WHITE PAPER

THE NEXT GENERATION PE PIPE RESIN

Dr. Jeroen Wassenaar
Market Segment Manager

Dr. Predrag Micic
Product Development Executive

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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.

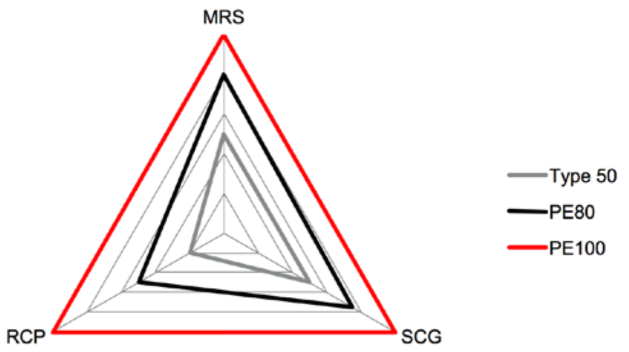

Figure 1. **Evolution of PE pressure pipe resins with respect to minimum required strength (MRS), slow crack growth (SCG), and rapid crack propagation (RCP). Relative scales have been applied.**

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.

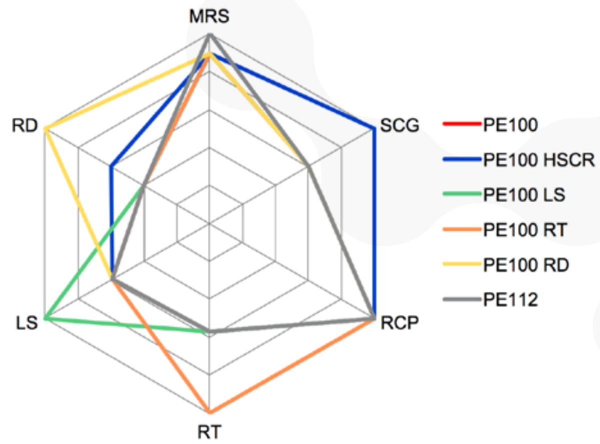

Figure 2. **Property balance for PE100 specialty resins optimised to operate under specific conditions. RT = Temperature Resistance, LS = Low Slump, RD = Resistance to Disinfectants.**

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.

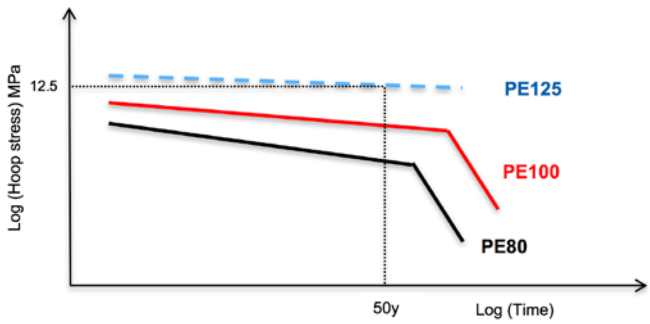

Figure 3. Hydrostatic strength curves (σ_{LPL}) at 20°C for PE80, PE100, and PE125 (projected).

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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Qenos Pty Ltd

471 Kororoit Creek Rd
Altona Victoria 3018 Australia

Phone 1800 063 573
ABN 62 054 196 771

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