UPDATED POLYETHYLENE PRODUCT STANDARDS DOING THEIR PART FOR A SUSTAINABLE FUTURE

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SHORT SUMMARY
The latest changes and improvements to the international and European product standards for PE piping systems for gas and water supply include: 1) the addition of PE 100-RC, 2) the development of an "Assessment of Conformity" part, and 3) the inclusion of hydrogen and disinfectants. These changes are essential to ensure that PE remains a sustainable and safe choice in the future, by adapting the standards to a changing environment with multiple market demands.

KEYWORDS
standardisation, certification, polyethylene, hydrogen, disinfectants

ABSTRACT
This paper discusses the latest changes and improvements to the international and European product standards for polyethylene (PE) piping systems for gas and water supply. The changes affect four relatively similar series of product standards for PE piping systems:

- *EN 1555 (European standards series for PE for gas supply)*
- *EN 12201 (European standards series for PE for water supply)*
- *ISO 4427 (international standards series for PE for water supply)*
- *ISO 4437 (international standards series for PE for gas supply)*

These standards were updated in roughly three steps. PE100-RC was first added to the standards. The Assessment of Conformity (AoC) of the standards was subsequently revised. Finally, hydrogen gas and disinfectants will be added to the standards.

One of the first steps was to include PE 100-RC. The main technical advantage of this material is that it is even more resistant to slow crack growth (SCG) than other PE grades, making it a good choice for trenchless techniques.
Standardisation of PE 100-RC has been a long-held wish in the industry, as the first PE 100-RC types were already introduced to the market in 2001. Experts agreed on a comprehensive set of test methods, including the strain hardening test (SHT), cyclic cracked round bar test (CRB), accelerated full notch creep test (AFNCT) and accelerated notched pipe test (ANPT).

Following the inclusion of PE 100-RC, a balanced agreement on the AoC has been reached in Europe. The AoC ensures that the compounds and products are of the required high quality, and also limits the burden of testing on the industry. Looking

beyond Europe, an AoC document that will provide global guidance on type testing (TT), batch release testing (BRT), process verification testing (PVT) and audit testing (AT) is being prepared for ISO 4437.

The product standards for gas and water supply are currently being revised again in response to two other important market demands: adding hydrogen gas to the standards for gas supply, and adding disinfectants to the standards for water supply.
The gas standardisation working group has prepared an annex with more information on the suitability of PE pipe systems for 100% hydrogen, and hydrogen mixed with natural gas. The annex shows that approved PE gas pipes are fully resistant to hydrogen gas.
An informative annex on secondary disinfection will be added to the product standards for water supply to inform users about the effect of disinfectants on PE pressure pipes.

NOMENCLATURE

AFNCT	Accelerated Full Notch Creep Test
ANPT	Accelerated Notch Pipe Test
AoC	Assessment of Conformity
AT	Audit Testing
BRT	Batch Release Testing
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CRB	cyclic Cracked Round Bar test
DIN	Deutsches Institut für Normung (German Institute for Standardization)
DN	Nominal size
DVGW	Deutscher Verein des Gas- und Wasserfaches (German Technical and Scientific Association for Gas and Water)
FNCT	Full Notch Creep Test
HDD	Horizontal Directional Drilling
ISO	International Organization for Standardization
KRV	Kunststoffrohrverband (German Plastic Pipes Association)
NPT	Notch Pipe Test
PAS	Publicly Available Standard
PE	Polyethylene
PLT	Point Load Test
PVT	Product Verification Testing
RC	Raised resistance to Cracking
RD	Raised resistance to Disinfection
SC	Subcommittee
SCG	Slow Crack Growth
SDR	Standard Dimension Ratio
SHT	Strain Hardening Test
TC	Technical Committee
TEPPFA	The European Plastic Pipes and Fittings Association
TT	Type Testing
WG	Working Group

INTRODUCTION – THE INITIAL DEVELOPMENT OF A PE PIPE STANDARD

For as long as polyethylene pipes have been in use, standardisation has been a very important topic. It is not without reason that a paper on standardisation was discussed during the very first Plastic Pipes Conference in Southampton in 1970. [1]

In the 1950s, with the introduction of systems that were expected to have a service life of at least 50 years, standardisation became essential to ensure sufficient pipe quality. This began with national standards, but it soon became clear that international cooperation would be beneficial. The leading organisation for international standards, including product standards, was (and still is) the International Organization for Standardization (ISO). The standardisation work was initially handled by subcommittee 6 of ISO/TC5. However, in recognition of the growing importance of plastic pipes and fittings, in 1970 the subcommittee was elevated to the status of a full Technical Committee: ISO/TC138 *"Plastic Pipes & Fittings*". [2]

It took until 15 January 1988 before the first edition of ISO 4437 was published: "*Buried polyethylene (PE) pipes for the supply of gaseous fuels – Metric series – Specification*". This international standard was initially a mere recommendation that functioned as a model for national standards. [3]

In the meantime it had become clear that plastic pipe standards could play a very important role in the organisation of the open market in what was then still called the European Economic Community. This prompted the establishment of the technical committee CEN/TC155 "*Plastics piping systems and ducting systems*" in 1988. This committee decided that systems standards should consist of independent parts, which would exclude test methods but include all the requirements and relevant test parameters. It was also agreed that supporting (test) standards should be developed, which would not contain requirements or relevant parameters. [3]

The following structure for polyethylene systems standards was agreed:

- Part 1: General
- Part 2: Pipes
- Part 3: Fittings
- Part 4: Ancillary equipment
- Part 5: Fitness for purpose of the system
- Part 6: Installation
- Part 7: Assessment of Conformity (AoC)

The European standards series for PE piping systems for the supply of gaseous fuels, the EN 1555 series, was published in December 2002. The EN 12201 series, which concerns PE piping systems for water supply, was published a few months later.
The ISO standards followed this new structure. The ISO 4427 series was first updated in 2007. This is the international standard for PE piping systems for water supply, which was originally published as one part in 1996. ISO 4437 (PE for gas) was given the same structure in 2014.

Aside from the changes to the structure of the standards, many other (technical) changes were made in the period between the publication of the first version of ISO 4437 in 1988 and the aforementioned update in 2014. These were necessary as developments in polyethylene had led to many substantial improvements in the quality of the material, including the slow crack growth resistance, impact resistance and fusion compatibility. Moreover, PE pipes have an excellent track record as a reliable and thus sustainable choice, because they are lightweight, corrosion proof and have low maintenance and installation costs, while still having an expected service life of more than 100 years [4].

This paper discusses the latest changes and improvements to the international and European product standards for PE piping systems for gas and water supply, which will ensure that PE continues to be a sustainable choice by adapting the standards to a changing environment. The improvements to the product standards consist of three phases:

1. The addition of PE 100-RC
2. Updates to the Assessment of Conformity (AoC)
3. The addition of hydrogen gas and disinfectants

These changes affect the four series of product standards mentioned above, which are relatively similar for PE piping systems:

- EN 1555 (European standards series for PE for gas supply)
- EN 12201 (European standards series for PE for water supply)
- ISO 4427 (international standards series for PE for water supply)
- ISO 4437 (international standards series for PE for gas supply)

PE is of course also standardised in the North American standards (ASTM, ASME and CSA). However, the European and international standards arose differently and take a different approach than the North American standards. The differences as regards stress rating and overall performance have led to many discussions through the years. [5, 6]
A separate paper would be needed to compare the two standard types. As such, this paper does not cover recent developments in North America.

PHASE 1 – THE INTRODUCTION OF PE 100-RC TO PROVIDE EXTRA SAFETY FOR VARIOUS INSTALLATION TECHNIQUES

It may seem strange that the PE 100 grade, which already performs very well, has been optimised even further. However, a PE grade that is even more resistant to slow crack growth (SCG) while maintaining a 100-year life expectancy would give extra safety, create new opportunities for applications and installations and may reduce costs [7]. SCG may occur as a result of point loads or scratches [8, 9]. Such a PE grade would be suited to unconventional (“no-dig”) pipe installation techniques, including Horizontal Directional Drilling (HDD) and pipe bursting. These rehabilitation techniques are very popular because they restore the performance of old (cast iron) pipelines with minimal excavation [10]. Although “no-dig” techniques have many benefits compared to open cut replacement, they may cause greater surface damage to the PE pipe. Moreover, for installation methods in which the excavated soil is used as the embedding material, PE with a low notch sensitivity and high SCG resistance is highly preferable.

Wavin (now Orbia) presented their new TS$^{DOQ®}$ pressure pipe, which used the XSC50 grade from Total (now TotalEnergies) at “Wasser Berlin” in 2000. This was the first pipe with layers of PE 100-RC. Other PE manufacturers also introduced their own PE 100-RC grades in the following years.

There was a high demand for these pipes in Germany in particular, and PE 100-RC soon became the established grade. Germany also took the lead in developing a PE standard that would set the requirements for this PE 100-RC grade [7]. The German Technical and Scientific Association for Gas and Water, DVGW, began preparations

for a PE 100-RC project in 1997. The project itself was finally launched in 2004 and the results were published in 2008 [11].
Because PE 100-RC had to be highly scratch resistant, it had to withstand two tests for at least one year: the Full Notch Creep Test (FNCT) specified in ISO 16770, and the Notch Pipe Test (NPT) specified in ISO 13479. The grade also had to have a high point load resistance. A special “point load test” (PLT) was developed to test this property. The PE grade had to withstand this test for at least one year. Finally, a thermal stability test was introduced to test the required life expectancy of 100 years. These requirements were published by DIN (the German Institute for Standardization) in April 2009 as Publicly Available Standard (PAS) 1075. [7]

Although the market responded positively to the development of a standard for PE 100-RC on which certification could be based, the one-year tests were impractical for the development of new PE 100-RC grades. Faster tests were needed. Moreover, there was criticism due to the lack of round robin data, and also because PAS 1075 [11] did not provide sufficient information for other independent laboratories to carry out the tests. In response, three international laboratories began redeveloping the PLT to create an open test method [12]. This led to the development of international test standard ISO/CD 22102. However, the failure behaviour for the PLT proved to be very complex [13]. Despite the work of the three research laboratories, the project to develop an international test standard was abandoned and the PLT was never included in any of the four CEN or ISO product standards for PE.

In the meantime, standardisation of PE 100-RC was also ongoing at CEN and ISO level. Due to the timing of the revision, the main effort was carried out in the working group that drafted the EN 1555 series. DVGW from Germany again took the lead in the development of suitable test methods [14]. Three tests of the polymer that had already been standardised were selected: the strain hardening test (SHT) specified in ISO 18488, the cyclic cracked round bar test (CRB) specified in ISO 18489 and the full notch creep test (FNCT) specified in ISO 16770 [15]. As the SHT and CRB were already very fast, an accelerated version of the FNCT was developed: the AFNCT. The project, which was carried out between November 2014 and December 2017, provided proof of reproducibility and limiting values for PE 100-RC. [14]

Figure 1. A universal tensile tester for SHT (in the background on the right a dynamic tensile tester for the CRB).

The EN 1555 standards series could not be completed without a suitable pipe test for part 2. The PLT was under development at the time, but still the subject of extensive debate. An accelerated version of the well-known notch pipe test (NPT) therefore attracted new interest [16].

The standard for the NPT, ISO 13479, was updated to include the test procedure for the accelerated notched pipe test (ANPT) for PE 100-RC pipes. The standard was finally published in June 2022.

The industry had been waiting a very long time for a new version of EN 1555 that included PE 100-RC. Due to time constraints in the standardisation process, the new EN 1555 series was published in July 2021, before the revised ISO 13479 was published. This was solved in the EN 1555 series by referring to the version of ISO 13479 “under preparation”.

In 2021, 21 years after the initial introduction of PE 100-RC, the PE market finally had a product standard for PE 100-RC that referred to open test standards. Part 1 of EN 1555 gives the requirements for the compound. These are the same as those for PE 100, with additional requirements as given in Table 1.

Table 1. Additional requirements for PE 100-RC compounds in EN 1555-1:2021.

Characteristic	Requirement	Test method
SHT (on granules)	≥ 53,0 MPa	ISO 18488
CRB (on granules)	≥ 1,5 × 10^6 cycles at an interpolated stress range of 12,5 MPa	ISO 18489
AFNCT (on granules)	≥ 550 h at an interpolated tensile stress of 4 MPa (or ≥ 300 h at 5 MPa)	ISO 16770
ANPT (on pipes)	≥ 300 h	ISO 13479

For part 2 of EN 1555 (pipes), two important decisions were made:

1. A coextruded pipe made of a combination of PE 100 and PE 100-RC layers would be regarded as PE 100.
2. Simply using a proven PE 100-RC compound for the pipe was insufficient; it was also necessary to prove the raised resistance to SCG for the pipe. Depending on the wall thickness of the pipe, the tests given in Table 2 are required. Note that the requirement for the SHT is slightly lower as a normal consequence of the manufacturing process, as also identified by the DVGW project [14].

Table 2. Additional requirements for PE 100-RC pipes in EN 1555-2:2021.

Characteristic	Requirement	Test method
SHT (for size group 1)	≥ 50,0 MPa	ISO 18488
ANPT (for size group 2)	≥ 300 h	ISO 13479
CRB (for size group 3)	≥ 1,5 × 10^6 cycles at an interpolated stress range of 12,5 MPa	ISO 18489

For part 3 and part 4 of EN 1555 (fittings and valves respectively), it was agreed that the PE 100-RC characteristic of the product should also be proved. For these products, the SHT was used with a required strain hardening modulus ≥ 50,0 MPa.

Once the EN 1555 series had been published, PE 100-RC could also be included in the other product standards. The EN 12201 series and ISO 4437 series were next in line for revision. Both standards series were published in early 2024. The test methods and requirements are identical to EN 1555, with the exception of a minor change to the CRB requirement. In the EN 12201 series, the CRB value must be converted and normalised to a diameter of 14 mm and an initial crack length of 1,40 mm. This requirement will also be added to the new revisions of EN 1555 and ISO 4437.

The ISO 4427 series is currently under revision. Once this standards series is published, the requirements for PE 100-RC will again be aligned in all product standards.

PHASE 2 – THE ASSESSMENT OF CONFORMITY AT ISO LEVEL PROVIDES A SUSTAINABLE BASIS FOR CERTIFICATION SCHEMES

Following the publication of parts 1 to 4 of EN 1555 in 2021, the AoC (part 7) was rapidly finalised and published just five months later (December 2021). The AoC specifies the scheme for type testing (TT), batch release testing (BRT), process verification testing (PVT) and audit testing (AT) of the products. A summary is given in Table 3.

Table 3. Summary of the SCG tests for PE 100-RC in the AoC (CEN/TS 1555-7:2021).

	Compound (Part 1)	Pipes (Part 2)	Fittings (Part 3)	Valves (Part 4)
TT, PVT and AT	SHT CRB AFNCT ANPT	SHT ANPT CRB	SHT	SHT
BRT	SHT or AFNCT	-	-	-

All the SCG tests as given in the relevant parts must be carried out for TT (first row in Table 3). The tests are carried out once for each compound (part 1) and size group (for pipes, part 2) or product range (for fittings and valves, parts 3 and 4 respectively).
All tests are also carried out for the PVT and AT (first row in Table 3). For compounds, the SHT and ANPT are carried out once every year, and the CRB and AFNCT once every two years (part 1). For pipes, fittings and valves, all tests are carried out once every two years (parts 2, 3 and 4).
BRT is only relevant for compounds (bottom row in Table 3). For compounds, only the SHT (or alternatively AFNCT) is carried out for BRT. This is carried out once for each batch and at least every seven days (part 1). No BRT is required for pipes, fittings and valves (parts 2, 3 and 4) for PE 100-RC.

As for the EN 12201 series, part 7 of this series was also updated following the publication of parts 1 to 4 in 2024. Due to a minor error, the Formal Vote had to be repeated. At the time of writing, it is expected that the AoC for EN 12201 will be published within a few months (in 2025).

A major difference between CEN standards and ISO standards is that the CEN standards were intended to be mandatory in the countries that participate in CEN from the start. This also meant that certification is rather complicated, as it includes harmonised European Standards, European Technical Approvals and approved listed national standards [3]. This topic is too complex for inclusion in this paper. It has already been under discussion for many, many years [17]. Nevertheless, this is the reason why the European standards series include a part 7 with the AoC, while ISO standards did not.
However, in a changing market, more and more countries are looking for a solid and sustainable basis for their certification schemes. While the AoC is not mandatory, it will

provide guidance on the TT, BRT, PVT and AT across the globe. In October 2023, ISO/TC 138/SC 4/WG 3 therefore decided to propose a new project to add a part 7 to ISO 4437. The contents of ISO/TS 4437-7 will be essentially identical to CEN/TS 1555-7. It will be published after publication of the latest revision of parts 1, 2 and 3 of this standards series. This is expected in late 2025 or early 2026. An AoC part will also be added to the ISO 4427 series.

PHASE 3 – MORE INFORMATION ABOUT HYDROGEN AND DISINFECTANTS TO ENABLE SAFE USE OF PE PIPES IN THE FUTURE

As mentioned above, the EN 1555 and ISO 4437 (both gas), and ISO 4427 (water) series are currently under revision in response to two other important market demands: adding hydrogen gas to the standards for gas supply, and adding disinfectants to the standards for water supply.

HYDROGEN

Hydrogen is a gaseous fuel that can be produced using sustainable energy sources, such as wind and solar energy. It can be used as part of the implementation of decarbonisation policies, and is therefore an essential part of the overall energy transition. Although neither the EN 1555 nor the ISO 4437 series exclude hydrogen, there was a need for a more explicit declaration. This was mainly because end users were, and still are, unfamiliar with hydrogen. They require proof from manufacturers that PE pipes are suitable for hydrogen distribution. An explicit declaration in the standard would make it immediately clear to all readers that PE piping systems conforming to the standard are indeed suitable for hydrogen distribution.

In the 2010 version of the EN 1555 series, the term “gaseous fuel” was defined as “*fuel which is in gaseous state at a temperature of 15 °C, at atmospheric pressure*”. The 2014 version of the ISO 4437 series contains almost the same definition. Following the revision of both standards series to include PE 100-RC, a note was added to this definition stating that “*There are proposals to inject gases from renewable sources in the natural gas network, e.g. hydrogen (H_2). This is the subject of ongoing research.*”

In the new versions of these standards, this note has been changed to: “*Typical gaseous fuels are for example natural gas, methane, butane, propane, hydrogen, manufactured gas, biogas, …, and mixtures of these gases.*”
A note has also been added to the scope that more explicitly mentions hydrogen, among other gases: “*For the purpose of this document the term gaseous fuels include for example natural gas, methane, butane, propane, hydrogen, manufactured gas, biogas, and mixtures of these gases.*”
However, by far the most important change is the addition of an annex that the gas standardisation working group has prepared to provide more information about the suitability of PE pipes systems for 100% hydrogen, and hydrogen mixed with natural gas. This informative annex in part 1 of the series contains two sections: information about chemical resistance, and information about permeation. These are described below.
Finally, a brief note has been added to parts 3 (fittings) and 4 (valves) stating that leak tightness testing under pressure with air/nitrogen is appropriate for all gaseous fuels, and thus also for hydrogen [18].

As regards chemical resistance, the new standards state that approved PE gas pipes are fully resistant to hydrogen at operating temperatures and pressures covered by the scope of the standard. No decrease in the service life of the PE pipes is therefore expected. This annex contains many literature references that support this claim based on experience, practical tests and laboratory investigations. The overwhelming proof of suitability has also prompted position papers from TEPPFA (The European Plastic Pipes and Fittings Association), DVGW (German Technical and Scientific Association for Gas and Water) and KRV (German Plastic Pipes Association) stating that PE pipe systems can be considered for use with hydrogen-methane based blends and pure hydrogen gas [19, 20, 21].

Figure 2. A test setup to measure the permeation through a PE pipe.

As regards permeation, a major concern of many pipe owners, regulators and the general public is that hydrogen will simply pass through the pipe wall. They fear that this will lead to unsafe situations and major economic losses. As this is untrue, the annex in the new standards includes a short explanation of the phenomenon, an overview of typical ranges of permeation coefficients and an example calculation. Permeation is the phenomenon in which a permeant (e.g. methane or hydrogen gas) passes through a physical barrier (e.g. a PE pipe wall). The permeation rate through the physical barrier depends on the permeability coefficient (which depends on the temperature), the difference in partial pressure, the surface area of the barrier and the thickness of the barrier.
Typical ranges of permeability coefficients of PE 80, PE 100 and PE 100-RC at various temperatures are given in the annex for both hydrogen and methane. These values, combined with the pressure of the gas and dimensions of the pipe, enable the end user to calculate the permeation rate. The standards give a calculation example based on a 1-km-long DN 110, SDR 11 PE pipe at 20 °C that is pressurised with a 10 bar(g) blend of 80% natural gas (of which 80% is methane, the rest is nitrogen and minor constituents) and 20% hydrogen. The permeation from such a pipeline will be:

- 7 to 13 litres of hydrogen and 2 to 8 litres of methane per day, or
- 0,6 to 1,1 grams of hydrogen and 1,5 to 5,6 grams of methane per day.

DISINFECTANTS

Studies of polyolefin (such as PE) pipes exposed to chlorinated water have been carried out since at least the 1990s [22, 23], as disinfectants may accelerate the ageing of polyolefin pipes. This may lead to premature failures and shorten the service life. Thirty years later, papers are still being written about the complexity of service life predictions and the accelerated ageing of polyolefins in chlorinated disinfectants [24]. Risk factors that influence the longevity of PE pipe networks include water temperature (thus geographical zone) and the type of disinfectant [25]. It was necessary to update the standards to address concerns in the market about premature failure.

Both the EN 12201 and ISO 4427 series deal with water for human consumption (potable water). However, neither of these series have given any guidance on this complex matter so far. Although “RD grades” have been commercialised [26], the standardisation working group decided that the standards should not be revised to include another PE grade. The standards have instead been revised to include guidance on the influence of disinfectants on PE pressure pipes. This is based on the statement by TEPPFA and the PE100+ association that the life expectancy of PE pipes used to carry water with the most common chlorinated disinfectants still far exceeds 50 years [27].

The informative annex, which is currently under development for ISO 4427, emphasises that the vast majority of PE piping systems for water intended for human consumption are not subject to premature failure and a shortened service life. The subject of the annex is “secondary disinfection”, in which a disinfectant is added to the water in the distribution system to ensure that there is no potential risk of bacteriological growth. “Primary disinfection”, which is used during the initial processing of source water at water purification plants, is beyond the scope of the standard.

The annex describes the use and aggressiveness of common secondary disinfectants, including chloramines and chlorine (based on sodium or calcium hypochlorite, or chlorine gas), and the less common chlorine dioxide. Chlorine dioxide is less commonly used as a secondary disinfectant, and more commonly as a primary disinfectant.
While there is typically no cause for concern in the case of chloramines in PE piping systems, operational factors and risk mitigation should be considered for chlorine. The annex recommends that the pipe manufacturer should be contacted for more information about the effects of chlorine dioxide.

Operational factors mentioned as important considerations include:

- Low water pH. While PE is not sensitive to the pH level alone, the aggressiveness of the secondary disinfectant may be affected.
- High water temperatures. There is an exponential impact from secondary disinfection at higher temperatures.
- High pipe stress. If the pipe is subjected to a high internal pressure (and thus a high stress in the pipe wall), the disinfectant can attack the PE more easily.

PPI TN-44 is an important source of additional information about these operational factors [28].

Finally, the annex lists several risk mitigation steps. The type of disinfectant, dosage, pipe stress (pressure or SDR) and burial depth (for temperature) are important factors in reducing the risk of service life degradation.

CONCLUSIONS

The latest changes and improvements to the international and European product standards for PE piping systems for gas and water supply are essential to ensure that PE continues to be a sustainable choice by adapting to a changing environment.

ACKNOWLEDGMENTS

All the experts of ISO/TC 138/SC 2/WG 4, ISO/TC 138/SC 4/WG 3 and CEN/TC 155/WG 12 are highly appreciated for their expertise and contributions to the product standards for PE piping systems.

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