

Chapter 1

General Properties of Polyvinyl Chloride Pipe

BACKGROUND

Polyvinyl chloride (PVC) was discovered in the late nineteenth century. Scientists at that time found the new plastic material unusual in that it appeared nearly inert to most chemicals. However, it was soon discovered that the material was resistant to change, and it was concluded that the material could not be easily formed or processed into usable applications.

In the 1920s, scientific curiosity again brought polyvinyl chloride to public attention. In Europe and America, extended efforts eventually brought PVC plastics to the modern world. Technology, worldwide and particularly in Germany, slowly evolved for the use of PVC in its unplasticized, rigid form, which today is used in the production of a great many extruded and molded products. In the mid-1930s, German scientists and engineers developed and produced limited quantities of PVC pipe. Some PVC pipe installed at that time continues to provide satisfactory service today. Molecularly oriented polyvinyl chloride (PVCO) pressure pipe has been installed in Europe since the early 1970s and in North America since 1991.

MATERIAL PROPERTIES OF PVC PIPE COMPOUNDS

Polyvinyl chloride pipe and fabricated fittings derive properties and characteristics from the properties of their raw material components. Essentially, PVC pipe and fabricated fittings are manufactured from PVC extrusion compounds. Injection molded fittings use slightly different molding compounds. PVCO is manufactured from conventional PVC extrusion compounds. The following summary of the material properties for these compounds provides a solid foundation for an understanding and appreciation of PVC pipe properties.

Polyvinyl chloride resin, the basic building block of PVC pipe, is a polymer derived from natural gas or petroleum, salt water, and air. PVC resin, produced by any of the common manufacturing processes (bulk, suspension, or emulsion), is combined

with heat stabilizers, lubricants, and other ingredients to make PVC compound that can be extruded into pipe or molded into fittings.

Chemical and taste-and-odor evaluations of PVC compounds for potable water conveyance are conducted in accordance with procedures established by NSF International.* The extracted water must not exceed the maximum contaminant levels established by the US Environmental Protection Agency's (USEPA) National Interim Primary Drinking Water Regulations (1975) and by the NSF limits of acceptance for residual vinyl chloride monomer and for taste and odor as shown in Table 1-1 of NSF Standard 61. Monitoring is conducted by NSF International or approved laboratories.

PVC pipe extrusion compounds must provide acceptable design stress properties as determined by long-term testing under hydrostatic pressure. Hydrostatic design stress ratings for pipe compounds are established after 10,000 hr of hydrostatic testing. Long-term performance of injection molded PVC fittings compounds are subject to at least 2,000 hr of hydrostatic testing.

AWWA's PVC pipe and fittings standards define the basic properties of PVC compound, using the American Society for Testing and Materials (ASTM) Specification D1784, *Standard Specification for Rigid Poly (Vinyl Chloride) (PVC) Compounds and Chlorinated Poly (Vinyl Chloride) (CPVC) Compounds*. The specification includes a five-digit cell class designation system by which PVC compounds are classified according to their physical properties.

As shown in Table 1-1, the five properties designated are (1) base resin, (2) impact strength, (3) tensile strength, (4) elastic modulus in tension, and (5) deflection temperature under loading. Figure 1-1 shows how the classification system establishes minimum properties for the compound 12454, which is used in PVC pressure pipe manufactured in accordance with AWWA C900, *Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 12 In. (100 mm Through 300 mm), for Water Distribution*;† AWWA C905, *Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 14 In. Through 48 In. (350 mm Through 1,200 mm), for Water Transmission and Distribution*;† and AWWA C909, *Molecularly Oriented Polyvinyl Chloride (PVCO) Pressure Pipe, 4 In. Through 12 In. (100 mm Through 300 mm), for Water Distribution*. The material classification can be found on the pipe as part of its identification marking.

Many of the important properties of PVC pipe are predetermined by the characteristics of the PVC compound from which the pipe is extruded. PVC pressure pipe manufactured in accordance with AWWA C900, C905, or C909 must be extruded from PVC compound with cell classification 12454-B or better. Those compounds must also qualify for a hydrostatic design basis of 4,000 psi (27.58 MPa) for water at 73.4°F (23°C) per the requirements of PPI† TR-3.

The manner in which selected materials are identified by this classification system is illustrated by a Class 12454 rigid PVC compound having the requirements shown in Table 1-1 and Figure 1-1.

CORROSION, PERMEATION, AND CHEMICAL RESISTANCE _____

PVC and PVCO pipes are resistant to almost all types of corrosion—both chemical and electrochemical—that are experienced in underground piping systems. Because PVC is a nonconductor, galvanic and electrochemical effects are nonexistent in PVC piping systems. PVC pipe cannot be damaged by aggressive waters or corrosive soils. Consequently, no lining, coating, cathodic protection, or plastic encasement is required when PVC and PVCO pipes are used.

*NSF International, 789 N. Dixboro Rd., Ann Arbor, MI 48105.

†Plastics Pipe Institute, 1275 K St. N.W., Suite 400, Washington, D.C. 20005.

Table 1-1 Cell class requirements for rigid poly (vinyl chloride) compounds*

Order No.	Designation Property and Unit	Cell Limits								
		0	1	2	3	4	5	6	7	8
1	Base resin	Unspecified	Poly (vinyl chloride) homopolymer	Chlorinated poly (vinyl chloride)	Ethylene vinyl chloride copolymer	Propylene vinyl chloride copolymer	Vinyl acetate-vinyl chloride copolymer	Alkyl vinyl ether-vinyl chloride copolymer		
2	Impact strength (Izod) min. J/m of notch ft-lb/in. of notch	Unspecified	<34.7 <0.65	34.7 0.65	80.1 1.5	266.9 5.0	533.8 10.0	800.7 15.0		
3	Tensile strength, min: MPa psi	Unspecified	<34.5 <5,000	34.5 5,000	41.4 6,000	48.3 7,000	55.2 8,000			
4	Modulus of elasticity in tension, min: MPa psi	Unspecified	<1,930 <280,000	1,930 280,000	2,206 320,000	2,482 360,000	2,758 400,000	3,034 440,000		
5	Deflection temperature under load, min. 1.82 MPa (264 psi): deg C deg F	Unspecified	<55 <131	55 131	60 140	70 158	80 176	80 194	100 212	110 230

Source: ASTM D1784, American Society for Testing and Materials, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

* The minimum property value will determine the cell number although the maximum expected value may fall within a higher cell.
 Note: Flammability. All compounds covered by this specification, when tested in accordance with method D635, shall yield the following results:
 average extent of burning of <25 mm; average time of burning of <10 sec.

Class	1	2	4	5	4
<i>Identification:</i> Poly (vinyl chloride) homopolymer					
<i>Property and Minimum Value:</i> Impact strength (Izod) (34.7 J/m [0.65 ft-lb/in.])					
Tensile strength (48.3 MPa [7,000 psi])					
Modulus of elasticity in tension (2,758 MPa [400,000 psi])					
Deflection temperature under load (70°C [158°F])					

Source: ASTM D1784, American Society for Testing and Materials, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

Note: The cell-type format provides the means for identification and close characterization and specification of material properties, alone or in combination, for a broad range of materials. This type format, however, is subject to possible misapplication since unobtainable property combinations can be selected if the user is not familiar with commercially available materials. The manufacturer should be consulted.

Figure 1-1 Class 12454 requirements

Permeation

The selection of materials is critical for water service and distribution piping in locations where the pipe may be exposed to significant concentrations of pollutants comprised of low molecular weight petroleum products or organic solvents or their vapors. Research has documented that pipe materials, such as polyethylene, polybutylene, polyvinyl chloride, and asbestos cement, and elastomers, such as those used in jointing gaskets and packing glands, may be subject to permeation by lower molecular weight organic solvents or petroleum products. If a water pipe must pass through an area subject to contamination, the manufacturer should be consulted regarding permeation of pipe walls, jointing materials, etc., *before* selecting materials for use in that area.

Chemical Resistance

Pipe. Response of PVC pipe under normal conditions to commonly anticipated chemical exposures is shown in Table A-1 in Appendix A. Resistance of PVC pipe to reaction with or attack by the chemical substances listed has been determined by research and investigation. The information is primarily based on the immersion of unstressed strips into the chemicals and, to a lesser degree, on field experience. In most cases, the detailed test conditions, such as stress, exposure time, change in weight, change in volume, and change in strength, were not reported. Because of the complexity of some organochemical reactions, additional long-term testing should be performed for critical applications. Data provided are intended only as a guide and should not necessarily be regarded as applicable to all exposure durations, concentrations, or working conditions. This chemical resistance data is similar for PVCO pipe.

Gaskets. A check of the chemical resistance of the gasket should be completed independently of that for the pipe. Because gasket and pipe materials are different, so too are their abilities to resist chemical attack. Similarly, charts for resistance of gasket materials to chemical attack are based on manufacturers' testing and experience. The use of these charts is complicated by the fact that more than one elastomer may be present in a rubber compound. Chemical resistance information for commonly used gasket materials is provided in Table A-2 in Appendix A.

Table A-2 is a general guide to the suitability of various elastomers currently used in these chemicals and services. The ratings are primarily based on literature published by various polymer suppliers and rubber manufacturers, as well as the opinions of experienced compounders. Several factors must be considered in using a rubber or polymer part. The most important of these factors include the following:

- Temperature of service. Higher temperatures increase the effect of all chemicals on polymers. The increase varies with the polymer and the chemical. A compound quite suitable at room temperature may perform poorly at elevated temperatures.
- Conditions of service. A compound that swells considerably might still function well as a static seal yet fail in any dynamic application.
- Grade of the polymer. Many types of polymers are available in different grades that vary greatly in chemical resistance.
- Compound itself. Compounds designed for other outstanding properties may be poorer in performance in a chemical than one designed especially for fluid resistance.
- Availability. Consult the elastomer manufacturers for availability of a compound for use as a PVC pipe gasket material.

If it is anticipated that gasket elastomers will be exposed to aggressive chemicals, it is advisable to test the elastomers.

ENVIRONMENTAL EFFECTS

The following paragraphs discuss the effects of environmental factors on PVC pipe, including temperature, biological attack, weather, abrasion, and tuberculation.

Thermal Effects

The performance of PVC pipe is significantly related to its operating temperature. Because it is a thermoplastic material, PVC will display variations in its physical properties as temperature changes (Figure 1-2). PVC pipe can be installed properly over the ambient temperature range in which construction crews can work. PVC pipe is rated for performance properties at a temperature of 73.4°F (23°C); however, it is recognized that operating temperatures of 33–90°F (1–32°C) do exist in water systems. As the operating temperature decreases, the pipe's stiffness and tensile strength increase, thereby increasing the pipe's pressure capacity and its ability to resist earth-loading deflection. At the same time, PVC pipe loses impact strength and becomes less ductile as temperature decreases, necessitating greater handling care in sub-zero weather. As the operating temperature increases, the impact strength and flexibility of PVC pipe increases. However, with the increase in temperature, PVC pipe loses tensile strength and stiffness; consequently, the pressure capacity of the pipe will be reduced and more care will be needed during installation to avoid excessive deflection.

Most municipal water systems operate at temperatures at or below 73.4°F (23°C). In these applications, the actual pressure capacity of PVC pipe will be equal to or greater than the product's rated pressure. Intermittent water system temperatures above 73.4°F (23°C) do not warrant derating of pipe or fitting pressure designations.

New users and installers of PVC pipe should be aware of the pipe's capacity to expand and contract in response to changes in temperature. The PVC coefficient of thermal expansion is roughly five times the normal value for cast iron or steel. Provisions must be made in design and installation to accommodate expansion and contraction if the pipeline is to provide service over a broad range of operating temperatures. In general, allowance must be made for $\frac{3}{8}$ in. of expansion or contraction for every

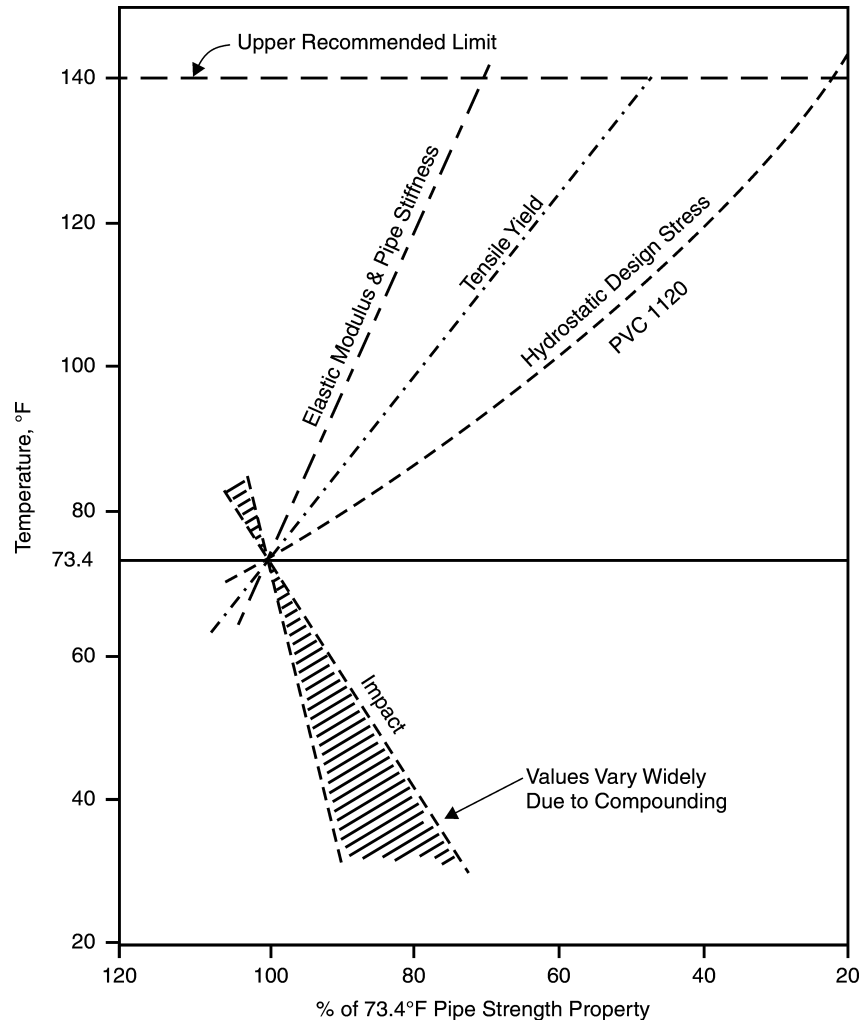


Figure 1-2 Approximate relationship for 12454 PVC for PVC pipe strength properties versus temperature

100 ft (30.5 m) of pipe for each 10°F (5.6°C) change in temperature. Gasketed joints provide excellent allowance for thermal expansion and contraction of PVC pipelines. The coefficient of thermal expansion for PVC is the same as for PVC.

Resistance to Biological Attack

PVC pipe is nearly totally resistant to biological attack. Biological attack can be described as degradation or deterioration caused by the action of living microorganisms or macroorganisms. Microorganisms that attack organic materials are normally listed as fungi and bacteria. Macroorganisms that can affect organic materials located underground include an extremely broad category of living organisms; for example, grass roots, termites, and rodents. The performance of PVC pipe in environments providing severe exposure to biological attack in its various anticipated forms has been studied and evaluated since the 1930s.

PVC pipe will not deteriorate or break down under attack from bacteria or other microorganisms, nor will it serve as a nutrient to microorganisms, macroorganisms, or fungi. No cases have been documented where buried PVC pipe products have degraded

or deteriorated because of biological action. As a result, no special engineering or installation procedures are presently required to protect PVC or PVCO pipe from any known form of biological attack.

Elastomeric seals are manufactured from organochemical materials, which can be formulated to produce a variety of properties. Some elastomers are susceptible to biological attack, whereas others provide resistance comparable to those inherent in polyvinyl chloride. PVC pipe manufacturers select gaskets produced from elastomeric compounds that provide high resistance. A material that will not support bacterial growth is a requirement, particularly in potable water systems.

In normal practice, when installing PVC pipe with gasketed joints, assembly of joints is facilitated using a lubricant applied in accordance with the manufacturer's instructions. Care must be exercised in the selection of this lubricant to ensure compatibility with the elastomeric seal and the PVC pipe and to ensure that the lubricant will not support the growth of fungi or bacteria. Care must also be taken to ensure that only the amount of lubricant required to facilitate assembly is used. Excess lubricant can adversely affect water quality and ultimately delay commissioning of a water system. *Only the lubricant recommended by the pipe manufacturer should be used.* These lubricants must also satisfy all NSF 61 requirements.

Weathering Resistance

PVC pipe can incur surface damage when subjected to long-term exposure to ultraviolet (UV) radiation from sunlight. This effect is called ultraviolet degradation. Unless specifically formulated to provide substantial protection from UV radiation (for example, PVC house siding), or unless a limited service life is acceptable, PVC pipe is not recommended for applications where it will be continuously exposed to direct sunlight without some form of physical protection (such as paint or wrapping).

Ultraviolet degradation in PVC occurs when energy from the UV radiation causes excitation of the molecular bonds in the plastic. The resulting reaction occurs only on the exposed surface of PVC pipe and penetrates the material less than 0.001 in. (0.025 mm). Within the affected zone of reaction, the structure of the PVC molecule is permanently altered with the molecules being converted into a complex structure typified by polyene formations. The polyene molecule causes a light yellow coloration on the PVC pipe and slightly increases its tensile strength.

Regarding the organochemical reactions that characterize ultraviolet deterioration of PVC, the following should be noted:

- UV degradation results in color change, slight increase in tensile strength, slight increase in the modulus of tensile elasticity, and decrease in impact strength in PVC pipe.
- UV degradation does not continue when exposure to UV radiation is terminated.
- UV degradation occurs only in the plastic material directly exposed to UV radiation and to an extremely shallow penetration depth.
- UV degradation of PVC pipe formulated for buried use will not have significant adverse effect with up to two full years of outdoor weathering and direct exposure to sunlight.

The above is also true in regard to PVCO pipe.

Abrasion

After years of investigation and observation, it has been established that the combination of PVC resin, extenders, and various additives in PVC compounds, plus the methods of extrusion for PVC pipe, produce a resilient product with good resistance to abrasive conditions.

Many investigations and tests have been conducted, both in North America and Europe, by manufacturers, independent laboratories, and universities seeking to define PVC pipe's response to abrasion. Although the approaches to the various tests and investigations have varied substantially, the data developed has been consistent in defining the extent of PVC pipe resistance to abrasion. The nature and resiliency of PVC pipe cause it to gradually erode over a broad area when exposed to extreme abrasion, rather than to develop the characteristic localized pitting and more rapid failure observed in pipe products with lower abrasion resistance.

PVC pipe is well suited to applications where abrasive conditions are anticipated. In extremely abrasive exposures, wear must be anticipated; however, in many conditions PVC pipe can significantly reduce maintenance costs incurred because of extreme abrasion. It should be noted that potable water, regardless of its makeup, is not considered abrasive to PVC pipe.

Tuberculation

Soluble encrustants (such as calcium carbonate) in some water supplies do not precipitate onto the smooth walls of PVC or PVCO pipe. Because these materials do not corrode, there is no tuberculation caused by corrosion by-products.