EROSION STUDY ON
BRASS INSERT FITTINGS
USED IN PEX PIPING SYSTEMS

TN-26

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Foreword

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The purpose of this technical note is to provide information on a test program to evaluate the effects of flowing water on copper alloy insert fittings used in crosslinked polyethylene (PEX) hot and cold water distribution tubing systems, and to provide information to aid in the design of PEX plumbing systems sized using model plumbing codes.

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EROSION STUDY ON BRASS INSERT FITTINGS
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1.0 INTRODUCTION

Many PEX plumbing systems are installed using some form of insert fitting, primarily produced from engineered polymers, as well as brass or other copper alloys. Because the insert portion of the fitting has a smaller diameter than the tube, the velocity of the water through the fitting is higher than the velocity of the water in the tube. Therefore, PEX systems delivering the same volume of water will have higher flow velocities in the tube and fittings than copper systems of the same nominal tube size.

Many plumbing codes have maximum recommended flow velocities for copper or copper alloys to prevent erosion of the material by the flowing water. Millions of brass insert fittings have been installed in PEX plumbing and heating systems over the past 40 or more years in Europe and North America. In that time, we are unaware of any erosion-induced failures of PEX piping systems.

To evaluate the subject of erosion corrosion of PEX copper alloy fittings, the Building & Construction Division of the Plastics Pipe Institute funded a test program at Materials Performance Inc. (MPI) in College Station, TX for performance testing of several designs of brass alloy PEX fittings. This testing was conducted in 1997 and 1998, but the findings are still considered relevant today.

Note 1:   PE-RT tubing was not part of this study because it was not in use in North America during this time. It has since been approved in model plumbing and mechanical codes in the USA. PE-RT tubing is produced to the same dimensions as PEX tubing and product standards from ASTM International and CSA Group allow it to be approved for use with the same types of fitting systems and materials as PEX tubing. Brass fittings complying with the standards listed in this TN may also be used with PE-RT tubing.

2.0 OBJECTIVE

The objective of this test program was to subject various brass insert fittings for PEX plumbing systems to flow velocities of hot, chlorinated water that represented the maximums that could occur if a plumbing system was sized according to the 2000 version of the IAPMO Uniform Plumbing Code.

Testing at these velocities continued until the accumulated volume was equivalent to 40 years of service in a typical single family residence.

The test was intended to demonstrate that these fitting designs and materials would resist erosion corrosion and flow-accelerated corrosion in typical residential plumbing applications.

3.0   TECHNICAL DEFINITIONS

The following definitions are provided for reference:

Corrosion: Chemical attack on the surface of a metal, forming a more stable ionic material, most commonly the electrochemical oxidation of metal through attack by oxygen, chlorine, sulfur, or other oxidizing agents.

Erosion: The process of gradual destruction of a material or surface through wear or surface abrasion, sometimes caused by excessive flow velocities in piping systems.

Erosion Corrosion: Degradation of a surface due to mechanical action coupled with a secondary corrosion element. Often caused by abrasion from suspended solids, cavitation, or turbulent fluid flow wearing away the passivation layer protecting an underlying material and causing rapid damage to the material through both physical wear of the material and further chemical attack.

Flow-accelerated Corrosion: A corrosion mechanism occurring when fast flowing fluid dissolves the passivation layer on metal surfaces and the metal again creates a passivation layer which is subsequently dissolved and the cycle repeats, resulting in rapid damage to the metal through bulk dissolution in the fluid stream.

pH: *potential of Hydrogen*, a measure of acidity or alkalinity of water. A pH value is a number from 0 to 14, with 7 defined as neutral. Values below 7 indicate acidity with increasingly acidic solutions as the number decreases, with 0 being the most acidic. Values above 7 indicate alkalinity which increases as the number increases, with 14 being the most alkaline or "basic". The scale is logarithmic, with each number change indicating the solution is ten times different from the prior number (i.e. a pH of 3 is ten times as acidic as a pH of 4)."

"Lead-free" fitting: a fitting made of a material with a weighted average of not more than 0.25% lead calculated across the wetted surfaces of a pipe fitting, plumbing fitting, or fixture. Lead cannot be added intentionally to such materials. See Section 1417 of the 2014 Safe Drinking Water Act (SDWA) of the United States.

4.0 TEST DESCRIPTION

The test program given to the lab is listed in Appendix. It is considered to be aggressive relative to most plumbing installations for the following reasons:

4.1. The water temperature was maintained at 140°F (60°C) for the duration of the test. In a normal residential plumbing system, some flows occur at lower temperatures on the hot-water side of the system because the water temperature decreases when the line is not in use.

4.2. In the test, the total volume of water was flowing at the elevated temperature. In a normal residential system, the total flow for the structure is divided between the hot and cold sides of the system. The only fittings that actually have the total volume of the water being used by a residence passing through them are the fittings on the cold-water inlet line before flow splits at the water heater.

4.3. The pH of the water was maintained between 6.5 and 6.7. This pH is corrosive to most metals and is lower and more aggressive than the average pH of 7.7 found in public water systems.

4.4. The water velocity used for the entire life of the test assumed all fixtures on a line would be open to their maximum flow capacity at the same time. In normal systems, usually only a small percentage of the maximum possible flow is experienced at one time, so most of the water flows at velocities that are much lower than the possible maximum.

4.5. The chlorine level of the water was maintained between 2.5 and 3.0 ppm for the duration of the test. The average chlorine level for public water systems in the U.S. is approximately 1.1 ppm. It would be an unusual circumstance for a residence to experience chlorine levels equal to the test condition for an extended period of time.

Three different fitting types, based on alloys and manufacturing techniques for use with PEX tubing, were tested:

- Fittings machined from brass rod Alloy C36000 produced to ASTM Standard Specification F1807
- Fittings machined from forged brass Alloy C37700 produced to ASTM Standard Specification F1807
- Fittings machined from forged brass Alloy C37700 produced to ASTM Standard Specification F1960

Note 2: Brass fittings made to ASTM Standard Specification F2080 were not included in the study reported in this TN. However, brass fittings made to ASTM F2080 have the same inside diameter and are produced from the same brass alloys as are used for ASTM F1960 brass fittings. Therefore, the conclusions based on test results for F1960 fittings would be expected to be the same for F2080 fittings.

Note 3:   The brass alloys tested were not "lead-free" alloys as per current requirements of the 2014 Safe Drinking Water Act (SDWA) of the United States, NSF/ANSI/CAN Standard 61, and other applicable regulations.

Note 4:   PPI is aware of unpublished academic research that indicates the commonly-used low-lead alloys used for fittings for use with PEX tubing do not appear to be more prone to erosion corrosion than the leaded alloys that were included in this study.

The total water flow through each size fitting during the test is listed below:

Nominal Tube Size	Water Flow
3/8	700,125 gallons
1/2	1,400,250 gallons
3/4	4,200,750 gallons

The water velocities for each type of fitting are listed below:

Nominal Tube Size	ASTM F1807	ASTM F1960
3/8	19.3 ft/sec	13.8 ft/sec
1/2	16.7 ft/sec	13.4 ft/sec
3/4	21.8 ft/sec	16.7 ft/sec

The results are tabulated and illustrated in the following tables and graphs:

Table 1   Weight loss of 3/4 fittings at end of test
Table 2   Weight loss versus gallons of flow through 3/4 elbows
Table 3   Weight loss of 1/2 fittings at end of test
Table 4[1]   Weight loss of 3/8 fittings at end of test

Because the 3/4 fittings had the highest flow velocities, the 3/4 elbows were selected to be checked for weight change at 1,000,000 gallon intervals during the test. As would be expected, the weight loss did trend up as the amount of water flowing through the fittings increased.

The fittings of each type with the largest weight loss were sectioned and examined for signs of pitting. There were no signs of localized pitting that would indicate a probability of early fitting perforation due to localized material loss.

Because of the very aggressive conditions during the test, a section of 3/4 PEX tube was also evaluated for any dimensional changes at the end of the test. There was no measurable change in dimensions of the PEX tube.

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[1] Table 4 does not have any nominal tube size 3/8 fitting data from F1960 type fittings because they were not available at the time of the test.

5.0   <u>RESULTS</u>

None of the brass insert fittings for PEX systems failed during this test. Observed weight losses after testing were less than 3% for all fittings. Internal diameter increases due to erosion were less than 1%.

Nominal tube size 3/4 copper sweat elbows with straight pieces of copper tube attached were subjected to the same condition as the 3/4 brass insert fittings for PEX, and these did not fail either.

6.0   <u>CONCLUSIONS</u>

The water conditions chosen for this test were at the severe end of normal potable water conditions, in terms of temperature, pH and chlorine concentration, and yet the results indicate that very little erosion occurs at these test conditions.
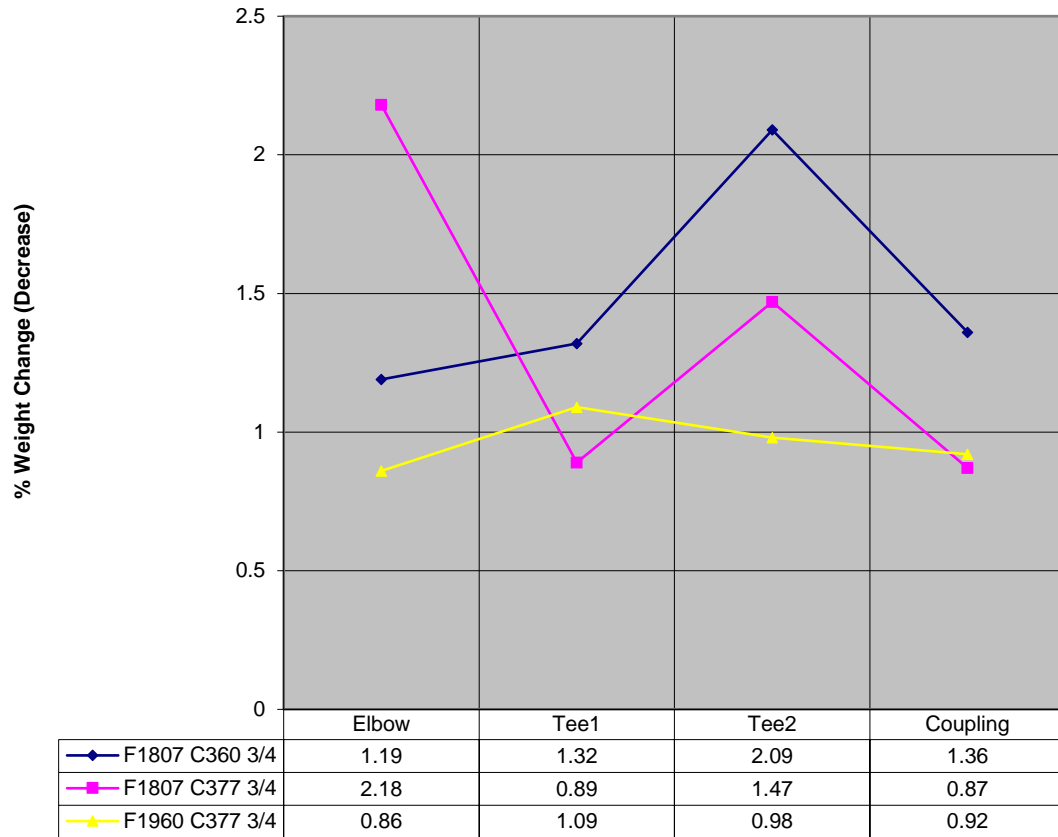
The water flow rates were the maximum that should be experienced when all fixtures on a given line are open and flowing at capacity. No failures of fittings occurred.

Based on these results, it seems unlikely that PEX plumbing systems using brass insert fittings, sized according to the tables in the Uniform Plumbing Code for copper tubing, will fail from erosion of the fittings caused by high water velocities in typical residential plumbing applications.
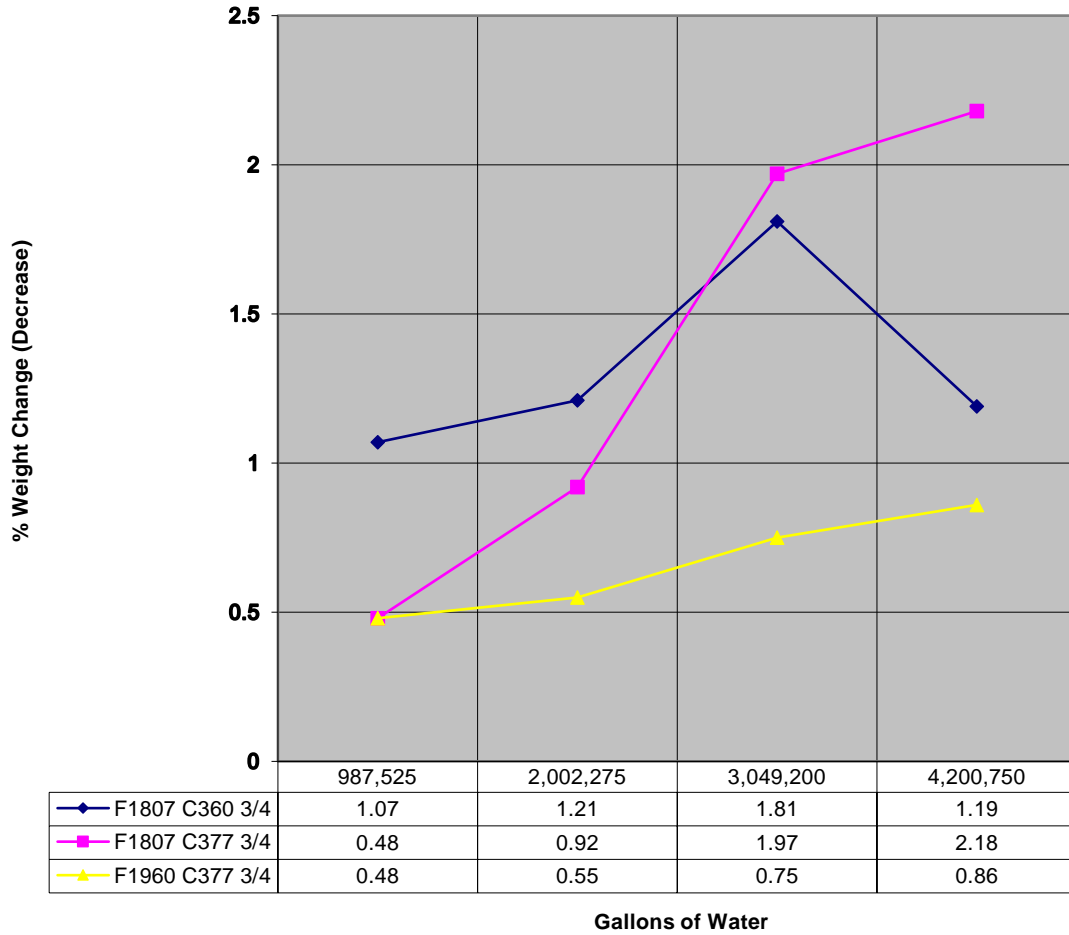
In other words, failures due to internal erosion of brass insert fittings in PEX plumbing systems would not be expected over a normal lifetime of a plumbing system. PEX tubing systems with brass insert fittings can be sized according to the tables published in the model plumbing codes without undue concern for erosion of the fittings in typical plumbing applications.

Table 1: % Weight Loss vs Fitting Type 3/4 Fittings

	Elbow	Tee1	Tee2	Coupling
F1807 C360 3/4	1.19	1.32	2.09	1.36
F1807 C377 3/4	2.18	0.89	1.47	0.87
F1960 C377 3/4	0.86	1.09	0.98	0.92

Fitting type

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Table 2: % Weight Loss vs Gallons Through 3/4 Elbows

	987,525	2,002,275	3,049,200	4,200,750
F1807 C360 3/4	1.07	1.21	1.81	1.19
F1807 C377 3/4	0.48	0.92	1.97	2.18
F1960 C377 3/4	0.48	0.55	0.75	0.86

Gallons of Water

Table 3: % Weight Loss vs Fitting Type 1/2 Fittings

	Elbow	Tee1	Tee2	Coupling
F1807 C360 1/2	0.75	1.29	1.65	1.68
F1807 C377 1/2	1.28	1.61	1.27	1.63
F1960 C377 1/2	0.95	0.91	0.89	1.04
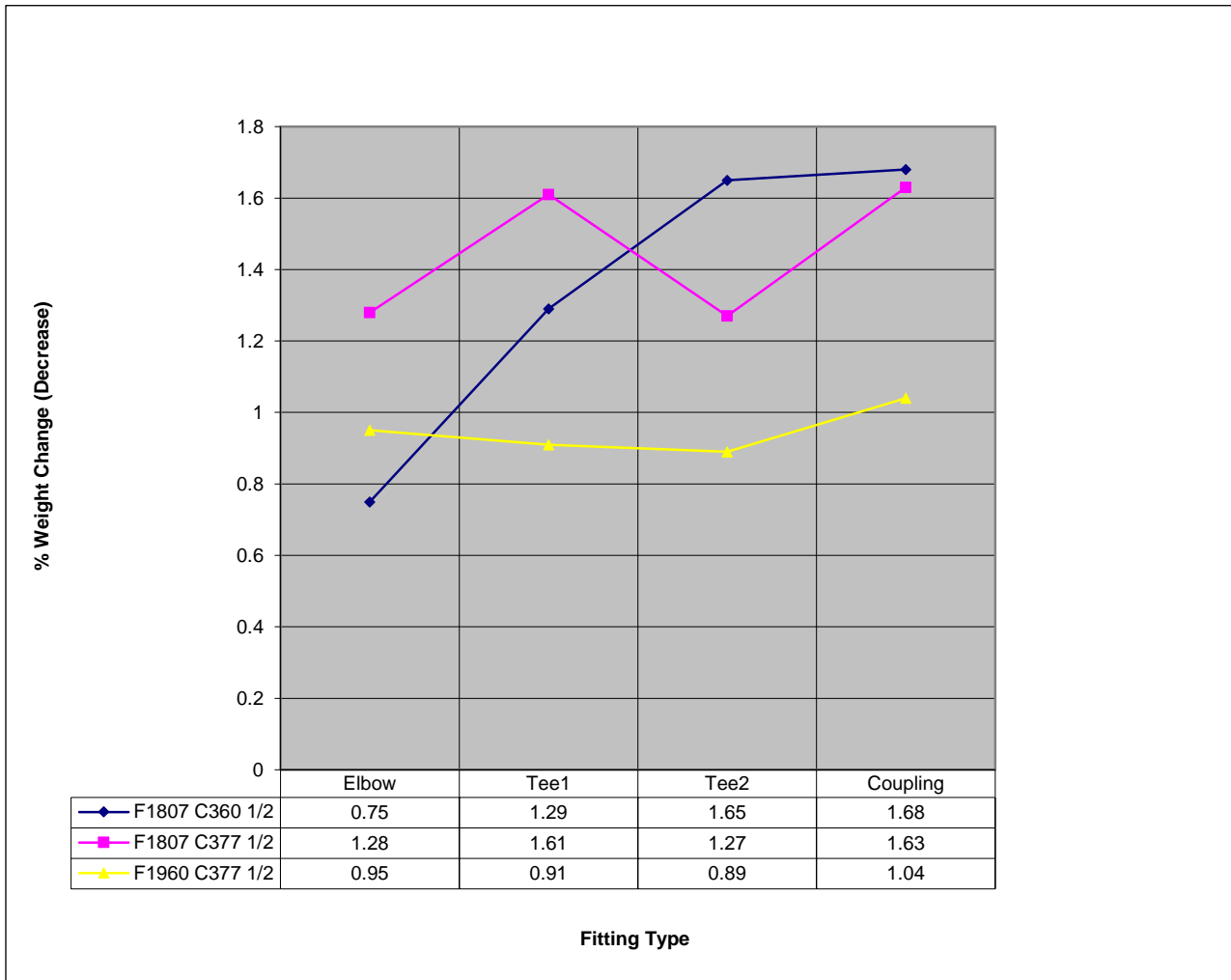
Fitting Type

Table 4: % Weight Loss vs Fitting Type 3/8 Fittings

	Elbow1	Elbow2	Tee1	Tee2	Coupling
F1807 C360 3/8	0.85	0.98	1.77	1.2	1.67
F1807 C377 3/8	0.93	0.64	1	1.71	1.86

Fitting Type
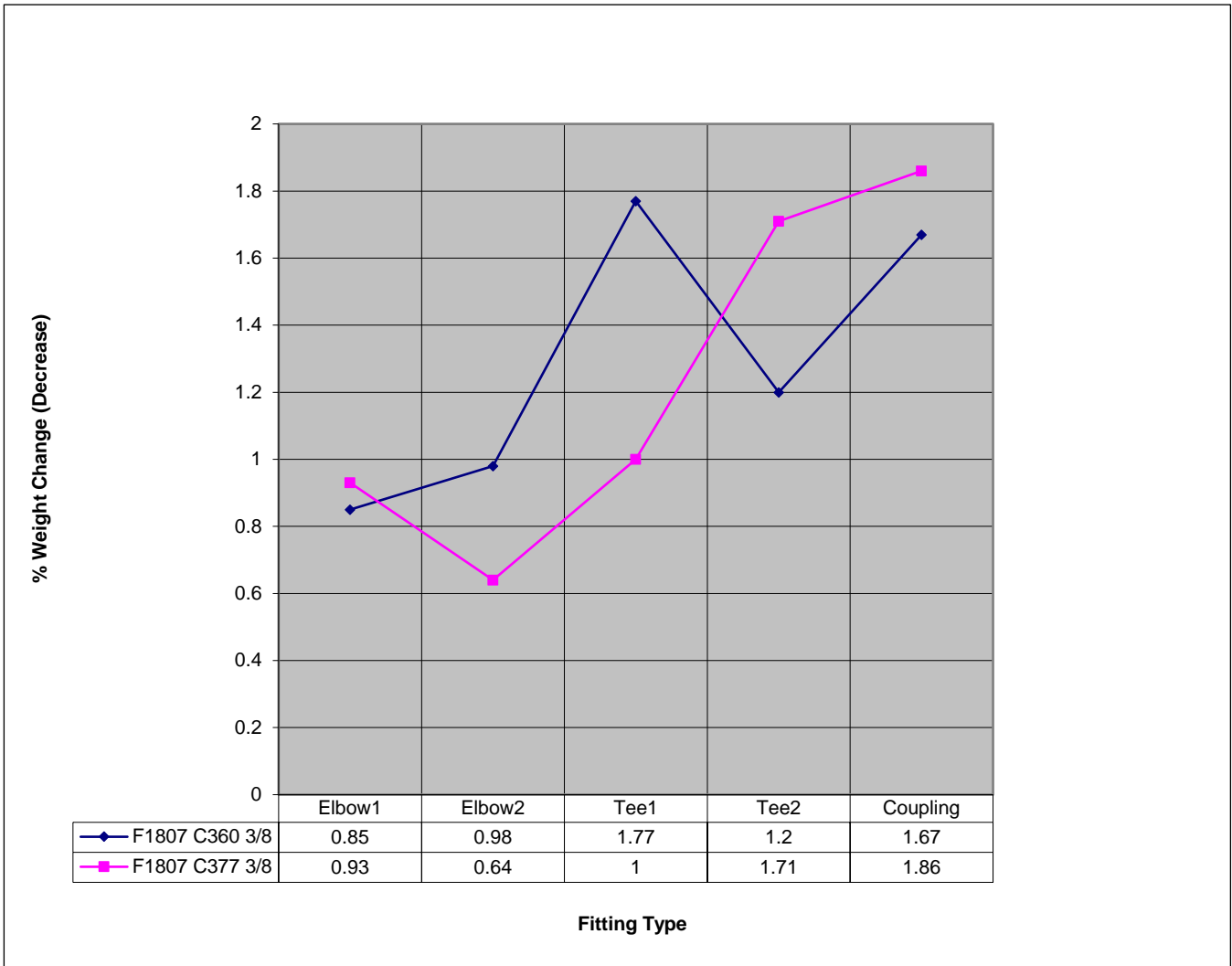
APPENDIX

Plastics Pipe Institute HTD Project 97-03 Revision 1, 10-08-99

Flow Erosion Test for PEX Fittings

Objective

The objective of this test procedure is to see if the water flow that might be experienced in a typical, non-recirculating plumbing system will cause failure of the metal fittings that are used in PEX plumbing systems in a reasonable lifetime. We will also check to see if there is any erosion evident in the PEX tube during this test.

Test Description

A system will be set up with fittings of all sizes and common geometries. Hot water will be circulated through the fittings at flow rates that result from sizing a plumbing system according to the Uniform Plumbing Code. The amount of water circulated will be equivalent to the average household usage for 40 years based on most recent usage information from AWWA and household population information from the U.S. Census Bureau. After testing, the fittings will be examined for signs of erosion and weighed to determine the percentage weight loss.

Water Temperature

The circulating water temperature will be 140°F at the inlet to the system. The exit temperature for any loop will not be below 135°F.

Water Quality

The pH of the water will be maintained between 6.5 and 6.7. The chlorine level will be maintained between 2.5 and 3.0 ppm. These values may be converted to ORP values for control purposes. The water shall be "Moderately Hard" as determined by one of the following measures. The hardness shall be between 3.6 and 7 grains per gallon, or the $CaCO_3$ shall be between 75 and 150 mg/l. The water shall be filtered using a potable water sediment filter. The filter shall have a nominal rating of 50 microns. To minimize the possibility of unexpected changes in water quality due to mineral or other chemical build ups, 5 gallons per hour of the circulating water should be replaced with make-up water.

Water Flow Rates

The water flow rates are taken from Table 6-4 in the Uniform Plumbing Code which gives the capacity of tubes of various lengths in Fixture Units. The maximum value shown for a size is the value that is used. Nominal tube size 3/8 is not covered in this table. For 3/8, we used the maximum Fixture Unit device that is shown to be acceptable for connection to a 3/8 tube which is 3 for a flush tank toilet in Table A-2. All values for fixture units are for private use. The Fixture Unit values were then converted to GPM by using Chart A-3.

Nominal Tube Size	WSFU	GPM
3/8	3	2.5
1/2	7	5
3/4	20	15

Water Volume

The volume of water to be passed through the fittings must be enough to simulate 40 years of service. The WaterWiser web page of the AWWA, updated in 1999, gives the average daily use per person as 72.5 gallons. The U.S. Census Bureau shows that the average household has slightly less than 3 people in it. To be conservative, we will assume a household with four people. This gives a total volume of 4,234,000 gallons used in 40 years. This will be the amount of water that must be passed through the 3/4 fittings.

With a flow rate of 15 GPM, 24 hours a day, 7 days a week, it will take 28 weeks for 4,234,000 gallons of water to pass through 3/4 fittings.

Using this length of time, the following amount of water will be passed through the 3/8 and 1/2 fittings at their target flow rates:

- 3/8 705,600 gallons
- 1/2 1,411,200 gallons

Water Velocities

Using the minimum inside diameters (ID) published in the fitting standards, the following water velocities (ft/sec) will occur in the fittings at the flow rates required by this test.

Nominal Tube Size	F1807 Brass	F1807 Copper	F1960 Brass
3/8	19.3	19.3	13.8
1/2	16.7	16.7	13.4
3/4	21.8	21.8	16.7

Data to be taken at Start of Test

For each fitting tested, the following information will be recorded:

- The ID of each insert portion of the fitting in thousandths of an inch (note if there is a smaller ID other than the insert portion of the fitting)
- The weight of each fitting to the hundredths of a gram

Other information to be recorded for each system:

- The weight of the copper assembly
- Wall thickness in 4 places on each end of a piece of nominal 3/4 tube
- Make a 3-inch long mark along the tube length at the location of each measurement; this tube will be cut out at the end of the test and the wall thickness will be checked at these marks

Installation Requirements

Each fitting shall be installed in PEX tube according to the manufacturer's instructions. The distance between any fitting and the next one must be at least 30 tube diameters except for the two 3/8 elbows. These two fittings should only have a distance of 2 inches between the insert portion of the fittings.

If the PEX tubing is bent or curved, no fitting shall be closer than 30 tube diameters downstream of the bend. The direction of flow through each fitting shall be marked on the fitting. A schematic of a typical set-up for a fitting system is shown in Figure 1. Other arrangements could be used.

Fittings to be Tested

At a minimum, two tees, an elbow and a coupling of each size, from each material from each standard shall be tested. One of the tees will be tested with flow in the straight through direction and the other will be tested with flow coming in the straight through direction and out the branch. For the nominal 3/4 size, 3 additional elbows will be installed in the system. One of these will be removed after 1 million gallons of water flow and the others will be removed at 2 and 3 million gallons of water flow.

If other fittings are required for plumbing the system and they will experience the flows, they will be included in the test. They should be kept in "systems". With flow metering valves and flow meters it is possible to have flow through the 3/4 fittings first with some diverted to flow through 1/2 fittings and some diverted to flow through the 3/8 fittings.

In addition to the fittings for PEX, we will test a 3/4 copper elbow assembly in each system. The assembly will consist of a 3/4 sweat x sweat elbow with 24 inch long pieces of Type M copper sweated into the fitting. The tube ends shall be reamed as recommended by the Copper Development Association and a flux and solder suitable for potable water applications shall be used. To connect this assembly to the PEX tube, sweat adapter fittings shall be used that are the same type as the other fittings in the system.

Data to be Taken During and at the End of the Test

If any fitting starts to leak because of a hole being eroded through the fitting, remove the fitting from the test and record the amount of water that had passed through the fitting to that point. Continue to test the other fittings to the completion of the test.

After the required amount of water has flowed through the fittings, carefully remove each fitting from the system. If saws are used, care must be taken not to nick or cut the fitting since this will affect the weight after testing.

Record the following information:

- The ID of each insert portion of the fitting in thousandths of an inch
- The weight of each fitting to the hundredths of a gram
- Calculate the percentage weight change for each fitting
- Visually inspect each fitting for signs of erosion (record any signs observed)
- For each system, section the fitting with the highest percentage weight loss and check for localized pitting. Take photos of each half of the fitting. This step is only at the end of the test
- The weight of the copper assembly
- The wall thickness of the 3/4 PEX tube at the locations marked at the start of the test after cutting off the portion that had been attached to the fitting

Remove fittings at the following times:

1. After 1 million gallons – one 3/4 elbow
2. After 2 million gallons – one 3/4 elbow
3. After 3 million gallons – one 3/4 elbow
4. At end of test – all other fittings

When fittings are removed for weights at the intermediate points, they should be replaced by like fittings of the same style.

Report

The report shall contain the following information:

- Description of test set-up including temperature controls, water quality controls and the source of the water
- A schematic of the test set-up
- Tables of all measurements and weights taken
- Tables of all calculated weight change percentages
- Photos of the sectioned fittings
- If no fittings leak because of erosion, a statement to that effect

Table A.1: Table of Fittings to be Tested For One System

Quantity	Description
1	3/4 X 3/4 Coupling
2	3/4 X 3/4 X 3/4 Tee
4	3/4 X 3/4 Elbow
1	3/4 X 1/2 X 3/4 Tee
1	3/4 X 3/4 X 3/8 Tee
1	1/2 X 1/2 Elbow
2	1/2 X 1/2 X 1/2 Tee
1	1/2 X 1/2 Coupling
2	3/8 X 3/8 X 3/8 Tee
2	3/8 X 3/8 Elbow
1	3/8 X 3/8 Coupling
1	3/4 Copper Assembly
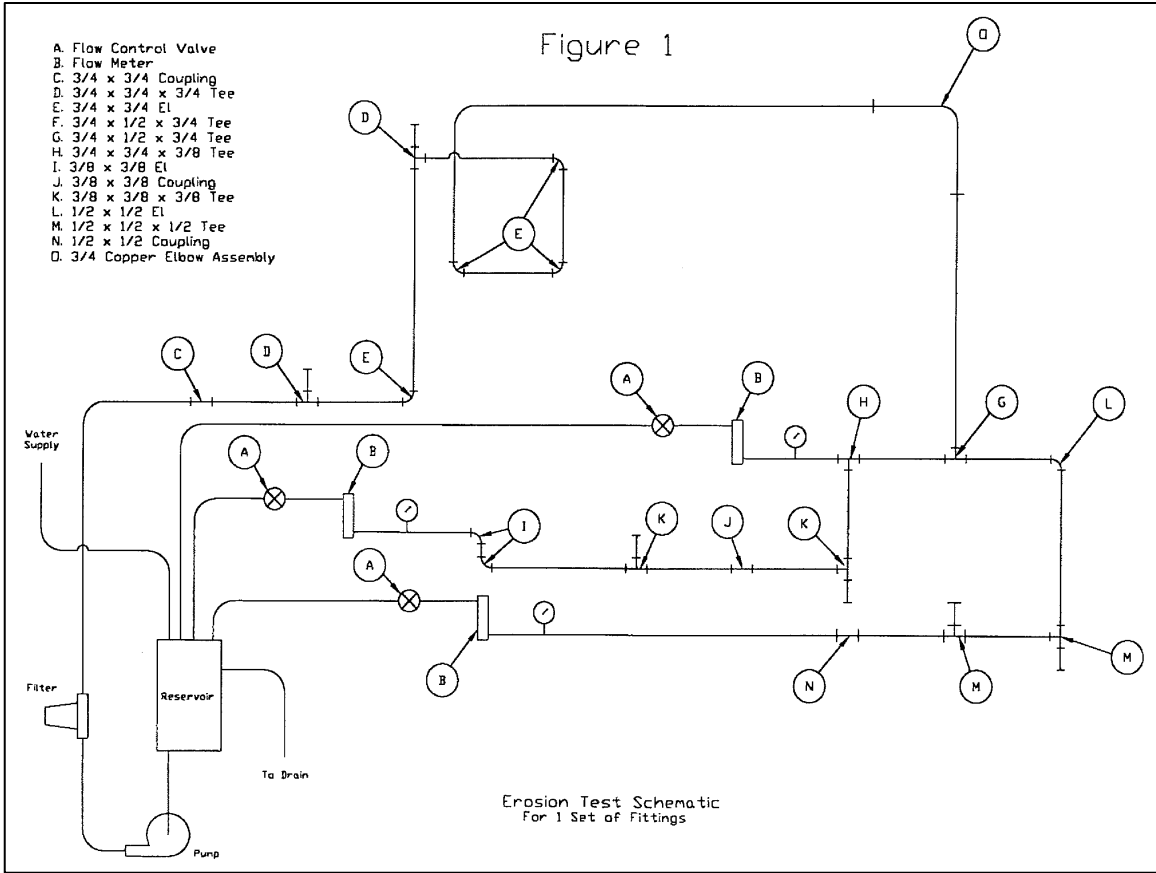
Figure A.1: Erosion Test Schematic for 1 Set of Fittings