High Performance Bimodal PE 100 Materials For Gas Piping Applications

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Abstract

This paper describes the key features of high performance bimodal PE 100 materials, which have a unique combination of the highest pressure rating for a PE material, outstanding resistance to SCG (slow crack growth) and outstanding resistance to RCP (rapid crack propagation). We will review the higher pressure rating of PE 100 materials obtained from ISO 9080 and ISO 12162 called the MRS (minimum required strength) and compare it to the North American pressure rating method called the HDB (hydrostatic design basis) obtained from ASTM D 2837. We will then review the changes that the Plastics Pipe Institute (PPI) members are making to several ASTM standards so that these PE 100 materials can achieve the same higher pressure ratings of the ISO method using ASTM standards. The new pipe material designation code for these PE 100 materials using the new ASTM terminology will likely be PE 4710. Finally, we will show that the pipe cost for the new high performance PE 100 and PE 4710 materials are actually lower than the traditional PE materials (PE 2406 and PE 3408). These high performance PE 100 materials rated using the ISO method not only have all the benefits we will describe, but they also have the lowest cost.

Background

Polyethylene (PE) has been the material of choice for the gas distribution industry both domestically and internationally for about 40 years. Over 15 years ago bimodal PE 100 materials were introduced in Europe. These PE 100 materials have a unique combination of having the highest pressure rating (PR), outstanding resistance to SCG along with outstanding resistance to RCP. PR, SCG and RCP are the three key properties for a plastic piping material, and these bimodal PE 100 materials have outstanding performance in all three areas. The higher pressure rating of these PE 100 materials results in a thinner wall for a given operating pressure, which can make PE very attractive compared to steel pipe for the large diameter pipe sizes. A thinner wall not only improves flow through the pipe, but also lowers the price of the pipe. This can be especially important for large diameter pipe and many times is the deciding factor whether a gas company uses PE pipe or steel pipe. With the many advantages of PE pipe compared to steel pipe, gas companies would prefer to use PE pipe for higher operating pressures and larger diameters. These bimodal PE 100 materials now make PE pipe more cost competitive with steel pipe, while maintaining all the benefits of PE piping for the gas industry.

ASTM Pressure Rating Method

The ASTM pressure rating method utilizes pipe samples tested at a constant temperature with the linear log stress – log time regression line extrapolated to 100,000 hours (11 years). This extrapolated value is called the long-term hydrostatic strength (LTHS) and the categorized value of the LTHS is called the HDB (Hydrostatic Design Basis) in accordance with ASTM method D 2837. These HDB values are published in PPI TR-4, which is available on the PPI website www.plasticpipe.org. The HDS (hydrostatic design stress) is the product of the HDB and the design factor for water, which is 0.50.

These PPI listings of HDB values are classified in accordance with the material's standard pipe material designation code. In this designation system, the plastic pipe material is identified by its standard abbreviated terminology in accordance with ASTM D 1600, "Standard Terminology Relating to Abbreviations, Acronyms, and Codes for Terms Relating to Plastics", followed by a four or five digit number. The first two or three digits, as the case may be, code the material's ASTM classification (short-term properties) in accordance with the appropriate ASTM standard specification for that material. The last two digits of this number represent the PPI recommended HDS (HDB times 0.5 design factor) for water at 73°F (23°C) divided by one hundred. An example of this pipe material designation code is as follows:

- PE 3408 is a polyethylene (the PE abbreviation is in accordance with ASTM D 1600) classified as a grade PE 34 with a density cell class of 3 and a slow crack growth cell class of 4 (in accordance with ASTM D 3350). It has an 800-psi maximum recommended HDS (1600 psi HDB times 0.5 design factor) at 73°F (23°C).

The gas engineer uses the pressure rating formula below to calculate the maximum operating pressure (MOP) for his PE pipe:

$$MOP = [2\,(HDB)\,(F) / (DR - 1)]$$

Where: MOP = maximum operating pressure, psig
HDB = hydrostatic design basis, psi
F (design factor) = 0.32 for gas pipe applications
DR = dimension ratio

An example calculation for a DR 11 PE 3408 pipe with an HDB of 1600 psi is:

$$P = [2\,(1600)\,(.32) / (11-1)] = 102 \text{ psig.}$$

This is the maximum operating pressure or pressure rating for buried DR 11 PE 3408 pipe using the DOT recommended design factor (F) of 0.32 for gas piping applications.

ISO Pressure Rating Method

The ISO pressure rating method utilizes pipe samples tested at three different temperatures with the linear log stress – log time 20°C regression line extrapolated to 480,000 hours (50 years). The lower confidence level of the extrapolated value is called the lower predictive level (LPL) and the categorized value of the LPL is called the MRS (minimum required strength) in accordance with ISO 9080 and ISO 12162. These MRS values are also published in PPI TR-4, which is available on the PPI website www.plasticpipe.org.

The PPI listings of MRS values are also classified in accordance with the material's standard pipe material designation code. In this ISO designation system, the plastic pipe material is identified by its standard abbreviated terminology followed by two or three digits, which are the MRS value multiplied by 10. An example of this ISO pipe material designation code is as follows:

- PE 100 is a polyethylene (the PE abbreviation is in accordance with ISO) with an MRS of 10 MPa.

The gas engineer uses the pressure rating formula below to calculate the maximum operating pressure (MOP) for his PE pipe:

$$MOP = [20\ (MRS)\ /\ (DR - 1)\ (C)]$$

Where:
MOP = maximum operating pressure, bar
MRS = minimum required strength, MPa
C (design coefficient) = minimum of 2.0 for gas pipe applications
DR = dimension ratio

An example calculation for a DR 11 PE 100 pipe with an MRS of 10 MPa is:

$$P = [20\ (10)\ /\ (11\text{-}1)\ (2)] = 10 \text{ bar} = 145 \text{ psig.}$$

This is the maximum operating pressure or pressure rating for buried DR 11 PE 100 pipe using the ISO 4437 recommended minimum design coefficient (C) of 2.0. The gas engineer may use a higher design coefficient if deemed appropriate for the installation.

NOTE: Because they are intended for different pressure rating methods, the design factor (F) should only be used with the ASTM HDB (11 year extrapolation), and the design coefficient (C) should only be used with the ISO MRS (50 year extrapolation) or CRS.

Another useful feature of the ISO pressure rating system is the CRS (categorized required strength) rating. For classification purposes, the MRS is always defined as the LPL at 20°C and 50 years. A PE 100 material will always be classified as a PE 100 material independent of the actual use conditions.

However, for design purposes, the ISO system provides the gas engineer with the opportunity to design his piping system at the actual use temperature and also for the desired design time. To do this, the gas engineer simply uses the CRS (categorized required strength) instead of the MRS in the PR equation. To maintain order in the plastic piping industry, these CRS values are also categorized values of the LPL. The difference is that the LPL is the extrapolated value at the desired use temperature (θ) and the desired time (t). ISO 9080 provides guidelines and restrictions for calculation of these LPL values. For longer term extrapolations, like 100 years, ISO 9080 requires longer term data to justify the extrapolation in accordance with the ISO 9080 requirements.

PPI publishes CRS values in TR-4 along with the MRS values. These CRS values are very easy to obtain because the resin manufacturer already has the stress rupture data at three temperatures, and he simply uses the 3- or 4-coefficent Rate Process Method equation of ISO 9080 to determine the LPL at the desired temperature and desired time. Examples of CRS values in TR-4 are provided in the table below, which is taken from TR-4 and available on the PPI website:

PPI TR-4 TABLE III.B.1 - CRS (θ, t)

For design purposes, the CRS (θ, t) may be determined at other desired temperature (θ) or time (t) conditions. The CRS (θ, t) is the categorized value of the ISO 9080 σ_{lpl} for a material at a temperature of θ°F (°C) and a time of t years, using the extrapolation limits of ISO 9080.

Company Name	Material Designation	Temp. (°F)	Time (yrs)	CRS (MPa)	Grade	Exp Date
ATOFINA	FINATHENE XT10 N/BLK (20C,100 yrs)	68	100	10	S	12/31/08
ATOFINA	FINATHENE XT10 N/BLK (40C,50 yrs)	105	50	8	S	12/31/08
BASELL POLYOLEFINE	HOSTALEN CRP 100 (20C,100 yrs)	68	100	10	S	12/31/08
BASELL POLYOLEFINE	HOSTALEN CRP 100 (40C,100 yrs)	105	100	8	S	12/31/08
BASELL POLYOLEFINE	HOSTALEN GM 5010 T3 (20C,100 yrs)	68	100	10	S	12/31/08
BASELL POLYOLEFINE	HOSTALEN GM 5010 T3 (40C,100 yrs)	105	100	8	S	12/31/08
DOW CHEMICAL	CONTINUUM DGDA 2490 BK 100 (20C,100 yrs)	68	100	10	S	12/31/06
DOW CHEMICAL	CONTINUUM DGDA 2490 BK 100 (40C,90 yrs)	105	90	8	S	12/31/06
DOW CHEMICAL	CONTINUUM DGDA 2490 BK 100 (60C,11 yrs)	140	11	6	S	12/31/06
DOW CHEMICAL	CONTINUUM DGDB 2490 BK 100 (20C,100 yrs)	68	100	10	S	12/31/06
DOW CHEMICAL	CONTINUUM DGDB 2490 BK 100 (40C,50 yrs)	105	50	8	S	12/31/06
DOW CHEMICAL	CONTINUUM DGDB 2490 BK 100 (60C,11 yrs)	140	11	6	S	12/31/06
SK CORPORATION	DX 800 (70C,60 yrs)	158	60	4	S	12/31/08
SK CORPORATION	DX 800 (95C,5 yrs)	203	5	3	S	12/31/08
UPONOR ALDYL	UAC 3700 ULTRA-STRIPE (40C,90 yrs)	105	90	8	S	12/31/06
UPONOR ALDYL	UAC 3700 ULTRA-STRIPE (60C,11 yrs)	140	11	6	S	12/31/06

Slow Crack Growth (SCG) Resistance

During rehabilitation or other installation techniques, PE pipe can be scored, scratched or damaged on the outside surface. These external scratches can lead to slow crack growth and eventual failure of the PE pipe. High performance bimodal PE 100 materials have tremendous increased resistance to slow crack growth (SCG) as demonstrated by two commonly used SCG test methods, the ISO NPT (notched pipe test) and the ASTM PENT (Pennsylvania notch test). The NPT requirement in the ISO 4437 gas pipe PE standard is 170 hours, compared with the performance of typical bimodal PE 100 materials of several thousand hours. The PENT requirement for PE materials in ASTM D 2513 is 100 hours; whereas the PENT failure time for some bimodal PE 100 materials is over 10,000 hours.

These SCG data demonstrate the tremendous increase in SCG resistance of the bimodal high performance PE 100 materials. This is a very important property of PE materials, because SCG is the failure mode observed in many gas piping PE failures. The early generation PE materials (like Aldyl "A", Century pipe and PE 3306) had much lower resistance to SCG and this resulted in premature SCG failures. The higher SCG resistance of these PE 100 materials will result in substantially improved performance.

Rapid Crack Propagation (RCP) Resistance

With gas engineers desiring to use PE pipe at higher operating pressures and larger diameters, the third key component of a PE piping material becomes more important – this is the resistance to rapid crack propagation (RCP). Although there have not been very many RCP failures in gas piping systems in North America, the few that have occurred have resulted in the AGA Plastic Materials Committee (PMC) requesting that an RCP requirement be added to ASTM D 2513, similar to the RCP requirement currently in the ISO PE gas pipe standard ISO 4437. PMC unanimously approved a motion to add the RCP critical pressure requirement of ISO 4437 (as measure by test method ISO 13477, known as the S-4 or small scale steady state test) to ASTM D 2513.

In most cases, as the pipe diameter increases, the critical pressure decreases. The critical pressure is the pressure below which RCP will not occur. The higher the critical pressure, the less likely the gas company will have an RCP event. The S-4 critical pressure for many of the PE 100 materials is 10 bar (145 psig) or higher, which converts to at least 600 psig operating pressure. This means that with PE 100 materials, RCP will not be a concern.

Another measure of RCP resistance is the critical temperature. This is defined as the temperature above which RCP will not occur. Therefore, a gas engineer wants to use a PE material with a critical temperature as low as possible. The S-4 critical temperature for a typical bimodal PE 100 material is -17°C compared to a unimodal PE 2406 (15°C) and a unimodal PE 3408 (9°C). With a PE 2406 material, RCP can occur if the ground temperature is 15°C (60°F) or below, and there have been a few reported RCP events with PE 2406 materials. For PE 3408 materials, RCP will not occur unless the ground temperature gets below 9°C, and for PE 100 materials, RCP will not occur unless the ground temperature gets below -17°C.

AGA/PPI/GTI IDF Program

PE 100 materials have been available in some countries for over 15 years. The resin suppliers have not brought these materials to North America because when they are pressure rated by ASTM D 2837, they are awarded a PE 3408. The ASTM method simply does not provide the differentiation needed to separate the unimodal PE 3408 materials from the high performance bimodal PE 100 materials. In the ISO 9080 system, some unimodal PE 3408 materials have a PE 63 rating, or 6.3 MPa MRS. There is a 45% difference in the pressure rating for these two materials, and the ASTM method gives them the same pressure rating of 1600 psi (PE 3408).

In an effort to provide the higher performance PE 100 materials with the higher pressure rating they deserve, PPI in conjunction with AGA and GTI have formed an IDF (increase design factor) committee. The purpose of this committee is to define the high performance parameters through ASTM standards that will justify a higher design factor of 0.40 or 0.45. Several changes to ASTM standards will be required to accomplish this.

Since the high performance PE 100 materials generally have a base resin density around 0.950 g/cc, the density cell class of ASTM D 3350 will be changed as follows:

Current cell class 3	0.941 – 0.955 g/cc
New cell class 3	0.941 – 0.947 g/cc
New cell class 4	0.948 – 0.955 g/cc

Most of the unimodal PE 3408 materials will continue to have a cell class 3 for base resin density. The PE 100 materials will have cell class 4 for base resin density.

The current requirement for PENT performance in ASTM D 2513 is 100 hours, which is a D 3350 slow crack growth cell class 6. Because the resin/pipe manufacturers did not want to change the familiar pipe material designation codes of PE 2406 and PE 3408 when this became a requirement, the slow crack growth cell class of 4 was changed to be cell class 4 or greater. Therefore a 100 hour PENT material, which was technically a cell class 6, could still be called a cell class 4, and thus still be a PE 2406 or PE 3408. PPI will now consider adding a new "slow crack growth" cell class 7 for 500 hours to provide differentiation for the high performance materials, as follows:

Current cell class 4	10 hours
Current cell class 6	100 hours
New cell class 7	500 hours

The current PE 3408 materials will still have a cell class 4 or 6. The PE 100 materials will have the new cell class 7.

With these two changes, the unimodal PE 3408 materials will still have the pipe material designation code of PE 3408. The PE 100 materials will have a new density cell class of 4 and a new slow crack growth cell class of 7. This would make their pipe material designation code PE 4708. However, the pressure rating would still be the same as a PE 3408. As a result, PPI will also introduce a higher design factor for these high performance PE 100 materials. This design factor will be 0.63 for water applications and 0.40 for gas applications. To qualify for this higher design factor, PPI will also make appropriate changes to PPI TR-3, such as incorporating a 50-year substantiation. Since the HDB of these materials will remain 1600 psi using the ASTM D 2837 pressure rating system, the new HDS for these materials would be 1600 psi times the new design factor of 0.63, or an HDS of 1000 psi. The final pipe material designation code for high performance PE 100 materials with all the changes would then be PE 4710.

Pipe Price Comparison

The best way to show the effect of this new pipe material designation code is to compare the DR (dimension ratio) that would be required for a particular operating pressure. If we consider 125 psig, which is the new maximum operation pressure allowed by DOT in Part 192, we arrive at the following table:

Required DR for MOP of 125 PSIG

	PE 2406	PE 3408	PE 2708	PE 4710	PE 100	PE 100
HDB, psi	1250	1600	1250	1600		
MRS/CRS, MPa					10	11.2 @ 55°F
Design factor	0.32	0.32	0.40	0.40		
Design coefficient					2.0	2.0
Required DR For 125 psig	7	9	9	11	12.5	14

A PE 2406 material with an HDB of 1250 psi and a 0.32 design factor would require a DR of 7 to operate at 125 psig. A PE 3408 material with an HDB of 1600 psi and a 0.32 design factor requires a DR of 9 to operate at the same 125 psig. If the PE 2406 material met all the requirements of a high performance PE material, it would have a pipe material designation code of PE 2708. With the design factor of 0.4, this PE 2708 pipe would require a DR of 9 to operate at 125 psig. If the PE 3408 material met all the requirements of a high performance PE material (like a PE 100), it would have a pipe material designation code of PE 4710. With the design factor of 0.4, this PE 4710 pipe would require a DR of 11 to operate at 125 psig. If the same PE 100 material were treated as a PE 100 material and pressure rated using the ISO 4437 design coefficient of 2.0, it would require a DR of 12.5 to operate at 125 psig. If this same PE 100 material was pressure rated using the ISO 4437 design coefficient of 2.0 and the average annual ground temperature was 55°F or below, we could use the CRS rating of 11.2 MPa and it would require a DR of 14 to operate at 125 psig. Obviously, as we go from DR 7 to DR 9 to DR 11 to DR 12.5 to DR 14, the wall thickness continues to decrease. This thinner wall results in lower cost for the price of the pipe as shown below for 6" pipe:

- PE 2406 DR 7 $5.38/ft
- PE 3408 DR 9 $5.05/ft
- PE 2708 DR 9 $4.35/ft
- PE 4710 DR 11 $5.00/ft
- PE 100 DR 12.5 $4.50/ft
- PE 100 DR 14 $4.10/ft
  (CRS at 55°F)

These are approximate pipe prices (FOB plant) for 6” pipe to operate at 125 psig, and will change with time. The important point to consider is the relative difference in pipe price for the various DR ratios. As you can see the pipe prices for the high performance PE 2708 and PE 4710 materials are lower than their counterparts because of the 0.40 design factor. The pipe price for the PE 100 material pressure rated as a PE 100 material is the lowest of all. Therefore, PE 100 materials not only have the combination of outstanding SCG resistance and outstanding RCP resistance, they also have the lowest pipe price! In some cases the PE 100 pipe price is 25% lower than conventional PE materials.

The examples shown below are pipe prices (FOB plant) for 12” pipe also operating at 125 psig:

- PE 2406 DR 7 $19.85/ft
- PE 3408 DR 9 $18.50/ft
- PE 2708 DR 9 $16.10/ft
- PE 4710 DR 11 $18.45/ft
- PE 100 DR 12.5 $16.50/ft
- PE 100 DR 14 $15.00/ft
  (CRS at 55°F)

The thinner wall of the PE 2708, PE 4710 and PE 100 materials can be significant when we consider large diameter applications even at lower operating pressures, such as 60 psig. The following table makes the same DR comparison for all these PE materials with an operating pressure of 60 psig.

<u>Required DR for MOP of 60 PSIG</u>

	PE 2406	PE 3408	PE 2708	PE 4710	PE 100
HDB, psi	1250	1600	1250	1600	
MRS, MPa					10
Design factor	0.32	0.32	0.40	0.40	
Design coefficient					2.0
Required DR for 60 psig	14	17.5	17.5	22	25

Again we see that the higher performance PE 2708 and PE 4710 materials have a higher DR, or thinner wall, and the PE 100 material has the thinnest wall.

This thinner wall results in lower cost (FOB plant) for the price of 6” pipe operating at 60 psig as shown below:

- PE 2406 DR 14 $3.00/ft
- PE 3408 DR 17.5 $2.80/ft
- PE 2708 DR 17.5 $2.40/ft
- PE 4710 DR 22 $2.65/ft
- PE 100 DR 25 $2.35/ft

Pipe prices for 12” pipe operating at 60 psig are:

- PE 2406 DR 14 $11.00/ft
- PE 3408 DR 17.5 $10.35/ft
- PE 2708 DR 17.5 $9.00/ft
- PE 4710 DR 22 $9.80/ft
- PE 100 DR 25 $8.65/ft

For a given operating pressure, the high performance bimodal PE 100 material has the combination of outstanding SCG resistance, outstanding RCP resistance, thinnest wall for greatest flow, and also the lowest pipe price.

The thinner wall for a given pipe size also results in a larger ID and greater flow. This is an important advantage for the gas engineer to consider in pipe selection. The example below shows the effect of thinning the wall for 12” pipe operating at 125 psig:

PE Material	**Dimension Ratio (DR)**	**Inside Diameter (% increase)**
PE 2406	7	8.89”
PE 3408	9	9.95” (10%)
PE 4710	11	10.29” (15%)
PE 100	12.5	10.59” (19%)
PE 100 (CRS at 55°F)	14	10.82” (22%)

12” PE 2406 pipe operating at 125 psig would require a DR 7 with an inside diameter of 8.89”. If we consider a PE 100 material operating at a ground temperature of 55F, the required DR for 125 psig operation is 14, which is a 22% increase in the insider diameter. This increase in inside diameter results in a considerable increase in the flow.

DOT Request for Waivers

The Department of Transportation (DOT) is aware of this PPI effort to change the various ASTM standards to incorporate the benefits of these bimodal high performance PE 100 materials. While these changes are in the process of being made, DOT would like to see some “in ground” field experience for these high performance PE materials using the higher design factor. Therefore, DOT is requesting that gas companies request waivers for use of PE 2708 or PE 4710 materials with a 0.4 design factor, or PE 100 materials with a 2.0 design coefficient. These are the calculated DR values shown in the previous examples in the tables. Use of these high performance PE materials will result not only in materials with outstanding SCG and RCP resistance, but also a thinner wall pipe which has increased flow and a lower pipe price. The thinner wall for greater flow and the lower pipe price may result in PE pipe being more cost competitive with steel pipe, especially in some large diameter applications.

Some gas companies have already converted to these new high performance bimodal PE 100 materials, such as the Dow Chemical CONTINUUM DGDA 2490 BK 100. An example of this is Public Service Electric and Gas (PSE&G) in New Jersey. Tony Romano of PSE&G stated:

> "I have been to several meetings where your PE 100 presentation was given. I agree with your research and we have officially become the first Gas Utility to purchase a complete line of PE 100 tubing and pipe. We also have had conversations with fitting manufacturers and have asked them to have a complete line of valves and fittings available to us for the 3rd quarter of 2005."

Summary

In this paper we have shown that the bimodal high performance PE 100 materials have a unique combination of outstanding resistance to SCG, outstanding resistance to RCP and the highest pressure rating, resulting in the thinnest wall for a particular operating pressure. When these PE materials are pressure rated using ASTM D 2837 they only get a PE 3408 rating, which does not at all differentiate them from the unimodal PE 3408 materials and does not provide the rating they deserve. PPI is in the process of rectifying this situation by making several revisions to the ASTM standards (D 3350, D 2837 and D 2513). While these changes are in progress, DOT is requesting that gas companies request waivers and install PE 4710 materials with a 0.4 design factor or PE 100 materials with a 2.0 design coefficient. By doing this, the gas company will not only be using a PE material with outstanding properties, but also using pipe with the lowest cost for the application. If gas companies are interesting in using the best PE material available today and paying a lower price for it, they should contact a manufacturer of PE 100 materials or a manufacturer of PE 100 pipe. Palermo Plastics Pipe Consulting is also available for DOT presentations to assist with requesting waivers.