The Development of Allowable Stresses for HDPE Piping

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ABSTRACT

This paper presents the development of allowable stress methodologies for polyethylene pressure piping compounds from the early materials of a half century ago through today's high performance piping compounds. Early assumptions that polyethylene compounds could be stress-rated like metals proved to be false. Investigations of premature field failures identified that sustained long-term stresses generated a slow crack growth failure mechanism that was not revealed through short term strength evaluations. This led to the development of long term stress evaluation methodologies, refinements and stronger requirements for polyethylene compounds to assure that slow crack growth failure would not occur within acceptable design lifetimes for polyethylene pressure piping. Recent developments in water piping standards have been questioned because out of date misconceptions have been misapplied to newer, higher-performing polyethylene piping. This paper tells the history of HDPE piping compound performance development to correct misconceptions and misunderstandings of HDPE piping performance.

TERMINOLOGY

Material Designation Codes

Material Designation Codes are used in North America by ASTM, AWWA, PPI and industry to describe basic characteristics of thermoplastic pressure piping compounds. The Material Designation Code[i] is the abbreviation for the thermoplastic followed by four numbers. The 1st and 2nd numbers are key physical properties. The 3rd and 4th numbers identify that the materials has been characterized for long-term pressure service. These two digits are the material's hydrostatic design stress, HDS, rating for water at 73°F in accordance with ASTM D2837[ii] and PPI TR-4[iii] in hundreds of psi with tens and units omitted.

The first several letters are the abbreviation for the thermoplastic in accordance with ASTM D1600. The abbreviation for polyethylene is PE. Depending on the thermoplastic, the physical properties represented by the 1st and 2nd numbers will be different. For polyethylene, the 1st number is the ASTM D3350[iv] cell classification property value for density, and the 2nd digit is the ASTM D3350 cell classification property value for slow crack growth resistance.

Polyethylene is composed on long carbon-carbon chain molecules. In the solid state, polyethylene is semi-crystalline thermoplastic. As polyethylene cools from melt, part of the material folds into crystalline structure. The balance of the solid polymer is randomly entangled molecules that surround the crystals. Density is a measure of the amount of crystalline structure and is a key polyethylene property because the amount of crystalline structure controls tensile and flexural properties.

Thermoplastic pressure piping compounds were developed and commercialized in the 1950's. Early pipe pressure ratings were calculated by applying a safety factor to the tensile yield strength of the material. However, thermoplastics were soon found to lose strength over time at sustained stress, proving that tensile yield strength could not be used for pipe pressure rating. Further, field experience soon revealed new non-ductile failure modes that were not related to tensile strength.

For polyethylene, a previously unknown failure mechanism of slow crack growth (SCG) was discovered. Unlike ductile tensile failure where the material elongates and then fails in the elongated region, SCG is a stress-cracking mechanism where cracks advance slowly through the pipe wall without evident ductile elongation. SCG is not chemical or stress embrittlement. It is a stress-cracking mechanism that arises from sustained tensile stress or concentrated stress that is less than ductile tensile stress. Resistance to SCG is critical to polyethylene's the long-term performance.

Thus material designation codes for polyethylene pressure piping materials identify the thermoplastic (PE), short term performance (density), long term failure resistance (SCG), and allowable long term stress rating (HDS).

PE3408

- PE
- 3 = ASTM D3350 density cell 3 (>0.940 to 0.947 g/cm^3 per ASTM D1505[v])
- 4 = ASTM D3350 SCG resistance cell 4 (>10 hours per ASTM F1473[vi])
- 08 = 800 psi HDS for water at 73°F (23°C) per PPI TR-4 (HDS = HDB x DF; 800 = 1600 x 0.50)

PE4710

- PE
- 4 = ASTM D3350 density cell 4 (>0.947 to 0.955 g/cm^3 per ASTM D1505)
- 7 = ASTM D3350 SCG resistance cell 7 (>500 hours per ASTM F1473)
- 10 = 1000 psi HDS for water at 73°F (23°C) per PPI TR-4 (HDS = HDB x DF; 1000 = 1600 x 0.63)

STRESS RATINGS FOR THERMOPLASTICS

HDB, HDS and DF – ASTM D2837 and PPI TR-3[vii] Requirements

It has long been known that thermoplastics lose strength under sustained applied stress. To determine safe allowable stresses, thermoplastics are tested to determine long-term stress ratings that are then reduced to an allowable stress or pressure rating.

HDB – Hydrostatic Design Basis

Thermoplastic pressure piping compounds are rated for internal pressure service in accordance with ASTM D2837, which is a procedure for conducting a series of sustained internal pressure tests. A prescribed data analysis is used to determine a long-term hydrostatic strength (LTHS) at 100,000 hours. The LTHS is then categorized as the hydrostatic design basis (HDB) rating for the thermoplastic compound. HDB is determined at a specific temperature such as 73°F (23°C) or 140°F (60°C) or 180°F (82°C), etc. The ASTM D2837 data analysis method requires a specific distribution of data points, testing up to 10,000 hours, and that all failures in the data set shall be ductile.

The purpose of the HDB is to provide a standardized design basis for determining an internal pressure rating at a given temperature. The 100,000 hour intercept was arbitrarily chosen for its statistical significance. ASTM D2837 requires testing to 10,000 hours, and 100,000 hours is the next log-decade. However, *the HDB rating does not represent a service life*.

HDS – Hydrostatic Design Stress

ASTM D2837 includes a procedure for determining hydrostatic design stress (HDS), which is the HDB reduced by a service (design) factor (DF) that is for an application such as water. ASTM D2837 does not specify DF values for applications; however, the HDS determination procedure prescribes how a DF for an application is to be developed.

> *"5.5 Hydrostatic Design Stress—Obtain the hydrostatic design stress by multiplying the hydrostatic design basis by a service (design) factor selected for the application on the basis of two general groups of conditions. The first group considers the manufacturing and testing variables, specifically normal variations in the material, manufacture, dimensions, good handling techniques, and in the evaluation procedures in this test method and in Test Method D1598 (Note 8). The second group considers the application or use, specifically installation, environment, temperature, hazard involved, life expectancy desired, and the degree of reliability selected (Note 9). Select the service factor so that the hydrostatic design stress obtained provides a service life for an indefinite period beyond the actual test period."* [Note 8 and Note 9 are informational notes in ASTM D2837.]

DF – Design Factor

From the ASTM D2837 excerpt above, a DF is the combination of two distinctly different groups of variables. The first group is directly related to the thermoplastic compound, pipe, and testing. It addresses variability in manufacturing the compound and test specimens, and variability in testing precision that affects the quality of the HDB of the thermoplastic compound. The second group is based on the product application or use; that is, installation quality, operating pressure and temperature stability, internal and external environment effects. For some critical applications, other performance considerations may also be added. For example, the DF for plastic piping used in U.S. gas distribution incorporates additional variables for safety and above ambient temperature.

Regarding the first group of DF variables, ASTM D2837 LTHS data is developed using sustained internal pressure testing of pipe samples. Resin manufacturing will result in lot to lot variations in PE resins. Differences in pipe extrusion equipment and processing procedures introduce variability in the pipe. Different laboratories conducting sustained pressure tests introduce variability in test results through different laboratory equipment. That is, the resin, the pipe and its testing are subject to variability. Higher quality, reduced variability data strengthens the compound's HDB rating

The second group addresses uncertainty in installation and operation for an application. Despite the best efforts of installers, installation quality will vary. Likewise operating conditions are seldom as benign as a sample resting quietly in a laboratory test tank. The installed internal and external environment generally introduces variability in temperature, internal pressure and dynamic loads and stresses such as varying water table or traffic loads.

The point of this DF discussion is that the DF applied to the long-term strength of a thermoplastic pressure piping compound is much more than a simple safety factor. The DF encompasses variability of compound, testing and the application. The DF is applied to the material's long-term design strength so that long term allowable stress is at a risk-acceptable level. A safety factor is simply a reduction of a short-term physical property that may have no relationship to long-term performance. For example, the tensile strength of a metal is typically used to determine a metal pipe's bursting strength. However, if the piping fails due to fatigue or corrosion, pressure rating based on tensile strength has little to do with long term performance regardless of the safety factor.

PPI's Hydrostatic Stress Board is an internationally recognized authority for thermoplastic material stress ratings and application design factors. The HSB initiated the development of ASTM and PPI procedures for thermoplastic pressure pipe material stress ratings in the 1960's, and have continued to develop policies and procedures as materials have improved. The HSB is responsible for developing design factors for North American thermoplastic water piping, and established the first DF, 0.50, in 1962[viii]. Based on the plastics performance information known at the time, the 0.50 DF was the industry expert's best risk-based engineering estimate for a conservative but reasonable level of certainty that pipe produced from thermoplastic pressure piping compounds would not fail in response to sustained hydrostatic stress. The 0.50 DF established by the HSB has been in use for over five decades to pressure rate North American pressure pipe made from thermoplastic compounds including PVC, CPVC, HDPE, ABS, PP, and PB. The diligence and expertise of the HSB is demonstrated by the unsurpassed performance of North American thermoplastic pressure piping products.

PPI TR-3 and ASTM D2837

PPI TR-3 is the PPI HSB policy for evaluating and listing long-term internal pressure strengths for thermoplastic (and other) pressure piping compounds, and for some piping constructions where plastics are part of the stress-bearing structure. PPI TR-3 listing policy is based on ASTM D2837, but extends D2837 by requiring separate data sets from three commercial resin lots, and when listing is based on pipe specimens, pipe from one of the lots must be manufactured by a commercial processor. These requirements for listing apply to all thermoplastic compounds. TR-3 further restricts changes that are allowed to listed compounds without retesting. PPI listings of material or product pressure strengths are published in TR-4. Listings in TR-4 include HDB's at various temperatures, and HDS ratings for water at 73°F (23°C).

HDS is determined by multiplying listed HDB's by a DF. Conventional thermoplastic materials are restricted to a 0.50 DF in accordance with TR-3 Section D.7.

> *D.7 ESTABLISHING THE HYDROSTATIC DESIGN STRESS FOR A MATERIAL*
>
> *D.7.1 The hydrostatic design stress (HDS) at 73□F (23°C) is derived by multiplying the HDB of the material by a design factor (DF). The Hydrostatic Stress Board will recommend a design factor for each material which has a HDB listed in TR-4.*
>
> *D.7.2 The recommended design factor shall not exceed 0.50, unless material-specific policies and requirements are developed and are included in the appropriate Part(s) of TR-3. The HDS calculated using this design factor will be used in establishing the thermoplastic pipe material designation code.*
>
> *D.7.3 Policies and requirements specific to polyethylene are listed under Part F.7 of TR-3.*
>
> *D.7.4 Policies and requirements specific to other materials will be added to TR-3 as they are considered and developed by the HSB.*

In 2004, the HSB published additional material performance requirements in TR-3 so that higher performing polyethylene compounds could qualify for a 0.63 DF. Only polyethylene compounds that meet the additional performance requirements qualify for the 0.63 DF. Unqualified lower performing compounds such as conventional HDPE (PE3408) and other thermoplastics are limited to the original 0.50 DF. The additional performance requirements allow higher performing polyethylene compounds to be operated at higher internal pressure stress without risk of premature failure. The additional performance requirements are published in PPI TR-3, Section F.7.

> *F.7 REQUIREMENTS FOR POLYETHYLENE (PE) MATERIALS TO QUALIFY FOR A HIGHER DESIGN FACTOR*
>
> *A PE material that meets the following requirements qualifies for a recommended design factor of 0.63. PE materials not meeting these requirements will have their HDS established as per Part D.7.*
>
> 1. *50 year substantiation according to Part F.5.*
>
> 2. *Minimum slow crack growth performance by ASTM F 1473 of 500 hours as required by ASTM D 3350.*
>
> 3. *LCL/LTHS ratio of at least 90% as per ASTM D 2837.*
>
> *These requirements apply to the PE material – meaning that all compounding ingredients and colorants are included matching the material formulation to be listed. The HDS calculated with this design factor will be used to establish the pipe material designation code to be listed in TR-4.*

TR-3 Section F.7 requirements allow higher operating stress with assurance that the risk of premature failure is less than that for PE3408 compounds. The TR-3 Section F.7 requirements for higher performing PE compounds mitigate premature failure risk as follows:

- Substantiation at 50 years

  ASTM D2837 and TR-3 use elevated temperature, accelerated testing to assure that the onset of the SCG failure mechanism is beyond a required limit. ASTM D2837 requires validation to assure that the onset of SCG is beyond 100,000 hours, which is the stress-time intercept for HDB. TR-3 applies a similar substantiation methodology to demonstrate that the onset of SCG failure is beyond 50 years (438,300 hours). This requirement confirms that the ductile failure mode upon which the HDB is based continues through at least 50 years.

- Increased SCG resistance

  TR-3 Section F.7 requires greater than 500 hours SCG resistance per ASTM F1473 (PENT). Conventional HDPE compounds typically meet 10 to 100 hours PENT SCG resistance. This requirement assures resistance to the effects of stress concentrations.

- Reduced variability in pipe test data

  ASTM D2837 requires that the ratio of the LTHS to the lower predictive limit be no less than 85%. TR-3 Section F.7 requires that the LTHS/LPL ratio be no less than 90%. This requirement assures the statistical significance of the mean LTHS. Per ASTM D2837, HDB is the categorized mean LTHS.

Polyethylene pressure pipe is known to fail under both ductile and SCG failure mechanisms, but in-service failures are predominantly the result of localized stress concentrations such as rock impingement, point loading, excessive or uneven loading, shear stresses and other installation-related conditions. Polyethylene pressure pipe seldom fails by ductile bursting and such failures are typically associated with a significant overpressure event. Extensive studies demonstrated that resistance to fracture by SCG is the primary determinant in resisting failure from concentrated localized stress. Accordingly, Section F.7 requires significantly increased resistance to the primary failure modes of polyethylene pressure piping compounds.

The 0.63 DF establishes a higher level of technical performance for polyethylene pressure piping compounds. It reflects an evolution in the understanding of the fracture mechanics of polyethylene compounds, and recognizes that the long term performance of polyethylene pressure piping is dependent on resistance to hydrostatic stress rupture and resistance to SCG.

Conventional thermoplastics such as PVC, CPVC, ABS, PP and conventional polyethylene compounds such as PE3408 meet standard ASTM D2837 and TR-3 requirements, but do not meet additional performance requirements. These materials are restricted to 0.50 DF per Section D.7. PE4710 compounds meet ASTM D2837 and standard TR-3 requirements, and the additional Section F.7 requirements. Therefore, PE4710 compounds qualify for the 0.63 DF and higher HDS rating.

Nothing in TR-3 or in HSB policy prevents the development of additional performance requirements that would allow other thermoplastic materials to operate at higher stress. In fact, Section D.7.4 is HSB's policy for developing higher operating stresses for qualified materials. Allowance for higher operating stress would necessarily follow the model established by the HSB and applied to polyethylene compounds. This model employs a fracture mechanics approach to evaluate the material's in-service failure modes, and then provides for the development of higher level material performance requirements that if met, would allow the material to reliably operate at higher stress.

The development of Section F.7 was a rigorous 3-year engineering effort by the HSB experts. After consensus balloting and publication, materials were then required to test to the additional requirements and qualify for the higher 0.63 DF, an additional yearlong process. PE4710 materials that qualified were first listed in 2005. Overall, the development and qualification of PE4710 was a four-year engineering endeavor. The implementation of the 0.63 DF is by no means a safety factor reduction. It is not only an increase in product performance, but also an increase in reliability.

COMPARING PE4710 TO PE3408

PE4710 is not the same and is superior to PE3408 for a number of reasons.

- PE4710 complies with PPI TR-3 Section F.7 requirements for higher performing PE compounds; PE3408 does not.
- PPI TR-3 Section F.7 requires substantiation at 50 years vs. validation at 100,000 h. PE4710 complies; PE3408 does not.
- A higher performing PE polymer structure is required to meet PPI TR-3 Section F.7 requirements. PE4710 has a molecular structure that provides higher performance; PE3408 does not.
- PE4710 has higher density and meets higher SCG requirements compared to PE3408.
    - >0.947 to 0.955 g/cm^3 for PE4710 vs. >0.940 to 0.947 g/cm^3 for PE3408
    - >500 h SCG resistance for PE4710 vs. >10 h SCG resistance for PE3408

Compliance with PPI TR-3 Section F.7 requires improved resistance to long-term SCG fracture. PPI TR-3 Section F.7 compliant PE4710 compounds must be more consistent because F.7 has tighter data quality requirements. PPI TR-3 Section F.7 substantiation requires that SCG cannot occur before 438,300 hours (50 years). ASTM D2837 validation is at 100,000 hours (11.4 years).

Illustrating PE3408

When ASTM D2837 data is presented graphically, the regression analysis yields a straight line when plotted on log-stress vs. log-time coordinates. This graphical presentation is typically called a stress-rupture curve. We can see the onset of SCG on the stress-rupture curve because the SCG curve has a steeper slope compared to the ductile failure curve.

Figure 1 shows the ductile HDB curve for PE3408 (black line), and the *minimum* validation requirement for PE compounds (red line). A PE compound does not validate if the SCG curve intersects the ductile curve before 100,000 hours. A PE compound that does not validate does not qualify for HDB rating or for PPI Listing, and is unsuitable for pressure piping. Figure 1 illustrates a minimum PE3408 operating at maximum allowable conditions.

For validated, HDB rated PE compounds, PPI TR-4 lists HDS ratings for water at 73°F by multiplying the HDB by the PPI DF for the application. For PE3408 compounds that meet standard ASTM D2837 and PPI TR-3 requirements, the PPI DF for water at 73°F (23°C) is 0.50, which yields a HDS for water at 73°F (23°C) of 800 psi (5.52 MPa).

For validated PE3408 compounds that are operated continuously at maximum HDS-based internal pressure, the earliest potential for the onset of SCG pipe wall leakage is when the HDS curve intersects the SCG curve. If the HDS for water service at 73°F (23°C) is plotted on the stress rupture curve, we can estimate that the onset of SCG failures will occur where the HDS intersects the SCG validation curve. This is the intersection of the green line and the red line in Figure 1. For PE3408 compounds, this intersection is after 100 in-service years.

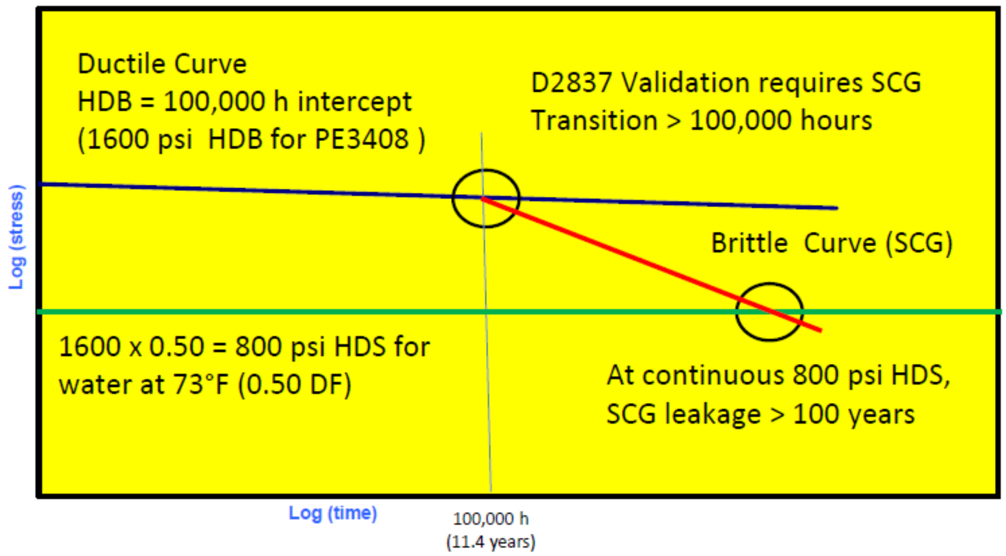

Figure 1 Stress Rupture Curve for PE3408 for Water at 73°F

The PE3408 depicted in Figure 1 is a minimum PE3408 that just complies with HDB and validation requirements (black and red curves). The HDS operating conditions (green curve) are for a 73°F (23°C) water system that operates continuously at HDS internal pressure. At 100,000 hours, the difference between the green line and the black line is the 0.50 DF. All PE3408 compounds exceed HDB and validation requirements so the red line is actually well to the right of the Figure 1 red line, and water systems seldom operate continuously at maximum pressure rating so for actual water systems, the green line is lower than the Figure 1 green line.

Illustrating PE4710

Figure 2 illustrates PE4710 performance for internal water pressure service. The black line is PE4710's ductile rupture HDB curve. Circled on the black line is the 100,000 intercept for the HDB of 1600 psi at 73°F (23°C). However, compared to PE3408 validation at 11.4 years, TR-3 Section F.7 requires substantiation at 50 years; that is, that the onset of SCG must be after the 50 year intercept with the HDB curve. For PE4710, this shifts the red SCG curve to the right at least 38.6 years.

Figure 2 illustrates a minimum PE4710 operating at maximum allowable conditions. As in Figure 1, the green line is the HDS curve which is the maximum allowable continuous internal pressure stress for water at 73°F (23°C). Because PE4710 complies with PPI TR-3 Section F.7 requirements, the PPI recommended HDS for PE4710 is 1000 psi (6.90 MPa), 200 psi (1.38 MPa) higher than is allowable for PE3408. But for PE4710, the HDS (green line) intercept with the PE4710 SCG curve (red line), the minimum point in time where SCG leakage may begin, is at least 150 years after the SCG intercept for PE3408.

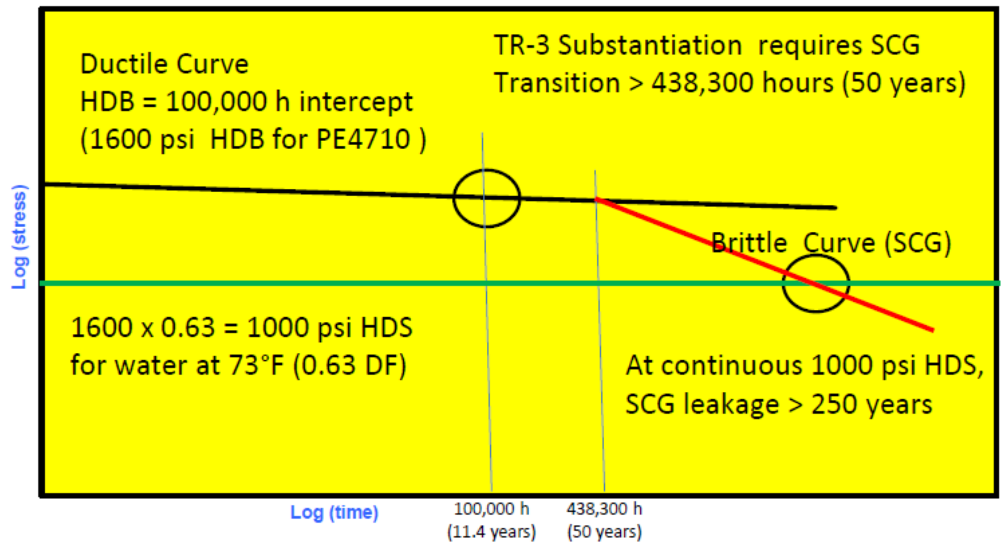

Figure 2 Stress Rupture Curve for PE4710 for Water at 73°F

The PE4710 depicted in Figure 2 is a PE4710 that just meets HDB and substantiation requirements (black and red curves), and the operating conditions (green curve) are for a 73°F (23°C) water system that operates continuously at HDS internal pressure. At 100,000 hours, the difference between the green line and the black line is the 0.63 DF. All PE4710 compounds exceed HDB and validation requirements so the red line is actually to the right of the Figure 2 red line, and water systems seldom operate continuously at maximum pressure rating so the green line for typical water system applications is actually lower than the Figure 2 green line.

POLYETHYLENE PRESSURE PIPING

Plastic Pipe Pressure Rating

The relationship between polyethylene compound stress rating (HDB), pressure rating, and pipe is described by the following equation.

$$PR = \frac{2\,HDS\,F_T}{(DR-1)} = \frac{2\,HDB\,DF\,F_T}{(DR-1)} \qquad \text{Equation (1)}$$

Where PR = pressure rating (or Pressure Class, PC) for water at 73°F, (23°C) psi (MPa)

HDS = PE compound hydrostatic design stress for water at 73°F (23°C), psi (MPa)

DR = dimension ratio

$$= \frac{D_o}{t_{min}}$$

D_o = pipe outside diameter, in (mm)
t_{min} = pipe minimum wall thickness, in (mm)
HDB = PE compound hydrostatic design basis, psi (MPa)
DF = service (design) factor for application such as water at 73°F (23°C)
F_T = Temperature compensation multiplier for temperatures other than 73°F (23°C)

Temperature compensation multipliers for use in Equation (1) are determined using HDB values at base temperature (73°F (23°C)) and high temperature (140°F (60°C) for polyethylene) and Equation (4)[ix].

$$F_T = \frac{HDB_B - HDB_H}{HDB_B} \frac{\frac{1}{T_B} - \frac{1}{T_I}}{\frac{1}{T_B} - \frac{1}{T_H}} \qquad \text{Equation (4)}$$

Where F_T = multiplier for intermediate temperature, T_I, °F (°C)
HDB_B = HDB at base temperature (73°F (23°C)), psi (MPa)
HDB_H = HDB at high temperature (140°F (60°C)), psi (MPa)
T_B = base temperature, °R (°K); (°F + 460 (°C + 273))
T_H = high temperature, °R (°K); (°F + 460 (°C + 273))
T_I = intermediate temperature, °R (°K); (°F + 460 (°C + 273))

Although similar, Equation (1) is not Barlow's Formula, which is presented below.

$$P = \frac{2\, s\, t}{(D_O)} \qquad \text{Equation (2)}$$

Where P = bursting pressure at ambient temperature, psi (MPa)
s = material strength in tension at ambient temperature, psi (MPa)
D_o = pipe outside diameter, in (mm)
t = pipe wall thickness, in (mm)

Barlow's formula may be modified with a safety factor, SF, to estimate a working pressure, WP, that provides a reserve against hydrostatic bursting.

$$WP = \frac{2\, s\, t}{(D_O\ SF)} \qquad \text{Equation (3)}$$

The key difference between Equation (1) and Barlow's Formula in Equation (3) is the stress term. For thermoplastics, the allowable stress in Equation (1) is the long term hoop tensile strength rating for the material (HDB) that is then reduced by a DF that addresses testing and application variables. In contrast, Barlow's Formula uses short-term material tensile strength reduced by a safety factor. Equation (1) provides a pressure rating for long-term internal pressure service where Barlow's Formula is for instantaneous bursting strength.

As previously discussed, tensile strength proved to be an especially poor indicator of plastic pipe field performance. Stress rupture testing per ASTM D2837 clearly shows that long term strength is significantly less than tensile strength, and field experience reveals failure modes other than ASTM D2837 ductile failure. Due to the significant difference between long-term and short-term performance, Barlow's Formula is an improper and inadequate procedure for thermoplastic pipe pressure rating.

The DF applied in thermoplastic pipe pressure rating is distinctly different from the SF applied to bursting strength per Barlow's Formula. Where DF incorporates an engineering evaluation of the variables involved in rating, installing and operating plastic pressure pipes, the Barlow's Formula SF is a simple reduction of tensile strength.

Short-Term Pressure Capability

In ASTM and AWWA polyethylene piping standards (current and proposed), Barlow's Formula is incorporated in short-term requirements where the minimum bursting stress or hoop tensile for polyethylene pipe must exceed 2900 psi for high density PE compounds. Quick burst testing is conducted per ASTM D1599[x]. Hoop tensile testing for larger pipes is conducted per ASTM D2290[xi].

CONSENSUS STANDARDS FOR POLYETHYLENE PIPING

Consensus standards for polyethylene water pressure piping are developed by several organizations, but predominantly by ASTM and AWWA. Since PPI finalized PE4710 requirements in 2004, PE4710 has quickly become the dominant HDPE pressure piping compound. In ASTM and AWWA polyethylene piping standards for pressure water piping, the requirements for polyethylene pressure piping materials are designed to assure long-term performance in water applications.

Polyethylene compound requirements address density, SCG resistance, HDB at ambient and elevated temperature, HDS for water, melt flow rate and UV resistance.

- High density assures short term mechanical strength to withstand pressure surges and to provide stiffness for external earth and live loads.
- SCG resistance assures long term resistance to concentrated stresses from impingement and shear loads, and to provide tolerance for variable installation quality.
- HDB at ambient temperature assures long term stress capacity. HDB at elevated temperature establishes the maximum internal pressure use

temperature, and assures long term pressure service capacity at maximum use temperature (typically 140°F/60°C).

- HDS requirements are set so that the polyethylene compound must qualify under PPI TR-3 DF requirements. Higher performing polyethylene compounds must qualify for the 0.63 DF
- Melt flow rates are established to assure high quality processing and fusion joining in accordance with ASTM standards.
- UV resistance requirements are established to prevent deterioration under long term storage or to provide for long-term use in exposed conditions.

ALLOWABLE STRESSES FOR PE4710 PIPING

Allowable stresses for PE4710 piping are determined in accordance with Equation (1). Allowable stresses address long-term performance, temperature, and risk and reliability for application and installation conditions. Allowable stresses for PE4710 are much more comprehensive than a simple mechanical property that is reduced by a safety factor.

CONCLUSION

Unlike metal piping where internal pressure stresses (pressure rating) is based on tensile strength against bursting that is unrelated to typical long-term water system field failures, allowable stresses for HDPE pressure piping are based on long-term stress-rupture testing and analysis, and performance properties that are specifically related to field performance. Decades of ongoing field performance analysis has progressively improved the performance of polyethylene materials against field failure. Today's high performance HDPE materials such as PE4710 can withstand greater stress for extended operating times with greater reliability.

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