Degradation of Engineered Plastics in High Chlorine and Temperature Environments - Stage 2

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Abstract

Dual check valves are failing earlier than expected, which is costing Water Corporation more than double to reactively replace them. Research to understand the damage mechanisms of Acetal and Noryl dual check valves along with an accelerated ageing methodology to predict their life span are the project objectives. To complete this, a test rig has been constructed to replicate in-service conditions and allow harsher conditions to be applied to accelerate ageing. Analysis through fourier transform infrared spectroscopy (FTIR) and microhardness testing are to be conducted to assess damage accumulation and model the expected life span. Oxidation, acidolysis and hydrolysis have been discovered to be the main damage mechanisms through a literature review, with oxidation leading to hydrogen abstraction being identified through FTIR results.

1. Introduction

Every home served by Water Corporation has a water meter to measure water usage. Integrated at the outlet of each water meter is a dual check valve (DCV), which prevents backflow in the case of back siphonage due to a lower pressure in the water reticulation network (Water Corporation, 2023). Failure of a DCV can contaminate the water supply with backflow containing dirt or bacteria, risking consumer health. This would create a negative image of Water Corporation, as it goes against their 2035 Strategic Plan's goal of 'safety for customers, communities, and employees' and diminishes trust within the community (Water Corporation, 2022).

In the North West Region (NWR) Water Corporation have experienced failures of DCVs significantly earlier than their 15 year expected life span. The decision to switch from Acetal to Noryl DCVs was made in 2017-2018 following a similar move by the Power and Water Corporation in the Northern Territory (Dang, 2016). However, uncertainty lies in the life span of DCVs which prompted this research project. The objective is to understand the underlying damage mechanisms and predict the life span of the DCVs to avoid a reactive, $200 replacement and instead plan for an active $90 replacement, saving more than half in replacement costs.

1.2 Current State of the Art

Stage one of this project conducted a spatial and statistical analysis of meter replacements and ruled out any correlation between high water supply pressure regions and an increased frequency of meter replacements, based on a case study of a town in the North West Region (Lim, 2022).

1.2.1 Acetal – Polyoxymethylene Copolymer

Acetal is an engineered thermoplastic, copolymer with a crystalline morphology (Mark, 2004). Acetal is predominantly polyoxymethylene which is made up from the CH_2O monomer (Siegert et. al, 2010). During production, additives such as formaldehyde scavenger antioxidants are added after polymerisation in an extruder or kneader (Siegert et. al, 2010). Phenolic antioxidants are also typically used in polyacetal (Brydson, 1999).

1.2.2 Noryl – Polyphenylene Oxide/ether (PPO/PPE) and Polystyrene (PS)

Noryl is a 30% glass fibre reinforced blend of polyphenylene oxide/ether (PPO/PPE) and polystyrene (PS), which is rated for potable water applications up to 85 ºC in Europe and North America (Sabic, 2017). It is made up of between 50 to 80 weight percent of polyphenylene ether and 20 to 50 weight percent of polystyrene (Chao et al, 1998). Polyphenylene ethers are made up of 2,6-dimethyl-1, 4-phenylene monomers and the antioxidant present is tridecylphosphite (Chao et al, 1998). The glass fibre added has a preferred length greater than or equal to 0.2 mm and a diameter between 5 to 50 micron (Nakanishi et al, 1971).

1.2.3 Polymer Damages

Both polymers are susceptible to damage from oxidation from hypochlorous acid formed due to the presence of free chlorine in potable water and thermal oxidation (Sigrid Lüft l, 2014). Acetal has also been found to be susceptible to hydrolysis and acidolysis, which leads to chain scission stemming from alkaline and acidic water conditions (Mark, 2004; Sigrid Lüft l, 2014).

2. Research Methodology

2.1 Test Rig Design

Duty point calculations were completed based off an 8 parallel water meter arrangement with a target flowrate of 24 L/min running through each DN20 meter, typical of in-service conditions. Loss factors for pipe fittings and instruments were taken from AS2200 while DN20 water meters exhibit a maximum pressure differential of 69 kPa from meter specifications at 24L/min (Itron, 2023). Straight pipe length friction factors were iteratively calculated using Colebrooke-White's equation.

2.2 Fourier Transform Infrared Spectroscopy (FTIR)

Attenuated total reflectance (ATR) is a FTIR simple sampling methodology that is used to understand the composition of polymer samples (Agilent Technologies, 2020). Infrared light is emitted onto the sample and the difference between the reflected wave and the emitted light is used to output a percentage transmittance (%T) versus wavenumber spectrum that helps to represent its molecular composition (Mathias, 2022). This experiment was conducted on the following samples.

Sample Type	Fresh		Endurance Tested		Failed from NWR	
	Acetal	Noryl	Acetal	Noryl	Acetal	Noryl
Number of samples	1	1	1	1	6	2

Table 1 FTIR samples scanned

Majority of scans were located at the barrel and valve head. Noticeable signs of degradation found on the valve collars were additionally scanned on some samples. Each piece was cut into 5 x 5 mm pieces, and the side not of interest was sanded until flat for secure mounting on the device.

2.3 Chlorine Soak

A pair of Acetal and Noryl DCVs were separately disassembled and placed in separate glass jars to soak in 200 mL of water with an average of 54 ppm of free chlorine across both jars at ambient conditions. Every two weeks the jars are visually observed, chlorine concentrations are measured, and each jar is re-dosed to maintain a target of 50 ppm.

3. Results and Discussion

3.1 Test Rig

Modifications to the existing test rig from Stage 1 were completed to replicate the conditions experienced by DCVs in the NWR. A parallel arrangement was chosen with identical upstream and downstream flow directions to maximise the chances of equal pressures across the meters. Opposing flow directions were rejected despite saving space due to a possibility for inconsistent pressure differentials across meters leading to unequal flow rates across meters. Drilled holes into two straight pipes to make up the manifold was rejected because gluing straight and tee piece fittings proved to be easier to assemble. An additional bypass return to the water tank is included to allow for cyclic solenoid actuation between the two solenoids to simulate DCV actuation. The typical water path is show in Figure 1.

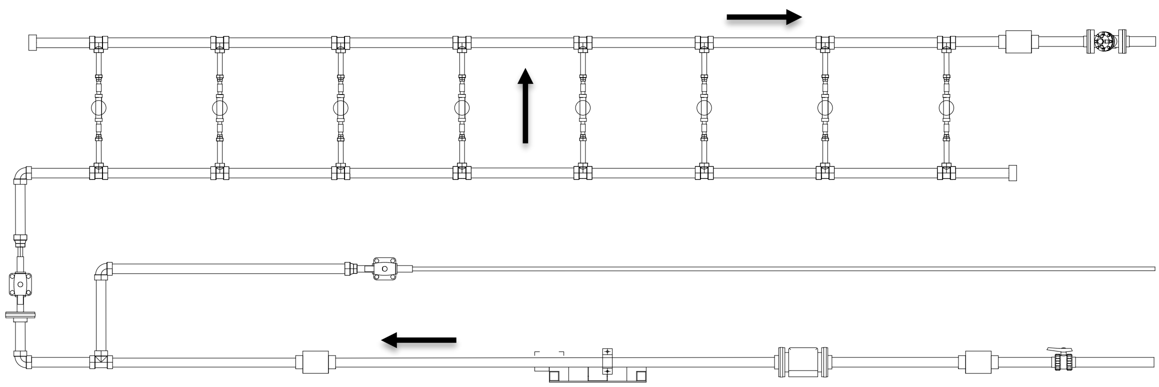

Figure 1 Test rig layout

The maximum calculated head loss from the rig is 18.69 m of head and the pump was selected to provide 211 L/min at a conservative 23.05 m of head. A control valve is placed at the downstream end of the system to regulate the flow and ensure 192 L/min runs through the 50 mm to deliver 24L/min at the meters.

3.2 FTIR Results

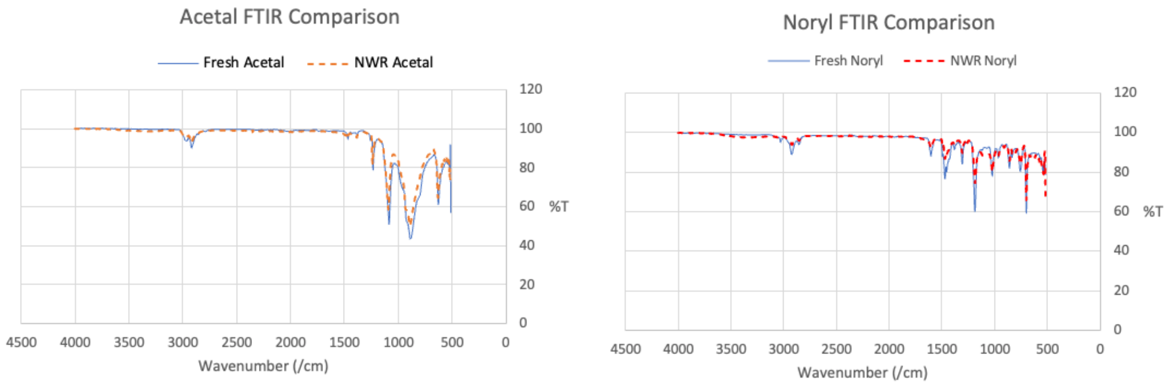

Figure 2 and 3 FTIR spectrums for fresh Acetal (2: left) and Noryl (3: right)

A key finding for Acetal is within the 3000cm^{-1} to 2840 cm^{-1} range that corresponds to a C-H hydrogen bond, the NWR and endurance tested samples generally exhibited around 2% higher percentage transmittance (%T) compared to the fresh sample in figure 2 (Erno Pretsch, 2009). This is a sign of possible hydrogen abstraction through chlorine oxidation breaking C-H bonds, as a higher %T indicates fewer C-H are present (Sigrid Lüft l, 2014). Noryl samples at 1220 cm^{-1}and 754 cm^{-1} represent the main PPE chain and the C-H bonds branching from these chains respectively (Hongying Hou, 2012). NWR and endurance tested samples showed an average 2% and 8% higher transmittance for 1220 cm^{-1} and 754 cm^{-1} respectively, indicating hydrogen abstraction occurs more than cleavage of the main chain. These results show damage due to oxidation is prevelant in both polymers.

3.3 Chlorine Soak Results

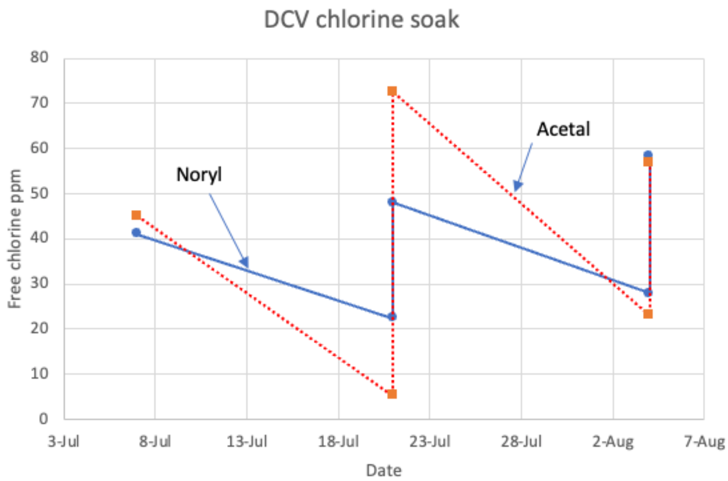

Figure 4 Free chlorine concentration of DCV soak test

Acetal samples exhibit greater rates of decline in chlorine concentration between re-dosing which could allude to a higher rate of oxidation due to hypochlorous acid within the Acetal as opposed to Noryl. No observable differences have been found from either sample when compared to their original state.

4. Conclusions and Future Work

The original objectives of understanding the damage mechanisms in both Acetal and Noryl and developing an accelerated ageing methodology are still being pursued. Through a literature review, it has been identified that Acetal is susceptible to oxidation, hydrolysis and acidolysis while Noryl undergoes similar oxidation damage. FTIR results exhibit higher transmittance due to a lack of C-H bonds in both polymers, supporting the hypothesis that oxidation from chlorine is an active damage mechanism.

Once construction of the test rig is completed, pump installation and commissioning to allow for DCV accelerated testing can commence. Further FTIR data analysis to identify and draw conclusions on other critical molecular bonds will be conducted. Mechanical testing utilising a microhardness indenter is in progress and will be conducted on the same samples subjected to FTIR. Finally, a full analysis on artificially aged samples created from using the test rig will likely extend beyond the project however, a foundation has been laid for future work to continue.

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