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Plastic Pipes

Plastic pipes for Piping Engineering issues

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Paper is introducing a research on thermoplastic pipes uses and design, as plastic pipes have been used widely in many oil, water, and gas process plants and pipelines for many issues instead of metal pipes as their lower cost, easier installation, and lighter weight than other metallic pipes.

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1. INTRODUCTION

Plastics piping are made from either of two basic groups of synthetic materials, thermoplastic and thermosetting. Thermoplastics can be softened and reshaped repeatedly by the application of heat. In contrast thermosetting materials are irreversibly set, or cured, or hardened into a permanent shape during factory manufacture. Once hardened into their final shape, thermosetting products cannot be softened and therefore may not be reshaped by heating.

Thermoplastic materials include minimal reinforcements, whereas thermosetting resins are almost always combined with reinforcements (such as glass fibers) and sometimes fillers (such as sand) to produce structurally integrated composite constructions.

1.1. Background

The first thermoplastic tubes were made in Germany during the 1930s from a PVC copolymer. Thermoplastics pipe was first manufactured commercially in the United States in 1940 from cellulose acetate butyrate (CAB) and was used by The Southern California Gas Company for distributing natural gas. Volume production commenced in 1948 when PE pipe was first offered for non-code-regulated water service applications. ABS and PVC pipe were first commercially made in the United States in 1949 and 1950, respectively. During the 1940s and 1950s many fundamental advances were introduced in polymer chemistry, materials formulation, and product fabrication technology, which laid the foundation for the thermoplastics pipe industry. Improvements in these areas are still continuing. However, the start of the evolution of thermoplastics piping as engineering materials is considered to have taken place in 1950 when an American Society for Testing and Materials (ASTM) group for plastics pipe standardization was organized. Soon thereafter the first ASTM standards covering materials, test methods, and piping products began to be issued. At present over 180 ASTM standards define plastic piping, plastic piping materials, test methods, and recommended practices for joining and installation. Numerous plastics piping standards have also been issued by other organizations.

1.2. Principle Materials

Thermoplastics account for the lion’s share of plastics used for piping. During 1989,over 95 percent of the approximately 7.5 billion pounds (3.75 million metric tons)of plastics that went into pipe, conduit, and fittings consisted of thermoplastics.1*Polyvinyl chloride* (PVC) accounted for about three-quarters of all thermoplastic pipe. The second most widely used thermoplastic is *polyethylene* (PE), accounting for about a 15 percent share, followed by *acrylonitrile-butadiene-styrene* (ABS), representing about a 4 percent share. The balance about 6 percent consists of special-purpose materials, such as chlorinated polyvinyl chloride (CPVC), cross link edpolyethylene (PEX), polybutylene (PB), polypropylene (PP), and various fluorinated polymers, Principlely polyvinylidene fluoride (PVDF).

In 1955, total U.S. Shipments of thermoplastic pipe were less than 40 million pounds (18,000 metric tons). By 1998, the rate of shipments had increased almost 200 fold, and it is still growing.

More footage of thermoplastic pipe is now being installed than that of all other types of piping materials combined. However, the total dollar value of installed thermoplastic pipe is second to and only about one-quarter of that of the leading material, steel.3 this is because the Principle use of thermoplastics piping is in the smaller sizes. But the very successful track record in these sizes has been leading to increasing acceptance and use of the larger diameters, which currently comprise the fastest growing segment. As of this writing, thermoplastic pipe is available through NPS 60 (DN1500) for pressure uses and NPS 108 (DN 2700) for sewer and drain applications.

2. SCOPE

This Paper reviews the Principle properties and uses of thermoplastics piping, discusses its advantages and limitations, and presents general and basic information on materials, properties, standardization, design, and installation. This information is intended to guide the reader in evaluating the applicability of thermoplastics piping for an intended application; in choosing the appropriate material and product; and in its proper design and installation. References are provided for more detailed information and for further guidance on these and related subjects.

3. AVAILABLE PRODUCTS

Plastics pipe and fittings are available in a vast array of materials, diameters, wall thicknesses, and designs. For non-pressure applications special wall constructions are offered—such as double wall, ribbed, and foamed core—which are designed to more economically achieve a desired longitudinal and diametrical pipe stiffness.

Most of these products are covered by national standards. Table 1.1, which lists common standards that cover Principle commercial products, also identifies each product’s primary application and gives the range of nominal sizes covered by the standard. As the updating of existing and the writing of new product standards is a dynamic ongoing process, the reader is advised to contact standards-issuing organizations for the latest status. The American Society for Testing and Materials (ASTM),*for example, each year updates a volume of it's ‘‘Annual Book of ASTM Standards’ ‘which includes all of its current standards covering plastics piping. The Plastics Pipe Institute (PPI) publishes a periodically updated report, PPI TR-5, which includes a comprehensive listing of North American and International Standards Organization (ISO) standards on thermoplastics piping. There are also many commercially available piping appurtenances, such as identified in Table D3.1, that are fabricated from plastics but which are not covered by any national standard. In addition, some pipe and fitting manufacturers and their distributors can custom-fabricate components that may or may not be shown in product catalogs. These specials include manholes for both infrastructure and industrial applications. Fabricated fittings intended for pressure service are often reinforced by an overwrap with a glass-fiber thermosetting resin composite.

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Table 1.1

Piping material and product standard	Subject product, or abbreviated title of standard	Nominal sizes range(in)	Principle applications
ABS,PP and PVC			
ASTM D3311	DWV fittings patterns	1¼–8	Drain, waste vent
ABS and PVC			
ASTM D2680	ABS and PVC sewer pipe of composite wall construction	4–15	Sewer drain
ASTM F409	Accessible and replaceable tube and fittings	1¼–1½	Drain, waste vent
ASTM F480	Thermoplastic water well casing	2–16	Water-well casing
ASTM F1499	Coextruded, composite DWV pipe	1¼–8	Drain, waste vent
CSAB181.5	Coextruded ABS/PVCDWV pipe	1¼–6	Drain, waste vent
ABS,PVC&CPVC			
ASTM F1488	Coextruded composite pipe	2–12	Drain, waste & vent; sewer
ABS			
ASTM D1527	ABS Pipe, Schedules 40and80	⅛–12	Coldwater; industrial
ASTM D2282	ABS Pipe, dimension ratio series	⅛–12	Coldwater; industrial
ASTM D2468	ABS Socket fittings, Schedule 40	⅛–8	Coldwater; industrial
ASTM D2661	ABSDWV pipe and fittings	1¼–6	Drain, waste & vent
ASTM D2750	ABS Utility conduit and fittings	1–6	Electrical duct
ASTM D2751	ABS Sewer pipe and fittings	3–12	Sewer drain
ASTM F628	ABS Foam core DWV	1¼–6	Drain, waste vent
CSAB181.1	ABSDWV pipe and fittings	1¼–6	Drain, waste vent
PA			
ASTM F1733	Butt heat fusion fittings for polyamide pipe	1/2 – 48	Gas distribution
CSAB137.12	Polyamide piping systems for gas service	1/2 – 8	Gas distribution

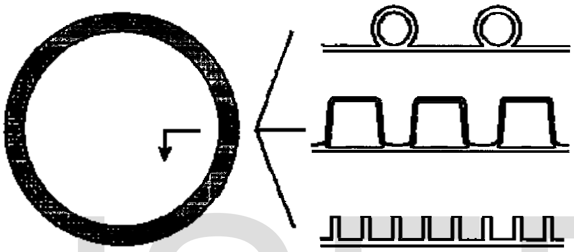
Table 1.1

Piping material and product standard	Subject product, or abbreviated title of standard	Nominal sizes range (in)	Principle applications
PE			
ASTM D2104	PE pipe, Schedule 40, ID based	1⁄2–6	Cold water, industrial
ASTM D2239	PE pipe, dimension ratio series, ID based	1⁄2–6	Cold water; industrial
ASTM D2447 PE	Pipe, Schedules 40 & 80	1/2–12	Cold water; industrial
ASTM D2609	Plastic inserts fittings for PE pipe	1/2–6	Cold water
ASTM D2683	PE fittings, socket fusion type	1/2 - 4	Cold water; natural gas;
ASTM D2737 PE	tubing	1/2 –2	Cold water
ASTM D3035	PE pipe, dimension ratio series	1/2 –6	Cold water; industrial
ASTM D3261	PE fittings, butt fusion type	1/2 –48	Cold water; natural

4. PRINCIPLE USES

Thermoplastics piping are routinely used for much common pressure and no pressure applications. Approximately 80 percent of the newly installed mains and 90 percent of the services for gas distribution are made of PE. Over 90 percent of rural water distribution mains and over 40 percent of municipal mains are made of PVC. Most of the smaller-diameter piping installed for agricultural and turf irrigation is made primarily from PE and PVC. CPVC and PEX piping are increasingly used for hot/cold water distributing piping for residential and other construction. In oil and gas production, significant quantities of PE pipe are used to convey water and well gases. Thermoplastics piping are also frequently used for commercial and industrial applications such as for conveying chilled and process waters, aqueous solutions of corrosive chemicals, slurries, foods, and substances that must remain uncontaminated by metallic ions.

More than half the tonnage of all thermoplastic pipes goes into no pressure uses. Over 85 percent of the newly installed underground building sewer connections are made of PVC. PVC also accounts for a similar share of the sewer collection mains in sizes NPS 4 through 18 (DN 100 through 450). About 80 percent of new single-family dwellings utilize either PVC or ABS drain, waste, and vent (DWV) piping. Most drainage systems, including those for building foundations, leaching fields, agriculture, and road construction now consist of thermoplastics piping, mostly PE and PVC. And both PVC and PE are increasingly used for larger diameter sewers, drains and culverts. One of the faster growing applications is the use of PE and PVC pipes of profile wall constructions for drainage, particularly alongside and under roadways (see Fig. 1.1). Another is the rehabilitation of older sewers, drains, and pressure pipelines by the insertion of new PE or PVC pipes.



Note - Other corrugation profiles are available

Fig. 1.1

4.1. Rehabilitation Technology

In one rehabilitation technology a PE or PVC pipe is deformed when manufactured into a ‘‘U’’ shape approximately one-half the diameter of the host pipe. At the installation site, the ‘‘U’’ deformed pipe is pulled through the damaged host pipe and then reformed by a combination of heat and pressure to tightly fit the shape of the host pipe (see Fig. 1.2)

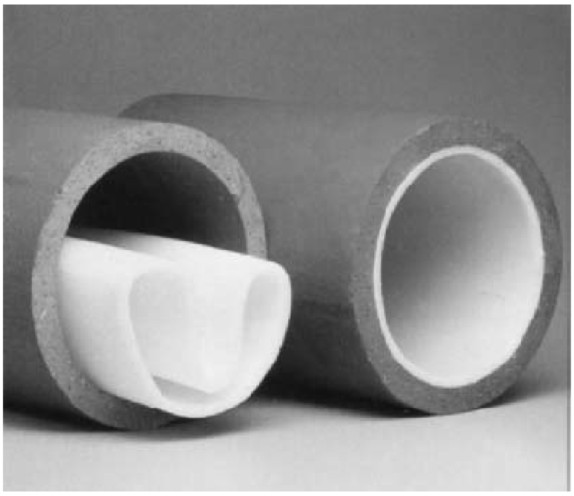


Fig. 1.2

5. ADVANTAGES AND LIMITATIONS

A number of important performance advantages have sparked the wide spread adoption of thermoplastics piping for so many pressures and no pressure uses.

5.1. Advantages

- The most universally recognized advantage is the piping's virtual freedom from attack by ambient water and moisture. Thermoplastics piping are not subject to surface attacks in any way comparable to the rusting or environmental corrosion of metals.
- Thermoplastics, being nonconductors, are immune to the electrochemical-based corrosion process induced by electrolytes such as acids, bases, and salts. In addition, plastics pipe materials are not vulnerable to biological attack. In sum, thermoplastics are not subject to corrosion in most environments in both aboveground and underground service. This has resulted in negligible costs for maintenance and external protection such as painting, plastic coating, galvanizing, electroplating, wrapping, and cathodic protection.
- Another Principle advantage offered by thermoplastics is their lower specific gravity, which results in ease of handling, storage, and installation, as well as in lower transportation costs. The smooth pipe surfaces yield low friction factors and very low tendency to fouling. They also offer very good abrasion resistance, even when conveying slurries that can rapidly abrade harder materials.
- High deformation capacity without fracture—or strain ability (Janson)—is another important performance feature, particularly for underground service. In response to earth loading, buried flexible pipes deform (deflect) and thereby activate additional and substantial support from the surrounding soil. This capability to activate additional support by deformation results in a pipe-soil structure that is capable of supporting earth fills and surface live loads of a magnitude that could fracture stronger but less stainable materials.
- Thermoplastics piping, particularly in the sizes under around NPS 18 (DN 450), can be ***competitive in cost*** to piping of other materials. In the larger sizes, thermoplastic swill oftentimes overcomes a first-cost disadvantage when consideration is given to their lower operating and maintenance costs and longer life.

5.2. Limitations

- The Principle limitations of thermoplastics arise from their relatively low strength and stiffness and greater sensitivity of mechanical properties to temperature.
- As a result, their primary use is for gravity and lower-pressure applications at near ambient temperatures. Some plastics qualify for hot water service, and there are some specialty materials that can be used to close to 300_F (149_C).

Notwithstanding these restrictions, thermoplastics piping satisfy the performance requirements fora very broad range of applications.

5.3. Requirements for successful design

Successful design with thermoplastics requires recognition of their viscoelastic nature. These materials do not exhibit the relatively simple stress/strain relationship that is characteristic of metals. Duration of loading, as well as temperature and environment, can have a profound effect on their stress-strain response, rupture strength, ultimate strain capacity, and other engineering properties. The extent to which duration of loading, temperature, and environment influence ultimate mechanical properties varies not only from one class of thermoplastic material to another (for example, between PVC and PE) but can also significantly differ within the same generic material, depending on the specific nature of the polymer (e.g., molecular weight, molecular weight distribution, degree of branching, and extent of copolymerization with other monomers), the type and quantity of polymer additives and modifiers, and the processing conditions. These factors must be recognized when characterizing the engineering properties of thermoplastic piping, particularly when defining allowable stress, strain, and upper temperature limits; and it goes without saying that for effective design and installation, they must be given consideration by the piping specifications creator, designer, and user.

Compared to traditional piping materials, thermoplastics have high coefficients of thermal expansion and contraction. For example, the thermal expansion rate can be from 6 to 10 times greater than that of metal pipe. This must be recognized both in design and installation, particularly for aboveground applications where resultant piping reaction may require frequent use of expansion loops or pipe supports. For aboveground piping more attention may also need to be given to proper pipe restraint because the low mass of thermoplastics provides less inertia against piping movements that may be induced by sudden changes in the fluid flow velocity. Additionally, aboveground thermoplastics should be positioned or protected against possible accidental mechanical damage.

Since thermoplastics are combustible, their use in certain locations may be limited by fire safety concerns and regulations. Construction and building codes address these concerns through various requirements, including the placing of thermoplastics piping inside suitable fire-resistant walls and chases and the use of fire stops when pipe penetrates through such structures.

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6. THERMOPLASTIC PIPING MATERIALS

6.1. Polymers Definition

The term polymer (from the Greek poly, meaning ‘‘many,’’ and mer meaning ‘‘unit’’) is used to denote the long-chain or network structure of macromolecules that are produced either naturally or that are made by man. The latter are referred to as synthetic polymers. Polymers which are the base material for plastics are oftentimes termed resins.

Polymers used for engineering applications consist of relatively long molecules in order to yield satisfactory levels of longer-term strength, ductility, and toughness.

Molecule size is denoted by molecular weight, which is the sum of the atomic masses of all the elements in the molecule. Since all the molecules in a polymer are not of the same size, the degree of polymerization is usually expressed by the polymer’s average molecular weight. The nature of the distribution of molecular sizes also bears a significant influence on a number of physical and mechanical properties. Thermoplastics used for piping applications tend to be of relatively high molecular weight (generally over 100,000) and of relatively narrow molecular weight distribution. However, the molecular weight cannot be so large as to result in a melt viscosity so high as to hinder proper fabrication of the end product. Another molecular structural parameter is the length and frequency of shorter molecular chains that occasionally branch out from the main polymer chain. These branches help determine how closely the polymer molecules can lie next to each other, which has an influence on the polymer’s physical and mechanical properties. The length and frequency of polymer branches may be controlled by conditions of chemical reaction, catalysts used, and by the copolymerization with other than the Principle monomer. For example, polyethylene pipe polymers are in fact copolymers of ethylene with small amounts of other olefin monomers such as propylene, butene, pentene, and hexene. Although the amount of other monomers used is low, and thereby the polymer still falls under the classification of polyethylene, it is enough to modify the polymer’s molecular structure—Principlely the number of short branches along the linear molecular chains—and thereby exert significant influence on engineering properties. Many commercial polymers, including polypropylene (PP) and polybutylene (PB), are also partial copolymers.

6.1.1 Chemical geometry

Chemical geometry, sometimes referred to as polymer architecture, also helps determine the relative physical arrangement of molecules to one another and, thereby, the polymer’s physical properties. Generally, the long molecules in polymers tend to align themselves near each other in a random symmetry analogous to spaghetti in a bowl. This random arrangement is referred to as the amorphous state. The proximity of polymer molecules to one another and their physical entanglement gives rise to mechanical forces that greatly account for a polymer's mechanical properties. PVC and ABS are polymers that are essentially amorphous materials.

6.2. Plastics Composition materials

Plastics are compounds of *resins* and *additives.* As previously explained, plastics are divided into two broad categories, *thermoplastics* and thermosets. Since thermoplastics are capable of being softened by heating and hardened by cooling, they can be shaped into articles by operations such as molding or extrusion, which take advantage of this capability.

6.2.1. Plastics Additives

Additives are incorporated into a thermoplastics composition to achieve specific purposes during fabrication or service. The precise nature and amounts of these additives depends on the plastic and its inherent properties; the processing method used to convert it to a finished article; and any desired modification of properties to achieve certain aesthetic, performance, or economic objectives.

The main kinds of additives that may be used in thermoplastic piping compositions include the following:

- Heat stabilizers. To protect the plastic against thermal degradation, particularly during processing.
- Antioxidants. To protect against oxidation during processing and when in service.
- Ultraviolet screens or stabilizers. To protect against ultraviolet radiation in sunlight during outdoor storage and weather-exposed service.
- Lubricants. To facilitate and improve fabrication by reducing viscosity and lessening frictional drag through dies and other surfaces.
- Pigments. To give the product a distinctive color.
- Processing aids. To facilitate material mixing and fusion during processing and thereby optimize the homogenization of material and its properties.
- Property modifiers. To enhance a particular property such as impact strength or flexibility.
- Fillers. Most often used to reduce volume cost; however, fillers may also be used to increase stiffness or to modify processing characteristics.

Additives are essential components of most thermoplastic piping compositions. They facilitate processing, enhance certain properties, give a product a distinctive appearance and color, and provide required protection during fabrication and service. There are only a few thermoplastics [e.g., certain fluorinated polymers such as polyvinylidene fluoride (PVDF)] that do not require the incorporation of some type of additive because they already have sufficient natural thermal stability and aging and weathering resistance.

The precise nature and quantities of additives that can be used for piping compositions are delimited by their effect on engineering properties, such as rigidity, impact strength, chemical resistance, creep resistance, rupture strength under long term loading, and fatigue endurance. For example, the use of an inorganic filler can compromise the natural resistance of polymers to very strong acids or bases. Also, too much filler, or use of a filler of a coarser grade, or its inadequate dispersion can introduce physical discontinuities, or internal faults, that can compromise long term strength, ductility, toughness, and fatigue endurance. Another example is the excessive use of liquid stabilizers or lubricants, which tends to plasticize the plastic and thereby make it less creep-resistant and more sensitive to temperature. Additionally, the properties of the base polymer used in a plastics piping composition are not only determined by the chemical elements, or atoms, from which the polymer is made, but are also profoundly influenced by the specific geometrical arrangement by which the polymer's atoms are combined to form a macromolecule. A most important molecular structural parameter is the length of the molecular chain. The longer the chain, the larger and heavier the molecule.

6.2.2. Crystalline Thermoplastics materials

Certain other polymers, such as PE, PP, PB, and PVDF, are partly crystalline materials. Portions of their polymer chains organize themselves in close and very well ordered arrangements called *crystallites;* other portions lie in the amorphous regions. The stronger physical bonds in the well-ordered, closely packed crystalline regions have significant influence over mechanical properties such as strength, stiffness, and toughness. The extent of crystallization and the size and nature of the crystalline regions, as well as the nature of the interconnectivity network of molecules running from one crystalline region to another can all be somewhat controlled by tailoring molecular architecture.

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The many possible variations in polymer structure, combined with the different types and amounts of additives that can be used, result in a great diversity of plastic compositions, even within a particular polymer group such as polyvinyl chloride (PVC) or polyethylene (PE). The defining and classifying of such compositions is, understandably, not a simple task. The primary standard plastic material specifications are issued by the American Society for Testing and Materials (ASTM). The first ASTM standards classified plastic materials by a ‘‘Type, Grade, and Class ‘system in accordance with three key properties. However, with the growing need to better define plastic materials by more than just three properties, a number of ASTM standards have adopted a cell classification system whereby each of a number of primary properties is given a property cell number depending on the property value.

6.2.4. Cell classification

All the resultant property cell numbers (there can be as many as needed) are then listed in a specified order.

For example in accordance with the cell classification system of ASTM D3350, ‘‘Standard Specification for Polyethylene Plastics Pipe and Fitting Materials,’’ Class 234424 polyethylene designates a material with properties that fall within the following range of values:

Property	Requirement
Density:	Cell 2 of property 1 [0.926 to 0.940 g/cm3]
Melt index:	Cell 3 of property 2 [_0.4 to 0.15 g/10 min]
Flexural modulus:	Cell 4 of property 3 [80,000 to _110,000 psi, 550 to760 MPa]
Tensile strength at yield:	Cell 4 of property 4 [3000 to _3500 psi, 21 to _24MPa]
Resistance to slow crack test method B, Condition C]	Cell 2 of property 5 [50 percent max failure after 24growths: hrs, when using
Hydrostatic design basis	Cell 4 of property 6 [1600 psi or 11 MPa] at 23_C

Although this newer cell-type format is a major improvement in classifying and specifying piping materials by a broader array of significant property and performance characteristics, it may not always be sufficiently definitive predictor of longer-term performance properties. The manufacturer may have to be consulted for further information. For example, two PE materials with the same ASTM material cell classification may have strength under long-term loading that responds somewhat differently to increasing temperature, or to fatigue loading, or to chemical environments.

A brief description of the major materials used for thermoplastics piping follows. The Principle standard piping products made from these materials, and their applications, are identified in Table 1.1. Nonstandard or specialty piping products are also offered from these materials.

7. COMMONLY USED THERMOPLASTIC PIPES

7.1. Polyvinyl Chloride (PVC) Pipe

PVC is used for potable water and drainage systems. It is one of the most widely used of the plastic pipes. It has a low pressure and temperature rating and very poor resistance to solvents.

In its virgin state PVC is a translucent, colorless, rigid polymer. When PVC was first commercialized it was softened by the addition of plasticizers, and the resultant compositions were primarily used in the manufacture of such items as luggage, upholstery, garden hose, wire coating, floor tiles, and laboratory tubing. Subsequent advances in extrusion and molding equipment, and in the availability of more effective stabilizer and lubrication additives, allowed for the extrusion of the much more viscous, rigid compositions which are the only ones suitable for piping. To differentiate these newer UN plasticized compositions from the early plasticized versions they were identified as UPVC, or rigid PVC. These designations are still often used. Of the commonly available thermoplastics, rigid PVC offers the highest strength and stiffness at the least volume cost, which accounts for its having become the leading plastic material for both pressure and non-pressure piping. Major uses include water mains; irrigation; drain, waste, and vent (DWV); sewage and drainage; well casing; electric conduit; and power and communications ducting. PVC is available in a much broader range of pipe sizes and wall thicknesses, fittings, valves, and appurtenances than in any other plastic.

PVC piping is joined primarily by two techniques, solvent cementing and elastomeric seals. Although it can be joined by thermal fusion, its melt viscosity is too high for making reliably strong joints under field conditions.

PVC piping is made only from rigid compounds containing no plasticizers and relatively small quantities of other ingredients. To minimize adverse effects on long term strength and chemical resistance, minimal quantities of additives are used in pressure pipe compounds. To improve impact strength for conduit and other applications that may be subject to mechanical abuse, small quantities of solid polymeric impact modifiers (but not plasticizers, which are generally liquids) are sometimes incorporated into the composition. When improved stiffness is desired, filler—generally very finely divided calcium carbonate—is added. Combinations of these and other additives can be used to optimize a rigid PVC composition for its intended application. The enhancement of a particular property by the use of additives may often require a trade-off with some other property. For the defining of rigid PVC compositions based on resultant properties, ASTM has established two material specifications based on the property cell classification system. One of these is ASTM D1784, ‘‘Standard Specification for Rigid Poly (Vinyl Chloride) and Chlorinated Poly (Vinyl Chloride) Compounds,’’ which classifies PVC materials in accordance with the nature of the polymer and four primary properties. These four properties are Base resin, Impact strength, Tensile strength, Modulus of elasticity in tension, Deflection temperature under load, and Chemical resistance is the fifth property in addition to first four properties. These properties are classified according to cell system according to ASTM D1784 tables for PVC materials.

Example for classification system according to ASTM D1784:

The manner in which a rigid PVC material is identified by this classification system is illustrated by a Class 12454-B PVC material which, according to Tables of ASTM D1784, would have to meet the following property requirements as following:

Property Requirement

Base resin:	Cell 1 of property 1 [poly (vinyl chloride) photopolymer]
Impact strength N-m/mm] :	Cell 2 of property 2 [0.65 ft-lbf/in, minimum, 0.035
Tensile strength:	Cell 4 of property 3 [7,000 psi, minimum or 48 MPa]
Modulus of elasticity in tension: minimum]	Cell 5 of property 4 [400,000 psi, or 2.8 GPa

Deflection temperature under load: Cell 4 of property 5 [158_F (70_C), minimum]

Chemical resistance: Must meet the minimum requirements listed under Suffix B in accordance to ASTM D1784 requirements.

Most PVC pressure pipe is made from materials that meet the minimum requirements of cell 12454-C, which, to maximize long-term strength, generally is formulated with minimal quantities of processing additives and property modifiers.

For pressure pipe applications, the cell classification system of ASTM D1784 is often complemented by one additional material requirement. All PVC pressure pipe standards require that the pipe be made from a formulation with a specified minimum long-term strength that has been established in accordance with ASTM D2837, ''Standard Method for Obtaining the Hydrostatic Design Basis for Thermoplastic Pipe Materials.'' Standards for products intended for the transport of potable water also require that the material meet certain minimum chemical extraction requirements designed to protect water quality matching with NSF 61 standard for potable water (National Sanitation Foundation Standard 61 for potable water).

Most ASTM and a number of other PVC pressure pipe standards identify PVC stress-rated materials by a four-digit number, of which the first two digits designate its type and grade in accordance with the older editions of ASTM D1784 and the last two identify, in hundreds of pounds per square inch, the material's maximum recommended hydrostatic design stress (HDS) for water at 73.4_F (23_C).

In accordance with ASTM convention, the maximum HDS is one-half the material's hydrostatic design basis (HDB), which refers to the material's long-term hydrostatic strength (LTHS) category when established in accordance with ASTM D2837. The following list describes the most common PVC stress-rated materials covered by this designation system:

1. PVC 1120 is a Type 1, Grade 1 PVC material (minimum cell class 12454-B) with a maximum recommended HDS of 2,000 psi (13.8 MPa.) for water at 73.4_F (23_C).

2. PVC 2110 is a Type 2, Grade 1 PVC material (minimum cell class 14333-D) with a maximum recommended HDS of 1,000 psi (6.9 MPa).

3. PVC 2116 is a Type 2, Grade 1 PVC material (same minimum cell class as above) with a maximum recommended HDS of 1,600 psi (11 MPa).

Since by the ASTM convention the maximum recommended HDS is one-half the material's HDB, it follows that the HDBs for these materials are 4,000 psi (27.6 MPa), 2,000 psi (13.8 MPa), and 3,200 psi (22.1 MPa), respectively. The Plastics Pipe Institute (PPI) lists a generic PVC 1120 formulation that provides for certain specified alternative choices of ingredients and formulation quantities that have been determined to allow the formulated compounds to satisfy both the short- and long-term requirements established for this material classification. This formulation, which is listed in PPI TR-3, ''Policies and Procedures for Developing Recommended Hydrostatic Strengths and Design Stresses for Thermoplastic Pipe Materials,'' is periodically updated to include any new alternate choices of ingredients that have been validated by means of both short-term and long term tests.

The other PVC material specification is ASTM D4396, ''Standard Specification for Rigid Polyvinyl Chloride (PVC) and Related Plastic Compounds for Non- Pressure Piping Products'' As indicated by its title, this specification covers compounds only intended for no pressure uses. It is similar to D1784 in that it is also based on the cell format and most of the same primary classification properties.

PVC pipe and fittings must conform to the following standards:

1. ASTM D 1785, PVC Plastic Pipe, Schedules 40, 80, and 120
2. ASTM D 2241, PVC Pressure-Rated Pipe (SDR Series)
3. ASTM D 2466, PVC Plastic Pipe Fittings, Schedule 40
4. ASTM D 2467, Socket-Type PVC Plastic Pipe Fittings, Schedule 80
5. ASTM D 2665, PVC Drain, Waste and Vent Pipe and Fittings

7.2. Chlorinated Polyvinyl Chloride (CPVC) Pipe:

CPVC is used for potable water and drainage systems. It has the same characteristics as those of PVC and is used where a stronger piping system with higher pressure and temperature ratings is required.

As implied by its name, CPVC is a chemical modification of PVC. It is very similar to PVC in many properties, including strength and stiffness at ambient temperature. But the extra chlorine in CPVC's chemical structure increases this material's maximum operating temperature limit by about 50_F (28_C) above that for PVC. Thus, CPVC can be used up to nearly 200_F (93_C) for pressure uses and up to about210_F (100_C) for non-pressure applications. Principle uses for CPVC in addition to mentioned uses above (potable water and drainage systems) are domestic hot water and cold water piping, residential fire-sprinkling piping, and many industrial applications which can take advantage of its elevated-temperature capabilities and superior chemical resistance.

CPVC materials are also classified by ASTM D1784. Similar to PVC, most CPVC standards that cover pressure-rated products identify stress-rated materials by a four-digit number that combines the older type and grade designation with the material's maximum recommended HDS for water at 73.4_F (23_C).Currently, the only recognized stress-rated CPVC designation is CPVC 4120, signifying a Type IV, Grade 1 material in accordance with ASTM D1784 with a maximum recommended hydrostatic design stress of 2,000 psi(13.8 MPa) for water at 73.4_F (23_C) in accordance with ASTM D2837. In addition, most CPVC pipe standards that cover products intended for elevated-temperature service, such as for hot water piping, require that the CPVC material have no less than a recommended HDS of 500 psi (3.5 MPa) (equivalent to an HDB of 1,000psi or 6.9 MPa) for water at 180_F (82_C).

CPVC pipe and fittings must conform to the following standards:

1. ASTM F 441, CPVC Plastic Pipe, Schedules 40 and 80 (IPS)
2. ASTM D 2846, CPVC Plastic Hot and Cold Water Distribution Systems
3. ASTM F 439, Socket-Type CPVC Plastic Pipe Fittings, Schedule 80
4. CPVC 4120material in accordance with ASTM D1784

7.3. Polypropylene (PP) Pipe:

Polypropylene is a polyolefin similar in properties to high-density PE but somewhat harder, more temperature-resistant, and lighter in weight, but less tough. It is also similar to PE in its chemical resistance and heat fusibility. As in the case of PE, PP can be joined to itself by socket fusion, butt fusion, and electro fusion.

Because of its greater stiffness and better tolerance to elevated temperatures PP= is sometimes chosen over PE where these qualities are advantageous (e.g., for aboveground piping and for the conveying of hot fluids). Principle applications for corrosive drainage piping, for which PP offers better solvent resistance than either ABS or PVC. A product line of PP corrosive drainage piping made from aflame-retardant grade of material is offered for use in laboratories and hospitals, and for chemical manufacturing. Another Principle application for PP is for conveying corrosive chemicals under pressure. For this application, socket fusion systems of pressure-rated PP pipe and pipe and fittings are available through NPS 6 (DN 150). At present there are no consensus standards covering PP pressure pipe; all available products are proprietary.

Polypropylene materials are classified by ASTM D4101, ‘‘Standard Specification for Polypropylene Molding and Extrusion Materials,’’ into two types. Type I covers materials that have the highest rigidity and strength but that offer only moderate toughness. Type II covers materials (copolymers of propylene with ethylene or other olefins) which tend to be less rigid and strong but have improved toughness, particularly at lower temperatures. Both types are used for pipe.

7.4. Acrylonitrile-Butadiene-Styrene (ABS) Pipe:

ABS is widely used as drainage pipe and is available in Schedules 40 and 80 with plain or socket ends. Joints are made by either solvent cement or threaded connections. Only Schedule 80 can be threaded.

ABS plastics are made by combining styrene-acrylonitrile copolymers with copolymers formed by reacting styrene-acrylonitrile with butadiene. The butadiene copolymers impart toughness, while the acrylonitrile copolymers contribute strength, rigidity, and hardness. The result is a tough, relatively strong plastic that is easy to mold and extrude.

The ABS family covers a wide range of materials. The proportions of the basic components and the way in which they are combined can be varied to produce a wide range of end properties. A major use of ABS for pipe is in the manufacture of drain-waste-vent (DWV) piping, for which it offers good rigidity, temperature resistance, low-temperature toughness, and the ability to make fast-setting solvent cemented joints. ABS has been used for pressure piping, primarily for water service applications, but it has been largely displaced by the stronger, more chemically resistant, and more economical PVC. However, compressed-air piping made from a proprietary extra-tough, shatter-resistant composition is currently marketed in Europe and the United States.

ABS materials are classified by ASTM D1788, ‘‘Standard Specification for Rigid Acrylonitrile-Butadiene-Styrene (ABS) Plastics,’’ in accordance with the cell class format by which each of three properties—impact strength (toughness), tensile stress at yield (short-term strength), and deflection temperature under load (temperature resistance)—is accorded a cell number depending on the property value.

The ASTM specification for ABS DWV pipe requires that the material have a minimum cell classification of ABS 2–2–2, which signifies the following minimum properties: notch impact strength of 2 ft-lb/in (0.1 N-m/mm) of notch, 180_F (82_C) deflection temperature, and 4,000 psi (2.8 MPa) tensile strength.

ABS pipe and fittings must conform to ASTM Standard D 2661, ABS Schedule40 Plastic Drain, Waste, and Vent Pipe and Fitting.

7.5. Polyethylene (PE) Pipe:

This material is widely used for chemical drainage piping systems. PE pipe and fittings are manufactured from flame-retardant material and are available in Schedule 40 or 80. Joining methods include solvent cement joints, threaded joints, or mechanical-type joints. (Only Schedule 80 can be threaded.).

Polyethylene polymers used for piping are classified into three types: a low density, relatively flexible form; a medium-density, somewhat stiffer and less-flexible form; and a high-density form, which is more rigid and stronger. Most pressure pipe is made of materials of densities lying around the high end of the medium density PEs and the lower end of the high-density materials. This range has established itself as offering the best balance of toughness, flexibility, and long-term strength. No pressure pipe is primarily made from the more rigid, higher-density materials.

PE, which is somewhat less strong and less rigid than PVC at ambient temperature, is the second most used plastic pipe material, primarily because of its toughness, ductility, and flexibility, even at low temperatures. PE pipes do not fracture under the expansive action of freezing water. In an emergency, smaller-diameter PE pipe scan be safely ‘‘squeezed-off’’ (clamped tightly) by suitable procedures, to shut down the flow of fluids. Also, PE pipe is much less prone to failure by a rapidly running crack.

These two last-named characteristics are important reasons why PE pipe is now used in over 85 percent of all current new installations of piping for gas distribution.

PE pipes also have superior fatigue endurance. This feature, plus their ability to dampen water hammer shock, has led to their use for applications such as ins ewer force mains, where repeated cyclic pressure changes tend to occur. The high strain ability and fracture resistance of PE have led to its selection for use in unstable soils and situations where axial bending and diametrical deflection are anticipated. Example installations that utilize this feature are methane collection systems for solid-waste sites, pipes installed by directional trenchless boring techniques, lake and river crossings, and outfall pipes discharging treated effluent into seas and oceans.

PE pipe is also used for the rehabilitation of old pipelines. Lengths of PE pipe which have been joined to the required length by the butt-fusion method are pulled, or sometimes pushed, inside the old line. New rehabilitation procedures have evolved by which, for ease of insertion, the diameter of the liner PE pipe is reduced by a squeeze-down procedure, or by folding the pipe into a U-shape. Once inside the old pipe, the strain memory in the material is relieved by a combination of heating and internal pressure, allowing the PE pipe to reground so that it fits snugly inside the existing pipe. The low stiffness of PE permits the coiling of smaller-diameter pipe [generally up to about 4 in (100 mm) although pipe up to NPS 6 (DN 150) diameter has been coiled for special jobs]. The coiled length can be hundreds of feet and sometimes over a thousand feet (300 meters) long, depending on material, wall thickness, and diameter. PE pipe is readily heat-fusible and can be joined to it or to fittings by the butt-fusion process. PE fittings are also available for joining pipe by the socket fusion and electro fusion processes.

For non-pressure buried pipe applications, such as for storm water, roadway, and land drainage, various designs of profile wall constructions have been developed which enhance pipe wall stiffness while minimizing material usage Because of their corrosion resistance, these pipes are displacing metallic drainage piping.

To protect the PE polymer during processing, storage, and service, PE piping compounds contain small quantities of heat stabilizers, antioxidants, and ultraviolet (UV) screens or UV chemical stabilizers. Black PE pipe materials incorporate very finely divided carbon black as both a coloring pigment and to screen the polymer against the potentially damaging UV radiation in sunlight. Nonblack piping compositions include a UV chemical stabilizer in addition to a coloring pigment (usually tan or yellow for gas, blue for water, and orange for communications ducting).The primary specification for identifying and classifying PE piping materials is ASTM D3350, ‘‘Standard Specification for Polyethylene Pipe and Fittings Materials. ‘Standard D3350 employs the cell class format to cover the diversity of materials used for piping. In addition, an ending code letter is used to designate the incorporation of a colorant and UV stabilizer.

A recent addition to ASTM D3350 is a new test for the classifying of PE’s resistance to crack growth under sustained tensile loading. The test method used for this purpose is ASTM F1473, ‘‘Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipe and Resins.’’

Prior to the issuance of ASTM D 3350, most PE piping standards referred to ASTM D1248, ‘‘Standard Specification for Polyethylene Plastics Molding and Extrusion Materials,’’ for the defining of material requirements. ASTM D1248classified PE by type, representing the material’s density category, and grade, reflecting combination of properties, primarily the melt flow or processing characteristics. Similar to PVC, PE piping standards classify PE stress-rated materials by means of a four-digit number, of which the first two digits refer to the older type and grade designation and the last two represent, in hundreds of pounds per square inch, the material’s maximum recommended hydrostatic design stress (HDS) for water at 73.4_F (23_C). The following list describes the commonly used PE piping materials in accordance with this traditional designation system:

1. PE 2406 is a Type 2 (i.e., medium-density), Grade 4 PE material, in accordance with ASTM D1248, which carries a recommended maximum hydrostatic design stress of 630 psi (4.3 MPa), for water at 73.4_F (23_C). [The ‘‘06’’ in the 2406designates the 630 psi (4.3 MPa) design stress.]

2. PE 3408 is a Type 3 (i.e., high-density), Grade 4 PE material, in accordance with ASTM D1248, which carries a recommended maximum hydrostatic design stress of 800 psi (5.5 MPa) for water at 73.4_F (23_C).

To relate this older designation system to the newer cell system of D 3350, the latter standard includes a cross-reference. The crossovers recognized by the 1993edition of D 3350 are presented in following Table 7.1.

PE material designation based on type and gradient accordance with former ASTM D1248, plus code for material's maximum recommended hydrostatic design stress for water, for 73_F	Corresponding minimum cell classification in accordance with cell classification system of ASTM D3350
PE 2406	PE 213333
PE 3406	PE 324433
PE 3408	PE 334434

Table 7.1

8. DESIGN AND INSTALLATION

Thermoplastics are viscoelastic materials; thus they exhibit a profoundly different stress-strain and stress-rupture response than do elastic materials. Nonetheless, elastic equations used for other types of piping are frequently applicable to thermoplastics piping, provided that their engineering behavior is represented through appropriately derived values of apparent modulus and strength.

Since these properties are greatly influenced by the history of the material's exposure to stress as well as by temperature and environment, proper use of traditional elastic equations requires appropriately established or estimated property values.
Long-term strength values for certain conditions [such as for water at 73_F (23_C)] are available, and in some cases (i.e., maximum recommended hydrostatic design stress) they may even be part of the product standard. In addition, some codes and suggested design protocols either list or give procedures for arriving at appropriate values of strength, stiffness, and allowable strain. As this is a still developing technology, not all properties for all materials are yet available in a standardized basis.

However, for the more frequently used materials, sufficient information for the majority of applications is either available or may be adequately estimated. While the viscoelasticity of thermoplastics somewhat complicates the process of selecting appropriate material constants, materials with high strain capacity help to facilitate design. Under a great many conditions thermoplastics display a ductile like behavior: They are able to deform significantly before fracture. This behavior helps to redistribute stresses and preclude failure by localized stress intensification which could initiate cracking in brittle like materials. Within certain limits, design of thermoplastics piping is based on average stress; localized stress concentrations are generally ignored.
Also, as previously pointed out, the strain capacity of thermoplastics under constant strain (where stresses can gradually decrease through stress relaxation) is often significantly greater than that under constant load (where stresses intensify as the material deforms). Allowable strain limits under constant strain can therefore often be greater than the fracture strains observed under sustained loading. For example, several investigations of PVC and PE pipes subjected to constant deflections over long periods of time show that the materials did not fail at sustained strains of as high as from 5 to 10 percent. These same strains corresponded to relatively short lifetimes when the materials were subject to constant load.
One simplification commonly employed in the North American design of flexible buried plastic pipes (the word *flexible* in this instance signifies that the pipe can undergo significant permanent deformation without cracking) assumes that internal pressure (constant load) and external loading (resulting largely in pipe bending stresses relieved by both pipe deformation and stress relaxation) are acting independently.

That is, the pipe wall thickness is chosen on the basis of internal fluid pressure, and then a separate analysis is made to ensure that the pipe is sufficiently strong and structurally stable under the external loads acting alone. In effect, localized fiber stresses due to bending and other external loadings are neglected.
Standard installation practices include recommendations for avoiding localized stress concentrations. For cases where localized strain cannot be avoided and where it may thus limit design, more rigorous design protocols based on a combined loading analysis are available.

There are many potential factors that could cause a material with apparent high strain capacity to shift from the ductile like to the brittle like state and as a result, fail at lower-than-expected strains. These can include temperature, environment, duration of loading, nature of loading (unrelieved or relieved by stress relaxation), stress triaxiality, fatigue, scale factors (such as wall thickness), damage (cuts, gouges), stored energy in system (such as residual stresses from manufacture), material imperfections (voids, contaminants), polymer aging, and chemical attack. Judging from the good track record that exists, these influences, although difficult to quantify, appear to have been adequately considered for typical uses by standards, design protocols, and installation practices. In addition, material requirements and improvements have been evolving that ensure greater durability in pipe products.

Furthermore, design practices give recognition to the effects on strength and stiffness and other long-term engineering properties by time, temperature, and environment.

Finally, installation recommendations address many of the unique characteristics of plastics that can affect structural integrity and durability. To be sure, the state of the art of thermoplastics piping is still evolving, and considerable work yet remains to be accomplished to further define materials properties and performance limits. Such work is ongoing, and for the latest information the reader is encouraged to refer to the growing literature, particularly to the papers presented at the various conferences that address plastics piping technology.

As demonstrated by the successful record of experience, sufficient information is available to successfully support proper application of thermoplastics over a very broad range of engineering uses. To best realize the performance potential of thermoplastics piping, the user should base materials selection and utilize design and installation practices on information, such as standards and recommended practices, which has been developed under the technical scrutiny of the consensus process of an established professional society or technical association, as well as upon the recommendations and reports issued by industry and independent sources.

The following material is an introduction to some of the more basic aspects of the design and installation of thermoplastics piping. More detailed recommendations suitable to a particular product and situation should be sought and followed.

9. COMMON DESIGN AND INSTALLATION CONSIDERATIONS

9.1. Internal Hydraulic Pressure

Thermoplastic pipe is pressure rated by means of the ISO

$$\mathrm{PR} = 2(\mathrm{HDS}) \times t/D_m$$

Where:

PR = pipe pressure rating, psi (MPa)

t = minimum wall thickness, in (mm)

Dm = mean diameter, in (mm)

HDS = HDB x DF, where HDB is in psi (MPa) units and DF is the pipe design factor

HDB is determined for each pipe type and lifetime, Figure 9.1 showing determining HDB for PVC 1120 pipe as an example.

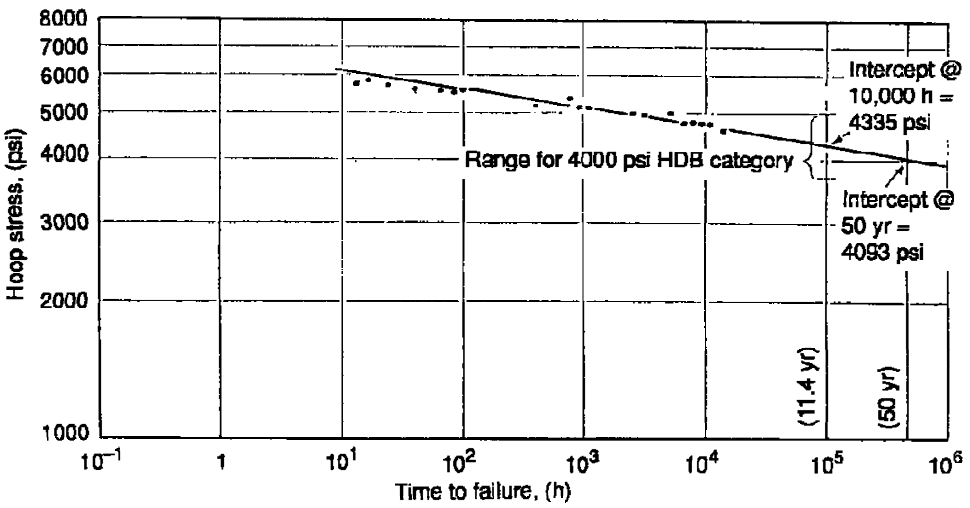


Fig. 9.1

Values of HDS for water at 73 F ° (23 C °) are specified by most ASTM and other standards that cover water and gas applications. The maximum HDS for water is generally determined by multiplying the material's HDB by a design factor (DF) of 0.5. In selecting the appropriate design factor, consideration is given to two general groups of conditions.

The first group considers the manufacturing and testing variables, specifically normal variations in the material, manufacture, dimensions, quality of handling techniques, and the accuracy of the long-term strength prediction.

The second group considers the application or use, specifically installation, environment, temperature, hazard involved, life expectancy desired, and the degree of reliability selected.

For gas pipe, a DF of 0.32 is prescribed by the federal code. Certain other codes and standards (e.g., those of AWWA) may prescribe specific design factors.

A DF smaller than 0.5 is used in applications where greater compensation is advisable for certain anticipated conditions (e.g., surges or temperature), or where the fluid conveyed may have some effect on the pipe material properties. The final determination of the appropriate DF for any given application is up to the discretion of the design engineer.

By assuming that a pipe's outside diameter is equal to *Dm _ t,* the previous equation takes the following form:

$$PR = 2(HDS)/(DR - 1)$$

Where:

DR = Ratio of average outside pipe diameter to minimum wall thickness.

9.1.1. Surge Pressure

Transient and regularly recurring surge pressures may cause damage to pipe and fittings by either of two possible effects: The surge exceeds the short-term fracture strength of the pipe or one of the components; or (and this is the more likely possibility) the repetitive changes in pressure exceed the fatigue endurance limit of the pipe or some piping component. Transient or water hammer surges result from sudden changes in velocity. The pressure rise caused by the velocity change can be estimated by means of the same equations used for calculating the effects of water hammer in other pipes. The only difference is that with plastics the appropriate material modulus is that for the condition of dynamic, instantaneous response (about 150,000 psi (1.0 GPa) and 460,000 psi (3.2 GPa) for high-density PE and PVC, respectively, at 73_F (23_C)). In cases of network piping it is suggested that a complete network analysis be performed for more accurate estimates of possible surge pressures.

Because of the lower stiffness of plastics, the surge pressure rise that occurs from water hammer is significantly lower than for metallic piping. For example, the surge pressure rise for each foot-per-second change in flow velocity is from about 16 to 20 psi (110 to 140 kPa) and 8 to 12 psi (55 to 83 kPa) for PVC and PE, respectively, at 73_F (23_C). The exact value depends on pipe wall thickness , the thicker the wall, the larger the pressure rise.

As noted previously, if there I no damage accrued by excessive fatigue, thermoplastic pipes have the capability to withstand momentary pressures that are significantly greater than the pipe' pressure rating.

This is due to the stress versus time-to-failure characteristics of thermoplastic pipe materials. However, if the sum of short-term pressure rise plus the sustained working pressure exceed the pipe's short-term burst strength, failure will result.

Entrapped air in a pipeline can produce sudden accelerations of air-separated water columns. The kinetic energy of these fast-moving columns can sometimes be high enough to fracture the pipe. For this reason, when plastic piping systems are first filled with water, either for operation or testing, they should be filled carefully and relatively slowly to minimize air entrapment.

Air should be vented from the high points before the system is pressurized. Other precautions should also be taken, such as carefully laying pipe to grade or using air vent-vacuum relief lines, to minimize the entrapment of air in operating pipelines.

When there exists a frequently recurring pressure surge of significant amplitude— say, over 25 percent of the operating pressure—the designer should evaluate the piping for adequacy of fatigue endurance. The resistance to fatigue varies from material to material. For example, PE pipe is quite tolerant; modern materials can withstand frequent surging up to one-half of the pipe pressure rating even when the pipe is operating at its full rating based on only static pressure considerations.

In the case of PVC pipe, which is somewhat more sensitive to effects of fatigue, the following equation has been proposed for estimating the maximum total hoop stress, due to both static and cyclic pressure, that PVC pipe can safely tolerate as a function of the total number of anticipated surge pressure events:

$$S' = \left(\frac{5.05 \times 10^{21}}{C'} \right)$$

Where:

S = maximum allowable total hoop stress, psi (no safety factor) (for S_ in MPa, multiply by 0.0069)

C = total number of cycles

Table 9.1

Suggested Maximum Sustained Working Pressures for Water for 73_F (23_C) for Schedule 40 and Schedule 80 PVC Fittings

Nominal size, in	Schedule 40		Schedule 80	
	Required minimum burst pressure by ASTM D2466 psig	Maximum suggested working pressure psig	Required minimum burst pressure by ASTM D2467 psig	Maximum suggested working pressure psig
½	1910	358	2720	509
¾	1540	289	2200	413
1	1440	270	2020	378
1¼	1180	221	1660	312
1½	1060	198	1510	282
2	890	166	1290	243
2½	970	182	1360	255
3	840	158	1200	225
3½	770	144	1110	207
4	710	133	1040	194
5	620	117	930	173
6	560	106	890	167
8	500	93	790	148
10	450	84	600	140
12	420	79	580	137

Note: This table is only intended as a general guide. Appropriate maximum working pressures may vary widely depending on specific fitting design and field conditions, particularly when repetitive surge pressure are present as these may lower the long-term strength because of fatigue effects. The fitting manufacturer should be consulted for recommendations.

9.2. Resistance to Vacuum and External Pressure

The performance of flexible pipe with thin walls that is made from materials with low modulus of elasticity can sometimes be limited by buckling under vacuum or external pressure.
A net external pressure can result from external hydrostatic loading, from internal negative pressure, from the temporary vacuum that may accompany pressure surging, or from a combination of these elements.
The buckling resistance of plastic pipes may be estimated using the following adaptation of the elastic buckling equation for thin tubes:

$$P_c = \left(\frac{24EI}{1 - \nu^2} \right) \times \frac{1}{D_m^3} C$$

Where:
Pc = critical buckling pressure, psi (MPa)
E = apparent modulus of elasticity, psi (MPa) (For short-term loading conditions, use the values of E and as obtained from short-term tensile tests; for long-term loading, appropriate values as determined from long-term loading tests should be employed)
I = pipe wall moment of inertia, in4/in (mm4/mm)
v = Poisson’s ratio (approximately 0.35 to 0.45 for long-term loading)
Dm = mean diameter, in (mm) _ diameter to centroid of pipe wall for profile wall pipe
C = Ovality correction factor, (r0/r1)3, where r1 is the major radius of curvature of the ovalized pipe, and r0 is the radius assuming no ovalization

For pipe of solid wall construction, for which I = t^3/12, the previous equation is usually expressed as follows:

$$P_c = \left(\frac{2\mathrm{E}}{1 - \nu^2} \right) \times \left(\frac{t}{D_m} \right)^3 \times C$$

Where
t = pipe wall thickness, in (mm)

According to this equation, pipe made to a constant ratio of diameter to wall thickness has the same resistance to hydraulic collapse, independent of pipe diameter.

For buried pipe, the stiffening effect of embedment can substantially increase the buckling capacity. This is discussed in section *11. CONSIDERATIONS FOR BELOWGROUND USES.*

9.3. Temperature Effects

As the system temperature increases, thermoplastics piping become less rigid, exhibits higher impact strength, and offers lower short- and long-term strength. The opposite effects take place as temperature decreases. The exact effect depends not only on material class but its specific composition. For example, there are PEs suitable for service at temperatures as high as around 160_F (71_C); whereas other PEs might only have sufficient strength through about 120_F (49_C). In the case of fittings, wall thickness and product design also influence the effects of temperature on strength.

The best way to determine the effect of temperature on long-term strength is through stress-rupture testing. PPI TR-4, ‘‘Recommended Hydrostatic Strengths and Design Stresses for Thermoplastic Pipe and Fittings Compounds,’’ lists recommended HDBs for various commercial grade thermoplastics for temperatures up to 200_F (93_C).

Because of its effect on stiffness, increasing temperature also decreases the collapse resistance of plastics pipe. Table D 9.2 lists approximate temperature de rating factors for some of the more commonly used materials.

This effect is in direct proportion to the change in the material’s apparent modulus of elasticity. This modulus changes with temperature at a rate roughly parallel with the strength de rating factors given in Table D 9.2.

Other principal effects to be considered in piping design and installation are those resulting from thermoplastics’ high coefficient of expansion and contraction.

Some potential consequences to be considered include:

1. Piping that is installed hot may cool sufficiently after installation to generate substantial tensile forces. The final connection should be made after the pipe has equilibrated to ambient, or to the desired temperature.
2. Unrestrained pipe may shrink enough to pull out from elastomeric gasket or compression joints. The pipe should be adequately restrained by the use of anchors, or the fitting should be designed to either resist pull-out forces or to tolerate the maximum anticipated pipe movement.
3. Piping exposed to cyclic temperature changes may be susceptible to fatigue damage at points subject to repetitive bending.
4. Pipe installed when ambient temperatures are low may buckle if the compression forces developed on subsequent pipe expansion are not adequately relieved.

Table 9.2

Effect of Temperature on Strength and Stiffness of Thermoplastics Pipe: Approximate Temperature D rating Factors

Temperature				**PVC**		
(F)	**PE**	**PEX**	**PB**	**Type 1**	**CPVC**	**PVDF**
70	1.0	1.0	1.0	1.0	1.0	1.0
80	0.95	0.95	0.97	0.88	—	0.93
90	0.90	0.91	0.92	0.75	—	0.87
100	0.80	0.87	0.86	0.62	0.78	0.82
110	0.75	0.83	0.82	0.50	—	0.76
120	0.70	0.79	0.77	0.40	0.65	0.71
130	0.50	0.76	0.72	0.30	—	0.65
140	0.40	0.73	0.68	0.22	0.50	0.61
150	0.20	0.69	0.69	NR	—	0.57
160	NR	0.66	0.58	NR	0.40	0.54
180	NR	0.63	0.48	NR	0.25	0.47
200	NR	0.50	0.40	NR	0.20	0.41
220	NR	NR	NR	NR	NR	0.38
250	NR	NR	NR	NR	NR	0.35
280	NR	NR	NR	NR	NR	0.28

10. CONSIDERATIONS FOR ABOVEGROUND USES

Thermoplastic piping systems in aboveground service must be properly supported to avoid excessive stresses and sagging. Valves and other heavy piping components should be individually supported. Piping should be located, or protected, to avoid mechanical damage. The piping layout should have sufficient flexibility or other means of mitigating excessive bending and axial stresses and fatigue effects induced by repetitive expansion-contraction.

10.1. Supports and Anchors

Horizontal runs require the use of hangers that are carefully aligned and are free of rough and sharp edges. Many hangers designed for metal pipe are suitable for thermoplastic pipe as well. These include the shoe, clamp clevis, sling, and roller types. To preclude high localized support pressures, it is generally advisable to modify the hangers by increasing the bearing area by inserting a protective sleeve of plastic between the pipe and the hanger.

Vertical lines must also be supported at intervals to reduce loads on the lower fittings. This can be accomplished by using riser clamps or double bolt clamps located just below a coupling or other fitting to support the pipe. When so located, these provide the necessary support without excessive compression of the pipe.

Anchors are used in thermoplastic piping systems as fixed points from which to direct expansion-contraction and other movements in a defined direction. Their placement is selected to prevent overloading of the piping, particularly at changes of direction where pipe movement could generate excessive bending and axial stresses.

Anchors should be placed as close to elbows and tees as possible. Guides are used to allow axial motion while preventing transverse movement. Both anchors and guides may be used in the control of expansion and contraction of pipelines. They should be of a style and be so located as to prevent overstressing of the pipe. A flexibility analysis can be used to determine suitable arrangements for anchors and guides.

10.2. Support Spacing

Support spacing requirements are computed using the same beam deflection equations used for metal piping. The minimum spacing requirement can result from either maximum allowable stress or maximum allowable pipe deflection considerations for the maximum anticipated service temperature. Maximum beam deflection, or sag, is frequently the controlling factor. Typical support spacing recommendations are presented in Table 10.1.

When the piping layout does not include sufficient changes in direction, appropriate expansion loops or offsets have to be provided. The size of the loops and offsets depend on the design (see Fig. 10.1), and the change in length of pipe that has to be accommodated. The dimensions of loops and offsets are calculated using the following equation for cantilevered beams loaded at one end.

$$L = \left[\frac{3}{2} \cdot \frac{E}{S}\right]^{0.5} [D_o(\Delta L)]^{0.5}$$

Where:

L = loop length, in (mm)

E = modulus of elasticity at the working temperature, psi (MPa)

S = maximum allowable stress at the working temperature, psi (MPa)

Do = outside pipe diameter, in (mm)

L = change in length due to temperature change, in (mm)

Assuming a maximum allowable strain of 0.01, as suggested by a plastics industry publication, the above equation reduces to:

$$L = 12.2[D_o(\Delta L)]^{0.5}$$

10.3. Expansion-Contraction

There are several methods used for controlling or compensating for axial and bending stresses caused by thermal expansion. Piping runs may include changes in direction which will allow the thermally induced length changes to be taken up safely. Where this method is employed, the pipe must be able to float except at anchor points.

When the piping layout does not include sufficient changes in direction, appropriate expansion loops or offsets have to be provided. The size of the loops and offsets depend on the design (see Fig. 10.1), and the change in length of pipe that has to be accommodated. The dimensions of loops and offsets are calculated using the following equation for cantilevered beams loaded at one end.

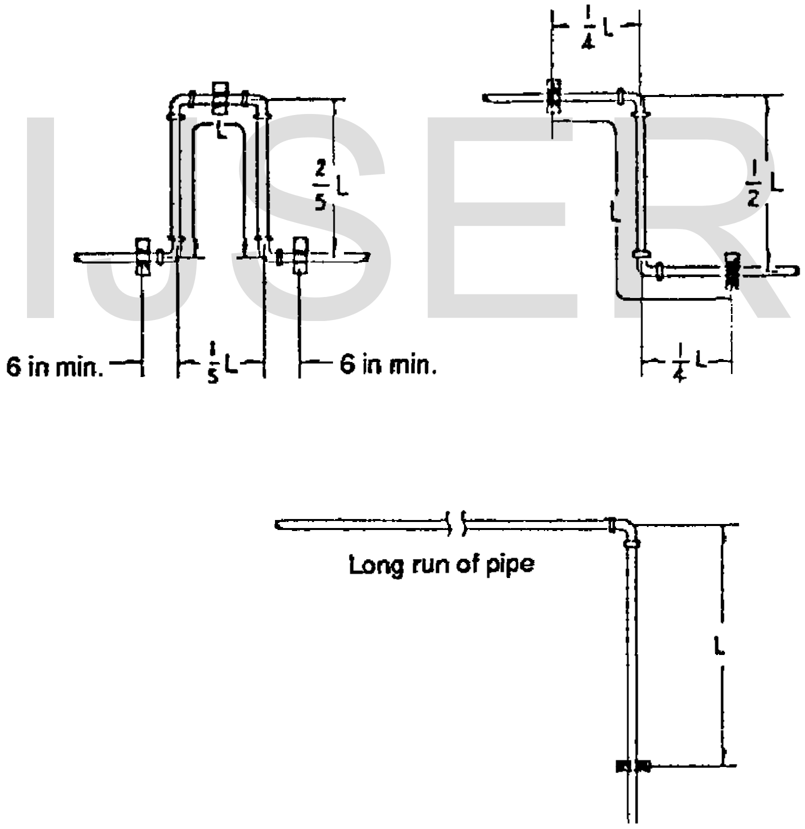


FIGURE 10.1

Expansion loops relieve thermal stresses by transforming them to bending stresses. The minimum loop strength L is generally determined by the maximum allowable bending stress or strain.

Because the fitting restrains the pipe, a separate check should be made with the manufacturer regarding the fitting's capacity to absorb expansion-contraction stresses and bending moments. Expansion joints of bellows and piston designs are available and sometimes used. However, piston expansion joints for pressure applications are generally expensive. Proper alignment of piston joints is critical to prevent binding. Bellows type joints can accept some lateral movement.

Table 10.1

Pipe Dimension	PVC			CPVC				PVDF				PP			
Nominal diam., in	60"F	100"F	140"F	60"F	100"F	140"F	180"F	80"F	100"F	140"F	160"F*	60"F	100"F	140"F	180"F
							Wall Schedule 40								
½	4½	4	2½	5	4½	4	2½	3¾	3½	2		1¾	1¾	1½	1¼
¾	5	4	2½	5½	5	4	2½	4	3¾	2½		2	2	1¾	1¾
1	5½	4½	2½	6	5½	4½	2½	4¼	4	2½		2	2	2	1¾
1¼	5½	5	3	6	5½	5	3	—	—	—		2½	2¼	2	2
1½	6	5	3	6½	6	5	3	4½	4½	2½		2½	2½	2¼	2
2	6	5	3	6½	6	5	3	4½	4½	2¼		3	2¼	2½	2¼
3	7	6	3½	8	7	6	3½					3½	2¼	3	2¾
4	7½	6½	4	8½	7½	6½	4					4	3¼	3½	3
6	8½	7½	4½	9½	8½	7½	4½								
8	9	8	4½												
							Wall Schedule 80								
½	5	4½	2½	5½	5	4½	2½	4½	4½	2½		2	2	2	1½
¼	5½	4½	2½	6	5½	4½	2½	4½	4½	3		2½	2½	2¼	2
1	6	5	3	6½	6	5	3	5	4¾	3		2½	2½	2¼	2
1¼	—	—	—	—	—	—	—	—	—	—		3	2¾	2½	2½
1½	6½	5½	3½	7	6½	5½	3½	5½	5	3		3	3	2¾	2½
2	7	6	3½	7½	7	6	3½	5½	5¼	3		3½	3¼	3	2¾
3	8	7	4	9	8	7	4					4	4	3½	3½
4	9	7½	4½	10	9	7½	4½					4½	4½	4	3½
6	10	9	5	11	10	9	5								
8	11	9½	5½												

* Continuous support recommended.

11. CONSIDERATIONS FOR BELOWGROUND USES

Design and installation of thermoplastic pipe for belowground uses recognizes its ‘‘flexible’’ conduit behavior. As noted earlier, the word *flexible* primarily signifies that the pipe has the capacity to sustain significant deflection without failure. Although this value is somewhat arbitrary, a pipe is often considered flexible if it can sustain 2 percent deflection.

Conduits that are strong and stiff and that fail at low deformations are classified as *rigid.* Both rigid and flexible piping systems take advantage of soil support to minimize internal stresses and must be designed and installed to avoid stress concentrations and deformations that could result in excessive localized stresses. Thus, the installed buried pipe is actually a pipe-soil system, with both the pipe and the soil contributing to the structural performance. This is an important concept for all types of buried piping systems.

Designing pipe for buried conditions may be different for pressure pipe and non pressure pipe. The stresses induced by internal pressure are often high relative to those in non pressure pipe, and the stresses in pressure pipe are constant (subject to creep), while the strains in non pressure pipe are constant (subject to relaxation, i.e., stresses relax with time). In addition, when subjected to internal pressure, a pipe rerounds, reducing the deflection and bending stresses that result from earth loading.

Thus, for many pressure pipes, a design that meets the requirements of the internal pressure condition can be considered adequate for buried applications, provided the pipe is properly installed in good-quality backfill materials. Although all designers should satisfy themselves to this through calculation checks, in general, if the following conditions are met, a pressure pipe design may be considered adequate for burial without checking the capacity for earth and live loads:

1. Minimum depth of cover of 3 ft (1 m) for live loads up to the magnitude of an AASHTO H20 truck.

2. Maximum depth of burial of 20 ft (6 m).

3. No unusual concentrated or surcharge loads exist.

4. Embedment materials are granular, stable, and compacted to at least 85 percent of maximum standard Proctor density.

5. The pipe is uniformly supported on bedding that is firm but not hard.

6. The pipe is protected from concentrated loads at transitions from soil support to structural support, such as fittings, foundation penetrations, and other connections.

For non pressure pipe, and for pressure pipe not meeting the just-noted criteria, the following conditions must be met in designing for earth loads:

1. The pipe should not deflect excessively under earth or live loads.

2. The pipe should safely resist maximum wall compressive thrust forces due to external loads.

3. The pipe should not buckle in response to anticipated external soil and hydrostatic loads.

4. The pipe should safely resist bending stresses that result from deflection.

Because of the wide variety of pipe wall profiles and material types, not all of these criteria will be significant for every type of pipe; for instance, resistance to wall compressive thrust forces is important for profile wall pipe, but rarely is significant for solid-wall pipe.

11.1. Pipe-Soil System Parameters

The behavior of pipe-soil systems is controlled by two parameters:

The hoop stiffness parameter SH

The bending stiffness parameter SB

These are both ratios of the soil stiffness to the pipe stiffness. An elasticity solution for pipe embedded in an infinite elastic media was developed by Burns and Richard23 and utilizes these two parameters to describe buried pipe behavior.

11.1.1. The hoop stiffness parameter

The hoop stiffness parameter is defined as:

$$S_H = M_s/\mathrm{PS}_H$$

Where:

SH = hoop stiffness parameter

Ms = constrained modulus of soil, psi (MPa)

PSH = pipe hoop stiffness parameter, psi (MPa)

The pipe hoop stiffness parameter is defined as:

$$\mathrm{PS}_H = EA/R$$

Where:

E = pipe material modulus of elasticity, psi (MPa)

A = pipe wall area per unit length of pipe, in2/in (mm2/mm)

R = radius to centroid of pipe wall, in (mm)

The pipe hoop stiffness parameter represents the change in pipe diameter that results from a radial pressure applied to the perimeter as shown in Fig. 11.1. This change in diameter results from a reduction in the pipe circumference due to the axial compressive stress produced by the loading.

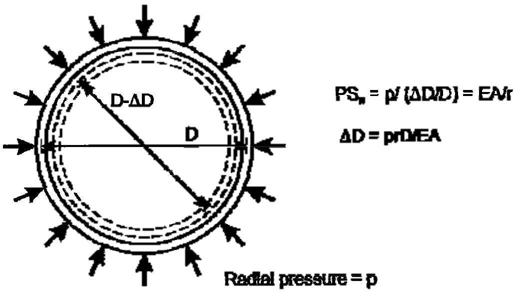


Fig.11.1 Pipe hoop stiffness

11.1.2. The bedding stiffness parameter

The bending stiffness parameter is defined as:

$$S_B = M_s / PS_B$$

Where:

SB = bending stiffness parameter

Ms = constrained modulus of soil, psi (MPa)

PSB = pipe bending stiffness parameter, psi (MPa)

The pipe bending stiffness parameter is defined as:

$$\mathrm{PS}_B = EI/R^3$$

Where

I = pipe wall moment of inertia per unit length, in4/in (mm4/mm)

The pipe bending stiffness parameter represents the change in diameter that results from a concentrated load as demonstrated in Fig. D11.2.This deformation results from flexural stresses produced by the concentrated loading.

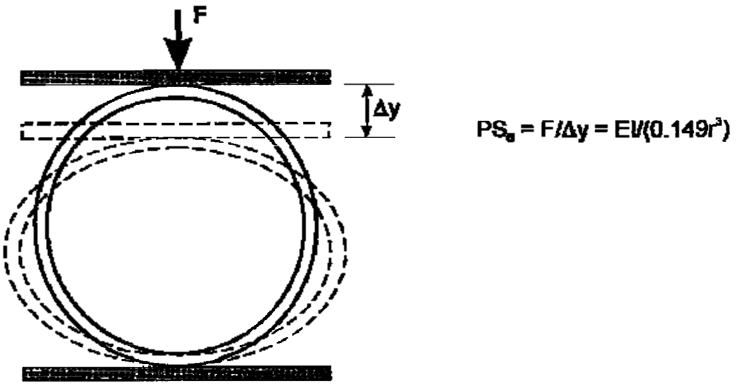


Fig.11.2 Pipe bending stiffness

In general: The hoop stiffness parameter represents a ratio of the soil stiffness to the pipe extensional stiffness, and the bending stiffness parameter represents the ratio of the soil stiffness to the pipe flexural stiffness. In a detailed analysis the Poisson’s ratio of the soil and the pipe material are also important; however, since most design methods are based on simplified models of behavior, and most pipe installation is completed by relatively crude methods, very little accuracy is lost by ignoring this parameter. The contribution of each of the hoop and bending stiffness parameters to the overall pipe soil system is important and bears discussion.

12. PE / METAL PIPE TRANSATION FITTING

The most often used piping material underground on the site is high-density polyethylene (HDPE) with heat-fused butt joints. Socket-type joints in large sizes have often been found to develop unacceptable stress in the pipe. The lower the standard dimension ratio (SDR) the higher pressure rating of pipe. Therefore, care must be taken to select the correct SDR pipe.

Commonly in process fields, codes do not permit plastic pipe to be run aboveground, thus Piping above ground shall be metal; therefore a transition fitting from plastic pipe to metallic pipe is required, conforming to ASTM D2517 , s shown on figure 11.3 Typical transition fitting.

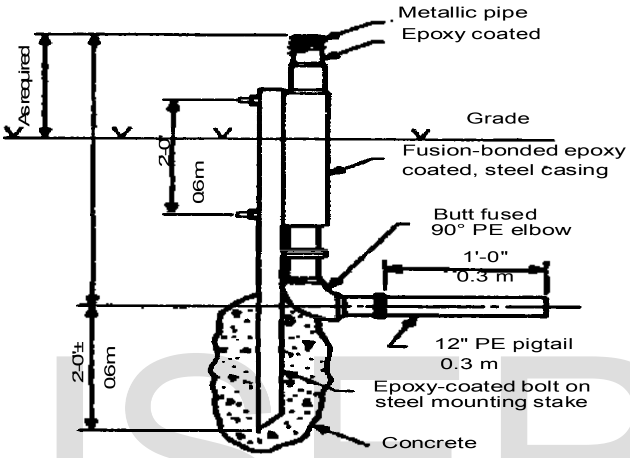


Fig.11.3 Typical transition fitting

12.1 Example, Vendor Print for PE / Metal Transition Fitting

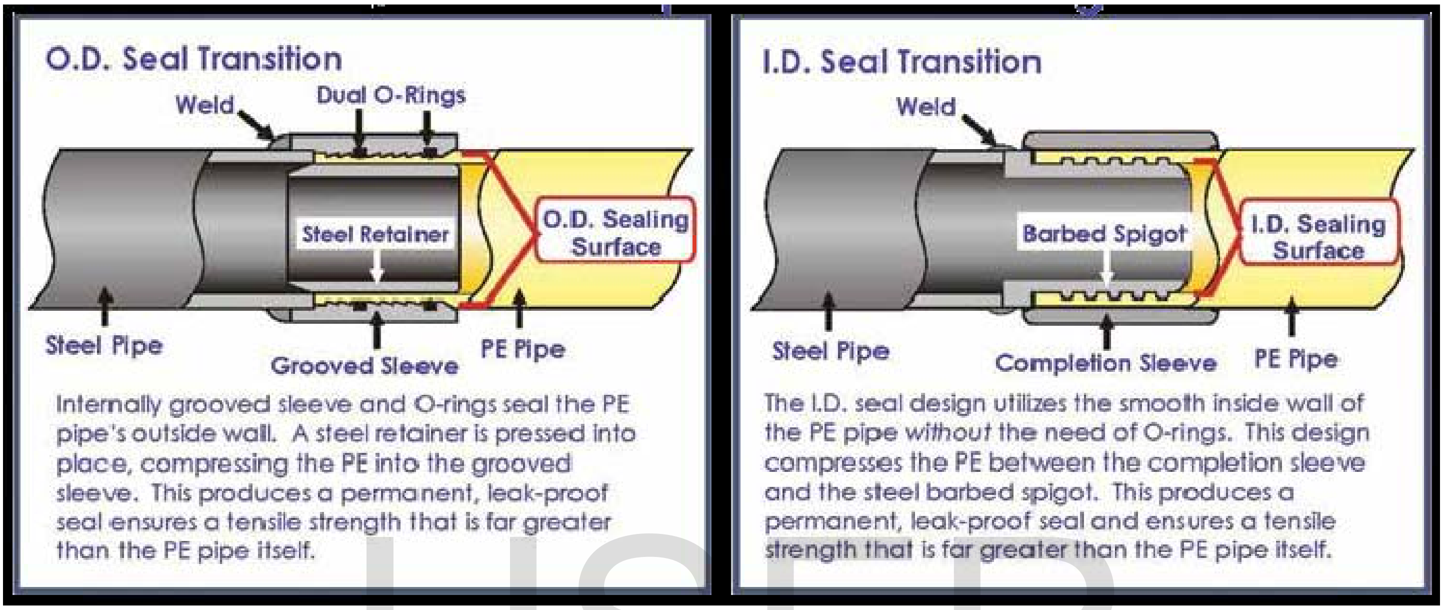
Lyall (Vendor's Name) is the only manufacturer that offers two distinct transition sealing methods allowing a larger choice of configurations to meet your requirements. Our one-piece, factory assembled transitions provide safe, economical and easy-to-install connections between gas carrying steel pipe and polyethylene (PE) pipe.

Proven Reliability - both designs have been approved by most natural gas, propane and industrial fluid companies with over 4 million in service.

Features

- Meets or exceeds all industry requirements.
- Epoxy or primer coatings available.
- Fusion bonded epoxy coating provides superior resistance to corrosion and mechanical damage.
- All welded joints are 100% pressure tested.
- Meets of exceeds the requirements of ASTM D2513 category 1, ASME B 31.8, US CFR 49 Part 192.
- Listed with IAPMO/UPC and certified to CSA B137.4

Two types of sealing are available as shown on following figure 11.4



Internally grooved sleeve and O-rings seal the PE pipe's outside wall. A steel retainer is pressed into place, compressing the PE into the grooved sleeve. This produces a permanent, leak-proof seal ensures a tensile strength that is far greater than the PE pipe itself.

The I.D. seal design utilizes the smooth inside wall of the PE pipe *without* the need of O-rings. This design compresses the PE between the completion sleeve and the steel barbed spigot. This produces a permanent, leak-proof seal and ensures a tensile strength that is far greater than the PE pipe itself.

Figure 11.4

Connection Options:

Steel End Options

- SCH 40 (standard) or SCH 80
- Primer or other coatings
- Internal Fusion Bonded Epoxy Coating (Victaulic Groove and Threaded O.D. seal models only)

PE Pipe End Connections/Options

- Squared ready for fusion
- Socket fusion fitting
- LYCOFIT ® Mechanical Fitting (PE size up to 2 IPS)
- Many choices of HDPE and MDPE pipe
- Commercial/industrial grade PE3408

Other Options

- Protector sleeves
- Wire clips
- Anodes
- Steel to PVC PE pipe (threaded O.D. only)

13. PLASTIC-LINED PIPING FOR CORROSION RESISTANCE

Plastic-lined piping and fittings consist of a metal housing lined with chemically resistant plastic. The combination of a chemical-resistant engineered plastic liner inside a relatively inexpensive but mechanically strong pipe or fitting housing allows for the safe and economical conveyance of corrosive and dangerous chemicals. For this reason, plastic-lined pipe finds widespread use in such industries as the chemical process, pulp and paper, and metal finishing industries. It is also the desired choice when product purity is of concern, particularly when metal corrosion by-products cannot be tolerated in the process fluid. Industries requiring such purity are pharmaceuticals, food, power generation, and electronics, to name a few.

When service conditions are within the capabilities of a plastic-lined piping system, it is often an economical alternative to expensive alloy piping. The methods of lining vary, but all achieve the same goal: to ensure that the liner and housing expand and contract as one unit, even though plastic and metal have greatly differing rates of expansion and contraction.

13.1. History

Plastic-lined pipe was first manufactured in the early 1940s and sold commercially in 1948.

The first piping system was made by mechanically reducing or swaging a steel tube housing down onto an extruded polyvinylidene chloride (PVDC) resin liner. Initially, plastic-lined pipe was not widely accepted by the chemical processing industries because the PVDC liner could only be used for acids and caustics to a maximum service temperature of 175_F (79_C). As new high-performance resins and different manufacturing techniques were developed, plastic-lined pipe was taken more seriously as a cost-efficient method of fighting corrosion.

Thanks to high standards developed by the various manufacturers in the plastic lined pipe industry and more than 50 years of success in very aggressive applications, plastic-lined pipe is a proven and accepted piping product wherever corrosive chemicals must be conveyed.

13.2. METHODS OF MANUFACTURE

The plastic-lined pipe industry uses both extrusion techniques for melt-extrudable type resins or sintering methods for processing polytetrafluoroethylene (PTFE) powder resins into their final forms. Sintering can be defined as forming a coherent bonded mass by heating a powder without melting it. The following sections provide a brief description of the type of processing used by the various manufacturers of plastic-lined piping products.

13.2.1. Liner Manufacturing Processes for PTFE Liners

Although PTFE fluorocarbon resins are thermoplastic materials, they do not flow readily as do most thermoplastics. Instead when PTFE melts at 647_F (342_C), it changes from a white solid to a transparent rubbery gel. Because of the extremely high viscosity of the melted PTFE, special techniques have been developed for converting granular PTFE resins to finished products. The basics steps common to all of these techniques are

- Compaction of the granular resin at a relatively low temperature into a compressed form so that it can be handled

- Heating of the compacted resin above its melting temperature (commonly called sintering) so that the polymer particles can coalesce into a strong homogeneous structure

- Cooling of the sintered product at a controlled rate to room temperature to achieve the desired degree of crystalline development

Voids caused by insufficient consolidation of PTFE resin particles during performing may appear in the finished articles. With reference to a temperature, for example 73_F (23_C), PTFE-liner specific gravities below 2.11 indicate a high-void content. The minimum accepted standard specific gravity as defined in ASTM F 1545 for PTFE-lined pipe is 2.14. Although void content is determined largely by particle characteristics and performing conditions, sintering conditions can also have an effect. Sintering at too high or too low a temperature can increase void content.

13.3. Liner Materials

Plastic lining materials fall into two main categories: fluorinated plastics and no fluorinated plastics. Fluorinated plastics are fully fluorinated, as in the case of polytetrafluoroethylene (PTFE), perfluoroalkoxy, and per fluoro ethylene propylene, or partially fluorinated, as in the case of ethylenete tra fluoro ethylene (ETFE) and polyvinylidenefluoride. It is the fluorine-carbon bonding of these materials that provides the outstanding resistance to chemical attack. In fact, the fully fluorinated plastics exhibit better chemical resistance than virtually any other material, including other metals, plastics, or composites. They also possess:

- High thermal stability

- Resistance to sunlight degradation

- Low smoke and flame characteristics

- Resistance to fungus and bacteria build-up

They generally have:

- Low permeability to most gases and liquids

- High purity in the virgin form

- Process ability, formability, and mold ability

- Cold weather impact strength

- High abrasion resistance

- Low coefficients of friction

- Approval for food contact use

13.3.1. Liner Types

- Polytetrafluoroethylene (PTFE).
- Fluorinated Ethylene Propylene (FEP).
- Perfluoroalkoxy (PFA).
- Ethylenetetrafluoroethylene (ETFE).
- Polyvinylidene Fluoride (PVDF).
- Polypropylene (PP).
- Polyvinylidene Chloride (PVDC).
- Polyethylene (PE).

The non fluorinated plastics, polypropylene (PP) and polyvinylidene chloride (PVDC), are more general purpose materials that provide good overall chemical resistance. They have lower temperature and chemical resistance than the fluoro polymer and are generally less expensive.

13.4. Installed Cost Comparisons

Specification of a corrosion-resistant piping system is a complex assignment, if for no other reason than the large number of available materials that vary both in cost and performance. The materials-selection phase usually yields a number of piping candidates that will perform adequately from a technical standpoint. Then a choice is made from the candidates on an economic basis. Three types of cost comparisons are common:

Material cost

Initial installed cost

Long-term life-cycle cost.

Many specifiers limit their economic analysis to materials costs only because they are relatively simple to estimate. Yet this approach poses a very real danger because it ignores what is often well over half of the true required investment for a piping system, that is, the in-place cost of the system, including fabrication and installation costs.

Many types of corrosion-resistant piping have relatively high material costs because they are supplied from the manufacturer in the form of prefabricated components. This, however, makes these materials relatively less expensive to install.

Conversely, many piping systems with low material costs often require the additional expense of fabrication at the job site prior to installation.

A widely used formatted study9 presents a comparison of initial installed costs for a broad variety of corrosion-resistant piping systems. It provides the engineer with a screening tool to help narrow the field of candidates for a piping project so that a final detailed economic study can be made on the specific piping arrangement under consideration. Factors considered in the study are: type of piping used, material costs, complexity of the piping system, fabrication and erection techniques, and labor rates and productivity in installation. Table 13.1 summarizes the installed cost ratios from the most recent publication for a NPS 2 (DN 50) complex piping system. The report list cost ratios are for NPS 2, 4, and 6 (DN 50, 100, and 150) piping layouts for both straight-run and complex arrangements. A plastic-lined metallic piping system offers clear advantages over both metal and solid-plastic piping systems. Compared to a piping system consisting of corrosion resistant metal, plastic-lined pipe provides equal or better resistance to chemical attack, depending on liner material. When comparing the installed cost of a flanged plastic-lined metallic piping system to a welded metallic piping system, the plastic lined system is often lower. See Table 13.1. This is especially true when comparing plastic-lined pipe to metal systems of higher alloy materials.

Compared to a plastic system made from the same material as the plastic liner, plastic-lined pipe provides higher service capabilities as well as higher mechanical strength. Plastic-lined piping systems are also available in a wider range of line sizes, with a broader selection of fittings, when compared to solid thermoplastic or thermosetting systems.

Plastic-lined pipe is not only used where chemical attack is a concern, it is also used where media contact with metal is detrimental, as in the case of ultra-pure chemicals and demonized water used in various processes in the electronics industry.

Table 13.1

PIPING MATERIAL COST RATIOS			
PVC (sch 80)	0.56	PTFE-lined FRP	3.20
CPVC (sch 80)	0.63	Monel (Sch 40)	3.24
		Alloy 20 (Sch 40)	3.32
Carbon steel (Sch. 40)	1.00	Nickel (Sch 10)	3.34
304L S.S. (Sch. 10)	1.13	Hastelloy C-276 (Sch 10)	3.52
Rubber-lined steel (Sch 40)	1.16		
316L S.S. (Sch. 10)	1.20	PTFE-lined 304L SS (Sch 10)	4.12
304L S.S. (Sch. 40)	1.31	Nickel (Sch 40)	4.27
316L S.S. (Sch. 40)	1.45	Titanium (Sch 10)	4.46
		Hastelloy C-276 (Sch 40)	4.46
FRP/vinyl ester	1.78		
FRP/epoxy	1.86	Hastelloy B (Sch 40)	5.71
FRP/polyester	1.86	Zirconium (Sch 10)	5.95
Polypropylene lined steel (Sch 40)	1.90		
Saran lined steel (Sch 40)	1.91	Zirconium (Sch 40)	7.04
PVDF-lined steel (Sch 40)	2.47		
Alloy 20 (Sch. 10)	2.60		
Monel (Sch 10)	2.61		
Glass-lined steel (Sch 40)	2.69		
PVDF (Sch 80)	2.71		
PTFE-lined steel (Sch 40)	2.94		
Titanium (Sch 10)	2.99		
FEP-lined steel (Sch 40)	2.99		

14. INSTALLATION

Concurrent with the development of structural design methods for thermoplastics, installation practices dedicated to these materials have also been developed. Noteworthy among these are ASTM D 2774, ‘‘Underground Installation of Thermoplastic Pressure Piping,’’ ASTM D 2321, ‘‘Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications,’’ and ASTM F 1668 ‘‘Construction Procedures for Buried Plastic Pipe.’’ A commentary on the installation issues that are critical to the long-term performance of flexible no pressure plastics pipe has been offered by T. J. McGrath.31 Howard has published a book devoted to pipe installation issues.27 Installation as well as design recommendations are also issued by various professional and trade associations. A number of these references are identified in the following section. A significant development in pipe installation practice is the use of controlled low-strength materials (CLSM, also known as flow able fill) for pipe backfill. CLSM is a mixture of sand, cement, fly ash, and water with excellent flow characteristics such that vibration is not required to place it around and under a pipe or other obstructions in a trench. Strengths are low, sometimes as low as 35 psi (240 kPa) at 28 days, in order to assure that the material can be excavated in the event that an encased utility requires a repair. In 1997 ASTM held a three-day symposium on the subject of CLSM, with many papers devoted to its use around pipes.43 One benefit of CLSM is that shrinkage is minimal after placement; thus, if used to backfill an entire trench the settlement and pavement damage that often occurs with soil backfill can be avoided. Pipe installation can be difficult if ground conditions are poor, and it is also expensive to provide full-time inspection of pipe-laying crews. Therefore, a key step in quality control of pipe installations is to check the pipe deflection levels after the installation is complete. This should be a standard part of all pipe installation specifications.

15. SOURCES OF ADDITIONAL INFORMATION

15.1. On New Developments

The inroads that thermoplastics piping has made in fuel gas distribution, sewer, water, agricultural, and highway drainage, and in various industrial uses has generated many studies regarding the durability and engineering performance of these materials. Topics of particular recent interest relate to the use of these materials for larger-diameter applications for which certain limits of performance, such as maximum depth of burial, buckling resistance, and compressive wall strength are often design limiting. A reader interested in these topics, as well as in the general state of the art, should consult the proceedings of the following periodically held symposia and conferences:

Proceedings of International Conferences on Pipeline Design and Installation, American Society of Civil Engineers, 345 East 47th Street, New York, NY 10017.

Proceedings of the Symposium on Buried Plastic Pipe Technology, American Society for Testing & Materials, 100 Bar Harbor Drive, West Conshohocken, PA 19428.

Proceedings of the Fuel Gas Plastic Pipe Symposium, American Gas Association, 1515 Wilson Boulevard, Arlington, VA 22209.

Proceedings of the National Conference on Flexible Pipes, Center for Geotechnical and Groundwater Research, Ohio University, Athens, OH 45701.

Proceedings of the International Conferences on Plastics Pipe, Plastics and Rubber Institute, 11 Hobart Place, London, England SW1W OHL.

15.2. Publications Related to Standards

The following publications contain much information that is useful for all applications of plastics piping, particularly with respect to design and installation:

ASME Guide for Gas Transmission and Distribution Piping Systems. Available from American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, NY 10017, (212) 705-7722.

AGA Plastic Pipe Manual for Gas Service. Available from American Gas

Association, 1515 Wilson Boulevard, Arlington, VA 22209, (703) 841-8454.

Maintenance of Operation of Gas Systems, November, 1970, Army TM5–654;

NAVFAC-MO–220; Air Force AFM 91–6. Available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

15.3. Associations

Various trade and technical associations issue reports, manuals, and lists of references on properties, design, and installation of plastics piping. A listing of current literature offerings may be obtained by contacting these organizations at the following addresses:

Thermoplastic pipe (industrial gas distribution, sewerage, water, and general uses):

The Plastics Pipe Institute, 1825 Connecticut Ave., N.W., Suite 680, Washington, DC 20009.

Thermoplastics pipe (plumbing applications): Plastics Pipe & Fittings Association, 800 Roosevelt Road, Building C, Suite 20, Glen Ellyn, IL 60137.

PVC piping (water distribution, sewerage, and irrigation): Uni-Bell PVC Pipe Association, 2655 Villa Creek Drive, Suite 155, Dallas, TX 75234.

"No-Dig" methods for the rehabilitation of existing buried pipelines: North American Society for Trenchless Technology, 435 North Michigan Avenue, Suite 1717 Chicago, IL 60611.

15.4. Codes

Thermoplastics piping for plumbing, heating, cooling and ventilating, sewer, water, fire protection, gas distribution, and other hazardous materials may be subject to the provisions of a code or other regulation. Nearly all plumbing codes allow plastics piping for certain applications. The major model building and plumbing codes from which most such codes are derived are issued by the following organizations:

BOCA: National Building Code ,BOCA National Mechanical Code, and BOCA National Plumbing Code. Building Officials and Code Administrators, International, Inc., 4051 West Flossmoor Road, Country Club Hills, IL 60478.

CABO: One and Two Family Dwelling Code. Council of American Building Officials, 5203 Leesburg Pike, Falls Church, VA 22041.

IAPMO: Uniform Plumbing Code. International Association of Building and Mechanical Officials, 20001 Walnut Drive South, Walnut, CA 91789–2855.

ICBO: Uniform Building Code and Uniform Mechanical Code. International Conference of Building Officials, 5360 South Workman Mill Road, Whittier, CA 90601.

PHCC: National Standard Plumbing Code. National Association of Plumbing Heating- Cooling Contractors, P.O. Box 6808, Falls Church, VA 22040.

SBCI: SBCCI Southern Building Code, SBCCI Southern Standard Plumbing Code, and SBCCI Southern Standard Mechanical Code. Southern Building Code Congress International, 900 Montclair Road, Birmingham, AL 35213.

American National Standards Institute

ANSI B31.3 Chemical Plant and Petroleum Refinery Piping. Thermoplastic Piping ANSI B31.8 Gas Transmission and Distribution Piping Systems. ANSI Z223, National Fuel Gas Code.

Some standards and various jurisdictions and authorities require that before pipe may be used for certain applications, it first must be approved for that use by a recognized, or specifically designated, organization. Organizations and approval programs for plastic pipe include the following:

For potable water:

NSF International, NSF Building, Post Office Box 1468, Ann Arbor, MI 48106.

Canadian Standards Association, 178 Rexdale Boulevard, Rexdale, Ontario,

Canada, M9W 1R3

For drain, waste, and vent:

NSF International and Canadian Standards Association (see above).

For meat- and food-processing plants:

U.S. Department of Agriculture, 14th and Independence S.W., Room0717 South, Washington, DC 20250.

For water pipe:

American Water Works Association, Denver, CO.

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