

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

Experience and long-term commitment

Over the past four decades, HDPE products for hot water pipe applications have been steadily replacing traditional materials such as copper. It all began more than 35 years ago with *Lupolen* HDPE used in cross-linked pipe (PE-X).

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

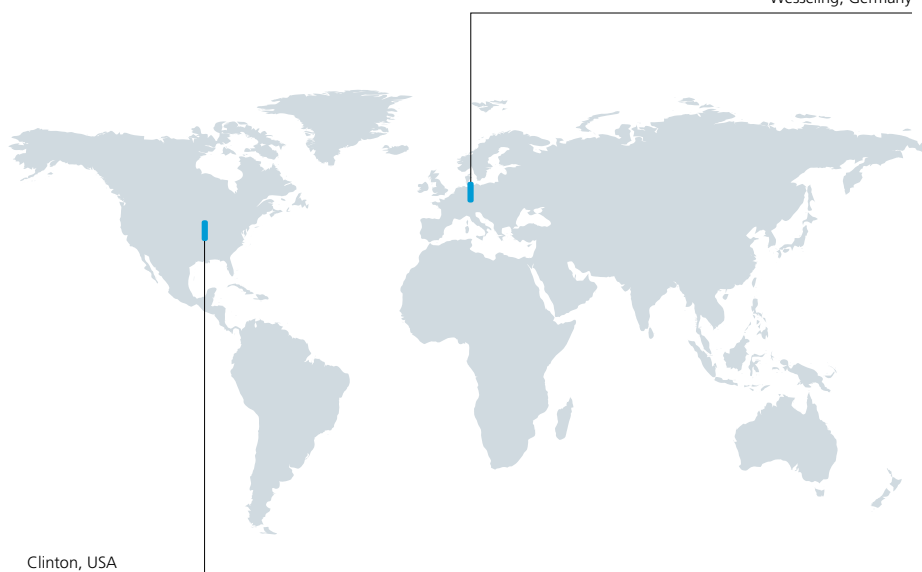
Lupolen 5261 Z Q 456 HDPE resin is produced using Phillips-Loop technology. Using unique LyondellBasell catalysts, the process enables fine tuning of the property balance required for grades used in the manufacture of PE-Xa pipe.

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).



Wesseling, Germany



Clinton, USA



Cross-linking makes the difference

Crosslinked 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

Fig 1. Schematic comparison of HDPE and PE-X

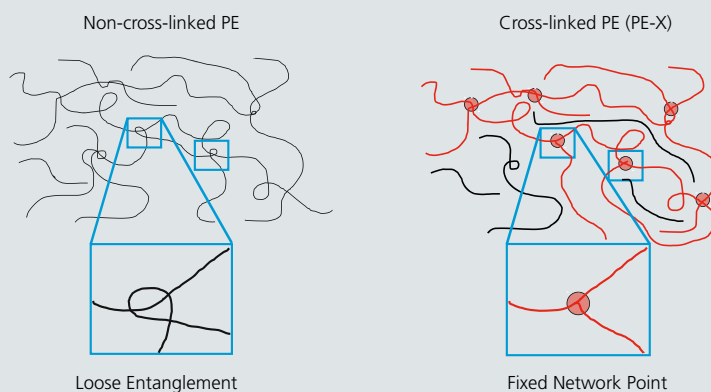
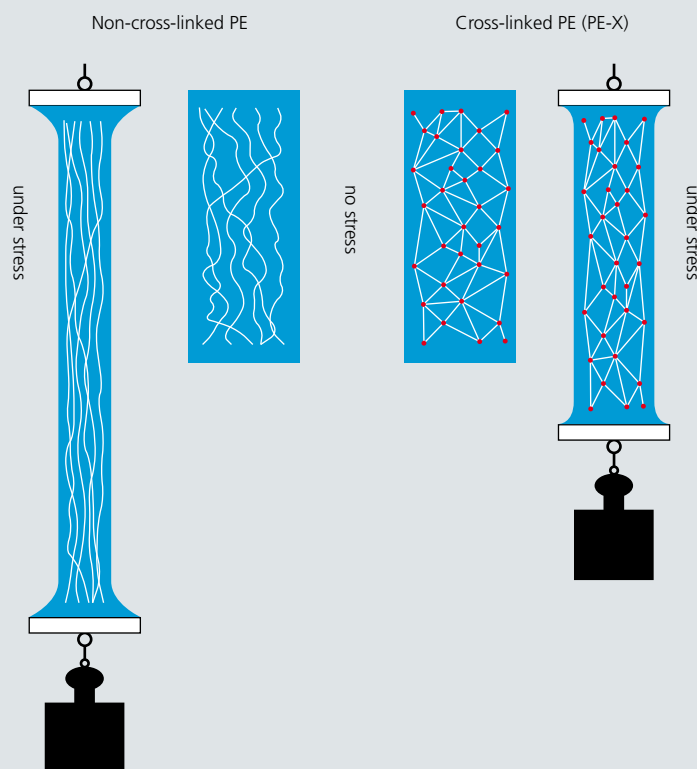


Fig 2. Schematic comparison of HDPE and PE-X



Three ways – one goal

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.

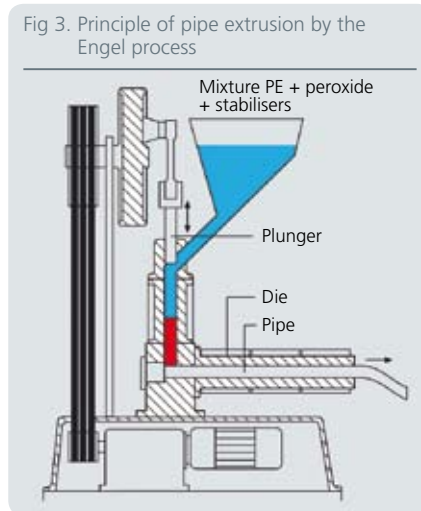


Fig 3. Principle of pipe extrusion by the Engel process



Fig 4. Infrared cross-linking unit Courtesy of Maillefer

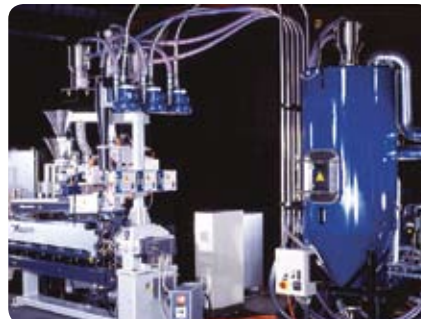
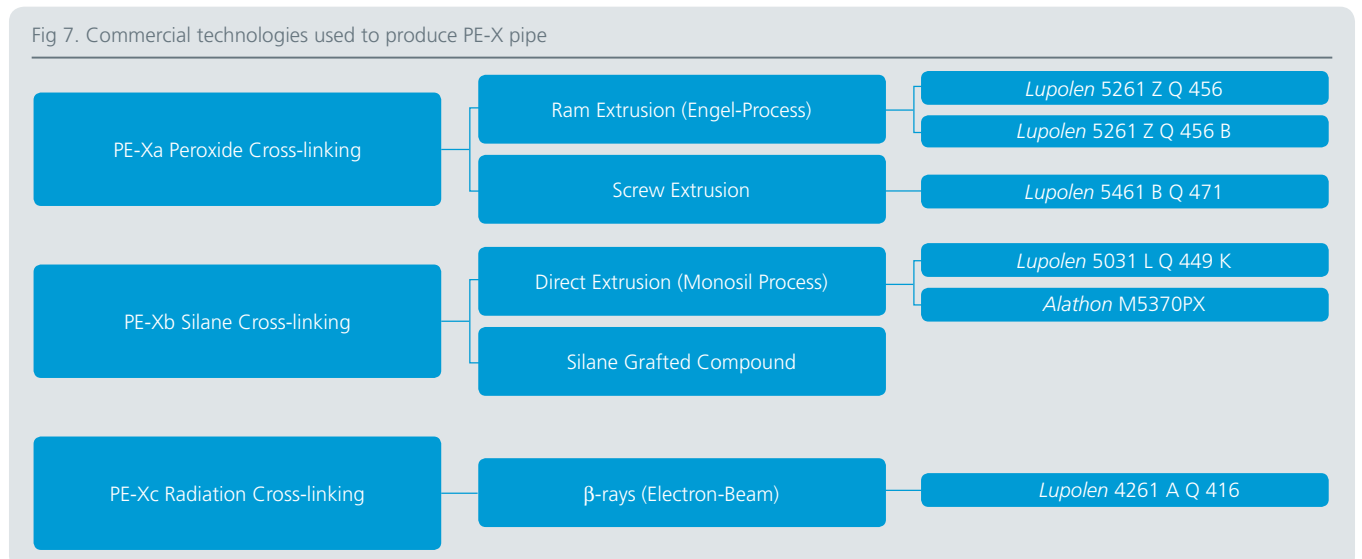


Fig 5. PE-Xb extrusion line Courtesy of Maillefer



Fig 6. Electron accelerator unit Courtesy of Golan



Heating and plumbing applications

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 sensivity, 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.



Fig 8. Underfloor heating, PE-Xa

Courtesy of Schütz



Fig 9. Wrapping unit Courtesy of Maillefer SA / Dreistern



Fig 10. Laser welding Courtesy of Hewing



Fig 11. Radiator connection Courtesy of Hewing



Fig 12. Bending tool Courtesy of Hewing

Heating and plumbing applications



Fig 13. Press fitting

Courtesy of Hewing



Fig 14. Geothermal heating system, PE-Xa

Courtesy of REHAU



Fig 15. District heating system, PE-Xa

Courtesy of Uponor



Fig 16. District heating pipe, PE-Xa

Courtesy of Uponor



Fig 17. PE-Xc pipes

Courtesy of Hewing



Fig 18. Concrete core tempering, PE-Xa

Courtesy of REHAU

Special 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.

Fig 19. Abrasion of PE-X in the sand slurry test, ISO 15527

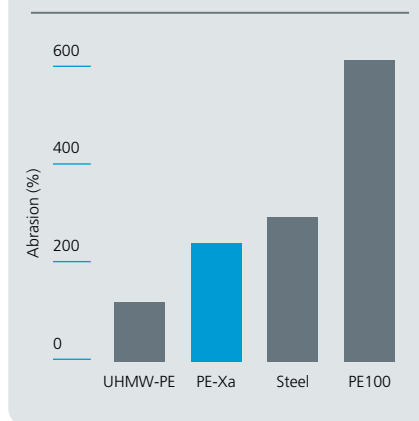


Fig 20. Abrasion of PE-X in the Darmstadt tipping test after 200.000 cycles, DIN 19565-1

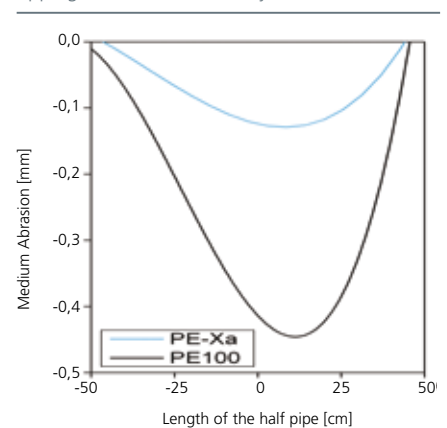


Fig 21. Abrasion sand slurry test

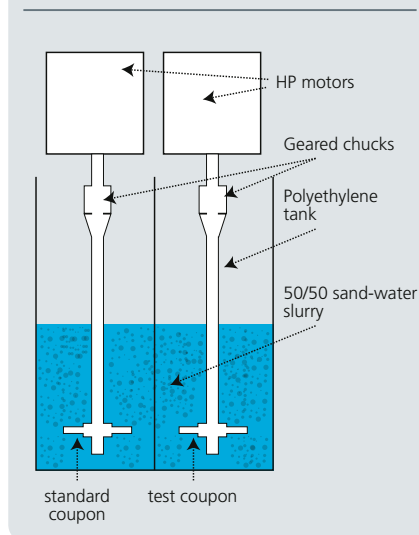
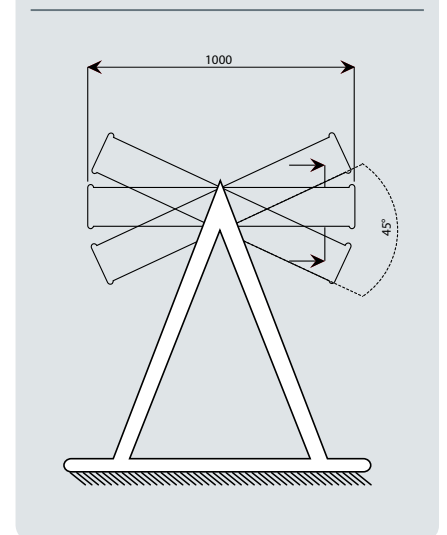


Fig 22. Abrasion Darmstadt tipping test



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.

Fig. 29 ISO 9080 evaluation

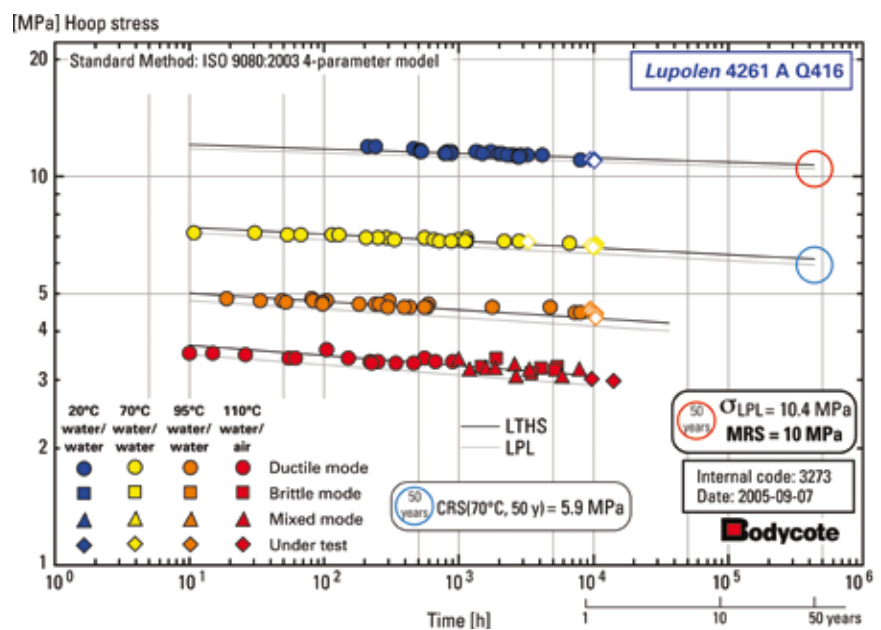
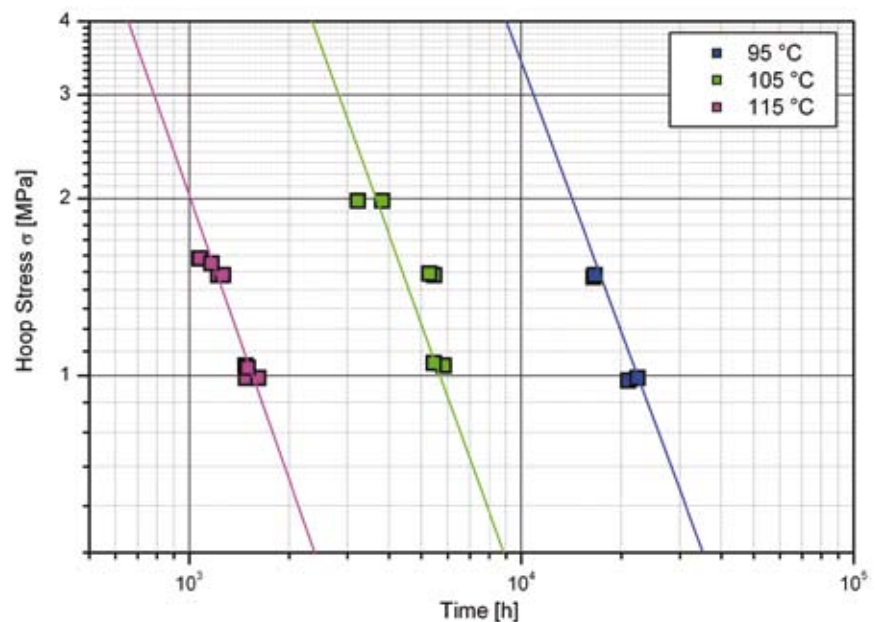


Fig. 30 Regression analysis of chlorine tests conducted at Jana laboratories



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

			<i>Lupolen</i> 5261 Z Q 456	<i>Lupolen</i> 5261 Z Q 456 B	<i>Lupolen</i> 5461 B Q 471	<i>Lupolen</i> 5031 L Q 449 K	<i>Alathon</i> M5370PX	<i>Lupolen</i> 4261 A Q 416
Typical Properties	Method	Unit						
General								
Technology			PE-Xa, Ram Extrusion	PE-Xa, Ram Extrusion	PE-Xa, Screw Extrusion	PE-Xb, Monosil Process	PE-Xb, Monosil Process	PE-Xc, β -rays
Supply Form			Powder	Powder	Powder	Pellets	Pellets	Pellets
Color			Natural	Natural	Natural	Natural	Natural	Natural
Physical								
Density	ISO 1183	g/cm ³	0.954	0.954	0.953	0.955	0.953	0.946
Bulk Density	ISO 60	g/dm ³	500	480	480	500	500	500
Average Particle Size	ISO 4610	μ m	750	850	850	—	—	—
Melt flow rate (MFR)								
190°C/21.6 kg	ISO 1133	g/10 min	2.0	3.0	10.0	—	—	8.5
190°C/5.0 kg	ISO 1133	g/10 min	—	—	0.5	12.5	—	0.5
190°C/2.16 kg	ISO 1133	g/10 min	—	—	—	4.0	6.8	—
Staudinger Index	ISO 1628	ml/g	450	420	330	200	180	350
Mechanical								
Tensile Modulus (23°C, v=1 mm/min, secant)	ISO 527	MPa	1100	1100	1100	1100	1100	850
Tensile Stress at Yield (23°C, v=50 mm/min)	ISO 527	MPa	27	27	28	26	28	24
Shore hardness (Shore D (3 sec))	ISO 868		65	65	64	62	62	62
Ball indentation hardness H132/30	ISO 2039-1	MPa	52	52	49	50	50	40
Thermal								
Vicat softening temperature (VST/A/50 K/h (9.8 N))	ISO 306/A	°C	132	132	130	125	127	125
Vicat softening temperature (VST/B/50 K/h (50 N))	ISO 306/B	°C	80	80	79	70	70	75

Notes: typical properties, not to be considered as specifications

LyondellBasell Industries

Worldwide Headquarter

P.O. Box 2416
3000 CK Rotterdam
The Netherlands

Tel: +31 10 275 5500

North America Offices

One Houston Center, Suite 700
1221 McKinney Street
Houston, TX 77010
P.O. Box 3646 (77253-3646)

Tel: +1 713 652 7200

Basell North America Regional Office
Delaware Corporate Center II
2 Righter Parkway, Suite 300
Wilmington, Delaware 19803, USA

Tel: +1 302 683 8000

Fax: +1 302 478 2796

European Sales Offices

Basell Deutschland GmbH
Industriepark Hoechst
Building B 852
65926 Frankfurt am Main
Germany

Tel: +49 69 305 85800

Fax: +49 69 305 85803

Basell Deutschland GmbH
Bruehler Strasse
50389 Wesseling
Germany

Tel: +49 2236 726000

Fax: +49 2236 726034

Basell Sales & Marketing Company B.V.

Groot Handelsgebouw
Weena 737
3013 AM Rotterdam
The Netherlands

Tel: +31 10 71 36 010

Fax: +31 10 71 36 400

Basell UK Ltd.

Carrington Site
Urmston
M31 4AJ, UK

Tel: +44 161 776 3020

Fax: +44 161 776 3027

Basell Polyoléfines France S.A.S.
81, avenue François Arago
F-92017 Nanterre Cedex, France

Tel: +33 (0) 1 55 51 2100

Fax: +33 (0) 1 55 51 2150

Basell Italia S.r.l.
Piazza Montanelli 20
I-20099 Sesto San Giovanni (Milano),
Italy

Tel: +39 02 24 342 1

Fax: +39 02 24 342 600

LyondellBasell Moscow
Uspensky per., 10., bld 1
127006 Moscow, Russia

Tel: +7 (495) 641 33 22

Fax: +7 (495) 641 33 23

Basell Poliolefinas
Comercial Española S.L.
Av. Diagonal, 615, 4th floor
E-08028 Barcelona, Spain

Tel: +34 93 365 2000

Fax: +34 93 365 2100

LyondellBasell Office
P.O. Box 31
FI-06101 Porvoo, Finland

Tel: +358 400 720979

Basell Sales & Marketing B.V.
organizacna zlozka
Prievozska 4/A
821 09 Bratislava
Slovakia

Tel: +421 2 5827 5136

Fax: +421 2 5827 5150

LyondellBasell
Sisikler Plaza
Derya Sk. 14/9
Sahrayi Cedit
34734 Istanbul, Turkey

Tel: +90 216 468 6800

Fax: +90 216 302 0541

India Sales Office

Basell Polyolefins India Pvt. Ltd.
303/305, B wing
Delphi Building
Hiranandani Business Park
Powai
Mumbai-400076, India

Tel: +91 22 6706 1111

Fax: +91 22 6706 1100

South and Central America Regional Office

Petroken Petroquimica Ensenada S.A.
Avda. Eduardo Madero 1020, 14/F
(C1106ACX) Buenos Aires, Argentina

Tel: +54 11 4393 3010

Fax: +54 11 4393 3085

Asia-Pacific Offices

Basell Asia Pacific Ltd.
12/F Caroline Centre
Lee Gardens Two
28 Yun Ping Road
Causeway Bay, Hong Kong

Tel: +852 2577 3855

Australia Sales Office

Basell Australia Pty. Ltd.
Level 2, 199 Toorak Road
South Yarra VIC 3141
Melbourne, Australia

Tel: +61 3 9829 9455

Fax: +61 3 9829 9531

Africa and the Middle East

Regional Office
Basell Gulf FZE
Dubai Airport Free Zone
P.O. Box 293611
Dubai, U.A.E

Tel: +971 4 204 5970

Fax: +971 4 204 5969

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our website at: lyondellbasell.com

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