



AEROSPACE MATERIAL SPECIFICATION

AMS2774™

REV. H

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Revised 2024-08

Superseding AMS2774G

Heat Treatment
Nickel Alloy and Cobalt Alloy Parts

RATIONALE

AMS2774H adds cycle interruptions and rework to 4.7 Report/Certification, corrects temperatures for Inconel Alloy 625 additively manufactured in Table 3, and adds Haynes 282 to Tables 4, 7, and 9 and Appendix A.

1. SCOPE

1.1 Purpose

This specification specifies the engineering requirements for heat treatment, by part fabricators (users) or subcontractors, of parts made of wrought or additively manufactured nickel or cobalt alloys, of raw materials during fabrication, and of fabricated assemblies in which wrought nickel or cobalt alloys are the primary structural components.

1.2 Application

1.2.1 Alloys

Detailed heat-treating instructions are specified for the age-hardenable (precipitation-hardenable) and non-age-hardenable alloys listed in 8.2. However, this specification may also be used for alloys other than those listed in 8.2, provided that temperatures, soaking times, and cooling requirements are specified by the cognizant engineering organization.

1.2.2 Heat Treatments

Heat treatments covered by this specification are as follows:

Solution Treating (see 2.5.9)

Annealing (see 2.5.2)

Stabilization Annealing (see 2.5.10)

Interstage Annealing (see 2.5.4)

Stabilization (see 2.5.11)

Precipitation (see 2.5.7)

Equalization (see 2.5.3)

Stress Relief (see 2.5.12)

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1.3 Safety - Hazardous Materials

While the materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials, this specification does not address the hazards that may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

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 +1 724-776-4970 (outside USA), www.sae.org.

AMS2750	Pyrometry
AMS2769	Heat Treatment of Parts in a Vacuum
ARP1820	Chord Method of Evaluating Surface Microstructural Characteristics
ARP1962	Training and Approval of Heat-Treating Personnel
AS7766	Terms Used in Aerospace Metals Specifications
HS-1086	Metals & Alloys in the Unified Numbering System

2.1.1 Titles of SAE publications listed in Tables 3, 4, 7, and 8 are presented in Appendix A.

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 E3	Preparation of Metallographic Specimens
ASTM E8/E8M	Tension Testing of Metallic Materials
ASTM E10	Brinell Hardness of Metallic Materials
ASTM E18	Rockwell Hardness of Metallic Materials
ASTM E21	Elevated Temperature Tension Tests for Metallic Materials
ASTM E139	Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials
ASTM E140	Hardness Conversion Tables for Metals Relationship among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness
ASTM E292	Conducting Time-for-Rupture Notch Tension Tests of Materials
ASTM E384	Microindentation Hardness of Materials

2.3 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

BB-H-1168	Helium, Technical
MIL-A-18455	Argon, Technical
MIL-PRF-27201	Propellant, Hydrogen
MIL-PRF-27401	Propellant Pressurizing Agent, Nitrogen
MIL-PRF-27407	Propellant Pressurizing Agent, Helium

2.4 CGA Publications (Compressed Gas Association)

Available from CGA, 8484 Westpark Drive, Suite 220, McLean, VA 22102, Tel: 703-788-2700, www.cganet.com.

CGA G-5.3	Commodity Specification for Hydrogen
CGA G-9.1	Commodity Specification for Helium
CGA G-10.1	Commodity Specification for Nitrogen
CGA G-11.1	Commodity Specification for Argon

2.5 Definitions

Terms used in AMS are defined in AS7766 and as follows:

2.5.1 AIR COOLING

The rate at which the parts, separated from one another sufficiently to allow free movement of air between them, would cool to room temperature after being removed from the furnace and placed in ambient air without forced motion of the air.

2.5.2 ANNEALING

A high-temperature heat treatment designed to produce a recrystallized grain structure and softening in a work-hardened alloy.

2.5.3 EQUALIZATION

An intermediate temperature stress-equalization treatment applied to Inconel X-750 rods, bars, and forgings by the producing mill or forge shop which, when followed by precipitation treatment, provides optimum balance in strength and notch-rupture ductility properties at service temperatures under 1100 °F (593 °C). This treatment is referred to as Condition A in Table 4.

2.5.4 INTERSTAGE ANNEALING

An annealing treatment performed between stages of forming or other fabricating operations in the process of manufacturing a part for the purpose of softening or restoring optimum workability properties to the alloy.

2.5.5 LOAD THERMOCOUPLES

A thermocouple attached to and in direct contact with the heaviest section of a part or representative sample. There should be no gap between the thermocouple and the part. It should be shielded against furnace radiation and protected against contamination from the furnace atmosphere or heating medium.

2.5.6 PARTS

Usually identified by a part number, parts are produced from raw material in accordance with requirements of a drawing, and, except for those parts produced in large quantities (e.g., rivets), are usually tested by nondestructive techniques only. They are heat treated by a fabricator/user, or his designee, to meet requirements of a drawing. The requirements are usually conveyed by a purchase order, fabrication outline, and/or heat-treating specification. Parts, at the time of heat treatment, may resemble raw material.

2.5.7 PRECIPITATION HEAT TREATMENT

An intermediate temperature heat treatment causing hardening and strengthening of the alloy by the precipitation of intermetallic compounds and, in some instances, of carbides from supersaturated solid solutions.

2.5.8 RAPID AIR COOLING

The rate at which the parts, separated from one another sufficiently to allow free movement of air between them, would cool to room temperature after being removed from the furnace and placed in shop air with rapid motion of the air forced over the parts by a fan or blower.

2.5.9 SOLUTION HEAT TREATMENT

A high-temperature heat treatment designed to place certain carbides and intermetallic compounds into solid solution.

2.5.10 STABILIZATION ANNEALING

A heat treatment used with some non-age-hardening alloys to cause a precipitation of carbides of a form and composition that does not sensitize the alloy to intergranular corrosion and that stabilizes the alloy against becoming sensitized during subsequent elevated temperature exposures.

2.5.11 STABILIZATION HEAT TREATMENT

An intermediate temperature precipitation heat treatment used with many age-hardening nickel alloys to cause a precipitation of discontinuous chromium carbides at grain boundaries prior to a lower temperature aging heat treatment that will cause a fine gamma-prime precipitation within the grains. This two-step precipitation results in an optimization of tensile and creep-rupture properties.

2.5.12 STRESS RELIEVING

A heat treatment used to remove or reduce stresses in work-hardened alloys.

2.5.13 THICKNESS

The minimum specified dimension of the heaviest section of the part.

3. TECHNICAL REQUIREMENTS

3.1 Equipment

3.1.1 Pyrometry

Shall conform to AMS2750.

3.1.2 Furnaces

3.1.2.1 Temperature Uniformity

Shall be as shown in Table 1 tested in accordance with AMS2750.

3.1.2.2 Vacuum furnaces and processing shall meet the requirements of AMS2769.

3.1.2.3 Heating Media

Protective atmospheres shall be used whenever the heat-treating temperature is above 1550 °F (843 °C), unless parts will have sufficient surface material removed after heat treatment to eliminate high-temperature atmospheric effects, such as oxidation, alloy depletion, and carburization. Certain alloys listed in 8.2 require protective atmospheres for heat treatments under 1550 °F (843 °C), and these requirements are noted with the detailed heat-treating instructions for these alloys. Acceptable protective atmospheres include argon, helium, hydrogen, vacuum, and vacuum with partial pressure of any of these three gases. In addition, for non-age-hardening alloys, neutral salt baths and exothermic gas atmospheres are acceptable protective atmospheres when approved by the cognizant engineering organization. Direct-fired furnaces shall be controlled so that there is no direct flame impingement on the parts.

3.1.2.3.1 Argon, Helium, and Hydrogen Gases

Shall meet the composition requirements of MIL-A-18455 (argon), CGA G-11.1, Grade C (argon), MIL-PRF-27407 (helium), CGA G-9.1, Grade L, minimum (helium), BB-H-1168, Grade A (helium), or MIL-PRF-27201 or CGA G-5.3, Grade B (hydrogen), as applicable. The dew point of the gas shall be -60 °F (-51 °C) or lower as the gas enters the furnace. Atmospheres of any of these gases in the furnace work zone shall have sufficient purity to avoid contamination or degradation of any part surfaces which will not have surface material removed after heat treatment.

3.1.2.3.2 Vacuum and Partial Pressure Atmospheres

Shall be sufficient to avoid contamination or degradation of any part surface which will not have surface material removed after heat treatment. Unless otherwise specified by the cognizant engineering organization, as a minimum, vacuum furnaces shall have a cold leak rate of a maximum of 20 µm/h, which shall be determined 15 to 60 minutes after closing the vessel and evacuation to 50 µm or lower, and shall be operated at pressures not higher than 10 µm Hg, unless argon, helium, hydrogen, or a mixture of argon and helium gas conforming to 3.1.2.3.1 is used to provide a partial pressure.

3.1.2.3.2.1 Argon or helium conforming to 3.1.2.3.1, or a mixture of the two, may be used to achieve partial pressures whenever necessary to avoid surface alloy depletion by sublimation of high vapor pressure elements, such as aluminum and chromium.

3.1.2.3.3 Salt Baths

Acceptable only for non-age-hardening alloys and, when approved by the cognizant engineering organization, shall be neutral with respect to the alloy being treated so as to avoid contamination or degradation of any part surfaces which will not be machined after heat treatment.

3.1.2.3.4 Exothermic Atmospheres

Acceptable only for non-age-hardening alloys and, when approved by the cognizant engineering organization, shall be produced by the combustion of fuel gas in air, shall be neutral to slightly reducing with respect to the parts being treated, and shall be sufficiently low in sulfur content to avoid contamination or degradation of any part surfaces which will not have surface material removed after heat treatment.

3.1.3 Auxiliary Equipment

Fixtures, jigs, hangers, trays, racks, etc., shall not cause contamination of the surface of parts and shall not reduce the heating, cooling, or quenching rates below those required for proper heat treatment.

3.1.4 Cooling

Shall be provided to cool parts according to the heat-treatment requirements specified for each alloy. Acceptable cooling media may include air, oil, water, water-polymer solutions, salt, brine (nominally 10% by weight NaCl), argon, helium, hydrogen, nitrogen, and vacuum. The medium selected shall not contaminate or degrade any part surface which will not be machined after heat treatment. When air cooling (AC) (see 2.5.1) or rapid air cooling (RAC) (see 2.5.8) is specified, cooling media shall be used that will provide protection, if required, to avoid contamination or degradation of finished surfaces; cooling rates shall be achieved that will be equivalent to, or faster than, rates that would be achieved by AC or RAC, as specified.

3.1.4.1 Cooling may be accelerated by backfilling to partial or positive pressure atmospheres with argon or helium conforming to 3.1.2.3.1, nitrogen conforming to either MIL-PRF-27401, Grade C or CGA G-10.1, Grade L, or combinations thereof, meeting the dew point requirements of 3.1.2.3.1.

3.1.4.2 Quenching

Quenching baths shall permit complete immersion of parts and free movement of the quenchant adjacent to all surfaces of parts. Equipment shall agitate or circulate the quenchant and/or the parts. The volume of the quenchant and the capabilities of auxiliary equipment shall be sufficient to maintain the quenchant temperature shown in Table 2.

3.2 Procedures

3.2.1 Cleaning

3.2.1.1 Prior to Heat Treatment

Parts shall be thoroughly cleaned to remove all foreign material, including greases, oils, inks, pencil marks, metal particles produced by machining or forming operations, and residual powder from the additive manufacturing process.

3.2.1.2 After Heat Treatment

Parts that have been heat treated in molten salt or cooled in oil, molten salt, brine, or water-polymer solution shall be thoroughly cleaned to remove all residues of these materials.

3.2.2 Racking

3.2.2.1 Except as permitted in 3.2.2.2, parts shall be racked to ensure uniform heating and cooling throughout the load. Parts shall not be nested unless tests with load thermocouples have demonstrated that the arrangement will not affect uniformity of heating and cooling and will not reduce cooling rate below minimum requirements.

3.2.2.2 Rivets, bolts, nuts, and other small parts may be racked or heated and soaked in baskets or in a continuous furnace. Parts shall not be nested. Maximum thickness of layers, and minimum space between layers, shall be 1 inch (25 mm).

3.2.3 Control Instruments

Shall be set either at the set temperature specified or at the offset temperature based on the last temperature uniformity determination. The offset temperature shall be within 5 °F (3 °C) for precipitation treatments and 10 °F (6 °C) for other treatments of the specified set temperature and shall be posted on the instrument. The offset temperature shall be selected to optimize the temperature distribution within the furnace so that the highest and lowest temperatures are equidistant from the set temperature in addition to the tolerance requirements of AMS2750 or AMS2769 as applicable.

3.2.3.1 The posting of the offset temperature shall include, or consist of, a statement of both the “desired” temperature and the corresponding “set” temperature, e.g., “When 1000 °F is desired, set at 1004 °F.”

3.2.4 Heat Treatment

Shall be performed as follows unless an alternate treatment has been specified by the purchase order or by the cognizant engineering organization:

3.2.4.1 The specified solution, annealing, stress-relief, and stabilization treatment for the non-age-hardening alloys listed in 8.2 shall be performed in accordance with Table 3. The specified solution, stabilization, precipitation, annealing, and stress-relief treatments for age-hardening alloys listed in 8.2 shall be performed in accordance with Table 4. Soaking times from Table 5 shall be used when soaking times are not specified in Table 3. Tolerances for the soaking times for both age-hardening and non-age-hardening alloys shall be as shown in Table 6.

3.2.4.1.1 Parts made of age-hardening alloys shall be heat treated to the precipitation-hardened condition. When a stabilization heat treatment is also shown for the alloy in Table 4, stabilization shall be applied to solution-treated parts before precipitation treatment.

3.2.4.1.2 Where temperature ranges are specified in Tables 3 and 4, it is the responsibility of the heat-treatment processor to select, for each lot of material, the specific temperature and time, within the ranges specified, that will produce heat-treated parts meeting all technical requirements of the drawing and applicable material specification.

3.2.4.2 Other Alloys Not Listed in 8.2 and Fabricated Assemblies of Cast and Wrought Alloys

Heat treatments for alloys not covered herein and for assemblies of cast alloys fabricated with wrought forms of the nickel or cobalt alloys in which the cast material is the primary structural component shall be as specified by the purchase order or by the cognizant engineering organization. This information shall include the heat-treatment name (e.g., annealing, precipitation), the set temperature, the soaking time, and quenchant or cooling medium.

3.2.4.3 Assemblies of Castings and Wrought Alloys

If wrought alloys covered by this specification are fabricated with castings into a single assembly in which the wrought material is the primary structural component, the heat treatment designated for the wrought material shall be used for the assembly.

3.2.4.4 Cycle Interruptions

If the precipitation, stabilization, or stress-relief cycle is interrupted due to power loss or furnace malfunction that causes the furnace temperature to drop below the required set point tolerance, the cycle may be continued to complete the required soak time. For example, if power is lost 1 hour and 20 minutes into an 8-hour precipitation cycle, the parts may be reheated to the precipitation temperature and continued for 6 hours and 40 minutes in order to complete the 8-hour cycle. The cumulative precipitation time shall not exceed the maximum time tolerance (for example, for an 8-hour cycle with an upper time tolerance of 30 minutes, the cumulative precipitation time shall not exceed 8 hours and 30 minutes). Only one such interruption is allowed per cycle. Further interruptions or exceeding the time tolerance requires reworking via resolution treatment (see 3.2.4.5).

3.2.4.5 Rework

Parts may be resolution treated, and reprecipitation heat treated when applicable, one time without cognizant engineering organization approval.

3.2.5 Start of Soaking Time

3.2.5.1 Batch Furnaces

Soaking time starts when all temperature sensors reach the specified set or offset temperature or, if load thermocouples (see 2.5.5) are used, when the part temperature reaches the temperature described by the set or offset temperature minus the appropriate tolerance (see 3.1.2.1).

3.2.5.1.1 Vacuum Furnaces

Unless otherwise specified by the cognizant engineering organization, load thermocouples shall be used to determine the start of soaking time except when this is impracticable, such as with two- or three-chamber oil or gas quench furnaces, in which case tests shall be conducted to establish the correct heat-up time for the load. Once a load has been qualified with load thermocouples, subsequent loads may be run without load thermocouples, provided records detailing the number of parts in the first qualified load are kept on file and provided that subsequent loads have an equal or fewer number of similar parts in the load and the distribution of the parts is the same as the distribution in the first load.

3.2.5.2 Continuous Furnaces

Shall be operated so that all part temperatures are within the allowed range (the range described by the specified set temperature and the tolerance specified in 3.1.2.1) for the specified time. Conformance to this requirement shall be verified by temperature uniformity tests, performed at the frequency specified in AMS2750, using load thermocouples, in a load representative of the weight and traverse speed of the parts to be heat treated.

3.2.6 Straightening After Heat Treatment

Shall be performed only when the straightening procedure and any subsequent stress relief are approved by the cognizant engineering organization.

3.3 Qualification

Facilities performing heat treatment in accordance with this specification shall be approved by the cognizant engineering or quality assurance organization (see 4.5). Personnel performing or directing the performance of heat treatment in accordance with this specification shall be approved in accordance with ARP1962 or other established procedures acceptable to the cognizant engineering organization.

3.4 Properties After Heat Treatment

3.4.1 Surface Contamination

3.4.1.1 The heat-treatment processor shall assume surfaces will not be machined after heat treatment unless the minimum amount of surface material to be removed after heat treatment is determined.

3.4.1.2 Surfaces of parts that are not to have surface material removed after heat treatment shall have no carburization, sulfidation, nitriding, or intergranular oxidation resulting from the heat-treating operations; evidence of such contamination shall be a continuous or general condition in the microstructure at the surface determined by the metallurgical examination in accordance with 3.5.1. On surfaces that are to have material removed after heat treatment, the depth of any of these conditions shall not exceed the depth of surface material to be removed in finishing the part.

3.4.2 Hardness

Parts shall conform to hardness requirements specified on the engineering drawing or purchase order.

3.4.2.1 If hardness requirements are not specified on the engineering drawing or purchase order, age-hardening alloys conforming to one of the AMS listed in Table 7 shall meet the hardness specified in Table 7 following precipitation treatment.

3.4.2.2 If hardness is not specified on the engineering drawing or purchase order or in Table 7, parts shall conform to the hardness requirements of the applicable material specification when the material specification contains hardness requirements for the heat-treatment condition represented by the parts.

3.4.3 Tensile and Stress Rupture

When required by the cognizant engineering organization, parts shall conform to tensile property and stress-rupture requirements of the applicable material specification when the material specification contains requirements for the heat-treatment condition represented by the parts.

3.5 Test Methods

The following test methods shall be used when applicable, unless otherwise specified by the cognizant engineering organization:

3.5.1 Surface Contamination

Testing shall be by metallurgical examination, at approximately 500X magnification, of etched specimens prepared in accordance with ASTM E3. The chord method described in ARP1820 may be used to enhance this examination.

3.5.2 Hardness

Shall be determined in accordance with ASTM E10, ASTM E18, or ASTM E384, as applicable. Unless otherwise specified by the cognizant quality assurance organization, hardness tests shall be performed on the thickest section of the part which is practical to test and where the test will not be detrimental to the function of the part.

3.5.3 Tensile Properties

Testing, when required by the cognizant engineering organization, shall be in accordance with ASTM E8/E8M or ASTM E21, as applicable.

3.5.4 Stress-Rupture Properties

Testing, when required by the cognizant engineering organization, shall be in accordance with ASTM E139 or ASTM E292, as applicable.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

Unless otherwise specified by the cognizant engineering or quality assurance organization, the heat-treatment processor shall be responsible for performance of all tests and inspections specified herein. The processor may use its own facilities or any commercial laboratory acceptable to the cognizant engineering or quality assurance organization.

4.1.1 The procuring activity reserves the right to perform any surveillance, tests, or inspection of parts and to review heat-treatment records and results of processor's tests and inspections to verify that the heat treatment conformed to specified requirements.

4.2 Records

Shall be kept available to the purchaser for not less than 5 years after heat treatment. The records shall contain all data necessary to verify conformance to requirements of this specification.

4.3 Classification of Tests

4.3.1 Acceptance Tests

For age-hardenable alloys as included in Table 4, hardness (see 3.4.2) is an acceptance test and shall be performed on each lot according to a sampling plan that conforms to the heat-treatment processor's shop procedures, unless otherwise specified by the cognizant engineering or quality assurance organization.

4.3.2 Periodic Tests

Surface contamination is a periodic test and shall be performed monthly on each furnace, except as provided in 4.3.2.1, for each type of atmosphere used in each furnace when: (a) heat-treating temperature is above 1550 °F (843 °C) and parts have less than 0.008-inch (0.20-mm) finishing stock on any surface or (b) parts are made of an alloy that Tables 3 or 4 specify shall require a protective atmosphere for heat treatments at lower temperatures and parts have any surface that will not have surface material removed after heat treatment.

4.3.2.1 Periodic surface contamination tests are not required on vacuum furnaces operating under 10 µm pressure, except as provided in 4.3.2.2.

4.3.2.2 Surface contamination tests shall also be performed whenever parts that have less than 0.008-inch (0.20-mm) finishing stock on any surface, and that have been heat treated at a temperature above 1550 °F (843 °C), show abnormal surface discoloration after heat treatment. The cognizant engineering organization is responsible for defining "abnormal surface discoloration."

4.3.3 Preproduction Tests

Surface contamination (see 3.4.1) is a preproduction test when: (a) heat-treating temperature is above 1550 °F (843 °C) and parts have less than 0.008-inch (0.20-mm) finishing stock on any surface or (b) parts are made of alloys that Tables 3 or 4 specify shall require a protective atmosphere for heat treatments at temperatures below 1550 °F (843 °C) and parts have any surface that will not have surface material removed after heat treatment. Preproduction tests shall be performed prior to, or on, the first production lot heat treated in each type of furnace equipment and for each type of atmosphere to be used in each furnace type.

4.3.3.1 When specified by the cognizant engineering or quality assurance organization, hardness (see 3.4.2), tensile (see 3.4.3), and stress-rupture (see 3.4.3) shall also be preproduction tests and shall be performed prior to, or on, the first production lot heat treated in each type of furnace equipment and for each type of atmosphere used in each furnace type.

4.4 Test Samples

4.4.1 Surface Contamination Tests (see 3.5.1)

4.4.1.1 For preproduction surface contamination tests (see 4.3.3), sample material of the same alloy representing the parts shall be supplied to the heat-treatment processor by the purchaser, or destructive testing of a part shall be authorized by the purchaser.

4.4.1.2 For periodic surface contamination tests (see 4.3.2), sample material shall be prepared in accordance with 4.4.1.2.1 and be either the same alloy as the production parts to be heat treated or shall be an alloy selected from Table 8.

4.4.1.2.1 Prior to furnace exposure, at least one surface shall be machined or ground. The test samples shall be exposed to the heat-treating atmosphere at the maximum temperature, or higher, and for the maximum time, or longer, required for heat treating the production parts.

4.4.2 When tensile (see 3.5.3) or stress-rupture (see 3.5.4) properties are required, sample material that represents the parts to be heat treated and is a size suitable for obtaining the test specimens required shall be supplied to the heat-treatment processor by the purchaser, or destructive testing of a part shall be authorized by the purchaser.

4.4.3 Hardness tests (see 3.5.2) shall be performed nondestructively on parts except when the parts are not of suitable size or shape or when the test will be detrimental to the function of the part; in these cases, suitable sample material that represents the parts shall be supplied to the heat-treatment processor by the purchaser for hardness tests.