Open Die Shaped Forgings for Use in the Petroleum and Natural Gas Industry

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1 Scope

1.1 Purpose

This API specification identifies requirements for the forging manufacturer qualification, production, marking, and documentation of open die shaped forgings for use 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 API specification is applicable to equipment used in the oil and natural gas industries where service conditions warrant the use of individually shaped open die forgings, including rolled rings. Examples include pressure containing or load bearing components.

Forged bar, rolled bar, and forgings from which multiple parts are removed are beyond the scope of this specification.

1.3 Forging Specification Levels (FSL)

This API specification establishes requirements for four forging specification levels (FSL). These four FSL designations define different levels of forged product technical, quality, and qualification requirements.

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, except that new editions may be used on issue and become mandatory upon the effective date specified by the publisher or six months from the date of the revision (where no effective date is specified).

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

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

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

ASTM A370,[1] *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*

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

ASTM E381, *Standard Method of Macroetch Testing of 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 ASTM E709, Standard Guide for Magnetic Particle Testing*

ASTM E1245, *Standard Practice for Determining the Inclusion or Second-Phase Constituent Content of Metals by Automatic Image Analysis*

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

ISO 9001, *Quality management systems – Requirements*

ISO 9712, *Non-destructive testing – Qualification and certification of NDT personnel*

ANSI/NCSL Z540.3,[2] *Requirements for the Calibration of Measuring and Test Equipment*

SAE AMS 2750,[3] *Pyrometry*

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

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

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 leaves the forging operation without any subsequent operations.

3.1.3
bloom/billet
A semi-finished hot rolled, forged, or extruded product, with a square, rectangular, or round cross section.

NOTE Bloom and billet can be used interchangeably.

3.1.4
calibration
Comparison and adjustment to a standard of known accuracy.

[2] NCSL International, 2995 Wilderness Place, Suite 107, Boulder, Colorado 80301–5404, www.ncsli.org.
[3] Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096–0001, www.sae.org.

3.1.5
compliance
Act or process of satisfying legal or other applicable requirements of a regulation or regulating body.

3.1.6
conformance
Act or process of satisfying the requirements of a specification, standard, RP, or other similar document.

3.1.7
crop/cropping
Removal of the end(s) of ingots, billets, or blooms that may contain primary pipe or other defects.

3.1.8
final forging
Final hot work process performed by the forging manufacturer.

3.1.9
forging
The product of a substantively compressive plastic working operation that consolidates the material and produces the desired shape.

NOTE The plastic working operation may be performed by a hammer press, press forging machine, or ring rolling machine, and must deform the material to produce a wrought structure.

3.1.10
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.

3.1.11
heat
Material originating from a final melt, or for remelted alloys, the material originating from a single remelted ingot.

3.1.12
heat treatment
Specified, timed sequence of controlled heating and cooling of materials for the purpose of changing physical or mechanical properties.

3.1.13
heat treat lot, batch furnace
Material placed on loading or carrying devices and moved through a heat treat cycle in the same furnace, including the same quenching practice.

3.1.14
hot work ratio
forging reduction ratio
A ratio measuring the change in the cross-sectional area during each hot working operation.

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

$$hot\,work\,ratio = \frac{A_i}{A_f}:1$$

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:

$$upset\,hot\,work\,ratio = \frac{A_f}{A_i}:1 \; or \; \frac{h_i}{h_f}:1$$

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 is 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 is used.

3.1.15
inclusions
Particles of nonmetallic compounds of metals and impurity elements, such as oxides, sulfides, or silicates, that are present in ingots and are carried over in wrought products.

3.1.16
ingot
A cast product intended for subsequent remelting or hot working by rolling, forging, or extrusion.

3.1.17
ladle refining
Practices used on molten steel in the ladle that are used to adjust and refine the melt chemistry.

3.1.18
forging manufacturer
An organization that performs forging activities in conformance with this specification.

3.1.19
melt practice
Type of process used to produce a heat of metal. Includes the use of equipment for melting and refining.

3.1.20
on-site
Forging manufacturer’s facility.

3.1.21
open die forging
Process where the hot mechanical forming of metals between flat or shaped dies in which metal flow is not completely restricted.

NOTE 1 The open die forging process uses hammers and presses to shape individual metal parts, usually using repeated strokes and continuous manipulation. Multiple open die forging operations can be combined to produce the required shape.

NOTE 2 The metal used in open die forging may be reheated several times during the forging process before the final product is achieved.

3.1.22
outsourced
outsourced activity
A function or process that is performed by an external supplier conforming to a quality management system for the activities performed on behalf of the forging manufacturer.

3.1.23
prolongation
An extension of metal added to a forging to permit removal and subsequent testing without destroying the forging. This extension is integrally made during the forging process and removed after final heat treatment.

3.1.24
relevant surface indication
Surface-rupture NDE indication with major dimensions greater than $^{3}/_{16}$ in. (5 mm).

NOTE Inherent indications not associated with a surface rupture are considered non-relevant.

3.1.25
rolled ring
Circular open die forgings produced on a ring mill.

3.1.26
starting material
The raw material used to produce a forging. Examples are billets, ingots, and blooms.

3.1.27
technical audit
An onsite documented review of procedures, processes, and controls performed by competent personnel.

3.1.28
traceability
The ability to verify the history, location, or application of an item by means of documented recorded identification.

3.1.29
wrought structure
A hot worked or forged structure that contains no cast dendritic elements.

3.2 Acronyms and Abbreviations

FSL	forging specification level
MPS	manufacturing process specification
MT	magnetic particle examination
NDE	nondestructive examination
QMS	quality management system
QTC	qualification test coupon
UNS	unified numbering system
UT	ultrasonic examination

WRC weight range class

4 Qualification

4.1 General

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

4.1.2 The forging manufacturer shall establish, document, implement, and maintain at all times a QMS conforming to API Specification Q1 or ISO 9001. In addition, the forging manufacturer shall be responsible for conforming to all the applicable requirements of this specification.

4.2 Qualification Forging

4.2.1 A qualification forging shall be produced, tested, and evaluated by the forging manufacturer to establish qualification for a range of products listed in Table 1. Forgings shall be produced in accordance with a manufacturing process specification, as specified in 5.3. The material group of the qualification forging shall be in accordance with Table 2. 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.

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 Section 4.4.

4.2.3 Repair welding is prohibited on the qualification forging.

Table 1—As-forged Weight Range classes (weight in pounds)

	< 2500 WRC1	≥ 2500 < 10,000 WRC2	≥ 10,000 WRC3
FSL-1	One qualification required		
FSL-2	One qualification required		One qualification required
FSL-3	One qualification required	One qualification required	One qualification required
FSL-4	Weight not applicable for FSL-4. Each forging shall be individually qualified.		

Table 2—Material Groups

Material Group	Description	Sub-Group	Sub-Group Examples/Grades
1	Carbon, microalloyed steels	1A	Carbon steels (UNS G1xxxx)
		1B	Microalloyed (with small addition of V, Nb, Ti, Mo, Zr, or B) steels (ASTM A909, A921)
2	Low-alloy steels	2A	Cr-Mo low-alloy steels (UNS G41xxx)
		2B	Ni-Cr-Mo medium carbon alloys (UNS G43xxx)
		2C	Cr-Ni-Mo low-alloy steels (UNS G86xxx)
		2D	$2^1/4$ Cr-1Mo steel (ASTM A182/A336 grade F22/UNS K21590)/ 9Cr-1Mo steel (ASTM A182 grade F9/UNS K90941)
		2E	ASTM A707 grades (modified)

Table 2—Material Groups (Continued)

Material Group	Description	Sub-Group	Sub-Group Examples/Grades
3	Austenitic, martensitic, and martensitic precipitation-hardening stainless steels	3A	Austenitic UNS S31603, S30400
		3B	Martensitic 410 SS (UNS S41000), F6NM (UNS S41500, S42400)
		3C	Precipitation hardening 17–4PH (UNS S17400), 15–5PH (UNS S15500)
4	Duplex and super duplex stainless steels	4A	Duplex UNS S31803, UNS S32205
		4B	Super duplex UNS S31260, S32750, S32760, S39277
5	Nickel-based alloys	5A	Solution annealed UNS N06625, N08825
		5B	Precipitation hardening UNS N07718, N07725, N09925, N09935, N09945

4.3 Limits of Forging Qualifications

Forging qualification variables are shown in Table 3.

Table 3—Variables of Forging Qualification

Variable	FSL-1	FSL-2	FSL-3	FSL-4
Change in material group (Table 2)	4.3.1	4.3.1	4.3.1	4.3.1
Change in forging practice that results in lower hot work ratio		4.3.2.2	4.3.2.2	4.3.2.2
Change in melting/refining practice used for the starting material		4.3.2.3	4.3.2.3	4.3.2.3
Change in as-forged weight class (Table 1)		4.3.2.4	4.3.2.4	4.3.2.4
Change from press/hammer to ring rolling		4.3.2.5	4.3.2.5	4.3.2.5
Increase in the minimum specified strength level above qualified			4.3.3.2	4.3.3.2
Change in basic type of forge equipment			4.3.3.3	4.3.3.3
Change in immediate post-forge thermal process on forgings				4.3.4.4
Change in subgroup of materials in groups 1, 2, 3, 4, 5 (Table 2)			4.3.3.4	4.3.3.4
Change in actual melt source used for starting material				4.3.4.2
Change in specific material grade within a material subgroup (Table 2)				4.3.4.3
NOTE This table provides a matrix of requirements and may not include all requirements; it should be used as a reference only.				

4.3.1 FSL-1

A change in material group as shown in Table 2 from the forging that was previously qualified requires requalification of the forging.

4.3.2 FSL-2

4.3.2.1 Qualification requirements specified for FSL-1 are required for FSL-2.

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

4.3.2.3 Any change in the melt practice used to qualify the forging requires a requalification.

4.3.2.4 A change in the as-forged weight range class as shown in Table 1 from the forging that was previously qualified requires requalification of the forging.

4.3.2.5 A change from press or hammer equipment to a ring rolling process.

4.3.3 FSL-3

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

4.3.3.2 An increase in the minimum specified yield strength or minimum specified tensile strength in accordance with the applicable design standard above the values qualified for a given material subgroup requires a requalification.

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

4.3.3.4 Any change of the subgroup in material groups 1, 2, 3, 4, and 5 from Table 2 requires a requalification.

4.3.4 FSL-4

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

4.3.4.2 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.

4.3.4.3 A change in specific material grade within a subgroup requires requalification of the forging (for example, 4130 and 4140 require separate qualifications).

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

4.4 Qualification Forging Evaluation

4.4.1 Visual Examination

4.4.1.1 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.

4.4.1.2 Photographs of the qualification forging in the as-forged condition shall be taken to document the configuration and general appearance.

4.4.2 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.

4.4.3 Nondestructive Examination

4.4.3.1 Surface Examination

4.4.3.1.1 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 to facilitate surface NDE.

4.4.3.1.2 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 reinspected to confirm their non-relevancy.

4.4.3.1.3 Acceptance Criteria

The following acceptance criteria shall apply:

a) no relevant indication with a major dimension equal to or greater than $^{3}/_{16}$ in. (5 mm);

b) no more than ten relevant indications in any continuous 6 in.^{2} (40 cm^2) area;

c) four or more relevant indications in a line separated by less than $^{1}/_{16}$ in. (1.6 mm) (edge-to-edge) are unacceptable.

4.4.3.2 Volumetric Examination

4.4.3.2.1 Sampling

As far as practical, the entire volume of each qualification forging shall be ultrasonically examined after final heat treatment is used to achieve mechanical properties, 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 to achieve mechanical properties, exclusive of stress-relief treatments or re-tempering to reduce hardness.

4.4.3.2.2 Test Method

All forgings shall be examined by the ultrasonic method in accordance with the flat-bottom-hole procedures specified in ASTM A388/388M, except that the immersion method may be used, and ASTM E428. 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 $^{1}/_{16}$ in. (1.6 mm) flat-bottom hole for metal thicknesses through $1^{1}/_{2}$ in. (38 mm), on a $^{1}/_{8}$ in. (3.2 mm) flat-bottom hole for metal thicknesses from $1^{1}/_{2}$ in. (38 mm) through 6 in. (150 mm), and on a $^{1}/_{4}$ in. (6.4 mm) flat-bottom hole for metal thicknesses exceeding 6 in. (150 mm).

4.4.3.2.3 Acceptance Criteria

The following acceptance criteria 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 $^{1}/_{2}$ in. (13 mm) of each other in any direction.

4.4.4 Test Piece

4.4.4.1 Based on the size and complexity of the forging, the qualification forging shall be evaluated using at least one of the following test pieces:

a) an integral prolongation, at a specified location;

b) a sacrificial forging;

c) a separately forged QTC representing the largest cross section is permitted for FSL-1 only.

4.4.4.2 When a prolongation is used, it shall remain integrally attached during all heat treatment operations except stress relief and any re-tempering or re-aging that may be required.

4.4.5 Mechanical Testing

4.4.5.1 Hardness testing shall be performed in accordance with ASTM E10, E110, or E18 on the cross section of the test piece, traversing the entire cross section in two perpendicular directions, with each traverse consisting of a minimum 5 points equally spaced across the cross section. Results shall be documented.

4.4.5.2 Tensile test specimens shall be removed from the test piece and tested in accordance with ASTM A370 at the following locations:

4.4.5.2.1 For cross sections greater than 4 in. (101.6 mm):

a) at or near the surface of the forging but not deeper than $1^{1}/_{4}$ in. (31.75 mm);

b) at $^{1}/_{4}$T of the thickest cross section (T is defined as the thickest cross section of the forging in the as heat treated condition);

c) at the location closest to $^{1}/_{2}$T of the thickest cross section of the forging in the final heat treated condition.

4.4.5.2.2 For cross sections 4 in. (101.6 mm) or less, testing shall be at $^{1}/_{2}$T.

In all locations, as geometry permits, specimens shall be removed in the longitudinal and transverse direction to the grain flow.

4.4.5.3 Charpy (CVN) impact specimens shall be removed from the $^{1}/_{4}$T and $^{1}/_{2}$T areas and tested in accordance with ASTM A370 at a temperature specified by the material specification. In all locations, as long as the geometry permits, specimens shall be removed in the longitudinal and transverse direction to the grain flow. Results shall be documented.

4.4.6 Chemical Analysis

4.4.6.1 The forging manufacturer shall specify the nominal chemical composition, including composition tolerances, of the material used for the qualification forging.

4.4.6.2 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.

4.4.7 Metallographic Examination—Applicable to FSL-3 and FSL-4 Only

4.4.7.1 General

4.4.7.1.1 A metallographic sample shall be removed from two locations, surface and $^{1}/_{4}$T of the heaviest cross section of the prolongation or sacrificial forging.

4.4.7.1.2 For Group 1 and Group 2 materials, steel cleanliness shall be determined in accordance with ASTM E45, Method A, and shall be within the limits shown in Table 4. The results shall be documented.

Table 4—ASTM E45 Method A Inclusion Rating Limits

FSL-1 / FSL-2 / FSL-3			FSL-4	
Inclusion Type	**Thin**	**Heavy**	**Thin**	**Heavy**
Type A sulfide	2	$1^1/_2$	1	0.5
Type B alumina	2	$1^1/_2$	1	0.5
Type C silicate	2	$1^1/_2$	1	0.5
Type D globular oxide	$1^1/_2$	$1^1/_2$	$1^1/_2$	1

4.4.7.1.3 For Group 1 and Group 2 materials, grain size shall be determined in accordance with ASTM E112 at the $^1/_4$T location. For carbon and low-alloy steels, the grain size shall be ASTM 5 or finer. For other materials, the grain size shall be appropriate for the alloy. Photomicrographs of grain size shall be taken at 100X.

4.4.7.1.4 For Groups 3 and 5, the microstructure shall be evaluated by techniques appropriate to characterize the alloy.

4.4.4.1.5 For Group 4, the microstructure shall be evaluated by techniques appropriate to characterize the alloy. The micrographic examination shall include a sample taken from the qualification forging and its qualification test coupon at the same location as specimens taken for mechanical testing. The ferrite content shall be tested in accordance with ASTM E562 or ASTM E1245. 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.

4.4.7.1.6 For Group 4, corrosion testing shall be performed in accordance with ASTM G48, method A. A sample shall be removed from the $^1/_4$T envelope of the heaviest cross section of the prolongation or sacrificial forging. For Subgroup 4A, the test temp shall be 25° ±1 °C. For Subgroup 4B, the test temp shall be 50° ±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 of immersion in the test solution when examined with a low-power magnification (20X), and the maximum weight loss shall be less than 1g/m^2.

4.4.7.2 Macroetch

One full cross-section sample shall be macroetched after the sample is removed from the prolongation or sacrificial forging in accordance with ASTM A604 or ASTM E381, as applicable, to show the wrought structure. Acceptance criteria shall be in accordance with the forging manufacturer's written procedure.

4.4.8 Acceptance of the Qualification Forging

4.4.8.1 Results of the examinations specified in Section 4 shall comply with the acceptance criteria specified in the forging manufacturer's MPS.

4.4.8.2 Samples 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.

4.5 Records of Qualification

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

a) Starting material, grade, UNS number (where applicable), heat number, material specification, material supplier name, material supplier mill, size, hot work ratio, cut weight, melt practice and ladle refinements,

cleanliness, actual chemistry, minimum/maximum element tolerance, incoming material inspection/evaluation method, MPS revision level, and qualification number.

b) Forging parameters: hot work temperature range, description of each forging operation (including product configuration at start and finish of each operation) and hot work ratio for each step, forge equipment used.

c) Post-forging parameters: time, temperature, and media of cooling/bake-out, heat treatment specification and actual times and temperatures, cooling media, heat treatment equipment used.

d) Test records: records of the examination, mechanical testing, and metallographic evaluations as described in Section 4.

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 material such as 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 material supplier.

5.1.2 The maintenance of an acceptable quality program, such as an ISO registration, is not sufficient by itself to satisfy the requirements of 5.1.1. Documented evidence that a starting material supplier has a historical and ongoing technical capability of producing materials meeting this specification, and who has proven, implemented procedures and capabilities in place to consistently produce acceptable product, is a minimum requirement. Options for the technical approval of a starting material supplier include one or more of the following.

a) material supplier with a minimum of one-year experience. Demonstration of acceptable experience shall include tests/inspections, quantity of material received, nonconformance analysis, etc.;

b) on-site technical audit at scheduled three-year intervals. A new starting material supplier shall be subject to an on-site technical audit, which includes the controls addressed in 5.1.3.

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

— chemistry controls;

— hydrogen controls;

— melting practice controls;

— teeming practice and ingot mold controls;

— hot work practice controls (method of forging, amount of reduction, forging temperature, etc.);

— cooling rate and method controls;

— ingot/billet cropping controls;

— starting material inspection and acceptance criteria (cleanliness requirements, limitations on porosity or inclusions, grain size, secondary phases, microstructure, macrostructure, etc.);

— material contamination controls (e.g., mercury, radioactivity).

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, at a minimum:

— material grade, including element chemistry ranges;

— melting practices and ladle refinements;

— forging reduction range, if applicable;

— acceptable cleanliness level range, as required by applicable FSL;

— acceptable inspection practices and criteria.

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, at a minimum, the material specification and the general variables listed in 5.4.1 and the heat treat parameters listed in 5.4.2. As part of the MPS, the forging steps shall be shown detailing initial and final dimensions during forging for each step of the forging process. This will also include documentation of the heat or reheat temperature ranges required for each hot work reduction step in a drawing and written documents.

5.4 Process Control Variables

5.4.1 General Variables

The following are general process control variables for the production of qualified forgings:

— size of starting material, cut weight, and tolerances;

— evaluation process used for incoming material and for determining cropped length of starting material;

— hydrogen flake-control method (bake-out, slow cool, etc.), if applicable;

— hot-working temperature range;

— overall hot work ratio from starting material;

— description of each forging operation, including general product configuration at the beginning and end of each different type of hot-work or forging operation and hot-work ratio for each step;

— acceptable forging equipment for production;

— inspection requirements;

— NDE, if applicable.

5.4.2 Heat Treat Parameters

The following are heat treat parameters, as applicable:

— furnace loading diagram, orientation, and spacing of production parts;

— heat treat times and temperatures for each processing cycle;

— forging configuration and dimensions at time of heat treatment;

— quenching medium and type of agitation (water/polymer, forced, horizontal; or vertical quench, ID/OD, etc.);

— quench medium start, maximum, and finish temperature and transfer time to quench.

5.5 Forging Production

5.5.1 General

Forgings shall be produced by the open die or ring rolled forging process in accordance with the MPS specified in 5.3. The overall hot-work ratio, as defined in 3.1.14, shall be sufficient to produce a wrought material structure throughout all sections of the forging. The overall hot-work ratio from starting stock to product shall be greater than or equal to that specified below for the applicable FSL.

a) FSL-1: 3.0:1

b) FSL-2: 3.0:1

c) FSL-3: 4.0:1

d) FSL-4: 4.0:1

For FSL-3 and FSL-4 material groups 1 and 2, when upsetting following cogging or drawing is considered in the hot-work ratio calculation, it shall be a minimum of 6.0:1.

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.

5.6 Inspection, Quality Control, Marking, and Documentation

5.6.1 Calibration 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 specification. 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.

5.6.2 Furnace Calibration

5.6.2.1 Forging furnaces shall be calibrated in accordance with the forging manufacturer’s written procedures.

5.6.2.2 Heat treatment furnaces shall be calibrated in accordance with recognized international standards, such as API 6A, Annex M, or SAE AMS 2750. Records of furnace calibration shall be maintained.

5.6.3 Visual Inspection

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

5.6.3.2 Results shall be documented and the material shall be dispositioned.

5.6.3.3 Any discontinuities discovered shall be evaluated and the disposition 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. NDE procedures shall be supported with a documented qualification record as required by the specified reference standard (such as API 20D or other applicable standards) to demonstrate the procedure effectiveness. All NDE procedures shall be approved by a level III examiner qualified in accordance with ASNT SNT-TC-1A or ISO 9712.

5.6.5 Dimensional Inspection

Dimensional inspection shall be performed on forgings produced to this specification. Each forging shall be inspected. The purchaser shall specify dimensions to be inspected. Acceptance criteria for dimensions shall be as required by the purchaser'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 Forging qualification records shall be traceable to the MPS with revision level.

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

5.9 Record Retention

The forging manufacturer shall establish and maintain documented procedures to control all documents and data required by this specification. Records required by this specification shall be maintained for 10 years. Documents and data may be in any type of media (hard copy or electronic) and shall be:

a) maintained to demonstrate conformance to specified requirements;

b) legible;

c) retained and readily retrievable;

d) stored in an environment to prevent damage, deterioration, or loss; and

e) available and auditable by the user/purchaser.

5.10 Marking

5.10.1 Each forging shall be marked with the following information. Examples are shown in Table 5:

a) forging manufacturer's name or mark;

b) part number;

c) material grade;

d) “API Spec 20B”, FSL, and material/sub-group;

e) date of manufacture (month and year);

f) heat number;

g) heat treat lot number, when applicable;

h) traceability number, if applicable;

i) weight range class; and

j) qualification record number.

Table 5—Example: Forging Marking

Forging Mark	Example
Forging manufacturer’s name, mark, or symbol	ABC
Pattern number	21179–01
Material grade	A182 –F55
API 20B, FSL number, and material/subgroup	20B-2–4B
Heat number	18081829
Heat treat lot number	HTN-3746
Traceability number	F-2796
Weight range class (see Table 1)	WRC1
Qualification record number	QRN-457630

5.10.2 Procurement drawings shall identify where stamping is appropriate. The above marking listed in 5.10.1 shall be applied using low-stress (dot, vibration, or rounded V) stamps. Conventional sharp V-stamping is acceptable in low-stress areas, such as the outside diameter of flanges, except as limited in the following:

a) For material group 1 and 2, sharp V-stamping is not permitted in high-stress areas unless subsequently stress-relieved at 1100 °F (590 °C) minimum.

b) For material groups 3, 4, and 5, conventional sharp V-stamping in high-stress areas shall not be permitted unless agreed with the purchaser.

5.11 Handling, Storage, and Shipping

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

6 Minimum Facility Requirements

The forging manufacturer shall have the on-site equipment and the personnel to perform the required processes to forge the product under the scope of this specification. The activities that shall be performed at the forging manufacturer’s facility are listed in Table 6.

Table 6—Minimum Facility Requirements

Item	Process Activity	Location
1	Receiving inspection	On-site activity
2	Final forging	On-site activity
3	Marking	On-site activity
4	Final inspection	On-site activity

NOTE Subsequent processing such as heat treatment, machining, NDE, and material testing may be outsourced.

Bibliography

[1] API Standard 20D, *Nondestructive Examination Services for Equipment Used in the Petroleum and Natural Gas Industry*

[2] ASTM A182, *Standard Specification for Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High Temperature Service*

[3] ASTM A336, *Standard Specification for Alloy Steel Forgings for Pressure and High Temperature Parts*

[4] ASTM A707, *Standard Specification for Forged Carbon and Alloy Steel Flanges for Low Temperature Service*

[5] ASTM A909, *Standard Specification for Steel Forgings, Microalloy, for General Industrial Use*

[6] ASTM A921, *Standard Specification for Steel Bars, Microalloy, Hot-Wrought, Special Quality, for Subsequent Hot Forging*

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