

# SPECIFICATION FOR CARBON AND ALLOY STEEL FORGINGS FOR THIN-WALLED PRESSURE VESSELS



SA-372/SA-372M



(23)

(Identical with ASTM Specification A372/A372M-20<sup>e1</sup>.)

# Specification for Carbon and Alloy Steel Forgings for Thin-Walled Pressure Vessels

## 1. Scope

1.1 This specification 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 are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

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

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.*

## 2. Referenced Documents

### 2.1 ASTM Standards:

- 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
- A530/A530M Specification for General Requirements for Specialized Carbon and Alloy Steel Pipe
- A788/A788M Specification for Steel Forgings, General Requirements
- E112 Test Methods for Determining Average Grain Size
- E165/E165M Practice for Liquid Penetrant Testing for General Industry
- E290 Test Methods for Bend Testing of Material for Ductility
- E433 Reference Photographs for Liquid Penetrant Inspection

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 <sup>A</sup>
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, R (Class 55)	85–110 [585†–760]	55 [380]	20	179
Grades E, F, G, H, J, R (Class 65)	105–130 [725–895]	65 [450]	19	217
Grades E, F, G, H, J, R (Class 70)	120–145 [825–1000]	70 [485]	18	248
Grades J, R (Class 90)	120–145 [825–1000]	90 [620]	18	248
Grades J, R (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
Grades N and P (Class 100)	115–140 [795–965]	100 [690]	16	248
Grades N and P (Class 120)	135–160 [930–1105]	120 [825]	14	277
Grades N and P (Class 140)	155–180 [1070–1240]	140 [965]	13	311

†Editorially corrected.

<sup>A</sup> When required by 6.6.

## 2.2 ASME Standard:

ASME Boiler and Pressure Vessel Code

## 3. Ordering Information and General Requirements

3.1 In addition to the ordering information required by Specification A788/A788M, 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 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 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 Practice*—The steel melting procedures of Specification A788/A788M shall apply except that for Grades M, N, P, and Grades J and Class 110 forgings, only steel that

has been vacuum treated before or during the pouring of the ingot, to remove objectionable gases, particularly hydrogen, shall be used.

4.2 *Production Methods*—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, and D and Classes 55, 65, and 70 of Grades E, F, G, H, and J forgings shall be normalized, normalized and tempered, liquid quenched and tempered, or normalized followed by liquid quench and temper.

4.3.2 Grades K, L, M, N, P, and Classes 90 and 110 of Grades J and R forgings shall be liquid quenched and tempered, or normalized followed by liquid quench and temper.

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, 90	1100 °F [595 °C]
Grade K	1100 °F [595 °C]
Grades L, N, P, R	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 before 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 A788/A788M shall comply with Table 1.

5.2 *Product Analysis*—The purchaser may use the product analysis provision of Specification A788/A788M 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 A788/A788M shall apply.

TABLE 1 Chemical Requirements

Element	Composition, %				
	Grade A	Grade B	Grade C	Grade D	Grade E Classes 55, 65, 70
Carbon	0.30 max	0.35 max	0.48 max	0.40–0.50	0.25–0.35
Manganese	1.00 max	1.35 max	1.65 max	1.40–1.80	0.40–0.90
Phosphorus, max	0.015	0.015	0.015	0.015	0.015
Sulfur, max	0.010	0.010	0.010	0.010	0.010
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
Molybdenum	...	...	...	0.17–0.27	0.15–0.25
Vanadium	...	...	...	...	...
Boron	...	...	...	...	...
	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	Grade K
Carbon	0.30–0.40	0.25–0.35	0.30–0.40	0.35–0.50	0.18 max
Manganese	0.70–1.00	0.70–1.00	0.75–1.05	0.75–1.05	0.10–0.40
Phosphorus, max	0.015	0.015	0.015	0.015	0.015
Sulfur, max	0.010	0.010	0.010	0.010	0.010
Silicon	0.15–0.35	0.15–0.35	0.15–0.35	0.15–0.35	0.15–0.35
Nickel	...	...	...	...	2.0–3.3
Chromium	0.80–1.15	0.40–0.65	0.40–0.65	0.80–1.15	1.00–1.80
Molybdenum	0.15–0.25	0.15–0.25	0.15–0.25	0.15–0.25	0.20–0.60
Vanadium	...	...	...	...	...
Boron	...	...	...	...	...
	Grade L	Grade M Classes 85 and 100	Grade N Classes 100, 120, 140	Grade P Classes 100, 120, 140	Grade R Classes 55, 65, 70, 90, 110
Carbon	0.38–0.43	0.23 max	0.35 max	0.40 max	0.35–0.50
Manganese	0.60–0.80	0.20–0.40	0.90 max	0.90 max	0.75–1.05
Phosphorus, max	0.015	0.015	0.015	0.015	0.015
Sulfur, max	0.010	0.010	0.015	0.015	0.010
Silicon	0.15–0.35	0.30 max	0.35 max	0.35 max	0.15–0.35
Nickel	1.65–2.00	2.8–3.9	1.5–2.25	2.3–3.3	...
Chromium	0.70–0.90	1.50–2.00	0.80–2.00	0.80–2.00	0.80–1.15
Molybdenum	0.20–0.30	0.40–0.60	0.20–0.40	0.30–0.50	0.15–0.25
Vanadium	...	0.08 max	0.20 max	0.20 max	...
Boron	...	...	...	...	5–20 ppm

5.4 *Temper Embrittlement Control*—The purchaser's attention is drawn to Supplementary Requirement S24 in Specification A788/A788M for application of the J Factor, which may be of assistance in the control of temper embrittlement in forgings produced to Specification A372/A372M.

## 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 A370, the material shall conform to 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 A530/A530M and Table 3. No

TABLE 3 Distance Between Plates for Flattening Tests<sup>A</sup>

Type	Distance Between Plates
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, R (Class 55)	0.7 $D$
Grades E, F, G, H, J, R (Class 65)	0.8 $D$
Grades E, F, G, H, J, R (Class 70)	0.8 $D$
and Grades J, R (Class 90)	0.9 $D$
Grades J, R (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 $D$
Grades N, P (Class 100)	0.8 $D$
Grades N, P (Classes 120, 140)	0.9 $D$

<sup>A</sup>  $D$  = outside diameter.

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 Test Methods E290 is required. In cases in which the Test Methods E290 method used stipulates a bend test pin or mandrel, the 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 for properties other than bending properties 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

TABLE 4 Maximum Pin Diameters and Minimum Angle for Bend Test

Type	Pin Diameter	Angle, deg
Grade A	2T	180
Grade B	2T	180
Grade C	3T	180
Grade D	4T	150
Grades E, F, G, H, J, R (Class 55)	4T	150
Grades E, F, G, H, J, R (Class 65)	4T	150
Grades E, F, G, H, J, R (Class 70)	4T	150
and Grades J, R (Class 90)	4T	150
Grades J, R (Class 110)	6T	150
Grade K	4T	150
Grade L	6T	150
Grade M (Class 85)	4T	150
Grade M (Class 100)	4T	150
Grades N, P (Class 100)	6T	150
Grades N, P (Classes 120, 140)	6T	150

treatment as the cylinders it represents. The method of quenching the test ring shall duplicate that of the cylinders; if the cylinders are quenched from the outside only, then the test ring shall have its ends closed. The length of test rings that will be liquid quenched shall 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, a representative forging, or an integral prolongation when the part is contour machined before heat treatment.

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 before 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  $\frac{3}{4}$  in. [20 mm]. The location of the specimens from a second surface shall be at least the greater of  $1\frac{1}{2}$  in. [40 mm] or  $2t$ .

#### 6.5 Number of Tests:

6.5.1 Up to 200 like forgings, each with a heat-treated weight of less than 1000 lb [450 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 kg] 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 4 h 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 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 A275/A275M.

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 E433 when inspected by the liquid penetrant method in accordance with Practice E165/E165M. 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 E112.

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 A388/A388M.

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.