**UW-17 PLUG WELDS**

(a) Plug welds may be employed in lap joints, in reinforcement around openings and in nonpressure structural attachments. They shall be properly spaced to carry their proportion of the load, but shall not be considered to take more than 30% of the total load to be transmitted.

(b) Plug weld holes shall have a diameter not less than \( t + \frac{1}{4} \) in. (6 mm) and not more than \( 2t + \frac{1}{4} \) in. (6 mm), where \( t \) is the thickness in inches of the plate or attached part in which the hole is made.

(c) Plug weld holes shall be completely filled with weld metal when the thickness of the plate, or attached part, in which the weld is made is \( \frac{5}{16} \) in. (8 mm) or less; for thicker plates or attached parts the holes shall be filled to a depth of at least half the plate thickness or \( \frac{5}{16} \) of the hole diameter, whichever is larger, but in no case less than \( \frac{5}{16} \) in. (8 mm).

(d) The allowable working load on a plug weld in either shear or tension shall be computed by the following formula:

\[
P = 0.63S(d - \frac{1}{4})^2
\]

\[
P = 0.63S(d - \frac{1}{6})^2
\]

where

- \( d \) = the bottom diameter of the hole in which the weld is made
- \( P \) = total allowable working load on the plug weld
- \( S \) = maximum allowable stress value for the material in which the weld is made (see UG-23)

**UW-18 FILLET WELDS**

(a) Fillet welds may be employed as strength welds for pressure parts within the limitations given elsewhere in this Division. Particular care shall be taken in the layout of joints in which fillet welds are to be used in order to assure complete fusion at the root of the fillet.

(b) Corner or tee joints may be made with fillet welds provided the plates are properly supported independently of such welds, except that independent supports are not required for joints used for the purposes enumerated in UG-55.

(c) Figures UW-13.1 and UW-13.2 show several construction details that are not permissible.

(d) Unless the sizing basis is given elsewhere in this Division, the maximum allowable load on fillet welds shall equal the product of the weld area (based on minimum leg dimension), the maximum allowable stress value in tension of the material being welded, and a joint efficiency of 55%.

**UW-19 WELDED STAYED CONSTRUCTION**

(a) Welded-in staybolts shall meet the following requirements:

1. The arrangement shall substantially conform to one of those illustrated in Figure UW-19.1;
2. The required thickness of the plate shall not exceed \( 1\frac{1}{2} \) in. (38 mm), except for Figure UW-19.1, sketches (e), (g), and (h). For plate thicknesses greater than \( \frac{3}{4} \) in. (19 mm), the staybolt pitch shall not exceed the smaller of 20 in. (500 mm) or the limits established in UG-47(f).
3. The provisions of UG-47 and UG-49 shall be followed; and
4. The required area of the staybolt shall be determined in accordance with the requirements in UG-50.

(b) Welded stays, substantially as shown in Figure UW-19.2, may be used to stay jacketed pressure vessels provided:

1. The pressure does not exceed 300 psi (2 MPa);
2. The required thickness of the plate does not exceed \( \frac{1}{4} \) in. (13 mm);
3. The size of the fillet welds is not less than the plate thickness;
4. The inside welds are properly inspected before the closing plates are attached;
5. The allowable load on the fillet welds is computed in accordance with UW-18(d);
6. The maximum diameter or width of the hole in the plate does not exceed \( 1\frac{1}{4} \) in. (32 mm);
7. The welders are qualified under the rules of Section IX;
8. The maximum spacing of stays is determined by the formula in UG-47(a), using \( C = 2.1 \) if either plate is not over \( \frac{7}{16} \) in. (11 mm) thick, \( C = 2.2 \) if both plates are over \( \frac{7}{16} \) in. (11 mm) thick.

(c) Welded stayed construction, as shown in Figure UW-19.2 or consisting of a dimpled or embossed plate welded to another like plate or to a plain plate, may be used, provided

1. The welded attachment is made by fillet welds around holes or slots as shown in Figure UW-19.2 or if the thickness of the plate having the hole or slot is \( \frac{1}{2} \) in. (12 mm) or less, and the hole is 1 in. (25 mm) or less in diameter, the holes may be completely filled with weld metal. The allowable load on the weld shall equal the product of the thickness of the plate having the hole or slot, the circumference or perimeter of the hole or slot, the allowable stress value in tension of the weaker of the materials being joined and a joint efficiency of 55%.
2. The maximum allowable working pressure of the dimpled or embossed components is established in accordance with the requirements of UG-101. The joint efficiency, \( E \), used in UG-101 to calculate the MAWP of the dimpled panel shall be taken as 0.80. This proof test may be carried out on a representative panel. If a representative panel is used, it shall be rectangular in shape and at least 5 pitches in each direction, but not less than...
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24 in. (600 mm) in either direction. The representative panel shall utilize the same weld details as will be used in the final construction.

(3) the plain plate, if used, shall meet the requirements for braced and stayed surfaces.

(6) The welds need not be radiographed, nor need they be postweld heat treated unless the vessel or vessel part in which they occur is required to be postweld heat treated.

UW-20 TUBE-TO-TUBESHEET WELDS

UW-20.1 Scope. These rules provide a basis for establishing weld sizes and allowable joint loads for full strength and partial strength tube-to-tubesheet welds.

UW-20.2 Definitions.

(a) Full Strength Weld. A full strength tube-to-tubesheet weld is one in which the design strength is equal to or greater than the axial tube strength, \( F_t \). When the weld in a tube-to-tubesheet joint meets the requirements of UW-20.4, it is a full strength weld and the joint does not require qualification by shear load testing. Such a weld also provides tube joint leak tightness.

(b) Partial Strength Weld. A partial strength weld is one in which the design strength is based on the mechanical and thermal axial tube loads (in either direction) that are determined from the actual design conditions. The maximum allowable axial load of this weld may be determined in accordance with UW-20.5, Nonmandatory Appendix A, or UW-18(d). When the weld in a tube-to-tubesheet joint meets the requirements of UW-20.5 or UW-18(d), it is a partial strength weld and the joint does not require qualification by shear load testing. Such a weld also provides tube joint leak tightness.

(c) Seal Weld. A tube-to-tubesheet seal weld is one used to supplement an expanded tube joint to ensure leak tightness. Its size has not been determined based on axial tube loading.

UW-20.3 Nomenclature. The symbols described below are used for the design of tube-to-tubesheet welds.

- \( a_c \): length of the combined weld legs measured parallel to the longitudinal axis of the tube at its outside diameter
- \( a_f \): fillet weld leg
- \( a_g \): groove weld leg
- \( a_m \): minimum required length of the weld leg(s) under consideration
- \( d_o \): tube outside diameter
- \( F_d \): design strength, but not greater than \( F_t \)
- \( F_f \): fillet weld strength, but not greater than \( F_t \)
- \( F_g \): groove weld strength, but not greater than \( F_t \)
- \( F_t \): axial tube strength
- \( f_w \): weld strength factor
- \( f_r \): ratio of the fillet weld strength to the design strength
- \( f_g \): ratio of the groove weld strength to the design strength
- \( S_a \): allowable stress at the design temperature as given in the applicable part of Section II, Part D
- \( S_t \): allowable stress in tube (see S, above)
- \( S_m \): allowable stress in weld (lesser of \( S_a \) or \( S_t \), above)
- \( t \): nominal tube thickness

NOTE: For a welded tube or pipe, use the allowable stress for the equivalent seamless product. When the allowable stress for the equivalent seamless product is not available, divide the allowable stress of the welded product by 0.85.

UW-20.4 Full Strength Welds. Full strength welds shown in Figure UW-20.1 shall conform to the following requirements:

(a) The size of a full strength weld shall be determined in accordance with UW-20.6.

(b) The maximum allowable axial load in either direction on a tube-to-tubesheet joint with a full strength weld shall be determined as follows:

\[ L_{max} = F_t \]

(1) For loads due to pressure-induced axial forces, \( L_{max} = F_t \)

(2) For loads due to thermally induced or pressure plus thermally induced axial forces:

\[ (a) \quad L_{max} = F_t \]

\[ (b) \quad L_{max} = 2F_t \]

UW-20.5 Partial Strength Welds. Partial strength welds shown in Figure UW-20.1 shall conform to the following requirements:

(a) The size of a partial strength weld shall be determined in accordance with UW-20.6.

(b) The maximum allowable axial load in either direction on a tube-to-tubesheet joint with a partial strength weld shall be determined as follows:

\[ L_{max} = F_f + F_g \]

(1) For loads due to pressure-induced axial forces, \( L_{max} = F_f + F_g \)

(2) For loads due to thermally induced or pressure plus thermally induced axial forces:

\[ (a) \quad L_{max} = 2F_t \]

\[ (b) \quad L_{max} = 2F_t \]

UW-20.6 Partial Strength Welds. Partial strength welds shown in Figure UW-20.1 shall conform to the following requirements:

(a) The size of a partial strength weld shall be determined in accordance with UW-20.6.

(b) The maximum allowable axial load in either direction on a tube-to-tubesheet joint with a partial strength weld shall be determined as follows:

\[ L_{max} = F_f + F_g \]

(1) For loads due to pressure-induced axial forces, \( L_{max} = F_f + F_g \)

(2) For loads due to thermally induced or pressure plus thermally induced axial forces:
Figure UW-20.1
Tube-to-Tubesheet Joints Acceptable to Determine Joint Strength by Calculation

Clad material
(if present)
typical

Face-Fillet Weld
(a)

Groove Weld
(b)

Combination Face-Fillet & Groove
where: \( a_c = a_f + a_g \) and \( a_f = a_g \)
(c)

Combination Face-Fillet & Groove
where: \( a_c = a_f + a_g \) and \( a_f \neq a_g \)
(d)

Inset Fillet Weld
where: \( a_f \leq t \)
(e)

Combination Inset Fillet & Groove
where: \( a_c = a_g + a_f \) (with fillet weld \( a_f \))
\( a_c = a_g \) (if no fillet weld)
(f)

Chamfer or groove to achieve \( a_g \)
typical
(-a) $L_{\text{max}} = F_f + F_g$, but not greater than $F_t$, for welded only tube-to-tubesheet joints, where the thickness through the weld throat is less than the nominal tube thickness $t$;

(-b) $L_{\text{max}} = 2(F_f + F_g)$, but not greater than $2F_t$ for all other welded tube-to-tubesheet joints.

**UW-20.6 Weld Size Design Formulas.** The size of tube-to-tubesheet strength welds shown in Figure UW-20.1 shall conform to the following requirements:

(a) For fillet welds shown in sketch (a),

$$a_f = \frac{a_c}{2}$$

(1) For full strength welds, $a_f$ shall not be less than the greater of $a_r$ or $t$.

(2) For partial strength welds, $a_f$ shall not be less than $a_r$.

(b) For groove welds shown in sketch (b),

$$a_g = \frac{a_c}{2}$$

(1) For full strength welds, $a_g$ shall not be less than the greater of $a_r$ or $t$.

(2) For partial strength welds, $a_g$ shall not be less than $a_r$.

(c) For combined groove and fillet welds shown in sketch (c), where $a_f$ is equal to $a_g$,

$$a_r = \sqrt{(0.75d_0)^2 + 2.73t(d_0 - t)f_w d - 0.75d_0}$$

(1) For full strength welds, $a_c$ shall not be less than the greater of $a_r$ or $t$.

(2) For partial strength welds, $a_c$ shall not be less than $a_r$.

Calculate $a_f$ and $a_g$: $a_f = a_c/2$ and $a_g = a_c/2$. 

---

Figure UW-20.1

Some Acceptable Types of Tube-to-Tubesheet Strength Welds

(a) (b) (c) (d)
(e) For inset fillet welds shown in sketch (e),
\[ a_r = 0.75 d_o - \sqrt{(0.75 d_o)^2 - 2.73 t (d_o - t) ft f_t} \]

(1) Full strength welds are not possible with this configuration.
(2) For partial strength welds, \( a_r \) shall not be less than \( a_t \), but may be no greater than \( t \). If \( a_r < t \), joint load cannot be calculated in accordance with this section. See UW-20.2(b)(2).

(f) For combined groove and inset fillet welds shown in sketch (f), \( a_r \) shall be determined as follows: Choose \( a_t \). Calculate \( a_r \):
\[ a_r = \sqrt{(0.75 d_o)^2 + 1.76 t (d_o - t) ft f_t f_o} - 0.75 d_o \]

(1) For full strength welds, \( a_r \) shall not be less than the greater of \( a_t + a_o \) or \( t \).
(2) For partial strength welds, \( a_r \) shall not be less than \( a_t + a_o \).

(c) Tube-to-tubesheet welds in the cladding of either integral or weld metal overlay clad tubesheets may be considered strength welds (full or partial), provided the welds meet the design requirements of UW-20. In addition, when the strength welds are to be made in the clad material of integral clad tubesheets, the integral clad material to be used for tubesheets shall meet the requirements in (1) and (2) for any combination of clad and base materials. The shear strength test and ultrasonic examination specified in (1) and (2) are not required for weld metal overlay clad tubesheets.

(1) Integral clad material shall be shear strength tested in accordance with SA-263. One shear test shall be made on each integral clad plate or forging and the results shall be reported on the material test report.
(2) Integral clad material shall be ultrasonically examined for bond integrity in accordance with SA-578, including Supplementary Requirement S1, and shall meet the acceptance criteria given in SA-263 for Quality Level Class 1.
(b) When the design calculations for clad tubesheets are based on the total thickness including the cladding, the clad material shall meet any additional requirements specified in Part UKJ.
(c) When tubesheets are constructed using linings, or integral cladding that does not meet the requirements of (a)(1) and (a)(2), the strength of the tube-to-tubesheet joint shall not be dependent upon the connection between the tube and the lining or integral cladding, as applicable.
(d) When the tubes are strength welded (full or partial) to integral or weld metal overlay clad tubesheets, \( f_t \) shall be the allowable stress value of the integral cladding or the wrought material whose chemistry most closely approximates that of the weld metal overlay cladding. The thickness of the integral or weld metal overlay material shall be sufficient to prevent any of the strength weld from extending into the base material.

**UW-20.7 CLAD TUBESHEETS.**

**UW-20.7 CLAD TUBESHEETS.**

(a) Tube-to-tubesheet welds in the cladding of either integral or weld metal overlay clad tubesheets may be considered strength welds (full or partial), provided the welds meet the design requirements of UW-20. In addition, when the strength welds are to be made in the clad material of integral clad tubesheets, the integral clad material to be used for tubesheets shall meet the requirements in (1) and (2) for any combination of clad and base materials. The shear strength test and ultrasonic examination specified in (1) and (2) are not required for weld metal overlay clad tubesheets.

(1) Integral clad material shall be shear strength tested in accordance with SA-263. One shear test shall be made on each integral clad plate or forging and the results shall be reported on the material test report.
(2) Integral clad material shall be ultrasonically examined for bond integrity in accordance with SA-578, including Supplementary Requirement S1, and shall meet the acceptance criteria given in SA-263 for Quality Level Class 1.

(b) ASM B16.5 slip-on flanges shall be welded using an internal and an external weld. See Figure UW-21, sketches (1), (2), and (3).

**Nomenclature**

\( t_n \) = nominal thickness of the shell or nozzle
\( X_{min} \) = the lesser of 1.4\( t_n \) or the thickness of the hub

(d) When ASM B16.5 slip-on flanges are shown to comply with all the requirements provided in Mandatory Appendix 2 of this Division, the weld sizes in Mandatory Appendix 2 may be used as an alternative to the requirements in (b).

**FABRICATION**

**UW-26 GENERAL**

(a) The rules in the following paragraphs apply specifically to the fabrication of pressure vessels and vessel parts that are fabricated by welding and shall be used in conjunction with the general requirements for Fabrication in Subsection A, and with the specific requirements for Fabrication in Subsection C that pertain to the class of material used.
(b) Each Manufacturer or parts Manufacturer shall be responsible for the quality of the welding done by his organization and shall conduct tests not only of the welding procedure to determine its suitability to ensure that welds that meet the required tests, but also of the welders and welding operators to determine their ability to apply the procedure properly.
(c) No production welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with Section IX shall be used in production.
(d) The Manufacturer (Certificate Holder) may engage individuals by contract or agreement for their services as welders on the job location shown on the Certificate of Authorization and at field sites if allowed by the Certificate of Authorization for the construction of pressure vessels or vessel parts, provided all of the following conditions are met:
(1) All Code construction shall be the responsibility of the Manufacturer.
(2) All welding shall be performed in accordance with the Manufacturer’s welding procedure specifications in accordance with the requirements of Section IX.
(3) All welders shall be qualified by the Manufacturer in accordance with the requirements of Section IX.
(4) The Manufacturer’s Quality Control System shall include as a minimum:
(a) a requirement for complete and exclusive administrative and technical supervision of all welders by the Manufacturer;
NONMANDATORY APPENDIX A
BASIS FOR ESTABLISHING ALLOWABLE LOADS FOR TUBE-TO-TUBESHEET JOINTS

A-1 GENERAL

(a) This Appendix provides a basis for establishing allowable tube-to-tubesheet joint loads, except for the following:

(I) Tube-to-tubesheet joints having full strength welds as defined in accordance with UW-20.2(a) shall be designed in accordance with UW-20.4 and do not require shear load testing.

(2) Tube-to-tubesheet joints having partial strength welds as defined in accordance with UW-20.2(b) and designed in accordance with UW-18(d) or UW-20.5 do not require shear load testing.

(b) The rules of this Appendix are not intended to apply to U-tube construction.

(c) Tubes used in the construction of heat exchangers or similar apparatus may be considered to act as stays which support or contribute to the strength of the tubesheets in which they are engaged. Tube-to-tubesheet joints shall be capable of transferring the applied tube load to the tubesheets. The design of tube-to-tubesheet joints depends on the type of joint, degree of examination, and shear load tests, if performed. Some acceptable geometries and combinations of brazed, welded, and mechanical joints are described in Table A-2. Some acceptable types of welded joints are illustrated in Figure A-2.

(1) Geometries, including variations in tube pitch, fastening methods, and combinations of fastening methods, not described or shown, may be used provided qualification tests have been conducted and applied in compliance with the procedures set forth in A-3 and A-4.

(2) Materials for welded or brazed tube-to-tubesheet joints that do not meet the requirements of UW-5 or UB-5, but in all other respects meet the requirements of Section VIII, Division 1, may be used if qualification tests of the tube-to-tubesheet joint have been conducted and applied in compliance with the procedures set forth in A-3 and A-4.

(d) Some combinations of tube and tubesheet materials, when welded, result in welded joints having lower ductility than required in the material specifications. Appropriate tube-to-tubesheet joint geometry, welding method, and/or heat treatment shall be used with these materials to minimize this effect.

(e) In the selection of joint type, consideration shall be given to the mean metal temperature of the joint at operating temperatures (see 3-2) and differential thermal expansion of the joint integrity. The following provisions apply for establishing maximum operating temperature for tube-to-tubesheet joints:

(1) Tube-to-tubesheet joints where the maximum allowable axial load is determined in accordance with UW-20.2(b)(1) shall be designed in accordance with UW-20.5 and

(2) Tube-to-tubesheet joints made by brazing, such as joint types a, b, b-1, and e, where the maximum allowable load is determined in accordance with A-2.

(3) Tube-to-tubesheet joints where the maximum allowable axial load is determined in accordance with A-2 considering friction only, such as joint types i, j, and k, or is controlled by friction in welded and expanded joints, such as joint types f, g, and h, shall be limited to temperatures as determined by the following:

(-a) those complying with (a)(1) or (a)(2) with or without expansion

(-b) those welded and expanded joints, such as joint types f, g, and h, where the maximum allowable axial load is determined in accordance with A-2 and is controlled by the weld

(-c) those welded-only joints, such as joint types a, b, b-1, and e, where the maximum allowable load is determined in accordance with A-2.

(2) Tube-to-tubesheet joints where the maximum allowable axial load is controlled by the weld shall be limited to the maximum temperature for which there are allowable stresses for the tube or tubesheet material in Section II, Part D, Subpart 1, Table 1A or Table 1B.

(3) Tube-to-tubesheet joints in this category are any of the following:

(-a) those complying with (a)(1) or (a)(2) with or without expansion

(-b) those welded and expanded joints, such as joint types f, g, and h, where the maximum allowable axial load is determined in accordance with A-2 and is controlled by the weld

(-c) those welded-only joints, such as joint types a, b, b-1, and e, where the maximum allowable load is determined in accordance with A-2.

(3) Tube-to-tubesheet joints where the maximum allowable axial load is determined in accordance with A-2 considering friction only, such as joint types i, j, and k, or is controlled by friction in welded and expanded joints, such as joint types f, g, and h, shall be limited to temperatures as determined by the following:

(-a) The operating temperature of the tube-to-tubesheet joint shall be within the tube and tubesheet time-independent properties of Section II, Part D, Subpart 1, Table 1A or Table 1B.

(-b) The maximum operating temperature is based on the interface pressure that exists between the tube and tubesheet. The maximum operating temperature is limited such that the interface pressure due to expanding the tube at joint fabrication plus the interface pressure due to differential thermal expansion, \((P_o + P_T)\), does not exceed 58% of the smaller of the tube or tubesheet yield strength listed in Section II, Part D, Subpart 1, Table Y-1 at the operating temperature. If the tube or tubesheet yield strength is not listed in Table Y-1, the operating temperature limit shall be determined as described in (-d) below. The interface pressure due to
expanding the tube at fabrication or the interface pressure due to differential thermal expansion may be determined analytically or experimentally.

(-c) Due to differential thermal expansion, the tube may expand less than the tubesheet. For this condition, the interfacial pressure, \( P_T \), is a negative number.

(-d) When the maximum temperature is not determined by (-b) above, or the tube expands less than or equal to the tubesheet, joint acceptability shall be determined by shear load tests described in A-3. Two sets of specimens shall be tested. The first set shall be tested at the proposed operating temperature. The second set shall be tested at room temperature after heat soaking at the proposed operating temperature for 24 hr. The proposed operating temperature is acceptable if the provisions of A-5 are satisfied.

(f) The Manufacturer shall prepare written procedures for joints that are expanded (whether welded and expanded or expanded only) for joint strength (see Non-mandatory Appendix HH). The Manufacturer shall establish the variables that affect joint repeatability in these procedures. The procedures shall provide detailed descriptions or sketches of enhancements, such as grooves, serrations, threads, and coarse machining profiles. The Manufacturer shall make these written procedures available to the Authorized Inspector.

**A-2 MAXIMUM AXIAL LOADING S**

The maximum allowable axial load in either direction on tube-to-tubesheet joints shall be determined in accordance with the following:

For joint types a, b, b,c, c, d, e,

\[
L_{\text{max}} = A_t S_{f_T} f_r
\]

For joint types f, g, h,

\[
L_{\text{max}} = \text{MIN}(A_t S_{f_T} f_r, A_t S_y f_T)
\]

For joint types i, j, k,

\[
L_{\text{max}} = \text{MIN}(A_t S_{f_T} f_r f_r f_T, A_t S_y)
\]

where

- \( A_t \) = tube cross-sectional area
  \[= \pi(d_o - t)t \]
- \( d_i \) = nominal tube inside diameter
- \( d_o \) = nominal tube outside diameter
- \( E \) = modulus of elasticity for tubesheet material at \( T \)
- \( E_t \) = modulus of elasticity for tube material at \( T \)
- \( f_o \) = factor for the length of the expanded portion of the tube. An expanded joint is a joint between tube and tubesheet produced by applying expanding force inside the portion of the tube to be engaged in the tubesheet. Expanding force shall be set to values necessary to effect sufficient residual interface pressure between the tube and hole for joint strength.
- \( P_e \) = tube expanding pressure. The following equation may be used:

\[
P_e = S_y t - f_o \left( \frac{S_y}{S_y} \right) + 1.945 - 1.384 \left( \frac{d_i}{d_o} \right)
\]

\( S_y \) = yield stress of tube material at \( T \)(for \( f = 1.0 \))

Acceptable values of \( f_T \) may range from 0 to greater than 1. When the \( f_T \) value is negative, it shall be set to 0.

- \( f_r \) = tube joint efficiency, which is set equal to the value of \( f_r \) (test) or \( f_r \) (no test)
- \( f_r \) (test) = tube joint efficiency calculated from results of tests in accordance with A-4 or taken from Table A-2 for tube joints qualified by test, whichever is less, except as permitted in A-3(k)
- \( f_r \) (no test) = tube joint efficiency taken from Table A-2 for tube joints not qualified by test
- \( f_r \) = factor for the overall efficiency of welded and expanded joints. This is the maximum of the efficiency of the weld alone, \( f_r(b) \), and the net efficiency of the welded and expanded joint.

- \( f_T \) = factor to account for the increase or decrease of tube joint strength due to radial differential thermal expansion at the tube-to-tubesheet joint

\[
f_T = \frac{P_o + P_T}{P_o}
\]

Acceptable values of \( f_T \) may range from 0 to greater than 1. When the \( f_T \) value is negative, it shall be set to 0.

- \( f_y \) = factor for differences in the mechanical properties of tubesheet and tube materials

\[
f_y = \text{MIN} \left( \frac{S_y}{S_{y,t}} \right)
\]

When \( f_y \) is less than 0.60, qualification tests in accordance with A-3 and A-4 are required.

- \( k \) = 1.0 for loads due to pressure-induced axial forces

\[= 1.0 \text{ for loads due to thermally induced or pressure plus thermally induced axial forces on welded-only joints where the thickness through the weld throat is less than the nominal tube wall thickness} \]

\[= 2.0 \text{ for loads due to thermally induced or pressure plus thermally induced axial forces on all other tube-to-tubesheet joints} \]

\( L_{\text{max}} = \) maximum allowable axial load in either direction on tube-to-tubesheet joint

\( P_e = \) tube expanding pressure. The following equation may be used:
value of \( f_r \) (test) so determined is less than the value for \( f_r \) (test) given in Table A-2, retesting shall be performed in accordance with (k) below, or a new three specimen test shall be performed using a new joint configuration or fabrication procedure. All previous test data shall be rejected. To use a value of \( f_r \) (test) greater than the value given in Table A-2, a nine specimen test shall be performed in accordance with (k) below.

(k) For joint types not listed in Table A-2, to increase the value of \( f_r \) (test) for joint types listed in Table A-2, or to retest joint types listed in Table A-2, the tests to determine \( f_r \) (test) shall conform to the following:

1. A minimum of nine specimens from a single tube shall be tested. Additional tests of specimens from the same tube are permitted, provided all test data are used in the determination of \( f_r \) (test). If a change in the joint design or its manufacturing procedure is necessary to meet the desired characteristics, complete testing of the modified joint shall be performed.

2. In determining the value of \( f_r \) (test), the mean value of \( L \) (test) shall be determined and the standard deviation, sigma, about the mean shall be calculated. The value of \( f_r \) (test) shall be calculated using the value of \( L \) (test) corresponding to \(-2\sigma\), using the applicable equation in A-4. In no case shall \( f_r \) (test) exceed 1.0.
NOTES:
(1) Sketches (a) through (d) show some acceptable weld geometries where thickness through the weld throat may be sized $\geq t$.
(2) Sketches (e) through (i) show some acceptable weld geometries where thickness through the weld throat is less than $t$.
(3) For these geometries where weld length cannot be established by dimensions prior to weld, dimension $a_c$ shall be verified during WPS qualification per QW-193 and design strength shall be calculated in accordance with A-2.
NOTES:
(1) Sketches (a) through (d) show some acceptable weld geometries where $a$ is not less than $1.4t$.
(2) Sketches (e) through (i) show some acceptable weld geometries where $a$ is less than $1.4t$. 