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High Performance PE Materials for Water Piping Applications

Municipal and Industrial Division



PLASTICS·PIPE·INSTITUTE™

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Foreword

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I. Abstract

This white paper describes the key advantages available to water companies who choose to use pipe produced from the higher performance polyethylene (PE) materials now available. This paper also reviews the changes to several PPI documents and ASTM standards to recognize the improved performance properties of these new generation PE materials.

Upon the introduction of higher performance PE piping materials into North America, it was determined that the current PE 3408 pipe material designation code did not sufficiently recognize the improved properties of these materials. For that reason, several PPI documents, AWWA standards and ASTM standards have been revised. The result of these revisions is the introduction of several new PE pipe material designation codes, such as PE 4710. The new PE pipe material designation codes identify high performance PE 4710 that is PPI rated for 73°F (23°C) water service at 1000 psi (6.9 MPa) hydrostatic design stress compared to the PE 3408 at 800 psi (5.5 MPa) HDS for the same service. The higher HDS for PE 4710 allows water companies to use higher pressures for the same DR pipes or to obtain greater flow capacity for the same pressure rating with higher DR (thinner wall) pipes. Compared to conventional PE materials, higher performance PE 4710 piping materials provide a more cost effective PE piping systems based on the significantly improved properties of the higher performance PE materials.

II. Background

Polyethylene (PE) has been used for water piping applications both domestically and internationally since the 1960's. In 1988 high performance PE materials were introduced in Europe. Recognizing the advantages afforded by higher performing PE materials, PPI and ASTM worked to characterize higher performing PE materials that culminated in PE 4710 designations that are now manufactured in the U.S. by a number of resin companies. Pipe made from these PE 4710 materials have a unique combination of having the highest PE pressure rating (PR), outstanding resistance to slow crack growth (SCG) along with increased resistance to rapid crack propagation (RCP). These are the three key engineering properties for evaluating a plastic piping material, and these high performance PE materials exhibit outstanding performance in all three areas. The increased working stress rating of these high performance PE materials allows use of a larger inside diameter (thinner wall) for a given operating pressure, which makes PE very attractive compared to steel or ductile iron pipe, especially for the large diameter pipe sizes. A larger inside diameter not only improves system capacity or flow, but also lowers the pipe cost and improves upon the already demonstrated lower on-site handling and installation costs of PE versus steel and ductile iron piping materials. Although these high performance PE materials may be relatively new in North America, they have over 20 years of very successful history worldwide for water piping applications.

The Plastics Pipe Institute (PPI) identified that the best way to take advantage of these high performance PE materials in North America was to incorporate them into the ASTM and AWWA standards by applying higher material specifications

that result in an increased hydrostatic design stress compared to conventional PE materials. Changes to support a higher HDS for water piping have been accomplished through revising PPI TR-3 and existing ASTM PE resin and pipe standards. The higher HDS for pressure rating can be a deciding factor whether a water company uses PE pipe or metal pipe. The premise for this increased HDS is that higher performing PE materials must demonstrate superior performance characteristics such that PE pipe would provide a safer, cost effective alternative piping system.

III. **ASTM Pressure Rating Method**

The ASTM pressure rating method utilizes pipe samples tested at a constant temperature with the log stress vs. log time regression line extrapolated to 100,000 hours. This extrapolated value is the long-term hydrostatic strength (LTHS) of the material, and the categorized value of the LTHS is called the Hydrostatic Design Basis (HDB) in accordance with ASTM standard test method D 2837. This HDB is reduced to a maximum working stress by a design factor (F) to establish the Hydrostatic Design Stress (HDS). The HDS is the product of the HDB and the design factor for water:

$$\text{HDS} = \text{HDB} \times F \text{ (for water)}$$

HDB and HDS values for various thermoplastic materials used for piping applications are published in PPI TR-4, which is available on the PPI website www.plasticpipe.org. These PPI listings of HDB and HDS 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 for water at 73°F (23°C) divided by 100. Examples of pipe material designation codes for PE materials are as follows:

- PE 3408 is a polyethylene (the PE abbreviation is in accordance with ASTM D 1600) with a density cell class of 3 and a slow crack growth (SCG) cell class of 4 (in accordance with ASTM D 3350). It has an 800 psi maximum recommended HDS for water at 73°F (23°C).
- PE 4710 is a polyethylene (the PE abbreviation is in accordance with ASTM D 1600) with a density cell class of 4 and a slow crack growth (SCG) cell class of 7 (in accordance with ASTM D 3350). It has a 1000-psi maximum recommended HDS for water at 73°F (23°C).

The water engineer then uses the pipe design formula below to calculate the pressure rating (PR) for this PE pipe:

$$\text{PR} = [2 (\text{HDS}) / (\text{DR} - 1)]$$

Where: PR = pressure rating, psig
 HDS = hydrostatic design stress, psi
 DR = dimension ratio

A sample calculation for a DR 11 PE 3408 pipe with a 73°F HDS of 800 psi is:

$$PR = [2 (800) / (11-1)] = 160 \text{ psig.}$$

This is the pressure rating for DR 11 PE 3408 pipe for water piping applications at temperatures up to 80°F.

A sample calculation for a DR 11 PE 4710 pipe with a 73°F HDS of 1000 psi is:

$$PR = [2 (1000) / (11-1)] = 200 \text{ psig.}$$

This is the pressure rating for DR 11 PE 4710 pipe for water piping applications at temperatures up to 80°F.

IV. PPI Program

A coordinated industry effort was undertaken to revise PPI documents and ASTM/AWWA/CSA standards to recognize the improved performance properties of these high performance PE materials. These newly defined performance properties enabled expanded classification of PE materials, and justified the use of a higher hydrostatic design stress for water piping applications. Several changes to PPI documents and ASTM standards were required to accomplish this. These included changes in the pipe material designation code:

- Base resin density – 1st digit in the code
- Slow crack growth (SCG) – 2nd digit in the code
- Hydrostatic design stress (HDS) – 3rd and 4th digits in the code

a) Base Resin Density

PE 3408 materials used for water pipe applications have a base resin density about 0.944 g/cc, which is a D 3350 density cell class 3 – this is the first digit in the pipe material designation code PE 3408. Most high performance PE 4710 materials have a base resin density around 0.950 g/cc. In order to differentiate the high performance HDPE materials from traditional HDPE materials, the density cell class of ASTM D 3350 was split to create a new density class 4 for the new high performance PE materials:

- Previous cell class 3 > 0.941 – 0.955 g/cc
- New cell class 3 > 0.941 – 0.947 g/cc
- New cell class 4 > 0.947 – 0.955 g/cc

Most high performance HDPE materials will have a density cell class 4 based on their base resin density around 0.950 g/cc.

b) Slow Crack Growth (SCG)

Slow crack growth is the dominant field failure mode for PE pipes. Simply put, it is a crack that can develop in PE pipe and grows slowly through the pipe wall. Poor backfill, excessive surface damage, rock impingement, excessively tight bend radiuses, improper backfill and other field conditions could cause localized stress concentrations resulting in slow crack growth in polyethylene pipes. The resistance to slow crack growth is a valuable property for PE pipes.

The PENT (Pennsylvania Notch Test - ASTM F 1473) measures relative resistance to slow crack growth using a laboratory test method. A specimen is cut from a compression molded plaque. It is precisely notched and then exposed to a constant tensile stress at a temperature of 176°F (80°C). The time to failure is recorded and this failure time is related to actual service life in the field. The PENT test has proven to be a very good indicator of SCG in PE pipes.

A published paper in Plastic Pipe VIII conference provided data, which correlated laboratory PENT values to field pipe performance. Based upon this data, a laboratory PENT value of 10 to 20 hours, should correlate to a field life of at least 100 years with very few failures. PPI determined that a requirement of at least 500 hours PENT slow crack growth resistance would provide assurance that high performance PE pipes will be highly unlikely to fail in the field in the slow crack growth mode.

The current PE 3408 requirement for PENT (ASTM F 1473) performance in ASTM water pipe standards is 10 hours, which is a D 3350 SCG (slow crack growth) cell class 4 – this is the second digit in the pipe material designation code PE 3408. ASTM D 3350 was revised to add a new SCG cell class 7 for 500 hours to recognize the elevated SCG resistance of the high performance PE materials.

- Current cell class 4 at least 10 hours
- Current cell class 6 at least 100 hours
- New cell class 7 at least 500 hours

With this change, the traditional HDPE materials will have a SCG cell class 4 or 6, where high performance PE materials will qualify for the new SCG cell class 7.

c) Hydrostatic Design Stress

The hydrostatic design stress (HDS) for PE 3408 materials is 800 psi for water at 73°F (23°C), which are the third and fourth digits in the pipe material designation code PE 3408. High performance PE materials that meet the increased performance requirements indicated below qualify to be listed in PPI TR-4 with a 1000 psi HDS for water at 73°F (23°C) if the PE material meets high performance criteria as published in PPI TR-3:

- 1) PENT value over 500 hours
- 2) 23°C stress regression line substantiated to 50 years
- 3) LCL/LTHS ratio over 90%

High performance PE 4710 materials that meet the additional high performance have a 1000 psi HDS, where the “10” is derived by dividing the 1000 psi HDS by 100.

V. Example of Engineering Benefits for PE 4710 vs. PE 3408

There are two ways that increased hydrostatic design stress may be utilized by the water design engineer. One way is to operate the PE pipe with a particular wall thickness at a higher pressure. The other way is to operate the PE pipe at the same pressure, but use a higher DR or thinner wall, which increases the inside diameter, and thus increases the flow or capacity.

The best way to show the impact of the new pipe material designation code PE 4710 is to show the effect of the HDS on the pressure rating. Table 1 shows the pressure rating (PR) for a PE 4710 (using the 1000 psi HDS) compared to a PE 3408 (using the 800 psi HDS) at various dimension ratios. For a given wall thickness, the PE pipe may be operated at a higher pressure when using a PE 4710 material compared to a PE 3408 material. For each DR, the pressure rating is about 25% higher for the PE 4710 pipe, due to the higher HDS.

Table 1 – Pressure Rating (psig) Comparison Between PE 4710 and PE 3408 for Water Applications

	DR 9	DR 11	DR 13.5	DR 17
PE 4710	252	202	161	126
PE 3408	200	160	128	100

Another benefit of the higher design stress for the PE 4710 compared to PE 3408 is to use a higher DR pipe. The higher DR (thinner wall) results in a larger inside diameter, lighter weight for the pipe and lower pipe cost. A key benefit of the larger inside diameter is increased water flow capacity. Table 2 shows the effect of the higher design stress for a PE 4710 compared to a PE 3408 operating at the same pressure. By using pipe that is one standard DR higher (for example DR 17 instead of DR 13.5), Table 2 shows the corresponding increase in capacity as a result of the larger inside diameter.

Table 2 - Comparative Water Flow Increase for 1 SDR Increase from PE 3408 to PE 4710

System Pressure	200 psig	160 psig	130 psig	100 psig
Capacity Increase	15.4%	12.0%	10.4%	7.3%

VI. Summary

This white paper describes the changes that have been made to PPI documents and ASTM standards to better and more fully recognize the improved properties of the high performance PE materials and the effects of these changes on the water piping industry. It also describes the PPI efforts to develop technical data to support use of these high performance PE piping materials with a higher hydrostatic design stress in the pipe design formula. The results of these efforts permit the use of the new high performance PE piping systems with a larger inside diameter for a given pressure (greater capacity) or higher pressures for a given wall thickness. Both of which offer significant cost and system benefits to the water utilities, and result in PE pipe being even more cost effective compared to steel and ductile iron pipe.