



AEROSPACE MATERIAL SPECIFICATION

AMS-H-81200

REV. D

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Superseding AMS-H-81200C

Heat Treatment of Titanium and Titanium Alloys

RATIONALE

AMS-H-81200D revises the temperature uniformity (3.2.1.7).

NOTICE

The original issue of this document was taken directly from Military Specification MIL-H-81200A and contained only minor editorial and format changes required to bring it into conformance with the publishing requirements of SAE technical standards. Revision A changed the heat treatment requirements for parts from "may be heat treated in accordance with the requirements of AMS2801" to "shall be heat treated in accordance with AMS2801". As an exception, it allowed continuation of heat treatment procedures for specific parts that had been previously acceptable to the purchaser. It also added the requirement that the heat treat parameters used for heat-treat-response-tests of raw material conform to the parameters used for heat treatment of parts (See 3.1.1).

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1. SCOPE

1.1 Purpose

This specification covers the heat treatment of titanium and titanium alloy mill products (raw material), including wrought and cast products, by material producers. This specification also covers furnace equipment requirements, test procedures, and general information for heat treating procedures, heat treating temperatures, and material test procedures for the heat treatment of titanium and titanium alloys. It also describes procedures that, when followed, have produced the desired properties within the limitations of the respective alloys.

1.2 Heat Treatments

The heat treatments covered by this specification are:

Anneal	Solution heat treatment
Beta anneal	Beta solution heat treatment
Recrystallization anneal	Age
Duplex anneal	Stress relief

1.3 Alloys

In addition to Commercially Pure Titanium (Ti40, Ti55, and Ti70), the following titanium alloys are covered by this specification:

Alpha alloys	Alpha-Beta alloys	Beta alloys
5Al-2.5Sn	6Al-4V	13V-11Cr-3Al
5Al-2.5Sn ELI	6Al-4V ELI	3Al-8V-6Cr-4Mo-4Zr
6Al-2Cb-1Ta-0.8Mo	6Al-6V-2Sn	15V-3Al-3Cr-3Sn
8Al-1Mo-1V	3Al-2.5V	10V-2Fe-3Al
	6Al-2Sn-4Zr-2Mo	
	6Al-2Sn-4Zr-6Mo	
	6Al-2Sn-2Zr-2Mo-2Cr-0.25Si	
	5Al-2Sn-2Zr-4Mo-4Cr	
	11Sn-5Zr-2Al-1Mo	

2. APPLICABLE DOCUMENTS

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

2.1 SAE Publications

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

AMS2750	Pyrometry
AMS2801	Heat Treatment of Titanium Alloy Parts

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 E 3 Preparation of Metallographic Specimens

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

ASTM E 290 Bend Testing Material for Ductility

ASTM E 1447 Determination of Hydrogen in Titanium and Titanium Alloys by the Inert Gas Fusion Thermal Conductivity/Infrared Detection Method

2.3 Order of Precedence

In the event of a conflict between the text of this document and the references cited herein, the text of this document shall take precedence. Nothing in this document, however, shall supersede applicable laws and regulations, unless a specific exemption has been obtained.

3. REQUIREMENTS

3.1 General

All heating and quenching equipment and procedures applied shall yield products complying with the requirements of appropriate acquisition documents. Equipment and procedures shall be designed to minimize the introduction of hydrogen, oxygen, nitrogen or other contaminants and in any case shall not allow introduction beyond levels established by the acquisition documents. Deviation from process requirements specified herein or the application of processes different from those contained herein, may be used provided that compliant products result, these exceptions have been proven satisfactory, and that they are made known to the purchaser with accompanying data or other justification to support the deviation prior to application of the deviant process.

3.1.1 Heat Treatment of Mill Products and Titanium Alloy Parts

The requirements specified herein are applicable to the heat treatment of mill products (raw material) (See 6.4.1). Producer heat treatment of heat-treat-response-test samples shall conform to AMS2801. Parts (See 6.4.2) shall be heat treated in accordance with AMS2801 except as specified in 3.1.1.1.

3.1.1.1 It is permissible, for specific parts, to use equipment, practices and test methods that conformed to AMS-H-81200 or MIL-H-81200 and were previously acceptable to the purchaser.

3.2 Heating Systems

3.2.1 Batch Furnaces

3.2.1.1 General Requirements

Such furnaces may employ electrical heating elements or fuel combustion as heat sources. Muffle furnaces and retorts are also allowed. Allowable environments surrounding the furnace charge during heating are: inert gas (argon or helium), vacuum, slightly oxidizing mixtures resulting from the combustion in air of hydrocarbons (gas or oil), and air itself. When removal of surface contamination from the heat treated product is not feasible, inert gas or vacuum environment shall be employed. The selection of an atmosphere shall be such as to establish conformance with 3.1.

3.2.1.2 Inert Gases

Inert gases within the furnace shall be circulated as necessary to protect all surfaces of the workpieces comprising the furnace charge. The dew point of the inert gases shall be minus 65 °F (minus 54 °C) or lower. This requirement shall be met during all stages of a heating, soaking or cooling cycle. Ducts and zones which are to contain furnace charges shall be so sealed as to prevent contamination of any charge to the degree that it is rendered nonconforming to specified material requirements.

3.2.1.3 Vacuum

Vacuum furnaces used for outgassing hydrogen shall be capable of reducing hydrogen concentrations within the charge to levels complying with 3.1. Vacuum furnaces and retorts used for prevention of surface contamination shall be capable of yielding product conforming to 3.1.

3.2.1.4 Combusted Hydrocarbons

Furnaces heated by the combustion in air of gas or oil shall contain a slightly oxidizing gas mixture. There shall be no impingement of flame upon the furnace charge.

3.2.1.5 Prohibited Atmospheres

Endothermic, exothermic, hydrogen, and cracked ammonia atmospheres shall not be used during any heat treatment operation.

3.2.1.6 Furnace Purging

Prior to thermal treatment of workpieces, each furnace that has contained an atmosphere unacceptable for heat treating titanium (See 3.2.1.5) shall be purged with air or inert gas, as applicable.

3.2.1.6.1 Purging Prior to Introducing Air or Combusted Hydrocarbons

The volume of purging air introduced shall be at least twice the volume of the furnace chamber. During purging, the minimum temperature within the chamber shall be the intended soaking temperature of the charge. When air-flow purging is impractical, the furnace temperature shall be set at 200 °F (111 °C) above the intended soaking temperature, and be held at that temperature for a minimum of 4 hours. Following purging, the furnace shall be stabilized at the required temperature, charged, and the charge heated and soaked in accordance with 3.2.1.7, as applicable. Following the thermal treatment and any subsequent cleaning, pickling, or other process that may introduce hydrogen contamination, specimens shall be taken from the charge and subjected to the test specified in 4.7.3. Results shall show compliance with 3.6.5, as applicable.

3.2.1.6.2 Purging Prior to Introducing Inert Gas

Procedures for purging shall comply with 3.2.1.2. The volume of gas introduced shall be at least twice the volume of the furnace chamber. Furnaces shall be charged while cold, and then purged and filled with inert gas. The charge shall then be heated and soaked in accordance with 3.2.1.7, as applicable. Following the thermal treatment, samples shall be taken from the charge and subjected to the test specified in 4.7.3. Results shall show conformance to 3.6.5, as applicable. Additionally, samples shall be taken from the charge and examined in accordance with 4.7.4.2. Results shall show conformance to 3.6.6.

3.2.1.7 Temperature Uniformity

Batch furnaces shall be so controlled during heating and soaking periods to maintain a temperature within the specified ranges of Tables 1, 3, 4, and 5, as applicable to the process. The minimum temperature and the maximum temperature of a range in Tables 1, 3, 4, and 5 are valid furnace control set points. For a given process and chosen furnace controller set point, applying offsets as applicable, furnaces must maintain the working zone temperature uniformity tolerance, as given below:

Heat Treatment	Temperature Uniformity Tolerance	
	°F	°C
Annealing	±25	±14
Beta annealing or beta solution heat treating	±25	±14
Recrystallization annealing	±25	±14
Duplex annealing	±25	±14
Solution heat treating	±25	±14
Stress relieving	±25	±14
Aging	±15	± 8

3.2.2 Continuous Furnaces

3.2.2.1 General Requirements

Continuous furnaces may be heated by radiation from electrically-energized heating elements or by combusted hydrocarbons.

3.2.2.2 Temperature Control

A temperature profile from furnace entry to exit shall be so developed and maintained that the charge within the working zone experiences the appropriate thermal cycle to the degree necessary for eventual product acceptability in terms of specified requirements.

3.2.2.3 Continuous Vacuum Furnaces

Continuous vacuum furnaces shall be so sealed as to minimize hydrogen, oxygen and nitrogen absorption of the product and in any case shall not allow absorption beyond levels established by the acquisition documents.

3.2.3 Continuous Induction Heating

Continuous induction heating shall be applied only to the annealing of thin-walled tubing and extrusions of thin sections. The technique shall be such that the workpiece being heated is of uniform temperature around the perimeter of its cross-section. Prior to production, values of the process parameters that produce acceptable product shall be determined and documented.

3.2.4 Pyrometry and Furnace Temperatures Control

The requirements and procedures for control and testing of furnaces, ovens, retorts, vacuum furnaces and allied pyrometric equipment used for heat treatment shall be in accordance with AMS2750.

3.2.4.1 System Accuracy

System accuracy tests shall be performed in accordance with AMS2750.

3.3 Quenching Facilities and Media

3.3.1 Quenching Baths

Quenching baths holding water or oil shall be of such dimensions, volume, and construction that products quenched therein will, upon aging, develop the properties specified within applicable product documents. Mechanical stirring of the bath may be applied when necessary.

3.3.2 Spray or Flow Quenching

Continuous furnaces discharging solution heat treated alloy sheet, plate, and strip may be equipped with a quenchant system that directs a spray or streams of quenchant onto the product as it emerges from the furnace. The spray or flow of quenchant shall be applied evenly over the workpiece width, top and bottom surfaces, over a period of time and at a volume rate such that the resulting product will upon aging develop properties meeting specified requirements.

3.3.3 Location of Quenching Facility

Quenching and handling facilities shall be located such that contact between quenchant and workpieces occurs within the time required for compliance with 3.1 and for the Ti-6Al-4V and Ti-6Al-4V ELI alloys, within the limits specified in Table 2.

3.3.4 Quenching Media

Use of molten salt baths for quenching is prohibited.

3.4 Ancillary Equipment

Jigs, fixtures, trays, hangers, racks, ventilators, etc. shall be so designed and constructed that each workpiece can be processed in accordance with this specification.

3.5 Thermal Treatment Parameter Values

The parameters (i.e., temperatures, times, etc.) for the various thermal treatment processes shall be as specified herein, except where deviation has been accepted by the purchaser in accordance with 3.1 (See 6.6).

3.5.1 Solution Heat Treating

Solution heat treating of parts, mill product, castings, and forgings shall be as specified in Table 1, as applicable.

3.5.2 Quenching

All heat treatable titanium alloys, except alloys that can be cooled in air or inert gas, shall be quenched by complete immersion in water or oil, as applicable, or by water spray or flow when applicable to quenching sheet, strip or plate. Maximum delay times for Ti-6Al-4V and Ti-6Al-4V ELI alloys shall conform to Table 2; for other alloys shall be as necessary to develop required properties.

3.5.3 Aging

Solution heat treated alloy workpieces shall be aged in accordance with Table 3, as applicable. Workpieces shall be cooled from the aging temperature in air, an inert gas, or in the aging furnace.

3.5.4 Stress-Relieving Treatment

Time-temperature cycles for stress relieving shall be as specified in Table 4, as applicable. Workpieces may be cooled from the stress relieving temperature in air, an inert gas, or in the stress-relieving furnace.

3.5.5 Annealing

Time-temperature cycles for annealing shall be as specified in Table 5, as applicable. For duplex annealing of Ti-6Al-4V and Ti-6Al-4V ELI alloys, see Table 5, note 6.

3.5.6 Beta Annealing

When beta annealing or beta solution heat treatment is specified (See 6.6), a lot of workpieces of Ti-6Al-4V, Ti-6Al-4V ELI, Ti-6Al-6V-2Sn, or other alpha-beta alloy shall be soaked at a temperature that is $50\text{ }^{\circ}\text{F} \pm 25$ ($28\text{ }^{\circ}\text{C} \pm 14$) above the determined beta transus of the lot (See 4.7.4.1). The soaking time shall be such that all portions of the furnace charge and of each workpiece including midsection are soaked for at least 30 minutes. Following soaking, the lot shall be cooled in air or inert gas to ambient temperature. Furnace cooling is not permitted. Water quenching shall not be performed unless specified in the contract or on the drawing. When water quenching is specified, the products of Ti-6Al-4V, Ti-6Al-4V ELI, and Ti-6Al-6V-2Sn shall be given a second anneal between $1350\text{ }^{\circ}\text{F}$ ($732\text{ }^{\circ}\text{C}$) and $1400\text{ }^{\circ}\text{F}$ ($760\text{ }^{\circ}\text{C}$) for 1 to 3 hours.

3.6 Process Requirements Other Than Those Specified in 3.5

3.6.1 General Requirements

All heating, quenching and other processing equipment used for thermal treating shall be capable of producing end product conforming to 3.1. All units of a lot shall be heated uniformly and on the whole piece, never on a portion only. For coiled product heated within a continuous furnace or straight product heated within an induction coil, the product shall be heated uniformly in its cross-section.

3.6.2 Surface Cleanliness

Prior to thermal treatment, surfaces of workpieces shall be free from heavy lubricants, halogen compounds, and other foreign matter, that will cause product to become noncompliant. Product coated with light oils need not be cleaned prior to thermal treatment, provided that the oil either vaporizes or burns off during preheating. Halogenated solvents (See sample list 6.3.5) and methanol shall not be used to degrease workpieces, unless the workpieces are subsequently cleaned using an alkaline solution or an acid pickle. Such cleaning shall be performed prior to thermal treatment.

3.6.3 Holding Fixtures

All racks, support or fixtures contacting workpieces shall be made of heat resistant metal such as 300 series stainless steel or nickel base alloys. The use of ceramic or other suitable non-reacting material is also permitted. Fixtures shall be designed to permit free flow of heating and quenching media around each workpiece and to minimize distortion of workpieces being treated.

3.6.4 Protective Coatings

The use of coatings to protect against scaling and to ease scale removal is permissible on condition that resultant product meets the requirements of 3.1. Such a condition shall be demonstrable by test data.

3.6.5 Hydrogen Contamination

Hydrogen concentrations in workpieces that are submitted for inspection, after all thermal treatments and manufacturer's processing, shall show no concentrations in excess of those specified in the acquisition documents when tested for in accordance with 4.7.3. Control of hydrogen absorption shall stem from control of furnace atmospheres, cleanliness of workpiece surfaces, and acid pickling. Where maximum hydrogen concentration is not specified in acquisition documents, the maximum allowable hydrogen concentration shall be as agreed upon between the purchaser and the producer.

3.6.5.1 Rework of Product Contaminated by Hydrogen

An excessive hydrogen concentration found in a lot may be reduced to an acceptable concentration by heating the lot in a vacuum furnace conforming to 3.2.1.3. Such action shall be reported to the purchaser. Heating under vacuum that results in overaging of a lot shall be cause for rejection of that lot. Salvage by re-solution heat treating and aging shall be performed only with the consent of the purchaser. Records of all re-heat treatments shall be prepared and maintained in accordance with 4.8.4.

3.6.6 Surface Contamination

Surface contamination after heat treatment shall be removed by chemical or mechanical means. The surfaces of machined, ground, blasted or acid-pickled workpieces shall not exhibit the effects of absorbed oxygen or nitrogen to the degree that the surface contamination of the product exceeds the levels specified in the acquisition documents when tested in accordance with 4.7.4.2.

3.7 Product Monitoring

Periodic monitoring of heat treated workpieces to determine compliance to 3.1 shall include the evaluation of tensile and bend properties.

3.7.1 Tensile Properties

Specimens taken from thermally treated workpieces in accordance with 4.6.3 and tested in accordance with 4.7.1 shall exhibit tensile strengths, yield strengths, elongations, and reductions in area in compliance with applicable requirements of acquisition documents. Tension testing shall be performed in accordance with Table 7 of this specification unless otherwise specified in the acquisition documents.

3.7.2 Bend Properties

Flat-rolled product of 0.1874 inch (4.76 mm) nominal thickness or less when sampled in accordance with 4.6.3.1 shall exhibit no cracks or separation in any direction when examined at 15 to 25X magnification after having been tested in accordance with 4.7.2.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

Unless otherwise specified in the contract or purchase order, the producer is responsible for the performance of all requirements as specified herein. The purchaser reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure that supplies and services conform to specified requirements.

4.1.1 Responsibility for Compliance

All items shall meet all requirements of Sections 3. The inspection set forth in this specification shall become a part of the producer's overall inspection system or quality program. The absence of any inspection requirements in the specification shall not relieve the producer of the responsibility of ensuring that all products or supplies submitted to the purchaser for acceptance comply with all requirements of the purchase document. 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 purchaser to accept defective material.