PIPE THREADS-WHAT IS THE LIMIT?

D. Wright, J. Wolgamott, G. Zink
StoneAge, Inc.
Durango, Colorado, U.S.A.

ABSTRACT

At present there is no established guideline in the waterblast industry regarding the maximum operating pressure of tapered pipe thread connections. This paper presents the results of tests to determine the failure point of tapered pipe threads when internally pressurized.

Male pipe threads machined on short sections of pipe with various inside diameters were tested to burst or thread failure in three stainless steel materials. Female pipe couplings in two stainless steel materials and with various outside diameters were also tested to failure. Pipe thread sizes from 1/8 to 1-1/4 NPT were studied. Variables such as the number of threads engaged and the effect of repeated assembly of pipe thread connections were also tested.

Comparisons between actual failure points and the predictions of common equations were made, in an effort to determine the best fit for making calculations. Hopefully, based on these tests and others, a consensus can be reached regarding the use of pipe threads in the waterblast industry.

1. INTRODUCTION

The purpose of this research was to find through testing at what pressures pipe thread connections fail, and to compare the actual values to predicted values to determine the best equations for calculating burst pressures. These values in combination with a factor of safety can then be used to determine safe operating pressures for these components.

A factor of safety is used to allow for uncertainty in material properties, geometry and the operating environment. Safety factors can be as high as 20 for structures such as dams, to as low as 1.5 for a commercial aircraft, which would not get off the ground if built like a dam, but must be inspected and maintained regularly. The Waterjet Technology Association has specified a safety factor of 2.5 for components used in a system chosen primarily with weight considerations in mind. This means that once the burst pressure of a component is determined by testing or calculation, this value is divided by 2.5 to determine the operating pressure for that component.

The two equations commonly used for calculating the burst pressure of a cylinder are known as Barlow (equation 1) and Lame′ (equation 2). The Barlow equation is used when the cylinder is considered to be thin walled, because it assumes the stress across the wall is constant. Thin walled is defined by the ratio of the inside diameter/wall being greater than ten. For cylinders with this ratio being less than ten, the Lame′ equation should be used, as it allows for decreasing stress values through the wall. All test samples used in these tests had a ratio less than ten.

$$P = 2 \, S \, t \, / \, D \qquad\qquad (1)$$

$$P = S \, (w^2 - 1) \, / \, (w^2 + 1) \qquad\qquad (2)$$

Where P = pressure (burst)
S = tensile strength of material
t = wall thickness
D = outer diameter
w = wall ratio (outer diameter / inner diameter)

The working pressure for the component then becomes $P / 2.5$ to account for the factor of safety. Variations to these equations account for the reduction of the wall thickness when threads are cut. The thread depth values are shown in Table 1 for each thread size tested. For externally threaded components two times the thread depth is subtracted from the outer diameter, while for internally threaded components two times the thread depth is added to the inner diameter.

2.0 TEST PROCEDURE

Two methods of pressurizing the test samples were used; a single stroke intensifier capable of pressures up to 560 MPa (80,000 psi) and a triplex plunger pump capable of pressures up to 280 MPa (40,000 psi). The intensifier was used where possible, except in cases where the test fittings leaked and the intensifier could not produce enough volume to maintain pressure. Some samples did not fail up to 560 MPa (80,000 psi); actual failure points for these are not known.

The male pipe samples were installed in 17-4 stainless steel test fittings with a calculated wall thickness to allow 560 MPa (80,000 psi) without yield. The female pipe couplings were tested with 17-4 stainless steel male threads. All fittings were assembled with Parker Thread Mate and Teflon tape and tightened to five turns of engagement.

Samples made from 303, 304A bar, 304L seamless schedule 160 pipe and 17-4 H900 stainless steel were tested. The properties of these materials are shown in Table 2; these are the values used for all calculations. All threads were machined, with a standard root radius of .15 mm (.006 in.).

3.0 TEST RESULTS

3.1 Male Pipe

Pipe sizes of 1/8, 1/4, 1/2, 3/4, 1, and 1-1/4 NPT were tested. Table 3 lists each test sample by size, material, type of failure and failure pressure.

Solid plugs of each size were made from 304A hot finished bar and tested to determine where thread failure occurred. The 1/8, 1/4 and 1/2 NPT plugs went to 560 MPa (80,000 psi) without failure, the limit of these tests. The 3/4, 1 and 1-1/4 NPT samples failed by shearing of the threads. The results of the plug tests are shown in Figure 1.

Figures 2 and 3 show the results of 1/8 and 1/4 NPT samples, machined from 304A bar, with two different inside diameters. These results are compared to values calculated with the Lame′, Barlow and Barlow with the thread depth allowance (Barlow-c) equations, using the nominal outer and inner diameters, as well as the calculated results with the thread depth removed from the outer diameter. Both 1/8 NPT samples failed by burst in the wall with the threaded end remaining intact; the burst failure in the thin walled 1/4 NPT sample started at the last thread root. The thick walled 1/4 NPT sample failed by burst in the wall and the threads remained intact. These four pieces are shown in Figure 4.

Three samples of 1/2 NPT 304A bar were machined, with three different inside diameters. The middle size inner diameter matched that of standard 1/2 schedule 160 pipe. In addition, a sample of 304L schedule 160 1/2 pipe was tested. These results are shown in Figure 5, again compared to calculated values. The thin walled sample burst failure started at the last thread root; burst failure occurred in the wall in the other two samples as well as in the pipe sample. Figure 6 shows these pieces.

Similar samples were prepared for 3/4 NPT, machined from bar as well as from 3/4 schedule 160 pipe. The results are shown in Figure 7, and Figure 8 shows these samples. All samples failed by burst, which began in the wall on all of these.

The same series of tests were performed on 1 NPT samples. However, only the thin walled piece machined from bar and the sample of 1 schedule 160 pipe failed by burst. The other two

machined pieces failed by thread shear. The results of these tests are shown in Figure 9, and the pieces are shown in Figure 10. Figure 11 shows all the pieces made from schedule 160 304 L pipe as a group; note that every failure occurred in the pipe wall, independent of the pipe threads.

Two samples of 1-1/4 NPT were machined from 304A bar, with two different inside diameters. The thin walled sample failed by burst, beginning at the last thread root. The thick walled sample failed by thread shear. These results and samples are shown in Figures 12 and 13.

Samples of each of the pipe sizes were also made from 17-4, in the H900 condition. These pieces had inside diameters at least as large as standard schedule 40 pipe sizes, as it was desired to have them fail below 560 MPa (80,000 psi). The results of these tests are shown in Figure 14, compared to the calculated values. The 1/8, 1/4 and 1/2 NPT samples failed by burst, shattering into multiple pieces. The 3/4 and 1 NPT samples broke cleanly off at the last exposed thread, while the 1-1/4 NPT sample burst out one side. These pieces are shown in Figure 15.

3.2 Pipe Couplings

Sample pipe couplings were made in both 303 and 17-4 H900 stainless steels, in sizes of 1/4, 1/2, 3/4 and 1 NPT, with two different outside diameters. Table 4 lists each test sample by size, material, type of failure and failure pressure.

The biggest difficulty of testing the couplings was due to yield causing a leak. If this occurred above the 280 MPa (40,000 psi) limit of the triplex pump, the only way to continue with the intensifier was to reassemble and retighten the fittings, which effectively results in more threads engaged, and allows reaching a burst failure if this process is repeated. However, it was found that failure due to thread shear occurred at much lower pressures than burst, as the coupling yielded and reduced the thread contact area. Therefore, when possible, the couplings were taken to failure by yield and thread shear, but in cases where they yielded and leaked suddenly without shear or rupture, this point was taken as the failure pressure.

In the case of 17-4, which has a yield strength very close to the tensile strength, it was possible to reach burst failure without a large leak in some of the couplings. The 1/4 NPT couplings of 17-4 stainless steel yielded and leaked without failing; these values are plotted in Figure 16, and are less than the calculated yield and burst values using the Lame′ equation. The thin walled 1/2 NPT made from 17-4 failed by burst, breaking into several pieces, while the thick walled coupling did not fail at 560 MPa (80,000 psi); Figure 17 shows these values compared to the calculated values. The 3/4 NPT 17-4 thin walled coupling failed by burst, a single split down the side, but the thick walled coupling failed by thread shear. Both failures were greater than that predicted by calculated burst; these values are shown in Figure 18. The thin walled 1 NPT 17-4 yielded and leaked between the calculated values for yield and burst. The thick walled coupling failed by thread shear above that calculated for burst; Figure 19 compares the actual values to the calculated values for burst and yield.

All of the failures in the 303 stainless steel were caused by thread shear as yield progressed. Both of the 1/4 NPT samples yielded and leaked, without our being able to make them fail. Actual values shown in Figure 20 are the points at which this occurred, compared to calculated

values using the Lame' equation for burst and yield. The same results occurred with the 1/2 NPT 303 couplings; these values are shown in Figure 21. The failures in the 1/4 and 1/2 NPT samples occurred close to the calculated burst; well above the calculated yield. Both of the 3/4 NPT couplings failed by thread shear; Figure 22 shows these results versus the calculated values. The 1 NPT samples also failed by thread shear; these results are plotted in Figure 23. The failures in the 3/4 and 1 NPT samples occurred about midway between the calculated yield and burst values.

3.3 Thread Engagement and Multiple Assembly

A series of tests to determine the effect of number of threads engaged was performed using the 3/4 NPT 303 stainless steel couplings with a 44 mm (1.75 in.) outer diameter, which were known to fail by thread shear. These results are shown in Figure 24. The coupling with 6.5 threads of engagement did not fail, but yielded and leaked; this point was used on the plot. Over the range tested, each thread of engagement resulted in a 12 percent difference.

Testing of multiple assemblies took place on a sample of 1/2 NPT 304L pipe and a 3/4 NPT 303 coupling with a 44 mm (1.75 in.) outer diameter. Each sample was assembled and disassembled 100 times. The 1/2 NPT pipe sample failed in the pipe wall, not in the thread. The 3/4 NPT sample failed by thread shear at 248 MPa (35,400 psi), with 5.75 threads engaged, 5 percent less than the value predicted from the thread engagement tests.

4.0 CONCLUSIONS

Figure 25 shows the average difference between the actual failures and the values predicted by the equations used for each material. The testing of the male pipe samples machined from 304A bar resulted in burst failures equal to or greater than values predicted by the Lame' equation for thick walled cylinders. Failures due to thread shear occurred in the 1 and 1-1/4 NPT heavy walled samples, where the burst pressure exceeded the thread strength. All samples of 304L pipe failed in the pipe wall, at values predicted by the Lame' equation, with no failures related to the pipe threads.

The 17-4 stainless steel male pipe samples showed some failures occurring at less than the predicted values of the Lame' equation; it is possible that the actual strength of these pieces was less than used in the calculations. Materials such as 13-8 and 15-5 are known to have better transverse toughness properties than 17-4 and would be recommended in cases where size or weight constraints require designs at the 2.5 times burst limit. Otherwise, with very strong materials such as 17-4, parts can be designed with much higher burst values without much sacrifice in weight.

The testing of the couplings of 303 and 17-4 showed a failure mode of thread shear to be much more likely than failure due to burst. The thread shear failures were caused by yield of the coupling. Actual failures due to yield and thread shear typically occurred above the calculated yield, but below the calculated burst.

1/8 NPT	.635 mm (.025 in.)
1/4 NPT	.973 mm (.038 in.)
1/2 NPT	1.288 mm (.0507 in.)
3/4 NPT	1.288 mm (.0507 in.)
1 NPT	1.590 mm (.0626 in.)
1 NPT	1.590 mm (.0626 in.)

Table 1. Thread depth

Material	Yield Strength	Tensile Strength
303 SS	245 MPa (35,000 psi)	630 MPa (90,000 psi)
304L SS pipe	238 MPa (34,000 psi)	595 MPa (85,000 psi)
304A SS bar	277 MPa (39,600 psi)	640 MPa (91,500 psi)
17-4 H900 SS	1190 MPa (170,000 psi)	1330 MPa (190,000 psi)

Table 2. Material properties

Size	Material	O.D.	I.D.	Failure Pressure	Failure Type
1/8	304A bar	10.3 mm (.405 in.)	Plug	560 MPa (80,000 psi)	No failure
1/8	304A bar	10.3 mm (.405 in.)	4.8 mm (.189 in.)	507 MPa (72,400 psi)	Burst
1/8	304A bar	10.3 mm (.405 in.)	6.6 mm (.260 in.)	294 MPa (42,000 psi)	Burst
1/8	17-4 H900	10.3 mm (.405 in.)	7.4 mm (.290 in.)	444 MPa (63,500 psi)	Burst
1/4	304A bar	13.7 mm (.540 in.)	Plug	560 MPa (80,000 psi)	No failure
1/4	304A bar	13.7 mm (.540 in.)	6.1 mm (.239 in.)	526 MPa (75,100 psi)	Burst
1/4	304A bar	13.7 mm (.540 in.)	8.9 mm (.350 in.)	286 MPa (40,900 psi)	Burst
1/4	17-4 H900	13.7 mm (.540 in.)	9.9 mm (.390 in.)	356 MPa (50,800 psi)	Burst
1/2	304A bar	21.3 mm (.840 in.)	Plug	560 MPa (80,000 psi)	No failure
1/2	304A bar	21.3 mm (.840 in.)	9.7 mm (.380 in.)	518 MPa (74,000 psi)	Burst
1/2	304A bar	21.3 mm (.840 in.)	11.8 mm (.466 in.)	403 MPa (57,500 psi)	Burst
1/2	304L pipe	21.3 mm (.840 in.)	11.8 mm (.466 in.)	313 MPa (44,700 psi)	Burst
1/2	304A bar	21.3 mm (.840 in.)	13.6 mm (.537 in.)	305 MPa (43,600 psi)	Burst
1/2	17-4 H900	21.3 mm (.840 in.)	15.7 mm (.618 in.)	403 MPa (57,500 psi)	Burst
3/4	304A bar	26.7 mm (1.050 in.)	Plug	464 MPa (66,300 psi)	Thread shear
3/4	304A bar	26.7 mm (1.050 in.)	13.3 mm (.525 in.)	394 MPa (56,300 psi)	Burst
3/4	304A bar	26.7 mm (1.050 in.)	15.5 mm (.611 in.)	321 MPa (45,800 psi)	Burst
3/4	304L pipe	26.7 mm (1.050 in.)	16.3 mm (.643 in.)	271 MPa (38,700 psi)	Burst
3/4	304A bar	26.7 mm (1.050 in.)	18.0 mm (.710 in.)	244 MPa (34,800 psi)	Burst
3/4	17-4 H900	26.7 mm (1.050 in.)	21.3 mm (.838 in.)	286 MPa (40,900 psi)	Burst
1	304A bar	33.4 mm (1.325 in.)	Plug	410 MPa (58,500 psi)	Thread shear
1	304A bar	33.4 mm (1.325 in.)	17.4 mm (.688 in.)	360 MPa (51,400 psi)	Thread shear
1	304A bar	33.4 mm (1.325 in.)	20.7 mm (.815 in.)	294 MPa (42,000 psi)	Thread shear
1	304L pipe	33.4 mm (1.325 in.)	20.7 mm (.815 in.)	266 MPa (38,000 psi)	Burst
1	304A bar	33.4 mm (1.325 in.)	24.6 mm (.970 in.)	196 MPa (28,000 psi)	Burst
1	17-4 H900	33.4 mm (1.325 in.)	26.6 mm (1.048 in.)	292 MPa (41,700 psi)	Burst
1-1/4	304A bar	42.2 mm (1.660 in.)	Plug	309 MPa (44,200 psi)	Thread shear
1-1/4	304A bar	42.2 mm (1.660 in.)	24.3 mm (.958 in.)	305 MPa (43,600 psi)	Thread shear
1-1/4	304A bar	42.2 mm (1.660 in.)	33.7 mm (1.328 in.)	170 MPa (24,300 psi)	Burst
1-1/4	17-4 H900	42.2 mm (1.660 in.)	34.0 mm (1.338 in.)	302 MPa (43,100 psi)	Burst

Table 3. List of male pipe samples and test results

Size	Material	O.D.	I.D.	Failure pressure	Failure type
1/4	303	21.3 mm (.840 in.)	11.1 mm (.438 in.)	340 MPa (48,600 psi)	Yield, leak
1/4	303	28.6 mm (1.125 in.)	11.1 mm (.438 in.)	441 MPa (63,000 psi)	Yield, leak
1/4	17-4 H900	16.8 mm (.661 in.)	11.1 mm (.438 in.)	418 MPa (59,700 psi)	Yield, leak
1/4	17-4 H900	18.8 mm (.741 in.)	11.1 mm (.438 in.)	526 MPa (75,100 psi)	Yield, leak
1/2	303	28.4 mm (1.120 in.)	18.3 mm (.719 in.)	232 MPa (33,100 psi)	Yield, leak
1/2	303	31.8 mm (1.250 in.)	18.3 mm (.719 in.)	317 MPa (45,300 psi)	Yield, leak
1/2	17-4 H900	26.1 mm (1.029 in.)	18.3 mm (.719 in.)	541 MPa (77,300 psi)	Burst
1/2	17-4 H900	28.9 mm (1.137 in.)	18.3 mm (.719 in.)	560 MPa (80,000 psi)	No failure
3/4	303	36.8 mm (1.450 in.)	23.4 mm (.922 in.)	178 MPa (25,400 psi)	Thread shear
3/4	303	44.4 mm (1.750 in.)	23.4 mm (.922 in.)	240 MPa (34,300 psi)	Thread shear
3/4	17-4 H900	32.5 mm (1.280 in.)	23.4 mm (.922 in.)	332 MPa (47,500 psi)	Burst
3/4	17-4 H900	36.3 mm (1.430 in.)	23.4 mm (.922 in.)	464 MPa (66,300 psi)	Thread shear
1	303	52.8 mm (2.080 in.)	29.4 mm (1.156 in.)	201 MPa (28,700 psi)	Thread shear
1	303	63.5 mm (2.500 in.)	29.4 mm (1.156 in.)	245 MPa (35,000 psi)	Thread shear
1	17-4 H900	40.7 mm (1.603 in.)	29.4 mm (1.156 in.)	441 MPa (63,000 psi)	Yield, leak
1	17-4 H900	45.4 mm (1.789 in.)	29.4 mm (1.156 in.)	456 MPa (65,200 psi)	Thread shear

Table 4. List of pipe coupling samples and test results
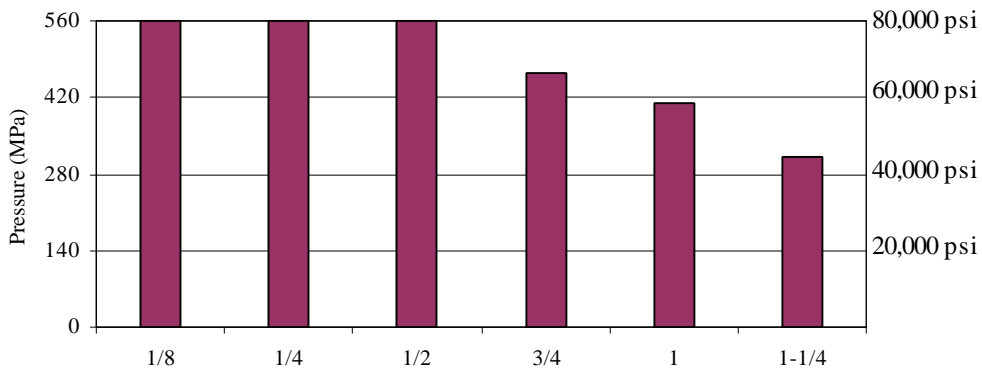
Figure 1. Pipe plug failure pressures, 304 male in 17-4 female
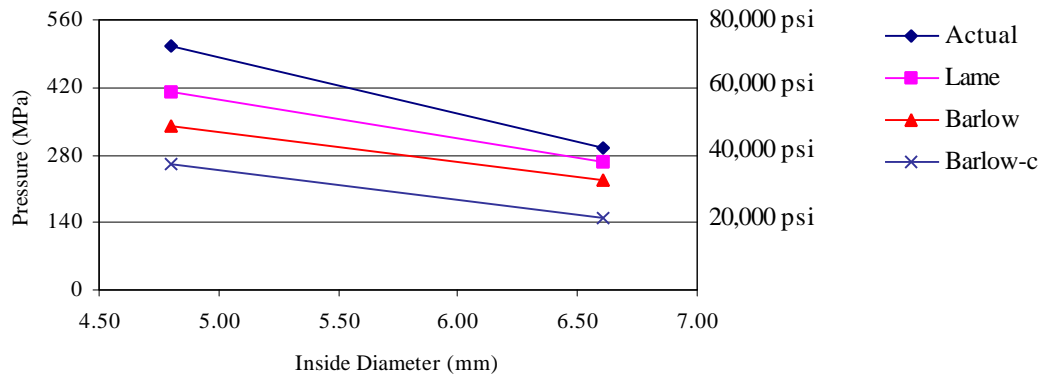
Figure 2. Results of 1/8 NPT 304 samples compared to calculated burst
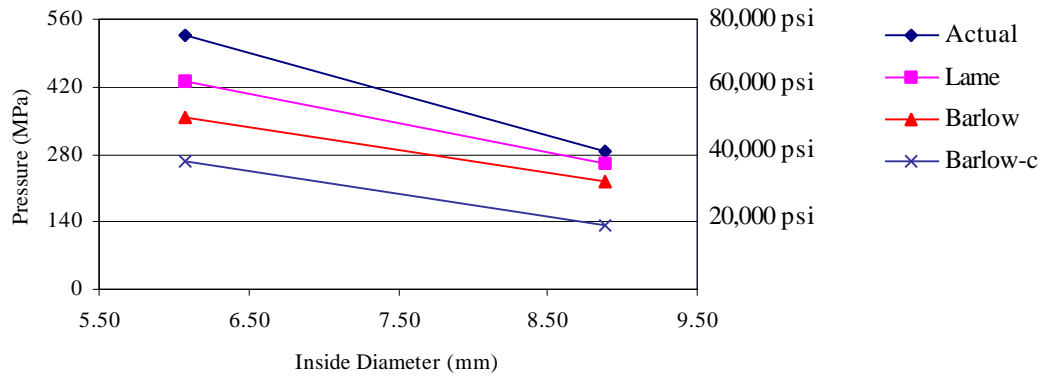
Figure 3. Results of 1/4 NPT 304 samples compared to calculated burst

Figure 4. 1/8 and 1/4 NPT 304 test samples
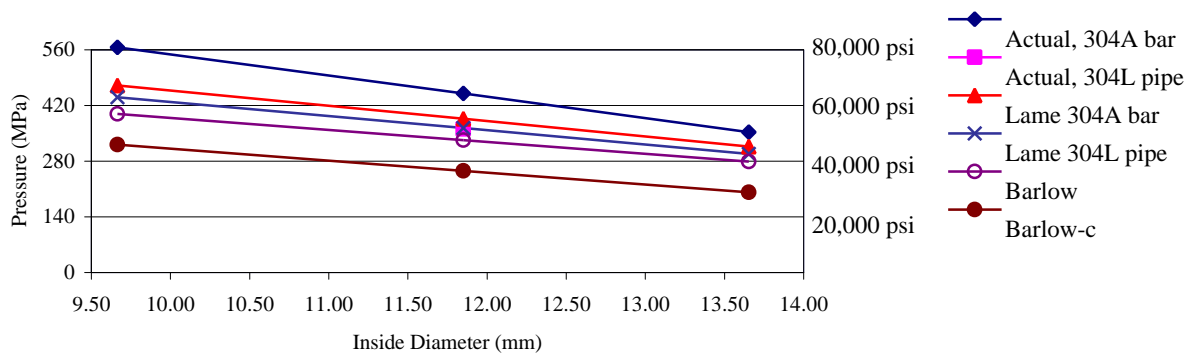
Figure 5. Results of 1/2 NPT 304 samples compared to calculated burst

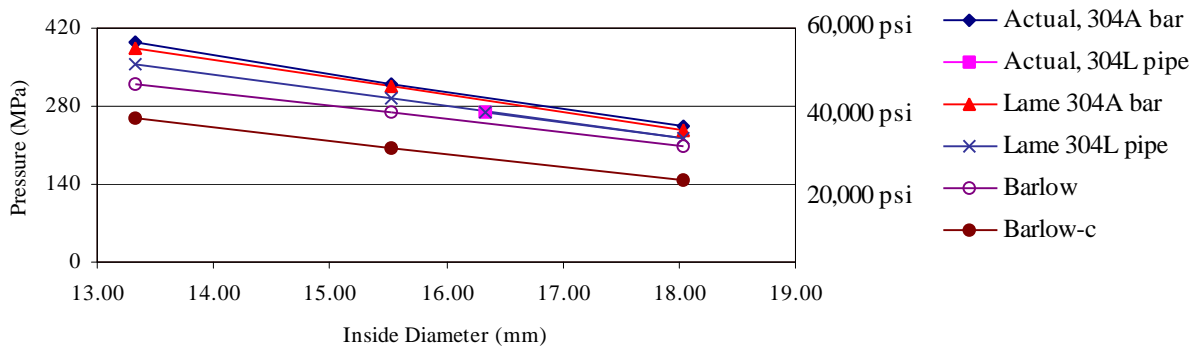**Figure 6. 1/2 NPT 304 test samples**

Figure 7. Results of 3/4 NPT 304 samples compared to calculated burst
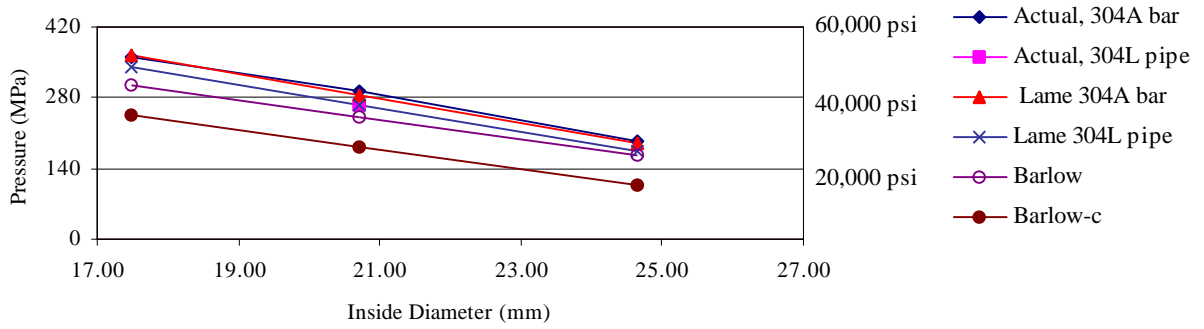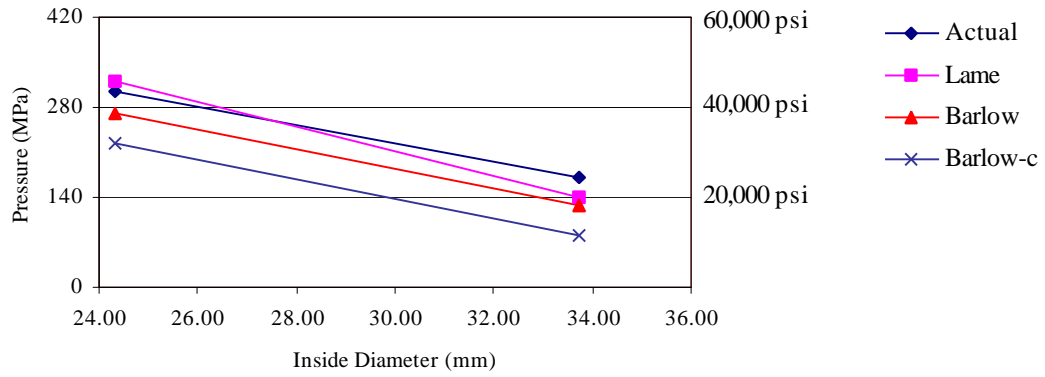

Figure 8. 3/4 NPT 304 test samples

Figure 9. Results of 1 NPT 304 samples compared to calculated burst

Figure 10. 1 NPT 304 test samples

Figure 11. 304L schedule 160 seamless pipe samples (1/2, 3/4, and 1 NPT)

Figure 12. Results of 1-1/4 NPT 304 samples compared to calculated burst

Figure 13. 1-1/4 NPT 304 test samples
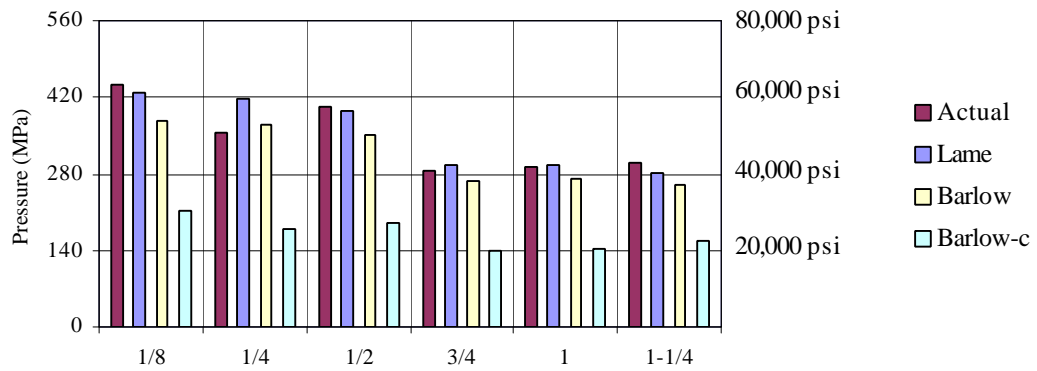
Figure 14. Results of 17-4 samples compared to calculated burst

Figure 15. 17-4 test samples
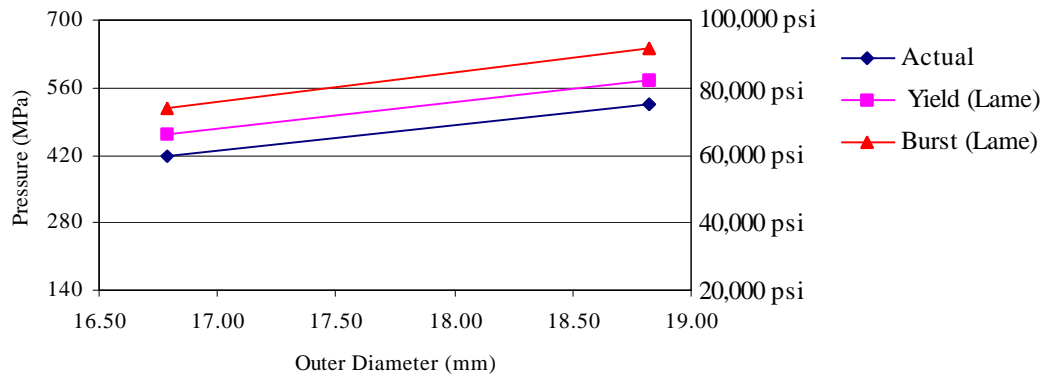
Figure 16. 1/4 NPT couplings, 17-4, failures compared to calculated yield and burst
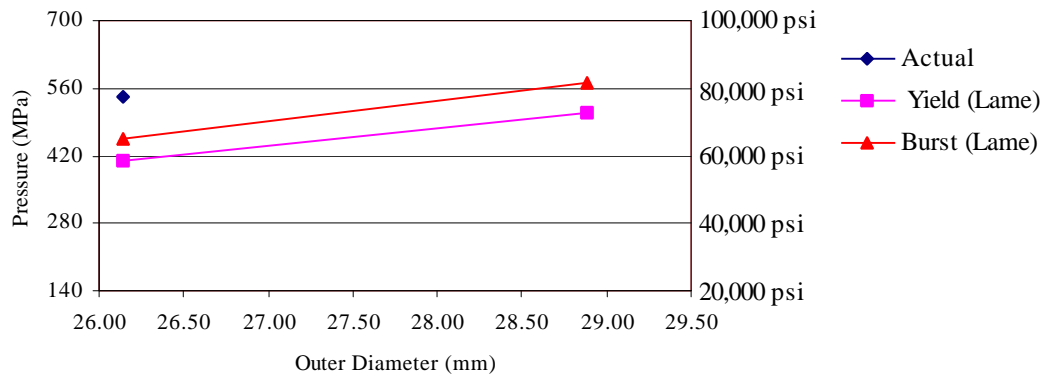
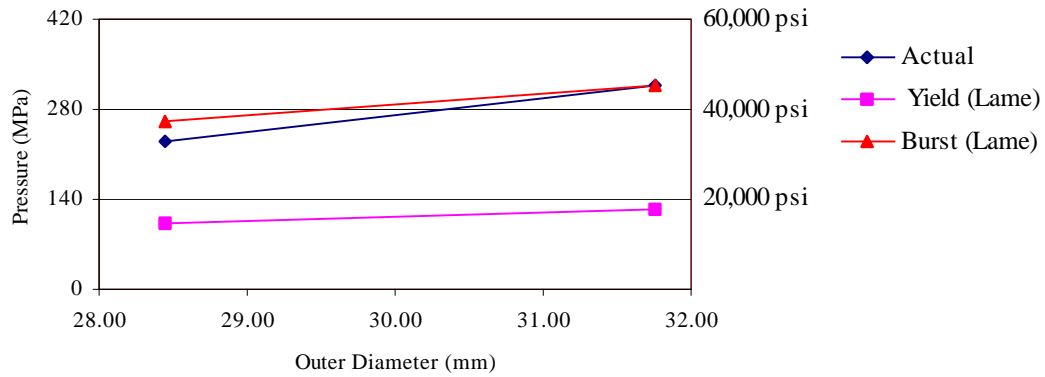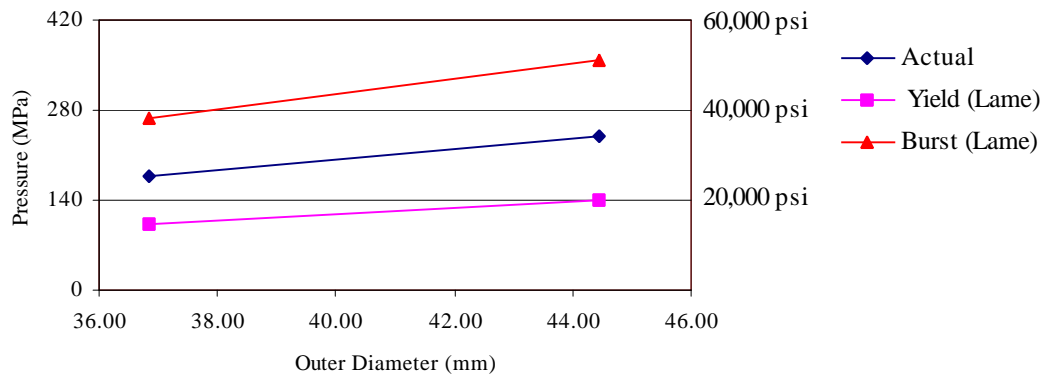**Figure 17. 1/2 NPT couplings, 17-4, failures compared to calculated yield and burst**
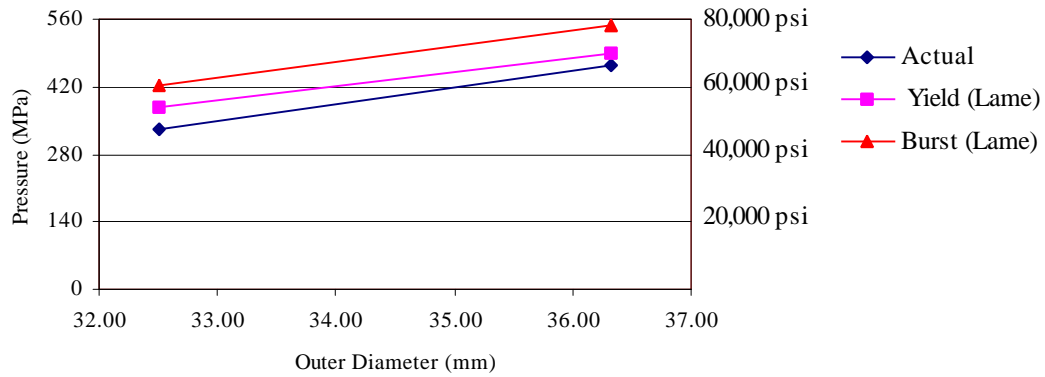
Figure 18. 3/4 NPT couplings, 17-4, failures compared to calculated yield and burst
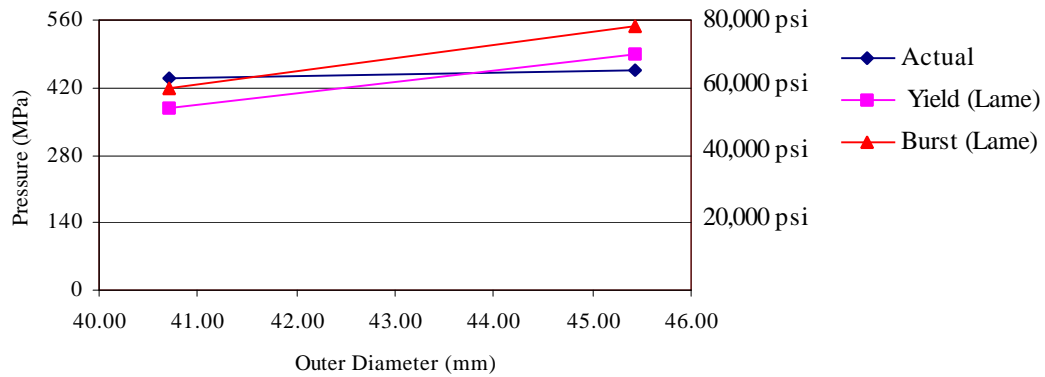
Figure 19. 1 NPT couplings, 17-4, failures compared to calculated yield and burst
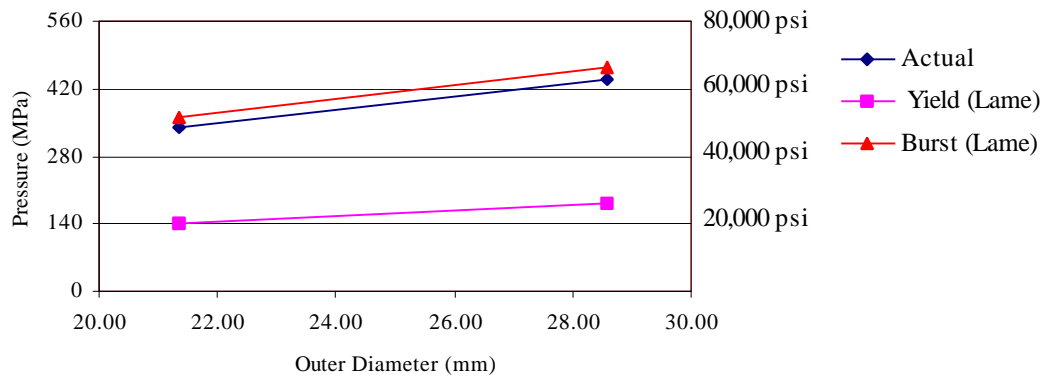
Figure 20. 1/4 NPT couplings, 303, failures compared to calculated yield and burst

Figure 21. 1/2 NPT couplings, 303, failures compared to calculated yield and burst

Figure 22. 3/4 NPT couplings, 303, failures compared to calculated yield and burst
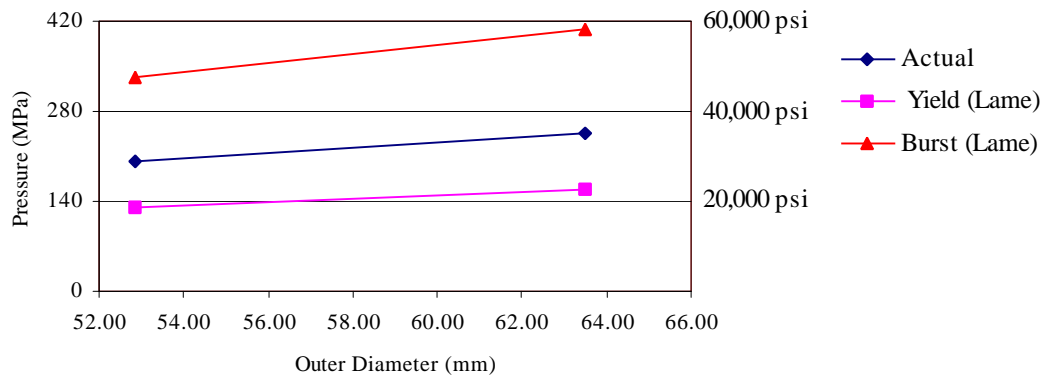

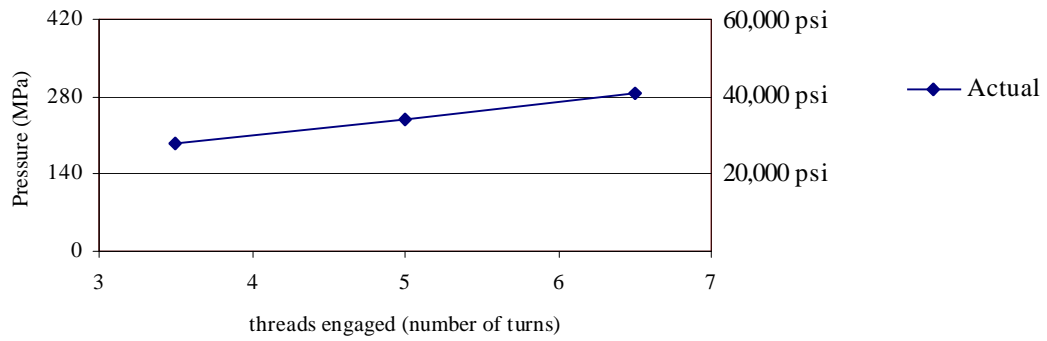**Figure 23. 1 NPT couplings, 303, failures compared to calculated yield and burst**

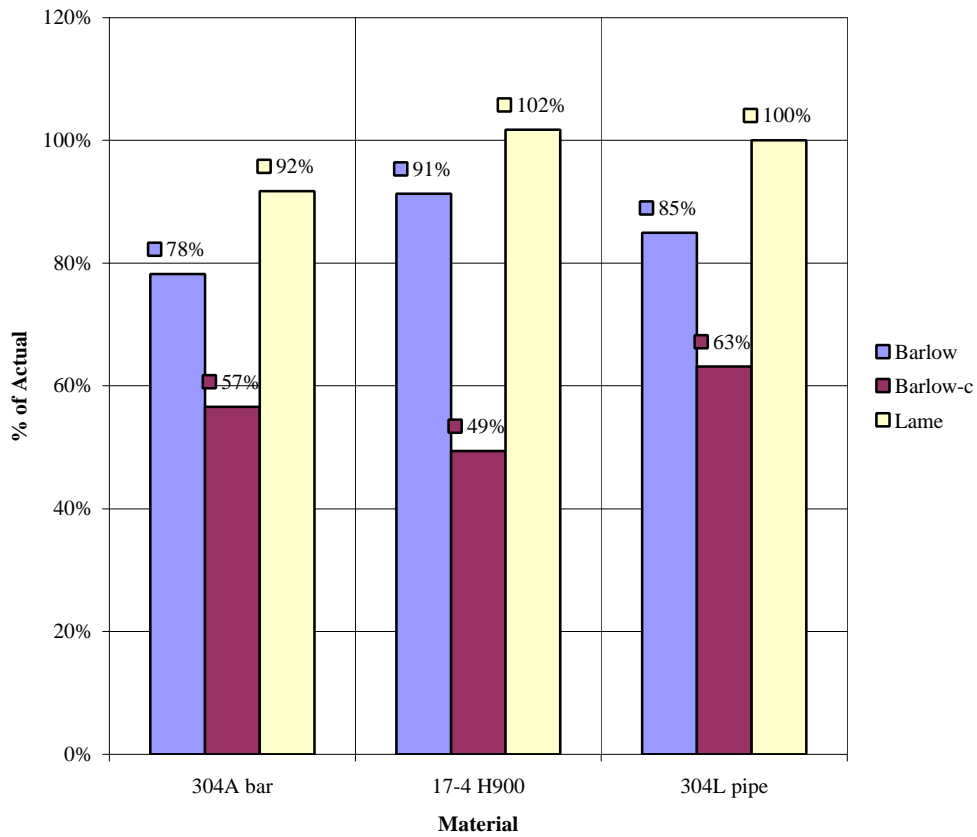**Figure 24. 3/4 NPT couplings, 303, effect of threads engaged**

Figure 25. Average of calculated values to actual failures, by material type