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Standard Specification for Hot-Formed Welded and Seamless High-Strength Low-Alloy Structural Tubing[1]

This standard is issued under the fixed designation A618/A618M; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. ~~Scope~~ Scope*

1.1 This specification covers grades of hot-formed welded and seamless high-strength low-alloy square, rectangular, round, or special shape structural tubing for welded, riveted, or bolted construction of bridges and buildings and for general structural purposes. When the steel is used in welded construction, the welding procedure shall be suitable for the steel and the intended service.

1.2 ~~Grade II has atmospheric corrosion resistance equivalent to that of carbon steel with copper (0.20 minimum Cu) Grades Ia and Ib have atmospheric corrosion resistance substantially better than that of Grade II (~~Square and rectangular tubing is produced with flats of 1 in. ~~Note 1~~). ~~When properly exposed to the atmosphere, Grades Ia and Ib can be used bare (unpainted) for many applications. When enhanced corrosion resistance is desired, Grade III, copper limits may be specified.~~to 16 in. [25 mm to 405 mm] and a specified wall thickness of 0.095 in. to 1.0 in. [2.5 mm to 25 mm]. Round tubing is produced with diameters of 1 in. to 48

~~NOTE 1—For methods of estimating the atmospheric corrosion resistance of low-alloy steels see Guide G101 or actual data.~~in. [25 mm to 1220 mm] and a specified wall thickness of 0.095 in. to 2.50 in. [2.5 mm to 65 mm].

1.3 This specification covers the following grades: Ia, Ib, II, III, IV, V, VI and VII.

1.4 The text of this specification contains notes and footnotes that provide explanatory material. Such notes and footnotes, excluding those in tables and figures, do not contain any mandatory requirements.

1.5 This specification is expressed in both inch-pound units and in SI units; however, unless the purchase order specifies the applicable M specification designation (SI units), the inch-pound units shall apply. The values stated in either SI units or inch-pound 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~~nonconformance with the standard.

1.6 *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.*

[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 A01.09 on Carbon Steel Tubular Products.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A370 Test Methods and Definitions for Mechanical Testing of Steel Products
A700 Guide for Packaging, Marking, and Loading Methods for Steel Products for Shipment
A751 Test Methods and Practices for Chemical Analysis of Steel Products
A941 Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys
G101 Guide for Estimating the Atmospheric Corrosion Resistance of Low-Alloy Steels

2.2 *Federal Standard:*[3]

Fed. Std. No. 123 Marking for Shipments (Civil Agencies)

2.3 *Military Standard:*[3]

MIL-STD-129 Marking for Shipment and Storage

3. Terminology

3.1 *Definitions*—For definitions of terms used in this specification, refer to Terminology A941.

4. Ordering Information

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

TABLE 1 Chemical Requirements

Element	Composition, %							
	Grade Ia		Grade Ib		Grade II		Grade III	
	Heat	Product	Heat	Product	Heat	Product	Heat	Product
~~Carbon, max~~	~~0.15~~	~~0.18~~	~~0.20~~	~~...~~	~~0.22~~	~~0.26~~	~~0.23[A]~~	~~0.27[A]~~
~~Manganese~~	~~1.00 max~~	~~1.04 max~~	~~1.35 max~~	~~1.40 max~~	~~0.85–1.25~~	~~1.30 max~~	~~1.35 max[A]~~	~~1.40 max[A]~~
Phosphorus, max	0.15	0.16	0.025	0.035	0.025	0.035	0.025	0.035
Sulfur, max	0.025	0.045	0.025	0.035	0.025	0.035	0.025	0.035
Silicon, max	...	...	...	...	0.30	0.33	0.30	0.35
~~Copper, min~~	~~0.20~~	~~0.18~~	~~0.20[B]~~	~~0.18[B]~~	~~0.20~~	~~0.18~~	~~...~~	~~...~~
~~Vanadium, min~~	~~...~~	~~...~~	~~...~~	~~...~~	~~0.02~~	~~0.01~~	~~0.02[C]~~	~~0.01~~

TABLE 1 Chemical Requirements[A]

Element	Composition, %															
	Grade Ia		Grade Ib		Grade II		Grade III		Grade IV		Grade V[E]		Grade VI[F]		Grade VII[F]	
	Heat	Product	Heat	Product	Heat	Product	Heat	Product	Heat	Product	Heat	Product	Heat	Product	Heat	Product
Carbon, max	0.15	0.18	0.20	...	0.22	0.26	0.23[B]	0.27[B]	0.22	0.25	0.25	0.27	0.20	0.22	0.20	0.22
Manganese, max	1.00	1.04	1.35	1.40	1.25	1.30	1.35[B]	1.40[B]	1.6	1.65	1.6	1.65	1.7	1.7	1.75	1.75
Phosphorus, max	0.15	0.16	0.025	0.035	0.025	0.035	0.025	0.035	0.025	0.030	0.025	0.030	0.025	0.030	0.025	0.030
Sulfur, max	0.025	0.045	0.025	0.035	0.025	0.035	0.025	0.035	0.020	0.025	0.020	0.025	0.020	0.025	0.020	0.025
Silicon, max	...	...	...	...	0.30	0.33	0.30	0.35	0.60	0.60	0.60	0.60	0.50	0.50	0.50	0.50
Copper, min	0.20	0.18	0.20[C]	0.18[C]	0.20	0.18	...	...	...	...	...	...	...	...	...	...
Vanadium, min	...	...	...	...	0.02	0.01	0.02[D]	0.01[D]	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.05
Chromium, min	...	...	...	...	...	...	...	...	...	...	...	...	0.10	0.10	0.20	0.20
Molybdenum, min	...	...	...	...	...	...	...	...	...	...	...	...	0.10	0.10	0.20	0.20

[A] Where an ellipsis (...) appears in this table, there is no requirement.
[B] For each reduction of 0.01 % C below the specified carbon maximum, an increase of 0.05 % manganese above the specified maximum will be permitted up to 1.45 % for the heat analysis and up to 1.50 % for the product analysis.
[C] If chromium and silicon contents are each 0.50 % min, then the copper minimums do not apply.
[D] ~~For Grade III, columbium~~ Columbium may be used in conformance with the following limits: 0.005 %, min (heat) and 0.004 %, min (product).
[E] Boron may be used up to a max. 0.0040 %.
[F] Other alloying elements, like tungsten, columbium or nickel, may also be used.

[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 U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Washington, DC 20401-0001, http://www.access.gpo.gov.

4.1.1 Quantity ~~(feet, metres,~~ (weight in metric tons, feet [meters], or number of lengths),

~~3.1.2 Grade (Table 1 and Table 2),~~

4.1.2 ~~Material (round, square, or rectangular~~Name of the material (hot-formed tubing),

4.1.3 Method of manufacture ~~(seamless, buttwelded, or hot-stretch-reduced electric-resistance~~ (seamless or welded),

4.1.4 Grade (Ia, Ib, II, III, IV, V, VI or VII),

4.1.5 Size (outside diameter and nominal wall thickness for round tubing and the outside dimensions and ~~calculated~~ nominal wall thickness for square and rectangular tubing),

4.1.6 Length ~~(specific~~ (random, multiple, or ~~random,~~specific; see ~~8.2~~12.4),

4.1.7 End condition (see ~~9.2~~16.5),

4.1.8 Burr removal (see ~~9.2~~16.5),

TABLE 2 Tensile Requirements

		Grades ~~Ia, Ib,~~ and II	Grade III				
	~~Walls ¾ in. [19.0 mm] and Under~~	~~Walls over ¾ to 1½ in. [19.0 to 38.0 mm], incl~~					
~~Tensile strength, min, ksi [MPa]~~[A]	~~70~~	~~[485] 50~~	~~67 [345]~~	~~[460] 46~~	~~65 [315]~~	~~[450] 50~~	~~[345]~~
~~Yield strength, min, ksi [MPa]~~[A]		~~Elongation in 2 in. or 50 mm, min, %~~	~~22~~		~~20~~		
~~Elongation in 8 in. or 200 mm, min, %~~		~~22 19~~	~~18~~	~~18~~			

TABLE 2 Tensile and Impact Requirements

	Thickness in. [mm]	Grades Ia, Ib, and II[A]	Grade III	Grade IV	Grade V	Grade VI	Grade VII
Tensile strength, min, psi [MPa]	≤ ¾ [19]	70 000 [485]	65 000 [450]	80 000 [550]	100 000 [690]	112 000 [770]	139 000 [960]
	> ¾ [19] and ≤ 1 ½ [38]	67 000 [460]	65 000 [450]	78 000 [540]	100 000 [690]	104 000 [720]	133 000 [920]
	> 1 ½ [38] and ≤ 2 ½ [65]	–	–	78 000 [540]	90 000 [620]	99 000 [680]	125 000 [860]
Yield strength, min, psi [MPa]	≤ ¾ [19]	50 000 [345]	50 000 [345]	67 000 [460]	90 000 [620]	100 000 [690]	129 000 [890]
	> ¾ [19] and ≤ 1 ½ [38]	46 000 [315]	–	64 000 [440]	84 000 [580]	94 000 [650]	123 000 [850]
	> 1 ½ [38] and ≤ 2 ½ [65]	–	–	62 000 [430]	73 000 [500]	84 000 [580]	116 000 [800]
Elongation in 2 in. or 50 mm, min, %	All	22	20	19	18	17	16
Elongation in 8 in. or 200 mm, min, %	All	19	18	17	16	15	14
Impact Energy, min. average ft/lbf [J] (see 10.4)		–	20 [27]	20 [27]	20 [27]	20 [27]	20 [27]
min. single ft/lbf [J] (see 10.4)			14 [19]	14 [19]	14 [19]	14 [19]	14 [19]

[A] For Grade II, when the material is normalized, the minimum yield strength and minimum tensile strength required shall be reduced by 5 ksi [35 MPa].

4.1.9 Certification (see Section ~~12.1~~18),

4.1.10 Packaging, package marking, and loading for shipment (see Section 20),

4.1.11 Product analysis (see Supplementary Requirements S1),

4.1.12 Specification designation (A618 or A618M, including ~~yeardate),~~ year date),

4.1.13 End use, and

4.1.14 Special requirements.

5. Process

5.1 The steel shall be made by ~~one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace.~~ basic-oxygen, or electric-arc-furnace steelmaking process.

5.2 Steel may be cast in ingots or may be strand cast.

5.3 ~~Steel may be cast in ingots or may be strand cast.~~ When steels of different grades are sequentially strand cast, identification of the resultant transition material is required. The producer shall remove the transition material by any established procedure that positively separates the grades.

6. Manufacture

6.1 The tubing shall be made by the seamless, ~~furnace-buttwelded~~furnace-butt-welded (continuous-welded), or hot-stretch-reduced electric-resistance-welded process.

6.2 The final cross section formation shall be made by a hot forming process.

6.3 The weld shall not be located within the radius of the corners of any tube having one or more flat sides.

6.4 It shall be permissible for tubing with a wall thickness greater than ½ in. [13 mm] to add a normalizing heat treatment.

6.5 A quenching and tempering process shall be used for Grade V, Grade VI and Grade VII and may be used for Grade IV.

~~**6. Chemical Composition**~~

~~6.1 When subjected to the heat and product analysis, respectively, the steel shall conform to the requirements prescribed in Table 1.~~

~~6.1.1 For Grades Ia and Ib, the choice and use of alloying elements, combined with carbon, manganese, and sulfur within the limits prescribed in Table 1 to give the mechanical properties prescribed in Table 2 and to provide the atmospheric corrosion resistance of 1.2, should be made by the manufacturer and included and reported in the heat analysis for information purposes only to identify the type of steel applied. For Grades Ia and Ib material, the atmospheric corrosion-resistance index, calculated on the basis of the chemical composition of the steel as described in Guide G101, shall be 6.0 or higher.~~

~~NOTE 2—The user is cautioned that the Guide G101 predictive equation for calculation of an atmospheric corrosion-resistance index has been verified only for the composition limits stated in that guide.~~

~~6.1.2 When Grade III is required for enhanced corrosion resistance, copper limits may be specified and the minimum content shall be 0.20 % by heat analysis and 0.18 % by product analysis.~~

~~6.2 *Heat Analysis*—An analysis of each heat of open-hearth, basic-oxygen, or electric-furnace steel shall be made by the~~

manufacturer. This analysis shall be made from a test ingot taken during the pouring of the heat. The chemical composition thus determined shall conform to the requirements specified in Table 1 for heat analysis.

6.3 *Product Analysis:*

6.3.1 An analysis may be made by the purchaser from finished tubing manufactured in accordance with this specification, or an analysis may be made from flat-rolled stock from which the welded tubing is manufactured. When product analyses are made, two sample lengths from a lot of each 500 lengths, or fraction thereof, shall be selected. The specimens for chemical analysis shall be taken from the sample lengths in accordance with the applicable procedures of Test Methods, Practices, and Terminology A751. The chemical composition thus determined shall conform to the requirements specified in Table 1 for product analysis.

6.3.2 In the event the chemical composition of one of the sample lengths does not conform to the requirements shown in Table 1 for product analysis, an analysis of two additional lengths selected from the same lot shall be made, each of which shall conform to the requirements shown in Table 1 for product analysis, or the lot is subject to rejection.

7. Heat Analysis

7.1 When subjected to heat analysis the steel shall conform to the requirements prescribed in Table 1.

7.1.1 For Grades Ia and Ib, the choice and use of alloying elements, combined with carbon, manganese, and sulfur within the limits prescribed in Table 1 to give the mechanical properties prescribed in Table 2 and to provide atmospheric corrosion resistance, should be made by the manufacturer and included and reported in the heat analysis for information purposes only to identify the type of steel applied. For Grades Ia and Ib material, the atmospheric corrosion-resistance index, calculated on the basis of the chemical composition of the steel as described in Guide G101, shall be 6.0 or higher.

NOTE 1—The user is cautioned that the Guide G101 predictive equation for calculation of an atmospheric corrosion–resistance index has been verified only for the composition limits stated in that guide.

7.1.2 When Grade III is required for enhanced corrosion resistance, copper limits may be specified and the minimum content shall be 0.20 % by heat analysis and 0.18 % by product analysis.

8. Product Analysis

8.1 When product analysis is ordered (see 4.1.11 and S1) the tubing shall conform to the requirements specified in Table 1.

9. Tensile Requirements

9.1 The material, as represented by the test specimen, shall conform to the tensile property requirements prescribed in Table 2.

9.2 Elongation may be determined on a gage length of either 2 in. [50 mm] or 8 in. [200 mm] at the manufacturer's choice.

10. ~~Mechanical~~Impact Requirements

10.1 *Tensile Properties:* For Grades III, IV, V, VI, VII the Charpy V-notch impact test specimens shall conform to the requirements prescribed in Table 2. Impact tests are not required for thicknesses smaller than or equal to 0.250 in. [6.3 mm], unless specified.

7.1.1 The material, as represented by the test specimen, shall conform to the requirements prescribed in Table 2.

7.1.2 Elongation may be determined on a gage length of either 2 in. [50 mm] or 8 in. [200 mm] at the manufacturer's option.

7.1.3 For material under 5⁄16 in. [8.0 mm] in thickness, a deduction from the percentage elongation of 1.25 percentage points in 8 in. [200 mm] specified in Table 2 shall be made for each decrease of 1⁄32 in. [0.8 mm] of the specified thickness under 5⁄16 in. [8.0 mm].

7.2 *Bend Test*—The bend test specimen shall stand being bent cold through 180° without cracking on the outside of the bent portion, to an inside diameter which shall have a relation to the thickness of the specimen as prescribed in Table 3.

7.3 *Number of Tests*—Two tension and two bend tests, as specified in 7.4.2, and 7.4.3, shall be made from tubing representing each heat. However, if tubing from one heat differs in the ordered nominal wall thickness, one tension test and one bend test shall be made from both the heaviest and lightest wall thicknesses processed.

10.2 *Test Specimens:* Charpy V-notch tests shall be made in accordance with Test Methods and Definitions A370. One test shall consist of a set of three specimens. Standard specimens 10 mm by 10 mm [0.394 in. by 0.394 in.] in cross section shall be used unless the material to be tested is of insufficient thickness, in which case the largest obtainable subsize specimens shall be used. Acceptance criteria for subsize specimens shall be in accordance with Test Methods and Definitions A370.

7.4.1 The test specimens required by this specification shall conform to those described in the latest issue of Test Methods and Definitions A370.

7.4.2 The tension test specimen shall be taken longitudinally from a section of the finished tubing, at a location at least 90° from the weld in the case of welded tubing, and shall not be flattened between gage marks. If desired, the tension test may be made on the full section of the tubing; otherwise, a longitudinal strip test specimen shall be used as prescribed in Test Methods and Definitions A370, Annex A2. The specimens shall have all burrs removed and shall not contain surface imperfections that would interfere with the proper determination of the tensile properties of the metal.

7.4.3 The bend test specimen shall be taken longitudinally from the tubing, and shall represent the full wall thickness of material. The sides of the bend test specimen may have the corners rounded to a maximum radius of 1/16 in. [1.6 mm].

10.3 *Test Methods:* One Charpy V-notch impact test shall be made from a length of tubing representing each lot.

7.5.1 The yield strength shall be determined in accordance with one of the alternatives described in Test Methods and Definitions A370.

7.5.2 The bend test shall be made on square or rectangular tubing manufactured in accordance with this specification.

10.4 TheRetests: test results of standard full-size longitudinal specimens shall meet a minimum average per set of three specimens and minimum single value as specified in Table 2. The specimen axis shall be parallel to the tubing axis and the notch shall be normal to the surface of the material. For wall thicknesses 1.5 in. [38 mm] and less, the specimens shall be located with their surface at least 0.08 in. [2 mm] from the material surface; for wall thicknesses greater than 1.5 in. [38 mm], the specimens shall be located with their axial plane at least ¼ times the wall thickness from the material surface.

7.6.1 If the results of the mechanical tests representing any heat do not conform to a requirement, as specified in 7.1 and 7.2, retests may be made on additional tubing of double the original number from the same heat, each of which shall conform to the requirement specified, or the tubing represented by the test is subject to rejection.

7.6.2 In case of failure on retest to meet the requirements of 7.1 and 7.2, the manufacturer may elect to retreat, rework, or otherwise eliminate the condition responsible for failure to meet the specified requirements. Thereafter, the material remaining from the respective heat originally represented may be tested, and shall comply with all requirements of this specification.

10.5 The maximum test temperature shall be 0°F [–18°C].

11. Dimensions

11.1 *Round Structural Tubing*—The dimensions are defined by outside diameter (OD) and the wall thickness (t).

11.2 *Square and Rectangular Structural Tubing*—The outside dimensions are defined by length of 1st side (H), length of 2nd side (B) and the wall thickness (t). The nominal weight (W) shall be calculated by the following equation:

$$W = \frac{490(2t\,(B+H) - (5.07\,t^2))}{144}\ lb/ft \tag{1}$$

$$\left[W = \frac{0.785(2t\,(B+H) - (5.07\,t^2))}{100}\ kg/m\right]$$

where:

W = weight, lb/ft [kg/m],
H = length of 1st side, or longer side at rectangular dimensions, inch [mm],
B = length of 2nd side, or shorter side at rectangular dimensions, inch [mm],
t = wall thickness, inch [mm].

NOTE 2—The resulting corresponding sectional properties should be calculated separately, for example, per ISO 12633-2.

11.3 *Special Shape Structural Tubing*—The dimensions and tolerances of special shape structural tubing are available by inquiry and negotiation with the manufacturer.

12. Dimensions and Permissible Variations

~~8.1 The dimensions of square, rectangular, round, and special shape structural tubing to be ordered under this specification shall be subject to prior negotiation with the manufacturer. The dimensions agreed upon shall be indicated in the purchase order.~~

12.1 ~~*Permissible Variations:*~~*Outside Dimensions:*

12.1.1 ~~*Outside Dimensions:*~~ *Round Structural Tubing—*

~~8.2.1.1 For round tubing 2 in. [50 mm] and over in nominal diameter, the outside diameter shall not vary more than ±1 % from the specified outside diameter. For sizes 1½ in. [38 mm] and under, the outside diameter shall not vary more than 1/64 in. [0.4 mm] over and more than 1/32 in. [0.8 mm] under the specified outside diameter.~~ For outside diameter greater than 2.0 in [50 mm], the outside diameter shall not vary more than ±1 % from the specified outside diameter. For outside diameter 2.0 in. [50 mm] and under, the outside diameter shall not vary more than ±1/48 in. [0.50 mm] from the specified outside diameter.

~~8.2.1.2 The specified dimensions, measured across the flats at positions at least 2 in. [50 mm] from either end of square and rectangular tubing and including an allowance for convexity and concavity, shall not exceed the plus and minus tolerance shown in Table 4.~~

12.1.2 ~~*Mass—*~~*Square, Rectangular, and Special Shape Structural Tubing*—The ~~mass of structural tubing shall not be less than the specified value by more than 3.5 %. The mass tolerance shall be determined from individual lengths or for round tubing sizes 4~~outside dimensions are measured across the flats at positions 2.0 in. [50 mm] from the ends of the tubing. For outside dimensions greater than 2.0 in. [50 mm], the outside dimensions shall not vary more than ±1 % from the specified ~~½ in. [114 mm] in outside diameter and under and square and rectangular tubing having a periphery of 14 in. [356 mm] and under shall be determined from masses of the customary lifts produced by the mill. On round tubing sizes over 4~~outside dimension. For outside dimensions 2.0 in. [50 mm] and under, the outside dimension shall not vary more than ±1/48 in. ~~[114 mm] in outside diameter and square and rectangular tubing having a periphery in excess of 14 in. [356 mm] the mass tolerance is applicable to the individual length.~~ [0.50 mm] from the specified outside dimension.

~~8.2.3 *Length*—Structural tubing is commonly produced in random mill lengths of 16 to 22 ft [4.9 to 6.7 m] or 32 to 44 ft [9.8 to 13.4 m], in multiple lengths, and in definite cut lengths (Section 3). When cut lengths are specified for structural tubing, the length tolerances shall be in accordance with Table 5.~~

~~**TABLE 5 Cut Length Tolerances for Structural Tubing**~~

	~~22 ft [6.7 m] and Under~~		~~Over 22 to 44 ft [6.7 to 13.4 m], incl~~	
	~~Over~~	~~Under~~	~~Over~~	~~Under~~
~~Length tolerance for specified cut lengths, in. [mm]~~	~~½ [13]~~	~~¼ [6]~~	~~¾ [19]~~	~~¼ [6]~~

TABLE 3 Permissible Variations in Length for Specific Lengths of Structural Tubing

	Specific Length			
	22 ft [7 m] and Under		Over 22 to 44 ft [7 m to 14 m], incl	
	Over	Under	Over	Under
Permissible variations in length, in. [mm]	½ [13]	¼ [6]	¾ [19]	¼ [6]