



Designation: A335/A335M – 10

Standard Specification for Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service¹

This standard is issued under the fixed designation A335/A335M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification² covers nominal wall and minimum wall seamless ferritic alloy-steel pipe intended for high-temperature service. Pipe ordered to this specification shall be suitable for bending, flanging (vanstoning), and similar forming operations, and for fusion welding. Selection will depend upon design, service conditions, mechanical properties, and high-temperature characteristics.

1.2 Several grades of ferritic steels (see **Note 1**) are covered. Their compositions are given in **Table 1**.

NOTE 1—Ferritic steels in this specification are defined as low- and intermediate-alloy steels containing up to and including 10 % chromium.

1.3 Supplementary requirements (S1 to S7) of an optional nature are provided. These supplementary requirements call for additional tests to be made, and when desired, shall be so stated in the order together with the number of such tests required.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. The inch-pound units shall apply unless the “M” designation of this specification is specified in the order.

NOTE 2—The dimensionless designator NPS (nominal pipe size) has been substituted in this standard for such traditional terms as “nominal diameter,” “size,” and “nominal size.”

2. Referenced Documents

2.1 ASTM Standards:³

¹ This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.10 on Stainless and Alloy Steel Tubular Products.

Current edition approved April 1, 2010. Published May 2010. Originally approved in 1951. Last previous edition approved in 2009 as A335/A335M-09a. DOI: 10.1520/A0335_A0335M-10.

² For ASME Boiler and Pressure Vessel Code applications see related Specification SA-335 in Section II of that Code.

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[A999/A999M Specification for General Requirements for Alloy and Stainless Steel Pipe](#)

[E92 Test Method for Vickers Hardness of Metallic Materials](#)

[E213 Practice for Ultrasonic Testing of Metal Pipe and Tubing](#)

[E309 Practice for Eddy-Current Examination of Steel Tubular Products Using Magnetic Saturation](#)

[E381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings](#)

[E527 Practice for Numbering Metals and Alloys in the Unified Numbering System \(UNS\)](#)

[E570 Practice for Flux Leakage Examination of Ferromagnetic Steel Tubular Products](#)

2.2 ASME Standard:

[B36.10M Welded and Seamless Wrought Steel Pipe](#)

2.3 Other Documents:

[SNT-TC-1A Recommended Practice for Nondestructive Personnel Qualification and Certification⁴](#)

[SAE J 1086 Practice for Numbering Metals and Alloys \(UNS\)⁵](#)

3. Ordering Information

3.1 Orders for material under this specification should include the following, as required, to describe the desired material adequately:

3.1.1 Quantity (feet, metres, or number of lengths),

3.1.2 Name of material (seamless alloy steel pipe),

3.1.3 Grade (**Table 1**),

3.1.4 Manufacture (hot-finished or cold-drawn),

3.1.5 Size using one of the following:

3.1.5.1 NPS and schedule number,

3.1.5.2 Outside diameter and nominal wall thickness,

3.1.5.3 Outside diameter and minimum wall thickness,

3.1.5.4 Inside diameter and nominal wall thickness, and

3.1.5.5 Inside diameter and minimum wall thickness.

3.1.6 Length (specific or random),

⁴ Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlington Ln., Columbus, OH 43228-0518, <http://www.asnt.org>.

⁵ Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, <http://www.sae.org>.

*A Summary of Changes section appears at the end of this standard.

TABLE 1 Chemical Requirements

Grade	UNS Designation ^A	Composition, %							
		Carbon	Manganese	Phosphorus, max	Sulfur, max	Silicon	Chromium	Molybdenum	Others
P1	K11522	0.10–0.20	0.30–0.80	0.025	0.025	0.10–0.50	...	0.44–0.65	...
P2	K11547	0.10–0.20	0.30–0.61	0.025	0.025	0.10–0.30	0.50–0.81	0.44–0.65	...
P5	K41545	0.15 max	0.30–0.60	0.025	0.025	0.50 max	4.00–6.00	0.45–0.65	...
P5b	K51545	0.15 max	0.30–0.60	0.025	0.025	1.00–2.00	4.00–6.00	0.45–0.65	...
P5c	K41245	0.12 max	0.30–0.60	0.025	0.025	0.50 max	4.00–6.00	0.45–0.65	... ^B
P9	S50400	0.15 max	0.30–0.60	0.025	0.025	0.25–1.00	8.00–10.00	0.90–1.10	...
P11	K11597	0.05–0.15	0.30–0.60	0.025	0.025	0.50–1.00	1.00–1.50	0.44–0.65	...
P12	K11562	0.05–0.15	0.30–0.61	0.025	0.025	0.50 max	0.80–1.25	0.44–0.65	...
P15	K11578	0.05–0.15	0.30–0.60	0.025	0.025	1.15–1.65	...	0.44–0.65	...
P21	K31545	0.05–0.15	0.30–0.60	0.025	0.025	0.50 max	2.65–3.35	0.80–1.06	...
P22	K21590	0.05–0.15	0.30–0.60	0.025	0.025	0.50 max	1.90–2.60	0.87–1.13	...
P23	K41650	0.04–0.10	0.10–0.60	0.030 max	0.010 max	0.50 max	1.90–2.60	0.05–0.30	V 0.20–0.30 Cb 0.02–0.08 B 0.0010–0.006 N 0.0015 max Al 0.030 max W 1.45–1.75 Ni 0.40 max Ti 0.005–0.060 Ti/N ≥ 3.5 ^C
P36	K21001	0.10–0.17	0.80–1.20	0.030 max	0.025 max	0.25–0.50	0.30 max	0.25–0.50	Ni 1.00–1.30 Cu 0.50–0.80 Cb 0.015–0.045 V 0.02 max N 0.02 max Al 0.050 max V 0.18–0.25 N 0.030–0.070 Ni 0.40 max Al 0.02 max Cb 0.06–0.10 Ti 0.01 max Zr 0.01 max V 0.15–0.25 N 0.03–0.07 Ni 0.40 max Al 0.02 max Cb 0.04–0.09 W 1.5–2.00 B 0.001–0.006 Ti 0.01 max Zr 0.01 max V 0.15–0.30 W 1.50–2.50 Cu 0.30–1.70 Cb 0.04–0.10 B 0.0005–0.005 N 0.040–0.100 Ni 0.50 max Al 0.020 max Ti 0.01 max Zr 0.01 max V 0.18–0.25 Ni 0.40 max Cb 0.060–0.10 B 0.0003–0.006 N 0.04–0.09 Al 0.02 max W 0.90–1.10 Ti 0.01 max Zr 0.01 max
P91	K91560	0.08–0.12	0.30–0.60	0.020	0.010	0.20–0.50	8.00–9.50	0.85–1.05	
P92	K92460	0.07–0.13	0.30–0.60	0.020	0.010	0.50 max	8.50–9.50	0.30–0.60	
P122	K92930	0.07–0.14	0.70 max	0.020	0.010	0.50 max	10.00–11.50	0.25–0.60	
P911	K91061	0.09–0.13	0.30–0.60	0.020 max	0.010 max	0.10–0.50	8.5–9.5	0.90–1.10	

^A New designation established in accordance with Practice E527 and SAE J 1086, Practice for Numbering Metals and Alloys (UNS).

^B Grade P 5c shall have a titanium content of not less than 4 times the carbon content and not more than 0.70 %; or a columbium content of 8 to 10 times the carbon content.

^C Alternatively, in lieu of this ratio minimum, the material shall have a minimum hardness of 275 HV in the hardened condition, defined as after austenitizing and cooling to room temperature but prior to tempering. Hardness testing shall be performed at mid-thickness of the product. Hardness test frequency shall be two samples of product per heat treatment lot and the hardness testing results shall be reported on the material test report.

3.1.7 End finish (Ends Section of Specification **A999/A999M**),

3.1.8 Optional requirements (Section **8**, **12** and **13** of this specification. See the Sections on Hydrostatic Test Requirements and Permissible Variation in Weight for Seamless Pipe in Specification **A999/A999M**),

3.1.9 Test report required (Certification Section of Specification **A999/A999M**),

3.1.10 Specification designation, and

3.1.11 Special requirements or any supplementary requirements selected, or both.

4. General Requirements

4.1 Material furnished to this specification shall conform to the applicable requirements of the current edition of Specification **A999/A999M**, unless otherwise provided herein.

5. Materials and Manufacture

5.1 Pipe may be either hot finished or cold drawn with the finishing treatment as required in **5.3**.

5.2 *Grade P2 and P12*—The steel shall be made by coarse-grain melting practice. Specific limits, if any, on grain size or

deoxidation practice shall be a matter of agreement between the manufacturer and purchaser.

5.3 Heat Treatment:

5.3.1 All pipe shall be reheated for heat treatment and heat treated in accordance with the requirements of **Table 2**.

NOTE 3—It is recommended that the temperature for tempering should be at least 100 °F [50 °C] above the intended service temperature; consequently, the purchaser should advise the manufacturer if the service temperature is to be over 1100 °F [600 °C].

NOTE 4—Certain of the ferritic steels covered by this specification will harden if cooled rapidly from above their critical temperature. Some will air harden, that is, become hardened to an undesirable degree when cooled in air from high temperatures. Therefore, operations involving heating such steels above their critical temperatures, such as welding, flanging, and hot bending, should be followed by suitable heat treatment.

6. Chemical Composition

6.1 The steel shall conform to the requirements as to chemical composition prescribed in **Table 1**.

7. Workmanship, Finish, and Appearance

7.1 The pipe manufacturer shall explore a sufficient number of visual surface imperfections to provide reasonable assurance

TABLE 2 Heat Treatment Requirements^A

Grade	Heat Treat Type	Normalizing Temperature, min or range °F [°C]	Cooling Media	Subcritical Annealing or Tempering Temperature, min or range °F [°C]
P1	full or isothermal anneal	...	...	...
	normalize and temper	...	...	1200 [650]
	subcritical anneal	...	...	1200-1300 [650-705]
P2	full or isothermal anneal	...	...	...
	normalize and temper	...	...	1250 [675]
	subcritical anneal	...	...	1200-1300 [650-705]
P5	full or isothermal anneal	...	...	...
	normalize and temper	...	...	1250 [675]
P5b	full or isothermal anneal	...	...	...
	normalize and temper	...	...	1250 [675]
P5c	full or isothermal anneal	...	...	...
	subcritical anneal	...	...	1325-1375 [715-745]
P9	full or isothermal anneal	...	...	...
	normalize and temper	...	...	1250 [675]
P11	full or isothermal anneal	...	...	...
	normalize and temper	...	...	1200 [650]
P12	full or isothermal anneal	...	...	...
	normalize and temper	...	...	1200 [650]
	subcritical anneal	...	...	1200-1300 [650-705]
P15	full or isothermal anneal	...	...	...
	normalize and temper	...	...	1200 [650]
P21	full or isothermal anneal	...	...	...
	normalize and temper	...	...	1250 [675]
P22	full or isothermal anneal	...	...	...
	normalize and temper	...	...	1250 [675]
P23	full or isothermal anneal	...	...	...
	normalize and temper	1900-1975 [1040-1080]	air or accelerated cooling	1350-1470 [730-800]
P36	normalize and temper ^B	1650 [900]	...	1100 [595]
P91	normalize and temper	1900-1975 [1040-1080]	...	1350-1470 [730-800] ^C
	quench and temper ^D	1900-1975 [1040-1080]	...	1350-1470 [730-800]
P92	normalize and temper	1900-1975 [1040-1080]	...	1350-1470 [730-800]
P122	normalize and temper	1900-1975 [1040-1080]	...	1350-1470 [730-800]
P911	normalize and temper	1900-1975 [1040-1080]	^E	1365-1435 [740-780]

^AWhere ellipses (...) appear in this table there is no requirement.

^BAlternatively, Grade P36, Class 2 shall be cooled from the austenitizing temperature by accelerated cooling in air or by liquid quenching.

^CExcept when Supplementary Requirement S7 is specified by the purchaser.

^DWhen mutually agreed upon between the manufacturer and the purchaser, quenching and tempering shall be permitted for thicknesses greater than 3 in. [75 mm].

^EAccelerated cooling from the normalizing temperature shall be permitted for section thicknesses greater than 3 in. [75 mm].

that they have been properly evaluated with respect to depth. Exploration of all surface imperfections is not required but may be necessary to ensure compliance with 7.2

7.2 Surface imperfections that penetrate more than 12½ % of the nominal wall thickness or encroach on the minimum wall thickness shall be considered defects. Pipe with such defects shall be given one of the following dispositions:

7.2.1 The defect may be removed by grinding provided that the remaining wall thickness is within specified limits.

7.2.2 Repaired in accordance with the repair welding provisions of 7.6.

7.2.3 The section of pipe containing the defect may be cut off within the limits of requirements on length.

7.2.4 Rejected.

7.3 To provide a workmanlike finish and basis for evaluating conformance with 7.2, the pipe manufacturer shall remove by grinding the following:

7.3.1 Mechanical marks, abrasions (see Note 5) and pits, any of which imperfections are deeper than ⅙ in. [1.6 mm].

NOTE 5—Marks and abrasions are defined as cable marks, dinges, guide marks, roll marks, ball scratches, scores, die marks, and the like.

7.3.2 Visual imperfections, commonly referred to as scabs, seams, laps, tears, or slivers, found by exploration in accordance with 7.1 to be deeper than 5 % of the nominal wall thickness.

7.4 At the purchaser's discretion, pipe shall be subject to rejection if surface imperfections acceptable under 7.2 are not scattered, but appear over a large area in excess of what is considered a workmanlike finish. Disposition of such pipe shall be a matter of agreement between the manufacturer and the purchaser.

7.5 When imperfections or defects are removed by grinding, a smooth curved surface shall be maintained, and the wall thickness shall not be decreased below that permitted by this specification. The outside diameter at the point of grinding may be reduced by the amount so removed.

7.5.1 Wall thickness measurements shall be made with a mechanical caliper or with a properly calibrated nondestructive testing device of appropriate accuracy. In case of dispute, the measurement determined by use of the mechanical caliper shall govern.

7.6 Weld repair shall be permitted only subject to the approval of the purchaser and in accordance with Specification A999/A999M.

7.6.1 After weld repair, Grades P23, P91, P92, and P122 shall be heat treated at 1350-1470 °F [730-800 °C].

7.6.2 After weld repair, Grade P911 shall be heat treated at 1365-1435 °F [740-780 °C].

7.7 The finished pipe shall be reasonably straight.

8. Product Analysis

8.1 At the request of the purchaser, an analysis of two pipes from each lot as defined hereafter shall be made by the manufacturer. A lot is all pipe of the same nominal size and wall thickness (schedule) which is produced from the same heat of steel and shall be limited as follows:

NPS Designator	Maximum Number of Lengths in a Lot
Under 2	400
2 to 5	200
6 and over	100

8.2 The results of these analyses shall be reported to the purchaser or the purchaser's representative, and shall conform to the requirements specified in Table 1.

8.3 For grade P 91 the carbon content may vary for the product analysis by -0.01 % and +0.02 % from the specified range as per Table 1.

8.4 If the analysis of one of the tests specified in 8.1 does not conform to the requirements specified in 6.1, an analysis of each billet or pipe from the same heat or lot may be made, and all billets or pipe conforming to the requirements shall be accepted.

9. Tensile and Hardness Requirements

9.1 The tensile properties of the material shall conform to the requirements prescribed in Table 3.

9.2 Table 4 lists elongation requirements.

9.3 Pipe of Grade P91 shall have a hardness inclusively in the range 190 to 250 HBW/196 to 265 HV [91 HRB to 25 HRC]. Pipe of Grades P92, P122, and P36 shall have a hardness not exceeding 250 HBW/265 HV [25 HRC].

9.4 Table 5 gives the computed minimum elongation values for each ½-in. [0.8-mm] decrease in wall thickness. Where the wall thickness lies between two values above, the minimum elongation value is determined by the following formula:

Direction of Test	Equation ^B
Longitudinal, all grades except P23, P91, P92, P122, and P911	$E = 48t + 15.00$ [$E = 1.87t + 15.00$]
Transverse, all grades except P23, P91, P92, P122, and P911	$E = 32t + 10.00$ [$E = 1.25t + 10.00$]
Longitudinal, P23, P91, P92, P122, and P911	$E = 32t + 10.00$ [$E = 1.25t + 10.00$]
Longitudinal, P36	$E = 32t + 5.0$ [$E = 1.25t + 5.0$]

where:

E = elongation in 2 in. or 50 mm, %, and
t = actual thickness of specimens, in. [mm].

TABLE 3 Tensile Requirements

	Grade							
	P1, P2	P12	P23	P91	P92, P911 P36 Class 1	P122	P36 Class 2	All Others
Tensile strength, min:								
ksi	55	60	74	85	90	90	95.5	60
MPa	380	415	510	585	620	620	660	415
Yield strength, min:								
ksi	30	32	58	60	64	58	66.5	30
MPa	205	220	400	415	440	400	460	205



TABLE 4 Elongation Requirements

Elongation Requirements					
	All grades except P23, P36, P91, P92, P122, and P911		P23, P91, P92, P122, and P 911		P36
	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal
Elongation in 2 in. or 50 mm, (or 4D), min, %:					
Basic minimum elongation for wall $\frac{5}{16}$ in. [8 mm] and over in thickness, strip tests, and for all small sizes tested in full section	30	20	20	...	15
When standard round 2-in. or 50-mm gage length or proportionally smaller size specimen with the gage length equal to 4D (4 times the diameter) is used	22	14	20	13	...
For strip tests a deduction for each $\frac{1}{32}$ -in. [0.8 mm] decrease in wall thickness below in. [8 mm] from the basic minimum elongation of the following percentage points shall be made	1.50 ^A	1.00 ^A	1.00 ^A	...	1.00 ^A

^A Table 5 gives the calculated minimum values.

10. Permissible Variations in Diameter

10.1 For pipe ordered to NPS [DN] or outside diameter, variations in outside diameter shall not exceed those specified in Table 6.

10.2 For pipe ordered to inside diameter, the inside diameter shall not vary more than $\pm 1\%$ from the specified inside diameter.

11. Permissible Variations in Wall Thickness

11.1 In addition to the implicit limitation of wall thickness for pipe imposed by the limitation on weight in Specification A999/A999M, the wall thickness for pipe at any point shall be within the tolerances specified in Table 7. The minimum wall thickness and outside diameter for inspection for compliance with this requirement for pipe ordered by NPS [DN] and schedule number is shown in ASME B36.10M.

12. Hydrostatic Test

12.1 Each length of pipe shall be subjected to the hydrostatic test, except as provided for in 12.2 or 12.3.

12.2 Unless otherwise specified in the purchase order, each length of pipe shall, at the option of the manufacturer, be subjected to the nondestructive electric test as shown in Section 13 in lieu of the hydrostatic test.

12.3 When specified by the purchaser, pipe shall be furnished without hydrostatic test and without nondestructive examination.

12.4 When specified by the purchaser, pipe shall be furnished with both the hydrostatic test and a nondestructive examination having been performed.

13. Nondestructive Examination

13.1 When selected by the manufacturer or when specified in the order, as an alternative to the hydrostatic test (12.2), or when specified in the purchase order in addition to the hydrostatic test (12.4), each pipe shall be examined by a nondestructive examination method in accordance with Practice E213, Practice E309 or Practice E570. The range of pipe sizes that may be examined by each method shall be subject to the limitations in the scope of the respective practices.

13.2 The following information is for the benefit of the user of this specification:

13.2.1 The reference standards defined in 13.8 are convenient standards for standardization of nondestructive examination equipment. The dimensions of these standards should not be construed as the minimum size imperfection detectable by such equipment.

13.2.2 Ultrasonic examination can be performed to detect both longitudinally and transversely oriented discontinuities. It should be recognized that different techniques should be employed to detect differently oriented imperfections. The examination may not detect short, deep imperfections.

13.2.3 The eddy current examination referenced in this specification has the capability to detect significant discontinuities, especially of the short abrupt type.

13.2.4 The flux leakage examination referred to in this specification is capable of detecting the presence and location of significant longitudinally or transversely oriented discontinuities. It should be recognized that different techniques should be employed to detect differently oriented imperfections.

13.2.5 The hydrostatic test of Section 12 has the capability to find imperfections of a size that permit the test fluid to leak through the pipe wall so that it may be either visually seen or detected by a loss of fluid pressure. This test may not detect very tight, through-wall imperfections, or imperfections that extend into the wall without complete penetration.

13.2.6 A purchaser interested in ascertaining the nature (type, size, location, and orientation) of discontinuities that can be detected in the specific application of these examinations should discuss this with the manufacturer of the tubular products.

13.3 Time of Examination:

Nondestructive examination for specification acceptance shall be performed after all mechanical processing, heat treatments and straightening operations. This requirement does not preclude additional testing at earlier stages in the processing.

13.4 Surface Conditions:

13.4.1 All surfaces shall be clean and free of scale, dirt, grease, paint, or other foreign material that could interfere with interpretation of test results. The methods used for cleaning and preparing the surfaces for examination shall not be detrimental to the base metal or the surface finish.

13.4.2 Excessive surface roughness or deep scratches can produce signals that interfere with the test (see 13.10.2.3).

13.5 Extent of Examination:

13.5.1 The relative motion of the pipe and the transducer(s), coil(s), or sensor(s) shall be such that the entire pipe surface is scanned, except for end effects as noted in 13.5.2.

TABLE 5 Calculated Minimum Elongation Values

Wall Thickness		Elongation in 2 in. or 50 mm, min, %			
		All grades except P23, P36, P91, P92, P122, and P911		P23, P91, P92, P122, and P911		P36
in.	mm	Longitudinal	Transverse	Longitudinal	Longitudinal
5/16 (0.312)	8	30	20	20	15
3/32 (0.281)	7.2	28	19	19	14
1/4 (0.250)	6.4	27	18	18	13
7/32 (0.219)	5.6	26	...	17	12
3/16 (0.188)	4.8	24	...	16	11
5/32 (0.156)	4	22	...	15	10
1/8 (0.125)	3.2	21	...	14	9
3/32 (0.094)	2.4	20	...	13	8
1/16 (0.062)	1.6	18	...	12	7

TABLE 6 Permissible Variations in Outside Diameter

NPS [DN] Designator	Over		Under	
	in.	mm	in.	mm
1/8 to 1 1/2 [6 to 40], incl.	1/64 (0.015)	0.40	1/64 (0.015)	0.40
Over 1 1/2 to 4 [40 to 100], incl.	1/32 (0.031)	0.79	1/32 (0.031)	0.79
Over 4 to 8 [100 to 200], incl.	1/16 (0.062)	1.59	1/32 (0.031)	0.79
Over 8 to 12 [200 to 300], incl.	3/32 (0.093)	2.38	1/32 (0.031)	0.79
Over 12 [300]	± 1 % of the specified outside diameter			

TABLE 7 Permitted Variations in Wall Thickness

NPS [DN] Designator	Tolerance, % from Specified	
	Over	Under
1/8 to 2 1/2 [6 to 65] incl., all t/D ratios ^A	20.0	12.5
Above 2 1/2 [65], t/D ≤ 5 % ^A	22.5	12.5
Above 2 1/2 [65], t/D > 5 % ^A	15.0	12.5

^A t = Specified Wall Thickness; D = Specified Outside Diameter.

13.5.2 The existence of end effects is recognized, and the extent of such effects shall be determined by the manufacturer, and, if requested, shall be reported to the purchaser. Other nondestructive tests may be applied to the end areas, subject to agreement between the purchaser and the manufacturer.

13.6 *Operator Qualifications*—The test unit operator shall be certified in accordance with **SNT-TC-1A**, or an equivalent, recognized and documented standard.

13.7 Test Conditions:

13.7.1 For examination by the ultrasonic method, the minimum nominal transducer frequency shall be 2.25 MHz.

13.7.2 For eddy current testing, the excitation coil frequency shall be 10 kHz, or less.

13.8 Reference Standards:

13.8.1 Reference standards of convenient length shall be prepared from a length of pipe of the same grade, size (NPS or outside diameter and schedule or wall thickness), surface finish and heat treatment condition as the pipe to be examined.

13.8.2 For ultrasonic testing, the reference notches shall be any one of the three common notch shapes shown in Practice **E213**, at the option of the manufacturer. The depth of the notch shall not exceed 12 1/2 % of the specified nominal wall

thickness of the pipe or 0.004 in. (0.1 mm), whichever is greater. The length of the notch shall be at least twice the diameter of the transducer(s). The width of the notch shall not exceed the depth.

13.8.3 For eddy current testing, the reference standard shall contain, at the option of the manufacturer, any one of the following discontinuities:

13.8.3.1 *Drilled Hole*—The reference standard shall contain three or more holes, equally spaced circumferentially around the pipe and longitudinally separated by a sufficient distance to allow distinct identification of the signal from each hole. The holes shall be drilled radially and completely through the pipe wall, with care being taken to avoid distortion of the pipe while drilling. The hole diameter shall vary with NPS as follows:

NPS Designator	Hole Diameter
1/2	0.039 in. (1 mm)
above 1/2 to 1 1/4	0.055 in. (1.4 mm)
above 1 1/4 to 2	0.071 in. (1.8 mm)
above 2 to 5	0.087 in. (2.2 mm)
above 5	0.106 in. (2.7 mm)

13.8.3.2 *Transverse Tangential Notch*—Using a round tool or file with a 1/4 in. (6.4 mm) diameter, a notch shall be filed or milled tangential to the surface and transverse to the longitudinal axis of the pipe. Said notch shall have a depth not exceeding 12 1/2 % of the specified nominal wall thickness of the pipe or 0.004 in. (0.1 mm), whichever is greater.

13.8.3.3 *Longitudinal Notch*—A notch 0.031 in. or less in width shall be machined in a radial plane parallel to the tube axis on the outside surface of the pipe, to have a depth not exceeding 12 1/2 % of the specified nominal wall thickness of the pipe or 0.004 in. (0.1 mm), whichever is greater. The length of the notch shall be compatible with the testing method.

13.8.4 For flux leakage testing, the longitudinal reference notches shall be straight-sided notches machined in a radial plane parallel to the pipe axis. For wall thickness less than 1/2 in. (12.7 mm), outside and inside notches shall be used; for wall thicknesses equal to or greater than 1/2 in., only an outside notch shall be used. Notch depth shall not exceed 12 1/2 % of the specified nominal wall thickness or 0.004 in. (0.1 mm), whichever is greater. Notch length shall not exceed 1 in. (25.4 mm), and the width shall not exceed the depth. Outside and inside notches shall have sufficient separation to allow distinct identification of the signal from each notch.