

(o) *Leakage test.* All spun cylinders and plugged cylinders must be tested for leakage by dry gas or dry air pressure after the bottom has been cleaned and is free from all moisture, subject to the following conditions and limitations:

(1) Pressure, approximately the same as but not less than service pressure, must be applied to one side of the finished bottom over an area of at least $\frac{1}{16}$ of the total area of the bottom but not less than $\frac{3}{4}$ inch in diameter, including the closure, for at least one minute, during which time the other side of the bottom exposed to pressure must be covered with water and closely examined for indications of leakage. Except as provided in paragraph (q) of this section, a cylinder must be rejected if there is leakage.

(2) A spun cylinder is one in which an end closure in the finished cylinder has been welded by the spinning process.

(3) A plugged cylinder is one in which a permanent closure in the bottom of a finished cylinder has been effected by a plug.

(4) As a safety precaution, if the manufacturer elects to make this test before the hydrostatic test, the manufacturer should design the test apparatus so that the pressure is applied to the smallest area practicable, around the point of closure, and so as to use the smallest possible volume of air or gas.

(p) *Acceptable results of tests.* Results of the flattening test, physical tests, burst test, and cycling test must conform to the following:

(1) Flattening required without cracking to ten times the wall thickness of the cylinder.

(2) Physical tests:

(i) An elongation of at least 6 percent for a gauge length of 24 times the wall thickness.

(ii) The tensile strength may not exceed 165,000 p.s.i.

(3) The burst pressure must be at least $\frac{2}{3}$ times the test pressure.

(4) Cycling—at least 10,000 pressurizations.

(q) *Rejected cylinders.* Reheat treatment is authorized for rejected cylinders. Subsequent thereto, cylinders must pass all prescribed tests to be acceptable. Repair by welding or spinning

is not authorized. For each cylinder subjected to reheat treatment during original manufacture, sidewall measurements must be made to verify that the minimum sidewall thickness meets specification requirements after the final heat treatment.

(r) *Marking.* (1) Cylinders must be marked by low stress type steel stamping in an area and to a depth which will insure that the wall thickness measured from the root of the stamping to the interior surface is equal to or greater than the minimum prescribed wall thickness. Stamping must be permanent and legible. Stamping on side wall not authorized.

(2) The rejection elastic expansion (REE), in cubic cm (cc), must be marked on the cylinder near the date of test. The REE for a cylinder is 1.05 times its original elastic expansion.

(3) Name plates are authorized, provided that they can be permanently and securely attached to the cylinder. Attachment by either brazing or welding is not permitted. Attachment by soldering is permitted provided steel temperature does not exceed 500 °F.

(s) *Inspector's report.* In addition to the requirements of §178.35, the inspector's report must indicate the rejection elastic expansion (REE), in cubic cm (cc).

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§ 178.45 Specification 3T seamless steel cylinder.

(a) *Type, size, and service pressure.* A DOT 3T cylinder is a seamless steel cylinder with a minimum water capacity of 1,000 pounds and a minimum service pressure of 1,800 psig. Each cylinder must have integrally formed heads concave to pressure at both ends. The inside head shape must be hemispherical, ellipsoidal in which the major axis is two times the minor axis, or a dished shape falling within these two limits. Permanent closures formed by spinning are prohibited.

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(b) *Material, steel.* Only open hearth, basic oxygen, or electric furnace process steel of uniform quality is authorized. The steel analysis must conform to the following:

ANALYSIS TOLERANCES

Element	Ladle analysis	Check Analysis	
		Under	Over
Carbon	0.35 to 0.50	0.03	0.04
Manganese	0.75 to 1.05	0.04	0.04
Phosphorus (max)	0.035	0.01
Sulphur (max)	0.04	0.01
Silicon	0.15 to 0.35	0.02	0.03
Chromium	0.80 to 1.15	0.05	0.05
Molybdenum	0.15 to 0.25	0.02	0.02

(1) A heat of steel made under the specifications in the table in this paragraph (b), the ladle analysis of which is slightly out of the specified range, is acceptable if satisfactory in all other aspects. However, the check analysis tolerances shown in the table in this paragraph (b) may not be exceeded except as approved by the Department.

(2) Material with seams, cracks, laminations, or other injurious defects is not permitted.

(3) Material used must be identified by any suitable method.

(c) *Manufacture.* General manufacturing requirements are as follows:

(1) Surface finish must be uniform and reasonably smooth.

(2) Inside surfaces must be clean, dry, and free of loose particles.

(3) No defect of any kind is permitted if it is likely to weaken a finished cylinder.

(4) If the cylinder surface is not originally free from the defects, the surface may be machined or otherwise treated to eliminate these defects provided the minimum wall thickness is maintained.

(5) Welding or brazing on a cylinder is not permitted.

(d) *Wall thickness.* The minimum wall thickness must be such that the wall stress at the minimum specified test pressure does not exceed 67 percent of the minimum tensile strength of the steel as determined by the physical tests required in paragraphs (j) and (k) of this section. A wall stress of more than 90,500 p.s.i. is not permitted. The minimum wall thickness for any cylinder may not be less than 0.225 inch.

(1) Calculation of the stress for cylinders must be made by the following formula:

$$S = [P(1.3D^2 + 0.4d^2)] / (D^2 - d^2)$$

Where:

S = Wall stress in psi;

P = Minimum test pressure, at least 5/8 service pressure;

D = Outside diameter in inches;

d = Inside diameter in inches.

(2) Each cylinder must meet the following additional requirement which assumes a cylinder horizontally supported at its two ends and uniformly loaded over its entire length. This load consists of the weight per inch of length of the straight cylindrical portion filled with water compressed to the specified test pressure. The wall thickness must be increased when necessary to meet this additional requirement:

(i) The sum of two times the maximum tensile stress in the bottom fibers due to bending (see paragraph (d)(2)(ii) of this section), plus the maximum tensile stress in the same fibers due to hydrostatic testing (see paragraph (d)(2)(iii) of this section) may not exceed 80 percent of the minimum yield strength of the steel at this maximum stress.

(ii) The following formula must be used to calculate the maximum tensile stress due to bending:

$$S = Mc / I$$

Where:

S = Tensile stress in psi;

M = Bending moment in inch-pounds ($wl^2/8$);

I = Moment of inertia— $0.04909 (D^4 - d^4)$ in inches fourth;

c = Radius (D/2) of cylinder in inches;

w = Weight per inch of cylinder filled with water;

l = Length of cylinder in inches;

D = Outside diameter in inches;

d = Inside diameter in inches.

(iii) The following formula must be used to calculate the maximum longitudinal tensile stress due to hydrostatic test pressure:

$$S = A_1 P / A_2$$

Where:

S = Tensile stress in psi;

A₁ = Internal area in cross section of cylinder in square inches;

P = Hydrostatic test pressure-psi;

A_2 = Area of metal in cross section of cylinder in square inches.

(e) *Heat treatment.* Each completed cylinder must be uniformly and properly heat treated prior to testing, as follows:

(1) Each cylinder must be heated and held at the proper temperature for at least one hour per inch of thickness based on the maximum thickness of the cylinder and then quenched in a suitable liquid medium having a cooling rate not in excess of 80 percent of water. The steel temperature on quenching must be that recommended for the steel analysis, but it must never exceed 1750 °F.

(2) After quenching, each cylinder must be reheated to a temperature below the transformation range but not less than 1050 °F., and must be held at this temperature for at least one hour per inch of thickness based on the maximum thickness of the cylinder. Each cylinder must then be cooled under conditions recommended for the steel.

(f) *Openings.* Openings in cylinders must comply with the following:

(1) Openings are permitted on heads only.

(2) The size of any centered opening in a head may not exceed one half the outside diameter of the cylinder.

(3) Openings in a head must have ligaments between openings of at least three times the average of their hole diameter. No off-center opening may exceed 2.625 inches in diameter.

(4) All openings must be circular.

(5) All openings must be threaded. Threads must be in compliance with the following:

(i) Each thread must be clean cut, even, without any checks, and to gauge.

(ii) Taper threads, when used, must be the American Standard Pipe thread (NPT) type and must be in compliance with the requirements of NBS Handbook H-28 (IBR, see §171.7 of this subchapter).

(iii) Taper threads conforming to National Gas Taper thread (NGT) standards must be in compliance with the requirements of NBS Handbook H-28.

(iv) Straight threads conforming with National Gas Straight thread (NGS) standards are authorized. These

threads must be in compliance with the requirements of NBS Handbook H-28.

(g) *Hydrostatic test.* Each cylinder must be tested at an internal pressure by the water jacket method or other suitable method, conforming to the following requirements:

(1) The testing apparatus must be operated in a manner that will obtain accurate data. Any pressure gauge used must permit reading to an accuracy of one percent. Any expansion gauge used must permit reading of the total expansion to an accuracy of one percent.

(2) Any internal pressure applied to the cylinder after heat treatment and before the official test may not exceed 90 percent of the test pressure.

(3) The pressure must be maintained sufficiently long to assure complete expansion of the cylinder. In no case may the pressure be held less than 30 seconds.

(4) If, due to failure of the test apparatus, the required test pressure cannot be maintained, the test must be repeated at a pressure increased by 10 percent or 100 psig, whichever is lower or, the cylinder must be reheat treated.

(5) Permanent volumetric expansion of the cylinder may not exceed 10 percent of its total volumetric expansion at the required test pressure.

(6) Each cylinder must be tested to at least $\frac{2}{3}$ times its service pressure.

(h) *Ultrasonic examination.* After the hydrostatic test, the cylindrical section of each vessel must be examined in accordance with ASTM E 213 for shear wave and E 114 for straight beam (IBR, Standard see §171.7 of this subchapter). The equipment used must be calibrated to detect a notch equal to five percent of the design minimum wall thickness. Any discontinuity indication greater than that produced by the five percent notch must be cause for rejection of the cylinder, unless the discontinuity is repaired within the requirements of this specification.

(i) *Basic requirements for tension and Charpy impact tests.* Cylinders must be subjected to a tension and Charpy impact as follows:

(1) When the cylinders are heat treated in a batch furnace, two tension specimens and three Charpy impact specimens must be tested from one of the cylinders or a test ring from each

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batch. The lot size represented by these tests may not exceed 200 cylinders.

(2) When the cylinders are heat treated in a continuous furnace, two tension specimens and three Charpy impact specimens must be tested from one of the cylinders or a test ring from each four hours or less of production. However, in no case may a test lot based on this production period exceed 200 cylinders.

(3) Each specimen for the tension and Charpy impact tests must be taken from the side wall of a cylinder or from a ring which has been heat treated with the finished cylinders of which the specimens must be representative. The axis of the specimens must be parallel to the axis of the cylinder. Each cylinder or ring specimen for test must be of the same diameter, thickness, and metal as the finished cylinders they represent. A test ring must be at least 24 inches long with ends covered during the heat treatment process so as to simulate the heat treatment process of the finished cylinders it represents.

(4) A test cylinder or test ring need represent only one of the heats in a furnace batch provided the other heats in the batch have previously been tested and have passed the tests and that such tests do not represent more than 200 cylinders from any one heat.

(5) The test results must conform to the requirements specified in paragraphs (j) and (k) of this section.

(6) When the test results do not conform to the requirements specified, the cylinders represented by the tests may be reheat treated and the tests repeated. Paragraph (i)(5) of this section applies to any retesting.

(j) *Basic conditions for acceptable physical testing.* The following criteria must be followed to obtain acceptable physical test results:

(1) Each tension specimen must have a gauge length of two inches with a width not exceeding one and one-half inches. Except for the grip ends, the specimen may not be flattened. The grip ends may be flattened to within one inch of each end of the reduced section.

(2) A specimen may not be heated after heat treatment specified in paragraph (d) of this section.

(3) The yield strength in tension must be the stress corresponding to a permanent strain of 0.2 percent of the gage length.

(i) This yield strength must be determined by the “offset” method or the “extension under load” method described in ASTM E 8 (IBR, see §171.7 of this subchapter).

(ii) For the “extension under load” method, the total strain (or extension under load) corresponding to the stress at which the 0.2 percent permanent strain occurs may be determined with sufficient accuracy by calculating the elastic extension of the gage length under appropriate load and adding thereto 0.2 percent of the gage length. Elastic extension calculations must be based on an elastic modulus of 30,000,000. However, when the degree of accuracy of this method is questionable the entire stress-strain diagram must be plotted and the yield strength determined from the 0.2 percent offset.

(iii) For the purpose of strain measurement, the initial strain must be set with the specimen under a stress of 12,000 p.s.i. and the strain indicator reading set at the calculated corresponding strain.

(iv) The cross-head speed of the testing machine may not exceed 1/8 inch per minute during the determination of yield strength.

(4) Each impact specimen must be Charpy V-notch type size 10 mm × 10 mm taken in accordance with paragraph 11 of ASTM A 333 (IBR, see §171.7 of this subchapter). When a reduced size specimen is used, it must be the largest size obtainable.

(k) *Acceptable physical test results.* Results of physical tests must conform to the following:

(1) The tensile strength may not exceed 155,000 p.s.i.

(2) The elongation must be at least 16 percent for a two-inch gage length.

(3) The Charpy V-notch impact properties for the three impact specimens which must be tested at 0 °F may not be less than the values shown as follows:

Size of specimen (mm)	Average value for acceptance (3 specimens)	Minimum value (1 specimen only of the 3)
10.0×10.0	25.0 ft. lbs.	20.0 ft. lbs.
10.0×7.5	21.0 ft. lbs.	17.0 ft. lbs.

Size of specimen (mm)	Average value for acceptance (3 specimens)	Minimum value (1 specimen only of the 3)
10.0x5.0	17.0 ft. lbs.	14.0 ft. lbs.

(4) After the final heat treatment, each vessel must be hardness tested on the cylindrical section. The tensile strength equivalent of the hardness number obtained may not be more than 165,000 p.s.i. (Rc 36). When the result of a hardness test exceeds the maximum permitted, two or more retests may be made; however, the hardness number obtained in each retest may not exceed the maximum permitted.

(l) *Rejected cylinders.* Reheat treatment is authorized for rejected cylinders. However, each reheat treated cylinder must subsequently pass all the prescribed tests. Repair by welding is not authorized.

(m) *Markings.* Marking must be done by stamping into the metal of the cylinder. All markings must be legible and located on a shoulder.

(n) *Inspector's report.* In addition to the requirements of §178.35, the inspector's report for the physical test report, must indicate the average value for three specimens and the minimum

value for one specimen for each lot number.

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§ 178.46 Specification 3AL seamless aluminum cylinders.

(a) *Size and service pressure.* A DOT 3AL cylinder is a seamless aluminum cylinder with a maximum water capacity of 1000 pounds and minimum service pressure of 150 psig.

(b) *Authorized material and identification of material.* The material of construction must meet the following conditions:

(1) Starting stock must be cast stock or traceable to cast stock.

(2) Material with seams, cracks, laminations, or other defects likely to weaken the finished cylinder may not be used.

(3) Material must be identified by a suitable method that will identify the alloy, the aluminum producer's cast number, the solution heat treat batch number and the lot number.

(4) The material must be of uniform quality. Only the following heat treatable aluminum alloys in table 1 and 2 are permitted as follows:

TABLE 1—HEAT OR CAST ANALYSIS FOR ALUMINUM; SIMILAR TO "ALUMINUM ASSOCIATION"¹ ALLOY 6061

[CHEMICAL ANALYSIS IN WEIGHT PERCENT²]

Si min/max	Fe max	Cu min/max	Mn max	Mg min/max	Cr min/max	Zn max	Ti max	Pb max	Bi max	Other		A1
										each max	total max	
0.4/0.8	0.7	0.15/0.4	0.15	0.8/1.2	0.04/0.35	0.25	0.15	0.005	0.005	0.05	0.15	Bal.

¹ The "Aluminum Association" refers to "Aluminum Standards and Data 1993", published by the Aluminum Association Inc.
² Except for "Pb" and "Bi", the chemical composition corresponds with that of Table 1 of ASTM B 221 (IBR, see § 171.7 of this subchapter) for Aluminum Association alloy 6061.

TABLE 2—MECHANICAL PROPERTY LIMITS

Alloy and temper	Tensile strength—PSI		Elongation—percent minimum for 2" or 4D ¹ size specimen
	Ultimate—minimum	Yield—minimum	
6061-T6	38,000	35,000	² 14

¹ "D" represents specimen diameters. When the cylinder wall is greater than 3/16 inch thick, a retest without reheat treatment using the 4D size specimen is authorized if the test using the 2 inch size specimen fails to meet elongation requirements.
² When cylinder wall is not over 3/16-inch thick, 10 percent elongation is authorized when using a 24t:6t size test specimen.

(5) All starting stock must be 100 percent ultrasonically inspected, along the length at right angles to the central axis from two positions at 90° to

one another. The equipment and continuous scanning procedure must be capable of detecting and rejecting internal defects such as cracks which have