Investigation of PVC Pipe Performance and Mechanical Property Deterioration

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Abstract

Polyvinyl Chloride (PVC) pipes have become a major part of the water network and distribution systems throughout the world, primarily attributed to their inexpensive manufacturing, light weight and inert nature. Currently, 39% of the Water Corporation's 52,000 km of freshwater/wastewater pipes are made from PVC, with this percentage expected to further increase. However, the Corporation has experienced an increasing number of unexpected PVC pipe failures, raising concerns regarding the performance and suitability of PVC. The objective of this project is to alleviate the concerns through a development of a knowledge base of PVC pipe performance, so as to be able to effectively assess the condition of PVC pipes in-service. A data analysis is performed to determine the performance trends of PVC pipes at the Corporation and to identify any underlying causes of failure. The data indicated that there is no single underlying failur mode, but it reaffirmed the increasing frequency in failures. In addition to the data analysis, mechanical testing is performed to determine the changes in material property due to certain factors – age, temperature and the presence of notches.

1. Introduction

The capacity to effectively assess the condition of pipes in-service is essential to the Water Corporation's stated purpose 'to provide sustainable management of water services to make Western Australia a great place to live and invest'. The consequences of pipe failures are not only an economic burden to both the consumers and the supplier (the Corporation), but also include significant social and environmental impacts. An unexpected failure may cause damage to the surrounding environment and put people's safety at risk (Gould et al. 2013). Secondly, the resulting loss of water creates an inefficient network system and unwanted disruptions to water supply. The loss of water is ever more significant due to the drying environment and results in large intangible costs for the Corporation through customer dissatisfaction and unplanned disruptions to the network.

The Corporation installs and operates many pipe materials, the most recently adopted being PVC. Ever since the Corporation started extensively using PVC in its network in 1985, the material has performed relatively well. Currently, it makes up 26% of fresh water pipes and 67% of wastewater pipes in WA, totalling over 20,200 km. PVC pipes are considered to be light-weight, cheap to manufacture, corrosion resistant and flexible (Carroll, 1984). With the Corporation's continual laying of new PVC pipe and expected future installations, it is imperative to develop an applicable knowledge base of PVC pipe performance and behaviour to support effective condition assessments for both existing and newly installed pipes.

The current school of thought regarding the service life of well processed and correctly installed PVC pipes is that they should last over 50 years (TNO, 2008). Due to PVC being a relatively new material in pipe application, there has not been sufficient time to critically analyse the lifetime performance of PVC pipe. In addition, PVC pipe continues to experience advancements in manufacturing quality, translating to improved performance characteristics since its initial installation by the Corporation. This is attributed to the industry's collective desire to better understand PVC material in pipe applications.

Adding to the complexity of the issue, the pipe failures can arise from a combination of different factors which have varying levels of impact in different situations. It is crucial that the Corporation perform its own studies, as external investigations and research are not sufficiently applicable to the exact environment of the Corporation. Following the completion of the project, it is expected that the developed knowledge base will enable the implementation of a condition assessment model that explicitly addresses PVC pipes used by the Corporation. This project marks the transition from a reactive approach to a proactive approach in handling PVC pipes in-service, and will largely benefit the Corporation.

1.1 Background Information

The PVC material used in liquid pipe application is unplasticised PVC, otherwise known as rigid PVC. Currently at the Corporation, there are two types of rigid PVC material used, as described in Table 1.

Title	Full Name	Application and Description
PVC-U	Unplasticised PVC	Original pipe type, formerly installed by the Corporation. The first type of unplasticised PVC, considered as the 'older' form of PVC.
PVC-M	Modified PVC	Incorporates an impact modifier that improves the fracture toughness and ductility. PVC-M pipe is currently installed by the Corporation, considered as the 'newer' form of PVC.

Table 1 PVC Pipe Types used by the Corporation

Although the Corporation do not presently install new PVC-U pipelines, the project focuses on the current situation at the Corporation. The exact proportion of PVC-U versus PVC-M presently in the network is unknown, consequently the project focuses on both PVC pipe types. Furthermore, PVC pipes are used to transport different water qualities, and through different pressurisation modes, as summarised in Table 2.

Water Type	Pressurised Flow	Non-pressurised Flow
Freshwater	100 %	0 %
Wastewater	9.7 %	90.3 %

Table 2 PVC Pipe Application Types at the Corporation

2. Methodology

The research program is split chronologically into two main tasks:

Task	Objectives
Data Analysis	- Understand the relative usage and current situation of PVC pipe - Identify any trends in failures or causes of failures
Laboratory Tests	- Investigate the change in mechanical properties due to different factors

Table 3 Main Sub tasks and Objectives of the Project

The findings from the data analysis have helped shape the laboratory tests, through the identification of failure trends and aspects of PVC properties that require further examination.

2.1 Data Collection and Analysis

The data was collected by performing different searches within the Corporation's database. All datasets were filtered and amalgamated to ensure the resulting collated data could be analysed and compared. The analysis performed on the datasets were at times restricted due to the availability or inconsistency in information. For example, the analysis of Failure Rate versus Age can only be performed locally. This is because failure information is taken from work orders, which do not provide the age of the pipes. The GIS (Geographic Information Systems) team have been able to source this information, but only for freshwater pipe work orders collected since 2005. Important information regarding the collected data such as that described above were fully considered when performing the analysis.

The first objective of the data analysis task mentioned in Table 3 provides the Corporation a clearer understanding on their usage and operation of PVC. Firstly, PVC pipe was compared to other materials, through looking at the amount of each material being laid yearly and the proportions of each material contributing to the network. Thereafter, a further analysis of PVC was performed, by investigating the length in operation versus parameters such as region of operation, pipe diameter and year of installation. The second objective of the data analysis is critical to the project as trends in failures or causes of failures are attempted to be found. To do so, PVC failures were investigated by looking at the failure rates (failures/km) in relation to certain parameters. These parameters are:

- Failure Age
- Installation Year
- Pipe Size
- Water Type
- Flow Type
- Region
- Time

2.2 Mechanical Testing

Mechanical tests will be conducted to determine the effects of temperature, age and presence of notches on material properties. The pipes used for testing are:

- PVC-U, DN 150
- PVC-U, DN 200
- PVC-M, DN 100

With limitations on the sample types available and creation of test environments, the types of tests to be performed are outlined in Table 4:

		Parameters		
		Age	**Temperature**	**Notches**
Test	**Tensile Strength**	PVC-M	PVC-M PVC-U	PVC-M PVC-U
	Fatigue Strength	PVC-M		PVC-M PVC-U
	Hardness	PVC-M	PVC-M PVC-U	

Table 4 Summary of Sample Types for each Test

2.2.1 Test Environments

The test environments are created as follows:

Parameter	Environment Description
Age	Samples were retrieved from the field when a section of the pipe failed
Temperature	A cardboard temperature box will be used with two hairdryers for the tensile test, and an open oven for the hardness test. Once the desired temperature is reached for 5 minutes, the test will be performed
Notches	The UWA mechanical workshop team will create notch sizes of varying depths

Table 5 Creation of each Test Environment

2.2.2 Hardness Test

The hardness of the pipe sample will be measured using a Shore D Durometer in accordance with ASTM D 2240. This test measures the resistance of the sample to material deformation due to a constant compressive load from a sharp object.

2.2.3 Tensile Test

The tensile test will be conducted on an Instron 5982 machine, in accordance with AS 1145. The tensile test will be performed until fracture, at a extension rate of 20 mm/min. The test specimen is machined from the pipe length using the CNC (computer numerical control) machine, with the tabs milled into a flat surface for desired gripping.

2.2.4 Fatigue Test

The fatigue test will be conducted on the Instron 8501 machine, a hydraulic driven machine allowing for cyclic motion. A stress amplitude of 30 MPa will be applied at a frequency of 4 Hz until failure of the material, and the number of cycles recorded for analysis. The dimensions of the barbell specimen will be the same as for the tensile test.

3. Results and Discussion

3.1 Data Analysis

The main findings are summarised in Table 6 below:

Parameter	Finding
Age	There is no underlying failure rate trend with age. A linear increase is experienced until 17 years, then a linear decrease.
Installation Year	Accounting for time in service, failure rates are relatively constant. There is a slight decrease in failure rate for pipes installed recently
Pipe Size	Failure rates are constant for varied pipe diameters
Water type	Failure rate for fresh water pipes are 3.5 times higher than wastewater pipes
Flow Type	Failure rate for pressurised pipes are 5 times higher than non-pressurised pipes
Region	All regions have a relatively constant failure rate
Time	The yearly failure rate is relatively constant

Table 6 Findings from Data Analysis

Most findings were in line with expectations: pressurised pipes are expected to have a higher failure rate as they are subjected to higher pressures thus experience larger stresses. With knowledge that all fresh water pipes are pressurised whilst the majority of wastewater is transported unpressurised, the similar difference in failure rate for pressurised pipes versus non-pressurised pipes and fresh water pipes versus non-pressurised pipes is expected. The most interesting finding is the increase then decrease in failure rates as pipe ages, illustrated in Figure 1. Although the declining failure rate for older pipes may be reasoned by the view that 'poorer' pipes have already failed and only the 'good' pipes are now left in the ground (a similar phenomenon observed with the Corporation's cast iron pipes); the data analysis highlights the need for further investigation of pipes ageing and their property deterioration.

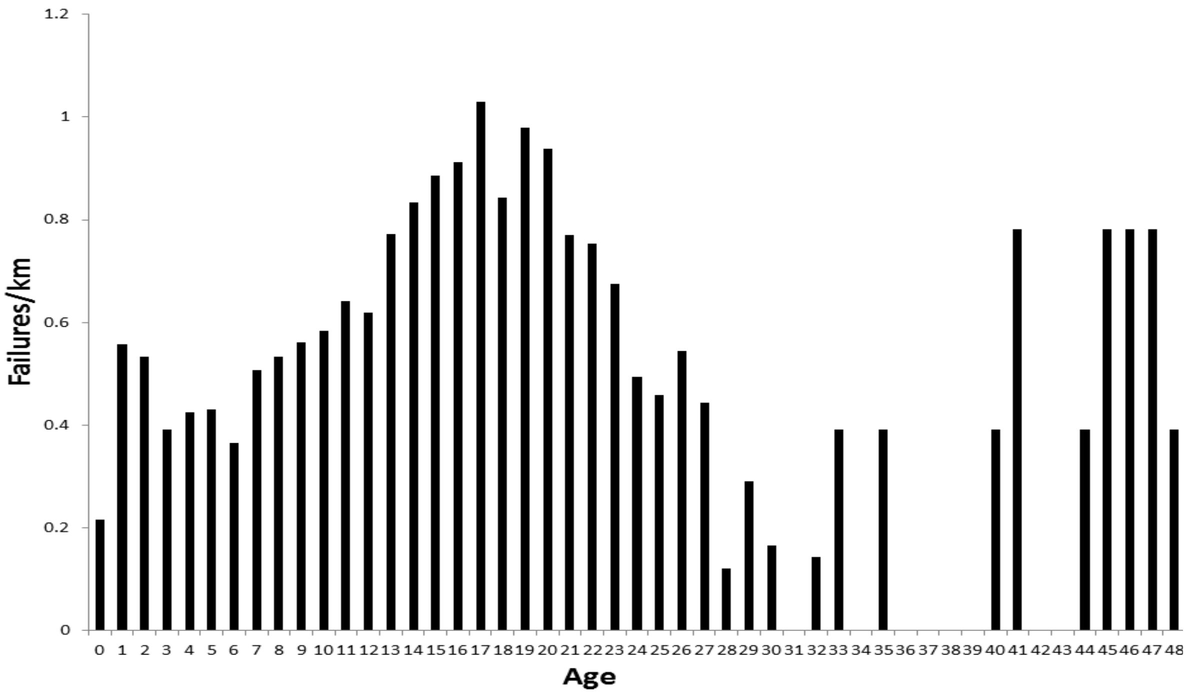

Figure 1 Fresh Water Pipe Failures since 2005

3.2 Applicability of Mechanical Tests

The parameters of pipe age, temperature and pre-existing notches are three aspects potentially affecting the performance of PVC pipe at the Corporation. Their relevance to the Corporation is explained:

Age The data analysis findings highlight the need for further investigation, with an interesting rise then fall in failure rate as age increases. All pipes will age until eventual failure or replacement, thus its effect is important.

Temperature The Corporation have performed internal studies investigating the temperature of PVC pipe experienced in different regions. These ranged from 20°C – 40°C.

Notches It is widely accepted that unwanted notches/scratches are created during poorly performed pipe installations. From previous failure analyses conducted by external material experts, the presence of notches were deemed a large contribution to the pipe's resulting failure.

4. Conclusions and Future Work

The first stage of data analysis has resulted in a clearer understanding of PVC pipe usage at the Corporation. Thereafter, the findings from the failure analysis were that pressurised pipes fail 5 times more often than non-pressurised pipes. The finding that failure rates do not increase consistently with age opposes the accepted knowledge and thus highlights the need for further investigation. Accordingly, the ongoing laboratory testing will continue to develop a knowledge base pertinent to the Corporation. In addition to ageing, the effects of temperature and presences of notches on mechanical properties are being investigated. At the completion of the project, the Corporation will have a substantial foundation of PVC knowledge to perform effective condition assessements on pipes in-service.

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