# The biggest threat for PVC pipes

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## Highlights

- Extensive testing on 8 exhumed PVC gravity sewer pipes with known defects is conducted.
- The major causes of PVC pipe failure are investigated and discussed.

## Introduction

Over the past decades, Polyvinyl Chloride (PVC) has become the dominant construction material for sewer gravity pipes, as well as for drinking water and gas distribution networks. This fact has led to numerous studies concerning the structural integrity and chemical resistance of PVC piping systems. Relevant research on exhumed gravity PVC sewer pipes suggests that there are no signs of impoverished physical or mechanical properties (Bauer, 1990; Alferink et al. 1995; Whittle and Tennakoon, 2005; Folkman, 2014). Furthermore, testing of chemicals usually found in sewers (i.e. $H_2SO_4$, $Na_2SO_4$, NaOH, NaClO-$Cl_2$, $ClO_2$) on PVC pipes has led to the conclusion that no significant chemical alterations in PVC composition are imposed (Bishop, 1990; Hawkins and Mass, 1994; Fumire 2008; Lasfar et al., 2014). However, inspection data from three different municipalities in The Netherlands (Almere, Amstelveen and Breda) indicate that all kinds of known defects already exist, and they even evolve in a relatively fast pace (Makris et al., 2020).

The present study aims at exploring this discrepancy between scientific research and observations in practice, by discussing the durability of eight exhumed PVC sewer pipes with known defects, which were subjected to numerous tests and analyses. The results of such comprehensive testing offer the opportunity to conclude on potential degradation and the overall performance of the examined pipes, laying the basis for establishing sewer asset management strategies.

## Methodology

**Pipe samples**

Eight operating PVC pipes were exhumed in cooperation with the municipalities of Almere and Breda, after investigation of relevant inspection data. The pipes were selected based on the year of installation, the existing defect and the feasibility of excavation. A brand-new PVC pipe was also included in the study to serve as a reference sample. The main characteristics of the tested pipes are presented in Table 1.

**Table 1.** Characteristics of PVC pipes used for analyses

| Sample | Installation year | Excavation year | DN | Embedded Core | Native Soil | Surface | Defect |
|---|---|---|---|---|---|---|---|
| Pipe 1 | 1976 | 2019 | 250 | - | Clay | Paved path | Crack at the connection |
| Pipe 2 | 1977 | 2018 | 250 | - | Sand | Paved street | Root intrusion |
| Pipe 3 | 1977 | 2019 | 250 | - | Clay | Paved street | Deformed at crown |
| Pipe 4 | 1978 | 2019 | 250 | Void | Clay | Paved path | Pointy break at side |
| Pipe 5 | 1979 | 2018 | 250 | - | Sand | Paved street | Break |
| Pipe 6 | 1980 | 2019 | 250 | Void | Clay | Paved street | Crack at bottom |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pipe 7 | 1995 | 2018 | 200 | Recycled | Sand | Paved street | Complicated crack |
| Pipe 8 | 2002 | 2018 | 160 | Foamed | Sand | Soil | Root intrusion |
| Reference Pipe | - | - | 250 | - | - | - | - |

**Analyses**

Specimens milled out of the exhumed pipes were subjected to extensive testing in order to gain insight in the main physical, chemical and mechanical properties. Table 2 provides an overview of the conducted analyses and the respective obtained information.

**Table 2.** Conducted tests on PVC pipes to identify degradation

| Testing method/property | Target |
|---|---|
| Density | Identification of crystallization |
| Intrinsic Viscosity | Characterization of molecular structure |
| Differential Scanning Calorimetry | Determination of glass and melting temperature, and level of gelation |
| Thermo-Gravimetric Analysis | Determination of characteristic decomposition temperature and rate |
| Fourier Transform Infrared Spectroscopy | Detection of changes in carbonyl and hydroxyl functional groups |
| Wavelength Dispersive X-ray Fluorescence | Identification of elemental composition (stabilizers, fillers, pigments) |
| Scanning Electron Microscopy with EDX | Microstructural analysis |
| Tensile tests | Determination of ultimate tensile stress, E-modulus, and elongation at break |
| Flexural tests | Determination of ultimate flexural stress and flexural modulus |

## Results and discussion

Comprehensive testing over the pipes highlighted which properties have actually been affected and to what extent. Focus is given in this section on results from mechanical testing, since they incorporate all types of present degradation, as well as production and installation quality (e.g. inherent defects or scratches). Tensile tests (Figure 2, left) indicated high variability among different pipes. Comparing single layer PVC pipes (Pipes 2 & 5) with the reference pipe, a translation was observed towards values of higher ultimate stress, higher E-modulus and lower strain at break. Nonetheless, elongations at break remained high. Regarding Pipe 7, with a recycled core, the average ultimate tensile stress was in proximity to the reference pipe although break occurred earlier. Pipe 8, incorporating a foamed core, showed the lowest values of ultimate stress and strain at break. Flexural testing revealed that the same pattern as in tensile testing exists for single layer pipes, with older pipes demonstrating higher values of ultimate flexural strength and flexural modulus. However, high variability was noticed in some cases among samples coming from the same pipe, especially in Pipe 2 (Figure 1, right).

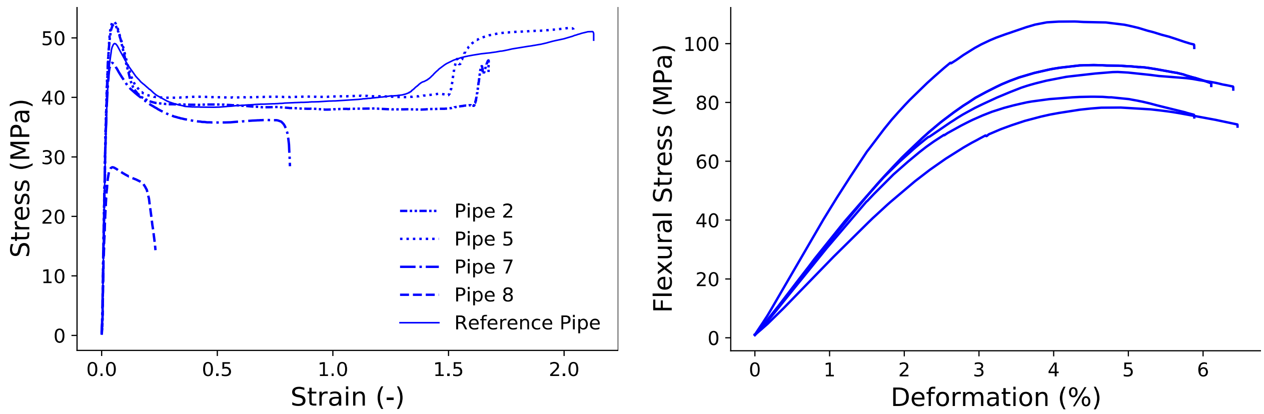


**Figure 1**. Stress – Strain curves derived by uniaxial tensile testing on one indicative specimen from: Pipe 2 (41 years), Pipe 5 (39 years), Pipe 7 (23 years, Recycled core), Pipe 8 (16 years, Foamed core), and Reference Pipe (left). Flexural Stress – Deformation curves derived by repeated 4-point flexural testing on five different specimens from Pipe 2 (right).

Figure 2 presents the in-situ images of the existing defects for Pipe 4 (left), Pipe 5 (middle), and Pipe 7 (right). Observation during excavation and visual examination of these pipes signify that the sources of the defects are clearly connected to human activity.

**Figure 2.** In-situ footage after excavation of Pipe 4 (left) and Pipe 5 (middle) with break due to 3rd party impact, and Pipe 7 (right) with crack due to poor installation quality.

## Conclusions & Future Work

Exhumation and testing of 8 PVC sewer pipes (17-43 service years) with known defects revealed factors that affect the pipe's operational lifetime. The main findings can be summarized in the following points:

- Alterations in properties among pipes originated from different production procedures, rather than a modified molecular structure or chain scission.
- Physical ageing was the most profound mechanism, resulting in high levels of brittleness and raising potential issues regarding the integrity of the pipe (e.g. during placement of new connections).
- Although it is currently a standard practice to use plastic non-pressurized pipes with a recycled or foamed core, under certain conditions such a core could lead to premature failures.
- The common cause of failure for most of the examined pipes stemmed from human activities in the surroundings of the pipe and/or poor installation quality.

Therefore, it is inadequate to develop sewer asset management strategies based only on the age of the pipe and the pipe material properties. The findings dictate the establishment of detailed protocols for handling and construction, close supervision during construction and measures against third party impacts.

Relevant future work includes the development of a vibro-acoustic method, which can be utilized for quantification of the ageing levels in plastic pipes.

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