PERFORMANCE PIPE
A DIVISION OF CHEVRON PHILLIPS CHEMICAL COMPANY LP

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Technical Note PP 816-TN
PE3608 & PE4710 Materials Designation Codes and Pipe Pressure Ratings

Since introducing polyethylene pipe resin in the 1950's, polyethylene (PE) manufacturers have worked continually to improve the material's performance. These improvements have resulted in a continual improvement from PE1404 materials to the current materials today referred to as PE4710 materials. Two of the most important characteristics for pipe material are resistance to long-term hydrostatic pressure and resistance to slow crack growth development under localized stresses. Testing protocols have been developed, improved, and standardized so that end users can be confident in getting the highest performance properties available from today's materials. Recent improvements in resin have been so significant that the resin classification system was changed to recognize and categorize higher properties for these newer materials. For instance, the term PE3408 is widely recognized however materials that were formerly classified as PE3408 are now split into three categories, PE3408, PE3608 or PE4710. PE4710 pipes offer higher service pressures or reduced wall thicknesses, increased hydraulic capacity and better overall mechanical properties than the former PE3408 pipes. The trade off in all of this is that PE4710 material has a more complex molecular structure and thus costs more for resin manufacturers to make, but the net result is generally a savings on the per foot pipe cost.

New Cell Classification

The ASTM D3350, "Standard Specification for Polyethylene Plastics Pipe and Fittings Materials" standard cell classification uses a series of digits to identify various properties of polyethylene pipe materials. For example, the cell classification for Performance Pipe's standard extra high molecular weight pipe grade resin for municipal and industrial (M&I) applications is 345464C.

In December 2005 ASTM changed this standard to expand the cell classification system. The 2005 change adds new limits to the base resin density cell. The density cell is the very first digit in the cell classification sequence. The changes essentially split the high density cell class into two categories; those with densities ranging from >0.940 g/cc^3 to 0.947 g/cc^3 and those with densities ranging from >0.947 g/cc^3 to 0.955 g/cc^3. Prior to the split the density code for high density was "3". After the split, the density code was left at "3" for the lower range of densities and changed to "4"for the higher range of densities. See Table 1.

In addition to the density change, D3350 also recognized higher slow crack growth resistance, which is designated by the fifth digit in the cell classification. By the nineties, PE materials had improved so much that the standard environmental stress crack test, ASTM D 1693, was unable to differentiate between better performing materials. Researchers at the University of Pennsylvania developed an extremely rigorous slow crack growth test referred to as the PENT test. ASTM wrote a standard for this test, ASTM D 1473. It was incorporated into D3350. At that time, the highest category in D3350 for the PENT test was a minimum test time of 100 hours. This performance was assigned a digit of "6". In the 2005, ASTM added a new class with a minimum PENT test time of 500 hours. The new designation code is "7". The University of Pennsylvania researchers early on concluded that one hour of PENT roughly equated to 13 years of service life.[1] While that analysis may be limited it does illustrate the tremendous slow crack growth resistance of the newer materials.

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The PENT test, like D1693, has limitations. While PENT may be useful as an indexing test, there is no accepted industry standard that assigns higher performance to materials with PENT higher than 500 hours. This is logical since it is observed that as the PENT time to failure increases the failure mode shifts from slow crack growth to tensile rupture, thus rendering the test questionable as an indicator of pipe long-term performance. See Krishnaswamy et al.[2]

As a result of the additions to D3350, the newest material, PE4710, is identified by the cell classification, 445474C and highlighted in Table 1.

Table 1. Pipe Properties and Cell Class Limits per ASTM D3350-05

Property	Test Method	0	1	2	3	4	5	6	7	8
1. Density, gm/cm^3	D1505	*a*	0.925 or lower	>0.925-0.940	>0.940-0.947	>0.947-0.955	>0.955	--	*b*	
2. Melt Index	D1238	*a*	>1.0	1.0 to 0.4	<0.4 to 0.15	<0.15	*c*	--	*b*	
3. Flexural Modulus, psi	D790	*a*	<20,000	20,000 to <40,000	40,000 to <80,000	80,000 to <110,000	110,000 to <160,000	>160,000	*b*	
4. Tensile Strength at Yield, psi	D638	*a*	<2200	2200 to <2600	2600 to <3000	3000 to <3500	3500 to <4000	>4000	*b*	
5. Slow Crack Growth Resistance I. ESCR a. Test condition (100% Igepal) b.Test duration, h c. Failure,max,% II. PENT (hours) Molded Plaque. 80^{o}C, 2.4 MPa Notch depth. F1473. Table 1	D1693 F1473	*a* *a* *a* *a*	A 48 50	B 24 50	C 192 20	C 600 20 10	30	100	500	*b* *b*
6. Hydrostatic Strength Classification I. Hydrostatic design basis, psi (23^{o}C) II. Minimum required strength, MPa (psi) (20^{O}C)	D2837 ISO 12162	*d*	800	1000	1250	1600	8 (1160)	10 (1450)		

Notes:
(a) Unspecified.
(b) Specify Value.
(c) Refer to ASTM D3350 Section 10.1.4.1.
(d) Not Pressure Rated.

Higher Performance Material

What are the implications of the higher density and higher PENT values on the performance of pipe made of this new material? The new materials have improved long term performance under hydrostatic stress. Pipe made from these materials is suitable to operate at higher hoop stresses than pipe made from lower cell class materials. ASTM does not assign hydrostatic strength ratings to pipe material. This is done by the Plastics Pipe Institute (PPI). Concurrent with the changes in D3350, the PPI assigned higher hydrostatic strength ratings for materials that met a minimum of 500 hours of PENT and certain additional material requirements.

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Pressure Rating PE Materials

To understand those requirements a little background in how materials are pressure rated is helpful. The recognized method for determining the long-term performance of thermoplastic materials is ASTM D 2837, "Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials". PPI's Technical Report 3 (TR-3) describes the methodology for establishing a pipe material's hydrostatic design basis. The hydrostatic design basis, HDB, for a thermoplastic materials is the long-term hoop tensile stress that the material can be expected to withstand for 100,000 hours at a specific temperature. Supplemental validation at elevated temperatures verifies long term performance against failure by cracking. Technical Report 4 (TR-4) lists the HDB as well as the recommended maximum hydrostatic design stress (HDS) in water service at various temperatures for listed thermoplastic materials. This information is available at www.plasticpipe.org. Until 2006, the highest HDS at 73°F assigned to any high density polyethylene material was 800 psi. Once the new cell classification was available in D3350, PPI approved new criteria for resins that would allow higher HDS values at 73°F. The new criteria included a minimum PENT value of 500 hours, a stress rupture curve with tighter data scatter requirements, and validation of the linearity of the stress rupture curve for 50 years. High density polyethylene materials meeting these requirements have a recommended maximum HDS of 1000 psi at 73°F. For pipes of the same dimension ratio (DR), the new HDS allows an almost 25% increase in the pipe's pressure rating.

Thermoplastic Materials Designation Code

Besides having a different cell class, the newer materials can be differentiated from other material by the thermoplastic materials designation code. The designation code is an abbreviated classification consisting of a two-letter identification for polyethylene, "PE", followed by four digits. The first digit corresponds to the density, the second to the stress crack resistance (or PENT value), and the last two designate the HDS at 73°F when divided by 100. For example, material with a cell class of 345464C which has an HDS of 800 psi would have a materials designation code of PE3608. The new material which has a cell class of 445474C and meets the PPI criteria for a higher HDS (1000 psi) has a materials designation code of PE4710. Prior to the 2005 revisions to D3350, the material designation code for Performance Pipe's high density pipe material having a cell class of 345464C was PE3408.[1] Based on the previous versions of D3350, both the PE4710 and the PE3608 material would have been designated as PE3408.[2, 3]

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[1] The discrepancy in the 2nd digit between the former 3408 and the new 3608 designation is due to the older version of D3350 using the designation of "4" to indicate either a slow crack growth resistance of 4 or 6.

[2] The 2005 changes to D3350 have introduced additional materials designation codes such as PE3710, which would be for a material having a cell class of 345474C material and meeting the TR-3 criteria for the higher HDS. The materials designation changes have also occurred with medium density material. For instance, material having a cell of 234373E and meeting the TR-3 criteria has a designation code of PE2708.

[3] Another material designation that is used in Europe has created some confusion with PE4710. That designation is PE100. While it has a lot of different meanings for different manufacturers the only requirement for a **material** to be PE100 is that it has a long term hydrostatic strength of 10 MPa (usually referred to as a Minimum Required Strength). An explanation of the MRS rating methodology is given in TR-3. While some PE100 resins may be excellent resins, the PE 100 designation covers no other important properties of the **pipe** such as stress crack resistance.

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Hydrostatic Design Stress

The hydrostatic design stress at 73°F assigned by PPI for Performance Pipe materials is shown in Table 2.

Table 2. Hydrostatic Design Stress for PE materials at 73°F

Material Designation Code	Hydrostatic Design Stress
PE 3608	800 psi
PE 4710	1000 psi

Last year Performance Pipe participated in changing the ASTM standards, F714 and D3035, to permit use of the PE4710 material at the new hydrostatic design stress. Because many specifications still call out PE3408 material, both standards allow pipe to be supplied with dual markings. That is, a pipe could be marked as PE3408/3608 or PE3408/4710 because the materials meeting the higher Material Designation Codes (i.e. PE3608 and PE4710) also meet the requirements of the lower (i.e. PE3408) Material Designation Code.

At the time of this writing, AWWA standards have not been changed. It may take until late 2008 or 2009 to accomplish this. Until the AWWA standards are changed, pipe made with PE4710 and marked AWWA cannot be rated at the higher pressures. Thus, the PE4710 material is limited to HDPE pipe produced to ASTM F714 or ASTM D3035 only. Although the PE4710 material has a higher pressure rating, it might be prudent to observe that the tensile strength of PE4710 is only about 10% higher than the former PE3408 material. PE4710 pipe manufactured to a higher DR but with the same pressure rating as a PE3408 pipe would in fact have lower tensile and compressive strength than the PE3408 pipe. Therefore, applications such as landfills, deep fills, directional drilling where the materials tensile and compressive strength govern design may not benefit as much from the newer material.

Pressure Rating of HDPE Pipe

The pressure rating of pipe made from PE3608 and PE4710 pipe grade resins is given in Appendix X5 of ASTM F 714. The pressure rating may be determined from Equation 1.

$$p = \frac{2(HDS)(F_T)(F_E)}{DR - 1}$$

Where:

p = pressure rating, psi
HDS = hydrostatic design stress at 73°F, psi (See Table 2.)
F_T = temperature design factor (See Table 3.)
F_E = environmental design factor (See Table 4.)
DR = dimension ratio (D_o/t_{min})

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Temperature Design Factor

The Hydrostatic Design Stress for polyethylene is established by testing at 73°F. As with all thermoplastics, as temperature increases, polyethylene has lower resistance to load. Therefore, the pressure rating decreases. The Temperature Design Factor adjusts the pressure rating for the application temperature. The temperature rating at 73°F is considered good to 80°F without need of a design factor.

Table 3. Temperature Design Factors (F_T)

Service Temperature °F	**≤ 80**	**90**	**100**	**110**	**120**	**130**	**140**
Design Factor (F_T)	1.00	0.90	0.78	0.75	0.63	0.60	0.50

For temperature between values in Table 3 a straight line interpolation may be used. The only exception to this is AWWA municipal water applications. AWWA M-55, "PE Pipe—Design and Installation", gives temperature design factors for up to 100°F and rounds them off to the nearest tenth. For values above 80°F but below 90°F it gives 0.9 and for values above 90°F and below 100°F it gives 0.8.

The maximum temperature for pressure service is 140°F, while the maximum temperature for non-pressure service is 180°F.

Environmental Design Factor

The Hydrostatic Design Stress for HDPE is determined in water. Other chemicals may have an affect on long term performance. The Industry normally accounts for this affect by using an environmental design factor. Other more aggressive chemicals such as strong oxidizers may have a detrimental affect on the pipe. Please see the Plastics Pipe Institute's Technical Report TR-19, "Thermoplastic Piping for the Transport of Chemicals" for a list of chemicals and effect.

Table 4. Environmental Design Factor (F_E)

Application	**F_E**
Fluids such as potable and process water, benign chemicals, dry natural gas (non-federally regulated), brine, CO_2, H_2S, wastewater, sewage, glycol/anti-freeze solutions	1.0
Fluids such as solvating/permeating chemicals in pipe or soil (typically hydrocarbons) in 2% or greater concentrations, natural or other fuel-gas liquid condensates, crude oil, fuel oil, gasoline, diesel, kerosene, hydrocarbon fuels	0.5

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Dimension Ratio

Thermoplastic pipes are commonly produced in accordance with a dimension ratio system. The dimension ratio, DR, is the ratio of the pipe's average outside diameter to its minimum wall thickness. As diameters change, the pressure rating remains the same for a given material, dimension ratio, and application.

Certain dimension ratios that meet an ANSI-specified preferred number series are Standard Dimension Ratios (SDR). SDR's and DR's are the same measure, but making pipe to SDR's allows manufacturers to standardize on product offerings.. Standard Dimension Ratios are: 41, 32.5, 26, 21, 17, 13.5, 11, 9, and 7.3. From one SDR to the next, there is about a 25% difference in minimum wall thickness.

Pressure Ratings for Specified DR's

Table 5 gives the pressure ratings for PE3608 and PE4710 pipe rounded to the nearest five or zero.

Table 5. Pipe Pressure Rating for Water at 80^{o}F for HDPE Pipe[4]

Pipe Pressure Ratings		
DR	**PE3608**	**PE4710**
7.3	255	315
9	200	255
11	160	200
13.5	130	160
17	100	125
21	80	100
26	65	80
32.5	50	65

[4] ASTM F 714 states the following, "The actual choice of pressure rating for a particular application rests with the system designer, taking into account applicable Codes and Regulations, transportation and on-site handling conditions, the quality of installation, the fluid being transported, the external environment, and the possibility of deviation from design operating conditions of internal pressure or external load. A reduced pressure rating should be applied at the designing engineer's discretion where warranted by consideration of these or other conditions for the particular application."

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Summary

Recent enhancements to materials have resulted in changes in ASTM D3350; ASTM F714; ASTM D3035; PPI TR3 & PPI TR4 to define, recognize, and categorize higher performance materials. (As of the writing of this Technical Note the remaining standards are currently being revised to include these higher performance criteria.) The higher performance materials are now referred to as PE4710 materials and have increased requirements on slow crack growth, data fit, and data extrapolation. The result of these increased criteria is pipe that can be safely operated at higher pressures.

References

1. N. Brown. (2007) "Intrinsic Lifetime of Polyethylene Pipelines", Polymer Engineering and Science, 47 (4), pg. 477-480.

2. R.K. Krishnaswamy, A.M. Sukhadia, and M.J. Lamborn (2007) “Is PENT a True Indicator of PE Pipe Slow Crack Growth Resistance?” See www.performancepipe.com. Technical Note 818.

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