Glass-Fiber-Reinforced Thermosetting-Resin Piping Systems

ASME Standards for Nonmetallic Pressure Piping Systems

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Fiber-Reinforced Thermosetting-Resin Piping Systems

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ASME Codes and Standards
Chapter 1
Scope and Definitions

1-1 SCOPE

(a) This Standard provides requirements for the design, materials, manufacture, fabrication, installation, examination, and testing of glass-fiber-reinforced thermosetting-resin (FRP) piping systems.

(b) FRP piping, as used in this Standard, includes pipe, flanges, bolting, gaskets, valves, fittings, special connecting components, and the pressure-containing or pressure-retaining portions of other piping components, whether manufactured in accordance with references cited in this Standard or specially designed. It also includes hangers and supports and other items necessary to prevent overstressing the pressure-containing components.

1-1.1 Content and Coverage

(a) This Standard addresses pipe and piping components that are produced as standard products, as well as custom products that are designed for a specific application. It covers FRP pipe and piping components manufactured by contact molding, centrifugal casting, filament winding, and other methods. Its intent is to provide a uniform set of requirements for FRP pipe and piping components that can be adopted by reference in the various piping codes, including sections of the ASME B31 Code for Pressure Piping. This Standard is published as a separate document to reduce duplication between piping codes.

(b) Requirements of this Standard apply to FRP piping systems typically used within the scope of the various sections of the ASME B31 Code for Pressure Piping (ASME B31.1, ASME B31.3, ASME B31.4, ASME B31.5, ASME B31.8, and ASME B31.9) and selected piping systems designed to the ASME Boiler and Pressure Vessel Code (BPVC), Section III, Division 1, Subsection ND.

1-1.2 Exclusions

This Standard does not provide requirements for the following:

(a) metallic pipe

(b) thermoplastics, ceramics, and other nonmetallic materials used to fabricate pipe and piping components

(c) dual laminate construction that combines thermoplastic linings with FRP pipe and fittings

(d) reinforced polymer mortar pipe

(e) products with fiber-reinforcement materials that are not made from glass

(f) nonmetallic pressure vessels, valves, and specialty components covered by other ASME codes and standards, such as ASME BPVC, Section X and ASME RTP-1

(g) piping for which the maximum internal pressure exceeds 1700 kPa (250 psi)

(h) piping for which the algebraic product of internal pressure [in kilopascals gauge (pounds per square inch gauge)] and internal diameter [in meters (inches)] exceeds 1262 kPag·m (7,200 psig·in.)

(i) piping used as ductwork conveying air or other gases at pressures within 6.89 kPag (1 psig) of the pressure of the surrounding atmosphere

1-2 TERMS AND DEFINITIONS

Commonly used terms relating to FRP piping are defined below. Some terms are defined with specific reference to piping. The definitions generally agree with those in ASME BPVC, Section X; ASME RTP-1; ASTM D883; and ASTM F412. Definitions taken unchanged from other standards are indicated by a footnote.

adhesive: a material designed to join together two other component materials by surface attachment (bonding).

adhesive joint: a bonded joint made using an adhesive on the surfaces to be joined.

assembly: synonymous with fabrication.

binder\(^1\): in a reinforced plastic, the continuous phase that holds together the reinforcement.

bloom\(^1\): a visible exudation or efflorescence on the surface of a material.

bonder\(^2\): one who performs a manual or semiautomatic bonding operation.

bonding procedure\(^2\): the detailed methods and practices involved in the production of a bonded joint.

Bonding Procedure Specification (BPS): a document providing in detail the required variables and procedures for the bonding process to ensure repeatability in the bonding procedure.

\(^1\)This definition is from ASTM D883.

\(^2\)This definition is from ASME B31.3.
Revised Name

ASME NM.2, Standard on Glass-Fiber-Reinforced Thermosetting-Resin Piping Systems

Revised Scope

This Standard provides requirements for the design, materials, manufacture, fabrication, installation, examination, and testing of glass-fiber-reinforced thermosetting-resin and dual laminate piping systems.

Glass-fiber-reinforced thermosetting-resin and dual laminate piping as used in this Standard includes pipe, flanges, bolting, gaskets, valves, fittings, special connecting components, and the pressure-containing or retaining portions of other piping components, whether manufactured in accordance with documents referenced in this Standard or specially designed. It also includes hangers and supports and other equipment items necessary to prevent overstressing the pressure-containing components.
2-2.3.7 Limits of Calculated Stresses Due to Sustained and OperatingLoads

(a) Internal Pressure Stresses. Limits of stress due to internal pressure are as stated in paras. 2-2.3.2 through 2-2.3.5. The following also apply:

(1) Sustained Loads. Limits of stress due to internal pressure and other sustained loads such as weight are as stated in section 2-4.

(2) Operating Loads. Limits of stress due to sustained loads plus operating loads such as those due to restraint of thermal expansion/contraction are as stated in section 2-4.

(b) External Pressure Stresses. The stress due to external pressure shall be considered adequate if it is not greater than one-quarter of the collapse pressure determined by test or calculation.

2-2.3.8 Limits of Calculated Stresses Due to Occasional Loads

(a) Operation. The total stress in any component due to the following loads shall not exceed the limits stated in section 2-4:

(1) sustained loads such as pressure and weight
(2) sustained plus operating loads such as those due to the restraint of thermal expansion and/or contraction
(3) occasional loads such as wind or earthquake

NOTE: Wind and earthquake forces need not be considered as acting concurrently.

(b) Test. Stresses due to test conditions are subject to the limitations in (a). It is not necessary to consider other occasional loads, such as wind and earthquake, as occurring concurrently with test loads.

2-2.3.9 Allowances. The minimum required thickness of a piping component shall include allowances for corrosion, erosion, and thread or groove depth. See also section 2-5.

2-3 PRESSURE DESIGN OF PIPING COMPONENTS

2-3.1 General

Components manufactured in accordance with specifications listed in Table 4-1.1-1 shall be considered suitable for use at their respective maximum design pressures in accordance with para. 2-2.2.1. The requirements in paras. 2-3.2 through 2-3.9 are intended for uniform static pressure design of components not covered by the specifications in Table 4-1.1-1, but may be used for a special or more rigorous design of such components, or to satisfy requirements of para. 2-2.2.2. Designs shall be checked for adequacy of mechanical strength under applicable loadings as described in section 2-1.

2-3.2 Straight Pipe

2-3.2.1 General

(a) The required thickness of straight sections of pipe shall be determined by eq. (2-3-1):

\[ t_m = t + c \]  

(2-3-1)

where

\[ c = \text{sum of mechanical allowances (thread or groove depth) plus corrosion-barrier and erosion allowances, mm (in.)}. \]

For threaded components, the nominal thread depth (dimension \( h \) of ASME B1.20.1) shall apply. If the tolerance of machined surfaces or grooves is not specified, it shall be assumed to be 0.5 mm (0.02 in.) plus the specified depth of the cut. Unless otherwise specified by the owner, the corrosion-barrier thickness shall be considered as sacrificial and shall not be included for structural contributions.

\[ t = \text{pressure design structural thickness, mm (in.), as calculated in accordance with para. 2-3.2.2 for pipe under internal pressure or para. 2-3.2.3 for pipe under external pressure}. \]

For piping with both internal and external pressure design requirements, minimum structural thickness shall be taken as the maximum value required. Minimum structural thickness shall not be less than 2.0 mm (0.080 in.).

\[ t_m = \text{minimum required thickness, mm (in.), including the corrosion-barrier and mechanical and erosion allowances} \]

The measured total pipe wall thickness, \( T \), for the manufactured pipe shall not be less than \( t_m \). In addition, the measured thickness of the structural wall shall not be less than \( t \).

(b) The requirements of para. 2-3.2 are intended to address uniform static pressure design only. Additional thickness may be required for other loadings, dynamic effects, or stability as required by section 2-4.

2-3.2.2 Straight Pipe Under Internal Pressure. To ensure that straight pipe has adequate axial-direction strength for loads other than pressure, it is necessary to include provisions for additional axial strength capacity in the initial internal pressure design equations. The internal pressure design structural thickness, \( t \), shall not be less than that calculated by eq. (2-3-2). The stress values for eq. (2-3-2) shall be taken from the appropriate table in ASME NM-3.3 or determined from qualification testing.

\[ t = K_1 \frac{PD}{2S} \]  

(2-3-2)
where

\[ D = (D_t + 2c) \]
\[ c = \text{sum of allowances defined in para. 2-3.2.1, mm (in.)} \]
\[ D_t = \text{inside diameter of pipe, mm (in.)} \]
\[ K_1 = \text{factor to provide additional available axial strength for loads other than pressure} \]
\[ = 1.0 \text{ for Type I and Type II laminates} \]
\[ = 1.67 \text{ for Type III laminates} \]
\[ S_{H(2:1)} = \text{allowable hoop tensile stress with coincident longitudinal stress equal in magnitude to one half that of the hoop stress, MPa (psi)} \]
\[ S_{H(2:1)} = \text{allowable longitudinal tensile stress with no coincident hoop stress, MPa (psi)} \]
\[ P = \text{internal design gauge pressure, MPa (psi)} \]
\[ S = \text{design stress from applicable table in ASME NM.3.3 or from qualification testing, MPa (psi)} \]
\[ (20) \]

### 2-3.2.3 Straight Pipe Under Uniform Pressure

**a) Without Qualified Rib Stiffeners.** The external pressure design structural thickness, \( t \), shall be established following the procedures outlined in ASTM D2924, \( E_{AT} \) shall not be less than that calculated by eq. (2-3-3). The elastic modulus and Poisson’s ratio values for eq. (2-3-3) shall be taken from the appropriate table in ASME NM-3.3 or calculated by lamination analysis in accordance with Mandatory Appendix II. For laminate types other than Type I, II, or III, in the absence of appropriate Poisson’s ratio values, the product of Poisson’s ratio values, \( \nu_{AT} \cdot \nu_{AT} \), may be taken as zero for conservatism in the following equation. A design factor, \( F \), of at least 4.0 for external pressure shall be used:

\[
 t = \left[ \frac{F P D_t^3 (1 - \nu_{AT}^2 \mu_{AT})}{2 P_e E_{AT}^2} \right]^{1/2} \tag{2-3-3}
\]

where

\[ D_t = \text{outside diameter of pipe, mm (in.)} \]
\[ E_{AT} = \text{pipe hoop-direction flexural modulus, MPa (psi)} \]
\[ F = \text{design factor; } F \geq 4.0 \]
\[ P_e = \text{external or vacuum design gauge pressure, MPa (psi)} \]
\[ \nu_{AT} = \text{Poisson’s ratio in the axial direction} \]
\[ \nu_{AT} = \text{Poisson’s ratio in the hoop direction} \]

**b) With Qualified Rib Stiffeners.** Qualified rib stiffeners are defined as circumferential stiffener rings that meet the requirements for minimum moment of inertia, \( I_a \), as calculated by eq. (2-3-4):

\[
 I_a = \frac{P_e D_t^3 (1 - \nu_{AT}^2 \mu_{AT})}{24 P_e} \tag{2-3-4}
\]

where

\[ E_S = \text{hoop tensile modulus of stiffener, MPa (psi)} \]
\[ L_x = \text{one-half the distance from the centerline of the stiffener to the next stiffener on one side plus one-half the centerline distance to the next stiffener on the other side of the stiffener, both measured parallel to the axis of the cylinder, mm (in.)} \]

The external pressure design structural thickness, \( t \),

\[
 t = \left[ \frac{P_e (1 - \nu_{AT}^2 \mu_{AT})^{3/4} L_x (P_e/2)^{3/2}}{0.8531 K_D \gamma E_{AT}^{3/4} E_{AT}^{1/4}} \right]^{2/5} \tag{2-3-5}
\]

where

\[ E_{AT} = \text{pipe axial tensile modulus, MPa (psi)} \]
\[ K_D = \text{a knockdown factor to cover all data points} \]
\[ = 1.0 \text{ for Type I, Type II, and Type III laminates} \]
\[ = 0.84 \text{ for all other laminate types} \]
\[ L_x = \text{greatest center-to-center distance between any two adjacent stiffener rings, mm (in.)} \]
\[ t = \text{external pressure design structural thickness, mm (in.)} \]
\[ \gamma = \text{reduction factor to better correlate theoretical predictions and test results} \]
\[ E_{AT} = 1.0 - 0.001 Z_p \text{ if } Z_p < 100 \]
\[ = 0.9 \text{ if } Z_p > 100 \]

\[
 Z_p = \frac{E_{AT}}{E_{AT}} \left( 1 - \nu_{AT}^2 \mu_{AT} \right)^{1/2} L_x^2 \left( \frac{D_t^4}{2} \right) \tag{2-3-6}
\]

2-3.3 Curved and Mitered Segments of Pipe

### 2-3.3.1 Smooth Radius Elbows Under Uniform Internal Pressure

To ensure that smooth radius elbows have adequate hoop-direction strength capacity for combined stresses due to internal pressure and bending, it is necessary to include provisions for
The end tangents and extrados shall not be less than the requirements of para. 2-3.2 for straight pipe \((m \geq 1.0)\).

**2-3.3.2 Mitered Elbows Under Uniform Internal Pressure.** Acceptable methods for pressure design of multiple and single miter bends are given in (a) and (b), where the requirements in (c) and (d) apply. Refer to Figure 2-3.3.2-1 for nomenclature used in eqs. (2-3-9) through (2-3-11) for the internal pressure design of mitered elbows.

(a) **Multiple-Miter Elbows.** The maximum allowable internal pressure, \(P_m\), shall be the lesser value calculated from eqs. (2-3-9) and (2-3-10). These equations are not applicable when angle \(\theta\) exceeds 22.5 deg:

\[
P_m = \frac{\alpha t}{r_2 \left( \frac{t}{r_2} + 0.643 \tan \theta \sqrt{r_2 t} \right)}
\]  
(2-3-9)

\[
P_m = \frac{\alpha t}{r_2 \left( \frac{R_1 - r_2}{R_1 - 0.5r_2} \right)}
\]  
(2-3-10)

where \(\alpha\) = design stress from applicable table in ASME NM.3.3 or from qualification testing, MPa (psi)

(b) **Single-Miter Elbows**

1. The maximum allowable internal pressure, \(P_m\), for a single miter bend with angle \(\theta\) not greater than 22.5 deg shall be calculated by eq. (2-3-9).
2. The maximum allowable internal pressure, \(P_m\), for a single miter bend with angle \(\theta\) greater than 22.5 deg shall be calculated by eq. (2-3-11):

\[
P_m = \frac{\alpha t}{r_2 \left( \frac{t}{r_2} + 1.25 \tan \theta \sqrt{r_2 t} \right)}
\]  
(2-3-11)

(c) The miter pipe wall thickness, \(t\), used in eqs. (2-3-9) through (2-3-11) shall extend a distance not less than \(M\) from the inside crotch of the end miter welds, where \(M\) equals the larger of the following:

\[2.5(r_2)^{0.5}\]

or

\[
tan \theta (R_1 - r_2)
\]

(d) For all miter elbows for which the inside joint is accessible, 30% to 50% of the required miter joint shall be applied as an inside weld. A corrosion barrier shall be applied over the inside joint. The requirement for an inside weld is mandatory for miters where \(D_i \geq 600\) mm (24 in.) diameter.
2-3.3.3 Curved and Mitered Segments of Pipe Under Uniform External Pressure. The wall thickness of curved and mitered segments of pipe subjected to external pressure may be determined as specified for straight pipe in paras. 2-3.2.1 and 2-3.2.3.

2-3.4 Branch Connections

2-3.4.1 Fabricated Branch Connections. A pipe having a branch connection is weakened by the opening that must be made in it, and unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide added reinforcement. The design of branch connections shall be based on the following, except as provided in paras. 2-3.4.2 and 2-3.4.3.

(a) Nomenclature. The following nomenclature is used in the equations for pressure design of branch connections:

\[ A_p = \text{area of reinforcement required on each side of branch, mm}^2 \text{ (in.}^2\text{);} \]

\[ A_T = \text{total area of reinforcement required on run pipe, mm}^2 \text{ (in.}^2\text{);} \]

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

\[ d = \text{inside diameter of branch pipe, mm (in.)} \]

\[ E_{OL} = \text{tensile modulus of the reinforcement (minimum of hoop and axial moduli), MPa (psi)} \]

\[ E_p = \text{tensile modulus of the run pipe (maximum of hoop and axial moduli), MPa (psi)} \]

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

\[ = 10.0 \text{ minimum} \]

\[ L_b = \text{length of reinforcement on branch pipe, mm (in.)} \]

\[ L_c = \text{longest chord length of opening, mm (in.)} \]

\[ L_p = \text{width of reinforcement pad on run pipe, mm (in.)} \]

\[ L_{po} = \text{width of reinforcement pad on outside of run pipe, mm (in.)} \]

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

\[ S = \text{design stress from applicable tab in ASME Section III or from qualification testing, MPa (psi)} \]

\[ S_{OL} = \text{tensile strength of reinforcement (minimum of hoop and axial strengths), MPa (psi)} \]

\[ S_{sb} = \text{shear strength of secondary bond on branch pipe, MPa (psi)} \]

\[ S_{sb} = \text{shear strength of secondary bond on run pipe, MPa (psi)} \]

\[ S_{tp} = \text{tensile strength of the run pipe (maximum of hoop and axial strengths), MPa (psi)} \]

\[ t_b = \text{thickness of reinforcement on branch pipe, mm (in.)} \]

\[ T_h = \text{thickness of run pipe required for pressure rating, mm (in.)} \]

\[ T_p = \text{thickness of reinforcement pad on run pipe, mm (in.)} \]

\[ T_{po} = \text{thickness of reinforcement pad on outside of run pipe, mm (in.)} \]

(b) General Provisions and Requirements. The following general provisions and requirements apply to the procedures presented in (c) and (d) for pressure design of branch connections:

(1) These procedures apply to branch connections for which \( d/D \leq 0.5 \). Branch connections for which \( d/D > 0.5 \) shall be designed by Design Method B, C, or D (see paras. 2-2.3.3 through 2-2.3.5).

(2) These procedures apply for branch connections for which the angle between the branch and run pipe is \( \geq 45 \) deg.

(3) For all branch connections for which the inside joint is accessible, 30% to 50% of the required reinforcement shall be applied as an inside lay-up. A corrosion barrier shall be applied over the inside joint. The requirement for an inside lay-up is mandatory for branch connections where \( D \geq 600 \text{ mm (24 in.) and } d \geq 200 \text{ mm (8 in.)} \).

(4) These procedures are intended to address pressure design only. Additional thicknesses may be required for external loads.

(5) When any two or more branches are so closely spaced that their reinforcements overlap, each branch connection shall be reinforced as required by (c) and (d). No portion of the reinforcement shall be considered as applying to more than one branch connection.

(c) Reinforcement of the Run Pipe

(1) The total area for reinforcement of the run pipe shall not be less than that determined by eqs. (2-3-12) and (2-3-13):
and external pressures that will be applied to it if it uses a listed fitting (a tee, lateral, or cross) in accordance with para. 2-3.1.

2-3.4.3 Integrally Molded Tee Fittings

(a) The minimum required pressure design structural thickness, \( t \), of the main run and branch regions of a molded tee shall be determined in accordance with eq. (2-3-18):

\[
t = m \frac{PD_R}{SR} \quad (2-3-18)
\]

where

\( D_R \) = inside diameter of the main run structural wall, mm (in.)

\( m \) = pressure stress multiplier for integral tees

= 1.4\( \lambda_R \)\(^{2.25} \)

The geometry factor, \( \lambda_R \), is given by the following equations:

1. For equal tees, \( D_B = D_R \)

\[
\lambda_R = \frac{D_R}{D_R} \quad (2-3-19)
\]

2. For unequal or reducing tees, \( D_B < D_R \)

\[
\lambda_R = \frac{D_B}{D_R} \quad (2-3-20)
\]

where

\( D_B \) = inside diameter of the tee branch structural wall, mm (in.)

\( t_B \) = minimum structural thickness of the tee branch, mm (in.); see Figure 2-3.4.3.1

\( t_R \) = minimum structural thickness of the main run of the tee, mm (in.); see Figure 2-3.4.3-1

(b) The following general provisions and requirements apply to the design of molded tees:

1. The design approach is applicable only to molded tees made of Type I or Type II laminates where \( D_B \leq 600 \text{ mm (24 in.)} \) and the run and branch regions are integrally formed with continuous laminates. Fabricated tees constructed from separate run and branch pipe joined together shall be qualified in accordance with para. 2-3.4.1 or para. 2-3.9.2, as applicable.

2. The minimum thickness of the reinforced region at the junction of the run and branch shall not be less than \( 1.5t_R \). See Figure 2-3.4.3-1.

3. The length of reinforced thickness of the branch region, \( L_{RB} \), shall be greater than or equal to half of the branch diameter, \( 0.5D_B \), but shall not be less than 100 mm (4.0 in.).

4. For \( D_B \leq 0.25D_R \), the minimum diameter of the reinforced thickness of the run region shall not be less than \( 3D_B \) or \( [D_B + 200 \text{ mm (8 in.)}] \), whichever is greater, followed by a minimum length-to-thickness taper of 4:1. See Figure 2-3.4.3-1, illustration (a).

5. For \( D_B > 0.25D_R \), the reinforced thickness of the main run, \( t_R \), shall encompass the entire circumference of the run pipe. The minimum length of the reinforced thickness of the main run shall not be less than \( (D_B + D_R) \) or \( [D_B + 200 \text{ mm (8 in.)}] \), whichever is greater. See Figure 2-3.4.3-1, illustration (b).

6. The requirements of para. 2-3.4.3 are intended to achieve sufficient thickness and length of the reinforced regions to manage pressure stresses at the junction of the run and branch. The dimensions of the fitting may need to be increased to allow for joining methods or thickness transitions. Refer to para. 2-3.4.4 for additional design considerations for tees.

2-3.4.4 Additional Design Considerations. The requirements of paras. 2-3.4.1 through 2-3.4.3 are intended to ensure satisfactory performance of a branch connection subjected only to uniform static pressure loading. The designer shall also consider the following:

(a) In addition to static pressure loadings, external forces and moments are applied to a branch connection by dynamic unbalanced pressure, thermal expansion and contraction, dead and live loads, and movement of piping terminals and supports. Branch connections shall be designed to withstand these forces and moments.

(b) Adequate flexibility shall be provided in a small line that branches from a large run, to accommodate thermal expansion and other movements of the larger line.

(c) If ribs, gussets, or clamps are used to stiffen the branch connection, their areas shall not be counted as contributing to the reinforcement areas determined in paras. 2-3.4.1 and 2-3.4.3.

2-3.5 Closures

2-3.5.1 General

(a) Closures not in accordance with para. 2-3.1 or (b) shall be qualified as required by para. 2-3.9.2.

(b) Ellipsoidal (2:1), hemispherical, and torispherical closures with internal pressure on the concave side shall be as calculated in eq. (2-3-21):

\[
t_m = t + c \quad (2-3-21)
\]

where

\( c \) = sum of allowances defined in para. 2-3.2.1, mm (in.)

\( t \) = pressure design structural thickness, calculated for the type of closure using eq. (2-3-22), (2-3-23), or (2-3-24), mm (in.)

\( t_m \) = minimum required thickness, including the corrosion-barrier and mechanical and erosion allowances, mm (in.)
(1) For an ellipsoidal (2:1) closure, concave to pressure

\[ t = \frac{PD}{\Delta} \leftarrow S_{H(2:1)} \]  

(2-3-22)

where

- \( D \) = inside diameter of pipe structural wall, mm (in.)
- \( D_i = D_i + 2c \)
- \( P \) = internal design gauge pressure, MPa (psi)
- \( \Delta \) = design stress from applicable table in ASME NM3.3 or from qualification testing, MPa (psi)

(2) For a hemispherical closure, concave to pressure

\[ t = \frac{PR_s}{\Delta} \leftarrow S_{H(2:1)} \]  

(2-3-23)

where

- \( R_s \) = inside spherical radius, mm (in.)

(3) For a torispherical closure, concave to pressure

\[ t = \frac{MRC}{\Delta} \leftarrow S_{H(2:1)} \]  

(2-3-24)

where

- \( M = \frac{3}{4}[3 + (R_c/r)^{0.5}] \)
- \( r \) = head knuckle radius, mm (in.); \( r \geq 0.06R_c \)
- \( R_c \) = head crown radius, mm (in.); \( R_c \leq D \)

For torispherical closures, the knuckle radius shall be externally reinforced in accordance with Figure 2-3.5.1-1. The reinforcement thickness shall be equal to the thickness of the closure as calculated in eq. (2-3-24). The thickness of a joint overlay near the knuckle radius tangent line contributes to the knuckle reinforcement.

(c) Joint overlays for connections to closures are subject to the requirements of para. 2-3.8.2.

2-3.5.2 Openings in Closures. A closure is weakened by an opening, and unless the thickness of the closure is sufficiently in excess of that required to sustain pressure, it is necessary to provide added reinforcement.
(a) For openings not larger than one-half the inside diameter of the closure, the amount of reinforcement required shall be determined in accordance with para. 2-3.4.1.
(b) All other openings in closures shall be qualified as required by para. 2-3.9.2.

2-3.6 Flanges

2-3.6.1 General

(a) Flanges not in accordance with para. 2-3.1, para. 2-3.6.2, or (b) shall be qualified as required by para. 2-3.9.2.

(b) Flat-face flanges for use with full-face, flat-ring gaskets shall be designed in accordance with Mandatory Appendix I.

2-3.6.2 Blind Flanges. Blind flanges not in accordance with para. 2-3.1 shall be designed in accordance with eq. (2-3-25). Otherwise, they shall be qualified as required by para. 2-3.9.2.

\[
t_m = D_{bc}\sqrt{0.25\frac{P}{S}} + c
\]

where
- \(c\) = sum of allowances defined in para. 2-3.2.1, mm (in.)
- \(D_{bc}\) = bolt circle diameter, mm (in.)
- \(P\) = internal design gauge pressure, MPa (psi)
- \(S\) = design stress from applicable table in ASME NM.3.3 or from qualification testing, MPa (psi)
- \(t_m\) = minimum required thickness, including the corrosion, fabrication, and mechanical and residual allowances.

Insert after NM.3.3:
(Refer to General Note (c) in tables for Type I and Type II laminates)

2-3.7 Reducers

Reducers not in accordance with para. 2-3.1 shall satisfy the minimum thickness requirements specified for straight pipe in para. 2-3.2 based on the diameter at any corresponding point along the length of the reducer.

2-3.8 Joints

2-3.8.1 General. Joints or joining components, including adhesive joints, not in accordance with para. 2-3.1, para. 2-3.6, or para. 2-3.8.2 shall be qualified as required by para. 2-3.4.2.

(a) Joints not in accordance with para. 2-3.1 shall satisfy the minimum thickness requirements specified for straight pipe in para. 2-3.2 using the appropriate design stress, \(S\), and other material properties for the joint laminate type from the applicable table in ASME NM.3.3 or from qualification testing.

(b) In addition to meeting the requirements of (a) for hoop-direction pressure loading, the butt-joint structural thickness shall provide axial-direction strength and stiffness that is no less than that of the components being joined. The minimum structural thickness of the butt-joint laminate, \(t_j\), shall also not be less than that determined by eqs. (2-3-26) and (2-3-27):

\[
t_j \geq \frac{E_p}{E_j} t_p
\]

\[
t_j \geq \frac{S_p}{S_j}
\]

where
- \(E_j\) = minimum axial modulus of butt-joint structural wall, MPa (psi)
- \(E_p\) = maximum axial modulus of pipe structural wall, MPa (psi)
- \(S_j\) = minimum axial strength of butt-joint structural wall, MPa (psi)
- \(S_p\) = maximum axial strength of pipe structural wall, MPa (psi). If test data are not available for \(S_p\), it is permissible to use 0.015\(E_p\). If the pipe and joint are constructed of the same structural laminate type and sequence, \(S_p\) may be taken as equal to \(S_j\).
- \(t_j\) = minimum required structural thickness of the butt-joint laminate, mm (in.)
- \(t_p\) = minimum required structural thickness of the pipe, mm (in.)

The minimum full thickness joint length per side shall be less than 50 mm (2.0 in.).

Beyond the full thickness length, the butt-joint laminate shall taper at a minimum length-to-thickness ratio of 6:1 on each side.

The length of the butt-joint overlay shall be sufficient to provide average secondary bond shear strength at least equal to the axial tensile strength of the weaker part. The minimum secondary bond length of the butt-joint laminate on each side of the joint centerline, \(L_j\), shall not be less than that determined by eq. (2-3-28):

\[
L_j = \frac{S_p}{S_{ss}}
\]

where
- \(L_j\) = minimum required joint bond length, per side, mm (in.)
- \(S_{ss}\) = minimum secondary bond shear strength, MPa (psi). \(S_{ss}\) shall not be taken to be greater than 10 MPa (1,500 psi).

No more than 50% of the taper length may be included in the calculations for minimum secondary bond length, \(L_j\).
Pipe Stress Equations

(a) The piping system is substantially restrained by periodic rigid anchors that maintain the straight lengths of piping in a pure tensile or compressive stress condition between anchor points, isolating terminal points and changes in direction from excessive strain.

(b) The piping system includes flexible joints or other expansion-absorbing devices that are located in a manner to ensure a minimized stress state in the piping system. Where flexible joints and expansion-absorbing devices are implemented, sufficient anchor and guide supports shall be incorporated to ensure that the piping movement is directed into the flexible joint.

(c) Comprehensive. A comprehensive piping system analysis shall be performed using a formal pipe stress analysis program. The comprehensive piping system analysis shall include the following elements:

1. an accurate model of the piping system routing and all components, including weights and dimensions.
2. actual orthotropic material properties that concisely represent the specified piping materials and construction, including resin type, wind angle, and glass content. Material properties may be based on historical test data or calculated values.
3. stress intensification factors and flexibility factors based on tested data or calculated values.
4. estimated stiffness of pipe supports and supporting structures.
5. estimated stiffness of terminal points and connecting equipment. Results shall be carefully evaluated to verify that they are realistic for the FRP system.
6. an evaluation of all design conditions, including occasional loading and transient events, if known.

Allowable stresses values shall be based on the methods defined in para. 2-2.3.

2.4.4.3 Basic Assumptions and Requirements. The designer shall treat the piping system as a whole. The designer shall recognize the significance of all parts of the line and all restraints introduced to reduce stresses on equipment or small branch lines, and the restraint introduced by support friction.

(a) Pipe Stress Equations

2.4.4.4 Pipe Stress Analysis Requirements

(a) Hoop Stress. For each load case, the applied hoop stress, \( S_{H0} \) shall be calculated using eq. (2-4-1):

\[
S_H = \sqrt{\frac{mPDm}{2T_s} + \frac{(i_{b}\!M_{b})^2}{Z_s}} + \frac{(i_{b}\!M_{b})^2}{Z_s}
\]

(2-4-1)

where

\( D_m = \) mean diameter of component, mm (in.)
\( D_o = \) outside diameter of component, mm (in.)
\( T_s = \) corrosion-liner thickness, mm (in.)

(b) Longitudinal Stress (Axial Tensile Stress). For each load case, the applied longitudinal stress (axial stress), \( S_{A0} \) shall be calculated using eq. (2-4-2a), (2-4-2b), (2-4-3a), or (2-4-3b), as applicable.

\[
S_A = \sqrt{\frac{PD_a^2}{D_s^2 - D_o^2} + \frac{F_{ax}}{A_s} \frac{Z_s}{Z_s} + \frac{(i_b M_b)^2}{Z_s}}
\]

(2-4-2a)

\[
S_A = \sqrt{\frac{PD_a^2}{D_s^2 - D_o^2} + \frac{F_{ax}}{A_s} \frac{Z_s}{Z_s} - \frac{(i_b M_b)^2}{Z_s}}
\]

(2-4-2b)

where

\( A_s = \) area, mm² (in.²)
\( D_s = \) outside diameter of structural wall, mm (in.)
\( D_o = D_s - 2T_s \)
\( F_{ax} = \) axial force (excluding pressure), N (lb)
\( i_b = \) stress intensification factor, hoop stress due to in-plane moment (see Mandatory Appendix III)
\( i_{bH} = \) stress intensification factor, hoop stress due to out-of-plane moment (see Mandatory Appendix III)
\( T_s = \) nominal thickness of component, mm (in.)
\( Z_s = \) section modulus, mm³ (in.³)

(c) Torsional Stress. For each load case, the applied torsional stress, \( S_{T0} \) shall be calculated using eq. (2-4-3a), (2-4-3b), as applicable.

\[
S_T = \pi \left\{ \frac{D_o^4}{16} - (D_o - 2T_s)^2 \right\} / 32D_s
\]

(2-4-3a)

\[
S_T = \pi \left\{ \frac{D_o^4}{16} - (D_o - 2T_s)^2 \right\} / 32D_s
\]

(2-4-3b)
(2) For Restrained Piping Systems

\[ S_A = \left( \frac{E_a}{E_h} \times \frac{P_{D_m}}{2T_s} + \frac{F_{ax}}{A_s} \right)^2 + \left( \frac{i_M}{Z_{s}} \right)^2 \] (2-4-3a)

\[ S_A = -\left( \frac{E_a}{E_h} \times \frac{P_{D_m}}{2T_s} + \frac{F_{ax}}{A_s} \right)^3 - \left( \frac{i_M}{Z_{s}} \right)^3 \] (2-4-3b)

where

- \( E_a \) = axial modulus of elasticity, MPa (psi)
- \( E_h \) = hoop modulus of elasticity, MPa (psi)
- \( \nu_{hl} \) = Poisson’s ratio for hoop stress causing longitudinal

Internal pressure produces tensile stress in a restrained piping system and therefore reduces the compressive axial stress when there are positive changes in temperature. The possibility of low pressure during such load cases shall be considered.

Restrained piping systems shall also be checked for column-type buckling in accordance with Nonmandatory Appendix A.

(c) Stresses Due to Sustained Loads. The stresses due to sustained loads such as pressure and weight shall meet the following criteria:

\[ S_H \leq k_2 S_{H_{\text{max}}} \]
\[ S_A \leq k_2 S_{A_{\text{allow}}} \]

where

- \( k_1 = 1.0 \) for sustained loads excluding the effects of displacement loads such as those induced by thermal displacement
- \( k_1 = 1.1 \) for sustained loads including the effects of displacement loads such as those induced by thermal displacement and settlement

\( S_{A_{\text{allow}}} \) = allowable longitudinal stress, MPa (psi). The allowable longitudinal stress depends on the magnitude of the applied hoop stress, \( S_H \) (see para. 2-2.3).

\( S_{H_{\text{max}}} \) = maximum allowable hoop stress (see para. 2-2.3), MPa (psi)

(d) Stresses Due to Occasional Loads. The total stress due to sustained loads and occasional loads such as wind or seismic shall meet the following criteria:

\[ S_H \leq k_2 S_{H_{\text{max}}} \]
\[ S_A \leq k_2 S_{A_{\text{allow}}} \]

where

- \( k_2 = 1.20 \) for occasional loads acting for no more than 8 h at any one time and no more than 800 h/yr
- \( k_2 = 1.33 \) for occasional loads acting for no more than 1 h at any one time and no more than 80 h/yr
- \( k_2 = 1.33 \) for pressure testing and leak testing loads

It is not necessary to consider wind loads, seismic loads, or testing loads as acting concurrently.

(e) Displacement Stresses. Stresses due to displacement strains such as those induced by thermal displacement shall be calculated using the modulus of elasticity at ambient temperature or the modulus of elasticity at design temperature, whichever is higher.

(f) Thermal Displacement. Thermal expansion shall be calculated using the maximum exposure temperature and the minimum expected installation temperature. Thermal contraction shall be calculated using the minimum exposure temperature and the maximum expected installation temperature.

(g) Elongation Due to Pressure. Elongation of the piping due to pressure shall be considered in the analysis. The strain due to pressure elongation shall be calculated using eq. (2-4-4):

\[ \epsilon_l = \frac{S_{Ap}}{E_l} - \nu_{hl} \frac{P_{D_m}}{2T_s E_h} \] (2-4-4)

where

- \( E_h \) = hoop modulus of elasticity, MPa (psi)
- \( E_l \) = longitudinal (axial) modulus of elasticity, MPa (psi)
- \( S_{Ap} \) = longitudinal (axial) stress due to pressure, MPa (psi)
- \( \epsilon_l \) = longitudinal (axial) strain due to pressure
- \( \nu_{hl} \) = Poisson’s ratio for hoop stress causing longitudinal

2-4.5 Reactions

Reaction forces and moments are used in design of restraints and supports for a piping system, and in evaluation of the effects of piping displacements on connected equipment. See para. 2-4.4.2 for analysis methods to determine reactions.

Where dynamic loads are identified, the piping shall be evaluated for those defined loads. Dynamic reactions due to pumps or valve actions should be evaluated. Proper restraints shall be added if required by stress analysis.
Acceptance Criteria

**For Restrained Piping Systems**

For \( \nu_{hl} \frac{E_a}{E_h} x \frac{PD_m}{2T_z} + \frac{F_{ax}}{A_x} \geq 0 \)

\[
S_A = \frac{E_a}{E_h} x \frac{PD_m}{2T_z} + \frac{F_{ax}}{A_x} + \left( \frac{iM_f}{Z_e} \right)^2
\]

For \( \nu_{hl} \frac{E_a}{E_h} x \frac{PD_m}{2T_z} + \frac{F_{ax}}{A_x} < 0 \)

\[
S_A = \frac{E_a}{E_h} x \frac{PD_m}{2T_z} + \frac{F_{ax}}{A_x} - \left( \frac{iM_f}{Z_e} \right)^2
\]

where

- \( E_a \) = axial modulus of elasticity, MPa (psi)
- \( E_h \) = hoop modulus of elasticity, MPa (psi)
- \( \nu_{hl} \) = Poisson's ratio for hoop stress causing longitudinal strain

**Additional Design Requirements**

It is not necessary to consider wind loads, earthquake loads, or testing loads as acting concurrently.

Displacement Stresses. Stresses due to displacement strains such as those induced by thermal expansion shall be calculated using the modulus of elasticity at ambient temperature or the modulus of elasticity at design temperature, whichever is higher.

Thermal Expansion/Contraction. Thermal expansion shall be calculated using the maximum operating temperature and the minimum expected installation temperature. Thermal contraction shall be calculated using the minimum operating or ambient temperature and the maximum expected installation temperature.

Elongation Due to Pressure. Elongation of the piping due to pressure shall be considered in the analysis. The strain due to pressure elongation shall be calculated using eq. (2.4-4):

\[
\varepsilon_l = \frac{S_{Ap}}{E_l} - \frac{PD_m}{2T_s E_h}
\]

where

- \( E_h \) = hoop modulus of elasticity, MPa (psi)
- \( E_l \) = longitudinal (axial) modulus of elasticity, MPa (psi)
- \( S_{Ap} \) = longitudinal (axial) stress due to pressure, MPa (psi)
- \( \varepsilon_l \) = longitudinal (axial) strain due to pressure
- \( \nu_{hl} \) = Poisson's ratio for hoop stress causing longitudinal strain

2-4.5 Reactions

Reaction forces and moments are used in design of restraints and supports for a piping system, and in evaluation of the effects of piping displacements on connected equipment.
(a) For restrained piping systems

\[ S_A = \frac{E_A}{1 - \nu_A^2} \left( \frac{P_D}{A_a} + \frac{P_{ex}}{A_a} \right) \left( 1 + \frac{P_{max}}{P_{max}} \right) + \left( \frac{h_{T/2}}{Z_a} \right)^2 + \left( \frac{h_{T/2}}{Z_a} \right)^2 \]  

(2-4-3a)

(b) For restrained piping systems

\[ S_A = -\frac{E_A}{1 - \nu_A^2} \left( \frac{P_D}{A_a} + \frac{P_{ex}}{A_a} \right) \left( 1 - \frac{P_{max}}{P_{max}} \right) + \left( \frac{h_{T/2}}{Z_a} \right)^2 + \left( \frac{h_{T/2}}{Z_a} \right)^2 \]  

(2-4-3b)

\[ \text{where} \]

\[ E_A \] = axial modulus of elasticity, MPa (psi)

\[ E_T \] = hoop modulus of elasticity, MPa (psi)

\[ \nu_{AT} \] = Poisson’s ratio for hoop stress causing longitudinal strain

\[ P_D \] = nominal operating pressure

\[ P_{max} \] = external pressure

\[ A_a \] = maximum allowable cross-sectional area

\[ h_{T/2} \] = thickness of the pipe

\[ Z_a \] = second moment of area

\[ c \] = constant

(d) Stresses Due to Occasional Loads. The total stress due to sustained loads and occasional loads such as wind or seismic shall meet the following criteria:

\[ S_{II} \leq k_2 S_{II,\text{max}} \]

\[ S_A \leq k_2 S_{A,\text{allow}} \]

where

\[ k_2 = 1.20 \] for occasional loads acting for no more than 8 h at any one time and no more than 800 h/yr

\[ = 1.33 \] for occasional loads acting for no more than 1 h at any one time and no more than 80 h/yr

\[ = 1.33 \] for pressure testing and leak testing loads

It is not necessary to consider wind loads, seismic loads, or testing loads as acting concurrently.

(e) Displacement Stresses. Stresses due to displacement strains such as those induced by thermal displacement shall be calculated using the modulus of elasticity at ambient temperature or the modulus of elasticity at design temperature, whichever is higher.

(f) Thermal Displacement. Thermal expansion shall be calculated using the maximum exposure temperature and the minimum expected installation temperature. Thermal contraction shall be calculated using the minimum exposure temperature and the maximum expected installation temperature.

(g) Elongation Due to Pressure. Elongation of the piping due to pressure shall be considered in the analysis. The strain due to pressure elongation shall be calculated using eq. (2-4-4):

\[ \varepsilon_p = \frac{S_{Ap}}{E_T} \left[ \frac{P_D}{2T_S} \right] \]  

(2-4-4)

\[ \text{where} \]

\[ E_T \] = hoop modulus of elasticity, MPa (psi)

\[ E_L \] = longitudinal (axial) modulus of elasticity, MPa (psi)

\[ S_{Ap} \] = longitudinal (axial) stress due to pressure, MPa (psi)

\[ \varepsilon_L \] = longitudinal (axial) strain due to pressure

\[ \nu_{AT} \] = Poisson’s ratio for hoop stress causing longitudinal strain

2-4.5 Reactions

Reaction forces and moments are used in design of restraints and supports for a piping system, and in evaluation of the effects of piping displacements on connected equipment. See para. 2-4.4.2 for analysis methods to determine reactions.

Where dynamic loads are identified, the piping shall be evaluated for those defined loads. Dynamic reactions due to pumps or valve actions should be evaluated. Proper restraints shall be added if required by stress analysis.
<table>
<thead>
<tr>
<th>Imperfection Name</th>
<th>Definition of Imperfection</th>
<th>Maximum Size and Cumulative Sum of Imperfections Allowable [After Repair. See General Notes (a) and (b). Imperfections Subject to Cumulative Sum Limitation Are Highlighted With an Asterisk.]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inner Surface Veil(s), Surfacing Mat</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>*¼ in. 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 or exterior only)</td>
<td>None</td>
</tr>
</tbody>
</table>

Replace with: Edges shall be sealed with 2 coats of resin, or as specified in the Design engineering design (e.g. veil capping or liner capping).
(a) Test Assembly. The test assembly shall be fabricated in accordance with the BPS and shall contain at least one of each different type of joint identified in the BPS. More than one test assembly may be prepared if necessary to accommodate all of the joint types or to ensure that at least one of each joint type is loaded in both circumferential and longitudinal directions. Test assemblies shall not have been pretested or pre-stress-relieved prior to first loadings and testing. The size of pipe and fittings in the test assembly shall be as follows:

(1) When the largest size to be joined is DN 100 (NPS 4) or smaller, the test assembly shall be the largest size to be joined.

(2) When the largest size to be joined is greater than DN 100 (NPS 4) and less than or equal to DN 1200 (NPS 48), the size of the test assembly shall be between 25% and 100% of the largest piping size to be joined, but shall be a minimum of DN 100 (NPS 4).

(3) When the largest size to be joined is greater than DN 1200 (NPS 48), the size of the test assembly shall be agreed upon between the owner and the employer.

(b) Burst Test Method. The test assembly shall be subjected to a burst test in accordance with ASTM D1599, Procedure B. The burst pressure shall be, as a minimum, 6 times pipe rated pressure. The time to burst may be extended as indicated in ASTM D1599.

(c) Burst Test. The test shall be conducted so that the joint is loaded in both the circumferential and longitudinal directions. All joints tested shall be unstrained.

5-2.2.6 Performance Requalification. Renewal of a bonding performance qualification shall be performed when

(a) a bonder has not used the specific bonding process for a period of 6 months or more, or

(b) there is specific reason to question the individual’s ability to make bonds that meet the BPS

5-2.3 Bonding Materials and Equipment

5-2.3.1 Materials

(a) Thermoset Resins

(1) The resin shall be checked to ensure that it is the product ordered. The resin shall be properly labeled.

(2) The resin shall be within the manufacturer’s recommended usable viscosity range. It shall be of normal color and clarity, and free from solid or gelled particles and dirt as determined by visual examination. There shall be no layering or separation of the resin.

(3) The resin shall be within the manufacturer’s specification for room-temperature gel time as determined by the manufacturer’s prescribed method.

(b) Glass Reinforcement

(1) The glass shall be checked to ensure that it is the product ordered. The glass shall have proper labeling.

(2) The glass shall be dry and clean. It shall be kept in its packaging container until time of use.

(c) Curing Agents

(1) Curing agents shall be checked to ensure they are the products ordered. They shall have proper labeling.

(2) Curing agents shall have no layering or separation.

5-2.3.2 Equipment. Fixtures and tools used in making joints shall be in such condition as to perform their functions satisfactorily. Fixtures, tools, equipment, and other devices used to hold or apply forces to the pipe shall function in a way that does not damage the pipe surface.

5-2.4 Preparation for Bonding

Preparation shall be defined in the BPS and shall specify the following requirements at minimum:

(a) cutting

(b) cleaning

(c) preheat

(d) end preparation

(e) fit-up

5-2.5 Bonding Requirements

5-2.5.1 General

(a) Production joints shall be made only in accordance with a written BPS that has been qualified in accordance with para. 5-2.2. Manufacturers of piping materials, bonding materials, and bonding equipment should consult in the preparation of the BPS.

(b) Production joints shall be made only by qualified bonders who have appropriate training or experience in the use of the applicable BPS and have satisfactorily passed a performance qualification test that was performed in accordance with a qualified BPS.

(c) Each qualified bonder shall be assigned an identification symbol. Unless otherwise specified in the engineering design, each pressure-containing bond or adjacent area shall be stenciled or otherwise suitably marked with the identification symbol of the bonder. Identification stamping shall not be used, and any marking paint or ink shall not be detrimental to the piping material. In lieu of marking the bond, the bonder may be identified on appropriate quality control records.

(d) Qualification in one BPS shall not qualify a bonder for any other bonding procedure.

(e) Longitudinal joints shall not be used.
5-3 ASSEMBLY AND ERECTION

5-3.1 Tolerances and Alignment

5-3.1.1 Piping Distortions

Any alignment of pipe that produces detrimental strain in equipment or piping components shall not be permitted.

5-3.1.2 Linear, Angular, and Rotational Tolerances

5-3.1.2.1 The tolerances on linear dimensions (intermediate or overall) shall apply to the face-to-face, face-to-end, and end-to-end measurements of fabricated straight pipe and headers; center-to-end or center-to-face measurements of nozzles or other attachments; or center-to-face measurements of bends, as illustrated in Figure 5-3.1.2.1-1. These tolerances shall not be cumulative.

5-3.1.2.2 When fittings or flanges are joined without intervening pipe segments, deviations greater than those specified in Figure 5-3.1.2.1-1 may occur due to the cumulative effects of tolerances on such components; these deviations are acceptable.

5-3.1.2.3 Angularity tolerances across the face, end preparation, and rotation of flanges are shown in Figure 5-3.1.2.1-1.

5-3.1.2.4 Flange face tolerances \( \frac{\pi}{32} \) Flange face draw-back and waviness shall not exceed 0.8 mm (\( \frac{\pi}{32} \) in.) as measured at or inside the bolt circle. No reverse drawback is permitted. See Figure 5-3.1.2.4-1.

5-3.1.3 Closer Tolerances

When closer tolerances than those given in paras. 5-3.1.2.1 through 5-3.1.2.3 are necessary, they shall be subject to agreement between the designer and the fabricator.

5-3.1.4 Flanged Joints

Unless otherwise specified in the engineering design, flanged joints shall be aligned as follows:

(a) Before bolting, mating gasket contact surfaces shall be aligned to each other within 1 mm/200 mm (\( \frac{\pi}{32} \) in./ft) measured across any diameter.

(b) The flanged joint shall be capable of being bolted such that the gasket contact surfaces bear uniformly on the gasket.

(c) Flange bolt holes shall be aligned within 3 mm (\( \frac{\pi}{8} \) in.) maximum offset.

5-3.1.5 Irregularities

Irregularities (i.e., gap, angular deflection, and misalignment) between two field-connected pipes and/or alignment of flange facings shall be within the tolerances as set in the engineering documentation and approved by the owner.

5-3.2 Flanged and Mechanical Joints

The preferred flanged joint assembly shall be one with two flat-face flanges with full-face gaskets having a 50 to 70 Shore A durometer. When other combinations of flanges and gaskets are used, the additional requirements of para. 5-3.2.5 shall be considered.

Mechanical joints that are not flanged shall be assembled in accordance with the manufacturer’s requirements and as shown on engineering documents.

Bolting torque sequence and limits shall be specified by the manufacturer for a particular flange and approved by the designer. Type of compound or lubricant shall directly relate to specified torquing values and gasket material.

5-3.2.1 Preparation for Assembly

Any damage to the gasket seating surface that would prevent gasket seating shall be repaired, or the flange shall be replaced.

5-3.2.2 Bolting Torque

(a) During assembly of flanged joints, the gasket shall be uniformly compressed to the proper design loading.

(b) Bolts shall be tightened to a predetermined torque.

(c) Narrow flat washers (see ASME B18.21.1, Type A) shall be used under all bolt heads and nuts.

5-3.2.3 Bolt Length

Bolt length should consider the presence of washers, nut height, and required thread protrusion. Nuts should engage the bolt threads for the full depth of the nut. The nut may be considered acceptably engaged if the lack of complete engagement is not more than one thread. The use of bolt tensioners requires that the threaded portion of the bolt extend at least one bolt diameter beyond the outside nut face on the tensioner side of the joint. Galvanized or coated bolts may require special tensioner puller sleeves.

5-3.2.4 Gaskets

No more than one gasket shall be used between contact faces in assembling a flanged joint.

5-3.2.5 Nonstandard Flanged Joints

When other than flat-face flanges with full-face gaskets having a 50–70 Shore A durometer are used, the following shall apply:

(a) Consideration shall be given to the strength of the flanges, and to sustained loads, displacement strains, and occasional loads described in Chapter 2.

(b) When mating raised-face to flat-face flanges, the following shall occur:

(1) The flange connection shall be designed to withstand the stresses during bolt-up.

(2) The appropriate spacer or filler rings shall be used to prevent overstressing of the flat-face flange.

(c) An appropriate bolt-up sequence shall be specified.

(d) Appropriate bolt-up torque limits specified by the manufacturer shall be approved by the designer, and those limits shall not be exceeded.
6-3.3.3 Piping With Expansion Joints

(a) Unrestrained expansion joints depend on external main anchors to resist pressure thrust forces. Except as limited in (c), a piping system containing unrestrained expansion joints shall be leak tested without any temporary restraints in accordance with section 6-3 up to 150% of the expansion joint design pressure. If the required test pressure exceeds 150% of the expansion joint design pressure and the main anchors are not designed to resist the pressure thrust forces at the required test pressure, for that portion of the test when the pressure exceeds 150% of the expansion joint design pressure, either the expansion joint shall be temporarily removed or temporary restraints shall be added to resist the pressure thrust forces.

(b) If the test pressure of piping attached to a vessel is the same as or less than the test pressure for the vessel, the piping may be tested with the vessel at the piping test pressure.

(c) If the test pressure of the piping exceeds the vessel test pressure, and it is not considered practicable to isolate the piping from the vessel, the piping and the vessel may be tested together at the vessel test pressure, provided the owner approves and the vessel test pressure is not less than 77% of the piping test pressure calculated in accordance with ASME B31.3, para. 345.4.2(b).

6-3.5 Pneumatic Leak Test

(a) Pneumatic leak tests shall be permitted only with the owner’s approval and as allowed by the referenced code.

(b) In general, with the exception of testing low-pressure piping systems, pneumatic testing should be avoided.

(c) Material properties and test temperature shall be considered when the hazards associated with pneumatic testing are evaluated.

(d) See also paras. 6-3.1(b) and 6-3.2.2(b).

NOTE: See ASME PCC-2, Article 501 for more detailed guidance on pneumatic testing.

6-3.5.2 Pressure Relief Device. A pressure relief device having a set pressure not higher than the test pressure shall be provided.

6-3.5.3 Test Fluid. The gas used as test fluid, if not air, shall be nonflammable, noncombustible, and nontoxic.

6-3.5.4 Test Pressure. The test pressure shall not be less than 1.1 times the design pressure and shall not exceed 1.33 times the design pressure.

6-3.5.5 Procedure

Step 1. The pressure shall be gradually increased until a gauge pressure that is the lesser of one-half the test pressure or 105 kPa (15 psi) is attained, at which time a preliminary check shall be made, including examination of joints in accordance with para. 6-2.4.1.

Step 2. The pressure shall be gradually increased in steps until the test pressure is reached; at each step, the pressure shall be held long enough to equalize piping strains.

Step 3. The test pressure should be maintained as indicated in para. 6-3.2.2(a).
Mandatory Appendix VI
Examination and Testing Requirements for Vinyl Ester Resin, Polyester Resin, and Additive Materials

VI-1 INTRODUCTION

(a) Sections VI-2 through VI-5 of this Appendix specify the minimum requirements for the inspections and tests that shall be performed by the fabricator’s personnel or an independent testing laboratory on resins and curing agents (curing agents include accelerators, promoters, and peroxides as required for specific resins systems).

(b) The requirements of sections VI-2 through VI-5 shall be satisfied if the product is accompanied by an acceptable certificate of analysis prepared by the constituent material manufacturer and it is accepted by the fabricator under the following conditions:

(1) The fabricator shall confirm that the products are the ones ordered and the label identifies the product, the product identification number, and the constituent manufacturer.

(2) The fabricator may record results of specific tests on the Resin Log Sheet, Form VI-6-1, provided the certificate of analysis is noted in the log sheet by a traceable identification and is available for review by concerned parties.

(c) If a certificate of analysis is not acceptable to the fabricator, then the inspections described in this Appendix shall be performed on at least one random sample from each lot or batch of material received from a supplier.

(d) If any containers or packages are damaged, then the contents of each damaged container shall be inspected according to the procedures of this Appendix.

NOTE: The requirements of this Appendix shall be met prior to use of resins and curing agents for fabrication of piping components to this Standard.

(e) The requirements of this Appendix will help ensure that the resins and curing agents are correctly identified; meet the constituent material manufacturer’s specification; and are suitable for proper fabrication, curing practice, and design requirements of equipment fabricated to this Standard.

VI-2 VISUAL INSPECTION

This section specifies the requirements for the inspection of resins, curing agents, and additives that will be used in fabricating pipe and piping components to this Standard.

VI-2.1 Safety

Refer to safety data sheets for the resin and curing-agent safety precautions.

VI-2.2 Requirements

(a) Resins

(1) Before use, resins shall be checked to ensure they are the products ordered and they comply with the following:

(-a) They have proper labeling for the specified product, including the constituent material manufacturer’s product name and identifying number.

(-b) A sample is of normal color and clarity for the specific resin, free from solid or gelled particles and dirt as determined by visual examination.

(-c) They are within the constituent material manufacturer’s specification limits for specific gravity, viscosity, and room-temperature gel time.

(2) Before a resin is used, its properties shall be determined by the test methods of sections VI-3 through VI-5 unless the manufacturer has developed and implemented test methods documented in their quality control (QC) program to generate the data required on the Resin Log Sheet, Form VI-6-1.

(3) Results of visual examinations and specific tests shall be recorded on the Resin Log Sheet, Form VI-6-1.

(b) Curing Agents

(1) Before use, curing agents shall be checked to ensure they are the products ordered and they comply with the following:

(-a) They have proper labeling for the specified product, including the constituent material manufacturer’s product name and identifying number.