PIPE EXTRUSION

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CONTENTS

WHITE PAPER

MINIMUM PERFORMANCE REQUIREMENTS OF HDPE PRESSURE PIPES

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Find out what it takes for HDPE pipes to last 50 years or more.
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Product and installation standards for HDPE pressure pipes have been established to ensure a target design life of at least 50 years under typical application conditions. It is essential that all actors involved in pipe value chain have a basic understanding of the minimum performance requirements listed in the standards and how conformance to the standards is assured. Failure to consistently meet the requirements may result in the structural integrity of the pipeline being compromised, service disruptions and ultimately a need for expensive replacement of pipe. As HDPE pressure pipes make their way into new applications, and new installation techniques emerge, additional requirements need to be considered to keep the target design life above 50 years.

HDPE PRESSURE PIPE IS ONE OF THE MOST POPULAR SYSTEMS USED FOR WATER AND GAS DISTRIBUTION NETWORKS. HDPE PRESSURE PIPE IS ALSO WIDELY USED IN A RANGE OF INDUSTRIAL APPLICATIONS INCLUDING MINING AND OIL & GAS. THE WIDESPREAD ADOPTION OF HDPE PRESSURE PIPE IS LARGELY ATTRIBUTABLE TO THE HIGH INTEGRITY OF THE SYSTEM THAT IS GOVERNED BY STRICT PERFORMANCE STANDARDS AND QUALITY ASSURANCE (QA) THAT IS SUPPORTED BY THIRD PARTY CERTIFICATION.

Performance and QA requirements need to be understood by the entire value chain, from raw material producer to asset owner. They also needs to be embedded in all company quality systems, including procurement practices and job tenders. Failure to consistently meet the performance requirements specified in relevant product and installation standards may result in the integrity of the system being compromised, leading to service disruptions, expensive repairs and in some cases risk of injury.

The aim of this white paper is to provide a basic overview of the requirements of the HDPE pipe standards and how conformance to these standards can be verified. The paper also highlights cases where performance beyond standard requirements is advisable.

The minimum requirements for polyethylene pipes used for pressurised water and gas distribution in Australia and New Zealand are provided in AS/NZS 4130:2018.

Table 1 shows an extract of the key performance requirements specified in the standard. AS/NZS 4130:2018 incorporates the requirements for raw material specified in AS/NZS 4131:2010.

The purpose of the performance standards is to ensure a minimum design life for HDPE pressure pipes of 50 years under typical installation conditions. Some of the key attributes of pressure pipe compounds per the standards are listed in Table 2.

PIGMENT DISPERSION

The raw material used in the manufacture of HDPE pipe must be a fully formulated compound containing antioxidants, UV light stabilisers and pigments.

Typically, carbon black fulfills the roles of both UV light stabiliser and pigment. The mixing of carbon black needs to be tightly controlled to ensure uniform dispersion within the polymer and protection against loss of properties of the pipe when exposed to UV.

Good dispersion of carbon black is best achieved in an intensive mixing process in a dedicated mixer when the pipe grade resin is being produced. A technically complex manufacturing process is needed to ensure sufficient carbon black content and adequate dispersion without overworking/ degrading the material.

Deveci and co-workers have demonstrated that mixing of carbon black masterbatch (CBMB) with a natural HDPE pipe resin in a conventional pipe extruder may result in inadequate dispersion of the carbon black even at reduced extrusion speed (Figure 1).[1] Through tensile testing, the study showed that the pipe samples with inadequate carbon black dispersion exhibited brittle failure and severely reduced elongation at break.

TABLE 1. KEY PERFORMANCE ATTRIBUTES OF PRESSURE PIPES ACCORDING TO AS/NZS 4130:2018 (NON-EXHAUSTIVE).

ATTRIBUTE	METHOD	REQUIREMENT
Classification	N/A	PN3.2 – PN25 depending on SDR and compound classification (PE100 or PE80)
Composition	N/A	Fully pre-compounded pipe extrusion compound according to AS/NZS 4131
Rework material	N/A	Only clean internal rework material from the same grade of resin is permitted
Striping/Jacketing compound	N/A	Needs to be manufactured from base resin compound conforming to AS/NZS 4131. Needs to contain at least 0.2% of HALS. AS/NZS 4131 thermal stability and dispersion requirements apply.
Dimensional tolerances	AS/NZS 1462.1	Wall thickness and out of roundedness will need to be within tolerances allowed in AS/NZS 4130 depending on pipe diameter and SDR
Effect on water	AS/NZS 4020	Pass. Surface area/volume ratio used in test specimens to be reported.
Resistance to internal pressure	AS/NZS 1462.6	PE100: > 165 hours (@80°C, @5.4MPa) PE80: >165 hours (@80°C, @4.5MPa)
Thermal stability	ISO 11357-6	>20 min (@ 200°C)
Slow crack growth resistance	ISO 13479	PE100: > 500 hours (@80°C, @920kPa) PE80: > 500 hours (@80°C, @800kPa)

TABLE 2. KEY PERFORMANCE ATTRIBUTES OF PRESSURE PIPE COMPOUNDS ACCORDING TO AS/NZS 4131:2010 (NON-EXHAUSTIVE).

ATTRIBUTE	METHOD	REQUIREMENT
Compound	N/A	Compounds shall be manufactured from polyethylene containing antioxidants, UV stabilisers and pigments necessary for their manufacture into pipes and fittings. Additives containing lead (Pb), cadmium (Cd) or mercury (Hg) shall not be used.
Thermal stability	ISO 11357-6	>40 min (@ 200°C)
Dispersion	AS/NZS 1462.28	Average maximum size of pigment agglomerates ≤ 60μm (Grade 3)
Volatile content	EN 12099	≤ 350 mg/kg
Classification	AS/NZS 1462.29	PE100: MRS > 10.0MPa (@ 20°C) PE80: MRS > 8.0MPa (@ 20°C)
Rapid crack propagation resistance	ISO 13477	PE 100: critical pressure > 1.0 MPa PE80: no requirement
Resistance to internal pressure	AS/NZS 1462.6	PE100: > 165 hours (@80°C, @5.4MPa) PE80: >165 hours (@80°C, @4.5MPa)
Slow crack growth resistance	ISO 13479	PE100: > 500 hours (@80°C, @920kPa) PE80: > 500 hours (@80°C, @800kPa)
Effect on water	AS/NZS 4020	Pass. Surface area/volume ratio used in test specimens to be reported.

> IT IS OF EXTREME IMPORTANCE TO MONITOR OXIDATION INDUCTION TIME (OIT) AND INVESTIGATE ANY SIGNIFICANT DECREASE FROM COMPOUND TO PIPE DURING MANUFACTURE, EVEN IF THE PIPE STILL MEETS THE MINIMUM OIT VALUE DEFINED IN THE STANDARD.

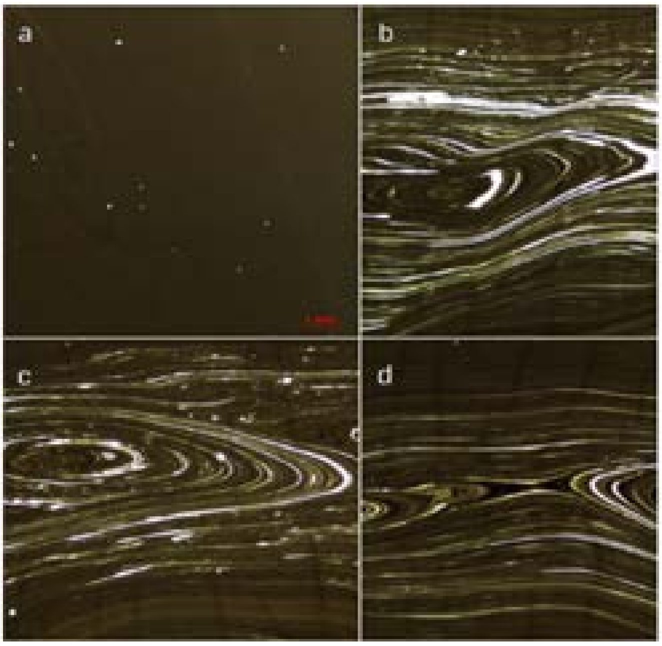

Figure 1. **Microscopy images of 15µm slices (cross-flow) taken from pipe specimens made from: (a) pre-compounded black PE100 at 100% extrusion speed, (b) natural resin + CBMB at 100% extrusion speed, (c) natural resin + CBMB at 80% extrusion speed and (d) natural resin + CBMB at 60% extrusion speed. Image reproduced with permission of authors in reference 1.**

THERMAL STABILITY

Thermal stability needs to be measured at both compound and pipe stage. The thermal stability results show if the antioxidant package is effective at providing short-term protection during pipe manufacture.

The data also provide information on the adequacy of any long-term protection against degradation for pipe that is in service. ISO 11357-6 standard uses Oxidation Induction Time (OIT) to measure thermal stability of the compound and pipe.

For pipe samples, OIT should always be measured at the inner wall. The standard specification for OIT allows for some decrease from compound to pipe (OIT 20 min on pipe vs 40 min on compound). However, field experience shows that in a well-controlled pipe manufacturing process, the OIT value remains largely unaffected from polymer to the produced pipe.

It is therefore of extreme importance to monitor Oxidation Induction Time (OIT) and investigate any significant decrease from compound to pipe during manufacture, even if the pipe still meets the minimum OIT value per the standard. This is illustrated in the set of commercial pipe extrusion runs summarised in Table 3.

Modern PE100 compounds will exhibit a minimal drop in OIT performance if extruded at melt temperatures below 230°C.

Increasing the pipe size will typically result in a larger drop in OIT, as the material in a thicker wall takes longer to cool and the surface of the pipe is exposed to oxygen at an elevated temperature for longer.

Increasing extruder throughput will result in higher melt temperatures, which may also adversely impact OIT. However, the melt temperature of different pipe compounds react differently to increases in extruder throughput.

TABLE 3. INFLUENCE OF COMPOUND, MELT TEMPERATURE AND EXTRUDER THROUGHPUT ON OIT OF PIPE EXTRUSION PROCESS ON A BATTENFELD 120MM LINE. THE OIT VALUES ON PIPE ARE THE AVERAGE OF MEASUREMENTS TAKEN FROM THE INSIDE TOP AND INSIDE BOTTOM SAMPLE POSITIONS OF THE PIPE.

PIPE COMPOUND	PIPE SIZE	MELT TEMPERATURE (°C)	EXTRUDER THROUGHPUT (KG/HR)	OIT @ 200°C TO ISO 11357-6 (MIN)
Alkadyne HDF145B (discontinued grade)	Compound	–	–	80
	DN450 SDR13.6	200	800	78
	DN450 SDR13.6	206	1150	78
Alkadyne HDF193B	Compound	–	–	81
	DN450 SDR13.6	209	800	83
	DN450 SDR13.6	220	1000	74

REWORK LIMITATIONS

Given the risk profile of pressure pipe applications, only internal rework using the same grade of resin is allowed during pipe extrusion. To prevent the introduction of contamination that might compromise pipe quality and expected service life, the incorporation of external rework or reground decommissioned pipes is strictly prohibited. Ensuring the integrity of product representation is another reason that different polymer grades should not be mixed. Pressure pipe is a highly regulated infrastructure and construction market segment. New or modified pipe compound grades are only commercialised following the completion of extensive Type Testing programs. These programs cover testing for all performance properties and ensure that newly developed pipe compounds meet the application requirements.

MOISTURE CONTENT

High levels of volatile content in the resin (in practice this is predominantly water) can lead to holes in the pipe wall or cause an uneven surface on the internal wall of the pipe, resulting in non-compliant pipes (Figure 2). Carbon black is a hygroscopic material that absorbs water if stored for long periods of time without adequate precautions. The water will evaporate during the melting process but cannot escape until it exits the extrusion die. While most compound manufacturers have adequate procedures in place to dry the product below the standard requirement, moisture may be introduced during transport of the resin to the pipe manufacturer. This is a particular problem during sea freight across the equator, due to a phenomenon known as “container rain” that can cause the product to fall out of specification.[2] The last line of defence is to dry the resin at the pipe manufacturing site before it enters the extrusion process. An effective drying system heats the resin at an elevated temperature while blowing through an optimised flow of dehumidified air.

PERMITTED COMPOUND CLASSIFICATIONS

Pipes manufactured according to AS/NZS 4130 only allow the use of pipe compounds classified as PE100 or PE80. These two classes of compounds differ in terms of hydrostatic strength, rapid crack propagation resistance and resistance to slow crack growth.

Since PE100 has higher performance requirements than PE80 in all these areas, pipes made from PE100 for the same pressure class have a lower wall thickness or higher standard dimension ratio (SDR = nominal diameter/wall thickness).

HDPE pipe materials of different classification based on a single property are not recognised by pipe application standards in Australia or in any other country that adheres to ISO standards. Certain materials designated as PE112 can be used to make PE100 pipes if they meet the minimum requirements for a PE100 compound. However, the use of PE112 will not result in any design or performance benefit for standard compliant HDPE pressure pipes as operating the pipe beyond the maximum allowable operating pressure for PE100 is not covered by Australian or International pipe product standards. ISO technical committee TC138/ SC4 concluded in 2000 that no further standardisation work would be done on PE112.[3]

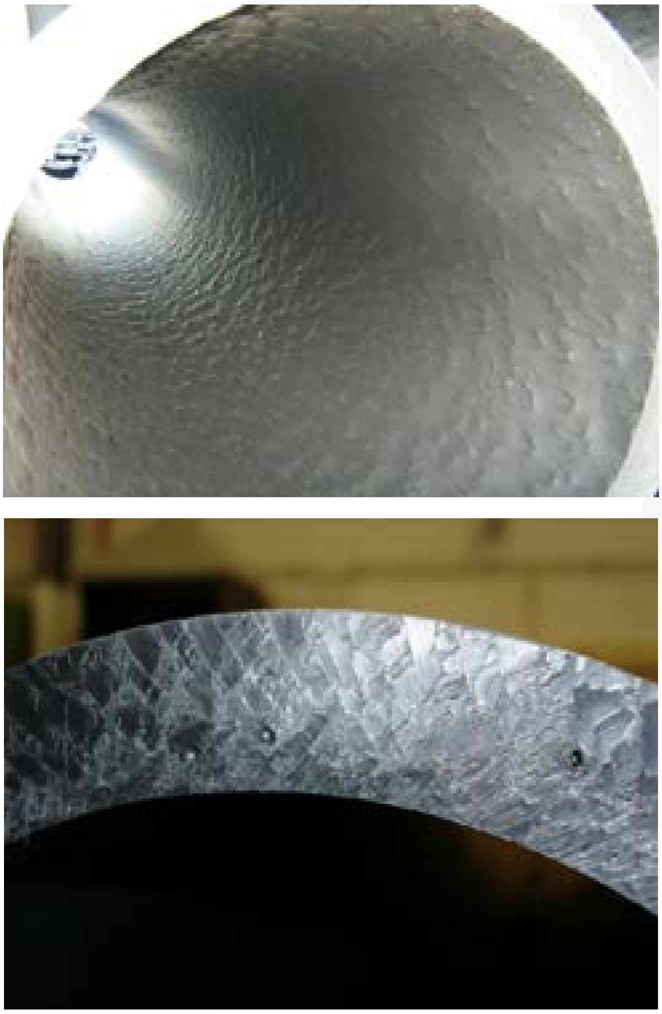

Figure 2. Example of pipe extruded from a resin with elevated moisture content resulting in uneven inner pipe wall (top) and holes in the pipe wall (bottom).

DIMENSIONAL TOLERANCES

Dimensional tolerances of pipes in terms of wall thickness variation and out of roundness are specified within AS/NZS 4130. While most modern pipe extrusion lines are capable of controlling these parameters within tight tolerances for wall thicknesses up to 60mm, manufacturing of large bore pipes with a greater wall thickness can still present a challenge, even to experienced manufacturers.

As polyethylene is a good thermal insulator, the time required to cool from the molten to the solid state increases with increasing wall thickness. During cooling, the molten polymer may be deformed by gravity or by an uneven flow, leading to slumping of the pipe (Figure 3).

Slumping can be avoided using a pipe compound with low slump properties. Low slump resins have a high melt strength which ensures that the shape of the die is maintained when the molten polymer exits the die head.

As larger pipe diameters and higher pressure ratings are becoming more commonplace, the requirement for tight dimensional tolerance control through low slump compounds is increasing.

Figure 3. **Example of DN500 PN25 pipe made with standard PE100 resin (top), showing severe slumping, and a pipe made within dimensional tolerance produced with a low slump PE100 resin (bottom).**

WATER QUALITY

It is essential that any pipe material used to distribute drinking water does not adversely impact the quality of the water. The AS/NZS 4020 standard requires that HDPE pipes (and other water contact products) are assessed for their effect on water. The test consists of exposing a fixed volume of cold water (<40°C) inside a small diameter pipe. The water extract is then tested for taste, appearance, toxicity and metal content. The results depend on the internal diameter of the pipe used in the test, as the surface contact area increases with decreasing diameter. Typically, a DN25 mm is used in the test, however, in practice HDPE pipe diameters as narrow as DN16 mm are used in water reticulation. Therefore, some end users will require water tests to be done on DN16 mm pipe, which represents the most challenging condition to meet the requirements of the AS/NZS 4020 standard.

HOW TO VERIFY CONFORMANCE

Given the highly technical nature of the requirements of pipe standards, third-party certification is a practical way for all actors in the pipe value chain to assess a material's conformance to the relevant standard. The standard also requires regular testing of products.

The test frequency depends on the test concerned, with some tests needed on every batch (Batch Release Test = BRT), some at an interval of 3 or 5 years (Process Verification Test = PVT), while some are only required when assessing a new or changed product (Type Test = TT).

Pressure pipe compounds are assessed upon application by PIPA (Plastic Industry Pipes Association of Australia) against AS/NZS 4131. If the compounds are compliant, they are listed in the POP004 guideline.[4]

The assessment also includes compliance with temperature rerating per POP013 and high stress-crack resistance (PE100 HSCR) per POP016. However, the listing does not guarantee that PVT or other tests are being undertaken at prescribed intervals, nor is there an audit of the manufacturing site.

Nonetheless, the POP004 list represents a credible and valuable check as to whether a pipe compound complies with the Australian standard.

Another way to verify compliance of pipes or compounds with the relevant standard is via Type Test Certification through a JAS-ANZ accredited certification body. These organisations assess conformance of a product to a recognised standard based on product tests from an ISO 17025 accredited test facility.

If requested, they will also perform an audit to assess the quality management plan to ensure the ongoing compliance of every batch produced. Type Test Certification allows manufacturers to use conformance statements and license marks on their product documentation to demonstrate product standard conformity along the value chain.

For plumbing products sold in Australia, certification is mandatory and regulated through the WaterMark of the Australian Building Codes Board (ABCB). WaterMark certification is available through accredited certification bodies.

The Water Services Association of Australia (WSAA) product appraisal scheme is a complementary program for infrastructure pipes. It assesses product conformity, design life and product use, including installation and maintenance.

EXCEEDING STANDARD PERFORMANCE

Product standards set the minimum requirements and any products that comply with the standards are expected to be fit for purpose in most applications that are covered by the standard. However, this does not mean that the product will be fit for purpose in every application and under all conditions encountered.

The use of HDPE pipe has become increasingly popular for industrial and mining applications where it can provide significant cost and performance benefits, such as corrosion resistance, rapid installation and abrasion resistance, compared to traditional materials. However, in many of these applications, temperatures will exceed the typical installation conditions of civil construction projects. Compliance to temperature rerating per PIPA POP013 will be important in these more-extreme applications. When high levels of temperature resistance are required, specialty PE100 Raised Temperature (RT) resins are available that can provide long term resistance to temperatures in excess of 70°C.

Pipe installation in urban environments is increasingly carried out using trenchless techniques such as horizontal directional drilling or pipe bursting. These installation methods put higher demands onto HDPE pipe due to the increased risk of damage to the pipe wall or presence of point loads that could lead to slow crack growth failure. Pipes with high stress-crack resistance made using a PE100 HSCR compound conforming to PIPA POP016 can mitigate such risks and will exhibit longer expected design life in such demanding installations.

Another environment in which conformance to minimum requirements is not sufficient to meet design life expectation is in applications where elevated water temperature and high disinfectant levels converge. Guidance on such conditions is given in PIPA POP018. In some cases, a material with a high resistance to disinfectants needs to be used to ensure fitness for purpose. Such materials and pipes are available for the Australian market and are being used where needed.

HOW THE RESIN MANUFACTURER CAN HELP

Resin manufacturers can support pipe manufacturers, contractors and asset owners to demonstrate or verify conformance of the compounds or pipes with the relevant standards through testing. The Qenos Technical Centre in Melbourne is well equipped with a wide variety of physical and chemical analysis techniques. It is accredited by NATA (accreditation numbers 2649 and 1914) for the majority of pipe test methods, including accreditation to ISO standards for resistance to internal pressure ISO 1167, long term hydrostatic strength ISO 9080, slow crack growth ISO 13479, and many others. Experienced technical service specialists at the Technical Centre can also analyse field samples to identify the resin used to make a pipe or assist in failure analysis.

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WHITE PAPER

HDPE PIPE IS HYDROGEN READY

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Find out how modern HDPE pipe networks support the safe and efficient distribution of hydrogen.
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Hydrogen derived from renewable energy is a highly promising low carbon fuel. Whilst the hydrogen economy has been slow to emerge, it is starting to attract significant interest due to its capacity to store and transport renewable energy. Existing natural gas distribution networks in Australia made from HDPE piping are a practical way to distribute hydrogen. Recent research supports safe and efficient hydrogen distribution through HDPE pipe networks with operating risks comparable to natural gas.

RENEWABLE ENERGY SOURCES SUCH AS WIND AND SOLAR ARE PROGRESSIVELY INCREASING THEIR SHARE IN THE ENERGY MIX. ADVANCES IN TECHNOLOGY ARE DRIVING DOWN THE COST CURVE, MAKING RENEWABLE ENERGY INCREASINGLY COMPETITIVE COMPARED TO TRADITIONAL (FOSSIL) ALTERNATIVES. ONE OF THE KEY CHALLENGES IS THE INTRINSIC INTERMITTENT NATURE OF WIND AND SOLAR. STORAGE OF EXCESS RENEWABLE ENERGY HARVESTED DURING SUNNY AND WINDY DAYS IS A KEY REQUIREMENT TO DECREASE THE DEPENDENCE ON FOSSIL RESOURCES AND TACKLE GLOBAL CLIMATE CHALLENGES. EXISTING HDPE GAS PIPE NETWORKS MAY PROVIDE A VIABLE OPTION AS STORAGE AND TRANSPORT CAPACITY FOR RENEWABLE ENERGY.

HDPE PIPE IS HYDROGEN READY

Renewable electricity may be used to produce hydrogen from water by electrolysis with pure oxygen as the only by product. Hydrogen may be used in fuel cells to power electric vehicles but can also be used as alternative to natural gas in power plants, homes and businesses. Importantly, natural gas distribution networks may act as a storage for excess hydrogen, similar to a battery. Trials are currently ongoing in NSW, SA, ACT, and WA to test whether networks and appliances are able to cope with natural gas containing hydrogen at 10% or more. This requires existing gas networks to be compatible with hydrogen. As the majority of natural gas networks in Australia rely on HDPE piping today, the latest research focuses on the suitability of HDPE piping for the transport of hydrogen gas.

Kiwa Technology, one of the world's leading laboratories for plastic pipe testing and research, in collaboration with Groningen Seaports in the Netherlands investigated the suitability of the latest generation HDPE pipe (PE100 HSCR) for the transport of pure hydrogen gas and published their findings in a paper presented at the 2018 Plastic Pipe Conference.[1] The study focused on the chemical resistance of HDPE to hydrogen, the permeation rate of hydrogen through HDPE and the electrofusion coupling of HDPE pipe segments exposed to hydrogen.

The chemical resistance of HDPE to hydrogen was tested by exposure of ring shaped specimens cut from a DN90 SDR11 PE100 HSCR pipe to hydrogen at a pressure of 2 bar for 1,000 hours whilst subjected to constant deformation at room temperature. The ring specimens were subsequently weighed and a tensile test was performed to investigate any change in mass or strength as a result of chemical attack. The results indicated no significant change in mass or tensile strength thus supporting the case that HDPE is inert to hydrogen.

Figure 1. **Peel test setup as per ISO 13954**

One of the strengths of HDPE piping is its ability to be repaired via electrofusion jointing. To ensure that HDPE pipe networks containing hydrogen maintain this ability, pipe sections of the same type described above were exposed to hydrogen at a pressure of 2 bar for 1,000 hours at room temperature. Subsequently, these sections were fused via an electrofusion coupler in accordance with the Dutch welding standard NTA 8828:2016. Tensile specimens were cut from the joints and then examined by visual inspection and using the peel test in accordance with ISO 13954 (Figure 1). No cavities were found in any of the test bars and the peel test resulted in ductile failure of the pipe itself rather than across the joint, indicating no detrimental effect of hydrogen on the ability of HDPE piping to be repaired after exposure to hydrogen.

Figure 2. **Permeation experimental setup in which the PE pipe (black with yellow stripes) is capped and pressurised whilst permeation is measured by gas chromatography in a stainless steel jacket pipe.**

Concerns have been raised about the ability of hydrogen to permeate through piping materials as hydrogen molecules are very small. Small molecules are able to permeate through any solid membrane, including pipe walls whether made from metal, concrete or plastic. The rate of permeation is determined by many factors including the size of the permeating molecule. Molecular hydrogen H_2 has a kinetic diameter of 2.89 Å whereas methane CH_4 has a kinetic diameter of 3.8 Å.

IT WAS SHOWN THROUGH PROLONGED EXPOSURE AND SUBSEQUENT MECHANICAL TESTING THAT HYDROGEN DOES NOT AFFECT THE INTEGRITY OF THE HDPE PIPE OR ITS ABILITY TO BE REPAIRED OR MAINTAINED THROUGH ELECTROFUSION JOINTING.

The Kiwa study revealed a permeation coefficient of 127 ml mm m^{-2} $bara^{-1}$ day^{-1} for hydrogen through HDPE at room temperature, which is roughly two times higher compared to methane at 56 ml mm m^{-2} $bara^{-1}$ day^{-1} (Figure 2). A DN90 mm SDR11 pipe operated at a hydrogen pressure of 2 bar would emit 4,360 litres of hydrogen per km per year. In comparison, the same pipeline transporting methane would emit 1,930 litres of methane per km per year (Figure 3). Gas loss through permeation for natural gas networks made form HDPE is considered negligible in comparison to the amount of gas that is being transported. This property does not differ significantly in the case of hydrogen.

In this context it is useful to take into account the lower energy density in terms of net heating value of hydrogen (10.81 MJ/m^3) compared to natural gas (36.65 MJ/m^3).[2] Considering also the lower operating temperature relative to research work, which is typically below 20°C for buried pipes, it is estimated that energy losses through hydrogen permeation are actually 30% lower for hydrogen compared to natural gas at equivalent network pressure (Figure 3).

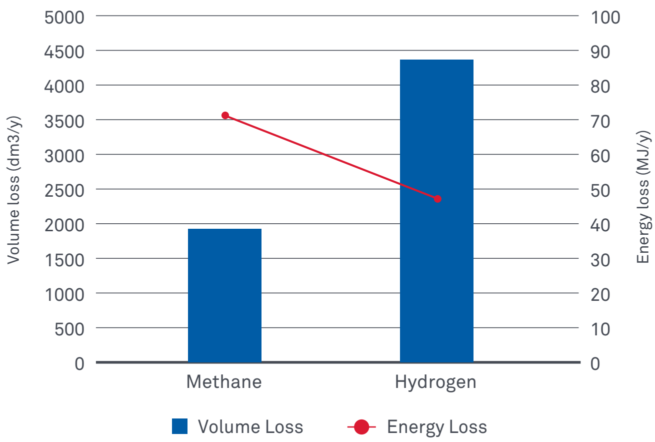

Figure 3. **Volume and energy loss per year through permeation for a 1km long DN90mm SDR11 pipeline operated at 2 bar transporting either methane (natural gas) or hydrogen at room temperature.**

The study concludes that when taking into account the different characteristics of methane and hydrogen, the operating risks relating to material integrity, network repair and maintenance, and gas permeability of HDPE networks are comparable.

The study indicates that modern HDPE pipe networks are fit for purpose for the transport of pure hydrogen at pressures up to at least 200 kPa, taking into account the specific characteristics of hydrogen such as its different chemical compatibility, higher rate of permeation and lower energy density that distinguish it from natural gas when adapting work procedures and safety instructions. This research strongly supports the ongoing trials in Australia where renewable hydrogen is injected to complement methane in HDPE natural gas networks.

References

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HOW THE RESIN MANUFACTURER CAN HELP

Transport of combustible gases and fluids remains a high risk application for polyethylene pipes, which is addressed through prescribed conservative design factors. Nonetheless, added robustness of the pipe may be required in trenchless installations, high risk areas or where squeeze-off is extensively used. This may be achieved through the selection of a polyethylene material with high stress crack resistance. Research and field performance identified resistance to Slow Crack Growth as the primary mechanism controlling service life in gas piping applications.

QENOS has developed Alkadyne® HCR193B – a new class of PE100 grade resin with stress crack resistance many times greater than standard PE100 resin. Developed in partnership with Australian pipe manufacturers, Alkadyne HCR193B has increased resistance to slow crack growth initiation caused by the presence of stress concentrators. The exceptional resistance to slow crack growth of Alkadyne HCR193B provides asset owners with greater confidence and a greater safety margin in trenchless installations and when utilising squeeze-off.

WHITE PAPER

THE NEXT GENERATION PE PIPE RESIN

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Learn about new PE100 specialty materials and the pipe resins of the future
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Polyethylene materials used in pressure pipe networks have a rich history of innovation extending over several decades. Continuous development has enabled manufacturers of PE products to address new applications and to develop new markets. PE100 is still the most advanced resin in terms of pressure rating. Various subclasses have been developed that have increased its suitability for large diameter pipes, trenchless installations, elevated temperatures, and environments containing high concentrations of disinfectants. The next generation resin – PE125 – is expected within the next 10-years. When the material becomes available, an industry wide effort will be required to define and agree the performance and installation standards. Asset owners will certainly benefit from its higher application pressure rating, lower material costs, and longer asset lifetime.

OVER THE LAST 70 YEARS, PLASTIC PIPING MATERIALS HAVE TRANSFORMED CIVIL ENGINEERING PRACTICES. COMPARED TO TRADITIONAL MATERIALS SUCH AS CONCRETE, CLAY, STEEL OR DUCTILE IRON, PLASTIC PIPES ARE FASTER TO INSTALL, HAVE LOWER FAILURE RATES, AND LAST LONGER. POLYETHYLENE (PE) HAS EMERGED AS THE MATERIAL OF CHOICE FOR GAS DISTRIBUTION, MINING, AND LARGE DIAMETER WATER PIPES, ESPECIALLY WHEN COMBINED WITH TRENCHLESS PIPE INSTALLATION. THIS WIDE ADOPTION IS DUE TO PE PIPING'S FLEXIBILITY, RESISTANCE TO CORROSION, WELDED JOINTS THAT ARE AS ROBUST AS THE PIPE ITSELF, AND EXCELLENT RESISTANCE TO SLOW CRACK GROWTH (SCG).

Evolution of the material's properties has played a central role in the continued success of PE piping systems. The first PE pipes used in Australia in the 1950's were based on HDPE Type 50. These early pipes were used for irrigation and mining, and in the 1960's for gas distribution.[1] The "50" designates a minimum required strength (MRS) of 5 MPa. This rating is an indication of the material's resistance to internal pressure when it is extruded into a pipe with a minimum design life of 50 years at 20°C. PE80 compounds were introduced in the 1980's. With an MRS of 8 MPa, the maximum allowed operating pressure (MAOP) rating of the pipes was raised. In the 1990's, PE100 was developed with an MRS of 10 MPa and an MAOP of 2500 kPa for water applications and 1000 kPa for gas use.

These more advanced materials not only provided pipes with higher pressure ratings but also enabled a reduction in the wall thickness for lower pressure rated pipes, improving the overall cost efficiency of the network. The ratio between wall thickness and pipe diameter is defined as the standard dimension ratio (SDR). The SDR has been standardised to ensure compatibility between piping components.[2] The higher the SDR, the lower the relative wall thickness of the pipe.

It is important to note that every increase in a material's resistance to internal pressure must be accompanied by an increase in the resistance against other potential modes of failure. Apart from third party damage, the most commonly observed mode of pipe failure in the field is "brittle" failure due to SCG. Review of the pipe failure statistics in Australia for early generation pipe resins *e.g.* in gas distribution, shows a failure rate of approximately 200 to 300 per annum. The highest percentage failure in 1983 was due to point loading (64%), whereas the highest percentage in 1986 was due to mechanical damage (66%). Mechanical damage and point loading accounted for the vast majority of identified PE pipe failures over the period.[3]

As the stress in the pipe wall increases with pressure, the pipe becomes more sensitive to crack initiation and growth. Consequently, PE100 pipes must pass more stringent specifications for SCG; for example at least 500 hours in the notched pipe test at 920 kPa compared to PE80, which is tested at 800 kPa.[4,5]

Another mode of failure that must always be considered during PE resin development is rapid crack propagation (RCP). RCP is of concern in applications where high internal gas pressure is combined with low application temperature, and so this additional requirement was introduced when PE100 was developed.

Figure 1 provides an overview of the relative improvements of the critical material properties of PE resins used for pressure pipe applications.

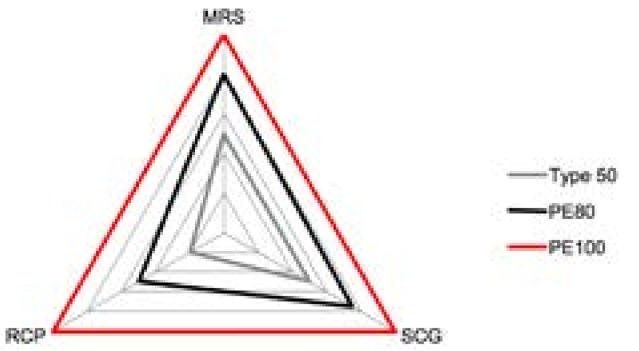

Figure 1. Evolution of PE pressure pipe resins with respect to minimum required strength (MRS), slow crack growth (SCG), and rapid crack propagation (RCP). Relative scales have been applied.

Another important factor in PE resin development is its resistance against long term oxidative degradation. Sophisticated stabilisation packages have been developed for the latest generation PE100 materials that offer protection for over 100 years, under normal service conditions. When temperatures exceed 20°C and/or pipes are used to transport water containing high concentrations of chlorine-based disinfectants, oxidation is accelerated and pipe-lifetime is reduced.

A key aspect in the development and market acceptance of polyethylene pipes is that standards keep pace with advancements in material performance. Product performance standards link the requirements for the material, pipes, fittings, valves and fitness for purpose, *i.e.* testing of the jointed components of the system. Before engineers can apply design factors based on new materials, the implications of the new material performance must be considered in the context of the piping system as a whole. The framework of international standards ISO 4437/4427, Australian and New Zealand AS/NZS 4131/4130 standards, in combination with National Codes such as the Water Services Association of Australia (WSAA) polyethylene pipeline code, or the Coal Seam Gas industry code of practice (CoP), underpins the integrity of current and future pipeline networks.[6,7]

Nearly 30 years after its initial introduction to the market, most PE piping systems are manufactured using PE100 or its analogue PE4710 in North America. But "what's next?" This paper provides an overview of the new developments within the PE100 class of compounds and discusses the potential benefits of the next generation of PE pipe materials.

INNOVATION WITHIN THE PE100 CLASS

As polyethylene pipe resins based on the PE100 material class have developed, various acronyms have been introduced. The main ones are clarified here and the performance of the different grades of PE100 are summarised in Figure 2.

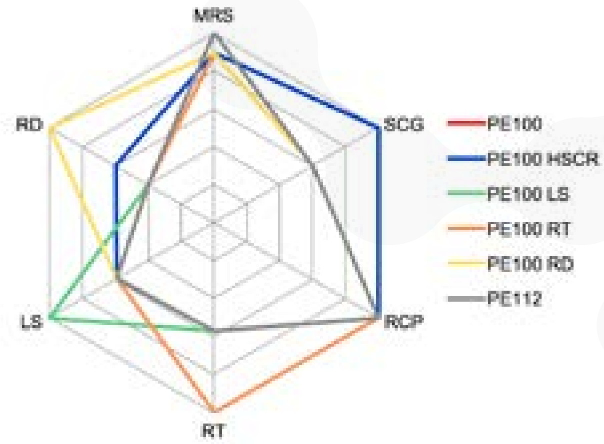

Figure 2. Property balance for PE100 specialty resins optimised to operate under specific conditions. RT = Temperature Resistance, LS = Low Slump, RD = Resistance to Disinfectants.

PE100 LS (Low Slump)

The higher-pressure characteristics of PE100 have enabled its use in water mains systems requiring diameters above 750 mm, for example. When the pipe wall thickness for large diameter-pipe in PN16-rated pipe networks exceeds 80 mm, control over dimensional tolerances becomes challenging, as gravity causes the molten PE to flow downwards after exiting the extrusion die, before fully solidifying. This "slumping" or "sagging" leads to a non-uniform wall-thickness distribution, which cannot be tolerated in pressurised pipe applications. Slumping is especially an issue for thick-walled pipes as the PE takes longer to solidify.[8]

Resin manufacturers developed "low slump" resins to address this market need. The modified rheology of these resins delivers exceptional melt strength, allowing pipes with up to 135 mm wall thickness to be manufactured. Installation of PN16 water mains with 1200 mm diameter are becoming commonplace in Australia.[9]

PE100 HSCR (High Stress Crack Resistant)

Trenchless pipeline installation reduces traffic disruption and community impact, making it increasingly popular for civil works in urban environments. PE100 is exceptionally well suited to horizontal directional drilling due to its toughness and flexibility, allowing sharper bends than other materials thus reducing bore length and cost. To account for the higher potential of damaging the pipe with notches or gauges that may lead to SCG, additional safety factors are applied.[10]

PE100 HSCR has been developed to provide a much higher safety margin to failure by SCG. It provides more than 5000 hours before failure in the notched pipe test, representing a tenfold increase compared to conventional PE100.[4] PE100 HSCR is now fully specified in the POP016 guideline published by the Plastics Industry Pipe Association of Australia (PIPA). It is also incorporated into installation standards, allowing design engineers to take advantage of higher system design life or opt for "fit for purpose" design alternatives using lower wall thickness.[11] The material characteristics are similar to PE100 RC (Resistant to Crack) resins that are defined in the publicly available specification DIN PAS 1075.[12]

> “ IT IS IMPORTANT TO START THE DISCUSSION ON PERFORMANCE SPECIFICATIONS FOR PE125 MATERIALS SO THAT ENGINEERS CAN TAKE FULL ADVANTAGE OF THE NEW MATERIALS AS SOON AS THEY BECOME AVAILABLE.

PE100 RT (Raised Temperature)

The design base for PE100 is a 50-year lifetime at 20°C. When buried with an adequate depth of cover, PE pipelines in moderate climates will not experience temperatures higher than 20°C. PE100 is increasingly used in industrial applications, particularly in the oil and gas industry.[13] While regular PE100 can be used at temperatures up to 60°C, additional design safety factors apply and lifetimes are reduced. For example at 60°C, using the temperature rerating table in PIPA's POP013 guideline, the pipe lifetime would be shortened to only 7 years.[14]

Polymer technology first used for plumbing and heating pipes has been incorporated into a fully PE100 compliant pressure pipe resin designated PE100 RT.[15] This recently developed material exhibits higher strength at elevated temperatures, allowing a reduction of safety factors. With an extrapolated lifetime over 60 years at 60°C, PE100 RT is ideally suited to high temperature applications typical of the coal seam gas industry, high voltage cable ducting, and Artesian bore water extraction. Guidance for pipeline design using PE100 RT materials is given in the recently updated ISO 15494 standard for industrial piping systems.[16]

PE100 RD (Resistant to Disinfectants)

Polyethylene pipes have been used in drinking water distribution networks for over 70 years. PE pipe resins are generally resistant to the low concentrations of chlorine-based disinfectants used to ensure potable water quality and safety standards. However, in certain regions of the world like Southern France and Northern Italy more aggressive disinfectants such as chlorine dioxide have been introduced into water reticulation systems, leading to premature failure of PE pipelines.[17] Similarly, very high concentrations of hypochlorite in combination with elevated water temperatures are also thought to shorten the lifetime of PE100 pipes.[18]

PE100 RD is a new resin that has been specifically developed to tolerate aggressive disinfection environments. Its increased resistance compared to regular PE100 has been demonstrated in accelerated aging experiments.[17] The use of PE100 RD is now specified in regions where chlorine dioxide is routinely added to drinking water. It is also a suitable option for water networks that require high concentrations of disinfectant.

PE112

Classification of plastic pipe materials (PE, PVC, PA, etc) used for pressure applications is governed by ISO 12162. The standard also includes nomenclature for materials with an MRS of 1 to 50 MPa.[19] The MRS classification is based on the lower confidence limit (σ_{LPL}) of hoop strength at 20°C for 50 years, which is derived from the extrapolation based on ISO 9080.[20] A polyethylene material with a σ_{LPL} value between 8 and 10 MPa is classified as PE80; while PE100 has a σ_{LPL} between 10 and 11.2 MPa. The σ_{LPL} at 20°C for 50 years of most commercially available PE100 resins is well above 10 MPa, thus offering an additional safety margin. The σ_{LPL} at 20°C for 50 years of some pipe resins is 11.3 MPa, which falls into the next defined class of 11.2 to 12.5 MPa. According to ISO 12162, these materials are designated as PE112.

Despite the higher MRS rating of PE112, the material does not allow increasing the MAOP or downgauging of the wall thickness for standard compliant pressure pipes as there is no provision for PE112 resins in the relevant product and installation standards.[21] For example, some polyethylene grades may have an MRS rating of 10 MPa but this does not automatically mean that the product can be classified as PE100. To be nominated as a PE100 resin, the product must meet all the specifications for all the different properties, as detailed in product standards such as ISO 4427/4437 and AS/NZS 4131/4130. ISO 12162 is also clear on this point and states in its introduction: "The classification in this International Standard does not qualify a material for a specific application. For specific applications, the relevant product standards require that additional mechanical and physical properties be met." For example, for pressurised transport of fluids, higher resistance to SCG and RCP may be required to take advantage of the higher MRS rating of PE112.

The gain in strength of PE112 is insufficient to permit a shift in SDR. As an example, a PN16 rated PE100 pipe for water requires an SDR of 11. The next pipe size up, with a lower wall thickness, is SDR 13.6, but this would give for PE112 a PN14.2 rated pipe. Part of the rapid success of PE80 and PE100 when introduced to the market, was the fact that the pipes still conformed to standardised dimensions as defined by SDR. Grouping pipes by SDR is efficient in terms of manufacturing costs and system assembly compatibility e.g. using jointing systems such as electrofusion components which are also defined by SDR. Minimal investment in new tooling was required by pipe manufacturers switching to PE80 or PE100 resins; welding compatibility was also maintained. Unfortunately, this is not the case for PE112 if alternative pipe sizes must be employed to take advantage of its higher strength.[22]

The next logical step in MRS is PE125, which would enable a PN16 rated pipe to be manufactured using SDR 13.6. This rationale was discussed by the ISO technical committee TC138/SC4 in 2000. The committee agreed that the next product standard classification for a PE pressure pipe grade will be PE125, and that no further standardisation work would be done on PE112.[23]

THE NEXT GENERATION: PE125

To downgauge pipe wall thickness by a full SDR size, the next generation of PE pressure pipe resin would require an MRS of at least 12.5 MPa. Such a resin would be classified as PE125 (Figure 3). Moreover, this material could raise the MAOP of polyethylene pipes, with an SDR of 7.4, to 3120 kPa and 1950 kPa for water and gas, respectively. These values take into account the commonly used safety factors of 1.25 (water) and 2.0 (gas). However, before its introduction, meaningful performance requirements for PE125 will need to be developed and incorporated into product standards ISO4427/4437 and AS/NZS 4131/4130. This approach would greatly facilitate the use of PE125 in the field.

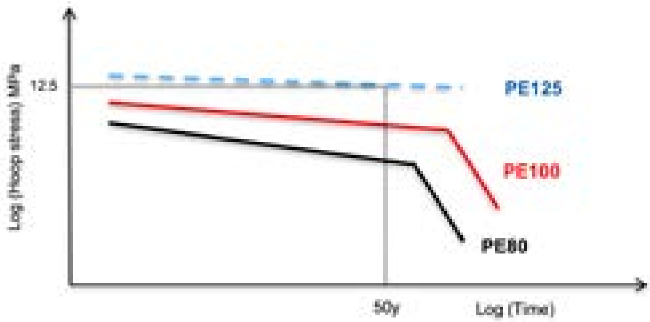

Figure 3. Hydrostatic strength curves (σ_{LPL}) at 20°C for PE80, PE100, and PE125 (projected).

The higher pressure rating and lower wall thickness of pipes made from PE125 will impact on installation methods. The extension of current welding techniques will need to be validated for PE125. Electrofusion fittings, valves, and other injection moulded components of the piping network may need to be produced from PE125. In these cases, the resin will need to exhibit the appropriate material flowability and mould shrinkage characteristics. When PE100 was first introduced, production of injection moulded fittings became more complicated and still only a few companies are able to manufacture these accessories. Other jointing techniques may emerge for PE125, *e.g.* a method based on pull resistant push-fit couplings suitable for large diameter pressure pipes. Ring stiffness and tensile strength will also need to be considered when reducing wall thickness further, particularly for small diameter pipes.

Although no PE125 resins are available commercially, a number of corporate and academic R&D laboratories around the world are working on the development of the new class of materials. In fact, PE125 resins are expected to be commercialised within a decade. To take advantage of the performance benefits offered by the next generation of pipe resin, it is important to start the discussion on performance specifications for PE125 materials. Early engagement of all stakeholders is especially important as the development of a new framework of pipe system standards is a lengthy process.

CONCLUSION

PE100 remains the most advanced class of commercially available polyethylene resin for pressure pipe applications. Ongoing innovation and developments of specialty resins that increase the performance for a specific property have seen the application range of PE100 broaden to accommodate larger bores, trenchless installations, higher temperatures, and more aggressive media.

The next generation of PE pipe resin, PE125, may not be available for several years. However, it is useful for the industry to consider the expected performance and installation standards of the new resin so that engineers can take full advantage of the new materials, as soon as they become available.

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WHITE PAPER

PE100 HSCR FOR TRENCHLESS PIPELINE INSTALLATIONS

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Dr. Jeroen Wassenaar
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August 2017

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Find out how PE100 HSCR provides pipelines with a higher safety margin against slow crack growth failure and enables "fit for purpose" design.
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THE DEPTH OF NOTCHES IN POLYETHYLENE PIPELINES ARE LIMITED TO 10% OF THE WALL THICKNESS TO ENSURE AN ADEQUATE SAFETY MARGIN AGAINST FAILURE FROM SLOW CRACK GROWTH. PE100 HSCR PROVIDES HIGHER PROTECTION AGAINST THIS TYPE OF FAILURE EVEN AT NOTCH DEPTHS OF 30% OF THE WALL THICKNESS.

Trenchless installation of polyethylene pipes is steadily gaining market acceptance as a method that provides both improved cost efficiency and reduced disturbance to the community and environs. However the increased exposure of the pipe surface to damage that is inherent in many of the trenchless techniques may lead to an increase in the potential for premature failure from slow crack growth linked to damage to the surface of the pipe. Engineers commonly specify thicker walled pipes in trenchless installations to lower the risk that any surface defects exceed 10% of the pipe wall thickness. PE100 HSCR, a new class of PE100 resin with High Stress Crack Resistance, enables the use of less conservative pipeline design safety factors in trenchless installations, thereby reducing material usage, improving flow characteristics and shortening welding time.

Polyethylene (PE) has a track record spanning over 50 years in pipeline applications and exhibits one of the lowest failure rates amongst pipe materials. Nonetheless, failures do occur and research indicates that the greatest threat to the structural integrity of a pipeline comes from external interference. Such damage can occur during installation or afterwards when for example excavation works are being carried out in the vicinity of the pipeline. PE pipes need to sustain their pressure loading for many years and show long-term resistance to creep rupture through "ductile" failure. However, as fairly conservative safety factors are used in pipe design, PE pipes have a large safety margin for pressure bearing capability and do not fail in over pressured "ductile" mode in real life operations.

The most common mode of failure for pressure pipes in service is "brittle" failure through the slow crack growth (SCG) failure mechanism. A slow growing crack may initiate and grow in the presence of a localised stress field, leading to failure within the expected service life of the pipeline. Crack initiation can be the result of damage to the pipe during transport, trenchless installation (scores, scratches and gouges), or later in service resulting from point loading due to rock or root impingement. Bending caused by ground movement can also impose additional stress on the pipe, thereby accelerating crack growth. Consequently, the resistance of the base PE to the initiation and subsequent growth of cracks originating from localised stress points is a key determinant in ensuring the long service life of PE pipelines.

Pipeline integrity is dependent on the design, operation and management of the pipeline. A safe pipeline starts with good design and the selection of a polyethylene pipe resin with sufficient stress crack resistance to enable it to withstand the demands of the installation and ongoing operation.

A rule of thumb has long been relied upon to minimise the likelihood of premature failure due to slow crack growth. This rule has been specified into installation standards and limits the maximum allowable depth of scratches, indentations and dents in PE pipe during installation to 10% of the wall thickness.

> THE RESISTANCE OF THE BASE PE TO THE INITIATION AND SUBSEQUENT GROWTH OF CRACKS ORIGINATING FROM LOCALISED STRESS POINTS IS A KEY DETERMINANT IN ENSURING THE LONG SERVICE LIFE OF PE PIPELINES.

WHAT ARE THE CONCERNS?

Trenchless installation techniques such as pipe bursting, slip- and swage-lining, and horizontal directional drilling, bring installation advantages both in cost efficiency and in minimising disturbance to the environment where the pipe installation is taking place. However these techniques have the potential to cause damage to the surface of the pipe, which could compromise pipe service life. For example in the pipe bursting process, the new pipe is exposed to potential damage arising from contact with the pipe being replaced, typically through contact with fragments of cast iron, clay or reinforced concrete pipe.

ASTT has published guidelines for trenchless construction (ASTT, 2009) which states in relation to pipe bursting[1]; *"Exterior pipe damage assessment is difficult to carry out and detect once installation is completed. Inspection for exterior damage should be carried out prior to installation to ensure the integrity of the pipe. Hydrostatic testing should also be performed prior to installing the pipe to ensure any defects are addressed. One of the common practice testing techniques is to pull out 2 – 7m of pipe and examine it after installation from the receiving chamber. This front section of the pipe tends to receive the most impact and damage from the installation process and is used as a guide for determining the general condition of the rest of the pipe."*

These guidelines, whilst useful and adopted in practice, only partially address the potential for damage. The assumption that the "front section of the pipe tends to receive the most impact and damage" is not always the case. Scratches in the surface of the pipe are localised areas of stress concentration that may lead to eventual failure arising from slow crack growth. While the practice of examining the leading end of the inserted pipe as it exits provides a degree of confidence, the examination does not ensure that there is no further damage. In addition, hydrostatic testing is a short term test method and cannot reveal the type of damage to PE100 pipe that is linked to the long term slow crack growth failure mode.

Concerns regarding the effects of surface damage may be addressed by the use of sacrificial pipe jackets. This approach adds cost and introduces the risk of interface de-cohesion which has been known to occur in multilayer pipes.

Pipeline designers looking for a greater level of certainty may choose to use higher safety factors which specify thicker pipe walls. In the horizontal directional drilling (HDD) of large bore pipes, SDR11 is typically sufficient to accommodate the high pulling forces and eliminate the risk of buckling. In cases where there is particular concern about pipe damage during installation the designer may choose to specify SDR9 pipes, though this will reduce throughput capacity and increase project costs.

HOW IS THE TOLERANCE TO SLOW CRACK GROWTH CAUSED BY NOTCHES MEASURED?

For PE100, AS/NZS 4131 requires a minimum of 500 hours at a stress of 920 kPa in the notched pipe test on SDR11 pipe in accordance with ISO 13479. In this test the pipe sample is notched in a standardized procedure to 20% of pipe wall thickness. The pipe is then pressurized to a stress of 920 kPa at 80°C and the time to brittle failure is recorded.

For PE100 HSCR (High Stress Crack Resistant), PIPA guideline POP016 outlines the following requirements[2]:

These additional requirements warrant that PE100 HSCR has a slow crack growth resistance that is significantly higher than that of conventional PE100.

Test	Minimum Requirement
NPT	5000 hours at a stress of 920 kPa in the notched pipe test (NPT) on SDR11 pipe in accordance with ISO 13479
FNCT	8760 hours in the full notch creep test (FNCT) according to ISO 16770
2NCT	3300 hours in the 2 notch creep test (2NCT) according to EN 12814-3
PLT	8760 hours in the point load test (PLT) according to DIN PAS 1075

HOW PE100 HSCR PROTECTS AGAINST SLOW CRACK GROWTH

Notch depth testing program

In order to assess performance with deeper notches, Qenos tested Alkadyne® HCR193B – a PE100 HSCR listed in PIPA guideline POP004[3] – in the notched pipe test with notches of depth greater than the standard 20%. The Notch Pipe Test simulates the damage that may occur during the installation of the pipe. This more aggressive test was designed to determine whether pipe made using Alkadyne® HCR193B could withstand deeper notches at test times beyond that required by the standard (AS/NZS 4131). All tests were conducted at 80°C and at 920 kPa internal pressure as required by AS/NZS 4131.

This test revealed that Alkadyne® HCR193B exceeds the slow crack growth resistance specifications for PE100 even with notches at 30% of the wall thickness as shown in Figure 1. This data supports the case for using PE100 HSCR in trenchless installations where there is a risk of deeper notches.

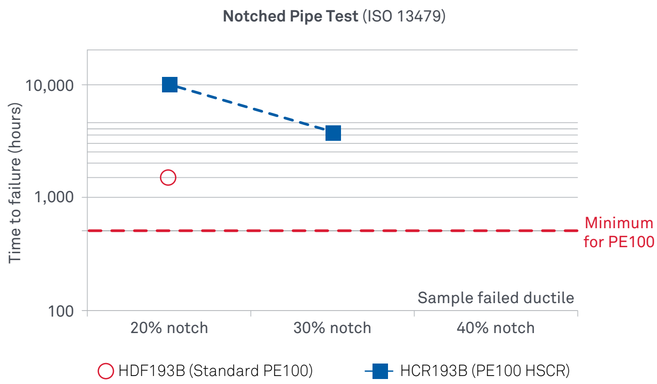

Figure 1: Notched Pipe Test according to ISO 13479 with varying notch depth. Test covered 110 mm SDR11 pipes with varied notch depth tested in hydrostatic pressure test at 920 kPa/80°C.

“Fit for purpose” pipe design

The additional safety margin for slow crack growth resistance provided by PE100 HSCR opens the door to rethink “fit for purpose” pipe design. The practice of increasing wall thickness (specifying a lower SDR) to address concerns of potential failure through the slow crack growth mechanism may be unnecessary when using PE100 HSCR.

Installation standards such as the newly released APGA code of practice for upstream PE gathering networks in the CSG industry allow for “fit for purpose” design when materials other than conventional PE100 are used[4]. Pipes made from Alkadyne® HCR193B featuring DN110 mm with varying wall thickness have been evaluated in the notched pipe test with a constant notch depth of 2.1 mm, as shown in Figure 2. The results indicate that a pipe made from HCR193B with SDR13.6 exhibits an equal or higher safety margin to slow crack growth failure compared to standard PE100 SDR11 pipe with the same notch depth.

In the prior example of large bore pipes installed by HDD, the selective use of PE100 HSCR in the sections of the pipe most vulnerable to damage could enable the use of SDR11 across the entire installation. In addition to reducing material usage, improving flow characteristics and shortening butt welding time, this would eliminate the requirement for adapters to connect the sections with different SDR and significantly reduce installation time.

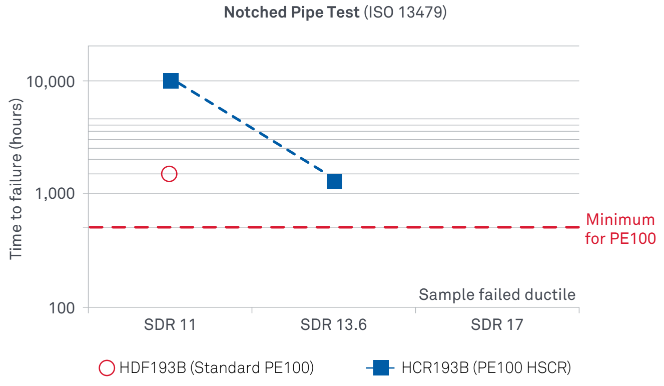

Figure 2: Notched Pipe Test ISO according to ISO13479 with varying wall thickness. Test covered 110 mm pipes of varying wall thickness with constant notch depth of 2.1 mm tested in hydrostatic pressure test at 920 kPa/80°C.

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WHITE PAPER

IMPORTANCE OF MATERIAL PROPERTIES DATA IN POLYETHYLENE PIPE DESIGN

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February 2017

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Find out about how material data supplied by PE resin manufacturers leads to more cost-efficient pipelines
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BY APPLYING THE ACTUAL PERFORMANCE DATA OF THE SELECTED PE100 RESIN WHEN DERATING OR APPLYING OF RISK FACTORS, PIPELINE ENGINEERS CAN BENEFIT FROM THE IMPROVED PERFORMANCE OF ADVANCED PE100 RESINS AND DESIGN MORE COST-EFFICIENT AND HIGHER PERFORMING PIPELINES – POTENTIALLY SAVING THOUSANDS OF DOLLARS.

Increasingly, engineers are specifying polyethylene pipe in new or replacement networks for the transport of water or gas.

Once the material and installation technique have been selected, engineers apply industry standard formulas to design the diameter and wall thickness of the PE pipe that will be suitable for the flow and pressure required for the network.

Risk factors are then applied to account for any potential risks that may be encountered by the pipe during installation or in use.

Often, pipe engineers use generic, base-line data to apply risk factors that "de-rate" the pipe – adding to the wall thickness and material costs.

WHAT ARE THE CHALLENGES THAT ENGINEERS FACE WHEN DESIGNING PIPELINES?

To ensure minimum design, construction and safety standards are met, it is common practice for engineers to follow prescribed guidelines set out in industry standards. The standards and procedures cover product and installation specifications relevant to the requirements of the application. However, following this prescribed design route may result in the addition of unnecessary costs or less than optimal operating conditions since:

- Not all PE100 grade pipes are the same. It is important to know the specific performance criteria of the PE100 resin used to produce the piping in order to optimize design.
- Opportunities to design for purpose – taking account of pressure, flow, temperature, installation and location conditions and based on actual material data – are missed.
- Purchasing PE100 grade pipe without establishing a relationship with the supplier could impede flow of valuable information.

Pipe diameter and wall thickness are key characteristics of pipeline design that impact on all project-related costs from materials and manufacturing, to transport and installation. Understanding the actual properties of the PE material mitigates against over-specifying the pipeline at the design stage – especially the wall thickness specification or operating conditions– while ensuring optimum, safe performance.

WHAT PROPERTIES ARE IMPORTANT TO CONSIDER?

The latest grade of high-density polyethylene PE100 resins offer engineers the opportunity to design pipe networks using the 'fit for purpose' method rather than follow a prescribed route. This approach is used extensively in the coal seam gas (CSG) industry and is equally beneficial for water and gas supply, mining, irrigation and waste management industries.

> USING ACTUAL PE MATERIAL DATA ALLOWS ENGINEERS TO DESIGN MORE COST-EFFICIENT PIPELINES – POTENTIALLY SAVING THOUSANDS OF DOLLARS

Since they were first introduced in the 1960s, the physical properties of PE pipe materials have continued to evolve. In addition to improvements in the Minimum Required Strength (MRS) rating, developments in the polymerisation process of some resins have led to an increase in resistance to both slow crack growth and rapid crack propagation and these materials now provide improved performance at elevated temperatures – all important properties that affect the final performance of the pipe beyond the generic class of PE100 resins.

WHAT IS THE DIFFERENCE BETWEEN PRESCRIBED DESIGN AND FIT FOR PURPOSE DESIGN?

In Australia, industries such as water distribution or coal seam gas extraction issue national codes and regulations which include product and installation specifications relevant to the requirements of the particular segment. The industry agency can make decisions independently of the prescribed design approach provided it is supported by the most up-to-date technical knowledge and operational practice. For example, the code of practice used in the coal seam gas industry allows "Prescribed Design" and "Fit for Purpose Design" to be used individually or together to complete a pipeline design [1].

Prescribed Design uses a series of formulae and tables derived from theoretical considerations and industry standard practice. Typically, industry standards specify the physical properties of pipes used to transport fluids under pressure. Specifications are provided regarding dimensional requirements and maximum operating pressure related to the service (design) factor and operating temperature.

To calculate the pipe design stress, S, and pipe dimensions, such as pipe wall thickness for a designated pipe diameter, the Minimum Required Strength (MRS) of the pipe material is divided by the overall Design Factor, F.

The pipe wall thickness requirements can be calculated from the following equation:

$$T_{min} = \frac{PD_{m\,min.}}{2S+P}$$

where

P = maximum design operating pressure of pipe, in MPa

$D_{m\,min.}$ = minimum mean outside diameter, in mm

$T_{min.}$ = minimum wall thickness of pipe, in mm

S = MRS/F, hydrostatic design stress at 20°C, in MPa

F has traditionally been used to account for unpredictable variations in material assessment and the design parameters for a specific installation and operating conditions. Given there is variation in all processes including production of pipe material and subsequent testing to determine MRS, a judgment based value of greater than 1.0 is used as the factor of safety. For PE pipes, the design factor is never less than 1.25.

The application conditions-related component of the overall design factor is left to the application engineer to incorporate via individual design safety factors (*f*x). These relate to the location of the pipeline, the operating pressure, type of fluid being conveyed, installation method, hydrostatic and dynamic loading, in addition to other considerations specific to the application. Recommendations on the selection of appropriate factors for the design of pipes are given in relevant Standards. A typical example of the application conditions related component of the design factor, F, is:

F = f_0 (Fluid)x f_1 (Temperature)x f_2 (Installation depth x f_3 (Installation method)

Fit for Purpose Design relies on a study of a real and present situation and the use of a rigorous risk assessment process to derive one or more of the factors used in the prescribed design case.

Fit for Purpose Design offers the opportunity for pipeline designers to utilise actual material data and advances in PE100 resin properties to design more efficient pipelines, especially in the calculation of the "*f*" risk factors used in calculating the overall design factor, F. This approach is used in gas [1] and water [2] industry applications [3,4].

WHAT IS TEMPERATURE DERATING AND HOW COULD AN ENGINEER BENEFIT FROM USING ACTUAL DATA?

Temperature derating refers to the value used for the operating temperature factor, f_1, in the design factor, F, equation.

The standard, minimum requirement is based on material testing up to 80°C over 1 year. Obtaining extra test pressure data on the PE100 resin for use at higher temperatures is an example of how Fit for Purpose Design could be utilized.

Data from the resin manufacturer's pressure tests, measured at high temperatures (up to 80°C) over 2 years, allows a designer to apply the performance of the specific PE100 resin being used in pipe manufacture. This gives designers the capability to optimise pipeline design for the desired temperature and lifetime and may allow a reduction in pipe wall thickness and material usage – or allow the pipe to be operated under higher flow, temperature and pressure conditions.

Pressure data collection at elevated temperatures in the Qenos Technical Centre, Altona

WHAT CAN BE DONE TO ASSESS THE APPLICATION OF OTHER RISK FACTORS?

As each individual risk factor (*f*) making up overall design factor, F, potentially results in an increase in the wall thickness, Fit for Purpose Design can also be applied to determine the fluid design factor (f_0), installation method (f_2) and location (f_3) risk factors.

For example, the location factor takes account of the risk of mechanical damage to the pipeline by first or third parties according to whether it is to be laid in a high density urban area, semi-urban or rural location. The location may require a design which offers greater contingency in terms of depth of installation, adjusted design factors or assessment of the contingency built into the PE100 resin performance. The last of these considerations includes assessing the PE100 resin's resistance to slow crack growth - data that is available from the resin manufacturer.

WHY CAN'T A PIPE BE DE-RATED USING MRS RATING ALONE?

Pipe design cannot be undertaken with consideration of a single property in isolation. For each application, the product standard guidelines require that additional mechanical and physical property performance benchmarks are met.

All PE100 grade resins have a Minimum Required Strength (MRS) specification of ≥10.0 MPa, which is an improvement on previous generation resins. While MRS is an important indicator of the pipe's ability to withstand pressure, it doesn't indicate a pipe's resistance to brittle failure. This is addressed only by selecting PE piping made from PE100 resins with high stress crack resistance (HSCR), such as Qenos Alkadyne HCR193B resins.

WHAT DOES AN ENGINEER NEED TO CONSIDER WHEN ASSESSING TRENCHLESS INSTALLATIONS?

The flexibility of PE piping enables installation techniques to be used that are cheaper, quicker and less disruptive than open trench methods. These "trenchless" methods are more demanding on the pipes, as long-lengths of PE piping are dragged through pre-drilled holes below ground or through existing pipe. To withstand damage to the wall of the pipe from abrasions during installation that increase the risk of brittle failure, the design engineer can either select a more resilient material or increase the f_2 risk factor that would lead to thicker pipe walls. The latest class of PE100 HSCR resins is suited to these harsh handling conditions due to their inherent resistance to slow crack growth and ability to be pulled, bent and welded.

SOURCING MATERIAL DATA: HOW THE RESIN SUPPLIER CAN HELP

Qenos has extensive experience in testing and analysing PE pipes and its technical services team can provide valuable material data to engineers on request to support design decisions relating to risk factors. Typical data sets include:

- Minimum Required Strength (MRS) data.
- Temperature/pressure data over extended time periods and at elevated temperatures.
- Resistance to slow crack growth testing data obtained under varied conditions.

CONCLUSION

By selecting a PE resin based on its actual physical properties and using Fit for Purpose Design, engineers can optimise the risk factors to design a cost-efficient network with:

- Higher performance benchmarks for pipelines by optimizing flow, temperature and pressure.
- Thinner walls – requiring less PE resin – while meeting all performance and safety criteria.
- Physical characteristics that make it suitable for faster, less-disruptive and cheaper trenchless installation methods.

REFERENCES

1. Australian Pipeline and Gas Association (APGA) Code of Practice for Upstream Polyethylene Gathering Networks in the Coal Seam Gas Industry, Version 4, October 2016, apga@apga.org.au
2. Water Services Association of Australia, WSA 01-2004 Polyethylene Pipeline Code Version 3.1
3. AS/NZS 4130:2009 Polyethylene (PE) pipes for pressure applications
4. AS/NZS 4645.1:2008 Gas distribution networks

WHITE PAPER

RESIDUAL LIFETIME ASSESSMENT OF PE PIPELINES

Dr. Predrag Micic
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August 2016

– How can a pipeline owner determine the remaining life of a pipe that has been in service for many years? –

Polyethylene pipes are tough, durable and have a design life of up to 100 years. How can a pipeline owner determine the remaining life of a pipe that has been in service for many years? An assessment of the current state of a pipe combined with a view on the ongoing service conditions provides the information that enables the residual lifetime to be estimated. This type of assessment allows the owners of pipeline assets to optimally plan pipeline maintenance and replacement and avoid unexpected failures.

ADVANCEMENTS IN THE MOLECULAR DESIGN OF PE MATERIALS HAVE IMPROVED THE DURABILITY AND SLOW CRACK GROWTH RESISTANCE OF PE PIPELINES. THE INCORPORATION OF ANTIOXIDANTS INTO THE PIPE MATERIAL PROTECTS PE PIPE FROM OXIDATIVE DEGRADATION.

A study conducted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the American Water Works Association noted that the average failure rate of PE pipes at 3.16 per 100 kilometres was significantly lower than the many other pipe materials:

- Asbestos cement (16)
- Ductile Iron (5.28)
- Iron (20.1)
- PVC (7.32)
- Steel (11.14)

The life expectancy of a PE pipeline system is highly dependent on the prevailing service conditions such as temperature, pressure and exposure to chemical agents. Pipelines may be exposed to conditions beyond the design parameters and this can lead to a variation in the expected lifetime of the pipes. An assessment of the condition and the residual lifetime of a PE pipeline can provide the asset owner with valuable information, potentially preventing costly and unnecessary maintenance or alerting of the risk of a potential failure.

THE FAILURE MODES OF PE PIPES

Ductile failure

A PE pipe that is operated beyond its pressure rating may experience ductile failure.

PE pipes are assigned a pressure rating classification that is associated with the material from which the pipe made. The PE100 classification specifies a Minimum Required Strength (MRS) of 10 MPa at 20°C after 50 years. This is the maximum stress at which the pipe can operate without risk of ductile failure.

The Hydrostatic Design Stress (HDS) is the stress at which the pipe has been designed to operate. The HDS will be lower than the MRS as a down-rating occurs to reflect the use of safety factors that account for concerns such as the proximity of the pipe to the urban environment. The HDS is incorporated into the calculations which determine the pipe wall thickness.

A pipe that is in good condition and operating within conditions that are consistent with its service design will not experience a ductile failure.

> THE LIFE EXPECTANCY OF A PE PIPELINE SYSTEM IS HIGHLY DEPENDENT ON THE PREVAILING SERVICE CONDITIONS SUCH AS TEMPERATURE, PRESSURE AND EXPOSURE TO CHEMICAL AGENTS.

Brittle failure

Environmental factors such as excessive heat, pressure and chemical agents in the medium being conveyed can lead to degradation in the strength of PE pipes. Processes which lead to the oxidation of the polyethylene, can negatively impact the polymer's structural integrity.

This type of degradation is known as brittle failure. Pipe resin manufacturers actively work to counter this form of failure by incorporating antioxidants into the material. The amount of antioxidant contained within the pipe resin is finite and will eventually be consumed in the presence of oxidising factors. Once the antioxidant has been consumed the polyethylene in the pipeline can start to oxidise leading to a decrease in the overall crack resistance of the pipe. This will eventually lead to the initiation and propagation of cracks within the pipeline.

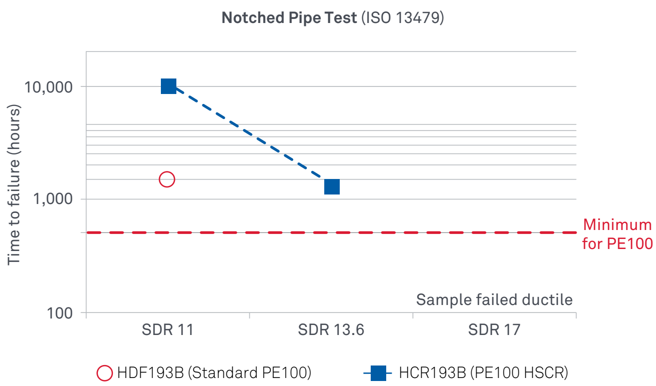
Pipes made from older generations of PE resin are more likely to undergo brittle failure, as the latest generations have significantly improved slow crack growth resistance properties.

THE FRAMEWORK OF A RESIDUAL LIFETIME ASSESSMENT

There is no set amount of time which a PE pipe should last. Engineers design pipe networks to last 50 years or longer and even after 50 years of service, the product may still perform at the level it did at the beginning of its lifetime.

A PE pipe's expected residual lifetime is heavily dependent on the service conditions. Brittle and ductile failure modes are associated with the pressure, temperature, UV exposure and the presence of oxidative agents.

The residual lifetime assessment requires analysis of the current condition of the pipe material as well as the operating history of the pipe.



CONDUCTING THE RESIDUAL LIFETIME ASSESSMENT – PIPE MATERIAL

The likelihood of brittle failure is the important consideration in the residual lifetime assessment of an existing pipeline.

The first step in the residual lifetime assessment is to verify that the pipe resin was manufactured in compliance with AS/NZS 4131. This standard specifies the physical properties that the PE resin must achieve in order to be suitable for pressure pipe applications.

While AS/NZS 4131 applies to the polyethylene resin performance, AS/NZS 4130 dictates requirements for the pipe's physical characteristics. This standard ensures that a particular pipe is designed to be capable of withstanding pressures inherent in the service conditions.

A certified PE testing laboratory such as the Qenos Technical Centre will carry out several tests to enable it to estimate the residual service life expectancy of an installed PE pipe:

- Oxidative induction time (OIT) is a measure of a compound's thermal stability, and indicates the level of antioxidant remaining in the pipe. The remaining antioxidant is able to protect the pipe resin from oxidative degradation.
- Fourier Transform Infrared Spectroscopy (FTIR) is an analytic technique used to quantify the amount of oxidative degradation that has already occurred in the pipe.
- Melt flow rate (MFR) is a technique that links the viscosity of melted polymers to their physical size. This measure informs the laboratory on the toughness of the material.

CONDUCTING THE RESIDUAL LIFETIME ASSESSMENT – OPERATING HISTORY

Miner's rule is one of the most widely used cumulative damage models for failures caused by fatigue. It states that if there are k different stress levels and the average number of cycles to failure at the ith stress, Si, is Ni, then the damage fraction, C, is:

$$\sum_{i=1}^{k} \frac{n_i}{N_i} = C$$

where:

ni is the number of cycles accumulated at stress Si.

C is the fraction of life consumed by exposure to the cycles at the different stress levels.

In general failure occurs when the damage fraction reaches 1.

The above equation can be thought of as assessing the proportion of life consumed at each stress level and then adding the proportions for all the levels together.

ISO 13760:1998 describes the method using Miner's rule for the calculation of cumulative damage for plastic pipes used for the conveyance of fluids under pressure. This approach is used by the material testing laboratory to calculate a PE pipe's expected residual lifetime.

In assessing the residual lifetime the laboratory will need access to the reports describing the original service conditions of the pipe. Miner's rule can then be applied to account for the cumulative impact of changes in parameters such as operational temperature, pressure and disparate environmental factors and to calculate the impact that these parameters will have on the residual lifetime.

ACCESSING PROFESSIONAL KNOWLEDGE

The science of the molecular architecture of polyethylene and the factors that induce degradation is complex. Experience in interpreting analytical tests such as OIT, FTIR and MFR is critical in assessing the residual lifetime of a pipe.

The Qenos Technical Centre in Melbourne has an extensive suite of state of the art analytical and physical testing instrumentation complemented by commercial and semi-commercial polymer processing equipment and NATA accreditation for a range of specialised polyethylene tests.

Qenos has amassed years of experience in producing polyethylene for pressure pipe applications and brings a strong advisory presence to the pipeline industry including in the assessment of residual service life of PE pipe.

WHITE PAPER

REALISING THE ADVANTAGES OF SQUEEZE-OFF AS A PIPE ISOLATION METHOD

Dr. Predrag Micic
(Product Development Executive)
October 2016

–
Find out how to maximise the lifetime of polyethylene pipe networks following flow-stopping using the squeeze-off technique
–

Utility companies throughout the world are tasked with the secure delivery of gas or water to homes and businesses on a continuous basis. To minimise service interruptions, the industry is fast replacing its pipeline infrastructure with high density polyethylene (HDPE) piping.

Among the many advantages of PE as a material for pipelines – including flexibility and resilience – the ease, speed and cost-implications of maintenance and repair are worthy of consideration.

Only pipes manufactured from PE can withstand the forces of "squeeze-off" – a procedure used to shut off the gas or water flow by compressing the pipe walls. Although not commonplace, there is a risk of damaging the pipe material during squeeze-off that could lead to field failures.

The risks can be mitigated by selecting PE piping made from resins with high stress crack resistance (HSCR) and by following best-practice procedures.

THE GAS OR WATER FLOW IN A POLYETHYLENE (PE) PIPE DISTRIBUTION SYSTEM CAN BE QUICKLY SHUT OFF FOR MAINTENANCE OR REPAIR BY SQUEEZING THE WALLS OF THE PIPE TOGETHER. THIS "SQUEEZE-OFF" PROCEDURE IS WIDELY USED BY PIPELINE ASSET OWNERS DUE TO ITS SPEED, SIMPLICITY, AND LOW-COST. HOWEVER, THE STRESS THAT THE PIPE SUFFERS DURING THE PROCEDURE CAN POTENTIALLY LEAD TO CRACK-INITIATION AND BRITTLE FAILURES.

It is possible to prolong the lifetime of PE pipelines by using a product manufactured from a resin that has been specifically developed to resist post squeeze-off failure. The latest class of PE100 resins have many times greater stress crack resistance than standard resins, resulting in increased pipe service life, lower maintenance costs and reduced replacement rates.

WHY IS THE USE OF SQUEEZE-OFF VALUABLE FOR PIPELINE ASSET OWNERS?

To repair pipe made from materials such as cast iron, steel or PVC, complex and expensive engineering designs are employed to avoid major disruption. This includes the installation of valves to stop gas or water flow. In contrast, due to the elasticity of the polymer, a simpler squeeze-off isolation technique can be used with pipe manufactured from PE. By compressing the pipe between two parallel rounded bars upstream and downstream of the fault, the damaged section of the pipe can be isolated quickly. Post-repair, the system is ready for use once the compressed section of pipe has been released.

Swift flow-stopping of utility pipe networks:

- Improves safety by stemming leakage of flammable gases
- Reduces water damage from burst mains pipes
- Minimises disruption and inconvenience, which is especially important within city or urban environments
- Lowers ongoing maintenance and repair costs

PRACTICAL CONSIDERATIONS OF SQUEEZE-OFF

Specially designed mechanical or hydraulic tools are used to fully compress PE pipe walls in order to cut off the flow of gas or water within the pipes, as shown in Figure 1.

> THE EXCEPTIONAL SLOW CRACK GROWTH RESISTANCE OF NEW PE100 RESINS PROVIDES ASSET OWNERS WITH GREATER CONFIDENCE AND AN ADDED SAFETY MARGIN WHEN UTILISING SQUEEZE-OFF.

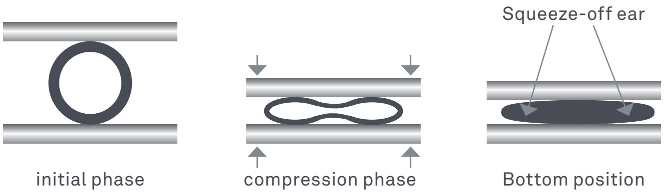


Figure 1. Principles of the squeeze-off technique

Executing squeeze-off incorrectly can damage or deform the pipe causing a concentration of stress in the pipe wall. If the forces are great enough to cause a crack to initiate, the crack may eventually propagate through the pipe ending in a brittle failure. To reduce the risk of failure, pipeline asset owners issue standard method documentation to ensure the best current practice is followed. In addition, the Water Services Association of Australia's (WASA) Polyethylene Pipeline Code [1] includes a section on recommended squeeze-off practice for water pipes, while ASTM International method F1041 advises on squeeze-off of PE piping used for gas distribution [2].

Standard procedures provide guidance on the following key aspects of the technique:

- Position of the squeeze tool in relation to any fittings in order to avoid damaging the pipe wall or fittings.
- The rate of compression is important as too much stress applied too quickly can lead to micro-tears within the pipe wall.
- The rate of release of the squeeze-off tool is even more important to allow even dispersal of the stress during squeeze-off release. This prevents damage from slow crack growth – a precursor to brittle failure.
- Close inspection of the pipe pre- and post-squeeze-off for signs of damage e.g. cracking or splitting. Squeeze-off should never be carried out at a site of potential weakness.
- On release of the squeeze, the pipe should be re-rounded if necessary and replaced if there is any indication of damage.
- Clear marking and recording of the location on the pipe that was compressed so that the same point isn't subject to squeeze-off in the future.

DEVELOPMENTS IN PE RESINS SINCE THE 1960s

Squeeze-off was first applied to high density PE pipe in the 1960s. Although very few field failures of PE piping have been reported, there is the potential for slow crack growth to initiate where the squeeze-off tool has been positioned on the pipe. Subsequent material developments have therefore concentrated on improving the resistance of the PE to slow crack growth at stress-concentrated sites. As indicated in Figure 2, the latest PE100 resins with high stress crack resistance (HSCR) exceed the time to failure requirements of the class multiple times. They also have many times greater stress crack resistance than standard PE100 resins.

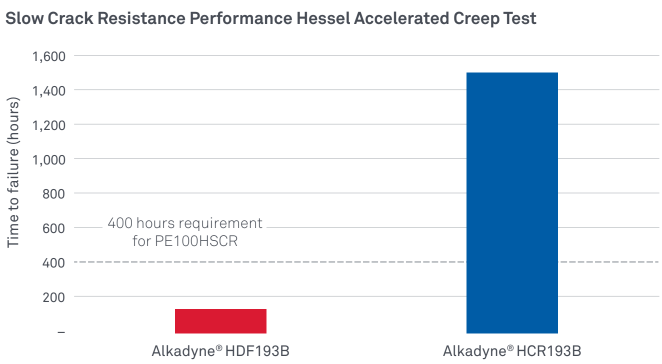


Figure 2. Relative resistance to slow crack growth of two grades of PE100 resins

HOW TO MITIGATE RISKS ASSOCIATED WITH INSTALLATION AND SQUEEZE-OFF

Installing new PE pipe networks or replacing existing pipelines is an extremely expensive undertaking that often causes inconvenience to the public.

Pipe made from the latest class of PE100 HSCR resins is highly resistant to slow crack growth, even under harsh handling conditions. The enhanced slow crack growth resistance of these new resins provides an extra level of confidence whenever squeeze-off is used to manage pipeline flows during planned or emergency maintenance. The avoidance of needing to replace the squeezed off pipe eliminates cost and reduces disruption to the community.

HOW THE RESIN SUPPLIER CAN HELP

QENOS has developed Alkadyne® HCR193B – a new class of PE100 grade resin with stress crack resistance many times greater than standard PE100 resin. Developed in partnership with Australian pipe manufacturers, Alkadyne HCR193B has increased resistance to slow crack growth initiation caused by the presence of stress concentrators. The exceptional resistance to slow crack growth of Alkadyne HCR193B provides asset owners with greater confidence and a greater safety margin when utilising squeeze-off.

Based in Australia, Qenos manufactures a range of world-class Alkadyne® PE100 polyethylene grade resins for use in pressure pipes. The company has also invested in a large pipe pressure testing facility where pipe is extruded for testing, and then subjected to high pressures and heat for up to three years.

REFERENCES

1. WSA 01-2004 Polyethylene Pipeline Code Version 3.1, www.wsaa.asn.au/
2. ASTM F1041 – 02(2016). Standard Guide for Squeeze-Off of Polyolefin Gas Pressure Pipe and Tubing, www.astm.org

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