# ASTM A350 / ASME SA350

## SPECIFICATION FOR CARBON AND LOW-ALLOY STEEL FORGINGS, REQUIRING NOTCH TOUGHNESS TESTING FOR PIPING COMPONENTS

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.

Although this specification covers some piping components machined from rolled bar and seamless tubular materials, it does not cover raw material produced in these product forms.

No limitation on size is intended beyond the ability of the manufacturer to obtain the specified requirements.

**A. General Requirements :-**

1. Product furnished to this specification shall conform to the requirements of Specification A 961.
2. In case of conflict between the requirements of this specification and Specification A 961, this specification shall prevail.

**B. Heat Treatment :-**

1. 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:
    i. Normalize — Heat to a temperature that produces an austenitic structure, holding sufficient time to attain uniform temperature throughout. Cool uniformly in still air.
    ii. Normalize 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.
    iii. 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 partially 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 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.
2. Grade LF787 forgings shall be furnished in either the normalized-and-precipitation heat treated condition or in the quenched-and-precipitation heat treated condition. The heat treatment procedures shall be as follows:
    i. 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 h, 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 h, and cool at any convenient rate.

ii. 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 h 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 h, and cool at any convenient rate.

**C. Chemical Composition :-**

The steel shall conform to the requirements as to chemical composition prescribed in Table 1.

**Table 1**

| Element | Grade LF1 | Grade LF2 | Grade LF3 | Grade LF5 | Grade LF6 | Grade LF9 | Grade LF787 |
|---|---|---|---|---|---|---|---|
| Carbon, max | 0.3 | 0.3 | 0.2 | 0.3 | 0.22 | 0.2 | 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 | 0.04 | 0.04 | 0.04 | 0.04 | 0.025 | 0.04 | 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[C] | 0.40 max[C] | 0.40 max[B] | 0.75–1.25 | 1.00–1.30 |
| Columbium | 0.02 max | 0.02 max | 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 | ... | ... |

[A] *When vacuum carbon-deoxidation is required, the silicon content shall be 0.12% maximum.*

[B] *The sum of copper, nickel, chromium, vanadium, and molybdenum shall not exceed 1.00% on heat analysis.*

[C] *The sum of chromium and molybdenum shall not exceed 0.32% on heat analysis.*

**D. Mechanical Properties :-**

1. Tension Tests:
   i. The material shall conform to requirements for tensile properties in Table 2.
   ii. Testing shall be performed in accordance with Test Methods and Definitions A 370.

**Table 2: TENSILE PROPERTIES AT ROOM TEMPERATURE[A]**

| | Grades | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | LF1 and LF5 Class 1 | LF2 Classes 1 and 2 | LF3 Classes 1 and 2 LF5 Class 2 | LF6 | | LF787 | | |
| | | | | Class 1 | Classes 2 and 3 | LF9 | 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]** | 30 [205] | 36 [250] | 37.5 [260] | 52 [360] | 60 [415] | 46 [315] | 55 [380] | 65 [450] |
| **Elongation:** | | | | | | | | |
| **Standard round specimen, or small proportional specimen, min % in 4D gage length** | 25 | 22 | 22 | 22 | 20 | 25 | 20 | 20 |
| **Strip specimen for wall thickness 5⁄16 in. (7.94 mm) and over and for all small sizes tested in full section; min % in 2 in. (50 mm)** | 28 | 30 | 30 | 30 | 28 | 28 | 28 | 28 |
| **Equation for calculating min elongation for strip specimens thinner than 5⁄16 in. (7.94 mm); min % in 2 in. (50 mm) t = actual thickness in inches** | 48t + 13 | 48t + 13 | 48t + 13 | 48t + 13 | 48t + 13 | 48t + 13 | 48t + 13 | 48t + 13 |
| **Reduction of area, min, %** | 38 | 30 | 35 | 40 | 40 | 38 | 45 | 45 |

[A] *See point D.3 for hardness tests.*

[B] *Determined by either the 0.2% offset method or the 0.5% extension under load method.*

[C] *For round specimens only.*

2. Impact Test:
    i. 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 point D.2.iii & D.2.iv. When subsize specimens are used, the impact energy values obtained shall conform to Table 5 at energy values proportional to standard size.
    ii. 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.
    iii. 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.
    iv. 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 the temperature reduction corresponding to the thickness of the material represented, and the temperature reduction corresponding to the specimen width actually tested.
3. Hardness Test:
    i. The hardness measurements shall be made in accordance with Test Methods and Definitions A 370.
    ii. The hardness of the forgings does not exceed 197 HB after heat treatment for mechanical properties.

**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 Energy 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] |
| LF787, 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 [°C] |
|---|---|
| LF1 | −20 [−29] |
| LF2, Class 1 | −50 [−46] |
| LF2, Class 2 | 0 [−18] |
| LF3, Classes 1 and 2 | −150 [−101] |
| LF5, Classes 1 and 2 | −75 [−59] |
| LF6, Classes 1 and 2 | −60 [−51] |
| LF6, Class 3 | 0 [−18] |
| LF9 | −100 [−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] | 3/4 Size [10 by 7.5 mm] | 2/3 Size [10 by 6.6 mm] | 1/2 Size [10 by 5 mm] | 1/3 Size [10 by 3.3 mm] | 1/4 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] |

[A] *Straight-line interpolation for intermediate values is permitted.*

**Table 6: CHARPY IMPACT TEST TEMPERATURE REDUCTION BELOW TABLE 5 TEST TEMPERATURE WHEN THE SUBSIZE CHARPY IMPACT WIDTH ALONG NOTCH IS LESS THAN 80% OF THE FORGING THICKNESS**

| Size of Bar | Thickness of the Material Represented (see D.2.iv), 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] |
| 3⁄4-size | 0.295 [7.5] | 5 [3] |
| 3⁄4-size | 0.276 [7] | 8 [5] |
| 2⁄3-size | 0.262 [6.67] | 10 [6] |
| 2⁄3-size | 0.236 [6] | 15 [8] |
| 1⁄2-size | 0.197 [5] | 20 [11] |
| 1⁄2-size | 0.158 [4] | 30 [17] |
| 1⁄3-size | 0.131 [3.33] | 35 [20] |
| 1⁄3-size | 0.118 [3] | 40 [22] |
| 1⁄4-size | 0.099 [2.5] | 50 [28] |

[A] *Straight-line interpolation for intermediate values is permitted.*

**E. Hydrostatic Test :-**

1. Forgings manufactured under this specification shall be capable of passing a hydrostatic test compatible with the rating of the finished item.

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