Polybutene-1 Piping Systems: Material-specific Properties and Typical Applications”

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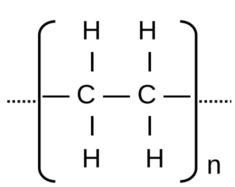
Polybutene-1 (PB-1) was introduced into piping applications in the mid 1960’s. During the past 25 years PB-1 has established itself in sanitary and heating applications, covering a small share in the European HTS market. PB-1 offers distinct advantages for planners, architects, construction companies, plumbers, and most important, for the end-user. Its double-digit average annual growth rate has led Basell to invest further in this fascinating material. A new PB-1 production plant is currently being built in Moerdijk, The Netherlands, and is due to come on-stream in 2003.

PB-1 is a thermoplastic polymer and a member of the polyolefin’s family. It is known especially for its flexibility, hoop strength and creep resistance.

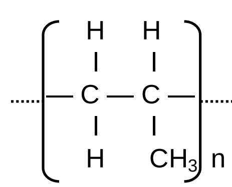
1. Typical Properties of PB-1 Homopolymers [1] - [6]

PB-1 is obtained by polymerisation of butene-1 with a stereo-specific Ziegler-Natta catalyst to create a linear, high molecular, isotactic, semi-crystalline polymer. PB-1 combines the typical properties of conventional polyolefins with some characteristics of technical polymers.

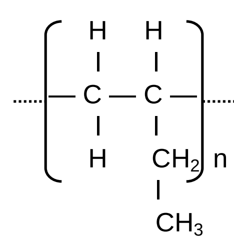
Due to its similar structure, PB-1 is very compatible with PP. It can be used in blends to improve certain characteristics of PP. On the other hand, PB-1 is not compatible with PE. PB-1 copolymers are blended in PE film grades for use in peelable packaging.



Polyethylene



Polypropylene



Polybutene-1

Crystallisation Behaviour

Solid PB-1 can exist in 4 crystalline states. Three of them are meta-stable (Form II, III and I’). During solidification from the molten state PB-1 mainly crystallises to tetragonal Form II. In course of a few days the material passes through a crystalline phase transformation to build the stable Form I.

Crystalline Form	Shape	Melt temperature	Density
I	twin hexagonal	121 – 130 °C	0.915 g/cm³
II	tetragonal	100 – 120 °C	0.900 g/cm³
III	ortho-rhombic	ca. 96 °C	0.897 g/cm³
I'	hexagonal without twins	95 – 100 °C	

The C_2H_5 side groups of PB-1 are long enough to create free volume between the molecules when the melt solidifies. During the recrystallisation phase the "voids" are filled and the material shrinks approx. 2 %. Hence, crystalline Form I is more dense and the product characteristics differ from Form II. The melting temperature, density, hardness, stiffness and yield stress increase, while the ultimate elongation remains unchanged. Once fully crystallised, PB-1 reaches its best mechanical performance.

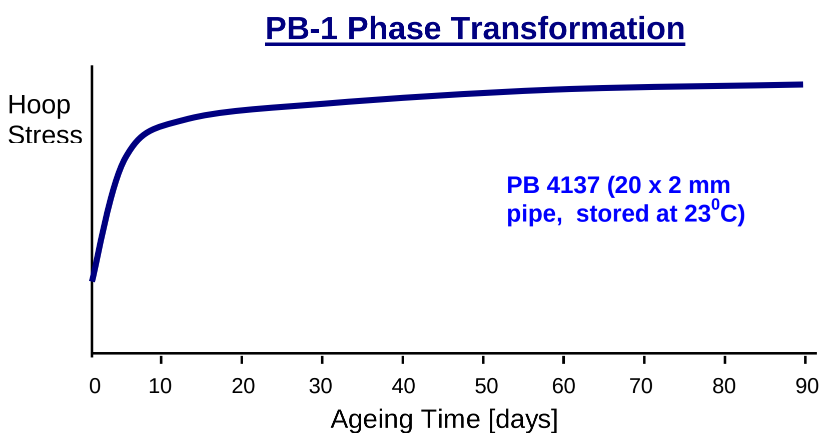


Figure 1: Hoop stress vs. ageing time of 20 x 2 mm pipes made from PB 4137

The recrystallisation continues over a long period but most of it is completed after 7-10 days (see figure 1). The speed of phase transformation depends on the temperature, hydrostatic pressure, structure, orientation and nucleation. The recrystallisation occurs fastest at room temperature. At 23°C and atmospheric pressure the phase transformation of PB-1 homopolymers takes about 1 week, however, at a pressure of 2000 bar it happens in only 10 minutes.
Additionally, the phase transformation can be strongly accelerated by mechanical treatment, e.g. by multi-directional bending.

Melt Properties

The rheological behaviour is very non-Newtonian, which means that the melt viscosity is shear-dependent. PB-1 is more sensitive to shear than other polyolefins (see fig. 2).

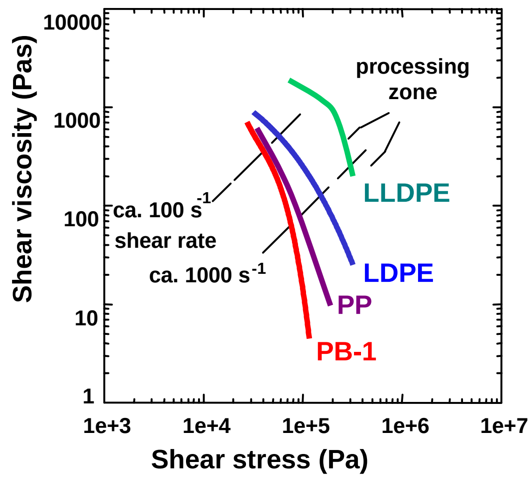


Figure 2: Shear viscosity vs. shear stress

Very strong orientation can lead to a drastic increase of the elastic modulus which results in embrittlement of the material. Usually, the level of orientation induced by the standard extrusion conditions is not critical. An easy tool to control the level of orientation is the measurement of the elongation at break. This can be done straight after pipe extrusion.

The melt strength of PB-1 is ca. twice as high as for PP, which results in better drawability and less sagging of the melt during extrusion.

The molecular weight, $M_{W,}$ of PB-1 is typically 2 –3 times that of a PP of similar MFR. Unexpectedly, the processability is not affected by the high molecular weight. PB-1 can be processed with conventional plastics manufacturing equipment. PB-1 is characteristically different in its processing behaviour compared to PP and PE, and thus, requires particular expertise in the manufacture of pipes and fittings.

The high molecular weight and the low shear viscosity make PB-1 an easily weldable material. Various connection techniques are feasible: socket welding, butt welding and electro-fusion welding are commonly applied for pipe installation.

Mechanical Properties

PB-1 is a semi-crystalline polymer with high isotacticity and high crystallinity. The crystalline part determines characteristics like density, stiffness, hardness, creep resistance, abrasion resistance, temperature resistance and chemical resistance. The amorphous part influences the mechanical strength, impact resistance, stress cracking resistance and compression set properties.
The crystalline domains in PB-1, the so-called spherulties, are connected with entangled tie-molecules from the amorphous part (see fig. 3). The high molecular weight and the relatively long C_2H_5 side chains make the bonds very strong.

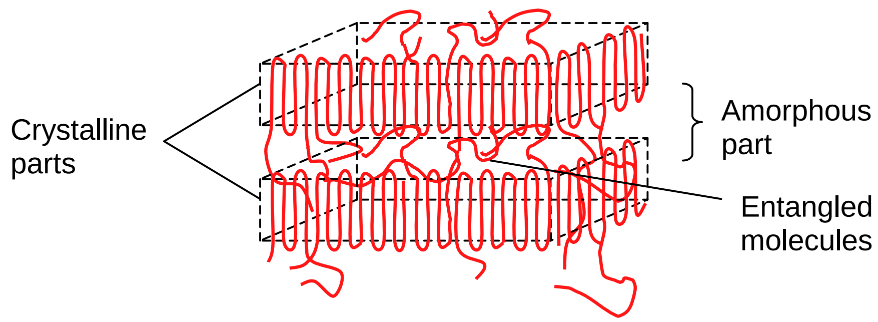


Figure 3: Chain entanglements between the crystalline domains

The peculiar tensile behaviour of PB-1 is based on these chain entanglements. PB-1 does not show the typical necking behaviour of other semi-crystalline polyolefins. Depending on the preparation of the test specimen, a very little yielding might be visible (see fig. 4).

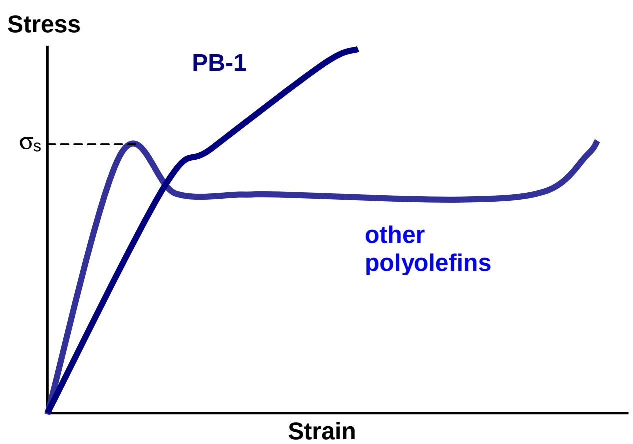


Figure 4: Tensile behaviour of PB-1 vs. other polyolefins

The above model also explains why PB-1 has an excellent burst pressure resistance, no sensitivity to stress cracking, good impact strength, good abrasion resistance, good compression set and retention of mechanical properties close to the melting point (see figure 5).

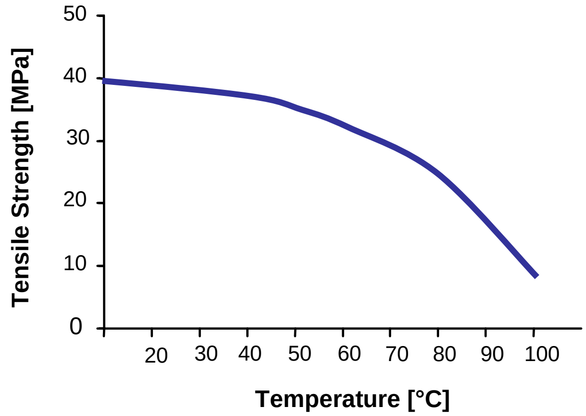


Figure 5: Tensile strength in function of the temperature

The softening temperature of PB-1 homopolymers is quite high (ca. 113°C).

Having a tensile modulus of ca. 400 MPa, PB-1 homopolymers are more flexible than PP-R (min. 850 MPa) and PEX (min. 600 MPa). The flexibility remains high even at low temperatures and allows easier handling during cold seasons, provided that temperatures do not drop below the glass transition temperature of PB-1.

Impact Resistance

PB-1 resists impact well. The IZOD notched impact strength (ISO 180) of PB-1 is classified "no break" at room temperature. The cold temperature performance is also very good because of the high flexibility and the low ductile/brittle transition temperature (ca. –18°C).

Compression Set

PB-1 homopolymer is a very flexible and soft material for a pipe grade. Its elastic recovery is excellent even though it is not crosslinked. The compression set at 23°C is ca. 55 %, and at 70°C ca. 64 %, according ASTM D395-89, method B.

Creep Resistance

PB-1 behaves differently from other polyolefins under load. It performs similarly to technical polymers like TPU or PA11 or PA12 (see figure 6).

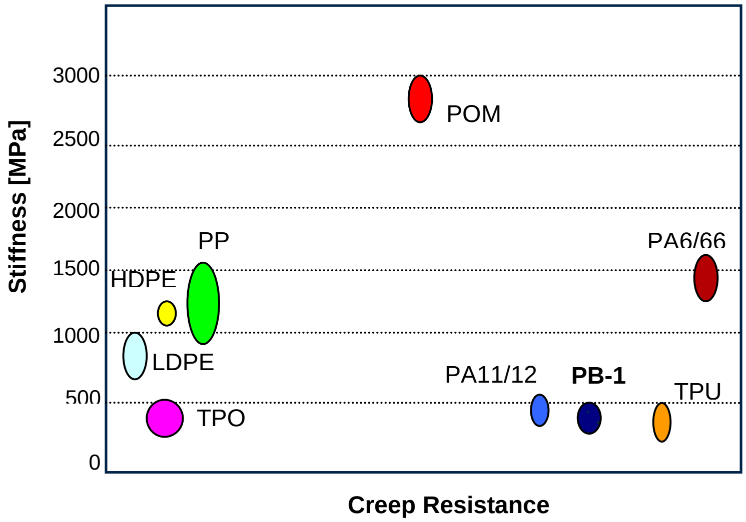


Figure 6: Stiffness vs. creep resistance of various polymers

After the initial strain induced by a given stress, there is very little cold flow if the stress is below the yield point of PB-1 at that temperature. This property is dependent on the polymer morphology. The long-term performance of PB-1 under mono-axial strain at different stresses and temperatures is depicted in figure 7.

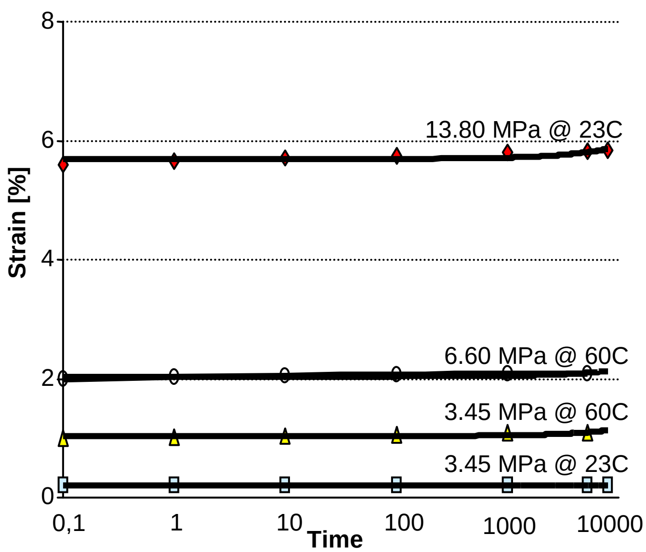


Figure 7: Creep strain of PB-1 at different stress and temperatures

Long-term Hydrostatic Performance

PB-1 is also highly creep-resistant when subjected to multi-axial strain like in a pressurised pipe. Long-term hydrostatic testing of PB-1 is done at a max. temperature of 110°C. This is only 15°C below the melting point, and thus, a clear demonstration of polybutene's creep performance at elevated temperature.

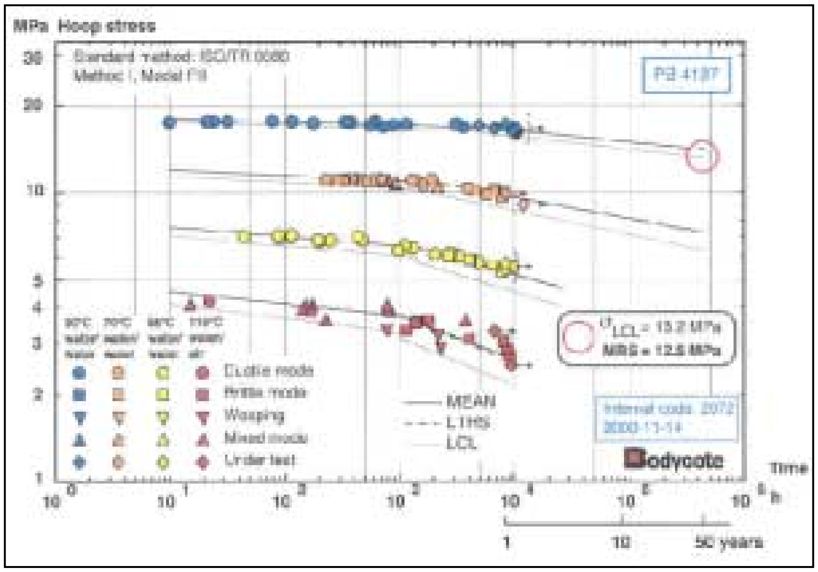


Figure 8: Regression analysis acc. ISO/TR 9080 of PB 4137 Grey

The regression analysis according ISO/TR 9080 of PB-1 homopolymers has proven the minimum required strength MRS of 12.5 MPa. Thus, polybutene-1 is classified as PB 125.

Abrasion and Wear Resistance

The wet abrasion resistance of PB-1 is excellent in sand/slurry type conditions. It performs as well as UHMW-PE which is well known for its outstanding abrasion and wear resistance. In dry conditions, however, PB-1 does not meet the high performance of UHMW-PE.

Sand slurry test at 23°C for 100 h (Basell internal method)	**specific wear rate (weight loss)**
UHMW-PE	0.46
PB-1 (MFR 0.1)	0.43
PB-1 (MFR 0.4)	0.44
HMW-HDPE	1.2
HDPE (MFR 0.1)	2.2
HDPE (MFR 0.3)	2.9
PP (MFR 0.8)	5

Environmental Stress Cracking (ESCR)

PB-1 is very insensitive to environmental stress cracking. It does not show any failure after 15,000 hours of exposure in 10 % Igepal C0630 solution at 50°C according to ASTM D1693.

Melt Index [g/10min]	Density [g/cm³]	Exposure Time [h]	Failures [%]
Polybutene-1			
0.4	0.913	15,000	0
2.0	0.911	15,000	0
Polypropylene			
3.5	0.902	1,123	75
0.7	0.904	15,000	40
Polyethylene			
0.2	0.921	20	50
0.2	0.921	40	100
0.7	0.915	15	100
4.5	0.922	17	100
5.6	0.959	16	100

PB-1 is even used as additive in blend to improve the ESCR of certain PE grades. The addition of 2-5 % PB-1 improves the stress crack resistance significantly. When used as a processing aid at similar concentrations, PB-1's can improve the extruder throughput significantly without increasing the motor torque.

Chemical Resistance

Being a polyolefin PB-1 possesses excellent chemical resistance. It is resistant to most acids, bases, detergents, oils, fats, alcohol, ketones and aliphatic hydrocarbons. PB-1 is sensitive to oxidising acids, aromatic and chlorinated hydrocarbons. In this regard, it is similar to PP.

2. Typical Applications [7] – [10]

More than 25 years of service in the field have shown that piping systems made from PB-1 exhibit a unique balance of properties. PB-1 is the preferred material when it comes to comparison based on material quality, connection techniques, laying, safety, long-term behaviour and environmental advantages.

PB-1 piping systems have been designed for use in plumbing and heating networks - e.g. hot and cold water transport, under floor heating, wall heating, ceiling cooling, radiator connections, district heating - as well as in industrial applications with contact to chemicals.

PB-1 barrier pipes are practically impermeable to oxygen, making them suitable for closed loop heating applications, where resistance to the ingress of oxygen through the pipe wall into the circulating water system is mandatory in order to resist corrosion of the system's metal components.

For hot and cold water installations in buildings, from basement distribution via riser pipes up to final distribution to each consumer, water flows in a corrosion-safe and encrustation-free system. The thermal expansion, noise transmission and the pressure loss inside the pipe are low.

PB-1 piping systems are being used for cold water transport in Asia, especially in regions which are subjected to soil movements due to geological activities. The flexibility and stress cracking resistance of PB-1 allows the pipe system to adapt to minor ground movement without compromising system integrity.

Installation & Connection Technology

PB-1 systems are easy to work with and economical to install. Simple handling and fast installation is dictated by PB-1's light weight, flexibility (even at cold ambient temperatures), low memory effect and the wide variety of available jointing techniques.

PB-1 has the added advantage that it can also be used for the production of fittings, thereby allowing the installation of complete piping systems, using just one type of raw material. The system producers have developed and commercialised sophisticated fitting programs which include tees, elbows, reducers, end caps, flange adapters, sockets etc.

The large variety of jointing techniques facilitate the construction of all-plastic networks with homogenous connections. The installer can choose from:

- socket welding,
- butt welding,
- electro-fusion welding,
- compression jointing, and
- push-fit systems.

Currently, pipe sizes from 6 mm to 110 mm diameter are being employed for domestic applications, and pipes up to 160 mm for district heating.

Standards & Environment

The PB-1 pipe materials appreciate a broad recognition of national and international standards, following extensive long-term testing. PB 4137 Grey is formulated to meet the stringent water quality standards for drinking water systems even at elevated temperatures.

PB-1 is classified as ‘environmentally friendly’, consuming less energy during manufacture, conversion, installation and use than competitive traditional materials. As a polyolefin, it can also be recycled.

3. Conclusions

PB-1 is a unique polyolefin with a number of properties that make it an excellent choice as a pipe material, evidenced by its continuing market acceptance growth in both Europe and Asia. In common with other polymers, it demonstrates numerous environmental benefits over the use of traditional materials. Rigorous codes & standards are in place to ensure long life and suitability for potable water and demanding high temperature applications. PB-1’s unique properties will ensure that it retains its position alongside the better-known polymers used in piping in the years to come.

4. Acknowledgement

The authors wish to thank the members of the Polybutene Piping Systems Association (PBPSA) for their contribution.

5. Literature

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Note: Basell does not sell PB-1 for use in pipe applications intended for use in North America, and requires its customers not to sell products made from PB-1 into pipe applications in North America.