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100 YEARS LIFETIME OF POLYETHYLENE PIPES - A REVIEW

Lukas Travnicek
Montanuniversität Leoben
Leoben, Austria

Gerald Pinter
Montanuniversität Leoben
Leoben, Austria

Florian Arbeiter
Montanuniversität Leoben
Leoben, Austria

Peter Sejersen
TEPPFA
Brussels, Belgium

Ludo Debever
TEPPFA
Brussels, Belgium

Anders Andtbacka
GF Piping Systems
Vaasa, Finland

SHORT SUMMARY

This article summarizes the state of knowledge on the long-term performance and durability of polyethylene (PE) pipes based on decades of research and testing. Drawing on findings from the original meta-study **[1]**, it highlights the current understanding of PE pipe lifetime under pressure and non-pressure conditions, the methodologies used for prediction, and the implications for their reliable use in infrastructure over long time periods.

KEYWORDS

100 years lifetime, PE pipes

ABSTRACT

Polyethylene (PE) pipes are widely used for pressure and non-pressure applications in infrastructure, particularly in water and gas distribution systems, cable protection, and sewer installations. Over several decades, PE has gained a reputation for its exceptional durability, chemical resistance, and adaptability to various environmental conditions. The introduction of higher-performance material grades, such as bimodal PE100 and PE100-RC, has further advanced the long-term reliability of these systems. One of the most critical factors influencing the acceptance of PE piping systems is their expected service lifetime, especially when competing with traditional materials like metal or concrete.

This paper presents a focused summary of findings from a broader meta-study that analyzed more than 100 years of cumulative knowledge on plastic piping systems. Here, the attention is restricted solely to PE materials, with an emphasis on the technical basis behind long-term performance claims, typical testing methods, and observed behaviors in both pressure and non-pressure applications. Particular attention is given to the definitions and assumptions used in lifetime prediction, the validation of service life through laboratory and field data. The evidence supports that PE piping systems, especially those made from modern grades, can confidently meet or exceed a service life of 100 years under standard operating conditions.

INTRODUCTION

Polyethylene (PE) is one of the most commonly used polymer materials for plastic piping systems worldwide. Since its introduction into the piping sector in the 1950s, its widespread application has extended across numerous sectors, including drinking water, gas supply, sewerage, cable protection, and industrial pipelines. The material's success lies in its excellent combination of mechanical strength, chemical and environmental resistance, and ease of installation via welding techniques.

Over the past decades, technological progress has significantly improved PE's performance characteristics. Early generations of PE, such as PE63 and PE80, have been largely replaced by more advanced grades like bimodal PE100 and PE100-RC. These materials resist well against slow crack growth (SCG), oxidative degradation, and mechanical stress. Today, the use of PE100-RC enables installation methods with reduced trench preparation or sand bedding, further increasing economic and environmental benefits.

One of the most relevant and often debated topics in the field of polymer piping systems is their actual expected lifetime. A safe and predictable service life is crucial for infrastructure planning, economic justification, and sustainability considerations. Based on the current standards, the design life of PE pipes in pressure applications is 50 years at 20°C. However, due to conservative testing conditions, the actual lifetime of PE pipes is expected to be much higher. The often-discussed milestone is 100 years.

This article aims to consolidate and present current knowledge regarding the expected lifetime of PE pipes in both pressure and non-pressure applications for conveying potable water, natural gas, sewage, and drainage. The assessment assumes typical operating conditions with pipe wall temperatures not exceeding 20 °C and that the pipes were manufactured, installed, and operated in accordance with relevant standards, such as EN, ISO, or ASTM. Applications designed for transporting aggressive industrial media or for carrying heated fluids—such as those used in underfloor heating—are excluded from article.

NOMENCLATURE

OIT	Oxidation induction time
PE	Polyethylene
PVC	Polyvinylchloride
SCG	Slow crack growth
SDR	Standard dimension ration
C	Compliance
C_{min}	Minimum design coefficient
t	time
$p_{int, max}$	Maximal internal pressure
σ_{LPL}	Lower prediction limit of stress

LIFETIME DEFINITION AND ITS EXPECTANCY

The different parts in a supply chain uses different terminology regarding pipes' lifetime – design life, service life and lifetime. Therefore, it is necessary to state the meaning of these terms first:

- **Design life:** The design life of a plastic pipe is the time during which it is expected to function by its producer, as long as the application conditions meet the specified boundary conditions.
- **Service life:** The service life is the time defined by maintenance operators. The end of service life can be either a failure or an operator's decision. Based on these two possibilities, the actual service life can be both longer, or shorter than the design life, as shown in Figure 1 below.
- **Lifetime:** The actual lifetime is the time for which a pipe operates until the pipe's failure. This time can vary significantly based on the actual boundary conditions, e.g. the installation and operational conditions. For example, in the case that a pipe is operated at a lower pressure, or temperature than specified in standards, the intrinsic lifetime of the pipe before failure can be much longer than the design life. If the lifetime is known to be longer than the design life, it would also be possible for operators to safely increase the service life, thus improving the overall performance of plastic pipes.

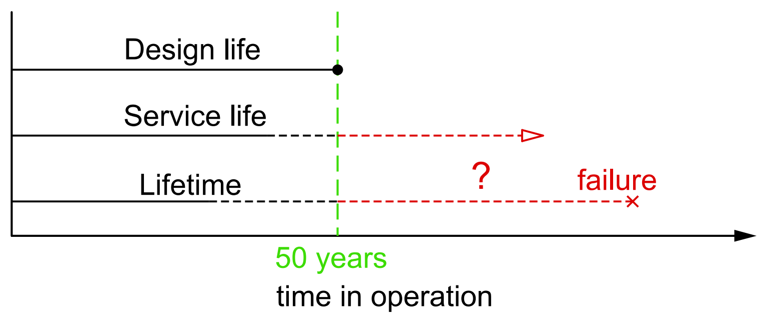

Fig. 1: Graphical representation of the terms of design time, service time, and lifetime.

Generally, the maximum design life for a plastic pipe is always stated as 50 years at a certain temperature and stress level in the pipe wall. However, if the manufacturing and operating conditions are in accordance with standards, the lifetime of a plastic pipe is expected to exceed the design life of 50 years due to several beneficial reasons stated below [2; 3]:

- Lower ground temperature than 20°C in 1 m depth underground
  - In the UK (Halesowen, West Midlands), between 6 and 15°C [4]
  - In the Czech Republic (Northern Moravia region), between 0.5 and 17°C [5]
  - In Germany (Potsdam), between 2 and 19°C [6]
- Lower temperature of sewage water in operation compared to standards (for non-pressure pipes)
  - According to measurements performed in different places in Austria and Germany, the average temperature of sewage water during the day measured outside of buildings was 25°C, with the maximum staying below 30°C [7]. The design standard considers 45°C (for diameter ≤ DN 200) or 35°C (for diameter > DN 200) [8].
- Tolerances for wall thicknesses are always 0+ tolerance range [9].
- Design coefficient used in the design
  - Minimum design coefficient for PE80 and PE100 is for water (C_{min} = 1.25) and gas (C_{min} = 2) [10].

- Lower internal stress level in pipes in operating conditions than in the design (for pressure pipes only)
    - $p_{int,\,max}$ = 7 bar in Czechia for water [11]
    - $p_{int,\,max}$ = 0.05 bar in Czechia for gas (in low-pressure systems) [12]
    - $p_{int,\,max}$ = 0.1 bar in the Netherlands for gas [13].

PRESSURE PIPES APPLICATIONS

The 50-year design basis and minimum expected lifetime for pressure water or gas pipe systems is secured by the hydrostatic pressure tests carried out at different temperatures defined by ISO 1167-1 [14] and ISO 1167-2 [15] with the following extrapolation of the results in accordance with ISO 9080 [16]. The extrapolation method defined in ISO 9080 provides an estimation of the 97.5% lower prediction limit of the stress (σ_{LPL}), which a thermoplastic pipe is able to withstand for 50 years at 20°C. The estimated σ_{LPL} is then used to determine the minimum required strength (MRS) for thermoplastic pipe material in accordance with ISO 12162 [10], where a classification and designation system is established.

Even though the design life is 50 years, in several standards (e.g. [17; 18; 19]) it is already noted that "Research on long-term performance prediction of existing PVC and PE water and gas distribution systems shows a possible service life of at least 100 years".

A number of experimental studies have been conducted on exhumed PE pipes to examine the premise that material degradation is neither occurring nor affecting mechanical properties and, thus, the potential service life. The often-used method to predict the residual lifetime of a pipe, which has been in use for decades, is the above-described hydrostatic pressure test. It characterizes well the material resistance against stress cracking and can be adjusted to the specific stress level in which the tested pipe was used. Other methods that can be used are based on the fracture mechanical description of a propagating crack in a specific material in combination with finite element simulations of crack propagations. On the other hand, the oxidative induced time (OIT) is often used to characterize the resistance against thermal oxidation and together with the Arrhenius law, it is used to predict the time until the stabilizers are used up, which according to several authors represents a conservative lifetime estimation. These methods have been applied in several dig-out studies that are described further in detail.

In 2001, Schulte [3] showed experimental results of hydrostatic pressure tests and creep tests of two types of HDPE - Hostalen GM 5010 T3 black (PE80 class) and Hostalen CRP 100 (PE100 class). Based on these results, it was concluded that the high-quality plastic pipe materials available on the market have a reliable service life of more than 100 years. Reasons were given for very conservative conditions in pipeline design compared to actual operating conditions - much higher internal pressure, use of safety coefficients in the design, and lower environmental influence (pipes are usually buried and therefore better protected).

In 2006, Schulte and Hessel [20] investigated HDPE (Hostalen GM5010) pipes (SDR = 11) that were installed in 1961 in Frankfurt and were transporting water until 2002. The operating conditions were: internal pressure 4.5 bar and a temperature of 20°C. No evidence of thermal aging was found in the studied pipes. Hydrostatic pressure tests were performed at different temperatures. Based on the obtained results, a remaining service life of 124 years was predicted at an operating pressure of 4.5 bar (without considering thermal aging). The thermal aging process was then described by the Arrhenius equation.

It was estimated that thermal aging would not occur for at least another 27 years, reaching a total lifetime of the pipes of at least 68 years.

In 2007, Hessel [21] estimated that the time until all thermal stabilizers in PE100 material are consumed based on thermal aging measurements performed at higher temperatures is more than 460 years. Therefore, the minimum lifetime for PE100 pipes can safely exceed 100 years at 20°C.

In 2009, Frank [22] investigated four different PE pipes that were transporting gas and water for up to 30 years. The molecular analysis did not show any significant polymer degradation as an indication of the aging of the materials. Moreover, the thermomechanical behavior delivered comparable values to the reference materials. The absence of post-crystallization on the outer pipe wall and a still existing typical amount of residual stresses showed that the mechanical material properties had been almost unaffected. Distinct OIT values and clearly detectable amounts of stabilizers in the pipes ensured sufficient stability for a continuation of service. Fracture mechanics investigations showed a decrease in failure times with pipe age, see Figure 2. Extrapolating creep crack growth through fatigue tests predicted sufficient stability for both pipes to remain in good order for 50 years despite not considering crack initiation times in the estimations.

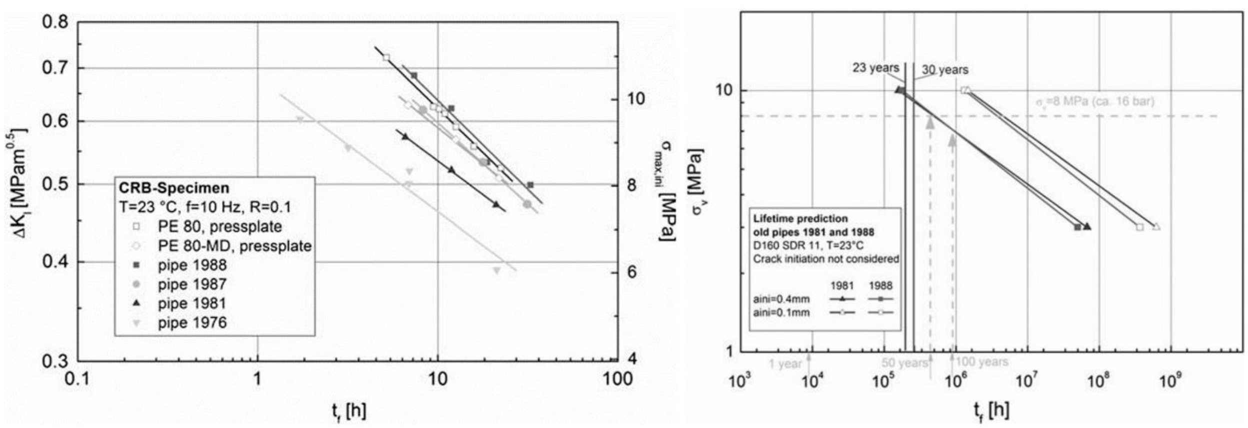

Fig. 2: Results of fatigue measurements (left) and estimated lifetime for studied pipe (right) [22].

NON-PRESSURE PIPES APPLICATIONS

Regarding drainage and sewage non-pressure PE pipes, the design lifetime is not directly specified in the standards [23; 24]. The standards define mechanical, physical, chemical, and other properties that the material and pipes should possess and experimental measurements that the material and pipes should pass in order to guarantee safe operation. Examples of such requirements are:

- Hydrostatic pressure test must pass 4 MPa for 165 h at 80°C or 2.8 MPa for 1000 h at 80°C
- Thermal stability test (OIT) for PE must be longer than 20 min at 200°C
- Pipe deflection limits of 9% after installation
- Ring-flexibility test up to 30% deflection

The dominant loading that non-pressure pipes are exposed to is caused by the weight of soil and traffic. Contrary to the pressurized pipes, non-pressure buried pipes are thus loaded in a 'constant strain' mode after the soil has settled. In practical terms it means that after the installation and a few years of operation, the soil in the trench settles, which results in a constant pipe deflection and constant strain in the pipe wall. Therefore, the limits of initial and long-term average pipe deflection and acceptable strain are specified in more detail in CEN/TS 15223 standard [25]. The pipe deflection is also dependent on the level of soil compaction. However, it was predicted in a TEPPFA study [7] that the limit of 8% deflection is not reached even after 100 years.

Due to the visco-elastic nature of plastic materials, the induced stress in the pipe wall is the highest at the beginning and decreases (relaxes) with time in use. Therefore, for a short period of time, the stress may be higher than the pipe was tested on, but it quickly decreases below the allowed limit. When investigating a pipe that has been used for decades, the crucial properties are resistance against chemicals and detergents that could harm the pipe's surface and accelerate the crack formation and the pipe's stiffness, that ensures the pipe's stability over time. These and other properties that have been studied by different researchers are described in detail further.

In 1991 [26] and later in 1995 [27], Janson summarized the results from his previous work on PE non-pressure pipes in his report. Several different pipe samples were exposed to constant deflection at 23°C for the stress relaxation measurement. The force that was needed to keep the pipe samples deflected was measured for over 5 years.

After the first 1000 h, a prediction of a level of stress presented in the PE pipe samples after 50 years had been made, based on the calculated compliance (C), which has a rectilinear course in the lin C vs. log t plot after some time. The same prediction was repeated after 5 years of measurements. The comparison of both predictions showed only a slight difference. It was further observed on these PE pipe samples, which have been kept constantly deflected, that after release, the E-modulus and pipe ring stiffness values were equal to or larger than the original short-term values. This increase was assumed to be due to the physical aging process taking place in the pipe material.

In addition, it was found that the short-term bending stresses (measured after 3 min.) in the PE pipe wall will relax to approximately 30 % of the original value after 50-100 years of constant bending strain caused by pipe deflection. Based on the predictions of the long-term properties, it was concluded that the service period for standardized gravity thermoplastics sewer pipes can certainly be 100 years or more if properly installed.

In 1996, Janson [28] studied PE pipes and their materials from several different perspectives: the pipes' mechanical stability, materials' long-term strength, materials' resistance against chemical and biological breakdown, and overall functional stability – focusing on the possibility of exceeding 100 years lifetime. Regarding the pipes' mechanical stability, it was concluded that the pipes' deflection would never exceed more than 15% within 100 years for pipes of stiffness class SN4 and higher for pipes that have been installed in a regular way. For worse burying conditions (e.g., loose or inhomogeneous, not well-packed clay), a higher stiffness class of 8 or 16 kPa should be considered. This means that the creep does not become critical within the 100-year period. The long-term material strength is secured if the bending strain is constant (the stress relaxation exists) and the pipe's material stabilization system is intact. Then, for normal operating temperatures up to 20°C, the pipe will function for at least 100 years. Chemicals and detergents that are present in sewer water do not harm the integrity of the pipe material and system due to the intrinsic property of the polymers and due to the stabilizers ensuring chemical stability safely for 100 years. Regarding the biological breakdown, it was stated that using plastic pipes for 50 years in favorable environments for bacteriological growth did not show any development of cultures that break down plastics. Thus, the safe operation can be assumed for a lifetime of 100 years. The final conclusion was that everything points towards at least 100 years of service life for buried sewer pipes made of today's high-quality virgin PE resins if the pipes are installed and used in accordance with the standards.

In 2005, Husan and McGrath [29] reported a Protocol for Predicting the Long-term Service of Corrugated HDPE Pipes. The data was later partially presented by Pluimer [30]. This study was initiated to determine requirements for assuring that corrugated HDPE pipe will provide a 100-year service life. It was demonstrated that tensile stresses are relatively low when pipe installation meets typical requirements and maintains changes in vertical diameter to less than 5%. Long-term tensile strain for the service condition should be less than 2.5%, corresponding to a long-term stress of approximately 3.4 MPa with an applied safety factor of 1.5. The general recommendation for the minimum depth of fill is larger than 0.6 m or one-half of the pipe diameter. Additionally, four long-term material properties of HDPE corrugated pipes were investigated, including stress cracking resistance of the pipe, antioxidant lifetime of the pipe, long-term tensile strength, and long-term flexural modulus. For each property, a set of tests at different temperatures and/or stresses shall be performed so that the 100-year behavior of the pipe at a site temperature of 23°C can be extrapolated and determined with confidence.

In 2016, Meijering [7] published a comprehensive technical report focused on 100-year service life of PE gravity sewer pipes. The results were partially summarized in 2014 in a conference paper [31]. It was concluded that using qualified polyolefin materials and pipes that are well extruded and installed according to good workmanship practice and standards, the test results of the 2 excavated PE pipes have shown that PE pipes are well qualified to reach a 100-year lifetime. Even for the first-generation PE (studied after 38 years in use) no significant reduction of hydrostatic pressure tests (see Figure 3), mechanical properties and stabilization was shown.

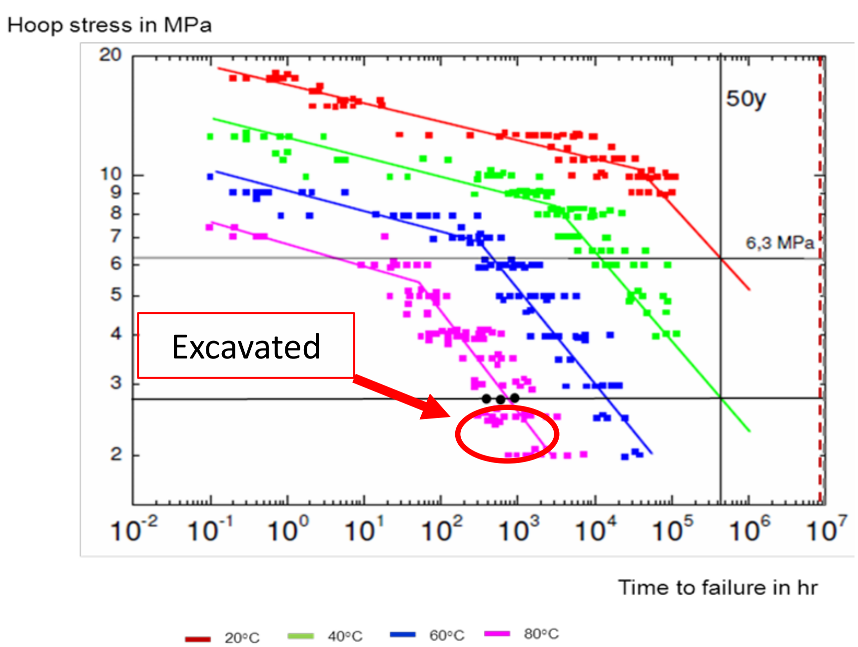

Fig. 3: Hydrostatic pressure test results from 1st generation HDPE pipe resins and 3 actual results from excavated pipes (black dots at 2.8 MPa) [7].

CONCLUSIONS

Research studies on pressurized PE pipes indicate that they are proven to fulfil a design life of 50 years.

Studies on different PE materials and PE pipes made of PE63, PE80 and PE100 operating for up to 47 years revealed great performance of the pipes. The available research considered stress cracking, as well as material aging. The predicted lifetimes based on both damage mechanisms were far beyond the design life of 50 years, even under the consideration of the impact of potential defects or the presence of residual stresses.

Contrary to pressurized plastic pipes, for non-pressure pipes there are no tests in place defining design life. The standards only define mechanical, physical, chemical, and other properties that the material and pipes should have and experimental measurements that the material and pipes should pass.

In non-pressure pipes, the dominant loading is caused by the weight of the soil. Therefore, the burying conditions are essential to secure safe long-term operation. Bad burying conditions (e.g., loose or inhomogeneous, not well-packed clay) may result in higher pipe deflection and greater susceptibility to creep damage. Based on the reviewed studies, the substances (chemicals and detergents) presented in sewer water seem harmless to pipe materials due to the stabilizers ensuring chemical stability safety for more than 100 years. Additionally, excavated pipes operating for up to 38 years showed no reduction in mechanical properties.

The study of published PE pipe research focused on both pressure and non-pressure pipes concludes that correctly installed and operated PE pipes put on the market today will have a service life exceeding 100 years.

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