Polybutene-1

General Presentation
**Polybutene-1: Content of the presentation**

- LyondellBasell (LYB) Introduction
- PB-1 Basic Properties
- PB-1 Typical Customer Applications
- PB-1 Primary Types
- PB-1 Product Portfolio
- PB-1 Properties
- PB-1 Key Features
- Conclusions
Introduction

LYB Introduction
Amazing Chemistry To Meet Consumer Needs

LyondellBasell products are basic elements used to make products that people depend on every day.

Diverse end markets

- Refining & Fuels
- Building & Construction
- Transportation
- Textiles & Furnishings
- Packaging
- Consumer
- Other

*Estimate based on revenue*
Global Reach

58 plants in 18 countries

More than 13,000 employees worldwide

Sales in more than 100 countries

North America
- Illinois
- Iowa
- Louisiana
- Mexico
- Michigan
- New Jersey
- Ohio
- Pennsylvania
- Tennessee
- Texas

South America
- Argentina
- Brazil

Europe
- France
- Germany
- Italy
- Netherlands
- Poland
- Spain
- UK

Asia Pacific
- Australia
- China
- Japan
- S. Korea
- Malaysia
- Thailand

AFME
- Saudi Arabia

Manufacturing Technology Centers

Owned and operated by LyondellBasell, its subsidiaries and/or joint ventures.
Our Product Lines And The End Markets We Serve…

**Olefins & Polyolefins**
- Americas
- Europe, Asia & Int’l

**End Uses**
- Food Packaging
- Textiles
- Automotive
- Appliances
- Films
- Flexible Piping

**Intermediates & Derivatives**
- Ethylene
- Propylene
- Polyethylene
- Polypropylene
  - Catalloy process resins
- PP Compounds
- Polybutene-1
- Propylene Oxide
- Styrene Monomer
- PG and PGE
- Acetyls
- Oxyfuels
- Ethylene Oxide
- EG and EOD

**End Uses**
- Insulation
- Home Furnishings
- Adhesives
- Consumer Products
- Coatings

**Refining**
- Gasoline
- Diesel
- Olefins Feed

**End Uses**
- Automotive Fuels
- Aviation Fuels
- Heating Oil
- Industrial Engine Lube Oils

**Technology**
- Process Licensing
- Catalyst Sales
- Technology Services

**End Uses**
- Polyolefin and Chemical Manufacturers

lyondellbasell.com
Global Rated Capacity Rank*

1. Polyolefins
   Polypropylene Compounds
   Oxyfuels
   Polypropylene

2. Propylene Oxide

3. Polyolefins Licensing

4. Polyethylene
   Propylene

5. Ethylene

Refining Capacity
268,000 barrels per day

*Positions based on LyondellBasell wholly owned capacity and pro rata share of JV capacities as of Dec. 31, 2011.
LyondellBasell Joint Ventures – Eastern Hemisphere

- **Basell Orlen Polyolefins**: PP (*Spheripol*) & PE (*Hostalen ACP*) – Poland
- **PolyMirae Company**: PP (*Spheripol*) – South Korea
- **SunAllomer Ltd**: PP Plant (*Spheripol*) – Japan
- **PolyPacific Polymers**: PP compounding – Australia
- **HMC Polymers Co Ltd**: Propane Dehydrogenation, PP (*Spheripol*) & PP (*Spherizone*) – Thailand
- **Al Waha Petrochemical Co.**: Propane Dehydrogenation & PP (*Spherizone*) – Saudi Arabia
- **Saudi Polyolefins Company (SPC)**: PP (Novolen) – Saudi Arabia
- **Saudi Ethylene and Polyethylene Company (SEPC)**: C2/C3 Cracker, PE (*Hostalen ACP*) & PE (*Lupotech T*) – Saudi Arabia
- **Lyondell Bayer Manufacturing Maasvlakte**: Propylene Oxide, Styrene Monomer – The Netherlands
- **Ningbo ZRCC Lyondell Chemical Co. Ltd.**: Propylene Oxide, Styrene Monomer – China
- **Nihon Oxirane Company Ltd.**: Propylene Oxide, Styrene Monomer, Propylene Glycol – Japan
LyondellBasell Joint Ventures – Western Hemisphere

- Indelpro: PP (Spheripol) & PP (Spherizone) – Mexico
- U.S. PO JV: Propylene Oxide, Styrene Monomer, (Channelview); Propylene Oxide, Tert-Butyl Alcohol (Bayport) – Texas, U.S.
- La Porte Methanol Company LP: Methanol – Texas, U.S.
- PO/SM II, LP: Propylene Oxide, Styrene Monomer – Texas, U.S.
Fostering Success in Our Communities

- Provide funding and other support for programs focused on improving education, environmental conservation or community prosperity
- Actively promote employee volunteerism
- Global Care Day: our annual day of worldwide community service
- Community Advisory Panels allow open dialogue with neighbors in communities where we operate
- Member of the American Chemistry Council and CEFIC
Basic Properties
Polybutene-1 is a polyolefin

Polyisobutylene (PIB)

\[ \text{C} \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{C} \quad \cdots \quad \text{n} \]

Polybutene-1 (PB-1)

\[ \text{H} \quad \text{H} \quad \text{C} \quad \text{C} \quad \text{CH}_3 \quad \text{CH}_2 \quad \cdots \quad \text{n} \]

It is important to note that PB-1 is often mistaken for polyisobutene, or PIB, which is an entirely different type of material - a low molecular weight oily liquid.
Using butene-1, which is, along with ethylene and propylene a fundamental building block of polyolefins, we have developed an innovative process technology to unlock the full potential of C4-olefin chemistry for our customers.

*Polybutene-1* is the result of polymerising butene-1 with a stereospecific catalyst to create a linear, high isotactic and semi-crystalline polymer.

These resins offer an exceptional combination of properties that make them ideally suited for creep resistant applications.

The following slides are presented to acquaint users with the properties of this unique material.
Polybutene-1 Historical Review

1954: Discovery by Prof. G. Natta’s research team

Mid 1960’s – 1970’s: First reference projects in pressure piping applications

1970-80’s: Introduction of PB-1 piping systems into heating, plumbing and industrial applications

1998: Montell Polyolefins enters Polybutene-1 business

2003: Basell starts up new 45 KT production plant in Moerdijk, NL

2008: Extension of plant capacity to >60 KT
Polybutene-1: Moerdijk plant

Capacity: 67 kt/a
Location: Moerdijk, NL

- 100% dedicated to PB-1
- Largest PB-1 plant in the world.
- Enhanced product quality
Typical Customer Applications
Typical Applications designed, developed and specified by LYB’s customers

Hot and Cold

Drinking Water Transport

Courtesy of Georg Fischer
Typical Applications designed, developed and specified by LYB’s customers

Surface Heating & Cooling Systems:

– Floor, ceiling, wall
– Embedded structured conditioning
– Snow and ice melting
– Greenhouses, stadium lawn heating

Images: courtesy of Gabo Systemtechnik
Typical Applications designed, developed and specified by LYB’s customers

High Temperature Heating Systems:

– District heating and cooling
– Geothermal pipelines
– Radiator connections
Typical Applications designed, developed and specified by LYB’s customers

Other pipe/tubing applications:

– Sprinkler systems
– Compressed air systems
– Industrial piping
– Automotive flexible tubing
**Polybutene-1: Peelable Packaging**

Modification of PE-films with PB-1 to make packaging “Easy-Open”

TEM pictures (Internal LYB test method)

Courtesy of LyondellBasell customers
Polybutene-1 in Blow-Moulding

PB-1 as inner-liner in blow-moulded hot water tanks

Courtesy of LyondellBasell customers
Polybutene-1 in Glass Filament Reinforced Water Tanks

PB-1 as inner-liner in long glass filament hot water tanks

Courtesy of LyondellBasell customers
Polybutene-1 in Specialty Applications

- Fibre modification: softness; elasticity …
- Hot melt adhesives
- Masterbatches
- Injection molding
- Film modification and …
  many more….  

Courtesy of LyondellBasell customers
Polybutene-1

Primary Types
Homopolymers

Homopolymer (1/3):

These grades are made in a reactor with pure butene-1 (C4) monomer and catalyst. The homopolymer grades are the stiffest and have the highest tensile strength at yield and creep resistance of the two primary types. In the natural state (no colorant added) Polybutene-1 homopolymers are translucent and have see-through or contact clarity with liquids. Polybutene-1 homopolymer has a glass transition temperature of \(-18^\circ\text{C}\).
Homopolymers

Homopolymer (2/3):

The homopolymers have exceptional creep resistance, even at elevated temperatures - a property that has caused them to be considered for many applications where there is continuous load:

- Pipes and fittings for hot water plumbing.
- Pressurized vessels such as hot water heaters, swimming pool pumps and filter housings, water softener and reverse osmosis tanks, auto surge tanks etc.
- Hose and tubing such as pneumatic tubing, pressurized beverage tubing, lined hydraulic tubing, retractable tubing etc.
- Seals such as beverage closure liners, architectural seals, and gaskets.
- Other structural components such as fasteners, cable ties, furniture parts and construction applications such as geogrids.
- Compression packaging films.
Homopolymers

Homopolymer (3/3):

The homopolymers also demonstrate outstanding abrasion resistance rivaling UHMW PE and the ability to absorb high levels of fillers making them suitable for a wide range of filled and flame retarded applications, or protective coatings:

- Wire and cable for down hole mining, plenum cable resins, and push pull cable.
- Retractable cord sets.
- Dip coating resins for dishwasher drain baskets, chutes and slides in material handling.
- Abrasion resistant tapes, films and pipe wrap.
Copolymers

Random Copolymer (1/2):

These polymers are made in a reactor with a small amount ethylene or propylene (or ethylene and propylene in some cases: terpolymers) added to disrupt the crystallinity of the polymer. The lower crystallinity makes this type of Polybutene-1 softer, more flexible and higher clarity. While it has a lower Tg than homopolymer, it has extremely slow crystallization rates making it rarely used as a pure (non-blended) product.
Copolymers

Random Copolymer (2/2):

These resins have very unique crystallization kinetics (slow) making them ideally suited for Hot Melt Adhesives (HMA):

- HMA applications that require long open time, (slow setting)
- HMA applications that need high temperature adhesive peel and shear strength
- HMA applications that need high creep resistance

The copolymers are also compatible with polypropylene (PP) and are an excellent blending material for PP to improve low temperature impact, improve clarity, and lower seal initiation temperature in polypropylene film.
Polybutene-1

Product Portfolio
# Polybutene-1 product portfolio (colored versions)

<table>
<thead>
<tr>
<th>Product type</th>
<th>MFR at 190 °C 2.16 kg (g/10min)</th>
<th>T\text{m1} (°C)</th>
<th>Flexural Modulus (MPa)</th>
<th>Density (g/cm³)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 1133 DSC ISO 178 ISO 1183</td>
<td>Polybutene-1 PB 4235-1 Ivory</td>
<td>0.6</td>
<td>127~129</td>
<td>450</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>Akoalit PB 4267 Grey</td>
<td>0.6</td>
<td>127~129</td>
<td>450</td>
<td>0.925 Homopolymer Ex reactor</td>
</tr>
<tr>
<td></td>
<td>Akoalit PB 4268 White</td>
<td>0.6</td>
<td>127~129</td>
<td>450</td>
<td>0.925 Random copolymer Ex reactor</td>
</tr>
<tr>
<td></td>
<td>Akoafloor PB R 509 Brown</td>
<td>0.7</td>
<td>124~126</td>
<td>330</td>
<td>0.925 Random copolymer Ex reactor</td>
</tr>
</tbody>
</table>
## Polybutene-1 product portfolio (natural color)

<table>
<thead>
<tr>
<th>Product type</th>
<th>MFR at 190 °C 2.16 kg (g/10min)</th>
<th>T&lt;sub&gt;m1&lt;/sub&gt; (°C)</th>
<th>Flexural Modulus (MPa)</th>
<th>Density (g/cm&lt;sup&gt;3&lt;/sup&gt;)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB0110M</td>
<td>ISO 1133</td>
<td>0.4</td>
<td>128</td>
<td>450</td>
<td>0.914</td>
</tr>
<tr>
<td>PB0300M</td>
<td></td>
<td>4.0</td>
<td>127</td>
<td>450</td>
<td>0.915</td>
</tr>
<tr>
<td>DP0400M*</td>
<td></td>
<td>15</td>
<td>126</td>
<td>450</td>
<td>0.915</td>
</tr>
<tr>
<td>PB0800M*</td>
<td></td>
<td>200</td>
<td>124</td>
<td>410</td>
<td>0.915</td>
</tr>
<tr>
<td>PB8640M</td>
<td></td>
<td>1.0</td>
<td>113</td>
<td>250</td>
<td>0.906</td>
</tr>
<tr>
<td>PB8340M</td>
<td></td>
<td>4.0</td>
<td>113</td>
<td>270</td>
<td>0.911</td>
</tr>
<tr>
<td>DP8220M</td>
<td></td>
<td>2.5</td>
<td>97</td>
<td>140</td>
<td>0.901</td>
</tr>
<tr>
<td>DP8510M*</td>
<td></td>
<td>40</td>
<td>94</td>
<td>120</td>
<td>0.897</td>
</tr>
<tr>
<td>DP8911ME*</td>
<td></td>
<td>200</td>
<td>95</td>
<td>120</td>
<td>0.895</td>
</tr>
<tr>
<td>KTAR05</td>
<td></td>
<td>0.8</td>
<td>114</td>
<td>25</td>
<td>0.890</td>
</tr>
<tr>
<td>KTMR05</td>
<td></td>
<td>1.0</td>
<td>-</td>
<td>&lt;10</td>
<td>0.870</td>
</tr>
</tbody>
</table>

*Made off-line with peroxide
### Polybutene-1 product portfolio (offgrades)

<table>
<thead>
<tr>
<th>Product type</th>
<th>Product description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB Film OG</td>
<td>Mix of PB-1 off-spec batches without color pigments (&quot;natural&quot;). Few colored pellets may be present.</td>
</tr>
<tr>
<td>PB Pipe OG</td>
<td>Mix of PB1 off-spec batches with different color pigments.</td>
</tr>
</tbody>
</table>

**Uses:**

- Excellent compatibility with PP.
  - Blends with PP to increase flexibility
  - Blends with PP to improve flow-ability
  - Reduction of melting point / Vicat.
  - Correction of shrinkage rate in injection moulding.
- Carrier for high percentage filler concentrates
- Can be of interest as purging agent or shut-down + start-up resin in extrusion
- Good dispersion in PE
Polybutene-1

Properties
Crystallization from the melt

Post melt and post mould crystallisation (1/3):

When *Polybutene-1* cools from the molten state it crystallizes in what is known as a Type II morphology. This form is soft and kinetically non-stable and over seven to ten days the *Polybutene-1* will transform or “polymorph” to the stable crystalline structure Type I. In molecular terms the polymer is arrayed in a helix with 11 monomer units per 3 turns of the helix in Type II, and like an uncoiling spring changes to 3 monomer units per turn of the helix. This change is irreversible without re-melting the polymer, and is accompanied by a substantial improvement in properties. Homopolymer tensile strength increases by 400%, the modulus increases by 25%, melting point rises from 114-116°C to 127-129°C, and the polymer hardens from a 39 Shore D to a 55 Shore D.
Crystallization from the melt

Post melt and post mould crystallisation 2/3):

- **Form II**
  - Kinetically favoured
  - Ageing (5 days) at room temperature and atmospheric pressure

- **Form I**
  - Thermo-dynamically stable
  - Ageing (10 min) at room temperature and elevated pressure

**MELT**
1 bar

2 kbar
Crystallization from the melt

Post melt and post mould crystallisation (3/3):

- Transformation from kinetically favorable Form II to thermodynamically stable Form I

- Impact on:
  - Density, rigidity, strength
  - Crystallinity level
  - Melting point, clarity

- PB-1 in stable form I has high
  - Molecular weight, $M_W$: ca. 700 000
  - Crystallinity, $X$: ca. 55%
Physical Properties

Melt Flow Index (MFI):

A method of measuring of melt viscosity at very low shear rates at 190°C. It is amount of material measured in decigrams that flow through a standardized orifice that is under a standard weight of 2160 grams in one minute. The measurement is inverse to the viscosity and molecular weight (i.e. higher melt index (MI) means lower viscosity and molecular weight). As noted in data sheets, it is meant to be considered as a target value. Production specifications for a particular resin has an allowable range of (± 3 sigma) which can vary from ± 0.15 for a target of 0.45 MI to ± 7 for a target of 30.

PB-1 MI range is from 0.4 g/10' up to 200 g/10'
**Physical Properties**

**Specific Gravity (Density) PB-1 in Type I:**

Is the relative density of a material compared to water at standardized conditions (1 g/ml).
All unfilled PB-1 types have a density ranging between 0.895-0.915 g/ml (solid).

**Tensile Strength at Yield:**

The stress required to strain a test specimen to its yield (plastic) point. It is the measure of the general strength of the material. Note that in the case of Polybutene-1 the polymers do not demonstrate necking, but instead strain harden after yielding.

**Elongation at Yield:**

The percent strain at the point of plastic yield. For most Polybutene-1 low MFI homopolymer grades this occurs around 25% while is around 35% for copolymer.
Physical Properties

Elongation at Break:

The percent strain at the point of specimen rupture. LYB data sheets report this number measured on compression molded samples that have very low orientation, and typically have values greater than 250%. Injection molded samples often have far lower elongation at break due to the high degree of orientation imparted in the injection molding process, and are typically less than 50%.

Flexural/Tensile Modulus:

A measure of the force required to bend or pull a specimen divided by the strain (eg. slope of stress strain curve). The data is generally reported as the 1% secant value at a crosshead speed of 1.27 mm/min.
Physical Properties

Hardness:

Hardness for *Polybutene-1* is generally reported on the Shore D (not for Plastomers: Shore A) scale and is a measure of indentation under a standardized load, time, and indenter geometry. The homopolymers are roughly 55D with the copolymer being considerably softer.

Gardner Impact Strength:

This falling ball impact test value is the multiaxial impact energy necessary to fracture a specimen at cold temperatures. Gardner impact on injection moulded homopolymers at −30°C. range from 0.5-1.0 Joule depending on nucleation and moulding conditions. Nucleation improves the impact performance at low temperature.
Izod Impact Strength:

A measure of the impact resistance of a sharply notched test specimen implies the notch sensitivity of the material. Consistent ductile failures or no failure at levels higher than 8 J/cm are reported as “no break”. As with other crystalline polymers, higher MI Polybutene-1 usually have lower notched Izod values. All homopolymers below 20 MI are no break at room temperature. As this test depends on a high internal stress (notch), rigid comparisons between dissimilar polymers are not recommended. Other uniaxial (eg. un-notched Izod, Charpy, Tensile impact) and multiaxial (eg. Gardner, dynatup, etc) tests may be more predictive of performance in an application and are widely used. These tests generally cannot be correlated to one another.
Physical Properties

Heat Distortion Temperature (HDT):
Is not used with flexible polymers as it is the temperature necessary to bend a 3 mm thick bar 0.5mm at 0.45 or 1.8 Mpa. A flexible polymer by its nature will deflect this much at room temperature under this load.

Vicat Softening Point:
Is generally used with soft polymers to measure the instantaneous (short-term) high temperature performance. In the indenter method a defined indenter and load are pushed against the specimen and the temperature is raised until the indenter penetrates the sample. In the ring and ball method, a sample sitting on a ring and under a defined ball is submersed in an oil bath, and the temperature is raised until the ball falls through the sample. The ring and ball Vicat of PB-1 homopolymers is 113-116°C while copolymers are in the range 75-105°C.
Electrical Properties

Natural *Polybutene-1* has electrical properties, which are described below. Fillers, flame retardant, colorants, etc. may change these properties significantly:

**Dielectric strength:**

Dielectric strength is the voltage required to puncture a sample of known thickness expressed as volts/mil of thickness. The rate of voltage application and sample thickness influences results. PB-1 homopolymer has a strength of 3310 volts/mil @ 3mil 1600 Amps 1 kV/ sec increase. This is similar to what you would get in LDPE, and far better then polar resins like nylon or PVC.
Electrical Properties

**Dielectric constant:**

Dielectric constant or specific inductive capacity is a measure of insulation’s ability to store electrical energy. The constant is the ratio of the resin’s electrical capacity to that of a vacuum. Most resins are influenced by frequency. PB-1 is again quite similar to LDPE and far better than polar products such as nylon, polyesters, or PVC.

**Dissipation factor:**

The dissipation factor is the tendency of a material used as a dielectric in a capacitor to convert electrical energy to heat. The ratio of the energy loss to the energy used to charge a capacitor is the dissipation factor, and is usually highly dependent on frequency. PB-1 is relatively unaffected by frequency. Polar resins have dissipation factors typically 10-20 times higher, and they are very susceptible to changes in frequency.
# Thermal Properties

The following data was generated on *Polybutene-1* homopolymers and, therefore, should only be used as an approximate guide for copolymer grades. For most practical calculations, the data may be sufficiently accurate. For critical applications, however, we recommend generating data for the specific grades to be used.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value 1</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melt thermal conductivity</td>
<td>7.62</td>
<td>J/cm.°C</td>
</tr>
<tr>
<td>Heat Capacity of Melt</td>
<td>2.5</td>
<td>J/g.°C</td>
</tr>
<tr>
<td>Heat of fusion</td>
<td>58.15</td>
<td>J/g</td>
</tr>
<tr>
<td>Heat Capacity of solid</td>
<td>2.1</td>
<td>J/g.°C</td>
</tr>
<tr>
<td>Solid thermal conductivity</td>
<td>7.92</td>
<td>J/hr.cm.°C</td>
</tr>
</tbody>
</table>
Polybutene-1

Key features
Flow behavior (1/2)

- Due to its shear thinning behaviour, PB-1 shows a sharp reduction in melt viscosity during processing
  - PB-1 is very easy to disperse
  - PB-1 is very shear dependent
Key features

Flow behaviour (2/2)

- The strong shear dependency results in:
  - easy dispersability
  - good wettability of fillers in a PB-1 matrix
  - loading of high amount of fillers in a PB-1 matrix
- PB-1 has a very low melt elasticity
  - The molten polymer chains have a low tendency to recoil back after applying and removing a stress
- When producing concentrates of pigments or fillers, PB-1 helps to wet and stabilise the single particles, avoiding them to re-agglomerate.
- Once in the solid state, PB-1 behaves as a normal polymer and does not present the characteristic issues shown by waxes (exudation, interference with surface properties, etc)
Creep resistance:

The resistance of a material to strain under load over time is a viscoelastic phenomena that is dependent on time, temperature, and load. *Polybutene-1* homopolymers demonstrate a remarkably good resistance to deformation under load at both ambient and elevated temperatures. In the following graph the creep behavior of PB-1 compared to other olefins:
Key features

Post melt shrinkage:
After cooling from the melt, there is about 0.5-1% shrinkage. High quench rates or cold tooling minimizes this.

Post mould shrinkage:
During the transformation to Type I morphology there is typically an additional 1.5–2% shrinkage. This is very predictable and many close tolerance parts are routinely molded by measuring the “green part” with the knowledge that it will consistently shrink to the correct dimension.

Bulk density:
For calculating the storage capacity of bins and silos, the bulk density of the pellets is about 0.5 g/ml.
Permeation:

Liquids and gases will permeate through *Polybutene-1*, as with all other plastics, at a rate specific to the liquid or gas and its temperature, concentration, and pressure. *Polybutene-1* is particularly resistant to moisture and has a water vapor transmission rate (WVTR) of 0.05 g/μm/cm²/day at 38°C, 90% RH (ASTM D 96 Method E). It has a rather poor resistance to the passage of gasses such as carbon dioxide, oxygen, and nitrogen. Permeation (ASTM D 1434 method M) at room temperature, 50% RH for O₂, N₂, and CO₂ respectively are about 9, 2.4, and 30 ml/μm/cm²/day.
Key features

Chemical resistance:

All types of *Polybutene*-1 are highly resistant to chemical attack. With little exception, inorganic and polar organic chemicals produce little to no effects at ambient temperature. Non-polar organic solvents such as gasoline, benzene, toluene, carbon tetrachloride, etc. will cause swelling and softening, particularly at elevated temperatures.

Environmental stress cracking:

*Polybutene*-1 has exceptionally good resistance to environmental stress cracking. Embrittlement that occurs with other plastics (eg. HDPE) in the presence of oils, detergents and other agents is not observed with these materials. Only very potent oxidising agents (eg. 98% sulfuric acid, fuming nitric acid, liquid bromine, etc.) produce stress cracking in PB-1. Using ASTM D1693 at 50°C, 10% Igepal C0630, these resins show no failure after 15000 hours of exposure.
Weathering resistance:

*Polybutene-1* without additional stabilization has limited resistance to weathering or exposure to UV light, a component of sunlight. The incorporation of 2.5% finely dispersed carbon black will absorb UV radiation and protect the polymer for long term exposure. Chemical UV stabilizers that do not influence color have been used in *Polybutene-1* and data is available upon request. A good example is a 50μm UV stabilized film sample was weathered for 400,000 Langleys in EMMQUA accelerated direct weathering with no loss in tensile or physical properties.
Key features

Radiation sterilisation:

Pure *Polybutene-1* resins are not recommended for applications where radiation (gamma) sterilisation is required due to both yellowing and loss of physical properties, including embrittlement.

Decorating:

Printing and adhesion is affected by oil, slip and antistat additions. All LYB resins are printable as supplied, but only after appropriate flame or corona treatment. The surface of *Polybutene-1* is quite resistant to a wide variety of chemical substances and therefore must be chemically altered to allow the adhesion of appropriately formulated paints, inks, and many adhesives. The surface tension should be 35-38 dynes/cm² for most applications. This treatment in perishable and will decay over several days or weeks. The incorporation of stearates, slip agents, or other oily agents may totally inhibit printability.
Key features

**Bonding/welding:**

*Polybutene-1* may be hot plate welded, hot bar sealed, spin and vibration welded using appropriate procedures. However, due to its microwave transparency, it cannot be radio frequency (RF) welded without the addition of other polymers or fillers.

**Abrasion resistance (1/2):**

*Polybutene-1* has remarkably good wear resistance to non impinging type of abrasion as typified in sand slurry type of testing as shown in next slide. In this test, samples are abraded by rotation in sand slurry at controlled temperature, and weight loss is measured per unit time. At elevated temperature *Polybutene-1* performance advantages are magnified.
Abrasion resistance (2/2):

The abrasion resistance of Polybutene-1 is also less sensitive to molecular weight than other resins - meaning even injection molded parts should be quite good in abrasion. This test is not indicative of scratch resistance from an abrader that is pressed into the sample under considerable loads.

### Material

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific wear rate (wt. Loss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultra High Molecular Weight PE (UHMW)</td>
<td>0.46</td>
</tr>
<tr>
<td>0.1 MI homopolymer PB-1</td>
<td>0.43</td>
</tr>
<tr>
<td>0.4 MI homopolymer PB-1</td>
<td>0.44</td>
</tr>
<tr>
<td>0MI HMWHDPE</td>
<td>1.2</td>
</tr>
<tr>
<td>0.1 MI HDPE</td>
<td>2.2</td>
</tr>
<tr>
<td>0.3 MI HDPE</td>
<td>2.9</td>
</tr>
<tr>
<td>0.8 MFR PP</td>
<td>5</td>
</tr>
<tr>
<td>PVC</td>
<td>8</td>
</tr>
</tbody>
</table>
Polybutene-1

Conclusions
Conclusions

*Polybutene*-1 is used as a pure resin but also it is used as a blend component to enhance the properties of PP and PE.

*Polybutene*-1's complete compatibility with PP ensures optimum dispersion. Once dispersed, PB-1 reduces the crystallinity of the PP matrix significantly. This imparts much greater softness, elasticity and flexibility.

Thanks to PB-1's relatively low melting point, thermally sensitive ingredients can be incorporated at levels of 70% or more, while *PB*-1's inherent flexibility and impact strength help to reduce the brittleness of, for example, flame-retardant composites.

PB-1 is used in compounds as either an extremely low level additive, at moderate levels for property modification of other olefins or resins, and to some extent as a the dominant polymer in a variety of compounds.
Conclusions

At low levels

-) PB-1 can act as an internal melt plasticizer when added to other olefins at levels between 2-5% and thus increases extruder throughputs (10-20%), injection molding spiral flow (5-10%) and improve a resin’s gloss and color brightness.

-) When added to HDPE or LDPE at levels between 3-7% it dramatically improves the stress crack resistance of the polyethylene and is used in wire coating of PE.

-) High flow grades are commercially used as masterbatch carrier resin where the additive is being effectively moved to the surface of a film or fiber. Here, PB-1's remarkable shear-thinning behaviour enables it to accept and disperse high levels of pigment or mineral filler. This same advantage ensures that the masterbatch itself disperses easily during subsequent processing in PP resin. Better pigment development can reduce total pigment expense.
Conclusions

- When added to polyethylene, plastomer, or ethylene copolymer sealant resins at levels between 10-30%, the sealant will peel apart easily (seal peal). It is used in films and lidstock compounds.

At moderate levels

- When the proper grade of PB-1 is added to polypropylene at levels between 10-50% the seal initiation temperature (SIT) of the polypropylene can be dramatically reduced. It is used in BOPP sealant layers.
- Addition of a high C2 content PB-1 coploymer can reduce the modulus and increase the elasticity and impact of polypropylene without sacrificing clarity. It is used in shrink film and cast film.
- It is used in combination with elastomers to create creep resistant thermoplastic elastomers for applications such as elastic films.
Conclusions

At high levels

- When blended with PP above 50% it imparts excellent creep resistance to a compound. It is used as compression packaging film, sausage casing, and specialty tapes applications.
- When blended at 60-70% with polyethylene it is used as a seal peel adhesive resin for polypropylene container lidstock.
- It can be compounded with reinforcing fillers to make creep resistant structural polymers that also demonstrate excellent toughness.
Conclusions

Another example, in hot melt adhesives, Polybutene-1 enables the formulator to tailor adhesive properties. The wide range of Polybutene-1 viscosities, including a grade containing residual peroxide for ultra-fluid adhesives, coupled with a range of ethylene copolymers with crystallisation times from 1 to 20 minutes, offer complete design freedom, such as:

• Tensile or cohesive strengths typically five times that of EVA or atactic PP over a broad temperature range
• Excellent adhesion to olefinic substrates
• Temperature capability from -20°C to >100°C (for the pure resin)
• Open times from 15 seconds to 30 minutes or more
• Extended pot life with appropriate stabilisation

… and of course, PB-1 offers chemical resistance similar to PP.
**Conclusions**

*Polybutene-1* is suitable for a variety of markets. Its property profile does not resemble other polyolefins or olefin copolymers. *Polybutene-1’s* outstanding creep resistance and crystallisation behaviour are unique amongst polyolefins yet its rheology enables it to disperse easily in PP & PE.

It presents new opportunities either as a pure resin or as a component of a more complex formulation. The applications described here represent only a fraction of the total potential of this material.

At LyondellBasell we are working with our customers to develop further mutual understanding of this unique polymer, jointly creating new products, new applications and new markets.
Thank you
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