Designation: A 372/A 372M – 03 (Reapproved 2008)

Standard Specification for Carbon and Alloy Steel Forgings for Thin-Walled Pressure Vessels[1]

This standard is issued under the fixed designation A 372/A 372M; 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 relatively thin-walled forgings (including gas bottles) for pressure vessel use. Three types of carbon steel and six types of alloy steel are included. Provision is made for integrally forging the ends of vessel bodies made from seamless pipe or tubing.

NOTE 1—When working to the chemical and tensile requirements of this specification, the influence of wall thickness and cooling rate will necessarily eliminate certain forging sizes in each class.

NOTE 2—Designations have been changed as follows:

Current	Formerly
Grade A	Type I
Grade B	Type II
Grade C	Type III
Grade D	Type IV
Grade E Class 55	Type V Grade 1 Class 55
Grade E Class 65	Type V Grade 1 Class 65
Grade E Class 70	Type V Grade 1 Class 70
Grade F Class 55	Type V Grade 2 Class 55
Grade F Class 65	Type V Grade 2 Class 65
Grade F Class 70	Type V Grade 2 Class 70
Grade G Class 55	Type V Grade 3 Class 55
Grade G Class 65	Type V Grade 3 Class 65
Grade G Class 70	Type V Grade 3 Class 70
Grade H Class 55	Type V Grade 4 Class 55
Grade H Class 65	Type V Grade 4 Class 65
Grade H Class 70	Type V Grade 4 Class 70
Grade J Class 55	Type V Grade 5 Class 55
Grade J Class 65	Type V Grade 5 Class 65
Grade J Class 70	Type V Grade 5 Class 70
Grade K	Type VI
Grade L	Type VII
Grade J Class 110	Type VIII
Grade M Class 85	Type IX Class A
Grade M Class 100	Type IX Class B

1.2 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.

1.3 Unless the order specifies the applicable "M" specification designation (SI units), the material shall be furnished to inch-pound units.

2. Referenced Documents

2.1 *ASTM Standards:* [3]

A 275/A 275M Practice for Magnetic Particle Examination of Steel Forgings

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

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

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

A 788/A 788M Specification for Steel Forgings, General Requirements

E 112 Test Methods for Determining Average Grain Size

E 165 Test Method for Liquid Penetrant Examination

E 290 Test Methods for Bend Testing of Material for Ductility

E 433 Reference Photographs for Liquid Penetrant Inspection

3. Ordering Information and General Requirements

3.1 In addition to the ordering information required by Specification A 788/A 788M, the purchaser shall include with the inquiry and order a detailed drawing, sketch, or written description of the forging and the areas of significant loading in the forging when required (see 6.4.2.2).

3.2 Material supplied to this specification shall conform to the requirements of Specification A 788/A 788M, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

3.3 If the requirements of this specification are in conflict with the requirements of Specification A 788/A 788M, the requirements of this specification shall prevail.

[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 March 1, 2008. Published April 2008. Originally published in 1953. Last previous edition approved in 2003 as A 372/A 372M – 03.

[2] For ASME Boiler and Pressure Vessel Code applications, see related Specification SA-372/SA-372M 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.

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4. Materials and Manufacture

4.1 *Melting Practice*:

4.1.1 The steel melting procedures of Specification A 788/A 788M shall apply except that for Grade M forgings, only steel that has been vacuum treated prior to or during the pouring of the ingot, in order to remove objectionable gases, particularly hydrogen, shall be used.

4.2 *Production Methods*:

4.2.1 Methods for the production of gas bottles and similar vessels shall include the cupping of slabs or plates, the piercing of billets or plates, and the subsequent drawing of cups so produced. Such semifinished forgings or seamless steel pipe or tubing shall be closed by spinning, swedging, or pressing. In all cases there shall be sufficient discard to ensure soundness in the completed forging.

4.3 *Heat Treatment*:

4.3.1 At the option of the manufacturer, Grades A, B, C, D and Classes 55, 65, 70 of Grades E, F, G, H, and J forgings shall be normalized, normalized and tempered, or liquid-quenched and tempered.

4.3.2 Grades K, L, M, and Class 110 of Grade J forgings shall be liquid-quenched and tempered.

4.3.3 When normalized forgings are to be tempered, or when forgings have been quenched, they shall be reheated to a subcritical temperature and held for at least ½ h/in. [25 mm] of maximum cross section.

4.3.3.1 Minimum tempering temperatures shall be as follows:

Grades E, F, G, H, J in Classes 55, 65, 70	1100°F [595°C]
Grade K	1100°F [595°C]
Grade L	1000°F [540°C]
Grade J Class 110	1000°F [540°C]
Grade M	1100°F [595°C]

4.3.3.2 If an attachment is welded onto a previously quenched and tempered pressure vessel, the post weld heat treatment temperature of a weldment shall not exceed the prior tempering temperature of the pressure vessel. Fabrication welding of pressure shell is not permitted. Attachment welding prior to heat treatment is not permitted.

4.3.4 All quenched and tempered forgings shall be subject to magnetic particle examination in accordance with Section 7.

4.3.5 Heat treatment is to be performed after all forming operations.

5. Chemical Composition

5.1 *Heat Analysis*—The heat analysis obtained from sampling in accordance with Specification A 788/A 788M shall comply with Table 1.

5.2 *Product Analysis*—The purchaser may use the product analysis provision of Specification A 788/A 788M to obtain a product analysis from a forging representing each heat or multiple heat.

5.3 Starting material produced to a specification that specifically requires the addition of any element beyond those listed in Table 1 for the applicable grade of material is not permitted. This does not preclude use of deoxidation or inclusion control additions. Supplementary Requirements S1 and S2 of Specification A 788/A 788M shall apply.

TABLE 1 Chemical Requirements

Elements	Composition, %				
	Grade A	Grade B	Grade C	Grade D	
Carbon	0.30 max	0.35 max	0.48 max	0.40–0.50	
Manganese	1.00 max	1.35 max	1.65 max	1.40–1.80	
Phosphorus, max	0.025	0.025	0.025	0.025	
Sulfur, max	0.025	0.025	0.025	0.025	
Silicon	0.15–0.35	0.15–0.35	0.15–0.35	0.15–0.35	
Nickel	—	—	—	—	
Chromium	—	—	—	—	
Molybdenum	—	—	—	0.17–0.27	
	Grade E Classes 55, 65, 70	Grade F Classes 55, 65, 70	Grade G Classes 55, 65, 70	Grade H Classes 55, 65, 70	Grade J Classes 55, 65, 70, 110
Carbon	0.25–0.35	0.30–0.40	0.25–0.35	0.30–0.40	0.35–0.50
Manganese	0.40–0.90	0.70–1.00	0.70–1.00	0.75–1.05	0.75–1.05
Phosphorus, max	0.025	0.025	0.025	0.025	0.025
Sulfur, max	0.025	0.025	0.025	0.025	0.025
Silicon	0.15–0.35	0.15–0.35	0.15–0.35	0.15–0.35	0.15–0.35
Nickel	—	—	—	—	—
Chromium	0.80–1.15	0.80–1.15	0.40–0.65	0.40–0.65	0.80–1.15
Molybdenum	0.15–0.25	0.15–0.25	0.15–0.25	0.15–0.25	0.15–0.25
	Grade K	Grade L	Grade M Classes 85 and 100		
Carbon	0.18 max	0.38–0.43	0.23 max		
Manganese	0.10–0.40	0.60–0.80	0.20–0.40		
Phosphorus, max	0.025 max	0.025	0.020		
Sulfur, max	0.025 max	0.025	0.020		
Silicon	0.15–0.35	0.15–0.35	0.30 max		
Nickel	2.0–3.3	1.65–2.00	2.8–3.9		
Chromium	1.00–1.80	0.70–0.90	1.50–2.00		
Molybdenum	0.20–0.60	0.20–0.30	0.40–0.60		
Vanadium			0.08 max		

6. Mechanical Properties

6.1 Mechanical tests for acceptance shall be made after the final heat treatment of the forgings.

6.2 *Tension Test*—When tested in accordance with Test Methods and Definitions A 370, the material shall conform to

TABLE 2 Mechanical Requirements

Type	Tensile Strength, ksi [MPa]	Yield Strength (0.2 % Offset), ksi [MPa], min	Elongation in 2 in. [50 mm], min, %	Hardness, HB, min[A]
Grade A	60–85 [415–585]	35 [240]	20	121
Grade B	75–100 [515–690]	45 [310]	18	156
Grade C	90–115 [620–795]	55 [380]	15	187
Grade D	105–130 [725–895]	65 [450]	15	217
Grades E, F, G, H, J (Class 55)	85–110 [545–760]	55 [380]	20	179
Grades E, F, G, H, J (Class 65)	105–130 [725–895]	65 [450]	19	217
Grades E, F, G, H, J (Class 70)	120–145 [825–1000]	70 [485]	18	248
Grade J (Class 110)	135–160 [930–1100]	110 [760]	15	277
Grade K	100–125 [690–860]	80 [550]	20	207
Grade L	155–180 [1070–1240]	135 [930]	12	311
Grade M (Class 85)	105–130 [725–895]	85 [585]	18	217
Grade M (Class 100)	120–145 [825–1000]	100 [690]	16	248

[A] When required by 6.6.

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the requirements of Table 2. The yield strength shall be determined by the 0.2 % offset method.

6.3 *Bending Properties*—Depending upon the outside diameter, *D*, and the wall thickness, *T*, of hollow or bored forgings, a bend test or flattening test will be required.

6.3.1 For bored or hollow forgings with outside diameters of 14 in. [355 mm] or less and with a *D/T* ratio of more than 10.0, a flattening test is required. This shall be carried out in accordance with Specification A 530/A 530M and Table 3. No breaks or cracks in the test ring are acceptable until the distance between the plates is less than that shown in Table 3.

6.3.2 For bored or hollow forgings with outside diameters over 14 in. [355 mm], or where the *D/T* ratio is 10.0 or less at the manufacturer's option, the flattening test specified in 6.3.1, or a transverse bend test in accordance with Arrangement C of Test Methods E 290 is required. The bend test pin diameter shall be as specified in Table 4. No cracks or ruptures in the test piece are allowable when the test piece is bent through the required angle.

6.4 *Orientation and Location of Test Specimens*:

6.4.1 Test specimens representing vessel bodies or shells shall be taken from a prolongation of a forging, from test rings that have been heat treated with the forgings they represent, or from a representative forging after heat treatment in accordance with 4.3.

6.4.1.1 Test specimens representing vessel bodies or shells shall be located at a position corresponding to the mid-wall location of the parallel side wall of the heat-treated forging and shall be oriented parallel to the longitudinal axis of the vessel.

6.4.1.2 A test ring shall be in the shape of a right circular cylinder having the same diameter and wall thickness as the cylinders it represents. In addition, the test ring shall be from the same heat of steel and be subjected to the same heat treatment as the cylinders it represents. The method of quenching the test ring must duplicate that of the cylinders; if the cylinders are quenched from the outside only, then the test ring must have its ends closed. The length of test rings that will be liquid quenched must be at least 24 in. [610 mm]. The ends of such test rings may be vented to prevent pressure buildup during heat treating.

6.4.2 Test specimens representing vessel covers or similar components may be taken from a full section prolongation of the cover, from a representative forging, or from an integral prolongation when the part is contour-machined prior to heat treatment.

TABLE 3 Distance Between Plates for Flattening Tests[A]

Type	Distance Between Plates, min, in. [mm]
Grade A	0.50 *D*
Grade B	0.6 *D*
Grade C	0.65 *D*
Grade D	0.7 *D*
Grades E, F, G, H, J (Class 55)	0.7 *D*
Grades E, F, G, H, J (Class 65)	0.8 *D*
Grades E, F, G, H, J (Class 70)	0.8 *D*
Grade J (Class 110)	0.9 *D*
Grade K	0.8 *D*
Grade L	0.9 *D*
Grade M (Class 85)	0.7 *D*
Grade M (Class 100)	0.8 *D*

[A] *D* = outside diameter.

TABLE 4 Maximum Pin Diameters and Minimum Angle for Bend Test

Type	Pin Diameter	Angle, deg
Grade A	2*t*	180
Grade B	2*t*	180
Grade C	3*t*	180
Grade D	4*t*	150
Grades E, F, G, H, J (Class 55)	4*t*	150
Grades E, F, G, H, J (Class 65)	4*t*	150
Grades E, F, G, H, J (Class 70)	4*t*	150
Grade J (Class 110)	6*t*	150
Grade K	4*t*	150
Grade L	6*t*	150
Grade M (Class 85)	4*t*	150
Grade M (Class 100)	4*t*	150

6.4.2.1 Test specimens taken from full size prolongations or representative forgings shall be located at a position midway between the center and the surface.

6.4.2.2 When forgings are contour-machined prior to heat treatment so that highly stressed surfaces are exposed, the test specimens may be taken at an equal distance (*t*) from the nearest quenched surface as the highly stressed area, but not less than ¾ in. [20 mm]. The location of the specimens from a second surface shall be at least the greater of 1½ in. [40 mm] or 2*t*.

6.5 *Number of Tests*:

6.5.1 Up to 200 like forgings, each with a heat-treated weight of less than 1000 lb [510 kg] when heat treated in a single batch furnace charge, shall have one tension test taken in accordance with 6.4.1 or 6.4.2 to represent each heat. In addition, for hollow or bored forgings, one bend or flattening test shall be taken in accordance with 6.3.

6.5.2 Like forgings, weighing less than 1000 lb [450 kg] each when heat treated in a continuous furnace, shall have one tensile test taken to represent each heat and not more than 200 forgings in any continuous period up to 4 h duration. In addition, bored or hollow forgings shall have one bend or flattening test taken per heat per 200 forgings in any continuous period up to 4 h duration in accordance with 6.3.

6.5.3 For heat-treated forgings weighing 1000 lb [450 kg] or more, one tension test shall be taken in accordance with 6.4.1 or 6.4.2 to represent each heat and not more than ten forgings in a heat-treat lot. In addition, hollow or bored forgings shall have one bend or flattening test, taken in accordance with 6.3, to represent each ten or fewer forgings from the same heat and heat-treatment lot.

6.6 *Hardness Testing*:

6.6.1 Forgings under 1000 lb [450 kgm] in weight, heat treated in a batch lot of up to 200 pieces (6.5.1) or in a continuous furnace run covering up to 200 pieces in up to four hours production (6.5.2) shall be subject to a uniformity check by Brinell hardness testing, or an equivalent method. For this purpose, 10 % of the furnace production shall be sampled and shall meet the minimum hardness specified in Table 2 for the type and shall also be within 20 Brinell points of the hardness of the forging from which the tensile test was taken.

6.6.2 In the event that the test sample does not meet these criteria, the remainder of that production group shall be hardness tested and all of those forgings that fall outside these

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limits shall be retempered or reheat-treated at the manufacturer's option and retested.

7. Magnetic Particle Examination

7.1 All quenched and tempered forgings shall be subject to magnetic particle examination after heat treatment. The methods used shall be in accordance with Practice A 275/A 275M.

7.2 Only direct current or rectified alternating (full or half wave) current shall be used as the electric power source for any of the magnetizing methods.

7.3 The forgings shall be free from linear indications indicative of cracks. In case of doubt as to the type of condition giving rise to linear magnetic particle indications, they may be inspected for Type II indications referenced in Reference Photographs E 433 when inspected by the liquid penetrant method in accordance with Test Method E 165. Alternatively, some other suitable method for classifying the indications may be used as agreed upon between the manufacturer and the purchaser.

8. Workmanship

8.1 If the thickness of a portion of the wall of a forging is less than that specified, the forgings may be accepted by the purchaser, provided that such irregularity will not require lowering the allowable working pressure below that for which the forging was designed.

9. Repair Welding

9.1 Repair welding shall be permitted when mutually agreed upon between the purchaser and the manufacturer and shall be performed in accordance with all the requirements of the applicable code or rules of construction.

10. Keywords

10.1 alloy steel forgings; carbon steel forgings; gas bottles; pressure vessels; thin wall

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser on the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon by the manufacturer and the purchaser.

S1.Grain Size

S1.1 When a grain size range is required, it shall be specified in the ordering information, and shall be determined by an agreed-upon method from Test Methods E 112.

S1.2 Samples for grain size estimation shall be taken from the tension test specimen location.

S2. Rough Machining

S2.1 Rough machining shall be performed in the sequence and manner as specified.

S3. Impact Testing

S3.1 Charpy V-notch test specimens shall be taken from the same location and in the same orientation as tension test specimens. The number of specimens, minimum energy values, and test temperature(s) shall be as specified.

S4. Fracture Toughness

S4.1 Specific fracture toughness requirements are levied by certain sections of the ASME Boiler and Pressure Vessel Code. Forgings in the permitted types shall comply with the applicable code sections.

S4.2 The necessary code references toughness criteria and test temperature data shall be included in the ordering information.

S5. Ultrasonic Examination

S5.1 Ultrasonic examination of forgings shall be carried out in accordance with Practice A 388/A 388M.

S5.2 Acceptance criteria shall be specified and shall be in accordance with the applicable Code or purchaser's specification and shall be included as part of the ordering information.

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