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Why Do PVC & CPVC Pipes Occasionally Fail?

By Dr. Duane Priddy, Plastic Failure Labs, Midland, MI

Preface

PVC and CPVC pipes and fittings are excellent products and have been used successfully for decades. There is a low failure rate and the use of PVC/CPVC materials offer significant advantages over metal piping materials including ease of installation and very low failure rates. I am not aware of any health cautions regarding the usage of PVC/CPVC pipes and fittings other than the need to install them properly without using incompatible materials during the installation. However, as with all plumbing products including metal piping, occasionally a pipe or fitting may fail. When a failure does occur, our experience indicates that most often the failure can be linked to improper installation practices. The intent of this article is to provide assistance regarding installation errors to avoid and thereby reduce the occurrence of a failure in PVC and CPVC plumbing. Again, let me emphasize that by teaching about the main causes of occasional failure of PVC and CPVC pipes and fittings, I am in no way suggesting that these plumbing products are less reliable or more prone to failure than any other plumbing material. Further, I am outraged by the misuse of my teachings by some to attack PVC and CPVC plumbing products as being inherently unsafe. If I were to build a home for my own family, I would use as much plastic plumbing in my home as possible to keep the costs to a minimum while providing my family with a safe living environment.

Most of the Main Causes of CPVC/PVC Pipe Failure Listed Below are Discussed in this Article

I. Improper System Engineering/Installation
   - A. Inadequate provision for linear thermal expansion
   - B. Excess use of Cement
   - C. Insufficient amount of Cement
   - D. Wrong Clamps used or Clamps too tight
   - E. Incompatible fire caulk used
   - F. Contact of outside of pipe with incompatible material (e.g., solder flux)

II. Improper Operation
   - A. Exposure to freezing temperatures without freeze protection
   - B. Over-pressurization
   - C. Pulsating water pressure
   - D. Use of incompatible materials around pipes

III. Contamination
   - A. Internal
     1. Use of contaminated antifreeze
     2. Contaminants from metal water supply piping; e.g., antimicrobial (MIC inhibitor) linings, corrosion inhibitors, phthalate plasticizers from pump seals/gaskets, refrigeration system lubricants
   - B. External
     1. Incompatible Fire Caulk
     2. Use of incompatible (black Proset) grommets to seal pipe against hole in concrete

3. Contact with incompatible plastic coated wires
4. Exposure to hot solder flux
5. Exposure to hot polyurethane foam insulation

IV. Manufacturing defects
  A. Dirty extrusion die
  B. Incomplete resin consolidation
  C. High stresses in pipe wall due to rapid cooling

V. Resin Defects
  A. Occlusions, char particles, voids
  B. Filler/pigment not well distributed

IV. Abuse by Distributor
  A. Store in sun
  B. Damage during transport

Introduction

PVC and CPVC pipes are one of the most extensively used plastic piping materials. The main reason for the great success of these pipes is their low cost, extremely low failure rate, and relative ease of installation. However, as with all piping materials, there are occasional failures. Occasional failures may be caused by a number of factors however improper installation is generally the most common cause when PVC and CPVC pipes fail.

Plastic Failure Labs is an independent forensic laboratory. We have been conducting forensic failure analyses of plastic parts for several years. We have carried out hundreds of forensic failure analysis investigations of CPVC and PVC pipes and fittings at the request of insurance companies, installers, pipe manufacturers, general contractors, condominium associations, and private owners. We have found that the overwhelming/most common cause of failure is improper installation practices. Sometimes installation errors result in contamination, although these two issues are not always related. The combination of pipes under stress plus the exposure to incompatible materials, can lead to environmental stress cracking failure or ESC. This is especially the case with CPVC sprinkler system piping if not adequately flushed as recommended in NFPA 13 to remove debris and trace chemicals. If CPVC fire sprinkler systems are not flushed, trace chemicals remain trapped inside for periods of time and may become absorbed into the CPVC. CPVC is a very ductile material. However, the combination of prolonged high stress and absorption of certain hydrocarbon contaminants may cause it to weaken and develop stress-cracks (Figure 1).

The most common causes of occasional failure of PVC and CPVC pipes and fittings are listed in Table 1. Also included in the table are common techniques that are used to detect the listed causes. There are many tools available to the forensic scientist but the most commonly used tools are optical microscopy, scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FT-IR), and gas chromatography-mass spectroscopy (GC-MS).

Figure 1. Formation of a stress-crack on the inside of a CPVC fire sprinkler pipe at a point where a tight-fitting clamp was used.

Table 1. Six main causes of occasional pipe failure and testing methods generally used for diagnoses:

Type of Failure	Root Cause of Failure	Tests
Improper installation	excessive cement	sectioning & inspection
	insufficient cement	sectioning & inspection
	wrong clamp used	site inspection
	clamps too far apart	site inspection
	clamps too tight	out-of-round/clamp marks
	no allowance for thermal expansion	site inspection
	pipes not properly aligned	site inspection
	short insertion	sectioning & inspection
	Pipe end not deburred	sectioning & inspection
	Pipe end not chamfered	sectioning & inspection
	non-square pipe cuts	sectioning & inspection
	wrong antifreeze used*	FTIR
Contamination	Incompatible thread sealants	FTIR/GC-MS
Chemical Compatibility	Incompatible thread cutting oils	FTIR
	Phthalates from gaskets/seals	GC-MS
	Incompatible MIC inhibitor	FTIR/ESI-MS/GC-MS
	Incompatible antifreeze*	GC-MS/FTIR
Product defects	pipe dimensions wrong	
	resin not fully consolidated	SEM
	weak extrusion knit-lines	
	dirty die creating extrusion lines	black light
	voids or particulates	OM/SEM/EDS
	residual stress due to rapid cooling	OM

Resin defects	resin MW too low	MI
	filler content wrong	TGA
	additives/pigments dispersion	SEM/EDS
	chlorine content wrong**	EA
Improper operation	water hammer	OM/SEM
	over-pressurization	OM/SEM
	area contamination	GC-MS/IR
	freezing	OM
Abuse by distributor	store in sun	IR
	damage during handling/transport	OM
	*unique to fire sprinkler pipes	
	**unique to CPVC	

Key: *OM=optical microscopy; IR=infrared microscopy; GC-MS=gas chromatography-mass spectroscopy; SEM/EDS=scanning electron microscopy/electron dispersive spectroscopy; EA=elemental analysis; DSC=differential scanning calorimetry; TGA=thermal gravimetric analysis*

Improper Installation

Excessive cement use: An installation problem that we occasionally see is the use of excessive cement. The solvents in the cement themselves are readily absorbed into CPVC and PVC; i.e., they readily are absorbed into the wall of the pipe and inside fitting socket resulting in solvation/softening of the material. Figure 2 shows a short piece of pipe with a fitting on each end having excess cement puddled inside the short piece of pipe. The solvents in the cement absorbed into the pipe wall resulting in softening of the pipe wall to the point that the pipe wall became swollen/softened and no longer had sufficient strength to hold water pressure resulting in blowout.

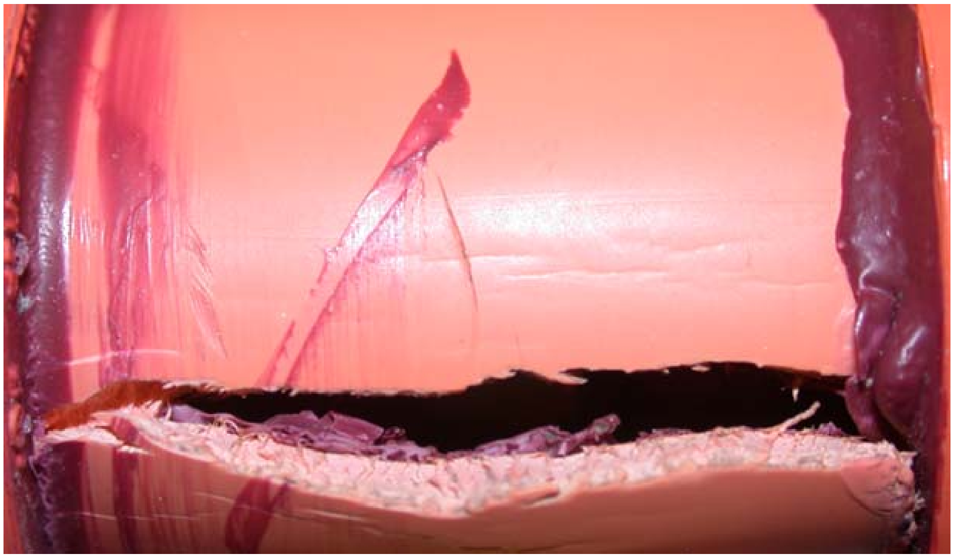

Figure 2. Puddling of excess cement inside of fitting ran into adjacent pipe resulting in softening and blowout of the pipe wall.

However, absorption of the solvents in the cement into the top layer of plastic in the pipe and fitting socket is necessary to achieve good bonding. The organic solvents in cement soften the surface of the pipe and fitting socket allowing the polymer molecules to intertwine to form a permanent bond. The organic solvents in the cement are volatile and quickly evaporate so that they are only around long enough to do their intended job but not long enough to cause the pipe to weaken. The problem is that occasionally installers utilize too much cement resulting in dribbles running down the inside of vertical runs of pipe. We have observed environmental stress cracks (ESC) both underneath (Figure 3) and adjacent (Figure 4) to cement dribbles. It is not known for certain exactly why ESC failures of pipes occasionally occur underneath or adjacent to cement dribbles. One theory is that the cement is porous and absorbs trace hydrocarbon contaminants present in the water and facilitates their absorption into the wall of the pipe. Another theory of the ESC cracking of CPVC immediately adjacent to a cement dribble is that the drying/shrinkage of the cement creates adjacent stresses on the inside surface of the wall of the pipe.

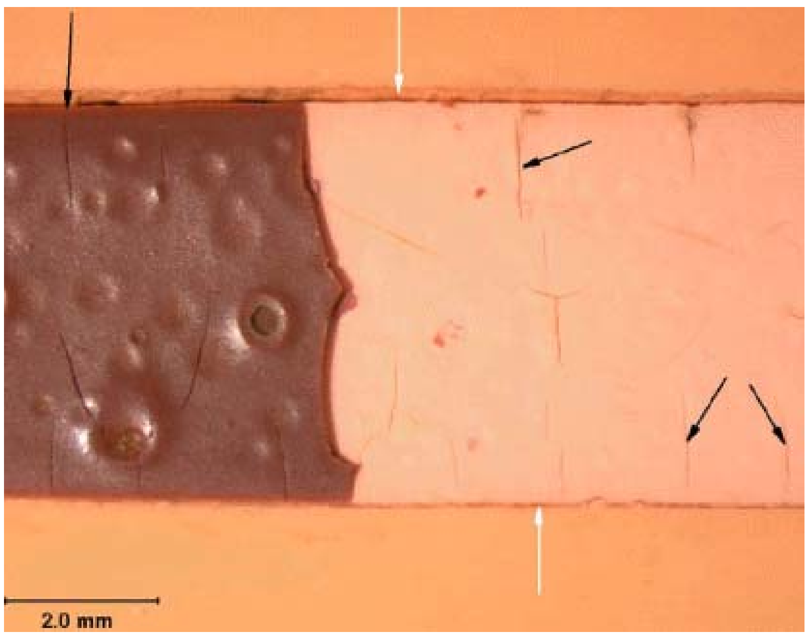

Figure 3. ESC of the inside surface of the wall of the pipe underneath a cement dribble

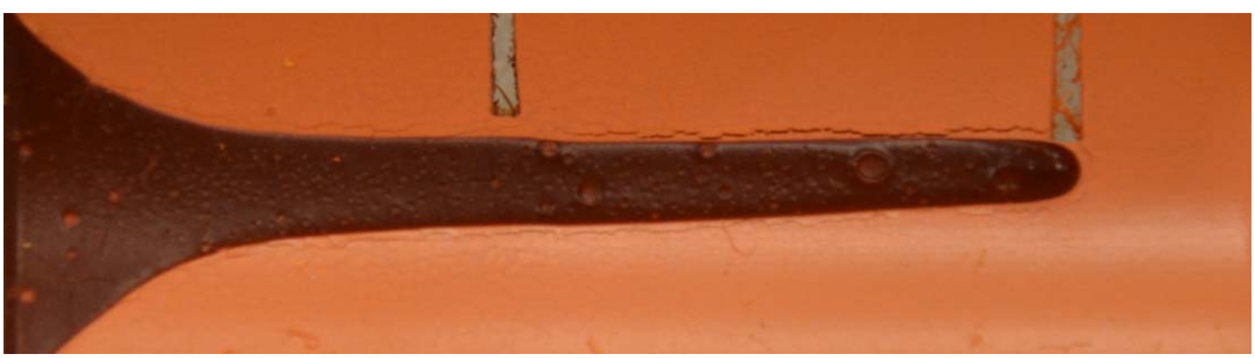

Figure 4. Cement dribble on inside of CPVC pipe with ESC cracks found around the periphery of the dribble.

When excessive cement is used on the outside of pipe it is not as much of a problem as on the inside. This is because, on the outside, the volatile organic solvents quickly evaporate. However, on the inside of the pipe, the organic solvents are trapped allowing more exposure time of the inside wall of the pipe to the solvent. By applying the excess cement to the end of the pipe, but not the fitting, when the pipe is inserted into the fitting, the excess cement is pushed down the outside of the pipe forcing the excess to the outside of the pipe. If excess cement is applied to the inside of the fitting, the excess ends up remaining trapped inside the fitting and either puddles inside the fitting or else runs down the inside of the pipe (Figure 4). It is generally quite easy to spot whether a fitting was assembled using a sufficient amount of cement by simple examination of the cement residue in the crevice between the fitting and the pipe as shown in Figure 5.

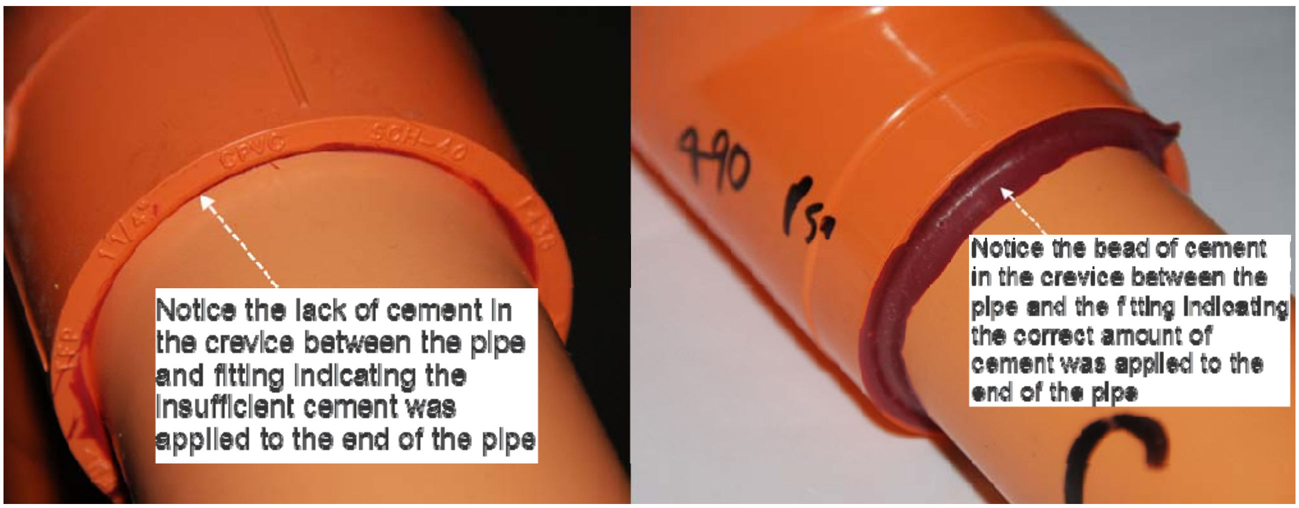

Figure 5. Photos showing the external appearance of a bad (left) and a good (right) joints.

<u>Insufficient cement use:</u> Sufficient cement must be applied to end up with complete coverage of the end of the pipe and the inside of the fitting so that a continuous bond is formed between the pipe and fitting surfaces. If insufficient cement is used, voids may form in the bond between the pipe and fitting. The presence of the voids results in a weakened assembly which may result in water leaking from the joint. *Note: We have developed a technique to non-destructively examine fittings to determine if voids exist between the pipe and fitting or if complete bonding has taken place. If desired, one of our forensic engineers can travel to a site and analyze suspect fitting assemblies to determine if voids are present in the bonded joints.*

Charlotte Pipe & Foundry's PVC/CPVC installation manual* recommends the following procedure for cement application:

> *"Apply a heavy, even coat of cement to the outside pipe end. Apply a medium coat to the fitting socket. Apply a second cement application on the pipe end. It is important to insure sufficient penetration of the solvent cement into the pipe and fitting surface(s) by wiping the cement with the dauber until the pipe markings have been removed from the pipe surface. Usually 3-5 rotations around the pipe with the dauber are sufficient to achieve proper softening. Immediately insert the pipe into the fitting socket completely to the stop, while rotating the pipe 1⁄4 turn."*

*note: always check with the pipe and fitting manufacturer for the most up-to-date instructions, as written instructions may be updated from time to time.

Deburring/Chamfer of Pipe Ends
When a pipe is cut, it should be cut square and any residue (burrs) that forms on the end of the pipe during the cutting operation should be removed. Further, the sharp outer edge on the end of the pipe should be rounded or chamfered. The rounded edge allows the cement placed on the inside of the fitting socket to be more evenly distributed as the pipe is inserted into the socket as well as helping to achieve complete insertion each time.

Incorrect Clamps and Contact with Conduit/Wire: Another very common cause of occasional failure is the use of the wrong type of support which places stress on the pipe. Also bending conduits around PVC or CPVC pipe can place high localized stress on the PVC/CPVC pipes in contact with the conduit. Some electrical wires, especially computer cables, should not be allowed to come into contact with PVC or CPVC pipes because the outer flexible sheath may contain plasticizers which can migrate into the pipe resulting in weakening and failure of the pipe. Figure 6 shows a photograph of a CPVC fire sprinkler pipe installation revealing contact of the pipe with electrical wire and a conduit – both should be avoided.

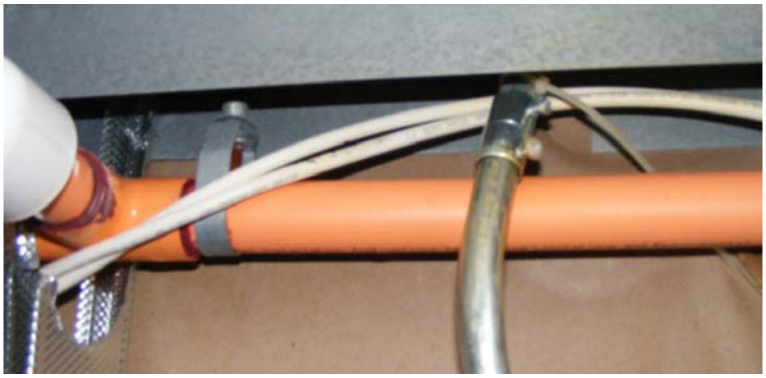

Figure 6. Picture of installation showing direct contact of conduit and electrical wires with CPVC pipe.

Thermal expansion: Most plastic pipes have a much higher coefficient of linear thermal expansion (CLTE) than non-plastic materials. The high CLTE of PVC/CPVC pipes must be compensated for during installation, especially in environments where large temperature changes are likely. The normal way to allow for thermal expansion is by installation of expansion loops in long runs of piping and the use of loose fitting or roller hangars that allow for slippage. A qualified system engineering professional should be consulted to ensure that the system is properly engineered to accommodate the possible temperature fluctuations encountered by the system and that proper expansion capabilities are incorporated into the system.

Freezing: The failure of CPVC fire sprinkler pipes due to freezing is not very common because the sprinkler pipes are normally located in tempered areas. Nonetheless, occasionally CPVC fire sprinkler pipes do freeze. If there is a chance of exposure of fire sprinkler pipes to freezing temperatures, it is important to fill the pipes with glycerin solution. High purity glycerin and propylene glycol solutions are the only antifreeze solution recognized as acceptable by the NFPA (NFPA 13:Section 7.6.2). Again, a highly experienced engineering professional should design the piping system to ensure that appropriate freeze protection is incorporated into the system.

Diagnoses of the failure of CPVC pipes due to freezing is a challenge. If CPVC pipes break due to radial expansion of ice inside a CPVC pipe (Figure 7), diagnoses is quite simple because the pipe generally expands causing the wall thickness to decrease and go out of spec (Figure 8). However, researchers at the University of Illinois found that generally when pipes freeze, radial expansion is constrained by the pipe wall forcing the ice to expand longitudinally. The linear expansion of the ice causes a pressure build-up between the ice plug and the outlet or inlet valve. It is the high pressure that causes the failure. This discovery led them to receive several patents (US 5,730,168, US 5,785,072, and US 5,785,073) on devices that protect pipes from failure due to freezing.

Figure 7. Picture of frozen CPVC pipe.

The frozen pipe shown in Figure 7 was thawed and then cut longitudinally in half by sawing through the pipe wall 180 degrees away from the fracture surface. Simply measuring the thickness of the pipe wall at the fracture surface and comparing the wall thickness 180 degrees opposite, reveals a large difference (Figure 8). The difference is cause by the slow tensile stretch and yielding/necking at the point of fracture. The yielding/necking at the point of fracture results in the thinning of the material at the point of fracture.

Figure 8. Wall thickness at fracture is significantly smaller than 180^{o} opposite.

<u>Pipe alignment</u>: Pipes must be installed without excessive bending deflection stresses on the pipe. Pipe manufacturer's instructions should be followed regarding the maximum allowable bending deflections of their pipes. Excessive bending deflection may lead to failure of both the pipe and the fittings to which the pipes are connected. Elbow and Tee fittings are subject to creep failure in the crotch (Figure 9) if pipes are not installed in 90 degree alignment.

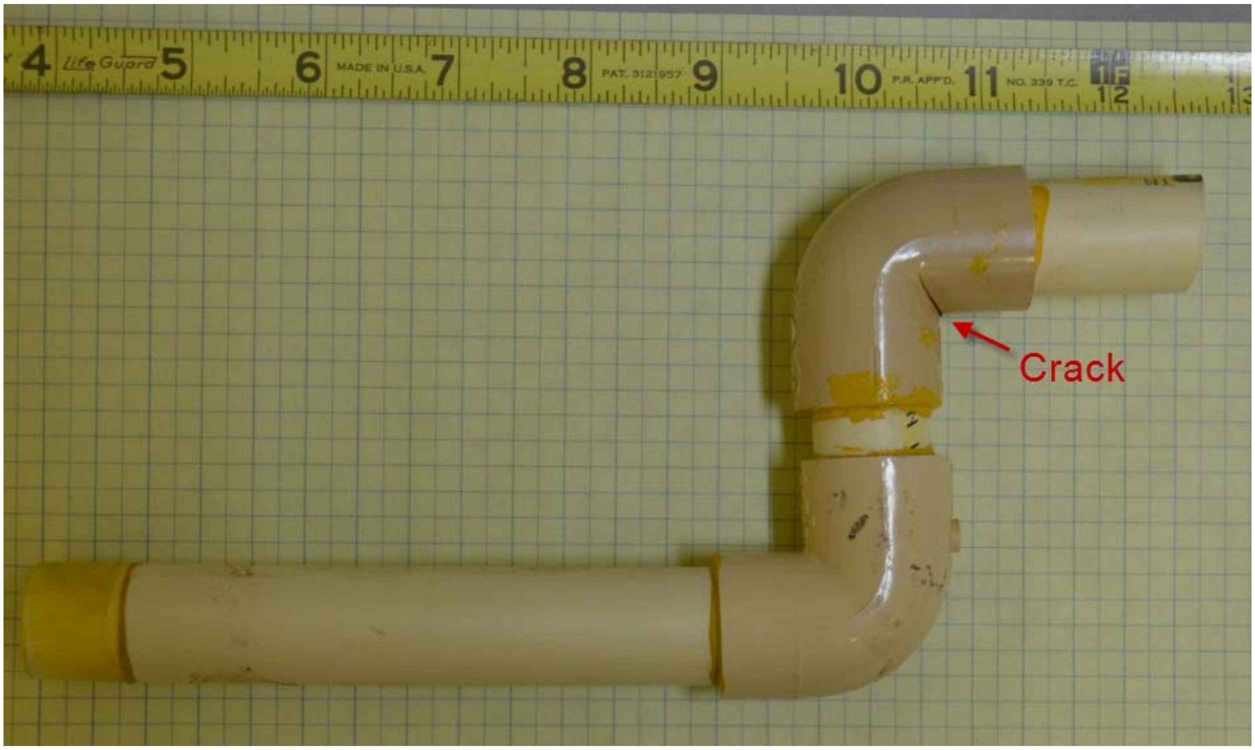

Figure 9. Pipes installed out of alignment placing high stress on the crotch of an elbow resulting in creep failure.

<u>Short insertion</u>: When PVC/CPVC pipes are inserted into fittings they should be inserted all of the way until the end of the pipe hits the stop. If they are short inserted, a pocket remains between the end of the pipe and the stop. This is a place where ESC failure may occur. The gap acts as a place where contaminants may accumulate and eventually ESC of the fitting take place. Recently we were involved in diagnosing the root cause of failure of two large hydronic heating systems having the recirculation loop constructed using CPVC pipes and fittings. Five fittings were received for forensic analysis. All five fittings failed in exactly the same way. The failure was initiated in the space between the end of the pipe and the insertion stop in the fitting. The failure mode was ESC. The heat exchanger leaked resulting in contamination of the recirculated water with refrigerant lubricant oil (polyol ester) which became concentrated in the short-insertion space causing failure of the fitting by ESC (Figure 10). We recently presented the results of our failure analysis at the Failure Analysis Division of the Society of Plastic Engineers Annual Technical Conference held in Boston, May 2011. A copy of the paper is available upon request.

<u>Contamination - Exterior</u>: Care must be taken not to allow PVC/CPVC pipes to contact other materials that contain aromatic ester plasticizers and flame retardants. Figures 11 and 12 show examples of failure due to contact of CPVC with other materials that contain non-compatible plasticizers. Figure 11 was a pipe removed from a condominium where a worker sealed all of the openings in walls using a fire caulk that contained phthalate plasticizers. A drop of excess fire caulk fell down onto a CPVC fire sprinkler pipe. GC-MS analysis of the caulk and the failed pipe revealed the presence of phthalate ester plasticizers. Phthalate esters are highly incompatible with PVC/CPVC pipes.

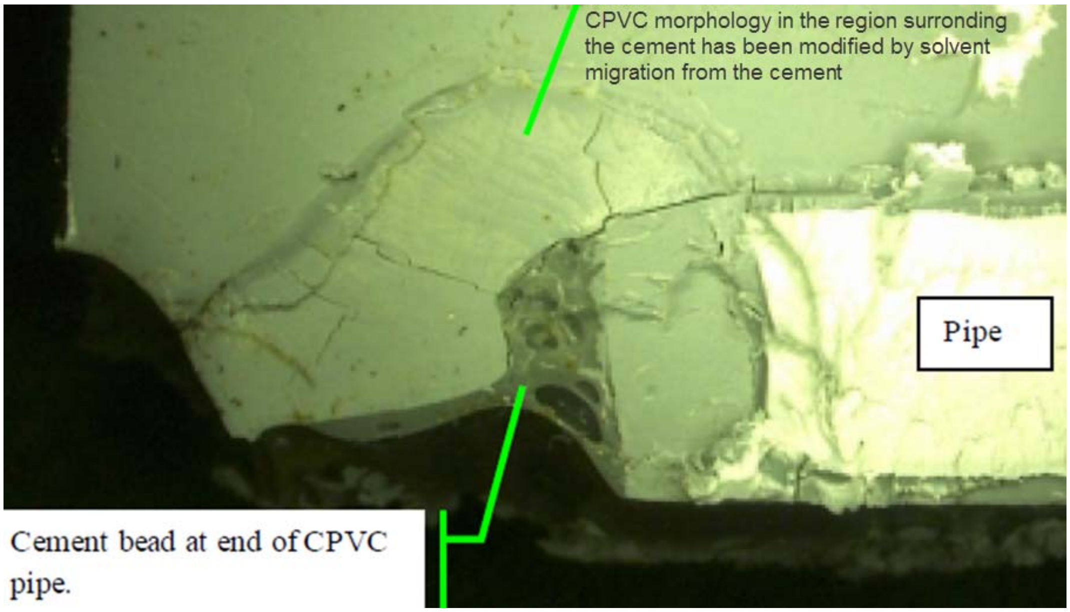

Figure 10. microscopic view of the fracture surface of a fitting removed from a hydroninc heating system. All of the fittings failed in exactly the same way; i.e., by absorption of lubricant oil from the refrigerant (due to a leak in the heat exchanger) into the pocket between the end of the pipe and the pipe insertion stop molded into the fitting socket.

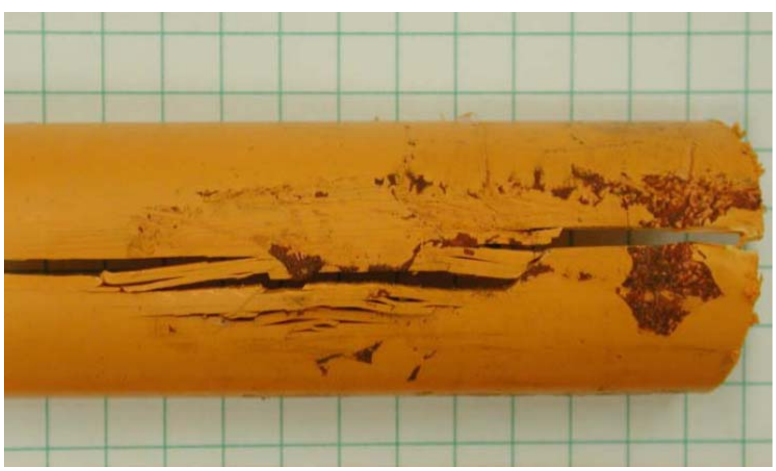

Figure 11. Failure of CPVC fire sprinkler pipe underneath fire caulk that fell on the exterior surface of the pipe.

Figure 12 shows an example of the failure of a CPVC potable water pipe where a black grommet (Proset) that was used to seal a PVC/CPVC pipe penetration through a concrete floor. It was well known that Proset black grommets are not compatible with PVC/CPVC because they contain phthalate ester plasticizers so metal foil tape was applied to the pipe as a prophylactic to protect the pipe from chemical contamination by the phthalate ester plasticizers in the grommet. Metal foil tape will likely not be sufficient to stop phthalate ester plasiticizers from migration from black Proset grommets. For the past few years, pipe manufacturers have strongly recommended against the use of such incompatible grommets and, as a result, ProSet now manufactures a white grommet which is compatible with PVC and CPVC pipes.

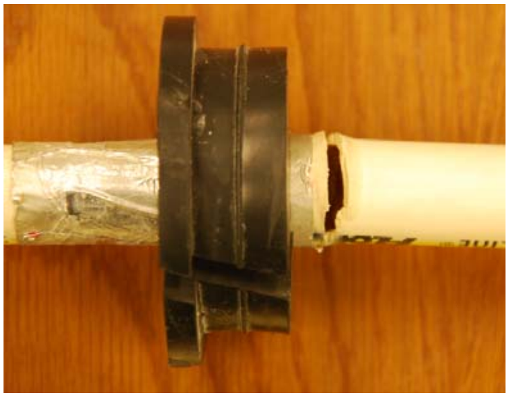

Figure 12. Failure of a CPVC potable water pipe due to migration of phthalate plasticizer from grommet down metal foil prophylactic used to protect the pipe.

Solder flux is another material that may contain chemicals that are incompatible with PVC/CPVC. If copper pipes are being soldered in the vicinity of PVC/CPVC pipes, hot flux can fall, spatter, or vaporize and condense on the outside surface of the PVC/CPVC pipes causing ESC failure.

Polyurethane spray foam (PUSF) insulation can be a problem. PUSF generates heat as it cures. If the heat is trapped by a thick layer of foam against the wall of the pipe, the heat can weaken and distort the pipe. Also, each PUSF manufacturer has formulations that contain additives such as fire retardants. Some of these formulations may not be compatible with PVC/CPVC. You should consult with the PUSF manufacturer before applying PUSF in spaces where it may contact PVC and CPVC pipes asking them if for their assurances of the chemical compatibility of their product with plastic piping materials. The CPVC pipe shown in Figure 13 is cracked. Examination of the crack surfaces in the leaking pipe shown in Figure 13 showed ESC failure by migration of chemicals from the outside surface of the pipe (Figure 14).

<u>Contamination – Interior:</u> Some products that are used in construction may contain chemicals that are not compatible with PVC/CPVC pipes and fittings. Therefore care must be exercised during installation to make sure that only approved materials (e.g., metal pipe thread sealants, cutting oils, fire caulks, antifreeze, antibacterial lined pipes, etc.) are used during installation. The Lubrizol Corporation is a global supplier of CPVC resin compounds which maintains the industry's only list of compatible products for use with pipe and fittings made from Lubrizol CPVC compounds. (see http://www.lubrizol.com/BuildingSolutions/ChemicalCompatibility.html)

Figure 13. CPVC pipe inside wall covered with PUSF.

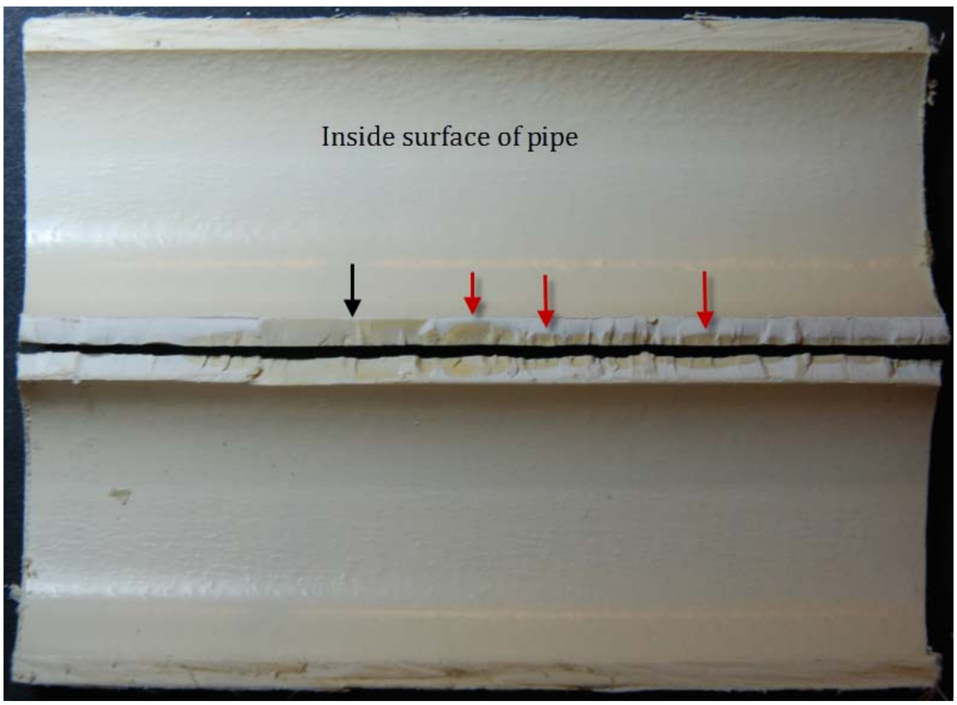

Figure 14. Close up view of the fracture surfaces showing distinctive thumbnail chemical penetration patterns from the outside wall of the pipe. Black arrow points to leak location and red arrows show thumbnail penetration zones that form as chemicals migrate into the outside wall of the pipe.

In fire sprinkler systems, generally steel piping is used to deliver the water to the CPVC portion of the system. Therefore, when internal contamination of the CPVC piping does occur, the most likely source of the contamination are the steel pipes. This is why it is important to thoroughly flush steel pipes before they are connected to CPVC piping. NFPA 13 installation instructions for fire sprinkler systems describes proper flushing procedures for steel pipes and specifies that the entire fire sprinkler system be periodically flushed.

Some anti-MIC or antimicrobial linings in steel pipes may contain traces of water extractible chemicals that are not compatible with CPVC. Figure 15 shows the effects of water containing various trace levels of an amine (didecylmethylamine, a contaminant often found in ABF-2) and its quaternary ammonium salt form on CPVC test specimens. Notice the extensive crazing and discoloration of the treated test specimens down as low as 0.001% or 10 ppm of amine leads to chemical attack and weakening of CPVC. Currently there are some MIC inhibitor products that have been approved by Lubrizol as being compatible with their Balzemaster CPVC pipes. The list continues to grow as additional products are tested and approved. Since it is not a static list, we suggest that you refer to the Lubrizol website for the most updated list (see http://www.lubrizol.com/BuildingSolutions/ChemicalCompatibility.html).

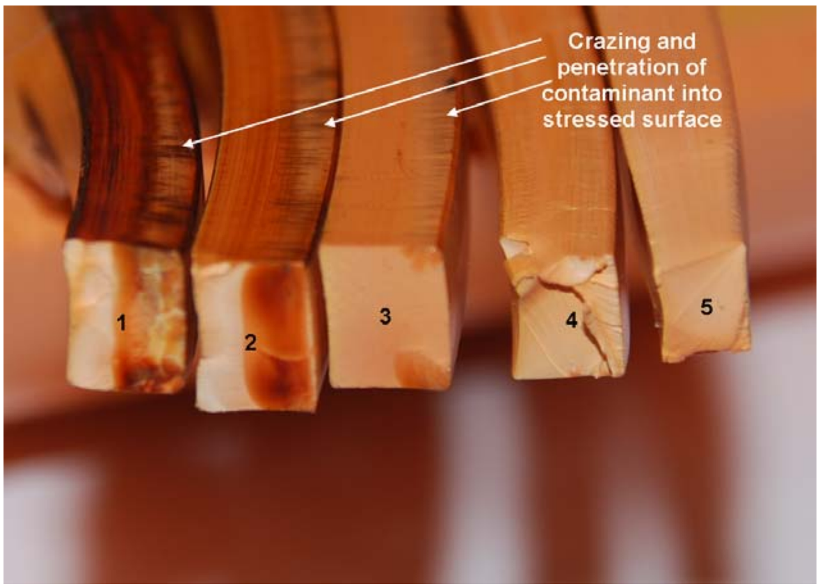

Figure 15. The effects (discoloration and crazing) of trace levels of chemical contaminants from ABF-II (amine and ammonium salt) on stressed CPVC test specimens. 1=0.1% amine in water, 2=0.01% amine in water, 3= 0.001% amine in water, 4=0.1% ammonium salt in water, 5=control.

We were the first to discover and express concern (in 2007) about the potential incompatibility of trace chemicals that may be extracted from ABF-2. This discovery has caused debate throughout the Fire Sprinkler Industry. Recently (3/30/10), FM Approvals completed a laboratory investigation of the issue. They identified extractible chemicals present in steel pipes having antimicrobial linings and performed chemical compatibility tests of the extracted chemicals with CPVC. The FM Approvals study concluded "in some cases degradation by reduction of "Elongation at Break" or Tensile Strength at Yield" was observed for CPVC specimens exposed for a maximum of 30 days to extracts from ABF/AMS coated steel pipe." This finding has also been challenged due to the way in which the chemical compatibility testing was conducted.

Internal Contamination by Refrigerant Lubricant Oil

PVC and CPVC piping is often used to recirculate the water in hydronic heating systems. Heat exchanger leaks are very rare. However, should a leak occur in a heat exchanger, the water in the recirculation loop may become contaminated with the oil lubricant in the refrigerant. Back when CFC was used as the refrigerant, the lubricant was mineral oil. When a leak occurred, no PVC or CPVC failure occurred because mineral oil is compatible with both PVC and CPVC. However, the change to HCFC refrigerants brought about the need to change to a more polar lubricant oil because mineral oil is not soluble in HCFC refrigerant. Most HCFC refrigerants utilize polyol ester oil (POE) as the lubricant. Unfortunately, POE oil is highly incompatible with PVC/CPVC (Figure 16) and leaks in heat exchangers can cause failure of the PVC or CPVC piping system (Figure 10). There is a need for hydronic heating system manufacturers to develop alternative refrigerant lubricants that are compatible with PVC and CPVC.

POE Exposure Time=0 POE Exposure Time=24 h

Figure 16. Exposure of a CPVC pipe test ring under stress becomes brittle after only a few hours of exposure to POE.

Pipe Defects

The manufacturing process of CPVC pipe is highly regulated with numerous required tests and standards. Plastic pipe is manufactured by extrusion of molten PVC/CPVC resin through a circular die with a mandrel held in place with thin metal vanes (often referred to as a “spider”). While passing through the die, the molten PVC or CPVC resin formulation is sliced by the mandrel vanes but then fuses back together again to produce a solid pipe. After the die, the pipe is cooled using a combination of air and water under controlled conditions so that the pipe does not end up with frozen in stresses which can affect the mechanical strength and chemical resistance of the pipe. Pipe defects, including residual stress, can result if the extrusion and cooling processes are not properly optimized. Pipes that contain high levels of frozen in stresses are like coiled springs looking for opportunities to relieve the stress. Stress relief can be achieved in several ways. One is by crazing which manifests itself by the formation of hundreds of tiny micro-cracks in the pipe wall. A pipe that has undergone extensive crazing in the pipe wall is shown in Figure 17. Extrusion lines (caused by a dirty die) create weak points in the pipe wall that are more susceptible to chemical attack resulting in failure by ESC. This mode of failure is indicated by the presence of perfectly straight parallel cracks running down the inside pipe wall (Figure 18). Pipes having these manufacturing defects are more susceptible to failure when exposed to water containing chemicals that are incompatible with the pipes and fittings.

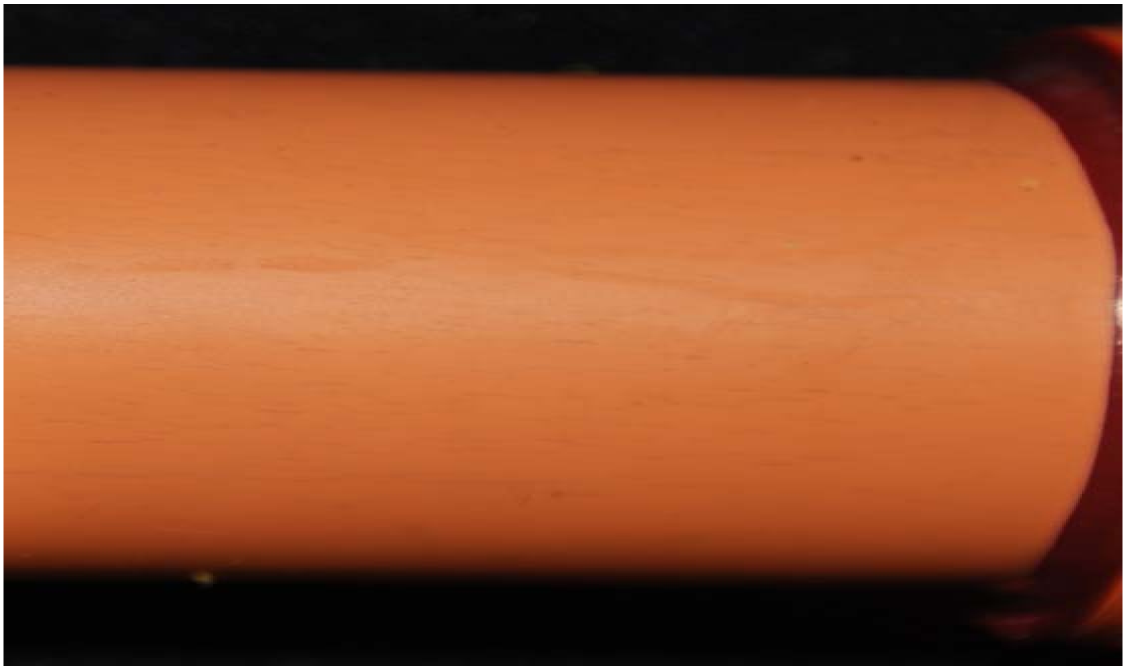

Figure 17. Extensive surface crazing of outside pipe wall.

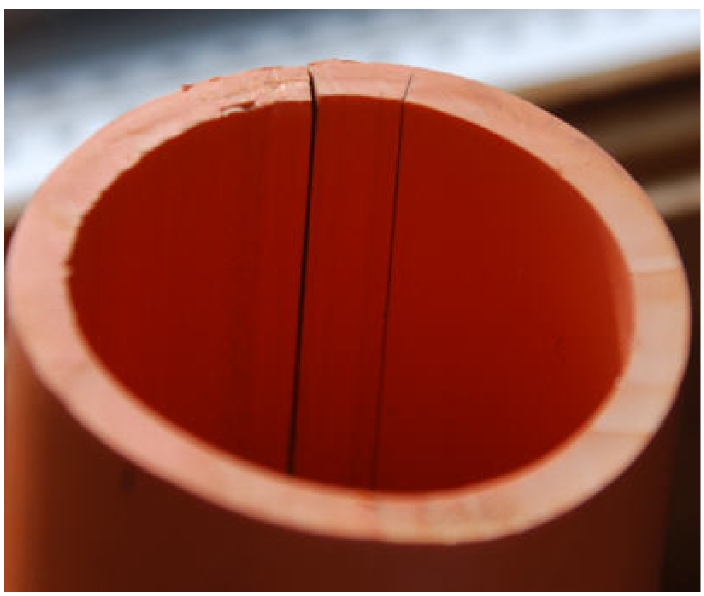

Figure 18. Weak extrusion lines (likely caused by dirty die) on the inside surface of a CPVC sprinkler system pipe resulting in the formation of parallel straight cracks upon exposure to water containing contaminants.

Forensic Failure Analysis Process

PVC/CPVC pipes and fittings are excellent products and have been used successfully for decades. There is a low failure rate and the use of PVC/CPVC materials offer significant advantage over steel piping materials. I am not aware of any health cautions regarding the usage of PVC/CPVC pipes and fittings other than the need to install them properly without using incompatible materials during the installation. If you are having a cracking problem with PVC or CPVC pipes, Plastic Failure Labs can analyze the pipes and/or the installation and diagnose the root cause of the problem. We are also highly experienced providing expert witness services should the pipe failure lead to litigation.

Our goal is to diagnose the cause of failure efficiently and quickly. In general, we carry out a laboratory examination of the pipes including measurement of pipe dimensions, examination of the pipe surfaces for physical damage, examination of the pipe surfaces for the presence of contaminants, examination of the crack fracture surfaces using optical or digital microscopy, and ASTM testing of the pipes.

Duane Priddy, Sr. is the founder and CEO of Plastic Failure Labs. The company is a leading provider of plastic consulting, expert witness, and plastic failure analysis services. Prior to starting Plastic Failure Labs, Dr Priddy was a Principal Scientist for Dow Plastics where he was involved in helping solve problems with plastic manufacture and plastic failure for over 30 years. Partially due to Dr. Priddy's pioneering forensic investigations of PVC/CPVC failure, he was recently awarded "Fellow" of the Society of Plastic Engineers. Please feel free to contact Dr. Priddy anytime by phone (989.385.2355) or email at priddy@plasticfailure.com.