Normalizing shall be accomplished by cooling from Table IA temperatures in circulated air or in a circulated protective atmosphere. The recommended minimum holding times at temperature are listed in Table IIA.

3.2.4.2 Annealing Classes A and B steel: Annealing (full annealing) of Classes A and B material shall be accomplished in accordance with Tables IA or IB, as applicable, and at suggested holding times in Table IIA. Sub-critical (partial) annealing of Class A material shall be accomplished by heating to 1200 °F-1250 °F and holding in that temperature range for two hours. Sub-critical annealing of Class B material shall be accomplished as specified in Tables IB and IIA, as applicable.

3.2.4.3 Annealing Class C steel: Annealing of Class C material shall be accomplished as specified in Tables IC and IIB, as applicable.

3.2.4.4 Stress relieving: Stress relieving before hardening of Class A material shall be accomplished at any temperature between 1000 °F and 1250 °F. Stress relieving after hardening of Classes A and B material shall be accomplished by heating to a maximum temperature of 50 °F below the tempering temperature. The recommended minimum holding times at temperature are listed in Table IIA. Stress relieving after hardening is prohibited on parts which have been peened or cold deformed; e.g., roll threaded. Stress relieving of Class C material shall be accomplished by either heating to 875 ± 25 °F maximum or to 1900 °F and rapid cooling. Hardened class D material shall be stress relieved for a minimum of one hour at 30 °F below the aging temperature.

3.2.5 Thermal treatment of mill products: Unless otherwise specified in the contract or purchase order, processing of mill products for which the tables are not applicable (e.g. raw material which is continuously heat-treated) shall be annealed, austenitized, quenched and tempered with proven commercial practices. Such practices shall provide equivalence with respect to end product mechanical properties, corrosion resistance, and microstructure, as required by the applicable material specification or engineering drawing, and shall be substantiated by tests or methods determined by the cognizant engineering organization.

3.3 Process requirements:

3.3.1 General: The equipment and processing techniques employed in the heat-treatment of material shall be fully capable of providing the combination of mechanical properties, corrosion resistance and microstructure in the product as specified in the appropriate procurement document.

3.3.1.1 Cleaning: Material shall be cleaned prior to heat-treatment as required to remove contaminants and leave no substance that could have a deleterious effect. Cleaning prior to heat treatment of mill products is not required provided no surface condition is retained which could have a deleterious effect on the product.

3.3.1.2 Spacing: Material shall be racked or supported to allow circulation of heating and quenching media; to ensure exposure of surfaces to heating and quenching media; and to minimize warpage during heating and quenching.

3.3.1.3 Approval for use of coatings or platings: Except for copper or nickel plating as described in footnote 8/ of 3.1.1.1, approval from the cognizant engineering organization shall be obtained prior to the use of coatings or plating for protection of surfaces during heat-treatment.

3.3.2 Mechanical properties: Parts made from Classes A and B steels shall, after heat treatment, be hardness tested in accordance with 4.3.2.1. Hardness test data shall be converted to equivalent tensile strengths as specified by ASTM A 370 (see 6.5) and the tensile strengths shall conform to the design requirements. Where a dispute exists in the hardness test, the tensile test shall be performed in accordance with ASTM E 8 and the test results shall conform to the design requirements. Parts made from the following Class D steels shall be accompanied through heat treatment by a minimum of one tensile specimen of the same alloy form and condition: AM 350 (thicker than .015 inch thickness), AM 355, all parts heat-treated to an RH temper, parts that are re-solution heat-treated, and all parts made from 17-4 PH and 15-5 PH heat treated to H1100 and H1150 tempers. Tensile specimens shall be tested in accordance with 4.3.2.2 and shall meet the requirements of the applicable drawing, design specification, or material specification. All other class D steel parts shall be hardness tested to the requirements of AMS 2759 and AMS 2759/3. When specified in the contract or purchase order, a minimum of one tensile specimen shall accompany any Class D steel solution heat-treated, aged or both. Consideration shall be given so that the tensile specimen is representative of the parts that are to be manufactured, i.e. they are of similar size and of the same alloy form and condition.

3.3.2.1 Permissible variations of Classes A and B steel from design ultimate strength: When a minimum acceptable strength level and no maximum strength level is specified by design or the applicable material specification, the maximum strength shall be 20 ksi above the minimum, except for Hy-Tuf and H-11 steels for which a maximum strength of 30 ksi above the minimum is acceptable. For 300 M steel, a maximum strength of 30 ksi above the minimum is acceptable, provided the maximum tensile strength does not exceed 305 ksi.

3.3.3 Surface contamination: When material is hardened, normalized before hardening or is rehardened after hardening, the requirements of 3.3.3.1, 3.3.3.2 and 3.3.3.3 shall apply. These requirements do not apply provided it is definitely known that sufficient material will subsequently be removed to eliminate any deleterious surface conditions.

3.3.3.1 Decarburization of Classes A and B material: The heating medium in furnaces used for normalizing Class A material and for hardening Classes A and B material shall be so controlled as not to produce excessive decarburization. For furnaces used to heat-treat material whose final hardness will be HRC 46 (220 ksi) and above, partial decarburization shall be judged excessive if greater than 0.003 inch deep on any finish machined surface. For furnaces used to heat-treat material whose final hardness will be less than HRC 46 (220 ksi) decarburization shall be not greater than 0.005 inch deep on any finish machined surface. The extent of decarburization shall be determined in accordance with 4.3.3.1. Any total decarburization at the surface is not acceptable.

3.3.3.2 Carburization and nitriding: The heating media in furnaces used for heating material shall be controlled to preclude carburization and nitriding. The extent of carburization and nitriding shall be determined in accordance with 4.3.3.1.

3.3.3.3 Intergranular attack: The heating media in furnaces used for heating material to temperatures above 1250 °F shall be controlled to preclude intergranular attack exceeding 0.0007 inch on material under 220 ksi and 0.0005 inch on other material. The depth of intergranular attack shall be determined by testing the specimens as specified in 4.3.3.2.

3.3.4 Consistency of quench effectiveness: Shall be determined by testing each quenchant in each tank initially and quarterly thereafter, by one of the methods in 4.4, and comparing the results with those obtained previously by the same method. The heat treating facility shall establish control limits for each quenching system. If the results indicate that a quenchant is outside the established limits, corrective action shall be taken and the test shall be repeated to verify restoration of the prior condition.

3.4 Heat treatment of parts:

Finished or semi-finished parts shall be heat treated in accordance with AMS 2759. Raw materials shall be heat treated in accordance with the requirements specified herein. Any references to parts heat treatment in this document are superseded by the requirements specified in AMS 2759.

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for inspection:

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

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

4.1.2 Control records: Records of system accuracy tests, furnace temperature surveys, calibration of control and recording instruments and date, time, temperature, and quenchant used in heat treating material shall be on file and available for review by contractors and Government representatives for five (5) years. In addition heat treaters of final parts shall keep furnace recorder charts for five (5) years.

4.1.3 Noncompliance: If any test result fails to meet the requirements specified herein, the cause of failure shall be determined. If attributable to equipment, repair shall be completed before the equipment is used for additional processing. The quality assurance organization responsible for the raw material in the case of mill processing, or for parts in the case of finished or semi-finished parts processing, shall evaluate possible effects of the deficiency on material processed since the last successful test. The evaluation and corrective actions shall be documented.

4.2 Equipment Calibration and tests:

4.2.1 Pyrometric calibration: Pyrometric equipment shall be calibrated in accordance with AMS 2750 and appendix thereto (see 3.1.2).

4.2.2 Test procedures for equipment: Heat-treating equipment shall be tested in accordance with AMS 2750 and appendix thereto (3.1.2).

4.3 Test procedure for material:

4.3.1 Surface contamination tests: Each furnace used for any of the following treatments shall be tested for conformance with 3.3.3: normalizing and austenitizing of classes A and B material, and solution treating and austenite conditioning of class D material. A furnace used exclusively for heat-treatment of material where all contamination on that material will subsequently be removed need not be tested.

4.3.1.1 Specimens of Classes A and B material, except H-11, shall be tested either in the tempered or in the untempered condition at the option of the cognizant engineering organization. H-11 specimens and specimens of Class D material shall be tested after completion of heat treatment. Specimens shall be metallographically prepared per 4.3.3 and tested per 4.3.3.1 and 4.3.3.2 for conformance to 3.3.3.

4.3.1.2 For material made from Class A steels with a final strength of 220 ksi or hardness of Rc 46 or higher, at least one specimen of the same alloy shall be heat treated with each load. For material that is damage tolerant or fracture critical, a minimum of one specimen of the same alloy shall be heat-treated with each load regardless of the final strength or hardness. If such material is reheat-treated, the original specimen, or a portion of the original specimen must accompany the material and be tested after the reheat-treatment in accordance with 3.3.3.

4.3.1.3 For lower strength material, under 220 ksi, made from Class A steels and material made from Classes B and D steels, at least one specimen shall be tested in accordance with 3.3.3 as follows with the first load of each alloy group as defined in 4.3.1.3.1:

a. Each month for atmosphere furnaces,
b. Each week for salt baths, and
c. Each occurrence that purge cycles are run for Class D steel as required by 3.1.1.2.

4.3.1.3.1 For the purposes of the monthly and weekly tests of 4.3.1.3, steels within the following groups may be considered to be the same alloy:

a. Class A steels of 0.45 percent carbon and lower.
b. Class A steels of above 0.45 percent carbon.
c. Class B steels: 403, 410 and 416.
d. Class D steels: 17-4 PH, 15-5 PH and PH 13-8 Mo.
e. Class D steels: 17-7 PH, PH 15-7 Mo and PH 14-8 Mo.

4.3.2 Mechanical Properties:

4.3.2.1 Hardness test of heat treated material made from Classes A, B and D steels: The frequency of hardness testing for material which has been final heat-treated, shall be in accordance with the sampling requirements of AMS 2759. The testing shall be performed in the heaviest section which is suitable and not detrimental to the function of the material. When heat treating standard components such as nuts and bolts or mill products, the sampling and hardness test requirements of the applicable component and steel specifications shall take precedence.

4.3.2.2 Tensile Tests: Where specified, specimens of the same alloy form and condition within class D steel, heat treated and aged in the same furnace charge, shall be tension tested in accordance with ASTM E 8. The testing shall encompass, as a minimum, one specimen representative of the part. When specified, Classes A and B material shall be similarly tension tested in accordance with ASTM E 8. When testing of a size representative of the part is impractical because of inability to make a representative specimen sufficiently small while still using an accepted tensile specimen or excessive in cost due to wasted steel from a blank which is much larger than that needed to produce a standard size tensile specimen, then a sample sufficient to accomodate one standard tensile bar in accordance with ASTM E 8 will be heat treated and aged with the furnace charge and considered to be a representative sample.

4.3.3 Metallographic tests: Specimens shall be metallographically prepared in accordance with ASTM E 3. Determination of decarburization, carburization, nitriding and intergranular attack shall be in accordance with 4.3.3.1 and 4.3.3.2.

4.3.3.1 Determination of surface chemistry changes: The depth of decarburization shall be determined by making a microhardness traverse per ASTM E 384 using at least 250X magnification and recording hardness versus depth below surface. The boundary of the decarburization shall be at the depth at which the hardness rises to the equivalent of 20 points Knoop below the core hardness. In addition, the microhardness and microstructure shall show no evidence of carburization or nitriding. The traverse shall show no evidence of increased hardness at the surface as indicated by (20) points knoop or equivalent above the core hardness.

4.3.3.2 Intergranular attack: Intergranular oxidation of Class A material shall be determined by metallographically etching specimens of these steels for 7 - 20 minutes in a freshly prepared boiling solution consisting of 16 grams of chromic acid and 80 grams of sodium hydroxide in 145 milliliters of water. Intergranular oxidation of Classes B and D material shall be determined metallographically by etching specimens of these steels for 1 - 2 minutes in a freshly prepared solution consisting of 1 gram of picric acid in 5 milliliters of hydrochloric acid and 100 milliliters of ethanol. Alternate etchants may be used provided their effectiveness with respect to revealing intergranular attack is substantiated.

4.4 Test procedures for quench rate control:

4.4.1 Comparative cooling curve evaluation: Variation in the quenching effectiveness of an oil, water, or aqueous polymer quenchant bath may be monitored using a suitable cooling curve evaluation procedure approved by the cognizant engineering organization.

4.4.2 Magnetic quenchometer: Variation in the quenching effectiveness of oil quenching media may be monitored using a magnetic quenchometer test as described in ASTM D 3520.

4.4.3 Hot wire test: When this test is used variation in the quenching effectiveness of oil quenching media shall be performed in accordance with the following.

4.4.3.1 Procedure: Pour 150 ml of oil to be tested in clean 250 ml beaker. Heat oil to 60 °C by placing thermometer in oil and heating on a hot plate (heat within 5 minutes). Place precut wire (No. 28 Cupron- 55% Copper, 45% Nickel-wire cut in 2.5 inch lengths) in clamps such that the wire is straight and taut. Wires that have been kinked or in any way flattened should not be used. When oil is at 60 ± 2 °C, remove thermometer and transfer beaker to Hot Wire Tester setup. The Hot Wire Tester consists of a dual spring clamp for holding the wire (1.0 inch of effective wire length), electrical leads to the control box which supplies 60 cycle A.C. current to each clamp. The current is steadily increased from 0 to 35 amperes in 4.5 seconds using solid state circuitry with a thyristor (triac) optically coupled to a stair case generator. Maximum current through the wire is displayed on a LED Digital Read Out. Immediately immerse clamped wire and holder in oil and turn on controls. Reading is completed within 10 seconds. The maximum current flow is read from the LED digital read out and recorded. Fresh wire can be placed in clamps and test repeated as quickly as manipulations can be performed. Tests must be performed in triplicate and the 3 results averaged. Readings should fall within ± 0.5 amps to be valid. Otherwise test should be repeated.

4.4.4 Mechanical properties test of all quenching media: Shall be performed by quenching specimens of alloy steel, of appropriate hardenability and dimensions and testing a mechanical property (e.g., hardness, strength, modulus) which varies directly or inversely with the effectiveness of quench. The specific test shall verify quenchant effectiveness by comparing the tested mechanical property results with those properties listed in the applicable drawing or material specification.

4.4.4.1 Specimen selection for mechanical properties test of all quenching media: Selection of the specimen dimensions/hardenability combination should be aimed at achieving approximately full hardening (e.g. 95% martensite) on the surface and significantly less hardening (e.g., less than 50% martensite plus bainite) at the center.

4.4.4.2 Tempering specimen for machining: Specimens may be tempered lightly (e.g., at 500 °F (260 °C)) after quenching to facilitate machining.

4.4.4.3 Testing area: Tests may be performed on (1) surface, sub-surface, mid-radius or center material, or (2) the entire section or any portion of it.

4.4.4.4 Conformance of testing: Hardness testing shall conform to ASTM E 18 for Rockwell hardness testing and ASTM E 10 for Brinell hardness testing. Tensile testing shall conform to ASTM E 8. Modulus testing shall be by a dynamic (resonant frequency) method similar to ASTM C 848.

5. PACKAGING:

This section is not applicable to this specification.

6. NOTES:

6.1 Intended use:

This specification is intended for the heat treatment of steel raw materials (see 6.1.1). It is not intended for the heat treatment of parts (see 6.1.2).

6.1.1 Raw material: Raw material includes, but is not limited to, such items as sheet, plate, wire, rod, bar, forgings and extrusions. It is usually identified by a heat or lot number and is usually tested destructively for acceptance. It is heat treated, by or for a material producer, in accordance with a material specification which may require, by reference, conformance to a heat treating specification.

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

6.2 Rate of heating:

When the steel, size, design of parts, or the operating conditions are such that no cracking or excessive warpage results, the material may be charged into the heat-treating furnace or bath at any desired temperature not exceeding the maximum temperature specified for the operation and the material involved. In continuous furnaces used to anneal and normalize mill products, a thermal head may be used. The temperature of the mill product shall not exceed the maximum processing temperature.

6.3 Holding-time intervals and protective coatings:

The holding-time intervals indicated by Tables IIA and IIB are approximately correct for heating in air, in a gaseous atmosphere, or in salt baths. The proper time interval will vary with the type of steel, capacity of heating elements, and size of charge, as well as with the thickness of the individual material and protective coatings.

6.4 Shape influence:

Much of the published literature and the data in this specification refers to round specimens of various diameters. In order to use the data successfully on actual parts, it is first necessary to visualize the parts as simple geometric shapes such as rounds, hexagons, squares, plates or tubes. These shapes can then be considered as the round size which will have approximately the same cooling rate as that of the simple shape. The relationship between the various simple shapes and the corresponding round size is indicated on Figure 1.

6.5 Hardness-tensile relationship:

The normal relationship between the tensile strength and hardness of carbon and low alloy steel is indicated in the hardness conversion table of ASTM A 370. The table is to be used as a guide as the relationship is not precise.

6.5.1 Narrow strength range (+ 5 ksi): When a narrow range in strength is required, tests to determine the relationship between hardness and strength should be made on the actual part. Hardness values should be considered as the average value obtained by at least three determinations, each of which should check within 2 points Rockwell, or 20 points Brinell or Vickers, or either of the other two values.

6.5.2 Thin-walled tubing hardness tests: On relatively thin-walled tubings or parts which cannot be firmly supported on the anvil of the test machine, only methods which measure the area of the impression (Vickers or Knoop) are acceptable. Any process which affects the surface, such as buffing and plating, or the presence of decarburized or porous areas and hard spots will affect the hardness and the corresponding relation between hardness and tensile strength.

6.6 Heating baths:

Material inserted in salt baths should be free from liquids and coatings which may sublime or become gaseous and thereby splatter or explode the contents of the bath. Precautions should be taken when heat-treating corrosion-resistant steel in salt baths to which carbonaceous rectifiers have been added. Such baths, while neutral to carbon and low alloy steel, may carburize corrosion-resistant steel and lower the impact properties and resistance to corrosion.

6.7 Verification of heat-treating procedures:

Hardness is not the only criterion of satisfactory heat-treatment since excessively coarsened grains, over-heated, or improperly tempered steel may show adequate hardness, but may be deficient in ductility and other mechanical properties. Parts are acceptable only when the requirements of this specification and applicable design requirements are met.

6.8 Classification of strength:

All references herein to strength or tensile strength refer to ultimate tensile strength.

6.9 Holding at temperature:

“Holding at temperature” refers to material time at temperature.

6.10 Classes A and B finish machined surfaces:

When parts made from Classes A and B steel containing finish machined surfaces are normalized or rehardened and these operations are not immediately before or after hardening, it is the manufacturer’s responsibility to assure that the combined effects of the treatment meet the requirements of 3.3.3. Finish machined surfaces are those from which less than 0.020 inch (Class A) and 0.010 inch (Class B) will subsequently be removed.

6.11 Definition of terms:

6.11.1 Material includes all forms of steel products described within the specification (mill products and parts).

6.11.2 Mill product is defined herein as a product which is commonly produced in: finished form as plate, sheet, strip, bar, rod, and structural shapes; semi-finished form as blooms, billets, slabs and tube rounds, and which are not supplied in heat treated form; forgings, castings and extrusions.

6.11.3 Part is a rough machined or finish machined individual piece made from wrought or cast stock heat treated by the user during the fabrication process, for qualification of response to heat treatment, or any other operation where achievement of final physical or mechanical properties is intended.

6.11.4 Cognizant engineering organization is the term applied to the engineering organization responsible for the design of the item being heat treated.

6.12 All requirements for 431 stainless steel have been deleted from this specification (see MIL-S-18732).

6.13 Subject term (Key Word) listing:

Annealing
Austenitizing
Furnace atmosphere
Heat Treatment
Normalizing
Pyrometry
Quenching
Steel Alloys
Tempering

6.14 The 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 specification. An (R) symbol to the left of the document title indicates a complete revision of the specification.

PREPARED UNDER THE JURISDICTION OF AMS COMMITTEE “B“

TABLE IA. Heat-Treatment procedure for Class A (carbon and low alloy steel)

SAE, 5/ AISI or producer's designation	Heating and cooling requirements: Normalizing temperature range 1/	Annealing temperature range 2/ 3/	Austenitizing temperature range	Approved Quenchant	Approximate tempering temperature °F – Tensile strength range - Ksi 10/: 90 - 125	125-150	150-170	160-180	180-200	200-220	220-240	240-260	260-280	280-300
1025	1600/1700	1575/1650	1575/1650	Water or polymer	700	-	-	-	-	-	-	-	-	-
1035	1600/1700	1575/1650	1525/1575	Oil,water,polymer	900	-	-	-	-	-	-	-	-	-
1045	1600/1700	1550/1600	1475/1550	Oil,water,polymer	1100	-	-	-	-	-	-	-	-	-
1095	1500/1600	1450/1525	1450/1525	Oil,water,polymer	-	-	1000	850	750	6/	-	-	-	-
3140	1600/1700	1450/1525	1475/1525	Oil,polymer	1250	1100	1000	825	700	-	-	-	-	-
4037	1600/1700	1525/1575	1525/1575	Oil,water,polymer	1200	1100	925	-	-	-	-	-	-	-
4130	1600/1700	1500/1600	1550/1600	Oil,water,polymer	1250	1050	925	850	725	-	-	-	-	-
4135	1600/1700	1525/1575	1550/1600	Oil,polymer	-	1125	1025	900	800	-	-	-	-	-
4140	1600/1700	1525/1575	1550/1600	Oil,polymer	1300	1175	1075	950	850	725	-	-	-	-
4150	1525/1650	1500/1550	1500/1550	Oil	-	1200	1100	975	800	-	-	-	-	-
4330V	1600/1700	1525/1600	1550/1650	Oil	-	-	-	-	1000	800	500	-	-	-
4335V	1600/1700	1525/1600	1550/1650	Oil	-	-	-	-	1000	800	-	-	-	-
4340	1600/1700	1525/1575	1500/1550	Oil	-	1200	1100	1050	925	850	-	-	14/	-
4640	1600/1700	1525/1575	1500/1550	Oil	1200	1100	1000	900	750	-	-	-	-	-
6150	1600/1700	1525/1575	1550/1625	Oil	-	-	-	-	-	7/	-	-	-	-
8630	1600/1700	1525/1575	1525/1600	Oil,water,polymer	1250	1050	925	850	725	-	-	-	-	-
8735	1600/1700	1525/1575	1525/1600	Oil,polymer	-	1125	1025	800	785	-	-	-	-	-
8740	1600/1700	1500/1575	1525/1575	Oil	-	1175	1075	950	850	725	-	-	-	-
Hy-Tuf 14/	1700/1750	1375/1425	1575/1625	Oil	-	-	-	-	-	-	550	-	-	-
300M 14/	1675/1725	1525/1575	1575/1625	Oil	-	-	-	-	-	-	-	-	-	575
H-11 18/	-	1550/1650	1825/1875	Air,Oil,polymer	-	-	-	-	1150	1100	1025	-	15/	-
98BV40	1550/1650	1525/1575	1540/1560	Oil	-	-	-	-	-	-	-	-	-	500
D6AC	1700/1750	1525/1575	1675/1725	Oil	-	-	-	-	1150	1100	1025	-	600	-
9Ni-4Co-.20C	1600/1700	1250/1150 21/	1525/1575	Oil,water,poly 4/	-	-	-	-	1050	-	-	-	-	-
9Ni-4Co-.30C	1625/1675	1250/1150 21/	1475/1525	Oil 4/	-	-	-	-	-	-	1000	-	-	-
52100	1600/1700 20/	1400/1450 9/	1500/1575 19/	Oil	-	-	-	-	-	-	-	-	-	8/
AF1410	1625/1675 22/	-	1500/1550	Oil 4/	-	-	-	-	-	-	950	-	-	-

TABLE IB. Heat-treatment procedure for Class B (martensitic corrosion-resistant) steel

SAE, AISI or producer's designation	Annealing °F		Transformation hardening cycle °F		Recommended subcritical anneal	Approximate tempering temperature °F for tensile strength – Ksi				
	Temperature	Furnace cool to approx. temp. shown or below	Austenitizing temp.	Quenchant 12/		100 (minimum)	120 (minimum)	Avoid tempering or holding within range from 23/	180 (minimum)	200 (minimum)
403	1500 to 1600	Furnace cool 25 to 50° per hour to 1100	1750 to 1850	Oil Air Polymer	1200 to 1450, air cool	1300	1100	700 to 1100	500	
410	1500 to 1600	Furnace cool 25 to 50° per hour to 1100	1750 to 1850	Oil Air Polymer	1200 to 1450, air cool	1300	1100	700 to 1100	500	
416	1500 to 1650	Furnace cool 25 to 50° per hour to 1100	1750 to 1850	Oil Air Polymer	1200 to 1450, air cool	1300	1075	700 to 1075	500	
420	1550 to 1650 for 6 hours	Furnace cool 25 to 50° per hour to 1100 followed by water quenching	1750 to 1850	Oil Air Polymer	1350 to 1450, air cool	1300 11/	1075	700 to 1075		600
440C	1550–1600 for 6 hours, or 1650 for 2 hrs +1300 for 4 hours	Furnace cool 25 to 50° per hour to 1100	1900 to 1950	Oil Air Polymer	1250 to 1350, air cool	Temper at 325 for Rockwell C 58 minimum 375 for Rockwell C 57 minimum 450 for Rockwell C 55 minimum				

TABLE IC. Annealing procedure for Class C (austenitic corrosion-resistant steel)

SAE AISI or producer's designation	Annealing treatment	
	Heating °F	Cooling 16/
201 and 202 17/	1850 to 2050	Water quench
301 302 and 303 17/	1850 to 2050	Water quench
304 304L and 308 17/	1850 to 2050	Water quench
309 17/	1900 to 2050	Water quench
310 316 and 316L 17/	1900 to 2050	Water quench
321 13/	1750 to 2050	Air or water quench
347 and 348 13/	1800 to 2050	Air or water quench

Footnotes to Tables IA, IB and IC:

1/ For the purpose of this specification, normalizing describes a metallurgical process rather than a set of properties. All steels are air quenched from temperature range.

2/ Furnace cool to 1000°F or below, except furnace cool 4330V, 4335V to 800°F, 4640 to 750°F, 4340 to 800°F and 300M to 600°F. Rate of furnace cool for alloy steels, except 4130, 8630, 4037 and 8735 should be 50°F per hour or slower.

3/ Recommended subcritical anneal temperature is 1250°F.

Footnotes to Tables IA, IB and IC - Continued

4/ Cool to -100°F for 1 hour minimum within 2 hours after quenching and before tempering.

5/ Steel alloys listed are the more frequent ones used. Alloys not listed should be heat treated as recommended by their manufacturers.

6/ In general - for spring temper, temper at 700° - 800°F for Rc 40-45.

7/ In general - for spring temper, temper at 725° - 900°F for Rc 43-47.

8/ For antifriction bearings, temper to Rc 58 to 65 at 300° - 450°F.

9/ The following annealing treatment for 52100 steel should be used:

Heat to 1430°F, hold for 20 minutes, and cool at controlled rates, as follows:

1430° to 1370°F at a rate not to exceed 20°F per hour.
1370° to 1320°F at a rate not to exceed 10°F per hour.
1320° to 1250°F at a rate not to exceed 20°F per hour.

10/ Absence of values indicates the respective steel is not recommended for this tensile strength range.

11/ Temper 420 steel: 300°F for Rc 52 minimum; 400°F for Rc 50 minimum; 600°F for Rc 48 minimum.

12/ Cooling in air or other gases is optional for small parts up to, and including, 0.250 inches in thickness. For 440C, cool to -90°F or lower immediately after quenching and before tempering and soak for 2 hours minimum; the delay between quenching and sub-zero cooling shall not exceed 1 hour.

13/ When stress relieving after welding is specified, hold for 1/2 hour minimum at temperature specified in Table IC or holding for 2 hours at 1650°F ± 25°F.

14/ a. 4340, 260 - 280 tempering must be between 425°F and 500°F.
b. 300M and Hy Tuf - tempering temperature is mandatory.

15/ Final tempering shall be at or above 1000°F. No tempering temperature shall be less than that of previous temper nor more than 25°F higher than the previous temper.

16/ Other means of cooling permitted provided it is substantiated by tests that the rate is rapid enough to prevent carbide precipitation.

Footnotes to Tables IA, IB and IC - Continued

17/ Stress relieving of unstablized grades, except 304L and 316L between 875 ± 25°F and 1500°F is prohibited. Stress relieving of stabilized grades should be at 1650°F for 1 hour.

18/ Multiple cyclic annealing may be permitted to prevent grain growth.

19/ Cool immediately after quenching and before tempering; delay shall not exceed 1 hour. Cool to -90°F or lower, and soak for 1 hour minimum.

20/ Normalizing is not recommended practice for 52100 steel.

21/ Duplex anneal - hold 4 hrs. ± 0.25 hrs. at 1250°F ± 25°F, air cool to room temperature, then reheat to 1150 ± 25°F and hold for 8 hrs ± 0.25hrs and air cool to room temperature.

22/ Overage to facilitate machining by normalizing plus 1250°F ± 25°F for not less than 6 hrs. and air cool.

23/ When approved by the cognizant engineering organization, parts may be tempered in 1000-1050°F range when 135-145 ksi tensile strength is required providing the parts are not subject to substantial impact loading or stress-corrosion conditions. Tempering these alloys in the range listed results in decreased impact strength and also reduced corrosion resistance. However, tempering in this range is sometimes necessary to obtain the strength and ductility required. When approved by the purchaser, material may be tempered in this range.

TABLE ID. Heat-treatment procedure for Class D (precipitation-hardening and maraging) steel

Steel	Solution treatment				Austenite conditioning				Transformation treatment			Aging temperature (°F) For minimum tensile strength - Ksi															
	1/	Temp. °F	Hold 3/	Quench 19/	1/	Max Temp °F	17/ Hold min.	Quench 19/	Temp. °F	Minimum Hold min.	Min. Time hr	130	135	140	145	150	155	165	170	175	180	185	190	200	205	210	220
Wrought 17-4 PH2/	A	1900	4/8/	Air, poly., Oil 9/							4		1150	1100	1075	1050	1025		925								
15-5PH20/											1												900				
Cast 17-4 PH2/	HC	2100	8/	Air 9/							1-1/2								925		900						
15-5 PH	A	1900	8/	Air 9/							4	1100				1000			935								
PH 13-8Mo	A	1700	8/	Air or Oil 10/							4		1150			1100				1050		1025			1000		950
17-7 PH 13/ 4/	A	1950		Water, poly., or air 18/	T	1400	90	Air 11/	+60	30	1-1/2										1050						
					R	1750	10	Air 11/	-100	480	1					1100	1080		1060		1050			950			
PH 15-7Mo	A	1950		Water	T	1400	90	Air 11/	+60	30	1-1/2												1050		1000		
			4/		R	1750	10	Air 11/	-100	480	1																950
			8/		R	1750	10	Air 11/	-100	480	1																950
PH 14-8Mo	A	1825	8/	Water	SR	1700	60	Air 11/	-100	480	1															1050	950
AM-350	A	1925	4/	Water oil or poly.	SCT	1710	6/	Water	-100 12/	180	3							1000	950			850					
AM-355	A	1900	5/	Water, Oil or poly.	T	1710	7/	Air	1400	180 10/	3							850									
					SCT	1800	120	Air	-100	180	2										850	(For castings only)					
					SCT	1710	6/	Water or Oil	-100 12/	180	3								1000			(For wrought products only)					
A-286	A	1800	8/	Air-blast, oil, water							16		1325 (air Cool)														
Custom 450		1900	60	Water, poly. or oil							4	1100			1050	1025			950		900						
455 14/	A	1525	30								4													1000			950
200 15/	A	1500	8/	Air							3													900			
250 15/16	A	1500	8/	Air							3																
300 15/ 16/	A	1500	8/	Air							3																