

Chapter 5

Standard Specifications, Standard Test Methods and Codes for PE (Polyethylene) Piping Systems

Introduction

The specification, design and use of PE piping systems is addressed by a number of standard specifications, standard test methods and codes including those issued by ASTM International (ASTM), American Water Works Association (AWWA), and Canadian Standards Association (CSA) as well as Technical Reports (TR's) and Technical Notes (TN's) published by the Plastics Pipe Institute (PPI). A listing of the more frequently referenced standards, reports and recommendations is presented in the Appendix to this Chapter.

This Chapter covers topics relating to PE pipe of solid wall or of profile wall construction. These topics include:

1. Material specifications relating to properties and classifications of PE materials for piping applications.
2. Standard requirements relating to pipe pressure rating, dimensions, fittings and joints.
3. Codes, standards and recommended practices governing the application of PE pipe systems in a variety of end uses.

Readers seeking information on PE pipes of corrugated wall construction are invited to visit PPI's web site at <http://plasticpipe.org/drainage/index.html>

Standard Requirements for PE Piping Materials

As discussed in Chapter 3, polyethylene (PE) is a complex polymer with properties that can be optimized based on the desired end use. Such modifications are effected by choice of catalyst system, polymerization conditions and, the use of a small quantity of co-monomer (a monomer or monomers other than ethylene). All these changes allow PE to be tailor made to a wide range of processing and performance requirements.

For classifying this wide array of property variations that find use in piping applications, ASTM issued standard D 3350, "Standard Specification for Polyethylene Plastic Pipe and Fittings Materials". This standard recognizes six properties that are considered important in the manufacture of PE piping, in the heat fusion joining of this material and, in defining its long-term performance capabilities. Each property is assigned into a "Cell" and, each cell consists of a number of "Classes". A cell number covers a narrow range of the larger overall range that is covered by a property "cell". These D 3350 property cells and classes are identified in Table 1.

TABLE 1

Cell Classification System from ASTM D 3350-06^{1,2}

Property	Test Method	0	1	2	3	4	5	6	7	8
Density, g/cm ³	D 1505	un-specified	0.925 or lower	>0.925 - 0.940	>0.940 - 0.947	>0.947 - 0.955	>0.955	—	specify value	—
Melt Index	D 1238	un-specified	>1.0	1.0 to 0.4	<0.4 to 0.15	<0.15	A	—	specify value	—
Flexural Modulus, MPa (psi), 2% secant	D 790	un-specified	<138 (<20,000)	138-<276 (20,000 to <40,000)	276-<552 (40,000 to <80,000)	552-<758 (80,000 to <110,000)	758-<1103 (110,000 to <160,000)	>1103 (>160,000)	specify value	—
Tensile strength at yield, MPa (psi)	D638	un-specified	<15 (<2000)	15- < 18 (2200-<2600)	18- <21 (2600-<3000)	21- <24 (3000-<3500)	24- <28 (3500-<4000)	>28 (>4000)	specify value	—
Slow Crack Growth Resistance I. ESCR	D1693	un-specified								
a. Test condition			A	B	C	C	—	—	—	specify value
b. Test duration, hours			48	24	192	600	—	—	—	
c. Failure, max. %			50	50	20	20	—	—	—	
Slow Crack Growth Resistance II. PENT (hours) Molded Plaque, 80°C, 2.4MPa, notch depth Table 1	F 1473	un-specified	—	—	—	10	30	100	500	specify value
Hydrostatic Strength Classification I. Hydrostatic design basis, MPa, (psi), (23°C)	D2837	NPR ^B	5.52 (800)	6.89 (1000)	8.62 (1250)	11.03 (1600)	—	—	—	—
Hydrostatic Strength Classification II. Minimum Required Strength, MPa (psi), (20°C)	ISO 12162	—	—	—	—	—	8 (1160)	10 (1450)	—	—

Notes to Table 1-A: Refer to 10.1.4.1 (ASTM D 3350) B: NPR = Not Pressure Rated, 1.) D 3350 is subject to periodic revisions, contact ASTM to obtain the latest version, 2.) The property and density are measured on the PE base resin; all the other property values are measured on the final compound.

In addition, by means of a Code letter, ASTM D3350 designates whether the material includes a colorant and also, the nature of the stabilizer that is included for protecting the material against the potential damaging effects of the ultraviolet (UV) rays in sunlight. Table 2 lists the Code letters that are used in D 3350 and what they represent.

TABLE 2
Code Letter Representation

Code Letter	Color and UV Stabilizer
A	Natural
B	Colored
C	Black with 2% minimum carbon black
D	Natural with UV stabilizer
E	Colored with UV stabilizer

For designating a PE material in accordance with ASTM D 3350 the cell number for each cell property is identified, and this is done in the same order as shown in Table 1. This is then followed by an appropriate Code letter to indicate color and stabilization as shown in Table 2. An example of this material designation system is presented in Table 3 for the case of a PE material having designation code PE445574C.

TABLE 3
Properties of a Cell number PE445574 Material

Digit Designating the Applicable Property Cell ⁽¹⁾	Class Number or Code Letter	Corresponding Value of Property (from Table1)
1st Digit – Density of PE base resin, gm/cm ³	4	>0.947 – 0.955
2nd Digit – Melt Index of compound, gm/10 minutes	4	<0.15
3rd Digit – Flexural Modulus of compound, psi (MPa)	5	110,000 - < 160,000 (758 - <1103)
4th Digit – Tensile Strength at Yield of compound, psi (MPa)	5	3,500 - <4,000 (24 - <28)
5th Digit – Resistance to Slow Crack Growth of compound (SCG), hrs.	7	500 minimum based on PENT test
6th Digit – Hydrostatic Design Basis for water at 73°F(23°C), psi of compound (MPa)	4	1600 (11.03)
Code Letter	C	Black with 2% minimum carbon black

(1) The density is that of the PE resin. All the other properties are determined on the final compounded material.

A PE material that complies with the Table 3 cell designation i.e. PE445574C would be a higher density (higher crystallinity), lower melt index (higher molecular weight) material that exhibits exceptionally high resistance to slow crack growth. In addition, it offers a hydrostatic design basis (HDB) for water at 73°F (23°C) of 1600 psi (11.03 MPa). Finally, it would be black and contain a minimum of 2% carbon black.

The cell classification system provides the design engineer with a very useful tool in specifying the requirements of PE materials for piping projects.

Standard PE Piping Material Designation Code

While all PE piping standards specify minimum material requirements based on the cell requirements of ASTM D3350, a simpler, short-hand, ASTM recognized material designation code is commonly used for quickly identifying the most significant engineering properties of a PE pipe material. An important feature of this designation code is that it identifies the maximum recommended hydrostatic design stress (HDS) for water, at 73°F(23°C). Originally, this designation code was devised to only apply to materials intended for pressure piping. However, there is a recognition that even in non-pressure applications stresses are generated which makes it prudent to use a stress rated material. This has led to the common practice of using this material designation code for quickly identifying all PE piping materials intended for pipes of solid wall or, of profile wall construction.

This code is defined in ASTM F412, “Standard Terminology Relating to Plastic Piping Systems”, under the definition for the term code, thermoplastic pipe materials designation. It consists of the ASTM approved abbreviation for the pipe material followed by four digits (e.g., PE4710). The information delivered by this code is as follows:

- The ASTM recognized abbreviation for the piping material. PE, in the case of polyethylene materials.
- The first digit identifies the density range of the base PE resin, in accordance with ASTM D3350, that is used in the material. As discussed in Chapter 3, the density of a PE polymer reflects the polymer’s crystallinity which, in turn, is the principal determinant of the final material’s strength and stiffness properties.
- The second digit identifies the compound’s resistance to slow crack growth (SCG), also in accordance with ASTM D3350. A material’s resistance to SCG relates very strongly to its long-term ductility, a property that defines the material’s capacity for safely resisting the effects of localized stress intensifications.
- The last two numbers identify the compound’s maximum recommended hydrostatic design stress (HDS) category ⁽¹⁾ for water, at 73°F(23°C). This recommendation is established in consideration of various factors but, primarily the following: The capacity for safely resisting the relatively well distributed stresses that are generated only by internal pressure, and, the capacity for safely resisting add-on effects caused by localized stress intensifications.⁽¹⁾

(1) More discussion on these topics later in this Chapter.

The Standard Designation Codes for materials which are recognized as of this writing by current ASTM, AWWA, CSA and other standards are listed in Table 4. This table gives a brief explanation of the significance of the code digits. It should

be recognized that a new material may be commercialized which qualifies for a code designation that has not been recognized as of this writing. For a listing of the most current recognized code designations the reader is invited to consult the periodically updated PPI publication TR-4. Contact PPI via their website, www.plasticpipe.org

TABLE 4
Standard Designation Codes for Current Commercially Available PE Piping Compositions

Standard Designation Code	What the Digits in the Code Denote		
	The 1st Digit	The 2nd Digit	The last two Digits ⁽¹⁾
	Cell Number Based on the Density Cell In accordance with ASTM D3350 (See Table 1)	Cell Number Based on the Resistance to SCG Cell In accordance with ASTM D3350 ⁽²⁾ (See Table 1)	Recommended Standard Hydrostatic Design Stress (HDS) Category, for water, at 73°F (23°C) (psi)
PE2406	Cell number 2	Cell number 4	630
PE2708		Cell number 7	800
PE3408	Cell number 3	Cell number 4	800
PE3608		Cell number 6	
PE3708		Cell number 7	800
PE3710			1,000
PE4708	Cell number 4	Cell number 7	800
PE4710			1,000

- (1) The last two digits code the Standard HDS Category in units of 100psi. For example, 06 is the code for 630psi and 10 is the code for 1,000psi.
- (2) It should be noted that the lowest Cell number for SCG resistance for pipe is 4. Based on research and experience a rating of at least 4 has been determined as sufficient for the safe absorption of localized stresses for properly installed PE pipe.

Standard Equation for Determining the Major Stress Induced in a Pressurized Pipe

There are two major stresses which are induced in the wall of a closed cylindrical vessel, such as a pipe, when it is subjected to internal fluid pressure. One runs along the axis of the vessel, often called the axial (longitudinal) stress, and the other, which is often called the hoop stress, runs along its circumference. Since the magnitude of the hoop stress is about twice that of the axial stress the hoop stress is considered as the significant stress for purposes of pressure pipe design.

The hoop stress is not constant across a pipe’s wall thickness. It tends to be larger on the inside than on the outside of a pipe. And, this tendency is heightened in the case of materials having high stiffness and in thicker walled pipes. However, in the case of pipes made from thermoplastics – materials which are characterized by significantly lower stiffness than metals – it has long been accepted that the hoop stress is constant through the pipe’s wall thickness. For such case the so called thin-walled hoop stress equation is accepted as satisfactory and it has been adopted by standards which

cover thermoplastics pipe. This equation, which more commonly is identified as the ISO (International Organization for Standardization) equation because it has been also adopted for thermoplastic pipes by that organization, is as follows:

$$(1) \quad S = \frac{P D_m}{2t}$$

WHERE

S = Hoop stress (psi or, MPa)

P = Internal pressure (psi or, MPa)

D_m = Mean diameter (in or, mm)

t = minimum wall thickness, (in or, mm)

Because PE pipe is made either to controlled outside diameters or in some cases, to controlled inside diameters the above equation appears in PE pipe standards in one of the following forms:

When the pipe is made to a controlled outside diameter:

$$(2) \quad S = \frac{P}{2} \left[\frac{D_o}{t} - 1 \right]$$

Where D_o is the average outside diameter

When the pipe is made to a controlled inside diameter:

$$(3) \quad S = \frac{P}{2} \left[\frac{D_i}{t} + 1 \right]$$

Where D_i is the average inside diameter

For purposes of pressure pipe design, the pipe's pressure rating (PR) is determined by the hydrostatic design stress (HDS) that is assigned to the material from which the pipe is made. Therefore, Equation (2) can be re-arranged and written in terms of HDS and as follows:

$$(4) \quad PR = \frac{2(HDS)}{\left[\frac{D_o}{t} - 1 \right]}$$

Where PR is the pressure rating (psi or, MPa) and HDS is the hydrostatic design stress (psi or, MPa)

And, Equation (3) becomes:

$$(5) \quad PR = \frac{2(HDS)}{\left[\frac{D_i}{t} + 1 \right]}$$

The term D_o/t is referred to as the *outside diameter dimension ratio* and the term D_i/t as the *inside diameter dimension ratio*. However, the convention in PE pipe standards is to limit these ratios to a standard few. The ASTM terms and abbreviations for these preferences are:

- *Standard Dimension Ratio (SDR)*, for a standard D_o/t dimension ratio
- *Standard Inside Diameter Ratio (SIDR)*, for a standard D_i/t dimension ratio

Standard Diameters

Standard specifications for PE pipe allow the pipe to be made to either controlled inside diameters or, to controlled outside diameters. The inside diameter system, applicable to small diameter sizes only, is intended for use with insert type fittings for which the pipe must have a predicable inside diameter, independent of pipe wall thickness. And the outside diameter systems are intended for use with fittings that require a predictable outside diameter, also independent of wall thickness.

There is but one standard inside diameter sizing convention, SIDR, and this system is based on the inside diameters of the Schedule 40 series of iron pipe sizes (IPS). But there are four standard outside diameter sizing conventions and these are as follows:

- The outside diameters specified for iron pipe sized (IPS) pipe
- The outside diameters specified for ductile iron pipe sizes (DIPS)
- The outside diameters specified for copper tubing sizes (CTS)
- The outside diameters specified by the International Standards Organization (ISO 161/1)

The scope of a consensus standard usually identifies the sizing convention system that is covered by that standard.

PE Pipe Standards are Simplified by the Use of Preferred Values

The most widely accepted standards for PE pipes are those that define pipes which when made to the same Dimension Ratio and from the same kind of material are able to offer the same pressure rating independent of pipe size (See Equations 4 and 5). These standards are commonly referred to as Dimension Ratio/Pressure Rated (DR-PR) so as to distinguish them from other standards, such as those based on Schedule 40 and 80 dimensioning, in which the Dimension Ratio varies from one size to the next.

For the purpose of limiting standard pressure ratings (PR) in DR-PR standards to just those few which adequately satisfy common application requirements these standards require that the Dimension Ratios be one of certain series of established preferred numbers. They also require that the pipe's pressure rating be determined based on a recognized HDS category that is also expressed in terms of a preferred

number (See previous discussion on PE pipe material designation code). The preferred numbers for both are derived from the ANSI Preferred Numbers, Series 10. The Series 10 numbers get that name because ten specified steps are required to affect a rise from one power of ten to the next one. Each ascending step represents an increase of about 25% over the previous value. For example, the following are the ANSI specified steps between 10 and 100: are 10; 12.5; 16.0; 20.0; 25.0; 31.5; 40.0; 50.0; 63.0; 80.0; 100.

A beneficial feature of the use of preferred numbers is that when a preferred number is multiplied or, is divided by another preferred number the result is always a preferred number.

The table that follows lists the Standard Dimension Ratios, all based on preferred numbers, which appear in the various ASTM, AWWA and CSA DR-PR based standards for PE pipe.

TABLE 5
Standard Dimension Ratios (SDRs)

Based on Mean Diameter (D_m/t) (Same numerical value as ANSI Preferred Number, Series 10)	Based on Outside Diameter SDR = (D_o/t (Series 10 Number + 1))	Based on Inside Diameter SDR = (D_i/t (Series 10 Number - 1))
5.0	6.0	4.0
6.3	7.3	5.3
8.0	9.0	7.0
10.0	11.0	9.0
12.5	13.5	11.5
16.0	17.0	15.0
20.0	21.0	19.0
25.0	26.0	24.0
31.5	32.5	30.5
40.0	41.0	39.0
50.0	51.0	49.0
63.0	64.0	62.0

The recognized standard HDS categories for water, at 73°F (23°C), are: 630 psi (4.34 MPa); 800 psi (5.52 MPa); and 1,000psi (6.90 MPa) (See discussion under the heading, Standard PE Piping Material Designation Code).

And, the standard pressure ratings for water, at 73°F (23°C), which are commonly recognized by DR-PR standard specifications for PE pipe are as follows: 250; 200; 160; 125; 100; 80; 63; 50; and 40 psig. However, individual standards generally only cover a selected portion of this broad range.