Why PVC & CPVC Plastic Fail?

January 26

2010

With over 100 plastic failure analysis studies commissioned and decades testifying as an expert for litigation surrounding PVC and CPVC plastic failures, CPC Plastics, Inc. explains why PVC and CPVC Plastics Fail and how we have helped our clients resolve their own PVC and CPVC plastic issues.

A culmination of decades of our work studying PVC & CPVC Plastic Failures

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History of Polyvinyl Chloride (PVC) Thermoplastic Polymers

Accidently discovered in the 1800's, reportedly twice, first in 1835 by H.V. Regnault and in 1872 by E. Baumann, where in both occasions the scientist found that white solids had formed inside flasks of vinyl chloride that had been left exposed to sunlight. However, it was not until the early 20th century that scientist began to investigate the viability of Polyvinyl Chloride (PVC) for commercial use, where they found it difficult to process the rigid and sometimes brittle polymer.

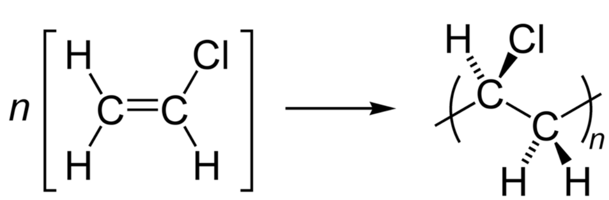
Then in 1926, reportedly Waldo Semon and the B.F. Goodrich Company developed a method of plasticizing PVC with various additives in their attempt to make a more flexible, processable, and commercially viable [*plastic*] material.

What is Polyvinyl Chloride (PVC)?

Polyvinyl chloride, generally abbreviated PVC, is a thermoplastic polymer. As seen in Figure 1 below, PVC is a vinyl polymer constructed of repeating vinyl groups (ethenyls) with one of their hydrogen's replaced with a chloride group. Since its commercialization in the early 1920's, PVC is the third most widely produced plastic, after polyethylene and polypropylene. Over 50% of PVC manufactured is widely used in construction industries because it is cheap, durable, and easy to assemble.

PVC is highly customizable and can be made softer and more flexible with the addition of plasticizers, the most common and widely used in Phthalates. However, recent and ongoing concerns surrounding the effects of long-term exposure to phthalates has resulted in new methods of plasticizing PVC. Today, PVC is widely used to make flexible hoses and tubing, plastic pipes and fittings, electrical insulation, waterbeds, pool toys, etc.

Figure 1 – The Polymerization of Vinyl Chloride



What is Chlorinated Polyvinyl Chloride (CPVC)?

Chlorinated polyvinyl chloride (CPVC) is a thermoplastic produced by chlorination of polyvinyl chloride (PVC) resin. CPVC is PVC (polyvinyl chloride), chlorinated by means of a free radical chlorination reaction. Typically, thermal or UV energy initiates this reaction, where decomposed chlorine gas creates free radical chlorine, which is then reacted with PVC in a post-production step, essentially replacing a portion of the hydrogen in the PVC with chlorine.

In this process, and depending on the manufacturer, varying amounts of chlorine is introduced into the polymer, allowing for a calculated method of determining the final mechanical properties of the material. Base CPVC is on average 50% PVC to 75% by mass. However, most commercial resins have a chlorine content of 63% to 69%. The increase in chlorine content of the CPVC has a direct and linier relationship to its glass transition temperature (T_g). However, under normal operating conditions, CPVC becomes unstable at 70% mass of chlorine.

As with PVC, during the processing or compounding process, various stabilizers, impact modifiers, pigments and lubricants are introduced during compounding to make the materials more processable, increase impact strength, and vary color. CPVC is significantly more ductile than PVC, allowing greater flexural and compression strength. Furthermore, CPVC can typically withstand corrosive water at temperatures greater than PVC, typically 40°C to 50°C (70°F to 90°F) higher, adding to its popularity as a material for water piping systems in residential as well as commercial construction. The increased mechanical strength properties of CPVC, makes it a viable candidate for plastic to metal pipe conversions, where environmental conditions limits its [*metals*] use.

Commercial Uses for PVC & CPVC Thermoplastic Resins

Most of us are familiar with PVC and CPVC used in plastic pipes and fittings, such as those found in our kitchen and bathroom plumbing. However, did you know that PVC is in everyday consumer products as well, such as alarm clocks and pool toys, and in medical products, from blood and I.V. bags to vinyl tubing? PVC is a highly versatile material that can be manufactured to be rigid or flexible, weather or heat resistant, impact resistant, thick or thin, and in any color of the rainbow.

The vast majority of PVC manufactured in the United States is used for the manufacture of plastic pipe. PVC and CPVC typically exhibit excellent chemical resistance qualities and durability making them popular choices for use in clean water distribution systems, sanitary collection of wastewaters, and fire suppression systems. In fact, PVC pipe accounts for more than seventy percent (70%) of new buried water distribution pipes, and more than seventy-five percent (75%) of sanitary sewer pipe, installed in the United States and Canada.

Construction
Medical
Packaging
Toys
Electronics
Automotive

PVC & CPVC Plastic Failures

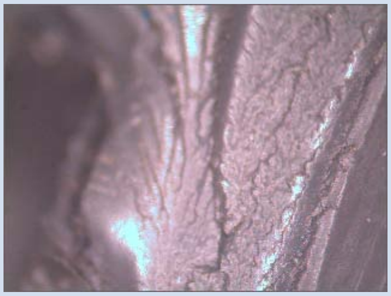
CPC Plastics, Inc. has examined hundreds of plastic failures, including PVC and CPVC Thermoplastics used in plumbing applications from water filtration, pool and spa heating, commercial and building plumbing systems, fire sprinkler systems, and consumer products. Our Failure Analysis Studies and Research into the root cause for failure has provided us with a unique perspective into the most common factors that cause [PVC and CPVC] plastic failure. In addition, CPC Plastics has worked with numerous clients to eliminate [PVC and CPVC] failures attributed to plastic materials and the plastic manufacturing processes.

Examples of PVC & CPVC Plastic Failures

When CPC Plastics, Inc. commissions a plastic Failure Analysis Study, our work typically involves a visual, photograph, and microscopy examination of the failed article(s). Figure 2 below are examples of PVC and CPVC failures that we have examined in part of our work in either analyzing plastic failures or our efforts in assisting clients in solving manufacturing defects.

Figure 2 – PVC & CPVC Inspection and Microscopy Photographs

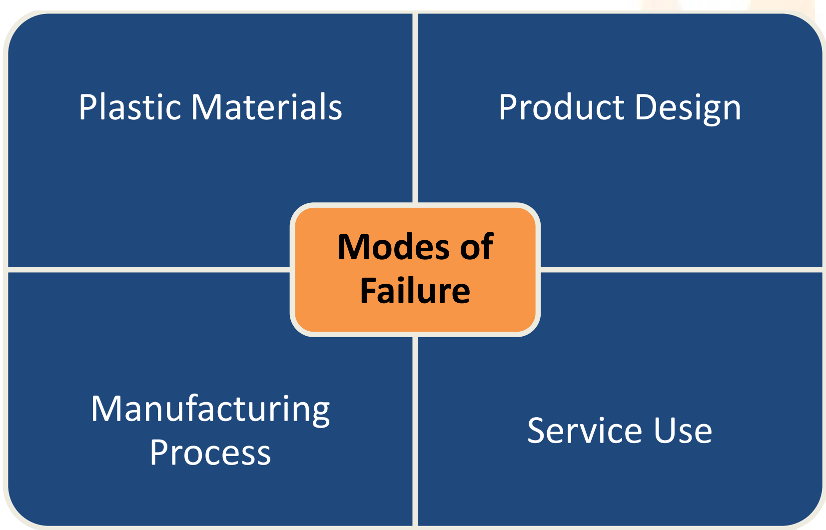
Manufacturing Defect - Voids	Excessive Glue (Adhesives)	Excessive Glue (Adhesives)
		

Material Degridation	Material Contamination	Envoirnmental Stress Cracking
		

Why do PVC and CPVC Plastics Fail?

Why do plastic parts fail? The primary mode, or cause, of failure for plastic parts, such as the parts manufactured from PVC and CPVC, can be directly attributed to one or more of the following, including Material, Design, Process, and/or Service Use, as illustrated in Figure 3 below. Additionally, we classify the method, or type, of failure as being attributed to one or more of the following, Mechanical, Thermal, Chemical, and/or Environmental.

Figure 3 – Modes of Plastic Failure



When examining each one of these failure modes further, many factors that affect each mode require thorough consideration.

Material Selection

Material selection is a common denominator for mistakes produced in the product design stages, typically an afterthought made by plastic design engineers. In fact, there are hundreds if not thousands of PVC and CPVC, grades, and custom [proprietary] compounds available in today's plastic marketplace, deciding on what type and grade of plastic is crucial in preventing plastics failure. In addition, plastic product designers and manufacturers must account for U.V. and Environmental exposure, chemical exposure, service temperatures, etc. The process of material selection must be carefully constructed and in full view of foreseeable and unforeseeable service-use.

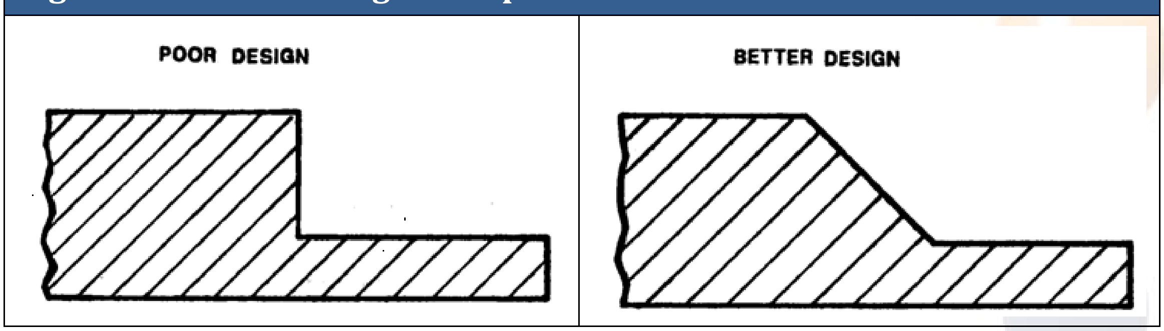
PVC & CPVC Product Design

In the design stage, sharp corners and improper wall thickness are common mistakes that lead to high areas of stress concentrations and tend localize stresses that can result in increased impact energy, leading to premature failure.

Common Mistakes made by Product Design Engineers

- **Sharp Corners**
- **Molded-In Defects**
- **Mechanical & Molded-In Stresses**
- **Poor Design Practices**
- **Poor Material Selection**
- **Understand the Application**

Figure 4 – How to Design a Proper Corner



PVC & CPVC Manufacturing Process

Unlike some traditional thermoplastic resins, PVC and CPVC plastic resins are more susceptible to degradation and most often require special equipment to properly manufacture and maintain consistent quality products. A myriad of failures can be exhibited in parts that have not been molded at the correct melt or mold temperatures or using tooling without adequate venting, etc. Under normal manufacturing of PVC and CPVC plastics creates a highly gases environment, which must be vented properly to allow air and gas to escape or voids (air pockets) can form, thereby decreasing part strength, and if not molded a the correct temperatures, can result in poor knit or weld line strengths.

PVC & CPVC Service Use

Essentially, service use encompasses what type of environment will the plastic exposed to, what chemicals will the plastic come in contact with, how the part is intended to be used, how it might be used, etc. In fact, a plastics design engineer must consider a multitude of service criteria, including life expectancy, environmental, chemical, foreseeable use, etc. Due to the almost infinite number of variables affecting service-use, correcting establishing the service-use criteria for plastics can be challenging to say the least.

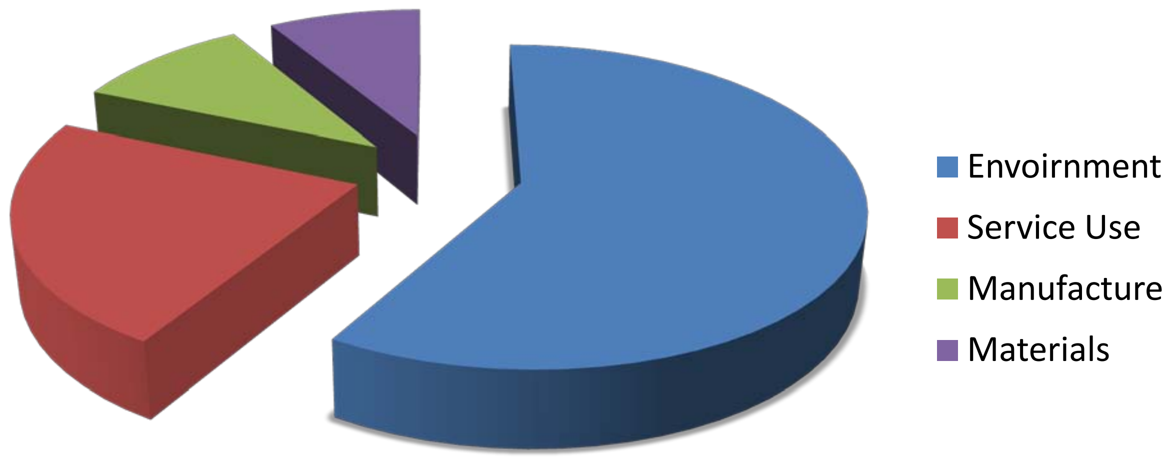
How to prevent PVC & CPVC Plastic Failures

There are three simple rules to follow to prevent plastics failures. Do your homework, do not take shortcuts, and test, test, test. A plastic product design engineer must have an infinite understanding of their product, what are the mechanical, thermal, environmental, and chemical loads, etc., they must establish foreseeable use, misuse, and abuse, and through testing determine if the product will meet the product requirements that they have established.

Figure 5 – PVC & CPVC Plastic Failures vs. Mode of Failure

The chart below is an average representation of the modes of failure exhibited in PVC and CPVC failures examined by CPC Plastics, Inc. within the past ten (10) years.

PVC & CPVC Failures vs. Mode of Failure



Methods of Testing PVC & CPVC Thermoplastic Resins

There are many methods and techniques of testing PVC and CPVC thermoplastic resins that CPC Plastics, Inc. relies on to determine the Mode of Failure or improve manufacturing process used in pipes and fittings used in commercial plumbing and buildings, water filtration, and industrial and consumer products, including Finite Element Analysis, Analytical Testing, and Process and Mold Qualification.

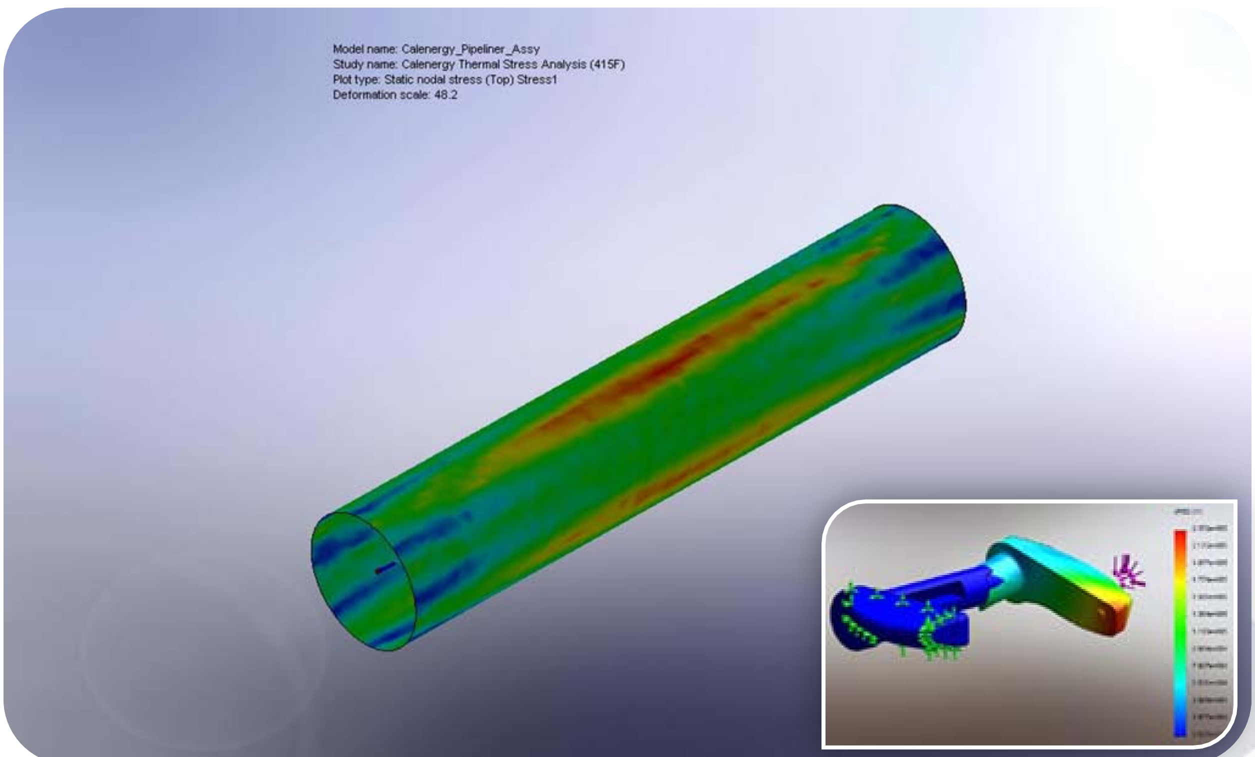
Finite Element Analysis

Development of Finite Element Analysis (FEA) began in earnest in the mid 1950's for airframe and structural analysis, and the key concepts of stiffness matrix and element assembly that were developed in the late 1950's are essentially in the same form as used today. FEA allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements. Today's FEA software provides a wide range of simulation options for controlling the complexity of both modeling and analysis of a system.

Essentially FEA allows us to reduce cost by simulating the testing of the model on a computer instead of expensive field-testing, reduce time to market by reducing the number of product development cycles, and improve products by quickly testing many concepts and scenarios before making a final decision. Furthermore, FEA's use in Plastic Failure Analysis of PVC and CPVC pipes, fittings, etc. is extremely beneficial as baseline material strength, environmental testing, and stress testing can provide valuable data and focal points.

In the illustration seen in Figure 6 below, the areas of greater stress concentration are highlighted by red, and the areas of less stress concentrations are colored green. The software allows you to measure the stress levels at any given point and quantify stress levels under a given loading condition, i.e. thermal, mechanical, etc.

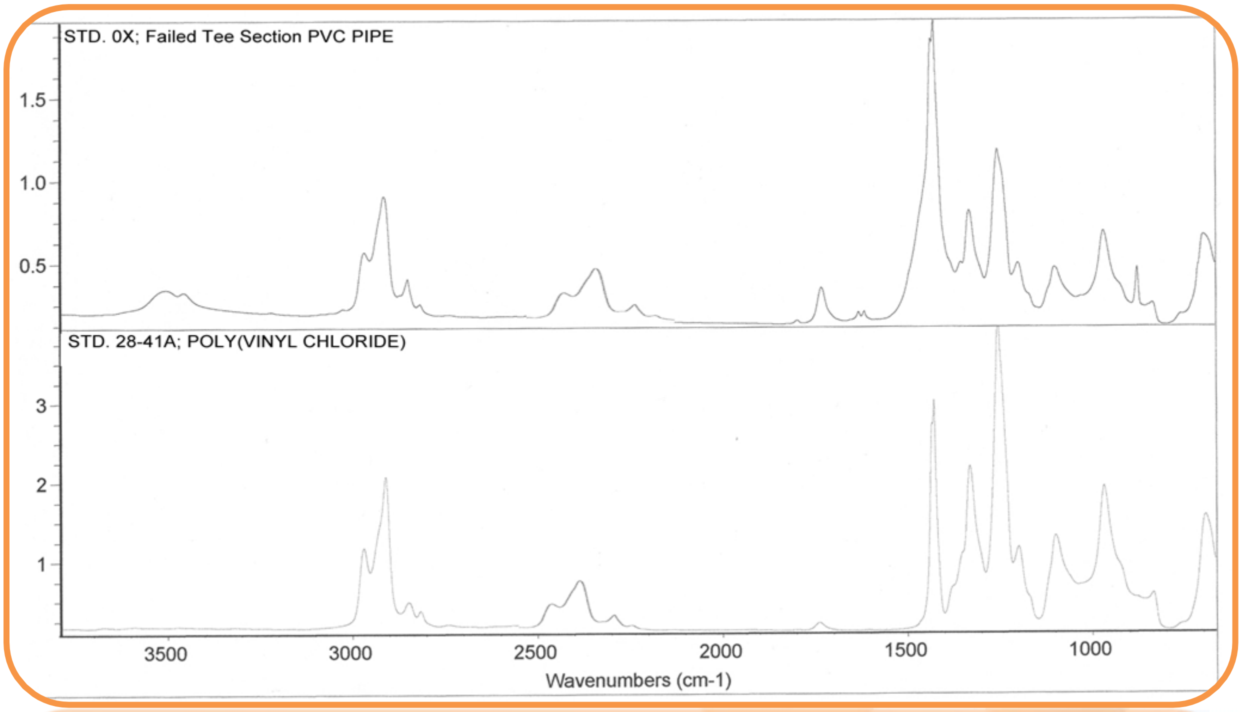
Figure 6 – Example(s) of FEA Stress Study on PVC and CPVC



Analytical Testing and Analysis

While FEA is useful in troubleshooting PVC and CPVC failures, Analytical Testing and Analysis may be required, depending on the failure mode. Analytical Testing typically requires destructive testing and can include Melt Flow Index and Fourier Transfer Infrared spectroscopy to analyze materials for proper mechanical properties and determine moisture, contamination, and degradation of sample materials. In fact, these tests are widely used in plastic forensics to compare and contrast actual material [mechanical] strength properties vs. a control sample, which allows us to determine if the failed product is manufactured to those same standards of the specified PVC and/or CPVC plastic materials.

Figure 7 – Example of Fourier Transfer Infrared Spectroscopy (FTIR) PVC Test



Types of Analytical Material Testing for PVC & CPVC

Depending on the nature of the PVC and CPVC failure, various other analytical material testing can be commissioned to address specific scientific test data requirements, including but not limited to the following:

- Flexural Properties - ASTM D790
- Stress Crazing of Transparent Plastics - ASTM F791
- Chemical Resistance of PVC/CPVC - ASTM D5260
- Scanning Electron Microscopy (SEM)
- Fourier Transform Infrared Analysis (FTIR) - ASTM E1252
- Glass Transition by DSC - ASTM D3418

- Izod Impact Test (Notched) ASTM D256
- Dynamic Mechanical Analysis - ASTM D4065
- Thermal Index - UL 746B
- Flammability - UL94, ASTM D635
- Melt Flow Index - ASTM D1238
- Ash Content - ASTM D2584, D5630
- Oven Aging - ASTM D573
- Durometer Hardness Shore Hardness - ASTM D2240

Summary of Why PVC & CPVC Plastics Fail

In summary, the overwhelming numbers of PVC and CPVC failures that we have examined and analyzed as part of our work in Failure Analysis have failed due as a direct result chemical exposure and/or service-use. Furthermore, CPC Plastics, Inc. witnessed multiple failures directly attributed to chemical attacks from glues (adhesives) and primers, and from thread cutting oils and sealants. Such [chemical] exposure stems from improver service-use, including installation, care, custody, etc., over tightening, excessive gluing, etc. is classified as having a Failure Mode consistent with Service Use.

Similarly, a significant amount of failures exhibiting poor manufacturing practices have also resulted in PVC and CPVC failure(s). As seen in Figure 2 earlier, manufactures must follow standard industry practices and material manufacturer's recommendations regarding processing conditions and machinery requirements, i.e. melt temperature, barrel size, screw compression, etc. CPC Plastics, Inc. has worked on numerous failures caused by voids, entrapped air, or material degradation due to improper processing conditions, i.e. Injection speed, injection and hold pressure, and barrel and mold temperatures each have an important role in the ability of the manufacturer to maintain consistent quality PVC and CPVC plastic products and assemblies.

Careful planning by the product designer and attention to detail when identifying a suitable PVC or CPVC plastic resin must be commonplace. Likewise, as we discussed earlier, PVC and CPVC thermoplastics are unforgiving when it comes to processing and machinery, and if you do not follow applicable industry standards and material recommendations for the PVC or CPVC resins they manufacture, failure(s) will manifest themselves at some point. In fact, manufacturing process variations can lead to part failures that can be extremely difficult to troubleshoot and very costly to correct.

Moreover, as we have discussed, Service Use criterion is critical to ensuring that a well manufactured and suitable PVC or CPVC thermoplastic resin can perform as intended by the designer. Proper direction and handling of PVC and CPVC products, i.e. pipe, fittings, joints, etc. are required to ensure proper installation methods and/or techniques are followed during installation and/or assembly. For pipe and plumbing applications, torque and/or glue (adhesive) specifications are essential criteria that if not followed correctly can lead to premature critical (PVC and CPVC) failure.

About the Author:

Clinton P. Cowen, President and Founder of CPC Plastics, Inc. since 1998, has worked almost two decades in plastics, Mr. Cowen has personally worked at more than 1000 plastic manufacturing facilities, and has offered testimony in over 100 cases involving plastic failure, such as the PVC and CPVC failure subject of this article. In addition, Mr. Cowen has provided plastic consulting and advisory services to television and print media organizations, such as Fox Business News and Plastics Industry News Magazines.

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If you or your organization are seeking guidance with PVC or CPVC materials, manufacturing, processing, design, or testing and analysis, please contact CPC Plastics, Inc. Toll Free: 866.828.0820 EXT: 201 for a confidential and free initial consultation.

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