Reinforced Thermoset Plastic Corrosion-Resistant Equipment

TENTATIVE
SUBJECT TO REVISION OR WITHDRAWAL
Specific Authorization Required for Reproduction or Quotation
ASME Standards and Certification
Part 2
Materials

2-100 SCOPE

Part 2 defines the materials comprising the glass-fiber reinforced thermoset polyester and vinyl ester resin laminates, and the types of laminates used to fabricate the RTP corrosion-resistant equipment. See Mandatory Appendix M-12 for thermoplastic lining materials used in dual laminate vessels.

2-200 LAMINATE COMPOSITIONS

The composition of the allowable RTP laminates is limited to the specific materials in Part 2 and Mandatory Appendices M-1 and M-2. Subpart 2A covers predefined standard laminates as representative flat laminates. Subpart 2B covers laminates developed using the Lamination Analysis Method, by which the modulus properties of laminates are obtained. Subpart 2C covers permissible tolerances for laminate thickness variation.

Construction and testing for properties of design basis laminates are required in Subpart 2A. Calculation of laminate properties by the Lamination Analysis Method (Mandatory Appendix M-3) is addressed in Subpart 2B.

Minimum inspections and tests to be performed on reinforcements, prior to their use, are described in Mandatory Appendix M-1.

Minimum inspections and tests to be performed on resins, curing agents, and common additives, prior to their use, are described in Mandatory Appendix M-2.

2-210 Resin and Reinforcement Substitution

The Fabricator shall use the same resins and reinforcements during fabrication as used in the design basis laminates and Lamination Analysis Method, with the exception of the surfacing veil, which may be changed as required for corrosion resistance.

2-300 MATERIALS

(21) 2-310 Resin Matrix

The resin shall be that polyester or vinyl ester specified by the User’s Basic Requirements Specification. Only resins with a heat deflection temperature (HDT) of at least 180°F (82°C) per ASTM D648 with a 264 psi (1.82 MPa) loading and a 1/8-in. (3-mm) specimen, as published by the resin manufacturer, shall be used. Properties established through testing at ambient temperature are valid up to 180°F (82°C) or up to 35°F (19°C) below the resin’s HDT, whichever is lower. When a maximum flame retardancy is specified by the UBRS, the flame spread rating shall be determined by the resin manufacturer according to ASTM E84 using all mat laminates greater than 0.1 in. (2.5 mm) thick. Verification of the flame spread rating is not required as a part of laminate qualification. Since flame spread can be determined only on flat laminate panels, verification is not required on fabricated equipment. Prior to use in laminate fabrications, the resin shall be inspected, tested, and found acceptable by the inspections and tests specified in Mandatory Appendix M-2.

(a) The catalyst/promoter/accelerator system shall be as recommended by the resin manufacturer and specified in the Fabricator’s written procedures.

(b) The resin shall not contain any pigment, dyes, colorants, or filler, except as follows:

(1) A thixotropic agent that does not interfere with visual inspection of laminate quality, or with the required corrosion resistance of the laminate, may be added for viscosity control.

NOTE: The addition of a thixotropic agent may reduce the resistance of a laminate to some corrosive chemical environments. It is the responsibility of the Fabricator to obtain approval from the selector of the resin prior to using a thixotropic agent in the inner surface (para. 2A-221) or the interior layer (para. 2A-222).

(2) Resin pastes used to fill crevices before overlay shall not be subject to these limitations.

(3) Pigments, dyes, or colorants may be added to the exterior surface when specified by the UBRS.

NOTE: The addition of pigment, dyes, or colorants may interfere with visual inspection of laminate quality.

(4) Flame retardant synergists shall be used only when required in the UBRS. If fire retardant synergists were used to obtain the specified ASTM E84 flame spread rating, the same type and amount must be used in the laminate.

NOTE: The addition of fire retardant synergists may interfere with visual inspection of laminate quality.

(5) Common additives, as described in Mandatory Appendix M-2, Article F, may be added without requalifying the standard laminate.
(6) Fillers or additives for abrasion resistance, thermal shock resistance, and electrical conductivity are allowed. A requalification of the design basis laminate is required if these fillers or additives are added to the structural laminate. All fillers or additives shall be approved by the End User and the resin supplier for the design chemical service.

Note that fillers may interfere with visual inspection of the laminate and could affect properties of the laminate.

2-320 Fiber Reinforcement

Fiber reinforcements shall be in compliance with the following references for each material type:

(a) fiberglass surfacing veil, organic fiber surfacing veil, carbon fiber surfacing veil, and fiberglass chopped strand mat — Mandatory Appendix M-1, Article A

(b) fiberglass spray-up roving and filament winding roving — Mandatory Appendix M-1, Article B

(c) fiberglass woven roving fabric, fiberglass unidirectional fabric, and fiberglass nonwoven multifabric — Mandatory Appendix M-1, Article C

(d) fiberglass milled fiber — Mandatory Appendix M-1, Article D

With the exception of surfacing veils, all fiberglass reinforcement shall be type E.

2-330 Balsa Wood Core

Balsa wood core materials shall be in compliance with Mandatory Appendix M-13.

SUBPART 2A
REQUIREMENTS FOR REPRESENTATIVE FLAT LAMINATES

2A-100 INTRODUCTION

A representative flat laminate is one made with the laminate sequence used in the design. Design basis laminates per para. 2A-300 are required.

2A-200 LAMINATE REQUIREMENTS

2A-210 Laminate Construction

Laminate construction shall be in accordance with the tabulated lay-up sequence for the specified type.

(a) Type I laminate structure is detailed in Table 2A-1.

(b) Type II laminate structure is detailed in Table 2A-2.

(c) Type X laminate structure is detailed in Subpart 2B.

2A-220 Laminate Composition

Laminates shall consist of a corrosion-resistant barrier (comprised of an inner surface and interior layer) and a structural layer. The reinforcement content of the corrosion barrier shall be 20% to 30% by weight.

2A-221 Inner Surface Corrosion-Resistant Barrier.

The inner surface exposed to the contents shall be a resin-rich layer reinforced with a surfacing veil providing a thickness of 0.01 in. to 0.02 in. (0.25 mm to 0.50 mm).

2A-222 Interior Layer Corrosion-Resistant Barrier.

The inner surface layer, exposed to the contents, shall be followed with an interior layer. This layer is composed of resin reinforced with noncontinuous glass fiber strands (1.0 in. to 2.0 in. (25 mm to 50 mm) long), applied in a minimum of two plies totaling a minimum of 3 oz/ft² (900 g/m²). These plies shall be layers of chopped strand mat and/or chopped roving. Each ply of mat or pass of chopped roving shall be well rolled to thoroughly wet out reinforcement and remove entrapped air prior to the application of additional reinforcement. The combined thickness of the inner surface and interior layer shall not be less than 0.10 in. (2.5 mm). The corrosion-resistant barrier is to exotherm and cool before the structural layer is applied.

2A-224 Outer Surface

(a) The outer surface of the finished laminate shall be a separately applied paraffinated resin coat that, when cured, passes the acetone test per ASTM C582, para. 9.2.2. This outer surface coat shall be applied either over the final mat ply of the structural layer or over an additional resin-rich layer when required by (b).

(b) When the UBRS indicates the outer surface will be subjected to spillage or a corrosive environment, a resin-rich layer, in accordance with para. 2A-221, shall be applied over the final mat ply of the structural layer prior to the application of the paraffinated resin coat in (a).
The UBRS may include provisions to minimize ultraviolet degradation of the laminate. Methods include use of ultraviolet absorbers, screening agents, or resins resistant to ultraviolet degradation, or incorporation of pigment of sufficient opacity in the paraffinated resin coat. Since pigmentation makes laminate inspection difficult, the resin-rich layer shall be applied only after the laminate has been inspected by the Inspector. This provision may be waived by the User.

Where the final lay-up is exposed to air, full surface cure shall be obtained by applying to the final lay-up a coat of paraffinated resin that, when cured, passes the acetone test. Other techniques such as sprayed, wrapped, or overlaid films are also acceptable methods to attain surface cure, provided the surface resin under the film passes the acetone test.

### Table 2A-1 Standard Laminate Composition Type I

<table>
<thead>
<tr>
<th>Nominal Thickness, in. (mm)</th>
<th>Sequence of Plies</th>
<th>Drafting Symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V M M M M M M M M</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18</td>
</tr>
<tr>
<td>0.18 (4.6)</td>
<td>V M M M M M M M M</td>
<td>V, 4M</td>
</tr>
<tr>
<td>0.23 (5.8)</td>
<td>V M M M M M M M M</td>
<td>V, 5M</td>
</tr>
<tr>
<td>0.27 (6.9)</td>
<td>V M M M M M M M M</td>
<td>V, 6M</td>
</tr>
<tr>
<td>0.31 (7.9)</td>
<td>V M M M M M M M M</td>
<td>V, 7M</td>
</tr>
<tr>
<td>0.35 (8.9)</td>
<td>V M M M M M M M M</td>
<td>V, 8M</td>
</tr>
<tr>
<td>0.40 (10.2)</td>
<td>V M M M M M M M M</td>
<td>V, 9M</td>
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<tr>
<td>0.44 (11.2)</td>
<td>V M M M M M M M M</td>
<td>V, 10M</td>
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<tr>
<td>0.48 (12.2)</td>
<td>V M M M M M M M M</td>
<td>V, 11M</td>
</tr>
<tr>
<td>0.53 (13.5)</td>
<td>V M M M M M M M M</td>
<td>V, 12M</td>
</tr>
<tr>
<td>0.57 (14.5)</td>
<td>V M M M M M M M M</td>
<td>V, 13M</td>
</tr>
<tr>
<td>0.61 (15.5)</td>
<td>V M M M M M M M M</td>
<td>V, 14M</td>
</tr>
<tr>
<td>0.66 (16.8)</td>
<td>V M M M M M M M M</td>
<td>V, 15M</td>
</tr>
<tr>
<td>0.70 (17.8)</td>
<td>V M M M M M M M M</td>
<td>V, 16M</td>
</tr>
<tr>
<td>0.74 (18.8)</td>
<td>V M M M M M M M M</td>
<td>V, 17M</td>
</tr>
</tbody>
</table>

**GENERAL NOTES:**

(a) Thicknesses above 0.74 in. (18.8 mm) nominal can be used by adding additional plies of mat.

(b) Actual thickness and glass content of each sequence of plies shall be established by each Fabricator based on his or her design basis laminate.

(c) Corrosion barrier (plies 1, 2, and 3) shall gel and exotherm before structural plies are added.

(d) Structural lay-up may be interrupted at intervals long enough to exotherm in accordance with Fabricator's procedure.

(e) A weight-equivalent layer or layers of chopped strand glass or mat may be used in place of layers of 1.5 oz/ft² (450 g/m²) mat.

**NOTES:**

1. Nominal thickness is calculated as follows:
   \[ V = 10 \text{ mil surface mat (veil)} - 0.010 \text{ in./ply (0.25 mm/ply)} \]
   \[ M = 1.5 \text{ oz/ft}^2 \text{ mat} - 0.043 \text{ in./ply (450 g/m}^2 \text{ mat} - 1.1 \text{ mm/ply)} \]

2. This information is based on historical data and may not reflect all laminates made today. Laminates made today are often thinner and have a higher glass content than noted in the Table. The Table should be used for establishing minimum glass plies per nominal laminate thickness. Ply thicknesses should be based on design basis laminates.

(c) The UBRS may include provisions to minimize ultraviolet degradation of the laminate. Methods include use of ultraviolet absorbers, screening agents, or resins resistant to ultraviolet degradation, or incorporation of pigment of sufficient opacity in the paraffinated resin coat. Since pigmentation makes laminate inspection difficult, the resin-rich layer shall be applied only after the laminate has been inspected by the Inspector. This provision may be waived by the User.

(d) Where the final lay-up is exposed to air, full surface cure shall be obtained by applying to the final lay-up a coat of paraffinated resin that, when cured, passes the acetone test. Other techniques such as sprayed, wrapped, or overlaid films are also acceptable methods to attain surface cure, provided the surface resin under the film passes the acetone test.

### 2A-300 REQUIREMENTS FOR PHYSICAL AND MECHANICAL PROPERTIES

(a) The Fabricator shall prepare design basis laminates for each combination of resin and glass to determine thickness and glass content. Straight line interpolation shall be used to determine values not tested directly. In addition, the Fabricator shall choose one or more of the following options to establish design values:

1. The Fabricator shall specify the minimum values in Table 2A-3. This method shall not be used where laminates are fabricated for use above 180°F (82°C).

2. The Fabricator shall obtain the tensile strength, tensile modulus, flexural strength, and flexural modulus of the design basis laminates in accordance with para. 2A-400. Results shall be certified by the individual who conducted or supervised the testing.

(a) When the corrosion barrier is included in the design as a contributor to the structural strength of the laminate, the following design basis laminates shall
include the inner surface, interior layer, and structural layer, but not the outer surface:

- Type I, 0.18 in. (4.6 mm) nominal thickness
- Type I, 0.48 in. (12.2 mm) nominal thickness
- Type I, 0.74 in. (18.8 mm) nominal thickness
- Type II, 0.22 in. (5.6 mm) nominal thickness
- Type II, 0.49 in. (12.5 mm) nominal thickness
- Type II, 0.76 in. (19.3 mm) nominal thickness
- Type X, 0.25 in. (6.4 mm) nominal thickness
- Type X, 0.50 in. (12.7 mm) nominal thickness
- Type X, 0.75 in. (19.1 mm) nominal thickness

When the corrosion barrier is excluded from the design, a contributor to the structural strength of the laminate per para. 6-930(d)(5)(-d), the following design basis laminates shall include only the structural layer:

- Type I, 0.35 in. (8.9 mm) nominal thickness
- Type II, 0.37 in. (9.4 mm) nominal thickness
- Type X, 0.38 in. (9.7 mm) nominal thickness

Properties of Types I, II, and noncylindrical X laminates in (-a) and (-b) above shall be established on flat laminates prepared under shop conditions. For Type II laminates, the woven roving is laid-up in square array with warp rovings parallel layer to layer, and test specimens are cut parallel to the warp rovings.

For design purposes, properties established at the applicable ASTM test method temperature are valid up to 180°F (82°C) or up to 35°F (19°C) below the resin's HDT, whichever is lower. Where laminates are fabricated for use at design temperatures above 180°F (82°C) or up to 35°F (19°C) below the HDT, certification of strength and modulus per paras. 2A-400(a) and 2A-400(b) shall be supplied at or above the specified temperature.

- The thickness and glass content of laminates shall be based on the data obtained from the Fabricator's design basis laminates. For laminate Types I, II, and X, thickness and glass content shall be determined from laminates described in (a)(2). Six thickness and glass content (weight percent) readings shall be taken on each design basis laminate. They shall be taken at 1 in. to 2 in. (25 mm to 50 mm) from each corner, except for two readings taken from the middle of the laminate. The highest thickness and glass content (weight percent) reading taken (of the six) shall be no more than 115% of the lowest reading taken. The six readings shall be averaged to give the design basis laminate thickness and glass content for each laminate tested. The average thickness value shall be from 85% to 115% of the nominal thickness listed in Tables 2A-1 and 2A-2.

2A-400 TEST METHODS

(a) Tensile strength and tensile modulus of elasticity shall be determined by ASTM D638, ASTM D3039 at 77°F (25°C), or ASTM D5083. The tensile modulus shall be determined using the data between 400 and 1,300 microstrain unless another strain range better represents the flat portion of the curve. Any strain range other than 400 and 1,300 microstrain shall be reported with the modulus value. Specimens shall be in accordance with Type III, Figure 1 of ASTM D638, or in accordance with para. 6.1.1 of ASTM D5083, except that actual laminate thickness shall be used.

(b) Flexural strength and flexural modulus of elasticity shall be determined by ASTM D790. The molded surface (corrosion barrier) shall be tested in compression.

(c) Glass content, weight percent, shall be determined in accordance with ASTM D2584.

(d) When required, the residual undisturbed glass fiber plies from ASTM D2584 shall be separated carefully and counted and/or weighed to confirm standard lay-up sequence.

(e) Thickness shall be measured with a micrometer or caliper. When the configuration of the part will not allow the use of these instruments, a digital magnetic intensity instrument or an ultrasonic thickness gage found to be accurate when measuring vessel cutouts shall be used.

(f) When required, thermal conductivity shall be measured in accordance with ASTM C177.

(g) When required, thermal expansion shall be measured in accordance with ASTM D696.

(h) For isotropic laminates, mechanical property testing in only one direction is required. For anisotropic laminates, testing in both the principal x and y directions is required.

2A-500 RECORDS

The results of all required tests shall be recorded and shall be available for review by the Inspector.

2A-600 ADDITIONAL STANDARD LAMINATE
COMPOSITIONS FOR SUBPART 2A

Other standard laminates may be used only after they have been listed as acceptable in Subpart 2A. In order for the new laminate to receive proper consideration,
information and data are required to properly categorize the laminate. In general, this information and data include, but are not necessarily limited to, the following:

(a) All materials of the laminate shall be identified and suggested specifications provided for any material not covered in Mandatory Appendix M-2.

(b) The laminate information needed includes tensile strength, tensile modulus, glass content, and thickness. The information shall be supplied in the form of Table 2A-1 and/or Table 2A-2, plus data for minimum properties of standard laminates, Table 2A-3. The data shall be generated from laminates made under typical shop conditions and tested per para. 2A-400. The information shall include the heat deflection temperature of the resin used, which is required to be 180°F (82°C) or greater.

NOTE: The requester should consider supplying data on laminates made using two or more widely different specific gravity resins by three or more fabricators, together with the appropriate Type I and/or Type II control laminate data.

Where the laminate is intended for special applications, requires special handling, or has known limitations or susceptibility to failure in certain services, precautionary requirements and information should be included in the submittal. The data should be submitted on laminates intended for use in place of the design basis laminates of Type I and/or Type II, as outlined in para. 2A-300(a)(2). Examples of representative field experiences should be submitted.

NOTE: When the new laminate is a minor modification of an existing standard laminate, the data required may be reduced with the concurrence of the Committee. When the data supplied is insufficient for an adequate evaluation, the Committee will request additional data.

2B-130 Structural Layer

(a) Application of the structural layer shall not alter the corrosion-resistant barrier.

(b) The first layer of the structural portion of the laminate shall be one or more plies of chopped strand mat totaling 0.75 oz/ft² (225 g/m²) minimum or equivalent chopped roving saturated with resin.

(c) The balance of the structural layer shall then be applied in strict duplication of the laminate sequence as designed per Mandatory Appendix M-3.

2B-140 Outer Surface

See para. 2A-224.

2B-200 REQUIREMENTS FOR PHYSICAL AND MECHANICAL PROPERTIES

(a) The resin matrix tensile modulus and specific gravity are measured on a fully cured 0.125-in. (3-mm) thick neat resin casting. Tensile modulus and cured specific gravity properties provided by the resin manufacturer may be used for design temperatures up to 180°F (82°C).

(b) Standardized tensile modulus and specific gravity for E glass shall be used for the Lamination Analysis Method (Mandatory Appendix M-3).

(c) Laminate properties shall be calculated using the Lamination Analysis Method contained in Mandatory Appendix M-3.

(d) The Fabricator shall prepare design basis laminates and test per para. 2A-300.

(e) For cylindrical laminates, the following mechanical property tests are required: flexural strength and modulus in the hoop and axial directions (corrosion barrier in compression) and tensile strength and modulus in the axial direction.

2B-300 TEST METHODS

(a) Glass content, weight percent, shall be determined in accordance with ASTM D2584.

(b) Matrix tensile modulus shall be determined in accordance with ASTM D638.

(c) Matrix specific gravity shall be determined in accordance with ASTM D792.

(d) Thickness of individual plies shall be determined with a microscope or other instrument having an accuracy of 0.001 in. (0.02 mm).

2B-400 RECORDS

For each laminate in para. 2B-130, wind angles, number of wind cycles, and supplemental reinforcement shall be recorded. The objective is to uniquely define each laminate. Also, for each laminate, results of testing done in...
(c) Where a maximum deflection is prescribed by formula in paras. 3A-200 through 3A-800, this shall be the maximum.

(d) Where no formula is prescribed in paras. 3A-200 through 3A-800 but other recognized engineering formulas are applicable, the rules of paras. 3A-120 through 3A-140 shall apply.

3A-120 Other Formulas

Details of design and construction for which no rule is provided in Subpart 3A, but for which other recognized engineering formulas exist, may be accepted by comparing calculated laminate stress with ultimate laminate strength to establish a minimum design factor.

3A-121 Laminate Types. Other recognized engineering formulas are applicable to Type I or Type II laminates, laminates in accordance with Subpart 2B, or combinations of Types I and II. Other combinations, e.g., Type II with laminates in accordance with Subpart 2B, require additional consideration. laminate design strengths are applicable to reinforcement patterns continuing in the plane of the membrane.

3A-122 Design Factors. The minimum design factors applied to ultimate strength-based design shall be 10 for sustained loads and combinations of sustained loads, and 5 for intermittent (short-term) loads taken individually and in combination with sustained loads.

3A-123 Loadings. Loadings to be considered include those listed in para. 3A-100.

3A-124 Laminate Strengths. Laminate tensile strength and flexural strength are as established in Subpart 2A. Ultimate secondary bond shear stress is considered to be 2,000 psi (13.79 MPa). Ultimate peel strength is considered to be 500 lb/in. (88 N/mm).

3A-125 Filament Wound Laminates. For design in accordance with this section, the ultimate hoop tensile strength of filament wound laminates wound at an angle of 54 deg or higher to the mandrel may be determined by testing or taken to be 0.01 times the calculated hoop tensile modulus. Axial tensile and flexural strength of filament wound laminates shall be established by testing.

3A-126 Combined Stress. Combined flexural and membrane stresses shall comply with the following rule:

\[
\frac{\sigma_{mc}}{S_f} + \frac{\sigma_{fc}}{S_f} \leq \frac{1}{F_{sus}}
\]

and

\[
\frac{\sigma_{mi}}{S_f} + \frac{\sigma_{fi}}{S_f} \leq \frac{1}{F_{int}}
\]

where

\[
F_{sus} = \text{design factor} = 10 \text{ for sustained loads}
\]

\[
F_{int} = \text{intermittent load design factor} = 5
\]

3A-127 Recognized Formulas. Other recognized formulas include stress calculations presented in various sections of the ASME pressure vessel codes, formulas included in the nonmandatory appendices of this Standard, and well-documented formulas presented elsewhere.

3A-130 Maximum Corrosion-Resistant Barrier Strain

In addition to the stress criteria listed above, the tensile strain in the corrosion-resistant barrier shall be limited to the following:

(a) for sustained loads: 0.0013 in./in. (mm/mm) for resins for which the tensile elongation of the cast resin is at least 4%, and 0.0010 in./in. (mm/mm) for all other resins. Elongation of the resin shall be determined in accordance with ASTM D638 at 77°F (25°C).

(b) for intermittent loads: 0.0020 in./in. (mm/mm).

It is not necessary to apply the corrosion barrier strain limits in (a) or (b) to Type I or Type II laminates. The stress criteria in Subpart 3A are adequate to limit the corrosion barrier strains to acceptable values in Type I and Type II laminates.

3A-140 Maximum Compressive Stress Stability

In addition to the stress criteria listed above, for all loading conditions and combinations (including external pressure) that result in compressive loads in a shell, the stress shall be limited to one-fifth of the critical buckling stress.

3A-150 Conservative Design

Where the application of para. 3A-110(d) indicates a less-conservative design than para. 3A-110(a), para. 3A-110(b), or para. 3A-110(c), additional justification shall be provided before using the less-conservative design.
3A-200 DESIGN FOR TOTAL INTERNAL PRESSURE

3A-210 Calculation of Minimum Thickness of Cylindrical Shells

(a) Contact molded construction is calculated as follows:

\[ t_h = \frac{P_h}{E_{ht} \cdot (0.001 \times \tau_h)} \]

\[ t_a = \frac{N_{ax}}{S_{az}} \]

\[ D_f = \text{inside diameter, in. (mm)} \]

\[ P = \text{design factor} = 10 \]

\[ N_{ax} = \text{axial force per circumferential inch of shell, lb/in. (N/mm)} \]

\[ S_{az} = \text{ultimate hoop tensile strength, psi (MPa)} \]

\[ \tau_h = \text{total wall thickness, in. (mm), for axial stress} \]

\[ t_h = \text{total wall thickness, in. (mm), for circumferential stress} \]

The shell thickness shall be the greater of \( t_a \) or \( t_h \) at the point considered by the calculation.

(b) Filament wound construction is calculated as follows:

\[ t_h = \frac{P h}{2(E_{af} \cdot \tau_h)} \]

\[ t_a = \frac{N_{ax}}{S_{az}} \]

NOTE: Corrosion-resistant barrier strain shall not exceed limits in para. 3A-130.

where

\[ E_h = \text{hoop tensile modulus, psi (MPa)} \]

The shell thickness shall be the greater of \( t_a \) or \( t_h \) at the point considered by the calculation.

3A-220 Design of Cylindrical Shells Under Combined Axial Loads

3A-221 Tensile Loads. The thickness of shells under combined axial tensile loads shall be equal to the largest value for \( t \) as calculated below:

(a) Shells under internal pressure shall meet the requirements of para. 3A-210.

(b) For shells under combined axial tensile design loads, \( t \) shall be calculated as follows:

\[ t = \frac{M_A}{n(D/2)^2 (S_{az}/F_a)} + \frac{F_A}{\pi D S_{ax}} + \frac{P D}{4 (S_{az}/F_a)} \]

where

\[ D = \text{inside diameter, in. (mm)} \]

\[ F_A = \text{axial tensile force resulting from design loads, lb (N)} \]

\[ M_A = \text{bending moment resulting from design loads, in.-lb (N-mm)} \]

\[ P = \text{internal pressure, psi (MPa)} \]

\[ S_{az} = \text{ultimate axial tensile strength, psi (MPa)} \]

(c) For shells under combined axial tensile loads resulting from design loads, including wind, snow, or seismic loads, \( t \) shall be calculated as follows:

\[ t = \frac{M_A + M_{Al}}{n(D/2)^2 (S_{az}/F_a)} + \frac{F_A + F_{Al}}{\pi D S_{ax}} + \frac{P D}{4 (S_{az}/F_a)} \]

3A-222 Compressive Loads. The thickness of shells under combined axial compressive loads shall be equal to the largest value for \( t \) as calculated below.

(a) Shells under external pressure shall meet the requirements of para. 3A-310.

(b) For shells under combined axial compressive design loads, \( t \) shall be the greater of \( t_1 \) or \( t_2 \) calculated as follows:

\[ t_1 = \frac{M_A}{n(D/2)^2 (S_{az}/F_a)} + \frac{E_{bt}}{E_{hf}^{0.5}} + \frac{P e}{0.3 E_{ef}(F_{bt}/2)^{0.5}} \]

\[ t_2 = \left\{ \frac{M_A}{n(D/2)^2 (S_{az}/F_a)} + \frac{E_{bt}}{E_{hf}^{0.5}} + \frac{P e}{0.3 E_{ef}(F_{bt}/2)^{0.5}} \right\} \]

where

\[ D = \text{inside diameter, in. (mm)} \]

\[ E_{ef} = \text{axial flexural modulus, psi (MPa)} \]

\[ E_{hf} = \text{axial compressive force resulting from design loads, lb (N)} \]

\[ F_{bt} = \text{design factor} = 10 \]

\[ F_{bt} = \text{design factor} = 5 \]

\[ S_{az} = \text{ultimate axial tensile strength, psi (MPa)} \]
3A-200 DESIGN FOR TOTAL INTERNAL PRESSURE

3A-210 Calculation of Minimum Thickness of Cylindrical Shells

(a) Contact molded construction is calculated as follows:

Hoop Loading
\[ t_h = \frac{PD_t}{2S_h/F} \]
Axial Loading
\[ t_a = \frac{N_{ax}}{S_a/F} \]

where

\( D_t \) = inside diameter, in. (mm)
\( F \) = design factor = 10
\( N_{ax} \) = axial force per circumferential inch of shell, lb/in. (N/mm)
\( P \) = total internal pressure, psig (MPa) (internal pressure plus hydrostatic head)
\( S_a \) = ultimate axial tensile strength, psi (MPa)
\( S_h \) = ultimate hoop tensile strength, psi (MPa)
\( t_a \) = total wall thickness, in. (mm), for axial stress
\( t_h \) = total wall thickness, in. (mm), for circumferential stress

The shell thickness shall be the greater of \( t_a \) or \( t_h \) at the point considered by the calculation.

(b) Filament wound construction is calculated as follows:

Hoop Loading
\[ t_h = \frac{PD_t}{2(0.001E_h)} \]
Axial Loading
\[ t_a = \frac{N_{ax}}{S_a} \]

or

\[ t_h = \frac{PD_tE}{2S_h} \]
\[ t_a = \frac{N_{ax}E}{S_a} \]

NOTE: Corrosion-resistant barrier strain shall not exceed limits in para. 3A-130.

where

\( E_h \) = hoop tensile modulus, psi (MPa)

The shell thickness shall be the greater of \( t_a \) or \( t_h \) at the point considered by the calculation.

3A-220 Design of Cylindrical Shells Under Combined Axial Loads

3A-221 Tensile Loads. The thickness of shells under combined axial tensile loads shall be equal to the largest value for \( t \) as calculated below:

(a) Shells under internal pressure shall meet the requirements of para. 3A-210.

(b) For shells under combined axial tensile design loads, \( t \) shall be calculated as follows:

\[ t = \frac{M_A}{\pi(D/2)^2(S_a/F)} + \frac{F_A}{\pi D(S_a/F)} + \frac{PD}{4(S_a/F)} \]

where

\( D \) = inside diameter, in. (mm)
\( F \) = design factor = 10
\( F_A \) = axial tensile force resulting from design loads, lb (N)
\( M_A \) = bending moment resulting from design loads, in.-lb (N-mm)
\( P \) = internal pressure, psi (MPa)
\( S_a \) = ultimate axial tensile strength, psi (MPa)

(c) For shells under combined axial tensile loads resulting from design loads, including wind, snow, or seismic loads, \( t \) shall be calculated as follows:

\[ t = \frac{|M_A| + |M_B|}{\pi(D/2)^2(S_a/F)} + \frac{F_A + F_B}{\pi D(S_a/F)} + \frac{PD}{4(S_a/F)} \]

where

\( F \) = design factor = 5
\( F_B \) = axial tensile force resulting from wind, snow, or seismic loads, lb (N)
\( M_B \) = bending moment resulting from wind, snow, or seismic loads, in.-lb (N-mm)

3A-222 Compressive Loads. The thickness of shells under combined axial compressive loads shall be equal to the largest value for \( t \) as calculated below.

(a) Shells under external pressure shall meet the requirements of para. 3A-310.

(b) For shells under combined axial compressive design loads, \( t \) shall be the greater of \( t_1 \) or \( t_2 \) calculated as follows:

\[ t_1 = \frac{|M_A|}{\pi(D/2)^2(S_a/F_1)} + \frac{|F_A|}{\pi D(S_a/F_1)} + \frac{PD}{4(S_a/F_1)} \]
\[ t_2 = \left( \frac{|M_A|}{\pi(D/2)^2} + \frac{|F_A|}{\pi D} + \frac{PD}{4} \right)^{0.5} \]

where

\( D \) = inside diameter, in. (mm)
\( E_{of} \) = axial flexural modulus, psi (MPa)
\( E_{eff} = (E_{of}E_{ht})^{0.5} \)
\( E_{ht} \) = hoop tensile modulus, psi (MPa)
\( F_A \) = axial compressive force resulting from design loads, lb (N)
\( F_1 \) = design factor = 10
\( F_2 \) = design factor = 5
\( M_A \) = bending moment resulting from design loads, in.-lb (N-mm)
\( P_e \) = external pressure, psi (MPa)
\( S_a \) = ultimate axial tensile strength, psi (MPa)
3A-250 Minimum Thickness of Toriconical Heads

(a) The minimum thickness of toriconical heads that have a half apex angle, \( \alpha \), not greater than 60 deg shall be calculated as follows:

The thickness of the conical portion, \( t_c \), of a toriconical head, where the knuckle radius is at least 6% of the inside diameter of the shell and not less than three times the knuckle thickness, shall be

\[
t_c = \frac{2 \cos \alpha \left( \frac{S_u}{F} \right)}{P_t}
\]

where

- \( D_c \) = inside diameter of the conical portion of a toriconical head at the point of tangency to the knuckle, measured perpendicular to the axis of the cone (see Figure 3-2), in. (mm)
- \( D_t \) = inside diameter of head skirt (see Figure 3-2), in. (mm)
- \( r \) = inside knuckle radius, in. (mm)
- \( \alpha \) = one-half of the included (apex) angle of the cone at the centerline of the head

See subpart 3A-230 for equation variable definitions not included above.

The minimum thickness of the knuckle, \( t_k \), shall be

\[
t_k = 0.5M(R_c/F) - \frac{P_t}{F_{int}}
\]

where

- \( M = 0.25(3 + \sqrt{R_c/r}) \)
- \( R_c \) = head crown radius, in. (mm) ≤ \( D_t \)
- \( r \) = head knuckle radius, in. (mm) ≥ 0.06\( R_c \)
- \( S_u \) = ultimate tensile strength, psi (MPa)

For a torispherical head where \( R_c = D_t \) and \( r = 0.06R_c \), the minimum thickness, \( t \), reduces to

\[
t = 0.885(S_u/F)
\]

For toriconical heads subject to internal loading, the knuckle radius shall be externally reinforced in accordance with Figure 3-1, sketch (a). The reinforcement thickness shall be equal to the thickness of the head as calculated above. The thickness of a joint overlay near the knuckle radius tangent line of a dished head contributes to the knuckle reinforcement. For torispherical heads not subject to internal loading, see Figure 3-1, sketch (b).

3A-240 Minimum Thickness of Ellipsoidal Heads

The minimum thickness of ellipsoidal heads (2:1) shall be calculated as follows:

\[
t = \frac{P_t}{2S_u/F}
\]
(c) For shells under combined axial compressive loads resulting from design loads and occasional loads, including wind, snow, or seismic loads, \( t \) shall be the greater of \( t_1 \) or \( t_2 \) calculated as follows:

\[
\begin{align*}
  t_1 &= \frac{|M_d| + |M_{fl}|}{\pi(D/2)^2(S_u/F_1)} + \frac{|F_d| + |F_{fl}|}{\pi D(S_u/F_1)} + \frac{P_D}{4(S_u/F_1)} \\
  t_2 &= \left( \frac{|M_d| + |M_{fl}|}{\pi(D/2)^2} + \frac{|F_d| + |F_{fl}|}{\pi D} + \frac{P_D}{4} \right) F_2^{0.5}
\end{align*}
\]

where

- \( F_B \) = axial compressive force resulting from wind, snow, or seismic loads, lb (N)
- \( F_1 \) = design factor = 5
- \( F_2 \) = design factor = 5
- \( M_B \) = bending moment resulting from wind, snow, or seismic loads, in.-lb (N·mm)

3A-230 Minimum Thickness of Torispherical Heads

The minimum thickness, \( t \), of torispherical heads shall be calculated as follows:

\[
t = \frac{M}{S_u} \leq 0.885PR_c
\]

where

- \( P \) = total internal pressure, psig (MPag) (internal pressure plus hydrostatic head)
- \( S_u \) = ultimate tensile strength, psi (MPa)
- \( F \) = design factor = 10
- \( M = \frac{1}{4}S_u (R_c/r) \)
- \( R_c \) = head crown radius, in. (mm) \( \leq D_i \)
- \( r \) = head knuckle radius, in. (mm) \( \geq 0.06R_c \)
- \( S_u \) = ultimate tensile strength, psi (MPa)

For a torispherical head where \( R_c = D_i \) and \( r = 0.06R_c \), the minimum thickness, \( t \), reduces to

\[
t = \frac{0.885PR_c}{S_u/F}
\]

For torispherical heads subject to internal loading, the knuckle radius shall be externally reinforced in accordance with Figure 3-1, sketch (a). The reinforcement thickness shall be equal to the thickness of the head as calculated above. The thickness of a joint overlay near the knuckle radius tangent line of a dished head contributes to the knuckle reinforcement. For torispherical heads not subject to internal loading, see Figure 3-1, sketch (b).

3A-240 Minimum Thickness of Ellipsoidal Heads

The minimum thickness of ellipsoidal heads (2:1) shall be calculated as follows:

\[
t = \frac{PD_i}{2S_u/F}
\]

3A-250 Minimum Thickness of Toriconical Heads

(a) The minimum thickness of toriconical heads that have a half apex angle, \( \alpha \), not greater than 60 deg shall be calculated as follows:

\[
t_c = \frac{PD_i}{2 \cos \alpha (S_u/F)}
\]

where

- \( D_i \) = inside diameter of the conical portion of a toriconical head at the point of tangency to the knuckle, measured perpendicular to the axis of the cone (see Figure 3-2), in. (mm)
- \( D_i = D_i - 2r(1 - \cos \alpha) \)
- \( r \) = inside knuckle radius, in. (mm)
- \( \alpha \) = one-half of the included (apex) angle of the cone at the centerline of the head

(b) Toriconical heads having a half apex angle, \( \alpha \), greater than 60 deg shall comply with Subpart 3B.

(c) For toriconical heads subject to internal loading, the knuckle radius shall be externally reinforced in accordance with Figure 3-2. The total reinforced knuckle thickness, \( t_{kr} \), shall be calculated in accordance with the rule in (a). The thickness of a joint overlay near the knuckle radius

\[
t_{kr} = 2t_k \text{ or } 2t_c, \text{ whichever is greater}
\]

For toriconical heads, compute the knuckle reinforcement length as follows:

\[
L_c = \sqrt{\frac{t_{kr}}{\cos \alpha}}
\]
(21) 3A-261 Flat-Bottom Knuckle Design

(a) The flat-bottom knuckle details displayed in Figure 4-3 are empirically based and suitable for shop fabricated tanks. These details may be used in lieu of a calculation-based design for tanks 16 ft (4.9 m) in diameter and smaller.

(b) When the Fabricator elects to use a knuckle detail that differs from Figure 4-3, the knuckle must be designed by calculation.

(c) For tanks greater than 16 ft (4.9 m) in diameter, the bottom knuckle must be designed by calculation.

(d) Knuckle design calculations must account for liquid pressure, design pressure uplift, foundation contact, knuckle thickness and radius, and discontinuities resulting from the knuckle-to-shell connection. A calculation method that may be used is axisymmetric finite element design with contact elements. The design criteria is strength-based for contact molded laminates and strain-based for filament wound laminates. For continuous loading, the design factors shall be 10 and 0.0010 in./in. (mm/mm) hoop direction, filament hoop laminates. For intermittent loading, the factors in para. 3A-440 shall be used.

(e) The Qualified Designer is responsible for recognizing the limitations of Figure 4-3 details and should give special consideration to tall tanks, high specific gravity contents, high design pressure, and combinations thereof.

3A-270 Minimum Thickness of Hemispherical Heads

For hemispherical heads under internal pressure, compute the minimum thickness, \( t \), as follows:

\[
t = \frac{2P_R}{K_D S_f}
\]

where \( P = \) design internal pressure, psi (MPa) \( R = \) inside radius of head, in. (mm) \( S_f = \) allowable stress, psi (MPa)

See subpart 3A-230 for equation variable definitions not included above.

3A-300 DESIGN FOR EXTERNAL PRESSURE

3A-310 Cylindrical Shells

The maximum allowable external pressure between stiffening elements is computed by the following:

\[
P_a = \frac{D_o}{t} \left( \frac{E_{af}}{E_{hf}} \right)^{1/2} \sigma_{f,a}^{1/2} \frac{1}{L} \frac{1}{(D_o/2)^{3/2}}
\]

where \( D_o = \) outside diameter of shell, in. (mm) \( E_{af} = \) axial flexural modulus, psi (MPa) \( E_{hf} = \) hoop flexural modulus, psi (MPa) \( \sigma_{f,a} = \) design factor of safety = 5

\( K_D = 0.84 \), a knockdown factor

\( \gamma = 1.0 \) for Type I and Type II laminates

\( L = \) design length of a vessel section, in. (mm), taken as the largest of the following:

(a) the distance between head-tangent lines plus one-third the depth of each formed head, if there are no stiffening rings (excluding conical heads and sections)

(b) the distance between cone-to-cylinder junctions for vessels with cone or conical heads, if there are no stiffening rings

(c) the greatest center-to-center distance between any two adjacent stiffening rings

(d) the distance from the center of the first stiffening ring to the formed head tangent line plus one-third the depth of the formed head (excluding conical heads and sections), all measured parallel to the axis of the vessel

\( P_i = \) total internal pressure, MAWP plus hydrostatic pressure when fluid head exists, psi (MPa)

\( \nu_{ah} = \) flexural Poisson’s ratio in the axial direction \( \approx 0.32 \) for all Type I and Type II laminates, except for Type II laminates with no liner.

\( \nu_{ah} = 0.853 \) for all Type I and Type II laminates.

NOTES:
(1) For design without calculating the Poisson’s ratios, the following apply:
(a) Type I Laminates. For an all Type I laminate, the flexural and in-plane Poisson’s ratios for axial and hoop are identical. Setting these to zero produces about a 9% reduction in allowable pressure.

(b) Type II Laminates. For all Type II laminates with no liner, the flexural and in-plane Poisson’s ratios are slightly different due to the 5/4 weave. Setting these to zero produces about a 5% reduction in allowable pressure. Setting the flexural and in-plane Poisson’s ratio equal to the in-plane Poisson’s ratios produces a <1% reduction in allowable pressure for standard Type II laminates. Any number of chopped strand mats plies may be added to the Type II laminate, so in the limit of an infinite number of Type I plies, the setting of the Poisson’s ratios to zero produces the same result as the Type I laminates above.
(c) Type X Laminates. For Type X laminates, the Poisson’s ratios need to be calculated per laminate analysis or determined by testing.

(2) Nonmandatory Appendix NM-16 provides an example of the NASASP-8007 solution for lateral and longitudinal pressure.

3A-320 Torispherical and Elliptical Heads

For torispherical heads, compute the allowable external pressure, \( P_a \), as follows:

\[
P_a = 0.36 \left( \frac{E_f}{F} \right) \left( \frac{F_t}{R_o} \right)^2
\]

For torispherical heads, compute the minimum thickness, \( t \), as follows:

\[
t = R_o \left( \frac{FP}{0.36E_f} \right)^{0.5}
\]

For elliptical heads, compute the allowable external pressure, \( P_a \), as follows:

\[
P_a = 0.36 \left( \frac{E_f}{F} \right) \left( \frac{F_t}{K_oD_{oh}} \right)^2
\]

For elliptical heads, compute the minimum thickness, \( t \), as follows:

\[
t = K_oD_{oh} \left( \frac{FP}{0.36E_f} \right)^{0.5}
\]

where

- \( D_{oh} \) = outside diameter of head, in. (mm)
- \( E_f \) = flexural modulus of elasticity for head, psi (MPa)
- \( K_o \) = factor depending on ellipsoidal head proportions as follows:

<table>
<thead>
<tr>
<th>Major to Minor Axis Ratio</th>
<th>( K_o )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>0.90</td>
</tr>
<tr>
<td>1.8</td>
<td>0.81</td>
</tr>
<tr>
<td>1.6</td>
<td>0.75</td>
</tr>
<tr>
<td>1.4</td>
<td>0.65</td>
</tr>
<tr>
<td>1.2</td>
<td>0.57</td>
</tr>
<tr>
<td>1.0</td>
<td>0.50</td>
</tr>
</tbody>
</table>

\( P_a \) = allowable external pressure, psi (MPa)

\( P_a \) = design external pressure, psi (MPa)

\( R_o \) = outside crown radius of head, in. (mm)

3A-330 Stiffening Rings

The required moment of inertia, \( I_o \), of a circumferential stiffening ring, including the effective length of the shell and the added stiffener ring, for cylindrical shells under external pressure or internal vacuum shall not be less than that determined by the following formula:

\[
I_o = \frac{Fbuc}{P_e} \frac{D_oE_h}{24E_h}
\]

where

- \( D_o \) = shell outside diameter, in. (mm)
- \( E_h \) = effective hoop modulus of shell and stiffener, psi (MPa)
- \( F_{design} = \) design factor = 5
- \( I_{e} \) = the calculated effective moment of inertia, in.\(^4\) (mm\(^4\)), considering the different moduli of the shell and stiffener and the resulting shift in neutral axis. \( I_e \) shall be greater than or equal to \( I_o \).
- \( I_o \) = moment of inertia, in.\(^4\) (mm\(^4\)), of stiffener and effective length of shell. The effective length of shell shall not be greater than the length of the shell under the ring plus no more than the length of the bending boundary layer (BBL) in the shell where the stresses are 50% of the peak values on each side of the centroid of the ring. See Nonmandatory Appendix NM-17 for the BBL formulation. Portions of shell shall not be considered as contributing to more than one stiffening ring.

\( L_e = \) one-half of the distance from the centerline of the stiffening ring to the next line of support on one side, plus one-half of the centerline distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the cylinder, in. (mm). A line of support is

(a) a stiffening ring that meets the requirements of this paragraph

(b) a circumferential line on a head at one-third the depth of the head from the head tangent line

(c) a cone-to-cylinder junction

\( P \) = actual external pressure, psi (MPa)

See Figure 3-3 for stiffener details and Nonmandatory Appendix NM-17 for example calculations. Other stiffener profiles meeting the required moment of inertia may be used.

3A-340 Top Head Loads

The top head, regardless of shape, shall be designed to support a 250 lb (1.11 kN) load on a 16 in.\(^2\) (10 300 mm\(^2\)) compact area without damage and with a maximum deflection of 0.5% of the shell diameter, or 0.50 in. (13 mm), whichever is less. For torispherical heads, this requirement can be satisfied by using the method presented in Nonmandatory Appendix NM-11.

3A-345 Fully Supported Flat-Bottom Heads Subject to External Pressure.

Flat-bottom heads shall be designed so that, when subject to the external pressure(s)

(a) calculated stresses in the head do not exceed

(1) one-tenth of the ultimate strength(s) of the laminates employed for sustained loads

(2) one-fifth of the ultimate strength(s) of the laminates employed for intermittent loads combined with sustained loads and
Type X Laminates. For Type X laminates, the Poisson’s ratios need to be calculated per laminate analysis or determined by testing.

(2) Nonmandatory Appendix NM-16 provides an example of the NASASP-8007 solution for lateral and longitudinal pressure.

3A-320 Torispherical and Elliptical Heads

For torispherical heads, compute the allowable external pressure, $P_a$, as follows:

$$P_a = 0.36 \left( \frac{E_f}{F} \right) \left( \frac{t}{R_o} \right)^2$$

For torispherical heads, compute the minimum thickness, $t$, as follows:

$$t = R_o \left( \frac{FP_d}{0.36E_f} \right)^{0.5}$$

For elliptical heads, compute the allowable external pressure, $P_a$, as follows:

$$P_a = 0.36 \left( \frac{E_f}{F} \right) \left( \frac{t}{K_o D_{oh}} \right)^2$$

For elliptical heads, compute the minimum thickness, $t$, as follows:

$$t = K_o D_{oh} \left( \frac{FP_d}{0.36E_f} \right)^{0.5}$$

where

$D_{oh} =$ outside diameter of head, in. (mm)

$E_f =$ flexural modulus of elasticity for head, psi (MPa)

$K_o =$ factor depending on ellipsoidal head proportions as follows:

<table>
<thead>
<tr>
<th>Major to Minor Axis Ratio</th>
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<tr>
<td>2.0</td>
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</tr>
<tr>
<td>1.6</td>
<td>0.73</td>
</tr>
<tr>
<td>1.4</td>
<td>0.65</td>
</tr>
<tr>
<td>1.2</td>
<td>0.57</td>
</tr>
<tr>
<td>1.0</td>
<td>0.50</td>
</tr>
</tbody>
</table>

$E_h =$ effective hoop modulus of shell and stiffener, psi (MPa)

$F =$ design factor = 5

$I_e =$ the calculated effective moment of inertia, in.$^4$ (mm$^4$), considering the different moduli of the shell and stiffener and the resulting shift in neutral axis. $I_e$ shall be greater than or equal to $I_c$.

$I_c =$ moment of inertia, in.$^4$ (mm$^4$), of stiffener and effective length of shell. The effective length of shell shall not be greater than the length of the shell under the ring plus no more than the length of the bending boundary layer (BBL) in the shell where the stresses are 50% of the peak values on each side of the centroid of the ring. See Nonmandatory Appendix NM-17 for the BBL formulation. Portions of shell shall not be considered as contributing to more than one stiffening ring.

$L_s =$ one-half of the distance from the centerline of the stiffening ring to the next line of support on one side, plus one-half of the centerline distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the cylinder, in. (mm). A line of support is

(a) a stiffening ring that meets the requirements of this paragraph

(b) a circumferential line on a head at one-third the depth of the head from the head tangent line

(c) a cone-to-cylinder junction

$P =$ actual external pressure, psi (MPa)

See Figure 3-3 for stiffener details and Nonmandatory Appendix NM-17 for example calculations. Other stiffener profiles meeting the required moment of inertia may be used.

3A-340 Top Head Loads

The top head, regardless of shape, shall be designed to support a 250 lb (1.11 kN) load on a 16 in.$^2$ (10 300 mm$^2$) compact area without damage and with a maximum deflection of 0.5% of the shell diameter or 0.50" (13 mm), whichever is less. See Nonmandatory Appendix NM-11 as an option to satisfy this requirement for torispherical top heads.

Concentrated Load: A 250 lb (1.11 kN) concentrated load on any 16 in.$^2$ (10 300 mm$^2$) compact area with a maximum deflection of 0.5% of the shell diameter or 0.50" (13 mm), whichever is less. See Nonmandatory Appendix NM-11 as an option to satisfy this requirement for torispherical top heads.

Uniform Load: 10 psf (0.48 kPa) plus the dead weight of the top head.

Unless specified by the UBRS, local building codes, or qualified designer, the minimum external loads are not required to be considered simultaneous (together).
(b) upward deflection of the flat bottom resulting from the external load will not exceed 1 1/2% of the diameter of the head for all external loading conditions.

Liquid contents of the vessel shall not be considered to reduce stresses or deflection.

NOTE: Where rigid internal equipment is fitted on or close to the bottom, a lower deflection limit may be required.

3A-350 Toriconical Heads

(a) For toriconical heads whose half apex angle, \( \alpha \), is \( \leq 60 \) deg, the maximum allowable external pressure between stiffening elements is computed by the following:

\[
P_a = \frac{K(E_{fs}(D_o/L)(t_c \cos \alpha)/D_b)^{2.5}}{1 - 0.45(t_c \cos \alpha)/D_b^{0.5}}
\]

Also check for stress in the cone, \( S_c \), as follows:

\[
S_c = \frac{P_d}{2t_c \cos \alpha}
\]

The stress, \( S_c \), must not exceed \( Su/F \).

For toriconical heads, compute the knuckle reinforcement length, \( L_c \), as follows:

\[
L_c = \sqrt{\frac{D_b t_k}{\cos \alpha}}
\]

The thickness of the knuckle, \( t_k \), shall be

\[
t_k = \sqrt{\frac{0.5MPa}{S_u/F}}
\]

where

- \( D_c = D_i - 2r(1 - \cos \alpha) \), in. (mm)
- \( D_i = \) inside diameter of the conical portion of a toriconical head at the point of tangency to the knuckle, measured perpendicular to the axis of the cone (see Figure 3-2), in. (mm)
- \( D_o = \) maximum outside diameter at the large end of the conical segment between stiffening elements (see Figure 3-2), in. (mm)
- \( E_{ac} = \) axial tensile modulus for the cone, psi (MPa)
- \( E_{hc} = \) hoop tensile modulus for the cone, psi (MPa)
- \( E_{rc} = \) resultant modulus for the cone, psi (MPa)
- \( F = \) design factor = 5
- \( K = 4 - 0.75(E_{ac}/E_{hc}) \) for U.S. Customary units
- \( = 4 - 0.75(E_{ac}/6900) \) for SI units
- \( L = \) conical segment slant height (see Figure 3-2), in. (mm)
- \( M = 0.25(3 + \sqrt{R_c/r}) \)
- \( P_a = \) allowable external pressure, psi (MPa)
- \( P_d = \) design external pressure, psi (MPa)

(b) When the half apex angle \( \alpha \) exceeds 60 deg, the toriconical head shall be designed in accordance with Subpart 3B.

(c) For toriconical heads subject to external pressure, the knuckle radius shall be externally reinforced in accordance with Figure 3-2. The total reinforced knuckle thickness \( t_{kr} \) shall be calculated in accordance with the rule in (a). The thickness of a joint overlay near the knuckle radius tangent line of a toriconical head contributes to the knuckle reinforcement.

(d) When Subpart 3A design rules are used, the secondary bond overlays shall be in accordance with para. 4-320.

3A-360 Stiffening Rings

The required moment of inertia, \( I_s \), of a circumferential stiffening ring for conical shells under external pressure shall not be less than that determined by the following formula:

\[
I_s = \frac{P_k(E_{hc}/\cos \alpha)^{1/2}}{24E_{hs}}
\]

where

- \( E_{hs} = \) hoop tensile modulus for the stiffening ring, psi (MPa)
- \( L_s = \) one-half of the conical segment slant distance from the centerline of the stiffening ring to the next line of support on one side, plus one-half of the conical segment slant distance from the centerline of the stiffening ring to the next line of support on the other side (see Figure 3-4), in. (mm). A line of support is
  (a) a stiffening ring that meets the requirements of this paragraph
  (b) a toriconical head-to-cylinder junction
  (c) apex of a toriconical head

See subpart 3A-350 for equation variable definitions not shown above.

3A-400 SEISMIC, WIND, AND SNOW LOADINGS

3A-410 Design Loadings

The loadings to be considered in designing vessels shall include seismic loads, wind loads, and snow loads, determined by vessel installation, location, and customer...
upward deflection of the flat bottom resulting from the external load will not exceed 1\(\frac{1}{2}\)% of the diameter of the head for all external loading conditions.

Liquid contents of the vessel shall not be considered to reduce stresses or deflection.

NOTE: Where rigid internal equipment is fitted on or close to the bottom, a lower deflection limit may be required.

3A-350 Toriconical Heads

For toriconical heads whose half apex angle, \(\alpha\), is \(\leq 60\) deg, the maximum allowable external pressure between stiffening elements is computed by the following:

\[
P_a = \frac{K(E_{rc}/F)(D_o/L)(t_c \cos \alpha)/D_b}{1 - 0.45(t_c \cos \alpha)/D_b^{0.5}}^{2.5}
\]

Also check for stress in the cone, \(S_c\), as follows:

\[
S_c = \frac{P_d D}{2 t_c \cos \alpha}
\]

The stress, \(S_c\), must not exceed \(S_{uc}/F\).

For toriconical heads, compute the knuckle reinforcement length, \(L_{kr}\), as follows:

\[
L_{kr} = \sqrt{\frac{D_b t_c}{\cos \alpha}} + 0.5 F
\]

where

\[
D_c = D_1 - 2r(1 - \cos \alpha), \text{ in. (mm)}
\]

\[
D_i = \text{inside diameter of the conical portion of a toriconical head at the point of tangency to the knuckle, measured perpendicular to the axis of the cone (see Figure 3-2), in. (mm)}
\]

\[
D_o = \text{maximum outside diameter at the large end of the conical segment between stiffening elements (see Figure 3-2), in. (mm)}
\]

\[
E_{rc} = \text{axial tensile modulus for the cone, psi (MPa)}
\]

\[
E_{hc} = \text{hoop tensile modulus for the cone, psi (MPa)}
\]

\[
E_{rc} = \text{resultant modulus for the cone, psi (MPa)}
\]

\[
x = \left(\frac{E_{ac}E_{hc}}{E_{rc}}\right)^{0.5}
\]

\[
F = \text{design factor} = 5
\]

\[
K = 4 - 0.75(E_{rc}/1,000,000) \text{ for U.S. Customary units}
\]

\[
= 4 - 0.75(E_{rc}/6900) \text{ for SI units}
\]

\[
L = \text{conical segment slant height (see Figure 3-2), in. (mm)}
\]

\[
M = 0.25(3 + R_c/r)
\]

\[
P_a = \text{allowable external pressure, psi (MPa)}
\]

\[
P_d = \text{design external pressure, psi (MPa)}
\]

\[
R_c = D_o/(2 \cos \alpha)
\]

\[
\text{inside knuckle radius (see Figure 3-2), in. (mm)}
\]

\[
(6\% \text{ minimum and at least three times the knuckle thickness)}
\]

\[
S_{uc} = \text{ultimate tensile strength, psi (MPa)}
\]

\[
t_c = \text{cone thickness (see Figure 3-2), in. (mm)}
\]

\[
t_k = \text{knuckle thickness (see Figure 3-2), in. (mm)}
\]

\[
\alpha = \text{one-half the apex angle in toriconical heads and sections (see Figure 3-2), deg}
\]

(b) When the half apex angle exceeds 60 deg, the toriconical head shall be designed in accordance with Subpart 3B.

(c) For toriconical heads subject to external pressure, the knuckle radius shall be externally reinforced in accordance with Figure 3-2. The total reinforced knuckle thickness \(t_{kr}\) shall be calculated in accordance with the rule in (a). The thickness of a joint overlay near the knuckle radius tangent line of a toriconical head contributes to the knuckle reinforcement.

(d) When Subpart 3A design rules are used, the secondary bond overlays shall be in accordance with para. 4-320.

3A-360 Stiffening Rings

The required moment of inertia, \(I_\theta\), of a circumferential stiffening ring for conical shells under external pressure shall not be less than that determined by the following formula:

\[
I_\theta = \frac{P_d L_s(D_c/\cos \alpha)^2 F}{24 E_{hs}}
\]

where

\[
E_{hs} = \text{hoop tensile modulus for the stiffening ring, psi (MPa)}
\]

\[
L_s = \text{one-half of the conical segment slant distance from the centerline of the stiffening ring to the next line of support on one side, plus one-half of the conical segment slant distance from the centerline of the stiffening ring to the next line of support on the other side (see Figure 3-4), in. (mm)}
\]

\[
(a) \text{ a stiffening ring that meets the requirements of this paragraph}
\]

\[
(b) \text{ a toriconical head-to-cylinder junction}
\]

\[
(c) \text{ apex of a toriconical head}
\]

3A-400 Seismic, Wind, and Snow Loadings

3A-410 Design Loadings

The loadings to be considered in designing vessels shall include seismic loads, determined by vessel installation, location, and customer demands.
specification as defined in the UBRS. The effects of liquid sloshing in large vessels shall be considered. The design shall be certified by a Qualified Designer experienced in the design of reinforced plastics.

3A-420 Specifying Design Loadings

The magnitude and orientation of the forces enumerated in para. 3A-410 shall be as specified by the UBRS (see para. 1-200). Examples of codes and design calculations are shown in Nonmandatory Appendix NM-3.

3A-430 Assumed Design Loadings

The vessel design shall be analyzed under the following loading combinations:
(a) sustained loads plus seismic load
(b) sustained loads plus snow load
(c) sustained loads plus wind load
(d) wind loads on an empty vessel

Seismic, wind, and snow loads are considered to act separately. The forces are not cumulative.

3A-440 Stresses From Loadings

Stresses produced by seismic, wind, or snow loading, in conjunction with any appropriate working stresses, shall be less than \( S_u/5 \), a design factor of 5 for contact molded construction. For filament wound construction, the hoop strain shall be less than 0.0020 in./in. (mm/mm) and the axial stress shall be less than \( S_u/5 \).

3A-450 Loading Design Examples

Examples of wind and snow load design are given in Nonmandatory Appendix NM-3. The wind load calculations are for static loading only and do not consider the effect of stress buildup due to resonant vibrations, which may be a factor in tall structures. These examples are given to illustrate the extent of analysis necessary to verify the resistance of equipment to these loads. Other methods of analysis may be used, provided that all of the stresses induced by these loads are considered and satisfy the requirements of Part 3.

3A-460 Hold-Down Lugs

3A-461 General. Concentrated loadings resulting from hold-down lugs shall be calculated. A design method for hold-down lugs is given in Nonmandatory Appendix NM-4. When hold-down lugs are attached in the shop or in the field, the attachment of the hold-down lugs shall be performed by secondary bonders qualified in accordance with Mandatory Appendix M-5, and the vessel pressure test per para. 6-950 shall be performed after the attachment of the lugs. Final inspection per para. 6-900 shall be completed after the hold-down lug attachment and testing.
have been completed. The Fabricator retains overall responsibility for all field work, testing, and inspection.

The hold-down lug shall be parallel to and above the datum plane for flat-bottom vessels as shown in Figure 4-1. Nonmandatory Appendix NM-4 suggests a minimum dimension of 0.50 in. (13 mm) between the datum plane and the bottom of the hold-down lug.

3A-462 Containment Area Flood Loading on Hold-Down Lugs

(a) When flooding is designated in the UBRS, hold-down lugs shall be designed to withstand uplift forces from flooding of the containment area.

(b) When the UBRS specifies that the bottom head and shell are not to be designed to withstand flooding of the containment area, the vessel nameplate or a separate label shall contain the following statement: "Bottom head and shell not designed for flooding of the containment area. Containment area flooding may result in damage and vessel leaks. Vessel must be inspected before being returned to service if containment area is flooded."

3A-500 LARGE DIAMETER RTP EQUIPMENT BODY FLANGES

Methods for designing flanges with full-face gaskets are given in Nonmandatory Appendices NM-2 and NM-12. Dimensions and allowable pressures for representative flanges with full-face gaskets are given in Table NM2-1. The maximum allowable design stress value shall be 3,000 psi (20.7 MPa) for flanges constructed of Type II laminates and 1,800 psi (12.4 MPa) for flanges constructed of Type I laminates.

3A-600 VESSELS SUPPORTED BY SHELL ATTACHMENTS

Where the vessel is supported by attachments to the shell, the attachments and associated reinforcement shall be designed to avoid exceeding allowable stresses both in the attachments and the shell. Attachments may be fabricated from RTP or metal as agreed upon by the User and the Fabricator.

The use of support lugs for vertical cylindrical vessels requires consideration of the forces caused by eccentric loading of the lugs. In small vessels, these radial forces may be accommodated by reinforcement of the shell. In vessels larger than 36 in. (910 mm) inside diameter, some type of a metallic ring–lug support should be used. A design method for metallic ring–lug supports is presented in Nonmandatory Appendix NM-5.

3A-700 REINFORCEMENT OF CIRCULAR OPENINGS

(a) Openings cut in cylindrical shells and heads for installation of nozzles and manways shall be reinforced by a circular area concentric with the cutout shown in Figures 4-7 and 4-8. Required patterns of reinforcement placement are shown in Figure 4-10.

(b) Only circular openings whose diameter does not exceed one-half of the vessel diameter are covered by these rules. Openings of other geometries and openings whose diameter exceeds one-half of the vessel diameter require special consideration and stress levels shall satisfy the limits of Subpart 3B.

(c) For circular nozzles, only openings with the largest dimension along one axis being no longer than two times the largest dimension along the axis 90 deg to the first axis are covered by these rules. These dimensions shall be measured from one cut edge to the opposite cut edge (the chord is measured in the hoop direction).

(d) These rules only cover reinforcement of cylinders and dished, elliptical, or conical heads using the thickness equations shown in Subpart 3A.

3A-710 Wall Thickness Definitions

\[ T_a = \text{actual structural wall thickness, in. (mm)} \]
\[ T_c = \text{calculated structural wall thickness, in. (mm)} \]
\[ T_t = \text{theoretical structural wall thickness, in. (mm)} \]

\[ T_a = \text{wall thickness obtained after fabrication, not including any sacrificial corrosion barrier} \]
\[ T_c = \text{wall thickness planned on being used to fabricate the vessel; calculated by summing the theoretical thickness of each layer, not including any sacrificial corrosion barrier} \]
\[ T_t = \text{minimum wall thickness that will satisfy the design conditions; does not include sacrificial corrosion barrier if it is specified} \]

Example: The design calculations establish that the wall thickness shall be at least 0.24 in. (6.1 mm) \( (T_t) \). A 0.29 in. (7.4 mm) \( (T_c) \) wall thickness is specified for fabrication. After fabrication, it is determined to be 0.32 in. (8.1 mm) \( (T_a) \).

\[ D = \text{vessel inside diameter, in. (mm)} \]
\[ d = \text{nozzle's largest hole dimension, in. (mm)} \]
\[ K = 1 \text{ for nozzles } \geq \text{NPS 6 (DN 150)} \]
\[ M = 1 \text{ for Type I or Type II wall laminates} \]
\[ = \frac{d}{6} \text{ for nozzles } < \text{NPS 6 (DN 150)} \]
\[ = \frac{1}{15000} \text{ for Type X laminates, for U.S. Customary units} \]
\[ = \frac{1}{103} \text{ for Type X laminates, for SI units} \]
\[ M = 1 \text{ for Type I or Type II laminates} \]
\[ = \frac{K}{10} \text{ for Type X laminates, for SI units} \]

\[ T = \text{vessel wall thickness, in. (mm)} \]
\[ t = \text{nozzle wall thickness, in. (mm)} \]
\[ t_r = \text{reinforcement thickness, in. (mm)} \]
\[ V = 1 \text{ for internal pressure} \]
\[ = \frac{1}{2} \text{ for external pressure} \]
\[ \sigma = \text{hoop tensile ultimate strength for cylinders, psi (MPa)} \]
**Table 4-1 Flange Flatness Tolerance**

<table>
<thead>
<tr>
<th>Inside Diameter, in. (mm)</th>
<th>Tolerance, in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 to 84 (50 to 2100)</td>
<td>$\pm\frac{1}{52}$ (0.8)</td>
</tr>
<tr>
<td>over 84 to 108 (2100 to 2700)</td>
<td>$\pm\frac{1}{66}$ (1.5)</td>
</tr>
<tr>
<td>over 108 to 144 (2700 to 3600)</td>
<td>$\pm\frac{1}{52}$ (2.4)</td>
</tr>
</tbody>
</table>

\(d\) The joint overlay for Type II contact molded laminates and for filament wound laminates shall consist of alternate plies of mat and woven roving equivalent to the structural portion of the thickest Type II laminate being joined or 0.22 in. (5.6 mm) minimum. Minimum ply width shall be 3 in. (75 mm). The woven roving shall not be greater in width than the layer of chopped strand mat it follows. Each successive mat ply shall extend ½ in. (13 mm) minimum beyond each side of the preceding mat ply.

\(e\) The corrosion-resistant overlay shall consist of a minimum of three plies, each of 1.5 oz/ft² (450 g/m²) chopped strand glass mat, with a minimum of one ply of surfacing veil on the surface exposed to the process environment. The minimum thickness of 0.02" (0.5 mm) (7.5 mm), with each successive layer of mat extending ½ in. (13 mm) minimum beyond each side of the preceding ply, followed by the surfacing veil extending ½ in. (13 mm) minimum beyond each side of the last ply of 1.5 oz/ft² (450 g/m²) mat.

\(f\) Following gel and peak exotherm of the overlay, a paraffinated top coat of resin shall be applied over the surfacing veil and the adjacent roughened surface.

\(g\) The overlay width and thickness that result from using \((c)\) and \((d)\) above apply only to the following joints: torispherical head to shell, ellipsoidal head to shell, the joints shown in Figure 4-3, cylindrical shell to cylindrical shell, and joints in the flat portion of a fully supported flat bottom. Nozzle installation overlays shall satisfy all the requirements of para. 4-430. For other overlay joints (Figure 4-4), the width and thickness shall be as determined by the Qualified Designer, and the joint design shall be as safe as those provided by the rules of this Standard.

\(4-330\) **Alternative Secondary Bond Overlays**

\(a\) Joints shall be constructed by any qualified fabrication method.

\(b\) The overlay strength for the joint shall be based on a design basis laminate.

\(c\) The structural layers may be included in the exterior overlay or the interior overlay. When structural layers are included in the interior overlay, they are to be covered with a corrosion-resistant overlay per para. 4-320(e).

The minimum exterior structural joint overlay thickness shall be 0.22 in. (5.6 mm).

**CAUTION:** The potential for chemical attack must be considered by the designer when a portion of the structural overlays are included in the interior overlay.

\(d\) The structural thickness of the joint shall satisfy the design conditions and shall be sufficient to withstand the stresses incurred by the joint, including but not limited to stresses from occasional loads such as wind, earthquake, or lifting and handling. Consideration shall be given to the effect of the joint design on the stability of the shell.

\(e\) The minimum overlay width shall be 6-in. (152-mm) full thickness plus 4:1 minimum tapers specified in Figure 4-2.

\(f\) The width of the overlay shall be sufficient to provide average secondary bond shear strength at least equal to the axial tensile strength of the weaker part.

\(g\) Average secondary bond shear stress shall not exceed 200 psi (1.4 MPa).

\(h\) The minimum axial and hoop tensile strengths of the overlay shall be 9,000 psi (62 MPa).

\(i\) The layer adjacent to the bond surface shall be a minimum of 0.75 oz/ft² (225 g/m²) mat or randomly chopped glass.

\(j\) Joint laminate sequencing, if interrupted, shall be stopped with an exothermic layer of mat or randomly chopped glass and must be resumed with mat or randomly chopped glass.

\(k\) The corrosion-resistant overlay shall satisfy all the requirements of paras. 4-320(e) and 4-320(f).

**4-400 FLANGED NOZZLES**

**4-410 Fabricating Flanged Nozzles**

All flanged nozzle necks may be fabricated by the hand lay-up or filament wound methods using Type I, Type II, or Type X laminates and in accordance with Figure 4-5(a) [Figure 4-5(b)] and Figure 4-6 and installed per Figures 4-7 through 4-10. The thickness of nozzle necks given in Figure 4-5(a) [Figure 4-5(b)] shall be the minimum thickness for all types of laminate construction used. In addition, if a filament wound laminate is used to fabricate the nozzle neck, the laminate properties shall be at least equivalent to those of a Type II hand lay-up laminate of equal thickness in both the hoop and axial directions. Nozzle flanges shall only be fabricated by the hand lay-up method using Type I or Type II laminates and in accordance with Figure 4-5(a) [Figure 4-5(b)] and Figure 4-6. The nozzle shall extend 6 in. (150 mm) from the outside diameter of the shell to the nozzle-flange face unless otherwise specified. Nozzles up to and including NPS 4 (DN 100) shall be gusseted per Figure 4-11.

Other gasket materials or flange dimensions than those given in Figure 4-5(a) [Figure 4-5(b)] are permissible provided the following are met:
circle. (A hole may occupy a portion of the area of the circle marked, such as on a flange face or at a point where a nozzle will penetrate a vessel wall.) Avoid selection of a spot to be measured that straddles an overlaid joint.

Average the six readings taken; this is the average spot thickness of the small area or component. Record all six measurements in the inspection report.

\[-(b)\] Determining the Average Thickness of a Major Part of a Piece of Equipment [Such as a Head, Shell, Nozzle (or Subassembly), or Manway Wall; Body or Manway Flange]. Four average spot thickness measurements shall be taken, located at the discretion of the Inspector, so as to be broadly distributed over a representative area of the part. The Inspector shall locate one area to be measured at what appears to be the thinnest portion of the part and a second area at what appears to be the thickest portion of the part. Avoid selection of spots falling over joints (overlays).

The other two areas shall be located so as to achieve a representative distribution over the area of the part.

Average the four average spot thicknesses; this is the average thickness of the major part. Record all measurement data in the inspection report.

\[-(c)\] Special Measurement Practices. Cylindrical shells designed with tapered walls or stepped thickness walls require treatment as a multiplicity of parts, where each part to be measured shall represent a wall thickness zone as designated in the design.

The measurement of nozzle or manway cutouts, each to represent one average spot thickness, is a convenient means to arrive at the average thickness of a vessel head or shell.

\[(3)\] Refer to Subpart 2C for permissible tolerances on laminate thickness variation.

\[(4)\] Variations in thickness may be caused by factors such as resin viscosity, mat or chop density, wetout, fabrication technique, etc. Refer to Mandatory Appendix M-7, para. M7-640, for requirements and procedures to compensate for these variations.

\[(g)\] The Inspector shall include results of dimensional and laminate thickness tests in the inspection report.

\[(h)\] Balsa Wood Core Laminate. Balsa wood core laminate shall be subject to the same average spot thickness rules as outlined in \[(f)\]. Average thickness records shall be taken on the interior and exterior laminate in accordance with \[(f)\].

\[(21)\] 6-930 Physical Property and Laminate Reinforcing Content Tests

\[(a)\] The Fabricator is responsible for producing laminates that will meet or exceed permissible mechanical property values as used in the design and as are established as minimum within Subpart 2A and/or Subpart 2B. Laminates shall also be in accordance with the reinforcing sequence and minimum reinforcing content as established in Subpart 2A and/or Subpart 2B.

\[(b)\] During the course of fabrication, the Fabricator shall ensure that laminate reinforcing and mechanical properties are controlled and are within the requirements of this Standard and the design. The Fabricator’s Quality Control Program shall include procedures and forms, to be used throughout fabrication, to control the ongoing process of checking laminate reinforcing and mechanical properties, and to ensure that they are within required tolerances prior to the final inspection.

All such ongoing checks and/or tests done to ensure quality control, but not including Proof Tests as described in \[(d)\], may be done by either the Fabricator or an independent testing laboratory and require certification only by the individual who conducted or supervised the testing.

\[(c)\] The Inspector shall visually inspect all nozzle and manway cutouts. At least one such cutout from each major component (or fabricated section if a component is fabricated in more than one section) that has a cutout shall be used to verify the reinforcing sequence in accordance with the design drawings. The Inspector shall note the results in the inspection report. With certain laminate reinforcing designs and some resins, it may not be possible to verify reinforcing sequence through visual inspection. In such cases, the Inspector shall require the Fabricator to conduct sufficient laminate burnout tests, in accordance with ASTM D2584, to verify the reinforcing sequence from the cutouts, to verify reinforcing content weight percent after the burnout test. For the reinforcing content weight percent shall also be determined and recorded in the inspection report.

\[(d)\] Laminate Proof Tests are mandatory for all vessels built to this Standard having a MAWP or MAEWP equal to or exceeding 2.0 psig (13.8 kPa). Additionally, Laminate Proof Tests are required on all vessels that are field fabricated and all vessels with an inside diameter equal to or greater than 16 ft (4.9 m).

\[(1)\] Fabricators shall verify through Proof Tests that the laminate mechanical property data, the reinforcing sequence, and reinforcing content weight percent data of the as-constructed head or cylindrical shell are in accordance with

\[-(a)\] the proof test values required in \[(3)\] or \[(4)\] shall meet or exceed design values.

\[-(b)\] the laminate sequence as specified in the design drawings.

\[(2)\] Proof Tests may be performed by an independent testing laboratory (contracted by the Fabricator) or by the Fabricator, provided proper test equipment is available. The test results shall be accepted, provided either the laboratory maintains ISO Certification that includes internal self-audits and third-party audits or the laboratory is accredited by the American Association for Laboratory Accreditation to conduct tests. If the laboratory conducting the tests is not accredited or certified to
Table 6-1 RTP Visual Inspection Acceptance Criteria

<table>
<thead>
<tr>
<th>Imperfection Name</th>
<th>Definition of Imperfection</th>
<th>Maximum Size and Cumulative Sum of Imperfections Allowable After Repair [Notes (1)–(4)]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inner Surface Veil(s), Surfacing Mat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level ➀</td>
</tr>
<tr>
<td>Burned areas</td>
<td>Showing evidence of thermal decomposition through discoloration or heavy distortion</td>
<td>None</td>
</tr>
<tr>
<td>Chips (surface)</td>
<td>Small pieces broken off an edge or surface</td>
<td>*½ in. (3 mm) diameter max. by 30% of veil(s) thickness max.</td>
</tr>
<tr>
<td>Cracks</td>
<td>Actual ruptures or debond of portions of the structure</td>
<td>None</td>
</tr>
<tr>
<td>Crazing (surface)</td>
<td>Fine cracks at the surface of a laminate</td>
<td>None</td>
</tr>
<tr>
<td>Delamination (internal)</td>
<td>Separation of the layers in a laminate</td>
<td>None</td>
</tr>
<tr>
<td>Dry spot (surface)</td>
<td>Area of surface where the reinforcement has not been wetted with resin</td>
<td>None</td>
</tr>
<tr>
<td>Edge exposure</td>
<td>Exposure of multiple layers of the reinforcing matrix to the vessel contents, usually as a result of shaping or cutting a section to be secondary bonded (interior of vessel only)</td>
<td>None</td>
</tr>
<tr>
<td>Foreign inclusion</td>
<td>Particles included in a laminate that are foreign to its composition (not a minute speck of dust)</td>
<td>*½ in. (4.5 mm) long max. by dia. or thickness not more than 30% of veil(s) thickness</td>
</tr>
<tr>
<td>Imperfection Name</td>
<td>Definition of Imperfection</td>
<td>Level ➀</td>
</tr>
<tr>
<td>-------------------</td>
<td>---------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Gaseous bubbles or blisters</td>
<td>Air entrapment within, on, or between plies of reinforcement, ( \frac{1}{64} \text{ in. (0.40 mm)} ) diameter and larger</td>
<td>Max. diameter ( \frac{1}{16} \text{ in. (1.5 mm)} ) by 30% of veil(s) thickness deep</td>
</tr>
<tr>
<td>Pimples (surface)</td>
<td>Small, sharp, conical elevations on the surface of a laminate</td>
<td>*Max. height or diameter ( \frac{1}{64} \text{ in. (0.40 mm)} )</td>
</tr>
<tr>
<td>Pit (surface)</td>
<td>Small crater in the surface of a laminate</td>
<td>( \frac{1}{8} \text{ in. (3 mm)} ) diameter max. by 30% of veil(s) thickness max.</td>
</tr>
<tr>
<td>Porosity (surface)</td>
<td>Presence of numerous visible tiny pits (pinholes), approximate dimension 0.005 in. (0.125 mm) (for example, 5 in any 1 in. × 1 in. (25 mm × 25 mm) area)</td>
<td>None more than 30% of veil(s) thickness</td>
</tr>
<tr>
<td>Scratches (surface)</td>
<td>Shallow marks, grooves, furrows, or channels caused by improper handling</td>
<td>*None</td>
</tr>
<tr>
<td>Blisters (surface)</td>
<td>Rounded elevations of the surface, somewhat resembling a blister on the human skin; not reinforced; fully resin filled</td>
<td>*None over ( \frac{1}{16} \text{ in. (4.5 mm)} ) diameter by ( \frac{1}{16} \text{ in. (1.5 mm)} ) in height</td>
</tr>
<tr>
<td>Wet-out (inadequate)</td>
<td>Resin has failed to saturate reinforcing (particularly woven roving)</td>
<td>None</td>
</tr>
</tbody>
</table>
Table 6-1 RTP Visual Inspection Acceptance Criteria (Cont’d)

<table>
<thead>
<tr>
<th>Definition of Visual Inspection Levels (to be Specified by User or User’s Agent): Level ➀ = Critically Corrosion Resistant Level ➁ = Standard Corrosion Resistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imperfection Name</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Wrinkles and creases</td>
</tr>
<tr>
<td>Allowable cumulative sum of highlighted imperfections</td>
</tr>
<tr>
<td>Allowable cumulative sum of highlighted imperfections</td>
</tr>
<tr>
<td>Maximum % repairs</td>
</tr>
</tbody>
</table>

NOTES:
(1) The acceptance criteria apply to condition of laminate after repair and hydrotest.
(2) Noncatalyzed resin is not permissible in any area of the laminate.
(3) Imperfections subject to cumulative sum limitation are highlighted with an asterisk.
(4) Refer to Mandatory Appendix M-7 for rules on repairs.
<table>
<thead>
<tr>
<th>Imperfection Name</th>
<th>Definition of Imperfection</th>
<th>Level 1 - Critically Corrosion Resistant</th>
<th>Level 2 - Standard Corrosion Resistant</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Burned areas</strong></td>
<td>Showing evidence of thermal decomposition through discoloration or heavy distortion</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><strong>Cracks</strong></td>
<td>Actual ruptures or debond of portions of the structure</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><strong>Crazing (surface)</strong></td>
<td>Fine cracks at the surface of a laminate</td>
<td>None</td>
<td>N/A</td>
<td>None</td>
</tr>
<tr>
<td><strong>Dry Spot (surface)</strong></td>
<td>Area of surface where the reinforcement has not been wetted with resin</td>
<td>None</td>
<td>N/A</td>
<td>None</td>
</tr>
<tr>
<td><strong>Edge Exposure</strong></td>
<td>Exposure of multiple layers of the reinforcing matrix to the vessel contents, usually as a result of shaping or cutting a section to be secondary bonded (interior of vessel only)</td>
<td>None</td>
<td>N/A</td>
<td>None</td>
</tr>
<tr>
<td><strong>Gaseous Bubbles or Blisters</strong></td>
<td>Air entrapment within, on, or between plies of reinforcement [1/64 in. (0.40 mm) diameter and larger]</td>
<td>Max. diameter 1/16 in. (1.5 mm) by 30% of veil(s) thickness deep</td>
<td>Max. diameter 3/16 in. (4.5 mm)</td>
<td>Max. diameter 1/16 in. (1.5 mm) by 50% of veil(s) thickness deep</td>
</tr>
<tr>
<td><strong>Porosity (surface)</strong></td>
<td>Presence of numerous visible tiny pits (pinholes), approximate dimension 0.005 in. (0.125 mm) [for example, 5 in any 1 in. x 1 in. (25 mm x 25 mm) area]</td>
<td>None more than 30% of veil(s) thickness</td>
<td>N/A</td>
<td>None more than 50% of veil(s) thickness</td>
</tr>
<tr>
<td><strong>Wet out (inadequate)</strong></td>
<td>Resin has failed to saturate reinforcing (particularly woven roving)</td>
<td>None</td>
<td>None</td>
<td>See note on right and General Note (e) below</td>
</tr>
<tr>
<td><strong>Wrinkles and Creases</strong></td>
<td>Generally linear, abrupt changes in surface plane caused by laps of reinforcement layers, irregular mold shape or Mylar overlap</td>
<td>Max. deviation 20% of wall or 1/16 in. (1.5 mm) whichever is less</td>
<td>Max. deviation 20% of wall or 1/8 in. (3 mm) whichever is less</td>
<td>Max. deviation 20% of wall or 1/8 in. (3 mm) whichever is less</td>
</tr>
</tbody>
</table>
Table 6-1  RTP Visual Inspection Acceptance Criteria (Cont’d)

<table>
<thead>
<tr>
<th>Imperfection Name</th>
<th>Definition of Imperfection</th>
<th>Level 1 - Critically Corrosion Resistant</th>
<th>Level 2 - Standard Corrosion Resistant</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chips (surface)</td>
<td>Small pieces broken off an edge or surface</td>
<td>1/8 in. (3 mm) diameter max. by 30% of veil(s) thickness max.</td>
<td>N/A</td>
<td>1/2 in. (13 mm) diameter max. by 1 in. (25 mm) length max. by 1/16 in. (1.5 mm) deep</td>
</tr>
<tr>
<td>Delamination (internal)</td>
<td>Separation of the layers in a laminate</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Foreign Inclusion</td>
<td>Particles included in a laminate that are foreign to its composition (not a minute spec of dust)</td>
<td>3/16 in. (4.5 mm) long max. by dia. or thickness not more than 30% of veil(s) thickness</td>
<td>3/16 in. (4.5 mm) long max. by dia. or thickness not more than 30% of interior layer thickness</td>
<td>1/4 in. (6 mm) long max. by dia. or thickness not more than 50% of veil(s) thickness max.</td>
</tr>
<tr>
<td>Pimples (surface)</td>
<td>Small, sharp, conical elevations on the surface of a laminate</td>
<td>Max. height or diameter 1/64 in. (0.40 mm)</td>
<td>N/A</td>
<td>Max. height or diameter 1/32 in. (0.80 mm)</td>
</tr>
<tr>
<td>Pit (surface)</td>
<td>Small crater in the surface of a laminate</td>
<td>1/8 in. (3 mm) diameter max. by 30% of the veil(s) thickness max.</td>
<td>N/A</td>
<td>1/16 in. (1.5 mm) deep</td>
</tr>
<tr>
<td>Scratches (surface)</td>
<td>Shallow marks, grooves, furrows or channels caused by improper handling</td>
<td>None</td>
<td>N/A</td>
<td>None more than 12 in. (300 mm) long</td>
</tr>
<tr>
<td>Blisters (surface)</td>
<td>Rounded elevations of the surface, somewhat resembling a blister on the human skin; not reinforced; fully resin filled</td>
<td>None over 3/16 in. (4.5 mm) diameter by 1/16 in. (1.5 mm) in height</td>
<td>N/A</td>
<td>None over 3/16 in. (4.5 mm) diameter by 1/16 in. (1.5 mm) in height</td>
</tr>
</tbody>
</table>

General Notes:
(a) Above acceptance criteria apply to condition of laminate after repair and hydrotest.
(b) Noncatalyzed resin is not permissible in any area of the laminate.
(c) Refer to Mandatory Appendix M-7 for rules on repairs.
(d) All Table 6-1 criteria are to be included in the Maximum % Repairs calculation, however only the Acceptance Criteria on this page are included in the Allowable Cumulative Sum of Imperfections calculation.
(e) Degree of saturation of layers of reinforcement may be determined by splitting cutouts.
(2) Laminates that are to have a balsa wood core applied over them after resin saturation and prior to curing shall be visually inspected prior to applying the balsa wood core.

(3) The Fabricator shall take the appropriate measures to ensure adhesion of the interior laminate to the balsa wood core.

**6-950 Pressure Tests and Acoustic Emissions**

(a) A water fill hydrostatic test shall be performed on all vessels with MAWP above 0.5 psig (3.4 kPa). The test pressure at the top of the vessel shall be 110% to 120% of the design pressure.

(b) A vessel with MAWP at or below 0.5 psig (3.4 kPa) shall be filled with water to at least its full designated liquid capacity, regardless of the specific gravity of the material to be contained.

(c) Vessels with an inside diameter less than or equal to 16 ft (4.9 m) and with MAEWP less than or equal to 6.0 in. (152 mm) of water, and vessels larger than 16-ft (4.9 m) inside diameter with MAEWP less than or equal to 1.0 in. (25 mm) of water, are exempt from vacuum testing. All other vessels designed for vacuum service shall be evacuated to the MAEWP.

**WARNING:** Suitable precautionary measures shall be taken to protect personnel and property from a catastrophic implosion failure during the test.

It should be noted that attainment of full vacuum is not practical. When the design vacuum cannot be achieved, the User or User’s Agent and the Fabricator shall agree on the absolute internal pressure to be achieved during the test. Internal test pressure shall be 12 psig or lower for vessels with a design vacuum that exceeds 12 psig external pressure. Such agreement shall be reached prior to the start of fabrication and shall be documented in the UBRS and inspection report.

(d) The Fabricator shall have written procedures for pressure testing. The test pressure shall be held for a minimum of 2 hr. No visible leakage is permissible during the 2-hr hold on an internal pressure test. Some leakage is permissible during a vacuum test, provided the vacuum test pressure is held for the 2-hr minimum. (This may require continuous connection to the vacuum source.) Subsequent to all pressure testing, the vessel shall pass a visual inspection per para. 6-940. During pressure testing, vessels shall be supported similar to the way they will be supported in loads imposed on the vessel and similar to those of the expected pressure test generates an upward force, all anchor bolts shall be secured. Vertical vessels may be hydropotted in the horizontal position if agreed upon by the User or User’s Agent and Fabricator, and indicated in the UBRS. The pressure at the highest point of the vessel in the test position shall be equal to 110% to 120% of the total pressure (hydrostatic plus design) at the lowest point in the design position. The User is cautioned that the horizontal test of a vertical vessel will not simulate all of the loading conditions of its final installed position.

(e) When it is not practical to conduct a pressure test until the equipment has been installed in service position, the test may be conducted at the installation site.

(f) The Inspector shall witness all pressure tests, verify the test results, and record results of the test in the inspection report.

(g) If acoustic emission tests are required by the UBRS or are mandatory under design provisions of this Standard [see para. 3B-500(c)], the Inspector shall witness the tests and verify that the procedures used were in accordance with Mandatory Appendix M-8.

**6-960 Procedures for Rectifying Nonconformities or Imperfections**

Mandatory Appendix M-7 describes approved procedures for rectifying nonconformities or imperfections. Mandatory documentation requirements for rectifying nonconformities or imperfections are outlined in Mandatory Appendix M-4, para. M4-400(c).

The Inspector shall include the documentation of nonconformity or imperfection rectification in the inspection report.
Table 7-1 Required Resins and Acceptable Fabrication Processes for Demonstration Laminates

<table>
<thead>
<tr>
<th>Type [Note (1)]</th>
<th>Initial Demonstration Laminate Thickness, in. (mm)</th>
<th>Redemonstration Laminate Min. Thickness, in. (mm) [Note (2)]</th>
<th>Required Resins [Note (3)]</th>
<th>Fabrication Process [Note (4)]</th>
<th>Qualification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>0.48 (12.2)</td>
<td>0.25 (6.4)</td>
<td>1 polymer or 1 vinyl ester</td>
<td>1, 2</td>
<td>All resins, all thicknesses</td>
</tr>
<tr>
<td>Type II</td>
<td>0.49 (12.4)</td>
<td>0.37 (9.4)</td>
<td>1 polymer or 1 vinyl ester</td>
<td>1, 2</td>
<td>All resins, all thicknesses</td>
</tr>
<tr>
<td>Filament wound</td>
<td>0.37 (9.4) min.</td>
<td>0.25 (6.4)</td>
<td>1 polymer or 1 vinyl ester</td>
<td>3</td>
<td>All resins, all thicknesses</td>
</tr>
</tbody>
</table>

**GENERAL NOTES:**

(a) A Fabricator shall qualify all fabrication processes to be used to construct vessels to this Standard.

(b) For initial certification, see Mandatory Appendix M-6, para. M6-200(b).

**(1)** provide acceptable demonstration laminates for the types of laminates required by the rules of this Standard;

**(2)** provide acceptable Proof Tests for a specific type of laminate and specific process per para. 6-930(d) [all requirements of paras. 7-600 through 7-620 are met with the completion of a successful Proof Test];

(c) Subpart 2A and/or Subpart 2B provides specific rules governing all laminates and refers to design basis laminates that a Fabricator is required to make in order to establish values for strength, thickness, and glass content. The demonstration laminates required by this Part are for the purpose of qualifying the Fabricator and shop procedures. They may also be used to qualify Laminators (see Mandatory Appendix M-5). Demonstration laminates and design basis laminates are not the same in purpose; hence requirements in terms of configuration, quantity to be produced, and tests may differ.

(d) Initial demonstration laminates and the redemonstration of the Fabricator’s ability to fabricate laminates are required for each type of laminate and each laminating process the Fabricator shall use on vessels fabricated to this Standard; refer to Table 7-1 [see (b)(2)].

(e) Each demonstration laminate shall be identified and labeled by the Fabricator in accordance with para. 7-900.

(f) Demonstration laminates shall be tested in accordance with this Standard by an independent testing laboratory. The independent testing laboratory shall return the remains of the demonstration laminate and specimens with a certified written report. The report shall state the results of the tests.

**Notes:**

(1) Designates laminate reinforcement and/or lay-up pattern.

(2) For redemonstration laminates, see Table 7-1.

(3) Generic classes of resins required.

(4) Process employed to produce the demonstration laminate.

**Tree leaf notes:**

(a) All Fabricators shall produce and qualify hand lay-up Types I and II laminates in accordance with requirements in Tables 7-1 through 7-3.
### Table 7-1 Required Resins and Acceptable Fabrication Processes for Demonstration Laminates

<table>
<thead>
<tr>
<th>Type [Note (1)]</th>
<th>Initial Demonstration Laminate Thickness, in. (mm)</th>
<th>Redemonstration Laminate Min. Thickness, in. (mm)</th>
<th>Required Resins [Note (2)]</th>
<th>Process [Note (3)]</th>
<th>Qualification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>0.48 (12.2)</td>
<td>0.25 (6.4)</td>
<td>1 polyester or 1 vinyl ester</td>
<td>1, 2</td>
<td>All resins, all thicknesses</td>
</tr>
<tr>
<td>Type II</td>
<td>0.49 (12.4)</td>
<td>Delete</td>
<td>1 polyester or 1 vinyl ester</td>
<td>1, 2</td>
<td>All resins, all thicknesses</td>
</tr>
<tr>
<td>Filament wound</td>
<td>0.37 (9.4) min.</td>
<td>0.37 (9.4)</td>
<td>1 polyester or 1 vinyl ester</td>
<td>3</td>
<td>All resins, all thicknesses</td>
</tr>
</tbody>
</table>

**GENERAL NOTES:**
(a) A Fabricator shall qualify all fabrication processes to be used to construct vessels to this Standard.
(b) For initial certification, see para. M6-200(b).

**NOTES:**
(1) Designates laminate reinforcement type.
(2) For redemonstration laminates, the fabrication process for Types I and II laminates may be 1 or 2.
(3) Generic classes of resins required for qualification.
(4) Process employed to produce the laminate:
1 — Hand lay-up.
2 — Spray-up using a chopper gun device.
3 — See para. 7-620(b).

(1) produce acceptable demonstration laminates as required by the rules of this Standard for initial qualification.

(2) provide acceptable Proof Tests for a specific type of laminate and specific process per para. 6-930(d) [all requirements of paras. 7-600 through 7-620 are met with the completion of a successful Proof Test].

(c) Subparts 2A and/or 2B provide specific rules governing all laminates and refer to design basis laminates that a Fabricator is required to make in order to establish values for strength, thickness, and glass content. The demonstration laminates required by this Part are for the purpose of qualifying the Fabricator and shop procedures. They may also be used to qualify Laminators (see Mandatory Appendix M-5). Demonstration laminates and design basis laminates are not the same in purpose; hence requirements in terms of configuration, quantity to be produced, and tests may differ.

(d) Initial demonstration laminates and the redemonstration of the Fabricator’s ability to fabricate laminates are required for each type of laminate and each laminating process the Fabricator shall use on vessels fabricated to this Standard; refer to Table 7-1.

(e) Each demonstration laminate shall be identified and labeled by the Fabricator in accordance with para. 7-900.

(f) Demonstration laminates shall be tested in accordance with this Standard by an independent testing laboratory. The independent testing laboratory shall return the remains of the demonstration laminate and specimens with a certified written report. The report shall state the results of the tests.

(g) A Fabricator’s shop is qualified to produce a specific type of laminate by a specific process provided the certified test report indicates that the demonstration laminate meets or exceeds the requirements of this Standard (see para. 7-700).

(h) Upon the successful completion of a Demonstration Laminate Test Program, Fabricators shall complete a document of "Demonstration Laminate Certification." This document is to be maintained within the Fabricator’s quality control files and a copy shall be made available to the User, User’s Agent, or Inspector on request. In this document, the Fabricator shall certify, via the dated signature of the Fabricator’s authorized agent, the following:

- The demonstration laminate samples were constructed according to all requirements of this Standard.
- Tests were conducted on the demonstration laminates according to all requirements of this Standard.
- The test data have been carefully examined by the Fabricator, and the results are in accordance with all requirements of this Standard.
- The next required date for demonstration of capability via demonstration laminates shall be indicated.
- Test reports from the independent testing laboratory are referenced by the specific date and/or reference number within the certification document and a copy attached thereto.

**7-610 Hand Lay-Up and Spray-Up Demonstration Laminates**

(a) All Fabricators shall produce and qualify hand lay-up Types I and II laminates in accordance with requirements in Tables 7-1 through 7-3.
M1B-420 Visual Inspection of Roving

(a) The roving ball shall be visually inspected for imperfections and contamination prior to use by the Fabricator. Record the date and the inspector’s name in Form M1B-1, column 7. If any roving ball is rejected, record the reason in the comments section in Form M1B-1.

(b) Roving balls having any of the following defects shall not be used for laminates made to this Standard:

(1) any package that exhibits foreign matter such as dirt, oil, grease, waste glass fiber, or beads of glass such that it would detract from the performance or appearance of the finished product

(2) balls that have been contaminated by water

M1B-430 Measurement of Roving Yield

From one roving ball per shipment, obtain a minimum of a 6 yd (5.5 m) sample (length $A$) of roving as required by para. M1B-310. Roving shall be pulled from the same side of the package as used in the Fabricator's process. If the roving is pulled from the outside of the package, sufficient material shall be removed and discarded so that the sample will be taken from undisturbed material. Remove the sample from the wrap reel. Double the sample several times and tie with a single knot. Using the balance required by para. M1B-320, weigh the sample to the nearest 0.1 g. Convert grams to ounces by multiplying grams by 0.0352. Two specimens from each package shall be measured and the average computed. Record as weight $A$.

Calculate the yield, yd/lb, using the following formula:

$$\text{yield, yd/lb} = \frac{16 \text{ oz/lb} \times \text{length } A}{\text{weight, oz}} \times \frac{96}{\text{weight, oz}}$$

Calculate the yield, km/g, using the following formula:

$$\text{yield, km/g} = \frac{\text{length } A, \text{ m}}{1000 \text{ m/km} \times \text{weight, g}}$$

Calculate the TEX, g/km, using the following formula:

$$\text{TEX, g/km} = \frac{1000 \text{ m/km} \times \text{weight, g}}{\text{length, m}}$$

Enter the yield of acceptable and unacceptable balls of roving in Form M1B-1, column 5. If the yield of the ball of roving is outside the manufacturer's specification, the remaining balls in the shipment are to be inspected per ASQ Z1.4 criteria, following the procedure specified in this paragraph. Balls whose yield is outside the manufacturer's specification shall not be used for laminates made to this Standard. Note the rejected roving balls with the word "rejected" next to the yield in column 5. Also, record the date and name of the person performing the yield measurement in column 6.

M1C-100 INTRODUCTION

This Article specifies the minimum inspections and tests that are to be performed on the rolls of fiberglass woven roving fabric, fiberglass unidirectional fabric, and fiberglass nonwoven biaxial fabric that are to be used to fabricate equipment to this Standard.

M1C-200 ACCEPTANCE INSPECTIONS

Acceptance inspections shall include inspection of all fabric rolls for proper packaging and identification, and contamination. This acceptance inspection is to be conducted on the unopened roll. Acceptance requirements and limits are as defined in para. M1C-410. Acceptance inspection shall include inspection of selected rolls for measurement of unit weight and verification of construction of fabric per ASQ Z1.4 criteria. Inspection for manufacturing imperfections shall be conducted during use of rolled goods. Acceptance requirements and limits are as defined in paras. M1C-420 through M1C-450.

Form M1C-1, or a similar form that contains the provisions to record the results of these required inspections, shall be used by the Fabricator and shall be retained in the inspection records. A separate form shall be used for each fabric manufacturer, fabric nomenclature, fabric unit weight [oz/yd2 (g/m2)], and fabric construction.

In lieu of performing the above inspections, measurements, and documentation, the Fabricator shall provide the User or User's Agent with a Certificate of Compliance from the material manufacturer. This Certificate shall ensure that materials were manufactured, inspected, and tested per the material supplier’s specifications.

M1C-300 EQUIPMENT AND MEASURING TOOLS REQUIRED

M1C-310 Inspection Table and Lights

An inspection table and adequate overhead lighting that are suitable for the inspection and testing of the fabric are required. The equipment used shall not introduce contamination to the fabric during inspection and testing.

M1C-320 Linear Measuring, Marking, and Cutting Tools

(a) A standard linear measuring tool (longer than width of roll) that measures the roll widths with minimum accuracy of $\pm \frac{1}{16}$ in. (±3 mm) is required.

(b) A 3 in. ± $\frac{1}{32}$ in. (76 mm ± 0.80 mm) square template is required.
(c) A fine-point felt-tip pen and scissors are required.

M1C-330 Laboratory Balance

A laboratory balance that measures to 0.1 g is required.

M1C-400 PROCEDURES AND ACCEPTANCE LIMITS

M1C-410 Roll Identification and Package Inspection

The fabric shall be packaged as shipped from the manufacturer’s factory. The fabric shall not be repackaged in the distribution of the material after the manufacturer has shipped the fabric. Verify that the fabric rolls as identified by the manufacturer have the same nomenclature as the fabric required by Part 2, and examine the packaging of the fabric for damage that renders the fabric unusable. Indicate acceptable rolls by recording the date and name of the person performing the examination in Form M1C-1, column 4.

For packaged rolls that are found to be acceptable for further inspection and tests, enter the fabric production date and lot number in Form M1C-1, columns 2 and 3.

M1C-420 Visual Inspection of Fabric

(a) As fabric is used, it shall be visually inspected for imperfections and contaminations by the Fabricator. Record date and name of inspector in Form M1C-1, column 9. If a roll is rejected, record the reason under the comments section in Form M1C-1.

(b) Fabric shall be uniform in color, texture, and appearance. The following imperfections and/or contaminations shall be removed from the fiberglass woven roving and fiberglass nonwoven biaxial fabric by making two parallel cuts across the width of the fabric and discarding the rectangular sections of fabric containing the following defects:

1. dirt spots (1/16 in. to 3/4 in. (4.5 mm to 19 mm) in diameter) in excess of one per 10 lineal feet (3 lineal meters) (dirt spots are defined as all foreign matter, dirt, grease spots, etc.)
2. missing ends for more than 2 consecutive feet (600 consecutive millimeters) in length
3. fuzz clumps or loops greater than 1 in. (25 mm) in height from the surface
4. warps (machine direction) or from 90 deg/270 deg
5. weft tails exceeding 1 in. (25 mm) or less than 1/8 in. (3 mm) in length.

(c) Fiberglass unidirectional fabric shall be uniform in color, texture, and appearance. The following imperfections and/or contaminations shall be removed from the fabric by making two parallel cuts across the width of the fabric and discarding the rectangular sections of fabric containing the following defects:

1. dirt spots (1/16 in. to 3/4 in. (4.5 mm to 19 mm) in diameter) in excess of one per 10 lineal feet (3 lineal meters) (dirt spots are defined as all foreign matter, dirt, grease spots, etc.)
2. missing ends in any direction less than one per lineal foot (300 lineal millimeters).
3. areas of the fabric less than 6 in. × 6 in. (150 mm × 150 mm) where rovings are disoriented or looped less than 1 in. (25 mm) in height from the surface. The number of these areas shall not exceed two per 5 lineal yards (4.6 lineal meters) of fabric. If so, the roll shall not be used for laminates made to this Standard.
4. areas of the fabric where rovings are disoriented or looped greater than 1 in. (25 mm) in height from the surface
5. rolls that have been contaminated by water or other substances

M1C-430 Width Measure of Fabric

With the linear measuring tool given in para. M1C-320, measure the width of the fabric at least 1 yd (1 m) from the beginning (leading) edge of the roll and at two additional positions at least 6 in. (150 mm) apart. Follow the manufacturer’s definition for the width of the particular fabric (see note below). Measure to the nearest 1/6 in. (3 mm). Average the three measurements and enter the measured width of acceptable and unacceptable rolls in Form M1C-1. Note the rejected rolls with the word “rejected” next to the width in column 5. Rolls with variations greater than ±1/2 in. (±13 mm) shall not be used in laminates made to this Standard.
Record the date and name of the person performing the width, weight, and construction measurements in column 8.

NOTE: Due to the methods of manufacturing fabrics, there are different ways of describing widths of fabrics.

**M1C-440 Unit Weight of Fabric**

Unroll the fabric on the inspection table and lay flat. Pull one fill pick from the sample or mark a line across the width of the fabric. Measure from the pulled pick or line using a 36-in. (915-mm) rule meeting the accuracy requirements of para. M1C-320. Pull another fill pick or mark off the 36-in. (915-mm) sample for cutting. Cut the 36-in. (915-mm) long sample across the width of the fabric using scissors. Measure the width of the fabric according to para. M1C-430. Weigh the sample to the nearest 0.1 g. Convert grams to ounces by multiplying grams by 0.0352. Calculate the unit weight in ounces per square yard using the following formula:

\[
\text{weight, oz} = \frac{36 \text{ in.}}{\text{yd}^2} \times \frac{\text{sample weight, oz}}{\text{sample width, in.}^2}
\]

Calculate the weight in grams per square meter using the following formula:

\[
\text{weight, g} = \frac{\text{sample weight, g}}{0.915 \text{ m} \times \text{sample width, m}^2}
\]

Rolls whose weight per square yard (square meter) are outside the manufacturer’s specification shall not be used for laminates made to this Standard. Enter the weight per square yard (square meter) of acceptable and unacceptable rolls in the inspection report shown in Form M1C-1. Note the rejected rolls with the word “rejected” next to the weight in column 6.

**M1C-450 Construction**

Unroll the fabric on the inspection table and lay flat. Perform the verification of construction in an area at least 1 yd (1 m) from the beginning of the roll and one-tenth of the width from the edge of the fabric. For example, on 60 in. (150 mm) material start at least 6 in. (150 mm) from one edge and 1 yd (1 m) from the beginning of the fabric. Using the template required by para. M1C-320, measure a 3-in. (76-mm) square and count the number of warp strands (if applicable) to the nearest half strand in the section. Repeat this three times diagonally across the fabric. Add the total warp strands counted in the three 3-in. (76-mm) squares and divide by nine. This will give picks per inch (per 25 millimeters) in the warp of the fabric. Repeat for the fill (weft) strands if applicable. Rolls whose picks per inch (per 25 millimeters) in either warp or fill are outside the manufacturer’s specification shall not be used for laminates made to this Standard. Enter the picks per inch (per 25 millimeters) in the warp and fill of acceptable and unacceptable rolls to the nearest 0.1 picks in Form M1C-1, column 7.

**ARTICLE D**

**FIBERGLASS MILLED FIBERS**

**M1D-100 INTRODUCTION**

This Article specifies the minimum inspections and tests that are to be performed on the packages of fiberglass milled fiber that are to be used to fabricate equipment to this Standard.

**M1D-200 ACCEPTANCE INSPECTIONS**

Acceptance inspections shall include inspection of the milled fiber for proper packaging and identification, and visual inspection for contamination. Acceptance requirements and limits are defined in paras. M1D-410 and M1D-420(a).

Form M1D-1, or a similar form that contains the provisions to record the results of these required inspections, shall be used by the Fabricator and shall be retained in the inspection records. A separate form shall be used for each milled fiber manufacturer, milled fiber nomenclature, and milled fiber length.

In lieu of performing the above inspections, measurements, and documentation, the Fabricator shall provide the User or User’s Agent with a Certificate of Compliance from the material manufacturer. This Certificate shall ensure that materials were manufactured, inspected, and tested per the material supplier’s specifications.

**M1D-300 EQUIPMENT REQUIRED**

An inspection table and adequate overhead lighting that are suitable for the inspection of the milled fiber are required. The equipment used must not introduce contamination to the milled fiber during inspection.

**M1D-400 PROCEDURES AND ACCEPTANCE LIMITS**

**M1D-410 Package Identification and Inspection**

The milled fiber shall be packaged as shipped from the manufacturer’s factory. The milled fiber shall not be repackaged in the distribution of the material after the manufacturer has shipped the milled fiber. Verify that the milled fiber as identified by the manufacturer has the same nomenclature as the milled fiber required by Part 2, and examine each package of milled fiber for damage that renders it unusable. Indicate acceptable milled fibers by recording date and name of the person performing the examination in Form M1D-1, column 4.
MANDATORY APPENDIX M-3
CALCULATIONS USING THE CLASSICAL LAMINATION THEORY (CLT) ANALYSIS METHOD

M3-100 SCOPE

This Appendix sets forth the micromechanics and classical lamination theory (CLT) analysis method to be used to calculate the laminate properties needed for design and analysis in Subpart 3A and the stress, strain, and strength analysis for Subpart 3B. The geometric and lamina notations used are defined in Figures M3-1 through M3-4.

The CLT method consists of integrating through the thickness of a laminate the physical and mechanical properties of each lamina of a laminate to determine the physical and mechanical properties of the total laminate. The constitutive equations thus formed (the ABD matrix) allow calculations of stresses and strains on a ply-per-ply basis for applied loads or applied deformations.

Direct calculation of laminate properties according to para. M3-400 is required for Subpart 3B design. However, the extensive calculations required for Subpart 3B are not necessary for Subpart 3A, and they would limit its usefulness. For Subpart 3A design, the minimum properties in Table 2A-3 or the properties from demonstration/qualification testing may be used. Paragraphs M3-200 (physical properties), M3-300 (micromechanics theory), M3-310 (unidirectional composites), and M3-320 (random-oriented fibers) present a shorter method for determining lamina elastic properties that may be used with Subpart 3A design rules instead of the equations in paras. M3-400 and M3-600.

The equations defining the theory of failure for use with Subpart 3B design are given in para. M3-500. They give rules for calculating the strength ratio, $R$, at a point from the stiffness coefficients and the resultant forces and moments at that point.

The elastic properties of oriented and random glass-fiber-reinforced laminas have been calculated from the theory of composite micromechanics. Per para. 2-320, only glass fibers are allowed for structural fiber reinforcement, and thus, the simplified micromechanics equations are based on isotropic fibers and isotropic resins. The micromechanics equations presented for oriented fiber composites are based on the work of Z. Hashin as modified by R. M. Christiansen and are used in MIL-HDBK-17-3F. The equations attributed originally to Halpin-Tsai as presented in the Delaware Composites Design Encyclopedia are also acceptable, as the results are nearly identical. The mechanical properties of randomly reinforced in-plane composites are computed by integrating the calculated oriented fiber properties of a fictitious laminate with the same resin and fiber properties but at volume fraction of the random lamina over all directions between 0 deg and 180 deg.

The properties of each lamina calculated as described above are used to assemble the CLT matrices and used for the subsequent laminate calculations.

Figure M3-1 Moment Resultants

GENERAL NOTE: Units are in.-lb/in. (N·mm/mm).
A limitation of basic CLT is that all calculations are performed about the midthickness of the laminate, and thus, it is only valid for balanced (equal numbers of lamina of each orientation above and below the midthickness) and symmetric (the laminate sequences are mirror images about the midthickness) laminates. In other words, the neutral axis of the laminate for bending in both in-plane directions must be at the midthickness of the laminate. This basic CLT does, however, predict the flexural properties correctly, as the results are independent of the plane about which the calculations are performed. To calculate the tensile properties, it is needed to determine the neutral axes in bending for the two structural directions. A simplified approach is shown in the design example in para. M3-610. Paragraph M3-620 demonstrates advanced laminate analysis techniques. The strain limits used for predicting strength have not been changed from ASME RTP-1-2007.

**M3-110 Notations Commonly Used in Laminate Analysis**

In CLT analysis of plate structures, it is conventional to use 1 and 2 as the principal axes of the material (local axes), defined as the fiber direction and transverse to the fiber direction, respectively, for an individual ply of the laminate, and 3 is in the through-the-thickness direction. The in-plane shear properties that are in the 1-2 direction are commonly compacted to be called the 6 direction.

The $x$ and $y$ directions (global or structural) are then the in-plane structural axes of the principal directions of the structure. Then, $z$ is in the thickness direction. Laminate theory for a cylinder typically uses $x$ as the axial direction and $y$ as the hoop direction.

The angle between the material principal axes and the structural axes of a unidirectional layer is commonly called theta, $\theta$ (see Figure M3-4), and the conventional notation is 0 deg for axial, and 90 deg for hoop. A ply is a lamina of the total laminate lay-up. A cover is defined as a layer of a plus-minus laminate or one layer of a hoop filament winding. When CLT analysis is applied to thin wall shells, the usual notation for the structural directions are $R$ (radial) for through the thickness, $Z$ for the axial direction, and $\theta$ for the angle between the axial direction of the shell and the fiber direction. The 1, 2, and 6 conventions defined above are typically used for the laminas that comprise the shell laminate.

Figures M3-1 through M3-4 show the notation conventions. Note that $N_{xy} = N_{yx}$, and $M_{xy} = M_{yx}$. $N_{xy}$ is the in-plane shear resultant, and $M_{xy}$ produces a saddle-type deformation with the diagonal corners moving equally up and down but in opposite directions. The in-plane force resultants have units of pounds per unit width, and the moment resultants have units of inch-pound per unit width, as is conventional in plate and shell theory.

**M3-200 PRELIMINARY CALCULATIONS FOR THE CLT METHOD**

Typically, the weight per area of the fiber reinforcement, density of the fiber, and density of the resin for a composite lamina are known. The thickness is then the unknown variable that defines each lamina. If the laminate physically exists, the layer thicknesses can be measured microscopically or determined from the fabrication of a sample. If the laminate does not physically exist for testing purposes, then either the glass content or thickness is assumed for each lamina and the corresponding value calculated. The volume fraction of glass fiber or the thickness for each lamina of the laminate are calculated using the micromechanics in the equations in para. M3-300.

All laminates designed on the basis of this initial assumption must be checked after fabrication to confirm the assumed value is reasonable and based on testing or published data.

The equations in the following example can be used to calculate the preliminary physical and mechanical properties of each lamina or ply. The numerical material properties are for the resin and fibers used for the filament wound portion of the designs for the examples in paras. M3-610 and M3-620.

**(U.S. Customary Units)**

Thickness: $t = 0.021$ in.

Weight per area of fiber reinforcement: $W = 1.508$ lb/ft$^2$ for the entire laminate, where the weights for the components are as follows:

- $W = 0.0938$ lb/ft$^2$ for chopped strand mat (CSM)
- $6.90 \times 10^{-3}$lb/ft for c-veil
- $0.142$ lb/ft$^2$ for 225-yield glass roving at 8 strands per inch
- $0.0926$ lb/ft$^2$ for 24-oz/yd$^2$ woven roving with 5/4 construction in the warp direction, and $0.0741$ lb/ft$^2$ in the weft direction

Specific gravity of resin: $SG_r = 1.2964$

Density of resin: $\rho_m = SG_r \times 0.0361$ lb/in.$^3 = 0.0468$ lb/in.$^3$

Density of fiber: $\rho_f = 0.0943$ lb/in.$^3$
The following are the effective material properties for the laminate:

<table>
<thead>
<tr>
<th>Material Properties</th>
<th>U.S. Customary Units</th>
<th>SI Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_x$</td>
<td>$1.187 \times 10^6$ psi</td>
<td>8180 MPa</td>
</tr>
<tr>
<td>$E_y$</td>
<td>$1.549 \times 10^6$ psi</td>
<td>10700 MPa</td>
</tr>
<tr>
<td>$\nu_{xy}$</td>
<td>0.36</td>
<td>0.36</td>
</tr>
<tr>
<td>$\nu_{yx}$</td>
<td>0.49</td>
<td>0.49</td>
</tr>
<tr>
<td>$G_{xy}$</td>
<td>$7.047 \times 10^5$ psi</td>
<td>4860 MPa</td>
</tr>
<tr>
<td>$E_{x}$ flexural</td>
<td>$1.142 \times 10^6$ psi</td>
<td>7870 MPa</td>
</tr>
<tr>
<td>$E_{y}$ flexural</td>
<td>$1.179 \times 10^6$ psi</td>
<td>8130 MPa</td>
</tr>
<tr>
<td>$\nu_{xy}$ flexural</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>$\nu_{yx}$ flexural</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>$D_{x}$ flexural</td>
<td>$4.550 \times 10^4$ lb-in.</td>
<td>$5.141 \times 10^5$ N-mm</td>
</tr>
<tr>
<td>$D_{y}$ flexural</td>
<td>$4.701 \times 10^4$ lb-in.</td>
<td>$5.311 \times 10^5$ N-mm</td>
</tr>
<tr>
<td>$E_{x}$ extensional</td>
<td>$5.065 \times 10^5$ lb-in.</td>
<td>$5.723 \times 10^5$ N-mm</td>
</tr>
<tr>
<td>$E_{y}$ extensional</td>
<td>$6.613 \times 10^5$ lb-in.</td>
<td>$7.472 \times 10^5$ N-mm</td>
</tr>
<tr>
<td>Midthickness</td>
<td>0.176 in.</td>
<td>4.47 mm</td>
</tr>
<tr>
<td>Neutral axis x</td>
<td>0.164 in.</td>
<td>4.17 mm</td>
</tr>
<tr>
<td>Neutral axis y</td>
<td>0.172 in.</td>
<td>4.37 mm</td>
</tr>
</tbody>
</table>

where the following assumptions have been made:

(a) Extension $E_x$ and $v_{xy}$ and flexural $E_{x}$ and $v_{xy}$ are calculated based on the neutral $x$ axis, such that an extensional load $N_x$ produces no curvature in the $x$ direction, and an $M_{xy}$ bending load produces no $x$-direction extension.

(b) Extensional $E_y$ and $v_{yx}$ and flexural $E_y$ and $v_{yx}$ are calculated based on the neutral $y$ axis, such that an extensional load $N_y$ produces no curvature in the $y$ direction, and an $M_{xy}$ bending load produces no $y$-direction extension.

(c) In-plane $G_{xy}$ is assumed to be the average of the $G_{xy}$ calculated using the $x$ and $y$ neutral axes.

**NOTES:**

(1) These are one-dimensional values, and the full ABD matrix needs to be used for laminates that have $B_{xy}$ terms present to determine the actual response of the laminate because of the additional coupling terms.

All properties using the advanced CLT are within a few percent of those calculated using the simplified 1D for the $E_i$ ($E_x$) and $E_j$ ($E_y$) values.

**M3-630 Stresses, Strains, and Strength Ratios Example**

Using the simplified design calculation example in para. M3-610 and assuming a biaxial pressure of 10.0 psig ($6.89 \times 10^{-2}$ MPa) and an inside diameter of 120 in. (3050 mm), the stresses, strains, and strength ratios are calculated; results are shown Table M3-3.

A comparison of the calculated $R$ values shows that there is close agreement between the four strength theories.

**M3-640 Macro or Smeared Property Formulation**

Resin crazing is allowed in the laminate, except for the liner materials. Filament wound, unidirectional, and woven roving materials can produce an artificially low $R$ value due to loads transverse to the fiber directions. Then, load transverse to the fiber direction may be protected due to the adjacent transverse fibers. The strength of the macro is not compromised, provided there is no fiber failure.

This example is based on the woven roving with properties as calculated in para. M3-310 and used in the design example.

The woven roving layer is modeled as a balanced and symmetric three-ply laminate as shown in Table M3-4. All the effective elastic properties and strengths per strain limits of this three-ply model can be determined as shown in this Table.

The strengths for this macro are based on the strain allowables in para. M3-310 and by discounting the strength of the transverse plies. The tensile strength in the 1 direction is the product of the strain allowable (0.020) and $E_x$, which is 46,900 psi (323.4 MPa). The tensile strength in the 2 direction is the product of the strain allowable (0.020) and $E_y$, which results in a strength of 40,520 psi (279.4 MPa). The other strengths are determined in a similar way, and the result is the following:
MANDATORY APPENDIX M-5
QUALIFICATION OF LAMINATORS AND SECONDARY BONDERS

M5-100 GENERAL REQUIREMENTS

(a) This Appendix specifies the rules for qualifying personnel to produce laminates and/or perform secondary bonding operations. Laminates and overlays thereof (secondary bonds) shall only be made by personnel who have been qualified in accordance with the rules of this Appendix.

(b) A Laminator is an individual actively engaged (continually present and possessing full control over the process) in producing laminates. This is not to preclude assistance being provided to the Laminator by one to four assistants.

(c) A Secondary Bonder is an individual who is actively engaged in joining and overlaying cured subassemblies of the vessel being fabricated. This is not to preclude assistance being provided to the Secondary Bonder by one or two assistants.

(d) The Fabricator shall maintain up-to-date records relating to qualification of each Laminator and Secondary Bonder. These records will document the date of last qualification and will include all calculations and test or inspection reports from both internal and independent laboratory testing programs used in the process of qualification. These records are subject to review on request by all parties engaged in the process of procurement or inspection.

M5-200 RESPONSIBILITY

It is the responsibility of the Fabricator to train and qualify Laminators and Secondary Bonders.

M5-300 QUALIFICATION OF LAMINATORS

(a) Laminators may qualify their capabilities at the time a Fabricator produces a demonstration laminate for the purpose of shop qualification.

(b) To qualify, a Laminator must produce one Type I demonstration laminate (see Part 7), fabricated of any polyester or vinyl ester resin, which upon test in accordance with the instructions in Part 7 fulfills the requirements of this Standard. A Laminator Qualification Report, Form M5-1, shall be completed and signed for each laminator qualification.

(c) All laminates made for qualification shall be identified in accordance with para. 7-900.

(d) Laminators shall be requalified if inactive for 6 months.

(e) The Certified Individual may require requalification of a Laminator at any time if there is cause to question the Laminator’s ability to produce laminates in accordance with the requirements of this Standard.

M5-400 QUALIFICATION OF SECONDARY BONDERS

(a) Secondary Bonders must qualify their capabilities in accordance with the procedures that follow:

(b) It is the responsibility of the Fabricator’s Quality Control Manager to

1. ensure compliance with procedures as outlined for the preparation and machining of test samples,

2. make or supervise the making of circumference measurements.

3. make, sign, and date a Secondary Bonder Qualification Report; see Form M5-2. Attached to the Secondary Bonder Qualification Report shall be copies of a Component Data Sheet, including all items listed in Form NM6-2. Two Component Data Sheets are required, one for the pipe test piece, the second for the overlay. The Component Data Sheets shall be appropriately identified.

M5-410 Making Pipe Test Pieces

(a) Three pipe test pieces shall be made by a qualified Laminator utilizing brightly pigmented polyester or vinyl ester resin.

(b) The resin must be one that the Fabricator has qualified through the production of a demonstration laminate.

(c) [Ref] Refer to Figure M5-1 for dimensions of pipe test pieces.

(d) [Ref] The Laminator shall apply a nonpigmented, paraffinized top coat to the pipe exterior.

(e) After lamination, application of paraffinized top coat, and cure, the pipe test pieces must be aged at 70°F (21°C) to 80°F (27°C) for at least 72 hr before the Secondary Bonder may begin to make overlays.

M5-420 Making Secondary Bond Test Assemblies

(a) The Secondary Bonder must overlay three pipe test pieces to make three secondary bond test assemblies as illustrated in Figure M5-2.
Figure M5-1 Pipe Test Piece

Type II laminate, 0.37 in. (9.4 mm) nominal thickness (per Table 2A-2)

1 in. to 1½ in. (25 mm to 32 mm) (typical)

Measurement locations

Approx. ⅛ in. (19 mm)

18 in. ± ⅛ in. (460 mm ± 3 mm)

Mark average circumference length in these areas [see para. M5-420(d)]

Figure M5-2 Secondary Bond Test Assembly

Secondary Bonder to mark name and/or employee no. at both ends of secondary bond test assembly, 90 deg to $C_4$ data. Quality Control Manager to mark a number at each end, 180 deg to $C_4$ data. (There must be a different number at each end of each assembly.)

Laminate sequence

2M, 3(MR), M, V (see paras. 4-320(b) through (d))

Add: Bond shall be of the same resin system as the pipe
**Figure M5-1 Pipe Test Piece**

Type II laminate, 0.37 in. (9.4 mm) nominal thickness (per Table 2A-2)

1 in. to 1 1/8 in. (25 mm to 32 mm) (typical)

Measurement locations

Approx. 3/4 in. (19 mm)

Mark average circumference length in these areas [see para. M5-420(d)]

18 in. ± 1/8 in. (460 mm ± 3 mm)

Pipe ID shall be 3 in. +/- 1/8 in. (76 mm +/- 3 mm)

**Figure M5-2 Secondary Bond Test Assembly**

Secondary Bonder to mark name and/or employee no. at both ends of secondary bond test assembly. 90 deg to C6 data. Quality Control Manager to mark a number at each end, 180 deg to C6 data. (There must be a different number at each end of each assembly.)

Laminate sequence 2M, 3(MR), M, V (see paras. 4-320(b) through (d))
M5-420 Making Secondary Bond Test Assemblies

(a) The Secondary Bonder must overlay three pipe test pieces to make three secondary bond test assemblies as illustrated in Figure M5-2.

(b) The Secondary Bonder shall prepare the pipe test pieces for overlay per para. 4-320(a). Care should be taken to maintain an even surface and constant circumference, avoiding removal of excess material that would result in grooves, tapers, or flat spots.

(c) After preparation for overlay, the circumference of the area to be overlayed shall be measured using a metal tape measure at the points indicated in Figure M5-1. This must be done for each of the three pipe test pieces to be overlayed. Measurements must be made in accordance with para. M5-400(b)(2). Measurement accuracy shall be ±1∕16 in. (∓1.5 mm) and rounded to the nearest 1∕16 in. (1.5 mm).

(d) For each of three pipe test pieces, the two circumference measurements shall be recorded in the Secondary Bonder Qualification Report. When recording measurements, express the values as the decimal equivalents of the measurements taken. Calculate the average of the three measurements, express the values as the decimal equivalents of the measurements taken. Calculate the average of the two circumference measurements and round it off to the nearest hundredth of an inch (0.2 millimeter); this value shall be marked on each pipe test piece.

(e) A unique specimen identifier is to be marked at each end of each test piece. See Fig. M5-2.

(f) The Secondary Bonder shall then overlay the three pipe test pieces, following instructions in paras. 4-320(b) through 4-320(d), so as to make secondary bond test assemblies as shown in Figure M5-2. Nonpigmented resin is to be used.

M5-430 Making and Measuring Secondary Bond Test Specimens

(a) After the overlay is cured, and cure is verified per the instructions in para. 6-910, machine the secondary bond test assemblies to make secondary bond test specimens in accordance with Figure M5-3.

(b) Each secondary bond test assembly makes two secondary bond test specimens when cut on the centerline of the overlay.

(c) A minimum of five secondary bond test specimens are required to be made for testing.

(d) Machining operations may be done by the Fabricator, at another firm or location, or at an independent testing laboratory.

M5-440 Testing Secondary Bond Test Specimens and Calculating Secondary Bond Shear Strength

(a) When machining is complete, five secondary bond test specimens must be tested by an independent testing laboratory.

(b) Prior to testing, the average engagement height of the shear collar must be determined for each secondary bond test specimen.

(c) Measurements and calculations to determine the average engagement height of the shear collar must be done at the independent testing laboratory where the test specimens are to be tested.

(d) To determine the average engagement height, \( h_a \), for each test specimen, proceed as follows:

1. Refer to Figure M5-3.
2. Using a vernier caliper, make three measurements of the shear collar height, \( L_a \), at approximately 120-deg intervals and record the measurements in the Secondary Bonder Qualification Report. The average of the three measurements, \( L_{av} \), shall be calculated; the value shall be rounded off to the nearest hundredth of an inch (0.2 millimeter), recorded in the report, and also marked on each test specimen in approximately the area shown in Figure M5-3. Refer to para. M5-420(d) for marking requirements. Measurement accuracy shall be ±0.010 in. (0.25 mm).

3. Using a vernier caliper with a depth slide, make three measurements of the relief bore depth, \( D_a \), at approximately 120-deg intervals. Follow the same general procedures as in (2) for recording measurements; averaging and rounding data to arrive at the average relief bore depth, \( D_{av} \), and marking the specimen. Measurement accuracy shall be ±0.010 in. (0.25 mm).

4. Calculate the engagement height, \( h_a \), for each test specimen as follows:

\[
 h_a = L_{av} - D_{av}
\]

Record the values of \( h_a \) in the Secondary Bonder Qualification Report and mark them on the test specimens in accordance with previous instructions. Testing of specimens may now commence.

(e) Specimens must be tested in compression in a laboratory testing machine such that the secondary bond area under the shear collar fails in shear. The crosshead speed shall be 0.05 in./min (1.3 mm/min).

(f) Peak load, \( P \), is to be recorded for each specimen, rounded off to the nearest 200 lb (890 N).

(g) Secondary bond shear strength, \( S_B \), is to be calculated for each test specimen as follows:

\[
 S_B = \frac{P}{C_u \times h_a} \text{lb/in.}^2 (\text{MPa})
\]

where

\[
 C_u = \text{average circumference of test specimen, in. (mm)}
\]
Figure M5-3 Secondary Bond Test Specimen

Top and bottom surfaces of specimen must be parallel [see Note (1)]

8 in. to 9 in. (200 mm to 230 mm)

1 in. (25 mm) min.  1 1/4 in. (32 mm) max.

1/8" (3 mm) min. width plunge cut. [see Note (2)]

1/8 in. to 3/16 in. (3 mm to 4.5 mm) plunge cut [see Note (2)]

1/8 in. (3 mm) max. 1/32 in. (0.8 mm) min. Slot [see Note (5)]

1/8 in. (3 mm) max. 1/32 in. (0.8 mm) min. [see Note (5)]

1/8 in. (3 mm) max. 1/32 in. (0.8 mm) min. [see Note (5)]

GENERAL NOTE: ✓ indicates machine lathe finish.

NOTES:
(1) Lack of parallelism may reduce test values.
(2) Plunge cut with squared nose parting tool to depth sufficient to expose pigmented laminate a full 360 deg and over total surface root of slot.
(3) Machine back pipe 3/4 in. (6 mm) minimum 3/16 in. (8 mm) maximum.
(4) Machine away internal surface of shear collar to be outboard of pipe external surface 3/32 in. (2.5 mm) minimum, a full 360 deg.
(5) Slot must extend completely through the wall of the shear collar (and pipe) and be of length sufficient to protrude fully into the plunge cut slot.

(4) The relief bore is to extend a minimum of 3/32 in. (2.5 mm) outboard of the external surface of the pipe for the full circumference of the relief bore.
Table M6-1 User's Basic Requirements Specification (UBRS) (As Required by the Provisions of ASME RTP-1)

User firm name __________ For display at Fabricator's shop

User's Agent firm name __________ Not applicable

Title of equipment __________ ASME RTP-1 demonstration vessel

User's designation no. __________ ASME RTP-1 A1

Installation location (name and address) __________ Fabricator's shop

UBRS prepared by (User or User's Agent):

Name __________ Mandatory Appendix M-6, ASME RTP-1

Phone no. __________ Not applicable

Date __________ 3/8/02

Address __________

1. Equipment description (equipment sketch and nozzle schedule must be attached):

   Storage vessel

2. Additional Fabricator responsibilities:

   [ ] Special requirements

   [ ] Acoustic emission testing

   [x] Inspection or testing requirements not listed in the Standard. A special hydrotest shall be performed, fully flooded (all air vented off). Water shall be ambient temperature. An acceptable Hydrostatic Proof test shall be in the range of 44.0 psig–46.0 psig (303 kPa – 317 kPa). Test shall be witnessed by a Qualified Designer. The Witness of Hydrotest form (Figure M6-3) shall be completed.

   [ ]

   [ ]

   [x] Visual inspection acceptance level (refer to Table 6-1 of ASME RTP-1):

   [ ] Level 1

   [x] Level 2

   Quantity limitations for gaseous air bubbles or blisters

---

Change “kPa” to “kPag”
Table M6-1 User’s Basic Requirements Specification (UBRS) (As Required by the Provisions of ASME RTP-1) (Cont’d)

3. Material selection
   3.1 Material selection by:
      [ ] Resin manufacturer (include data per section 4 of this document)
      [ ] Fabricator (include data per section 4 of this document)
      [ ] End User. Applicable User’s specifications/standards, codes, ordinances, FDA requirements, etc. (list and specify; attach copies of local code/ordinance requirements)

   [x] Other... As required by Mandatory Appendix M-6

   3.2 Material of construction:
      Resin ____________ Clear chloric polyester ____________ Catalyst/cure system CoNap/MEKP ____________
      Veil ____________ Fiberglass surfacing veil ____________ Barcol hardness per para. 6-910(b)(4) NA ____________
      [ ] Lift lugs: [ ] RTP [ ] Carbon steel [ ] Other ____________
      [x] Hold-down lugs: [x] RTP [ ] Carbon steel [ ] Other ____________

4. Chemical service data (shall be provided when Fabricator or resin manufacturer is making material selection)

   4.1 Description of process function and process sequence: Not applicable

   4.2 Contents:

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Max. %</th>
<th>Min. %</th>
<th>Exposure Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potable water</td>
<td>100</td>
<td>100</td>
<td>Continuous</td>
</tr>
</tbody>
</table>

4.3 pH range: ______ max. ______ min.

5. Design
   5.1 Design conditions:

<table>
<thead>
<tr>
<th></th>
<th>Operating</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal pressure</td>
<td>14.0 psig (96.5 kPa)</td>
<td>15.0 psig (103 kPa)</td>
</tr>
<tr>
<td>External pressure</td>
<td>0.0 psig (0.0 kPa)</td>
<td>0.0 psig (0.0 kPa)</td>
</tr>
<tr>
<td>Temperature</td>
<td>80°F (27°C)</td>
<td>150°F (66°C)</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Liquid level</td>
<td>Full</td>
<td>Full</td>
</tr>
</tbody>
</table>

Change “kPa” to “kPag”
On this date __________ the following parties do certify by their signatures that they have witnessed a hydrostatic test of the RTP demonstration vessel as constructed by

Fabricator’s name ____________________________

Address ____________________________

and that this vessel did successfully contain the hydrostatic test pressure of 45.0 psig (310 kPa) for 2 hours without leakage or cracking of any of its parts.

(a) Fabricator’s Inspector’s signature ____________________________

(signature)

(print name)

(b) Qualified Designer’s signature (and seal)

______________________________

(signature)

(print name)

(c) Fabricator’s authorized agent ____________________________

GENERAL NOTES:
(a) This form may be reproduced and used without written permission from ASME if used for purposes other than republication.
(b) Attach this witness form directly to the Fabricator’s Data Report (Form 1-2).
(c) An acceptable test pressure range is 44.0 psig to 46.0 psig (303 kPa to 317 kPa).
MANDATORY APPENDIX M-9
GLOSSARY

accelerator: a material added to the resin to increase the rate of polymerization (curing).

audit: a systematic review to assess the implementation of prescribed procedures, specifications, or standards.

axial: in the direction of the axis (lengthwise centerline) of the equipment.

Barcol hardness test: test to determine the surface indentation hardness of the resin, which is directly related to the degree of cure. The Barcol Impressor is the instrument used for measuring polyester and vinyl ester resin hardness (ASTM D2583).

binder: chemical treatment applied to the random arrangement of glass fibers to give integrity to mats. Specific binders are utilized to promote chemical compatibility with the various laminating resins used.

blister: raised spot on the surface of a laminate caused by a subsurface air void.

bonding: joining of two or more parts by adhesive forces.

bond strength: force per unit area necessary to rupture a bond in interlaminar shear.

burned areas: areas of laminate showing evidence of decomposition (e.g., discoloration and/or cracking) due to excessive resin exotherm.

burn out (burn off): thermal decomposition of organic materials (resins and binders) from a laminate specimen in order to determine the weight percent of resin and glass reinforcement (synthetic reinforcements decompose together with the resin and binder).

catalyst: an organic peroxide material used to activate the polymerization reaction of a resin, causing it to harden (polymerization initiator).

certify: to attest, by signature and date, to conformance to procedures, specifications, or standards. Where certification is required by a Qualified Designer, certification shall include application of the PE stamp.

chopped strand mat: reinforcement made from randomly oriented glass strands that are held together in form using a binder. Each strand has a sizing.

chopper gun: a machine that is used to cut continuous fiberglass roving to predetermined lengths [usually 1/2 in. (13 mm) to 2 in. (50 mm)] and propel the cut strands to the mold surface. In the spray-up process, a catalyzed resin spray is deposited simultaneously on the mold. When intersperse layers are provided in filament winding, the resin spray is often not used.

contact molding: process for molding RTP in which reinforcement and resin are placed in or on a mold. Cure is either at room temperature using a catalyst-promoter system or by heat in an oven. Includes both hand lay-up and spray-up. For the purposes of this Standard, laminates manufactured with a process other than filament winding are contact molded.

corrosion layer (barrier): see paras. 2A-221 and 2A-222.

coverage: in hoop filament winding, the complete covering of the mandrel surface by a single layer of glass reinforcement and resin. In helical winding, two layers must be applied to achieve one coverage.

crazing: the formation of tiny hairline cracks in varying degrees throughout the resin matrix, particularly in resin-rich areas.

critical service: see para. 1-210(c).

curing agents: materials used to initiate the polymerization of a resin. The catalyst is the primary agent. Promoters and accelerators are secondary or assisting agents.

cut edge: end of a laminate resulting from cutting that is not protected by a corrosion barrier.

delamination: physical separation or loss of bond between laminate plies.

dished end: radiused end closure for a cylindrical vessel, as opposed to a flat or coned end.

dry spot: an area where the reinforcement fibers have not been sufficiently wetted with resin.

edge sealing: application of reinforcement and resin, or resin alone, to seal cut edges and provide a corrosion-resistant barrier. The final layer of resin shall be paraffinned.

entrapped air void: cavity in a laminate caused by a trapped gas bubble.

environment: state of the surroundings in contact with the internal or external surface. Included are the temperature, pressure, chemical exposure, exposure to sunlight, relative humidity, liquids, and/or gases.
equipment: vessels used for the storage, accumulation, or processing of corrosive or otherwise hazardous substances at pressures ranging from full vacuum to 15.0 psig (103 kPa).

equipment assembler: person who puts together the component parts, e.g., joining sections, installation of nozzles, etc.

exotherm: evolution of heat by the resin during the polymerization reaction. The word exotherm is often used, however, to designate the maximum temperature reached during the polymerization process.

exotherm ply: that ply of chopped strand mat at which the lamination process is stopped to allow gelation and exotherm of the existing laminate.

exterior layer: outer surface layer of a laminate; see para. 2A-224.

Fabricator: producer of RTP equipment. The Fabricator combines resin and reinforcing fibers to prepare the final product.

fiber: a fine solid thread of glass.

fiberglass roving: a number of strands or filaments of glass fibers gathered together with little or no twist.

fiberglass woven roving: heavy fabric woven from glass fiber rovings.

fiber wetting: coating (wetting) of the fiberglass with resin by means of roll-out or immersion.

filament: see fiber.

filament winding: a process for forming RTP parts by winding either dry or resin-saturated continuous roving strands onto a rotating mandrel.

fillers: inert materials that are added to the resin to increase density, increase viscosity, improve abrasion resistance, enhance resin application properties, decrease resin shrinkage, reduce cost, etc.

fill picks: the rovings in a woven roving that run in the transverse direction of the fabric, i.e., across the roll width of the fabric.

fit-up: the match between joining parts, elements, or components.

flame retardant resin: halogenated resins that can be used with or without additives to provide a laminate having a reduced flame spread as measured in accordance with NFPA 255, Standard Method of Surface Burning Characteristics of Building Materials (UL723, ASTM E84). The resins are not fire retardant in their liquid state.

flame spread rating: index number resulting from testing in accordance with NFPA 255, Standard Method of Surface Burning Characteristics of Building Materials (UL723, ASTM E84).

gap filling: the filling of voids between joined parts, elements, or components with resin putty or resin.

gel: the initial jellylike solid phase that develops during the polymerization of resin.

gel time: time from the initial mixing of the resin with catalyst to when gelation begins.

glass content: weight percent of glass fiber reinforcement in the laminate.

gun roving: fiberglass roving designed for use in a chopper gun for spray-up application.

hand lay-up: a method of contact molding wherein the glass fiber reinforcement is applied to the mold, in the form of chopped strand mat or woven roving, by hand or from a reel. The resin matrix is applied by various methods including brush, roller, or spray gun. Consolidation of the composite laminate is by rolling.

heat deflection temperature: temperature at which a specified bar specimen deflects 0.010 in. (0.25 mm) when loaded as a simple beam to a constant 264 psi (1.82 MPa) (see ASTM D648, Test Method for Deflection Temperature of Plastics Under Flexural Load). Usually the test medium.

independent testing laboratory: the laboratory conducting the tests required by ASME RTP-1 must be an entity separate organizationally, legally, and financially from the Fabricator and User or User’s Agent. Additionally, no commercial, financial, or individual relationships shall exist between the parties that might compromise efforts to produce and report accurate test results. It is expected, however, that a commercial purchase order, contract, or agreement will be employed by the parties to arrange for testing services. The independent testing laboratory must be equipped and staffed with the necessary skilled personnel to conduct the tests in accordance with the requirements of the Standard.

initiator: see catalyst.

inner surface: see para. 2A-221.

interior layer: see para. 2A-222.

intersperse: see para. 2A-222.

isophthalic polyester: a polyester made from isophthalic acid.

joint overlay: an overlay laminate that joins the adjoining surfaces of two contacting parts or elements.
equipment: vessels used for the storage, accumulation, or processing of corrosive or otherwise hazardous substances at pressures ranging from full vacuum to 15.0 psig (103 kPa).

equipment assembler: person who puts together the component parts, e.g., joining sections, installation of nozzles, etc.

exotherm: evolution of heat by the resin during the polymerization reaction. The word exotherm is often used, however, to designate the maximum temperature reached during the polymerization process.

exotherm ply: that ply of chopped strand mat at which the lamination process is stopped to allow gelation and exotherm of the existing laminate.

exterior layer: outer surface layer of a laminate; see para. 2A-224.

Fabricator: producer of RTP equipment. The Fabricator combines resin and reinforcing fibers to produce the final product.

fiber(glass): a fine solid thread of glass.

fiberglass roving: a number of strands or filaments of glass fibers gathered together with little or no twist.

fiberglass woven roving: heavy fabric woven from glass fiber rovings.

fiber wetting: coating (wetting) of the fiberglass with resin by means of roll-out or immersion.

filament: see fiber.

filament winding: a process for forming RTP parts by winding either dry or resin-saturated continuous roving strands onto a rotating mandrel.

fillers: inert materials that are added to the resin to increase density, increase viscosity, improve abrasion resistance, enhance resin application properties, decrease resin shrinkage, reduce cost, etc.

fill picks: the rovings in a roving that run in the transverse direction of the fabric, i.e., across the roll width of the fabric.

fit-up: the match between joining parts, elements, or components.

flake retardant resin: halogenated resins that can be used with or without additives to provide a laminate having a reduced flame spread as measured in accordance with NFPA 255, Standard Method of Surface Burning Characteristics of Building Materials (UL723, ASTM E84). The resins are not fire retardant in their liquid state.

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glass content: weight percent of glass fiber reinforcement in the laminate.

gun roving: fiberglass roving designed for use in a chopper gun for spray-up application.

hand lay-up: a method of contact molding wherein the glass fiber reinforcement is applied to the mold, in the form of chopped strand mat or roving, by hand or from a reel. The resin matrix is applied by various methods including brush, roller, or spray gun. Consolidation of the composite laminate is by rolling.

heat deflection temperature: temperature at which a specified bar specimen deflects 0.010 in. (0.25 mm) when loaded as a simple beam to a constant 264 psi (1.82 MPa) (see ASTM D648, Test Method for Deflection Temperature of Plastics Under Flexural Load). Usually refers to a resin casting, not a laminate.

helical winding: filament winding where the reinforcement is placed at some angle (other than 0 deg or 90 deg) to the axis of rotation.

hot patch: several small fiberglass mat tabs, saturated with highly catalyzed resin, used to hold butted or joined parts or components in preparation for bonding.

hydrostatic test: pressure test of equipment using water as the test medium.

independent testing laboratory: the laboratory conducting the tests required by ASME RTP-1 must be an entity separate organizationally, legally, and financially from the Fabricator and User or User’s Agent. Additionally, no commercial, financial, or individual relationships shall exist between the parties that might compromise efforts to produce and report accurate test results. It is expected, however, that a commercial purchase order, contract, or agreement will be employed by the parties to arrange for testing services. The independent testing laboratory must be equipped and staffed with the necessary skilled personnel to conduct the tests in accordance with the requirements of the Standard.

initiator: see catalyst.

inner surface: see para. 2A-221.

interior layer: see para. 2A-222.

intersperse: chopped fiberglass used in a filament wound laminate, usually in thin layers between winding coverages.

isophthalic polyester: a polyester made from isophthalic acid.

joint overlay: an overlay laminate that joins the adjoining surfaces of two contacting parts or elements.
laminate: the total of the part constructed by combining one or more layers of material (reinforcement and/or resin). As used in this Standard, the corrosion laminate consists of the corrosion-resistant barrier, the structural layer, and the outer surface.

laminate composition: the sequence of reinforcement materials on a type, class, and category basis that make up a laminate.

laminate element: a part of the structural layer of a filament wound laminate that is described by the wind angle, number of coverages with supplementary reinforcement (if used), and the required sequence.

laminate structure (Type I, hand lay-up): see Table 2A-1.

laminate structure (Type II, hand lay-up): see Table 2A-2.

laminate structure (Type X): see Subpart 2A.

lamination analysis: procedure by which, given the amount and properties of the resin and the properties and orientation of the reinforcement, it is possible to calculate the elastic properties of the individual layers and the total laminate.

layout: the arrangement and location of parts, elements, and/or components that reflect the design of a product.

leno strands: a pair of warp ends at each edge of a woven fiberglass fabric.

liner: see paras. 2A-221 and 2A-222.

longitudinal: see axial.

lot, resin: a resin lot is a quantity of resin that is formulated to its final composition in a single vessel, tested and assigned a unique number, and covered by a certificate of analysis.

mandrel: mold around which a laminate is formed to fabricate a cylindrical section.

Manufacturers: producers of materials of construction, e.g., resin, reinforcement fibers, catalysts, common additives, etc.

manway: large nozzle or opening in a vessel for the purpose of entry by personnel.

materials: ingredients (reinforcements, resins, catalysts, and common additives) that are used to fabricate the equipment.

matrix: resin phase of a fiberglass resin composite.

minor repairs: repairs that do not exceed the area of repair allowed in Part 6 and meet the minimum visual acceptance level indicated in the UBRS.

mold: the form over which or into which resin and reinforcements are placed to form the composite product shape.

mold release agents: see parting agents.

monomer: a basic compound that can react with itself to form a polymer.

MSPI: Manufacturer’s Specific Product Identification.

oblation: the process by which cylindrical tank shells are compressed to create shapes varying from oval to figure eight. This action is taken to facilitate over-the-road shipment or installation in a confined space.

original document: the original source document or a reproduction of the original source document bearing an original signature.

overlay: laminates used overbase RTP structures to secure a joint, seal a seam, attach a nozzle, etc.

paraffinated resin: resin containing a small amount of dissolved paraffin (usually 0.1% to 0.5%). Polymerization of polyesters is inhibited by contact with the atmosphere. During cure, the paraffin migrates to the surface, sealing it against atmospheric exposure.

parting agents: also called mold release agents. Compounds that assist in releasing an RTP part from its mold.

peroxide catalyst: see catalyst.

pit: small crater in the surface of the laminate (see Table 6-1).

polystyrene resin: resin produced by the polycondensation of diblocky derivatives and dibasic organic acids or anhydrides, wherein at least one component contributes ethylenic unsaturation yielding resins that can be compounded with styril monomers and reacted to give highly cross-linked thermoset resins.

postcuring: process of applying heat [180°F (82°C) to 200°F (93°C)] to an RTP part, following the exotherm cycle. Proper postcuring will shorten the time to total cure.

profile: the roughness (smoothness) of the surface.

promoter: a material that activates the catalyst that cures the resin (also see accelerator).

PVA: abbreviation for polyvinyl alcohol, a parting agent.

quality assurance: the program by which the Fabricator provides evidence that the quality control system has been followed in the construction of the product.

quality control: the program a Fabricator uses to fabricate the equipment in compliance with this Standard.

referee samples: laminate specimens submitted to establish a level of quality for judging acceptance/rejection of production equipment.

reinforcement: glass fibers having the form of chopped roving, continuous roving, fabric, or chopped strand mat. These fibers are added to the resin matrix to strengthen and improve the properties of the resin.

release film: film used to facilitate removal of the part from the mold or mandrel. Oriented polyester film, 3 mil to 5 mil (Mylar: Rm, Types A, S, or D; or Melinex 11®, Types S, O, or 442), has been found suitable for this purpose.
**resin:** the matrix of the laminate.

**resin putty:** resin filled with clay, fumed silica, milled glass fibers, or other inert materials to provide puttylike consistency.

**resin-rich layer:** term often used to describe the corrosion barrier. The term does not imply excessive resin content.

**resin richness:** excessive amounts or uneven distribution of resin in the laminate. Such areas are subject to cracking. Resin richness is the result of improper wet-out procedures as well as inadequate or improper roll-out techniques or drainage.

**roll-out:** densification of the laminate by working reinforcement into the resin and the air out of the resin using a roller (a serrated metal or thermoplastic roller is often used for this purpose).

**rough profile:** the result of sanding, machining, or otherwise abrading a laminate surface to produce a roughened surface for bonding.

**roving:** a plurality of strands or filaments gathered together with little or no twist in a package known as a roving ball.

**RTP:** reinforced thermoset plastic.

**secondary bond strength:** adhesive force that holds a separately cured laminate to the basic substrate laminate.

**sizing:** surface treatment or coating applied to filaments to improve the filament-to-resin bond.

**slugs:** unfiberized beads of glass.

**spray-up:** method of contact molding wherein resin and chopped strands of continuous filament glass fiber roving are deposited on the mold directly from a chopper gun.

**strain:** elongation per unit length.

**strand:** a plurality of filaments gathered together and bonded with sizing.

**stress:** load per unit area.

**structural layer:** the portion of the laminate construction providing the primary mechanical strength.

**surface preparation:** the act of roughening, priming, or otherwise treating laminate surfaces to achieve surface conditions that are conducive to adhesion of subsequently applied laminate bonds.

**surfacing veil:** thin mat of fiberglass, synthetic organic fiber, or carbon fiber that is used to reinforce the corrosion-resistant resin-rich layer on the inside or outside of equipment or to provide a smooth surface on the outside of equipment.

**Tex:** linear density of roving expressed in grams per 1 000 m.

**Type I, Type II, and Type X laminates:** see laminate structure.

**unidirectional rovings:** continuous parallel roving strands of glass fibers held together with periodic cross strands.

**User:** organization for which the equipment is being fabricated.

**UV absorber:** compounds that are added to resins to enhance their ultraviolet resistance.

**veil:** see surfacing veil.

**vinylester resin:** resin characterized by reactive unsaturation located predominately in terminal positions that can be compounded with styryl monomers and reacted to give highly cross-linked thermoset copolymers.

**visual acceptance criteria:** see para. 6-940.

**voids:** unfilled space caused by air or gas by entrapment of such gases during lay-ups of glass. Excessive voids reduce the strength and chemical resistance of the laminate, particularly if the voids are at the resin-glass interface.

**warp ends:** the roving in a woven roving that runs in the longitudinal direction of the fabric, i.e., along the roll length of the fabric.

**wind angle:** angle from the axis of rotation at which the reinforcement strands are placed in the filament winding process.

**wind cycle:** in filament winding, one traversing of the carriage to the end of the mandrel and return to the original position. Depending on bandwidth, part diameter, and wind angle, one or more wind cycles will be needed to achieve one coverage.

**yield:** linear density of roving, expressed in yards per pound.
Mandatory Appendix M-12
Dual laminate vessels

Article A General Requirements

Article B Materials

Article C Design

Article D Fabrication

Article E Inspection and Test

Article F Shipping and Handling

Article G Shop Qualification

Article H Qualification of Welders

Article I Glossary

ARTICLE A

GENERAL REQUIREMENTS

M12-100 INTRODUCTION

This Appendix includes the following:

Article A General Requirements

Article B Materials

Article C Design

Article D Fabrication

Article E Inspection and Test

Article F Shipping and Handling

Article G Shop Qualification

Article H Qualification of Welders

Article I Glossary

ARTICLE B

MATERIALS

M12B-100 SCOPE

This Article defines the thermoplastic lining materials that are used to fabricate dual laminate equipment, including the joining or welding materials and the bonding materials to bond the thermoplastic lining to the RTP structure. Bond strength requirements are also included. The RTP structural layer shall be in accordance with Part 2 of this Standard.

M12B-200 THERMOPLASTIC LINING MATERIALS

Thermoplastics are used as corrosion-resistant linings in dual laminate constructions. These materials are described in Tables M12B-1 and M12B-2. Table M12B-1 contains the ASTM specifications for materials used in this Standard. Table M12B-2 contains typical physical and mechanical properties for general comparisons. For purposes of design and selection, the thermoplastic manufacturer’s property data shall be used. Although most thermoplastic sheet materials are supplied as individual flat sheets, some sheet materials may be supplied as rolls. In this standard, sheet material is intended to mean both flat sheets and sheets supplied as rolls. Thermoplastics used to construct the liner shall not contain regrind. Thickness shall be as follows:

(a) Nominal lining thickness shall be from 0.08 in. to 0.20 in. (2.0 mm to 5.0 mm). The appropriate thickness for an application is a balance between thicker linings, which allow less permeation, and thinner linings, which result in less internal stress during forming.

(1) Lining thicknesses from 0.06 in. to 0.08 in. (1.5 mm to 2.0 mm) may be used if the Fabricator has qualified in that thickness prior to fabricating a vessel.
(b) specific thermoplastic material
(c) specific Welder’s name
(d) certification for each separate combination of (a), (b), and (c)

M12G-520 Bonding Capability

Each Fabricator shall bond the RTP overlay to thermoplastic liners with sufficient strength to satisfy the requirements of para. M12B-614. The shop survey team shall verify bond strength test records and shall determine that the Fabricator has the equipment and trained personnel to determine bond strength.

M12G-530 Demonstration Vessel

(a) The Fabricator shall produce a demonstration vessel, which shall be inspected by the ASME shop survey team. For the purposes of this qualification demonstration vessel, the lining system shall be divided into the following lining classes:

<table>
<thead>
<tr>
<th>Lining Classification</th>
<th>Demonstration Vessel Top Half</th>
<th>Demonstration Vessel Bottom Half</th>
</tr>
</thead>
<tbody>
<tr>
<td>A [Note (1)]</td>
<td>Fabric bonded lining</td>
<td>Chemically bonded lining</td>
</tr>
<tr>
<td>B [Note (2)]</td>
<td>Fabric bonded lining</td>
<td>Fabric bonded lining</td>
</tr>
<tr>
<td>C [Note (3)]</td>
<td>Chemically bonded lining</td>
<td>Chemically bonded lining</td>
</tr>
</tbody>
</table>

NOTES:
(1) Fabric and chemically bonded thermoplastic linings.
(2) Fabric bonded thermoplastic linings only.
(3) Chemically bonded thermoplastic linings only.

A Fabricator selects the appropriate lining classification and builds a demonstration vessel accordingly. The Fabricator is restricted to fabricating vessels to this Standard in only that class of lined vessels for which he/she has built a demonstration vessel that has passed the qualification procedure.

(b) The demonstration vessel shall be fabricated according to Figure M12G-1 and Table M12G-1.

(c) A Fabricator who is not certified to fabricate solid RTP vessels may qualify for a restricted certificate for dual laminate vessels only.

M12G-531 Demonstration Vessel Quality Requirements

(a) The demonstration vessel shall be inspected by the ASME shop survey team and shall meet the following requirements:

1. The vessel shall meet all visual inspection requirements of this Appendix.
2. The layout of thermoplastic sheets and the weld map shall conform to the requirements of para. M12C-300.
3. The vessel shall be tested to full vacuum. No debonding of the lining will be evident.

(b) Failure to meet any of the requirements in (a) above shall cause the Fabricator to fail for qualification to fabricate to ASME standards that class of dual laminate vessel.

(c) The vessel shall be sectioned and placed on permanent display in the same manner as the RTP vessel.

M12G-540 Procedures

The Fabricator shall have the following procedures clearly defined and established:

(a) spark testing
(b) welding
(c) forming
(d) safety
(e) stress relieving

M12G-550 Fabricator Certification

A Fabricator shall be certified to fabricate only dual laminate vessels by constructing one demonstration vessel in accordance with Figure M12G-1. The following conditions shall be met:

(a) The hydrotest required in Mandatory Appendix M-6 is performed before the vacuum test required in M12G-531(a)(3).

(b) The visual requirements of the liner (Table M12E-1) are substituted for the visual requirements of the RTP liner.

(c) The RTP structural overlay of the dual laminate vessel is in complete accordance with requirements of this Standard.

ARTICLE H
QUALIFICATION OF WELDERS

M12H-100 GENERAL REQUIREMENTS

(a) This Article specifies the rules for qualifying personnel to weld thermoplastic parts together. Thermoplastic linings will be assembled only by personnel who have been qualified in accordance with the requirements of this Article.

(b) A Welder is an individual who joins thermoplastic parts together using fusion bonding processes.

(c) The Fabricator will maintain up-to-date records relating to qualification of each Welder. These records will document the date of last qualification, and will include all calculations and test or inspection reports.
Important Notes:
1) Anchor clips are force multiplying devices and significantly increase anchor bolt pull out loads.
2) Anchor bolt pullout and shear loads shall be communicated to the foundation engineer.
3) Anchor clip design shown here is for small loads. Large loads will require a much more robust design. All anchor clips must be designed for the relevant loads. Fabricator may specify not-to-exceed loads for these type of lugs and clips.
4) Anchor clips may be used in conjunction with either anchor lugs or with a FRP shear collar.
5) Anchor clips, as shown, do not resist shear. Field fit shear stops must be included in the design. Special care must be taken if bearing stress is applied to the FRP knuckle. The preferred method is to apply bearing stresses to the tang of the anchor lug.

Width of clip shall be greater than or equal to width of tank lug and positioned on the same radial line.
NONMANDATORY APPENDIX NM-7
ACCEPTANCE INSPECTION BY USER'S INSPECTOR

NM7-100  SCOPE
Rules for mandatory visual and physical inspection of RTP corrosion-resistant vessels by the Inspector as defined in para. 1-400 are covered elsewhere in this Standard. The acceptance criteria for inspection of all vessels for special User specification or instructions are the responsibility of the User or User's inspector.

NM7-200  USER'S INSPECTION
Any special inspections required by the User shall be carried out by an inspector approved and/or authorized by the User of the vessel.

NM7-300  INSPECTION AND RESPONSIBILITY
The Fabricator has a responsibility to the User to comply with all specifications, instructions, or drawings. Fabrication should not proceed beyond a point designated by the User's inspector until the specified inspections have been made.

The User's inspector has the duty to verify that all requirements have been met.

Required hold point inspections and Inspection Checklist Forms may be used by the User's inspector.

Suggested checklists are given in Tables NM7-1 and NM7-2.

NM7-400  DIMENSIONS
(a) It is suggested that all vessels be inspected by the User's inspector for conformance with dimensions and tolerances compatible with the planned installation.

(b) Tolerances concerning the location and/or orientation of nozzles, manways, attachments, and other vessel elements that do not concern vessel strength are not a mandatory portion of this Standard.

(c) Figure NM7-1 includes a number of suggested dimensional tolerances for nozzles, mounting lugs, etc., that the User may consider for the planned installation of the equipment.

(d) To include dimensional tolerances from Fig. NM7-1 (or any other such tolerances) to govern the fabrication, the User must specifically reference such in the User's Basic Requirements Specification.

NM7-500  GASEOUS BUBBLES, BLISTERS, AND POROSITY
Refer to Table 6-1 for comments on these imperfections. Note that mandatory size limits are established, but no limits are established on quantity.

Though there is general consensus that a minimum of such imperfections reflects good workmanship, there is a lack of sufficient technical data to accurately relate these particular imperfections to shortened equipment life.

It is suggested that the User consult with the Fabricator about these imperfections and then establish requirements in the purchase contract or UBRS.

NM7-600  PACKAGING, SHIPMENT, AND INSTALLATION
The User's inspector should check that all equipment is handled, packaged, and shipped according to the purchase order.

The User's inspector should ensure that all information is correct on nameplates and that nameplates are permanently installed.

The User's inspector should ensure that all joining or assembly kits required for field installation are complete and ready for shipment.

The Inspection and Test Plan shown in Table NM7-3 will aid the Inspector to confirm the Reliability and Safety of newly fabricated FRP equipment through verification of compliance to related specifications, standards, and contract documents. User’s Quality Assurance (QA) Inspectors shall verify compliance through a review of the User’s/Owner’s specifications and User’s Basic Requirements Specification (UBRS) (Part 1, 1-200 and Table 1-1) of RTP-1, the manufacturer’s quality control documentation, and through physical and visual inspection of the equipment.

Refer to Mandatory Appendix M9-Glossary, of RTP-1, for proper terminology. Refer also to Part 6, Inspection and Tests and Table 6-1, RTP Visual Inspection Acceptance Criteria, as a descriptive guide to each aspect of this Test Plan.
### Table NM7-3 Inspection and Test Plan

<table>
<thead>
<tr>
<th></th>
<th>Fabricator</th>
<th>Third Party Inspector</th>
<th>User/Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Number</td>
<td></td>
<td>EQ #:</td>
<td></td>
</tr>
<tr>
<td>Client</td>
<td>PURCHASE ORDER #:</td>
<td>EQ NAME:</td>
<td></td>
</tr>
<tr>
<td>Vendor</td>
<td>SHOP ORDER #:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Pre-Fabrication

1. I. Pre-fab Meeting
2. a) Code, specifications, expectations, and potential discussed and understood
3. b) UBRS review and acceptance
4. c) Fabricator’s ASME-RTP-1 Accreditation verified
5. d) Review of Fabricator’s Quality Control Program
6. e) ITP discussed and all R - Review, W - Witness, H - Hold points set

#### Materials

7. I. Resins
8. a) Additives/Cure Process
9. b) Catalyst
10. Verify gel times, amount (%) catalyst used
11. Inspector’s Note: Weather App can provide “Screen Shot” photographic record of current weather conditions. (i.e.: temperature, humidity, dew point)
12. c) Flame Retardant additive, if required, amount (%) used
13. d) Top coats (Wax coat)
14. e) Pigments
15. II. Reinforcement
16. a) Type of Fiberglass (verify manufacturer if specified)
17. b) Surface veil
18. c) Roving
19. d) Filament winding
20. e) Fiberglass cloth/Woven Roving (Mat/WR "MWR")
21. Chopped Strand Mat (CSR)
22. III. Material and Documentation Review
23. a) Materials traceability documentation
24. b) Component Data Sheets Review
25. c) Personnel Qualifications Review (Laminators/Secondary Bonders)
26. d) Proof tests

#### Inspection and Testing

28. I. Physical Inspection
29. a) Dimension/Orientation/Configuration
30. b) Wind/Helix angle - Spiral wound tanks/vessels
31. Formula - WA = 90°-(measured angle/2)
32. c) Tank Bottom Flatness
33. d) Flange Flatness
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<table>
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<tbody>
<tr>
<td>34</td>
<td>1) Drawback</td>
</tr>
<tr>
<td>35</td>
<td>2) Bolt holes straddle centerlines</td>
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<tr>
<td>36</td>
<td>3) Backside spot-facing</td>
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<tr>
<td>37</td>
<td>3a) Bolt holes and spot-faces clear of resin drips and exposed glass</td>
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<tr>
<td>38</td>
<td>3b) Spot-faces properly sized and flat for washer seating</td>
</tr>
<tr>
<td>39</td>
<td>e) Laminate Thickness</td>
</tr>
<tr>
<td>40</td>
<td>Use nozzle cutouts and/or exposed edges at nozzle installation points for ply count</td>
</tr>
<tr>
<td>41</td>
<td>Verify retention of cutouts if specified</td>
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<tr>
<td>42</td>
<td>Glass Content - Ignition/Burn Test, if specified</td>
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<tr>
<td>43</td>
<td>f) Anchor/Hold-down Lugs</td>
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<td>44</td>
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<td>45</td>
<td>1) Will lug and nuts clear knuckle reinforcement</td>
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<tr>
<td>46</td>
<td>2) Field installation - lug hole drilling equipment interferences (nozzles/knuckle)</td>
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<tr>
<td>48</td>
<td>a) Refer to Table 6-1, Visual Inspection Acceptance criteria</td>
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<td>51</td>
<td>b) Overall Appearance</td>
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<tr>
<td>52</td>
<td>1) Color and consistency throughout</td>
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<tr>
<td>53</td>
<td>Consult causes if not (see ASTM D2653)</td>
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<tr>
<td>54</td>
<td>c) Surface Conditions</td>
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<tr>
<td>55</td>
<td>1) Pinholes/voids</td>
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<tr>
<td>56</td>
<td>2) Exposed glass/Frayed edges</td>
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<tr>
<td>58</td>
<td>3a) Glass tie-ins at bottom/back of flanges</td>
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<tr>
<td>59</td>
<td>3b) Wrapped with C-veil/Nexus veil</td>
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<tr>
<td>60</td>
<td>Inspector’s Note: Pay particular attention to ground level and limited access nozzles</td>
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<tr>
<td>61</td>
<td>d) Nameplate Verification [Code and Buyer’s Specification]</td>
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<td>62</td>
<td>III. Cure Verification</td>
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<td>63</td>
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<td>65</td>
<td>Inspector’s Note: Environmental conditions can affect these tests</td>
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<td>Inspector’s Note: Employ extreme caution with pneumatic testing.</td>
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<td>70</td>
<td>c) Vacuum</td>
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<td>d) Acoustic Emission (AE)</td>
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**POST FABRICATION**

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II. Field Installation

a) See NM-8

Inspector’s Note: Pre-installation meeting with Construction Manager and team recommended.

FRP cannot be handled as is steel. Torque values must be closely monitored to avoid flange cracking.

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