Reinforced Thermoset Plastic Corrosion-Resistant Equipment
1-310 Qualifications of the RTP-1 Qualified Designer

The RTP-1 Qualified Designer is the person(s) in direct charge of performing the engineering design of an RTP-1 certified tank and shall be experienced in the use of this Standard. The qualifications and experience required of the RTP-1 Qualified Designer will depend on the complexity and criticality of the system and the nature of the individual’s experience. As a minimum the individual shall have all of the following qualifications:

(a) Completion of an engineering degree, accredited by an independent agency {such as ABET (US and international), NBA (India), CTI (France), and CNAP (Chile)}, requiring the equivalent of at least 4 yr of study that provides exposure to fundamental subject matter relevant to the design of tanks and pressure vessels, plus a minimum of 5 yr of experience in the design of related tanks and pressure vessels including design calculations for pressure, sustained and occasional loads, and cyclic or thermal loading conditions.

(b) Professional Engineering registration in one or more of the states of the United States or provinces of Canada or alternatively recognized by a jurisdiction outside the United States or Canada.

At least 5 yr direct experience with design and fabrication including materials selection of RTP tanks and vessels using the RTP-1 Standard, ASME Boiler and Pressure Vessel Code, Section X, or EN 13121 or other recognized international fiberglass vessel or tank code or standard.

1-400 INSPECTION

This Standard requires that specific inspections be carried out by Inspection Personnel experienced in the fabrication of RTP vessels. In addition, other inspections may be carried out as a part of the Fabricator’s Quality Control Program. Throughout this Standard, Inspection Personnel are referred to as either inspector(s) (lowercase “i”), Inspector(s) (uppercase “I”), or Certified Individual(s) (uppercase “CI”).

A Certified Individual is an employee of the Fabricator authorized by ASME to use its marks. The Certified Individual’s principal responsibility is to protect the ASME mark by carrying out the duties described in 1-430 of this Standard. (Refer to NM10-500.)

An Inspector is an individual who shall be mutually acceptable to the User and Fabricator, and shall carry out duties in accordance with this Standard. An Inspector’s reporting relationship to management shall be independent of the Fabricator’s production and marketing groups (see 1-430). An Inspector may also be the Certified Individual or the inspector, but not both.

An inspector is an employee of the Fabricator engaged in the daily inspection activities during the course of fabrication. Such activities include, but are not limited to, thickness verifications, visual inspections, dimensional verifications, ply sequence verification, resin cure, etc. The inspector (i) may be the Inspector(i) but shall not be the Certified Individual (CI).
Form 1-1  User's Basic Requirements Specification (UBRS) (As Required by the Provisions of ASME RTP-1) (Cont’d)

<table>
<thead>
<tr>
<th>Wind/seismic/snow code (include edition or year)</th>
<th>Basic wind speed MPH (m/s)</th>
<th>Classification category</th>
<th>Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic wind speed MPH (m/s)</td>
<td>Classification category</td>
<td>Exposure</td>
<td></td>
</tr>
<tr>
<td>Elevation above grade ft (m)</td>
<td>Topographic factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latitude</td>
<td>Longitude</td>
<td>Seismic Risk Category</td>
<td></td>
</tr>
<tr>
<td>Snow load psf (kPa)</td>
<td>Capacities: Operating gal (L) Flooded gal (L)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.2 Mechanical agitator: [ ] Required [ ] Not required
- Dead load lb (N)
- Static bending moment ft-lb (N·m)
- Dynamic bending moment ft-lb (N·m)
- Torque ft-lb (N·m)
- Horsepower hp (W)
- Impeller speed RPM
- Impeller diameter in. (mm)
- Number of impellers
- Foot bearing: [ ] Yes [ ] No

5.3 Heating and cooling:
- [ ] Electric panels
- [ ] Steam coil
- [ ] Steam sparger
- [ ] Heat exchanger
- [ ] Other

5.4 Mechanical and other forces:
- [ ] Violent chemical reaction
- [ ] Subsurface introduction of gas or vapor
- [ ] Subsurface introduction of steam
- [ ] Transmitted mechanical load/force
- [ ] Impact due to introduction of solids
- [ ] Vacuum from pump down (or vessel draining)
- [ ] Vacuum from cool down
- [ ] Other

5.5 Corrosion barrier excluded from s:
- [ ] Yes
- [ ] No

5.6 Declaration of critical service (only)
- [ ] Yes
- [ ] No

5.7 Operation and Environmental Factor (must be greater than or equal to 1.0):

5.8 Hydrostatic test gaskets
- [ ] Specified service gasket
- [ ] Fabricator's standard
- [ ] Other

6. Designation of Inspector (Review paras. 1-400, 1-430, and 1-440 of ASME RTP-1. It shall be noted that ASME RTP-1 establishes numerous duties for the inspector, which necessitates that the Inspector be present in the fabrication shop throughout a major portion of the fabrication interval). Inspector shall be:
- [ ] Fabricator's Quality Control principal
- [ ] User's representative
- [ ] Other
6. Approval of UBRS
   6.1 Authorized User's representative:
      Name ___________________________________________ Title ____________________________
      Signature __________________________________________ Date ____________
   6.2 Authorized Fabricator's representative:
      Name ___________________________________________ Title ____________________________
      Signature __________________________________________ Date ____________

Additional requirements: __________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

GENERAL NOTE: This form may be reproduced and used without written permission from ASME if used for purposes other than republication.
Arrangements for Inspection Personnel shall be resolved prior to the start of fabrication.

1-410 Duties of the Certified Individual

The Certified Individual shall

(a) perform an annual audit to verify that the Fabricator’s Quality Assurance Program is current and in effective operation
(b) verify that the qualifications of the Inspector and inspectors are in accordance with the Fabricator’s Quality Assurance Program
(c) verify that corrective actions resulting from ASME audits are properly resolved
(d) verify that corrective actions taken to resolve vessel nonconformities are in accordance with the Fabricator’s Quality Assurance Program
(e) verify that the responsibilities and activities of the Inspector are in accordance with the requirements of the Standard
(f) verify that vessels are manufactured by qualified Laminators and Secondary Bonders
(g) sign the Fabricator’s Partial Data Report subsequent to completion of all inspections by the Inspector, in the case that only components are being produced
(h) approve by signing of the ASME Fabricator’s Certificate of Compliance on the Fabricator’s Data Report subsequent to completion of all inspections by the Inspector

1-420 Qualifications of the Certified Individual

The Certified Individual shall meet the following qualifications:

(a) education and experience (minimum of high school diploma and 5 yr of experience in the RTP corrosion resistance industry)
(b) demonstrated inspection ability to the Fabricator employing the Certified Individual
(c) satisfactory expertise and experience according to the complexity of the assignment
(d) knowledge of ASME RTP-1
(e) knowledge of Fabricator’s Quality Assurance Program and shop procedure
(f) knowledge and ability to evaluate and monitor procedures and performance
(g) knowledge of keeping and maintaining records

1-430 Inspector’s Duty

The Inspector shall make all the inspections necessary to verify that the requirements of this Standard and the Fabricator’s Design Report have been met. The Inspector of the vessel does not have the duty of determining the completeness or correctness of the design calculations; however, the Inspector does have the duty of establishing that the Fabricator of the vessel has the UBRS and the Fabricator’s Design Report on file, and that the requirements of para. 1-300 have been met.

1-440 Access for the Inspector

The Inspector shall be permitted free access, at all times while work on the vessel is being performed, to all parts of the Fabricator’s shop that concern the fabrication of the vessel and to the site of field fabrication or erection during the period of field fabrication, erection, and testing. The Fabricator shall keep the Inspector informed of the progress of the work and shall notify the Inspector in advance when the vessel or materials will be ready for any required tests or inspection.

1-500 FABRICATOR’S QUALITY CONTROL PROGRAM

A written description of the Quality Control Program, that explains which documents and procedures the Fabricator will use to produce equipment to this Standard, shall be available for review. The Quality Control Program shall be in accordance with the requirements of Mandatory Appendix M-4. See Nonmandatory Appendix NM-6 for an example of a Fabricator’s Quality Control Program.

1-510 Fabricator’s Demonstration of Capability

See Part 7.

1-520 Certification

(a) In order for any vessel to be marked with the ASME Certification Mark with RTP Designator, the Fabricator shall meet the requirements of ASME CA-1 (refer to Part 8). The Fabricator has the responsibility of complying with all the requirements of this Standard and the UBRS. The Fabricator also has the responsibility to certify that any work done by others also complies with all the requirements of this Standard. This responsibility includes providing the Inspector with all required information and assuring that the detailed examinations and tests are performed at the stages of fabrication that permit them to be meaningful.
(b) The Certified Individual, subsequent to completion of all inspections by the Inspector (see Part 6), shall complete and sign the Fabricator’s Data Report or Fabricator’s Partial Data Report as applicable. See Forms 1-2 and 1-3. An original document of such Data Reports shall be sent or delivered to the User (or User’s Agent). Copies of such Data Reports shall be retained in the Fabricator’s record system in accordance with Mandatory Appendix M-4, para. M4-300(c).
(c) The Inspector shall sign the Inspector’s Certification on the Fabricator’s Data Report (or Partial Data Report) only when the Inspector is satisfied that all requirements of this Standard have been met.
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

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 1/16-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 6, may be added without requalifying the standard laminate.
There are two types of laminate thickness tests. 1) Average Spot Thickness of Small Area or Component (such as a nozzle); and 2) Average Thickness of Major Part (such as a head, shell or body flange).

SUBPART 2C
PERMISSIBLE TOLERANCES FOR LAMINATE THICKNESS VARIATION

There are two types of laminate thickness tests. The first, average spot thickness, is used to measure a small area or a small component [see para. 6-920(f)(2)]. The second, average thickness of a major part, is used to measure a large area, such as a shell or head, where several average spot thicknesses can be taken [see para. 6-920(f)(2)].

2C-100 TOLERANCE FOR AVERAGE SPOT THICKNESS

The thinnest value (of six) shall be equal to or greater than 90% of the design thickness of the laminate. The thickest value (of six) shall be no more than 120% of the thinnest value. The average of six thickness values must be no less than 95% nor more than 125% of the design thickness of the laminate. See para. 2C-300 for exceptions.

2C-200 TOLERANCE FOR AVERAGE THICKNESS OF A MAJOR PART

The average thickness of a major part is the average of four average spot thickness values. The average thickness of a major part shall be not less than 95% nor more than 120% of the design thickness of the laminate. See para. 2C-300 for exceptions.

2C-300 EXCEPTIONS AND ADJUSTMENTS

Fabricators may add additional material to achieve the design thickness. All such additions shall be in accordance with the full repeating sequence of structural plies. The repeating construction of reinforced laminate may result in an over-thickness, which is permissible. Corrosion-resistant barrier total thickness in excess of the design thickness may not be used as part of the design structural layer thickness. The design corrosion resistant barrier thickness, design structural layer thickness, and design total thickness for each major part shall each meet the tolerances of Subpart 2C.

Fabricators may add additional material to achieve the design thickness. All such additions shall be in accordance with the repeating design ply sequence. The average thickness of the corrosion-resistant barrier and structural layers shall meet the requirements of Subpart 2C. Over-thickness up to 140% is permissible for corrosion barriers with a design of 0.200”. At no time shall any over-thickness of the barrier be used as part of the structural thickness. Over-thicknesses greater than the stated tolerances is permissible when accepted by the Qualified Designer and User and is reflected in the Design Report.

Refer to 6-920(f)(2)(-a) for the prescribed method of determining the average thickness of a small area or component. The thinnest value (of six) shall be • 90% of the design thickness. The acceptable average thickness shall be • 100% up to 135% of design. For average thickness > 135%, see 2C-300.

Refer to 6-920(f)(2)(-b) for the prescribed method of determining the average thickness of a major part. The acceptable average thickness shall be • 100% up to 135% of design. For average thickness > 135%, see 2C-300.
3A-261 Flat-Bottom Knuckle Design

(a) The flat-bottom knuckle details displayed in Figure 4-2 are empirically based and suitable for shop fabricated tanks. These details may be used in lieu of a calculation-based design for tanks up to 16 ft (4.9 m) in diameter.

(b) When the Fabricator elects to use a knuckle detail that differs from Figure 4-2, the knuckle must be designed by calculation.

(c) For tanks 16 ft (4.9 m) in diameter and above, 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 4-2 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:

\[
t = \frac{PR_s}{2S_a}
\]

where

\( P \) = design internal pressure, psi (MPa)

\( R_s \) = inside radius of head, in. (mm)

\( S_a \) = allowable stress, psi (MPa)

3A-300 DESIGN FOR EXTERNAL PRESSURE

3A-310 Cylindrical Shells

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

\[
P_a = \frac{KD(0.853)P_{bf}^{3/4}E_{bf}^{1/4}E_{at}^{1/4}t^{5/2}}{(1 - \nu_{ah}\nu_{ha})^{1/2}L(D_o/2)^{3/2}FS}
\]

where

\( D_o \) = outside diameter of shell, in. (mm)

\( E_{bf} \) = axial flexural modulus, psi (MPa)

\( E_{at} \) = axial tensile modulus, psi (MPa)

\( E_{bf} \) = hoop flexural modulus, psi (MPa)

\( FS \) = design factor of safety = 5

\( KD = 0.84 \), a knockdown factor

\( = 1.0 \) 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

\( e \) the distance from the first stiffening ring in the cylinder to the cone-to-cylinder junction

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

\( t \) = wall thickness, in. (mm) (nominal)

\( Z_p = \frac{E_{bf}^{3/2}E_{af}^{1/2}}{E_{bf}^2} \left( 1 - \nu_{ah}\nu_{ha} \right)^{1/2} \frac{L^2}{(D_o/2)t} \)

\( y \) = reduction factor developed to better correlate theoretical predictions and test results

\( = 1 - 0.001Z_p \) if \( Z_p \leq 100 \)

\( = 0.9 \) if \( Z_p > 100 \)

\( \nu_{ah} \) = flexural Poisson’s ratio in the axial direction \(~ S_{54}/S_{44} \), where \( S_{54} \) and \( S_{44} \) are terms in the inverted form of the laminate \( ABD \) stiffness matrix, \( S_a \) (see para. M3-520)

\( \nu_{ha} \) = flexural Poisson’s ratio in the hoop direction \(~ S_{45}/S_{55} \)

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 mat 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.
Part 4  Fabrication

4-100 SCOPE

Part 4 sets forth fabrication details that are used in conjunction with the design rules and procedures of Part 3. Figures 4-1 through 4-6 are required only when Subpart 3A design rules are used. Figure 4-7 is an optional stiffener detail, and Figure 4-8 is an optional skirt attachment detail. All other figures and tables in Part 4 are required to be used in conjunction with the design rules of Subparts 3A and 3B. Where complete details are not given, it is intended that the Fabricator shall provide details of design and construction that shall be as safe as those provided by the rules of this Standard.

4-110 Fabrication Requirements

All fabrication shall satisfy all requirements of the User's Basic Requirements Specification and the Fabricator's Design Report using the fabrication procedures of Part 4 and drawings certified by the Qualified Designer prior to application of the ASME Certification Mark with RTP Designator.

4-115 Overlay Taper Length

The edges of all overlays shall have a minimum taper length of 4 times the thickness.

4-120 Large Diameter Fabrication Details

For vessels over 16 ft (4.9 m) inside diameter, the fabrication details given in Part 4 may be modified as long as the design loadings and stresses meet the requirements of Part 3B. The tolerances given in Part 4 shall be modified as follows: Maximum out-of-roundness shown in Figure 4-9 shall not exceed ±1% of the inner diameter for diameters up to and including 16 ft (4.9 m). For diameters greater than 16 ft (4.9 m), the maximum tolerance shall be ±1% of the radius. In no case shall the tolerance exceed 2 in. (50 mm) on the radius, unless agreed to by the purchaser in the UBRS. Offset joints shall be ground or filled with reinforced resin putty and/or mat to a minimum taper of 4:1. Maximum putty thickness shall not exceed 1/2 in. (13 mm). Joint width shall be increased by the width of the putty, if used. Oblated shell sections shall not contain any secondary bonds except for minor repair areas for the inner surface and interior layer.

4-200 LARGE DIAMETER BODY FLANGES

Body flanges shall be flat and true to a required tolerance given in Table 4-1. If machining of the flange face is required, the machined surface shall have the original corrosion barrier restored and sealed with resin. All bolt holes shall be back spot-faced for ASME B18.21.1 Type A Narrow washers. Bolt holes and spot facing shall be resin coated. Overall machine facing of the back of flanges in lieu of spot facing is permitted, provided the hub is not undercut.

4-300 SHELL JOINTS

4-310 Shell-to-Shell Joints

Shell-to-shell joints shall be of either butt or bell-and-spigot construction as shown in Figure 4-3. No longitudinal shell joints are permitted.

(b) The thickness of the overlay shall be the thickness required for an equivalent hand lay-up laminate regardless of the type laminate being joined. A Type II laminate structure, as shown in Table 2A-2, shall be used for overlays of Type II laminates. Type I laminate overlays, as shown in Table 2A-1, shall be used when making Type I laminate joints.

(c) The joint overlay to Type I contact molded laminates shall consist of chopped strand mat plies only. The number of plies shall be not less than the number of structural plies for the structural portion of the thickest laminate being joined or 0.22 in. (5.6 mm) minimum. The first ply shall have a minimum width of 3 in. (75 mm). Each successive ply shall overlap the preceding ply by 1/16 in. (8 mm) minimum on each side.

(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
6-400 CONDITIONS FOR INSPECTION

(a) The Fabricator shall ensure that the vessel is clean and free of foreign materials to permit the Inspector to inspect all accessible surfaces.

(b) The Fabricator shall position and ensure that the vessel is in suitable condition to permit reasonable and safe access for inspection.

(c) The Fabricator shall provide reasonable and safe means, such as ladders and/or platforms, to permit the Inspector to safely inspect accessible inner and outer surfaces of the vessel.

(d) The User’s inspector should be familiar with the possible hazards and safety requirements associated with the use of all RTP materials and fabrication methods. The User’s inspector should observe safety requirements set up by the Fabricator and should be alert to fabricating shop hazards that might be associated with hydrostatic testing of equipment.

6-500 EQUIPMENT DESIGN

The Inspector shall examine the Fabricator’s design records and reports and verify that the vessel conforms to the latest revision of approved drawings and the UBRS, and that the Fabricator’s Design Report has been certified by a Qualified Designer.

6-600 MATERIALS

The Inspector shall verify that materials used in fabrication of a vessel comply with the requirements of this Standard and the UBRS.

6-700 FABRICATION

The Inspector shall establish hold points and make periodic inspections and measurements of the vessel as are required by this Standard to verify that fabrication is in accordance with the requirements of this Standard and the UBRS.

At the completion of each hold point inspection, the Inspector shall report results on forms provided in the Fabricator’s Quality Control Program, and highlight any discrepancies requiring corrective action.

6-800 FABRICATOR’S QUALITY ASSURANCE PROGRAM

The Inspector shall make such checks as are necessary to verify that the Fabricator’s Quality Assurance Program is in effective operation. In addition, the Certified Individual shall perform an annual audit of the Fabricator’s Quality Assurance Program.

Any discrepancies shall be promptly brought to the Fabricator’s attention for discussion and resolution.

6-900 FINAL INSPECTION

(a) At the time of final inspection, the Fabricator shall provide to the Inspector the final revision of all of the following documents:

(1) design drawings

(2) UBRS

(3) completed and signed copies of all forms from the Fabricator’s Quality Control Manual that were used during fabrication to check and verify compliance with this Standard and the design

(4) any copies of Fabricator’s Partial Data Reports, with signed Certificates of Compliance, applicable to the finished fabrication (see Form 1-3)

(5) copies of all inspection reports made by any inspector/Inspector during the course of fabrication

(6) completed original document of the Fabricator’s Data Report, applicable to the vessel to be inspected, with the Certificate of Compliance signed and dated by the authorized representative of the Fabricator (see Form 1-2)

(7) copy of the final revision of the Fabricator’s Design Report

(8) the nameplate that is to be applied to the vessel, so that the Inspector may verify that the nameplate meets the requirements of the UBRS and para. 1-540

(b) Design drawings shall show design thicknesses and the laminate reinforcing sequence for every section or member. If, during the course of fabrication, it was necessary to add repeatable units to the laminate [see para. 6-920(f)(4)], this change shall be noted and highlighted on the drawings provided to the Inspector.

(c) The Fabricator shall also make available to the Inspector all nozzle and manway cutouts, each identified clearly as to its point of origin on the vessel.

(d) Upon completion of final inspection, the Inspector shall prepare a brief report summarizing his/her inspection activities and findings, and submit the report to the Fabricator as an attachment to the Certificate of Compliance.

(e) When the Inspector has completed the inspections and found the results to be within required tolerances, the Inspector shall present his/her inspection report along with any findings to the Certified Individual. The Certified Individual shall sign and date the Certificate of Compliance prior to returning it to the Fabricator with the inspection report.

(f) Paragraphs 6-910 through 6-960 describe the minimum basic tests that shall be made, witnessed, or verified by the Inspector prior to or at the time of final inspection.

6-910 Resin Cure

(a) During the course of fabrication, the Fabricator shall make all such checks necessary to ensure that resin additives, promotion, catalyzation, dilution, and
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 Subparts 2A and/or 2B. Laminates shall also be in accordance with the reinforcing sequence and minimum reinforcing content as established in Subparts 2A and/or 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, using samples taken from the cutouts, to verify reinforcing sequence through count after the burnout test. For each such test made, 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

The test results shall be accepted providing the laboratory maintains either 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.

(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 providing the laboratory maintains either ISO Certification that includes internal self-audits and third-party audits or the laboratory is accredited to conduct the test by the American Association for Laboratory Accreditation. If the laboratory conducting the testing services is not accredited or certified to conduct
the laboratory shall maintain annually calibrated testing equipment and then the testing procedures shall be reviewed by the fabricator. The fabricator shall specify and document in the UBRS acceptable parties to review and approve the written procedures unless the review and approval is conducted by a registered professional engineer. In all cases, the test results shall be reviewed by a registered Professional Engineer to determine if they meet the design requirements.

(5) Specimen requirements shall be as follows:

(a) Test specimens shall not be machined on the inner or outer surface.

(b) Specimens prepared from cylinder cutouts for isotropic laminates as defined above shall be cut in the axial direction of the cylinder to minimize surface curvature.

(c) Specimens prepared from flat laminates containing woven roving shall have their long axis parallel to the warp of the woven roving.

(d) When the design requires that all or a portion of the corrosion barrier is to be excluded as a contributor to the structural strength of a laminate, then tests of laminates as fabricated would not yield correct data. In such cases, that portion to be excluded as a contributor to structural strength shall be removed from test specimens prior to testing. By so doing, tensile strength and tensile modulus test data produced may be compared with the actual structural design values used and the thicknesses of structural portions of laminates that were specified in the design.

This may be conveniently accomplished by placing a piece of release film on (or within) the corrosion barrier during lamination of the shell, at manway cutout location, or on an extended length of shell near the mandrel end. CAUTION: Mark the release film location prominently! A failure to completely remove material covering release film could cause delamination during service.

Test samples shall then be prepared from material taken from the release film location.

The Fabricator shall proof test a sample plate for vessels with proof test requirements and no material available for proof testing, (2). The sample plate shall use the same method of fabrication, laminate sequence, and material lot numbers used to fabricate the vessel. The Laminator(s) fabricating the vessel shall prepare the sample plate simultaneously during fabrication. The Laminator(s) shall construct the sample plate in the same area as the

(6) The Inspector shall include copies of all mechanical property and reinforcing content Proof Test reports in the inspection report.

(b) Prior to making a visual examination, the Inspector shall review the UBRS to determine which Visual Inspection Acceptance Level has been specified.

(c) The Inspector shall visually check interior and exterior surfaces. (Inspection may be made with the aid of a light placed behind the section to detect air voids, delamination, lack of fiber wetting, and other imperfections as described in Table 6-1.)

(d) Visual inspection shall be made before an exterior pigmented coating or insulation is applied to the shell or heads of a vessel. Where exterior pigmentation or insulation has been specified, the Fabricator, User, and Inspector must discuss and agree on visual inspection methods and arrange for closely timed and scheduled inspections.

(e) The Inspector shall record the results of the visual inspection in the inspection report.

(f) Balsa Wood Core Laminates

(1) Visual inspection of the component shall be required from the interior side of the laminate to check for delamination of the balsa wood core.

(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 Emission Tests

(a) A water fill hydrostatic test shall be performed on all vessels with MAWP above 0.50 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.
Table 7-2 Dimensional Requirements for Hand Lay-Up and Spray-Up Demonstration Laminates

<table>
<thead>
<tr>
<th>Req. No.</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>A demonstration laminate shall be square within ±0.3 deg, measuring 24 in. ± 0.15 in. (600 mm ± 150 mm) on each side.</td>
</tr>
<tr>
<td>(2)</td>
<td>The peak deviation from flatness of the inner surface shall not exceed 3/16 in. (0.48 mm).</td>
</tr>
<tr>
<td>(3)</td>
<td>The average thickness of a demonstration laminate shall be within ±0.3 mm.</td>
</tr>
<tr>
<td>(4)</td>
<td>Edges of a demonstration laminate shall be smooth and not jagged. Edge indentation or chips shall not exceed 1/32 in. (0.80 mm) in depth.</td>
</tr>
<tr>
<td>(5)</td>
<td>For demonstration laminates made by the spray-up process, a 24 in. × 24 in. (600 mm × 600 mm) test sample shall be cut from the center of an approximately 30 in. × 30 in. (750 mm × 750 mm) laminate.</td>
</tr>
</tbody>
</table>

(b) Fabricators who plan to produce laminates by the spray-up (chopper gun) process shall also produce and qualify spray-up Types I and II laminates in accordance with requirements in Tables 7-1 through 7-3.

(c) After fabrication, the Fabricator shall identify each demonstration laminate in accordance with the instructions in para. 7-900.

(d) The quality control records shall contain a description of the fabrication procedure used to produce each demonstration laminate.

(e) The mechanical properties of each demonstration laminate shall be determined in accordance with para. 7-1000.

7-620 Filament Wound Demonstration Laminates

(a) Fabricators who plan to produce laminates by the filament winding process shall produce and qualify filament wound laminates in accordance with the requirements in Table 7-1. Qualification for filament winding shall be in addition to qualification for Type I or II laminates.

NOTE: Both qualifications are required for Fabricators planning to construct filament wound vessels to this Standard, as Type I or II laminates are required for the fabrication of heads or when joining the subassemblies of vessels together.

(b) Since there are many process variations employed to produce filament wound laminates, each requiring distinctly different tooling, controls, and skills, this Standard requires that a Fabricator qualify all the process variations to be used in the construction of filament wound vessels to this Standard.

Some examples of process variations, each requiring a demonstration laminate, are:

(1) Dry continuous filament winding
(2) Wet (bath) continuous filament winding
(3) Tape winding in conjunction with (1) or (2)
(4) Spray-up in conjunction with (1) or (2)

It is possible to qualify more than one of the above variations in a single demonstration laminate, as long as the resulting laminating process shall routinely be employed to produce vessels to this Standard.

(c) Demonstration laminates shall have a Type I hand lay-up or spray-up liner over which the structural filament wound layer is applied. This liner shall exotherm and cool before the structural filament wound layer is applied.

(d) A minimum of one ply of 0.75-oz/ft² (225 g/m²) chopped strand mat or an equivalent weight by the chopped spray method shall be applied over the liner immediately before starting the filament wound structural layer.

(e) A filament wound demonstration laminate shall be a 24 in. × 24 in. ± 0.15 in. (600 mm × 600 mm ± 150 mm) section cut from a hoop, which wound on a mandrel with a minimum diameter of 8 ft (2.4 m) to minimize the effects of curvature on sample testing. The width of the hoop shall be greater than 24 in. (600 mm) to avoid turning a 0.25 in. (6 mm) for re-demonstration section cut from which test samples shall be taken.

(f) The thickness of the demonstration laminate shall be 0.37 in. (9.4 mm) minimum, but may be increased up to 0.63 in. (16 mm) to allow for variations in winding or laminating sequences that require thicknesses over 0.37 in. (9.4 mm) to complete.

(g) Filament wound demonstration laminates shall be tested in accordance with para. 7-1000. Tensile strength and tensile modulus per para. 7-1000(c) shall be obtained in the axial direction only. Also, disregard para. 7-1000(a)(2).

(h) Refer to para. 7-900(a)(4). Fabricators shall provide a comprehensive description of the filament wound laminate sequence.

7-700 Minimum Test Values from Demonstration Laminates

(a) Type I or II Demonstration Laminates

(1) Dimensions shall be within tolerances outlined in Table 7-2.

(2) Barcol hardness readings shall show that 80% of the readings meet or exceed 90% of the resin manufacturer’s published casting hardness data.

(3) Tensile strength and tensile modulus values shall meet or exceed the values given in Table 2A-3.

(b) Filament Wound Demonstration Laminates

(1) Dimensions shall be within tolerances outlined in paras. 7-620(e) and 7-620(f).

(2) Refer to (a)(2) for Barcol hardness requirements.

(3) Axial tensile strength and tensile modulus values shall meet or exceed those values given for a Type I laminate in Table 2A-3.
name of the Fabricator of the vessel and certificate number

Fabricator’s serial number for the vessel

year stamped

User’s identification number (if specified in the UBRS)

Manufacturer’s Specific Product Identification for resin

appropriate Visual Inspection Level (Level 1 or Level 2)

for vessels defined as “Atmospheric” in the UBRS

(see also para. 3-300), the words

(a) “Design Pressure — Atmospheric”

(b) “Maximum Temperature”

for other vessels

(a) “Maximum Allowable Working Pressure at Maximum Temperature”

(b) “Maximum Allowable External Working Pressure at Maximum Temperature”

design basis specific gravity of contents

the designation “Critical Service” if applicable

Specified pressures shall be gage pressures given in units as specified in the UBRS. Temperatures shall be in units specified in the UBRS.

(b) If the vessel is optionally registered, the National Board Mark and Registration Number shall be stamped on the nameplate. The legend “National Board Registration Number” is optional.

8-860 Requirements for RTP Nameplate Design

(a) Paper Nameplates

(1) Paper shall be at least 0.004 in. (0.1 mm) thick and of high quality, white bond or linen base.

(2) All markings shall be black, highly visible and readable, on a white background.

(3) Markings, including the ASME Certification Mark with RTP Designator, shall be made in indelible ink of such nature as not to be water or resin soluble.

(b) Cast, Etched, Embossed, Engraved, or Stamped Nameplates

(1) Material shall be 300 series stainless steel or other suitable corrosion-resistant material.

(2) Thickness shall be sufficient to resist distortion due to the application of the marking, but in no case shall be less than 0.020 in. (0.5 mm)

(3) Markings including the RTP Designator may be produced by casting, etching, embossing, stamping, or engraving. The ASME Certification Mark shall be stamped. All stamps for applying the ASME Certification shall be obtained from ASME.
MANDATORY APPENDIX M-6
DEMONSTRATION VESSEL

M6-100 GENERAL

Fabricators shall design, fabricate, and satisfactorily test a demonstration vessel in accordance with the instructions contained in this Appendix.

The design and fabrication of the demonstration vessel require a comprehensive understanding of this Standard by the Fabricator. These involve a full demonstration of the Fabricator’s ability to design, execute drawings, qualify demonstration laminates, establish design values from design basis laminates, qualify Laminators and Secondary Bonders, and fabricate under effective overview of the Fabricator's Quality Control Program, all in full accordance with the requirements of this Standard.

No Fabricator shall claim qualification to fabricate to this Standard until having satisfactorily completed and tested the demonstration vessel in accordance with the instructions herein.

M6-200 PRELIMINARY REQUIREMENTS

(c) The three-quarter section from the demonstration vessel shall be placed on display at the Fabricator's shop for viewing by the ASME Certification Audit Team. No paints, coloration or pigmentation shall be applied to the demonstration vessel. The Fabricator has the option to retain or dispose of the vessel after initial issuance of an ASME RTP-1 Certificate number.

(b) The Fabricator shall have constructed and shall have successfully completed testing of demonstration laminates and design basis laminates of those laminate types and that resin specified by the UBRS for the demonstration vessel (see Part 7 for requirements of demonstration laminates).

(c) The Fabricator shall have trained and qualified those Laminators and Secondary Bonders who will construct the demonstration vessel (see Mandatory Appendix M-5).

M6-300 DESIGN, FABRICATION, AND TESTING OF THE DEMONSTRATION VESSEL

Design and drafting requirements shall be demonstrated by the Fabricator in full accordance with this Standard.

All instructions for fabrication and testing of the demonstration vessel are contained in the UBRS identified as Table M6-1 (see Figure M6-1).

M6-400 REQUIREMENTS SUBSEQUENT TO TESTING

(a) Subsequent to completion of successful testing, the Fabricator shall section (cut) the demonstration vessel to reveal details and the integrity of laminates and secondary bonds. Instructions for sectioning are included in the UBRS (see Figure M6-2). The Fabricator may polish or grind the cut edges, but no resin, resin putty, or any other material is to be applied to such cut edges.

(b) The quadrant sectioned from the demonstration vessel may be retained or disposed of by the Fabricator, at the Fabricator’s option.

(c) The three-quarter section from the demonstration vessel shall be placed on display at the Fabricator’s shop for viewing by prospective customers. No paints, coloration, or pigmentation shall be applied to the demonstration vessel.

(d) Subsequent to the completion of successful testing, the Fabricator shall execute a Fabricator’s Data Report (see Form 1-2). Attached to the Data Report shall be all information required by the Data Report, plus the following additional items:

(1) a copy of the Witness of Hydrotest form (see Figure M6-3)

(2) certified test reports of all required demonstration and design basis laminates [see para. M6-200(b)]

(3) certified test reports covering the qualification of Laminators and Secondary Bonders [see para. M6-200(c) and Mandatory Appendix M-3]

(4) a photograph of the sectioned demonstration vessel

All of the above shall be organized and bound as a single document. The Fabricator may reproduce as many copies of this document as desired.
(e) At least one copy of the document described in (d) above shall be available at the place of display of the demonstration vessel.

(e) At least one copy of the document described in (d) above shall be available for review as long as the Fabricator holds a RTP Certificate of Authorization.
GENERAL NOTE: Laminate thicknesses shall be based on design pressure and temperature, and laminates shall be of the type specified here (see UBRS).

Replace "FRP" with "RTP"
MANDATORY APPENDIX M-8
ACOUSTIC EMISSION EXAMINATION

M8-100 SCOPE

This Appendix states the criteria that a vessel shall satisfy to pass an acoustic emission examination. Equipment requirements are given in Article 11 of Section V of the ASME Boiler and Pressure Vessel Code.

NOTE: Additional background information concerning acoustic emission testing is contained in Recommended Practice for Acoustic Emission Testing of Fiberglass Tanks/Vessels, published by The Society of the Plastics Industry, Inc.

M8-200 GENERAL

(a) Discontinuities located with acoustic emission examination shall be evaluated by other techniques, e.g., visual, ultrasonic, dye penetrant, etc., and shall be repaired and retested as appropriate.

(b) A vessel for which an acoustic emission examination is required shall satisfy the criteria of Table M8-1. If the vessel does not, it is not in compliance with the requirements of this Standard.

(c) The acoustic emission examination is done in conjunction with the hydrostatic test. Therefore, it shall be witnessed by the Inspector, and he or she shall verify the acoustic emission examination report.

M8-300 DEFINITIONS AND INSTRUMENT CALIBRATION

The criteria in Table M8-1 are defined in part by the reference amplitude threshold, a counts parameter, \( N_C \), and an amplitude parameter, \( A_m \). The quantities are defined in this Appendix. The amplitude parameter is defined in terms of the reference amplitude threshold and the threshold of acoustic emission detectability.

M8-310 Threshold of Acoustic Emission Detectability

The threshold of acoustic emission detectability shall be determined using a 4 ft × 6 ft × \( \frac{3}{4} \) in. (1.2 m × 1.8 m × 19 mm) 99% pure lead sheet. The sheet shall be suspended clear of the floor. The threshold of detectability is defined as the average measured amplitude of ten events generated by a 0.01 in. (0.3 mm) pencil (2H) lead break at a distance of 4 ft 3 in. (1.3 m) from the sensor. A break shall be done at an angle of approximately 30 deg to the test surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 6 in. (150 mm) from the 4-ft (1.2 m) side and mid-distance between the 6-ft (1.8 m) sides.

M8-320 Reference Amplitude Threshold

(a) For large amplitude events, the reference amplitude threshold shall be determined using a 10 ft × 2 in. × \( \frac{3}{4} \) in. (3 m × 50 mm × 19 mm) clean, mild-steel bar. The bar shall be supported at each end by elastomeric, or similar, isolating pads.

(b) The reference amplitude threshold is defined as the average measured amplitude of ten events generated by a 0.01 in. (0.3 mm) pencil (2H) lead break at a distance of 7 ft (2.1 m) from the sensor. A break shall be done at an angle of approximately 30 deg to the test surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 12 in. (300 mm) from the end of the bar on the 2-in. (50-mm) wide surface.

M8-330 Count Criterion, \( N_C \), and \( A_m \) Value

(a) The count criterion, \( N_C \), shall be determined either before or after the test using a 0.3-mm pencil (2H) lead broken on the surface of the vessel. A break shall be done at an angle of approximately 30 deg to the test surface with a 0.1 in. (2.5 mm) lead extension. Calibration points shall be chosen so as to be representative of different constructions and thicknesses, and should be performed above and below the liquid line (if applicable), and away from manways, nozzles, etc.

(b) Two calibrations shall be carried out for each calibration point. One calibration shall be in the principal direction of the surface fibers (if applicable), and the second calibration shall be carried out along a line at 45 deg to the direction of the first calibration. Breaks shall be at a distance from the calibration point so as to provide an amplitude-decibel value, \( A_m \), midway between the threshold of detectability and the reference amplitude threshold.

The count criterion, \( N_C \), shall be ten times the number of counts recorded from seven lead breaks at each of the two calibration points. The lead breaks shall be done with a 0.01 in. (0.3 mm) diameter (2H) pencil lead. The breaks shall be made with the lead at an angle of approximately 30 deg to the test surface with a 0.1 in. (2.5 mm) lead extension. When applying the count criterion, the value that is representative of the region where activity is observed should be used.
Acoustic emission examinations shall be performed following a written procedure. The procedure shall satisfy the requirements of para. T-1128 in Article 11 of Section V of the ASME Boiler and Pressure Vessel Code.

### Table M8-1 Acceptance Criteria

<table>
<thead>
<tr>
<th>Emissions during hold</th>
<th>First Filling</th>
<th>Subsequent Fillings</th>
<th>Significance of Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>None beyond 2 min</td>
<td>None beyond 2 min</td>
<td>Measure of continuing permanent damage</td>
<td></td>
</tr>
<tr>
<td>Felicity ratio</td>
<td>Not applicable</td>
<td>Greater than 0.95</td>
<td>Measure of severity of previously induced damage</td>
</tr>
<tr>
<td>Total counts</td>
<td>Less than $N_c$</td>
<td>Less than $N_c/2$</td>
<td>Measure of overall damage during a load cycle</td>
</tr>
<tr>
<td>Number of events</td>
<td>Less than 10</td>
<td>Less than 10</td>
<td>Measure of high energy microstructural failures.</td>
</tr>
</tbody>
</table>

GENERAL NOTE: An acceptable vessel shall meet all the criteria listed above. Background noise shall be properly discounted when applying acceptance criteria.

**NOTE:** (1) Varies with instrument manufacturer. See para. M8-330 for the definition of $N_c$.

**NOTE:** (2) Varies with instrument manufacturer.

---

**M8-500 WRITTEN REPORT OF RESULTS**

The results of an acoustic emission examination shall be reported in a written document satisfying the requirements of para. T-1190 in Article 11 of Section V of the ASME Boiler and Pressure Vessel Code. The report shall be made available for review and acceptance by the Inspector.

The results of an acoustic emission examination shall be documented according to the reporting requirements of ASTM E1067. A copy of the report shall be provided to the Inspector.

---

(1) $A_m$ is the decibel level defined in Paragraph A2.5 of ASTM E1067.
(2) Cumulative duration value $N_D$ is defined in Paragraph A2.5 of ASTM E1067.
(3) High amplitude hits are those having amplitude equal to or greater than the Reference Amplitude Threshold defined in Paragraph A2.3 of ASTM E1067.
(4) All criteria above are per channel.
maximum measurement shall be entered in Form M12B-3, column 5. After other dimensions are entered, the inspector shall enter the date and his/her name in column 6 if all measurements are within the requirements of this Standard.

(b) Sufficient measurements should be made to ensure that all of the material used is within thickness requirements. Measurements across two widths at each end and at least every 50 ft (15 m) of length shall be made and recorded.

(c) The sheet’s measured fiber-free thickness shall be ±10% of the specified nominal fiber-free thickness.

M12B-614.4 Bond Strength Requirements

(a) Bond strength tests must be conducted on each production run of thermoplastic material intended for lining in dual laminates. The bonded sample will be made using the RTP resin specified and the laminating technique to be used in the vessel to be fabricated. The thickness of the RTP laminate structure will be that thickness compatible with the selected bond strength test method.

(b) When a bonding resin is used, the bonding resin used to generate bond test samples will be the same bonding resin used to fabricate the vessel.

(c) Bond strength tests must be performed with the conductive target in place over the entire test sample.

(d) The minimum bond strength results (excluding nozzle necks) are as follows:

(1) for the climbing drum test, ASTM D1781, the bond strength must be at least 50 in.-lb/in. (220 N·mm/mm)
(2) for the lap shear test, ASTM D3846 or BS 4994 B-10, the bond shear strength must be at least 1,015 psi (7 MPa)

(e) Separate records will be kept for each bond strength test accomplished. Results will be maintained in the Quality Control Log and the test operator will enter his/her initials and the date the test was made in Form M12B-3, column 8. Test results lower than the values in (d) will be entered in Form M12B-3 in the comments section and will be cause for rejection of that material.

M12B-614.5 Disposition of Nonconforming Material. Sheets with defective areas may be cut, routed, or sheared to remove and discard the defective areas. Care must be used in handling cracked or crazed sheets, as mechanical treatments may cause the crack to propagate. After eliminating areas with defects, the remaining material may be used.

M12B-620 Welding Consumables

M12B-621 Introduction. This section describes the minimum inspections, tests, and acceptance criteria to be performed on thermoplastic welding consumables used for filler materials in welding thermoplastic material to fabricate equipment to this Standard. Consumables include weld rod, continuous coils of weld “wire,” cap strips, and extrusion weld materials.

M12B-622 Acceptance Inspection

(a) Acceptance inspection will include inspection of welding materials for proper packaging and identification, inspection for imperfections and contamination, and measurement of dimensions. Acceptance requirements
ARTICLE D
FABRICATION

M12D-100 SCOPE AND OPTIONS

This Article sets forth the required and recommended fabrication details that are used to fabricate a thermoplastic lined RTP vessel. Where necessary, fabrication details of the RTP part of the dual laminate vessel, as modified by the requirements of the thermoplastic lining, are presented. The general provisions of Part 4 of this Standard do apply.

This Article covers the forming and welding of the vessel lining walls and ends; the installation and fabrication details for nozzles, manways, and other attachments; and areas for welding thermoplastic liners shall have provisions for controlling dust, ventilation, cleanliness, and temperature.

(a) The thermoplastic lining will be fabricated before the RTP laminate is overlaid.

(b) The vessel lining is fabricated by formed (thermoforming or cold forming) components and welding them together.

(c) The end closure (or vessel head) linings may be fabricated separately from the shell lining. The RTP structure may be laid up on the separate parts or after the entire vessel lining is assembled.

M12D-200 MACHINING OF THE THERMOPLASTIC LINING

Sheets, plates, edges of heads, and other parts (internal ends or projections of nozzles, manway necks, etc.) may be cut to shape and size by mechanical means such as machining, drilling, shearing, sawing, grinding, or by other processes that are not detrimental to the lining material. After machining, all burrs, flashing, and other loose material will be removed prior to further fabrication or use. Excessive stresses may be induced by machining processes and stress relief may be required.

M12D-300 FORMING

Thermoplastic sheets may be formed into the required shapes using established procedures that are in the Fabricator’s Procedures Manual (see para. M12G-540).

M12D-310 Limits on Thinning of Lining During Forming

All forming processes will reduce the thickness of the lining. Design and the forming process conditions will be such that the thinnest area of the lining after forming is at least 90% of the nominal sheet thickness.

M12D-320 Thermoforming

In general, thermoforming is preferred over cold forming because thermoforming requires much less force and the internal stresses after forming are minimized. More brittle materials and materials with greater thickness are more difficult to form and thermoforming may be necessary to avoid cracking or substantial spring-back.

M12D-400 WELDING

This section sets forth rules and guidelines for the fusion welding of thermoplastic linings to generate the vessel lining configuration. Included are welds to assemble shells, end closures, nozzles, manways, and wall attachments.

The types of welding allowed for this Standard are

(a) hot gas welding
(b) extrusion welding [but see para. M12D-421(b) for limitations]
(c) hot plate welding
(d) flow fusion welding

All welds will be full penetration welds.

M12D-410 Welder Qualification

All welds will be made by a Welder qualified in that type of welding and using that type of thermoplastic material. Procedures for Welder qualification are set forth in Article H.

M12D-420 Welding Procedures

(a) The gap between lining material before welding shall be no more than 0.06 in. (1.5 mm) at any location. For assembly of large components [over 6 ft (1.8 m) in diameter], the gap shall not exceed 0.13 in. (3.0 mm) at any location. For assembly after RTP overlay, the maximum gap between lining material shall be no more than 0.13 in. (3.0 mm).

(b) Misalignment of all butt welds shall be no more than 20% of the thickness of the thermoplastic material. For lining material of different thicknesses, see Figure M12D-1.

Figure M12D-1 Maximum Offset Allowed for Joints Between Sheets With Different Thicknesses

Offset max. 0.2T
GENERAL NOTES:
(a) Laminate thicknesses are to be based on design pressure and temperature, and laminates are to be of the type specified here (see UBRS).
(b) Each head shall have a weld seam with a length exceeding the tank radius.
**PE:** polyethylene.

**peel strength test:** a test that peels the lining off of a dual laminate composed of a thermoplastic lining and an FRP structural laminate to determine the bond strength. Three such tests are the climbing drum test (ASTM D1781), the peel test (BS 4994), and the floating roller peel test (ASTM D3167).

**PFA:** Teflon® PFA or perfluoroalkoxy fluoropolymer.

**PP:** polypropylene.

**PTFE:** see TFE.

**purge material:** a different thermoplastic, such as PP, used to clean out remaining weld filler material from a weld tool, such as an extruder, to prevent difficulty in continuing welding after cooling the tool.

**PVC:** polyvinylchloride.

**PVDF:** polyvinylidene fluoride.

**spark test:** a high voltage test for detecting flaws in plastic by emitting a loud crack sound when a spark passes through a flaw in the plastic to the conductive ground or target.

**speed welding:** a hand fusion weld process where the filler rod is fed to the weld using hand force through a tube to the weld bead; this process is more efficient and rapid than **hand welding**, where the filler rod is held separately in one hand.

**stress crack:** an external or internal rupture in a plastic caused by tensile stresses less than its short-time mechanical strength.

**stress relief:** a heat treatment given  
(a) to received materials before fabrication to remove residual internal stresses incurred during thermoplastic processing steps or  
(b) to welded parts to remove or reduce internal stresses from fabrication steps such as welding or thermoforming

**surface contamination:** any undesired foreign material adhering to the surfaces of material used in the fabrication of dual laminate products. Examples are lubricants and other processing aids; dirt, oil, and foreign matter from the environment; residual adhesive from protective films; solvent and any other cleaning residues; etc.

**target:** conductive material behind a weld or behind the liner itself that becomes a ground for high voltage spark testing.

**TFE:** tetrafluoroethylene; also used to indicate PTFE, poly-tetrafluoroethylene.

**thermal cycle test:** a test using ten thermal cycles to qualify the bond strength; no debonding indicates satisfactory bond strength. The temperature extremes are usually boiling water and a dry-ice-acetone bath, −108°F (−78°C).

**thermoforming:** a process for shaping sheet material by deforming at elevated temperature to allow shaping with low forces and less danger of cracking.

**undercut:** a groove in a weld extending below the surface of the base thermoplastic sheets and usually located at the edge of the weld bead.

**virgin material:** material (sheet, rod, or strip) that has been manufactured from new, not recycled, plastic and that has not been used earlier in any other service.

**weld bead:** the material in the weld comprised of plastic from the applied welding rod and melted plastic from the base sheet material.

**weld factor:** the average tensile strength of welded samples divided by the average tensile strength of the unwelded sheet material. The resulting number is often expressed in percent. **Short term weld factor** is a weld factor from tensile strength tests done in a short time, i.e., minutes. **Long term weld factor** is a weld factor based on tensile creep strength of weld samples compared to unwelded sheet material.

**welding:** a process for joining by using heat or other form of energy to fuse together two pieces of material.
(e) **Bending Moments Due to Lug**

\[ M_{ax} = \frac{P}{4} \beta_x, \text{ in.-lb/in.} \]

\[ M_{hp} = vM_{ax}, \text{ in.-lb/in.} \]

(f) **Loads Due to Pressure, \( p \)**

\[ N_{ax} = \frac{pR_m}{2}, \text{ lb/in.} \]

\[ N_{hp} = pR_m, \text{ lb/in.} \]

(g) **Combined Stresses**

\[ \sigma_{ax} = \frac{N_{ax}}{t_k} \pm 6 \frac{M_{ax}}{I_k} \]

\[ \sigma_{hp} = \frac{N_{hp}}{t_k} \pm 6 \frac{M_{hp}}{I_k} \]

(1) Allowable stresses for intermittent loading

\[ \sigma_{ax} = 0.002 \times \text{axial tensile modulus} \]

\[ \sigma_{hp} = 0.002 \times \text{hoop tensile modulus} \]

(2) For continuous loading

\[ \sigma_{ax} = 0.001 \times \text{axial tensile modulus} \]

\[ \sigma_{hp} = 0.001 \times \text{hoop tensile modulus} \]

**NM4-500 EXAMPLES**

**NM4-510 Wound Lug Example**

12 ft × 24 ft straight height
specific gravity = 1.2
hydro head = (24)(0.433)(1.2) = 12.5 psig
Lower course
\[ t_w = PD_s/2S_a = (12.5)(144)/(2)(1,500) = 0.60 \text{ in.} \]

Use 0.64 in. nominal.
\[ t_b = 0.37 \text{ in.} \]
\[ t_k = 0.64 + 0.37 = 1.01; \text{ use } 1.00 \text{ in.} \]

Approximate vessel weight as follows:
- top head = 275 lb
- shell = 3,500 lb
- bottom = 340 lb
- total vessel = 4,115 lb

Calculate wind uplift on roof of vessel.

\[ U = A_t(P_G G) \]

where
\[ A_t = \text{plan area of vessel top, ft}^2 \]
\[ G = \text{wind pressure} = 25 \text{ psf} \]
\[ P_G = \text{uplift coefficient} \]
\[ U = (\pi/4)(D^2)(0.88)(25) = 2,488 \text{ lb uplift} \]

Calculate the wind overturning moment.

\[ M_Q = 0.5S_f GDH^2 + 0.25GDH_p(H + H_D/3) \]

\[ = (0.5)(0.7)(25)(12)(24)^2 + (0.25)(25)(12)(24 + \frac{7}{3}) \]

\[ = 60,480 + 3,700 \]

\[ = 64,180 \text{ ft-lb} \]

Net uplift is

\[ U_{net} = U - W + 4M_Q/D \]

\[ = 2,488 - 4,115 + (4)(64,180)/12 = 19,766 \text{ lb} \]

Assume eight lugs. Then load per lug is

\[ F = 19,766/8 = 2,471 \text{ lb/lug} \]

Assume lug configuration. Assume a 12-in. high angle with 4-in. projection and 6-in. width. Assume the load eccentricity \( e = 2.5/2 \) in. from the vessel wall to the centerline of the anchor bolt or to the point of load application by a hold-down clip.

The lug must be checked for simple bending, which will establish its minimum thickness.

\[ M = \text{bending moment} \]

\[ M/Z = \text{bending stress} \]

\[ S = \text{allowable bending} = 20,000 \text{ psi} \]

\[ Z = \text{section modulus} = bd^2/6 = wt_{lug}^2/6 \]

\[ w = 6 \text{ in.} \]

\[ Z_{min} = \text{minimum required section modulus} \]

\[ = M/S = 6,177.5/20,000 = 0.309 \text{ in.}^3 \]

\[ t_{lug} = (6Z_{min}/w)^{1/2} = [(6)(0.3009)/6]^{1/2} = 0.55 \text{ in.} \]

Use 5/8 in. thick lug.

Unit radial load on overwrap

\[ W_{max} = 3Fe/h^2 \]

\[ = 3(2,471)(2.5)/12 = 129 \text{ lb/in.} \]

Radial load due to moment

\[ P = W_{max}h/2 \]

\[ = (129)(12)/2 = 774 \text{ lb} \]

Hoop overwind load

\[ T_{tot} = PR_m/w \]

\[ = (774)(72)/6 = 9,288 \text{ lb} \]

Assume overwrap thickness \( t_1 = 0.38 \text{ in.} \) Hoop overwind tensile stress is

\[ \sigma = t/h_{t1} = 9,288/(11)(0.38) = 2,222 \text{ psi} \]

\[ < 40,000/5 = 8,000 \text{ psi allowable (OK)} \]

Shear across vessel wall
NM4-500 Shear Ledge Design

Lugs may be attached to a shear ledge that is secondary bonded to the shell near the bottom of the vessel.

\( h_L = \) Height of shear ledge, in. (4 in, min.)
\( t_L = \) Thickness of shear ledge in contact with dog clip, in (1 in, min.)
\( w_L = \) Width of anchor lug, in (3 in, min.)
\( A_c = \) Contact area between shear ledge and each lug, in\(^2\)
\( = w_L \times t_L \)
\( b_s = \) Base width of secondary bond shear area between vessel and shear ledge at each lug, in\(^2\)
\( = w_L + 2 \times h_L \)
\( A_s = \) Secondary bond shear area between vessel and shear ledge at each lug, in\(^2\)
\( = h_L \times (w_L + b_s) / 2 \)
\( N = \) Number of lugs
\( U = \) Net uplift, lbf
\( S_c = \) Compressive stress in shear ledge under lug, psi
\( = U / (N \times A_c) \)
\( S_s = \) Secondary bond shear stress between vessel and shear ledge at lug, psi
\( = U / (N \times A_s) \)
Fig. NM4-6  Shear Ledge

General Notes:
1. The shear ledge shall be constructed of hoop filament winding with interspersed layers of wet chop or contact molded Types I or II.
   a. The first layer of filament winding shall be embedded in wet chop.
2. Flat-bottom knuckles to be manufactured in accordance with Fig. 4-2 prior to the attachment of the shear ledge.
3. Overlap between secondary bond shear areas is not recommended. Further analysis shall be completed if overlapping secondary bond shear areas cannot be avoided.
4. Penetrations through the secondary bond shear area are not allowed and penetrations through the shear ledge in areas outside of the secondary bond shear area are discouraged. In all cases, 1” minimum in the top 50% of the total height and 25% of the total shear ledge height shall be continuous around the entire tank (i.e. uninterrupted by penetrations).
5. The anchor design shall consider resisting horizontal forces as the anchor ledge is for resisting uplift forces only.
6. The tensile load in the anchor will be greater than the uplift at the shear ledge due to lever effect.
\[
\tau_w = P/\ell_{kw} = \frac{774}{(1.00)(6)} = 129 \text{ psi}
\]

\[< 3,000/2 = 1,500 \text{ psi allowable (OK)}\]

Coefficient of bending in the vessel wall
\[\beta = \frac{1.28/(R_m t_k)^{1/2}}{128/[((72)(1.00))^{1/2}} = 0.151 \text{ in.}^{-1}\]

Unit radial loading is
\[P^* = P/w = \frac{774}{6} = 129 \text{lb/in.}\]

Axial and hoop bending loads
\[M_{ax} = \frac{P^*/4\beta}{129/((4)(0.151)} = 213.6 \text{ in.-lb/in.}\]

\[M_{hp} \equiv \nu M_{ax} = (0.3)(213.6) = 64 \text{ in.-lb/in.}\]

Axial load due to pressure
\[N_{ax} = p R_m/2\]

However, \(p = 0\) for no pressure above the liquid (atmospheric vessel). Therefore, \(N_{ax} = 0\).

Hoop load due to pressure
\[N_{hp} = p R_m\]

where
\[p = 12.5 \text{ psig hydrostatic (hoop direction)}\]

\[N_{hp} = (12.5)(72) = 900 \text{ lb/in.}\]

Axial and hoop stresses
\[\sigma_{ax} = \frac{N_{ax}}{t_k} + \frac{6 M_{ax}}{t_k^2}
\]
\[= 0 + \frac{(6)(213.6)}{(100)^2} = 1,281.6 \text{ psi}\]

\[\sigma_{hp} = \frac{N_{hp}}{t_k} + \frac{6 M_{hp}}{t_k^2}
\]
\[= 900/1.00 + \frac{(6)(64)}{(100)^2} = 1,284 \text{ psi}\]

**NM4-520 Secondary Bonded Lug Example**

Using the same example problem as in para. NM4-510, assume a lug attached by secondary bonding is elected for use.

Again assume eight lugs with an uplift load of 2,471 lb/lug \(\times 8 = 19,768 \text{ lb total.}\)

Assume the same lug geometry as before, and check the required minimum lug height. Lug width to vessel diameter ratio \(w/D_o = 6/145.6 = 0.041\). From Figure NM4-3, assuming eight lugs, \(M_l = 0.024\).

\[
h = \left[\frac{6\rho_w W_e M_l^{1/2}}{N_S t_k}\right]^{1/2}
\]

\[= \left[\frac{(6)(145.6)(19,768)(2.5)(0.024)}{(8)(1,500)(1.0)^2}\right]^{1/2}
\]

\[= 9.28 \text{ in. (min.)}\]

For simplicity and to permit comparison, again use 12 in. high lug, 6 in. wide.

As before, check the lug for simple bending to establish its minimum thickness.

Unit radial load on overwrap
\[W_{max} = 3Fe/h^2 = (3)(2,471)(2.5)/12 = 129 \text{ lb/in.}\]

Total radial load due to lug moment
\[P = W_{max} h/2 = (129)(12)/2 = 774 \text{ lb}\]

Next calculate the tensile perimeter
\[2h_l + w = (2)(11) + 6 = 28 \text{ in.}\]

The tensile perimeter load = \(P/tensile \text{ perimeter} = 774/28 = 27.6 \text{ lb/in.} < 50 \text{ lb/in.}\)

The minimum required area of secondary RTP bond overlay on the vessel wall, or the area of overlay on the upstanding leg of the lug below the retainer bar required for shear, shall be not less than

\[A_R = W/200N = 19,768/(200)(8) = 12.4 \text{ in.}^2/\text{lugs}\]

Proceeding as before, the overlay hoop load is
\[T_{tot} = PR_m/w = (774)(72)/6 = 9,288 \text{ lb}\]

The overlay hoop tensile stress, assuming overlay thickness \(t_1 = 0.38 \text{ in.}\), is
\[\sigma = \frac{T_{tot}}{h_1 t_1} = 9,288/(11)(0.38) = \frac{2,222 \text{ psi} < 3,000 \text{ psi}}{\text{Shear across vessel wall}}\]

\[\tau_w = P/\ell_{kw} = \frac{774}{(1.0)(6)} = 129 \text{ psi}\]

Coefficient of bending in vessel wall
\[\beta = \frac{1.28/(R_m t_k)^{1/2}}{128/[((72)(1.00))^{1/2}} = 0.151 \text{ in.}^{-1}\]

Unit radial loading
\[P^* = P/w = \frac{774}{6} = 129 \text{ lb/in.}\]

Bending loads
\[M_{ax} = \frac{P^*/4\beta}{129/((4)(0.151)} = 213.6 \text{ in.-lb/in.}\]

\[M_{hp} \equiv \nu M_{ax} = (0.3)(213.6) = 64 \text{ in.-lb/in.}\]
Since the overlay is not a full circumferential winding, all stresses due to internal pressure and/or hydrostatic head are presumed to be taken by the vessel shell itself. Thus, the bending stresses in the overwrap are due only to the bending loads introduced by the lug.

Bending stresses
\[ \sigma_{ax} = \frac{6M_{ax}}{t_1^2} = \frac{(6)(213.6)}{(0.38)^2} = 8,875 \text{ psi} \]
\[ \sigma_{hp} = \frac{6M_{hp}}{t_1^2} = \frac{(6)(64)}{(0.38)^2} = 2,659 \text{ psi} \]

Since these stresses are much too high, the thickness of the overwrap must be increased. Try 1.0 in.

\[ \sigma_{ax} = \frac{6M_{ax}}{t_1^2} = \frac{(6)(213.6)}{(1.0)^2} = 1,281.6 \text{ psi} \]
\[ \sigma_{hp} = \frac{6M_{hp}}{t_1^2} = \frac{(6)(64)}{(1.0)^2} = 384 \text{ psi} \]

If we set a stress limit of \( S_a \) for loads due to uplift, we can solve directly for the overlay thickness \( t_2 \). Use the greater of
\[ t_{\text{min}} = \sqrt{\frac{6M_{ax}}{S_a}} \]
or
\[ t_{\text{min}} = \sqrt{\frac{6M_{hp}}{S_a}} \]

It can thus be seen that the required overlay thickness is approximately equal to the vessel wall at the bottom knuckle region. The use of more hold-down lugs would reduce the load per lug. This may not be cost effective, however, since more anchor bolts are required.
NM4-630 Shear Ledge Example

Using the same example problem as in para. NM4-510, assume a shear ledge is elected for use with the following parameters:

\[ h_L = 8 \text{ in} \]
\[ t_L = 1 \text{ in} \]
\[ w_L = 6 \text{ in} \]
\[ N = 8 \]
\[ U = 19,768 \text{ lbf} \]

Calculate the contact area between the shear ledge and each lug.
\[ A_c = w_L \times t_L = 6 \times 1 = 6 \text{ in}^2 \]

Calculate the base width of the secondary bond shear area between the vessel and shear ledge at each lug.
\[ b_s = w_L + 2 \times h_L = 6 + 2 \times 8 = 22 \text{ in} \]

Calculate the secondary bond shear area between the vessel and shear ledge at each lug.
\[ A_s = h_L \times (w_L + b_s)/2 = 8 \times (6 + 22)/2 = 112 \text{ in}^2 \]

Calculate the compressive stress in the shear ledge under one lug.
\[ S_c = U/(N \times A_c) = 19,768/(8 \times 6) = 412 \text{ psi} \quad < 15,000/5 = 3,000 \text{ psi} \quad \text{(OK)} \]

Calculate the secondary bond shear stress between the vessel and shear ledge at one lug.
\[ S_s = U/(N \times A_s) = 19,768/(8 \times 112) = 22.1 \text{ psi} \quad < 2,000/5 = 400 \text{ psi} \quad \text{(OK)} \]
NONMANDATORY APPENDIX NM-5
RING SUPPORT OF VESSELS

NM5-100 SCOPE

This Appendix provides methods for the design and checking of metallic support rings for vertical vessels. It is recommended that continuous loads be handled by metallic bands or double rings. These procedures cover lugs attached to thin bands and double rings.

The band is proportioned to fully resist the bending moments applied by the support lugs. No credit is taken for the buckling strength of the RTP shell, a conservative assumption.

NM5-200 BAND WITH LUGS

The thin band design utilizes a band height that is two times the height of the lug for dissipation of the stresses induced by the reaction of the lug (see Figure NM5-1).

NM5-210 Nomenclature

- \( b \): spacing between lug gussets, in.
- \( D \): outside diameter of vessel, in.
- \( d \): lug projection, in.
- \( E \): load eccentricity, in.
- \( h_L \): height of lug, in.
- \( M_L \): moment coefficient at lug, dimensionless (see Figure NM5-2)
- \( N \): number of lugs
- \( S \): allowable stress of band, psi\(^1\)
- \( S_{ae} \): allowable stress of lug, psi\(^1\)
- \( S_r \): allowable stress of rings or section, psi\(^1\)
- \( S_y \): yield stress of ring, psi
- \( t_b \): thickness of band, in. (\( \frac{3}{4}\) in. minimum)
- \( t_c \): thickness of shear collar, in.
- \( t_g \): thickness of lug gusset or bearing plate, in.
- \( W \): maximum supported vessel weight, lb (larger of operating or hydrotest weight)
- \( Z_r \): required section modulus of radial rings, in.\(^3\)

\(^1\)All stress values per ASME Boiler and Pressure Vessel Code, Section II, Part D.

NM5-220 Design Procedure

Assume a band thickness. The following band thicknesses are recommended as a starting point (based on specific gravity of 1.0). Vessels with a height-to-diameter ratio greater than 1.25 will require a band thickness greater than the following:

<table>
<thead>
<tr>
<th>Diameter, in.</th>
<th>Band Thickness, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 48</td>
<td>( \frac{7}{8} )</td>
</tr>
<tr>
<td>49 to 60</td>
<td>( \frac{3}{4} )</td>
</tr>
<tr>
<td>61 to 84</td>
<td>( \frac{1}{2} )</td>
</tr>
<tr>
<td>85 to 96</td>
<td>( \frac{3}{8} )</td>
</tr>
<tr>
<td>97 to 120</td>
<td>( \frac{3}{4} )</td>
</tr>
</tbody>
</table>

Determine the required height of the lug based on the following:

\[
 h_L = \left( \frac{6DWEM_L}{S\eta t_b^2} \right)^{1/2} \tag{1}
\]

If the lug height becomes unreasonable, e.g., greater than about 12 in high, or the required band thickness becomes excessive, a double ring or rolled structural channel should be considered (see para. NM5-300).

NM5-230 Split-Ring Flanges

Bands may be split and flanged for ease of assembly around the vessel, or where corrosion of support elements may require their replacement. End flanges at the split must be bolted face to face without inducing stress in the RTP shell. Flanges must be designed to develop the full structural capacity of the ring (see para. NM5-500 and Figure NM5-3).

NM5-240 Thickness of Gussets and Baseplate

The required minimum thicknesses of the gussets and baseplate shall be not less than the largest of the following:

\(a\) Shear

\[
t_g = 0.62SW/h_L S_{ae} N \tag{2}
\]

\(b\) Bending

\[
t_g = 2WE/S\eta h_L^2 \tag{3}
\]

\(c\) Compression

\[
t_g = 0.5W/dS_{ae} N \tag{4}
\]

\(d\) Lateral Stability

\[
t_g = d/16 \tag{5}
\]
The minimum leg size of the continuous fillet welds attaching the gussets and base to the band shall equal \(1.4t_g\).

**NM5-250 Shear Collar**

Shear collar height shown in Figure NM5-1 is minimum. Actual shear and compressive stresses shall be calculated. Shear collar heights and thicknesses shall be compared to minimums shown and increased as necessary.

**NM5-300 DOUBLE-RING SUPPORT**

Double-ring supports are a method of providing supports of reasonable proportions where the loads and/or lug eccentricities are large. The support is comprised of a channel fabricated of two continuous rings or a rolled structural channel (see Figure NM5-4). This support ring is proportioned to resist all bending and torsional loads without introducing any significant local loads into the FRP shell.

This paragraph provides a method for checking the stress in a support ring of a vertical vessel. The procedure is limited to thin ring beams with three or more evenly spaced lugs. Thin rings are those whose thickness in the radial direction is less than one-tenth their radius.

Double rings support the vessel by means of a shear collar.

**NM5-310 Nomenclature**

- \(b\) = spacing between lug gussets, in.
- \(D\) = outside diameter of vessel, in.
- \(d\) = radial projection of ring or channel from web or band, in.
- \(E\) = load eccentricity from centerline web to centerline anchor bolt, in.
- \(e\) = eccentricity of support reaction force, in. (see Figure NM5-4)
- \(e^*\) = location of center of torsional shear from centerline of web or band, in.
- \(h\) = height of ring section, in.
- \(h_b\) = height of band, in.
  \[h = h_b + 1\]
- \(I\) = moment of inertia of ring section about a centroid axis in the plane of the ring, in.\(^4\)
- \(J\) = torsional stiffness constant of ring section, in.\(^4\)
- \(M_b\) = bending moment at a section of ring, in.-lb
- \(M_{L}\) = moment coefficient at lugs, dimensionless
- \(M_t\) = twisting moment at a section of ring, in.-lb
- \(N\) = number of lugs
- \(R\) = inside radius of double-ring support, in.
- \(S_r\) = allowable stress of ring or section, psi

**NM5-320 Design Procedure for Double Rings on a Band**

A double-ring support may be fabricated by adding two rings to a steel band. The vessel is supported by a shear collar, in this case bearing on the top of the steel support band [see Figure NM5-4, sketch (a)].

**Step 1:** Assume a desired ring height and gusset spacing. Since the vessel diameter, support eccentricity, weight, and desired number of support points are known, an approximate section modulus for the ring can be calculated

\[
Z_r = \frac{DWcM_{L}}{NhS_r} \tag{6}
\]

This is the estimated minimum section modulus for each of two rings mounted on a steel band. The resulting double ring must be checked for bending and torsional stresses as follows.

**Step 2:** Determine the location of the center of shear, \(e^*\). This must be added to the projection of the lug, \(E\), from the centerline of the bolt hole to the centerline of the web to obtain the total eccentricity, \(e\), for the double-ring support.

For double rings on a band [see Figure NM5-4, sketch (a)]

\[
e^* = \frac{d^2(h - t_g)^2t_g}{4l} \tag{7}
\]

\[
e = e^* + E
\]

**Step 3:** Determine the ratio \(e/R\).

**Step 4:** Calculate \(Z_r\). For double rings on a band [see Figure NM5-4, sketch (a)]
NONMANDATORY APPENDIX NM-12
FRP FLANGE DESIGN

NM12-100 SCOPE

This Appendix provides a design procedure applicable to full-face flanges for nozzles, manways, vessel body flanges, and duct flanges. The procedure is intended for FRP flanges where the lay-up of the hub and flange form an integral bond with the shell wall or where a pipe stub, flange, and hub are made as an integral unit. The procedure is based on controlling the bending stress in the flange from the gasket pressure during bolt up and from the operating loads. Bolt loading is calculated to ensure gasket seating and to maintain gasket pressure under the operating conditions. Maximum and minimum bolt torques are calculated to ensure that sufficient load is applied to seat the gasket and to ensure that the flange is not overstressed. Hub clearances and edge clearances are calculated and compared to minimum clearances to ensure that there is sufficient room for the bolts and that the bolts are not too close to the outer edge of the flange.

NM12-200 NOMENCLATURE

The following symbols are used in the formulas for the design of flat-face flanges:

- \( B.C.D. \) = bolt circle diameter, in.
- \( b_x \) = bolt spacing, in.
- \( D_b \) = diameter of bolts, in.
- \( e_c \) = edge clearance, in.
- \( h_c \) = hub clearance, in.
- \( h_b \) = hub height, in.
- \( h_t \) = hub thickness, in.
- \( I.D. \) = inside flange diameter, in.
- \( m \) = gasket factor = 0.5
- \( N \) = number of bolts in flange
- \( n_t \) = nozzle wall thickness, in.
- \( O.D. \) = outside flange diameter, in.
- \( P \) = internal design pressure, psi
- \( P_a \) = axial load on flange, lb
- \( T_{\text{max}} \) = maximum bolt torque, ft-lb
- \( T_{\text{min}} \) = minimum bolt torque, ft-lb
- \( t_g \) = flange thickness required to seat gasket, in.
- \( t_o \) = flange thickness under operating loads, in.
- \( y \) = gasket seating stress = 50 psi
- \( \sigma_b \) = design bolt tensile stress, psi
- \( \sigma_{bg} \) = bolt stress at flange design stress, psi
- \( \sigma_{bg} \) = bolt stress required to seat gasket, psi
- \( \sigma_{bo} \) = bolt stress under operating loads, psi
- \( \sigma_f \) = design flange flexural stress, psi
- \( \sigma_n \) = design nozzle wall tensile stress, psi

NM12-300 CALCULATION PROCEDURE

Calculate the following initial design parameters (refer to Figures NM12-1 and NM12-2):

\[
A_b = \text{bolt root area} = 0.25\pi(0.91D_b - 0.055)^2
\]

\[
a_1 = \text{moment arm for axial load, in.} = 0.5(B.C.D. - I.D. - n_t)
\]

\[
a_2 = \text{moment arm for pressure load, in.} = 1.5w_i
\]

\[
a_3 = \text{moment arm for gasket load, in.} = 0.5(w_o + w_i) - w_o
\]

\[
F_1 = \text{axial load on flange, lb} = P_a + 0.25\pi(I.D.)^2P
\]

\[
F_2 = \text{pressure load inside gasket, lb}
\]