New PE Pipe materials – designed for tough conditions

Robin Bresser – Marketing Manager, Borouge
KL, March 2012
Contents

1. Brief intro to Borouge
2. Pipe markets and the importance of quality
3. High Stress Crack Resistant PE100
4. Extra-Large pipe systems for the petroleum industry
5. 5 years of Water for the World
A brief Introduction to Borouge
Borouge.... A successful joint venture combining resources, feedstock and technology leadership
Borouge – a leading force in the international plastics market

- Borouge – A JV between ADNOC and Borealis, combining the best of Europe and the Middle East. Formed in 1998, production start up in 2001 in Ruwais, Abu Dhabi

- The Borouge 1 and 2 plants produce over 2,000,000 t/y of Polyethylene (PE) and Polypropylene (PP) of different types

- This will increase to over 4,000,000 t/y in 2014 following the commissioning of Borouge 3.
Providing Solutions in Polyolefins

Infrastructure

Automotive

Advanced Packaging
Successful innovation requires closely working with the pipe "value chain"
Markets and the importance of Quality
Asia construction industry to maintain 10% growth over next years

Borouge Region Construction Industry Value ($bn)

Data Source: BMI
# Global Annual Cost of NRW

<table>
<thead>
<tr>
<th></th>
<th>Marginal Cost of Water (US$/m³)</th>
<th>Average Tariff (US$/m³)</th>
<th>Cost of Physical Losses</th>
<th>Lost Revenue due to Commercial Losses</th>
<th>Total cost of NRW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Developed Countries</strong></td>
<td>0.3</td>
<td>1.0</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td><strong>Eurasia (CIS)</strong></td>
<td>0.3</td>
<td>0.5</td>
<td>2</td>
<td>2</td>
<td>4</td>
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<tr>
<td><strong>Developing Countries</strong></td>
<td>0.15</td>
<td>0.15</td>
<td>5</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>10</strong></td>
<td><strong>8</strong></td>
<td></td>
<td><strong>18</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Estimated Values, billion US$/year*

*Source: The challenge of reducing NRW in Developing countries*
Total Pipe market for ME and Asia (Plastic equivalent) = 17,100Kt in 2010

Plastic Pipe Market (non-PO) = 5,400Kt (32%)
Plastic Pipe Market (PO) = 3,500Kt (20%)
Non-Specified PO Pipe Market = 2,200Kt
Specified PO Pipe Market = 1,300Kt (8%)
Non-Plastic Pipe Market = 8,200Kt (48%)

Sources: Fredonia market study 2010, Borouge Market study 2010
Traditional Piping materials are less than ideal to prevent water leakages

- failing due to metallic corrosion and
- brittle fracturing
- encrustation within the pipes influencing water quality
PE pipe systems help meet leakage targets better

Aahrus water company (DK)- failure rates in 2003

<table>
<thead>
<tr>
<th>Material</th>
<th>Failures/100 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast-Iron</td>
<td>40</td>
</tr>
<tr>
<td>Steel</td>
<td>30</td>
</tr>
<tr>
<td>Fibre-cement</td>
<td>5</td>
</tr>
<tr>
<td>PVC</td>
<td>10</td>
</tr>
<tr>
<td>PE</td>
<td>2</td>
</tr>
</tbody>
</table>
Material identification statistics in China (2006-2011)

<table>
<thead>
<tr>
<th>Year</th>
<th>Non Borouge Material</th>
<th>Borouge Material</th>
<th>Total Test Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>62</td>
<td>20</td>
<td>82</td>
</tr>
<tr>
<td>2007</td>
<td>82</td>
<td>42</td>
<td>123</td>
</tr>
<tr>
<td>2008</td>
<td>123</td>
<td>115</td>
<td>238</td>
</tr>
<tr>
<td>2009</td>
<td>150</td>
<td>147</td>
<td>397</td>
</tr>
<tr>
<td>2010</td>
<td>192</td>
<td>201</td>
<td>393</td>
</tr>
<tr>
<td>2011</td>
<td>227</td>
<td>317</td>
<td>544</td>
</tr>
</tbody>
</table>

- **2006**: 76% non Borouge material, 34% Borouge material, 100% total test numbers
- **2007**: 23% non Borouge material, 77% Borouge material, 100% total test numbers
- **2008**: 23% non Borouge material, 77% Borouge material, 100% total test numbers
- **2009**: 23% non Borouge material, 77% Borouge material, 100% total test numbers
- **2010**: 11% non Borouge material, 89% Borouge material, 100% total test numbers
- **2011**: 9% non Borouge material, 91% Borouge material, 100% total test numbers
More than 50 years history of the PO pipe

1950s
- 1st PE pressure pipe installed, PE63

1970s
- PE80 gains market share in gas and water
- Steel pipe coating PE introduced
- Borealis (Neste) entered PE pipe

1980s
- Medium density PE80 launched

1990s
- Bimodal PE100 introduced
- Borouge entered PE pipe market
- PO pipe market grew at 7-8%

2000s
- PE63 extrapolated lifetime validated by Basell labs
- Specialised PE100’s introduced (Low Sag, IM and HSCR)
Development of PE Pipe materials

Borsafe HE3490-LS-H is the latest innovation in the development of polyethylene
High Stress Crack Resistant PE100
Increasing use of demanding installation techniques with polyethylene pipes

- Pipe Bursting
- Ploughing in
- Loose Lining
- Directional Drilling
- Sandless Bedding
- Tight / Swage Lining
Pipes are subjected to more demanding installation conditions

- Increasingly demanding conditions
  - Standard bedding / open trench
  - No sand backfill / stony soil
  - Close fit systems / deformed pipe
  - Slip lining DI or concrete pipes
  - Pipe bursting & relining
  - Close fit-site deform - Swagelining
  - Directional drilling operations
Borouge HSCCR PE100 materials

Borouge HSCCR materials bring:

- Cost saving potential created by trenchless techniques
- Additional safety factor demanding installation conditions, such as sandless bedding and rock impingement from second excavation.
- Additional security at a minimum cost increase particularly in the congested area of HK where digging up the road is so difficult and expensive.
- The value to be shared
Borouge HSCR PE100 materials

- **SCG**
  Slow Crack Growth Resistance

- **RCP**
  Rapid Crack Propagation Resistance

- **MRS**
  Minimum Required Strength - 50 Years

- Improved performance of electro-fusion welds
Latest PE material to meet demanding conditions in trenchless and sand free installation
An example of challenging conditions - pipe bursting

- Pipe bursting can be used on cast iron, asbestos cement and PVC mains and a wide variety of sewers and drains

- Depending on the host pipe material some systems employ pneumatic or hydraulic breakers whilst others rely on cutting heads. The same sized or larger PE pipe is then drawn through behind the breaker

- During installation the PE pipe may be heavily scratched and scored by the many sharp shards and fragments from the fractured host pipe

- After installation the host pipe fragments surround the new pipe and any ground movement can cause these to exert point loads on the surface
An example of challenging conditions - horizontal directional drilling

When the product pipe is being pulling through the back reamed pilot bore it can be scratched if it comes in to contact with surround hard material.

After installation ground movement can cause surrounding hard materials to exert point loads on the surface of the pipe.
Savings in horizontal directional drilling through BorSafe LS-H

Some utility organizations insist that PE100 pipes used for directional drilling must be SDR 11, to reduce the effects of pipes being scored during installation, even if the pressure rating of the pipeline is 10 bar or less (SDR 17).

By specifying a HSCR PE100 we can use SR 17 pipes, hence substantially reducing the pipe cost and slightly reducing the installation costs due to a 33% reduction in pipe weight.
When pipelines are laid in rocky conditions and when they are provided with minimal cover at crossings they can be subjected to significant scratching and point loads, particularly when not provided with a sand bed and surround.
Rock impingement can lead to premature failure

Picture from Hessel Ingenieutechnik: crack on inner wall
Savings in sand less bedding through BorSafe LS-H

- In typical installations the cost of the pipe is typically between 20 and 30%, depending on pressure rating and level of competition etc.
- Pipe laying with a sandless bed and surround significantly reduces installation costs in areas were sand has to be imported.
- Additional security from point load of rock impingement.
BorSafe LS-H improves weld quality

- Poor quality joints is one of the main reasons for failures of PE systems

- The Slow Peel Test method, developed by Kiwa, is measuring the long-term quality of Electrofused joints

- BorSafe LS-H showed the best results in this test program
How resistance to slow crack growth is tested and the relevant standards
Long-term testing to demonstrate the stress crack resistance

Tests done on pipes

Notch Pipe Test (ISO13479)  
(Scratches)

Point-Load Test  
(Rock impingement)
### HSCR specifications developed in Europe - above ISO 4427 and EN12201

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<th>Specification/Guideline</th>
<th>Test method</th>
<th>Requirement</th>
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<td>Germany DVGW GW 323: “Quality Guideline for Burst-lining”</td>
<td>FNCT</td>
<td>Gas &gt;3300h, Water &gt;2700h</td>
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<tr>
<td>Germany DIN-Certco ZP 14.6.36 TW/G</td>
<td>NPT</td>
<td>&gt;5000h</td>
</tr>
<tr>
<td>“Multilayer pipes with integrated protection layer”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany DIN-Certco ZP 14.24.39: “Sand-less bedding installation”</td>
<td>FNCT, NPT, PLT</td>
<td>&gt;3300h, &gt;5000h, &gt;8760h</td>
</tr>
<tr>
<td>Germany PAS 1075: “Pipes made from Polyethylene for alternative installation techniques”</td>
<td>FNCT, PLT</td>
<td>&gt;8760h, &gt;8760h</td>
</tr>
<tr>
<td>Italy IIP: “Installation Guidelines for PE pipes for alternative installation techniques”</td>
<td>NPT, FNCT, PLT, ACT</td>
<td>&gt;5000h, &gt;8760h, &gt;8760h, &gt;300h</td>
</tr>
<tr>
<td>France Dossier Technique CSTB: “Installation without Sand Bedding”</td>
<td>NPT, FNCT, PLT, ACT</td>
<td>&gt;5000h, &gt;3500h, &gt;8760h, &gt;300h</td>
</tr>
</tbody>
</table>
The Notched Pipe Test Method (NPT) for testing external scratch resistance

- Standard test method used in EN12201, EN1555, ISO4427 and ISO4437
- Used for measuring slow crack growth resistance
- Requirements in these standards are 500 hours
- The test involves cutting 4 notches equally spaced around the sample pipe and closely simulates ‘accelerated’ real life conditions

- Standard: ISO 13478
- Test media: water/water
- Test temperature: 80°C
- Test pressure: PE80= 8bar, PE100= 9.2 bar
Undertaking the notched pipe test at 80°C accelerates the aging process.

Example: PE100 pipe 110x10mm (SDR11)

- EN12201 / EN1555: >165 hrs
- KS ISO4427 / ISO4437: >500 hrs

4 notches cut to between 18 and 22% of the wall thickness.

Typical good quality PE100:
1000 - 2000 hrs

HSCR PE100 > 8,760 hrs (1 Year)
How do we simulate rock impingement?

Point Load Testing (PLT)

- Simulates a buried pressure pipe subjected to a point load from a stone.
- Pipe sample under pressure at 8 bar at 80°C in water with 2% Arkapol.
- The piston is pushed into the sample until yield strength has been reached.
- The deformation is maintained until failure of the pipe sample.
- To meet the requirements the sample must achieve 8760 hours without failure.
- Developed by Hessel Ingenieurtechnik in Germany.
The Point-Load Test method (PLT), for rock impingement

• Point-loading on the outside of a pipe which is subjected to internal pressure

• Detergent and temperature used to shorten the time to failure

• Test developed by Dr Hessel

• Typical conditions: 80°C, 4N/mm², Arkopal N-100

• Under these conditions, failure time > 8760 h is correlated to > 100 years at 20°C with water (acc. to publication by Dr. Hessel)

• Test done on pipe, close to « real life conditions »
The Full Notch Creep Test (FNCT) to ISO 16770

Test specimen of 110 x 10 x 10 mm with a 1.6 mm notch running all the way round the sample.

Stress ($\sigma$) = 4 MPa

Temperature = 80°C

Accelerator = 2% Arkopal detergent
Other tests to measure slow crack growth performance

- **Accelerated Creep Test (ACT)**
  Essentially a FNCT undertaken at a higher temperature and with a different detergent. Developed by Dr Hessel.

- **2 Notch Creep Test (2NCT)**
  A thin rectangular sample with a notch cut on either side, otherwise similar to the FNCT. Undertaken in accordance with EN 12814

- **Circular Cracked Round Bar Test (CCRB)**
  This fatigue accelerated test in which a circular bar with a circumferential crack is subjected to a sinusoidal load having a frequency of 5 – 10Hz.

- **“SABIC” Strain Hardening Test**
  A thin rectangular sample (0.3 x 20 mm) is extended at a constant rate of 20 mm / min until the strain reaches 1200% or the sample fails. This is an indirect test method.
How do High Stress Crack Resistant PE100s perform dramatically better than regular materials
Polyethylene molecular diagrams - effects of different comonomers

Ethylene is the raw material from which PE and PP are produced. Using hexene rather than butene as the comonomer gives a PE with longer side branches.
Tough molecular structure inhibits Slow Crack Growth
## Product innovation example: PE100 HSCR

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MRS Classification</td>
<td>PE63</td>
<td>PE80</td>
<td>PE100</td>
<td>PE100 (HSCR)</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>High Density (1st Gen)</td>
<td>High Density (2nd Gen)</td>
<td>Medium Density</td>
<td>High Density (3rd Gen)</td>
<td>High Density (3rd Gen)</td>
</tr>
<tr>
<td>Slow crack growth by Notched Pipe (ISO 13479)</td>
<td>4.0MPa ~50 hrs</td>
<td>4.0MPa &gt;165 hrs</td>
<td>4.0MPa &gt;500 hrs</td>
<td>4.6 MPa &gt;500 hrs</td>
<td>4.6 Mpa &gt;8760 hrs</td>
</tr>
</tbody>
</table>
PE100 HSCR – Improved Resistance to Slow Crack Growth for Demanding Installation
Case Stories
## Importance of case stories to demonstrate end user confidence and cost savings

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Installation Details</th>
<th>Outside Dia. (mm)</th>
<th>Project Owner or End User</th>
<th>Country</th>
<th>Year of Completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tianjin Eco-City</td>
<td>Trenched and Directional Drilling</td>
<td>800</td>
<td>Tianjin TEDA Water Co.</td>
<td>China</td>
<td>2009</td>
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<td>Föhr Island Water Supply</td>
<td>Trenched and Directional Drilling</td>
<td>160</td>
<td>Föhr Water Supply Association</td>
<td>Germany</td>
<td>2009</td>
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<tr>
<td>Cavigny Waste Treatment Centre Fire Main</td>
<td>Trenched</td>
<td>110</td>
<td>Viola Environment</td>
<td>France</td>
<td>2009</td>
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<tr>
<td>Puli-khumri Water Pipeline</td>
<td>Trenched</td>
<td>180 - 250</td>
<td>Ministry of Urban Development</td>
<td>Afghanistan</td>
<td>2010</td>
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<tr>
<td>Porvoo Terminal Fire Main</td>
<td>Trenched and Directional Drilling</td>
<td>300 - 500</td>
<td>Borealis</td>
<td>Finland</td>
<td>2010</td>
</tr>
<tr>
<td>Minigish Water injection Plant 8” Pipeline Rehabilitation</td>
<td>Reduced Diameter Close Fit Lining</td>
<td>200</td>
<td>Kuwait Oil Co. (KOC)</td>
<td>Kuwait</td>
<td>2010</td>
</tr>
<tr>
<td>Fengxian Water Pipeline Rehabilitation</td>
<td>Reduced Diameter Close Fit Lining</td>
<td>300</td>
<td>Shanghai, Fengxian Water Co.</td>
<td>China</td>
<td>2010</td>
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<tr>
<td>West Pomerania Water Supply and Sewerage</td>
<td>Trenched and Directional Drilling</td>
<td>63 - 315</td>
<td>West Pomerania Water &amp; Sewerage Co.</td>
<td>Poland</td>
<td>2011</td>
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<tr>
<td>Asab Flowline and Water Injection Line Relining</td>
<td>Reduced Diameter Close Fit Lining</td>
<td>150</td>
<td>Abu Dhabi Company for Onshore Oil Operations (ADCO)</td>
<td>UAE</td>
<td>Under Construction</td>
</tr>
<tr>
<td>Al Ghalbi Water Injection Lines</td>
<td>Reduced Diameter Close Fit Lining</td>
<td>200</td>
<td>Daleel Petroleum</td>
<td>Oman</td>
<td>Under Construction</td>
</tr>
<tr>
<td>Waitakkere Water Plant</td>
<td>Directional Drilling</td>
<td>850</td>
<td>Watercare Services</td>
<td>New Zealand</td>
<td>2011</td>
</tr>
</tbody>
</table>
Waste Water Pipeline with costs savings of 30% thanks to trenchless installation

- Authority of Haarbach, Germany want to link local waste water to district waster water disposal system
  - This will safeguard the quality of the ground water in the adjacent drinking water protection area
- Directional drilling tecnology chosen to minimise destroying freshly laid road
  - High stress crack resistance PE100 material chosen to avoid risk of failure in the stoney soil and spillage into water protection area
- BorSafe HE3490LS-H (63-110mm) chosen for the 7.2km of pipelines using directional drilling installation

Fig. 1: Laid-out PE100-RC pipe in the drinking water protection area
Safeguarding the water supply to China's Eco-City with BorSafe HE3490-LS-H

The background

Development of the Sino-Singapore Eco-City

In November 2007 a formal agreement was signed by Wen Jiabao, Prime Minister of P.R.C. and Lee Hsien Loong the Prime Minister of Singapore to jointly develop a resource efficient, environmentally friendly and socially harmonious city in China. The site chosen for the Sino-Singapore Tianjin Eco-city was the Tianjin Binhai New Area, which is 45km from Tianjin and 150km from Beijing. The total area is over 30 sq km and the city is planned to have 350,000 residents by 2020.

The construction of the eco-city started in September 2008 and by June of 2009 6 billion RMB (approximately $880 million) had already been spent on this prestigious development.
Tianjin Eco-city uses HE3490-LS-H for directional drilling canal crossing

- A 30km² Eco-city jointly developed by Singapore developer and China government in Tianjin with 350,000 residents by 2020
- 4.5km water pipeline for the city crossed the 400 m wide Ji Canal using directional drilling
- 800mm OD, SDR 17 pipe PE100 HSCR - HE3490-LS-H chosen for the directional drilling section to provide the highest resistance to any surface damage
New BorSafe™ PE100 HSCR solving installation problems in the eco-city in Tianjin

Tianjin TEDA water company: “the provision of pipe produced from high stress crack resistant BorSafe™ HE3490-LS-H for the canal crossing addressed all our concerns regarding installation and possible abrasion damage.”
HSCR PE100 pipeline in the mountains of Afghanistan

The background

New water supply for drought prone city in the highlands of Afghanistan

A new polyethylene water pipeline was required to link the city of Puli-khumri in the highlands of northern Afghanistan with a reservoir. The city, which is the capital of Baghlan Province, is high in the Hindu Kush mountain range at an altitude of around 1,700 metres. The population of the city has grown rapidly over recent years and is now over 60,000 and therefore an additional source of water is very welcome in this area which is prone to severe droughts and the integrity of the pipeline is paramount.
A strategic Pipeline in the Mountains of Afghanistan with PE100-HSCR, Puli Kshamri, Hindi Kush Mount
• Water from reservoir higher up in mountains for 60,000 population in drought-prone regions
• Remote and mountainous terrain will impose high cost to import special backfill material
• Sieved material dug from trench used
Relining Kuwait’s water injection lines using BorSafe™ HE3490-LS-H

The background

Internal corrosion of steel water injection lines a major problem

Internal corrosion of steel water injection lines is a problem for many oil companies in the Middle East, especially as the wells become older and the levels of hydrogen sulphide increase.

Recently the Kuwaiti Oil Company (KOC) has begun to suffer from an increasingly ‘sour’ supply mainly due to presence of hydrogen sulphide. These concerns have encouraged their engineers to try and seek a solution to internal corrosion.
The Kuwait Oil Company flow line relining project

- Steel flow lines – corroding after less than 3 years in operation
- KOC were looking for robust solutions required that were technically & commercially acceptable
- Speedy installation important

The stakeholders
- Kuwait Oil Company – owner
- KAI, Kuwait – pipe producer
- APS, Dubai - installer
- Borouge, Abu Dhabi – material supplier
BorSafe PE100 HSCR solving oil pipe internal corrosion problems in Kuwait

A ‘tough’ PE100 liner was proposed for a relatively new steel pipe, which was already showing signs of corrosion.

For the highest security the liner pipe was specified in BorSafe HE3490-LS-H so that any defects or scores introduced during installation would not develop into cracks.
HSCR PE100 pipes in Australia’s mines

- 800mm diameter PE100 pipes were used
- Pipes were installed by Swagelining
- Some concerns about installation damage overcome by using ‘high stress crack resistant’ grade.
Pioneering extra-large pipes

- The Borouge plants in Abu Dhabi are cooled with sea water pumped 2.5 km
- For Borouge 1 large GRP pipes were used which failed twice causing emergency shutdowns of the plant
- Over 5 years we worked with consulting engineers to design the Borouge 2 cooling system with PE pipes
- 4 x 1600mm PE100 3 bar pressure feed lines and 6 gravity return lines (10 ktons) have been installed on time and are operating without problems
Cooling water from the sea:
4 x 2.5 km inlet pipelines, 6 x 2.5 km outfall
Welding & installation of 1600mm pipeline
Above ground seawater discharge unit
Meeting the needs of even larger pipes

- 3 meter spiral wound PP-HM pipe
- Unique butt welding process
- Cooling intake pipe for a new refinery
Industrial projects provide huge potential for PO gravity pipes worldwide

1 - Refinery projects:

• Require sea water intake and out fall pipelines, usually up to 3.5m in diameter, covering areas of potentially >30km.

2. Power Plants:

• Same requirements for all future power and desalination plants in the region – estimated 25 power plants planned in the Middle East alone.

3 - Petrochemical projects:

• Sea water intake gravity pipes of up to 3.5m and underground sewage/drainage pipes required

• An estimated 20 large scale petrochemical complexes planned in Middle East/Asia over the next 4 years.
Water for the World
Plastics are creating value for society…

- Less CO$_2$ emissions
- Clean water distribution and sanitation
- Access to reliable energy
- Advanced communication networks
- Safe medical devices
- Food protection and safety
CSR innovation example: ‘Water for the World’

Borealis and Borouge Leadership Forum, Abu Dhabi in 2006

Szechuan, China in 2009
Water for the World - Mission

A programme developed by Borouge and Borealis to foster local knowledge and partnerships throughout the value chain to provide sustainable solutions for the availability of safe drinking water and sanitation.
‘Water for the World’ has had a visible and positive impact

- Since Borouge and Borealis launched the Water for the World programme in 2007 we have helped over 250,000 people around the world.

- Some past important projects:
  - Water supply to Malkapur village in India
  - Victims of the earthquake Sichuan, China
  - Patients in two hospitals in Vietnam
  - School in Endallah, Tanzania
  - Water for victims of the floods in Pakistan
  - Gulf Plastic Pipes Academy, Abu Dhabi

- Links plastic products with helping communities around the world

Spreading knowledge on jointing of PE pipe systems in Malkapur, India
Water for the World in India

- **Jadan Ashram**
  - New water supply to village, school & hospital (over 2000 people).

- **Nagpur**
  - New water supply to slum area & regular housing.

- **Malkupur**
  - New “24x7” water supply to 30,000 people.

- **Hattikore**
  - Water supply project for 3000 people.

- **Bhaktapur**
  - New water supply to schools and housing (over 2500 people).

- **East & West Godavari Dist**
  - New water supply to 450 villages (7 lakh population).

- **Bangalore**
  - WSUP water supply in 3 slum areas.
W4W: Improving the image of plastics by helping communities around the world

Malkapur, India 2008

Hanoi, Vietnam, 2010

Kandol, Pakistan 2011

Szechuan, China 2009
Do good things then talk about them: > 5 years of BorPipe magazine
Thank you for your attention
Back Up
HSCR PE100 materials

PE100-RC is quickly growing in Europe, Germany and Poland are at the forefront.

Source: AMI, Borealis
International standards

- Standards related to the manufacture of ‘regular’ PE100 pressure pipes
  - ISO 4427 : 2007  Parts 1 – 3 *(voting for its updates)*
    Plastics piping systems - Polyethylene (PE) pipes and fittings for water supply
  - ISO 4437 : 2007
    Buried polyethylene (PE) pipes for the supply of gaseous fuels - Metric
  - EN 12201 : 2003 ➔ *now 2011*
    Plastics piping systems for water supply - Polyethylene (PE)
  - EN 1555 : 2010  Parts 1 - 5
    Plastics piping systems for the supply of gaseous fuels - Polyethylene (PE) - Part 2: Pipes
  - EN 13244 : 2002  Parts 1 – 5 *(replaced, merged into EN12201)*
    Plastics piping systems for buried and above-ground pressure systems for water for general purposes, drainage and sewerage - Polyethylene (PE)
## International standards

### HSCR standards developed in Europe in addition to ISO 4427 and EN12201

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<td>&gt;5000h</td>
</tr>
<tr>
<td>Germany DIN-Certco ZP 14.24.39: “Sand-less bedding installation”</td>
<td>FNCT, NPT, PLT</td>
<td>&gt;3300h, &gt;5000h, &gt;8760h</td>
</tr>
<tr>
<td>Germany PAS 1075: “Pipes made from Polyethylene for alternative installation techniques”</td>
<td>FNCT, PLT</td>
<td>&gt;8760h, &gt;8760h</td>
</tr>
<tr>
<td>Italy IIP: “Installation Guidelines for PE pipes for alternative installation techniques”</td>
<td>NPT, FNCT, PLT, ACT</td>
<td>&gt;5000h, &gt;8760h, &gt;8760h, &gt;300h</td>
</tr>
<tr>
<td>France Dossier Technique CSTB: “Installation without Sand Bedding”</td>
<td>NPT, FNCT, PLT, ACT</td>
<td>&gt;5000h, &gt;3500h, &gt;8760h, &gt;300h</td>
</tr>
</tbody>
</table>
Slow crack growth (SCG) and fast test methods

Strong needs for shorter term SCG evaluation

Standard PE 100 and High-SCR PE 100 “PE 100-RC” under usual FNCT testing conditions (James McGoldrick et al)
Slow crack growth (SCG) and fast test methods

- Material approval testing (PAS1075 4.2.1) and quality assurance of the material (PAS1075 4.2.2) take too long time— not practical!

- FNCT, NPT and PLT are not accepted in international standards of PE100-RC because they rely on one lab and other labs cannot reproduce these tests—ACT.

- Fast test methods of SCG being evaluated by ISO workgroup --- strain hardening and crack round bar (CRB)
# Slow crack growth (SCG) and fast test methods

<table>
<thead>
<tr>
<th>Methods</th>
<th>Specimen</th>
<th>Test media</th>
<th>Conditions</th>
<th>Duration</th>
<th>Standards</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>PENT</td>
<td>Pipe/CM 3 notches</td>
<td>Air/water</td>
<td>2.8MPa 80°C</td>
<td>Too long</td>
<td>ISO16241</td>
<td>Can measure COD</td>
</tr>
<tr>
<td>NPT</td>
<td>SDR11 pipe 4 notches</td>
<td>Water</td>
<td>9.2bar, 80°C</td>
<td>&gt;500hr &gt;8760hr RC</td>
<td>ISO13479 ISO14479</td>
<td>Notch 20% wall thickness</td>
</tr>
<tr>
<td>FNCT</td>
<td>Pipe/CM 4 1.6mm notches</td>
<td>2w% Arkopal N-110</td>
<td>4MPa, 80°C</td>
<td>&gt;8760hr</td>
<td>ISO16770</td>
<td></td>
</tr>
<tr>
<td>ACT</td>
<td>2w% NM-5</td>
<td>4MPa, 90°C</td>
<td>&gt;320hr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLT</td>
<td>Pipe</td>
<td>2w% Arkopal N-110</td>
<td>4MPa 80°C</td>
<td>8760hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2NCT</td>
<td>Pipe/CM 2 notches</td>
<td>2w% Arkopal N-110</td>
<td>4MPa, 80°C</td>
<td>&gt;3300hr</td>
<td>EN12814-3</td>
<td></td>
</tr>
<tr>
<td>ACT</td>
<td>2w% NM-5</td>
<td>4MPa, 90°C</td>
<td>&gt;160hr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NRT</td>
<td>Pipe ring</td>
<td>Air</td>
<td>80°C</td>
<td>On-set slow cracking time</td>
<td>DRAFT ISO TC138/WG17</td>
<td></td>
</tr>
<tr>
<td>CRB</td>
<td>Round bar</td>
<td>Air</td>
<td>23°C</td>
<td>A few days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SH</td>
<td>CM</td>
<td>Air</td>
<td>80°C, s-s ratio beyond NDR</td>
<td>A few hrs</td>
<td>By Sabic</td>
<td></td>
</tr>
</tbody>
</table>
Slow crack growth (SCG) and fast test methods

**Crack Round Bar** test is performed using a servo-hydraulic closed loop testing machine; a sinusoidal load and a ratio of minimum load, $F_{\text{min}}$, to maximum load, $F_{\text{max}}$, is used. The tests are conducted at 23 °C and these testing parameters ensure that SCG leads to brittle failure of the specimens.

Fracture mechanic principles for fast parameter generation for new & used materials
Fracture mechanics combined with FEM for lifetime prediction for pipes & fittings
Slow crack growth (SCG) and fast test methods

- Strain hardening method

![Diagram showing strain hardening process and its effects on material properties](image)
Slow crack growth (SCG) and fast test methods

- Strain hardening method

**Equipment**
- Tensile tester (load cell e.g. 200 N)
- Temperature chamber (80 °C)
- Optical extensometers

**Samples**
- Compression molded sheets
- Punch
- Possibility to add optical markers
- Tool to accurately measure thickness & width of samples
Slow crack growth (SCG) and fast test methods

Data interpretation

- Lambda (true strain) is calculated on the basis of the gauge length:

  \[ \lambda = \frac{\Delta L}{L_0} + 1 \]

- The true stress is calculated assuming conservation of sample volume between the gauge marks:

  \[ \sigma_t = \frac{F}{A\lambda} \]

- The strain hardening modulus \(<G_p>\) is calculated as the average difference quotient:

  \[ \langle G_p \rangle = \frac{1}{N} \sum_{i=1}^{N} \frac{\sigma_{i+1}}{\lambda_{i+1}} - \frac{\sigma_i}{\lambda_i} \]

The calculation of \(<G_p>\) for this study is performed typically between draw ratio’s 9 and 12.
# Slow crack growth (SCG) and fast test methods

<table>
<thead>
<tr>
<th>Methods</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| **Current methods** | • Well established in standards  
• Accepted to use by the industry  
• Reasonable investment | • Long testing time, especially for HSCR materials.  
• Some methods need additional chemicals  
• More materials used  
• Poor correlation  
• Cost per sample |
| **CRB** | • No chemical used  
• No elevated temperature  
• Short testing time  
• Highly reproducible  
• Good for both quality control and long life prediction | • No standard  
• High initial investment  
• Data interpretation is a little complicated |
| **SH** | • No Chemical used  
• Small amount of material use  
• Very short testing time  
• Good for quality control | • Need to correlate with ESCR  
• Strict temperature control  
• Reproducible is not as good as CRB |
NRW loss reduction is key objective of Pipeline management

Source: Water and Sanitation Program of the World Bank
What is the problem with our water and sanitation systems?

- Infrastructures in many countries were initially installed in the late 19th Century, more than 100 years old now.
- These old water systems have a leakage rate of more than 30% and need replacement or renovation.
- The situation will be aggravated by climate change and rising urban populations.
- Pipeline renovation and new pipelines that are more robust than before are needed.
History of materials use for Water Piping

- Late 1800’s to 1920s: “Pit” cast iron + rope & molten lead
- 1920’s to 1960’s: “Spun” cast iron + leadite & cement lining
- 1950’s to 1960’s: Ductile iron + weld & rubber gaskets
- 1960’s to now: Plastics like Polyethylene (PE)
  - 1960’s: Unimodal High Density PE63
  - 1970’s: Unimodal High Density and Medium Density PE80
  - 1990’s: Bimodal High Density and Medium Density PE80
  - Bimodal PE100
  - 2000’s: Bimodal High Stress Crack Resistance PE100, PE100-HSCR
PE is the dominant material for drinking water in Europe – small diameters

% Share of Km by Material - Diameters < 180mm - AMI market study

- Major Countries: Germany, France, UK, Italy, Spain, Holland
- Central Europe: Poland, Hungary, Cze Rep, Slovak Rep
- Minor Countries: Belgium, Austria, Switzerland, Ireland, Portugal
- Scandinavia: Sweden, Denmark, Finland, Norway
Key reasons PE is the right solution

(1) Flexible and coilable:
- Savings in transportation and installation
- Safety in bending the pipes and ground movements

(2) Toughness and Long Life Time
- First pipes installed 40 years+ ago-still in use although first gen. materials
- Resistance to external notches, scratches, etc… have constantly improved
- Recent materials are almost insensitive to external damages and can be installed in rough conditions

(3): corrosion free

(4): leak tightness by fusion jointing
fully end load resistant. No pull out even under severe ground movement like earthquakes.
# PE failure statistic in earthquakes

<table>
<thead>
<tr>
<th>Material</th>
<th>Mains</th>
<th>Branches</th>
<th>Services</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>0</td>
<td>4607</td>
<td>6151</td>
<td>10758</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>583</td>
<td>0</td>
<td>33</td>
<td>616</td>
</tr>
<tr>
<td>PE</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Kobe Earthquake killed 6,000 people and destroyed 440,000 homes.

Afterwards failures within gas system were analysed by Osaka Gas Co.

In steel systems no pipes failed but many joints.

In cast iron system both pipes and joints failed.

In PE system no pipe or joint failures.

Publication of these results created a major surge in PE usage in Japan.
Failure statistics (1) : UK, 1995 to 2003

UKWIR Water Mains National Failure Database

Promising Results for PE pipes on collected data