Designation: A 691 – 98 (Reapproved 2002)

Standard Specification for Carbon and Alloy Steel Pipe, Electric-Fusion-Welded for High-Pressure Service at High Temperatures[1]

This standard is issued under the fixed designation A 691; 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 reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification[2] covers carbon and alloy steel pipe, electric-fusion-welded with filler metal added, fabricated from pressure-vessel-quality plate of several analyses and strength levels and suitable for high-pressure service at high temperatures. Heat treatment may or may not be required to attain the desired mechanical properties or to comply with applicable code requirements. Supplementary requirements are provided for use when additional testing or examination is desired.

1.2 The specification nominally covers pipe 16 in. (405 mm) in outside diameter and larger with wall thicknesses up to 3 in. (75 mm) inclusive. Pipe having other dimensions may be furnished provided it complies with all other requirements of this specification.

1.3 Several grades and classes of pipe are provided.

1.3.1 *Grade* designates the type of plate used as listed in Table 1.

1.3.2 *Class* designates the type of heat treatment performed in the manufacture of the pipe, whether the weld is radiographically examined, and whether the pipe has been pressure tested as listed in 1.3.3.

1.3.3 Class designations are as follows (Note 1):

Class	Heat Treatment on Pipe	Radiography, see Section	Pressure Test, see Section
10	none	none	none
11	none	9	none
12	none	9	8.3
13	none	none	8.3
20	stress relieved, see 5.3.1	none	none
21	stress relieved, see 5.3.1	9	none
22	stress relieved, see 5.3.1	9	8.3
23	stress relieved, see 5.3.1	none	8.3
30	normalized, see 5.3.2	none	none
31	normalized, see 5.3.2	9	none
32	normalized, see 5.3.2	9	8.3
33	normalized, see 5.3.2	none	8.3
40	normalized and tempered, see 5.3.3	none	none
41	normalized and tempered, see 5.3.3	9	none
42	normalized and tempered, see 5.3.3	9	8.3
43	normalized and tempered, see 5.3.3	none	8.3
50	quenched and tempered, see 5.3.4	none	none
51	quenched and tempered, see 5.3.4	9	none
52	quenched and tempered, see 5.3.4	9	8.3
53	quenched and tempered, see 5.3.4	none	8.3

NOTE 1—Selection of materials should be made with attention to temperature of service. For such guidance, Specification A 20/A 20M may be consulted.

1.4 Optional requirements of a supplementary nature are provided, calling for additional tests and control of repair welding, when desired.

1.5 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

A 20/A 20M Specification for General Requirements for Steel Plates for Pressure Vessels[3]

A 204/A 204M Specification for Pressure Vessel Plates, Alloy Steel, Molybdenum[3]

A 299/A 299M Specification for Pressure Vessel Plates, Carbon Steel, Manganese-Silicon[3]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[4]

A 387/A 387M Specification for Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum[3]

A 435/A 435M Specification for Straight-Beam Ultrasonic Examination of Steel Plates[3]

A 530/A 530M Specification for General Requirements for Specialized Carbon and Alloy Steel Pipe[5]

A 537/A 537M Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel[3]

E 165 Test Method for Liquid Penetrant Examination[6]

E 709 Practice for Magnetic Particle Examination[6]

[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 A01.09 on Carbon Steel Tubular Products.

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[2] For ASME Boiler and Pressure Vessel Code applications, see related Specification SA-691 in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Vol 01.04.

[4] *Annual Book of ASTM Standards*, Vol 01.03.

[5] *Annual Book of ASTM Standards*, Vol 01.01.

[6] *Annual Book of ASTM Standards*, Vol 03.03.

TABLE 1 Plate Materials

Pipe Grade	Type of Steel	ASTM Specification		HB, max[A]
		Number	Grade	
CM-65	carbon-molybdenum steel	A 204/A 204M	A	201
CM-70	carbon-molybdenum steel	A 204/A	B	201
CM-75	carbon-molybdenum steel	A 204/A 204M	C	201
CMSH-70	carbon-manganese-silicon steel, normalized	A 537/A 537M	1	
CMS-75	carbon-manganese-silicon steel	A 299/A 299M	. . .	. . .
CMSH-80	carbon-manganese-silicon steel, quenched and tempered	A 537/A 537M	2	
½ CR	½ % chromium, ½ % molybdenum steel	A 387/A 387M	2	201
1CR	1 % chromium, ½ % molybdenum steel	A 387/A 387M	12	201
1¼ CR	1¼ % chromium, ½ % molybdenum steel	A 387/A 387M	11	201
2¼ CR	2¼ % chromium, 1 % molybdenum steel	A 387/A 387M	22	201
3CR	3 % chromium, 1 % molybdenum steel	A 387/A 387M	21	201
5CR	5 % chromium, ½ % molybdenum steel	A 387/A 387M	5	225
9CR	9 % chromium, 1 % molybdenum steel	A 387/A 387M	9	241
91	9 % chromium, 1 % molybdenum, vanadium, columbium	A 387/A 387M	91	241

[A] Hardness values listed are applicable to S3.

2.2 *ASME Boiler and Pressure Vessel Code:*[7]
Section II, Material Specifications
Section III, Nuclear Power Plant Components
Section VIII, Unfired Pressure Vessels
Section IX, Welding Qualifications

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 A *lot* shall consist of 200 ft (61 m) or fraction thereof of pipe from the same heat of steel.

3.1.1.1 The description of a lot may be further restricted by use of Supplementary Requirement S12.

4. Ordering Information

4.1 The inquiry and order for material under this specification should include the following information:

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

4.1.2 Name of the material (steel pipe, electric-fusion-welded),

4.1.3 Specification number,

4.1.4 Grade and class designations (see 1.3),

4.1.5 Size (inside or outside diameter, nominal or minimum wall thickness),

4.1.6 Length (specific or random),

4.1.7 End finish,

4.1.8 Purchase options, if any (see 5.2.3, 11.3, 11.4, 13.1), and

4.1.9 Supplementary requirements, if any (refer to S1 through S12).

5. Materials and Manufacture

5.1 *Materials*—The steel plate material shall conform to the requirements of the applicable plate specification for the pipe grade ordered as listed in Table 1.

5.2 *Welding*:

5.2.1 The joints shall be double-welded full-penetration welds made in accordance with procedures and by welders or welding operators qualified in accordance with the ASME Boiler and Pressure Vessel Code, Section IX.

5.2.2 The welds shall be made either manually or automatically by an electric process involving the deposition of filler metal.

5.2.3 The welded joints shall have positive reinforcement at the center of each side of the weld, but no more than ⅛ in. (3.2 mm). This reinforcement may be removed at the manufacturer's option or by agreement between the manufacturer and purchaser. The contour of the reinforcement shall be smooth, and the deposited metal shall be fused smoothly and uniformly into the plate surface.

5.2.4 When radiographic examination in accordance with 9.1 is to be used, the weld reinforcement shall be governed by the more restrictive provisions of UW-51 of Section VIII of the ASME Boiler and Pressure Vessel Code instead of 5.2.3 of this specification.

5.3 *Heat Treatment*—All classes other than 10, 11, 12, and 13 shall be heat treated in a furnace controlled to ± 25°F (14°C) and equipped with a recording pyrometer so that heating records are available. Heat treating after forming and welding shall be to one of the following:

5.3.1 Classes 20, 21, 22, and 23 pipe shall be uniformly heated within the post-weld heat-treatment temperature range indicated in Table 2 for a minimum of 1 h/in. of thickness or for 1 h, whichever is greater.

5.3.2 Classes 30, 31, 32, and 33 pipe shall be uniformly heated to a temperature in the austenitizing range and not exceeding the maximum normalizing temperature indicated in Table 2 and subsequently cooled in air at room temperature.

5.3.3 Classes 40, 41, 42, and 43 pipe shall be normalized in accordance with 5.3.2. After normalizing, the pipe shall be reheated to the tempering temperature indicated in Table 2 as a minimum and held at temperature for a minimum of ½ h/in. of thickness or for ½ h, whichever is greater, and air cooled.

5.3.4 Classes 50, 51, 52, and 53 pipe shall be uniformly heated to a temperature in the austenitizing range, and not exceeding the maximum quenching temperature indicated in Table 2 and subsequently quenched in water or oil. After quenching, the pipe shall be reheated to the tempering temperature indicated in Table 2 as a minimum and held at that temperature for a minimum of ½ h/in. of thickness or for ½ h, whichever is greater, and air cooled.

[7] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990.

TABLE 2 Heat Treatment Parameters

Pipe Grade	ASTM Specification	Post-Weld Heat-Treat Temperature Range (Stress Relieving), °F (°C)	Normalizing Temperature, max unless otherwise noted, °F (°C)	Quenching Temperature, max unless otherwise noted, °F (°C)	Tempering Temperature, min, °F (°C)
CM-65	A 204/A 204M	1100 to 1200 (590 to 650)	1700 (925)	. . .	. . .
CM-70	A 204/A 204M	1100 to 1200 (590 to 650)	1700 (925)	. . .	. . .
CM-75	A 204/A 204M	1100 to 1200 (590 to 650)	1700 (925)	. . .	. . .
CMSH-70	A 537/A 537M	1100 to 1200 (590 to 650)	1700 (925)	. . .	. . .
CMS-75	A 299/A 299M	1100 to 1200 (590 to 650)	1700 (925)	. . .	. . .
CMSH-80	A 537/A 537M	1100 to 1200 (590 to 650)	[A]	1700 (925)	1100 to 1250 (590 to 675)
½CR	A 387/A 387M	1100 to 1300 (590 to 705)	1850 (1010)	1700 (925)	1150 to 1375 (620 to 745)
1CR	A 387/A 387M	1100 to 1350 (590 to 730)	1850 (1010)	1700 (925)	1150 to 1375 (620 to 745)
1¼CR	A 387/A 387M	1100 to 1375 (590 to 745)	1850 (1010)	1700 (925)	1150 to 1375 (620 to 745)
2¼CR	A 387/A 387M	1200 to 1400 (650 to 760)	1850 (1010)	1700 (925)	1250 to 1400 (675 to 760)
3CR	A 387/A 387M	1200 to 1400 (650 to 760)	1850 (1010)	1700 (925)	1250 to 1400 (675 to 760)
5CR	A 387/A 387M	1200 to 1400 (650 to 760)	1850 (1010)	1650 (900)	1300 to 1400 (705 to 760)
9CR	A 387/A 387M	1325 to 1375 (715 to 745)	[B]	. . .	1325 to 1375 (715 to 745)
91	A 387/A 387M	1350 to 1420 (730 to 770)	1900 to 2000 (1040 to 1095)	1900 min (1040 min)	1350 to 1440 (730 to 780)

[A] Requires quenching and tempering.
[B] 9 CR steel is an air-hardenable steel, at times retaining austenite down to near atmospheric temperature. Good practice is to allow the steel to cool to 150°F or lower before subjecting the steel to a tempering treatment or post-weld heat treatment.

5.4 Grade 91 shall be produced only to classes 4X and 5X. In addition, post-weld heat treatment is required after weld repair.

6. General Requirements

6.1 Material furnished to this specification shall conform to the applicable requirements of the current edition of Specification A 530/A 530M, unless otherwise provided herein.

7. Chemical Requirements

7.1 *Product Analysis of Plate*—The pipe manufacturer shall make an analysis of each mill heat of plate material. The product analysis so determined shall meet the requirements of the plate specification to which the material was ordered.

7.2 *Product Analysis of Weld*—The pipe manufacturer shall make an analysis of finished deposited weld metal from each 200 ft (61 m) or fraction thereof. Analysis shall conform to the welding procedure for deposited weld metal.

7.3 Analysis may be taken from the mechanical test specimens. The results of the analyses shall be reported to the purchaser.

7.4 If the analysis of one of these tests specified in 7.1 or 7.2 does not conform to the requirements specified, analyses shall be made on additional pipes of double the original number from the same lot, each of which shall conform to the requirements specified. Nonconforming pipe shall be rejected.

8. Mechanical Requirements

8.1 *Tension Test*:

8.1.1 *Requirements*—Transverse tensile properties of the welded joint shall meet the minimum requirements for ultimate tensile strength of the specified plate material.

8.1.2 *Number of Tests*—One test specimen shall be made to represent each lot of finished pipe.

8.1.3 *Test Specimen Location and Orientation*—The test specimen shall be made transverse to the weld at the end of the finished pipe and may be flattened cold before final machining to size.

8.1.4 *Test Method*—The test specimen shall be made in accordance with QW-150 in Section IX of the ASME Boiler and Pressure Vessel Code. The test specimen shall be tested at room temperature in accordance with Test Methods and Definitions A 370.

8.2 *Transverse-Guided-Weld-Bend Tests*:

8.2.1 *Requirements*—The bend test shall be acceptable if no cracks or other defects exceeding ⅛ in. (3.2 mm) in any direction be present in the weld metal or between the weld and the pipe metal after bending. Cracks that originate along the edges of the specimens during testing, and that are less than ¼ in. (6.3 mm) in any direction shall not be considered.

8.2.2 *Number of Tests*—One test (two specimens) shall be made to represent each lot of finished pipe.

8.2.3 *Test Specimen Location and Orientation*—Two bend test specimens shall be taken transverse to the weld at the end of the finished pipe. As an alternative, by agreement between the purchaser and the manufacturer, the test specimens may be taken from a test plate of the same material as the pipe, the test plate being attached to the end of the cylinder and welded as a prolongation of the pipe longitudinal weld seam.

8.2.4 *Test Method*—Bend tests shall be made in accordance with Test Methods and Definitions A 370, A 2.5.1.7. For wall thicknesses over ⅜ in. (9.5 mm) but less than ¾ in. (19.0 mm) side-bend tests may be made instead of the face and root-bend tests. For wall thicknesses ¾ in. and over both specimens shall be subjected to the side-bend test.

8.3 *Pressure Test*—Classes X2 and X3, pipe shall be tested in accordance with Section 20 of Specification A 530/A 530M.

9. Radiographic Examination

9.1 The full length of each weld of classes X1 and X2 shall be radiographically examined in accordance with requirements of the ASME Boiler and Pressure Vessel Code, Section VIII, Paragraph UW-51.

9.2 Radiographic examination may be performed prior to heat treatment.

10. Rework

10.1 *Elimination of Surface Imperfections*—Unacceptable surface imperfections shall be removed by grinding or machining. The remaining thickness of the section shall be no less than the minimum specified in Section 11. The depression after grinding or machining shall be blended uniformly into the surrounding surface.

10.2 *Repair of Base Metal Defects by Welding*:

10.2.1 The manufacturer may repair, by welding, base metal where defects have been removed, provided the depth of the repair cavity as prepared for welding does not exceed ⅓ of the nominal thickness, and the requirements of 10.2.2, 10.2.3, 10.2.4, 10.2.5, and 10.2.6 are met. Base metal defects in excess of these may be repaired with prior approval of the customer.

10.2.2 The defect shall be removed by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair welding.

10.2.3 The welding procedure and welders or welding operators are to be qualified in accordance with Section IX of the ASME Boiler and Pressure Vessel Code.

10.2.4 The full length of the repaired pipe shall be heat treated after repair in accordance with the requirements of the pipe class specified.

10.2.5 Each repair weld of a defect where the cavity, prepared for welding, has a depth exceeding the lesser of ⅜ in. (9.5 mm) or 10 % of the nominal thickness shall be examined by radiography in accordance with the methods and the acceptance standards of Section 9.

10.2.6 The repair surface shall be blended uniformly into the surrounding base metal surface and examined and accepted in accordance with Supplementary Requirements S6 or S8.

10.3 *Repair of Weld Metal Defects by Welding*:

10.3.1 The manufacturer may repair weld metal defects if he meets the requirements of 10.2.3, 10.2.4, 10.3.2, 10.3.3, and 10.4.

10.3.2 The defect shall be removed by suitable mechanical or thermal cutting or gouging methods and the repair cavity examined and accepted in accordance with Supplementary Requirements S7 or S9.

10.3.3 The weld repair shall be blended uniformly into the surrounding metal surfaces and examined and accepted in accordance with 9.1 and with Supplementary Requirements S7 or S9.

10.4 *Retest*—Each length of repaired pipe of a class requiring a pressure test shall be hydrostatically tested following repair.

11. Dimensions, Mass, and Permissible Variations

11.1 The wall thickness and weight for welded pipe furnished to this specification shall be governed by the requirements of the specification to which the manufacturer ordered the plate.

11.2 Permissible variations in dimensions at any point in a length of pipe shall not exceed the following:

11.2.1 *Outside Diameter*—Based on circumferential measurement, ± 0.5 % of the specified outside diameter.

11.2.2 *Out-of-Roundness*—The difference between major and minor outside diameters, 1 %.

11.2.3 *Alignment*—Using a 10-ft (3-m) straightedge placed so that both ends are in contact with the pipe, ⅛ in. (3.2 mm).

11.2.4 *Thickness*—The minimum wall thickness at any point in the pipe shall not be more than 0.01 in. (0.3 mm) under the specified nominal thickness.

11.3 Circumferential welded joints of the same quality as the longitudinal joints shall be permitted by agreement between the manufacturer and the purchaser.

11.4 Lengths with unmachined ends shall be within −0, +½ in. (−0, +13 mm) of that specified. Lengths with machined ends shall be as agreed between the manufacturer and the purchaser.

12. Workmanship, Finish, and Appearance

12.1 The finished pipe shall be free of injurious defects and shall have a workmanlike finish. This requirement is to mean the same as the identical requirement that appears in Specification A 20/A 20M with respect to steel plate surface finish.

13. Product Marking

13.1 The marking shall be stenciled using a suitable heat-resistant paint or metal stamped using low-stress stamps. Wall thicknesses under 0.500 in. (12.7 mm) shall not be metal stamped without prior approval. The purchaser may specify that material 0.500 in. (12.7 mm) and over shall not be metal stamped.

13.2 In addition to the marking provision of Specification A 530, the class marking in accordance with 1.3.3 shall follow the grade marking, for example, 3CR-33.

13.3 *Bar Coding*—In addition to the requirements in 13.1 and 13.2, bar coding is acceptable as a supplemental identification method. The purchaser may specify in the order a specific bar coding system to be used.

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall be applied only when specified by the purchaser in the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon in writing by the manufacturer and purchaser, Supplementary requirements shall in no way negate any requirement of the specification itself.

S1. Tension and Bend Tests

S1.1 Tension tests in accordance with 8.1 and bend tests in accordance with 8.2 shall be made on specimens representing each length of pipe.

S2. Charpy V-Notch Test (for pipe with nominal wall thickness of ½in. (12.7 mm) and greater)

S2.1 *Requirements*—The acceptable test energies shall be as shown in Table number A1.15 of Specification A 20/A 20M for the applicable plate specification unless otherwise stated in the order. As an alternative, the test temperature may be 10°F (−12°C).

S2.2 *Number of Specimens*—Each test shall consist of at least three specimens.

S2.2.1 One base-metal test shall be made from one pipe length per heat, per heat-treat charge, and per nominal wall thickness.

S2.2.2 One weld-metal and one heat-affected zone (HAZ) metal test shall be made in accordance with NB 4335 of Section III of the ASME Boiler and Pressure Vessel Code.

S2.3 *Test Specimen Location and Orientation:*

S2.3.1 Base-metal specimens of stress-relieved, normalized, and normalized and tempered pipe shall be taken in accordance with the provisions for tension specimens in the body of this specification.

S2.3.2 Base-metal specimens of quenched and tempered pipe shall be taken in accordance with the provisions of NB 2225 of Section III of the ASME Boiler and Pressure Vessel Code.

S3. Hardness Tests

S3.1 Hardness determination shall be made on both ends of each length of pipe to the parent metal, weld, and the heat-affected zone and must meet the hardness requirements in Table 1.

S4. Product Analysis

S4.1 Product analysis shall be made on each length of pipe. Individual lengths failing to conform to the chemical requirements prescribed in the applicable specification listed in Table 1 shall be rejected.

S5. Metallography

S5.1 The manufacturer shall furnish one photomicrograph to show the microstructure at 100× magnification of the weld metal or base metal of the pipe in the as-finished condition. The purchaser shall state in the order: the material, base metal or weld, and the number and locations of tests to be made. This test is for information only.

S6. Magnetic Particle Examination of Base Metal

S6.1 All accessible surfaces of the pipe shall be examined in accordance with Practice E 709. Accessible is defined as: All outside surfaces, all inside surfaces of pipe 24 in. (610 mm) in diameter and greater, and inside surfaces of pipe less than 24 in. in diameter for a distance of one pipe diameter from the ends.

S6.2 Butt-weld end preparations are to be completely magnetic-particle examined in accordance with Practice E 709.

S6.3 *Acceptance Standards*, shall be by agreement between the manufacturer and the purchaser.

S7. Magnetic Particle Examinations of Weld Metal

S7.1 All accessible welds shall be examined in accordance with Practice E 709. Accessible is defined as: All outside surfaces, all inside surfaces of pipe 24 in. (610 mm) in diameter and greater, and inside surfaces of pipe less than 24 in. in diameter for a distance of one pipe diameter from the ends.

S7.2 Butt-weld end preparations are to be completely magnetic-particle examined in accordance with Practice E 709.

S7.3 *Acceptance Standards*, shall be by agreement between the manufacturer and the purchaser.

S8. Liquid Penetrant Examination of Base Metal

S8.1 All accessible surfaces of the pipe shall be examined in accordance with Test Method E 165. Accessible is as defined in S7.1.

S8.2 Butt-weld end preparations are to be completely liquid penetrant examined in accordance with Test Method E 165.

S8.3 *Acceptance Standards*, shall be by agreement between the manufacturer and the purchaser.

S9. Liquid Penetrant Examination of Weld Metal

S9.1 All accessible surfaces of the pipe shall be examined in accordance with Test Method E 165. Accessible is as defined in S6.1.

S9.2 *Acceptance Standards*, shall be by agreement between the manufacturer and the purchaser.

S10. Ultrasonic Test

S10.1 *Plate in Flat:*

S10.1.1 One hundred percent on one surface shall be scanned.

S10.1.2 Straight search shall be used in accordance with Specification A 435/A435M.

S10.1.3 Acceptance standards shall be in accordance with Specification A 435/A 435M or as by agreement between the manufacturer and the purchaser.

S11. Repair Welding

S11.1 Repair of base metal defects by welding shall be done only with customer approval.

S12. Description of Term

S12.1 *lot*—all pipe of the same mill heat of plate material and wall thickness (within ±¼ in. (6.4 mm)) heat treated in one furnace charge. For pipe that is not heat treated or that is heat treated in a continuous furnace, a lot shall consist of each 200 ft (61 m) or fraction thereof of all pipe of the same mill heat of plate material and wall thickness (within ±¼ in. (6.4 mm)), subjected to the same heat treatment. For pipe heat treated in a batch-type furnace that is automatically controlled within a 50°F (28°C) range and is equipped with recording pyrometers so that heating records are available, a lot shall be defined the same as for continuous furnaces.