



Designation: ~~A1091/A1091M – 16~~^{ε1} A1091/A1091M – 21

Standard Specification for Steel Castings, Creep-Strength Enhanced Ferritic Alloy, for Pressure-Containing Parts, Suitable for High-Temperature High-Temperature Service¹

This standard is issued under the fixed designation A1091/A1091M; 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.

^{ε1} NOTE—Table 3 was editorially corrected in April 2017.

1. ~~Scope~~ Scope*

1.1 This specification covers creep-strength enhanced alloy steel castings for valves, flanges, fittings, and other pressure-containing parts intended primarily for high-temperature service (see **Note 1**). However, they are not restricted to such ~~applications~~, applications and the castings may be used for other applications for which the attributes of the material, as defined by this specification, are suitable.

1.2 One grade of martensitic alloy steel, Grade ~~€91~~, C91 (UNS Number J84090), is covered (see **Note 2**). It is provided in two classes, differentiated by the type of heat treatment after ~~weld repairs~~, welding. This and similar steels are characterized by a predominantly tempered martensitic or tempered Bainitic microstructure that is stabilized by the precipitation of temper-resistant particles at various precipitate nucleation sites in the microstructure. Such steels are designed to have creep-rupture strengths significantly superior to those of alloys of nominally similar compositions, but in which the precipitates or nucleation sites are absent. Since this crucial difference cannot be revealed by room-temperature mechanical property tests, these alloys require tighter controls on manufacturing and processing.

NOTE 1—The grades covered by this specification represent materials that are generally suitable for assembly with other castings or wrought steel parts by fusion welding. It is not intended to imply that these grades possess equal degrees of weldability; therefore, it is the responsibility of the purchaser to establish a suitable welding technique. Since these grades possess varying degrees of suitability for high-temperature service, it is also the responsibility of the purchaser to determine which grade shall be furnished, due consideration being given to the requirements of the applicable construction codes.

NOTE 2—The committee formulating this specification has included one grade of material that is considered to represent a type of ferritic alloy steel suitable for valves, flanges, fittings, and other pressure-containing parts. Additional alloy steels will be considered for inclusion in this specification by the committee as the need becomes apparent.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. 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~~ nonconformance with the standard.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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 A01.18 on Castings.

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

2. Referenced Documents

2.1 *ASTM Standards:*²

~~A335/A335M Specification for Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service~~
~~A703/A703M Specification for Steel Castings, General Requirements, for Pressure-Containing Parts~~
~~A802/A802M Practice for Steel Castings, Surface Acceptance Standards, Visual Examination~~
~~A985/A985M Specification for Steel Investment Castings General Requirements, for Pressure-Containing Parts~~
~~A999/A999M Specification for General Requirements for Alloy and Stainless Steel Pipe~~

2.2 *ANSI Standards/Standard:*³

~~ANSI B46.1 Surface Texture~~

2.3 *ASME Boiler and Pressure Vessel Code/Code:*⁴

~~ASME Boiler and Pressure Vessel Code Section I~~
~~ASME Boiler and Pressure Vessel Code Section III~~
~~ASME Boiler and Pressure Vessel Code Section IV~~
~~ASME Boiler and Pressure Vessel Code Section VIII~~
~~ASME Boiler and Pressure Vessel Code Section IX~~
~~ASME Boiler and Pressure Vessel Code Section XII~~

2.4 *Other ASME Codes/Codes:*⁴

~~B16.34 Valves Flanged, Threaded and Welding End~~
~~B31.1 Power Piping~~
~~B31.3 Process Piping~~

2.5 *AWS Specifications/Specifications:*⁵

~~A5.5/A5.5M Low-Alloy Low-Alloy Steel Electrodes for Shielded Metal Arc Welding~~
~~A5.23/A5.23M Low-Alloy Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding~~
~~A5.28/A5.28M Low-Alloy Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding~~
~~A5.29/A5.29M Low-Alloy Low-Alloy Steel Electrodes for Flux Cored Arc Welding~~

3. General Conditions for Delivery

3.1 Except for investment castings and centrifugally cast pipe, castings furnished to this specification shall conform to the requirements of Specification ~~A703/A703M~~, including any supplementary requirements that are indicated in the purchase order. Failure to comply with the general requirements of Specification ~~A703/A703M~~ constitutes nonconformance with this specification. In case of conflict between the requirements of this specification and Specification ~~A703/A703M~~, this specification shall prevail.

3.2 Investment castings furnished to this specification shall conform to the requirements of Specification ~~A985/A985M~~, including any supplementary requirements that are indicated in the purchase order. Failure to comply with the general requirements of Specification ~~A985/A985M~~ constitutes nonconformance with this specification. In case of conflict between the requirements of this specification and Specification ~~A985/A985M~~, Specification ~~A985/A985M~~ shall prevail.

3.3 Centrifugally cast pipe furnished under this specification shall conform to the requirements of Specification ~~A999/A999M~~, including any supplementary requirements that are indicated in the purchase order. Failure to comply with the general requirements of Specification ~~A999/A999M~~ constitutes nonconformance with this specification. In case of conflict between the requirements of this specification and Specification ~~A999/A999M~~, this specification shall prevail.

4. Ordering Information

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

4.1.1 Except for centrifugally cast pipe, pipe:

² 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.

³ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

⁴ Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, http://www.asme.org.

⁵ Available from American Welding Society (AWS), 8669 NW 36 St., #130, Miami, FL 33166-6672, http://www.aws.org.

4.1.1.1 A description of the casting by pattern number or drawing (dimensional tolerances shall be included on the casting drawing),

4.1.1.2 Grade and ~~Class~~class of steel,

4.1.1.3 Options in the specification (see 5.1.5, 5.2, 7.1.4, 8.4, 10.3.5, and 10.3.7, 10.3.8.2, and 10.3.8.3),

4.1.1.4 Whether the castings are to be produced using the investment casting process, and

4.1.1.5 The supplementary requirements desired including the standards of acceptance.

4.1.2 Centrifugally cast ~~pipe~~pipe:

4.1.2.1 Quantity (feet, centimeters, or number of lengths),

4.1.2.2 Name of material (centrifugally cast pipe),

4.1.2.3 Grade of steel,

4.1.2.4 Size (outside or inside diameter and minimum wall thickness),

4.1.2.5 Length (specific or random) (Section on Permissible Variations in Length of Specification A999/A999M),

4.1.2.6 End finish (Section on Ends of Specification A999/A999M),

4.1.2.7 Options in the specification (see 5.1.5, 5.2, 7.1.4, 8.4, 10.3.5, and 10.3.7, 10.3.8.2, and 10.3.8.3),

4.1.2.8 Whether the castings are to be used in ASME Boiler ~~&~~and Pressure Vessel Code Sections I, III, IV, VIII, and XII construction; or in ASME Codes B16.34, B31.1, B31.3, or other ASME construction ~~codes~~and codes, and

4.1.2.9 The supplementary requirements desired.

5. Materials and Manufacture

[ASTM A1091/A1091M-21](https://standards.iteh.ai/catalog/standards/sist/fcb633fb-0ece-4d08-915f-40e871077f54/astm-a1091-a1091m-21)

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5.1 ~~Heat Treatment~~Heat Treatment—Castings shall be furnished in the austenitized and tempered condition.

5.1.1 Before heat treatment, castings shall be allowed to cool to a temperature below the transformation range.

5.1.2 Castings shall be heat treated by heating to a temperature range of 1900 to ~~1975~~1975 °F [1040 to ~~1080~~1080 °C] and either air cooled or accelerated cooled from the austenitizing temperature by air blasting or liquid quenching, to a temperature of ~~200~~200 °F [~~95~~95 °C] or below, followed by tempering at 1350 to ~~1470~~1470 °F [730 to ~~800~~800 °C].

5.1.3 Compliance with the temperature ranges specified in 5.1.2, for castings heat treated singly, shall be verified by a thermocouple or thermocouples placed directly on the castings.

5.1.4 Compliance with the temperature ranges specified in 5.1.2, for castings heat treated in batches, shall be verified by thermocouples placed on selected castings in each batch.

5.1.5 Unless specified by the purchaser, the number and locations of thermocouples to be placed on each casting, or on castings in each heat-treatment batch, shall be at the discretion of the producer.

5.1.6 A record of the final austenitizing and tempering heat ~~treatment~~treatment and, if specified in the order (see 10.3.7), of any and all subsequent ~~sub-critical~~subcritical heat treatments, shall be made and shall be shown on the material test report. The record shall include both the number and locations of thermocouples applied to each casting, or to each heat-treatment batch of castings.

5.2 *Machining*—Centrifugally cast pipe shall be machined on the inner and outer surfaces to a roughness value no greater than ~~250~~250 $\mu\text{in.}$ [6.35 μm] arithmetical average deviation (AA) from the mean line unless otherwise specified as in ANSI B46.1.

6. Chemical Composition

6.1 *Heat Analysis*—An analysis of each heat shall be made by the manufacturer to determine the weight percentages of elements specified in **Table 1**. The analysis shall be made on a test sample taken from the ladle. The chemical composition thus determined shall steel shall conform to the requirements specified in **Table 1** (see **Note 3**).

NOTE 3—The role of alloying elements in the development of Grade C91 has been extensively investigated. V and Cb (Nb) contribute to precipitation strengthening by forming fine and coherent precipitation of M(C, N)X carbo-nitrides in the ferrite matrix. V also precipitates as VN during tempering or during creep. The two elements are more effective in combination. Therefore, the addition of strong nitride-forming elements, those with a stronger affinity for nitrogen than Cb (Nb) and V, as de-oxidation ~~agents;~~ agents interferes with these high-temperature strengthening mechanisms.⁶

7. Mechanical Properties

7.1 *Tensile Testing*—Testing:

7.1.1 One tension test shall be made from each heat per heat treatment lot. Test results shall conform to the tensile requirements specified in **Table 2**.

7.1.2 If a specimen is machined improperly or if flaws are revealed by machining or during testing, the specimen may be discarded and another substituted from the same heat.

7.1.3 Except as permitted by **7.1.4**, and except for investment castings, test coupons from which tension test specimens are prepared shall be removed from heat-treated casting prolongations.

7.1.4 When agreed upon between the manufacturer and the purchaser, test coupons from which test specimens are prepared shall be cast as separate blocks from the same heat as the casting represented. The test blocks shall be heat treated in the same manner as the casting represented.

TABLE 1 Chemical Requirements Composition Requirements for Grade C91 (UNS Number J84090)^A

Element	Composition, % Weight %
Grade Identification Symbol	C91
UNS Number	J84090
Carbon	0.08–0.12
Carbon	0.08–0.12
Manganese	0.30–0.60
Phosphorus	0.025
Sulfur	0.010
Silicon	0.20–0.50
Nickel	0.40
Chromium	8.0–9.5
Molybdenum	0.85–1.05
Molybdenum	0.85–1.05
Columbium ^A	
(Niobium) ^A	0.060–0.10
Niobium ^B	0.060–0.10
Nitrogen	0.030–0.070
Vanadium	0.18–0.25
Aluminum	0.02
Titanium	0.01
Zirconium	0.01

^A All values are maximums unless a range is provided.

^B Columbium (Cb) and Niobium (Nb) refer to the same Element 41. Both names are acceptable for use in A01 specifications.

⁶ Viswanathan, R. and Bakker, W. T., *Materials for Ultra Supercritical Fossil Power Plants*, EPRI, Palo Alto, CA, 2000. TR-114750.



TABLE 2 Tensile Requirements

Grade	Tensile Strength, ksi [MPa]	Yield Strength ^A , min, ksi [MPa]	Elongation in 2 in. [50 mm], min, % ^B	Reduction of Area, min, %
C91	85 [585] to 110 [760]	60 [415]	18	45

TABLE 2 Tensile Requirements^A

Grade (UNS Number)	Tensile Strength, ksi [MPa]	Yield Strength, ^B ksi [MPa]	Elongation in 2 in. [50 mm], % ^C	Reduction of Area, %
C91 (J84090)	85–110 [585–760]	60 [415]	18	45

^A All values are minimums unless a range is provided.

^B Determined by 0.2 % offset method.

^C When ICI test bars are used in tensile testing as provided for in Specification [A703/A703M](#), or [A985/A985M](#) for investment castings, the gauge length to reduced length to reduced section diameter ratio shall be 4 to 1.

7.2 *Hardness Testing*—Each casting shall be Brinell hardness tested in accordance with Supplementary Requirement S13 of [A703/A703M](#); or, Specification [A703/A703M](#) for investment castings, Supplementary Requirement S13 of or [A985/A985M](#); or, for centrifugally cast pipe, 14.3.2 of for investment castings [A335/A335M](#), and shall have a Brinell hardness of 185 to 248 HBW.

8. Quality

8.1 All accessible surfaces of the castings shall be examined visually and shall be free of adhering sand, scale, cracks, and hot tears. Other surface discontinuities shall meet the visual acceptance standards specified in the order. Practice [A802/A802M](#) or other visual standards may be used to define acceptable surface discontinuities and finish. Unacceptable visual surface discontinuities shall be removed and their removal verified by visual examination of the resultant cavities. When methods involving high temperature temperatures are used in the removal of discontinuities, castings shall be preheated to at least 400°F [200°C].

8.2 Except for centrifugally cast pipe, hollow castings larger than NPS 4 [DN 100], and whose internal surfaces are not accessible to the visual examination in 8.1; shall be examined by the ultrasonic examination prescribed in Supplementary Requirement S7 of Specification [A703/A703M](#); or for investment castings, of Supplementary Requirement S7 of Specification [A985/A985M](#).

8.2.1 Castings producing a signal equal to or greater than the lowest signal produced by the referenced discontinuities shall be considered to contain defects, and they shall be identified and separated from the acceptable castings. The area producing the signal may be re-examined.

8.2.2 Castings containing defects shall be rejected if the test signals were produced by imperfections that cannot be identified or were produced by cracks or crack-like imperfections.

8.2.3 Castings containing defects may be repaired. To be accepted, a repaired casting shall pass the ultrasonic examination and shall meet the minimum wall thickness requirements of the purchase order.

8.3 Each length of centrifugally cast pipe shall be ultrasonically examined in accordance with Specification [A999/A999M](#).

8.4 When additional inspection is desired, Supplementary Requirements S4, S5, S6, and S10; S10 of Specification [A703/A703M](#); or, for investment castings, Specification [A985/A985M](#), may be ordered.

9. Permissible Variations in Dimensions of Centrifugally Cast Pipe

9.1 *Thickness*—The wall thickness of centrifugally cast pipe shall not vary over that specified by more than 1/8 in. [3 mm]. There shall be no variation under the specified wall thickness.

10. Rework, ~~Weld Repair, Welding, and Retreatment~~

10.1 Defects, as defined in Section 8, shall be removed and their removal verified by visual inspection of the resultant cavities. Defects that are located by inspecting with supplementary requirements specified in the order shall be removed or reduced to an acceptable size.

10.2 If removal of the defect does not ~~infringe~~impinge upon the minimum wall thickness, if applicable, the depression may be blended uniformly into the surrounding surface.

10.3 ~~Weld repair~~Welding is permitted, subject to the following requirements:

10.3.1 Only welders and procedures qualified in accordance with ASME Boiler and Pressure Vessel Code, Section IX, shall be used.

10.3.2 All ~~weld repairs~~welding shall be made with one of the processes and consumables shown in **Table 3**. In addition, the sum of the Ni+Mn content of all weld consumables used for weld repair shall not exceed 1.0 %.

10.3.3 ~~Weld repairs~~Welding shall be inspected to the same quality standards that are used to inspect the castings.

10.3.3.1 When Supplementary Requirement S4 of ~~A703/A703M~~, or Specification A703/A703M for investment or ~~A985/A985M~~ castings, ~~S4~~ or for investment castings ~~A985/A985M~~, is specified, ~~weld repairs~~welds shall be inspected by magnetic particle examination to the same standards that are used to inspect the castings.

10.3.3.2 When Supplementary Requirement S5 of Specification A703/A703M or for ~~A985/A985M~~ investment castings, ~~S5~~ or for investment castings ~~A985/A985M~~ is specified, ~~weld repairs~~welds on castings that have leaked on hydrostatic test, or on castings in which the depth of any cavity prepared for ~~repair~~welding exceeds 20 % of the wall thickness or 1 in. [25 mm], [25 mm], whichever is smaller, or on castings in which any cavity prepared for welding is greater than approximately ~~10 in.~~10 in.²⁻² [65 cm²], shall be radiographed to the same standards that are used to inspect the castings.

10.3.4 ~~Weld repairs~~Welds shall be considered major in the case of a casting that has leaked on hydrostatic test, or when the depth of the cavity prepared for welding exceeds 20 % of the wall thickness or 1 in. [25 mm], whichever is smaller, or when the extent of the cavity exceeds approximately 10 in.²⁻² [65 cm²]. ~~Weld repairs~~Welds not meeting these requirements shall be considered minor ~~weld repairs~~welds.

10.3.5 Major ~~weld repairs~~welds shall be subject to the prior approval of the purchaser.

10.3.6 The locations, lengths, widths, and depths of major ~~weld repairs~~welds shall be included in the material test report.

10.3.7 When specified by the purchaser, the locations of all ~~weld repairs~~welds shall be included in the material test report.

10.3.8 *Post-Weld Heat Treatment*—All ~~weld repairs~~welds shall be heat treated in accordance with one of the following requirements, as applicable:

10.3.8.1 For castings for which re-austenitizing does not lead to unacceptable distortion, defined as violation of the tolerances of the specification or contained in the purchase order, the following shall apply: Castings containing a weld ~~repair~~ made after the austenitizing and tempering heat treatment in 5.1 shall be re-austenitized and tempered according to the requirements of 5.1. Local heat treatment is not permitted.

10.3.8.2 For castings for which re-austenitizing does lead to unacceptable distortion, and with the agreement of the purchaser, in lieu of re-austenitizing and tempering, the following shall apply:

TABLE 3 Welding Consumables

Process	Specification	Classification
SMAW	A5.5/A5.5M	E90XX-B9
SAW	A5.23/A5.23M	EB9 + Neutral Flux
GTAW	A5.28/A5.28M	ER90S-B9
FCAW	A5.29/A5.29M	E91T1-B9

(1) ~~Weld repairs~~ Welds shall be heat treated within the temperature range of 1350 to ~~1470°F~~ 1470 °F [730 to ~~800°C~~ 800 °C], for a minimum holding time based on the maximum thickness of the casting.

(2) Castings having a maximum thickness ~~≤ 5~~ ≤ 5 in. [125 mm] shall be held at temperature for ~~1 hr/in. [1 hr/25 mm]~~, 1 h per inch of thickness [1 h per 25 mm of thickness], except that 30 ~~min~~ minutes minimum is permitted for castings having a maximum thickness less than ~~1 in.~~ 1 in. [25 mm].

(3) Castings having a maximum thickness ~~> greater than~~ 5 in. [125 mm] shall be held at temperature for ~~5 hr~~ 5 h, plus 15 ~~min~~ minutes for each additional ~~in.~~ inch [25 mm] over 5 in. [125 mm].

10.3.8.3 Local ~~post-weld~~ ~~post-weld~~ heat treatment is permitted only by agreement between the producer and the purchaser. Process requirements, to ~~assure~~ ensure that the minimum ~~post-weld~~ ~~post-weld~~ heat treatment is reached in ~~weld repairs~~ welds and that the maximum ~~post-weld~~ ~~post-weld~~ heat treatment is not exceeded anywhere on the casting, shall be as agreed upon by the producer and the purchaser.

10.3.8.4 Castings shall be designated as Class 1 or Class 2, depending on the type of weld ~~repair~~ (see 10.3.4) and heat treatment, as shown in Table 4.

NOTE 4—For Class 2 castings, ASME or other construction codes may assign allowable stresses or pressure ratings different from and more conservative than those of Class 1 castings. Consult the applicable construction code for further guidance.

11. Rejection

11.1 Each casting received from the producer may be inspected by the purchaser and, if it does not meet the requirements of the specification based on the inspection and test methods as outlined in the specification, the casting may be rejected and the producer shall be notified. Disposition of rejected castings shall be a matter of agreement between the producer and the purchaser.

12. Certification and Marking

12.1 Certification and marking of castings shall meet the certification and marking requirements of Specification ~~A703/A703M~~, ~~or A985/A985M~~, or ~~A999/A999M~~, as applicable, except that for centrifugally cast pipe, the certification and marking requirements of Specification ~~A999/A999M~~ are mandatory.

12.2 In addition to the requirements of 12.1, the certification shall include the locations of ~~weld repairs~~ welds as required by 10.3.6 and 10.3.7.

12.3 In addition to the requirements of 12.1, the class designation (see Table 4) shall be included in the certification and marking of the castings.

13. Keywords

13.1 casting; centrifugal; ferritic; high-temperature service; investment casting; ~~Martensitic~~ martensitic; pipe; pressure containing; steel castings

SUPPLEMENTARY REQUIREMENTS

TABLE 4 Classification of Castings

Type of Weld Repair	Heat Treatment	Class
None	None	Class 1
None	None	Class 1
Major or Minor	Re-austenitized and Tempered	Class 1
Minor	Tempered	Class 1
Major	Tempered	Class 2