PIPE LINING PRESSURE TEST

Test Performed for: Dan Warren, A&W Maintenance/Warren Environmental
Test Performed at: A&W Maintenance/Warren Environmental, 137 Pine Street, Middleboro, MA 02346
Test Performed: November 21, 2007

Specimen Description

Two specimens, designated SILVER and BLUE were prepared (Figure 1). Both specimens were 4 in. diameter Schedule 40 steel pipe having the properties given in Table 1 (ANSI). Specimens were 4 in. long with an additional approximately 2.5 in. of threaded region at each end to accommodate the end caps necessary for the test.

	ID	OD	nominal wall thickness	cross sectional area
Schedule 40 steel pipe	4.03 in.	4.50 in.	0.24 in.	3.17 in^2

Table 1 Dimensional properties of ANSI Schedule 40 steel pipe.

Specimens were provided with two inlets approximately 60° from each other. Six drill holes were provided around the remaining circumference of the pipe at approximately 42° intervals (i.e.: no holes were provided in the 60° region between the inlets). The hole diameters provided were (in order from one inlet) ⅜ in., ¼ in., ¼ in., ¾ in. ¼ in. and ⅜ in.

The SILVER specimen was lined with a ¼ in. (nominal) layer of structural epoxy. The BLUE specimen was lined with a 5/32 in. epoxy impregnated felt liner and interior impermeable membrane. As shown in Figure 1, the uniformity of the BLUE lining was exceptional while the SILVER lining was "off-center" resulting a thicker layer on one side of the pipe and a thinner layer on the other – although the average was ¼ in. The lining thickness near the ¾ in. hole (failure location as described below) was approximately ¼ in.

(a) SILVER Specimen

inlets and ⅜ in filled hole

⅜, ¼, ¼ and ¾ in. filled holes

(b) BLUE specimen

Figure 1 Test Specimens.

Prior to the reported test, the SILVER specimen had been pressurized to 1000 psi on at least 4 occasions. The BLUE specimen had never been tested previously and the lining was reported to be only 24 hours old at the time of testing.

Test Method

Specimens were pressurized using a 2300 psi capacity piston-style pump. The hydraulic fluid used was water. Specimens were purged of air and sealed using butterfly valves. Pressure was applied at a rate resulting in approximately 1000 psi being developed in 30 seconds. For the SILVER specimen, pressure was increased until failure as described below. For the BLUE specimen, pressure was increased to 2500 psi and maintained at this level or slightly above for approximately 2 minutes. Pressure was then released. The BLUE specimen was retested following visual inspection. In the subsequent test, a pressure of 3000 psi was achieved although, as described below, the lining system had failed at this point. The test set up is shown in Figure 2. Both tests were conducted outdoors in an ambient temperature of approximately 40°F.

A discrepancy was discovered between readings of the digital pressure gage on the pump and the analog dial gage on the specimen. A correction was applied as described in Appendix A and all values reported are those at the analog dial gage connected directly to the specimen.

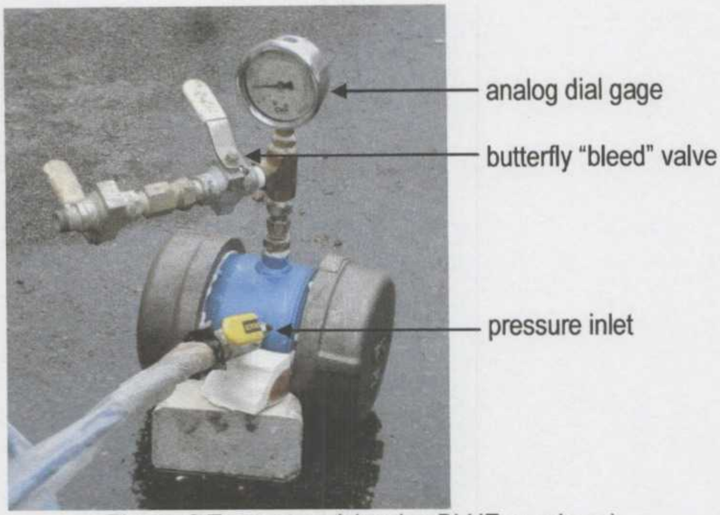
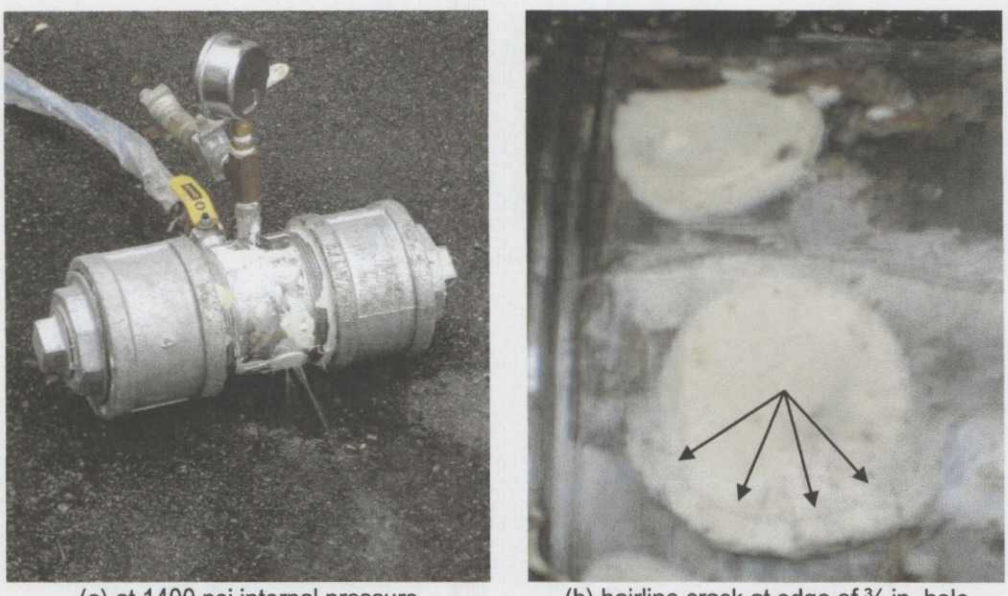


Figure 2 Test set-up (showing BLUE specimen).

Test Results

SILVER Specimen

The SILVER specimen achieved 1400 psi internal pressure. At this pressure, the ¾ in. hole failed as described below. The failure resulted in water leaking from around the edge of the ¾ in. hole as shown in Figure 3.



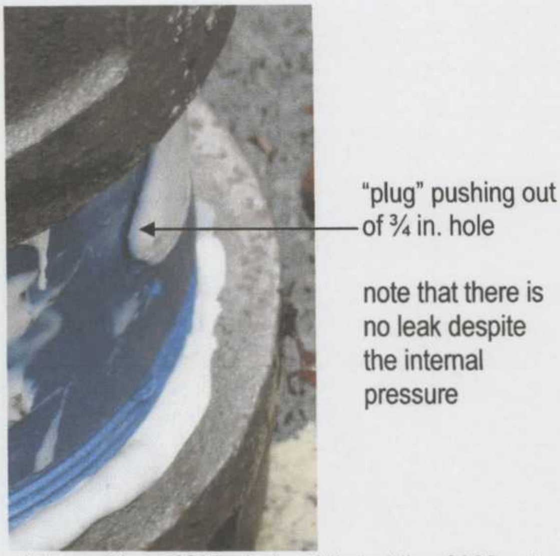
(a) at 1400 psi internal pressure (b) hairline crack at edge of ¾ in. hole

Figure 3 Failure of SILVER Specimen.

BLUE Specimen

The BLUE specimen achieved and maintained 2500 psi internal pressure. Following the test, a hairline fracture around the ¾ in. hole was noted. This failure, identical to that seen in the SILVER specimen and described below, did not result in leaking water. The specimen was repressurized to 3000 psi. At this pressure, the "plug" in the ¾ in. hole was clearly "pushing out" (Figure 4), however no leak was observed indicating that the interior impermeable liner remained intact.

(a) following initial test to 2500 psi showing hairline crack around edge of ¾ in. hole

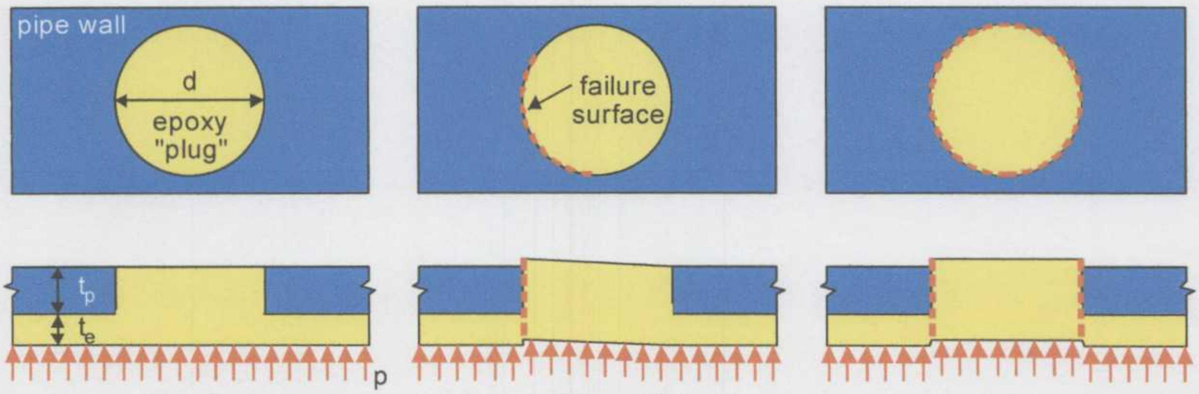


(b) condition of ¾ in. hole while holding 3000 psi internal pressure

Figure 4 Failure of BLUE Specimen

Description and Discussion of Failure Mode

Both failures are best described as the "plug" of epoxy material being "pushed out" of the hole drilled through the wall of the pipe. The failure appears to initiate at one side of the hole and subsequently propagates around the hole (Figure 5). This is indicative of a shear failure where the failure initiates at the "weakest section" or section around the hole circumference were the lining is thinnest.



(a) pipe wall and epoxy plug

(b) initiation of failure (see Figures 3b and 4a)

(c) "push-out" (see Figure 4b)

Figure 5 Schematic description of "push-out" failure.
(Provided interior impermeable liner remains intact, no leaking was evident even at partial push-out)

The shear stress around the circumference of the hole is calculated as follows:

$$ShearStress = \frac{Applied\,Force}{Resisting\,Area} = \frac{p\pi d^2/4}{\pi d(t_e + \alpha t_p)} = \frac{pd}{4(t_e + \alpha t_p)}$$

where p = internal pressure (psi)
d = diameter of drilled hole (in.)
t_e = thickness of epoxy liner (in.)
t_p = pipe wall thickness (in.)
α = ratio of epoxy shear stress to adhesive/friction around edge of hole plug

While the value of α is unknown, it can be calculated knowing the shear strength of epoxy.

The relevant result from this calculation is that the applied shear forces are proportional to the hole size. Thus the shear failure should be expected to occur at the largest defect/hole. While no specific conclusions can be drawn from the tests conducted, it is implied that the internal pressure that may be resisted is inversely proportional to the diameter of the hole. Logically, this relationship will be limited by other limit states and the actual pipe capacity, although these parameters cannot be assessed in the present tests, whose capacity is limited by the limit state described above.

If the value of α is taken as unity, the apparent shear capacity of the epoxy system is found as shown in Table 2. It is likely that the shear failure in the BLUE specimen occurred at an internal pressure lower than 2500 psi, although this cannot be confirmed. Based on observations (Figure 4), the failure had not propagated completely around the ¾ in. hole at this pressure however.

	p (psi)	d (in.)	t_e (in.)	t_p (in.)	shear stress at failure (psi)
SILVER	1400	0.75	0.25	0.24	536
BLUE	2500	0.75	0.16	0.24	1172

Table 2 Apparent shear capacity of epoxy.

Future Work

This report discussed two tests and is therefore noted to have no statistical significance. Nonetheless, the promise for repairing pressurized pipe is demonstrated. It is recommended that a formal test program addressing operational parameters and anticipated damage conditions be undertaken. A minimum of ten specimens should be tested under each condition to establish some statistical precision data. An outline of such a recommended test program is attached in Appendix B. With direction, a formal scope of work can be developed.

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APPENDIX A – DIGITAL PRESSURE GAGE CORRECTION

During testing it was observed that the digital pressure gage connected to the pump was reading incorrectly. The analog dial gage connected directly to the test specimen is believed to yield correct readings. To assess the correction necessary to correlate the digital and analog readings a simple calibration was performed. The analog dial gage was connected in parallel with the digital pressure gage and readings were taken. Figure A.1 shows this correlation between readings. Over the range of actual pressure (analog dial gage) greater than 500 psi, the correlation is linear with an R^2 coefficient greater than 0.99. The correction is as follows:

$$\text{actual pressure} = 0.987(\text{digital reading}) + 450.6 \text{ [psi]}$$

Thus the actual pressure determined for the SILVER test is: 0.987(980) + 450.6 = 1418 psi. This value is reported. This need for correction was identified prior to testing the BLUE specimen and the dial gage readings were used directly in this case.

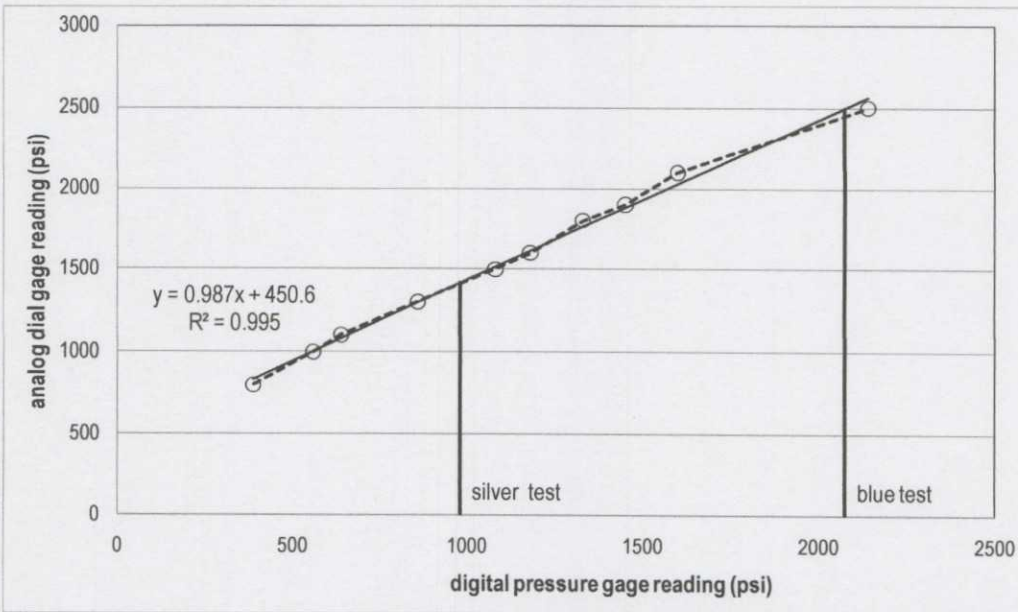

Figure A.1 Digital pressure gage correlation.

APPENDIX B – OUTLINE OF PROPOSED TEST PROGRAM

Anticipated Application
Oil and gas brine water operation piping:

- Continuous operating pressure: 200 psi; spiking to 600 psi. Operating temperature: 140°F

Oil and gas brine water injection lines:

- Continuous operating pressure: 1600 psi. Operating temperature: 140°F

Repair Method
Epoxy-impregnated felt liner and impermeable inner membrane as tested in BLUE specimen.

Test Standards to be followed
To be determined. However appropriate standards will include

- proof pressure;
- pressurizing history;
- shake-down requirements; and,
- time to maintain pressure

Test Parameters – single parameter specimens are recommended

parameter	variations	variations	incremental cost
pipe type	2	carbon steel concrete-lined carbon steel	specimen cost only
pipe diameters	3	4 in. 6 in. 8 in.	separate test set-up required for each diameter in addition to specimen cost
defect size	3	pinhole ¼ in. ½ in.	specimen cost only
epoxy thickness	2	5/32 in. ¼ in.	specimen cost only
temperature of hydraulic fluid	2	ambient (70°F) elevated (140°F)	nominal; heating element added to test set-up in addition to specimen cost

Recommending 10 specimens per parameter (unless otherwise indicated by test standards) to establish precision data results in 720 specimens if all permutations are tested. Test program should be designed to allow elimination of permutations. As an example, it is not likely necessary to test all pipe diameters, additionally; pipe diameter is a parameter having an incremental cost.

Test Set-up
Capable of testing 10 specimens in parallel and isolating individual specimens. Instrumentation to capture pressure-time histories for all specimens; strain data on selected specimens.

Material Characterization of Epoxy Lining System Required
The following data is required (at a minimum) to properly assess anticipated results:

- shear strength and modulus
- flexural strength and modulus
- glass transition temperature, T_G