(b) **Acceptance Criteria.** Cracks, lack of fusion, incomplete penetration, or undercutting are unacceptable regardless of size or length (see Table K341.3.2). In addition, for an internal slag inclusion, tungsten inclusion, or linear indication

(1) for nominal wall thickness, $t_w$, greater than or equal to 13 mm ($\frac{1}{2}$ in.) but less than 25 mm (1 in.), the acceptance criterion for the thickness to be examined specified in para. 344.6.2 applies.

(2) for nominal wall thickness, $t_w$, greater than or equal to 25 mm (1 in.), the acceptance criteria specified in ASME BPVC, Section VIII, Division 3, KE-333 for the thickness to be examined apply.

K344.7 In-Process Examination

Paragraph 344.7 applies in its entirety.

K344.8 Eddy Current Examination

K344.8.1 Method. The method for eddy current examination of pipe and tubing shall follow the general guidelines of ASME BPVC, Section V, Article 8, subject to the following specific requirements:

(a) Cold drawn austenitic stainless steel pipe and tubing, selected in accordance with Table K305.1.2 for eddy current examination, shall pass a 100% examination for longitudinal defects.

(b) A calibration (reference) standard shall be prepared from a representative sample. A longitudinal (axial) reference notch shall be introduced on the inner surface of the standard to a depth not greater than the larger of 0.1 mm (0.004 in.) or 5% of specimen thickness and a length not more than 6.4 mm (0.25 in.).

K344.8.2 Acceptance Criteria. Any indication greater than that produced by the calibration notch represents a defect; defective pipe or tubing shall be rejected.

K344.8.3 Records. For pipe and tubing that passes this examination, a report shall be prepared that includes at least the following information:

(a) material identification by type, size, lot, heat, etc.
(b) listing of examination equipment and accessories
(c) details of examination technique (including examination speed and frequency) and end effects, if any
(d) description of the calibration standard, including dimensions of the notch, as measured
(e) examination results

K345 LEAK TESTING

K345.1 Required Leak Test

Prior to initial operation, each piping system shall be leak tested.

(a) Each weld and each piping component, except bolting and individual gaskets to be used during final system assembly and pressure-relieving devices to be used during operation, shall be hydrostatically or pneumatically leak tested in accordance with para. K345.4 or K345.5, respectively. The organization conducting the test shall ensure that during the required leak testing of components and welds, adequate protection is provided to prevent injury to people and damage to property from missile fragments, shock waves, or other consequences of any failure that might occur in the pressurized system.

(b) In addition to the requirements of (a) above, a leak test of the installed piping system, excluding pressure-relieving devices to be used during operation, shall be conducted at a pressure not less than 110% of the design pressure to ensure tightness, except as provided in (c) or (d) below.

(c) If the leak test required in (a) above is conducted on the installed piping system, the additional test in (b) above is not required.

(d) With the owner’s approval, pressure-relieving devices to be used during operation may be included in the leak test required in (b) above. The leak test pressure may be reduced to prevent the operation of, or damage to, the pressure-relieving devices, but shall not be less than 90% of the lowest set pressure of the pressure-relieving devices in the system.

(e) For closure welds, examination in accordance with para. K345.2.3(c) may be substituted for the leak test required in (a) above.

(f) None of the following leak tests may be used in lieu of the leak tests required in para. K345.1:

(1) initial service leak test (para. 345.7)
(2) sensitive leak test (para. 345.8)
(3) alternative leak test (para. 345.9)

K345.2 General Requirements for Leak Tests

Paragraphs 345.2.4 through 345.2.7 apply. See below for paras. K345.2.1, K345.2.2, and K345.2.3.

K345.2.1 Limitations on Pressure

(a) **Through-Thickness Yielding.** If the test pressure would produce stress (exclusive of stress intensification) in excess of $S_y$ at the outside surface of a component at test temperature, as determined by calculation or by testing in accordance with para. K304.7.2(b), the test pressure may be reduced to the maximum pressure that will result in a stress (exclusive of stress intensification) at the outside surface that will not exceed $S_y$.

(b) The provisions of paras. 345.2.1(b) and (c) apply.

K345.2.2 Other Test Requirements. Paragraph 345.2.2 applies. In addition, the minimum metal temperature during testing shall be not less than the impact test temperature (see para. K323.3.4).

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**See para. K304.1.2, footnote 4.**
equivalent) shall apply, except that for straight threaded connections, the external thread groove depth need not be considered provided
(a) it does not exceed 20% of the wall thickness;
(b) the ratio of outside to inside diameter, $D/d$, is greater than 1.1;
(c) the internally threaded attachment provides adequate reinforcement; and
(d) the thread plus the undercut area, if any, does not extend beyond the reinforcement for a distance more than the nominal wall thickness of the pipe.

\[ t = \text{pressure design wall thickness, as calculated in para. K304.1.2 for internal pressure, or in accordance with the procedure listed in para. K304.1.3 for external pressure} \]

\[ t_m = \text{minimum required wall thickness, including mechanical, corrosion, and erosion allowances} \]

Adequate reinforcement by the attachment is defined as that necessary to ensure that the static burst pressure of the connection will equal or exceed that of the unthreaded portion of the pipe. The adequacy of the reinforcement shall be substantiated as required by para. K304.7.2.

(18) **K304.1.2 Straight Pipe Under Internal Pressure**

(a) Except as provided in (b) below for solution heat treated austenitic stainless steels and certain nickel alloys with similar stress–strain behavior, the internal pressure design wall thickness, $t$, shall be not less than that calculated in accordance with eq. (34a) for pipe with a specified outside diameter and minimum wall thickness, or eq. (34b) for pipe with a specified inside diameter and minimum wall thickness.\(^4\)

\[ t = \frac{D - 2c_t}{2} \left(1 - \epsilon^{-P/S} \right) \quad (34a) \]

or

\[ t = \frac{d + 2c_t}{2} \left(\epsilon^{-P/S} - 1 \right) \quad (34b) \]

Alternatively, the internal design gage pressure, $P$, may be calculated by eq. (35a) or (35b).\(^4\)

\[ P = S \times \ln \left[ \frac{D - 2c_t}{D - 2(T - c_l)} \right] \quad (35a) \]

or

\[ P = S \times \ln \left[ \frac{d + 2(T - c_l)}{d + 2c_t} \right] \quad (35b) \]

where

- $D = \text{outside diameter of pipe}$
- $d = \text{inside diameter of pipe}$
- $S = \text{allowable stress from Table K-1}$
- $T = \text{pipe wall thickness (measured or minimum in accordance with the purchase specification)}$
- $d = \text{inside diameter of pipe}$
- $c_t = \text{internal, } c_o = \text{external, } c_e = \text{specified as internal, } c_i = \text{specified as external, } c_m = \text{assumed to be internal, i.e., } c = c_e$ and $c_o = 0$.

(b) At design temperatures where allowable stress, $S$, values in Table K-1 are in **boldface** (solution heat treated austenitic stainless steels and certain nickel alloys with similar stress–strain behavior only), the internal pressure design wall thickness, $t$, shall be not less than that calculated in accordance with eq. (34c) for pipe with a specified outside diameter and minimum wall thickness, or eq. (34d) for pipe with a specified inside diameter and minimum wall thickness.\(^4\)

\[ t = \frac{D - 2c_t}{2} \left(1 - \epsilon^{-P/S} \right) \]

or

\[ t = \frac{d + 2c_t}{2} \left(\epsilon^{-P/S} - 1 \right) \]

Alternatively, the internal design gage pressure, $P$, may be calculated by eq. (35c) or (35d).\(^4\)

\[ P = S \times \ln \left[ \frac{D - 2c_t}{D - 2(T - c_l)} \right] \quad (35c) \]

or

\[ P = S \times \ln \left[ \frac{d + 2(T - c_l)}{d + 2c_t} \right] \quad (35d) \]
\[ t_m = \text{minimum required wall thickness, including mechanical, corrosion, and erosion allowances} \]

Adequate reinforcement by the attachment is defined as that necessary to ensure that the static burst pressure of the connection will equal or exceed that of the unthreaded portion of the pipe. The adequacy of reinforcement shall be substantiated as required by para. K304.7.2.

**K304.1.2 Straight Pipe Under Internal Pressure**

(a) Except as provided in (b) below for solution heat treated austenitic stainless steels and certain nickel alloys with similar stress–strain behavior, the internal pressure design wall thickness, \( t \), shall be not less than that calculated in accordance with eq. (34a) for pipe with a specified outside diameter and minimum wall thickness, or eq. (34b) for pipe with a specified inside diameter and minimum wall thickness.

\[ t = \frac{D - 2c_i}{2} \left[ 1 - \exp \left( \frac{-P}{S} \right) \right] \quad (34a)^{3, 4, 5} \]

or

\[ t = \frac{d + 2c_i}{2} \left[ \exp \left( \frac{P}{S} \right) - 1 \right] \quad (34b)^{3, 4, 5} \]

Alternatively, the internal design gage pressure, \( P \), may be calculated by eq. (35a) or (35b).

\[ P = S \times \ln \left[ \frac{D - 2c_i}{D - 2(T - c_i)} \right] \quad (35a)^{4, 5} \]

or

\[ P = S \times \ln \left[ \frac{d + 2(T - c_i)}{d + 2c_i} \right] \quad (35b)^{4, 5} \]

where

\[ D = \text{outside diameter of pipe. For design calculations in accordance with this Chapter, the outside diameter of the pipe is the maximum value allowable under the specifications.} \]

\[ d = \text{inside diameter of pipe. For design calculations in accordance with this Chapter, the inside diameter of the pipe is the maximum value allowable under the specifications.} \]

\[ P = \text{internal design gage pressure} \]

\[ S = \text{allowable stress from Table K-1} \]

\[ T = \text{pipe wall thickness (measured or minimum in accordance with the purchase specification)} \]

(b) At design temperatures where allowable stress, \( S \), values in Table K-1 are in **boldface** (solution heat treated austenitic stainless steels and certain nickel alloys with similar stress–strain behavior only), the internal pressure design wall thickness, \( t \), shall be not less than that calculated in accordance with eq. (34c) for pipe with a specified outside diameter and minimum wall thickness, or eq. (34d) for pipe with a specified inside diameter and minimum wall thickness.

\[ t = \frac{D - 2c_i}{2} \left[ 1 - \exp \left( \frac{-1.155P}{S} \right) \right] \quad (34c)^{4, 5} \]

or

\[ t = \frac{d + 2c_i}{2} \left[ \exp \left( \frac{1.155P}{S} \right) - 1 \right] \quad (34d)^{4, 5} \]

Alternatively, the internal design gage pressure, \( P \), may be calculated by eq. (35c) or (35d).

\[ P = \frac{S}{1.155} \ln \left[ \frac{D - 2c_i}{D - 2(T - c_i)} \right] \quad (35c)^{4, 5} \]

or

\[ P = \frac{S}{1.155} \ln \left[ \frac{d + 2(T - c_i)}{d + 2c_i} \right] \quad (35d)^{4, 5} \]

**K304.1.3 Straight Pipe Under External Pressure.**

The pressure design thickness for straight pipe under external pressure shall be determined in accordance with para. K304.1.2 for pipe where \( D/t < 3.33 \), if at least one end of the pipe is exposed to full external pressure, producing a compressive axial stress. For \( D/t \geq 3.33 \), and for \( D/t < 3.33 \) where external pressure is not applied to at least one end of the pipe, the pressure design wall thickness shall be determined in accordance with para. 304.1.3 except that the stress values shall be taken from Table K-1.

**K304.2 Curved and Mitered Segments of Pipe**

**K304.2.1 Pipe Bends.** The minimum required wall thickness \( t_m \) of a bend, after bending, may be determined as for straight pipe in accordance with para. K304.1, provided that the bend radius of the pipe centerline is equal to or greater than ten times the nominal pipe outside diameter and the tolerances and strain limits of para. K332 are met. Otherwise the design shall be qualified as required by para. K304.7.2.

**K304.2.2 Elbows.** Manufactured elbows not in accordance with para. K303 and pipe bends not in accordance with para. K304.2.1 shall be qualified as required by para. K304.7.2.
K345.5, respectively. The organization conducting the test shall ensure that during the required leak testing of components and welds, adequate protection is provided to prevent injury to people and damage to property from missile fragments, shock waves, or other consequences of any failure that might occur in the pressurized system.

(b) In addition to the requirements of (a) above, a leak test of the installed piping system, excluding pressure-relieving devices to be used during operation, shall be conducted at a pressure not less than 110% of the design pressure to ensure tightness, except as provided in (c) or (d) below.

(c) If the leak test required in (a) above is conducted on the installed piping system, the additional test in (b) above is not required.

(d) With the owner’s approval, pressure-relieving devices to be used during operation may be included in the leak test required in (b) above. The leak test pressure may be reduced to prevent the operation of, or damage to, the pressure-relieving devices, but shall not be less than 90% of the lowest set pressure of the pressure-relieving devices in the system.

(e) For closure welds, examination in accordance with para. K345.2.3(c) may be substituted for the leak test required in (a) above.

(f) None of the following leak tests may be used in lieu of the leak tests required in para. K345.1:

(1) initial service leak test (para. 345.7)
(2) sensitive leak test (para. 345.8)
(3) alternative leak test (para. 345.9)

K345.2 General Requirements for Leak Tests

Paragraphs 345.2.4 through 345.2.7 apply. See below for paras. K345.2.1, K345.2.2, and K345.2.3.

K345.2.1 Limitations on Pressure

(a) Through-Thickness Yielding. If the test pressure would produce stress (exclusive of stress intensification) in excess of $S_{y}$ at the outside surface of a component at test temperature, as determined by calculation or by testing in accordance with para. K304.7.2(b), the test pressure may be reduced to the maximum pressure that will result in a stress (exclusive of stress intensification) at the outside surface that will not exceed $S_{y}$.

(b) The provisions of paras. 345.2.1(b) and (c) apply.

K345.2.2 Other Test Requirements. Paragraph 345.2.2 applies. In addition, the minimum metal temperature during testing shall be not less than the impact test temperature (see para. K323.3.4).

K345.2.3 Special Provisions for Leak Testing. Paragraphs K345.2.3(a), (b), and (c) below apply only to the leak test specified in para. K345.1(a). They are not applicable to the installed piping system leak test specified in para. K345.1(b).

(a) Piping Components and Subassemblies. Piping components and subassemblies may be leak tested either separately or as assembled piping.

(b) Flanged Joints. Flanged joints used to connect piping components that have previously been leak tested, and flanged joints at which a blank or blind flange is used to isolate equipment or other piping during the leak test, need not be leak tested.

(c) Closure Welds. Leak testing of the final weld connecting piping systems or components that have been successfully leak tested is not required, provided the weld is examined in-process in accordance with para. 344.7 and passes the required 100% radiographic examination in accordance with para. K341.4.2.

K345.3 Preparation for Leak Test

Paragraph 345.3 applies in its entirety.

K345.4 Hydrostatic Leak Test

Paragraph 345.4.1 applies. See paras. K345.4.2 and K345.4.3 below.

K345.4.2 Test Pressure for Components and Welds.

Except as provided in para. K345.4.3, the hydrostatic test pressure at every point in a metallic piping system shall be as follows:

(a) not less than 1.25 times the design pressure.

(b) when the design temperature is greater than the test temperature, the minimum test pressure, at the point under consideration, shall be calculated by eq. (38)

$$P_T = 1.25PS_y/S$$  \hspace{1cm} (38)

where

$P =$ internal design gage pressure

$P_T =$ minimum test gage pressure

$S =$ allowable stress at component design temperature for the prevalent pipe material; see Appendix K, Table K-1

$S_T =$ allowable stress at test temperature for the prevalent pipe material; see Table K-1

(c) in those cases where the piping system may not include pipe itself, any other component in the piping system, other than pipe-supporting elements and bolting, may be used to determine the $S_T/S$ ratio based on the applicable allowable stresses obtained from Table K-1. In those cases where the piping system may be made up of equivalent lengths of more than one material, the $S_T/S$ ratio shall be based on the minimum calculated ratio of the included materials.

K345.4.3 Hydrostatic Test of Piping With Vessels as a System. Paragraph 345.4.3(a) applies.

K345.5 Pneumatic Leak Test

Paragraph 345.5 applies, except para. 345.5.4. See para. K345.5.4 below.