



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

This standard is issued under the fixed designation A 508/A 508M; 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 inch-pound units or SI (metric) units are to be regarded separately as standards. Within the text and the tables, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independent of the other. Combining values from the two systems may result in nonconformance with the specification.

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 3V	Class 3V
Grade 6 Classes 1, 2, 3, and 4	N/A

2. Referenced Documents

2.1 ASTM Standards:

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings³

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products⁴

A 388/A 388M Practice for Ultrasonic Examination of Heavy Steel Forgings³

A 788 Specification for Steel Forgings, General Requirements³

E 208 Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels⁵

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection⁶

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 2300*⁷

3. Ordering Information

3.1 *Purchase Order*—In addition to the ordering information required by Specification A 788, 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, 6.2.1, 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

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.

Current edition approved April 10, 2003. Published July 2003. Originally approved in 1964. Last previous edition approved in 1999 as A 508/A 508M – 95 (1999).

² For ASME Boiler and Pressure Vessel Code applications see related Specification SA-508/SA-508M in Section II of that Code.

³ *Annual Book of ASTM Standards*, Vol 01.05.

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

⁵ *Annual Book of ASTM Standards*, Vol 03.01.

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

⁷ Available from American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017.

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 A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.4 If the requirements of this specification are in conflict with the requirements of Specification A 788, 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 A 788 are permitted.

4.1.2 The molten steel shall be vacuum treated in accordance with the methods described in Specification A 788, prior to or during the pouring of the ingot, in order to remove objectionable gases, particularly hydrogen.

Grade 6 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 for Classes 1, 2, 3 and 4.

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.

4.2.2 *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 [600°C]
Grades 3V and 3VCb	1250°F [675°C]
Grade 22, Class 3	1200°F [650°C]
Grade 6, Classes 1, 2, 3, and 4	1200°F [650°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 re-austenitize 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 A 788 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 A 788 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 A 788 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 A 788.

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:

TABLE 1 Chemical Requirements

	Composition, %									
	Grade 1	Grade 1A	Grade 2	Grade 3	Grade 4N	Grade 5	Grade 22	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 ^A	0.15–0.40	0.15–0.40	0.15–0.40	0.15–0.40	0.15–0.40	0.30 max	0.50 max	0.10 max	0.10 max	0.15–0.35
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	...	...	...	...	...	...	...	...	0.015–0.070	0.01 max ^E
Copper	...	...	...	...	...	...	...	...	0.25 max	...
Calcium	...	...	...	...	...	...	...	...	0.0005–0.0150	...
Boron	...	...	...	...	...	...	...	0.001–0.003	...	...
Titanium	...	...	...	...	...	...	...	0.015–0.035	0.015 max	^B
Aluminum	...	...	...	...	...	...	...	...	...	0.05 max

^A When vacuum carbon-deoxidation is required by Supplementary Requirement S 11, the silicon content shall be 0.10 % maximum.

^B International addition of Cb and Ti not permitted.



TABLE 2 Tensile Requirements

	Grades 1 and 1a	Grades 2 Class 1 and 3 Class 1	Grades 2 Class 2 and 3 Class 2	Grades 4N Class 1 and 5 Class 1	Grades 4N Class 2 and 5 Class 2	Grade 4N Class 3	Grade 22 Class 3	Grades 3V and 3VCb	Grade 6 Class 1	Grade 6 Class 2	Grade 6 Class 3	Grade 6 Class 4
Tensile strength, min [0.2 % offset], ksi [MPa]	70 to 95 [485 to 655]	80 to 105 [550 to 725]	90 to 115 [620 to 795]	105 to 130 [725 to 895]	115 to 140 [795 to 965]	90 to 115 [620 to 795]	85 to 110 [585 to 760]	85 to 110 [585 to 760]	85 to 110 [655 to 825]	95 to 120 [655 to 825]	100 to 125 [690 to 760]	105 to 130 [725 to 895]
Yield strength, min [0.2 % offset], ksi [MPa]	36[250]	50[345]	65[450]	85[585]	100[690]	70[485]	55[380]	60[415]	75[415]	75[515]	80[550]	85[585]
Elongation in 2 in. or 50 mm, min, %	20	18	16	18	16	20	18	18	18	18	18	18
Reduction of area, min, %	38	38	35	45	45	48	45	45	35	35	35	35

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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 2) 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 3) 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.

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 6 Classes 1, 2, 3, and 4	6 in. [150 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] gage length, as shown in Test Methods and Definitions A 370.

6.2 *Impact Test:*