



Plastics Industry Pipe Association
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Plastics Pipe in Water and Waste Water Infrastructure

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The purpose of this paper is to broadly look at what issues are significant when considering a plastics pipe system in the water and waste water industry.

Condition assessment of pipeline systems in the water and waste water industries has focussed on dealing with the corrosion of metallic pipe systems or assessing cracking damage and failed joints in clay and concrete pipe systems. This is understandable, given the historical use of clay, concrete and metallic pipe systems in water and waste water infrastructure applications, coupled with the well known problems of these materials.

The metallic pipe systems, predominately based on cast iron and steel, have the condition assessments aimed at quantifying the effects of corrosion from external agents such as soil or the atmosphere, and from internal agents caused by contact with water and sewerage. These assessments also involve the condition of the protective coatings and linings necessary to protect the ferrous materials from their environment.

With clay (or concrete) pipe systems in sewers, the assessments quantify the amount of cracking in the pipes themselves and determine the extent of joint failure. Concrete has the added issue of corrosion from soil and, most importantly, damage from common sewer gasses like hydrogen sulphide.

The replacement of these older systems is being done using plastics pipe systems. The gas, water and waste water systems of Australia are very soundly based on Polyethylene (PE), Polyvinyl Chloride (PVC) and Polypropylene (PP) pipe systems. In addition there is the significant replacement of copper plumbing pipe with Polypropylene (PP), Polybutylene (PB) and Crosslinked Polyethylene (PEX) to complete the move away from metals, concrete and clay to modern polymers.

The reasons for this transition are based on better performance coupled with an overall better value proposition with plastics. Because these plastics are essentially resistant to the environmental hazards that degrade metals, concrete and clay, they are attractive. However, this raises the question of how to assess the condition of a pipe that is not susceptible to the hazards the major infrastructure agencies have been coming to terms with for generations.

Pipeline Life Expectancy

The Water Services Association of Australia has assigned life expectancy ratings for all approved plastics pressure and non pressure pipe systems at in excess of 100 years when installed and operated in accordance with the code.

The life expectancy of a plastics pipe is often confused with the arbitrary factor used in pipe material standards for the purpose of determining the design stress. This arbitrary point has been chosen, by convention, to be the value on a regression curve of pressure versus time at a point 50 years out. Based on the extrapolation of the stress versus time regression data to 50 year it has been incorrectly assumed that plastics pipe systems have a life expectancy of 50 years. In reality, such systems can reasonably be expected to last 100 years or more.

PE and PVC pipes and fittings were introduced into Australia during the 1950's, mainly for water supply and irrigation, but also for fuel gas and industrial applications. The first Australian Standard for

PE pressure pipes was ASK119-1962 and the first for PVC pressure pipes was ASK138-1963.

The creep rupture characteristics of these materials necessitated a new method for selection of design stress, compared with other materials in use at the time - AC, CI, GWI, etc. The method adopted was one already in use in Europe of using the creep rupture (stress regression) curve, on which a time is selected to establish the associated burst stress. Applying a design factor to the burst stress gives the design stress. The time chosen was 50 years, already adopted in Europe, and still in use today in AS/NZS, ISO, and CEN Standards.

The use of this particular time interval has led to the misunderstanding that it represents the pipe life. Similarly, the use of 50 year modulus values for use in ring deflection calculations for non-pressure pipes has also led to the same misunderstanding.



The following extract from WSA01-2004, Polyethylene Pipeline Code, explains why prediction of system life should not be based on the arbitrarily chosen time value. **Whilst this quoted section from the WSAA code only mentions PE, the information applies equally to all plastics.**

PRESSURE

Selection of allowable stress is based on long term pressure testing in the laboratory and regression analysis applied to the data obtained. The 50 year point is arbitrarily chosen for this basis, as for all thermoplastics pipes. A factor is applied to the 50 year point in order to provide the design stress.

It shall not be taken that either:(a) the pipes weaken with time; or (b) the predicted life is 50 years.

System life is dependent on many factors. If the design stress were used in relation to the regression curve, predicted pipe life would be indefinite, not 50 years. As with other materials, the life is dependent on manufacture, transport, handling, installation, operation, protection from third party damage and other external factors.

Provided that PE pipeline system components are appraised and supplied to nominated industry standards under third-party product certification systems, and provided pipelines are designed and constructed correctly, then the likelihood of failure is minimised. For correctly manufactured and installed systems, the actual life cannot be predicted, but can logically be expected to be well in excess of 100 years before major rehabilitation is required.

If a system life is to be assigned beyond 100 years, it has to be based on the likelihood of failure arising from the above factors, not the pipe regression curve. Pipe strength has been shown not to decrease with time-in fact, it increases slightly. "Instantaneous " burst pressure after a period in service will be at least equal to that of new pipe.

NON-PRESSURE

The life of non-pressure PE pipelines will be dependent on performance under four main conditions:

- (a) Soil mechanics and pipe mechanics stability.
- (b) Pipe material strength.
- (c) Chemical and biological stability.
- (d) Functional stability.

The life of thermoplastic non-pressure pipeline systems has been extensively studied and reported. For example, the report titled *Plastics Pipes-How Long Can They Last*, by Prof Lars-Eric Janson of VBB Sweco Consulting Group reaffirmed a 1987 report concluding that the answer to the above question was "at least 100 years".

The latest report, produced in 1996, states that "...it has been clearly found that nothing has emerged, which contradicts the statement made in 1987." It also states that the report refers mainly to buried gravity sewer pipes, but the conclusions can in most cases be applied for pressure applications. The aim of the work was to verify the claim of "at least 100 years".

The summary states that "...one can thus conclude that everything is pointing to at least 100 years practical service life for today's buried sewer pipes made of high quality virgin PVC-U and PE resins, on condition that the pipes are used in accordance with the prevalent national standard installation instructions."

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Fatigue

Many materials will fail at a lower stress when subjected to cyclic or repetitive loads than when under static loads. This type of failure is known as fatigue.

The gradual diurnal pressure changes which occur in most distribution pipelines as a result of demand variation will not cause fatigue. The only design consideration required for this type of pressure fluctuation is that the maximum pressure should not exceed the pressure rating of the pipe. Whilst most gravity pressure pipelines operate substantially under constant pressure, pumped lines frequently do not. Pressure fluctuations in pumped mains result from events such as pump start-up and shutdown and valves opening and closing. It is essential that the effects of this type of loading be considered in the pipeline design phase to avoid premature failure.

In the case of thermoplastics pipe materials, fatigue is only relevant where a large number of stress cycles are anticipated. The important factors to consider are the magnitude of the stress fluctuation and the loading frequency.

The fatigue response of thermoplastics pipe materials has been extensively investigated. The results of laboratory studies can be used to establish a relationship between stress range, defined here as the difference between the maximum and minimum stress, and the number of cycles to failure. From these relationships it is possible to derive load factors that can be applied to the operating pressures, to enable selection of an appropriate class of pipe.

The two key reference documents covering fatigue design of PE and PVC pressure pipe systems are PIPA's Industry Guidelines:

- POP10A, *Polyethylene pressure pipes design for dynamic stresses*
- POP101, *PVC pressure pipes design for dynamic stresses* Both these

documents are freely accessed from the Technical Guidelines page.

Analysis of the fatigue environment relative to the type and pressure class of the pipeline will give an indication of likely remaining life for a pipeline in a fatigue environment. This technique could also be employed to assess the impact of operational changes on the expected life of a pipeline in a fatigue environment – potentially extending the pipeline life by improving the fatigue envelope from the original design.

Weathering and exposure to sunlight

In the water and waste water industry the majority of all pipelines are buried and therefore protected from weathering and exposure to UV radiation. Plastics pipe systems generally are designed for installation in either buried situations or in above ground applications where they are not exposed to direct sunlight. It is expected that plastics pipes are often stored in direct sunlight for anything up to 2 years prior to installation and are formulated accordingly. Such exposure is expected and the relevant Australian Standards for plastics pipe systems address this issue comprehensively.

When exposed outdoors to weathering, the properties of polymers, such as human skin, timber and plastics, are subject to change. Primarily, the effect is one of photo-oxidation brought about by incident wavelengths within the ultraviolet range, although additional factors may contribute. In the case of plastics, photo-oxidation may result in loss of impact strength, resistance to slow crack growth, and thermal stability. This is a surface effect, and the bulk polymer is not necessarily affected. Pigment fade may also be a consideration.

Plastics pipes can be used in exposed applications – and often are by other industries such the mining industry, irrigation or in stormwater collection systems. Where such cases occur using either black PE pipe or simply painting PVC with a light coloured acrylic water based paint is all that is required to ensure satisfactory long term performance.

Polyethylene Pipes:

Protective additives such as carbon black and hindered amine light stabilisers (HALS) are used in order to minimise degradation. The use of carbon black optimises UV stabilisation and thus black pipes dominate general usage.

For coloured compounds, stabilisation has not been as effective as carbon black, but the introduction of HALS (hindered amine light stabilisers) has enabled greatly improved UV resistance, albeit still not to the level of carbon black.

Requirements for additives and product performance are included in AS/NZS 4130 and AS/NZS 4131.

WSAA require pipes to be suitable for use after two years of outdoors exposure during storage in Australia. In the case of black PE pipes, WSAA allows permanent exposure for above ground PE sewers.



PVC Pipes:

Australian PVC pipes include pigments and inhibitors in their formulations that provide protection from the effects of UV exposure during storage or in cases where long term exposure is likely the levels of these components are higher to provide much longer term protection.

Where storage times prior to installation are likely to exceed 12 months it is recommended that PVC pipes be stored under a roof or covered with a light coloured open weave cloth such as hessian. Under no circumstances should black plastic of any kind be used as black plastic sheeting of all kinds can generate excessive temperatures during hot weather.

Where permanent exposure conditions occur it is recommended that to protect the PVC pressure pipe from the effects of UV exposure it should simply be painted with a light coloured acrylic based paint system.

Deflection and flexibility

In spite of the enormous volume of research and literature devoted to the subject of the behaviour of flexible pipes, deflection or distortion under soil loadings, there is still a preoccupation by some that deflection of plastics pipe is an indication that the pipe will fail. Similarly, there is often an implication that rigid pipe systems are not installation sensitive.

One does not need to look far for technical papers to counter the second point. Such a paper is "Cracking of stormwater pipes and the significance of construction loads" by Demartini, Hansen and Lee from Brisbane City Council ⁽¹⁾. In an audit of concrete pipe drainage projects in the mid to late 90's "some degree of cracking was found in all pipe sizes less than 900mm diameter". They concluded the cracking "was likely related to trench backfilling and compaction methods".

The significance and consequence of pipe deflection is misrepresented in many publications.

Flexible pipe systems are designed to accommodate ground movement. Excessive deflection has the potential to impact on the pipeline in two basic areas – the strain generated in the pipe wall and joint performance. Thermoplastics (such as PVC, Polyethylene and Polypropylene) are not strain limited materials ⁽²⁾⁽³⁾⁽⁴⁾⁽⁵⁾. Hence from the perspective of deflection leading to excessive strain in the pipe wall - this is simply not a limiting case. Deflection is not a limiting functional parameter. The subject is well researched by Moser, Janson, and others ⁽³⁾⁽⁴⁾ and for the common thermoplastics PVC and PE, no strain limit could be found under constant strain conditions.

The selection of a deflection limit is an arbitrary one. "Design long term deflections of 15% are accepted and this is based on the limits of joint performance specification." ⁽²⁾. Deflections have little impact on the flow through pipelines – for example a pipe deflected by 15% will only experience a 5% reduction in flow capability. The most recent developments in this area of specification – ISO 21138-1 ⁽⁶⁾ recommend an average deflection limit of 10% - in other words recognising that deflections above 10% are acceptable.

Myths (often compounded by misleading assertions by rigid pipe suppliers) about flexible plastics pipe in the context of AS/NZS 2566 such as "the key measure of this structural integrity is the extent of the deflection that has occurred in the installed pipe" and "failure to detect even one deflection which has exceeded the specified limits could result in catastrophic failure of the pipeline" is erroneous. Exceeding the arbitrary limit of 7.5% does not mean the pipe integrity is at risk and certainly does not mean that "catastrophic failure" is likely.

In terms of condition assessment, deflection is an indication of how well the pipe was installed in relation to the compaction of the trench material. Even if significant deflections have occurred (up to 15% as discussed above), they should not be interpreted as an indication of imminent pipe failure. Deflections beyond this level could indicate that joint performance may be compromised and should be investigated.

References

1. Demartini C, Hansen B, and Lee D, "Cracking of stormwater pipes and the significance of construction loads", Pipes Wagga 1999.
2. Chapman P G, Croker L, and Menolotto F, "Practical use and performance testing of light weight thermoplastics pipes", Pipes Wagga 2005.
3. Janson L E, "Plastics pipes for water supply and sewerage disposal", 4th ed, 2003
4. Moser A P, Shupe O K, and Bishop R R, "Is PVC pipe strain limited after all these years", Buried Plastic Pipe technology, ASTM STP 1093, ASTM, 1990.
5. Bishop R R, "Polyvinyl Chloride (PVC) pipe samples exposed to various environments and constant strain", Buried Plastic Pipe Technology, ASTM STP 1093, ASTM, 1990.
6. ISO 21138-1 "Plastics piping systems for non-pressure underground drainage and sewerage structured wall piping systems of unplasticised poly (vinyl chloride) (PVC-U), polypropylene (PP) and polyethylene (PE) part 1: material specifications and performance criteria for pipes, fittings and system".

Chemical Resistance

In water and waste water infrastructure pipelines there is little risk of pipeline systems coming into contact with harmful chemicals in the concentrations necessary to structurally damage the pipe nor have exposure times that would be long enough to cause concern. The reason for this is that most trade wastes are now regulated and the number of genuinely contaminated sites is both well known and very small in number.

Where plastics pipes are used to transport treatment chemicals in the water industry PIPA and WSAA have collaborated to produce the Industry Guideline POP201, *Resistance of plastics pipes and fittings to water and wastewater chemicals*. This document is freely accessed from the Technical Guidelines page and the WSAA website (www.wsaa.asn.au).

Considerations for plastics

pipe Water Supply

For normal water supply work, PVC and PE pipes are totally unaffected by soil and water chemicals. The question of chemical resistance is likely to arise only if they are used in unusual environments or if they are used to convey chemical substances.

Sewerage

PVC, PE and PP will not be affected by anything that can be normally found in sewage effluent. However, if some illegal discharge is made then most chemicals are more likely to attack the rubber ring (common to most modern pipe systems) than the pipe. Because of modern pollution controls on sewage discharges, plastics pipe systems can be safely used in any municipal sewerage network including areas accepting industrial effluent.

Resistant

PVC is resistant to many alcohols, fats, oils and aromatic free petrol as well as most common corroding agents including inorganic acids, alkalis and salts. PE is very resistant to (non oxidising) strong acids, strong bases and salts.

Non-resistant

PVC should not be used with esters, ketones, ethers and aromatic or chlorinated hydrocarbons. PVC will absorb these substances and this will lead to swelling and a reduction in tensile strength.

PE and PP are mildly affected by aliphatic solvents although aromatic and chlorinated solvents will cause some swelling. Both PE and PP are attacked by strongly oxidising substances such as halogens and concentrated inorganic acids such as nitric, sulphuric (including oleum), perchloric, etc.

Factors Affecting Chemical Resistance

The following comments are relevant to where plastics pipes are used to convey water and wastewater treatment chemicals. Factors that can affect the rate and type of chemical attack that may occur are:

Concentration

In general, the rate of attack increases with the concentration, but in many cases there are threshold levels below which no significant chemical effect will be noted.

Temperature

As with all processes, rate of attack increases as the temperature rises. Again, threshold temperatures may exist.

Period of contact

In many cases rates of attack are slow and of significance only with sustained contact. In general PVC is considered relatively insensitive to "stress corrosion".

Chemical resistance of elastomers

Many pipeline systems rely on elastomeric seals at joints. The table below gives some general guidance to the resistance of different elastomers to the general classification of chemicals.

Material & designation	Generally resistant to	Generally not resistant to
Natural Rubber NR	Most Moderate Chemicals Wet or Dry, Organic Acids, Alcohols, Ketones, Aldehydes	Ozone, Strong Acids, Fats, Oils, Greases, Most Hydrocarbons
Styrene Butadiene Rubber SBR	As for Natural Rubber	As for Natural Rubber
Polychloropene (Neoprene) CR	Moderate Chemicals & Acids, Ozone, Fats, Greases, Many Oils & Solvents	Strong Oxidising Acids, Esters, Ketones, Chlorinated, Aromatic & Nitro Hydrocarbons
Ethylene Propylene Diene Monomer EPDM	Animal & Vegetable Oils, Ozone, Strong & Oxidising Chemicals	Mineral Oils & Solvents, Aromatic Hydrocarbons
Nitrile Rubber NBR	Many Hydrocarbons, Fats, Oils, Greases, Hydraulic Fluids, Chemicals	Ozone, Ketones, Esters, Aldehydes, Chlorinated & Nitro Hydrocarbons

Mechanical Damage

Mechanical damage can occur to any pipe system. In the case of metallic pipe systems that damage need only occur to the coating to result in premature failure. For plastics pipe, mechanical damage is likely to take the form of surface scoring. The allowable levels of scoring are nominated in the WSAA installation guides and in AS2032 and AS2033.

- PVC pressure pipes. 10% of the wall thickness up to a maximum of 1mm.
- PVC non –pressure pipes up to 10% of the wall thickness.
 - For sandwich construction pipes, up to 10% of the total wall but no deeper than the inner or outer wall thickness.
 - For structured wall pipes no deeper than 10% of the wall thickness and no more than 2 consecutive broken ribs.

Applications where scoring is more likely to occur, are trenchless installations such a pipe cracking. Historically pipe cracking installations have not suffered from excessive scoring and there have been no indication that pipelines installed using this technique have performed differently from those installed using open trench options.

Compounding this historically good performance is that modern PE100 materials (the most common PE material used in the water industry) have significantly better resistance to slow crack growth than earlier PE materials. This improvement in slow crack growth properties provides even greater confidence that these pipe systems will perform as designed and if scoring does occur are better equipped to resist the formation of a crack as a result of this type of damage.

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