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ERRATA 3

Page 29, Section 8.4.7.4.2, the fourth bullet shall be amended:

- no relevant indications in pressure-sealing areas, in the root area of rotary threads, or in the stress-relief features of threaded joints.

Drilling and Well Servicing Equipment

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Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

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Drilling and Well Servicing Equipment

1 Scope

This specification provides general principles and specifies requirements for design, manufacture, and testing of new drilling and well-servicing equipment and of replacement primary load-carrying components manufactured subsequent to the publication of this specification.

This specification is applicable to the following equipment:

- a) rotary tables;
- b) rotary bushings;
- c) high-pressure mud and cement hoses;
- d) piston mud-pump components;
- e) drawworks components;
- f) manual tongs;
- g) safety clamps not used as hoisting devices;
- h) blowout preventer (BOP) handling systems;
- i) pressure-relieving devices for high-pressure drilling fluid circulating systems;
- j) snub lines for manual and power tongs;
- k) rotary slips, both manual and powered;
- l) slip bowls; and
- m) spiders, both manual and powered.

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.

[API Specification 5B](#), *Specification for Threading, Gauging and Thread Inspection of Casing, Tubing, and Line Pipe Threads*

[API Specification 6A](#), *Specification for Wellhead and Christmas Tree Equipment*

[API Specification 9A](#), *Specification for Wire Rope*

[API Recommended Practice 9B](#), *Recommended Practice on Application, Care, and Use of Wire Rope for Oilfield Service*

[API Specification 16A](#), *Specification for Drill-through Equipment*

AGMA 2004-C08 ¹, *Gear Materials, Heat Treatment and Processing Manual*

AISC 360-05 ², *Specification for Structural Steel Buildings*

ASME B1.1-2003 ³, *Unified Inch Screw Threads (UN and UNR Thread Form)*

ASME B1.2, *Gages and Gaging for Unified Inch Screw Threads*

ASME B16.34, *Valves Flanged, Threaded, and Welding End*

ASME B30.9, *Slings*

ASME B31.3, *Process Piping*

ASME Boiler and Pressure Vessel Code, Section V: *Nondestructive Examination*

ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, *Rules for Construction of High Pressure Vessels*

ASME Boiler and Pressure Vessel Code, Section VIII, Division 2: *Rules for Construction of High Pressure Vessels - Alternative Rules*

ASME Boiler and Pressure Vessel Code, Section IX: *Welding and Brazing Qualifications*

ASNT SNT-TC-1A ⁴, *Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing*

[ASTM A370](#) ⁵, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

[ASTM A388](#), *Standard Practice for Ultrasonic Examination of Steel Forgings*

[ASTM A751](#), *Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products*

[ASTM A770](#), *Standard Specification for Through-Thickness Tension Testing of Steel Plates for Special Applications*

[ASTM E4](#), *Standard Practices for Force Verification of Testing Machines*

[ASTM E125](#), *Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings*

[ASTM E165](#), *Standard Test Method for Liquid Penetrant Examination*

[ASTM E186](#), *Standard Reference Radiographs for Heavy-Walled (2 to 4 1/2-in. (51 to 114-mm)) Steel Castings*

[ASTM E280](#), *Standard Reference Radiographs for Heavy-Walled (4 1/2 to 12-in. (114 to 305-mm)) Steel Castings*

[ASTM E428](#), *Standard Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Examination*

[ASTM E446](#), *Standard Reference Radiographs for Steel Castings Up to 2 in. (51 mm) in Thickness*

[ASTM E709](#), *Standard Guide for Magnetic Particle Examination*

¹American Gear Manufacturers Association, 500 Montgomery Street, Suite 350, Alexandria, Virginia 22314, www.agma.org.

²American Institute of Steel Construction, One East Wacker Drive, Suite 700, Chicago, Illinois 60601, www.aisc.org.

³ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.

⁴American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228, www.asnt.org.

⁵ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

AWS D1.1 ⁶, *Structural Welding Code-Steel*

AWS QC1, *Standard for AWS Certification of Welding Inspectors*

CI-1500 ⁷, *Test Methods for Fiber Rope*

DNV ⁸, *Rules for the Certification of Lifting Appliances*

EN 287 (all parts) ⁹, *Qualification Test of Welders—Fusion Welding—Steels*

ISO 148 ¹⁰, *Steel—Charpy Impact Test (V-notch)*

ISO 6892, *Metallic Materials—Tensile Testing*

ISO 7500-1, *Metallic Materials—Verification of Static Uniaxial Testing Machines—Part 1: Tension/compression Testing Machines—Verification and Calibration of the Force-measuring System*

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

MSS SP-53 ¹¹, *Quality Standard for Steel Castings and Forgings for Valves, Flanges and Fittings and Other Piping Components—Magnetic Particle Examination Method*

MSS SP-55, *Quality Standard for Steel Castings for Valves, Flanges and Fittings and Other Piping Components—Visual Method for Evaluation of Surface Irregularities*

NFPA T2.12.10 R1 ¹², *Recommended Practice—Hydraulic Fluid Power—Systems and Products—Testing General Measurement Principles and Techniques*

SAE J517, *Hydraulic Hose*

3 Terms, Definitions, and Acronyms

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

3.1 Terms and Definitions

3.1.1

anisotropic material

A material for which properties vary with changes in test direction relative to an initial datum.

3.1.2

average limit load

The numerical average of primary load which causes the limiting component to release the primary load in load limiting designs (reference Annex E).

⁶American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, www.aws.org.

⁷Cordage Institute, 994 Old Eagle School Road, Suite 1019, Wayne, Pennsylvania 19087, <http://www.ropecord.com>

⁸Det Norske Veritas, Veritasveien 1, 1322, Hovik, Oslo, Norway, www.dnv.com.

⁹European Committee for Standardization, Avenue Marnix 17, B-1000, Brussels, Belgium, www.cen.eu.

¹⁰International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.

¹¹Manufacturers Standard Society of the Valve and Fittings Industry, Inc., 127 Park Street, N.E., Vienna, Virginia 22180-4602, www.mss-hq.com.

¹²National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169-7471, www.nfpa.org

3.1.3**BOP handling systems and equipment**

Equipment designed for the purpose of storing, lifting, lowering, and transporting BOP stacks used on drilling and/or production facilities or rigs.

3.1.4**BOP stack**

BOPs assembled as a unit, including all attachments.

3.1.5**buffered components**

All primary load carrying components with the exception of the limiting component in load limiting designs (reference Annex E).

3.1.6**buffered load**

The minimum load capacity of all primary load-carrying components except for the limiting component in load-limiting designs (reference Annex E).

3.1.7**creep**

The time-dependent increase in deformation of a component when subjected to a constant stress.

3.1.8**critical area**

Highly stressed regions on a primary load-carrying component.

3.1.9**design load**

Sum of the static and dynamic loads that would induce the maximum allowable stress in the equipment.

3.1.10**design safety factor****DSF**

Factor to account for a certain safety margin between the maximum allowable stress and the minimum specified yield strength of the material.

3.1.11**design verification test**

Test undertaken to validate the integrity of the design calculations used.

3.1.12**drilling liquids**

Liquid solutions and suspensions (referred to as mud) conveyed at high pressure through the high-pressure mud piping system, mud standpipe, rotary hose, rotary swivel stem, drill string, and drill bit to accommodate the drilling process.

NOTE For the purpose of this specification, drilling liquids do not include fluids containing pressurized air or gases of any kind.

3.1.13**dynamic load**

Load applied to the equipment due to acceleration effects.

3.1.14**end connector**

A fitting located at the end of a hose assembly featuring line pipe threads as specified in [API 5B](#), or for example a flange or hub as specified in [API 6A](#), or hammer lug union, that is butt-welded to or is manufactured as an integral part of the hose coupling material that allows a hose assembly to be connected to a piping system.

NOTE See Figure 11.

3.1.15**equivalent round****ER**

Standard for comparing variously shaped sections to round bars, used in determining the response to hardening characteristics when heat treating low-alloy and martensitic corrosion-resistant steels.

3.1.16**glass transition temperature**

The temperature below which elastomers exhibit brittle, glass-like behavior.

3.1.17**hazardous area or zone**

A location where fire or explosion hazards may exist due to flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers or flyings.

3.1.18**high pressure**

Working pressure values ranging from 10.3 MPa to 103.4 MPa (1500 psi to 15,000 psi).

NOTE See Table 10.

3.1.19**high-pressure cement hose**

A hose used strictly for the conveyance of cement slurries at high pressure.

3.1.20**high-pressure mud hose**

A rotary hose, vibrator hose, or jumper hose.

3.1.21**hose assembly**

Consists of hose body and hose coupling.

NOTE See Figure 11.

3.1.22**hose body**

Plain end hose with no hose couplings or end connectors attached.

3.1.23**hose coupling**

Fitting attached to the ends of the hose body.

3.1.24**hose design family**

Hose assemblies of different internal diameters and working pressures with the same number of reinforcing plies and utilizing the same method of hose coupling attachment and designed to the same design methodology and maximum allowable stress criteria.

3.1.25**identical design concept**

Property of a family of units whereby all units of the family have similar geometry in the primary load-carrying areas.

3.1.26**jumper hose**

A flexible hose assembly used to convey high-pressure drilling liquids that is located anywhere in the high-pressure mud piping system between the mud-pump discharge outlet and the mud standpipe manifold on the drill floor to accommodate relative movement between them.

3.1.27**kelly bushing**

An adapter that is fitted in the master bushing and by either square, pin, or other method, transmits torque from the rotary table to the kelly; simultaneously, it allows vertical movement of the kelly when it works down.

3.1.28**load-limiting component**

A component, material, or mechanism that will release or limit the primary load in the event of an overload in load-limiting designs (reference Annex E).

3.1.29**linear indication**

An indication, revealed by NDE, having a length at least three times its width.

3.1.30**load variance**

γ

A measure of how widely values are dispersed from the average value in load limiting designs (reference Annex E).

3.1.31**loose gear**

Off-the-shelf equipment including, but not limited to, shackles, chain, hooks, connecting links, turnbuckles, binders, sheave blocks, and swivels used in an assembly to suspend, secure, or lift a load.

3.1.32**maximum allowable stress**

Specified minimum yield strength divided by the design safety factor.

3.1.33**maximum working temperature**

The upper limit of the temperature range specified in 9.7.3.

3.1.34**minimum bend radius****MBR**

The minimum hose bending radius dimension measured from the centerline of the hose specified in Table 10.

NOTE See Figure 11.

3.1.35**moon pool guidance system**

Structure installed to prevent contact between the BOP stack and the structure of a floating MODU during the deployment and retrieval of the BOP stack.

3.1.36**multiple load paths**

Two or more independent mechanical or structural primary load-carrying components incorporated in a BOP handling system that collectively support the static and dynamic load simultaneously.

3.1.37**primary load**

Load that arises within the equipment when the equipment is performing its primary design function.

3.1.38**primary load-carrying component**

Component of the equipment through which the primary load is carried.

3.1.39**proof load test**

Production load test undertaken to validate the structural soundness of the equipment.

3.1.40**rated load**

Maximum operating load, both static and dynamic, to be applied to the equipment.

NOTE The rated load is numerically equivalent to the design load.

3.1.41**rated speed**

Rate of rotation, motion, or velocity as specified by the manufacturer.

3.1.42**rated working pressure**

The maximum internal pressure equipment is designed to contain and/or control.

3.1.43**repair**

Removal of defects from, and refurbishment of, a component or assembly by welding during the manufacturing process.

NOTE The term "repair," as referred to in this specification, applies only to the repair of defects in materials during the manufacture of new equipment.

3.1.44**rotary hose**

A flexible hose assembly used to convey high-pressure drilling liquids between the top of the mud standpipe and the rotary swivel.

3.1.45**rotary slip system**

The combination of rotary slips and their accompanying slip bowls.

3.1.46**rotary slips**

A device for the purpose of suspending tubular goods of any type from the rotary table, not capable of being used as elevators, that have some element on the internal diameter to grip the outer diameter surface of the pipe body of various tubular goods, and a tapered outside diameter to fit inside slip bowls that are operated manually or by spring(s) and/or pneumatic or hydraulic power that are installed above, on, in, or partly in the master bushing.

3.1.47**rounded indication**

Indication, revealed by NDE, with a circular or elliptical shape and having a length less than three times its width.

3.1.48**safe working load**

Design load reduced by the dynamic load.

3.1.49**size class**

Designation of the dimensional interchangeability of equipment specified herein.

3.1.50**size range**

Range of tubular diameters to which an assembly is applicable.

3.1.51**sling**

An assembly typically manufactured from wire rope, chain, or synthetic material used for lifting when connected between a load and a lifting mechanism.

3.1.52**slip bowls**

A cylindrical body with a tapered inner surface, either one piece or segmented, that supports the slips.

3.1.53**snub line**

Wire rope, one end of which is fastened to the end of a pipe tong handle attachment point and the other end secured to hold the tong stationary while the tong is in use.

NOTE Snub lines do not work over a sheave or bend.

3.1.54**special process**

Operation that may change or affect the mechanical properties, including toughness, of the materials used in the equipment.

3.1.55**spiders**

A device for the purpose of suspending tubular goods of any type from the drilling structure, not capable of being used as elevators, that have some element on the internal diameter to grip the outer diameter surface of the pipe body of various tubular goods, that are operated manually or by spring(s) and/or pneumatic or hydraulic power or other assist device or method.

3.1.56**static load**

The load exerted on the BOP handling system by the static weight of the BOP stack.

3.1.57**stress relaxation**

The time-dependent reduction in stress of a component when subjected to a constant strain (see creep).

3.1.58**test unit**

Prototype unit upon which a design verification test is conducted.

3.1.59**vibrator hose**

A flexible hose assembly used to convey high-pressure drilling liquids between two piping systems or between the mud-pump discharge outlet and the high-pressure mud piping system for the purpose of attenuating noise and/or vibration, or compensating for misalignment and/or thermal expansion.

3.1.60**wire rope design factor**

The ratio between documented minimum breaking strength and the working load limit as applied to wire rope and slings.

NOTE This term should not be confused with design safety factor defined in 3.1.10.

3.1.61**working load limit**

A load value assigned to loose gear by the manufacturer that is a fraction of the breaking load value that should not be exceeded during use of BOP handling systems and equipment.

3.2 Acronyms

BOP	blowout preventer
HAZ	heat-affected zone
MODU	mobile offshore drilling unit
NDE	nondestructive examination
PTFE	polytetrafluoroethylene
PWHT	post-weld heat treatment
SMYS	specified minimum yield stress
TIR	total indicated runout

4 Design**4.1 Design Conditions**

Drilling equipment shall be designed, manufactured, and tested such that it is in every respect fit for its intended purpose. The equipment shall safely transfer the load for which it is intended. The equipment shall be designed for safe operation.

The following design conditions shall apply.

The design load and the safe working load are defined as in Section 3. The operator of the equipment shall be responsible for the determination of the safe working load for specific operations.

Unless changed by a supplementary requirement (see A.3 and A.4), the design and minimum operating temperature for rotary tables and drawworks is 0 °C (32 °F). The design and minimum operating temperature for safety clamps, spiders, rotary slips, slip bowls, rotary bushings, rotary adapters, rotary slip systems, and manual tongs is –20 °C (–4 °F), unless changed by a supplementary requirement. See Annex A for supplementary requirements that apply only when specified.

Caution—Use of equipment covered by this specification at rated loads and temperatures below the design temperatures noted above is not recommended unless appropriate materials with the required toughness properties at lower design temperatures have been used in the manufacture of the equipment (see A.3 and A.4).

4.2 Strength Analysis

4.2.1 General

The equipment design analysis shall address excessive yielding, fatigue, or buckling as possible modes of failure.

The strength analysis shall be based on the elastic theory. Alternatively, ultimate strength (plastic) analysis may be used where justified by design documentation.

All forces that may govern the design shall be taken into account. For each cross section to be considered, the most unfavorable combination, position, and direction of forces shall be used.

4.2.2 Simplified Assumptions

Simplified assumptions regarding stress distribution and stress concentration may be used, provided that assumptions are made in accordance with generally accepted practice or based on sufficiently comprehensive experience or tests.

4.2.3 Empirical Relationships

Empirical relationships may be used in lieu of analysis, provided such relationships are supported by documented strain gauge test results that verify the stresses within the component. Equipment or components that, by their design, do not permit the attachment of strain gauges to verify the design shall be qualified by testing in accordance with 5.6.

4.2.4 Equivalent Stress

The strength analysis shall be based on elastic theory. The nominal equivalent stress, according to the Von Mises–Hencky theory, caused by the design load shall not exceed the maximum allowable stress σ_{allow} as calculated by Equation (1).

$$\sigma_{\text{allow}} = \frac{S_{Y \min}}{F_{DS}} \quad (1)$$

where

$S_{Y \min}$ is the specified minimum yield strength;

F_{DS} is the design safety factor.

4.2.5 Ultimate Strength (Plastic) Analysis

An ultimate strength (plastic) analysis may be performed under any one of the following conditions:

- a) for contact areas;
- b) for areas of highly localized stress concentrations caused by part geometry and other areas of high-stress gradients where the average stress in the section is less than or equal to the maximum allowable stress as defined in 4.2.4.

In such areas, the elastic analysis shall govern for all values of stress below the average stress.

In the case of plastic analysis, the nominal equivalent stress according to the Von Mises–Hencky theory shall not exceed the maximum allowable stress σ_{allow} as calculated by Equation (2).

$$\sigma_{\text{allow}} = \frac{S_{\text{ULTmin}}}{F_{\text{DS}}} \quad (2)$$

where

S_{ULTmin} is the specified minimum ultimate tensile strength;

F_{DS} is the design safety factor.

4.2.6 Stability Analysis

The stability analysis shall be carried out according to generally accepted theories of buckling.

4.2.7 Fatigue Analysis

The fatigue analysis shall be based on a time period of not less than 20 years, unless otherwise agreed.

The fatigue analysis shall be carried out according to generally accepted theories. A method that may be used is defined in Reference [13].

4.3 Size Class Designation

The size class designation for equipment shall represent dimensional interchangeability in accordance with Section 9.

4.4 Rating

4.4.1 Rotary tables, spiders, rotary slips, slip bowls, rotary slip systems, rotary bushings (other than Kelly bushings), rotary adapters, master bushings, and manual tongs furnished under this specification shall be rated in accordance with the requirements specified herein.

4.4.2 The static ratings for all bearings within the primary load path shall meet or exceed the rated load for the equipment.

4.4.3 Manual tongs shall be assigned torque ratings by the manufacturer for all configurations for which the tong is designed.

4.5 Load Rating Basis

The load rating shall be based on:

- the design safety factor (DSF) as specified in 4.6 unless specified otherwise in Section 9;
- the minimum specified yield strength of the material used in the primary load-carrying components;
- the stress distribution as determined by design calculations and/or data developed in a design verification load test as specified in 5.6.

4.6 Design Safety Factor (DSF)

4.6.1 The DSF is intended as a design criterion and shall not under any circumstances be construed as allowing loads on the equipment in excess of the rated load.

4.6.2 DSF for spiders, rotary slips, and rotary slip systems shall be established as specified in Table 1.

4.6.3 The minimum DSF of structural components in the primary load path of rotary tables and rotary bushings shall be 1.67.

4.6.4 The minimum DSF for manual tongs and jaws shall be established as specified in Table 2.

Table 1—Minimum Design Safety Factors for Spiders and Rotary Slips

Load Rating R	Design Safety Factor F_{DS}
< 1334 kN (150 short tons)	3.00
1334 kN to 4448 kN (150 short tons to 500 short tons) inclusive	$3.00 - 0.75 (R - 1334)/3114^a$ $3.00 - 0.75 (R - 150)/350^b$
> 4448 kN (500 short tons)	2.25
^a In this formula, the value of R shall be expressed in SI units of kilonewtons.	
^b In this formula, the value of R shall be expressed in USC units of short tons.	

Table 2—Minimum Design Safety Factors for Manual Tongs

Torque Rating R	Design Safety Factor F_{DS}
$\leq 41 \text{ kN m } (30 \times 10^3 \text{ ft-lb})$	3.00
$> 41 \text{ kN m } (30 \times 10^3 \text{ ft-lb})$ to $136 \text{ kN m } (100 \times 10^3 \text{ ft-lb})$	$3.00 - 0.75 (R - 41)/95^a$ $3.00 - 0.75 (R - 30 \times 10^3)/(70 \times 10^3)^b$
$\geq 136 \text{ kN m } (100 \times 10^3 \text{ ft-lb})$	2.25
^a In this formula, the value of R shall be expressed in SI units of kilonewton meters.	
^b In this formula, the value of R shall be expressed in USC units of foot-pounds.	

4.7 Shear Strength

For purposes of design calculations involving shear, the ratio of yield strength in shear to yield strength in tension shall be 0.58.

4.8 Specific Equipment

See Section 9 for equipment-specific design requirements.

4.9 Design Documentation

Documentation of design shall include methods, assumptions, calculations, and design requirements. Design requirements shall include, but not be limited to, those criteria for size, test and operating pressures, material, environmental and specification requirements, and other pertinent requirements upon which the design is to be based.

The requirements also apply to design change documentation.

5 Design Verification

5.1 General

To ensure the integrity of the design and supporting calculations, equipment shall be subject to design verification testing when required in Section 9.

Design verification testing shall be performed in accordance with documented procedures.

Design verification testing shall be carried out or certified by personnel who are independent of those having direct responsibility for the design and manufacture of the product and are qualified to perform their task.

Design verification testing may consist of one or more of the listed tests as required by the specific equipment sections of this specification:

- a) function testing,
- b) pressure testing,
- c) load testing.

5.2 Design Verification Function Test

5.2.1 Sampling of Test Units

One unit of each model of equipment shall be subjected to function testing if the equipment transmits force, motion, or energy by means of continued movement of the equipment parts.

5.2.2 Test Procedure

The manufacturer shall establish a procedure documenting the duration, applied load, and speed of the test. For equipment designed for continuous operation, the test unit shall be operated at rated speed for a minimum of 2 hours. For equipment designed for intermittent or cyclical operation, the test unit shall be operated at rated speed and established duty cycles equivalent to 2-hour operation or 10 duty cycles, whichever is greater, unless otherwise specified by Section 9.

5.2.3 Qualification

The unit shall operate without noted loss of power. The temperature of the bearings and lubrication oil shall be within acceptable limits as established by the design and documented in the test procedure.

5.3 Design Verification Pressure Test

5.3.1 Sampling of Test Units

Each design of pressure-containing items or, as defined in Section 9, primary load-carrying components, where the primary load is pressure, shall be hydrostatically tested for design verification. Hydraulic power transmission components are excluded from this test.

5.3.2 Test Procedure

The test pressure shall be 1.5 times the maximum rated operating pressure. Cold water, water with additives, or the fluid normally used in actual service shall be used as the test fluid. Tests shall be performed on the completed part or assembly before painting.

The hydrostatic test shall be applied for two cycles. Each cycle shall consist of the following four steps:

- a) the primary pressure-holding period,
- b) the reduction of the test pressure to zero,
- c) thorough drying of all external surfaces of the item being tested,
- d) the secondary pressure-holding period.

The pressure-holding periods shall not start until the test pressure has been reached and the equipment and pressure-monitoring gauge isolated from the pressure source. The pressure-holding periods shall not be less than three minutes.

5.3.3 Qualification

After each test cycle, the test item shall be carefully inspected for the absence of leakage or permanent deformation. Failure to meet this requirement or premature failure shall be the cause for a complete reassessment of the design, followed by repetition of the test.

5.3.4 Individual Parts

Individual parts of the unit may be tested separately if the test fixture duplicates the loading conditions applicable to the part in the assembled unit.

5.4 Design Verification Load Test

5.4.1 General

When required by the specific equipment paragraphs of Section 9, equipment shall be subjected to a design verification load test.

5.4.2 Sampling of Test Units

To qualify design stress calculations applied to a family of units with an identical design concept but of varying sizes and ratings, one of the following options shall apply.

- a) A minimum of three units of the design shall be subjected to design verification load testing. The test units shall be selected from the lower end, middle, and upper end of the load rating range.

- b) Alternatively, the required number of test units can be established on the basis that each test unit also qualifies one load rating above and one below that of the selected test unit. (This option would generally apply to limited product rating ranges.)

5.4.3 Test Procedure

The test procedure is as follows.

- a) An assembled test unit shall be loaded to the maximum rated load. After this load has been released, the unit shall be checked for its intended design functions. The function of all of the equipment parts shall not be impaired by this loading.
- b) Strain gauges shall be applied to the test unit at all places where high stresses are anticipated, provided that the configuration of the unit permits such techniques. The use of finite-element analysis, models, brittle lacquer, and so forth is recommended to confirm the proper location of the strain gauges. Three-element strain gauges are recommended in critical areas to permit determination of the shear stresses and to eliminate the need for exact orientation of the gauges.
- c) The design verification test load to be applied to the test unit shall be determined in accordance with Table 3.
- d) The test unit shall be loaded to the design verification test load. This test load should be applied incrementally, reading the strain gauge values and observing for evidence of yielding. The test unit may be loaded as many times as necessary to obtain adequate data.
- e) The stress values computed from the strain gauge readings shall not exceed the values obtained from design calculations (based on the design verification test load) by more than the uncertainty of the testing apparatus specified in 5.7. Failure to meet this requirement or premature failure of any test unit shall be a cause for complete reassessment of the design, followed by additional testing of an identical number of test units as originally required, including a test unit of the same load rating as the one that failed.
- f) Upon completion of the design verification load test, the test unit shall be disassembled and the dimensions of each primary load-carrying component checked for evidence of permanent deformation.
- g) Individual parts of a test unit may be load-tested separately if the holding fixtures duplicate the loading conditions applicable to the part in the assembled unit.

5.5 Determination of Rated Load

The rated load shall be determined from the results of the design verification load test and/or stress distribution calculations required by Section 4. The stresses at that rating shall not exceed the maximum allowable stress. Localized yielding shall be permitted at areas of contact. In a unit that has been design verification load tested, the critical permanent deformation determined by strain gauges or other suitable means shall not exceed 0.2 % except in contact areas. If the stresses exceed the allowable values, the affected part or parts shall be redesigned to obtain the desired rating. Stress distribution calculations may be used to load rate the equipment only if the stress values determined in the analysis are no less than the stresses observed during the design verification load test.

5.6 Alternative Design Verification Test Procedure and Rating

Destructive testing of the test unit may be used, provided the yield and tensile strengths of the material used in the equipment have been determined. This may be accomplished using tensile test specimens from the same heat and heat treatment lot as the parts represented, and meeting the requirements of ISO 6892 or [ASTM A370](#).

Each component of an assembly shall be qualified under the most unfavorable loading configuration. Components may be qualified using either of the following methods.

- a) The ratio T_R shall be computed for each component in the assembly. The smallest of these ratios shall be used in the equations.
- b) Each component may be load tested separately if the holding fixtures duplicate the loading conditions applicable. In this case, the ratio, T_R , used for each test shall be that computed for the specific component tested.

$$R = L_b \times \frac{T_R}{F_{DS}} \quad (3)$$

$$T_R = \frac{S_{Ymin}}{S_{ULTa}} \quad (4)$$

where

L_b is the breaking load;

S_{Ymin} is the specified minimum yield strength;

S_{ULTa} is the actual tensile strength;

F_{DS} is the design safety factor (4.6);

R is the load rating.

Since this method of design qualification is not derived from stress calculations, qualification shall be limited to the specific model, size, size range, and rating tested.

Table 3—Determination of Test Loads

Load Rating R	Design Verification Test Load
$\leq 11,120$ kN (1250 short tons), and all torque ratings	$0.8 \times R \times F_{DS}$, but not less than $2R$
$> 11,120$ kN $\leq 14,678$ kN (> 1250 short tons ≤ 1650 short tons)	$C \times R$
$> 14,678$ kN (1650 short tons)	$1.5 \times R$
in SI units $C = 2 - 0.5 \times \left(\frac{R - (11,120)}{3558} \right), \text{ in kilonewtons}^a$ or, in USC units $C = 2 - 0.5 \times \left(\frac{R - 1250}{400} \right), \text{ in short tons}^b$ where R is the load rating in kilonewtons (short tons) or kilonewton meters (foot-pounds), as applicable; F_{DS} is the design safety factor as defined in 3.1.10 and 4.6. NOTE To make development and qualification of equipment with load ratings above 11,120kN (1250 short tons) practical, the test load factor is adjusted, largely because of geometry and material limitation for test fixtures. ^a In this formula, the value of R shall be expressed in SI units of kilonewtons. ^b In this formula, the value of R shall be expressed in USC units of short tons.	

5.7 Load Test Apparatus

The loading apparatus used to duplicate the working load on the test unit shall be calibrated in accordance with ISO 7500-1 or [ASTM E4](#) so as to ensure that the prescribed test load is obtained. For loads exceeding 3560 kN (400 tons), the load-testing apparatus may be verified with calibration devices traceable to a Class A calibration device and having an uncertainty of less than 2.5 %.

Test fixtures shall load the unit (or part) in the same manner as in actual service, and with the same areas of contact on the load-bearing surface. All equipment used to load the unit (or part) shall be verified as to its capability to perform the test.

5.8 Design Changes

When any change in design or manufacture is made that results in changes to the calculated load rating, supportive design verification testing in conformance with this section shall be carried out. The manufacturer shall evaluate all changes in design or manufacture to determine whether the calculated load ratings are affected. This evaluation shall be documented.

5.9 Records

All design verification records and supporting data shall be subject to the same controls as specified for design documentation in Section 11.

6 Materials Requirements

6.1 General

This section describes the various material qualification, property, and processing requirements for primary load-carrying and pressure-containing components unless otherwise specified.

6.2 Written Specifications

Materials used in the manufacture of primary load-carrying components of equipment to which this specification is applicable shall conform to a written specification that meets or exceeds the design requirements.

6.3 Metallic Materials

6.3.1 Mechanical Properties

6.3.1.1 Impact Toughness

Impact testing shall be in accordance with ISO 148 (V-notch Charpy) or [ASTM A370](#) (V-notch Charpy).

When it is necessary for subsize impact test pieces to be used, the acceptance criteria shall be multiplied by the appropriate adjustment factor listed in Table 4. Subsize test pieces of width less than 5 mm (³/₁₆ in.) are not permitted.

For design temperatures below those specified in 4.1, supplementary impact toughness requirements may apply. See Annex A, Supplementary Requirements SR2 and SR2A.

6.3.1.2 Through-thickness Properties

Where the design requires through-thickness properties, materials shall be tested for reduction of area in the through-thickness direction in accordance with [ASTM A770](#). The minimum reduction shall be 25 %.

Table 4—Adjustment Factors for Subsize Impact Specimens

Specimen Dimensions mm × mm	Adjustment Factor
10.0 × 7.5	0.833
10.0 × 5.0	0.667

6.3.2 Material Qualification

6.3.2.1 General

The mechanical tests required by this specification shall be performed on qualification test coupons representing the heat and heat-treatment lot used in the manufacture of the component. Tests shall be performed in accordance with the requirements of ISO 6892, ISO 148, or [ASTM A370](#), or equivalent national standards, using material in the final heat-treated condition. For the purposes of material qualification testing, stress relief following welding is not considered heat treatment, provided that the PWHT temperature is below that which changes the heat-treated condition of the base material. Material qualification tests may be performed before the stress-relieving process, provided that the stress-relieving temperature is below that which changes the heat-treatment condition.

6.3.2.2 Equivalent Rounds

Determine the size of the qualification test coupon for a part using the equivalent round method. Figure 1 and Figure 2 illustrate the basic models for determining the equivalent round (ER) of simple solid and hollow parts. Any of the shapes shown may be used for the qualification test coupon. Figure 3 describes the steps for determining the governing equivalent-round for more complex sections. Determine the ER of a part using the actual dimensions of the part in the “as-heat-treated” condition. The ER of the qualification test coupon shall be equal to or greater than the equivalent-round dimensions of the part it qualifies, except that the ER is not required to exceed 125 mm (5 in.). Figure 4 and Figure 5 illustrate the procedure for determining the required dimensions of an [ASTM A370](#) keel block.

6.3.2.3 Material Test Coupons

6.3.2.3.1 Qualification test coupons shall either be integral with the components they represent, or be separate from the components, or be taken from sacrificed production part(s). In all cases, test coupons shall be from the same heat as the components they qualify, shall be subjected to the same working operations and shall be heat treated together with the components.

6.3.2.3.2 Test specimens shall be removed from integral or separate qualification test coupons so that their longitudinal centerline axis is entirely within the center core $\frac{1}{4}T$ -thickness ($\frac{1}{4}T$) envelope for a solid test coupon, or within 3 mm ($\frac{1}{8}$ in.) of the mid-thickness of the thickest section of a hollow test coupon. The gauge length of a tensile specimen or the notch of an impact specimen shall be at least $\frac{1}{4}T$ from the ends of the test coupon.

6.3.2.3.3 Test specimens taken from sacrificed production parts shall be removed from the center core $\frac{1}{4}T$ envelope location of the thickest section of the part.

6.3.2.3.4 For components to be machined entirely from wrought material that has been fully heat treated as a solid or tubular bar, whereby the standard $\frac{1}{4}T$ envelope is either wholly or partly outside the volume of the critical and/or non-critical areas of the finished component, the test specimens cut from the bar may alternatively be taken from a more representative volume as defined by:

- a) volume OD defined by a $\frac{1}{3}T$ envelope determined by using the maximum finished OD and the minimum finished ID of the final component;
- b) the volume ID shall be equal to, or greater than, the minimum finished ID of the component.

EXAMPLE

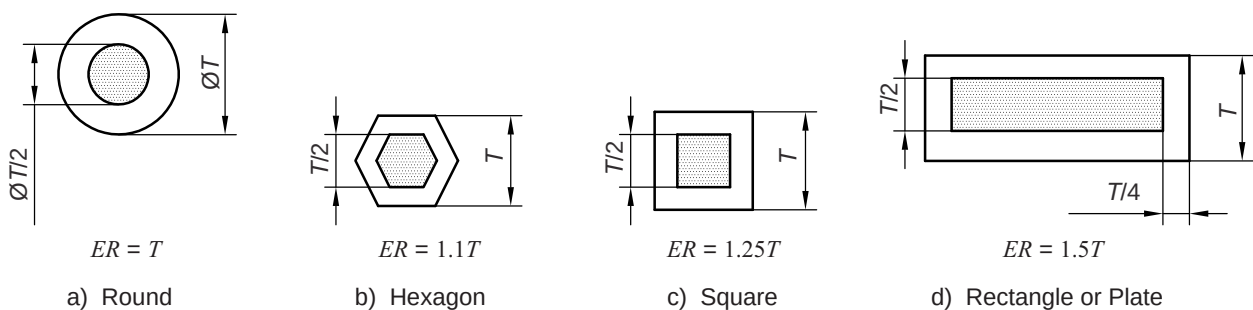
6 in. OD 4340 mod bar, normalized, quenched and tempered (NQT);

part final dimensions have maximum OD of 5.5 in., minimum ID of 2.5 in.;

$$T = (5.5 - 2.5)/2 = 1.5 \text{ in.} \quad \frac{1}{3}T = 0.5 \text{ in.}$$

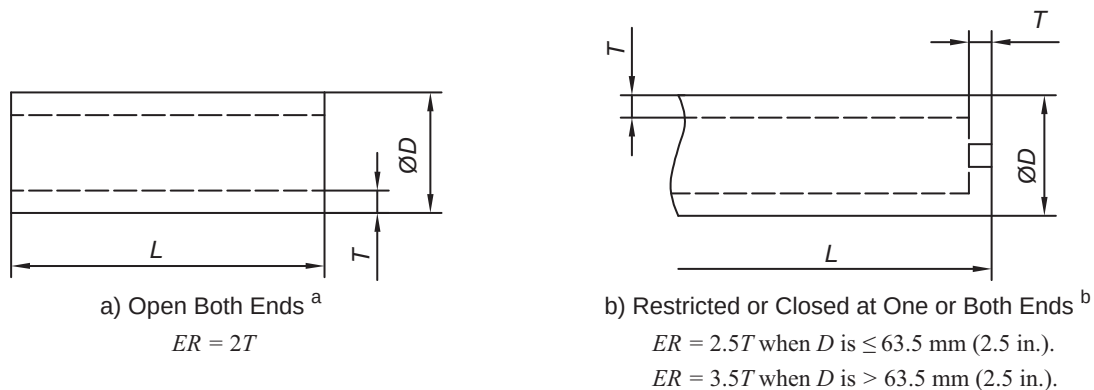
The $\frac{1}{3}T$ envelope of the finished part would have a 4.5 in. OD;

therefore, the specimens could be removed from anywhere within the volume defined by 4.5 in. OD 2.5 in. ID; (the $\frac{1}{3}T$ outer envelope and the finished ID of the component).



NOTE When L is $< T$, consider section as a plate of thickness L .

Figure 1—Equivalent Round (ER) Models—Solids of Length L



^a When L is $< D$, consider as a plate of thickness T . When L is $< T$, consider as a plate of L thickness.

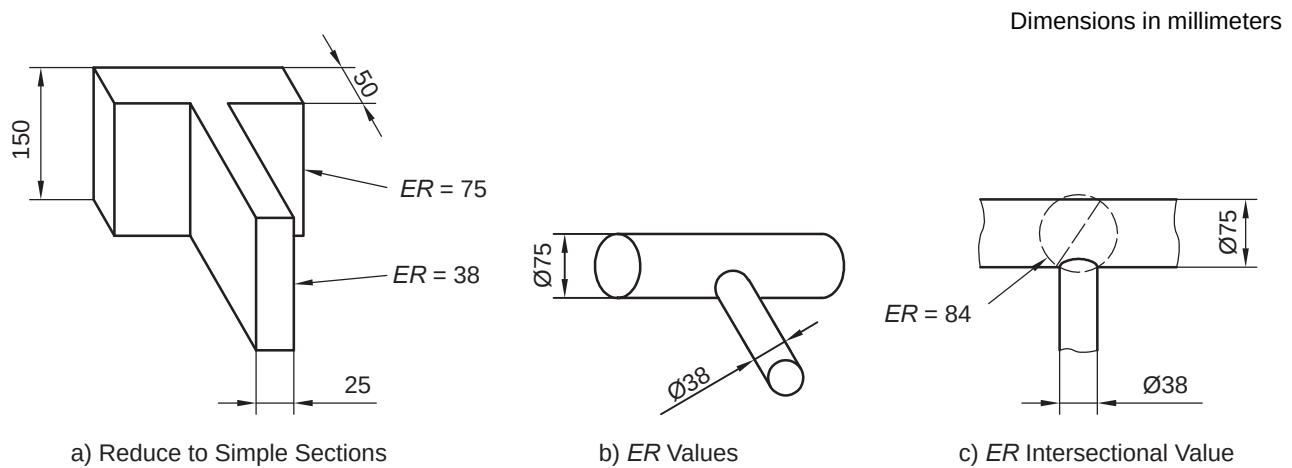
^b Use maximum thickness, T , in the calculation.

Figure 2—Equivalent Round (ER) Models—Tube (Any Section)

6.3.3 Manufacture

6.3.3.1 The manufacturing processes shall ensure repeatability in producing components that meet all the requirements of this specification.

6.3.3.2 All wrought materials shall be manufactured using processes that produce a wrought structure throughout the component.

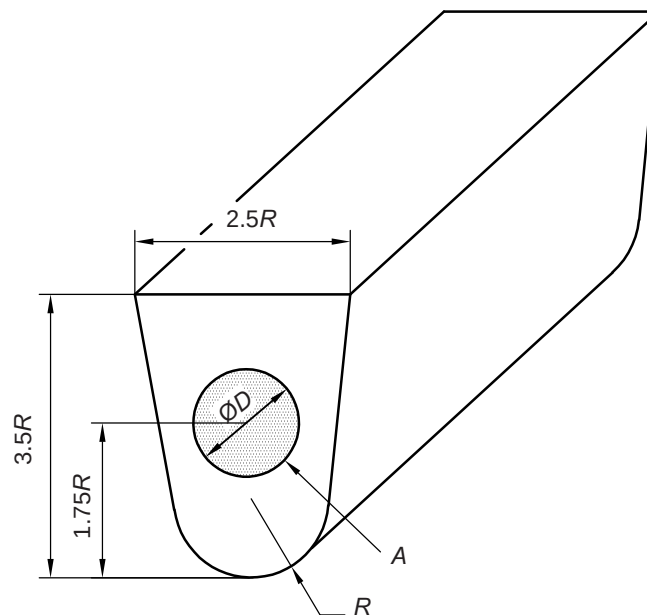


The following steps should be used in determining the governing *ER* for complex sections:

- a) reduce the component to simple sections;
- b) convert each simple section to an equivalent round;
- c) calculate the diagonal through the circle that would circumscribe the intersection of the *ER* values.

Use the maximum *ER* value, whether for a single section or an intersection, as the *ER* of the complex section.

Figure 3—Equivalent Round (ER) Models-Complex Shapes

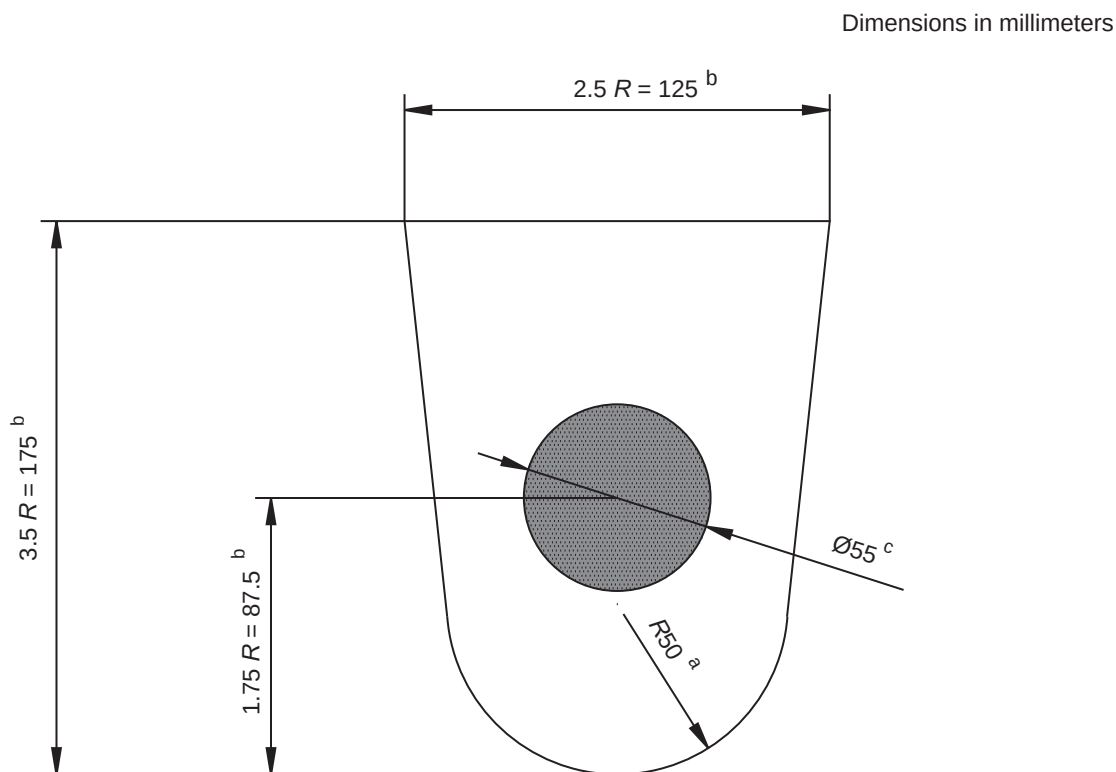


$$R = ER/2.3$$

$$D = 1.1R$$

NOTE Shaded area A indicates $1/4T$ envelope for test specimen removal.

Figure 4—Equivalent Round (ER) Models—Keel Block Configuration



To develop a keel block for $ER = 115$ mm:

- a) note that $R = ER/2.3 = 50$ mm and $D = 1.1R$,
- b) construct a keel block as illustrated in Figure 3 using multiples of R .

- a $R = ER/2.3 = 50$ mm.
- b Keel block dimensions.
- c Diameter D .

Figure 5—Development of Keel Block Dimensions

6.3.3.3 All heat treatment operations shall be performed utilizing equipment qualified in accordance with the requirements specified by the manufacturer or processor. The loading of the material within heat treatment furnaces shall be such that the presence of any one part does not adversely affect the heat treating response of any other part within the heat treatment lot. The temperature and time requirements for heat treatment cycles shall be determined in accordance with the manufacturer's or processor's written specification. Actual heat treatment temperatures and times shall be recorded, and heat treatment records shall be traceable to relevant components.

NOTE See Annex B for recommendations on qualification of heat-treating equipment.

6.3.4 Chemical Composition

The material composition of each heat shall be analyzed in accordance with the requirements of [ASTM A751](#) (see ISO TR 9769 for further information), or equivalent national standard, for all elements specified in the manufacturer's written material specification.

6.4 Non-metallic and Composite Materials

6.4.1 General

The use of non-metallic and composite materials to manufacture primary load carrying components shall be permitted provided that the materials meet the properties required for the design.

6.4.2 Mechanical Properties

6.4.2.1 General

The mechanical property requirements for all non-metallic materials shall be specified with appropriate limits for properties critical to the function of the equipment.

6.4.2.2 Test Temperature

The material properties shall be qualified at a minimum temperature of -4°F (-20°C) unless otherwise specified in Section 9, and at a specified maximum temperature corresponding to the maximum recommended operating temperature. A lower minimum test temperature is required if SR2B is specified (see Annex A.5).

6.4.2.3 Test Specimen Orientation

Test specimens taken from materials exhibiting anisotropic behavior shall be tested in the direction that would result in the worst case, limiting value of the mechanical property in question.

6.4.2.4 Creep, Stress Relaxation, and Rate Effects

Materials susceptible to creep and/or stress relaxation shall be tested for resistance to these effects under the most severe conditions encountered in service, including, but not limited to, time, temperature, stress, and strain. The presence of creep and/or stress relaxation shall not cause loss of function for the component under operating conditions.

Materials for which mechanical properties are dependent upon the rate of loading shall be tested at the most severe rate of loading encountered in service.

6.4.2.5 Equivalent Yield Strength

For materials that do not exhibit a well-defined yield strength, the value of the ultimate strength multiplied by 0.80 or 5 % of the elastic modulus, whichever is less shall be used as the equivalent yield strength.

6.4.3 Environmental Factors

Non-metallic materials shall be tested for chemical attack by any chemicals likely to be encountered in service. At a minimum, the testing shall indicate which chemicals affect the serviceability of the equipment or its ability to be used at the rated load.

Non-metallic materials shall be evaluated for the effect of ultraviolet radiation and other environmental factors. The evaluation shall include exposure likely to be encountered in service over the expected life of the component.

6.4.4 Material Qualification

6.4.4.1 General

The mechanical tests required by this specification shall be performed on qualification test coupons representing each unique batch of finished material used in the manufacture of the component. Non-metallic components manufactured from the same lot of materials with the same chemistry within the same lot for all processes shall be considered a unique batch. Non-metallic materials may be prequalified for temperature, orientation, creep, stress relaxation, load rate effects, and chemical properties. The properties of a prequalified material shall meet or exceed the values required for design. Prequalification shall not be applied to mechanical properties. Mechanical properties shall be tested for each batch.

6.4.4.2 Material Test Coupons

Qualification test coupons shall be from the same unique batch as the components they qualify, subjected to the same manufacturing operations, and exposed to the same environmental conditions as the components they qualify.

6.4.4.3 Manufacture

The manufacturing processes shall ensure repeatability in producing components that meet all the requirements of this specification.

All thermal operations shall be performed utilizing equipment qualified in accordance with the requirements specified by the manufacturer or processor. The loading of the material within furnaces and ovens shall be such that the presence of any part does not adversely affect the response of any other part within the same load. The temperature and time requirements shall be performed according to the manufacturer's written specification.

NOTE See Annex B for recommendation on qualification of thermal processing equipment.

6.4.5 Documentation

The manufacturer shall provide specific procedures for the inspection of all non-metallic materials (including frequency, methods, equipment, and acceptance and rejection criteria) to the user/owner in an inspection and maintenance manual upon delivery of the equipment under a purchase agreement. These procedures shall also include recommendations for maximum intervals for replacement due to aging and shelf life of replacement components. The manufacturer shall also provide instructions and information regarding the material's resistance to chemical attack, along with a list of what types of chemicals will affect the serviceability of the equipment or its ability to be used at its designated rated load. In addition, the manufacturer shall provide the minimum and maximum temperatures that the equipment can be used at its designated rated load, plus any other ambient conditions that could adversely affect the ability of the equipment to be operated at its designated rated load.

6.4.6 Additional Requirements

6.4.6.1 Polymers and polymer composites, including polymer matrix and polymer fiber composites, with a glass transition temperature above the minimum design operating temperature shall not be used.

6.4.6.2 Ceramic and ceramic matrix composites shall only be used as compression members in primary load-carrying components.

6.4.6.3 Aramid Fiber Cordage with Unbonded Elastomeric Coating Loaded in Simple Tension—The material shall be qualified and controlled for conformance to the manufacturer's written specification. The material specification shall contain, as a minimum with appropriate limits, the uncoated cordage diameter, the denier of the cordage, the coated cord diameter, the twist density, and the tensile strength. The tensile strength shall be tested in accordance with CI-1500. All mechanical testing is to be performed on no less than a single fully encapsulated cord.

The material shall be prequalified for cyclical loading. A sample of the material as described above shall be loaded in tension to a load corresponding to the rated load and have load completely removed for a minimum of 1500 cycles or the number of cycles corresponding to the design life of the component, whichever is greater. The same specimen shall then be loaded in tension until fracture. The load to fracture the specimen after cyclic testing shall not be less than the specified tensile strength.

7 Welding Requirements

7.1 General

This section describes requirements for the fabrication and repair welding of primary load-carrying and pressure-containing components, including attachment welds.

7.2 Welding Qualification

All welding undertaken on components shall be performed using welding procedures that are qualified in accordance with ASME *BPVC*, Section IX, AWS D1.1, and/or [ASTM A488](#). This welding shall only be carried out by welders or welding operators who are qualified in accordance with the aforementioned standards or BS EN 287.

Welding procedures for base materials that are not listed in the above standards shall be qualified individually or as a group based on weldability, tensile properties, or composition. Where the ductility of the parent metal is such as to render it incapable of meeting the bend test requirements of ASME *BPVC*, Section IX, the bend test shall be conducted in the following manner: a bend bar comprised of parent metal heat treated to the ductility and strength requirements of the applicable specification shall be bent to failure. The side bend specimen taken from the weld test coupon shall then be capable of being bent to within 5 ° of the angle thus determined.

7.3 Written Documentation

Welding shall be performed in accordance with welding procedure specifications (WPS) written and qualified in accordance with the applicable standard. The WPS shall describe all the essential, non-essential, and supplementary essential (when required) variables as listed in the applicable standard. Written prequalified welding procedures in accordance with the applicable standard may be used.

The procedure qualification record (PQR) shall record all essential and supplementary essential (when required) variables of the weld procedure used for the qualification tests. Both the WPS and the PQR shall be maintained as records in accordance with the requirements of Section 11.

7.4 Control of Consumables

Welding consumables shall conform to American Welding Society (AWS) or consumable manufacturer's specifications.

The manufacturer shall have a written procedure for storage and control of weld consumables. Materials of low-hydrogen type shall be stored and used as recommended by the consumable manufacturer to retain their original low-hydrogen properties.

7.5 Weld Properties

The mechanical properties of the weld, as determined by the procedure qualification test, shall at least meet the minimum specified mechanical properties required by the design. When impact testing is required for the base material, it shall also be a procedure qualification requirement. Results of testing in the weld and base material HAZ shall meet the minimum requirements of the base material. In the case of attachment welds, only the HAZ of material requiring impact testing shall meet the above requirements.

All weld testing shall be undertaken with the test weldment in the applicable post-weld heat-treated condition.

7.6 Post-weld Heat Treatment (PWHT)

PWHT of components shall be in accordance with the applicable qualified WPS.

7.7 Quality Control Requirements

Requirements for quality control of welds shall be in accordance with Section 8.

7.8 Specific Requirements—Fabrication Welds

Weld joint types and sizes shall meet the manufacturer's design requirements and shall be documented in the manufacturer's WPS.

7.9 Specific Requirements—Repair Welds

7.9.1 Access

There shall be adequate access to evaluate, remove, and inspect the nonconforming condition that is the cause of the repair.

7.9.2 Fusion

The selected WPS and the available access for repair shall be such as to ensure complete fusion with the base material.

7.9.3 Forgings and Castings

All repair welding shall be performed in accordance with the manufacturer's written welding specifications. WPSs shall be documented and shall be supplied at the purchaser's request.

The manufacturer shall document the following criteria for permitted repairs:

- defect type,
- defect size limits,
- definition of major/minor repairs.

All excavations, prior to repair, and the subsequent weld repair shall meet the quality control requirements specified in Section 8.

7.9.4 Heat Treatment

The WPS used for qualifying a repair shall reflect the actual sequence of weld repair and heat treatment imparted to the repair item.

8 Quality Control

8.1 General

This section specifies the quality control requirements for equipment and material. All quality control work shall be controlled by the manufacturer's documented instructions, which shall include appropriate methodology and quantitative and qualitative acceptance criteria.

Instructions for NDE activities shall be sufficiently detailed regarding the requirements of this specification and those of all applicable referenced specifications. All NDE instructions shall be approved by an examiner qualified to an ASNT SNT-TC-1A, Level III examiner.

The acceptance status of all equipment, parts, and materials shall be indicated either on the equipment, parts, or materials or in the records traceable to the equipment, parts, or materials.

8.2 Quality Control Personnel Qualifications

NDE personnel shall be qualified and/or certified in accordance with ASNT SNT-TC-1A or ISO 9712.

Personnel performing visual inspection of welding operations and completed welds shall be qualified in accordance with:

- AWS QC1 or equivalent standard, or
- the manufacturer's documented training program (to be equivalent to above).

All personnel performing other quality control activities directly affecting material and product quality shall be qualified in accordance with the manufacturer's documented procedures.

8.3 Measuring and Test Equipment

Equipment used to inspect, test, or examine material or other equipment shall be identified, controlled, calibrated, and adjusted at specified intervals in accordance with documented manufacturer instructions, and consistent with a recognized industry standard (e.g. ISO 10012-1 ^[2], MIL STD 120 ^[12]), to maintain the required level of accuracy.

8.4 Quality Control for Specific Equipment and Components

8.4.1 General

The quality control requirements shall apply to all primary load-bearing and/or pressure-containing equipment and components unless specified otherwise.

The manufacturer shall establish and maintain critical area drawings identifying high stress areas, which shall be used in conjunction with this section.

For purposes of this section, critical areas shall be defined as all areas where the stress in the component is

$$\geq \frac{0.75S_{ymin}}{F_{DS}} \quad (5)$$

where

S_{Ymin} is the specified minimum yield strength;

F_{DS} is the design safety factor.

If critical areas are not identified on critical area drawings, then all surfaces of the component shall be considered critical.

Areas of components in which the stress is compressive, and/or where the stress level is

$$\leq \frac{0.1 S_{Ymin}}{F_{DS}} \quad (6)$$

where

S_{Ymin} is the specified minimum yield strength;

F_{DS} is the design safety factor.

shall be exempt from the acceptance criteria defined in 8.4.7.4. The low-stress areas thus defined may be identified on the critical area map.

8.4.2 Chemical Analysis

Methods and acceptance criteria for metallic materials shall be in accordance with 6.3.4.

8.4.3 Tensile Testing

Methods and acceptance criteria shall be in accordance with 6.3 and 6.4.

8.4.4 Impact Testing

Methods and acceptance criteria shall be in accordance with 6.3 and 6.4.

8.4.5 Traceability

Components shall be traceable by heat and heat-treatment lot identification.

Identification shall be maintained on materials and components through all stages of manufacturing and on the finished components or assembly. Manufacturer's documented traceability requirements shall include provisions for maintenance and replacement of identification marks and identification control records. Fasteners and pipe fittings shall be exempt from the traceability requirements, provided they are marked in accordance with a recognized industry standard.

8.4.6 Visual Examination

Components shall be visually examined. Visual examination of castings shall meet the requirements of MSS SP-55. Examination of wrought material shall be in accordance with the manufacturer's documented procedures.

8.4.7 Surface NDE

8.4.7.1 General

All accessible surfaces of each finished component shall be inspected in accordance with 8.4.7 after final heat treatment and final machining operations.

If the equipment is subjected to a load test, the qualifying NDE shall be carried out after the load test. For materials susceptible to delayed cracking, as identified by the manufacturer, NDE shall be carried out no earlier than 24 hours after the load test. The equipment shall be disassembled for this inspection. Conducting surface coatings shall be removed prior to examination. Nonconducting surface coatings shall be removed prior to examination unless it has been demonstrated that the smallest relevant indications, as defined in 8.4.7.3, can be detected through the maximum applied thickness of the coating.

8.4.7.2 Method

Ferromagnetic materials shall be examined by the magnetic particle method in accordance with ASME BPVC, Section V, Subsection A, Article 7 and Subsection B, Article 25 or [ASTM E709](#). Machined surfaces shall be examined by the wet fluorescent method; other surfaces shall be examined by a wet method or dry method.

Non-ferromagnetic materials shall be examined by the liquid penetrant method in accordance with ASME BPVC, Section V, Subsection A, Article 6 and Subsection B, Article 24 or [ASTM E165](#).

The use of prods should be avoided if possible. If prods are used, all prod burn marks shall be removed by grinding and the affected areas re-examined by the liquid penetrant method.

8.4.7.3 Evaluation of Indications

Only those indications with major dimensions greater than 2 mm ($1/16$ in.) and associated with a surface rupture shall be considered relevant. Inherent indications not associated with a surface rupture (i.e. magnetic permeability variations, non-metallic stringers, etc.) shall be considered non-relevant. If magnetic particle indications greater than 2 mm ($1/16$ in.) are believed to be non-relevant, they shall either be examined by the liquid penetrant method to confirm they are non-relevant, or they shall be removed and re-inspected to confirm they are non-relevant.

Relevant indications shall be evaluated in accordance with the acceptance criteria specified in 8.4.7.4.

8.4.7.4 Acceptance Criteria

8.4.7.4.1 Castings

[ASTM E125](#) shall be applied as a reference standard for the evaluation of magnetic particle indications on castings. The acceptance criteria shall be as specified in Table 5.

Table 5—Castings Indication Acceptance Criteria

Type	Discontinuity Descriptions	Maximum Permitted Degree	
		Critical Areas	Non-critical Areas
I	Hot tears, cracks	None	Degree 1
II	Shrinkage	Degree 2	Degree 2
III	Inclusions	Degree 2	Degree 2
IV	Internal chills, chaplets	Degree 1	Degree 1
V	Porosity	Degree 1	Degree 2

8.4.7.4.2 Wrought Materials

The following acceptance criteria shall apply for surface NDE of wrought materials:

- no relevant indications with a major dimension equal to or greater than 5 mm ($3/16$ in.);
- no more than 10 relevant indications in any continuous 40 cm² (6 in.²) area;
- no more than 3 relevant indications in a line separated by less than 2 mm ($1/16$ in.) edge-to-edge;
- no relevant indications in pressure-sealing areas, in the root area of rotary threads, or in the stress-relief features of threaded joints.

8.4.7.5 Non-metallic Components

The manufacturer shall have written specifications defining the maximum discontinuity size, orientation, grouping, etc. for each type of discontinuity expected. The discontinuity types considered are to be, at a minimum, voids, cuts, cracks, delaminations, and/or tears.

The methods for detection and measurement of the expected discontinuity shall be specified and proven effective in detecting discontinuities as small as 75 % of the maximum allowable size or severity. All primary load carrying components are to be examined in both critical and non-critical areas.

8.4.8 Volumetric NDE of Castings

8.4.8.1 Method

Radiographic examination of castings shall be in accordance with ASME *BPVC*, Section V, Subsection A, Article 2 and Subsection B, Article 22 with the restriction that fluorescent intensifying screens shall not be used.

Ultrasonic examination shall be in accordance with ASME *BPVC*, Section V, Subsection A, Article 5 and Subsection B, Article 23. The component(s) shall be examined by the straight-beam method in accordance with SA-609 of Article 23 and shall be supplemented by angle beam examination as in T-534.2 of Article 5 in areas where a back reflection cannot be maintained during the straight-beam examination, or where the angle between the two surfaces of the component is more than 15 °.

8.4.8.2 Sampling

Primary-load-carrying castings shall be examined by volumetric NDE on the following sampling basis as a minimum:

- all areas of initial or prototype castings shall be examined by ultrasonic or radiographic methods until the results of such examination indicate that a satisfactory production technique has been established;
- thereafter, one casting out of each production lot or, for production lots of less than 10 castings, 1 out of every 10 production castings shall be volumetrically examined in all critical areas as identified on critical area drawings. If any casting shows any indications outside the acceptance criteria defined in 8.4.8.3, two more castings from that production lot shall be examined by the same method. If the two additional castings are acceptable, the remainder of the batch may be accepted and the initial non-conforming casting shall be repaired or scrapped.

8.4.8.3 Acceptance Criteria

8.4.8.3.1 General

Areas of components where the stress level is less than the value of low stress [as calculated in Equation (6)] shall be exempt from volumetric examination.

8.4.8.3.2 Radiography

The acceptance criteria for radiographic examination are based on the Standard Reference Radiographs of [ASTM E446](#), [ASTM E186](#), or [ASTM E280](#) depending on the wall thickness being examined.

In all cases, cracks, hot tears, and inserts (defect types D, E, and F, respectively) are not permitted.

The remaining indication types shown in the reference radiographs shall meet Severity Level 2 in all critical areas and Severity Level 3 in non-critical areas. Critical areas shall be as defined in 8.4.1. If critical areas are not identified on critical-area drawings, then all areas of the component shall be considered critical.

8.4.8.3.3 Ultrasonic Examination

The acceptance criteria for both straight-beam and angle-beam ultrasonic examination of castings are based on SA-609 in ASME BPVC, Section V, Subsection B, Article 23, Quality Level 3, with the exception that Quality Level 1 shall apply within 50 mm (2 in.) of the casting surface. Discontinuities indicated as having a change in depth of 25 mm (1 in.) or half the thickness, whichever is the lesser, are not permitted.

8.4.9 NDE of Welds

8.4.9.1 General

If examination is required, essential welding variables and equipment shall be monitored during welding. The entire accessible weld, plus at least 13 mm ($\frac{1}{2}$ in.) of surrounding base metal, shall be examined in accordance with the methods and acceptance criteria of 8.4.9.

The NDE required under 8.4.9 shall be carried out after final heat treatment.

8.4.9.2 Fabrication Welding

8.4.9.2.1 Visual Examination

All fabrication welds shall be visually examined in accordance with ASME *BPVC*, Section V, Subsection A, Article 9. Undercuts shall not reduce the thickness in the affected area to below the design thickness, and shall be ground to blend smoothly with the surrounding material.

Surface porosity or exposed slag are not permitted on or within 3 mm ($\frac{1}{8}$ in.) of sealing surfaces.

8.4.9.2.2 Surface NDE

All primary-load-carrying and pressure-containing welds and attachment welds to primary-load-carrying and pressure-containing components shall be examined as specified in 8.4.7.2.

The following acceptance criteria shall apply:

- no relevant linear indications (see 3.1.29);
- no rounded indications (see 3.1.47) with a major dimension greater than 4 mm ($\frac{1}{8}$ in.), for welds whose depth is 17 mm ($\frac{5}{8}$ in.) or less;
- no rounded indications with a major dimension greater than 5 mm ($\frac{3}{16}$ in.) for welds whose depth is greater than 17 mm ($\frac{5}{8}$ in.);
- no more than three relevant indications in a line separated by less than 2 mm ($\frac{1}{16}$ in.) edge-to-edge.

8.4.9.2.3 Volumetric NDE

Primary load-bearing and pressure-containing welds shall be examined by either ultrasonic or radiographic methods. Ultrasonic examination shall be in accordance with ASME *BPVC*, Section V, Subsection A, Article 5, and radiographic examination shall be in accordance with ASME *BPVC*, Section V, Subsection A, Article 2. This applies to full-penetration welds only.

Acceptance criteria shall be in accordance with the requirements of ASME *BPVC*, Section VIII, Division 1, UW-51 and Appendix 12, as appropriate.

8.4.9.3 Repair Welds

8.4.9.3.1 Weld Excavations

Magnetic particle examination shall be performed on all excavations for weld repairs, with the method and acceptance criteria as specified in 8.4.7.

8.4.9.3.2 Repair Welds in Castings

All repair welds in castings shall be examined in accordance with 8.4.7.2. Acceptance criteria shall be identical to those for fabrication welds (see 8.4.9.2).

8.4.9.3.3 Repair of Welds

NDE of the repairs of weld defects shall be identical to that of the original weld (see 8.4.9.2).

8.5 Dimensional Verification

Verification of dimensions shall be carried out on a sample basis as defined and documented by the manufacturer.

All main load-bearing and pressure-sealing threads shall be gauged to the requirements of the relevant thread specification(s).

8.6 Proof Load Testing

When proof load testing is required, as indicated under the relevant equipment headings of Section 9, the following requirements shall apply.

- a) Each production unit or primary load-carrying component shall be load-tested in accordance with the requirements of this section.