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**Document Name:** CGA C-5: Cylinder Service Life-Seamless Steel High Pressure Cylinders

**CFR Section(s):** 49 CFR 173.302a(b)(3)(i)(A)

**Standards Body:** Compressed Gas Association

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CYLINDER SERVICE LIFE
SEAMLESS STEEL
HIGH PRESSURE CYLINDERS

FIFTH EDITION
REAFFIRMED 1995

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1 Introduction

1.1 Compressed gas cylinders manufactured in accordance with U.S. Department of Transportation (DOT) or Transport Canada (TC). Specifications should remain safe unless damaged by corrosion, accident, or abuse. A cylinder shall be accepted or rejected for service on the basis of the expansion data obtained by hydrostatic test, and visual inspection.

1.2 This pamphlet contains detailed methods of determining average wall thickness that can be applied to the re-testing of seamless, high pressure cylinders conforming to Specifications ICC 3, ICC/DOT 3A, 3AX, 3AA, 3AAX and DOT 3T. The water jacket hydrostatic test shall be made in accordance with Compressed Gas Association publication C-1, Methods for Hydrostatic Testing of Compressed Gas Cylinders [1]. The visual inspection shall be made in accordance with CGA publication C-6, Standards For Visual Inspection of Steel Compressed Gas Cylinders [2].

1.3 This publication provides the procedures required qualifying cylinders for filling to 10% in excess of their marked service pressure in accordance with 49 CFR 173.302(c) of the DOT Regulations (see Appendix B) [3]. A cylinder is no longer qualified for filling to 10% in excess of its marked service pressure when the wall stress limitations contained in 49 CFR 173.302(c) are exceeded [3].

1.4 The flow chart contained in Appendix A graphically illustrates the service life control procedures described in this pamphlet.

1.5 The suggestions contained in this pamphlet do not apply to cylinders manufactured under specification DOT (ICC) 3HT. Because of the special provisions of this specification, separate recommendations covering service life and standards for visual inspection of these cylinders are contained in CGA publication C-6, Standard for Requalification of DOT (ICC) 3HT Cylinders [4].

2 Basic considerations

2.1 Service life control by hydrostatic test in a water jacket or other approved apparatus is a requirement of DOT Regulations, 49 CFR 173.34(e)(1)(3), through limiting the permanent expansion to 10% of total expansion [3]. The Regulations also permit using the water jacket method only for limiting the cylinder wall stress and wall thickness through maximum elastic expansion limit to qualify cylinders for charging to 10% in excess of their marked service pressure (49 CFR 173.302(c)-See Appendix B) [3]. Cylinders meeting these wall stress and elastic expansion requirements and also used in certain dry gas service can be retested every ten years instead of every five years. Reference 49 CFR 173.34(e)(15) [3].

1 In 1967 the Department of Transportation was established and among other things assumed responsibility for the safety regulations formerly administered by the Interstate Commerce Commission over explosives and other dangerous articles. These are now known as the Hazardous Materials Regulations of DOT and specifications for cylinders are included in these regulations. Wherever reference is made to DOT cylinders, it is equally applicable to similar cylinders marked “ICC” and the same cylinders made to Canadian Regulations which may be marked “TC,” “CTC,” “BTC” (Board of Transport Commissioners for Canada) or “CRC” (Canadian Railway Commission).

2 References in this document are shown by bracketed numbers and are listed in their order of appearance.
2.2

The direct method of applying wall stress limitations is to measure the wall thickness with either mechanical, electronic, ultrasonic, or radiographic thickness gauges. However, the most practical method is the use of elastic expansion obtained by the water jacket test. This is done by establishing a maximum allowable elastic expansion and rejecting cylinders that show elastic expansions at test pressure that exceed the computed rejection limit.

2.3

Experiments have proven the direct relationship between the elastic expansion of the cylinder and the average wall stress as expressed in the Clavarino formula. The average wall thickness has also been proven to be directly related to the average wall stress as expressed in the Bach formula. These values are interrelated by a proportionality constant which is commonly referred to as the "K" factor.

2.4

The "K" factor is a constant indicating the flexibility of the cylinder ends which varies with cylinder design. Since the "K" factor is constant, it is very important to segregate cylinders of different design and use the appropriate "K" factor.

2.5

Certain cylinders are of such design and method of fabrication that the use of a "K" factor and the elastic expansion measurement in order to requalify for charging to 10% in excess of their marked service pressure is unlikely. These cylinders had sidewall thickness at time of manufacture which corresponds to average wall stress above the upper limits set forth in 49 CFR 173.302(c) (i.e., for DOT 3AA-cylinders designed to 70 000 psi wall stress exceeding the 67 000 psi average wall stress limit) [3]. They were qualified under the maximum wall stress limits, since the minimum wall thickness has been established through measurement by the cylinder manufacturer. To determine whether cylinders of this type remain qualified for charging to 10% in excess of their marked service pressure at time of retest, measurement of minimum wall thickness, as described in 2.2 is required. Cylinders manufactured from sheet or plate, rather than from a billet or tubing, are most likely to fall in this category. When there is doubt, the cylinder manufacturer should be contacted. The minimum wall thickness allowed can be calculated from the following formula:

\[
t = \frac{D}{2} \left[ 1 - \sqrt{\frac{S - 1.3P}{S + 0.4P}} \right]
\]

Where

- \( S \) = Maximum wall stress limitation (173.302(c)).
- \( P \) = 5/3 times marked service pressure.
- \( D \) = Outside diameter.
- \( T \) = Minimum wall thickness allowed.

3 Sources of "K" factors

If a "K" factor is required, it should be obtained from one of the following 3 sources:

3.1

Select the "K" factor from table 2. Various cylinder designs are described by the data in the table.

3.2

Contact the cylinder manufacturer for the "K" factor, if the cylinder design is not contained in table 2.
3.3

Calculate the "K" factor if it cannot be obtained from the two sources listed above. The following procedure can be used:

3.3.1

Select at least three (3) cylinders typical of the design.

3.3.2

Determine the following properties of each cylinder:

- Outside diameter in inches.
- Wall thickness in inches.
- Internal volume in cubic centimeters (cc).
- Elastic expansion in cubic centimeters.
- Test pressure in pounds per square inch (psi).

3.3.3

Suggested methods to determine the above listed properties

- Using II-tape, measure diameter in six or more locations. The average of those readings is the diameter.
- Two convenient methods are:
  1. By ultrasonic thickness measuring device. Take readings over the entire sidewall at locations equidistanted apart on about 3 inch centers. The average of those readings is the wall thickness.
  2. By weight of steel. Cut the ends off the cylinder about 6 inches from the point of curvature. Weigh the shell and calculate t by the following formula:

\[
t = \frac{D}{2} - \sqrt[4\text{th}]{\frac{W}{4.890 \cdot L}}
\]

- Outside diameter in inches
- Weight in pounds
- Length in inches.

- Weigh cylinder empty and full of water three (3) or more times. Determine contents in weight of water for each test. The average of those tests in pounds multiplied by the specific volume of water is the internal volume. The specific volume must be for the actual water temperature (454.06 cc per pound at 60 °F).

- Determine the elastic expansion in the water jacket hydrostatic test. Run at least three (3) tests on each cylinder. The average of those readings is the EE.

- Is the test pressure for the particular cylinder design in psi?

3.3.4

Determine "K" factor by solving the following formula, using the values for various properties as determined above.

\[
K = \frac{EE \times (D^2 - d^2)}{P \times V \times D^2}
\]

\[
d = D - 2t
\]
4 Determination of elastic expansion rejection limits

4.1

The most practical method of determining limiting wall stresses at the present time, and the method recommended for use by the average cylinder owner is the indirect method based upon computing the limiting wall stress from the elastic expansion at test pressure by means of the water jacket hydrostatic test.

4.2

This is done by setting up a maximum allowable elastic expansion according to the Bach and Clavarino formulas and rejecting any cylinders that show elastic expansions at test pressure that exceeded the computed rejection limit.

4.3 The Bach Formula

The limiting wall stress has been established at minimum test pressure, and the allowable minimum wall thickness which will develop this wall stress can be readily computed from the Bach formula which is given below:

\[ S = P \times \left( \frac{1.3D^2 + 0.4d^2}{D^2 - d^2} \right) \]

Where

- \( S \) = Wall stress at test pressure, in pounds per square inch.
- \( P \) = Test pressure in pounds per square inch.
- \( D \) = Outside diameter inches.
- \( d \) = Inside diameter in inches.

This formula may also be written:

\[ S = \frac{1.3D^2 + 0.4d^2}{D^2 - d^2} = \frac{1.3(D/d)^2 + 0.4}{(D/d)^2 - 1} \]

The computations for this formula have already been worked out, and the results are tabulated in Table 1 for the major range covered by ICC/DOT cylinders.

4.4 The Clavarino Formula

The Clavarino formula expresses the relationship between the elastic expansion and the cylinder O.D. and I.D. and from this, the wall thickness can be computed.

\[ EE = PKV (16.387) \times \left[ \frac{D^2}{D^2 - d^2} \right] \]

Where

- \( EE \) = Elastic expansion (total less permanent) in c.c.
- \( P \) = Test pressure in pounds per square inch.
- \( K \) = Factor (from Section 3, above).
- \( V \) = Internal volume in cubic inches
- 16.387 = Number of cc in 1 cubic inch.
- \( D \) = Outside diameter in inches.
- \( d \) = Inside diameter in inches.
- \( t \) = Wall thickness = \( 1/2 (D - d) \).
4.5

**Example:** As an example, determine the elastic expansion rejection limit for the following cylinder:

Chrome/moly (4130X) steel cylinder stamped ICC/DOT 3AA 2015

- \( d = 9.00 \) inches (outside diameter)
- \( L = 51.0 \) inches (length)
- \( V = 2640 \) cubic inches
- \( S = 67,000 \) psi (ICC/DOT limitation for filling to 10% in excess of the marked service pressure, reference 49 CFR 173.302(c) [3])
- \( k = 1.24 \times 10^{-7} \) (for sources for "K" factor, see Section 3)
- \( P = 3360 \) psi (5/3 x 2015)

Therefore, substituting in the Bach formula:

\[
S = P \times \frac{1.3D^2 + 0.4d^2}{D^2 - d^2}
\]

\[
67,000 = 3360 \times \frac{1.3(9.0)^2 + 0.4d^2}{(9.0)^2 - d^2}
\]

\( D = 8.6157" \) and \( t = 0.192" \)

Where \( t = \) Wall Thickness = \( (D-d)/2 \)

Instead of the laborious computation involved, a simpler method is to use the figures of Table 1 as follows:

\[
\frac{S}{P} = \frac{67,000}{3360} = 19.9405
\]

from table 1,

\[
\frac{D}{d} = 1.0446
\]

\( d = 8.6157" \)

and \( t = 0.192" \)

To determine the elastic expansion rejection limit, substitute in the Clavarino formula:

\[
EE = PKV (16.387) \times \left[ \frac{D^2}{D^2 - d^2} \right] = (3360)(1.24 \times 10^{-7})(2640)(16.387) \times \left( \frac{(9.0)^2}{(9.0)^2 - (8.6157)^2} \right) = 216 \text{ cc}
\]

Cylinders that exceed the 216 cc limitation on retest are therefore considered as thin wall rejects and are rejected for further service at 10% in excess of their marked service pressure.

4.6

A simplified way of determining the elastic expansion rejection limit is to solve the combined Bach/Clavarino formula as follows:

---

3 This equation appears in 49 CFR 173.302(c) under Note 1 and is used to calculate the elastic expansion rejection limit using the average wall stress limitation. (See Appendix B) [3].
Using the known values from 4.5 above and substituting

\[ EE = KV (16.387) \times \left( \frac{S + 0.4P}{1.7} \right) \]

\[ EE = (1.24 \times 10^{-7}) (2640) (16.387) \times \left( \frac{67000 + 4(3360)}{1.7} \right) = 216 \text{ cc} \]

4.7

For those cylinder users not desiring to calculate their own "K" factors and elastic expansion rejection limits, values are provided in table 2 for many commonly used cylinder types and sizes. The "K" factors and water volumes used in the calculations of elastic expansion rejection limits were the lowest values reported from the various cylinder manufacturers and are generally for cylinders with bottoms convex to pressure (bumped-back bottoms). These values vary with the method of cylinder manufacture and end design.

5 References
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Table 1—Solutions of Bach stress formula

\[
\frac{S}{P} = \frac{1.3 \cdot 0.2^{2} + 0.4 \cdot d^{2}}{d^{2} - 0.2^{2} + 0.4} = \frac{1.3 \cdot (d/d)_{1}^{2} + 0.4}{(d/d)_{1}^{2} - 1}
\]
Table 2—Standard elastic expansion and K-factor limits

Unless otherwise calculated

2a—Industrial high pressure seamless steel cylinders

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<th>Test pressure (psi)</th>
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<td>3000</td>
<td>9</td>
<td>51</td>
<td>1.30</td>
<td>225</td>
</tr>
<tr>
<td>250</td>
<td>3A CR-MO 3)</td>
<td>1800</td>
<td>3000</td>
<td>9</td>
<td>51</td>
<td>1.30</td>
<td>225</td>
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<td>250</td>
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<td>1800</td>
<td>3000</td>
<td>9</td>
<td>51</td>
<td>1.30</td>
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<td>250</td>
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<td>3000</td>
<td>9</td>
<td>51</td>
<td>1.30</td>
<td>225</td>
</tr>
</tbody>
</table>

NOTES

1) Dimensions of cylinders and tubes are nominal figures and may vary slightly with various cylinder manufacturers.
2) For data on cylinders not listed or for additional information, contact the original cylinder manufacturer.
3) Prior to 1948, the designation “3AA” was not used to indicate cylinders made from alloy steels and made to higher wall stresses than 3A cylinders. Therefore, the elastic expansion rejection limits listed for cylinders made of chrome-moly or alloy steels must not be used to indicate the suitability of a cylinder for further services unless the cylinder can be identified as being made from chrome-moly or alloy steel.
4) All Taylor-Wharton/Harrisburg Steel manufactured "W.D." (War Department) cylinders 9" O.D. x 51 inches long and stamped 3A2260 or 3A2265, and 91/4" O.D. x 55 inches long and stamped 3A2400, were manufactured from 4130 chrome-moly steel and quality under the “3AA” specification. However, "W.D." cylinder 9" O.D. x 51" long stamped 3A1800, 3A2015 or 3A2400 may be either “3A” or “3AA” cylinders and shall be handled per note 3
5) Marison Co. began producing this cylinder model in 1986 and each cylinder is stamped "REE 16.7."
### 2b—Medical high pressure seamless steel cylinders

<table>
<thead>
<tr>
<th>Letter size cylinder</th>
<th>ICC/DOT Spec.</th>
<th>Service pressure (psi)</th>
<th>Test pressure (psi)</th>
<th>Nominal dimensions</th>
<th>&quot;K&quot; factor (x 10^7)</th>
<th>Elastic expansion rejection limit (cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 3AA</td>
<td>2015</td>
<td>3360</td>
<td>3 1/4</td>
<td>13</td>
<td>1.3</td>
<td>7.2</td>
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<td>3360</td>
<td>4 1/4</td>
<td>16 3/4</td>
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<td>14.5</td>
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<td>E 3AA</td>
<td>2015</td>
<td>3360</td>
<td>4 1/4</td>
<td>25 3/4</td>
<td>1.24</td>
<td>23.1</td>
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<td>3360</td>
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<td>7</td>
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<td>8 1/2</td>
<td>51</td>
<td>1.30</td>
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<td>H 3A</td>
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<td>178</td>
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<td>2015</td>
<td>3360</td>
<td>9</td>
<td>51</td>
<td>1.24</td>
<td>216</td>
</tr>
</tbody>
</table>

**NOTE**—Industrial gas cylinders are frequently used in medical gas service. Refer to table 2a for data.

### 2c—Tube trailer high pressure seamless steel cylinders

<table>
<thead>
<tr>
<th>ICC/DOT Spec.</th>
<th>Service pressure (psi)</th>
<th>Test pressure (psi)</th>
<th>Nominal dimensions</th>
<th>&quot;K&quot; factor (x 10^7)</th>
<th>Elastic expansion rejection limit (cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3A</td>
<td>2400</td>
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<td>9 5/8</td>
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<td>1.25</td>
</tr>
<tr>
<td>3A</td>
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<td>4000</td>
<td>9 5/8</td>
<td>21-0</td>
<td>1.25</td>
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<td>3A</td>
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<td>4000</td>
<td>11700</td>
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<td>1.25</td>
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<td>3A</td>
<td>2400</td>
<td>4000</td>
<td>9 5/8</td>
<td>21-0</td>
<td>1.26</td>
</tr>
<tr>
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<td>2400</td>
<td>4000</td>
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</tr>
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<td>3A</td>
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<td>4000</td>
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<td>1.26</td>
</tr>
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<td>21-0</td>
<td>1.26</td>
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<td>21-0</td>
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<td>3000</td>
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<td>1.2624</td>
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<tr>
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<td>4000</td>
<td>22</td>
<td>32-10</td>
<td>1.2998</td>
</tr>
<tr>
<td>3AAXSP5372</td>
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<td>22</td>
<td>34-4</td>
<td>1.2998</td>
</tr>
<tr>
<td>3T</td>
<td>2400(4)</td>
<td>4000</td>
<td>22</td>
<td>18-6</td>
<td>1.2863</td>
</tr>
<tr>
<td>3T</td>
<td>2400(4)</td>
<td>4000</td>
<td>22</td>
<td>19-0</td>
<td>1.2863</td>
</tr>
<tr>
<td>3T</td>
<td>2400(4)</td>
<td>4000</td>
<td>22</td>
<td>34-4</td>
<td>1.2863</td>
</tr>
<tr>
<td>3T</td>
<td>2400(4)</td>
<td>4000</td>
<td>22</td>
<td>36-0</td>
<td>1.2863</td>
</tr>
<tr>
<td>3T</td>
<td>2400(4)</td>
<td>4000</td>
<td>22</td>
<td>40-0</td>
<td>1.2863</td>
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<tr>
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<td>4750</td>
<td>22</td>
<td>34-4</td>
<td>1.2998</td>
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<tr>
<td>3T</td>
<td>2850</td>
<td>4750</td>
<td>22</td>
<td>36-0</td>
<td>1.2998</td>
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<tr>
<td>3T</td>
<td>2850</td>
<td>4750</td>
<td>22</td>
<td>40-0</td>
<td>1.2998</td>
</tr>
</tbody>
</table>

**NOTES**

1. Dimensions of cylinders and tubes are nominal figures and may vary slightly with various cylinder manufacturers.

2. Cylinders having stamped service pressure (SP) other than 2400 psi are to have REE calculated using the following formula:

   \[ \text{REE} = 0.002103V \left( 67,000 + 0.4P \right) \]

   where \( P = \text{Test Pressure} \times \frac{5}{3} \)

   \( V = \text{Cylinder Volume (cu. ft.)} \)

3. Cylinders manufactured to Special Permit No. 5372 (issued March, 1968) having a .431" minimum wall which preceded cylinders manufactured to DOT 3T specification (8-73) having a .415" minimum wall.

4. Cylinders having stamped service pressures (SP) other than 2400 psi are to have REE calculated using the following formula:

   \[ \text{REE} = 0.002143V \left( 87,000 + 0.4P \right) \]

   where \( P = \text{Test Pressure} \times \frac{5}{3} \)

   \( V = \text{Cylinder Volume (cu. ft.)} \)
Appendix A—Flow chart for service life control

VISUAL INSPECTION

FAILED
MUST BE SCRAPPED

PASSED
REHEAT TREATMENT

HYDROSTATIC TEST

FAILED
10% PERMANENT EXPANSION REQUIREMENT
MUST BE REHEAT-TREATED AND REQUALIFIED (3) OR SCRAPPED

FAILED
ELASTIC EXPANSION REJECTION LIMIT AND PASSED 10% PERMANENT EXPANSION
MAY BE USED AT MARKED SERVICE PRESSURE OR A LOWER SERVICE PRESSURE

PASSED
10% PERMANENT EXPANSION REQUIREMENT ONLY (CC LIMITS NOT USED)
PASSED
MEETS SIDEWALL THICKNESS REQUIREMENT PER SECTION 2.5

PASSED
ELASTIC EXPANSION REJECTION LIMIT AND 10% PERMANENT EXPANSION REQUIREMENTS
MAY BE USED AT MARKED SERVICE PRESSURE, A LOWER SERVICE PRESSURE, OR A PRESSURE 10% IN EXCESS OF THE MARKED SERVICE PRESSURE.

(1) Visual inspection must be conducted in accordance with Compressed Gas Association C-6 [2].

(2) May be conducted after the hydrostatic test depending on the existing shop practice.

(3) Reheat-treated cylinders must be requalified in accordance with 49 CFR 173.34 [3].
Appendix B—DOT Hazardous Materials R 173.302(c) special filling limits

(c) Special filling limits for specifications 3A, 3AX, 3AA, 3AAX, and 3T cylinders. Specifications 3A, 3AX, 3AA, 3AAX, and 3T (§§ 178.36, 178.37, 178.45 of this subchapter) cylinders may be charged with compressed gases, other than liquefied, dissolved, poisonous, or flammable gases to a pressure 10 percent in excess of their marked service pressure, provided:

(1) That such cylinders are equipped with frangible disc safety relief devices (without fusible metal backing) having a bursting pressure not exceeding the minimum prescribed test pressure.

(2) That the elastic expansion shall have been determined at the time of the last test or retest by the water jacket method.

(3) That either the average wall stress or the maximum wall stress shall not exceed the wall stress limitation shown in the following table: (See notes 1 and 2) [3].

<table>
<thead>
<tr>
<th>Type of steel</th>
<th>Average wall stress limitation</th>
<th>Maximum wall stress limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain carbon steels over 0.35 carbon and medium manganese steels</td>
<td>53,000</td>
<td>58,000</td>
</tr>
<tr>
<td>Steels of analysis and heat treatment specified in spec. 3AA</td>
<td>67,000</td>
<td>73,000</td>
</tr>
<tr>
<td>Steel of analysis and heat treatment specified in spec. DOT-3T</td>
<td>87,000</td>
<td>94,000</td>
</tr>
<tr>
<td>Plain carbon steels less than 0.35 carbon made prior to 1920</td>
<td>45,000</td>
<td>48,000</td>
</tr>
</tbody>
</table>

NOTE 1—The average wall stress shall be computed from the elastic expansion data using the following formula:

\[ S = \frac{1.7 EE}{KV} - 0.4P \]

where

- \( S \) = wall stress, pounds per square inch;
- \( EE \) = elastic expansion (total less permanent) in cubic centimeters;
- \( K \) = factor \( x 10^{-7} \) experimentally determined for the particular type of cylinder being tested;
- \( V \) = internal volume in cubic centimeters (1 cubic inch = 16.387 cubic centimeters);
- \( P \) = test pressure, pounds per square inch.

Formula derived from formula of Note 2 and the following:

\[ EE = PKV \times \frac{D^2}{D^2 - d^2} \]
NOTE 2—The maximum wall stress shall be computed from the formula:

\[ S = P \frac{(1.3D^2 + 0.4d)^2}{D^2 - d^2} \]

where

- \( S \) = wall stress, pounds per square inch;
- \( P \) = test pressure, pounds per square inch;
- \( D \) = outside diameter, inches;
- \( d = D - 2t \), where \( t \) = minimum wall thickness determined by a suitable method.

(4) That an external and internal visual examination made at the time of test or retest shows the cylinder to be free from excessive corrosion, pitting, or dangerous defects.

(5) That a plus sign (+) be added following the test date marking on the cylinder to indicate compliance with paragraphs (c) (2), (3) and (4) of this section.