ABSTRACT

This paper presents the results of a small sample of ASME B16.9 welding tee burst tests. The intent of this study was to make a comparison between what is commonly accepted in industry as a B16.9 welding tee to the burst test requirements of B16.9 paragraph 9. The tests conducted show that the current fabrication techniques and some accepted criteria for B16.9 certification can produce thin sections in the tee which do not meet the required burst test pressures.

The test descriptions and results are presented as well as recommendations for future study and potential modifications to the ASME B16.9 standard to address the concerns.

INTRODUCTION

This paper summarizes the results of burst tests conducted by Paulin Research Group (PRG) for the purpose of determining whether there is a safely concern with respect to the fabrication techniques and acceptability criteria used in the industry for some ASME B16.9[1] welding tees.

Wall thickness measurements from a small, random, collection of B16.9 stainless steel welding tees and subsequent inquiries indicated that some manufacturers in certain circumstances are providing welding tees with thicknesses throughout the body and crotch of the tee that are equal to or less than the wall thickness of the matching nominal pipe. One of ten sampled tees was found to have wall thicknesses at every measured point on the tee body equal to or less than the nominal wall thickness of the intended matching pipe. It was thought at the time that these tees would not satisfy either the B16.9 burst test requirements as outlined in B16.9 paragraph 9, or the mathematical analyses requirements of B16.9 paragraph 2.2.

Interviews conducted with various suppliers suggested that this practice is not common, but is not unusual either, and is expected more often when commodity orders are produced in ductile alloy materials and it is to the manufacturers benefit to use as little material as possible for each tee. The consensus among manufacturers was that the requirements of B16.9 paragraph 2.2 were not sufficiently clear for welding tees, and that almost any tee wall thickness could be used by a manufacturer providing it is greater than the minimum allowed for the matching pipe specification, (generally 87.5% of nominal).

In practice, it appears that an acceptable wall thickness is any thickness accepted by the purchaser, which in at least some situations is almost any thickness. In light of this situation, burst tests were conducted to evaluate the strength of tees fabricated with uniformly thin sections with respect to the nominal
matching pipe to determine if any safety-related issues exist that should be immediately addressed.

Table 1: Burst Tests Conducted

<table>
<thead>
<tr>
<th>#</th>
<th>Tee Description</th>
<th>Attached Pipe</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4&quot; Sch. 80 &quot;thin&quot; Welding Tee Large Crotch</td>
<td>4&quot; Sch. 80 A106B Pipe; Length=20&quot;</td>
<td>Intended to replicate the B31.1-H burst test recommendation.</td>
</tr>
<tr>
<td>2</td>
<td>4&quot; Sch. 80 &quot;thin&quot; Welding Tee Large Crotch</td>
<td>4&quot; Sch. 160 API 5L X65 Pipe; Length=4.5&quot;</td>
<td>Intended to replicate a &quot;hedged&quot; B16.9 burst test.</td>
</tr>
<tr>
<td>3</td>
<td>4&quot; Sch. 80 &quot;thin&quot; Welding Tee Large Crotch</td>
<td>4&quot; Sch. 80 A106B Pipe; Length = 4.5&quot;</td>
<td>Intended to replicate a B16.9 welding tee test on a large crotch radii tee.</td>
</tr>
<tr>
<td>4</td>
<td>4&quot; Sch. 80 &quot;thin&quot; Welding Tee Small Crotch</td>
<td>4&quot; Sch. 80 A106B Pipe; Length = 4.5&quot;</td>
<td>Intended to replicate a B16.9 welding tee test on a small crotch radii tee.</td>
</tr>
<tr>
<td>5</td>
<td>4&quot; Sch. 40 B16.9 Tee Off-the-Shelf</td>
<td>4&quot; Sch. 80 A 106B Pipe; Length = 4.5&quot;</td>
<td>Off the shelf B16.9 carbon steel welding tee w/ sch. 80 pipe.</td>
</tr>
<tr>
<td>7</td>
<td>4&quot; Sch. 40 B16.9 Tee Off-the-Shelf</td>
<td>4&quot; Sch. 40 A 106B Pipe; Length = 4.5&quot;</td>
<td>Off the shelf B16.9 carbon steel welding tee w/ sch. 40 pipe.</td>
</tr>
</tbody>
</table>

NOMENCLATURE

D = outside diameter of the tee
Db = outside diameter of branch pipe
Dh = outside diameter of run pipe
Dx = Db - 2 Tx
dcrotch = rx' - rx
K= Reinforcement Factor
P = computed minimum proof test pressure for fitting per B 16.9
Pb = estimated burst pressure of tee when the matching pipe has a thickness Tp and a tensile strength of Sp
Pb' = tested burst pressure of tee when matching pipe has a thickness of Tp' and a tensile strength of Sp'.
rx = radius of crotch; where not given rx = 0.05Db.
Sp = actual tensile strength of the branch pipe determined on a specimen representative of the pipe.
Sr = actual tensile strength of the test fitting determined on a specimen representative of the test fitting.
Tbody = thickness of the sidewall of the tee
Tp= Thickness of attached pipe
tb = pressure design thickness of branch pipe
Th = nominal pipe wall thickness for the pipe that the fitting marking identifies
th = pressure design thickness of run pipe
Tx = thickness of crotch

TEST DESCRIPTION

Six burst tests were conducted as detailed in Table 1. Welding tees #1 thru #4 were manufactured using an axial compression, cold extrusion process from 4" Schedule 40 pipe. The tees were then heat treated to satisfy A 234 WPB material requirements. "Lengths" give the axial dimension of the straight pipe attached to each end of the fitting. When the length is 20", there will be 3 sections of 20" pipe welded to each end of the welding tee.

The manufacturer of tees 1 through 4 attempted to make the thinnest tees possible without damaging the material. This particular manufacturer has been in the fitting business for more than 30 years and has designed and built most of the extrusion machines used at their own facility. They sell B16.9 tees and other products in a large variety of size ranges. Two dies are available, a large radius die and a small radius die. Tees 1 through 3 were extruded using the large radius die.

Large Crotch welding tees have an approximately 1.25" crotch radius measured in the longitudinal plane of the tee. Small Crotch welding tees have an approximately 5/8" crotch radius measured in the longitudinal plane of the tee. API 5L X65 and X70 pipe are dual certified.

Tests #5 and #7 were fabricated from off the shelf B16.9 welding tees purchased from a material supplier in Houston, Texas. Purchase requirements were 4" Schedule 40 B16.9 tee, compatible with A106 B pipe. The tees were fabricated in Malaysia.

Test #6 was not conducted and replaced with test #7 as Tests #5 and #6 were originally intended to be straight pipe burst pressure failures for comparison to the tee failures. After tests #1 through #4 were conducted, it was decided to take the material from Test #5 and use it to fabricated a 4" sch. 40 off-the-shelf B16.9 burst test with sch. 80 attached pipe, and to add a test #7 that is a 4" sch. 40 off-the-shelf B16.9 burst test with sch. 40 attached pipe.

Each of the tees in specimen #1 through #7 have the thickness and material properties that have been observed in commercial 4" std wall B16.9 welding tees. (Tests #5 and #7 were purchased as 4" STD WALL B16.9 welding tee.) Pressure requirements for B16.9 Paragraph 9.3 require that a successful burst test pressure must be
at least equal to the computed minimum proof test pressure defined as:

\[ P = 2 \frac{S_t \times \text{Th}}{D} \]

B 16.9 Para 9.3

The tees used in this test were fabricated using a procedure identical to the procedure used to fabricate B16.9 tees. The manufacturer was asked to make the tees as “thin” as possible without jeopardizing the material strength due to excessive thinning during forming. Generally, when welding tees are extruded the tee fabrication is started with a pipe thickness larger than the matching nominal required for the tee. For the tees used in tests #1 through #4, schedule 40 pipe was used as the starting point for the tee fabrication.

As can be seen in Figure 1, the majority of the thicknesses resulting from the forming process are in excess of the 4” schedule 40 pipe nominal of 0.237 in. The crotch wall thickness average for the long crotch radii tees (tests 1 through 3), is 0.321”, 1.35 times the matching schedule 40 nominal wall thickness. The observed increase in thickness is due to axial compression that is a part of the tee extrusion process.

The 4” schedule 80 nominal pipe wall thickness is 0.337 inch. The average sidewall thickness for the large crotch radii tees is 0.281 inch. 87.5% of the nominal wall for 4” schedule 80 pipe is 0.875 \times 0.337 = 0.294 inch. The tees are clearly under what should be considered reasonable for 4” schedule 80 pipe.

Figure 1. Measurements of welding tee specimens

RESULTS

The proof test pressure required for 4” schedule 80 matching pipe would be:

\[ P = 2 \frac{S_t \times \text{Th}}{D} = 2(76,500)(0.337)/4.5 = 11,458 \text{ psi} \]

The proof test pressure required for 4” schedule 40 matching pipe would be:

\[ P = 2 \frac{S_t \times \text{Th}}{D} = 2(76,500)(0.237)/4.5 = 8058 \text{ psi} \]

The proof test pressure required for the 4” schedule 40 B16.9 “off-the-shelf” welding tee is:

\[ P = 2 \frac{S_t \times \text{Th}}{D} = 2(67,585)(0.237)/4.5 = 7118 \text{ psi} \]

Test failures are shown in the photograph Figure 2.

Figure 2. Test specimens after failure
The burst tests consistently failed at the crotch location as expected. Table 3 shows the actual recorded burst test pressure, as well as the required burst test pressure for the Sch 40 and Sch 80 tees per the requirements of B16.9.

Table 3: Burst Pressures from Test

<table>
<thead>
<tr>
<th>#</th>
<th>Tee Description</th>
<th>Actual Burst Pressure (psi) (1)</th>
<th>Sch 40 Tee Required Burst Pressure P (psi)</th>
<th>Sch 80 Tee Required Burst Pressure P (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4&quot; Sch. 80 &quot;thin&quot; Welding Tee Large Crotch UTS=76,500 psi</td>
<td>7685</td>
<td>8058</td>
<td>11,458</td>
</tr>
<tr>
<td>2</td>
<td>4&quot; Sch. 80 &quot;thin&quot; Welding Tee Large Crotch UTS=76,500 psi</td>
<td>8070</td>
<td>8058</td>
<td>11,458</td>
</tr>
<tr>
<td>3</td>
<td>4&quot; Sch. 80 &quot;thin&quot; Welding Tee Large Crotch UTS=76,500 psi</td>
<td>7610</td>
<td>8058</td>
<td>11,458</td>
</tr>
<tr>
<td>4</td>
<td>4&quot; Sch. 80 &quot;thin&quot; Welding Tee Small Crotch UTS=76,500 psi</td>
<td>8327</td>
<td>8058</td>
<td>11,458</td>
</tr>
<tr>
<td>5</td>
<td>4&quot; Sch. 40 Off-the-Shelf B16.9 Welding Tee UTS=67,585 psi</td>
<td>6696</td>
<td>7118</td>
<td>n/a</td>
</tr>
<tr>
<td>7</td>
<td>4&quot; Sch. 40 Off-the-Shelf B16.9 Welding Tee UTS=67,585 psi</td>
<td>6229</td>
<td>7118</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Notes:
(1) Burst pressure is taken as the maximum pressure reading recorded from the digital gage during the test.

The table above shows that none of the tested tees have met their intended minimum required burst pressure. Burst tests 1 and 3 have even failed the burst test requirements of B16.9 for a Sch 40 tee even though they were manufactured from a Sch 80 pipe.

A more detailed table of the controlling properties of the welding tees and the burst test results is shown in Table 4.

Table 4: Burst Strength Controlling Properties

<table>
<thead>
<tr>
<th>#</th>
<th>Tee-Pipe Configuration</th>
<th>Crotch Radius rx (in)</th>
<th>Avg Crotch Thk Tx (in) (2)</th>
<th>Pipe Thk Tb (in)</th>
<th>UTS Tee S_T (psi)</th>
<th>UTS Pipe S_p (psi)</th>
<th>Actual Burst Pressure (psi) (1)</th>
<th>Tee Req'd Burst Pressure P (psi)</th>
<th>Pipe Req'd Burst Pressure P (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sch. 80 Thin tee large crotch 5D pipe length</td>
<td>1.25</td>
<td>0.3205</td>
<td>0.337</td>
<td>76,500</td>
<td>75,000</td>
<td>7685</td>
<td>8058</td>
<td>7900</td>
</tr>
<tr>
<td>2</td>
<td>Sch. 80 thin tee large crotch X65 sch. 160 pipe 1D length</td>
<td>1.25</td>
<td>0.317</td>
<td>0.531</td>
<td>76,500</td>
<td>87,160</td>
<td>8070</td>
<td>8058</td>
<td>9181</td>
</tr>
<tr>
<td>3</td>
<td>Sch. 80 thin tee large crotch sch. 80 attached pipe 1D length</td>
<td>1.25</td>
<td>0.3265</td>
<td>0.337</td>
<td>76,500</td>
<td>75,000</td>
<td>7610</td>
<td>8058</td>
<td>7900</td>
</tr>
<tr>
<td>4</td>
<td>Sch. 80 thin tee small crotch sch. 80 attached pipe 2D length</td>
<td>0.625</td>
<td>0.3605</td>
<td>0.337</td>
<td>76,500</td>
<td>75,000</td>
<td>8327</td>
<td>8058</td>
<td>7900</td>
</tr>
<tr>
<td>5</td>
<td>Sch. 40 OTS tee 1D sch. 80 pipe length attached</td>
<td>1</td>
<td>0.296</td>
<td>0.337</td>
<td>67,585</td>
<td>75,000</td>
<td>6696</td>
<td>7119</td>
<td>7900</td>
</tr>
<tr>
<td>7</td>
<td>Sch. 40 OTS tee 1D sch. 40 pipe length attached</td>
<td>1</td>
<td>0.2945</td>
<td>0.237</td>
<td>67,585</td>
<td>76,500</td>
<td>6229</td>
<td>7119</td>
<td>8058</td>
</tr>
</tbody>
</table>

Notes:
(1) – Maximum pressure during test (burst/proof test pressure).
(2) – Average of all crotch thickness measurements taken of tee at center of crotch. Measurements taken from inside of tee.

The length of the attached pipe has less than a 1% effect on the magnitude of the burst pressure when the...
The tensile strength of the tee is matched to the tensile strength of the pipe. (Based on a comparison of tests #1 and #3.)

When the tensile strength of the tee is less than the tensile strength of the pipe, the thickness and tensile strength of the attached pipe can increase the burst strength of the tee by 7.5% based on a comparison of tests #2 and #3; and tests #5 and #7.

For contoured tee test configurations similar to those included in the present burst test series, the effect of the attached pipe thickness and strength on the burst test pressure can be estimated by the following relationship when the tees are identical:

$$P_b = P_b' \left( \frac{T_p}{T_p'} \right)^{0.1} \left( \frac{S_p}{S_p'} \right)^{0.1} \text{ Eq. E1}$$

The Eq. E1 relationship is defined by the relationship between tees 1, 2, and 3; and between 5 and 7. 1,2,3 are considered identical tees with different attached pipe. 5 and 7 are also identical tees with different attached pipe. The tees 1,2,3 are different from the tees 5,7 due to: 1)method of fabrication, 2)tensile strength, 3)crotch radii and thicknesses (small).

The burst pressure of a contoured welding tee is a function of the thickness of the crotch and the crotch radius. A smaller crotch radius generally results in more material closer to the tee centerlines and a greater burst pressure.

The relationship between tees that behave similar to those included in the present burst test series can be expressed using the following relationship:

$$P_b = P_b' \left( \frac{T_p}{T_p'} \right)^{0.3} \left[ 1 + \frac{D_{crotch}}{2D} \right]^{0.3} \left( \frac{S_p}{S_p'} \right)^{0.3} \text{ Eq. E2}$$

It seems possible that the attached pipe ratios can be combined with the tee property ratios into a single relationship expression. This relationship is based on a small set of data and should be confirmed by additional testing.

$$P_b = P_b' \left( \frac{T_p}{T_p'} \right)^{0.3} \left( \frac{S_p}{S_p'} \right)^{0.3} \left( \frac{D_{crotch}}{2D} \right)^{0.3} \text{ Eq. E3}$$

Equations E1 and E2 can be validated for the six tee tests reported here. The Excel table below provides this comparison. There are two sets of identical tees in Table 5. Tees #1,2,3 are close in geometry, and Tees #5,7 are close in geometry. Equation E1 can be used to relate the different end pipe conditions used in the tests. The Pb calculated from E1 in Table 5 shows the calculated burst pressure for tests 2 and 3 based on test #1. The burst pressure for test 5 is calculated using Eq. E1 and the burst pressure from Test #7.

A comparison of the results is shown in Table 6.

### Table 5. Tee Specimen Comparison using Equation E1 and E2

<table>
<thead>
<tr>
<th>Specimen #</th>
<th>Crotch Radius (rx)</th>
<th>Crotch Thickness (Tx)</th>
<th>Pipe Thickness (Tp)</th>
<th>UTS of Tee (Psi)</th>
<th>UTS of Pipe (Psi)</th>
<th>Actual Burst Pressure (psi)</th>
<th>Pb calculated from Eq E1 (psi)</th>
<th>Pb calculated from Eq E2 (psi)</th>
<th>Pb calculated from Equation E2/Actual Burst Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.25</td>
<td>0.3205</td>
<td>0.337</td>
<td>76500</td>
<td>75000</td>
<td>7685</td>
<td>7867</td>
<td>1.024</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.25</td>
<td>0.317</td>
<td>0.337</td>
<td>76500</td>
<td>87160</td>
<td>8070</td>
<td>8164</td>
<td>0.972</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.25</td>
<td>0.3265</td>
<td>0.337</td>
<td>76500</td>
<td>75000</td>
<td>7610</td>
<td>7911</td>
<td>1.040</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.625</td>
<td>0.3605</td>
<td>0.337</td>
<td>76500</td>
<td>8327</td>
<td>8327</td>
<td>6846</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0.296</td>
<td>0.337</td>
<td>67585</td>
<td>6696</td>
<td>6439</td>
<td>6836</td>
<td>1.022</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>0.2945</td>
<td>0.237</td>
<td>67585</td>
<td>6229</td>
<td>6836</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 Equation E1 Specimen Comparison
The equation E3 can be used to relate each test to every other test and so an 6x6 matrix of comparisons can be generated to get an evaluation of the quality of the correlation. The burst pressures calculated in the 6x6 matrix will be:

**Table 7. Equation E3 Comparison 6x6 Matrix**

<table>
<thead>
<tr>
<th>Specimen #</th>
<th>1'</th>
<th>2'</th>
<th>3'</th>
<th>4'</th>
<th>5'</th>
<th>7'</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>find 1 from 1'</td>
<td>find 1 from 2'</td>
<td>find 1 from 3'</td>
<td>find 1 from 4'</td>
<td>find 1 from 5'</td>
<td>find 1 from 7'</td>
</tr>
<tr>
<td>2</td>
<td>find 2 from 1'</td>
<td>find 2 from 2'</td>
<td>find 2 from 3'</td>
<td>find 2 from 4'</td>
<td>find 2 from 5'</td>
<td>find 2 from 7'</td>
</tr>
<tr>
<td>3</td>
<td>find 3 from 1'</td>
<td>find 3 from 2'</td>
<td>find 3 from 3'</td>
<td>find 3 from 4'</td>
<td>find 3 from 5'</td>
<td>find 3 from 7'</td>
</tr>
<tr>
<td>4</td>
<td>find 4 from 1'</td>
<td>find 4 from 2'</td>
<td>find 4 from 3'</td>
<td>find 4 from 4'</td>
<td>find 4 from 5'</td>
<td>find 4 from 7'</td>
</tr>
<tr>
<td>5</td>
<td>find 5 from 1'</td>
<td>find 5 from 2'</td>
<td>find 5 from 3'</td>
<td>find 5 from 4'</td>
<td>find 5 from 5'</td>
<td>find 5 from 7'</td>
</tr>
<tr>
<td>7</td>
<td>find 7 from 1'</td>
<td>find 7 from 2'</td>
<td>find 7 from 3'</td>
<td>find 7 from 4'</td>
<td>find 7 from 5'</td>
<td>find 7 from 7'</td>
</tr>
</tbody>
</table>

The prime (') indicator is used to identify the variables in Table 7. For example, 2' means all properties associated with specimen #2 are used for the primed terms in Eq. E3. Each burst test pressure will be calculated from every other burst test pressure and the ratio against the actual burst test pressure found. For equation E3 to perform without error, each ratio should be exactly 1.

The calculated burst pressures using Eq. E3 are given in Table 8 below:

**Table 8. Burst Pressures (psi) calculated from E3**

<table>
<thead>
<tr>
<th>Specimen #</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7685</td>
<td>7621.4</td>
<td>7567.8</td>
<td>7666.6</td>
<td>7696.9</td>
<td>7413.3</td>
</tr>
<tr>
<td>2</td>
<td>8137.4</td>
<td>8070</td>
<td>8013.3</td>
<td>8329.7</td>
<td>8150.0</td>
<td>7849.7</td>
</tr>
<tr>
<td>3</td>
<td>7727.9</td>
<td>7683.9</td>
<td>7610</td>
<td>7910.5</td>
<td>7739.9</td>
<td>7454.6</td>
</tr>
<tr>
<td>4</td>
<td>8132.0</td>
<td>8055.7</td>
<td>7999.1</td>
<td>8327</td>
<td>8140.1</td>
<td>7840.1</td>
</tr>
<tr>
<td>5</td>
<td>6684.1</td>
<td>6628.7</td>
<td>6582.1</td>
<td>6846.2</td>
<td>6696</td>
<td>6449.2</td>
</tr>
<tr>
<td>7</td>
<td>6455.8</td>
<td>6402.4</td>
<td>6357.4</td>
<td>6612.4</td>
<td>6467.3</td>
<td>6229</td>
</tr>
</tbody>
</table>

The calculated to actual burst test pressure ratios are given in Table 9:

<table>
<thead>
<tr>
<th>Specimen #</th>
<th>1'</th>
<th>2'</th>
<th>3'</th>
<th>4'</th>
<th>5'</th>
<th>7'</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.992</td>
<td>0.985</td>
<td>1.024</td>
<td>1.002</td>
<td>0.965</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.008</td>
<td>1.000</td>
<td>0.993</td>
<td>1.032</td>
<td>1.010</td>
<td>0.973</td>
</tr>
<tr>
<td>3</td>
<td>1.015</td>
<td>1.007</td>
<td>1.000</td>
<td>1.039</td>
<td>1.017</td>
<td>0.980</td>
</tr>
<tr>
<td>4</td>
<td>0.975</td>
<td>0.967</td>
<td>0.961</td>
<td>1.000</td>
<td>0.978</td>
<td>0.942</td>
</tr>
<tr>
<td>5</td>
<td>0.998</td>
<td>0.990</td>
<td>0.983</td>
<td>1.022</td>
<td>1.000</td>
<td>0.963</td>
</tr>
<tr>
<td>7</td>
<td>1.036</td>
<td>1.028</td>
<td>1.021</td>
<td>1.062</td>
<td>1.038</td>
<td>1.000</td>
</tr>
</tbody>
</table>

This result suggests that the burst pressure from each test can be predicted from any other test within 6%, and most tests can be predicted within about 2%. The relationship developed in Eq. E3 above could be used to help set guidelines used when conducting burst tests.

**DISCUSSION**

There are two types of hydroforming machines that use fluid as an internal pressure medium - one that utilizes proprietary external compressive loading of the part during forming and one that does not. The machine that does not use external compressive loading relies solely on internal pressure to plastically deform the blank, and form the branch portion of the tee. In this method there can be significant upsetting (thickening) of the blank during the forming process.

Pipe is used in both cases as the starting “blank”. Each machine requires a longer starting pipe stub, since the forming process causes each stub to “draw up”. Shorter blanks are generally needed when external loading is also used in the forming process.

All of the tee specimens #1 through #4 were cold formed in one push using the machine with the external loading since there is more control of this process. Typically the forming process is tonnage limited with respect to cold forming. If the tonnage estimated is available and the press will accept the pipe size then the first attempt will be to cold form the part. Tees that are very large with wall thicknesses greater than schedule 80 will usually be hot formed. The hydroforming process is very good for those schedules between 5S and 40S where you can’t economically hot form them.

The majority of hydro-formed tees made in the US are specialty tees (large and thick), stainless tees. Carbon steel tees are commodity products and are typically found from foreign providers. Domestic components (2012) are
often three times more expensive than foreign components. As can be seen from this test procedure, commodity manufacturers apparently optimize the design wall thickness. This minimizes material required, the energy needed to form the tee, and reduces the number of rejects. (Thinner parts are easier to form without damage than thicker parts.) As can also be seen, some of these fittings clearly do not satisfy B16.9 proof test requirements.

A common area replacement diagram used for many years by fitting designers is shown in the sketch below taken from the Kellogg “Design of Piping Systems” manual [5]. The Kellogg approach requires that the designer evaluate the non-regular area that is identified as “A” in the figure.

Figure 3. Pg. 71 Kellogg “Design of Piping Systems”

\[
S_A = \frac{P(E + \frac{1}{2} A)}{A}
\]

\[S_A \geq P(E/A + 0.5)\]  
Eq. E4

ASME B31.3[3] also provides a guideline for the pressure design of contoured branch connections in Fig. 304.3.4, provided herein as Figure 4. The B16.9 extruded components tested here do not show the reinforcing area inside the ID of the branch pipe.

Figure 4. B31.3 Extruded Outlet Header Nomenclature

Using B31.3 Paragraph, 304.3.4, crude relationships between contoured tees can be developed, assuming that the design pressure is appropriately established for the pipe. Per Eq. (9a):

\[A_2 + A_3 + A_4 \geq A_1.\]  
B31.3 Eq. 9a

\[A_4 = (2)(3.1415/2)(rx)(Tx - tb)\]  
Eq. E5

\[A_3 = 0\]  
Eq. E6

\[A_2 = (2)(Dx/2-rx)(Tx - th)\]  
Eq. E7

\[A_1 = K (th)(Dx)\]  
Eq. E8

Rationale:

A3=0: For most welding tees evaluated, the extruded portion of the tee above the crotch is very thin, equal to or less than the nominal wall thickness of the branch. Assuming that A3=0 for these tees seems very reasonable. A manufacturer would have to take a different fabrication approach than an extrusion one to prepare a geometry with a thicker zone above the crotch in the branch.

However, when Db/Dh is significantly less than 1, it is likely that the tee thickness will be greater than the branch thickness since the nominal branch thickness is less than the run thickness. In these cases, it is not believed that the minimum thickness at the crotch would be problematic.

A4=(2)(pi/2)(rx)(Tx-tb): This is double the excess material in the crotch, assuming the crotch thickness is uniform, which is a reasonable assumption based on the tees included in this test program. A finer analysis could review the cross sections of different tees and could come up with a standard “multiplier” on this estimate.

A2=(Dx−Dx/2−rx)(Tx-th)=(2)(Dx/2-rx)(Tx-th): This is the material in the tee body adjacent to the crotch within the limits of reinforcement.

We must also multiply the area required by K per B31.3 Eq. 9, where K is:

1) For Db/Dh > 0.6, K = 1.0  
Eq. E9
2) For \( 0.6 \geq \frac{Db}{Dh} > 0.15 \), \( K = 0.6 + \frac{2}{3}(\frac{Db}{Dh}) \),  

\[ \text{Eq. E10} \]

3) For \( \frac{Db}{Dh} < 0.15 \), \( K = 0.7 \).  

\[ \text{Eq. E11} \]

This would make the welding tee minimum thickness dimension design equation:

\( A_2 + A_3 + A_4 \geq A_1 \).  

\( \text{B31.3 Eq. 9a} \)

\((2)(Dx/2-rx)(Tx – th) + 0+ (2)(3.14/2)(rx)(Tx – tb) \geq K(th)(Dx)\)

\[ \text{Eq. E12} \]

Using the approximate area replacement calculations, each of the test tees would be undersized. The ratio of the required thickness to the available thickness for each tee, (in accordance with the Eq. E12 approximation), is shown in Table 10.

<table>
<thead>
<tr>
<th>Spec. #</th>
<th>( rx ) (in)</th>
<th>A1 (in²)</th>
<th>Min. Req’d A2+A3+ A4 (in²)</th>
<th>Min. Tx Req’d per Eq E12</th>
<th>Tx Actual (in)</th>
<th>TxReq’d/ Dx Actual (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.25</td>
<td>0.954</td>
<td>0.954</td>
<td>0.412</td>
<td>0.321</td>
<td>1.285</td>
</tr>
<tr>
<td>2</td>
<td>1.25</td>
<td>0.954</td>
<td>0.954</td>
<td>0.412</td>
<td>0.317</td>
<td>1.300</td>
</tr>
<tr>
<td>3</td>
<td>1.25</td>
<td>0.954</td>
<td>0.954</td>
<td>0.412</td>
<td>0.327</td>
<td>1.262</td>
</tr>
<tr>
<td>4</td>
<td>0.625</td>
<td>0.954</td>
<td>0.957</td>
<td>0.439</td>
<td>0.361</td>
<td>1.218</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0.954</td>
<td>0.956</td>
<td>0.422</td>
<td>0.296</td>
<td>1.426</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>0.954</td>
<td>0.956</td>
<td>0.422</td>
<td>0.295</td>
<td>1.433</td>
</tr>
</tbody>
</table>

It appears that in changing the B31.3 Code in 1984 to permit reduced crotch tees, an unsafe allowance may have been permitted, instead of a necessary restriction maintained. (B31.1 never had the minimum crotch thickness requirement in its Appendix D.)

In some schools of thought, the minimum requirement of a burst test can be considered to be established when the failure of the tee in the worst condition, would always have resulted in the failure of the attached pipe. Provisions that require derating of single burst tests that satisfy proof test requirements will cause manufacturers to move toward the less precise method of evaluation, i.e. the numerical calculation.

**CONCLUSION**

The results of the burst tests conducted show that some off-the-shelf welding tees stamped per B16.9 do not satisfy B16.9 proof test requirements. Also, the same tees that do not satisfy B16.9 proof test requirements do not satisfy simplified area replacement calculations. Figure 5 summarizes the results of the burst tests performed.

**RECOMMENDATIONS**

From the burst tests performed, there are several potential modifications to B16.9 that could tighten the status quo to achieve the desired design margins as intended. Criteria for welding tee evaluations could include

a) Burst Tests per B16.9
b) Design equations per EN 10253-2 [6]
c) Twice Elastic Slope Methodology
d) ASME Section VIII-2 [2] Part 5.3.3.2 Approach to prevent void formation

Concern over the B16.9 burst test procedure seems unwarranted given its historic successes and the difficulty when attempting to produce a better test. Additional criteria can also be part of the test procedure and some minimum design equations would likely aid in producing a more consistent B16.9 product. (The test should be required for some materials, geometries and processes, but a mathematical analysis should be performed for each tee geometry and heat.)
If pipe failure is permitted to satisfy a proof test for an attached component (B31.H), the tensile strength of the attached pipe should be appropriately established so that a misleading comparison is avoided.

B16.9 proof tests should probably be considered invalid when the pipe fails instead of the tee in a proof test and the tensile strength of the pipe is materially less than the tensile strength of the tee used in the test. If the pipe fails first and the pipe tensile strength is less than the tee tensile strength, there is no guarantee that the tee is at least as strong as the matching pipe of a similar material. For a proof test, a manufacturer might inadvertently pair a pipe with 12.5% under tolerances and a minimum tensile strength with a test component having high or maximum tensile strengths. In this case, when components of more typical tensile strengths are used the tee would fail before the matching pipe.

It would be desirable, but not practical to request that the pipe used in proof tests should be within 5% of the specified matching nominal wall thickness for the component and that the tensile strength of the matching pipe should be within 5% of the tensile strength of the welding tee. (This would eliminate concern for mismatched strengths of attached pipe.) The pipe tensile strength can be greater than the tee tensile strength, but efforts should be expended to keep them as close as possible. It is believed that these restrictions would minimize the artificial strengthening of the fitting due to the attached pipe but would still permit meaningful tests of the fitting to be conducted. (This is because 1D or 1/2D attached pipe is stronger than longer runs of pipe and so using pipe that is close to the strength and thickness of the tee will still result in failure of the tee unless the tee is significantly stronger than the shortened attached pipe. Equations E1 through E3 might be helpful estimating these relationships so that effective proof tests can be designed.

The proof test equation as expressed in B16.9 para. 9.3 seems reasonable, especially when the failure occurs in the fitting and the above guidelines are followed. It should be noted however, that even this approach may not guarantee that failures would at all times occur in the attached pipe, since tensile strengths can vary widely between the tee and the matching pipe. The B16.9 proof test criteria does reasonably guarantee however, that when the weakest possible (MIN strength) welding tee material is matched with the weakest possible (MIN strength) attached pipe, that the pipe will fail first, and this should likely be considered the B16.9 design objective.

It seems reasonable to insist that contoured fittings comply with some simplified minimum required thickness equation similar to that shown in Eq. E12 in addition to the "nationally recognized standard" requirement that is already in B16.9 para. 2.2, and that qualification documentation for any fittings should be available from the manufacturer upon request. If Eq. E12 is used, it should guarantee that the minimum wall of the fitting will be larger than that of the matching pipe, although the crotch thickness in typical tee configurations is directly proportional to the proof test pressure.

B16.9 Paragraph 9.2.2 should be adhered to carefully when designing burst tests. The applicable sentence is: "Straight seamless or welded pipe sections whose calculated bursting strength is at least as great as the proof test pressure as calculated by para. 9.3 shall be welded to each end of the fitting to be tested." This prevents the test designer from inadvertently attaching weaker pipe to the test. Equation E1 or some similar relationship could be used to relate the attached pipe strength to the increase in proof test capacity.

Another option for exploration would be EN-10253-2 specified welding tees. These are generally expensive, but they have the thicknesses spelled out in the standard.

The ‘twice elastic slope’ methodology, as outlined in ASME Section III, Division 1 [7] Mandatory Appendix II, Fig II-1430-1 for the categorization of failure when performing a numerical analysis could provide more guidance if incorporated into B16.9 paragraph 2.2. Alternatively, local failure per ASME VIII-2 Part 5.3.3.2 may also be a potential limiting criteria. Some test and investigation may suggest how this might (or might not) limit pressure design of welding tees.

FUTURE WORK

The study conducted was a small sample of only six burst tests. Although it points to a potential problem in the industry, additional burst tests of “off-the-shelf” stainless B16.9 tees should likely be conducted since those tees have been seen to have the thinnest walls with respect to the matching pipe wall thickness. (Three sch. 10S 4” stainless tees have been ordered.)

REFERENCES
2. ASME, 2013, Boiler and Pressure Vessel Code Section VIII Division 2, American Society of Mechanical Engineers, New York, NY
3. ASME, B31.3-2012, Process Piping, American Society of Mechanical Engineers, New York, NY

7. ASME, 2013, Section III, Division 1, American Society of Mechanical Engineers, New York, NY