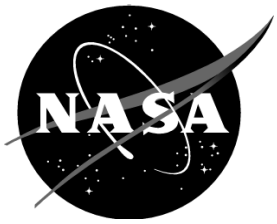
Process Specification for the Heat Treatment of Steel Alloys

Engineering Directorate

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Process Specification for the Heat Treatment of Steel Alloys

Prepared by: Mary Dunbar Digitally signed by Mary Dunbar Date: 2026.06.17 10:25:01 -05'00' _____
Mary Dunbar Date
Materials and Processes Branch/ES4

Reviewed by: JOHN FIGERT (affiliate) Digitally signed by JOHN FIGERT (affiliate) Date: 2026.06.17 10:28:51 -05'00' _____
John Figert Date
Materials and Processes Branch/ES4

Approved by: MARYJANE O'ROURKE Digitally signed by MARYJANE O'ROURKE Date: 2026.06.23 16:57:30 -05'00' _____
Mary Jane O'Rourke Date
Materials and Processes Branch/ES4

REVISIONS		
VERSION	**CHANGES**	**DATE**
Baseline	Original version	5/96
A	Expanded sec. 3.0, furnace chart info., tensile requirements	5/27/98
B	Changed Training Requirements, Updated to SAE AMS-H-6875A	7/21/99
C	Modified Training Requirements, Labeling Tensile Bars & Stock	2/24/00
D	Included Information on Post-Weld Stress Relief, Reduced Labeling Tensile Bars & Stock Requirements	8/24/00
E	Changed sec. 6.0 on aging requirements for A286. Updated document due to reorganization from EM2 to ES4.	6/06/02
F	Reviewed for accuracy and updated author.	10/04/06
G	Clarified the Usage Statement	8/10/09
H	Verify current condition of raw stock material; added statement on tool and die steels; added Table 1 and Table 2; subdivided PROCESS VERIFICATION section; added ASTM E18 under REFERENCES section; replaced JSC 8500 with JPR 8500.4 under REFERENCES section; updated and added definitions to section 10.0; other grammatical changes.	10/2011
I	Deleted Structural Engineering Division logo; updated revision, date, and *Approved by* signature; added Figure 1 on heat tint to Section 3.1 Process Sequence; deleted statement on 2hr delay between welding and stress relieving as previously noted in Section 3.1 Process Sequence; added AMS 2759/13 (Gaseous Nitrocarburizing) to Table 2; reworded most of Section 10.0 Definitions; added MTR definition to Section 10.0 Definitions; alphabetized definitions in Section 10.0 Definitions; minor grammatical corrections.	12/2019
J	Replaced SAE AMS-H-6875 with SAE AMS2761; updated Table 1 with new references from SAE AMS2761; updated publication titles in Table 2; updated Figure 1; added definitions to Section 10.0; formatting and grammatical corrections.	6/2026

1.0 SCOPE

This process specification establishes the engineering requirements for the heat treatment of steel and stainless steel alloys.

2.0 APPLICABILITY

This specification shall be applicable whenever the heat treatment of steel or stainless steel alloys is invoked per section 3.0, "Usage." Heat treatment of steel and stainless steel alloys may be performed on raw stock material (includes, but not limited to, plate, bar, forgings, and extrusions) or on parts produced from raw material.

3.0 USAGE

The material to be heat treated shall be listed on the drawing, in the heat treat condition in which the material is to be procured. The procurement specification shall be listed alongside the material to be heat treated. Availability of product forms and tempers may be obtained from a manufacturing production controller or from an ES4 materials engineer.

This process specification shall be called out on the engineering drawing by using an appropriate drawing note. The specific heat treat process or combination of processes shall be noted along with the final temper. For example:

For Class A (Carbon and Low Alloy Steels):
QUENCH AND TEMPER TO 160-180 KSI PER NASA/JSC PRC-2001.

For Class B (Martensitic Corrosion Resistant Steels (CRES)):
QUENCH AND TEMPER AT 450°F PER NASA/JSC PRC-2001.

For Class C (Austenitic CRES):
ANNEAL PER NASA/JSC PRC-2001.

For Class D (Precipitation Hardening Corrosion Resistant (CRES) and Maraging Steels):
AGE HARDEN TO CONDITION H1025 NASA/JSC PRC-2001.

3.1 Process Sequence

Unless otherwise specified on the engineering drawing, all parts shall be heat treated before final machining to remove scale and decarburization, as well as to avoid dimensional changes. Scale and decarburization, typically produced at temperatures above 1200°F, are

normally detrimental to the finished part and cannot be removed by mechanical or chemical finishing techniques. After heat treating, a minimum of 0.020" will be removed from all scaled or decarburized rough machined surfaces during final machining.

In some cases, it may be necessary to heat treat after final machining. It is recommended to restrict heat treat processes to those such as tempering, which are performed at low temperatures. Heat tint, which ranges in color from straw to light blue may form during these low temperature heat treatments, as demonstrated below in Figure 1.

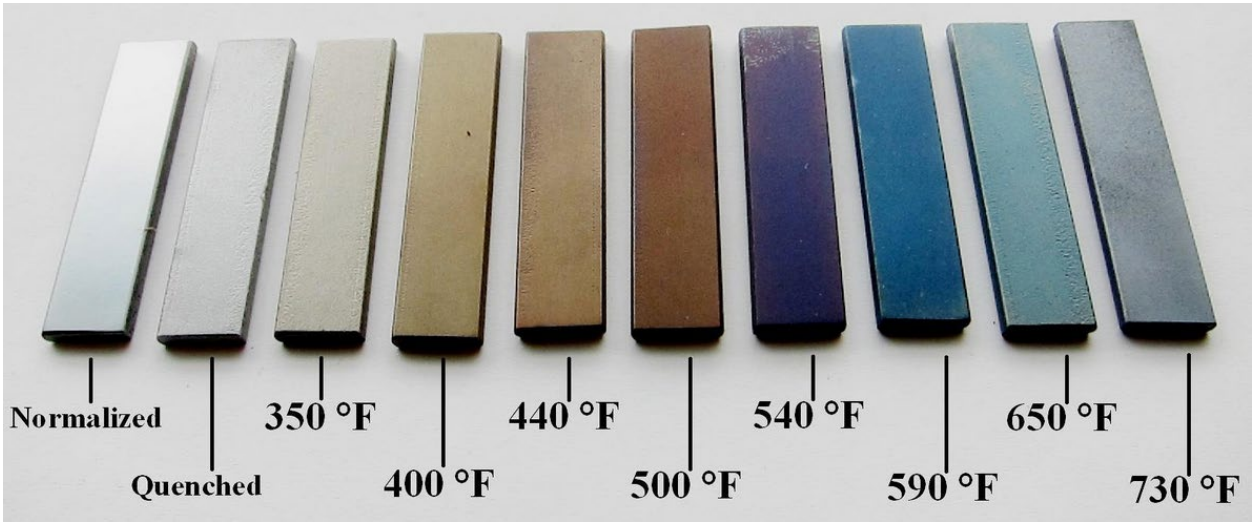


Figure 1: Heat Tint Color Post Tempering of Steel Samples at Various Temperatures in Circulating Air

It may be required to remove heat tint for cosmetic purposes. An appropriate finishing procedure to remove the heat tint shall be called out on the engineering drawing, if heat treating will result in a heat tinted surface that will not be removed by final machining. For example:

HEAT TREAT AFTER FINAL MACHINING. REMOVE HEAT TINT BY ELECTROPOLISHING PER NASA/JSC PRC-5009.

Class A and Class B steels often require a stress relieving heat treatment after welding operations. Stress relieving after welding should be performed as soon as possible after the welding operation. Post stress relieving on Class C and Class D steels may not be necessary for specific reasons. A qualified welding procedure for the specific application needs to be reviewed before making the stress relieving note. For example:

STRESS RELIEVE AT 1000°F FOR 2 HOURS IMMEDIATELY AFTER WELDING.

4.0 REFERENCES

All documents listed are assumed to be the current revision unless a specific revision is listed.

Document Number	Document Name
SAE AMS2761	Society of Automotive Engineers, Inc., Aerospace Material Specification, *Heat Treatment of Steel Raw Materials*
SAE AMS2759	Heat Treatment of Steel Parts General Requirements
ASTM E18	American Society for Testing and Materials Specification, *Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*
ASTM A370	American Society for Testing and Materials Specification, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*
MMPDS	Handbook, *Metallic Materials Properties Development and Standardization*
TI-2000-01	Training Instruction: Training for Heat Treat Personnel
SAE ARP1962	Training and Approval of Heat-Treating Personnel

The following references were used in developing this process specification:

Document Number	Document Name
SOP-007.1	Preparation and Revision of Process Specifications
JPR 8500.4	Engineering Drawing System Requirements

5.0 MATERIALS REQUIREMENTS

Current heat treat condition shall be verified before performing any subsequent heat treatment on raw stock material. Subsequent heat treatment shall be performed per SAE AMS2761.

Material requirements for parts shall be as specified in SAE AMS2759.

6.0 PROCESS REQUIREMENTS

6.1 Raw Stock Steel and Stainless Steel Material

All heat treatment of raw steel and stainless steel alloys shall comply with the requirements specified in section 3 of SAE AMS2761 and the corresponding drawing requirements.

Specific heat treating times and temperatures are provided in various tables in SAE AMS2761. Table 1 below provides a list of these heat treating tables.

Table 1: List of Tables with Heat Treating Times and Temperatures Per SAE AMS2761

Table	Name
3	Recommended heat-treatment procedure for carbon and low alloy (Class A) steel
4	Recommended heat-treatment procedure for martensitic corrosion resistant (Class B) steel
5	Recommended annealing and annealing/quenching (to solutionize carbides) procedure for austenitic corrosion resistant (Class C) steel
6	Recommended solution and austenitic heat-treatments for precipitation hardening corrosion resistant and maraging (Class D) steel
7*	Recommended precipitation heat-treatments for precipitation hardening corrosion resistant and maraging (Class D) steel
8	Recommended heat-up and minimum holding times for carbon and low alloy (Class A) steels
9	Suggested recommended heat-up and holding times for austenitic stainless (Class C) steels
10	Recommended tempering conditions for carbon and low alloy (Class A) steels

**An exception to Table 7 must be noted when age hardening A286. The age hardening time and temperature provided by Table 7 yields the minimum tensile strength that can be attained for A286, without cold working the material. The tensile strength of A286 can be increased by the amount of cold work input into the material. The age hardening time and temperature for A286 material that has been cold worked is not listed in Table 7. The corresponding material specification(s) shall be used to age harden A286 material that has been cold worked.*

Tools and equipment shall be as specified in SAE AMS2761. Safety precautions and warning notes shall be as specified in SAE AMS2761.

6.2 Steel and Stainless Steel Alloy Parts

All heat treatment of steel and stainless steel alloy parts shall comply with the requirements specified in section 3 of SAE AMS2759 and the corresponding drawing requirements.

Specific heat treating times and temperatures are provided in various derivations of SAE AMS2759. Table 2 below provides a list of these SAE AMS2759 derivations.

Table 2: List of SAE AMS2759 Derivations

Steel and Stainless Steel Heat Treat Procedures	SAE AMS2759 Derivations
Heat Treatment of Carbon and Low-Alloy (Class A) Steel, Minimum Tensile Strength Below 220 ksi	SAE AMS2759/1
Heat Treatment of Low-Alloy Steel, Minimum Tensile Strength 220 ksi and Higher	SAE AMS2759/2
Heat Treatment of Precipitation-Hardening Corrosion-Resistant, Maraging, and Secondary Hardening (Class D) Steels	SAE AMS2759/3
Heat Treatment of Austenitic Corrosion-Resistant (Class C) Steels	SAE AMS2759/4
Heat Treatment of Martensitic Corrosion-Resistant (Class B) Steels	SAE AMS2759/5
Gas Nitriding of Low-Alloy Steel	SAE AMS2759/6
Carburizing and Heat Treatment of Carburizing Grade Steel	SAE AMS2759/7
Ion Nitriding	SAE AMS2759/8
Hydrogen Embrittlement Relief (Baking) of Steel Parts	SAE AMS2759/9
Automated Gaseous Nitriding Controlled by Nitriding Potential	SAE AMS2759/10
Stress Relief of Steel Parts	SAE AMS2759/11
Automated Gaseous Nitrocarburizing, Controlled by Potentials	SAE AMS2759/12
Gaseous Nitrocarburizing	SAE AMS2759/13
*Heat Treatment of Parts in a Vacuum	SAE AMS2769

*Not an SAE AMS 2759 specification.

Tools and equipment shall be as specified in SAE AMS2759. Safety precautions and warning notes shall be as specified in SAE AMS2759.

6.3 Tool and Die Steels

An ES4 materials engineer shall be consulted for process requirements and specific heat treating times and temperatures for heat treatment of tool and die steels.

7.0 PROCESS QUALIFICATION

Not required. However, work instructions shall be generated for implementing this process specification. The work instructions shall contain sufficient detail to ensure that the manufacturing process produces consistent, repeatable products that comply with this specification.

8.0 PROCESS VERIFICATION

8.1 Verification of Heat Treat Cycles

Verification of furnace temperatures shall be accomplished by recording the furnace temperatures on strip charts or other suitable hard copy recordings. Furnace charts for heat treatment shall be maintained with the hardware's work order router package (or equivalent documentation).

8.2 Heat Treat Verification by Hardness Test

Heat treat verification of steel and stainless steel is typically achieved by measuring hardness per ASTM E18.

8.2.1 Notations Related to Hardness Tests

Hardness tests will be performed on the raw stock material or the semi-finished part unless otherwise specified on the engineering drawing. Hardness impressions will be machined away during subsequent machining for most parts. When hardness impressions must be made on the finished part, a test location shall be chosen by the designer and the materials engineer that will not be detrimental to the function of the finished part. Notes must be included on the engineering drawing, such as:

HARDNESS TEST SHALL BE PERFORMED ON FINISHED PART IN SPECIFIED LOCATION

Hardness tests may be performed on sample parts instead of finished parts. Sample parts shall be sketched and/or described on the engineering drawing. They may have a simplified contour and may use nominal dimensioning. Sample parts shall be made from the same lot of raw stock material and shall be processed before heat treatment in an identical manner as the finished parts.

When the heat treating process includes quenching, the sample parts must be of similar cross section as the finished parts or shall be parted from the same lot of raw stock material that will be used for finished parts post heat treatment. If finished parts must be processed in more than one batch and sample parts are needed, each batch must have its own set of labeled sample parts.

When a hardness test is to be performed on a sample part, special instructions shall be included on the engineering drawing, such as:

HARDNESS TEST SHALL BE PERFORMED ON SAMPLE PART. SAMPLE PART SHALL CONSIST OF ONE 1" LENGTH OF THE SAME RAW STOCK MATERIAL USED FOR FINISHED PARTS.

OR

HARDNESS TEST SHALL BE PERFORMED ON 2" PROLONGATION OF RAW STOCK MATERIAL THAT IS PARTED AFTER HEAT TREATMENT.

8.2.2 Hardness Test Results

Hardness test results shall meet the values that appear on the procurement specifications or the drawing requirements.

8.3 Heat Treat Verification by Tensile Test

When tensile tests are required by the drawing for more critical parts, tensile tests shall be performed according to ASTM A370 by either the JSC Structures Test Laboratory, the Receiving Inspection and Test Facility (RITF), or an accredited mechanical testing laboratory.

8.3.1 Notations Related to Tensile Tests

Sample parts for tensile coupons shall be machined according to ASTM A370, using full-sized coupons whenever possible. Sample parts shall be machined from the same lot of raw stock material and processed before heat treatment in an identical manner as the finished parts. The number of coupons, grain direction (when applicable), and any special acceptance criteria (i.e.: tensile strength, % elongation, etc.) shall be noted on the engineering drawing when tensile testing is required. For example:

TENSILE TESTING IS REQUIRED AND SHALL BE PERFORMED ON SAMPLE PART(S). SAMPLE PARTS SHALL CONSIST OF THREE 6" LENGTHS OF THE SAME RAW STOCK MATERIAL LOT USED FOR FINISHED PARTS.

8.3.2 Labeling of Tensile Coupons

Tensile coupons shall be labeled individually. Label information shall always include the material lot certification number. If the tensile bars or tensile coupons are made prior to heat treating, the tensile bars or tensile coupons shall be labeled using austenitic stainless tags and austenitic stainless wire. If the tensile bars or tensile coupons are made after heat treating, cotton string and paper tags may be used instead of stainless tags and wire. Paper tags shall include the material type, the material lot certification number, and the work order router number.

8.3.3 Tensile Test Results

Tensile test results for Class A, Class B, and Class C steels shall meet the yield strength and elongation drawing requirements per MMPDS. Tensile tests are not required to verify annealed condition of Class C steels.

8.4 Miscellaneous

Hardness testing and tensile testing are not required for post weld stress relieving operations, except for rare exceptions.

9.0 TRAINING AND CERTIFICATION OF PERSONNEL

All heat treatment of steel and stainless steel alloys used for flight hardware shall be performed by qualified operators who have been certified according to the requirements in TI-2000-01, Training for Heat Treat Personnel. For vendors, a training program consistent with the recommended practices in SAE ARP 1962 shall be required.

10.0 DEFINITIONS

Age Harden	Aging that causes hardening constituents to strain and strengthen the lattice.
Annealing	A heat treatment consisting of heating to and holding at a suitable temperature, followed by slow rate cooling, used primarily to soften metallic materials.
Austenitizing	Forming austenite by heating a ferrous alloy into the transformation range (partial austenitizing) or above the transformation range (complete austenitizing).
Carburizing	A heat treatment process consisting of heating a ferrous alloy in a carbon-rich environment to diffuse carbon into the outer layer of the part, creating a case-hardened surface.
Cryogenic Treatment	Treatment carried out after quenching to transform retained austenite into martensite, involving cooling and holding at a cryogenic temperature.

Decarburization	Loss of carbon from the surface of a carbon-containing alloy by reaction with other elements (usually oxygen) during heat treatment
Heat Tint	A thin, tightly adhering oxide layer that forms when steels are heat treated at low temperatures, or for a short time, in air or in a mildly oxidizing atmosphere. The color ranges from straw to light blue.
Material Lot	A single batch (bar, forging, extrusion, etc.) of material that is produced by the mill vendor and is documented by an MTR.
Material Test Report (MTR)	A report generated by a mill and provided by a mill or a material vendor when procuring raw stock. MTRs include mill lot elemental chemistry data, as-received mechanical properties such as hardness and/or tensile strength, as well as demonstrable mechanical properties such as tensile strength, yield strength, percent elongation, and reduction of area
Nitriding	A heat treatment process consisting of heating a ferrous alloy in a nitrogen-rich environment to diffuse nitrogen into the outer layer of the part, creating a case-hardened surface.
Nitrocarburizing	A heat treatment process consisting of heating a ferrous alloy in an environment rich in both carbon and nitrogen to diffuse these elements into the outer layer of the part, creating a case-hardened surface.
Normalizing	A heat treating cycle for steels above the ferrite/austenite transformation temperature followed by cooling in air.
Quenching	Rapid cooling from the austenitizing or solution heat treating temperature.
Tempering	Reheating hardened steel to decrease hardness and to increase both ductility and toughness.
Scale	A heavy, penetrating oxide layer that forms when steels are heat treated at higher temperatures, or

	at longer times, in air or other oxidizing atmospheres.
Solid Solution	A single, solid, homogeneous crystalline phase containing two or more chemical species.
Solutionizing	A heat treatment that dissolves precipitates into a solid solution.
Stress Relieving	Heating to a suitable temperature (50°F below the tempering temperature), holding long enough to reduce residual stresses, and then cooling slowly enough to minimize the development of residual stresses.