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Standard Specification for Quenched and Tempered Vacuum-Treated Carbon and Alloy Steel Forgings for Pressure Vessels¹

This standard is issued under the fixed designation A508/A508M; 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.

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

1. Scope *

1.1 This specification² covers quenched and tempered vacuum-treated carbon and alloy steel forgings for pressure vessels such as those used in reactor systems. Specifically, it covers forgings for vessel closures, shells, flanges, tube sheets, rings, heads, and similar parts.

1.2 All grades are considered weldable under proper conditions. Welding technique is of fundamental importance, and it is presupposed that welding procedure and inspection will be in accordance with approved methods for the grade of material used.

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 with the standard.

1.4 Unless the order specifies the applicable “M” specification designation, the material shall be furnished to the inch-pound units.

NOTE 1—Grades 1 and 1A are composed of different chemistries but have the same mechanical requirements.

NOTE 2—Designations have been changed as follows:

Current	Formerly
Grade 1	Class 1
Grade 1A	Class 1A
Grade 2 Class 1	Class 2
Grade 2 Class 2	Class 2A
Grade 3 Class 1	Class 3
Grade 3 Class 2	Class 3A
Grade 4N Class 1	Class 4
Grade 4N Class 2	Class 4A
Grade 4N Class 3	Class 4B
Grade 5 Class 1	Class 5
Grade 5 Class 2	Class 5A
Grade 22 Class 3	Class 22B
Grade 22 Classes 4, 5, 6, and 7	
Grade 3V	Class 3V

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:³

A275/A275M Practice for Magnetic Particle Examination of Steel Forgings

A370 Test Methods and Definitions for Mechanical Testing of Steel Products

A388/A388M Practice for Ultrasonic Examination of Steel Forgings

A788/A788M Specification for Steel Forgings, General Requirements

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 A01.06 on Steel Forgings and Billets.

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² For ASME Boiler and Pressure Vessel Code applications see related Specification SA-508/SA-508M 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.

A966/A966M Practice for Magnetic Particle Examination of Steel Forgings Using Alternating Current
 E208 Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels
 E428 Practice for Fabrication and Control of Metal, Other than Aluminum, Reference Blocks Used in Ultrasonic Testing

2.2 American Society of Mechanical Engineers Standard:

Boiler and Pressure Vessel Code—Section III, Articles NB 2300, NC 2300, ND 2300, NE 2300, NF 2300, NG 2300⁴

3. Ordering Information

3.1 *Purchase Order*—In addition to the ordering information required by Specification A788/A788M, the purchaser shall include with the inquiry and order a detailed drawing that locates the areas of significant loading in the forging (when required), the method of selecting test locations (see 6.1.5 and 6.1.6), and purchase options (see 4.2.2, 6.2, and 10.1) and any supplementary requirements desired.

3.2 *Forging Drawing*—Each forging shall be manufactured in accordance with a purchaser-approved drawing showing the prequenched dimensions, the finished dimensions, the surfaces that will be subjected to significant loading, and the locations of mechanical test specimens.

3.3 Material supplied to this specification shall conform to the requirements of Specification A788/A788M, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.3.1 When specified by the purchaser, it is permissible to perform Magnetic particle examination using the AC yoke in accordance with Test Method A966/A966M instead of using Test Method A275/A275M (see 8.2.1).

3.4 The optional minimum silicon content as expressed in Footnote B to Table 1, if required.

3.5 If the requirements of this specification are in conflict with the requirements of Specification A788/A788M, the requirements of this specification shall prevail.

4. Materials and Manufacture

4.1 Melting Process:

4.1.1 The steel shall be made by the basic electric-furnace process except when secondary ladle refining or the remelting process is employed, in which case the melting processes of Specification A788/A788M are permitted.

4.1.2 The molten steel shall be vacuum treated in accordance with the methods described in Specification A788/A788M, prior to or during the pouring of the ingot, in order to remove objectionable gases, particularly hydrogen.

Grade 22 Classes 4, 5, 6, and 7 liquid steel shall be produced to a fine grain melting practice which has been shown to result in a prior austenitic grain size of five or finer.

4.1.3 *Discard*—Sufficient discard shall be made from each ingot to secure freedom from piping and excessive segregation.

4.2 Heat Treatment:

4.2.1 *Preliminary Heat Treatment*—After forging and before reheating, the forgings shall be cooled to provide substantially complete transformation of austenite. Preliminary heat treatment may be applied to improve machinability and to enhance subsequent heat treatments.

⁴ Available from American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017.

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

TABLE 1 Chemical Requirements

	Composition, %									
	Grade 1	Grade 1A	Grade 2	Grade 3	Grade 4N	Grade 5	Grade 22 ^A	Grade 3V	Grade 3VCb	Grade 6
Carbon	0.35 max	0.30 max	0.27 max	0.25 max	0.23 max	0.23 max	0.11–0.15	0.10–0.15	0.10–0.15	0.28–0.33
Manganese	0.40–1.05	0.70–1.35	0.50–1.00	1.20–1.50	0.20–0.40	0.20–0.40	0.30–0.60	0.30–0.60	0.30–0.60	0.75–1.15
Phosphorus	0.025 max	0.025 max	0.025 max	0.025 max	0.020 max	0.020 max	0.015 max	0.020 max	0.020 max	0.025 max
Sulfur	0.025 max	0.025 max	0.025 max	0.025 max	0.020 max	0.020 max	0.015 max	0.020 max	0.010 max	0.025 max
Silicon ^B	0.40 max	0.40 max	0.40 max	0.40 max	0.40 max	0.40 max	0.30 max	0.35 max	0.10 max	0.35 max
Nickel	0.40 max	0.40 max	0.50–1.00	0.40–1.00	2.8–3.9	2.8–3.9	0.25 max	...	0.25 max	0.75–0.95
Chromium	0.25 max	0.25 max	0.25–0.45	0.25 max	1.50–2.00	1.50–2.00	2.00–2.50	2.8–3.3	2.7–3.3	0.70–1.00
Molybdenum	0.10 max	0.10 max	0.55–0.70	0.45–0.60	0.40–0.60	0.40–0.60	0.90–1.10 max	0.90–1.10	0.90–1.10	0.30–0.45
Vanadium	0.05 max	0.05 max	0.05 max	0.05 max	0.03 max	0.08 max	0.02 max	0.20–0.30	0.20–0.30	0.05 max
Columbium	0.01 max	0.01 max	0.01 max	0.01 max	0.01 max	0.01 max	0.01 max	0.01 max	0.015–0.070	0.01 max
Copper	0.20 max	0.20 max	0.20 max	0.20 max	0.25 max	0.25 max	0.25 max	0.25 max	0.25 max	0.25 max
Calcium	0.015 max	0.015 max	0.015 max	0.015 max	0.015 max	0.015 max	0.015 max	0.015 max	0.0005–0.0150	0.015 max
Boron	0.003 max	0.003 max	0.003 max	0.003 max	0.003 max	0.003 max	0.003 max	0.001–0.003	0.003 max	0.003 max
Titanium	0.015 max	0.015 max	0.015 max	0.015 max	0.015 max	0.015 max	0.015 max	0.015–0.035	0.015 max	0.015 max
Aluminum ^C	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.025 max	0.015 max	0.015 max	0.025 max

^A For Grade 22 Classes 5, 6, and 7 with section thickness at heat treat of 8 in. or greater, the carbon and manganese shall be held to 0.13 to 0.15 and 0.50 to 0.60, respectively.

^B When required by the purchaser a minimum silicon content of 0.15 % shall apply for Grades 1, 1A, 2, 3, and 4N.

^C Aluminum content reported shall be the combined total soluble and insoluble aluminum.

4.2.2 *Heat Treatment for Mechanical Properties*—The forgings shall be heated to a temperature which produces an austenitic structure and then quenched in a suitable liquid medium by spraying or immersion. For Grade 4N, Classes 1 and 3, the austenitizing temperature shall be 1540°F [840°C] min to 1640°F [895°C] max. Quenching shall be followed by tempering at a subcritical temperature and holding at this temperature for a minimum time of one-half hour per inch of maximum section thickness. Except when Supplementary Requirement S 13 is specified for Grades 2 and 3, the minimum tempering temperatures shall be as follows:

Grades 1, 1A, 2 Class 2, and 3 Class 2	1150°F [620°C]
Grades 2 Class 1 and 3 Class 1	1200°F [650°C]
Grades 4N Classes 1 and 2, and 5 Classes 1 and 2	1100°F [595°C]
Grade 4N Class 3	1125°F [605°C]
Grades 3V and 3VCb	1250°F [675°C]
Grade 22, Class 3	1200°F [650°C]
Grade 22, Classes 4, 5, 6, and 7	1100°F [593°C]

Specific cooling rates from the tempering temperature shall be applied if Supplementary Requirement S14 is specified.

4.3 For Grades 1, 1A, 2, 2A, 3, or 3A, a multiple stage austenitizing procedure may be used whereby the forging is first fully austenitized and liquid quenched, followed by reheating within the intercritical temperature range to partially reaustenitize and again liquid quenched. On completion of the austenitizing/quenching cycles, the forgings shall be tempered at a subcritical temperature as described in 4.2.2.

5. Chemical Composition

5.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A788/A788M shall comply with Table 1 except that the additional features of Supplementary Requirements S7, S8, S9, and S11 shall also apply as individually specified in the ordering information.

5.2 *Product Analysis*—The manufacturer shall use the product analysis provision of Specification A788/A788M to obtain a product analysis from a forging representing each heat or multiple heat. The permissible variations provided in the table on Permissible Variations in Product Analysis for Killed Steel in Specification A788/A788M apply for manganese, nickel, chromium, molybdenum, and vanadium only. Boron is not subject to product analysis. The purchaser may also make this determination in accordance with Specification A788/A788M.

6. Mechanical Properties

6.1 Tension Test:

6.1.1 The steel shall conform to the requirements of Table 2.

6.1.2 The location and number of tension test specimens for each forging or multiple forging shall be as follows:

6.1.2.1 *Multiple Forgings Separated into Identical Individual Forgings with Rough Machined Weights not Exceeding 1000 lb [455 kg] Prior to Quenching and Tempering Treatment*—At least one individual forging from each multiple forging in each heat-treating lot shall be tested using the test specimen locations of 6.1.5 or 6.1.6 as specified on the purchase orders, except that test specimens located at midlength may be closer to the ends of the production forging than the specified distance to the second surfaces. All forgings shall be quenched and tempered in the same furnace charge. All forgings from the multiple shall be Brinell hardness tested after heat treatment and forgings not tested for mechanical properties shall have a Brinell Hardness within 20 points of the Brinell Hardness of the forging that has been tested for mechanical properties.

6.1.2.2 *Forgings or Multiple Forgings (Note 3) with Rough Machined Weights Less than 10 000 lb [4540 kg] and Having a Heat-Treated Length (Exclusive of Test Prolongation) of 80 in. [2032 mm] or Less*—A test prolongation (Note 4) shall be located at one end. One tension test specimen shall be taken from the test prolongation.

6.1.2.3 *Forgings or Multiple Forgings with Rough Machined Weights Less than 10 000 lb [4540 kg] and Having a Heat-Treated Length (Exclusive of Test Prolongations) Exceeding 80 in. [2032 mm]*—A test prolongation shall be located at each end. One tension test specimen shall be taken from each test prolongation. An orientation of 180° shall be established between the two tension test specimens.

6.1.2.4 *Forgings or Multiple Forgings with Rough Machined Weights Over 10 000 lb [4540 kg] and Having a Heat-Treated Length (Exclusive of Test Prolongation) of 80 in. [2032 mm] or Less*—A test prolongation shall be located at one end. Two tension test specimens shall be taken from the test prolongation and shall be oriented 180° apart.

6.1.2.5 *Forgings or Multiple Forgings with Rough Machined Weights Over 10 000 lb [4540 kg] and Having a Heat-Treated Length (Exclusive of Test Prolongations) Exceeding 80 in. [2032 mm]*—A test prolongation shall be located at each end. The tension test specimens oriented 180° apart from each other shall be taken from each test prolongation. The two tension specimens located in one test prolongation shall be oriented 90° in relation to the two tension specimens located in the other test prolongation.

NOTE 3—Multiple forgings in 6.1.2.2 through 6.1.2.5 are those which will be separated after the quench and temper treatment.

NOTE 4—A test prolongation is defined as that integral test metal located at an end of the forging or forging multiples.

6.1.3 Samples for mechanical test specimen shall be removed from forgings after the quenching and tempering heat treatment. The sample material shall be subjected to a simulated post weld heat treatment if Supplementary Requirement S1 is specified.

6.1.4 For upset disk forgings, the longitudinal axis of the test specimens shall be in the tangential direction. For all other parts, the longitudinal axis of the specimens shall be parallel to the direction of major working of the forging.



TABLE 2 Tensile Requirements

	Grades														
	Grades 1 and 1a	Grades 2 and 3 Class 1	Grades 2 and 3 Class 2	Grades 4N and 5 Class 1	Grades 4N and 5 Class 2	Grades 22 Class 3	Grades 3V and 3Vcb	Grades 6 Class 1	Grades 6 Class 2	Grades 6 Class 3	Grades 6 Class 4	Grades 22 Class 4	Grades 22 Class 5	Grades 22 Class 6	Class 7
Tensile strength, ksi [MPa]	70-95 [485-655]	80-105 [550-725]	90-115 [620-795]	105-130 [725-895]	115-140 [795-965]	150-175 [1035-1215]	180-210 [1245-1445]	20-18 [138-125]	20-18 [138-125]	20-18 [138-125]	20-18 [138-125]	20-18 [138-125]	20-18 [138-125]	20-18 [138-125]	105-130 [725-895]
Yield strength, min [0.2 % offset], ksi [MPa]	36 [250]	50 [345]	65 [450]	85 [585]	100 [690]	120 [825]	150 [1035]	60 [415]	60 [415]	60 [415]	60 [415]	60 [415]	60 [415]	60 [415]	85 [585]
Elongation in 2 in. or 50 mm, min, %	20	18	16	18	16	16	18	18	18	18	18	18	18	18	18
Reduction of area, min, %	38	38	35	45	45	45	45	35	35	35	35	35	35	35	35

6.1.5 Each forging shall be manufactured in accordance with a purchaser-approved drawing, showing the prequenched dimensions, the finished dimensions, the surfaces that will be subjected to critical stresses, and the location of mechanical test specimens.

6.1.6 The tension test specimens shall be positioned so that the longitudinal axis and mid-length is in accordance with one of the following methods:

6.1.6.1 *Method 1*— t by $2t$, where t is the distance from the area of significant loading (see 3.1) to the nearest quenched surface. However, they shall not be nearer to one quenched surface than $\frac{3}{4}$ in. [20 mm] and to the second quenched surface than $1\frac{1}{2}$ in. [40 mm].

6.1.6.2 *Method 2*— $\frac{1}{4} T$ by T , where T is the maximum thickness of the forging as heat treated. Where this method of testing is employed, the following limitations for as-treated thickness shall generally apply:

Grades 1 and 1a	3 in. [75 mm], max
Grades 2 Class 2 and 3 Class 2	6 in. [150 mm], max
Grades 2 Class 1 and 3 Class 1	8 in. [205 mm], max
Grade 4N Class 2 and 5 Class 2	16 in. [405 mm], max
Grade 4N Class 1 and 5 Class 1	30 in. [760 mm], max
Grade 4N Class 3	40 in. [1015 mm], max
Grades 3V and 3VCb	20 in. [510 mm], max
Grade 22 Class 3	20 in. [510 mm], max
Grade 22 Classes 4, 5, 6, and 7	12 in. [305 mm], max

6.1.6.3 *Method 3*—Test specimens shall be taken from a representative separate test forging made from the same heat of steel and shall receive substantially the same reduction and type of hot working as the production forgings that it represents and shall be of the same nominal thickness as the as-quenched production forgings. The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forgings. Test specimens shall be removed from the region midway between the mid-thickness and the surface, and not closer than T to a second heat treated surface with the same limitation on forging thickness as in 6.1.6.2. This method shall be limited to forgings with a rough machined weight of not more than 1000 lb [455 kg].

6.1.6.4 *Method 4*—A thermal buffer ring, at least T by T in cross section, or segments of such a ring at least $3T$ in length, shall be welded to the test end of a forging prior to heat treatment for mechanical properties. The buffer material may be any weldable carbon or low-alloy steel and shall be joined to the forging with a partial-penetration type weld which completely seals the buffered surface. The test coupons shall be removed from the forging in the region buffered by the ring or ring segments. If ring segments are used, the test coupons shall be removed from the forging in the area under the buffer ring segment at a minimum distance of T from each end of that segment. In either case, the test specimens shall be located at a minimum distance of $\frac{1}{2}$ in. [13 mm] from the buffered surface of the forging, and at least $\frac{1}{4} T$ from a quenched surface of the forging.

NOTE 5—For forgings with a maximum thickness of 2 in. [50 mm], the specimens shall be taken at midthickness and at least 2 in. from a second surface. This provision is applicable to all four methods in 6.1.6.

6.1.7 Tension specimens shall be the standard 0.5 in. [12.5 mm] round by 2 in. [50 mm] gauge length, as shown in Test Methods and Definitions A370.

6.2 *Impact Test*—The steel shall conform to the requirements of Table 3, or Supplementary Requirement S10 may be specified instead of these requirements.

6.2.1 *Number, Location, and Orientation of Specimens:*

6.2.1.1 One set of three Charpy V-notch specimens shall be taken from each tensile specimen location required in 6.1.2. Orientation shall be the same as in 6.1.4. When S10 is specified, the required number of tests shall be governed by NB, NC, ND, NE, NF, or NG 2300, as applicable.

6.2.1.2 The requirements of 6.1.3 also apply to impact specimens.

6.2.1.3 The longitudinal axis and mid-length of the impact specimen shall be located similarly to the longitudinal axis of the tension test specimens as defined in 6.1.6. The axis of the notch shall be normal to the nearest heat-treated surface of the forging. When S10 is specified the orientation shall be governed by NB, NC, ND, NE, NF, or NG 2300.

6.2.2 Impact specimens shall be Charpy V-notch as shown in Test Methods and Definitions A370.

7. Workmanship and Quality Level Requirements

7.1 See requirements in 8.1, 8.2.2, 8.3.1.1, and 8.3.2.2.

8. Nondestructive Inspection Requirements

8.1 *General Requirements*—Dimensional and visual inspections, and magnetic particle and ultrasonic inspection shall be conducted by the manufacturer. Forgings shall be free of cracks, thermal ruptures, or other injurious indications.

8.2 *Magnetic Particle Inspection:*

8.2.1 Following final machining by the manufacturer all accessible surfaces of each forging shall be examined by the continuous current magnetic particle method. This examination shall be in accordance with Test Method A275/A275M unless the purchaser has required the use of the AC yoke in accordance with Test Method A966/A966M instead (see 3.3.1).

8.2.2 The following conditions are subject to rejection or removal:



TABLE 3 Charpy Impact Requirements

	Grades 1 and 1a at +40°F [4.4°C]	Grades 2 Class 1 and 3 Class 1 at +40°F [4.4°C]	Grades 2 Class 2 and 3 Class 2 at +70°F [21°C]	Grades 4N (all classes) and 5 (all classes) at -20°F [-29°C]	Grade 22, Class 3, and Grades 3V and 3VCb at 0°F [-18°C]	Grade 6 Classes 1, 2, 3, and 4 at -75°F [-59°C]	Grade 22 Classes 4, 5, 6, and 7 at -75°F [-60°C]
Minimum average value of set of three specimens, ft·lbf (J) ^A	15 [20]	30 [41]	35 [48]	35 [48]	40 [54]	20 [27]	40 [55]
Minimum value of one specimen, ft·lbf (J)	10 [14]	25 [34]	30 [41]	30 [41]	35 [50]	15 [20]	35 [50]

^A Not more than one specimen from a set may be below this value.