Process Specification for the Heat Treatment of Nickel Alloys

Engineering Directorate

Structural Engineering Division

February 2020

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

Process Specification for the Heat Treatment of Nickel Alloys

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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	7/21/99
C	Modified Training Requirements, Labeling Tensile Bars & Stock.	2/24/00
D	Included Information on Postweld Heat Treatment, Reduced Labeling Tensile Bars & Stock Requirements	8/24/00
E	Updated document due to reorganization from EM2 to ES4.	1/20/04
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 Table 1; labeled existing process requirement modifications table as Table 2; subdivided PROCESS VERIFICATION section; replaced JSC 8500 with JPR 8500.4 under REFERENCES section; other grammatical changes.	10/2011
I	Deleted Structural Engineering Division logo; updated revision, date, and Approved by signature; replaced scale with high temperature oxidation in Section 3.1 Process Sequence; added air environment to Section 3.1 for minimum 0.010" removal post heat treatment during final machining; removed scale definition from Section 10.0 Definitions and replaced with high temperature oxidation; minor grammatical corrections.	02/2020

1.0 SCOPE

This process specification establishes the engineering requirements for the heat treatment of nickel and cobalt alloys.

2.0 APPLICABILITY

This specification shall be applicable whenever the heat treatment of nickel or cobalt alloys is invoked per section 3.0, "Usage". Heat treatment of nickel and cobalt alloys may be performed on raw stock material (sheet, strip, foil, plate, tube, wire, rod, bar, rings, extrusions, and forgings) 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 process or combination of heat treat processes shall be noted, along with the final temper. For example:

AGE HARDEN TO S1750SPD PER NASA/JSC PRC-2003

OR

AGE HARDEN PER NASA/JSC PRC-2003

OR

ANNEAL PER NASA/JSC PRC-2003

3.1 PROCESS SEQUENCE

Unless otherwise specified on the engineering drawing, all parts shall be heat treated before final machining to eliminate effects of oxidation, alloy depletion, sensitization, and dimensional changes. High temperature oxidation that is produced when nickel and cobalt alloys are heat treated above 1500°F cannot normally be completely removed by mechanical or chemical finishing techniques. After heat treatment in an air environment, a minimum of 0.010" will be removed during the final machining.

In some cases, it may be necessary to heat treat after final machining. If heat treating will result in a heat tinted surface that will not be removed by final machining, an appropriate finishing procedure to remove the heat tint shall be called out on the engineering drawing. For example:

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

Most postweld heat treat operations, when required, on nickel-based and cobalt-based alloys are generally anneals or anneals plus aging. A qualified welding procedure for the specific application needs to be reviewed before making the postweld heat treat note. For example:

AFTER WELDING, ANNEAL AND AGE HARDEN TO S1750SDP PER NASA/JSC PRC-2003.

4.0 <u>REFERENCES</u>

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

AMS 2774	Society of Automotive Engineers Aerospace Materials Specification, *Heat Treatment, Wrought Nickel Alloy and Cobalt Alloy Parts*
ASTM E8	American Society for Testing and Materials Specification, Standard Test Methods of Tension Testing of Metallic Materials
ASTM E18	American Society for Testing and Materials Specification, Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
MMPDS	Handbook, Metallic Materials Properties Development and Standardization
TI-2000-01	Training Instruction: Training for Heat Treat Personnel
SAE ARP 1962	Training and Approval of Heat-Treating Personnel

The following references were used in developing this process specification:

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

5.0 MATERIALS REQUIREMENTS

Material requirements for parts shall be as specified in AMS 2774. The current heat treat condition shall be verified before performing any subsequent heat treatment.

6.0 PROCESS REQUIREMENTS

All heat treatment of nickel and cobalt alloys shall comply with the process requirements in AMS 2774 and the engineering drawing requirements.

A description of the names for various heat treatments (e.g., S1750SDP) and the heat-treating times and temperatures may be found in various tables in AMS 2774. Table 1 provides a list of these heat-treating tables.

Table 1: List of Tables with Heat Treating Times and Temperatures Per AMS 2774*

Table	Name
1	Temperature tolerance
2	Quenchant temperature
3	Heat treatment of non-age hardenable nickel alloy and cobalt alloy parts
4	Heat treatment of age hardenable nickel alloy and cobalt alloy parts
5A	Soaking time for non-age hardenable nickel alloy and cobalt alloy parts, inch/pound units
5B	Soaking time for non-age hardenable nickel alloy and cobalt alloy parts, SI units
6	Tolerance for the soaking times specified in tables 3, 4, and 5 for heat treatment of nickel alloy and cobalt alloy parts
7	Hardness requirements for age-hardenable nickel alloy and cobalt alloy parts in the precipitation heat treated condition

***Table 9 in AMS 2774 provides a list of alloy designations and the corresponding AMS specification to be used in conjunction with Tables 1-7.**

Table 2 provides a list of modifications to the process requirements presented in AMS 2774:

Table 2: Modifications to Process Requirements in AMS 2774

Alloy	Spec	Heat Treat Variation	Acceptance Change
MP35N	AMS 5844	Use 1100°F precipitation set temperature.	Precipitation heat treat shall be verified by tensile testing.
MP159	AMS 5842	Use 1225°F precipitation set temperature.	No change.
Alloy 718 Bar S1750SDP	AMS 5662 AMS 5596 AMS 5889	Use 100°F per hour cool instead of furnace cool during precipitation heat treatment.	Use 36 HRC instead of 331 HB.
Alloy 718 Bar S1950DP	AMS 5664 AMS 5597	No change. No change.	Use 38 HRC instead of 341 HB.

Tools and equipment shall be as specified in AMS 2774. Safety precautions and warning notes shall be as specified in AMS 2774.

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

8.0.1 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. If a vacuum furnace is to be used to solution heat treat nickel or cobalt alloys that require air cooling or rapid air cooling, it shall be equipped with metal elements, metal shields and an argon quench system capable of rapidly cooling parts from the annealing temperature to below 1200°F. Furnace charts for heat treatment shall be maintained with the hardware's work order router package.

8.0.2 Heat Treat Verification by Hardness Test

Verification of nickel and cobalt alloy heat treat is generally achieved by measuring hardness. Hardness tests shall be performed per ASTM E18.

8.0.2.1 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 TESTS SHALL BE PERFORMED ON FINISHED PART IN LOCATION SPECIFIED.

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 processed before heat treatment in an identical manner as the finished parts.

When the heat-treating process includes quenching, the samples must be of similar thickness and mass as the finished parts or shall be parted from the finished parts after quenching.

When a hardness test is to be performed on a sample part, the following notation should be included on the engineering drawing:

HARDNESS TEST SHALL BE PERFORMED ON SAMPLE PART.

8.0.2.2 Hardness Test Results

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

8.0.3 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 EB by either the JSC Structures Test Laboratory, the Receiving Inspection and Test Facility (RITF), or an accredited mechanical testing laboratory.

8.0.3.1 Notations Related to Tensile Tests

Sample parts for tensile coupons shall be machined according to ASTM EB, 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 LOT OF MATERIAL USED FOR FINISHED PARTS.

8.0.3.2 Labeling of Tensile Coupons

Tensile bars or tensile coupons shall be individually labeled immediately after manufacture. Label information shall always include 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 material type, the material lot certification number, and the work order router number.

8.0.3.3 Tensile Test Results

Tensile test results for nickel and cobalt alloys shall meet the minimum values listed in MMPDS. If no tensile values are available in MMPDS for a specific alloy, acceptance values must be listed on the engineering drawing.

9.0 <u>TRAINING AND CERTIFICATION OF PERSONNEL</u>

All heat treatment of steel and stainless-steel alloys used on 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	A heat treatment process which consists of applying a relatively low temperature for sufficient time to strengthen the alloy to the desired temper.
Air Cooling	The rate at which the parts, separated from one another sufficiently to allow free air movement, would cool to room temperature after being removed from the furnace and placed in shop air without rapid motion of the air forced over the parts by a fan or blower.
Alloy Depletion	Change in composition of an alloy near the surface when one element, typically chromium, evaporates at high temperatures, usually in a vacuum furnace.
Decarburization	The loss of carbon from the surface of an alloy because of heating in a medium (usually oxygen) that reacts with the carbon.
Heat Tint	A thin, tightly adhering oxide skin that forms when alloys 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.
High Temperature Oxidation	Heavy oxide formation composed of two layers - an oxide scale layer and a layer of combined alloy depletion, internal oxidation, and sensitization. Removal of the oxide scale to shiny metal is not adequate to eliminate internal oxidation, alloy depletion, and sensitization.
Precipitation Heat Treat	An intermediate temperature heat treat process that causes hardening and strengthening of the alloy by the precipitation of intermetallic compounds and, in some cases, carbides from supersaturated solid solutions.
Rapid Air Cooling	The rate at which the parts, separated from one another sufficiently to allow free air movement, would cool to room motion of the air forced over the parts by a fan or blower.
Stress Relief	A thermal cycle to relieve residual stresses.