

# Corrosion-resistant Bolting for Use in the Petroleum and Natural Gas Industries

## **BALLOT # 6738**

API Specification 20F, 3<sup>rd</sup> Edition

## **1 Scope**

### **1.1 Purpose**

This standard specifies requirements for the qualification, production, and documentation of corrosion-resistant bolting used in the petroleum and natural gas industries.

### **1.2 Applicability**

This standard applies when referenced by an applicable API equipment standard or otherwise specified as a requirement for compliance.

### **1.3 Bolting Specification Levels**

This standard establishes requirements for two bolting specification levels (BSL). These two BSL designations define different levels of technical, quality, and qualification requirements: BSL-2 and BSL-3. The BSLs are numbered in increasing levels of requirements in order to reflect increasing technical, quality, and qualification criteria. BSL-2 and BSL-3 are intended to be comparable to BSL-2 and BSL-3, as found in API 20E. BSL-1 is omitted from this standard.

## **2 Normative References**

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document applies (including any addenda/errata).

API Q1, *Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry*

API 6A, *Specification for Wellhead and Christmas Tree Equipment*

API 6HT, *Heat Treatment and Testing of Carbon and Low Alloy Steel Large Cross Section and Critical Section Components*

API Standard 6ACRA, *Age-hardened Nickel-based Alloys for Oil and Gas Drilling and Production Equipment*

API Specification 20B, *Open Die Shaped Forgings for Use in the Petroleum and Natural Gas Industry*

API 20D, *Qualification of Nondestructive Examination Services for Equipment Used in the Petroleum and Natural Gas Industry*

API 20H, *Heat Treatment Services - Batch Type for Equipment Used in the Petroleum and Natural Gas Industry*

API 20J, *Qualification of Distributors of Metallic Materials for Use in the Petroleum and Natural Gas Industries*

API 20N, *Heat Treatment Services—Continuous Furnace for Equipment Used in the Petroleum and Natural Gas Industry*

ASME B1.1, *Unified Inch Screw Threads (UN, UNR, and UNJ Thread Forms)*

ASNT ACCP, *ASNT Central Certification Program*

ASNT SNT-TC-1A, *1 Personnel Qualification and Certification in Nondestructive Testing*

ASTM A370-21<sup>1</sup>, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

ASTM A453, *Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels*

ASTM A751, *Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products*

ASTM A962/A962M-22, *Standard Specification for Common Requirements for Bolting Intended for Use at Any Temperature from Cryogenic to the Creep Range*

ASTM A1082, *Standard Specification for High Strength Precipitation Hardening and Duplex Stainless Steel Bolting for Special Purpose Applications*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*<sup>1</sup>

ASTM E354 *Standard Method for Chemical Analysis of High-Temperature, Electrical, Magnetic, and Other Similar Iron, Nickel and Cobalt Alloys*

ASTM E1476, *Standard Guide for Metals Identification, Grade Verification, and Sorting*

ASTM F788, *Standard Specification for Surface Discontinuities of Bolts, Screws, and Studs, Inch and Metric Series*

ASTM F812, *Standard Specification for Surface Discontinuities of Nuts, Inch and Metric Series*

ISO 965-1, *ISO general purpose metric screw threads —Tolerances — Part 1: Principles and basic data*

ISO 9001, *Quality management systems – Requirements*

ISO 9712, *Non-destructive Testing—Qualification and Verification of NDT Personnel*

ISO 17781, *Petroleum, petrochemical and natural gas industries – Test methods for quality control of microstructure of ferritic / austenitic (duplex) stainless steels*

ISO/IEC 17020, *Conformity assessment – Requirements for the operation of various types of bodies performing inspection*

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<sup>1</sup> ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, [www.astm.org](http://www.astm.org).

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

NACE MR0175/ISO 15156<sup>2</sup>, *Petroleum and natural gas industries—Materials for use in H<sub>2</sub>S-containing environments in oil and gas production*

NORSOK M630, *Material data sheets and element data sheets for piping*

SAE AMS2750<sup>3</sup>, *Pyrometry*

SAE AMS5844, *Alloy, Corrosion-Resistant, Round Bars, 20Cr-35Ni-35Co-10Mo, Vacuum Induction Plus Consumable Electrode Vacuum Remelted, Solution Heat Treated and Work Strengthened*

### **3 Terms, Definitions, Acronyms, and Abbreviations**

#### **3.1 Terms and Definitions**

For the purposes of this document, the following terms and definitions apply.

##### **3.1.1**

##### **bolting**

All-thread studs, tap-end studs, double-ended studs, headed bolts, cap screws, screws, and nuts.

##### **3.1.2**

##### **bolting manufacturer**

An organization that, through the use of manufacturing equipment and processes appropriate for the bolting product form, transforms raw material into finished bolting.

##### **3.1.3**

##### **cold-formed bolts, screws, and nuts**

Parts formed through the mechanical cold upsetting of wire, rod, or bar in order to generate the bolt or screw head (cold heading) or the configuration of the nut.

##### **3.1.4**

##### **corrosion-resistant bolting**

Bolting manufactured from metal that achieves improved resistance to corrosion through the addition of alloying elements.

##### **3.1.5**

##### **final acceptance testing**

Testing performed, by either the bolting manufacturer or a supplier, that demonstrates conformance to the product requirements of this specification.

NOTE See section 5.13.1 for details of final acceptance testing

##### **3.1.6**

##### **final inspection**

The bolting manufacturer's review of product to determine and document conformity to all order requirements before being deemed complete or shipped

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<sup>2</sup> AMPP, 15835 Park Ten Place, Houston, TX 77084, [www.nace.org](http://www.nace.org)

<sup>3</sup> SAE International, [www.sae.org](http://www.sae.org)

### **3.1.7**

#### **heat**

Material originating from a final melt, or for remelted alloys, the raw material originating from a single remelted ingot.

### **3.1.8**

#### **heat lot**

- a) Batch furnace: bolting or raw material of a single heat and diameter, heat treated together as a single solution annealing, quenching, and aging or precipitation hardening charge;
- b) Continuous furnace (applies to ASTM A453 Grade 660 Class D only): bolting or raw material of a single heat and diameter heat treated without interruption in a continuous charge, as defined in ASTM A453.

### **3.1.9**

#### **hot-formed bolts, screws, and nuts**

Parts formed through the mechanical hot upsetting of wire, rod, or bar in order to generate the bolt or screw head (hot heading) or the configuration of the nut.

### **3.1.10**

#### **machined bolts, screws, and nuts**

Parts manufactured by machining from raw material to generate the bolt, screw head, or the configuration of the nut.

### **3.1.11**

#### **manufacturing process specification**

##### **MPS**

A written document describing the complete production sequence and method.

NOTE MPSs are usually proprietary by manufacturer and not for general publication, but are available to customers or authorized third parties for information.

### **3.1.12**

#### **production lot**

Parts from the same heat treatment lot, grade, and nominal diameter that are grouped or processed together during the manufacturing process.

### **3.1.13**

#### **raw material**

Bar, coil, rod, or wire used to manufacture bolting.

### **3.1.14**

#### **raw material manufacturer**

The organization(s) responsible for melting, refining, or cold/hot working of metals used to produce raw material as defined in 3.1.13

NOTE A distributor is not considered a raw material manufacturer.

NOTE Cold/hot working does not include heading or nut forming operations under this definition

### **3.1.15**

#### **technical authority**

A competent and technically qualified person or organization with evidence to demonstrate the expertise, skills, and experience regarding quality and manufacturing processes necessary to perform the required verification(s).

### **3.1.16**

#### **wrought structure**

A structure that contains no cast dendritic elements.

### 3.2 Abbreviations

BSL	bolting specification level
MPS	manufacturing process specification
NDE	nondestructive examination
QMS	quality management system
UNS	unified numbering system
TUS	temperature uniformity survey
PMI	Positive Material Identification

## 4 Bolting Qualification

### 4.1 General

4.1.1 The bolting manufacturer shall qualify to one or more of the nine bolting types listed below and to one or more of the two BSLs.

- a) Bolting Type A: machined studs;
- b) Bolting Type B: machined bolts, screws, and nuts;
- c) Bolting Type C: cold-formed bolts, screws, and nuts with cut or cold-formed threads;
- d) Bolting Type D: hot-formed bolts and screws <1.5 in. (M36) nominal diameter;
- e) Bolting Type E: hot-formed bolts and screws ≥1.5 in. (M36) nominal diameter;
- f) Bolting Type F: roll threaded studs, bolts, and screws <1.5 in. (M36) diameter;
- g) Bolting Type G: roll threaded studs, bolts, and screws ≥1.5 in. (M36) diameter;
- h) Bolting Type H: hot-formed nuts <1.5 in. (M36) nominal diameter;
- i) Bolting Type I: hot-formed nuts ≥1.5 in. (M36) nominal diameter.

NOTE Alternate geometry bolting manufactured in accordance with this specification may be specified by the purchaser, provided the bolting can be classified under one of the categories above.

4.1.2 The bolting manufacturer shall have a quality management system that conforms to the requirements of API Q1.

4.1.3 Qualification to the higher BSL shall qualify to the lower BSL.

4.1.4 Qualification bolts and nuts shall be produced from raw material procured from an approved raw material manufacturer as defined in 4.7.3 and manufactured in accordance with an applicable manufacturing process specification (MPS) for a bolting material.

4.1.5 Regular production equipment and processes shall be used for qualifications.

**4.1.6** The activities identified as “Not Permitted” in Table 1 shall not be outsourced. Activities that may be outsourced are identified with “Permitted” in the applicable column.

**Table 1— Outsourced Activities**

<b>Activity</b>	<b>BSL-2 &amp; 3</b>
Receiving inspection	<b>Not Permitted</b>
Forging	Permitted
Heat treating	Permitted
Rough machining	Permitted
Final machining	<b>Not Permitted</b>
Threading cutting and rolling	<b>Not Permitted</b>
Mechanical testing	Permitted
Metallography	Permitted
Chemical analysis	Permitted
Hardness testing	Permitted
NDE surface	Permitted
NDE volumetric	Permitted
PMI	Permitted <sup>a</sup>
Final marking <sup>b</sup>	<b>Not Permitted</b>
Coating	Permitted
Final inspection <sup>c</sup>	<b>Not Permitted</b>
<sup>a</sup> Shall be performed onsite at bolting manufacturer's facility <sup>b</sup> Final marking as per 8.2 <sup>c</sup> The bolting manufacturer shall have a written procedure documenting the requirements for final inspection of product	

**4.1.7** The bolting manufacturer shall retain and have available an MPS (see 5.2) and qualification records (see 4.6) for each product qualified. The qualification records shall show all of the products, processes, and sizes qualified and all of the Table 3 requirements for each qualification, including the results of tests and inspections.

**4.1.8** Bolting shall be produced from raw material manufactured by a qualified raw material manufacturer as defined in 4.7.3.

**4.1.9** Bolting shall be manufactured in accordance with an applicable manufacturing process specification (MPS) from a bolting material grade listed in 4.4. The MPS shall address all of the applicable essential variables listed in Table 2 and variables/parameters listed in 5.2.

**4.1.10** If no products of a qualified bolting type listed in 4.1 are manufactured to a qualified MPS within five years of the previous qualification or manufacturing of that bolting type, requalification shall be required prior to manufacturing the given bolting type.

## **4.2 Essential Variables**

**4.2.1** For final product manufacturing, raw material manufacturer, and supplier qualifications to remain valid, all BSL-2 and BSL-3 production shall be within the essential variables listed in Table 2.

**4.2.2** A process change to any parameter in Table 2, outside of the limits defined at qualification, shall require product requalification per the requirements of Section 4.

NOTE This product requalification is not meant to impact the scope of product types approved under a bolting manufacturer's monogram license.

**4.2.3** Requalification testing may be performed on a sample from a production lot.

**Table 2 - Limits of Changes to Essential Variables**

Process	Essential Variable	
Raw Material <sup>b</sup>	2	Change to the forming method (e.g. forging to rolling or vice versa) <sup>c</sup>
Hot Heading/Nut Forming	1	Change in the method of heating (e.g. induction to furnace or vice versa) <sup>d</sup>
	2	Change to the forging location <sup>a, d</sup>
Heat Treatment	1	Change in time and temperature parameters outside of defined limits specified in MPS <sup>c, e</sup>
	2	Change in quenching medium (e.g. oil to polymer or air) <sup>c, e</sup>
	3	Change to the heat treatment location <sup>a, c</sup>
Material Grade	1	Change to the material grade (e.g. 718 to 925) <sup>c</sup>
	2	Change to the material designation <sup>c, f</sup>
<sup>a</sup> A change in location is constituted by any of the following: <ul style="list-style-type: none"> <li>– moving an operation from one bolting manufacturer's facility to another</li> <li>– moving an operation from one supplier location to another supplier or supplier location</li> <li>– moving an operation from a supplier location to the bolting manufacturer's location or vice versa</li> </ul> <sup>b</sup> Raw material supplier qualification and testing shall be in accordance with 4.7.3 and 4.7.4 <sup>c</sup> Product requalification may be performed on any Bolting Type, and shall constitute requalification of all Bolting Types <sup>d</sup> Product requalification shall be performed for each of the following applicable Bolting Types D, E, H, & I <sup>e</sup> Product requalification shall be performed for each bolting material group as defined in section 4.3.1 a, b, c, or d. Requalification of one alloy within a bolting material group shall requalify all alloys within a bolting material group. <sup>f</sup> Material designation refers specifically to the various material designations within API 6ACRA. This essential variable does not apply to the 20F material grades that are not included in API 6ACRA.		

### 4.3 Qualification Testing

**4.3.1** Bolting shall be tested and evaluated in order to establish qualification to the bolting types listed in 4.1 and a BSL.

**4.3.2** Qualification parts shall meet all the requirements indicated in Table 3 for the applicable sections of this standard.

NOTE Qualification may be performed on parts specifically manufactured for qualification or random parts selected from a production lot.

**4.3.3** Chemical, mechanical, metallurgical, dimensional, visual, and hardness tests of qualification parts shall be performed by a laboratory accredited to ISO/IEC 17025.

**4.3.4** NDE of qualification parts shall be performed by a laboratory accredited to either ISO/IEC 17020 or ISO/IEC 17025.



**Table 3—Bolting Test Requirements**

BSL	Material	Heat Treatment	Chemical Composition	Mechanical	Metallurgical	Hardness	NDE Surface	NDE Volumetric	Dimensional, Thread Fit, and Visual	PMI
BSL-2	5.4.1	5.3.2	5.6	5.7.2	5.8.	5.9.2	5.10.2.1	5.10.3.1	5.11.2	5.12.2
BSL-3	5.4.2	5.3.2	5.6	5.7.3	5.8	5.9.2	5.10.2.2	5.10.3.2	5.11.3	5.12.3

## 4.4 Bolting Materials

**4.4.1** The following bolting material groups are covered by this standard:

- a) age-hardened nickel-based alloys in accordance with API 6ACRA;
- b) age-hardened austenitic iron-based ASTM A453 Grade 660 Class D;
- c) cold-reduced only, or cold-reduced and high-temperature aged heat treated condition cobalt-based alloy UNS R30035 in accordance with SAE AMS5844 for chemical composition, melting practice, solution annealing, furnace tolerances, and average grain size; and NACE MR0175/ISO 15156 for aging and mechanical properties.
- d) The following duplex (ferritic-austenitic) grades in accordance with ASTM A1082
  - I. S31803
  - II. S32205
  - III. S32750
  - IV. S32760
  - V. S39277

**4.4.2** All requirements of the referenced industry standard shall be met, except as modified by this standard. For R30035, the equipment manufacturer's bolting material specification and the requirements herein shall be met. In the case of conflict between the requirements of referenced specifications and this standard, the requirements of this standard shall apply.

## 4.5 Acceptance of Qualification Bolting

### 4.5.1 General

Results of the tests specified in Table 3 shall conform with the acceptance criteria specified in Section 5 and the bolting manufacturer's written specification. Results shall be documented in accordance with 4.6

### 4.5.2 Qualification Samples

**4.5.2.1** Samples failing to meet acceptance criteria shall be cause for reevaluation of the MPS and the processes and procedures used and requalification is required.

**4.5.2.2** When a qualification sample selected from a production lot (see 3.1.12) fails to meet acceptance criteria, the entire lot shall be rejected.

**4.5.2.3** Should the bolting manufacturer choose to continue the qualification process with the same production lot, the entire production lot shall be reprocessed. A maximum of three full heat treatment cycles is permitted for API 6ACRA alloys and ASTM A453 Grade 660 Class D.

**4.5.2.4** For reprocessed lots, all qualification tests shall be repeated. Should any of the qualification tests fail to meet the acceptance criteria, the entire lot shall be rejected.

**4.5.2.5** If reprocessing results in any changes to the MPS, the MPS shall be revised to reflect the new process control variables.

## **4.6 Records of Qualification**

The following records are required to document the qualification of bolting:

- a) BSL
- b) Bolting type (see 4.1)
- c) Applicable ASTM or API specification, including editions or revisions (N/A to UNS R30035)
- d) For UNS R30035, the applicable equipment manufacturer's bolting material specification
- e) heat number and heat treatment lot identifier ;
- f) raw material manufacturer;
- g) raw material refining method;
- h) size;
- i) essential variables (see table 2);
- j) MPS;
- k) record of test results, as applicable, in Section 4 and Section 5;
- l) evidence of lab accreditation;
- m) records of qualification test failures and corrective action;
- n) suppliers(s) name, address, and records of qualification for each subcontracted process.

## **4.7 Suppliers**

### **4.7.1 BSL-2**

**4.7.1.1** The bolting manufacturer shall have a documented and fully implemented procedure for qualifying suppliers performing processes listed in table 1.

**4.7.1.2** Raw material manufacturers shall be qualified in accordance with 4.7.3.

**4.7.1.3** Only qualified suppliers shall be used to perform outsourced processes.

**4.7.1.4** Supplier qualification shall be in conformance with API Q1.

**4.7.1.5** Suppliers shall have an appointed technical authority with documented competency, per the requirements of ISO 9001 or API Q1.

**4.7.1.6** Suppliers shall have a quality management system in conformance with ISO 9001 or API Q1 and the QMS scope shall be relevant to the service being supplied.

**4.7.1.7** Suppliers performing processes listed in table 1 shall be evaluated by a technical authority.

**4.7.1.8** The bolting manufacturer shall define the minimum appropriate level of education, training, and experience, relevant to the process being necessary to qualify as a technical authority in their QMS;

**4.7.1.9** The initial qualification process shall include an onsite audit and technical evaluation performed by a technical authority.

**4.7.1.10** Suppliers shall be re-audited, at a minimum, by the bolting manufacturer's technical authority every 3 years.

**4.7.1.11** Suppliers of NDE services shall have a quality management system accredited to ISO 17020 or ISO 17025 and other lab service providers shall have a quality management system accredited to ISO 17025.

**4.7.1.12** For NDE services, verifying current accreditation to ISO 17020 or ISO 17025, specific to the testing performed by the supplier, may be used in lieu of onsite audits. For other lab services, verifying current accreditation to ISO 17025, specific to the testing performed by the supplier, may be used in lieu of onsite audits.

**4.7.1.13** Subcontracted NDE processes shall be qualified per the requirements of API 20D.

## **4.7.2 BSL-3**

**4.7.2.1** Requirements specified for BSL-2 shall be required for BSL-3.

**4.7.2.2** Validation of subcontracted processes listed in table 1, exclusive of testing performed by an ISO 17020 or ISO 17025 accredited NDE service provider or ISO 17025 accredited laboratory, shall require a first article evaluation consisting of a minimum of 3 pieces.

## **4.7.3 Raw Material Manufacturers**

**4.7.3.1** For BSL-2 raw material manufacturers, qualification of product shall consist of testing per 4.7.4, every 3 years. The bolting manufacturer, in accordance with API Q1, shall evaluate the raw material manufacturer.

**4.7.3.2** For BSL-3 raw material manufacturers, qualification of product shall consist of testing per 4.7.4, every 3 years. The bolting manufacturer, in accordance with API Q1, shall evaluate the raw material manufacturer and perform a technical audit per the requirements of Annex A at a minimum frequency of once every 3 years.

**4.7.3.3** When raw material is supplied by a stockist or distributor, traceability shall be maintained per the requirements of API 20J.

**4.7.3.4** The raw material manufacturer shall maintain documented evidence of technical capability to produce materials meeting this specification and shall have documented procedures that demonstrate capability to consistently produce acceptable product.

**4.7.3.5** Raw material manufacturer shall have a quality management system in conformance with ISO 9001 or API Q1, and the QMS scope shall be relevant to the service being supplied.

#### 4.7.4 Raw Material Testing Requirements

**4.7.4.1** Raw material may be supplied to the bolting manufacturer in either the final heat-treated condition or a condition requiring further heat treatment. At the intervals specified in 4.7.4, the bolting manufacturer shall perform a technical verification of the supplied raw material for each raw material manufacturer to the condition supplied, per the requirements of Table 4.

**4.7.4.2** The bolting manufacturer shall perform testing on a sample heat treatment lot for each supplied bolting material purchased as per 4.4, as applicable to the raw material manufacturer. Additionally, the bolting manufacturer shall verify all heat treatment processes used meet the requirements for the applicable BSL.

**4.7.4.3** Qualification to a higher BSL shall qualify to a lower BSL.

**Table 4 – Raw Material Retesting & Validation Requirements for Technical Verification**

BSL	Chemical Composition	Heat Treatment	Tensile	Charpy	Hardness	Metallurgical
<b>BSL-2</b>	5.6	5.3.2	5.7.2	5.7.2	5.9.2	5.8
<b>BSL-3</b>	5.6	5.3.2	5.7.3	5.7.3	5.9.2	5.8

## 5 Production of Qualified Bolting

### 5.1 Material Specifications

**5.1.1** In addition to the requirements of 4.4, the bolting manufacturer shall prepare and document raw material requirements in the form of a material specification. The material specifications shall include the following:

- a) material grade, including chemical composition limits;
- b) primary melt and remelt practices
- c) hot work reduction ratio (not required for cold-reduced UNS R30035 material);prop
- d) acceptable microstructure (applicable only to alloys covered by API 6ACRA or, NORSOK M630, ISO 17781 );
- e) heat treatment requirements, including mill heat treatments;
- f) mechanical properties;
- g) inspection practices and criteria

**5.1.2** The bolting manufacturer shall document acceptance of incoming raw material to the requirements of the material specification prior to use in the production of bolting.

## **5.2 Manufacturing Process Specification**

### **5.2.1 General**

The bolting manufacturer shall prepare an MPS to include, as a minimum, allowable levels for all bolting manufacturing parameters, including the process control variables listed in 5.2.2, the forging/hot heading parameters listed in 5.2.3, and the heat treatment parameters listed in 5.2.4.

The requirements of Annex B shall be followed during processing.

### **5.2.2 Process Control Variables**

The following are general variables, as applicable:

- a) bolting grades
- b) heading equipment; hot-forming heating method; heat treating equipment and processes;
- c) machining and threading equipment ( e.g. single point (lathe), multiple chaser, roll, cutting tap; form tap;
- d) machining and threading control methods;
- e) mill source (name and address);
- f) raw material forming method (e.g. forging or rolling)
- g) outsourced activity supplier (name and address).

### **5.2.3 Forging/Hot Heading Parameters**

The following are forging/hot heading parameters, as applicable;

- a) equipment;
- b) heating method (e.g. furnace, induction);
- c) temperature control (e.g. thermocouple, optical or infrared pyrometer, fail safe cut-off);
- d) times and temperatures;
- e) product dimensional control.

### **5.2.4 Heat Treatment Parameters**

The following are heat treatment parameters, as applicable:

- a) equipment (e.g. batch, continuous);
- b) times and temperatures;
- c) cooling media (including type, polymer concentration (if applicable), quench temperature, agitation, etc...);
- d) control and calibration methods;

- e) furnace load diagram or photo. For mill heat treated products, this requirement is waived, provided that the bolting manufacturer has performed first article evaluation in accordance with 5.1.2 a) 2).

### 5.3 Manufacturing Requirements

#### 5.3.1 General

**5.3.1.1** The bolting manufacturer shall meet all manufacturing parameters specified for the applicable BSL.

**5.3.1.2** The bolting manufacturer shall maintain heat treatment lot traceability.

#### 5.3.2 BSL-2 and BSL-3 Requirements

**5.3.2.1** Forging and hot heading shall be in accordance with the manufacturer's standard procedure.

NOTE The alloys permitted to be forged in this specification can tear during forging without appropriate process controls.

**5.3.2.2** Manufacturing processes shall be performed so as to minimize the potential for the introduction of stress risers that can occur from sharp angles and tool marks.

NOTE Stress risers can result in premature failure of bolting. Examples of stress risers that commonly occur in bolting manufacturing are tool marks in the load path, sharp angles in the head-to-shank fillet of a bolt, and high-stress stamping practices. See ASTM F788 and ASTM F812 for additional examples.

**5.3.2.3** Threads may be cut or rolled. Unified national threads shall be "R" (UNR controlled radius series) for external threads and UN for internal threads (ASME B1.1). Metric threads shall incorporate a nonreversing curvature root profile, in accordance with ISO 965-1, regardless of mechanical properties. Other thread forms may be applied when specified by the purchaser.

NOTE For more information regarding the impact of cut vs rolled threads on the HISC resistance of age-hardened nickel alloys, see API TR21D.

**5.3.2.4** Heat treatment shall be in accordance with the applicable standards listed in 4.4 except that direct resistance and induction is prohibited.

**5.3.2.5** A maximum of three full heat treatments is permitted, inclusive of incoming condition.

**5.3.2.6** Furnace temperature uniformity surveys (TUSs) and instrument calibration shall be in conformance with one or more of the standards listed:

- a) Batch Heat Treatment: API 20H, API 6A, SAE AMS2750 (class 1, 2, 3, 4, or 5 for solution annealing class 1, 2, or 3 for precipitation hardening furnaces);
- b) Continuous Heat Treatment: API 20N, API 6A, SAE AMS2750 (class 1, 2, 3, 4, or 5 for solution annealing class 1, 2, or 3 for precipitation hardening furnaces);

**5.3.2.7** Heat treatment of API 6ACRA material shall be performed and qualified after the material's final hot-forming operation.

**5.3.2.8** Heat treatment of ASTM A453 660 Class D shall be in accordance with ASTM A453.

**5.3.2.9** Heat treatment of UNS R30035 shall be in accordance with NACE MR0175/ISO 15156.

**5.3.2.10** Heat treatment of duplex (ferritic-austenitic) grades shall be in accordance with NORSOK M630 or ISO 17781.

**5.3.2.11** The following shall apply to material heat treated by the bolting manufacturer or a supplier other than the raw material manufacturer:

- a) Stacking or bundling of materials shall not be permitted. Stacking of racks or baskets in which single layers of materials are placed is permitted.
- b) Materials shall not be placed directly on the furnace hearth (floor).
- c) Materials shall be within the working zone of the furnace that was established in the TUS.
- d) Materials shall be loaded in such a manner that avoids any flame impingement from the burners (open-fired furnaces only).
- e) Temperature shall be monitored using a contact thermocouple on a part or a heat sink. This referenced thermocouple part shall be placed either in a location deemed to have the slowest heating rate or centrally in the furnace load.
- f) A furnace loading diagram or photo shall be prepared for each load configuration.
- g) Water, oil, and polymer quenching shall be controlled in accordance with API 20H.

NOTE Improper loading of parts can deleteriously affect the heat treatment of each part.

**5.3.2.12** The manufacturer shall have a written forging procedure defining, at a minimum, the parameters defined in 5.2.3. When induction heating is used for forging, the manufacturer's procedure shall include temperature monitoring equipment and an automatic fail-safe system to prevent overheating.

**5.3.2.13** For forging furnaces, TUS and calibration requirements shall be in accordance with the manufacturer's written procedures.

**5.3.1.14** Welding of raw material and bolting shall not be permitted.

### **5.3.3 Plating and Coating**

Plating and coating shall be provided as specified by the purchaser.

## **5.4 Raw Material**

### **5.4.1 BSL-2**

**5.4.1.1** The material shall have a fully wrought structure.

**5.4.1.2** The hot work reduction ratio based on starting material diameter shall be a minimum of 4.0:1. This requirement does not apply to UNS R30035.

**5.4.1.4** All elements intentionally added to the heat shall be reported.

**5.4.1.5** The material shall conform to the requirements of the relevant API or ASTM Standard, or to SAE AMS5844 for UNS R30035, except as modified by this standard. In the case of conflict between the requirements of referenced specifications and this standard, the requirements of this standard shall apply.

**5.4.1.6** For UNS R30035, the bolting manufacturer shall have a written specification that complies with the SAE AMS5844 chemical composition, melting practice, solution annealing, furnace tolerances, and average grain size, with additional requirements shown below.

**5.4.1.7** UNS R30035 shall meet the hardness and heat treatment requirements specified in NACE MR0175/ISO 15156.

**5.4.1.8** UNS R30035 shall only be forged or formed and heat treated/reheat treated by the raw material manufacturer.

**5.4.1.9** Raw material used for duplex (ferritic-austenitic) grades shall conform to bar requirements of NORSOK M630 or ISO 17781.

**5.4.1.10** Duplex (ferritic-austenitic) grades shall only be forged or formed and heat treated/reheat treated by the raw material manufacturer

#### **5.4.2 BSL-3**

**5.4.2.1** The requirements specified for BSL-2 are required for BSL-3.

**5.4.2.2** In addition to the heat analysis performed by the mill, the bolting manufacturer shall perform a product analysis and the chemical composition shall be in accordance with the applicable bolting material specifications specified in 4.4.

### **5.5 Examination and Test Requirements**

**5.5.1** When inspecting or testing production lots, per the requirements of Table 3, a sample that fails to meet the applicable requirements shall result in the rejection of the entire lot. The rejected lot shall be dispositioned by one of the following methods:

a) scrapped;

b) Retesting in accordance with the following:

If the results of a mechanical test do not conform to specified requirements, the manufacturer may perform a double retest in compliance with the applicable governing test methods. If both retests pass, then the associated lot will be considered acceptable. In the case of impact testing, a single retest, consisting of three additional test specimens, may be performed. However, each individual impact value must be greater than the minimum specified average value and a lateral expansion not less than the required minimum value when specified.

c) inspected 100 % and the defective parts removed; or

d) reworked.

**5.5.2** In the case of rework or 100 % inspection, the lot shall be reinspected or tested for the failed characteristic and any characteristics affected by the rework.

**5.5.3** Parts modified after inspection has occurred shall be reinspected or retested, as applicable.

**NOTE** To determine conformance with the specified requirements, observed or calculated values are rounded to the nearest unit in the last right-hand place of figures used in expressing the limiting value, in conformance with the rounding method of ASTM E29.



## **5.6 Chemical Analysis**

Methods and practices relating to chemical analysis shall be in accordance with ASTM A751 or ASTM E354, as applicable. The frequency of chemical analysis shall be one per heat. Results shall be documented on the test report.

## **5.7 Mechanical Properties**

### **5.7.1 General**

Mechanical properties testing shall be performed by the raw material manufacturer or bolting manufacturer after all thermal treatments and strain hardening, excluding threading operations. All mechanical property tests required by the applicable API standard, NACE/ISO standard, ASTM standard, or manufacturer's specification shall be performed on each heat treatment lot. Results shall be documented on the test report.

NOTE For more information regarding the impact of strain hardening due to cut or rolled threads on the HISC resistance of age-hardened nickel alloys, see API TR21D.

### **5.7.2 BSL-2**

The results shall conform to the requirements of the relevant API standard, NACE/ISO standard, ISO standard, ASTM standard, or manufacturer's specification for UNS R30035.

### **5.7.3 BSL-3**

The requirements for BSL-2 are required for BSL-3. When any of the testing has been performed by the raw material manufacturer, the bolting manufacturer shall perform a retest.

## **5.8 Metallurgical Requirements**

All microstructure evaluations required by the applicable API standard, NACE/ISO standard, ISO standard, ASTM standard, or manufacturer's specification shall be performed on each heat treatment lot. Results shall be documented on the test report.

## **5.9 Hardness Test Requirements**

### **5.9.1 General**

Hardness testing shall be performed in accordance with ASTM A370-21, Annex A3.

### **5.9.2 BSL-2 and BSL-3**

Hardness test results shall conform to the applicable API standard, NACE/ISO standard, ISO standard, ASTM standard, or manufacturer's specification shall be performed on each heat treatment lot. Each piece shall be tested.

## **5.10 Nondestructive Examination Requirements**

### **5.10.1 General**

**5.10.1.1** NDE processes shall be qualified per the requirements of API 20D.

**5.10.1.2** Personnel performing surface and volumetric NDE shall be certified to Level 2 or 3 per ISO 9712, ASNT ACCP, or ASNT SNT-TC-1A.

**5.10.1.3** Personnel approving surface and volumetric NDE procedures shall be certified to Level 3 per ISO 9712, ASNT ACCP, or ASNT SNT-TC-1A.

## **5.10.2 BSL-2**

**5.10.2.1** Surface NDE shall be required on bolting after final heat treatment, all machining and threading, and prior to coating or plating. Liquid penetrant examination shall be performed in accordance with ASTM A962/A962M-22 S56. Acceptance criteria shall be per ASTM A962/A962M-22 S57. Sampling plan shall be as per Table 5. Results shall be documented in an examination report.

NOTE When performing liquid penetrant examination, caution should be exercised to avoid excessive washout of penetrant from indications in threads.

**5.10.2.2** Ultrasonic examination is required on heat-treated material for manufactured bolting, with a nominal diameter greater than 2.5 in. (M64), after heat treatment and prior to threading. Ultrasonic examination shall be performed in accordance with API 6A volumetric NDE examination of stems (PSL-3 and PSL-4). The criteria for calibration shall be based on the final product dimensions. Each piece shall be examined. Results shall be documented in an examination report.

## **5.10.3 BSL-3**

**5.10.3.1** Surface NDE requirements specified for BSL-2 shall be required for BSL-3, except each piece shall be inspected.

**5.10.3.2** Volumetric NDE requirements specified for BSL-2 shall be required for BSL-3, except that inspection shall be required for all products with a nominal diameter 1 in. (M24) or greater.

## **5.11 Dimensional, Thread Fit, and Visual Inspection**

### **5.11.1 General**

**5.11.1.1** All dimension and thread fit inspections shall meet the requirements of ASTM A962/A962M-22. Dimensions not specified by ASTM A962/A962M-22 shall be as specified by the purchaser.

**5.11.1.2** Oversizing of nut threads or undersizing of bolt threads is not permissible.

**5.11.1.3** Visual inspection shall be performed in accordance with ASTM F788 and ASTM F812.

**5.11.1.4** Inspections shall be performed prior to coating or plating.

**5.11.1.5** Results shall be documented in an inspection report.

### **5.11.2 BSL-2 Sample Size**

Sample size shall be in accordance with Table 5.

### **5.11.3 BSL-3 Sample Size**

Each piece shall be dimensionally inspected.

**Table 5—Sampling<sup>a,b</sup>**

Lot Size	Sample Size
2 to 8	ALL
9 to 50	8
51 to 90	13
91 to 150	20
151 to 280	32
281 to 500	50
501 to 1200	80
1201 to 3200	125
3201 to 10,000	200
10,001 to 35,000	315
35,001 to 150,000	500
150,001 to 500,000	800
500,001 and over	1250
Based on ANSI/ASQ Z1.4 Table 1	General Inspection Level II
NOTE Based on ANSI/ASQ Z1.4:2003 (R2018) Table 1, general inspection level II	
<sup>a</sup> Acceptance number is zero. <sup>b</sup> Sample shall be random.	

## 5.12 Positive Material Identification

### 5.12.1 General

**5.12.1.1** Pieces shall be examined using methods conforming to ASTM E1476 and ASTM A751 to confirm the material type.

**5.12.1.2** PMI shall be performed after all machining and prior to coating or plating.

### 5.12.2 BSL-2 Sample Size

Sample size shall be in accordance with Table 5. If any of the samples fail, the entire lot shall be examined.

### 5.12.3 BSL-3 Sample Size

Each piece shall be examined.

## 5.13 Final Acceptance Testing

### 5.13.1 BSL-2 & BSL-3 Final Acceptance Testing

**5.13.1.1** All chemical, mechanical, and metallurgical tests required by this specification shall be performed by a laboratory accredited to ISO/IEC 17025.

**5.13.1.2** Hardness testing, dimensional inspection, visual inspection, and PMI shall be performed in accordance with the bolting manufacturer's QMS.

**5.13.1.3** Nondestructive examination shall be performed by a laboratory accredited to either ISO/IEC 17020 or ISO/IEC 17025.

## **6 Calibration Systems**

Inspection, measuring, and testing equipment used for acceptance shall be identified, inspected, calibrated, and adjusted at specific intervals in accordance with ISO 17025 and this standard. Calibration standards shall be traceable to the applicable national or international standards agency and shall be no less stringent than the requirements included herein. Inspection, measuring, and testing equipment shall be used only within the calibrated range. Calibration intervals shall be established based on repeatability and degree of usage and shall meet applicable test method requirements.

## **7 Test Report**

### **7.1 General**

The test report shall be supplied to the purchaser and shall include the following as applicable:

### **7.2 BSL-2 and BSL-3**

- a) manufacturing process specification reference number including revision;
- b) copy of original mill certificate;
- c) cold-reduced production run number (for UNS R30035 only);
- d) chemistry check analysis;
- e) hot work reduction ratio (not required for UNS R30035);
- f) heat treat parameters including times, temperatures, quench media, and diagram or photo of furnace loading; results of mechanical tests;
- g) results of macrostructure evaluations (if applicable for the material grade);
- h) results of microstructure evaluations (if applicable for the material grade);
- i) results of dimensional and thread fit inspection;
- j) results of visual inspection
- k) results of NDE inspections;
- l) results of Positive Material Identification
- m) type of coating, where applicable production lot quantity, i.e. actual lot size manufactured;

- n) method of thread forming, i.e. machine cut or roll thread
- o) BSL qualification level;
- p) product marking;
- q) certification that the product meets the requirements of this standard;
- r) additional certification requirements stated in API 6ACRA and ASTM A453, and the purchaser's or manufacturer's specification for UNS R30035;
- s) statement of no weld repair.

**7.2.1** Product that has been retested or reheat treated as per ASTM A962/A962M-22, Section 16 (exclusive of retempering) shall be identified as such on the certificates.

## **8 Marking**

### **8.1 Product Marking**

**8.1.1** Product marking for Grade 660 Class D shall be in accordance with ASTM A453.

**8.1.2** Product marking for ferritic-austenitic stainless steels shall be in accordance with ASTM A1082

**8.1.3** Product marking for API 6ACRA and UNS R30035 shall consist of the manufacturer's identification and the grade identification listed in Table 6.

**Table 6—API 6ACRA and UNS R30035 Grade Identification Markings**

API 6ACRA or UNS and Material Designation		Marking
<b>N06625</b>	<b>95K</b>	<b>N0A</b>
N07716	120K	N1A
N07716	140K	N1B
N07718	120K	N2A
N07718	140K	N2B
N07718	150K	N2C
N07725	120K	N3A
N09925	110K	N4A
N09935	110K	N5A
N09945	125K	N6A
N09946	140K	N7A
N09946	150K	N7B
N09946	160K	N7C
N09955	120K	N8A
N09955	140K	N8B
R30035 work strengthen only		R3A
R30035 work strengthen and aged 1300 °F		R3B
R30035 work strengthen and aged 1350 °F		R3C
R30035 work strengthen and aged 1425 °F		R3D
R30035 work strengthen and aged 1450 °F		R3E
R30035 work strengthen and aged 1475 °F		R3F
R30035 work strengthen and aged 1500 °F		R3G

## 8.2 Marking Required by this Specification

**8.2.1** Bolting shall be marked with unique heat treatment lot identification and the following:

- “20F2” for BSL-2;
- “20F3” for BSL-3.

**8.2.2** A raw material “cast” or “heat” number (or any part thereof) shall not be used as the unique heat treatment lot traceability.

**8.2.3** Each piece 1 in. (M24) nominal diameter and larger shall be marked. For bolting less than 1 in. (M24) nominal diameter, the bolting shall be securely containerized to maintain heat treatment lot identification and traceability. Multiple heat treatment lots shall not be mixed in a single container. Containers used in the processing, storing, and shipping of bolting not individually marked shall be clearly labeled with all marking information required by the ASTM specification, as applicable, and this standard.

**8.2.4** Where bolting is specified to be coated or plated, the required markings shall be applied prior to coating or plating.

**8.2.5** Markings on coated or plated bolting shall be legible after coating or plating.

## **9 Record Retention**

The bolting manufacturer shall establish and maintain documented procedures to control all documents and data required by this standard. Records required by this standard shall be maintained for a minimum of 10 years from the date of manufacture. Documents and data may be in any type of media (hard copy or electronic) and shall be:

- a) maintained to demonstrate conformance to specified requirements;
- b) legible;
- c) retained and readily retrievable;
- d) stored in an environment to prevent loss.
- e) available and auditable by user/purchaser.

## **10 Storage and Shipping**

Bolting shall be packaged for storage and shipping in accordance with the written specifications of the bolting manufacturer.





## Annex A (Normative)

### Raw Material Manufacturer Technical Audit Requirements

#### A.1 General

- A.1.1** As a part of the technical audit, the bolting manufacturer shall ensure that a raw material manufacturer has implemented controls for the raw material essential variables in Table 2 for each grade of raw material ordered.
- A.1.2** On-site technical audits of the raw material manufacturer shall be performed and documented by the bolting manufacturer's technical authority (see 3.1.18). The bolting manufacturer shall document the approval of the technical audit report.
- A.1.3** Raw material manufacturers shall be qualified to a specific grade listed in 4.4.1 per facility location.

#### A.2 Technical Audit Questions

Table A.1 lists individual mill operations of raw material manufacturers. When an individual mill operation is applicable to the raw material being qualified by the bolting manufacturer, the technical audit questions listed for that operation shall be included in the raw material manufacturer technical audit.

**Table A.1 – Technical Mill Audit Questions**

Operation	Technical Audit Questions	Industry Guidelines
Electric Furnace (EF)	What type of furnace is used?	Electric Furnace or Electric-Arc Furnace
	How is final chemical composition controlled?	Internal melt aims; either electronic software calculations or manual elemental reversion rate calculations
	How are the transfer ladles maintained at temperature?	Pre-heating at temperatures greater than 212 °F (100 °C)
	How is pouring temperature controlled?	Either calibrated thermocouple or optical/infrared pyrometer
	How and when is scrap tested for radioactivity?	Either when entering the facility or prior to building scrap load for addition to the EF; testing by manual or automated Geiger Counter or Gamma ray radiography
Vacuum Degassing (VD)	How is residual gas content determined?	Either time under negative pressure from empirical data or chemical analyses
	How is the ladle vacuum controlled and maintained?	Digital control; scheduled maintenance procedures
Argon-Oxygen Decarburization (AOD)	How are additions controlled?	Internal melt aims; either electronic software calculations or manual elemental reversion rate calculations

	How are the Argon and Oxygen ratios controlled?	Pneumatic pressure controls; use of tuyeres
	How is tapping chemical composition controlled?	Internal melt aims; either electronic software calculations or manual elemental reversion rate calculations;
Ingot Pouring (Teeming)	What is the pouring process (top or bottom)?	Bottom pouring acceptable for all BSLs;  Top pouring is acceptable for BSL-1 only
	What are methods used to control top pour process?	Steady state flow upon start of pouring/teeming, no breaks or pauses allowed during pour
	How is ladle temperature maintained?	Ladle hot topping insulation or cover, proper slag layer without breaks/separation in layer, and/or controlled superheating
	Is Argon shrouding used?	Recommended to prevent ladle stream oxidation
	What are the hot-topping practices?	Use of insulating sideboards, insulating powder or cover (i.e., Vermiculite), a reduction in ladle pouring rate, and/or other insulating methods
	How are ingot cropping practices controlled?	Either historical established minimums for ingot tops and bottoms or by ultrasonic testing
Continuous Casting (Concast)	What type of continuous caster (vertical, traditional bend, etc.) is used?	All are acceptable
	What is the frequency of tundish changes?	Shall be based on refractory life
	How are heat transitions identified and controlled?	Either historical established minimum lengths for transition material scrapping, chemical analyses, or other transition material identification that is unique from each heat
	How is superheat, cast speed, and strand cooling controlled?	Each shall be documented for the intended grade; monitored by either calibrated thermocouple or optical/infrared pyrometer
	Is electromagnetic stirring used? If yes, where in the cast?	At least one location is recommended prior to the intersection of any two cast strand solidification fronts (for square bar) or prior to the "V" solidification point (for round bar)

		NOTE: The actual location and number of setups are based on type of caster in use
Vacuum Induction Melting (VIM)	What is the pouring process (top or bottom)?	Top and bottom pouring acceptable for all BSLs.
	How is the vacuum controlled and maintained?	Digital pressure monitoring; automatic vacuum pumping controls with required minimum negative pressure value
	How is final chemical composition controlled?	Internal melt aims; either electronic software calculations or manual elemental reversion rate calculations
	How is scrap chemical composition controlled?	Internal melt aims; known chemical composition prior to addition into ladle
Vacuum Arc Remelting (VAR)	How are melt rate and hot-topping practices controlled?	Computer controlled melt rate step-down practices; directionally controlled solidification
	What is the electrode size?	All sizes acceptable
	How is vacuum controlled and maintained?	Digital pressure monitoring; automatic vacuum pumping controls with required minimum negative pressure value
	How is final re-melt ingot chemical composition controlled?	Internal melt aims; either electronic software calculations or manual elemental reversion rate calculations
	What is/are the final ingot size(s)?	All sizes acceptable to achieve proper hot work ratio for applicable BSL
Electro-Slag Remelting (ESR)	How are melt rate and hot-topping practices controlled?	Computer controlled melt rate step-down practices; directionally controlled solidification
	How is cooling maintained in the molds?	Copper-lining and water cooled, or other means established by the ESR manufacturer
	How is flux added and controlled?	Calculated flux dry weight based on grade and ingot size; manual or automatic additions acceptable
	Is slag/flux cap thickness controlled?	Defined by calculated flux dry weight based on grade and ingot size
	What is the electrode size?	All sizes acceptable

	How is final re-melt ingot chemical composition controlled?	Internal melt aims; either electronic software calculations or manual elemental reversion rate calculations
	What is/are the final ingot size(s)?	All sizes acceptable to achieve proper hot work ratio for applicable BSL
Mill Testing and Quality Control	Is lab testing in-house? If yes, is the lab ISO 17025 qualified?	Yes or no; identify lab qualifications
	How are the chemical composition samples during steelmaking identified and controlled?	Unique identification traceable to heat
	Is the lab capable to perform trace element analysis?	Yes or no; identify lab capabilities
	Is Positive Material Identification (PMI) capability available?	Yes or no; identify lab capabilities
	Is NDE available? If yes, is there a certified Level III available?	Yes or no; identify NDE qualifications
	Is ultrasonic examination available? If yes, is ultrasonic examination controlled per 5.9.3.2 and 5.9.4.2?	Yes or no; identify NDE capabilities and qualifications
Hot Work/Reduction Ratios	How is hot work calculated?	Per API 20B
	Is hot work continuous or discrete?	Hot work shall be uniform throughout the bar cross-section
	How is hot working temperature controlled?	Either calibrated thermocouple or optical/infrared pyrometer
	What is the maximum hot work ratio possible?	No limit
	How is raw material hot worked to achieve appropriate reduction??	All methods are acceptable as long as bars have a wrought, homogeneous microstructure
Heat Treatment (only for bar heat treated by the raw material manufacturer)	Do furnaces meet the survey and calibration requirements of API 6A, SAE AMS2750 or SAE AMSH6875?	Furnaces surveyed annually; thermocouples calibrated every 3 months
	Is induction heating per ASTM A1100 used?	Yes or no; identify capabilities and qualifications
	Is heat treatment controlled per 5.3.2, 5.3.3, and 5.3.4?	Yes or no; identify capabilities and qualifications
	What is maximum transfer time?	Bar shall be transferred to the quench tank, or full quenching underway, within 90 seconds upon completely exiting the furnace

	What method is used to control and maintain quench temperature?	Either calibrated thermocouple or optical/infrared pyrometer
Traceability and Marking	How are individual bar identifications maintained?	Bars shall be hard-stamped, tagged, or marked with indelible ink
	What is the minimum bar size for physical stenciling/stamping of the identification?	No limit; identify capabilities
	How are bar surface defects addressed?	Procedure for identifying surface defects; no weld repair allowed



## **Annex B** (normative)

### **Avoidance of Contamination of Nickel Alloys**

#### **B.1 Introduction**

Nickel alloys may become contaminated during various manufacturing operations. Contamination with some substances may result in embrittlement and cracking failures, while contamination with other substances may result in pitting and corrosion failures.

#### **B.2 Lubricants**

Sulfur can embrittle nickel alloys at elevated temperatures, such as those used for heat treating or forging the nickel alloys. Sulfur-containing lubricants may be used during manufacturing, but shall be completely removed prior to any hot forging or heat treatment operations.

Chlorine can promote pitting corrosion of nickel alloys after long exposure. Chlorine-containing lubricants may be used for cold forming but shall be completely removed after the forming operations.

Pigmented oils and greases should be selected with care. Oils and greases with lead carbonate, zinc oxide, or other low melting point metals shall not be used. These low melting point metallic compounds can embrittle nickel alloys during exposure to elevated temperatures, such as those used for heat treating or forging nickel alloys.

#### **B.3 Marking Materials**

Markers containing sulfur, chlorine, phosphorus, and low melting point metals can cause embrittlement or corrosion issues as described above and shall not be used.





## Bibliography

- [1] API TR21D, *A Study of the Effect of Thread Forming on the Susceptibility of Precipitation Hardened Ni-Based Alloy Fasteners to Hydrogen Embrittlement; First Edition*

Ballot Draft