POSITION PAPER

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100 years lifetime of PVC-U and PVC-Hi pressure pipe systems buried in the ground for water and natural gas supply

1. Introduction

TEPPFA and PVC4Pipes have identified the need for explaining the difference between the design point at 20 degree/50 years and the expected life time of PVC-U and PVC-Hi pressure pipe systems. Research, extrapolation studies and studies of dug-up pipes in service for years, show minimal degradation and extrapolative tests performed on these test samples confirm an expected service life in excess of 100 years.

2. Design vs. service life

Design basis must not be confused with the actual life time of a plastic pipe system. In real life, the service life is expected to be more than 100 years due to a number of reasons,

- Lower real pressure level (stress) over the whole lifetime
- Lower real temperatures in the ground
- Tolerances for wall thicknesses are always in the zero to “plus” tolerance range
- In the design stage a safety factor is applied

3. Design basis of PVC pressure pipe systems

The 50 year design basis and minimum service life for a PVC pressure water or gas pipe systems is secured through the established standards ISO 9080[1] and ISO12162[2]. ISO 9080 provides an extrapolation method to estimate the 97.5% lower prediction limit of the stress (σ_{LPL}) which a thermoplastic pipe is able to

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withstand for 50 years at 20°C. Extrapolation is made from data obtained through hydrostatic pressure tests carried out at different temperatures in accordance with ISO 1167-1[3] and ISO 1167-2[4]. ISO 12162 establishes a classification and designation system for thermoplastic pipes, based on their minimum required strength (MRS) derived from their σ_{LPL}.
A PVC-U pipe with 25 MPa $\leq \sigma_{LPL} < 28$ MPa has an MRS of 25 MPa and is designated as PVC-U 250. ISO 12162 also specifies a method for calculating the design stress σ_S from the MRS and a design coefficient C (σ_S=MRS/C). Unless otherwise specified in a specific product standard, a minimum design coefficient (C_{min}=1.6 for PVC-U, C_{min}=1.4 for PVC-Hi) is used.

The product standard ISO 1452[5] specifies the specific requirements for a solid wall PVC-U piping system and its components intended for the supply of water under pressure, as well as for waste water under pressure. ISO 1452-1 sets general requirements for the PVC-U compounds used in these systems. Whatever its composition, a compound needs to reach a σ_{LPL} corresponding to a MRS of 25 MPa for all pipes and fittings. An MRS of 20 MPa is allowed for some injection moulded fittings. If long-term experience is available with a compound known to have an MRS of 25 MPa, a streamlined testing scheme to verify compliance can be used.

PVC-U has been in practical use for water systems for more than 80 years and monitored closely ever since by the water utilities for performance, reliability and maintenance management. ISO 1452-1 recognizes in its paragraph 3.1.5.1., that “research on long-term performance prediction of existing PVC water distribution systems shows possible service life of at least 100 years”.

PVC has been the preferred material for low pressure (30 and 100 mbar) gas distribution systems in European countries such as the Netherlands for more than 60 years. PVC-U has been used up till the 1970’s and has been progressively replaced by PVC-Hi since this time as it was thought that PVC-U could not be able to keep a high impact resistance needed in case of third party interference. The product standard ISO 6993-16 specifies the specific requirements for a PVC-Hi piping system used for the supply of natural gas. The PVC-Hi compound should contain at least 7%w of impact modifier and, whatever the remaining composition of the compound, the extruded material needs to reach a □LPL corresponding to an MRS of 18 MPa as determined by ISO 9080.

4. Dig-up studies proving a 100+ year service life

The first PVC pipes were manufactured in 1934 in the Bitterfeld-Wolfen chemical area (Germany). These pipes were used for different applications such as potable water pipes, transparent food contact pipes (brewery applications) as well as industrial pipes (chemical laboratory and plant applications).7 The first large scale installation of PVC pipes took place in 1936 in Germany, for drinking water distribution and gravity drainage systems in various residential areas (among them, the Berlin Olympic Village); most of these pipes are still in service today. Many PVC pipe systems have already far exceeded the end of the specified service life of 50 years, without any indication in the statistics maintained by the utilities of any ageing-related failures.

This is confirmed by many dig-up reports reporting the mechanical performances of PVC-U and PVC-Hi pressure pipes installed by contractors at a variety of locations and in continuous service for decades.

In 1985, Lancashire [8] studied PVC-U water pipes exhumed after 4 to 16 years' service in the UK, and concluded that ageing was not a significant factor influencing the performance of the pipes. Stress regression tests showed that all pipes would be expected to exceed a 100 year life under normal operating conditions.

In 1996, Alferink et al.[9] tested PVC-U pressure pipes exhumed from the Dutch water network ranging up to 37 years of age. From 19 pipe samples, it was concluded that there was virtually no change in the mechanical properties of the pipes due to ageing. They concluded that old PVC-U water pressure pipes still fulfill the most important functional requirements.

In 2001, Stahmer et al.[10] reported mechanical tests done following Australian standards on water pipes exhumed after 25 years of operation in a variety of terrains and installation conditions in Australia. As the results were the same as expected for contemporary pipes tested at the time of manufacture, no degradation in strength or elongation at break of the PVC-U material could be observed. The long-term performance of the system has been clearly dependent upon the initial pipe quality, handling and installation.

In 2004, Hülsmann et al.[11] reported tests on some of the first PVC-U water pipes installed in Germany. One set of tests examined 24 pipe specimens exhumed after 23 and 53 years' service. From long term hydrostatic pressure testing at 60°C, they concluded that another 100 years of safe operation could be expected under realistic conditions at 4-5 bar water pressure.

In 2005, Boersma et al.[12] examined the chemical and physical ageing of PVC-U water pipes. They concluded that that chemical and physical ageing at 15°C have no significant influence on the quality of PVC-U water distribution pipes. Chemical ageing can be neglected as pipes contained enough unreacted stabilizer. The measured yield strength of pipes in service up to 30 years did not show any change with pipe age. They also tested PVC-U pipes for stress regression, slow crack growth, and fatigue and concluded that the service life of the PVC-U pressure pipes produced with the quality control procedures typically used in Europe, should exceed 100 years. The physical ageing in well-gelled pipes leads to marginal decrease in slow crack growth resistance.

In 2005, Burns et al.[13] reviewed methods to analyze the expected life of PVC-U water pipes. Fracture mechanics-based models were produced to predict the conditions under which pipe failure will occur in service. These models were calibrated against failure rates recorded in a number of North American and Australian utilities. They concluded that 100 years is a conservative estimate for a properly designed and installed pipe.

In 2006, Breen[14] studied five excavated water pipe specimens in operation for periods ranging from 6 to 42 years. He performed chemical and physical ageing tests on the PVC-U along with tensile, burst test, slow crack growth, impact test, and fatigue measurements. He concluded that the existing PVC-U tap water pipe systems in the Netherlands will operate for at least 100 years provided that the internal and external loads do not result in hoop stresses which will exceed 12.5 MPa and that no micro-crack and mechanical damages are present in the PVC-U pipes.

In 2008, Hermkens et al.[15] summarized the findings of tests done on PVC-U gas pipes excavated after up to 50 years of service from the Dutch gas grid. Impact tests show no significant decrease in impact resistance with respect to time of service. The impact resistance of the PVC-U pipes which have been in use for many years have been shown to be mainly dependent on the initial quality fixed during the production of the pipe.

In 2014, Folkman[16] reported on quality control tests on 8 PVC-U water pipes that had been in continuous service between 20 and 49 years. The standardized tests included pipe dimensions, acetone immersion, burst pressure and hydrostatic integrity tests. Samples of the pipe having been successfully tested after 49 years' service had already passed all the quality control tests after 22 years' service. This has demonstrated the intact ability of this quality pressure PVC-U pipe to perform its intended purpose after a half century.

In 2016, Weller et al. [17] summarized the results obtained with an improved impact test on 103 PVC-U and PVC-Hi gas pipes excavated after up to 50 years of service from the Dutch gas grid. The PVC-Hi pipes installed after 1973 were found to have on average a better resistance to impact than the very first PVC-U pipes installed in the 1960's. However, it was concluded that the better produced PVC-U pipes installed in the early 1970's had an impact resistance at least as good as an average PVC-Hi pipe.

While similar PVC resins are used in all the pressure pipes tested above (K-value in the 66-68 range, similar polydispersity), stabiliser packages differ depending on the region. The above consistent results obtained across all regions, demonstrate that a reliable service in excess of 100 years can be obtained whatever the stabilizer used. The overriding factors influencing the long term performances are the initial pipe quality and the quality of the pipe handling and installation procedures. Ensuring an optimum gelation level is the most important initial pipe quality factor to ensure an optimal balance of mechanical performances on the long term. The gelation level can be qualitatively evaluated by the Dichloromethane Test (ISO 985218) or by the indirect quantitative DSC methods (ISO18373-119 and ISO18373-220).

Literature references

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About TEPPFA

TEPPFA is founded in 1991 in Brussels and is the trade association for the plastic pipe and fitting industry in Europe. Via direct members and National Associations, we are representing more than 400 manufacturers of plastic pipe systems and also have resin manufacturers as members. More at: www.teppfa.eu.

About PVC4Pipes

PVC4Pipes is the ECVM's value chain platform created to promote the acceptance and utilisation of PVC in pipe systems through technical projects, appropriate standardization, regulatory and communication activities. Our partners come from all across the value chain. This includes the raw materials – PVC resin and additives – manufacturers and those which manufacture the wide array of PVC pipes and fittings available in today's market, as well as technology institutes and trade associations. www.pvc4pipes.com.