Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries

API SPECIFICATION 20E
THIRD EDITION, XXXXXXXXXXXXXXXXX 202X

API MONOGRAM PROGRAM EFFECTIVE DATE: XXXXXX XX, 202X

Introduction

This specification is the result of updating requirements from API 20E, Second Edition. API 20E, Third Edition was developed based on input from the API 20E Task Group of technical experts. The technical revisions have been made to accommodate the needs of industry to move this specification to a higher level of service to the petroleum and natural gas industry.

Highlights of some of the significant changes between the second and third editions include:

— metric equivalencies for thread descriptions have been added

— essential variables were identified and added

— labs performing qualification lot testing for all BSLs and final acceptance testing of BSL-2 and BSL-3 product are now required to be ISO 17025 accredited by an authorized entity

— grade 2H and 2HM nuts have been limited to BSL-1 applications

— grade B23 and B24 bolting has been restricted to classes 3, 4, & 5

— supplier audit frequencies have been defined

— triennial verification of incoming raw material using defined testing criteria is now required

— API 20H and 20N have been added as acceptable furnace qualification methodologies

— ASTM A1100 has been added as an acceptable induction heating process qualification methodology

— coating and plating processes have been identified as critical and will require validation per API Q1

— ASTM F519 testing has been replaced with ASTM F606 section 7 testing, as the method to verify that a plating process does not cause internal hydrogen embrittlement

— a maximum yield strength limit of 135 ksi has been imposed for BSL-2 and BSL-3

— NDE processes conforming with API 20D

— guidance for the allowance of oversizing of internal threads

— oversized nuts are required to be stamped with an “O” for purposes of identification

— final documentation to include copies of the original bolting manufacturer’s test reports

— use of the heat number as the manufacturing lot number has been prohibited

— minimum manufacturing facility requirements have been added

Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries

1 Scope

1.1 Purpose

This standard specifies requirements for the qualification, production, and documentation of alloy and carbon steel bolting used in the petroleum and natural gas industries.

1.2 Applicability

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

1.3 Bolting Specification Levels

This standard establishes requirements for three bolting specification levels (BSLs). These three BSL designations define different levels of technical, quality, and qualification requirements, BSL-1, BSL-2, and BSL-3. The BSLs are numbered in increasing levels of requirements in order to reflect increasing technical, quality, and qualification criteria.

1.4 Bolting Types

This standard covers the following finished product forms, grouped according to the processes, and sizes for qualification purposes:

a) machined studs;

b) machined bolts, screws, and nuts;

c) cold formed bolts, screws, and nuts with cut or cold formed threads (BSL-1 only);

d) hot formed bolts and screws <1.5 in. (M36) nominal diameter;

e) hot formed bolts and screws ≥1.5 in. (M36) nominal diameter;

f) roll threaded studs, bolts, and screws <1.5 in. (M36) diameter;

g) roll threaded studs, bolts, and screws ≥1.5 in. (M36) diameter;

h) hot formed nuts <1.5 in. (M36) nominal diameter;

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.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API Specification 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, 2nd Edition, *Heat Treatment and Testing of Carbon and Low Alloy Steel Large Cross Section and Critical Section Components*

API 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*

ANSI/ASQ Z1.4, *Sampling Procedures and Tables for Inspection by Attributes*

ASTM [1] A29/A29M, *Standard Specification for General Requirements for Steel Bars, Carbon and Alloy, Hot-Wrought*

ASTM A193/A193M, *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High Pressure Service and Other Special Purpose Applications*

ASTM A194/A194M, *Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service or Both*

ASTM A320/A320M, *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for Low Temperature Service*

ASTM A370, *Standard Test Method and Definitions for Mechanical Testing of Steel Products*

ASTM A540/A540M, *Standard Specification for Alloy Steel Bolting for Special Applications*

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

ASTM A941, *Standard Terminology Relating to Steel, Stainless Steel, Related Alloys and Ferroalloys*

ASTM A962/A962M-22, *Standard Specification for Common Requirements for Steel Fasteners or Fastener Materials, or Both, Intended for Use at Any Temperature from Cryogenic to the Creep Range*

ASTM A1100, *Standard Guide for Qualification and Control of Induction Heat Treating*

ASTM B850-98 (2015), *Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement*

ASTM E10, *Standard Test Method for Brinell Hardness of Metallic Materials*

ASTM E18, *Standard Test Method for Rockwell Hardness of Metallic Materials*

ASTM E45, *Standard Test Method for Determining the Inclusion Content of Steel*

[1] ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

ASTM E112, *Standard Test Method for Determining Average Grain Size*

ASTM E140, *Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness*

ASTM E381, *Standard Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings*

ASTM E384, *Standard Test Method for Microindentation Hardness of Materials*

ASTM F606/F606M-19, *Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets*

ASTM F1470-12, *Standard Practice for Fastener Sampling for Specified Mechanical Properties and Performance Inspection*

ANSI/ASME B1.1, *Unified Inch Screw Threads (UN and UNR Thread Form)*

ISO 17020 [2], *Conformity assessment – Requirements for the operation of various types of bodies performing inspection*

ISO 17025, *General Requirements for the Competence of Testing and Calibration Laboratories*

SAE AMS2750 [3]*, Pyrometry*

SAE AMSH6875, *Heat Treatment of Steel Raw Materials*

3 Terms, Definitions, and Abbreviations

3.1 Terms and Definitions

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

3.1.1
banding
The separation of one or more phases or constituents in a two-phase or multiphase microstructure, or of segregated regions in a single phase or constituent microstructure, into distinct layers parallel to the deformation axis due to elongation of microsegregation.

3.1.2
bolting
All-thread studs, tap-end studs, double-ended studs, headed bolts, cap screws, screws, and nuts.

3.1.3
bolting manufacturer
An organization qualified for the production and marking of this bolting, who through the use of manufacturing equipment and processes appropriate for the bolting product form, transforms raw material into finished bolting and marks the bolting as meeting the specification.

3.1.4

[2] International Organization for Standardization, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, www.iso.org.
[3] SAE International, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096, www.sae.org.

cold formed bolts, screws, and nuts
Parts formed through the mechanical cold (at a temperature below the recrystallization temperature) up-setting of wire, rod, or bar in order to generate the bolt or screw head (cold heading) or the configuration of the nut.

3.1.5
final quality heat treatment
The final heat treatment, inclusive of stress relieving, in the manufacturing process of bolting.

NOTE This definition does not extend to coating/plating curing or baking operations.

3.1.6
hard banding
A banded microstructure which exhibits a white, featureless phase when examined using etchants such as various nital solutions. These white, featureless bands have extremely high hardness levels (typically > 100HK difference from adjacent bands) due to microsegregation.

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 treatment lot
a) Batch furnace: bolting or raw material of a single heat and diameter, heat treated together as a single austenitizing, quenching, tempering, and stress-relieving charge.

b) Continuous furnace: bolting or raw material of a single heat and diameter heat treated without interruption in a continuous charge (see 5.7.1).

3.1.9
hot formed bolts, screws, and nuts
Parts formed through the mechanical hot (at a temperature above the recrystallization temperature) up-setting 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 Manufacturing process specification is usually proprietary by manufacturer and not for general publication but is available for review by customers or authorized third parties.

3.1.12
nominal diameter
The bolting thread size, as referred to in the description of the bolting.

NOTE: For example, the nominal diameter of a ¾"-10 bolt is ¾"

3.1.13
production lot
Bolting of a single nominal diameter and grade made from the same heat treatment lot.

3.1.14
raw material
Bar, coil, rod, or wire used to manufacture bolting.

3.1.15
raw material manufacturer
The steel mill or forging supplier of raw material used to produce qualified bolting.

NOTE A distributor is not considered a raw material manufacturer.

3.1.16
supplier
A provider of subcontracted products or services associated with the essential variables of this specification.

NOTE Suppliers do not include the raw material manufacturer.

3.1.17
technical authority
A competent and technically qualified person or organization with the expertise, skills, and experience regarding quality and manufacturing processes necessary to perform the required verification(s).

NOTE Technical authority may also be considered a Subject Matter Expert (SME).

3.1.18
wrought structure
Structure that contains no cast dendritic elements.

3.2 Abbreviations

BSL bolting specification level

MPS manufacturing process specification

NDE nondestructive examination

UNS Unified Numbering System

TUS Temperature Uniformity Survey

4 Qualification Bolting

4.1 General

4.1.1 The manufacturer shall have a quality management system that meets or exceeds the requirements of API Q1.

4.1.2 The manufacturer may qualify to one or more of the nine bolting types listed in 1.4 and to one or more of

the three BSLs.

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

4.1.4 The process control activities associated with the manufacturing of bolting shall be as identified in Table 1 for each manufacturing site. The manufacturer shall maintain equipment and personnel to ensure conformance to the requirements listed in Table 1 for all activities performed by the manufacturer.

Table 1—Process Control Requirements

Process Control Activity	Performed by:		
	Bolting Manufacturer	Outsourced – BSL-1	Outsourced – BSL-2 & 3
Receiving inspection	X	Not Permitted	Not Permitted
Forging	X	X	X
Heat treating	X	X	X
Rough machining	X	X	X
Final machining	X	X	Not Permitted
Threading cutting and rolling	X	X	Not Permitted
Tensile and impact testing	X	X	X
Metallography	X	X	X
Chemical analysis	X	X	X
Hardness testing	X	X	X
NDE surface	X	X	X
NDE volumetric	X	X	X
Marking	X	Not Permitted	Not Permitted
Coating	X	X	X
Final inspection	X	Not Permitted	Not Permitted

4.1.5 Bolting shall be produced from raw material procured from a qualified supplier as defined in Section 4.7 and manufactured in accordance with an applicable manufacturing process specification (MPS) from a bolting material grade listed in Section 4.4. The MPS shall address all of the processes that contain essential variables as listed in Section 4.2.

4.1.6 If no products of a qualified bolting type listed in Section 1.4 are manufactured to a qualified MPS within 5 years of the previous qualification or manufacturing of that bolting type, requalification shall be required prior to manufacturing the given bolting type. Additionally, if any changes are made to the essential variables associated with a bolting manufacturing process, requalification shall be required.

4.1.7 The manufacturer shall retain and have available an MPS (see 5.2) and qualification records (see 4.6) for each bolting type qualified. The qualification records shall show all of the products, processes, and sizes qualified in addition to all of the results of tests and inspections required per Table 3.

4.2 Essential Variables

For final product manufacturing, raw material manufacturer, and supplier qualifications to remain valid, all production shall be within the essential variables listed in Table 2. Changes to any of the parameters in Table 2,

outside of the limits defined in the applicable MPS or procedure, requires verification or validation of the changed essential variable in accordance with the requirements of API Q1. The verification or validation shall demonstrate the ability of these processes to achieve specified requirements. The manufacturer shall have a procedure for control of changes to the essential variables and shall retain and have available, records of these verifications or validations. Essential variables for each BSL are identified with an "X" in the applicable column.

Table 2 - Limits of Changes to Essential Variables

Process	Essential Variable		BSL-1	BSL-2	BSL-3
Raw Material	a	Change to the casting process (bottom pour ingot to continuous cast or vice versa)		X	
	b	Change to the pouring practice		X	X
	c	Change to the chemical composition		X	X
	d	Change in acceptance criteria for metallurgical testing		X	X
	e	Change to the melting practice		X	X
	f	Change to the forming method		X	X
	g	Change in the raw material manufacturer or raw material manufacturer location (steel mill) [a, b]	X	X	X
Forging	h	Change in the type of forging equipment		X	X
	i	Change in the method of heating		X	X
	j	Change in the temperature monitoring method		X	X
	k	Reduction in the minimum forging capacity		X	X
	l	Change to the forging location [a,b]	X	X	X
Heat Treatment	m	Change in time and temperature parameters		X	X
	n	Change in equipment type (e.g., continuous to batch, gas-fired, electric)		X	X
	o	Change in type or location of furnace temperature monitoring equipment		X	X
	p	Change in cooling methods or media		X	X

	q	Change in furnace control and calibration method/acceptance criteria		X	X
	r	Change to the furnace loading practice		X	X
	s	Increase in the transfer time		X	X
	t	Change to the heat treatment location [a, b]	X	X	X
Machining[c]	u	Change in type of machining or threading equipment (e.g., CNC to manual, single point threading to chaser threading)		X	X
	v	Change in machining location [a, b]	X	X	X

[a] Location refers to the physical address and/or ownership of the facility.

[b] A change in location is constituted by any of the following:
- moving an operation from one bolting manufacturer's facility to another
- moving an operation from one supplier location to another supplier or supplier location
- moving an operation from a supplier location to the bolting manufacturer's location or vice versa
- a change in ownership of the bolting manufacturer's or supplier's facility

[c] Within the context of Table 2, machining only refers to final dimension machining.

4.3 Qualification Testing

4.3.1 Bolting shall be tested and evaluated in order to establish qualification to the bolting types listed in Section 1.4 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 All required tests, including those certified by the raw material manufacturer, shall be performed by a laboratory accredited to ISO/IEC 17025. For ultrasonic examination, magnetic particle inspection, and liquid penetrant inspection, accreditation to ISO/IEC 17020 is an acceptable alternative to ISO/IEC 17025.

Table 3 – Bolting Test Requirements

BSL	Material	Forge/ Heat Treat	Chemistry	Mechanical	Metallurgical	Hardness	NDE Surface	NDE Volumetric	Dimensional and Visual Inspection
BSL-1	5.4.1	5.3.2	5.6	5.7.1	5.8.2	5.8.5.2	5.9.2	5.9.2	5.10.1
BSL-2	5.4.2	5.3.3	5.6	5.7.2	5.8.3	5.8.5.3	5.9.3.1	5.9.3.2	5.10.3

BSL-3	5.4.3	5.3.4	5.6	5.7.2	5.8.4	5.8.5.4	5.9.4.1	5.9.4.2	5.10.4

4.4 Material grades

4.4.1 The following bolting material grades are covered by this standard:

— ASTM A193/A193M Grades B7 and B7M;

— ASTM A194/A194M Grades 7 and 7M,

— ASTM A194/A194M Grades 2H and 2HM (BSL-1 only);

— ASTM A320/A320M Grades L7, L7M, and L43;

— ASTM A540/A540M Grades B22 and B23, classes 3, 4, & 5;

— equipment manufacturer's proprietary bolting material specification.

4.4.2 All requirements of the referenced ASTM specifications or the equipment manufacturer's proprietary bolting material specification shall be met 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.

4.4.3 The location of tensile and impact specimens must be based on the nominal diameter of the final bolting product and not on the diameter of the starting bar or forging at the time of heat treatment.

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 Section 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 3.1.13), fails to meet acceptance criteria, the entire lot shall be rejected.

4.5.2.3 Should the manufacturer choose to continue the qualification process with the same production lot, the entire production lot shall be reprocessed. A maximum of two full reheat treatments is permitted.

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 qualification:

a) BSL;

b) Bolting type (see section 1.4);

c) ASTM specification number, edition, and grade or the equipment manufacturer's proprietary bolting material specification;

d) heat number;

e) steel manufacturer;

f) steel refining method;

g) size;

h) essential variables (see Table 2);

i) MPS;

j) record of test results, as applicable per Table 3;

k) test laboratory qualification;

l) records of qualification test failures and corrective action;

m) supplier(s) name and address and records of qualification for each subcontracted process.

4.7 Suppliers

4.7.1 General

4.7.1.1 The bolting manufacturer shall have a documented and fully implemented procedure for qualifying suppliers performing operations using the essential variables listed in Table 2.

4.7.1.2 Raw material manufacturers shall be qualified in accordance with Section 4.7.2. All others shall be qualified in accordance with Section 4.7.1.

4.7.1.3 Only qualified suppliers shall be used to perform subcontracted operations.

4.7.1.4 For BSL-2 and BSL-3 product, the initial qualification process shall include an onsite audit and technical evaluation performed by a technical authority.

4.7.1.5 Qualification to a higher BSL shall qualify a lower BSL.

4.7.1.6 Processes for essential variables listed in Table 2 shall be evaluated by a technical authority in accordance with applicable frequencies in Table 4

4.7.1.7 Suppliers shall be re-audited, at a minimum, by the bolting manufacturer's technical authority at the frequency specified in Table 4.

Table 4 - Maximum Frequencies for Supplier Audits and Raw Material Testing by Bolting Manufacturer

BSL	Audit Type	Quality/Technical Audit	Raw Material Testing (4.7.3)
1	Remote or Onsite	5 years	5 years
2	Onsite	3 years	3 years
3	Onsite	3 years	3 years

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

4.7.1.9 Qualification of subcontracted processes used to produce BSL-3 products shall be qualified with a statistically relevant sample per Table 7, of each subcontracted process per the manufacturer's documented procedure.

4.7.1.10 Supplier 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.

4.7.1.11 For BSL-2 and BSL-3 product, suppliers of NDE services shall have a quality management system accredited to ISO 17020 or ISO 17025 and 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 Raw Material Manufacturers

4.7.2.1 Raw material manufacturers shall be qualified for each grade and heat treat condition of material supplied by the raw material manufacturer as required per Section 4.7.3.

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

4.7.2.3 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.

4.7.2.4 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.

4.7.2.5 For BSL-1 raw material manufacturers, qualification of product shall consist of testing per Section 4.7.3. The bolting manufacturer, in accordance with API Q1, shall evaluate the raw material manufacturer.

4.7.2.6 For BSL-2 and BSL-3 raw material manufacturers, in addition to the requirements of Section 4.7.3, a technical audit shall be performed and shall follow the requirements of Annex A.

4.7.3 Raw Material Testing Requirements

4.7.3.1 Raw material may be supplied to the bolting manufacturer in either the heat-treated condition or a condition requiring further heat treatment. At the frequency specified in Table 4, a technical verification of the

supplied raw material shall be performed for each raw material manufacturer, per the requirements of Table 5. For the purposes of this specification, the following raw material conditions shall apply:

a) Supplied condition H: Raw material received by the bolting manufacturer in its final austenitizing, quench, and tempered state (excluding any stress relief), and

b) Supplied condition A: Raw material to be subsequently heat treated after receipt by the bolting manufacturer (excluding any stress relief)

4.7.3.2 For condition H material, testing shall be performed on a random heat for each bolting grade used by the manufacture in section 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.

4.7.3.3 For condition A material, testing shall be performed on a random heat for each Unified Numbering System (UNS) designation associated with the bolting grades listed in section 4.4, as applicable to the raw material manufacturer.

4.7.3.4 Testing of material in supplied condition H shall also qualify supplied condition A. Testing of material in supplied condition A shall not qualify supplied condition H.

4.7.3.5 Qualification to a higher BSL shall qualify to a lower BSL.

Table 5 – Raw Material Retesting & Validation Requirements for Technical Verification

BSL	Supplied Condition	Chemistry	Heat Treatment	Tensile	Charpy	Hardness	Metallurgical
BSL-1	H[a]	5.4.1	5.3.2	5.7.2.2	5.7.2.2	5.8.5.2	ASTM A962
	A[b]	5.4.1	---	---	---	---	ASTM A962
BSL-2	H	5.4.2	5.3.3	5.7.2.2	5.7.2.2	5.8.5.3	5.8.3
	A	5.4.2	---	---	---	---	5.8.3.1.2 & 5.8.3.2
BSL-3	H	5.4.3	5.3.4	5.7.2.2	5.7.2.2	5.8.5.4	5.8.3
	A	5.4.3	---	---	---	---	5.8.3.1.2 & 5.8.3.2

[a] As-received heat-treated condition
[b] As-received condition

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. For BSL-1, this may be the applicable ASTM specification. For BSL-2 and BSL-3, material specifications shall include the following:

a) material grade, including element chemistry and allowable ranges;

b) acceptable melt practices and ladle refinements, as applicable per BSL;

c) acceptable hot work reduction range, as applicable per BSL;

d) acceptable cleanliness level range, as applicable per BSL;

e) heat treatment requirements, as applicable per BSL;

f) mechanical properties, as applicable per BSL;

g) acceptable inspection practices and criteria, as applicable per BSL.

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

The bolting manufacturer shall prepare an MPS to include, at a minimum, acceptance criteria for all bolting manufacturing parameters including the essential variables listed in Table 2

5.3 Manufacturing Requirements

5.3.1 General

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

5.3.2 BSL-1 Requirements

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

5.3.2.2 Manufacturing processes shall be performed so as to avoid the introduction of stress risers that can occur from sharp angles and tool marks. Threads may be cut or rolled. Unified National Threads shall be "R" (UNR controlled radius series) for external threads and UN for internal threads (ANSI/ASME B1.1). Metric threads shall incorporate a non-reversing curvature root profile, in accordance with ISO 965-1, regardless of mechanical properties.

5.3.2.3 Heat treatment shall be in accordance with the applicable standard listed in 4.4.1, except that direct resistance heating is not permitted.

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

a) Batch Heat Treatment: API 20H, API 6A, AMS-H-6875, AMS 2750

b) Continuous Heat Treatment: API 20N, API 6A, AMS-H-6875, AMS 2750

c) Induction Heat Treatment: ASTM A1100

Induction heat treatment processes cannot undergo a TUS, as such the manufacturing procedure validation testing requirements of ASTM A1100 shall be followed for heat treatment to achieve final mechanical properties.

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

5.3.2.5 Welding of bolting is prohibited.

5.3.3 BSL-2 Requirements

5.3.3.1 Requirements specified for BSL-1 are required for BSL-2.

5.3.3.2 The manufacturer shall have written forging/hot heading and heat treatment procedures defining, at a minimum, the essential variables defined in Table 2.

5.3.3.3 When forging/hot heading or heat treatment is outsourced, the supplier's forging or heat treatment procedures shall be approved by the bolting manufacturer.

5.3.3.4 When induction heating is used for forging, the manufacturer's equipment shall include temperature monitoring equipment and an automatic fail-safe system to prevent overheating.

5.3.3.5 ASTM A320/A320M Grade L43, ASTM A540/A540M Grade B23, and the equipment manufacturer's proprietary bolting material specification based on AISI 4340 material shall be double tempered.

5.3.3.6 When threads are rolled, parts shall subsequently be stress relieved at a temperature 25°F (14°C)-50 ºF (28 ºC) below the final tempering temperature, which is intended to establish mechanical properties. This stress relief requirement is also met if the final temper heat treatment is done after any type of thread forming.

5.3.3.7 Furnace loading shall be in accordance with API 6HT, Section 6.3.3.

5.3.3.8 Furnace loading diagram or photo shall be prepared for each load configuration.

5.3.3.9 Water, oil, and polymer quenchant media shall be controlled in accordance with API 6HT, Section 6.2.2.

5.3.4 BSL-3 Requirements

5.3.4.1 Requirements specified for BSL-2 are required for BSL-3.

5.3.4.2 A minimum of one contact thermocouple attached to a part shall be used to verify heat treatment times and temperatures. This referenced thermocoupled part shall be placed either in a location deemed to have the slowest heating rate or centrally in the furnace load.

5.3.4.3 Batch process heat treatment shall be required.

5.3.5 Plating and Coating

5.3.5.1 Plating and coating shall be provided only when specified by the purchaser.

5.3.5.2 For BSL-2 and BSL-3 bolting, plating, and coating processes are critical and shall be validated/revalidated in conformance with API Q1.

5.3.5.3 Coating application process validations shall be valid unless a gap of three years in supply has elapsed.

5.3.5.4 Plating and coating shall be specified in accordance with industry or the equipment manufacturer's proprietary bolting material specification.

5.3.5.5 Zinc electroplating is not permitted for BSL-3 bolting used in splash zone or subsea service

5.3.5.6 Internal hydrogen embrittlement prevention:

— All electroplated parts, except parts of Grades B7M, L7M, 2HM, and 7M, shall be baked within 2 hours after plating at 375 ºF–425 ºF (191 ºC–218 ºC) for 8 hours minimum at temperature.

NOTE Refer to ASTM B850-98 (2015) Class ER9.

— The requirements of 5.3.2.4 shall apply to the ovens used for baking.

— Verification that the plating process does not induce hydrogen embrittlement in API 20E bolting shall be performed.
— This verification shall consist of performing a sustained load test per ASTM F606-19, section 7 . The test shall be performed once for each plating process, as defined by the variables listed above.

- This verification shall be performed per Table 4minimum frequency. A change to any of the variables listed below, will require another verification test per this section. Record of this embrittlement verification testing shall be kept by the bolting manufacturer.
  - Type of electroplating
  - Minimum thickness
  - Baking temperature range
  - Bath type: acid vs alkaline
  - Plating process: rack vs barrel
  - Plating supplier

5.3.5.7 The following shall be reported on plating and coating certificates of conformance:

a) part description;

b) specification number and revision (year date for ASTM specifications);

c) description of plating/coating including type, thickness, finish, and other applicable requirements;

d) statement of conformance with to section 5.3.5.

5.4 Raw Material

5.4.1 BSL-1

5.4.1.1 The steel shall be fully wrought.

5.4.1.2 The hot work reduction ratio based on starting material diameter shall be a minimum of 4.0:1.

5.4.1.3 The steel shall conform to the requirements of the standards listed in 4.4.1, as applicable.

5.4.1.4 Intentional additions of boron are not allowed.

5.4.1.5 All elements intentionally added to the heat shall be reported.

5.4.2 BSL-2

5.4.2.1 The requirements specified for BSL-1 are required for BSL-2.

5.4.2.2 Melting method of the raw material shall be fine grain practice as defined by ASTM A941. Steel shall be produced by electric furnace or vacuum induction melting followed by secondary refining practices or ladle refining.

5.4.2.3 The allowable sulfur content shall be 0.025 % maximum, and the allowable phosphorus content shall be 0.025 % maximum.

5.4.2.4 Residual boron content shall not exceed 0.0005 %.

5.4.3 BSL-3

5.4.3.1 The requirements specified for BSL-2 are required for BSL-3 except as specified below.

5.4.3.2 The hot work reduction ratio based on starting material diameter shall be 10.0:1 minimum.

5.4.3.3 Allowable sulfur content shall be 0.015 % maximum, and the allowable phosphorus content shall be 0.015 % maximum.

5.4.3.4 The continuous cast steel making process is prohibited.

5.4.3.5 In addition to the heat analysis performed by the raw material manufacturer, the bolting manufacturer shall perform a product analysis in accordance with ASTM A29.

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:

- Scrapped;
- Retested per ASTM A962;
- Inspected 100 % and the defective parts removed; or
- 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 characteristic affected by rework.

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

5.6 Chemical Analysis

Methods and practices relating to chemical analysis shall be in accordance with ASTM A751. The frequency for 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 including stress relief. When heat treated without interruption in continuous furnaces, as defined in 3.1.8, testing shall be as follows: Not fewer than two tests for the first 20,000 lb. (9000 kg) or less, and an additional test for every 10,000 lb. (4500 kg) or fraction thereof.

The specimen location for destructive mechanical testing shall be based on the nominal diameter of the final product.

Results shall be documented on the test report.

5.7.2 BSL-2 and BSL-3

5.7.2.1 For bolting grades requiring tensile results, actual tested yield strength shall not exceed 135 ksi (930 MPa)

NOTE Refer to API 21TR1, Annex A for additional information regarding strength and hardness limits in subsea environments.

5.7.2.2 When any of the testing has been performed by the raw material manufacturer, the bolting manufacturer shall perform a retest.

5.8 Metallurgical Requirements

5.8.1 General

The following tests shall be performed, as applicable to the specified BSL. Any of the specified tests not performed by the raw material manufacturer shall be performed by the bolting manufacturer. Results shall be documented on the test report.

The specimen location for metallurgical testing shall be based on the nominal diameter of the final product.

5.8.2 BSL-1

The microstructure and macrostructure shall conform to the requirements of the standards listed in 4.4.1, as applicable.

5.8.3 BSL-2

5.8.3.1 Microstructure Testing

5.8.3.1.1 General

Microstructure specimens shall be tested in accordance with ASTM E45, Method A, for inclusion content. For other microstructure evaluations, the specimens shall be taken in the longitudinal direction at ¼*T*.

5.8.3.1.2 Inclusion Content

The microstructure shall conform to the requirements of Table 6. One test shall be conducted per heat.

5.8.3.1.3 Grain Size

Grain size shall be determined for each heat in accordance with ASTM E112 following etching with a suitable reagent. Grain size shall conform to Table 6. Testing shall apply after the final quality heat treatment.

5.8.3.1.4 Microstructure

The microstructure shall be predominately tempered martensite. One test shall be performed per each heat. Testing shall apply after the final quality heat treatment.

5.8.3.1.5 Banding

Hard banding in microstructures, as shown in Figure 1, are not permitted. When a banded microstructure is observed of questionable acceptability, a minimum of 3 Knoop micro-hardness readings per test, in accordance with ASTM E384, shall be taken on the most predominant bands. The test load shall be 500 g, unless extremely thin bands are observed that will not permit an accurate 500 g test, in which case it is permissible to reduce the test load to as low as 50 g to obtain an accurate reading. Individual readings shall not exceed 470 HK. One test shall be conducted per heat. Testing shall apply after the final quality heat treatment.

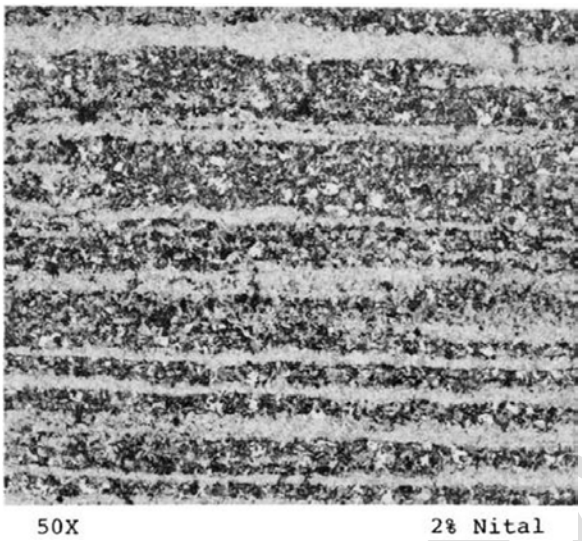

Figure 1 - A micrograph of rejectable hard banding

Table 6—Microstructure and Macrostructure Requirements for BSL-2 and BSL-3

Test	BSL-2	BSL-3
Inclusion content, ASTM E45 Method A	Severity Level Number 2 for thin, 1.5 for thick, all categories	Severity Level Number 2 for thin, 1.5 for thick, all categories
Inclusion test frequency	One per heat	One per heat
Grain size	Size 5 or finer	Size 5 or finer
Grain size test frequency	One per heat	One per heat treatment lot
Microstructure	Predominately tempered martensite	Predominately tempered martensite
Microstructure test frequency	One per each heat	One per heat treatment lot
Macrostructure testing	ASTM E381 S1, R1, C2	ASTM E381 S1, R1, C2
Macrostructure test frequency	One per heat	One per heat
Banding	Figure 1 is not permitted	Figure 1 is not permitted
Banding test frequency	One per each heat	One per heat treatment lot

5.8.3.2 Macrostructure Testing

Macrostructure specimens shall be prepared and evaluated in accordance with ASTM E381 and ASTM A962. The results shall meet the requirements of Table 6. One test shall be conducted per heat.

5.8.4 BSL-3

5.8.4.1 Requirements specified for BSL-2 are required for BSL-3.

5.8.4.2 For grain size and banding, one test shall be performed per each heat treatment lot.

5.8.4.3 When any hard banding is observed, the hardness test evaluation required under BSL-2 shall be required for a minimum of 2 bands.

5.8.5 Hardness Test Requirements

5.8.5.1 General

Hardness testing shall be performed in accordance with ASTM A370 Annex A3. In the case of electromagnetic sorting, ASTM E566 shall apply. Results shall be documented on the test report.

5.8.5.2 BSL-1

5.8.5.2.1 Hardness Testing of Bars and Bolting

The hardness test results shall conform to the requirements of ASTM A193/A193M, ASTM A194/A194M, ASTM A320/A320M, ASTM A540/A540M or the equipment manufacturer's proprietary material specification as applicable, except that maximum hardness for Grades B7, L7, 2H, 7, L43, B22, B23 and the equipment manufacturer's proprietary material specification shall not exceed 34 HRC (319 HBW). Conversion, when necessary, between hardness scales shall be in conformance with ASTM E140. Test frequency shall conform to ASTM F1470, Table 3, sample size A except when 100 % hardness testing is required by the ASTM specification for the grade.

NOTE Refer to API 21TR1, Annex A for additional information regarding strength and hardness limits in subsea environments.

5.8.5.2.2 Hardness Testing of Bars Heat Treated by the Induction Method

For bars heated by induction, a cross section of the bar shall be taken at the same test frequency as the required for lot testing of the heat-treated bar per ASTM A193/A193M. The cross-section shall be ground and a Rockwell hardness traverse performed with tests as close to the edge as permitted by ASTM E18, approximately mid radius, and approximately center. All hardness measurements in the traverse shall meet the acceptance criteria of 5.8.5.2.1.

Electromagnetic testing for hardness in accordance with ASTM A193/A193M is permitted.

5.8.5.3 BSL-2

5.8.5.3.1 Hardness Testing of Bars and Bolting

Hardness testing requirements specified for BSL-1 are required for BSL-2 except that when a hardness traverse for bars heat treated by induction is required, all readings shall be within 3 HRC.

5.8.5.3.2 Hardness Testing of Bolting

Each piece shall be tested.

5.8.5.3.3 Proof Load Testing of Nuts

Nuts shall undergo proof load testing in accordance with the applicable material specification.

In the case of ASTM A194/A194M nuts, S4 shall apply.

Alternatively, if the proof loads specified in S4 cannot be achieved due to equipment limitations, a sample nut from each heat treatment lot shall be cross-sectional hardness tested in accordance with ASTM A370, Annex 3. Hardness shall meet the acceptance criteria of 5.8.5.2.1.

5.8.5.4 BSL-3

5.8.5.4.1 Hardness testing requirements and yield strength limits specified for BSL-2 shall be required for BSL-3.

5.8.5.4.2 Electromagnetic testing for hardness is not permitted.

5.9 Nondestructive Examination Requirements

5.9.1 General

5.9.1.1 NDE processes shall be qualified per the requirements of API 20D

5.9.1.2 Personnel performing surface and volumetric NDE (magnetic particle and ultrasonic examination) shall be certified to ISO 9712 Level 2, ASNT ACCP Level 2 or ASNT SNT-TC-1A Level 2

5.9.1.3 Personnel approving surface and volumetric NDE (magnetic particle and ultrasonic examination) procedures shall be certified to ISO 9712, Level 3, ASNT ACCP Level 3 or ASNT SNT-TC-1A Level 3.

5.9.2 BSL-1

No requirements.

5.9.3 BSL-2

5.9.3.1 Surface NDE is required on bolting after final quality heat treatment, all machining and thread rolling, and prior to coating or plating. Magnetic particle examination shall be in accordance with ASTM A962 S55, including personnel qualification. Acceptance criteria shall be per ASTM A962 S57. Sampling plan shall be as per Table 7. Results shall be documented on an examination report.

5.9.3.2 Ultrasonic examination is required on heat treated material for manufactured bolting, with a nominal diameter greater than 2.5 in. (M64), after all thermal treatment, excluding post-machining stress relief or temper, and prior to threading. Ultrasonic examination shall be performed in accordance with API 6A volumetric NDE examination of stems (PSL-3 and PSL-4), including personnel qualification. The criteria for calibration shall be based on the final product dimensions. Each piece shall be examined. Results shall be documented on the test report.

5.9.4 BSL-3

5.9.4.1 Surface NDE requirements specified for BSL-2 are required for BSL-3 except each piece shall be inspected.

5.9.4.2 Ultrasonic examination is required on heat treated material for manufactured bolting, with a nominal diameter greater than 1 in. (M24), after all thermal treatment, excluding stress relief, and prior to threading. Ultrasonic examination shall be performed in accordance with API 6A volumetric NDE examination of stems

(PSL-3 and PSL-4), including personnel qualification. The criteria for calibration shall be based on the final product dimensions. Each piece shall be examined. Results shall be documented on the test report.

5.10 Dimensional and Visual Inspection

5.10.1 General

All dimensions and visual inspections shall meet the requirements of the applicable ASTM or the equipment manufacturer's specification. Inspections shall be performed prior to coating. Results shall be documented on an inspection report. Undersizing of external threads is not permissible. Oversizing of internal threads shall only be provided when:

a) specified and defined by the purchaser, and
b) explicitly allowed by the API product specification or the intended application.

5.10.2 BSL-1 Sample Size

Sample size shall be as required by the applicable ASTM specification.

5.10.3 BSL-2 Sample Size

Sample size shall be in accordance with Table 7.

5.10.4 BSL-3 Sample Size

Each piece shall be dimensionally and visually inspected.

5.11 Final Acceptance Testing

5.11.1 BSL-1 Final Acceptance Testing

All testing shall be performed in accordance with this specification and the applicable material specifications.

5.11.2 BSL-2 & BSL-3 Final Acceptance Testing

All required tests, including those certified by the raw material manufacturer, shall be performed by a laboratory accredited to ISO 17025. For ultrasonic examination, magnetic particle inspection, and liquid penetrant inspection, ISO 17020 is an acceptable alternative to ISO 17025.

Table 7—Sampling for Dimensional, Visual, and Surface NDE Inspection

Manufactured 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 1 Acceptance number is zero. NOTE 2 Sample shall be random.	

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.

7.2 BSL-1

BSL-1 test reports are as required by the applicable ASTM or equipment manufacturer's proprietary material specification.

7.3 BSL-2 and BSL-3

7.3.1 BSL-2 and BSL-3 test reports shall be original copies from the bolting manufacturer and shall include the

following, as applicable:

- manufacturing process specification reference number including revision;
- copy of original mill certification;
- hot work reduction ratio;
- heat treat parameters including times, temperatures, quench media, and diagram or photo of furnace loading;
- results of mechanical tests;
- results of macrostructure evaluations;
- results of microstructure evaluations;
- results of dimensional inspection;
- results of visual inspection;
- results of NDE inspections;
- type of coating, where applicable;
- manufactured lot quantity, i.e., actual lot size manufactured;
- method of thread forming, i.e., machine cut or thread rolled;
- BSL qualification level;
- certification that the product meets the requirements of this standard; and
- statement of no weld repair.

7.3.2 Product that has been retested or reheat treated as per ASTM A962, section 16 (exclusive of retempering) shall be identified as such on the certificates.

8 Marking

8.1 ASTM Product Marking

Product marking shall be in accordance with ASTM A193/A193M, ASTM A194/A194M, ASTM A320/A320M, ASTM A540/A540M, ASTM A962/A962M or the equipment manufacturer's proprietary bolting material specification, as applicable.

NOTE The referenced ASTM specifications require physical marking of individual parts for headed bolting $^{1}/_{4}$ in. (M6) nominal diameter and larger, for studs $^{3}/_{8}$ in. (M10) nominal diameter and larger and for nuts of all sizes.

8.2 Marking Required by This Specification

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

a) "20E1" for BSL-1,

b) "20E2" for BSL-2,

c) "20E3" for BSL-3.

8.2.2 A raw material "cast" or "heat" number (or any part thereof) shall not be used as the unique manufacturing lot number.

8.2.3 Bolting with oversized internal threads shall have a "-O" appended to the product marking. For example, an oversized BSL-2 nut shall be marked "20E2-O".

8.2.4 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 relevant ASTM or equipment manufacturer's proprietary bolting material specifications and this standard.

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

8.2.6 Markings on coated or plated fasteners 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 with 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 3.1.17). 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	Minimum Acceptance Criteria
Electric Furnace (EF)	What type of furnace is used?	Electric Furnace or Electric-Arc Furnace
	How is final chemistry 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 chemistry 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 not acceptable
	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)?	Bottom pouring acceptable for all BSLs; Top pouring is not acceptable
	How is the vacuum controlled and maintained?	Digital pressure monitoring; automatic vacuum pumping controls with required minimum negative pressure value
	How is final chemistry controlled?	Internal melt aims; either electronic software calculations or manual elemental reversion rate calculations
	How is scrap chemistry controlled?	Internal melt aims; known chemistry 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 chemistry 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 chemistry 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 chemistry 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 PMI capability available?	Yes or no; identify lab capabilities
	Is NDE available? If yes, is there a certified ASNT 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
	Are bars upset forged?	Bars shall 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 AMS-H-6875?	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 120 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

Bibliography

[1] ANSI/ASQ [4] Z1.4-2003 (R2013), *Sampling Procedures and Tables for Inspection by Attributes*

[2] ISO 9001, *Quality Management Systems — Requirements*

[3] API 21TR1, *Materials Selection for Bolting*

[4] American Society for Quality, 600 North Plankinton Avenue, Milwaukee, WI 53203, https://asq.org.