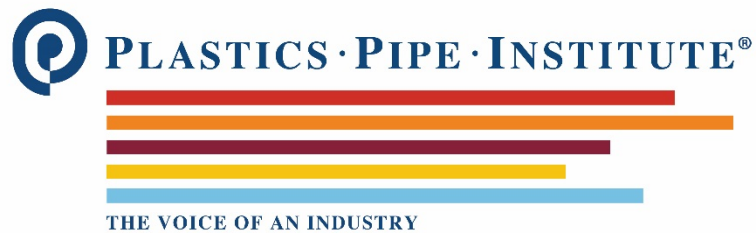


**The Nature of the
0.63 Design Factor (DF) for
Qualified Polyethylene Pipe
Compounds
HSB-R-01/2015**



FOREWORD

This technical report was developed and published with the financial support and technical assistance of the members of the PPI (Plastics Pipe Institute, Inc.). The members have shown their interest in quality products by assisting independent standards-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

The principal contributors to this technical report were PPI's Hydrostatic Stress Board (the HSB). The HSB is an independent arm of the PPI composed of industry recognized experts knowledgeable in all aspects of hydrostatic testing and performance and the long-term strengths of thermoplastic piping materials. Membership on the HSB represents all facets of the thermoplastics pipe community including polyethylene, polypropylene, PVC, PEX, composite piping products and others as necessitated by current industry practice.

The purpose of this technical report is to provide important information regarding actions and recommendations taken by the Hydrostatic Stress Board in qualifying polyethylene pipe compounds for the application of a 0.63 design factor. Information provided herein includes the final decision of the Hydrostatic Stress Board, a summary and discussion of the research undertaken that resulted in the 0.63 recommendation and a brief history on the origin of the 0.50 design factor and how the 0.63 design factor relates to it.

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The Plastics Pipe Institute

www.plasticpipe.org

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HSB-R-01/2015

The Nature of the 0.63 Design Factor (DF) for Qualified Polyethylene Pipe Compounds

Introduction

Historically, a design factor of 0.50 has been applied to all thermoplastic pipe compounds used in the context of the ASTM/PPI stress rating method prevalent throughout North America. This factor has proven to be adequate over the decades for all thermoplastic pipe compounds. In 2001, it was necessary for the Hydrostatic Stress Board of the Plastics Pipe Institute to consider a design factor greater than 0.50 for certain polyethylene pipe compounds. The purpose of this action was to address a discrepancy that existed within the ASTM/PPI (American Society for Testing and Materials/Plastics Pipe Institute) and ISO (International Organization for Standardization) stress rating methods as they pertain to the evolving technical performance of modern polyethylene (PE) pipe compounds.

In 2005, at the recommendation of the Polyolefin Committee, the Hydrostatic Stress Board of the Plastics Pipe Institute (PPI-HSB) determined that certain polyethylene (PE) resin compounds that demonstrated specific levels of technical performance beyond those established by current industry standard practice could qualify for the application of a 0.63 design factor (DF) to establish the hydrostatic design stress for water at 73° F. To qualify for the application of the higher design factor, it was determined that these polyethylene pipe compounds must meet or exceed three specific criteria in addition to what has historically been required by PPI TR-3 policies and ASTM D2837.^{(1) (2)}

The three additional performance requirements are as follows:

- 1) The 100,000 hour hydrostatic design basis as determined in accordance with ASTM D2837 must be substantiated as defined in PPI TR-3 out through 50 years. This requirement thereby assures the linearity of the regression analysis out through a much longer time period than the traditional 100,000 hr (11.4 years) used heretofore.
- 2) Statistical analysis of the regression data per ASTM D2837 for a specific polyethylene compound must exhibit a 90% LCL/LTHS. This is higher than the lower 85% LCL/LTHS ratio traditionally required by the ASTM/PPI compound recommendations. LCL refers to the Lower Confidence Limit and LTHS refers to the Long Term Hydrostatic Strength.
- 3) Inherently higher levels of resistance to failure by slow crack growth (SCG) as evidenced by minimum PENT test results of 500 hours in accordance with ASTM F1473.⁽³⁾

This recommendation represented the culmination of an extensive study undertaken by a task group within the Polyolefins Committee of the PPI-HSB from 2001 through 2004 in which the technical performance characteristics of new polyethylene pipe resin compounds (many of which were designated as PE100 materials under the International Organization for Standardization (ISO) standards system) were compared to the currently commercially available pressure pipe compounds published in PPI's TR-4.⁽⁴⁾

At the time of the recommendation and the subsequent changes to the ASTM/PPI material designation and listing protocol, these specific requirements were felt to be necessary and sufficient to allow for the use of the 0.63 DF while ensuring a safe and long-term design with modern polyethylene pipe compounds. This report summarizes the approach and rationale undertaken by the Polyolefins Committee task group in establishing the 0.63 DF for PE resin compounds.

The Origin of the 0.50 DF

Various notes and memos from PPI indicate that the original 0.50 DF was not determined by a direct structured engineering approach. Rather, the 0.50 DF was established in 1962 by industry consensus based on a thorough review of hydrostatic stress rupture data that was accumulated between 1958 and 1962 for various thermoplastic pipe compounds that were being utilized within the industry at that point in time.^{(5) (6) (7)} Analysis of these notes and memos clearly indicates that the 0.50 DF was a responsible selection at that time of a factor that could be applied to all thermoplastic pipe compounds, which would provide a conservative yet reasonable level of certainty that pipe produced from any of these compounds would not fail in response to hydrostatic stress based on stress-regression principles and pipe material performance that were known at that time. As it turned out, the selection of the 0.50 DF represented a sound decision, as its application has served the industry very well as it relates to hydrostatic stress performance of thermoplastic pipe compounds in general since that time.

However, it should be noted that while the 0.50 DF has served the thermoplastics pipe industry well since its inception, it was developed with a limited understanding of the overall factors that influence the successful long-term performance of plastic pipe systems in field service. In the intervening years, materials research has led to considerable advancements in technical understanding leading to improvements in resins utilized in pipe compounds, most notably with respect to polyethylene. Today's PE compounds, having improved SCG resistance, are now considered to be the 4th generation since the 1960's.

The Nature of the 0.50 DF

As noted, the 0.50 DF was established by industry consensus for application to all thermoplastic pipe compounds based solely on the review of hydrostatic stress data available at that time. At that point, hydrostatic performance was felt to be the principle design state of importance and little regard was given to the nature or the characteristics of the actual stress-rupture failures for any type of thermoplastic material. That is to say, that the type of failure, or failure mechanism, incurred as a result of hydrostatic stress was of limited interest at that point and field service history did not call to question the significance of this important aspect.

Today, the understanding of the long-term performance of plastics piping systems has advanced considerably to include the factors leading to the successful long-term performance of plastic pipe and the important role that fracture mechanics plays in determining the long-term serviceability of thermoplastic pipe compounds such as polyethylene. A closer look at each of these perspectives will reveal the conservative nature of the 0.50 DF as it is applied to polyethylene pipe compounds having improved SCG resistance when the types of failure mechanisms are considered or how a pipe made from these compounds is likely to fail in service.

The Evolution of Stress-Rupture Testing for Polyethylene Pipe

Within North America, a standardized approach is utilized to stress-rate polyethylene pipe compounds. Pipe specimens are placed on hydrostatic test in accordance with ASTM D1598 and the resulting stress-rupture data is analyzed in accordance with ASTM D2837.⁽⁸⁾ The stress regression analysis results in a long-term hydrostatic strength (LTHS) at the 100,000 hour (11.4 year) time intercept. The LTHS is then categorized into one of a series of hydrostatic design basis (HDB's) to establish a design limit. A design factor, DF, is then applied to the HDB to establish a hydrostatic design stress (HDS) that is used as shown in Equation 1 to establish a pressure rating at a specific temperature for a specific pipe product.

$$P = 2 \times HDS / (SDR-1)$$

[Equation 1]

Where: P	= pressure rating for water service at a specific temperature
HDS	= hydrostatic design stress at a specific temperature = HDB x DF
HDB	= hydrostatic design basis for water at a specific temperature
DF	= design factor
SDR	= standard dimension ratio = outside diameter (inches)/wall thickness (inches)

The ASTM stress rating method has been broadly utilized since its initial publication in 1969. Prior to this it had been published as Commercial Standard CS255 in 1961 by the US Department of Commerce. However, it should be noted that the method has, over time, been revised and updated repeatedly. Of particular importance relative to the long-term performance of PE piping, is a revision that requires validation of PE pipe compounds evaluated in accordance with the standard.

The validation requirement for PE pipe compounds was the direct result of a key learning that occurred approximately ten years after the adoption of the ASTM D2837 protocol. In that time period, reports of brittle-like failures of polyethylene pipe in the field were received. Moreover, these failures did not appear to be a sole consequence of internal pressure. Rather, these failures were determined to be largely the consequence of stress intensification associated with rock impingements, surface gouges, geometric considerations such as sharp bending radii, differential soil settlement and other installation related factors.⁽⁹⁾ Further, these type of failures appeared to exhibit a response mechanism that was substantially different from that of ductile yielding in response to over-pressurization that is the primary failure mechanism resulting from ASTM D2837 hydrostatic testing.

These incidents of field failures suggested that a transition had occurred in the response of polyethylene (PE) stress intensification associated with the application or service. An investigation of these failures revealed that their occurrence was associated with polyethylene compounds that did exhibit linear ductile rupture behavior throughout 10,000 hours as required by the ASTM protocol. However, at some point after the 10,000 hours, it was possible for the slope of the stress rupture curve to change signifying a difference in the failure mechanism. This change in slope was determined to be associated with a transition from ductile to brittle like failure in response to the application of stress. In other words, the failure mechanism changed from one of ductile yielding and failure in response to the continued application of stress to one of slow crack growth (SCG), a fracture mechanics phenomenon that has been the focus of extensive research. Figure 1 shows a set of hydrostatic stress-rupture curves at multiple temperatures for typical early grades of PE in which the change in response is illustrated by a dramatic shift in the slope of the resulting hydrostatic stress rupture curves.

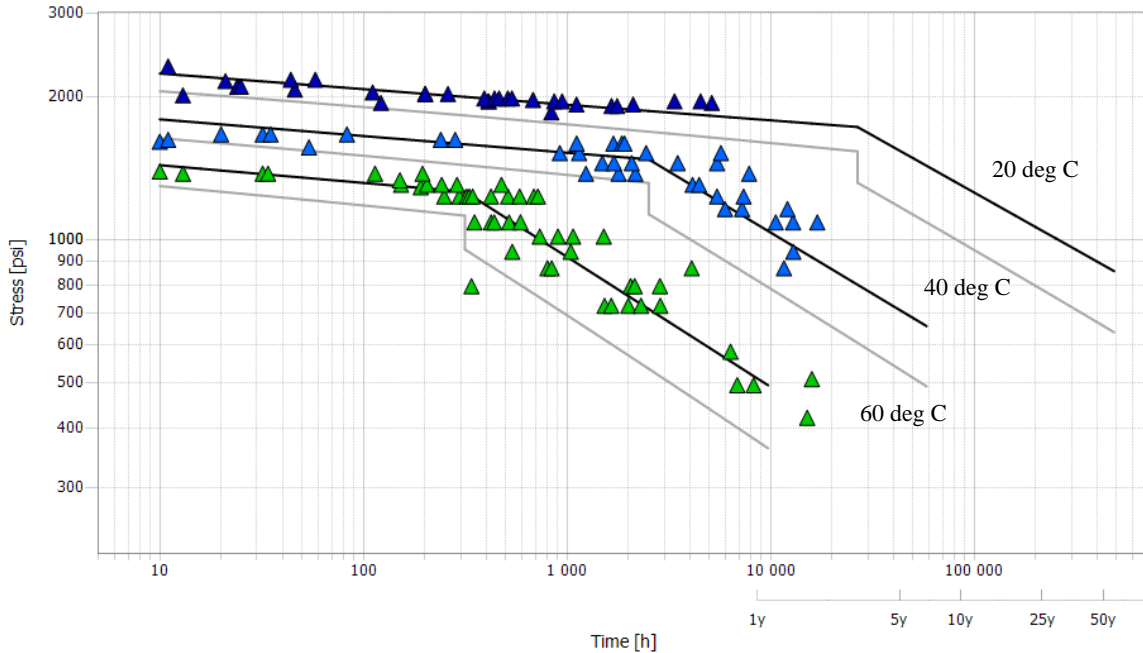


Figure 1: Early Generation (circa 1970s) PE materials showing forecast of ductile/brittle transition at three different temperatures. These materials were used very successfully for 40+ years using a 0.5 DF or higher.

As a result of these findings, the industry came to the understanding that ASTM D2837 was not designed to determine the cause of a failure. In the case of PE, failure could be caused by visco-elastic deformation that could be arrested by utilization of a lower stress. Alternatively, failure could occur by slow crack growth. In which case, the utilization of a lower stress would defer failure of the pipe under test to a later time period. In light of this understanding, the industry recognized that, in the case of PE, supplementary testing was required. As such, the industry revised ASTM D2837 to include a requirement for validation of the PE pipe compounds. Validation is a structured test protocol that assures a particular PE piping compound remains in the ductile state throughout its 100,000 hour (11.4 year) LTHS regression intercept. As a consequence of this, extensive research was undertaken on polyethylene pipe compounds that has dramatically improved the slow crack growth resistance of these materials. The resulting improvements can be seen in the typical stress-regression curves for newer, qualified PE compounds shown in Figure 2. These improvements thus assure that pipes produced from these compounds continue to operate in the ductile state and are much less susceptible to failures resulting from stress intensifications that routinely occur in pipe applications.

More recently, the PE pipe industry has integrated substantiation of linearity in the 73 deg F regression out through the 438,000 hour (50 year) intercept for certain critical applications such as natural gas distribution. Substantiation provides another level of confidence that the PE pipe produced from compounds meeting this requirement will continue to operate in a ductile state greatly reducing the concern for failure attributed to stress intensification.

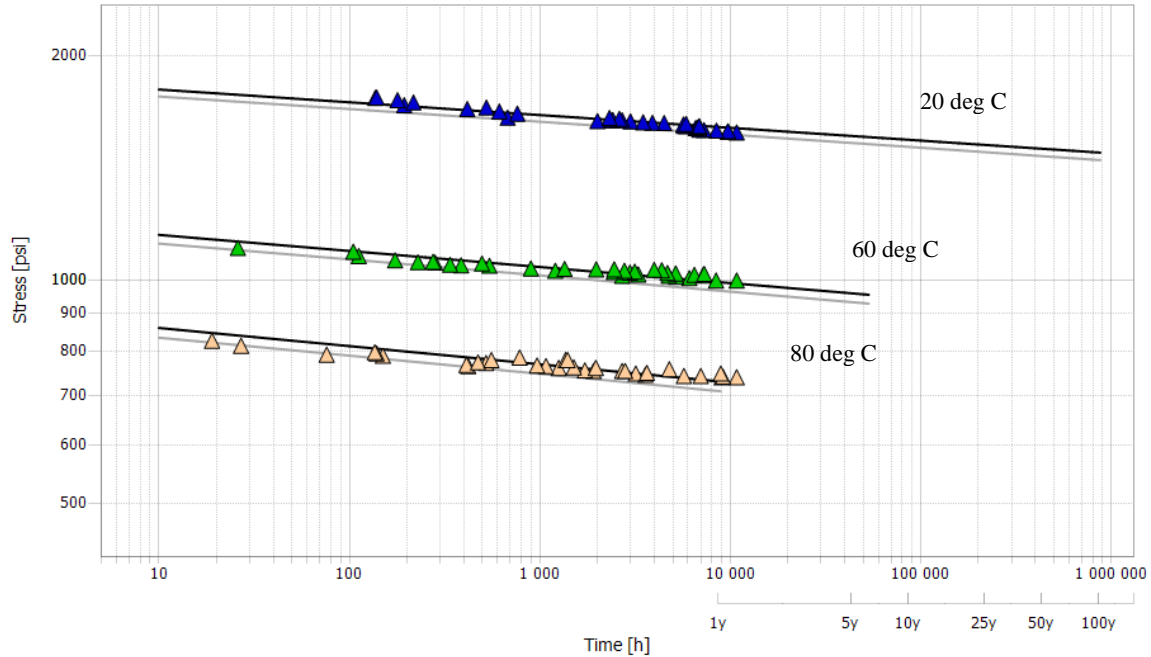


Figure 2: ISO 9080 Stress rupture curves for PE materials with no transition to brittle type failures at 20°, 60° and 80° C.

Several important findings are derived from this history and each of these has been studied extensively over the last 30 years.

- 1) Historically, some polyethylene pipe compounds produced in the 1960's and 1970's exhibited a transition from a ductile to a brittle-like failure mechanism in response to the long-term application of stress, age, stress intensification, etc.
- 2) As evidenced by the field failure history of PE pipe, this transition from ductile to brittle failure mode should be considered a principal design limit independent of and in addition to traditional hydrostatic strength properties characterized in ASTM D2837 testing.
- 3) The understanding of the material science associated with the ductile-brittle transition in visco-elastic thermoplastics has resulted in major improvements in the slow crack growth (SCG) resistance of the high performance PE pipe compounds. Further, it is this property, resistance to SCG that is of equal importance to hydrostatic strength as a design limit for the long-term performance of polyethylene piping systems.
- 4) Advancements in PE polymer science have resulted in PE pipe compounds that have been shown to increase the time to failure at 73 deg F and elevated temperatures with no ductile-brittle transition and very minimal data scatter such that confidence in their long term performance capabilities is substantially increased.

Fracture Mechanics and Polyethylene Pipe:

Fracture mechanics provides an understanding of failure mechanisms in various materials and, through that understanding, establishes a basis for designing and improving materials to tolerate or resist the application of certain types of stress. Over and above this, fracture mechanics helps us to understand that different materials respond differently to stress and this, in turn, is a significant factor that must be considered in determining how a compound responds when placed in service in any pipe application.

From a fracture mechanics point of view, materials can respond in a ductile or brittle manner based on the physical and molecular structure of the material and the presence of flaws or cracks within that material. In some cases, such as that of visco-elastic polyethylene, materials can exhibit both ductile and brittle response mechanisms in reaction to the application of stress depending on the duration and manner of the applied load.

Fracture mechanics teaches us that ductile materials exhibit the ability to undergo safe deformation at points of localized stress intensification. This capability induces a shedding or blunting effect which reduces the intensity of the localized stress intensification at the crack tip, a reaction that results in the safe redistribution of stresses around that point and into the bulk matrix of the material, or pipe wall in this case.

Brittle materials, on the other hand, behave quite differently. In the case of brittle materials, a localized stress intensification can lead to development of a crack, which under the effect the imposed stress can continue to grow to a size that compromises the pipe's intended function. In the case of polyethylene, this is a process known as slow crack growth (SCG), an area of fracture mechanics that has been studied in considerable detail for many years.^{(10) (11)} It is this phenomena (SCG), an irreversible failure mechanism, that has been demonstrated to be a significant factor for the service life of PE plastic pipe systems.

In the 1980's, a fracture mechanics based test method for PE pipe compounds was developed by Dr. Norman Brown of the University of Pennsylvania called the PENT test. The results obtained using this elevated temperature accelerated test method were correlated to field performance experience of various kinds of PE pipes that had been installed during previous years. The range of PE pipe compounds included those that exhibited a clear ductile-brittle transition to those that did not. Using the correlations, Dr. Brown concluded that a fracture mechanics based test method can be used as an indicator of long-term performance of PE pipe compounds for resistance to failure via slow crack growth. He further concluded that a PENT value in excess of 100 hours should provide the assurance of resistance to failure due to slow crack growth for not less than 50 years.^{(12) (13)} The PENT test method has since been formalized as ASTM F1473 and has been added to the PE pipe material requirements of ASTM D3350 in supplementation to the ASTM D2837 LTHS requirement as a means by which to integrate a fracture mechanics based approach to PE piping system design.⁽¹⁴⁾ Over and above this, the PPI-HSB has performed extensive work on the correlation of the PENT test to elevated temperature hydrostatic testing of PE pipe compounds.⁽¹⁵⁾

It is this fracture mechanics based phenomenon, slow crack growth, and the ability of a pipe compound to resist this type of failure mechanism that is of major importance in determining the long-term performance of polyethylene piping systems. Further, it is on this basis that the Polyolefins Committee of PPI's HSB set out to study the differences between PE compounds designated as PE3408 pipe materials under the ASTM/PPI system versus those designated as PE100 under the ISO standards systems.

The Polyolefins Committee (POC) Task Group:

In 2001, The Polyolefins Committee of the HSB established a task group whose scope was to investigate recent developments and the introduction of higher performance PE piping compounds into the international PE pipe industry in the late 1980'and early1990's. These newer materials were designated as PE100 compounds under the ISO standards system and assigned a higher level of hydrostatic design stress than the predecessor PE80 materials. Of specific interest to the POC task group was the fact that under the then-current ASTM/PPI system of material classification there was not a means to differentiate between PE compounds designated as PE80/PE3408 and these new compounds designated as PE100. Under the ASTM/PPI system in place at that time, all of these compounds would be classified the same, as PE3408's, and the new PE100 products would be unrecognized.

The POC recognized that the PE100 compounds had slightly higher stress regression curves than the older PE 80 compounds, but were being utilized at 25% higher design stresses. In accordance with ISO practice, the hydrostatic design stress (HDS) is determined by dividing the categorized Lower Predictive Limit (LPL) of the LTHS by a design coefficient of 1.25. This results in an HDS of 8.0 MPa (1160psi), a value that is equivalent to the application of a 0.71 design factor to a 1600 psi (.e.g. 3408) HDB under the evaluation methodology used in North America.

The POC observed that these PE compounds were introduced in 1989 for operation within the ISO standards system at higher stress levels and undertook an investigation of the key physical properties or performance parameters that differentiated them from those compounds previously designated as PE80 within the ISO system and those designated PE3408 within the PPI/ASTM system. Over the course of that evaluation, the POC task group recognized that the forecast of these compound's long-term rupture strength under the effect of hydrostatic stress alone was not the sole determinant affecting both the safe design stress and the useful service life of these newer PE pipe compounds.

Additionally, the nature of the ASTM D 2837 evaluation methodology is such that the long-term stress applied to a viscoelastic material is sufficiently conservative so that failure from over-pressurization is not a common failure method. Figure 3 graphically illustrates that the burst stress from over-pressurization is about four times the design stress utilizing the traditional 0.50 design factor for PE 3608 compounds, and about 3.3 times the design stress using the 0.63 design factor for PE 4710 compounds – still a more than adequate margin of safety against burst. The POC Task Group concluded that it is the fracture mechanics behavior of the material that is the determinant of its capacity for safely resisting localized stress intensifications.

Over the course of three years, the POC Task Group compiled significant amounts of hydrostatic stress rupture, slow crack growth (SCG) and physical property data for analysis. Specific materials that were investigated included older PE3408, modern PE3408, modern PE2406, PE80, PE100, and PE100+ pipe compounds as designated within the ASTM and ISO standards systems, respectively.

The POC Task Group studied the differences and similarities of the selected PE pipe compounds on the basis of these two perspectives; hydrostatic performance and resistance to slow crack growth. Through a thorough analysis of the data compiled and with the benefit of extensive literature review, the Task Group concluded on some very specific observations. These were:

- 1) Rarely, do PE piping systems fail in service in response to over-pressurization (i.e. a ductile burst). Rather, PE pipe failures typically occur as a result of stress intensification from various sources through a process known as slow crack growth (SCG).
- 2) With the requirement of validation (and in some cases, substantiation), the linearity of stress-rupture data used to perform the long-term stress regression analysis of the newer high performance PE compounds is significantly improved. This higher degree of linearity over that exhibited by the older PE3406 and PE3408 compounds upon which the original 0.50 DF was developed effectively provides a much more predictable operational boundary for the newer, higher performance PE compounds from a hydrostatic perspective. That is to say, that ductile-brittle transition (a change in the slope of the stress-rupture curve at a given temperature) is either not present or is delayed so far out into the future (in excess of 50+ years) as to be of no engineering significance.
- 3) Additionally, these newer PE pipe compounds all possess an SCG resistance several orders of magnitude above the older, more traditional PE80 and PE3408 materials when analyzed in accordance with ASTM F1473.
- 4) Under the ISO standards system, the newer PE compounds qualify for a 25% increase in their maximum working stress (i.e. HDS). However, upon analysis, the LPL's of these PE100 compounds were not on the order of 25% higher than the predecessor PE80 compounds. So the question became, on what basis could ISO technical committee members confidently move in the direction of a notably higher stress rating? The POC

Task Group observed that a key difference is in their greatly elevated resistance to slow crack growth.

- 5) Finally, given the inherent differences in the ASTM and ISO listing protocols, it is necessary to create some means by which to insure that a ductile-brittle transition does not exist in the materials that would be analyzed and listed in accordance with the ASTM/PPI procedure.

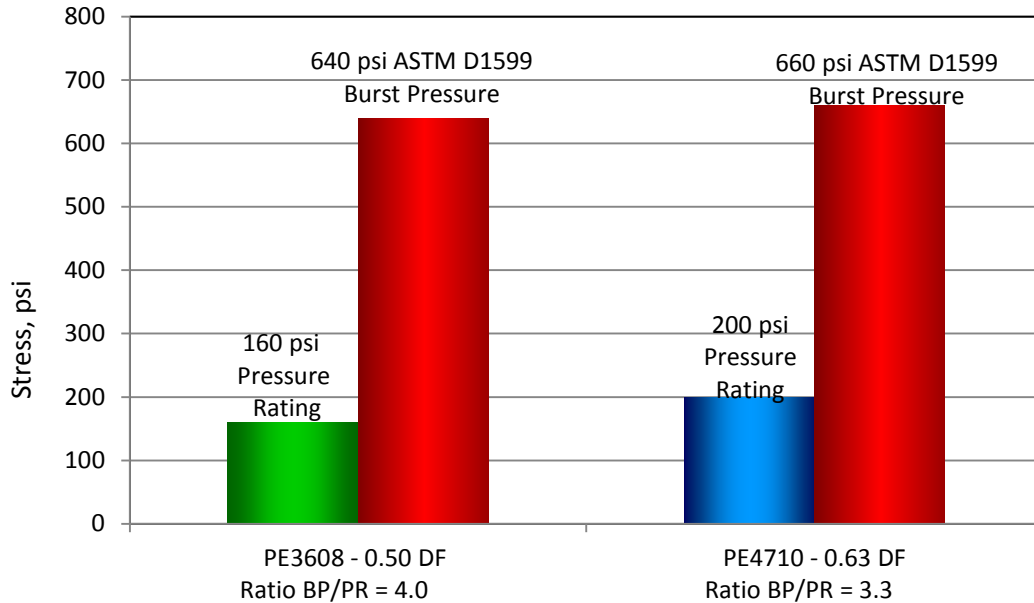


Figure 3: Pressure Rating Versus ASTM D1599 Burst Pressure for 2", 3" and 4" DR 11 PE Pipe

The POC Task Group Recommendations:

The POC Task Group investigated the differences in the material science properties (hydrostatic strength and slow crack growth) of those PE pipe compounds generally designated as PE80 and/or PE100 within the ISO system as compared to the traditional PE3408 and PE2406 in use at that time under the ASTM system. This investigation occurred over the course of three years and in late 2004, the POC Task Group came forward to the POC with its findings and recommendations.

It was clear to the Task Group based on their research and analysis, that certain polyethylene pipe compounds that met or exceeded specific levels of technical performance beyond those required by then-current industry ASTM standards could operate closer to the ductile limit of the material without sacrificing long-term performance. This is based on the significantly improved level of ductility, which is demonstrated by the inherently higher resistance to slow crack growth of these newer compounds. The specific levels of technical performance were as follows.

- 1) The hydrostatic design basis (HDB) as determined in accordance with ASTM D2837 must be substantiated out through 50 years, by a separate supplementary test, thereby assuring the linearity of the regression analysis out through a much longer time period than the traditional requirement of 100,000 hours (11.4 years) used heretofore.

- a) Such supplementary testing is unique to polyethylene pipe compounds that may exhibit a knee or discontinuity in linearity in the stress-rupture curve signifying a change in the failure mode. In the case of other thermoplastics there is no currently required test that confirms the assumption of continuing linearity through 50 years because the existence of a knee has not been documented for these materials.
 - b) The role of the supplementary test is to demonstrate that the ductile failure performance mechanism, which is the determinant mechanism during the experimental period, shall also be the determinant during the extrapolation period, through at least 50 years.
- 2) Statistical analysis of the data used in the regression analysis performed in accordance with ASTM D2837 for a specific polyethylene compound must exhibit a 90% LCL/LTHS ratio as opposed to the lower 85% LCL/LTHS ratio traditionally required by the ASTM/PPI material recommendation protocol. LCL refers to the Lower Confidence Limit and LTHS refers to the Long Term Hydrostatic Strength. Stress rupture plots in which failures occur by the ductile failure mechanism result in substantially less scatter, which results in a significantly higher degree of certainty in the mean LTHS forecast.
 - 3) Inherently higher levels of resistance to slow crack growth (SCG) failure as evidenced by minimum PENT test results of 500 hours in accordance with ASTM F1473, which is an accelerated fracture mechanics based test conducted at elevated temperatures. Testing of this type has shown that a compound with a minimum PENT resistance of 500 hours will not have a ductile/brittle transition at 73° F for hundreds of years. A higher resistance to slow crack growth propagation provides a significant margin of safety against SCG failures of PE pipe systems.

The Task Group determined that there was indeed a significant enhancement in the technical performance of these improved material science based PE pipe compounds. They concluded that these criteria provided an effective basis of differentiation between those compounds that were capable of higher levels of sustained stress without a compromise in the long-term integrity of an HDPE pipe system constructed from these products as compared to the more traditional PE3408 or PE80 pipe compounds. In their opinion, pipe compounds meeting these very stringent criteria qualified for a higher design stress by application of a design factor higher than the traditional 0.50.

The findings and recommendations of the POC Task Group were reviewed and analyzed by the POC at large over the course of several months. On February 23, 2005, the POC voted unanimously to accept the findings of the POC Task Group and to carry their recommendations forward to the Hydrostatic Stress Board (HSB) at large. The HSB at large represents all aspects of the thermoplastic piping industry (PE, PVC, CPVC, PEX, various engineering polymers and thermoplastic composites). The HSB reviewed the recommendations of the POC Task Group as approved by the POC. On August 11, 2005, the HSB voted by consensus to accept the recommendations of the POC Task Group and the POC.

The Basis for the 0.63 DF:

The POC Task Group realized that a recommendation for a design factor of 0.63 was a departure from the traditional North American industry practice of applying a design factor of 0.50 to the HDB across all thermoplastic pipe compounds regardless of their long-term performance capabilities particularly as it related to resistance to slow crack growth and fracture mechanics based failure mechanisms. However it was also clear that based on prevailing industry practice within the ISO standards arena and the character of these newer PE pipe compounds, that many piping systems had been in operation utilizing a design coefficient of 1.25 resulting in a design stress of 1160 psi for PE100 compounds since the early 1990's with no sacrifice in the continuous safe operation of these systems.⁽¹⁶⁾ This is essentially equivalent to utilizing a 0.71 design factor

for PE compounds with a 1600 psi HDB under the ASTM standards system notwithstanding that some of these ISO based systems may apply an additional application or service factor beyond the standard 1.25 design coefficient. This is derived by dividing the 1160 psi operating stress within the ISO system by the 1600 psi HDB within the ASTM system.

To the POC Task Group, there were three additional advantages to the selection of the 0.63 design factor.

- 1) The selection of the 0.63 design factor represented the next step up in the R10 preferred number series which is consistent with the guidance of ASTM D2837 and industry practice. Further, it was felt that this conservative increase in design factor was well within the performance envelop for these new, high performance PE pipe compounds and would not compromise the long-term hydrostatic operation in water service.
- 2) This R10 preferred number step – from 0.50 to 0.63 – represents a 25% increase in the design stress value for these high performance polyethylene compounds. This corresponds directly with the 25% design stress increase these same compounds received under the ISO system when they went from the PE80 to PE100 designation.
- 3) Additionally, the 0.63 design factor represented a responsible selection of a design factor that was intermediate to the operating ranges for the newer PE pipe compounds as utilized within the context of the two prevailing standards systems that currently existed at that time:
 - a) The historical and “time honored” 0.50 design factor for thermoplastic pipe compounds listed and used under the jurisdiction of the ASTM system, and
 - b) The effective 0.71 design factor (1160 psi/1600 psi) in use for those high performance compounds listed and used within the jurisdiction of the ISO system.

As can be seen here, the POC Task group felt that the selection of the 0.63 design factor represented a reasonable increase in operating pressure for piping systems that were produced from these newer PE compounds that met all three of the recommended performance criteria. The increase in operating stress as compared to the ultimate long-term strength for piping systems produced from the newer pipe compounds was marginal as compared to the significantly higher resistance to SCG of these compounds over the older PE3408 pipe compounds that exhibited a discernible ductile/brittle transition when tested in accordance with ASTM D2837.

Conclusions:

Based on the efforts of the POC task group, their respective findings, and the actions of the HSB, the following points are observed:

- 1) The recommendation of the 0.63 design factor to be used for polyethylene pipe compounds meeting very specific technical criteria was developed through an extensive research initiative undertaken by a task group within the Polyolefins Committee of the HSB over the 2001-2004 time frame.
- 2) The recommendation for the 0.63 design factor and the criteria by which polyethylene compounds must qualify for the 0.63 design factor was then reviewed and approved by both the POC and the HSB Committee.
- 3) The specific technical criteria established by the HSB to qualify for the 0.63 design factor are:
 - a) The hydrostatic design basis (HDB) as determined in accordance with ASTM D2837 must be substantiated out through 50 years by a separate supplementary method,

thereby assuring the linearity of the 73 deg F regression analysis through a much longer time period than the D2837 requirement of 100,000 hours (11.4 years) used heretofore.

- i) A supplementary test such as this is unique to polyethylene pipe compounds that may exhibit a knee or discontinuity in linearity in the stress-rupture curve signifying a change in failure mode. In the case of other thermoplastics, there is no currently required test that confirms the assumption of linearity because the existence of a knee has not been documented for these materials.
 - ii) The role of the supplementary test is to demonstrate that the ductile failure mechanism which is the determinant failure mechanism during the experimental period is also the determinant within the extrapolation period out through 50 years.
- b) Statistical analysis of the test data used to forecast the long-term hydrostatic strength in accordance with ASTM D2837 for a specific polyethylene compound must exhibit a 90% LCL/LTHS ratio as opposed to the lower 85% LCL/LTHS ratio required by the existing standard methodology. Decreased scatter in the test data results in a significantly higher degree of certainty in the mean LTHS forecast. LCL refers to the Lower Confidence Limit and LTHS refers to the Long Term Hydrostatic Strength.
 - c) Inherently higher levels of resistance to the slow crack growth (SCG) failure mechanism, as evidenced by minimum PENT test results of 500 hours in accordance with ASTM F1473 provides a significant margin of safety against SCG failure of PE pipe systems.
- 4) Polyethylene pipe compounds that meet or exceed these three technical performance criteria would qualify for the use of a 0.63 design factor in accordance with ASTM standards and PPI practice.⁽¹⁷⁾⁽¹⁸⁾ However, it should be noted that certain code agencies may specify other DF values for their applications. A good example of this would be the Department of Transportation (DOT) that establishes and controls design factor designations for natural gas distribution.
 - 5) In addition to hydrostatic stress, there exist other sources of stress that are considered in the HSB's evaluation of the long-term performance of thermoplastic pipe compounds. It is the ability of the newer, qualified PE pipe compounds to better resist or shed these other forms of highly localized stress based on their respective fracture mechanics properties, most notably resistance to SCG, which provides a basis for the recommendation of a 0.63 design factor for these materials.⁽¹⁹⁾
 - 6) The establishment of a 0.63 design factor represents a new level for polyethylene pipe compounds. It also reflects an evolution in the POC's understanding of fracture mechanics and slow crack growth as being of equal importance to hydrostatic stress rupture data in projecting the long-term performance of polyethylene piping systems.

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