Assessment of Polybutylene Plumbing Installation after 18 Years of Service

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INTRODUCTION

Engineering Systems Inc. (ESI) was retained by a property owner to evaluate the condition of the polybutylene (PB) plumbing system in a multi-unit apartment complex. The owner was doing a general rehabilitation project on the apartment units and desired to know the condition of the behind-the-wall PB plumbing pipe. The analysis included a site inspection of the plumbing system in the complex and laboratory testing of pipe samples removed from the apartments.

The on-site inspection of the plumbing system was conducted in November, 2011. At that time, PB pipe samples were selected and removed for laboratory testing. The hot water pipe closest to the water heater connection was selected from several apartments for testing, as well as a few cold water pipes from the same units. The laboratory testing of the PB pipe samples included a visual and microscopic inspection of the samples, dimensional measurements, quick burst testing, oxidation induction time testing, long-term hydrostatic pressure testing, and Fourier Transfer Infrared Spectroscopy (FTIR).

SITE INSPECTION DETAILS

During the site inspection, the plumbing connections near the water heater were examined in sixteen units that were undergoing rehabilitation. Table 1 lists the units that were inspected and the samples that were taken. The test samples included four different production date codes for Qest PB pipe and one date code for Vanguard PB pipe. The PB piping entered each apartment building under the concrete slab from a valve box in front of each building. As part of the rehabilitation project, the drywall had been removed in the mechanical room that housed the furnace and water heater. The typical layout of the PB piping is shown in Figures 1 and 2 for one of the first floor apartments and upstairs apartments, respectively.

In general the installation of the PB pipe in the apartment complex was excellent. The tubing was properly secured to studs and was not excessively bent. Approximately 18 inches of copper pipe was present between each water heater and the beginning of the PB hot water piping. The system utilized wrought copper fittings and either Qest or Vanguard ¾" PB tubing. The crimp ring diameters were within specification as measured with a Qest "Go-No Go" gage for PB piping with copper crimp rings. The crimp diameters were at the high end of the range (0.945" to 0.960"), which is common for crimped connections using wrought copper fittings. The crimp rings from all of the samples that were removed for testing were within the proper diameter range. There were no problems with the installation of the PB piping that were noted during the inspection. The chlorine level was measured at a sink faucet in the office at the site, using the DPD (N,N diethyl-p-phenylenediamine) method and Aquacheck chlorine strips. The free chlorine measurement for the cold water was approximately zero with both methods, while the total combined chlorine was approximately 3 ppm.

TESTING OF PB SAMPLES

A total of 17 pipe samples from fifteen of the sixteen units that were inspected (no samples were taken from Bldg. A, Unit #1). The testing included dimensional analysis, micro-Fourier Transform infrared spectroscopy (micro-FTIR), oxidation induction time (OIT), short-term burst pressure and long-term hydrostatic stress-rupture tests.

Dimensions

The dimensions of the samples were measured per ASTM D 2122 [1], for average outside diameter (O.D.) and minimum wall thickness. The wall thickness was measured at eight locations around the circumference of the pipe, noting the average and minimum value. The average O.D. was measured using a circumferential wrap tape. The measured dimensions of pipe from each of the five date codes are shown in Table 2. The pipe outside diameters were still all within that specified in ASTM D 3309 [2]. The wall thicknesses generally still met the 0.080-inch minimum wall except for a few pipes where the measured minimum wall was 0.078 to 0.079. This is not unusual for pipe that has been in service for 18 years at elevated temperature, causing some creep of the material. It is apparent from these dimensional measurements that the pipes all originally met the dimensional requirements for new pipe in the ASTM D 3309 standard.

Table 1. Units Inspected and PB Samples Taken.

Building #	Unit #	Samples Taken
A	6	Vanguard (8-10-93) hot water pipe
A	5	Vanguard (8-10-93) hot water pipe
A	4	Vanguard (8-10-93) hot water pipe
A	3	Vanguard (8-10-93) hot water pipe
A	2	Vanguard (8-10-93) hot water pipe
A	1	None
B	2	Qest (2-1-93) hot water pipe
B	1	Qest (apparently 2-1-93) hot water pipe
C	8	None – This unit had been changed out to PEX due to a fire.
C	7	Unit above unit where fire had occurred Qest (11-30-92) hot water pipe Qest (12-1-92) cold water pipe Qest (11-30-92) cold water pipe
C	6	Qest (11-30-92) hot water pipe
C	5	Qest (2-1-93) hot water pipe
C	4	Qest (12-2-92) hot water pipe
C (removed by owner prior to inspection)	3	Qest (12-1-92) hot water pipe Qest (12-2-92) cold water pipe
C	2	Qest (12-1-92) hot water pipe
C	1	Qest (11-30-92) hot water pipe

Table 2. Dimensions of ¾" PB Tubing Samples

Sample Designation	Average O.D., in.	Avg. Minimum Wall, in.
Qest 11-30-92	0.876	0.080 (avg. 0.081)
Qest 12-01-92	0.877	0.078 – 0.079 (avg. 0.080)
Qest 12-02-92	0.878	0.082 (avg. 0.083)
Qest 02-01-93	0.878	0.080 (avg. 0.081)
Vanguard 08-10-93	0.878	0.078 – 0.079 (avg. 0.080)
ASTM D 3309 Requirement	0.875 ± 0.004	0.080 + 0.010

Micro-FTIR – Check for Oxidation

Seventeen PB pipe samples that were removed from the site were analyzed by micro-FTIR spectroscopy for extent and depth of oxidation at the inner wall of the PB tubing. Most of the samples chosen were from the hot water side nearest to the water heater, areas that represent the most aggressive in-service environment.

Oxidation of polyolefins such as PB results in the formation of carbonyl groups onto the PB molecules [3]. These groups have characteristic infrared absorption frequencies. Among these groups, the strongest absorption peak is observed at about 1715 to 1720 cm^{-1}. Weaker peaks are observed at 1735 and 1775 cm^{-1}. The stabilizer compounded into the PB has a small carbonyl peak at 1740 cm^{-1}. When oxidation occurs, a peak around 1715 cm^{-1} is formed, which progressively increases in intensity as the degree of oxidation increases. The carbonyl index is defined as the ratio of this carbonyl absorbance to that of the polymer backbone absorption band at 1465 cm^{-1}. The use of this ratio compensates for any differences in sample thickness and serves as an internal standard.

In the present study, the carbonyl index was profiled through the thickness of the PB tubing in order to determine the extent and depth of the oxidation, if it existed. This profiling is possible with a Micro-FTIR instrument that allows one to focus the infrared beam at a precise location on the sample. The analysis was conducted using a Perkin Elmer Spectrum 100 FTIR instrument with a Multi-Scope micro-FTIR accessory. The samples consisted of microtomed cross sections of the tubing wall. The infrared spectra were recorded in 0.03 mm increments (~0.0012 inches), using an aperture of approximately 0.3 mm x 0.03 mm. The profiling was continued inward from the inner surface of the tubing until no absorbance at 1715 cm^{-1} was detected. The carbonyl index was also measured at the core of the tubing for comparison with the inner surface measurements.

Table 3 shows the carbonyl index measurements obtained on the PB pipe samples. There was very little indication of any oxidation in the samples tested. Carbonyl indices of less than approximately 0.05 indicate insignificant oxidation of the PB material. Any minimal oxidation that was detected in the samples was less than one thousandth of an inch in depth. In order for oxidation to negatively affect the PB pipes, the carbonyl index should be at least 0.1 and the depth of oxidation at least two thousandths of inch deep. None of the pipes analyzed show anything but superficial oxidation that will not negatively affect the long-term performance of the pipe.

Table 3. Carbonyl Index (C.I.) Measurements on PB Pipe Samples.

Sample Building-Unit	C.I. 0 to 0.0012 in.	C.I. 0.0012 to 0.0024 in.	C.I. 0.0024 to 0.0036 in.	C.I. Core
B-1-Hot	0.018	0.009	--	0.004
B-2-Hot	N.D.*	N.D.*	--	0.009 (1740 cm^{-1})
A-2-Hot	0.017	0.006	--	0.005
A-3-Hot	0.011	0.0001	--	0.007 (1740 cm^{-1})
A-4-Hot	0.007	0.008	--	N.D.
A-5-Hot	0.023	0.004	--	0.009 (1740 cm^{-1})
A-6-Hot	0.0002	0.0005	--	0.0149 (1740 cm^{-1})
C-1-Hot	0.058	0.042	--	0.012 (1740 cm-1)
C-2-Hot	0.033	0.013	--	0.005 (1740 cm^{-1})
C-3-Hot	0.036	0.006	--	0.011 (1740 cm^{-1})
C-3-Cold	0.009	0.007 (1740 cm^{-1})	--	0.007 (1740 cm^{-1})
C-4-Hot	0.020	0.002 (1740 cm^{-1})	--	0.013 (1740 cm^{-1})
C-5-Hot	0.014	0.006	--	0.007 (1740 cm^{-1})
C-6-Hot	0.019	0.010 (1740 cm^{-1})	--	0.011 (1740 cm^{-1})
C-6-Cold	0.070	0.009	0.007	0.009 (1740 cm^{-1})
C-7-Hot	0.051	0.016	0.014 (1740 cm^{-1})	0.003 (1740 cm^{-1})
C-7-Cold	0.020	0.015	0.007	0.017 (1740 cm^{-1})

*N.D. = Not Detected

Oxidation Induction Time (OIT)

The oxidation induction time (OIT) was measured on ten of the pipe samples at 200°C per ASTM D3895 [4]. This test is a relative measure of the amount of antioxidant still remaining in the pipe after extrusion and service. OIT was measured at the core of the tubing samples in order to ascertain whether residual levels of anti-oxidant still exist in the samples. The core OIT's are shown in Table 4.

Table 4. Core OIT Measurements on PB Samples at 200°C

Sample (Building-Unit)	Core OIT at 200°C, minutes
B-2-Hot	19.1
A-3-Hot	35.6
A-5-Hot	30.8
C-1-Hot	30.4
C-2-Hot	45.0
C-3-Cold	55.1
C-4-Hot	54.2
C-6-Hot	24.5
C-7-Cold	54.0
C-7-Hot	8.8

OIT testing is significant because it demonstrates that there is still antioxidant present after more than 18 years of service. This is consistent with observations made in some of the FTIR spectra of the presence of antioxidant at the core and the inside surface (at 1740 cm^{-1}). The lower value for the hot water pipe from Bldg. C - 7 is likely due to the fact that this unit was above a unit that had a fire and the pipe sample had smoke damage on the outer surface of the pipe and likely was exposed to higher temperatures. The 20 to 50 minute values indicate that a substantial portion of the antioxidant remains in the pipes to protect them from oxidation.

Quick Burst Tests

Quick burst tests were performed on several of the PB pipe samples. These tests were performed according to ASTM D1599 [5]. This test method determines the maximum pressure that will fail a plastic pipe when the pressure is ramped from zero to the burst pressure within 60 to 70 seconds. The minimum requirements for PB pipe and fitting assemblies are 440 psi at 23°C and 250 psig at 82°C [2]. All of the PB pipe samples tested far exceeded these minimum requirements at both temperatures, as shown in Table 5, demonstrating that the 18-year-old pipe still meets the ASTM burst requirement for new, unused PB pipe.

Table 5. Quick Burst Test Results on PB pipe Samples

Sample (Building-Unit)	Test Temperature, °C	Burst Pressure, psig
C-3-H-1	23.0	674
C-1-H-1	23.0	692
C-2-H-1	23.0	685
C-4-H-1	23.0	715
B-1-H-1	23.0	712
A-2-H-1	23.0	641
ASTM D 3039 Minimum Requirement	23.0	440
C-1-H-2	82.2	309
C-6-H-1	82.2	310
A-2-H-2	82.2	318
ASTM D 3039 Minimum Requirement	82.2	250

Sustained Pressure Tests

Hydrostatic stress rupture tests are being performed on samples of the PB pipe removed from the apartment complex. This testing is above and beyond the required 1000-hour sustained pressure tests called out in ASTM D3309 for the pipe. Testing was initiated on the PB pipe samples following the protocol in ASTM D 2837 [6]. In this case testing was initiated to obtain an E-2 data set (per Plastics Pipe Institute TR-3 [7]) to demonstrate how the 18-year-old PB pipe compares to the stress rupture data for new, unused pipe.

The E-2 data set includes a minimum of 10 data points with failure times ranging from 10 to more than 2000 hours. This data was then analyzed according to the procedure in ASTM D2837 to estimate the hydrostatic design basis (HDB) for the PB samples. The data were plotted on a graph with 107,000 hours of long term hydrostatic test data obtained on new, unused PB pipe that was reported by Springborn Laboratories in 1995 [8] (Figure 3). This testing continued for more than 3000 hours and established that the long-term sustained pressure performance of the pipe is comparable to or better than published data on new, unused PB pipes. The pipes have surpassed the expected failure times at the test hoop stresses, as shown in Table 6 below.

Table 6. Hydrostatic Pressure Test Results

Sample	Test Pressure, psig	Hoop Stress, psi	Test or Failure Time	Remarks
2921-6-H-2	475	2334	3051.2	On Test
2921-5-H-1	475	2334	3051.2	On Test
2905-6-H-1	475	2334	3051.2	On Test
2905-3-H-2	490	2438	3051.2	On Test
2905-4-H-1	490	2438	3051.2	On Test
2905-6-H-2	490	2441	3051.2	On Test
2921-2-H-2	507	2525	3053	On Test
2921-5-H-2	507	2525	3053	On Test
2905-3-H-1	507	2525	3053	On Test
2921-7-H-1	525	2648	935.0	On Test
2905-4-H-2	550	2778	35	Failure between 21 and 50 hours
2921-4-H-2	560	2711	53	Failed

CONCLUSIONS

Based on the site inspection, examination and testing of PB samples that were removed from the apartments (detailed above) and experience in plastic pipe materials performance, the PB piping system in this apartment complex appeared to be in excellent condition and had not degraded to any significant extent during its 18 years of service. The pipe samples appear to have met the ASTM requirements for dimensions and burst strength. It is anticipated that the pipe will also perform as well as new pipe in the long-term pressure tests that are under way. There is no evidence of any significant oxidation of the pipe and OIT measurements demonstrate that the PB pipe is still well protected by antioxidants.

The PB compound used in the Qest and Vanguard piping at the site was PB4137, a compound manufactured by Shell Chemical that had approximately twice as much stabilizer as the earlier PB compounds that were used in PB piping, and thus, should have approximately twice the life expectancy. Data from Shell suggests that the lifetime of PB in a plumbing system at 1 ppm free chlorine (higher than that measured on-site) should have a projected lifetime of 88 years, if the daily hot water consumption is 6 hours per day [9]. According to a Stevens Institute of Technology report, the average hot water usage in single-family homes in the U.S. is less than 1 hour per day. The lifetime calculation goes up to 170 years if the hot water usage is 2 hours per day. The OIT and FTIR measurements on these PB pipe samples confirm that the pipe has not degraded as a result of their 18 years in service. In addition to the good properties exhibited by the pipe, the installation of the system was very good. The pipes were properly restrained and did not appear to be severely bent or stressed. The piping is not routed through any attic spaces either, which eliminates any additional heating from the environment. The crimping of the fittings was also according to manufacturer's specifications in terms of outer diameter and position.

The PB plumbing system should continue to perform well into the future. It is very hard to predict when and if a plumbing system will develop a leak, since there are many potential causes of leaks. This plumbing system should continue to perform as well or better than any plumbing system that has been in service for 18 years. We have seen no evidence of material defects or degradation that should shorten the lifetime of this system. Excessive stress on PB pipe can lead to failure in some cases. We did not observe any evidence that excessive stress was applied to the PB piping in this system. In fact, as stated above, the installation was very good. However, we cannot rule out the fact that there may be a few pipes that are highly stressed and could possibly leak at some time in the future.

References

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3. K. Karlsson, G.D. Smith and U.W. Gedde, *Polym. Eng. & Sci.* **32**(10), 649 (1992).
4. ASTM D3895-07, "Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry," *2011 Annual Book of ASTM Standards, Volume 08.02,* ASTM International, West Conshohocken, PA.
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6. ASTM D 2837-11, "Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products," *2010 Annual Book of ASTM Standards, Volume 08.04,* ASTM International, West Conshohocken, PA.
7. PPI TR3 / 2010 / HDB / HDS / PDB / SDB / MRS Policies, *Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Hydrostatic Design Stresses (HDS), Pressure Design Basis (PDB), Strength Design Basis (SDB), and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe,* Plastics Pipe Institute, Irving, TX (2010).
8. Springborn Laboratories Project 2621.30 Test Report (107,000 hour level), to Shell Oil Company, March 21, 1995.
9. Shell Oil Company, private communication.

Figure 1. Typical layout of PB piping in a first floor apartment.

Figure 2. Typical layout of PB piping in a second floor apartment.

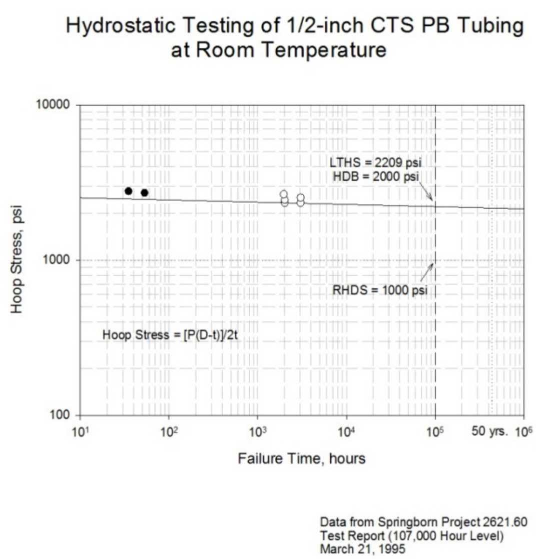

Figure 3. Hydrostatic pressure test results (symbols) superimposed on results of testing of new, unused PB pipe (line).