Lupolen HDPE used in PE-X pipes

Ultimate pipe performance through cross-linking
About LyondellBasell

LyondellBasell Industries is one of the world’s largest polymers, petrochemicals and fuels companies. We are the global leader in polyolefins technology, production and marketing; a pioneer in propylene oxide and derivatives; and a significant producer of fuels and refined products, including biofuels.

Headquartered in The Netherlands, LyondellBasell has combined annual revenues of approximately $50 billion* and more than 15,000 employees worldwide.

Our vertically integrated facilities, broad product portfolio, manufacturing flexibility, superior technology base and reputation for operational excellence allow us to deliver exceptional value to our customers across the petrochemical chain – from refining through to advanced product applications.

LyondellBasell is dedicated to ongoing research and development programs that meet the ever-changing requirements of our diverse customers, including the creation of new catalysts, processes and products. Our materials are used in virtually every market to manufacture countless goods and products that enhance quality of life for people around the world. From fresh food packaging, clean fuels and durable textiles to medical applications, construction materials and automotive parts, the uses for LyondellBasell materials are almost unlimited.

At LyondellBasell, we clearly recognize the importance of being a responsible corporate citizen in our communities. We are committed to operating our businesses with the highest principles of integrity, ethics and corporate responsibility, as well as the highest standards of health, safety and environmental performance.

Adding value for customers

Customers in the pipe industry, including steel pipe coating companies, are served by a dedicated team which offers benefits that provide a competitive advantage.

- High market reputation
- Experience
- Quality of products, services and people
- Leadership in technology and innovation
- Global Pipe, Industrial Sheet and Pipe Coating business unit, with sales and technical service teams in Europe, North America and Asia/Pacific

*Based on 2008 revenues

Cover left picture: Underfloor heating, PE-Xc. Courtesy of Hewing;
Cover right picture: Big PE-Xa pipe. Courtesy of Golan
Since that time, LyondellBasell has been the leading supplier of materials used in the manufacture of hot water pipe made from cross-linked polyethylene (PE-X).

Beginning with underfloor heating, continuing with sanitary pipe and moving into anti-freeze pipe applications, producers of PE-X pipe have been selecting Lupolen high density polyethylene for decades.

In 1968, inventor Thomas Engel patented a process that used Lupolen 5261 Z, one of LyondellBasell’s state-of-the-art grades from Wesseling (Germany), to create the first cross-linked PE pipe. In 1972, Wirsbo (now known as Uponor) developed the first commercial PE-X application – underfloor heating pipe.

Expanded production in North America

Lupolen 5261 Z Q 456 HDPE resin is produced using Phillips-Loop technology. Using unique LyondellBasell catalysts, the process enables fine tuning of the property balance required for grades used in the manufacture of PE-Xa pipe.

In 2009, LyondellBasell began the production of Lupolen 5261 Z Q 456 resins at its Clinton, Iowa, USA plant in order to serve North American PE-Xa pipe manufacturers with locally produced base resin.

LyondellBasell offers customers quality PE-X grades on a global basis through plants located in Germany (Wesseling and Frankfurt) and the US (Clinton, Iowa and Matagorda, Texas).
Cross-linking makes the difference

Cross-linked Polyethylene (PE-X) contributes to more safety and comfort in our daily life. The three-dimensional network in the material is the main contributor to the superior performance.

Well-known examples of cross-linked materials include rubber used for tires, wood for furniture and leather for shoes and clothing. All of these materials exhibit superior performance in comparison to their non-cross-linked counterparts (latex, cellulose, animal skin) and improve comfort and safety of daily life. The same is true for PE-X. Polymer materials consist of numerous polymer chains, which are entangled like a plate of spaghetti. (Fig. 1). The longer the chains the harder it is for a single chain to move its position inside the group of molecules. This explains why high molecular weight materials show better creep behavior than low molecular weight materials. For pipe applications, high molecular weight resins with low creep behavior are the materials of choice. Through a chemical reaction, the chains become connected to one another, which significantly improves creep behavior. This creep behavior can be improved by several orders of magnitude. After cross-linking the chains, to form a three-dimensional network, a single polymer chain can no longer change its position within the group of molecules.

The network inside the resin (Fig. 2) improves the material properties, especially at higher temperatures, making it the material of choice for customer hot water applications. In comparison to non-cross-linked PE, PE-X has the following properties:

- Higher creep strength at elevated temperatures
- Virtually no stress crack formation
- Increased abrasion resistance
- Improved performance regarding rapid crack propagation
- Considerably lower notch sensitivity
- Higher impact strength at low temperatures
- Improved chemical resistance
Polyethylene is cross-linked during or after pipe extrusion. Three different conversion methods, PE-Xa, PE-Xb and PE-Xc, result in the production of PE-X pipe with outstanding properties.

Peroxide cross-linking technology is known as PE-Xa, which requires specialized equipment and knowledge. Two methods commonly used include ram extrusion (Engel process, Fig. 3) and ram extrusion in combination with an infrared cross-linking unit (Fig. 4), or a salt bath. In both cases, the pipe is already cross-linked at the end of the extrusion line.

Silane cross-linking produces PE-Xb pipes, which can be produced either in a direct extrusion process (Monosil process) or by using grafted compounds in combination with a catalyst masterbatch. For the Monosil process, specially designed extrusion equipment is necessary (Fig. 5). For PE-Xb, the cross-linking takes place after this step in a hot water bath or a sauna.

PE-Xc pipes are produced using standard extrusion equipment. The cross-linking of the pipe takes place after extrusion using β-irradiation. For this cross-linking step an electron accelerator is required (Fig. 6).

Additional technical details are provided in our brochure “Technical Manual – Materials used in Pipe Extrusion”.

Fig. 7 illustrates the different Lupolen grades that are used by customers in PE-X pipe.
PE-Xa pipes were used more than 35 years ago for the first time in underfloor heating systems. Today, heating and plumbing are still the major applications, in addition to geothermal and district heating systems.

Underfloor heating systems (Fig. 8) provide warmth and comfort to homes. In recent years, many systems have been developed, which can be installed after the completion of a building, and particularly in older homes and particularly for renovation.

Metal composite pipe has become increasingly popular, with fast growing market share. These pipes are wrapped during production longitudinally with aluminum tape (Fig. 9), followed by welding of the metal by a laser (Fig. 10). The bending tightness is one of the major properties appreciated by plumbers and installers, because it enables them to bend pipe easily around corners (Fig. 11) by using special equipment (Fig. 12). In general the pipe is connected by press fittings (Fig. 13), push fittings are also becoming popular.

Pipe made from PE-Xa is the product of choice for geothermal heating (Fig. 14). PE-X pipe shows almost no scratch sensitivity, and in combination with the high impact strength, damage during installation can be significantly minimized or prevented.

Today, flexible district heating pipe (Fig. 16) with prefabricated insulation (Fig. 15) is often used in projects where the heating unit is in one building and the surrounding neighborhood is connected via the pipes. With a maximum operating temperature of 80 °C, the media pipe can be produced using PE-X, which offers significant advantages compared to steel pipe, such as flexible installation, corrosion resistance and easy connectivity.

A concrete core tempering made from PE-Xa is shown in Fig. 18. These systems provide a economical solution for cooling and heating of public buildings.
Heating and plumbing applications
The very good mechanical properties offered by PE-X pipe open the door to a variety of industrial and special applications. The vast majority of PE-X pipe is PE-Xa pipe, because PE-Xa pipe can be produced up to a diameter of 500 mm, whereas PE-Xb and PE-Xc pipe are limited to diameters of up to 110 mm.

In comparison to HDPE, PE-X exhibit much better abrasion resistance, making it the choice of customers for the transport of abrasive slurries in the chemical or mining industry. The results of a PE-Xa pipe specimen tested in the sand slurry test are illustrated in Fig. 19. PE-Xa pipe exhibits a three-fold improvement in resistance under these high shear conditions compared to PE100 pipe.

Similar behavior is observed in the “Darmstädter tipping test”, where a half pipe filled with a mixture of sand, gravel and water undergoes thousands of cycles (Fig. 20). These low-shear test conditions are very close to real conditions in normal sewage pipe systems.

Potential customer applications that require pipe with high abrasion resistance include pipe for fish feeding (Fig. 23) or pipe used in bore-hole applications (Fig. 28). PE-X pipe is also used for gas and water networks, especially in combination with unconventional pipe-laying technologies, such as trenchless pipe-laying or relining. Our customers report that pipe made from PE-X shows almost no tendency to stress cracking and can be installed without sand bedding.
Special applications

Fig. 23 Pipes for fish feeding, PE-Xa Courtesy of Golan

Fig. 24 Gas and water pipes with rock impingement, PE-Xa Courtesy of Golan

Fig. 25 Coil with big PE-Xa pipe Courtesy of Golan

Fig. 26 Fermenter heating for the production of biogas, PE-Xa Courtesy of REHAU

Fig. 27 Pipelaying by helicopter, PE-Xa Courtesy of Golan

Fig. 28 Borehole application, PE-Xa Courtesy of Golan
High-performance material

Tests carried out at the Bodycote materials testing institute in Sweden and at Jana Laboratories in Canada confirmed that irradiated cross-linked pipe made from Lupolen 4261 A Q 416 can provide high levels of performance in hot water applications.

Pressure performance

Conducted according to ISO 9080 standards, the tests simulated a 50 year service life at temperatures of 70 °C. The results showed the material’s excellent hydrostatic strength under these conditions (Fig. 29).

PE-Xc pipe produced from Lupolen 4261 A Q 416 resin fulfill ISO 15875-2 requirements. This includes the requirements for the application classes 1, 2, 4 and 5 according to ISO 10508.

The stabilization package is compliant with most drinking water regulations worldwide, and Lupolen 4261 A Q 416 resins meet the food approval regulations of the EU. Detailed information can be found in LyondellBasell’s RAPIDS for Lupolen 4261 A Q 416 resins.

Chlorine resistance

Conducted according to the ASTM F2023 standard, the test simulated a 50 year service life at temperatures of 60 °C in the presence of 4 ppm of chlorine. The results of the regression analysis are illustrated in Fig. 30. Testing times of over 20,000 h at temperatures of 95 °C show the pipe’s excellent performance under these conditions.

When tested in accordance with the NSF P171 protocol and ASTM F2023 standard, the irradiated cross-linked pipe made from Lupolen 4261 A Q 416 met the requirements for domestic continuous recirculation and traditional domestic listings as defined by NSF P171 and the ASTM F876 requirement of 50 years for intermittent hot water service.
Technical data

Processability
By using Lupolen 4261 A Q 416, high line speeds with smooth pipe surfaces can be achieved. The high melt strength results in very good dimensional stability of the extruded pipe, which enables customers to produce thin-walled pipes within small tolerances. The grade can be processed like normal PE80 or PE100 materials. Easy production start up for the production of hot water pipe can be achieved, as existing machine equipment for HDPE or PP-R can be used.

Cross-linking
Cross-linking of pipe by β-radiation is necessary in order to achieve the final properties of the pipe. The degree of cross-linking must be at least 60% according to ISO 15875. Customers who operate cross-linking units reported that an average dosage of 120 kGray is required to achieve a degree of crosslinking higher than 60%.

Availability
Lupolen HDPE resins used by customers in the production of cross-linked pipe are available worldwide. Alathon M5370 PX is only available in the USA.

Table 1 – Material properties

<table>
<thead>
<tr>
<th>Typical Properties</th>
<th>Method</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Technology</td>
<td>PE-Xa, Ram Extrusion</td>
<td>PE-Xa, Ram Extrusion</td>
</tr>
<tr>
<td>Supply Form</td>
<td>Powder</td>
<td>Powder</td>
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<tr>
<td>Color</td>
<td>Natural</td>
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<tr>
<td>Physical</td>
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<tr>
<td>Density</td>
<td>ISO 1183</td>
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<td>Bulk Density</td>
<td>ISO 60</td>
<td>g/dm³</td>
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<tr>
<td>Average Particle Size</td>
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<tr>
<td>Melt flow rate (MFR)</td>
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<td></td>
</tr>
<tr>
<td>190°C/21.6 kg</td>
<td>ISO 1133</td>
<td>g/10 min</td>
</tr>
<tr>
<td>190°C/5.0 kg</td>
<td>ISO 1133</td>
<td>g/10 min</td>
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<td>190°C/2.16 kg</td>
<td>ISO 1133</td>
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<td>Staudinger Index</td>
<td>ISO 1628</td>
<td>m/g</td>
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<tr>
<td>Mechanical</td>
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<tr>
<td>Tensile Modulus (23°C, v=1mm/min, secant)</td>
<td>ISO 527</td>
<td>MPa</td>
</tr>
<tr>
<td>Tensile Stress at Yield (23°C, v=50 mm/min)</td>
<td>ISO 527</td>
<td>MPa</td>
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<tr>
<td>Shore hardness (Shore D (3 sec))</td>
<td>ISO 868</td>
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<tr>
<td>Ball indentation hardness H132/30</td>
<td>ISO 2039-1</td>
<td>MPa</td>
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<tr>
<td>Thermal</td>
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<tr>
<td>Vicat softening temperature (VST/A/50 Kf (9.8 N))</td>
<td>ISO 306/A</td>
<td>°C</td>
</tr>
<tr>
<td>Vicat softening temperature (VST/B/50 Kf (50 N))</td>
<td>ISO 306/B</td>
<td>°C</td>
</tr>
</tbody>
</table>

Notes: typical properties, not to be considered as specifications
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