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Standard Specification for Welded Austenitic Stainless Steel Feedwater Heater Tubes¹

This standard is issued under the fixed designation A 688/A 688M; 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 specification² covers welded austenitic stainless steel feedwater heater tubes including those bent, if specified, into the form of U-tubes for application in tubular feed-water heaters.

1.2 The tubing sizes covered shall be $\frac{5}{8}$ to 1 in. [15.9 to 25.4 mm] inclusive outside diameter, and average or minimum wall thicknesses of 0.028 in. [0.7 mm] and heavier.

1.3 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 shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 ASTM Standards:

A 262 Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels³ ~~A 1016/A 1016M Specification for General Requirements for Ferritic Alloy Steel, Austenitic Alloy Steel, and Stainless Steel Tubes~~

A 480/A 480M Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip³

A 941 ~~Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys⁴~~ Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys⁴

~~A 1016/A 1016M Specification for General Requirements for Ferritic Alloy Steel, Austenitic Alloy Steel, and Stainless Steel Tubes⁴~~

E 527 Practice for Numbering Metals and Alloys (UNS)⁴

2.2 Other Standard:

SAE J1086 Practice for Numbering Metals and Alloys (UNS)⁵

3. Terminology

3.1 *Definitions Of Terms*—For definitions of terms used in this specification, refer to Terminology A 941.

4. Ordering Information

~~4.1 Orders for material to this specification should include the following as required to adequately describe the desired material:~~

Ordering Information

4.1 It is the responsibility of the purchaser to specify all requirements that are necessary for material under this specification. Such requirements may include, but are not limited to, the following:

4.1.1 Quantity (length or number of pieces),

4.1.2 Material description,

4.1.3 Dimensions—Outside diameter, wall thickness (minimum or average wall), and length,

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 A01.10 on Stainless and Alloy Steel Tubular Products.

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² For ASME Boiler and Pressure Vessel Code applications see related Specification SA-688 in Section II of that Code.

³ *Annual Book of ASTM Standards*, Vol 01.03.

⁴ *Annual Book of ASTM Standards*, Vol 01.01.

⁵ Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096.

*A Summary of Changes section appears at the end of this standard.

- 4.1.4 Grade (chemical composition) (Table 1),
- 4.1.5 U-bend requirements, if order specifies bending, U-bend schedules or drawings shall accompany the order,
- 4.1.6 Optional requirements—Purchaser shall specify if annealing of the U-bends is required or whether tubes are to be hydrotested or air tested (see 11.6)
- 4.1.7 Supplementary requirements—Purchaser shall specify on the purchase order if material is to be eddy current tested in accordance with Supplementary Requirements S1 or S2, and if special test reports are required under Supplementary Requirement S3, and,
- 4.1.8 Any special requirements.

5. General Requirements

5.1 Material furnished to this specification shall conform to the applicable requirements of the latest published edition of Specification A 1016/A 1016M unless otherwise provided herein.

6. Materials and Manufacture

- 6.1 The tube shall be made from flat-rolled steel by an automatic welding process with no addition of filler metal.
- 6.2 Subsequent to welding and prior to final heat treatment, the tubes shall be cold worked either in both the weld and base metal, or in the weld metal only. The method of cold work may be specified by the purchaser. When cold drawn, the purchaser may specify the minimum amount of reduction in cross-sectional area or wall thickness, or both.
- 6.3 Many surface contaminants may have detrimental effects on high temperature properties or corrosion resistance of tubing. Contamination by copper, lead, mercury, zinc, chlorides, or sulfur may be detrimental to stainless steels. The manufacturer shall employ techniques that minimize surface contamination by these elements.

7. Cleaning Before Annealing

7.1 All lubricants or coatings used in the manufacture of straight-length tube or in the bending shall be removed from all surfaces prior to any annealing treatments. U-bends on which a lubricant had been applied to the inside surface during bending shall have the cleanness of their inside surface confirmed by blowing close fitting acetone-soaked felt plugs through 10 % of the tubes of each bend radius. Dry, oil-free, air or inert gas shall be used to blow the plugs through the tubes. If the plugs blown through any tube shows more than a light gray discoloration, all tubes that have had a lubricant applied to the inside surface during bending shall be recleaned. After recleaning 10 % of the tubes of each bend radius whose inside surface had been subjected to bending lubricants shall be retested.

8. Heat Treatment

8.1 All finished straight tubing or straight tubing ready for U-bending shall be furnished in the solution-annealed condition. The annealing procedure, except for N08367 and N08926, shall consist of heating the material to a minimum temperature of 1900°F [1040°C] followed by a rapid cooling to below 700°F [370°C]. The cooling rate shall be sufficiently rapid to prevent harmful carbide precipitation as determined in Section 13. UNS N08367 shall be solution annealed from 2025°F [1107°C] minimum followed by rapid quenching.

8.2 N08926 shall be heat-treated to a minimum temperature of 2010°F [1100°C] followed by quenching in water or rapidly cooling by other means.

TABLE 1 Chemical Requirements

Element	Grade.....	TP 304	TP 304L	TP 304LN	TP 316	TP 316L	TP 316LN	TP XM-29	TP 304N	TP 316N	...	...	...	...
	UNS Designation ^A	S30400	S30403	S30453	S31600	S31603	S31653	S24000	S30451	S31651	N08367	N08926	S31254	S32654
Composition, %														
Carbon, max		0.08	0.035	0.035	0.08	0.035	0.035	0.060	0.08	0.08	0.030	0.020	0.020	0.020
Manganese, max ^B		2.00	2.00	2.00	2.00	2.00	2.00	11.50–14.50	2.00	2.00	2.00	2.00	1.00	2.0–4.0
Phosphorus, max		0.040	0.040	0.040	0.040	0.040	0.040	0.060	0.040	0.040	0.040	0.03	0.030	0.030
Sulfur, max		0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.01	0.010	0.005
Silicon, max		0.75	0.75	0.75	0.75	0.75	0.75	1.00	0.75	0.75	1.00	0.5	0.80	0.50
Nickel		8.00–11.00	8.00–13.00	8.00–13.00	10.00–14.00	10.00–15.00	10.00–15.00	2.25–3.75	8.00–11.0	10.00–14.00	23.50–25.50	24.00–26.00	17.5–18.5	21.0–23.0
Chromium		18.00–20.00	18.00–20.00	18.00–20.00	16.00–18.00	16.00–18.00	16.00–18.00	17.00–19.00	18.0–20.0	16.0–18.0	20.00–22.00	19.00–21.00	19.5–20.5	24.0–25.0
Molybdenum		2.00–3.00	2.00–3.00	2.00–3.00	...	...	2.00–3.00	6.00–7.00	6.0–7.0	6.0–6.5	7.0–8.0
Nitrogen ^C		0.10–0.16	...	...	0.10–0.16	0.20–0.40	0.10–0.16	0.10–0.16	0.18–0.25	0.15–0.25	0.18–0.22	0.45–0.55
Copper		0.75 max	0.5–1.5	0.50–1.00	0.30–0.60

^A New designation established in accordance with Practice E 527 and SAE J1086.
^B Maximum, unless otherwise noted.
^C The method of analysis for nitrogen shall be a matter of agreement between the purchaser and manufacturer.

8.3 If heat treatment of U-bends is specified, it shall satisfy the annealing procedure described in 8.1 and 8.2, and shall be done as follows:

8.3.1 The heat treatment shall be applied to the U-bend area plus approximately 6 in. [150 mm] of each leg beyond the tangent point of the U-bend.

8.3.2 If the heat treatment specified in 8.3 is accomplished by resistance-heating methods wherein electrodes are clamped to the tubes, the clamped areas shall be visually examined for arc burns. Burn indications shall be cause for rejection unless they can be removed by local polishing without encroaching upon minimum wall thickness.

8.3.3 Temperature control shall be accomplished through the use of optical or emission pyrometers, or both. No temperature-indicating crayons, lacquers, or pellets shall be used.

8.3.4 The inside of the tube shall be purged with a protective or an inert gas atmosphere during heating and cooling to below 700°F [370°C] to prevent scaling of the inside surface. The atmosphere should be noncarburizing.

9. Surface Condition

9.1 The straight tubes, after final annealing, shall be pickled using a solution of nitric and hydrofluoric acids followed by flushing and rinsing in water. If bright annealing is performed, this requirement does not apply.

9.2 A light oxide scale on the outside surface of U-bend area shall be permitted for tubes which have been electric-resistance heat treated after bending.

10. Chemical Composition

10.1 Product Analysis:

10.1.1 When requested in the purchase order, a product analysis shall be made by the supplier from one tube or coil of steel per heat. The chemical composition shall conform to the requirements shown in Table 1.

10.1.2 A product analysis tolerance of Specification A 480/A 480M/A480M shall apply. The product analysis tolerance is not applicable to the carbon content for material with a specified maximum carbon of 0.04 % or less.

10.1.3 If the original test for product analysis fails, retests of two additional lengths of flat-rolled stock or tubes shall be made. Both retests, for the elements in question, shall meet the requirements of this specification; otherwise all remaining material in the heat or lot (Note 1) shall be rejected, or at the option of the producer, each length of flat-rolled stock or tube may be individually tested for acceptance. Lengths of flat-rolled stock or tubes that do not meet the requirements of this specification shall be rejected.

NOTE 1—For flattening and flange requirements, the term “lot” applies to 125 tube groupings, prior to cutting to length, of the same nominal size and wall thickness, produced from the same heat of steel and annealed in a continuous furnace.

11. Mechanical Requirements

11.1 Tensile Properties:

11.1.1 The material shall conform to the tensile properties shown in Table 2.

11.1.2 One tension test shall be made on a specimen for lots of not more than 50 tubes. Tension tests shall be made on specimens from two tubes for lots of more than 50 tubes (Note 2).

11.2 Hardness:

11.2.1 Grade TP XM-29 tubes shall have a hardness number not exceeding 100 HRB or its equivalent. Tubes of all other grades shall have a hardness number not exceeding 90 HRB or its equivalent. This hardness requirement is not to apply to the bend area of U-bend tubes which are not heat treated after bending.

11.2.2 Brinell or Rockwell hardness tests shall be made on specimens from two tubes from each lot.

NOTE 2—For tension, hardness, and corrosion test requirements, the term “lot” applies to all tubes prior to cutting to length, of the same nominal diameter and wall thickness, produced from the same heat of steel and annealed in a continuous furnace at the same temperature, time at heat, and furnace speed.

11.3 Reverse Bend Test:

11.3.1 One reverse bend test shall be made on a specimen from each 1500 ft [460 m] of finished tubing.

11.3.2 A section 4 in. [100 mm] minimum in length shall be split longitudinally 90° on each side of the weld. The sample shall then be opened and bent around a mandrel with a maximum thickness of four times the wall thickness, with the mandrel parallel

TABLE 2 Tensile Requirements

Grade	304, 316	304L, 316L	XM-29	304N, 316N	304LN, 316LN	...	...	...	...	...
UNS Designation	S30400, S31600	S30403, S31603	S24000	S30451, S31651	S30453, S31653	N08367	N08367	N08926	S31254	S31254	S32654
Tensile strength, min ksi [MPa]	75 [515]	70 [485]	100 [690]	80 [550]	75 [515]	$t \leq 0.187$	$t > 0.187$	94 [650]	100 [690]	95 [655]	120 [825]
Yield strength, min ksi [MPa]	30 [205]	25 [175]	55 [380]	35 [240]	30 [205]	45 [310]	45 [310]	43 [295]	45 [310]	45 [310]	65 [450]
Elongation in 2 in. or 50 mm, min, %	35	35	35	35	35	30	30	35	35	35	40

to the weld and against the original outside surface of the tube. The weld shall be at the point of maximum bend. There shall be no evidence of cracks, or of overlaps resulting from the reduction in thickness of the weld area by cold working. When the geometry or size of the tubing make it difficult to test the sample as a single piece, the sample may be sectioned into smaller pieces provided a minimum of 4 in. of weld is subjected to reverse bending.

NOTE 3—The reverse bend test is not applicable when specified wall is 10 % or more of the specified outside diameter, or the wall thickness is 0.134 in. [3.4 mm] or greater, or the outside diameter size is less than 0.375 in. [9.5 mm]. Under these conditions, the reverse flattening test of Specification A 1016/A 1016M shall apply.

11.4 *Flattening Test*—Flattening tests shall be made on specimens from each end of one finished tube, not the one used for the flange test, from each lot (Note 1).

11.5 *Flange Test*—Flange tests shall be made on specimens from each end of one finished tube, not the one used for the flattening test, from each lot (Note 1).

11.6 *Pressure Test:*

11.6.1 Each straight tube or each U-tube after completion of the bending and post-bending heat treatment, shall be pressure tested in accordance with one of the following paragraphs as specified by the purchaser.

11.6.1.1 *Hydrostatic Test*—Each tube shall be given an internal hydrostatic test in accordance with Specification A 1016/A 1016M, except that the test pressure and hold time, when other than that stated in Specification A 1016/A 1016M, shall be agreed upon between purchaser and manufacturer.

11.6.1.2 *Air Underwater Test*—Each tube shall be air underwater tested in accordance with Specification A 1016/A 1016M.

12. Nondestructive Test (Electric Test)

12.1 Each straight tube shall be tested after the finish heat treatment by passing it through a nondestructive tester capable of detecting defects on the entire cross section of the tube, in accordance with Specification A 1016/A 1016M.

13. Corrosion Resisting Properties

13.1 One full section sample 1 in. [25.4 mm] long from the center of a sample tube of the smallest radius bend which is heat treated shall be tested in the heat treated condition in accordance with Practices A 262.

13.2 One full-section sample 1 in. [25.4 mm] long from each lot (Note 2) of straight tubes shall be tested in the finished condition in accordance with Practices A 262.

13.3 The appearance of any fissures or cracks in the test specimen when evaluated in accordance with Practices A 262 indicating the presence of intergranular attack, shall be cause for rejection of that lot.

14. Permissible Variations in Dimensions (Fig. 1)

14.1 Permissible variations from the specified outside diameter shall be in accordance with Specification A 1016/A 1016M. Those tolerances do not apply to the bent portion of the U-tubes. At the bent portion of a U-tube for $R = 2 \times D$ or greater, neither the major nor minor diameter of the tube shall deviate from the nominal diameter prior to bending by more than 10 %. If less than $2 \times D$ is specified, tolerances could be greater.

14.2 *Permissible Variations from the Specified Wall Thickness:*

14.2.1 Permissible variations from the specified minimum wall thickness shall not exceed +20 % – 0.

14.2.2 Permissible variations from the specified average wall thickness are ± 10 % of the nominal wall thickness.

14.2.3 The wall thickness of the tube in the U-bent section shall not be less than value determined by the equation:

$$t_f = \frac{4RT}{4R + D}$$

where:

t_f = wall thickness after bending, in. [mm],

T = minimum wall thickness of 14.2.1 or 14.2.2, in. [mm],

R = centerline bend radius, in. [mm], and

D = nominal outside tube diameter, in. [mm].

14.3 *Permissible Variations from the Specified Length:*

14.3.1 *Straight Lengths*—The maximum permissible variations for lengths 24 ft [7.3 m] and shorter shall be $+\frac{1}{8}$ in. [3 mm], –0; for lengths longer than 24 ft [7.3 m], an additional over tolerance of $+\frac{1}{8}$ in. [3 mm] for each 10 ft [3 m], or fraction thereof, shall be permitted up to a maximum of $+\frac{1}{2}$ in. [13 mm].

14.3.2 *U-Bends*—In the case of U-tubes, the length of the tube legs as measured from the point of tangency of the bend and the tube leg to the end of the tube leg, shall not be less than specified, but may exceed the specified values by the amount given in Table 3. The difference in lengths of the tube legs shall not be greater than $\frac{1}{8}$ in. unless otherwise specified.

14.4 The end of any tube may depart from square by not more than the amount given in Table 4.

14.5 The leg spacing measured between the points of tangency of the bend to the legs shall not vary from the value ($2R$ – specified tube outside diameter) by more than $\frac{1}{16}$ in. [1.5 mm] where R is the center-line bend radius.

14.6 The bent portion of the U-tube shall be substantially uniform in curvature, and not to exceed $\pm \frac{1}{16}$ in. [1.5 mm] of the nominal center-line radius.