HISTORICAL REVIEW OF THE PE 100-RC CONCEPT – HOW PE4710 COMPARES TO PE 100-RC

PPI TN-68

2023

Plastics Pipe Institute
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Foreword

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The purpose of this technical note is to provide general information about the development and history of the high slow crack growth (SCG) resistant high-density polyethylene (HDPE) material designations such as PE4710, PE 4710 PLUS, PE 100 and PE 100-RC.

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This Technical Note, TN-68, was first issued in July 2023.

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HISTORICAL REVIEW OF THE PE RC CONCEPT – HOW PE4710 COMPARES TO PE 100-RC

1.0 INTRODUCTION

The purpose of this document is to provide perspective on the Slow Crack Growth (SCG) resistance requirements for the PE 100-RC designation in comparison with the North American PE4710 designation and to provide a common basis and understanding to industry. Although the PE 100-RC concept has been around since 2009, there is a lack of clarity to the implications of the designation and a lack of consensus on whether a comparable designation has value for the North American industry given the already elevated SCG resistance requirements of PE4710. The development of the PE 100-RC designation was not due to documented performance issues with PE 100. This grade designation has been promoted internationally by the PE 100+ Association and is now being introduced into ISO[i] and CEN[ii] standards.

This Technical Note will familiarize the reader with the historical background on the development of the **PE 100**, **PE 100-RC**, **PE4710**, and **PE 4710 PLUS** designations. The associated performance requirements for these designations are discussed.

This Technical Note <u>is not</u> intended to make any statements or claims of technical superiority or improved field performance of one material designation system over the other nor the suitability for any given application.

2.0 BACKGROUND & SCOPE

Polyethylene (PE) pipe has historically been the material of choice for demanding applications such as gas distribution, oil and gas production, potable water and industrial process water handling on a global basis. The inherent flexibility and ductility of PE piping systems combined with the integrity of the heat fusion method of joining have also made it a preferred material for innovative trenchless installation techniques such as horizontal directional drilling (HDD), plowing, pipe bursting and compression-fit liners.

The ever-expanding range of applications for PE pipe resulted in a sustained evolution of increasing resistance to SCG behavior in PE pressure pipe and

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[i] ISO, the International Organization for Standardization, is a nonprofit organization that develops and publishes standards (i.e., ISO standards). Headquartered in Geneva, Switzerland, ISO is composed of 162 member countries.

[ii] CEN, the European Committee for Standardization, is an association that brings together the National Standardization Bodies of 34 European countries and provides platform for the development of European Standards (i.e., EN standards) and other technical documents in relation to various kinds of products, materials, services and processes.

fitting compounds. This evolution has occurred within the context of two internationally recognized standards systems, ASTM International (ASTM) and the International Organization for Standardization (ISO).

Within ASTM, the performance evolution of polyethylene pipe compounds has culminated in the establishment of the PE4710 material designation. Within ISO, a similar technical evolution had resulted in the establishment of the PE 100 piping material designation. In 2009, the PE 100-RC classification was introduced within DIN PAS 1075[1] to recognize a higher level of technical performance compared to PE 100.

As comparisons are being made between PE4710 and PE 100-RC materials, PPI has developed this Technical Note in an effort to provide the background and history of PE 100-RC and to provide the technical basis in which PE 100-RC can be compared to PE4710.

3.0 THE PE 100-RC CONCEPT

3.1. PAS 1075 and Technical Basis for RC Requirements

The PE 100-RC designation has its roots in a paper authored by Dr. Joachim Hessel. Hessel's work was prompted by a belief that Slow Crack Growth (SCG) resistance was of critical importance to the practice of using "sandless" or native backfill installations and in trenchless installation applications. Sand bedding was, and continues to be, a common requirement in some jurisdictions and applications. SCG was the principal focus because direct burial with ungraded native fill would mean that the PE pipe could be exposed to some increased level of point loading or other irregularities within the fill compared to sand bedding.

Hessell presented a new proprietary testing protocol that provided the basis for 100-year service life performance as it relates to resistance to SCG[2]. In 2009, Hessel's work was formalized into a Publicly Available Specification (PAS 1075[1]) that ultimately provided a starting point for the technical basis for the designation PE 100-RC within standards.

3.2. ISO Test Methods Developed in Support of PE 100-RC:

While PAS 1075 did not progress within the ISO organization to a Technical Specification or Standard, the desire to recognize the higher levels of technical performance was pursued. ISO Technical Committee 138[3] (TC 138) recognized that the requirements of PAS 1075 specified, at a minimum, one full year of testing and the number of laboratories certified to conduct the required testing was limited. To this end, TC 138 Subcommittee 5, Working Group 20 on *Slow Crack*

Growth investigated alternative testing methods by which to characterize and specify the PE 100-RC level of performance. The TC 138 Subcommittee 5, Working Group 5 on *Test Methods* then established four key ISO test methods, all of which are required for qualification as a PE 100-RC compound. These test methods and corresponding requirements are summarized in Table 1.

These four test methods combined are necessary for qualification of a PE 100-RC compound: Strain Hardening (SH)[4], Cracked Round Bar (CRB)[5], Accelerated Full Notch Creep Test (AFNCT)[6], and Accelerated Notched Pipe Test (ANPT)[7].

With the establishment of these four required ISO test methods, efforts have turned to incorporation of these requirements within industry product standards. CEN has published the PE 100-RC test requirements, as shown in Table 1, in the EN 1555[8] series gas pipe product standards. Furthermore, efforts are now underway by CEN and ISO to introduce the same requirements within EN 12201[9] series for water, ISO 4437[10] series for gas, and ISO 4427[11] series for water.

Table 1 - ISO PE 100-RC Compound Test Methods and Requirements

Test Method	Title	Requirement
ISO 18488	"Polyethylene for pipe applications – Resistance to slow crack growth – Strain hardening method"	G*p* ≥ 53 MPa for 5 specimens, 300 µm @ 80º C
ISO 18489	"Polyethylene pipes – Resistance to slow crack growth under fatigue loading – Cracked round bar method"	> 1.5 x 10^6 cycles, 14 mm test specimen in air at 23º C
ISO 16770	"Plastics – Determination of environmental stress cracking (ESC) of polyethylene – Full notch creep test (FNCT)"	≥ 550 hours @ 90 C and 4 MPa in 2% Lauramine oxide, or ≥ 300 hours @ 90 C and 5 MPa in 2% Lauramine oxide
ISO 13479	"Polyolefin pipes for the conveyance of fluids — Determination of resistance to crack propagation — Test method for slow crack growth on notched pipes" – Appendix D – Accelerated Notched Pipe Test	300h @ 80°C and 9.2 bar in 2% Nonylphenol solution.

4.0 THE ASTM PE4710 DESIGNATION

4.1. History and Background of ASTM Polyethylene Material Classifications

As the performance of PE compounds improved, the North American industry revised the cell classifications of ASTM D3350[12] and the associated material designations to reflect the improved properties and performance levels. The pivotal changes were the technological advancements of PE pressure pipe compounds resulting in progression of the material designations from PE3406 to PE3408 (mid 1980s), and from PE3608 to PE4710 (mid 2000s)[13]. PE4710 designated compounds are the highest performing pressure pipe compounds under the current ASTM product standards and the ASTM D3350 categorization system.

4.2. ASTM SCG Requirements

Within the ASTM system of North America, the SCG requirement for designation as a PE4710 compound is determined by Test Method ASTM F1473[14]. The results are commonly referred to as the "PEnnsylvania Notch Test (PENT) performance." Currently, a minimum 500-hrs PENT performance is required to qualify for the PE4710 material designation. In reality, many of the PE4710 pressure pipe compounds test well above this required minimum. It is not uncommon to see these modern compounds test to 2,000, 5,000 or over 10,000-hrs PENT.

Studies by Brown[15,16] evaluated the failure rates of the early generation PE compounds in gas distribution service to predict long term failure rates. Their results determined that a 25 – 35-hrs minimum PENT performance drives the failure, by SCG, to essentially zero for the conditions and operating systems that were studied. The current minimum 500-hrs PENT requirement for PE4710, in accordance with ASTM D3350, is approximately 20 times greater than the minimum where SCG failures are expected to be eliminated.

4.3. Other SCG Resistance Requirements within North American Standards

Two standards bodies have recognized the higher PENT performance of some PE4710 materials. For purposes unrelated to backfill material selection, CSA and ASME have recognized and established higher performing PE4710 with PENT minimum values of 2,000 hrs. ASME established the requirement to ensure safety in elevated temperature nuclear power secondary cooling water applications[17]. CSA established the requirement to permit the use of higher design factors (DF) in gas (0.45 DF) and water (0.71 DF) applications[iii] and now recognizes these higher performance compounds as PE 4710 PLUS materials. To date, ASTM standards have not categorized performance above 500-hours PENT.

[iii] In the Canadian standards, the compounds with a minimum 2000-hour PENT are referred to as PE 4710 PLUS. As a result of the added performance and confidence in the product, the design factor is increased from 0.40 to 0.45 for gas distribution applications and from 0.63 to 0.71 for water applications, as specified in CSA B137.4 - Polyethylene (PE) piping systems for gas services and CSA B137.1 - Polyethylene (PE) pipe, tubing, and fittings for cold-water pressure services, respectively, for PE 4710 PLUS piping. A result of this higher design factor is that the design pressure of 230 psig for PE 4710 PLUS pipe for is now equivalent to the design pressure of 232 psig for PE 100 pipe.

5.0 COMPARISON OF PE4710, PE 4710 PLUS, PE 100 AND PE 100-RC

This section provides a direct comparison of the requirements of compounds meeting the PE4710, PE 4710 PLUS, PE 100 and PE 100-RC designations and discusses the implications in service. As stated in the introduction, this Technical Note is not intended to make any statements or claims of technical superiority or improved field performance of one material designation system over the other nor the suitability for any given application.

Table 2 provides a direct comparison of the SCG resistance test requirements for the various North American and ISO material designations. Importantly, the RC designation is not a recognition of performance differences or improvements in either the long-term ductile strength or oxidative resistance of PE compounds or the resulting pipe. It should also be noted that although the ISO and EN (i.e., European) product standards for PE gas and water pipe require pre-compounded materials, the RC test methods requirements (Table 1) are performance based so the use of pre-compounded material is not specified. The test methods being used to determine RC performance level can also be applied to inline compounded pipe.

In the ASTM system, the SCG category is part of the definition of the pipe material designation code; whereas, in the ISO standards the minimum SCG requirement(s) reside in the product standards. As detailed in Section 4.2, the current PE4710 requirement of 500-hrs translates to well over 100-yrs of service life for properly installed and operated systems. Although, the Notch Pipe test has a lower estimated acceleration factor (1-hr equivalent to ~0.5-yrs), with a requirement of 500-h, it also translates to well over 100-yrs of service life.

It should be remembered that many of the compounds available today far exceed these minimum requirements. Additionally, it should be noted that many PE4710 compounds also achieve the PE 100 classification in accordance with ISO 9080[18] and ISO 12162[19]. Furthermore, many PE 100 compounds achieve the PE 4710 material designation. Although a PE compound is able to demonstrate the highest performance in both the ASTM and ISO systems and vice versa, the technical assessments and requirements differ.

Table 2 - SCG Tests and Minimum Requirements by Material Designation of the Predominant Water and Gas Piping Standards

Test Method	PE4710[a]	PE 4710 PLUS[b]	PE 100[c] Water/gas pipe	PE 100-RC[d] gas pipe
	Compound Requirements		Product Standard Requirements	
PENT	>500	>2000	-	-
Notched Pipe	-	-	>500 h	-
Accelerated Full Notch Creep (AFNCT)	-	-	-	No failures less than specified hours depending on test stress
Accelerated Notched Pipe	-	-	-	>300h
Strain Hardening	-	-	-	Gp ≥ 53.0 MPa
Cracked Round Bar	-	-	-	≥1.5x10^{6} cycles

[a] Various ASTM and CSA product standards (e.g., ASTM F714, ASTM D2513, CSA B137.4)
[b] CSA B137.1, B137.4 and Z662
[c] ISO 4427 & ISO 4437 product standards
[d] EN 1555 series product standards

6.0 INSTALLATION CONSIDERATIONS

As detailed above, the resistance of the PE piping material to SCG failure has been extensively investigated, characterized and requirements established. Installation processes, whether trenched or trenchless, have the potential to damage the pipe exterior surfaces. Once installed, the piping system may be subject to ground movement or other loads that create additional stresses or stress risers on the pipe. The PE piping industry recognizes that the improved SCG resistance of PE piping compounds has enhanced the expected long-term performance in these situations.

A detailed discussion of the relationship between pipe compounds and installation techniques is outside the scope of this document. There exists a wide range of trenchless installation techniques, such as horizontal directional drilling (HDD), plowing and pipe bursting. Pipe installed using these techniques may be exposed to the surrounding soil environment, and associated forces, without the same embedment normally provided in trenched applications. Additionally, pipe that is pulled into place may be exposed to surface damage during the pulling process and potentially subjected to point loading in service. However, studies on trenchless techniques have shown that scratch depths in excess of 10% wall thickness seldom occur[20,21]. Research has shown that scratch depths of this magnitude do not impact the long-term performance of pipe[22,23,24].

7.0 SUMMARY

This PPI Technical Note summarizes the history and background of the developments leading to the recognition of the increased SCG resistance in PE pressure pipe, culminating in the current PE4710, PE 4710 PLUS, PE 100 and PE 100-RC material designations. Although the PE compounds available are fairly similar, it was shown that the test methods and requirements for assessing the performance of the designations differ significantly. CEN and ISO are progressing, within their systems of standards, with recognition of the PE 100-RC material designation.

Although the PE 100-RC designation has been around since 2009, there is a lack of clarity to the implications of the designation and a lack of consensus on whether a comparable designation has value for the North America industry. Based on field experience, the current PE4710 compounds have proven resistance when utilizing current ASTM recommended installation practices and embedment particle sizes .

This Technical Note is not intended to make any statements or claims of technical superiority or improved field performance of one material designation system over the other nor the suitability for any given application. Rather, this Technical Note familiarizes the reader with the historical background on the development of the **PE 100**, **PE 100-RC**, **PE4710**, and **PE 4710 PLUS** designations, and discusses the associated performance requirements for these designations.

ENDNOTES

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[3] ISO/TC 138 Committee responsible for plastics pipes, fittings and valves for the transport of fluids

[4] *ISO 18488 - Polyethylene for pipe application – Resistance to slow crack growth – Strain Hardening test method,* International Organization for Standardization, Switzerland, 2015

[5] *ISO 18489 - Polyethylene pipes – Resistance to slow crack growth under fatigue loading – Cracked Round Bar method*, International Organization for Standardization, Switzerland, 2015

[6] *ISO 16770* - *Plastics – Determination of environmental stress cracking (ESC) of polyethylene – Full notch creep test (FNCT)*, International Organization for Standardization, Switzerland, 2019

[7] *ISO 13479 - Polyolefin pipes for the conveyance of fluids — Determination of resistance to crack propagation — Test method for slow crack growth on notched pipes,* International Organization for Standardization, Switzerland, 2022

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[10] *ISO 4437* series, *Plastics piping systems for the supply of gaseous fuels - Polyethylene (PE)*, International Organization for Standardization

[11] *ISO 4427* series, *Plastics piping systems for the supply of water supply and drainage and sewerage under pressure - Polyethylene (PE)*, International Organization for Standardization

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