ASTM A350/A350M-07

Standard Specification for Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components[1]

1. Scope :-

1.1 This specification covers several grades of carbon and low-alloy steel forged or ring-rolled flanges, forged fittings and valves intended primarily for low-temperature service and requiring notch toughness testing. They are made to specified dimensions, or to dimensional standards, such as the ASME and API Specifications referenced in Section . Although this specification covers some piping components machined from rolled bar and seamless tubular materials (see), it does not cover raw material produced in these product forms.

1.2 No limitation on size is intended beyond the ability of the manufacturer to obtain the specified requirements. However, Class 3 of Grade LF787 is only available in the quenched-and-precipitation heat treated condition.

1.3 Supplementary requirements are provided for use when additional testing or inspection is desired. These shall apply only when specified by the purchaser in the order.

1.4 This specification is expressed in both inch-pound units and in SI units. However, unless the order specifies the applicable "M" specification designation (SI units), the material shall be furnished to inch-pound units.

1.5 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in non-conformance with the specification.

2. Raferenced Documents :-

2.1 ASTM Standards:3
A370 Test Methods and Definitions for Mechanical Testingof Steel Products
A788/A788M Specification for Steel Forgings, General Requirements
A961/A961M Specification for Common Requirements for Steel Flanges, Forged Fittings, Valves, and Parts for Piping Applications
2.2 ASME Standards:
B 16.5 Steel Pipe Flanges and Flanged Fittings4
B 16.9 Factory-Made Wrought Steel Butt-Welding Fit-tings4
B 16.10 Face-to-Face and End-to-End Dimensions of Fer-rous Valves4
B1611 forged steel fitting, socket-welding and Threaded[4]
B 16.30 Unfired Pressure Vessel Flange Dimensions4
B 16.34 Valves-Flanged, Threaded, and Welding End4
B 16.47 Large Diameter Steel Flanges4
2.3 ASME Boiler and Pressure Vessel Code:
Section IX Welding Qualifications2
2.4 AWS Standards:

A 5.1 Mild Steel Covered Arc-Welding Electrodes5
A 5.5 Low-Alloy Steel Covered Arc-Welding Electrodes5
2.5 API Standards:6
600 Steel Gate Valves with Flanged or Butt-Welding Ends
602 Compact Design Carbon Steel Gate Valves for Refinery Use
605 :Large Diameter Carbon Steel Flanges

3. Ordering Information :-
   3.1 It is the purchaser's responsibility to specify in the purchase order information necessary the needed material. In addition to the ordering information guidelines in Specification A961/A961M, orders should include the following information:
      3.1.1 The number of test reports required (see Section 14).
      3.1.2 Additional requirements (see Table 1 Footnotes).
4. General Requirements :-
   4.1 Product furnished to this specification shall conform to the requirements of specification A961/A961M, including any supplementary requirements that are indicated in the purchase order. Failure to comply with the general requirements of specification A961/A961M constitutes non-conformance with this specification. In case of conflict between the requirements of this specification and Specification A961/A961M, this specification shall prevail.
5. Manufacture :-
   5.1 Melting Process — The steel shall be produced by any of the following primary processes; open-hearth, basic-oxygen, electric-furnace, or vacuum-induction melting (VIM). The primary melting may incorporate separate degassing or refining, and may be followed by secondary melting using electroslag remelting (ESR), or vacuum-arc remelting (VAR).
      5.1.1 The steel shall be fully killed, fine-grain practice.
      5.1.2 The molten steel may be vacuum treated prior to or during pouring of the ingot.
   5.2 Discard — A sufficient discard shall be made to secure freedom from injurious piping and undue segregation.
   5.3 Forging Process:
      5.3.1 Material for forgings shall consist of ingots, or forged, rolled, or strandcast blooms, billets, slabs, or bars.
      5.3.2 The finished product shall be a forging as defined in the Terminology section of Specification A 788/A788M.
      5.3.3. Except for flanges of all types, hollow, cylindrically-shaped parts may be machined from rolled bar or seamless tubular materials provided that the axial length of the part is approximately parallel to the metal flow lines of the stock. Other parts, excluding flanges of all types, may be machined from hot-rolled or forged bar up through and including NPS 4. Elbows, return bends, tees, and header tees shall not be machined directly from bar stock.
      5.4 Heat Treatment:
      5.4.1 After hot working and before reheating for heat treatment, the forging shall be allowed to cool substantially below the transformation range.

5.4.2 Forgings of grades other than Grade LF787 shall be furnished in the normalized, or in the normalized and tempered, or in the quenched and tempered condition described by the following procedures:

5.4.2.1 Normalize — Heat to a temperature that produces an austenitic structure, holding sufficient time to attain uniform temperature throughout. Cool uniformly in still air.

5.4.2.2Normalize and Temper — Subsequent to normalize, reheat to 1100 °F [590 °C] minimum, holding at temperature a minimum of 30 min/in. [30 min/25 mm] of maximum thickness, but in no case less than 30 min. Cool in still air.

5.4.2.3 Quench and Temper — The procedure for quenching shall consist of either (1)fully austenitizing the forgings followed by quenching in a suitable liquid medium or (2) using a multiple stage procedure whereby the forging is first fully austenitized and rapidly cooled, then reheated to partiall reaustenitize, followed by quenching in a suitable liquid medium. All quenched forgings shall be tempered by reheating to a temperature between 1100°F [590°C] and the lower transformation temperature, holding a temperature a minimum of 30 min/in. [30 min/25 mm] of maximum thickness but in no case less than 30 min. Cool in still air.

5.4.3 Grade LF787 forgings shall be furnished in either the normalized-and-precipitation, heat-treated condition or in the quenched-and-precipitation, heattreated condition. The heat treatment procedures shall be as follows:

5.4.3.1 Normalized-and-Precipitation Heat Treated — Heat to a temperature in the range from 1600 to 1725°F [870 to 940°C], hold at the temperature for a time sufficient to attain uniform temperature throughout, soak at the temperature for not less than 1⁄2 hr, and remove from the furnace and cool in air. Subsequently, heat to a temperature in the range from 1000 to 1200°F [540 to 650°C], soak at the temperature for not less than 1⁄2 hr, and cool at any convenient rate.

5.4.3.2 Quenched-and-Precipitation Heat Treated — Heat to a temperature in the range from 1600 to 1725°F [879 to 940°C], hold at the temperature for a time sufficient to attain uniform temperature throughout, soak at the temperature for not less than 1⁄2 hr and quench in a suitable liquid medium by immersion; reheat to a temperature in the range from 1000 to 1225°F [540 to 665°C], hold at the temperature for not less than 1⁄2 hr, and cool at any convenient rate.

TABLE 1 Chemical Requirements

Composition, %

Element	Grade LF1	Grade LF2	Grade LF3	Grade LF5	Grade LF6	Grade LF9	Grade LF787
Carbon, max	0.30	0.30	0.20	0.30	0.22	0.20	0.07
Manganese	0.60-1.35	0.60-1.35	0.90 max	0.60-1.35	1.15-1.50	0.40-1.06	0.40-0.70
Phosphorus, max	0.035	0.035	0.035	0.035	0.025	0.035	0.025
Sulfur, max	0.040	0.040	0.040	0.040	0.025	0.040	0.025
Silicon[A]	0.15-0.30	0.15-0.30	0.20-0.35	0.20-0.35	0.15-0.30	....	0.40 max
Nickel	0.40 max[B]	0.40 max[B]	3.3-3.7	1.0-2.0	0.40 max[B]	1.60-2.24	0.70-1.00
Chromium	0.30 max[b,c]	0.30 max[b,c]	0.30 max[c]	0.30 max[c]	0.30 max[b,c]	0.30 max[c]	0.60-0.90
Molybdenum	0.12 max[b,c]	0.12 max[b,c]	0.12 max[c]	0.12 max[c]	0.12 max[b,c]	0.12 max[c]	0.15-0.25
Copper	0.40 max[B]	0.40 max[B]	0.40 max	0.40 max	0.40 max[B]	0.75-1.25	1.00-1.30

Columbium	0.02 max[D]	0.02 max[D]	0.02 max	0.02 max	0.02 max	0.02 max	0.02 min
Vanadium	0.08 max	0.08 max	0.03 max	0.03 max	0.04-0.11	0.03 max	0.03 max
Nitrogen	....	....	....	....	0.01-0.030	....	....

6. Chemical Composition :-

6.1 Heat Analysis:

6.1.1. An analysis of each heat of steel shall be made by the steel producer from samples taken preferably during the pouring of the heat. The results shall conform to Table 1. Leaded steel shall not be permitted.

6.2 Product Analysis:

6.2.1 The purchaser may make a product analysis on products supplied to this specification in accordance with specification A961/A961M.

7. Mechanical Properties :-

7.1 Tension Tests:

7.1.1 Requirements — The material shall conform to requirements for tensile properties in Table 2.

7.1.1.1 The test specimen shall be obtained from a rough or finished production forging, or prolongation thereof, or it may be obtained from separately forged test blanks from the same heat of steel as the production forging. The test blank shall be reduced by forging in a manner similar to that for the products represented, and shall receive approximately the same hot working and reduction and the same heat treatment as the finished products represented. The test material shall be treated in the same furnace at the same time as the forging it represents, subject to the requirements of 7.1.2.1.

7.1.1.2 The test specimen shall represent all forgings from the same heat and heat-treatment load whose maximum thicknesses do not exceed the thickness of the test forging or blank by more than 1⁄4 in. [6 mm].

7.1.2 Number of Tests — One tension test at room temperature shall be made in accordance with 6.1.1.2 from each heat in each heat-treatment load.

7.1.2.1 If heat treatment is performed in either a continuous or a batch-type furnace controlled with 625°F [614°C] of the required heat-treatment temperature and equipped with recording pyrometers so that complete records of heat treatment are available and if the same heat-treating cycles are used on the forgings represented by the tension test, then one tension test from each heat shall be required, instead of one tension test from each heat in each heat treatment load in accordance with 7.1.1.2.

7.1.3 Test Locations and Orientations — The test specimen shall be removed from the heaviest section of the forging or test blank, at locations described in 6.1.3.1, 6.1.3.2, 6.1.3.3, or as close to these locations as practical, subject to forging size and geometry.

7.1.3.1 For forgings or test blanks having a maximum heat-treated thickness, T, of 2 in. [50 mm] or less, the longitudinal axis of the test specimen shall be taken at mid-thickness and its mid-length shall be at least 2 in. [50 mm] from a second heat-treated surface, exclusive of the T dimension surfaces. (This is normally referred to as 1⁄2 T by 2 in. [50 mm]).

7.1.3.2 For forgings or test blanks having a maximum heat-treated thickness, T, greater than 2 in. [50 mm], the central axis of the test specimen shall be taken at least 1⁄4 T from the nearest heat-treated surface and at least T or 4 in. [100 mm], whichever is less, from

any second heat-treated surface. See Fig. 2 for test specimen location in separately forged test blanks for quenched and tempered forgings.
7.1.3.3 Metal Buffers – The required distances from hear treated surfaces may be obtained with metal buffers instead of integral expansions. Buffer material may be carbon or low alloy steel, and shall be joined to the forging with a partial penetration weld that seals the buffered surface. Specimens shall be located at ½ in. [13 mm] minimum from the buffered surface of the forging. Buffers shall be removed and the welded areas subjected to magnetic particle test to assure freedom from cracks unless the welded areas are completely removed by subsequent machining.
7.1.3.4 The test specimen shall have its longitudinal axis located parallel to the direction of major working of the forging or test blank.
7.1.3.5 With prior purchaser approval, tests may be taken at a depth (t) corresponding to the distance from the area of significant loading to the nearest heat treated surface and at least twice this distance (2t) from any second surface. However, the test depth shall not be nearer to one treated surface than 3⁄
4 in.[19 mm] and to the second treated surface than 1 1⁄2 in. [38 mm]. This method of test location would normally apply to contour-forged parts, or parts with thick cross sectional areas where 1⁄4 T × T testing (7.1.3.2) is not practical. Sketches showing the exact test locations shall be approved by the purchaser when this method is used.
7.1.4 Test Method — Testing shall be performed in accordance with Test Methods and Definitions A370. The test specimen shall be as large as is practicable and shall be machined to the form and dimensions of Fig. 7 of Test Methods and Definitions A 370. When seamless tubular materials are used, testing shall be performed on longitudinal specimens in accordance with Annex A2, Steel Tubular Products, of Test Methods and Definitions A370.
7.2 Impact test:
7.2.1 Requirements — The material shall conform to the requirements for impact properties in Table 3 when tested at the applicable standard temperature in Table 4 within the limits of 7.2.4.2 and 7.2.4.3. When subsize specimens are used, the impact energy values pbtained shall conform to Table 5 at energy values proportional to standard size. Exceptions to this requirement are permissible when Supplement S4 is specified by the purchaser. Impact tests may be made at temperatures different from those in Table 5, provided that the test temperature is at least as low as the intended service temperature, and that the forging is suitably marked to identify the reported test temperature.
7.2.1.1 The test specimens shall be machined from material obtained as in 7.1.
7.2.2 2 Number of Tests — Three specimens shall constitute one test set. There shall be the same number of test sets as tension tests in 7.1.2.
7.2.3 Test Locations and Orientations — The test specimen shall be located and oriented as described in 7.1.3. The area under the notch of the impact test specimen shall be used to locate the specimen with respect to the second heat-treated surface. The base of the notch shall be perpendicular to the nearest heat treated surface.
7.2.4 Test Method — The notched bar impact test shall be made in accordance with the procedure for the Charpy V-notch type test as described in Test Methods and Definitions A 370.
7.2.4.1 Standard size specimens shown in Fig. 11 of Test Methods and Definitions A370 shall be used for the impact test. Where the material is of insufficient thickness, or the

shape of the forging precludes standard size, the largest obtainable subsize specimen described in Test Methods and Definitions
A 370 shall be used.

7.2.4.2 Where subsize specimens are used and represent forged material with thicknesses equal to or greater than 0.394 in. [10 mm], and where the largest obtainable specimen has a width along the notch of at least 8 mm, such specimen shall be tested at the temperature in Table 4. Where the largest obtainable specimen has a width along the notch less than 8 mm, the temperature for testing shall be lower than the temperature in Table 4 by the amount shown in Table 6 for the actual specimen width tested.

7.2.4.3 Where subsize specimens are used and represent forged material with thicknesses less than 0.394 in. [10 mm], and where the largest obtainable specimen has a width along the notch of at least 80% of the forging thickness, the specimen shall be tested at the temperature in Table 4. Where the largest obtainable specimen has a width along the notch of less than 80% of the material thickness, the temperature for testing shall be lower than the temperature in Table 4 by an amount equal to the difference (referring to Table 6) between th temperature reduction corresponding to the thickness of the material represented, and the temperature reduction corresponding to the specimen width actually tested.

7.3 Hardness Test:

7.3.1 Except when only one forging is produced, a minimum of two forgings shall be hardness tested per batch or continuous run as defined in 7.1.2.1 to ensure that hardness of the forgings does not exceed 197 HB after heat treatment for mechanical properties. The hardness measurements shall be made in accordance with Test Methods and Definitions A 370. When only one forging is produced, it shall be hardness tested to ensure that it meets the 197 HB maximum of this specification. The purchaser may verify that this requirement has been met by testing at any location on the forging, provided that such testing does not render the forging useless.

TABLE 2 tensile Properties at Room Temperature[A]

	Grades							
	LF1 and LF5 Class 1	LF2 Classes 1 and 2	LF3 Classes 1 and LF 5 Class 2	LF 6		LF 9	LF 787	
				Class 1	Class		Class 2	Class 3
Tensile strength, ksi [MPa]	60-85 [415-585]	70-95 [485-655]	70-95 [485-655]	66-91 [455-630]	75-100 [515-690]	63-88 [435-605]	65-85 [450-585]	75-95 [515-655]
Yield strength, min, ksi [MPa]B,C Elongation:	30 [205]	36 [250]	37.5 [260]	52 [360]	60 [415]	46 [315]	55 [380]	65 [450]
Standard round specimen, or small proportional specimen, min % in	25	22	22	22	20	25	20	20
4D gage length Strip specimen to wall thickness 5⁄16 in. (7.94	28	30	30	30	28	28	28	28

mm) and over and for all small sizes tested in full section; min % in 2 in. (50 mm)								
Equation for calculating min elongation for strip specimens thinner than 5⁄16 in. (7.94 mm); min % in 2 in. (50 mm) t p actual thickness in inches	48t+13	48t+15	48t+15	48t+15	48t+13	48t+13	48t+13	48t+13
Reduction of area, min, %	38	30	35	40	40	38	45	45

TABLE 3 Charpy V-Notch Energy Requirements for standard Size [10 by 10 mm] Specimens

Grade	Minimum Impact Energy Required for Average of Each Set of Three Specimens, ft·lbf[j]	Minimum Impact Enerагy Permitted for One Specimen only of a Set, ft-lbf[J]
LF1 and LF9	13 [18]	10 [14]
LF2, Class 1	15 [20]	12 [16]
LF3 Class 1	15 [20]	12 [16]
LF5 Class 1 and 2	15 [20]	12 [16]
LF 787 Classes 2 and 3	15 [20]	12 [16]
LF6, Class 1	15 [20]	12 [16]
LF2, Class 2	20 [27]	15 [20]
LF3, Class 2	20 [27]	15 [20]
LF6, Classes 2 and 3	20 [27]	15 [20]

TABLE 4 Standard Impact Test Temperature for Standard Size [10 by 10 mm] Specimens

Grade	Test Temperature, °F
LF1	-20[-29]
LF2 Class	-50[-46]
LF2 Class	-0[-18]
LF3 Classes 1 and 2	-15[-101]
LF5 Classes 1 and 2	-75[-59]
LF6 Classes1 and 2	-60[-51]
LF6 Class 3	-0[-18]
LF9	-10[-73]
LF787 Class 2	-75[-59]
LF787 Class 3	-100[-73]

TABLE 5 Minimum Equivalent Absorbed Energy ft·lbf (J) For Various Specimen Sizes[A]

Standard Size [10 by 10 mm]	¾ size [10 by 7.5 mm]	2/3 size [10 by 6.6 mm]	½ size [10 by 5 mm]	1/3 size [10 by 3.3 mm]	¼ size [10 by 2.5 mm]
15 [20]	12 [16]	10 [14]	8 [11]	5 [7]	4 [6]
13 [18]	10 [14]	9 [12]	7 [10]	5 [7]	4 [6]
12 [16]	10 [14]	9[12]	7 [10]	4 [6]	3 [5]
10 [14]	8 [11]	7 [10]	5 [7]	3 [5]	3 [5]

TABLE 6 Charpy Impact Test Temperature Reduction Below Table 4 Test Temperature when the Sub size Charpy Impact Width along Notch is less than 80% of the forging Thickness

Size of Bar	Thickness of the Material Represented (see 7.2.4.3), or Charpy, Impact Specimen Width Along the Notch[A], in. [mm]	Temperature Reduction °F [°C]
Standard	0.394 [10]	0 [0]
Standard	0.354 [9]	0 [0]
Standard	0.315 [8]	0 [0]
¾-size	0.295 [7.5]	5 [3]
¾-size	0.276 [7]	8 [5]
2/3-size	0.262 [6.67]	10 [6]
2/3-size	0.236 [6]	15 [8]
½-size	0.197 [5]	20 [11]
½-size	0.158 [4]	30 [17]
1/3-size	0.131 [3.33]	35 [20]
1/3-size	0.118 [3]	40 [22]
¼-size	0.099 [2.5]	50 [28]

8. Hydrostatic Test
9. Workmanship, Finish, and Appearance
10. Retests
11. Rework and Retreatment
12. Inspection
13. Rejection and Rehearing
14. Certification :-

14.1 Test reports are required and they shall include certification that all requirements of this specification have been met, and shall be traceable to the forging represented. The specification designation included on test reports shall include year of issue and revision letter, if any. The manufacturer shall provide the following where application:

14.1.1 Type heat treatment, Section 5,

14.1.2 Chemical analysis results, Section 6 (Table 1),

14.1.3 Product analysis results, 6.2 (Tables 1),

14.1.4 Tensile property results, Section 7 (Table 2) report the yield strength and ultimate strength, in ksi [MPa], elongation and reduction in area, in percent,

14.1.5 Impact test results, 7.2 (Tables 3, 4, 5, and 6),

14.1.6 Hardness results, 7.3.1,

14.1.7 Any supplementary testing required by the purchase order, and

14.1.8 If repaired by welding, letter W is to follow the ASTM designation.

15. Product Marking
16. Keywords :-

16.1 carbon equivalent; pipe fittings, steel; piping applications; pressure containing parts; steel flanges; steel forgings, alloy; steel forgings, carbon; steel valves; temperature service applications, low

Supplementary Requirements :-

S1. Other Impact Test Temperatures
S2. Stress-Relieved Test Specimens
S3. Lateral Expansion
S4. Vacuum Carbon-Deoxidized Steels
S5. Special Impact Test Requirements for Flanges (Note S5.1)
S6. Carbon Equivalent