| SAE Aerospace<br>An SAE International Group | **AEROSPACE MATERIAL SPECIFICATION** | **SAE AMS-H-6875** | **REV. B** |
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| | | Issued 1998-11<br>Reaffirmed 2006-04<br>Revised 2010-11<br><br>Superseding AMS-H-6875A | |

# Heat Treatment of Steel Raw Materials

RATIONALE

AMS-H-6875B results from clarifying furnace class per AMS2750.

NOTICE

The initial SAE publication of this document was taken directly from U.S. Military Standard MIL-H-6875H, Amendment 2. This SAE Standard may retain the same part numbers established by the original military document. Any requirements associated with Qualified Products Lists (QPL) may continue to be mandatory for DoD contracts. Requirements relating to QPLs have not been adopted by the SAE for this standard and are not part of this SAE document.

## 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 6.3) test procedures. This specification is applicable only to the heat treatment of raw material (See 6.3.1); it does not cover the requirements for the heat treatment of steel parts (See 3.4 and 6.3.2). This specification also describes procedures that, when followed, will produce the desired properties and material qualities within the limitations of the respective alloys tabulated in Tables 1A, 1B, 1C and 1D. Alloys other than those specifically covered herein may be heat treated using all applicable requirements of this specification.

#### 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.

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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 1A, 1B, 1C, and 1D, 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 issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

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

AMS2418 Plating, Copper

AMS2424 Plating, Nickel, Low-Stressed Deposit

AMS2750 Pyrometry

AMS2759 Heat Treatment of Steel Parts, General Requirements

AMS2759/3 Heat Treatment, Precipitation-Hardening Corrosion-Resistant and Maraging Steel Parts

AMS-QQ-N-290 Nickel Plating (Electrodeposited)

2.2 ASTM Publications

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

ASTM A 262 Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels

ASTM A 370 Mechanical Testing of Steel Products

ASTM C 848 Young’s Modulus, Shear Modulus, and Poisson’s Ratio for Ceramic Whitewares by Resonance

ASTM D 3520 Quenching Time of Heat Treating Fluids (Magnetic Quenchometer Test)

ASTM E 3 Metallographic Specimens, Preparation of

ASTM E 8 / E 8M Tension Testing of Metallic Materials

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ASTM E 10 Brinell Hardness of Metallic Materials

ASTM E 18 Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials

ASTM E 384 Knoop and Vickers Hardness of Materials

## 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 shown in Table 1. Supplementary protective coatings, in accordance with 3.3.1.3, may be used where necessary.

TABLE 1 - FURNACE ATMOSPHERE REQUIREMENTS

| 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 that will have a minimum of 0.020 inch metal removed from all surfaces after heat treatment or that 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 that 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 AMS2418 or nickel plated per AMS2424 or AMS-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.

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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 AMS2750.

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 AMS2750.

3.1.2.1 All furnaces shall be instrumented to a minimum of Type D Instrumentation in accordance with AMS2750. Unless the material specification temperature tolerance or range requires a different furnace class or otherwise indicated herein, furnace class requirements per AMS2750 are shown in Figure 1:

FIGURE 1 - FURNACE CLASS REQUIREMENTS

| AMS-H-6875 Process | AMS2750 Furnace Class |
|---|---|
| Tempering (after hardening) of<br>- D6AC and 9Ni-4Co (Class A) alloy steels<br>- other (Class A) low alloy steels - 220 ksi (1517 MPa) UTS and higher | Class 2 (±10 °F/6 °C) |
| Aging of (Class D) PH stainless steels at 1025 °F (552 °C) and below | Class 2 (±10 °F/6 °C) |
| Aging of (Class D) PH stainless steels above 1025 °F (552 °C) | Class 3 (±15 °F/8 °C) |
| All Other Processes | Class 5 (±25 °F/14 °C) |

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.

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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 1A through 1D. 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 that 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 1A through 1D, 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 Tables 1A through 1D, 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.

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3.2 Thermal Treatment

3.2.1 Rate of heating

Heating rates shall be controlled to prevent damage to the material (See 6.4). Pre-heating at 1000 to 1200 °F is recommended before heating material above 1300 °F if the material:

Has been previously hardened above Rc 35, or is made of steel of 0.50 (nominal) percent carbon or over, or

Has abrupt changes of section, or sharp re-entrant angles, or

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 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 that they are subsequently to be heat-treated.

3.2.2.2 Austenitizing

The austenitizing temperature shall conform to Tables 1A and 1B, 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 2A.

3.2.2.3 Quenching

Material shall be quenched from the austenitizing temperature in the quenchant specified in Tables 1A or 1B, as applicable. Material shall be cooled to or below the quenchant temperature before tempering. Material should be tempered within 2 hours after quench or within 2 hours after reaching room temperature after cold treatment. If hardened parts cannot be tempered within 2 hours of quenching, they can be snap tempered for 1 hour at 400 °F ± 25 or as appropriate to prevent cracking. Mill products shall be quenched in a manner consistent with commercial practice where Tables 1A and 1B 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.

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3.2.2.4 Tempering

Material shall be tempered in accordance with Table 3. When multiple tempering is used, material shall be cooled to room temperature between tempering treatments. The tempering temperatures listed in Tables 1A or 1B 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 that 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 1D. The aging temperature in Table 1D 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 1A temperatures in circulated air or in a circulated protective atmosphere. The recommended minimum holding times at temperature are listed in Table 2A.

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 1A or 1B, as applicable, and at suggested holding times in Table 2A. Sub-critical (partial) annealing of Class A material shall be accomplished by heating to 1200 to 1250 °F and holding in that temperature range for 2 hours. Sub-critical annealing of Class B material shall be accomplished as specified in Tables 1B and 2A, as applicable.

3.2.4.3 Annealing Class C Steel

Annealing of Class C material shall be accomplished as specified in Tables 1C and 2B, 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 2A. Stress relieving after hardening is prohibited on parts that have been peened or cold deformed; e.g., roll threaded. Stress relieving of Class C material shall be accomplished by either heating to 875 °F ± 25 maximum or to 1900 °F and rapid cooling. Hardened Class D material shall be stress relieved for a minimum of 1 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 that 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.

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## 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 that 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 4.2.2.1. Hardness test data shall be converted to equivalent tensile strengths as specified by ASTM A 370 (See 6.7) 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 / E 8M 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 0.015 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 4.2.2.2 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 AMS2759 and AMS2759/3. 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.

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#### 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 4.2.3.1. 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 4.2.3.1.

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 4.2.3.2.

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 4.3, 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 AMS2759. 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 AMS2759.

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 specified 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.

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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 5 years. In addition heat treaters of final parts shall keep furnace recorder charts for 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 Test Procedure for Material

4.2.1 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.

4.2.1.1 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 4.2.3 and tested per 4.2.3.1 and 4.2.3.2 for conformance to 3.3.3.

4.2.1.2 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.

4.2.1.3 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 4.2.1.3.1:

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

4.2.1.3.1 For the purposes of the monthly and weekly tests of 4.2.1.3, steels within the following groups may be considered to be the same alloy:

Class A steels of 0.45 percent carbon and lower.

Class A steels of above 0.45 percent carbon.

Class B steels: 403, 410 and 416.

Class D steels: 17-4 PH, 15-5 PH and PH 13-8 Mo.

Class D steels: 17-7 PH, PH 15-7 Mo and PH 14-8 Mo.

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4.2.2 Mechanical Properties

4.2.2.1 Hardness Test of Heat Treated Material Made from Classes A, B and D Steels

The frequency of hardness testing for material that has been final heat-treated, shall be in accordance with the sampling requirements of AMS2759. The testing shall be performed in the heaviest section that 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.

4.2.2.2 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 / E 8M. 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 / E 8M. 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 that 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 / E 8M will be heat treated and aged with the furnace charge and considered to be a representative sample.

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4.2.3 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 4.2.3.1 and 4.2.3.2.

4.2.3.1 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 that 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.

4.2.3.2 Intergranular Attack

Intergranular oxidation of Class A material shall be determined by metallographically etching specimens of these steels for 7 to 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 to 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.

4.3 Test Procedures for Quench Rate Control

4.3.1 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.

4.3.2 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.

4.3.3 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.

4.3.3.1 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 °C ± 2, 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 that 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.

4.3.4 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) that 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.

4.3.4.1 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.

4.3.4.2 Tempering Specimen for Machining

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

4.3.4.3 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.

4.3.4.4 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 / E 8M. 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.

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## 6. NOTES

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

6.2 Terms used in AMS are clarified in ARP1917.

### 6.3 Intended Use

This specification is intended for the heat treatment of steel raw materials (See 6.3.1). It is not intended for the heat treatment of parts (See 6.3.2).

#### 6.3.1 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 that may require, by reference, conformance to a heat treating specification.

#### 6.3.2 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.

### 6.4 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.

### 6.5 Holding-Time Intervals and Protective Coatings

The holding-time intervals indicated by Tables 2A and 2B 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.

### 6.6 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 that 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 2.

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6.7 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.

6.7.1 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, of either of the other two values.

6.7.2 Thin-Walled Tubing Hardness Tests

On relatively thin-walled tubings or parts that cannot be firmly supported on the anvil of the test machine, only methods measure the area of the impression (Vickers or Knoop) are acceptable. Any process that 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.

6.8 Heating Baths

Material inserted in salt baths should be free from liquids and coatings that 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.

6.9 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.

6.10 Classification of Strength

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

6.11 Holding at Temperature

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

6.12 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.

6.13 Definition of Terms

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

6.13.2 Mill product is defined herein as a product that 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 that are not supplied in heat treated form; forgings, castings and extrusions.

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6.13.3 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.

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

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

PREPARED BY AMS COMMITTEE “E“

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TABLE 1A - 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 | - | - | - |

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TABLE 1B - 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<br>375 for Rockwell C 57 minimum<br>450 for Rockwell C 55 minimum | | | | |

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