

# Closed Die Forgings for Use in the Petroleum and Natural Gas Industry

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# Closed Die Forgings for Use in the Petroleum and Natural Gas Industry

## 1 Scope

### 1.1 Purpose

This API standard specifies requirements for the qualification and production of closed die forgings for use in API service components in the petroleum and natural gas industries when referenced by an applicable equipment standard or otherwise specified as a requirement for compliance.

### 1.2 Applicability

This standard is applicable to equipment used in the oil and natural gas industries where service conditions warrant the use of closed die forgings. Examples include pressure-containing or load-bearing components.

### 1.3 Forging Specification Levels (FSLs)

This standard establishes requirements for four different FSLs. These FSL designations define different levels of forged product technical, quality, and qualification requirements.

## 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 (including any amendments) applies.

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

ASTM A388/A388M, *Standard Practice for Ultrasonic Examination of Steel Forgings*

ASTM A604, *Standard Practice for Macroetch Testing of Consumable Electrode Remelted Steel Bars and Billets*

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

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

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

ASTM E110, *Standard Test Method for Indentation Hardness of Metallic Materials by Portable Hardness Testers*

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

ASTM E165, *Standard Practice for Liquid Penetrant Examination for General Industry*

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

ASTM E428, *Standard Practice for Fabrication and Control of Metal, Other than Aluminum, Reference Blocks Used in Ultrasonic Testing*

ASTM E562, *Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count*

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

ASTM E709, *Standard Guide for Magnetic Particle Testing*

ASTM G48, *Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution*

ANSI/NCSL Z540.3<sup>2</sup>, *Requirements for the Calibration of Measuring and Test Equipment*

DNV-RP-F112<sup>3</sup>, *Design of Duplex Stainless Steel Subsea Equipment Exposed to Cathodic Protection*

ISO 2859-1<sup>4</sup>, *Sampling procedures for inspection by attributes-Part 1: Sampling plans indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

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

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

#### 3.1 Terms and Definitions

##### 3.1.1

##### **acceptance criteria**

Defined limits placed on characteristics of materials, processes, products, or services.

##### 3.1.2

##### **as-forged**

The condition of a forging as it comes out of the finisher cavity without any subsequent operations.

##### 3.1.3

##### **blank**

A piece of stock for forging that is cut from bar or billet with length to provide the exact amount of material needed for a single forging.

##### 3.1.4

##### **bloom/billet**

A semi-finished, clogged, hot-rolled, or continuous-cast metal product of uniform section, usually rectangular with radiused corners or round.

##### 3.1.5

##### **calibration**

Comparison and adjustment to a standard of known accuracy.

##### 3.1.6

##### **closed die forging**

The shaping of hot metal completely within the walls or cavities of two or more dies that come together to enclose the work piece on all sides. The impression for the forging can be entirely in either die or divided between the two dies. Impression die forging, often used interchangeably with the term closed die forging, refers to a closed die operation in which the dies contain a provision for controlling the flow of excess material, or flash, that is generated.

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<sup>2</sup> NCSL International, 2995 Wilderness Place, Suite 107, Boulder, Colorado 80301-5404, [www.ncsli.org](http://www.ncsli.org).

<sup>3</sup> Det Norske Veritas, Veritasveien 1, NO-1322 Hovik, Norway, [www.dnv.com](http://www.dnv.com)

<sup>4</sup> International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, [www.iso.org](http://www.iso.org).

**3.1.7****crop**

Removal of the end(s) of ingot, billet, or bloom that can contain primary pipe or other defects.

**3.1.8****dies**

The metal blocks into which forging impressions are machined and from which forgings are produced.

**3.1.9****discontinuities**

Includes cracks, laps, folds, cold shuts, and flow-through as well as internal defects such as inclusion, segregation, and porosity. Discontinuities are not necessarily considered to be defects. Internal discontinuities can be detected and evaluated using volumetric NDE techniques such as ultrasonic or radiographic examination.

**3.1.10****final forging**

The last heating and/or deformation operation in the forging sequence.

**3.1.11****final inspection**

The final dimensional and documentation release of the forging.

**3.1.12****flakes**

Randomly oriented internal thermal cracks (shatter cracks) in steels resulting from critical combinations of stress and hydrogen content.

**3.1.13****flow lines**

Patterns in a forging resulting from the elongation of nonhomogeneous constituents in the grain structure of the material in the direction of working during forging; usually revealed by macroetching.

See grain flow (3.1.15).

**3.1.14****forging lot**

Forgings produced in one production run using the same forging equipment and the same MPS forging parameters.

**3.1.15****grain flow**

Fiber-like lines appearing on polished and etched sections of forgings caused by orientation of the constituents of the metal in the direction of working during forging.

See flow lines (3.1.13).

**3.1.16****grain size**

An expression that rates the number of grains per unit area of cross section as determined by metallographic examination.

**3.1.17****heat**

A term used to identify the material produced from a single melting operation.

**3.1.18****heat treatment**

A sequence of controlled heating and cooling operations applied to metal to impart desired properties.

**3.1.19****hot work reduction****forging reduction**

A ratio measuring the change in the cross-sectional area during each hot working operation

For other than upset forging, the hot work ratio for a single hot work operation can be calculated using the following relationship.

The hot work ratio is  $(A_i / A_f):1$

where

$A_f$  is the final cross-sectional area;

$A_i$  is the initial cross-sectional area.

For upset forging, the hot work ratio for a single hot work operation can be calculated using the following relationship:

The upset hot work ratio is  $(A_f / A_i):1$  or  $(h_i / h_f):1$

where

$A_f$  is the final cross-sectional area;

$A_i$  is the initial cross-sectional area;

$h_f$  is the final forging height;

$h_i$  is the initial material height.

The total hot work reduction ratio is defined as the product of the individual reduction ratios achieved at each step in the hot work operation from ingot cross section to the final hot work cross section. The ingot cross section shall be the cross section of the ingot obtained after casting or the final remelt step and any ingot grinding or surface preparation prior to the hot working. When the cross section of the starting material or forged part varies, the cross section resulting in the lowest calculated hot work ratio shall be used.

**3.1.20****inclusions**

Particles of nonmetallic compounds of metals and impurity elements that are present in starting material and are carried over in wrought products.

**3.1.21****ingot**

A casting intended for subsequent rolling, forging, or extrusion.

**3.1.22****ingotism**

A term used to describe the remnants of dendritic structure which can occasionally be found in forgings.

**3.1.23****ladle refining**

Practices used on molten steel in the ladle that adjust and refine the melt chemistry.

**3.1.24****lap**

A forging defect caused by folding the metal back on its own surface during its flow in the die cavity.

**3.1.25****macroetch**

A testing procedure for conditions such as porosity, inclusions, segregation, carburization, and flow lines from hot working. Macroetching is done by applying a suitable etching solution to the suitably prepared metal surface so that the structure revealed by the action of the reagent can be observed visually.

**3.1.26****marking**

Markings placed on the forging in accordance with this specification.

**3.1.27****material procurement**

The purchase of starting material.

**3.1.28****melt practice**

Type of equipment and processes used to melt and refine a heat of metal.

**3.1.29****off-site activity**

Activity performed at a facility owned by the same company as the forging manufacturer and having a Q1 or ISO 9001 compliant Quality Management System for the activities performed.

**3.1.30****on-site activity**

Activity performed at the forging manufacturer's facility.

**3.1.31****receiving verification**

Inspection and review of incoming starting material and attendant documentation.

**3.1.32****starting material**

The raw material used to produce a forging. Some examples of starting materials are billets, ingots, blooms, and blanks.

**3.1.33****traceability**

The ability to verify the history, location, or application of an item by means of documented recorded identification.

**3.1.34****wrought structure**

Structure that contains no cast dendritic elements.

### 3.2 Acronyms and Abbreviations

BOF	basic oxygen furnace
FSL	forging specification level
MPS	manufacturing process specification
NDE	nondestructive examination
UNS	unified numbering system
T	thickness

## 4 Qualification

### 4.1 General

This standard gives the requirements for four forging specification levels (FSLs). The FSLs are numbered in increasing levels of severity from 1 to 4 in order to reflect increasing technical, quality and qualification requirements. The subparagraphs in Section 4 describe the conditions that, when met, allow the forging to receive the appropriate FSL level.

### 4.2 Qualification Forging

**4.2.1** A qualification forging shall be produced, tested and evaluated by the forging manufacturer in order to establish qualification for a range of products listed in Tables 1 and 2. Forgings shall be produced in accordance with a manufacturing process specification (MPS), as specified in 5.3. The material group of the qualification forging shall be in accordance with Table 1. Qualification forgings are to be in their completed forged form, with the addition of any specified rough machining and full heat treatment to establish the final mechanical properties required of the finished product. Qualification forgings shall be produced in accordance with the requirements of Section 4, Section 5, and the forging manufacturer's written specification that defines acceptance criteria.

**Table 1—Material Groups**

Material Group	Description	Typical Examples
Group 1	Carbon and low-alloy carbon steels	SAE 4130 SAE 8630 ASTM A182 F22
Group 2	Austenitic, martensitic, and PH martensitic stainless steels	ASTM A182 F6 ASTM A182 F6NM ASTM A182 F316 UNS S17400
Group 3	Corrosion-resistant alloys	UNS N07718 UNS N06250
Group 4	Duplex stainless steel	ASTM A182 F51 ASTM A182 F53 ASTM A182 F55

**Table 2—As-forged Weight Range Classes (weight in pounds)**

	<200	≥200 and <1000	≥1000 and <2400	≥2400
FSL-1	One qualification forging required			
FSL-2	One qualification forging required		One qualification forging required	
FSL-3	One qualification forging required	One qualification forging required	One qualification forging required	One qualification forging required
FSL-4	Weight not applicable for FSL-4. Each forging shall be individually qualified.			

**4.2.2** A forging qualified to a specific FSL also qualifies lower FSLs (e.g. FSL-4 qualifies FSL-3, FSL-2, and FSL-1 forgings) within the limitations of 4.4.

**4.2.3** Repair welding is prohibited on the qualification forging.

### **4.3 Qualification Forging Evaluation**

All qualification tests shall be performed in the final heat treated condition.

#### **4.3.1 Visual Examination**

**4.3.1.1** Visual inspection of the forging shall be performed in accordance with the forging manufacturer's procedures for cracks, laps, seams and other anomalies. Results shall be documented and the material shall be dispositioned.

**4.3.1.2** Photographs of the qualification forging shall be taken to document the surface finish, configuration, and general appearance. Results shall be documented.

#### **4.3.2 Hardness Testing**

Brinell and/or Rockwell hardness testing shall be performed on the surfaces of the qualification forging in accordance with ASTM E10, ASTM E110, or ASTM E18 to ensure the forging is within the specified limits. Results shall be documented.

#### **4.3.3 Nondestructive Examination**

##### **4.3.3.1 Surface Examination**

###### **4.3.3.1.1 Sampling**

All accessible surfaces of each qualification forging shall be examined by liquid-penetrant (PT) or magnetic-particle (MT) methods after final heat treatment and any machining operations. Forgings may have to be rough machined or ground in order to facilitate surface NDE.

###### **4.3.3.1.2 Test Method**

All forgings shall be examined in accordance with procedures specified in ASTM E709 (MT) or ASTM E165 (PT). If any indications are believed to be non-relevant on the basis that they are not associated with a surface rupture (i.e. magnetic permeability variations, non-metallic stringers), they shall be examined by liquid-penetrant surface NDE methods or removed and re-inspected to confirm their non-relevancy.

#### 4.3.3.1.3 Acceptance Criteria

The following acceptance criteria shall apply and results of the examination shall be documented:

- a) no relevant indication with a major dimension equal to or greater than  $\frac{3}{16}$  in. (5 mm),
- b) no more than 10 relevant indications in any continuous 6 in.<sup>2</sup> (40 cm<sup>2</sup>) area,
- c) four or more relevant indications in a line separated by less than  $\frac{1}{16}$  in. (1.6 mm; edge-to-edge) are unacceptable.

#### 4.3.3.2 Volumetric Examination

##### 4.3.3.2.1 Sampling

As far as practical, the entire volume of each qualification forging shall be ultrasonically examined after final heat treatment and prior to machining operations that limit effective interpretation of the results of the examination. For quench-and-tempered products, the volumetric inspection shall be performed after final heat treatment exclusive of stress-relief treatments or re-tempering to reduce hardness.

##### 4.3.3.2.2 Test Method

All forgings shall be examined by the ultrasonic method in accordance with the flat-bottom-hole procedures specified in ASTM A388/388M and ASTM E428, except that the immersion method may be used. Hollow forgings shall be examined using the angle beam method and acceptance criteria specified in ASTM A388/A388M. The distance amplitude curve (DAC) shall be based on a  $\frac{1}{16}$  in. (1.6 mm) flat-bottom hole for metal thicknesses through 1 $\frac{1}{2}$  in. (38 mm), on a  $\frac{1}{8}$  in. (3.2 mm) flat-bottom hole for metal thicknesses from 1 $\frac{1}{2}$  in. (38 mm) through 6 in. (150 mm), and on a  $\frac{1}{4}$  in. (6.4 mm) flat-bottom hole for metal thicknesses exceeding 6 in. (150 mm). The results of the examination shall be documented.

##### 4.3.3.2.3 Acceptance Criteria

The following acceptance criteria shall apply:

- a) no single indication exceeding reference distance amplitude curve;
- b) no multiple indications exceeding 50 % of reference distance amplitude curve. Multiple indications are defined as two or more indications (each exceeding 50 % of the reference distance amplitude curve) within  $\frac{1}{2}$  in. (13 mm) of each other in any direction.

#### 4.3.4 Test Material

Test material shall be taken from a sacrificial forging. More than one sacrificial forging may be necessary to obtain all required tests. All forgings used for qualification testing shall come from the same heat and heat treat lot and forging lot.

#### 4.3.5 Mechanical Testing

**4.3.5.1** Hardness testing shall be performed in accordance with ASTM E10, ASTM E18, or ASTM E110 on the thickest cross section traversing the entire cross section in two directions. Each traverse shall consist of a minimum of five points equally spaced across the cross section. Results shall be documented.



**4.3.5.2** Tensile test specimens shall be removed from the sacrificial forging and tested in accordance with ASTM A370 at each of the following locations:

- a) at or near the surface of the forging but not deeper than 1<sup>1</sup>/<sub>4</sub> in. (31.75 mm);
- b) at 1<sup>1</sup>/<sub>4</sub> T of the thickest cross section; and
- c) at the location closest to 1<sup>1</sup>/<sub>2</sub> T of the thickest cross section of the forging.

In each of the locations above, as geometry permits, specimens shall be removed in the longitudinal and transverse direction relative to the grain flow. Results shall be documented.

**4.3.5.3** Charpy (CVN) impact specimens shall be removed from the same locations as the tensile tests (4.3.5.2) and tested in accordance with ASTM A370 at a temperature specified by the MPS. In all locations, as the geometry permits, specimens shall be removed in the longitudinal and transverse direction to the grain flow. Results shall be documented.

#### **4.3.6 Chemical Analysis**

**4.3.6.1** The forging manufacturer shall specify in the MPS, the nominal chemical composition, including composition tolerances, of the material used for the qualification forging.

**4.3.6.2** Material composition shall be determined on a heat basis (or on a remelt ingot basis for remelt grade materials) in accordance with a nationally or internationally recognized standard. Results shall be documented.

#### **4.3.7 Metallographic and Corrosion Testing**

##### **4.3.7.1 Microscopic Examination**

**4.3.7.1.1** A metallographic sample shall be removed from two locations, the surface and 1<sup>1</sup>/<sub>4</sub> T of the thickest cross section of the sacrificial forging.

**4.3.7.1.2** For Group 1 materials, steel cleanliness shall be determined in accordance with ASTM E45, Method A, and shall be within the limits shown in Table 3. The results shall be documented.

**Table 3—ASTM E45 Method A Inclusion Rating Limits**

<b>Inclusion Type</b>	<b>Thin</b>	<b>Heavy</b>
Type A sulfide	2	1 1/2
Type B alumina	2	1 1/2
Type C silicate	2	1 1/2
Type D globular oxide	1 1/2	1 1/2

**4.3.7.1.3** For Group 1 materials, grain size shall be determined in accordance with ASTM E112 at the 1<sup>1</sup>/<sub>4</sub> T location. For carbon and low alloy steels the grain size shall be ASTM 5 or finer. Photomicrographs of grain-size specimens shall be taken at 100×. The results shall be documented.

**4.3.7.1.4** For Group 2 and Group 3, the microstructure shall be evaluated by appropriate techniques and acceptance criteria defined in the MPS. Deleterious phases revealed during microstructural examination shall be reported. All results shall be documented.

**4.3.7.1.5** For Group 4, the microstructure shall be evaluated by appropriate techniques and acceptance criteria defined in the MPS. The micrographic examination shall include a sample taken from the qualification forging at the same location as specimens taken for mechanical testing. The ferrite content shall be tested in accordance with ASTM E562. The ferrite content shall be in the range of 35 % to 65 % (volume fraction). Samples shall be electrolytically etched in either NaOH or KOH, and in such a manner as to provide maximum contrast for austenite and ferrite phase discrimination. A minimum of 15 fields and 16 points per field shall be used. Austenite spacing shall be determined in accordance with DNV RPF112. Deleterious phases revealed during microstructural examination shall be reported. All results shall be documented.

#### **4.3.7.2 Corrosion Testing**

**4.3.7.2.1** For Group 4, corrosion testing shall be performed in accordance with ASTM G48, Method A. A sample shall be removed from the  $\frac{1}{4}$  T envelope of the thickest cross section of the sacrificial forging. For 22 Cr, the test temperature shall be  $25 \pm 1$  °C. For 25 Cr, the test temperature shall be  $50 \pm 1$  °C. Test duration for both subgroups shall be 24 hours. Sides of the test specimens shall be ground to a 120 grit finish (or better) with the edges rounded. The test material shall show no evidence of pitting after 24 hours immersion in the test solution when examined with a low power magnification (20×) and the maximum weight loss shall be less than 1 g/m<sup>2</sup>. The results shall be documented.

#### **4.3.7.3 Macroetch**

**4.3.7.3.1** One full cross section sample shall be removed from the sacrificial forging and shall be macroetched in accordance with ASTM A604 or ASTM E381, as applicable, to show the wrought structure and internal integrity as verified by macro or micro examination. This sample shall examine a plane generally perpendicular to the direction of major hot working. Acceptance criteria shall be in accordance with the forging manufacturer's written procedure. The results shall be documented.

**4.3.7.3.2** One full cross section sample shall be removed from the sacrificial forging and shall be macroetched to reveal grain flow. This sample shall examine a plane generally parallel to the direction of major hot working. Photographs shall be taken of the etched section demonstrating the structure and grain flow with accompanying linear scale. The results shall be documented.

#### **4.3.8 Acceptance of the Qualification Forging**

**4.3.8.1** Results of the examinations specified in 4.3 shall comply with the acceptance criteria specified in the forging manufacturer's MPS.

**4.3.8.2** Tests failing to meet the acceptance criteria shall be cause for re-evaluation of the processes and procedures used. A revision of the MPS and requalification is required.

### **4.4 Limits of Forging Qualifications**

#### **4.4.1 FSL-1**

**4.4.1.1** A change in the type of furnace used in the starting material melt practice to basic oxygen furnace (BOF) melt practice requires requalification of the forging.

**4.4.1.2** A change in material group as shown in Table 1 from the forging that was previously qualified requires requalification of the forging.

#### **4.4.2 FSL-2**

**4.4.2.1** Qualification requirements specified for FSL-1 are required for FSL-2.

**4.4.2.2** A change to the forging practice resulting in a lower hot work ratio than that used to produce the qualification forging requires a requalification.

**4.4.2.3** Any change in the melt practice used to qualify the forging requires a requalification. When ladle refining steps are used to produce the starting material for the qualification forging, the elimination of ladle refining steps from the starting material used for production forgings shall require requalification of the forging.

**4.4.2.4** A change in the as-forged weight range class as shown in Table 2 from the forging that was previously qualified requires requalification of the forging.

#### **4.4.3 FSL-3**

**4.4.3.1** Qualification requirements specified for FSL-1 and FSL-2 are required for FSL-3.

**4.4.3.2** An increase in the minimum specified yield strength or minimum specified tensile strength in accordance with the applicable MPS above the minimum specified values qualified for a given material group requires a requalification.

**4.4.3.3** A change in the basic type of forge equipment used (mechanical, press, hammer, etc.) from the forging that was previously qualified requires requalification of the forging.

**4.4.3.4** Requalification is required when the minimum cleanliness requirement of the finished closed die forging is more stringent than the previously qualified forging as determined in accordance with ASTM E45.

#### **4.4.4 FSL-4**

**4.4.4.1** Qualification requirements specified for FSL-1, FSL-2, and FSL-3 are required for FSL-4.

**4.4.4.2** A change in the actual melt source used to supply the starting material from the forging that was previously qualified requires requalification of the forging.

**4.4.4.3** A change in specific material grade requires requalification of the forging (Ex. 4130 and 4140 require separate qualifications).

**4.4.4.4** A change in the immediate post-forge thermal process used from the forging that was previously qualified requires requalification of the forging.

**4.4.4.5** A change in MPS heat treat parameters in 5.4.2 used from the forging that was previously qualified requires requalification of the forging.

### **4.5 Records of Qualification**

The following records are required to document the qualification of the forging.

a) Starting material:

- 1) grade-UNS number, where applicable;
- 2) heat number;
- 3) material specification to include minimum/maximum element ranges;
- 4) supplier name;

- 5) melt source;
  - 6) size;
  - 7) casting method (static ingot or continuous cast);
  - 8) hot work ratio, if applicable;
  - 9) cut weight;
  - 10) melt practice and ladle refinements;
  - 11) cleanliness;
  - 12) heat analysis chemistry;
  - 13) incoming material inspection/evaluation method.
- b) Forging parameters:
- 1) forge equipment used,
  - 2) hot work temperature,
  - 3) description of each forging operation including product configuration at start and finish of each operation,
  - 4) hot work ratio for each operation.
- c) Post-forge parameters:
- 1) cooling media,
  - 2) thermal treatment (if applicable) including temperature and time for each cycle,
  - 3) thermal treatment equipment (if applicable).
- d) Heat treatment:
- 1) furnace loading diagram, orientation and spacing;
  - 2) heat treat times and temperatures for each processing cycle;
  - 3) forging configuration and dimensions at time of heat treatment;
  - 4) quenching medium and type of agitation (water/polymer, forced, horizontal; or vertical quench, ID/OD, etc.);
  - 5) quench medium, start and finish temperature, and transfer time to quench.
- e) Test records as required in 4.3.

## 5 Production Forgings

### 5.1 Qualification of Procurement Sources for Starting Material

**5.1.1** Only melt source facilities that are approved by the forging manufacturer shall be used to supply starting billet or ingot material. The forging manufacturer shall have a documented procedure, fully implemented, for qualifying starting material suppliers for each specific size and grade of starting material. The approval process shall be based on both a quality assurance and a technical evaluation. The approval process shall establish the methodology by which the starting material supplier will be evaluated on an ongoing basis to maintain their status as an approved supplier.

**5.1.2** The starting material supplier shall maintain an internationally recognized quality management system such as ISO 9001, API Q1, etc. The forging manufacturer shall have documented evidence that a supplier of starting material has the technical capability of producing materials meeting the material specification requirements and who has proven, implemented procedures and capabilities in place to consistently produce acceptable product.

**5.1.3** Options for the technical approval of suppliers of starting material for FSL 1 or FSL 2 forgings shall include one or more of the following. Options for technical approval of suppliers of starting material for FSL 3 and FSL 4 forgings shall include two or more of the following:

- a) demonstration of acceptable supplier experience over an extended period of time, which shall include tests, inspections, quantity of material received, and nonconformance analysis;
- b) on-site technical audit at scheduled intervals;
- c) starting material receipt inspection that includes, on a routine basis, a chemistry check and a macroetch;
- d) starting material first article cut up evaluation;
- e) technical assessment questionnaire.

**5.1.4** The forging manufacturer is responsible for ensuring that a starting material supplier has implemented controls addressing the following for each size and grade of starting material ordered:

- a) chemistry;
- b) hydrogen as applicable;
- c) melting practice;
- d) teeming practice and ingot mold;
- e) hot work practice (method of hot work, amount of reduction, hot work temperature), as applicable;
- f) cooling method;
- g) ingot/billet cropping;
- h) starting material inspection and acceptance criteria (cleanliness requirements, limitations on porosity, grain size, secondary phases, microstructure, macrostructure), as applicable;
- i) material contamination controls (e.g. mercury, radioactivity);
- j) traceability.

## 5.2 Material Specifications

**5.2.1** Starting material requirements shall be documented in the form of material specifications. Material specifications shall be developed by the forging manufacturer or the purchaser. Material specifications shall include as a minimum:

- a) material grade, including element chemistry ranges;
- b) melting practices and ladle refinements;
- c) acceptable forging reduction range, if applicable;
- d) inspection methods and acceptance criteria as applicable.
- e) size, tolerances, and configuration.

**5.2.2** The forging manufacturer shall document acceptance of incoming starting material to the requirements of the material specification prior to use for production of forgings.

## 5.3 Manufacturing Process Specification (MPS)

The forging manufacturer shall prepare a manufacturing process specification (MPS) to include, as a minimum, the material specification and the parameters listed in 5.4.

## 5.4 Process Control Parameters

The following are general process control parameters for the production of qualified forgings.

a) Forging parameters:

- 1) size of starting material, cut weight and tolerances;
- 2) evaluation process used for incoming material;
- 3) overall hot work ratio from ingot or continuous-cast bloom to starting material size;
- 4) description of each forging operation, including general configuration at the beginning and end of each different type of hot work or forging operation and hot-work ratio and hot work calculations for each step;
- 5) hot-working temperature for each forging step;
- 6) hydrogen flake-control method (bake-out, slow cool, etc.), if applicable;
- 7) acceptable forging equipment for each forging operation.

b) Heat treat parameters:

- 1) furnace loading diagram, orientation and spacing of production parts;
- 2) heat treat times and temperatures for each processing cycle;
- 3) forging configuration and dimensions at time of heat treatment;

- 4) quenching medium and type of agitation (water/polymer, forced, horizontal, or vertical quench, ID/OD, etc.);
  - 5) quench medium, start and finish temperature, and transfer time to quench.
- c) Test parameters:
- 1) dimensional and visual inspection;
  - 2) NDE, if applicable;
  - 3) mechanical testing;
  - 4) other required testing.

## **5.5 Forging Production**

### **5.5.1 General**

Forgings shall be produced by closed die forging in accordance with the MPS specified in 5.3. The overall hot work ratio from ingot or continuous-cast bloom to product shall be greater than or equal to 4 to 1 unless specifically agreed by the purchaser and the forging manufacturer.

### **5.5.2 Mechanical and Material Testing**

The forging manufacturer shall perform mechanical or material testing of the production forgings as specified in the purchasing document.

### **5.5.3 Forging Workmanship**

Forgings produced shall have a wrought structure throughout. If any of the conditions listed below are found they shall be cause for rejection unless otherwise agreed:

- a) piping or harmful segregation (the presence of which would indicate insufficient discard from the starting ingot);
- b) bursts, flakes, cracks, seams, laps, or other injurious defects detrimental to the end use of the part;
- c) any open discontinuities (porosity, shrinkage, piping, cracks, etc.) when macroetched;
- d) inhomogeneous microstructure in any given area, however, some banding may be present in heavy sections as this is normal and will not be cause for rejection;
- e) evidence of macro segregation (ingotism).

## **5.6 Inspection, Quality Control, Marking, and Documentation**

### **5.6.1 Calibrations Systems**

Inspection, measuring, and testing equipment used for acceptance shall be identified, inspected, calibrated, and adjusted at specific intervals in accordance with ANSI/NCSL Z540.3 and this standard. Calibration reference gauges shall be traceable to the applicable national or international standards agency. Reference gauge acceptance criteria 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.

## **5.6.2 Furnace Survey and Instrument Calibration**

**5.6.2.1** Forging furnaces shall be surveyed and furnace instrumentation shall be calibrated in accordance with the forging manufacturers written procedures.

**5.6.2.2** Heat treatment furnaces shall be surveyed and furnace instrumentation shall be calibrated in accordance with an internationally recognized standard such as AMS 2750 or API Specification 6A.

## **5.6.3 Visual Inspection**

**5.6.3.1** Visual inspection of the production forging for cracks, laps, seams, and other anomalies shall be performed in accordance with the forging manufacturer's inspection procedures.

**5.6.3.2** Any discontinuities discovered shall be evaluated.

**5.6.3.3** Inspection results and dispositions shall be documented.

## **5.6.4 Nondestructive Examination (NDE)**

**5.6.4.1** Production forgings shall be capable of meeting the NDE requirements of the applicable API product specification.

**5.6.4.2** NDE shall be performed as specified in the purchasing documents.

## **5.6.5 Dimensional Inspection**

Dimensional inspection shall be performed on products produced to this standard. Sampling shall be in accordance with ISO 2859-1, Level II, 1.5 AQL. The forging manufacturer shall specify and verify critical dimensions. Acceptance criteria for critical dimensions shall be as required by the forging manufacturer's written specification.

## **5.7 Repair Welding**

Repair welding is not permitted on forgings produced to this specification.

## **5.8 Traceability**

**5.8.1** Full traceability of forgings shall be maintained with respect to material heat, MPS with revision level, and heat treatment loads.

**5.8.2** Forgings produced to this specification shall be traceable to the applicable forging qualification record.

## **5.9 Marking**

**5.9.1** Each forging shall be marked with the following:

- a) forging manufacturer's name or mark,
- b) part number,
- c) API 20C and FSL number,
- d) traceability number (as defined in 5.9.2), and
- e) heat number.



**5.9.2** The traceability number shall refer to documentation containing the following as a minimum: heat number, heat treat lot number, MPS, material grade, specified material strength, date of manufacture, purchase order number, NDE and inspection results, and forging qualification record. At the option of the forging supplier, these items may be marked on the forging.

**5.9.3** Procurement drawings or instructions shall identify where marking is appropriate. The above marking listed in 5.9.1 shall be applied using low-stress metal (dot or rounded V) stamps or vibration technique.

## **5.10 Records Type and Retention**

**5.10.1** The forging manufacturer shall establish and maintain documented procedures to control all documents and data required by this standard. 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 for 10 years from date of manufacture;
- d) stored in an environment to prevent damage, deterioration, or loss;
- e) available and auditable by the user/purchaser.

### **5.10.2 Required Records**

The following records shall be maintained:

- a) mill test report;
- b) forge reduction;
- c) heat treat records;
- d) mechanical properties;
- e) NDE, if applicable;
- f) inspection records.

## **5.11 Handling, Storage, and Shipping**

Forgings shall be packaged for storage or transit in accordance with the documented procedures of the forging manufacturer.

# **6 Facility Requirements**

## **6.1 Minimum Facility Requirements for the Forging Manufacturer**

The forging manufacturer shall have on-site equipment and personnel to perform the required processes needed to produce forgings under the scope of this specification as identified in Table 4.

## **6.2 Activities Applicable to a Forging Manufacturer**

The activities for a forging manufacturer are listed in Table 4 and shall be performed at the applicable facility.

**Table 4—Minimum Facility Requirements**

Item	Process Activity	Location
1	Material Procurement	Performed on-site or off-site
2	Receiving Verification	Performed on-site or off-site
3	Final forging	Performed on-site
4	Marking	Performed on-site
5	Final Inspection	Performed on-site

## **Annex A** **(informative)**

### **Use of API Monogram by Licensees**

#### **A.1 Scope**

The API Monogram® is a registered certification mark owned by the American Petroleum Institute (API) and authorized for licensing by the API Board of Directors. Through the API Monogram Program, API licenses product manufacturers to apply the API Monogram to new products which comply with product specifications and have been manufactured under a quality management system that meets the requirements of API Q1. API maintains a complete, searchable list of all Monogram licensees on the API Composite List website ([www.api.org/compositelist](http://www.api.org/compositelist)).

The application of the API Monogram and license number on products constitutes a representation and warranty by the licensee to API and to purchasers of the products that, as of the date indicated, the products were manufactured under a quality management system conforming to the requirements of API Q1 and that the product conforms in every detail with the applicable standard(s) or product specification(s). API Monogram program licenses are issued only after an on-site audit has verified that an organization has implemented and continually maintained a quality management system that meets the requirements of API Q1 and that the resulting products satisfy the requirements of the applicable API product specification(s) and/or standard(s). Although any manufacturer may claim that its products meet API product requirements without monogramming them, only manufacturers with a license from API can apply the API Monogram to their products.

Together with the requirements of the API Monogram license agreement, this annex establishes the requirements for those organizations who wish to voluntarily obtain an API license to provide API monogrammed products that satisfy the requirements of the applicable API product specification(s) and/or standard(s) and API Monogram Program requirements.

For information on becoming an API Monogram Licensee, please contact API, Certification Programs, 1220 L Street, N. W., Washington, DC 20005 or call 202-682-8145 or by email at [certification@api.org](mailto:certification@api.org).

#### **A.2 Normative References**

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

#### **A.3 Terms and Definitions**

For purposes of this annex, the following terms and definitions apply:

##### **A.3.1**

##### **API monogramable product**

Product that has been newly manufactured by an API licensee utilizing a fully implemented API Q1 compliant quality management system and that meets all the API specified requirements of the applicable API product specification(s) and/or standard(s).

##### **A.3.2**

##### **API specified requirements**

Requirements, including performance and licensee-specified requirements, set forth in API Q1 and the applicable API product specification(s) and or standard(s).

**NOTE** Licensee-specified requirements include those activities necessary to satisfy API specified requirements.

### **A.3.3**

#### **API product specification**

Prescribed set of rules, conditions, or requirements attributed to a specified product which address the definition of terms; classification of components; delineation of procedures; specified dimensions; manufacturing criteria; material requirements, performance testing, design of activities; and the measurement of quality and quantity with respect to materials; products, processes, services, and/or practices.

### **A.3.4**

#### **licensee**

Organization that has successfully completed the application and audit process and has been issued a license by API.

### **A.3.5**

#### **design package**

Records and documents required to provide evidence that the applicable product has been designed in accordance with API Q1 and the requirements of the applicable product specification(s) and/or standard(s).

## **A.4 Quality Management System Requirements**

An organization applying the API Monogram to products shall develop, maintain, and operate at all times a quality management system conforming to API Q1.

## **A.5 Control of the Application and Removal of the API Monogram**

Each licensee shall control the application and removal of the API Monogram in accordance with the following:

- a) Products that do not conform to API specified requirements shall not bear the API Monogram.
- b) Each licensee shall develop and maintain an API Monogram marking procedure that documents the marking/monogramming requirements specified by this annex and any applicable API product specification(s) and/or standard(s). The marking procedure shall:
  - 1) define the authority responsible for application and removal of the API Monogram;
  - 2) define the method(s) used to apply the Monogram;
  - 3) identify the location on the product where the API Monogram is to be applied;
  - 4) require the application of the licensee's license number and date of manufacture of the product in conjunction with the use of the API Monogram;
  - 5) require that the date of manufacture, at a minimum, be two digits representing the month and two digits representing the year (e.g. 05-12 for May 2012) unless otherwise stipulated in the applicable API product specification(s) or standard(s); and
  - 6) require application of the additional API product specification(s) and/or standard(s) marking requirements.
- c) Only an API licensee may apply the API Monogram and its designated license number to API monogramable products.
- d) The API Monogram license, when issued, is site-specific and subsequently the API Monogram shall only be applied at that site specific licensed facility location.

- e) The API Monogram may be applied at any time appropriate during the production process but shall be removed in accordance with the licensee's API Monogram marking procedure if the product is subsequently found to be out of conformance with any of the requirements of the applicable API product specification(s) and/or standard(s) and API Monogram Program.

For certain manufacturing processes or types of products, alternative API Monogram marking procedures may be acceptable. Requirements for alternative API Monogram marking are detailed in the API Policy, API Monogram Program Alternative Marking of Products License Agreement, available on the API Monogram Program website at <http://www.api.org/alternative-marking>.

## **A.6 Design Package Requirements**

Each licensee and/or applicant for licensing must maintain a current design package for all of the applicable products that fall under the scope of each Monogram license. The design package information must provide objective evidence that the product design meets the requirements of the applicable and most current API product specification(s). The design package(s) must be made available during API audits of the facility.

In specific instances, the exclusion of design activities is allowed under the Monogram Program, as detailed in Advisory # 6, available on API Monogram Program website at <http://www.api.org/advisories>.

## **A.7 Manufacturing Capability**

The API Monogram Program is designed to identify facilities that have demonstrated the ability to manufacture equipment that conforms to API specifications and/or standards. API may refuse initial licensing or suspend current licensing based on a facility's level of manufacturing capability. If API determines that additional review is warranted, API may perform additional audits (at the organization's expense) of any subcontractors to ensure their compliance with the requirements of the applicable API product specification(s) and/or standard(s).

## **A.8 API Monogram Program: Nonconformance Reporting**

API solicits information on products that are found to be nonconforming with API specified requirements, as well as field failures (or malfunctions), which are judged to be caused by either specification deficiencies or nonconformities with API specified requirements. Customers are requested to report to API all problems with API monogrammed products. A nonconformance may be reported using the API Nonconformance Reporting System available at <http://compositelist.api.org/ncr.asp>.



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