

Designation: A1098/A1098M - 16

Standard Specification for Welded Austenitic Alloy Steel Boiler, Superheater, Condenser, and Heat Exchanger Tubes with Textured Surface(s)¹

This standard is issued under the fixed designation A1098/A1098M; 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 covers average or minimum-wall thickness welded tubes made from various grades of austenitic alloy steel materials in which the (1) external tube surface, (2) internal tube surface, or (3) both internal and external tube surfaces have a textured configuration for improved heat transfer or fluid flow or both. Texture surface(s) are produced by cold forming a specified configuration on the surface(s) of base strip material, prior to welding. The produced welded textured tubes may be used in boilers, superheaters, condensers, evaporators, heat exchangers, and other similar heat transfer apparatus in diameters up to and including 1.5 in. [38 mm] for various wall thicknesses up to and including 0.079 in. [2 mm].

1.2 The tubing sizes and thicknesses usually furnished to this specification are $\frac{3}{8}$ in. [10 mm] inside diameter (ID) to 1.5 in. [38 mm] outside diameter and 0.020 to 0.079 in. [0.5 to 2 mm], inclusive, in wall thickness. Tubing having other dimensions may be furnished provided such tubes comply with all other requirements of this specification.

1.3 Optional supplementary requirements are provided and, when one or more of these are desired, each shall be so stated in the order.

1.4 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 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. The inch-pound units shall apply unless the "M" designation of this specification is specified in the order.

1.5 The following safety hazards statement pertains only to the test method and the Supplementary Requirements of this specification. A specific warning statement is given in the Supplementary Requirements. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

- 2.1 ASTM Standards:²
- A249/A249M Specification for Welded Austenitic Steel Boiler, Superheater, Heat-Exchanger, and Condenser Tubes
- A262 Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
- A370 Test Methods and Definitions for Mechanical Testing of Steel Products
- A480/A480M Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip
- A941 Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys
- A1016/A1016M Specification for General Requirements for Ferritic Alloy Steel, Austenitic Alloy Steel, and Stainless Steel Tubes
- E527 Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)
- 2.2 ASME Standard:³

Boiler and Pressure Vessel Code Section VIII Para UW-51

- 2.3 SAE Standards:⁴
- SAE J1086 Practice for Numbering Metals and Alloys (UNS)

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 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.

³ Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, http:// www.asme.org.

⁴ Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096, http://www.sae.org.

3. Terminology

3.1 For definitions of general terms used in this specification, refer to Terminology A941.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *plain cylindrical ring gauges, n*—a cylindrical metal ring whose inside diameter is furnished to gauge tolerance.

3.2.2 *plain ending*, *n*—portion of the tube that has no surface texture.

3.2.3 *primary character, n*—largest texture impressed on material.

3.2.4 *primary pattern*, *n*—combination of primary characters.

3.2.5 *secondary character, n*—finecut texture impressed on material.

3.2.6 *secondary pattern, n*—combination of secondary characters.

3.2.7 *textured surface*, *n*—impressing a series of characters or textures into the material with the intent of improving heat transfer and fluid flow characteristics in the final welded tube.

3.3 Symbols:

3.3.1 D-outside tube diameter-nominal

3.3.2 D_i —inside tube diameter

3.3.3 *ID1*—top of primary character to bottom of secondary character. See Fig. 1 cross section A-A for view of primary character and secondary character pattern.

3.3.4 *ID2*—top of primary character to top of secondary character

3.3.5 *ID3*—top of secondary character to top of secondary character

3.3.6 *ID4*—top of primary character to bottom of primary character at intersection of the base (each on opposite sides of the tube)

3.3.7 *ID5*—top of primary character to top of primary character (each on opposite sides of the tube)

3.3.8 *ID6*—top of secondary character to bottom of secondary character 3.3.9 P_a —angle of the primary character unit (if any)

3.3.10 P_a —angle of the secondary character unit (if any)

3.3.11 P_c —primary character center spacing

- 3.3.12 P_d —primary character diameter
- 3.3.13 P_{hi}—primary character height (inside)

3.3.14 P_{ho} —primary character height (outside)

3.3.15 S_c —secondary character center spacing

3.3.16 S_d —secondary character diameter

3.3.17 S_{hi} —secondary character height (inside)

3.3.18 S_{ho} —secondary character height (outside)

3.3.19 W—wall thickness (no pattern)

3.3.20 W_1 —wall thickness peak inside to valley outside (secondary character)

3.3.21 W_2 —wall thickness valley inside to peak outside (secondary character)

3.3.22 W_3 —wall thickness base of primary character

3.3.23 W_4 —wall thickness in wall of the primary character

4. Ordering Information

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

4.1.1 Quantity (feet, metres, or number of lengths);

4.1.2 Name of material welded tubes (WLD);

4.1.3 Grade (refer to Table 1);

4.1.4 Size (outside diameter and wall thickness);

4.1.5 Length (specific or random);

4.1.6 Hydrostatic testing or non-destructive electric testing (see Section 16);

4.1.7 Test report required (see Certification Section of Specification A1016/A1016M);

4.1.8 Specification designation;

4.1.9 Special requirements and any supplementary requirements selected.



(a) longitudinal view

Cross-Section A-A



(b) cross-sectional view

FIG. 1 Views of a Representative Textured Tube Showing Variables that Describe the Possible Primary and Secondary Texturizations that May be Applied to the Inside Surface of a Tube, Outside Surface of the Tube, or Both the Inside and Outside Surfaces of the Tube

A1098/A1098M – 16

Secondary Pattern Detail

Primary Pattern Detail



(a) Sample secondary (background) surface

(a) Sample primary surface

NOTE — One, both, or more patterns may be used and combined. Each pattern made up of a variety of possible shapes.

FIG. 2 Details Regarding the Sample Representative Geometry of the Patterns Used to Texture the Flat Strip Material before It is Used to Create a Welded Tube

UNS Designation ^B	Туре ^С	Carbon ^D	Manganese	Phosphorus	Sulfur	Silicon	Chromium	Nickel	Molybdenum	Nitrogen	Copper	Other Elements ^{E,F}
j			/	Austenitic (Chr	omium-Nic	kel) (Chromiu	m-Nickel-Mol	lybdenum)				
N08904	904L	0.020	2.00	0.045	0.035	1.00	19.0-23.0	23.0-28.0	4.00-5.00	0.10	1.00-2.00	
S30103	301L ^G	0.03	2.00	0.045	0.030	1.00	16.0–18.0	6.0-8.0		0.20		
S30153	301LN ^G	0.03	2.00	0.045	0.030	1.00	16.0–18.0	6.0-8.0		0.07-0.20		
S30200	302	0.15	2.00	0.045	0.030	0.75	17.0–19.0	8.0-10.0		0.10		
S30400	304	0.07	2.00	0.045	0.030	0.75	17.5–19.5	8.0-10.5		0.10		
S30403	304L	0.030	2.00	0.045	0.030	0.75	17.5–19.5	8.0-12.0		0.10		
S30415		0.04-0.06	0.80	0.045	0.030	1.00-2.00	18.0–19.0	9.0-10.0		0.12-0.18		Ce
												0.03-0.08
S30441		0.08	2.0	0.045	0.030	1.0-2.0	17.5–19.5	8.010.5		0.10	1.5-2.5	Nb
												0.1-0.5
												W 0.2–0.8
S30451	304N	0.08	2.00	0.045	0.030	0.75	18.0–20.0	8.0–10.5		0.10-0.16		
S30453	304LN	0.030	2.00	0.045	0.030	0.75	18.0–20.0	8.0-12.0		0.10-0.16		
S31600	316	0.08	2.00	0.045	0.030	0.75	16.0–18.0	10.0–14.0	2.00-3.00	0.10		
S31603	316L	0.030	2.00	0.045	0.030	0.75	16.0–18.0	10.0–14.0	2.00-3.00	0.10		
S31635	316Ti ^{<i>G</i>}	0.08	2.00	0.045	0.030	0.75	16.0–18.0	10.0–14.0	2.00-3.00	0.10		Ti 5 × C +
												N) min,
	-											0.70 max
S31640	316Cb ^G	0.08	2.00	0.045	0.030	0.75	16.0–18.0	10.0–14.0	2.00-3.00	0.10		Nb 10 \times
												min, 1.10
												max
S31651	316N	0.08	2.00	0.045	0.030	0.75	16.0–18.0	10.0–14.0	2.00-3.00	0.10-0.16		
S31653	316LN	0.030	2.00	0.045	0.030	0.75	16.0–18.0	10.0–14.0	2.00-3.00	0.10-0.16		
S31700	317	0.08	2.00	0.045	0.030	0.75	18.0–20.0	11.0–15.0	3.0-4.0	0.10		
S31703	317L	0.030	2.00	0.045	0.030	0.75	18.0–20.0	11.0–15.0	3.0-4.0	0.10		
S31725	317LM	0.030	2.00	0.045	0.030	0.75	18.0–20.0	13.5–17.5	4.0-5.0	0.20		
S31726	317LM ^G N	0.030	2.00	0.045	0.030	0.75	17.0–20.0	13.5–17.5	4.0–5.0	0.10-0.20		
S31727		0.030	1.00	0.030	0.030	1.00	17.5–1930	15.5-16.5	3.8-4.5	0.15-0.21	2.80-4.00	
S31753	317LN ^G	0.030	2.00	0.045	0.030	0.75	18.0-20.0	11.0-15.0	3.0-4.0	0.10-0.22		

TABLE 1 Chemical Composition Requirements, %^A

^AMaximum unless range or minimum is indicated.

^BDesignation established in accordance with Practice E527 and SAE J1086.

^CUnless otherwise indicated, a grade designation originally assigned by the American Iron and Steel Institute (AISI).

^DCarbon analysis shall be reported to nearest 0.01 % except for the low-carbon types, which shall be reported to nearest 0.001 %.

EThe element columbium and its chemical symbol (Cb) are equivalent to the element niobium and its chemical symbol Nb.

When two minimums or two maximums are listed for a single type, as in the case of both a value from a formula and an absolute value; the higher minimum or lower maximum shall apply.

^GCommon name, not a trademark, widely used, not associated with any one producer.

4.1.9.1 Additional requirements may include the various inside or outside diameters (Fig. 1), texture wall thickness

values (see Fig. 3), and length of untextured sections if required; effective diameter and wall thickness of the modified





TUBE OUTSIDE

FIG. 3 Details Regarding the Wall Thickness of the Representative Sample Geometry of the Patterns Used to Texture the Flat Strip Material before It is Used to Create a Welded Tube

section; number of secondary textured character units per unit length; number of primary textured character units per unit length; and the total tube length.

5. General Requirements

5.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A1016/A1016M unless otherwise provided herein.

6. Manufacture

6.1 The strip used to form welded tubes shall be textured by cold working on one or both surfaces before being formed into a tube.

6.2 The tubes may have plain ends or have untextured sections within the tube length as specified in the purchase order.

6.3 The tubes shall be made from flat rolled steel using an automatic welding process with no addition of filler metal.

6.4 Subsequent to welding and before final heat treatment, the tubes may be worked only in the welded portion. Cold working and the method of cold working shall be at the option of the manufacturer unless specified otherwise in the purchase order.

7. Chemical Composition

7.1 The heat analysis shall conform to the chemical composition requirements given in Table 1.

8. Heat Treatment

8.1 Tubes shall be provided in the solution annealed condition as specified in Table 2.

9. Product Analysis

9.1 If specified in the purchase order an analysis of the strip supplied from the material producer will be provided to the

TABLE 2 Heat	Treatment	Requirements
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Designation/Type	Temperature ^A	Cooling/Testing				
		Requirements				
Austenitic (Chromium-Nickel) (Chromium-Nickel-Molybdenum)						
All Cr-Ni steels except	1900°F [1040°C]	В				
the following:						
N08904	2000°F [1095°C]	С				
S31727	1975 to 2155°F [1080 to 1180°C]	С				

^AMinimum unless otherwise indicated.

^BQuenched in water or rapidly cooled by other means at a rate sufficient to prevent reprecipitation of carbides as demonstrable by the capability of passing the test for resistance to intergranular corrosion specified in S7.

^CQuenched in water or rapidly cooled by other means.

purchaser of the tube; however, if specified as a requirement, an analysis of either one length of flat-rolled stock or one tube shall be made for each heat. The chemical composition thus determined shall conform to the requirements given in Section 7 and Table 1.

9.2 A product analysis tolerance of Table A1.1 in Specification A480/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.

9.3 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 the specification; otherwise, all remaining material in the heat or lot (refer to Section 18 and Table 3) shall be rejected or, at the option of the producer, each length of

TABLE 3 Number of Tubes in a Lot Heat Treated by the Continuous Process

Size of Tube	Size of Lot			
Less than or equal to 1.5 in. [38 mm] but over	Not more than 75 tubes			
1 in. [25 mm] in outside diameter or over				
1 in. [25 mm] in outside diameter and under or				
equal to 0.079 in. [2 mm] in wall thickness				
1 in. [25 mm] or less in outside diameter	Not more than 125 tubes			



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.

9.4 Any tests that are specified and required are performed on textured lengths of the tube in accordance with this specification need not be performed on both the textured and the plain sections of the tube.

10. Tensile Requirements

10.1 All portions of the tubes shall conform to the tensile requirements as stated in Table 4.

10.2 For calculating the mechanical properties, the crosssection to be used is calculated from the wall thickness with no pattern.

11. Hardness Requirements

11.1 The tubes shall have a Rockwell hardness number not exceeding those in Table 4. These values will be evaluated in both the textured and untextured sections (if both are present). The evaluation method will follow the method prescribed in Specification A1016/A1016M.

11.2 Hardness values for the textured section will be determined using micro-hardness values taken from the cross section.

12. Reverse-Bend Test Requirement

12.1 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 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 areas 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. [100 mm] of weld is subjected to reverse bending.

13. Dimensions, Mass, and Permissible Variations

13.1 *Diameter*—The outside diameter of the untextured or textured sections shall be measured by flat anvil micrometers or equivalent, such as laser micrometer, unless otherwise agreed upon between the producer and the customer.

13.2 *Wall Thickness*—The starting material strip wall thickness shall conform to the requirements for tube wall thickness prescribed in accordance with Specification A1016/A1016M. Wall thickness tolerances shall be ± 10 % of specified wall for all tubing sizes or other agreed tolerance variation values agreed between the producer and the customer. Strip material may be redistributed, but material may not be removed from the surface by any method.

13.2.1 The wall thickness (Fig. 3: W, W1-W4) of textured and untextured sections of the tube shall not exceed the thickness tolerances shown in Specification A1016/A1016M unless otherwise agreed to between the manufacturer and purchaser. No tube wall thickness at any point shall be less than the minimum thickness requirements for wall thickness, prescribed in Specification A1016/A1016M which is specified for the plain sections or in the textured sections unless customer and manufacturer agree after evaluating test data of similarly produced textured tubes.

LINS		Tensile Strength, min		Yield Strength, min ^B		Elongation ^C in	Hardness, max ^D	
Designation	Туре	MPa	ksi	MPa	ksi	50 mm or 2 in., min, %	Brinell, HBW	Rockwell B
N08904	904L ^E	490	71	220	31	35		90
S30103	301L ^E	550	80	220	32	45	217	95
S30153	301LN ^E	550	80	240	35	45	217	95
S30200	302	515	75	205	30	40	201	92
S30400	304	515	75	205	30	40	201	92
S30403	304L	485	70	170	25	40	201	92
S30415		600	87	290	42	40	217	95
S30441		515	75	205	30	40	201	92
S30451	304N	550	80	240	35	30	217	95
S30453	304LN	515	75	205	30	40	217	95
S31600	316	515	75	205	30	40	217	95
S31603	316L	485	70	170	25	40	217	95
S31635	316Ti ^E	515	75	205	30	40	217	95
S31640	316Cb ^E	515	75	205	30	30	217	95
S31651	316N	550	80	240	35	35	217	95
S31653	316LN	515	75	205	30	40	217	95
S31700	317	515	75	205	30	35	217	95
S31703	317L	515	75	205	30	40	217	95
S31725	317LM ^E	515	75	205	30	40	217	95
S31726	317LMN ^E	550	80	240	35	40	217	95
S31727		550	80	245	36	35	217	95
S31753	317LN	550	80	240	35	40	217	95

TABLE 4 Mechanical Test Requirements

^AUnless otherwise indicated, a grade designation originally assigned by the American Iron and Steel Institute (AISI).

^bYield strength shall be determined by the offset method at 0.2 % in accordance with Test Method and Definitions A370. Unless otherwise specified (see Specification A480/A480M, Paragraph 4.1.11 Ordering Information), an alternative method of determining yield strength may be based on total extension under load of 0.5 %. ^cElongation for thickness, less than 0.38 mm [0.015 in.] shall be 20 % minimum, min 25.4 mm [1 in.].

^DEither Brinell or Rockwell B Hardness is permissible.

^ECommon name, not a trademark, widely used, not associated with any one producer.



13.3 Alternative Methods:

13.3.1 Wall thickness shall be evaluated using any instrument (that is, pointing micrometer, optical, microscopic, and so forth) that is capable of satisfying the required accuracy. Testing frequency shall be one tube per lot for lots as described in Table 3. Alternative methods of measurement able to measure the OD and wall include electronic micrometers, a no-go snap gauge, ring gauge, non-contact profilometers or optical methods with the same tolerance and accuracy.

Note 1-Plan cylindrical ring gauges are used to check the outside diameter limit on manufactured parts.

13.4 *Length*—The length of the tubes shall not be less than that specified in the purchase order.

13.4.1 The length of plain ends, as measured from the tube end to the first textured character, shall not be less than that specified but may exceed the specified value by 0.5 in. [13 mm].

13.4.2 The length of textured sections and untextured portions shall be as specified; ± 0.25 in. [6 mm].

13.5 *Squareness of Cut*—The angle of the cut of the end of any tube may depart from square by not more than 0.016 in. [0.4 mm].

13.6 *Straightness*—The tube shall be reasonably straight and free of bends or kinks.

14. Workmanship, Finish, and Appearance

14.1 Finished tubes shall have smooth ends free of burrs and shall not deviate from straightness by more than 0.030 in. [0.8 mm] in 3 ft [900 mm] on length.

15. Mechanical Tests Required

15.1 *Tension Test*—One tension test shall be made on a specimen for size of lots described in Section 18 and Table 3.

15.2 *Flattening Test*—One flattening test shall be made on specimens from each end of one finished tube, not the one used for the flange test, from each lot (refer to Table 3).

15.3 *Flange Test*—One flange test shall be made on specimens from each end of one finished tube, not the one used for the flattening test, from each lot (refer to Table 3).

15.4 *Reverse-Bend Test*—One reverse-bend test shall be made on a specimen from each 1500 ft [450 m] of finished tubing.

15.5 *Hardness Test*—Brinell or Rockwell hardness tests shall be made on specimens from two tubes from each lot (refer to Table 3). If hardness values are taken from textured tube sections, cross-sectional micro-hardness values should be taken. The tubing specified shall conform to the hardness values prescribed here or values agreed between the producer and the customer.

16. Nondestructive Tests

16.1 Each tube shall be subjected to either the hydrostatic or the nondestructive electric test, as described in Specification A1016/A1016M. The purchaser may specify which test is to be used. The default choice will be eddy current, either in-line or off-line, producer choice. 16.2 The eddy current calibration standard shall have four holes drilled not larger than 0.031 in. [0.787 mm] in diameter radially through the texturized wall in each of four successive planes at 0, 90, 180, and 270 degrees. Use a suitable drill jig to guide the drill taking care to avoid distortion of the sample hole or the wall. Locate one hole in the weld. The other holes are to be at the high point of the outside diameter.

16.2.1 Only the drilled hole calibration standard shall be used.

16.2.2 The standard shall match the tube OD, wall, alloy, and specific texture.

16.2.3 The signal to noise ratios less than three shall be considered acceptable for this specification provided the calibration hole can reliably be detected above background noise.

16.3 *Hydrostatic Pressure Test*—When a hydrostatic pressure test is used, it shall be done in accordance with Specification A1016/A1016M using the wall thickness of sheet with no texture. This would be the "t" in Specification A1016/A1016M.

17. Forming Operations

17.1 If the tubes will be inserted in a boiler or heatexchanger, the tubes shall withstand typically expanding and bending without showing cracks or flaws and also shall withstand all forging, welding, and bending operations necessary for application without developing defects.

18. Sampling

18.1 For flattening and flange testing, the term lot applies to all tubes prior to cutting of the same nominal size and wall thickness which are produced from the same heat of steel. When final heat treatment is in a batch-type furnace, a lot shall include only those tubes of the same size and from the same heat that are heat treated in the same furnace charge. When the final heat treatment is in a continuous furnace, the number of tubes of the same size and from the quantity of the tubes as prescribed in Table 3.

18.2 For tensile, wall thickness measurement, and hardness test requirements, the term lot applies to all tubes prior to cutting, of the same size and design dimensions (refer to 4.1.4 and 4.1.9) that are produced from the same heat of steel. When final heat treatment is in a batch-type furnace, a lot shall include only those tubes of the same size and the same heat that is heat treated in the same furnace charge. When the final heat treatment is in a continuous furnace, a lot shall include all tubes of the same size, design dimensions and heat, heat treated in the same furnace at the same temperature, time at heat, and furnace speed (refer to Table 3).

19. Product Marking

19.1 The marking shall be as prescribed in Specification A1016/A1016M.

20. Keywords

20.1 alloy steel tube; austenitic stainless steel; boiler tubes; condenser tube; feedwater heater tubes; heat exchanger tube;



high-temperature applications; stainless steel tube; steel tube; superheater tube; temperature service applications—high; textured and untextured sections; textured character units; textured configuration; textured heat transfer tube; textured lengths; textured surface; textured surface strip material; textured tubes; textured wall thickness; welded steel tube

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order.

S1. Stress-Relieved Annealed Tubes

S1.1 For use in certain corrosives, particularly chlorides in which stress corrosion may occur, tubes in some grades may be specified in the stress-relieved annealed condition. Details of these supplemental requirements shall be agreed upon by the manufacturer and the purchaser.

S1.2 When stress-relieved tubes are specified, tubes shall be given a heat treatment at 1550 to 1650°F [845 to 900°C] after roll straightening. Cooling from this temperature range may be either in air or by slow cooling. No mechanical straightening is permitted after the stress-relief treatment.

S1.3 Straightness of the tubes shall be a matter of negotiation between the purchaser and manufacturer.

S2. Minimum Wall Tubes

S2.1 When specified by the purchaser, tubes shall be furnished on a minimum wall basis. Such tubes shall satisfy the minimum wall thickness requirements of Specification A1016/ A1016M rather than the specified wall requirements of this specification. In addition to the marking required by Section 19, the tubing shall be marked S2.

S3. Pneumatic Test

S3.1 The tubing shall be examined by a pneumatic test (either air under water or pneumatic leak test) in accordance with Specification A1016/A1016M.

Note S3.1—The pneumatic, air underwater or pressure differential tests when applied, may be performed before the tube is cut to final length but shall be performed after modification, bending, offline heat treatment, or other forming operations.

S3.2 Air Underwater Pressure Test:

S3.2.1 Each tube may be tested in accordance with Specification A1016/A1016M except using test pressure or specified by the purchaser. See Note S3.1.

S3.3 Pressure Differential Test:

S3.3.1 Each tube may be tested in accordance with Specification A1016/A1016M. The procedure and acceptance criteria shall be agreed upon between the manufacturer and purchaser. See Note S3.1.

S4. Hydrostatic Test

S4.1 In addition to the non-destructive electric test, the hydrostatic test may be specified. When examined with this test method, each tube shall be tested in accordance with Specification A1016/A1016M using the wall thickness of the plain strip material that was used to produce the modified surface.

S4.2 Method is to use wall thickness of sheet with no texture; this would be "t" in Specification A1016/A1016M. D would be the textured tubing, nominal diameter and reference equation 3 and 4 in Specification A1016/A1016M.

S5. Stabilizing Heat Treatment

S5.1 Subsequent to the solution anneal required in Section 8, certain grades follow the requirements that will be given a stabilization heat treatment at a temperature lower than that used for the initial solution annealing heat treatment. The temperature of stabilization heat treatment shall be at a temperature as agreed upon between the purchaser and manufacturer.

S5.2 The applicable grades from Table 1 are UNS S31635 and S31640.

S6. Unstraightened Tubes

S6.1 When the purchaser specifies tubes unstraightened after final heat treatment (such as coils), the straightness requirement of Section 14 shall not apply and the minimum yield strength specified in Specification A249/A249M shall be reduced by 35 MPa [5 ksi].

S6.2 On the certification, and wherever the grade designation for unstraightened tubing appears, it shall be identified with the suffix letter "U" (for example, 304-U and so forth).

S7. Intergranular Corrosion Test

S7.1 When specified, material shall pass intergranular corrosion tests conducted by the manufacturer in accordance with Practices A262, Practice E. (See Note S7.1.)

Note S7.1—Practice E requires testing on the sensitized condition for low carbon or stabilized grades, and on the as-shipped condition for other grades.

S7.2 A stabilization heat treatment in accordance with Supplementary Requirement S5 may be necessary and is permitted in order to meet this requirement for the grades containing titanium or columbium.

S8. Weld Decay Test

S8.1 This test is not applicable to alloys with a nickel content \geq 19.0 % or a molybdenum content \geq 4.00 % or both.

S8.2 When specified by the purchase order, one sample from each lot of tubing (refer to Table 3) shall be subjected to testing in a boiling mixture of 50 % reagent grade hydrochloric acid and 50 % water.

S8.3 Approximately 2 in. [50 mm] long samples shall be prepared from a production length of tubing. Shorter, 1 in. [25 mm] samples may be used for small diameter (0.5 in. [13 mm]

and below) tubing. Split the sample longitudinally to allow for easy micrometer measurements. The sample may be one piece which contains the weld and at least 90° of base metal to one side of the weld. Alternately, the sample may be two separate pieces with one containing the weld and a similar size section from the balance of the tube opposite the weld consisting of 100 % base metal. Remove all burrs and sharp edges by lightly grinding. Remove dust and grease by cleaning with soap and water on other suitable solvents. Then, place sample(s) in the flask. It is not recommended to test more than four samples together or to mix alloy types.

S8.4 Prepare the hydrochloric acid solution by slowly adding reagent grade (approximately 37 %) hydrochloric acid to an equal volume of distilled water. (**Warning**—Protect eyes and use rubber gloves when handling acid. Mixing shall be done under a hood and testing shall be run under a hood.)

S8.5 The test container shall be a 0.38 gal [1 L] Erlenmeyer flask equipped with ground-glass joints and an Ahlin condenser. The volume of the solution shall be approximately 24 fl oz [700 mL].

S8.6 Measure the thickness of the tube at five locations along the weld area and five locations along the base-metal section. In both cases, take measurements at approximately equal longitudinal intervals along the section lengths. Make these measurements with a sharp pointed micrometer accurate to at least 0.001 in. [0.25 mm]. The micrometer shall be suitable for measuring the small features in the surface after testing. Typical pin micrometers have tapered anvils with a tip radius of less than 0.015 in. [0.4 mm].

S8.7 Immerse the samples into the solution. Add boiling chips and bring to a boil. Allow the chips to remain boiling throughout the test. The time of testing shall be that which is required to remove 40 to 60 % of the original base-metal thickness (usually 2 h or less). If more than 60 % of the base-metal thickness remains, the sample may be removed after 24 h.

S8.8 At the end of the test period, remove the samples from the solution, rinse with distilled water, and dry.

S8.9 After exposure to the test solution, repeat the tube thickness measurement as in S8.6. If the thinning is not uniform across the width of the weld, then two sets of weld-metal measurement are required. One set of measure-

ments is to be taken along the centerline of the weld. The second set of measurements is to be taken in the thinnest area of the weld.

S8.10 Calculate the corrosion ratio, R, for both sections of the weld as follows in Eq 1:

$$R = \frac{W_o - W}{B_o - B} \tag{1}$$

where:

 W_{o} = average weld-metal thickness before the test,

W = average weld-metal thickness after the test,

- B_o = average base-metal effective thickness (thickness of the strip before cold working modified) before the test, and
- B = average base-metal effective thickness (thickness of the strip before cold-working modified) after the test.

S8.10.1 A corrosion ratio of 1.25 or less for the thinnest section of the weld is permissible. Other criteria, such as a ratio of 1.00 or less, may be specified upon agreement between the producer and the purchaser.

S9. Special Applications

S9.1 For special applications, such as hydraulic expansion of tubes into tube sheets, there shall be no dimensional indication of the weld. Tubes ordered to this requirement shall bear the additional marking of NB.

S10. Additional Measurements

S10.1 Measurements of primary character (P_{hi}) using depth gauges of suitable depth gauge for the pattern shall be made on each lot as described in Table 3.

S11. Radiographic Examination

S11.1 The entire length of weld in each welded pipe shall be radiographically examined, using X-radiation, in accordance with Paragraph UW-51 of Section VIII Division 1 of the ASME Boiler and Pressure Vessel Code. In addition to the marking required by Section 19, each pipe shall be marked "RT" after the specification and grade. Requirements of S11 shall be required in the certification.

Note S11—When specified, the special testing in this supplement is intended for special ASME applications and is permissible to use a 100 % joint efficiency. It is not mandatory for all ASME applications.

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