Investigation of Root Cause of Polyethylene Pipe Leaks and Bursts

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Abstract

Increased failure rates of polyethylene (PE) water reticulation pipes in the North West Region (NWR) of Western Australia have necessitated frequent and costly service repairs. Aside from inefficient resource allocation, these also significantly impact environmental and safety issues.. This project is in the second year of an investigation into the root cause of increased failure rates, and aims to offer possible solutions for minimizing the occurrence of failure.

The project combines historical data analysis, laboratory tests of field samples from the NWR and experimentally aged samples from pilot test systems to identify and categorize the key contributors to pipe failure. Preliminary investigations indicate significant deterioration in mechanical and chemical properties of PE pipes after several years in service, owing to a combination of inadequate installation/maintenance practices, environmental conditions and water conditions in the NWR.

1. Introduction

Polyethylene (PE) pipes have been increasingly used or installed in the water supply network due to various advantages offered over traditional metal pipes, such as high chemical stability, bio-inertness and transportability. PE pipes were first installed in the region in the 1990s, and have become the dominant material type for property service connections. PE pipe failures have increased in recent years, with some pipes failing as early as five years into service. This has impacted pipe maintenance costs, operational constraints and customer service.

An investigation into the root cause of PE pipe failure was initiated by Wong (2017), with the findings guiding this project. This project seeks to better understand the failure mechanism associated with PE100/high density polyethylene (HDPE) pipes, and facilitate better estimation of pipe reliability to aid the Water Corporation in implementing more efficient investment strategies. This is being achieved through a combination of literature review, historical data analysis, controlled testing systems and laboratory experiments.

2. Methodology

2.1 Pilot Test Systems

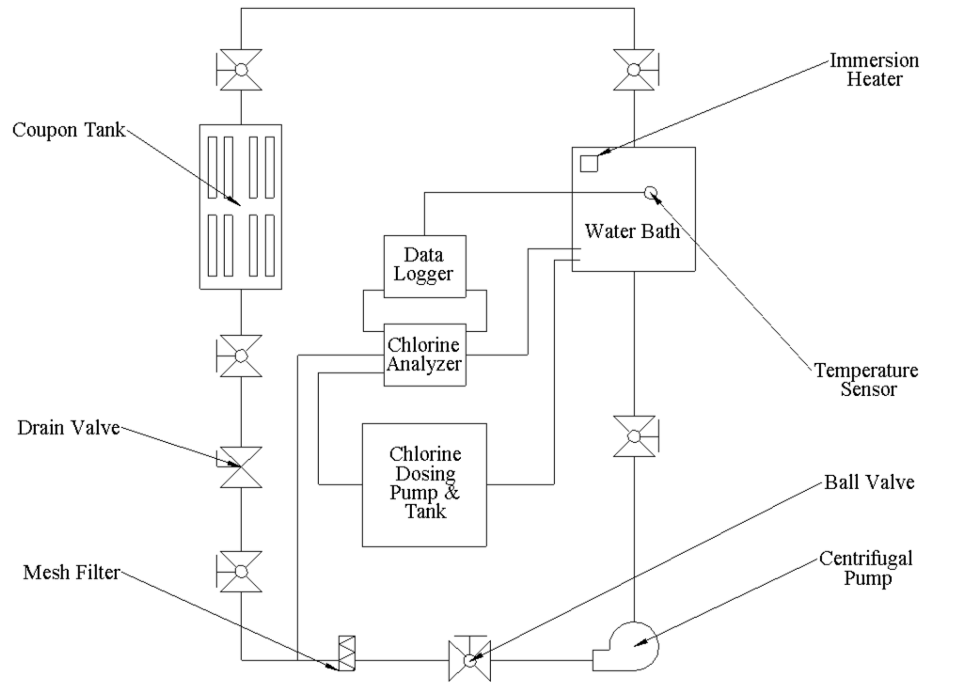

Figure 1 Schematic for pilot test system in AMSI workshop.

The main pilot test system was designed by Wong (2017) to observe degradation of HDPE pipes under controlled conditions. The closed loop system possesses a constant flow rate of *3 l/s* at *8 m* dynamic pump head. A chlorine dosing pump connected to a residual chlorine analyzer regulates the residual chlorine in the system to mimic water supply system conditions, while a water bath system maintains the chosen test temperature. Improvements made in 2018 include the addition of a mesh filter to capture rust or foreign particles suspended in the system. Due to malfunctions in the water bath unit, it was replaced with an industrial immersion heater. In addition, a data logger and temperature sensor were installed alongside the pre-existing chlorine sensor to record and store temperature and chlorine concentration data. The current setup is shown in the schematic in Figure 1.

Every test run starts with eight 15 *cm* long DN25 PE100 pipe samples, labelled 1A to 8A. After a week, sample 1A is replaced by a sample labelled 1B. In the second week, sample 2A will be replaced by sample 2B. This is repeated until samples 1A through 8A have been replaced by samples 1B to 8B. At the end of week 9, the B samples are removed. This produces two sets of PE samples, each containing aged samples from one to eight weeks old.

An existing chlorine analyzer rig in the Asset Monitoring System Investigations (AMSI) workshop consisting of a semi-close looped flow, temperature and chlorine logging capabilities was modified to store five DN25 PE100 pipe samples. The chlorine and temperature values will fluctuate according to the workshop's operating conditions, and is expected to provide an estimate of HDPE pipe performance in the Perth Metropolitan Area for comparison against the higher temperature controlled tests (intended to cover conditions possible in NWR). This Perth Baseline Test (PBT) will involve five samples that are replaced at two week intervals to yield two sets of samples aged 2, 4, 6, 8 and 10 weeks old.

2.2 Laboratory Testing

Thermoanalysis using Differential Scanning Calorimetry (DSC) reveals the oxidation induction time (OIT) for the HDPE samples. The OIT provides an indication of the residual antioxidant content in the polymer, thus indicating its susceptibility to chemical degradation. The rate of antioxidant consumption is dependent on temperature, pH, physical and chemical composition of the polymer, and disinfectant concentration and strength (ORP - oxidation reduction potential). The extent of antioxidant loss in pilot test samples determined through their OIT values will be compared to results from the failed field samples to investigate the relationship between temperature and antioxidant consumption.

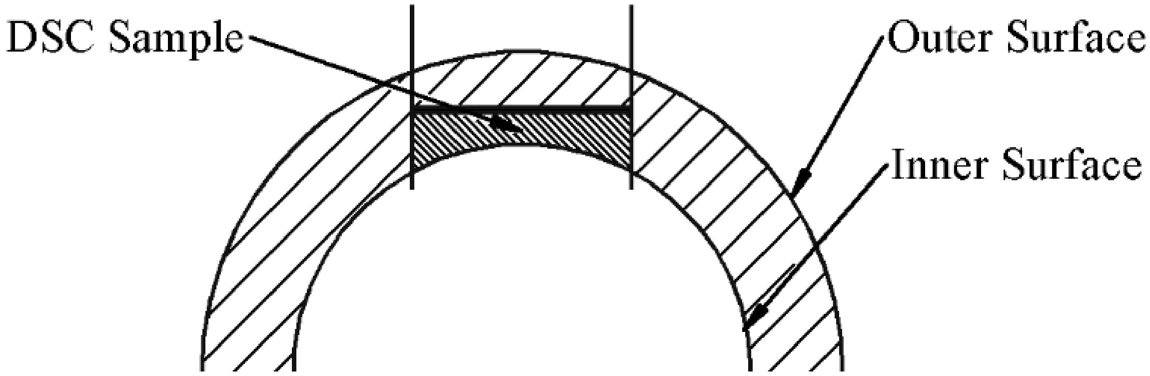

Figure 2 Depiction of DSC sample preparation from pipe cross section.

For each sample, a *10±1 mg* inner cross section annotated in Figure 2 is placed flat side down into a sample pan that is inserted into a heating chamber. The outer sections are omitted to remove data variations caused by exposure to sunlight or moisture during storage. The OIT test equilibrates the nitrogen gas filled heating chamber at *40°C*, then linearly ramps to *200°C* at *10°C/min* and is held isothermally for 5 minutes. Oxygen gas is then introduced to the isothermal system until oxidation occurs. Oxidation is characterized by exothermic reactions causing an increase in differential heat flow between a reference pan and sample pan.

2.3 Historical Data

Data extracted from various Water Corporation databases have been used for statistical analysis to identify factors associated with the increased failures. Additionally, results of the desktop study by Wong (2017) will be updated with more recent data.

3. Preliminary Results and Discussion

3.1 Pilot Test System Progress

Pilot Test 1 (PT1) commenced on 4th April 2018, and ran for nine weeks until 30th May 2018, yielding 16 samples aged between 1 to 8 weeks old. The chlorine concentration was stable and consistent, maintaining a value of *1.00 ± 0.05 ppm* throughout the run. Similarly, pH values were maintained between *7.6* and *8.0* with intermittent acid dosing to replicate site conditions in the NWR. Temporary loggers and manual recordings were used to compensate for the lack of a data logger. A total of 18 hours of temperature data were recorded, ranging from *38°C* to *50°C* with an average of *43°C*. A re-run of this test is planned to start during August with improved logging capabilities and better temperature control.

Pilot Test 2 (PT2) commenced on 18th July 2018 and is in progress at the time of writing. As for PT1, the chlorine concentration and pH were maintained at *0.95 ± 0.1 ppm* and *7.8 ± 0.2* respectively. The test rig was maintained at an average temperature of *29.4°C* with minimum temperatures of *26°C* and maximum temperatures of *32°C* due to the analog nature of the heater control system. The PBT is also in progress, with temperatures ranging from *24°C* to *35°C* and chlorine concentrations between *0.3 and 0.9 ppm*.

3.2 Differential Scanning Calorimetry Results

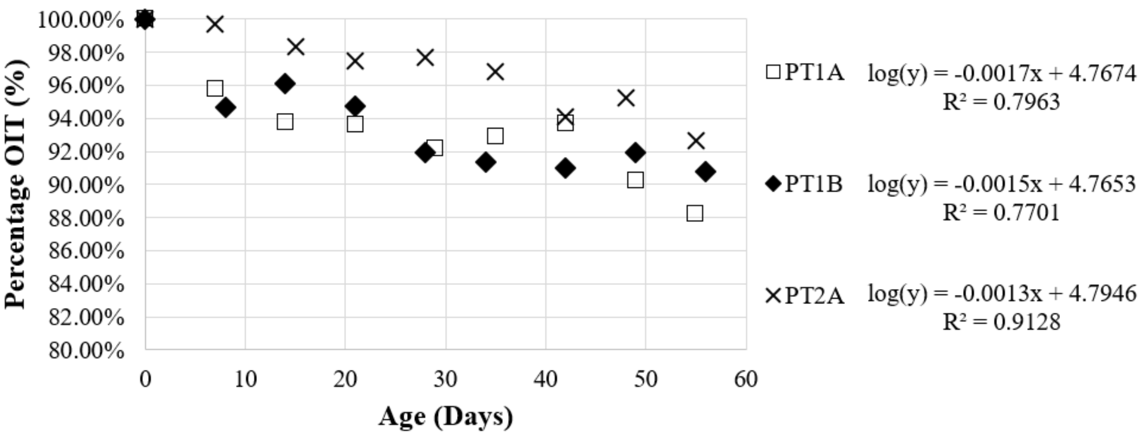

Figure 3 Percentage OIT remaining in samples from Pilot Test 1 and 2.

Figure 3 shows the percentage OIT with respect to new samples in HDPE samples from PT1 and PT2. The percentage values are calculated based on the average starting OIT value for Iplex PE100 DN25 pipes, which was determined to be 120.3 ± 3.3 minutes (99% confidence limit) from testing of four new, un-aged samples. A significant initial consumption of antioxidants can be seen in PT1, which could be attributed to higher temperatures enabling physical diffusion of particles at the pipe surface into the water. It is also possible that the higher thermal kinetic energy of molecules in the system has facilitated hydrolysis of the antioxidants, but this will be verified through Fourier Transform Infrared Spectroscopy (FTIR) analysis. Since antioxidant consumption is expected to exponentially decay over time, log-linear trendlines between OIT values and age (days) are shown in Figure 3. The gradients for PT1 are steeper than the preliminary results for PT2 and OITs are significantly lower, indicating that elevated temperatures are associated with an acceleration in the consumption of antioxidants in PE pipes.

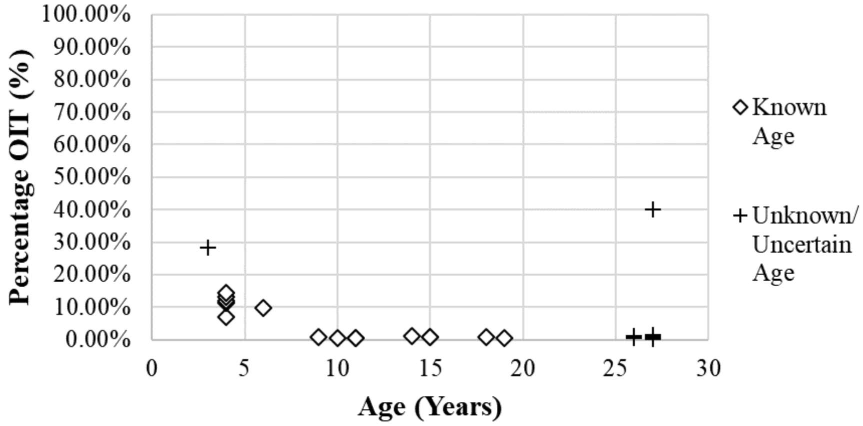

Figure 4 Percentage OIT remaining in samples from failed field samples.

The OIT data in Figure 4 contains four sample points by Wong (2017) and new data collected for 29 other samples. PE pipes with no recorded installation dates were assigned the maximum age of 27/28 years based on the introduction date of PE pipes in the region. This corresponds to the outlier OIT value for a 27 year old pipe. In general, it is evident that HDPE pipes are depleted of antioxidants within 4 – 10 years, becoming completely susceptible to chemical degradation. This raises uncertainty regarding the manufacturer lifetime expectancy of 50 years given such an early potential onset of chemical degradation in the absence of antioxidant protection.

3.3 Historical Data Analysis

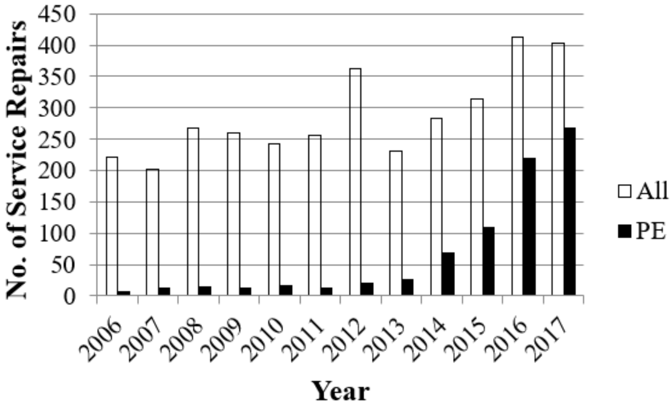

Figure 5 Number of service repairs in a town by year.

Failure frequency analysis done by Wong (2017) is updated in Figure 5 to confirm that PE-related failures continue to increase, with 66.3% of service repairs in 2017 being PE-related.

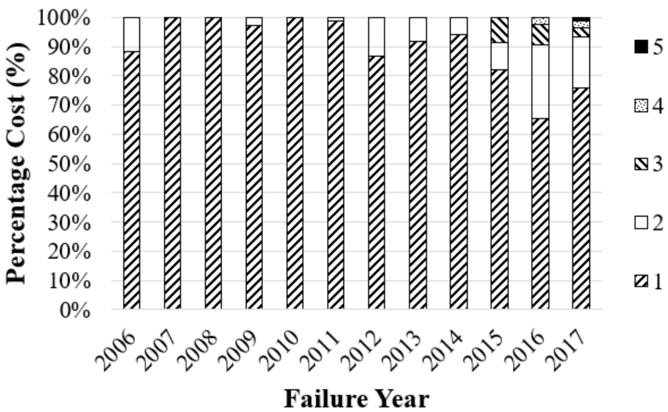

Figure 6 Cropped percentage cost of the X^{th} instance of failure by year.

Failure data analysis of existing PE pipe reticulation suggested the occurrence of repeated failures on individual service connections. Figure 6 is a cropped percentage bar graph showing the relative cost of first to fifth instances of failure. In 2016 and 2017, 23.98% and 16.47% of service repair costs were attributed to the second to fifth instances of failure on the same service connection. Another parameter investigated was the time between failures, which is summarized in Table 1. Comparison of the averages and ranges of inter-failure times suggest that repairing a leak either diminishes the overall integrity of the entire pipe length or at best fails to improve it, leaving it susceptible to future failures.

Failure Number	Number of Occurrences	Average Months between Failure	Range of Months between Failures
1	651	N/A	N/A
2	124	43.8	18 – 48
3	33	11.5	1 – 48
4	10	3.8	1 – 15
5	5	9.2	4 – 16

Table 1 Repeated failure frequency and time to failures from 2006 to 2017.

The aspect ratio at the failure location of the failed field samples have also been measured, calculated as a ratio of the largest diameter and the smallest diameter measured on the pipe. Out of the 33 field samples, 24 exhibited significant physical deformation with aspect ratios ranging from 1.1 to 1.31. This is indicative that the pipes have sustained significant mechanical damage, confirmed by visual inspection of failed samples. Azis (2016) also found that careless installation practices, abrasive backfill material and inadequate repair practices were common in the NWR. These findings imply that increased repeated failures are worsened by the diminishing cost effectiveness of repeated repairs.

Data analysis of local service pressure and failure frequency revealed no evident correlation.

4. Conclusions and Future Work

This study has identified environmental conditions and work practices as major contributors to increased PE pipe failure. Higher operating temperatures accelerate the depletion of antioxidants within the polymer, exposing it to direct chemical degradation at an earlier date. Additionally, work practices for installation and repair of service connection failures appear to inflict mechanical damage to the pipes, which causes early onset of crack initiation and propagation of already embrittled pipes.

Future work for this project includes the completion of PT2, PBT, a repeated run of PT1 and OIT testing for all respective samples. Additionally, FTIR, scanning electron microscopy and artificially induced fracture testing will further develop the understanding of the failure mechanism. Spatial cluster analysis of failure data will further explore the effects of maintenance practices on pipe lifespan, but this depends on data availability and suitability. Future work beyond this project could also involve hydrostatic testing for intact PE field samples to study the changes in mechanical performance after chemical degradation.

5. Acknowledgements

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6. References

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