

ASTM - A333/A333M
Standard Specification for
Seamless and Welded Steel Pipe for Low-Temperature
Service and Other Applications with Required Notch
Toughness

This specification covers nominal (average) wall seamless and welded carbon and alloy steel pipe intended for use at low temperatures and in other applications requiring notch toughness.

Some product sizes may not be available under this specification because heavier wall thicknesses have an adverse effect on impact properties.

A. Manufacture :-

1. Except as provided in point A.2, the pipe shall be made by the seamless or welding process with the addition of no filler metal in the welding operation. Grade 4 shall be made by the seamless process.
2. Grade 11 pipe may be produced by welding with or without the addition of filler metal. The following requirements shall apply for Grade 11 welded with the addition of filler metal.
 - i. The joints shall be full-penetration, full fusion double welded or single-welded butt joints employing fusion welding processes as defined in "Definitions," ASME Boiler and Pressure Vessel Code, Section IX.
 - ii. The weld surface on either side of the weld may be flush with the base plate or may have a reasonably uniform crown, not to exceed 1/8 in. [3 mm].
 - iii. Radiographic Examination- All welded joints shall be fully radiographed in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, latest edition, paragraph UW-51.
 - iv. As an alternative to radiographic examination, the welded joints may be ultrasonically examined in accordance with Appendix 12 of the ASME Boiler and Pressure Vessel Code, Section VIII, Division.
 - v. Repair Welding.
 - vi. Transverse Tension Test.
 - vii. Transverse Guided-Bend Weld Test.
 - viii. Charpy V-notch Impact Tests.C

B. Heat Treatment :-

1. All seamless and welded pipe, other than Grades 8 and 11, shall be treated to control their microstructure in accordance with one of the following methods:
 - i. Normalize by heating to a uniform temperature of not less than 1500 °F [815 °C] and cool in air or in the cooling of an atmosphere controlled furnace.
 - ii. Normalize as in 'point B.1.i', and, at the discretion of the manufacturer, reheat to a suitable tempering temperature.
 - iii. For the seamless process only, reheat and control hot working and the temperature of the hotfinishing operation to a finishing temperature range from 1550 to 1750 °F [845 to 945 °C] and cool in air or in a controlled atmosphere furnace from an initial temperature of not less than 1550 °F [845 °C].
 - iv. Treat as in 'point B.1.iii' and, at the discretion of the manufacturer, reheat to a suitable tempering temperature.
 - v. Seamless pipe of Grades 1, 6, and 10 may be heat treated by heating to a uniform temperature of not less than 1500 °F [815 °C], followed by quenching in liquid and reheating to a suitable tempering temperature, in place of any of the other heat treatments provided for in 'point B.1'.
2. Grade 8 pipe shall be heat treated by the manufacturer by either of the following methods:
 - i. Quenched and Tempered :-

Heat to a uniform temperature of 1475 ± 25 °F [800 ± 15 °C]; hold at this temperature for a minimum time in the ratio of 1 h/in. [2 min/mm] of thickness, but in no case less than 15 min; quench by immersion in circulating water. Reheat until the pipe attains a uniform temperature within the range from 1050 to 1125 °F [565 to 605 °C]; hold at this temperature for a minimum time in the ratio of 1 h/in. [2 min/mm] of thickness, but in no case less than 15 min; cool in air or water quench at a rate no less than 300 °F [165 °C]/h.

ii. Double Normalized and Tempered :-

Heat to a uniform temperature of 1650 ± 25 °F [900 ± 15 °C]; hold at this temperature for a minimum time in the ratio of 1 h/in. [2 min/mm] of thickness, but in no case less than 15 min; cool in air. Reheat until the pipe attains a uniform temperature of 1450 ± 25 °F [790 ± 15 °C]; hold at this temperature for a minimum time in the ratio of 1 h/in. [2 min/mm] of thickness, but in no case less than 15 min; cool in air. Reheat to a uniform temperature within the range from 1050 to 1125 °F [565 to 605 °C]; hold at this temperature for a minimum time of 1 h/in. [2 min/mm] of thickness but in no case less than 15 min; cool in air or water quench at a rate not less than 300 °F [165 °C]/h.

3. Whether to anneal Grade 11 pipe is per agreement between purchaser and supplier. When Grade 11 pipe is annealed, it shall be normalized in the range of 1400 to 1600 °F [760 to 870 °C].
4. When specified in the order the test specimens shall be taken from full thickness test pieces which have been stress relieved after having been removed from the heat-treated pipe. The test pieces shall be gradually and uniformly heated to the prescribed temperature, held at that temperature for a period of time in accordance with Table 1, and then furnace cooled at a temperature not exceeding 600 °F [315 °C]. Grade 8 shall be cooled at a minimum rate of 300 °F [165 °C]/h in air or water to a temperature not exceeding 600 °F [315 °C].

Table 1

Metal Temperature ^{A,B}				Minimum Holding Time, h/in. [min/mm] of Thickness
Grades 1, 3, 6, 7, and 10		Grade 4 ^C		
°F	°C	°F	°C	
1100	600	1150	620	1 [2.4]
1050	565	1100	600	2 [4.7]
1000	540	1050	565	3 [7.1]

^A For intermediate temperatures, the holding time shall be determined by straight line interpolation.

^B Grade 8 shall be stress relieved at 1025 to 1085 °F, [550 to 585 °C], held for a minimum time of 2 h for thickness up to 1.0 in. [25.4 mm], plus a minimum of 1 h for each additional inch [25.4 mm] of thickness and cooled at a minimum rate of 300 °F [165 °C]/h in air or water to a temperature not exceeding 600 °F [315 °C]. ^C Unless otherwise specified, Grade 4 shall be stress relieved at 1150 °F [620 °C].

C. Chemical Composition :-

The steel shall conform to the requirements as to chemical composition prescribed in Table 2.

Table 2

Element	Grade 1 ^A	Grade 3	Grade 4	Grade 6 ^A	Grade 7	Grade 8	Grade 9	Grade 10	Grade 11
Carbon, max	0.3	0.19	0.12	0.3	0.19	0.13	0.2	0.2	0.1
Manganese	0.40– 1.06	0.31– 0.64	0.50– 1.05	0.29– 1.06	0.90 max	0.90 max	0.40– 1.06	1.15– 1.50	0.60 max
Phosphorus, max	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.035	0.025
Sulfur, max	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.015	0.025

Silicon	... ^B	0.18– 0.37	0.08– 0.37	0.10 min	0.13– 0.32	0.13– 0.32	...	0.10– 0.35	0.35 max
Nickel	...	3.18– 3.82	0.47– 0.98	0.40 max	2.03– 2.57	8.40– 9.60	1.60– 2.24	0.25 max	35.0– 37.0
Chromium	...	...	0.44– 1.01	0.30 max	...	...	...	0.15 max	0.50 max
Copper	...	...	0.40– 0.75	0.40 max	...	...	0.75– 1.25	0.15 max	...
Aluminum	...	...	0.04– 0.30	...	...	...	...	0.06 max	...
Vanadium, max	...	...	...	0.08	...	...	...	0.12	...
Columbium, max	...	...	...	0.02	...	...	...	0.05	...
Molybdenum, max	...	...	...	0.12	...	...	...	0.05	0.50 max
Cobalt	...	...	...	...	...	...	...	...	0.50 max

^A For each reduction of 0.01 % carbon below 0.30 %, an increase of 0.05 % manganese above 1.06 % would be permitted to a maximum of 1.35 % manganese.

^B Where an ellipsis (...) appears in this table, there are no reporting requirements for those elements.

D. Tensile Requirements :-

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

Table 3

		Tensile strength, min	Yield strength, min
Grade 1	psi	55 000	30 000
	Mpa	380	205
Grade 3	psi	65 000	35 000
	Mpa	450	240
Grade 4	psi	60 000	35 000
	Mpa	415	240
Grade 6	psi	60 000	35 000
	Mpa	415	240
Grade 7	psi	65 000	35 000
	Mpa	450	240
Grade 8	psi	100 000	75 000
	Mpa	690	515
Grade 9	psi	63 000	46 000
	Mpa	435	315
Grade 10	psi	80 000	65 000
	Mpa	550	450

Grade 11	psi	65 000	35 000
	Mpa	450	240

Table 3(continue)

	Elongation in 2 in. or 50 mm, (or 4D), min, %:	Basic minimum elongation for walls 5/16 in. [8 mm] and over in thickness, strip tests, and for all small sizes tested in full section	When standard round 2-in. or 50-mm gage length or proportionally smaller size test specimen with the gage length equal to 4D (4 times the diameter) is used	For strip tests, a deduction for each 1/32 in. [0.8 mm] decrease in wall thickness below 5/16 in. [8 mm] from the basic minimum elongation of the following percentage
Grade 1	Longitudinal	35	28	1.75 ^B
	Transverse	25	20	1.25 ^B
Grade 3	Longitudinal	30	22	1.50 ^B
	Transverse	20	14	1.00 ^B
Grade 4	Longitudinal	30	22	1.50 ^B
	Transverse	16.5	12	1.00 ^B
	Longitudinal	30	22	1.50 ^B
Grade 6	Transverse	16.5	12	1.00 ^B
Grade 7	Longitudinal	30	22	1.50 ^B
	Transverse	22	14	1.00 ^B
Grade 8	Longitudinal	22	16	1.25 ^B
	Transverse	...	...	...
Grade 9	Longitudinal	28	...	1.50 ^B
	Transverse	...	...	...
Grade 10	Longitudinal	22	16	1.25 ^B
	Transverse	...	...	...
Grade 11	Longitudinal	18 ^A	...	...

Table 3(continue)

Wall Thickness		in.	5/16 (0.312)	9/32 (0.281)	1/4 (0.250)	7/32 (0.219)	3/16 (0.188)	5/32 (0.156)	1/8 (0.125)	3/32 (0.094)	1/16 (0.062)
		mm	8	7.2	6.4	5.6	4.8	4	3.2	2.4	1.6
Elongation in 2 in. or 50 mm, min, %^C	Grade 1	Longitudinal	35	33	32	30	28	26	25	23	21
		Transverse	25	24	23	...	...	...	...	...	...
	Grade 3	Longitudinal	30	28	27	26	24	22	21	20	18
		Transverse	20	19	18	...	...	...	...	...	...
	Grade 4	Longitudinal	30	28	27	26	24	22	21	20	18
		Transverse	16	15	15	...	...	...	...	...	...

Grade 6	Longitudinal	30	28	27	26	24	22	21	20	18
	Transverse	16	15	15	...	...	...	...	...	...
Grade 7	Longitudinal	30	28	27	26	24	22	21	20	18
	Transverse	22	21	20	...	...	...	...	...	...
Grade 8	Longitudinal	22	21	20	18	17	16	15	13	12
	Transverse	...	...	...	...	...	...	...	...	...
Grade 9	Longitudinal	28	26	25	24	22	20	19	18	16
	Transverse	...	...	...	...	...	...	...	...	...
Grade 10	Longitudinal	22	21	20	18	17	16	15	13	12
	Transverse	...	...	...	...	...	...	...	...	...

^A Elongation of Grade 11 is for all walls and small sizes tested in full section.

^B The following table gives the calculated minimum values.

^C Calculated elongation requirements shall be rounded to the nearest whole number.

Note—The preceding table gives the computed minimum elongation values for each 1/32-in. [0.80-mm] decrease in wall thickness. Where the wall thickness lies between two values shown above, the minimum elongation value is determined by the following equation:

Grade	Direction of Test	Equation
1	Longitudinal	$E = 56t + 17.50$ [$E = 2.19t + 17.50$]
	Transverse	$E = 40t + 12.50$ [$E = 1.56t + 12.50$]
3	Longitudinal	$E = 48t + 15.00$ [$E = 1.87t + 15.00$]
	Transverse	$E = 32t + 10.00$ [$E = 1.25t + 10.00$]
4	Longitudinal	$E = 48t + 15.00$ [$E = 1.87t + 15.00$]
	Transverse	$E = 32t + 6.50$ [$E = 1.25t + 6.50$]
6	Longitudinal	$E = 48t + 15.00$ [$E = 1.87t + 15.00$]
	Transverse	$E = 32t + 6.50$ [$E = 1.25t + 6.50$]
7	Longitudinal	$E = 48t + 15.00$ [$E = 1.87t + 15.00$]
	Transverse	$E = 32t + 11.00$ [$E = 1.25t + 11.00$]
8 and 10	Longitudinal	$E = 40t + 9.50$ [$E = 1.56t + 9.50$]
9	Longitudinal	$E = 48t + 13.00$ [$E = 1.87t + 13.00$]

where: E = elongation in 2 in. or 50 mm, in %, and

t = actual thickness of specimen, in. [mm].

E. Impact Requirements :-

- For Grades 1, 3, 4, 6, 7, 9, 10, and 11, the notched-bar impact properties of each set of three impact specimens, including specimens for the welded joint in welded pipe with wall thicknesses of 0.120 in. [3 mm] and larger, when tested at temperatures in conformance with 'point I.1' shall be not less than the values prescribed in Table 4.
- For Grade 8 each of the notched bar impact specimens shall display a lateral expansion opposite the notch of not less than 0.015 in. [0.38 mm].
- When the average lateral expansion value for the three impact specimens equals or exceeds 0.015 in. [0.38 mm] and the value for one specimen is below 0.015 in. [0.38 mm] but not below 0.010 in. [0.25 mm], a retest of three additional specimens may be made. The lateral expansion of each of the retest specimens must equal or exceed 0.015 in. [0.38 mm].

Table 4

Size of Specimen, mm	Minimum Average Notched Bar Impact Value of Each Set of Three Specimens ^A		Minimum Notched Bar Impact Value of One Specimen Only of a Set ^A	
	ft·lbf	J	ft·lbf	J
10 by 10	13	18	10	14
10 by 7.5	10	14	8	11
10 by 6.67	9	12	7	9
10 by 5	7	9	5	7
10 by 3.33	5	7	3	4
10 by 2.5	4	5	3	4

^A Straight line interpolation for intermediate values is permitted.

F. Lengths :-

- If definite lengths are not required, pipe may be ordered either in single random lengths of 16 to 22 ft with maximum 5 % of the lengths between 12 and 16 ft, or in double random lengths with a minimum average of 35 ft and an absolute minimum length of 22 ft with maximum 5 % of the lengths between 16 and 22 ft.

G. Mechanical Testing :-

1. Transverse or Longitudinal Tensile Test and Flattening Test.
2. Impact Test. 3. Impact Tests (Welded Pipe).

H. Specimens for Impact Test:-

1. Notched bar impact specimens shall be of the simple beam, Charpy-type, in accordance with Test Methods E23, Type A with a V notch.

I. Impact Test :-

1. Except when the size of the finished pipe is insufficient to permit obtaining subsize impact specimens, all material furnished to this specification shall be tested for impact resistance at the minimum temperature for the respective grades as shown in Table 5.
2. When subsize Charpy impact specimens are used and the width along the notch is less than 80 % of the actual wall thickness of the original material, the specified Charpy impact test temperature for Grades 1, 3, 4, 6, 7, 9, 10, and 11 shall be lower than the minimum temperature shown in Table 5 for the respective grade. Under these circumstances the temperature reduction values shall be by an amount equal to the difference (as shown in Table 6) between the temperature reduction corresponding to the actual material thickness and the temperature reduction corresponding to the Charpy specimen width actually tested.
3. The notched bar impact test shall be made in accordance with the procedure for the simple beam, Charpy-type test of Test Methods E23.
4. Impact tests specified for temperatures lower than 70 °F [20 °C] should be made with the following precautions :-
 - i. The impact test specimens as well as the handling tongs shall be cooled a sufficient time in a suitable container so that both reach the desired temperature.
 - ii. The temperature shall be measured with thermocouples, thermometers, or any other suitable devices and shall be controlled within ± 3 °F [2 °C].
 - iii. The specimens shall be quickly transferred from the cooling device to the anvil of the Charpy impact testing machine and broken with a time lapse of not more than 5 s.

Table 5

Grade	Minimum Impact Test Temperature	
	°F	°C
1	-50	-45
3	-150	-100
4	-150	-100
6	-50	-45
7	-100	-75
8	-320	-195
9	-100	-75
10	-75	-60
11	-320	-195

Table 6

Specimen Width Along Notch or Actual Material Thickness		Temperature Reduction, Degrees Colder ^A	
in.	mm	°F	°C
0.394	10 (standard size)	0	0
0.354	9	0	0
0.315	8	0	0
0.295	7.5 (3/4 std. size)	5	3
0.276	7	8	4
0.262	6.67 (2/3 std. size)	10	5
0.236	6	15	8
0.197	5 (1/2 std. size)	20	11
0.158	4	30	17
0.131	3.33 (1/3 std. size)	35	19
0.118	3	40	22
0.099	2.5 (1/4 std. size)	50	28

^A Straight line interpolation for intermediate values is permitted

J. Hydrostatic or Non-destructive Electric Test :-

1. Each pipe shall be subjected to the non-destructive electric test or the hydrostatic test. The type of test to be used shall be at the option of the manufacturer, unless otherwise specified in the purchase order.
2. The hydrostatic test shall be in accordance with Specification A999/A999M.
3. *Non-destructive Electric Test*—Non-destructive electric tests shall be in accordance with Specification A999/A999M, with the following addition:
 - i. If the test signals were produced by visual imperfections (listed in 15.3.2), the pipe may be accepted based on visual examination, provided the imperfection is less than 0.004 in. (0.1 mm) or 12. % of the specified wall thickness (whichever is greater).
 - ii. *Visual Imperfections:* iii. Scratches,
 - iv. Surface roughness, v. Dings,

- vi. Straightener marks, vii. Cutting chips, viii. Steel die stamps, ix. Stop marks, or
- x. Pipe reducer ripple.

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