Rilsan®

RILSAN® PA 11: CREATED FROM A RENEWABLE SOURCE

ARKEMA

Contents

1 Introduction

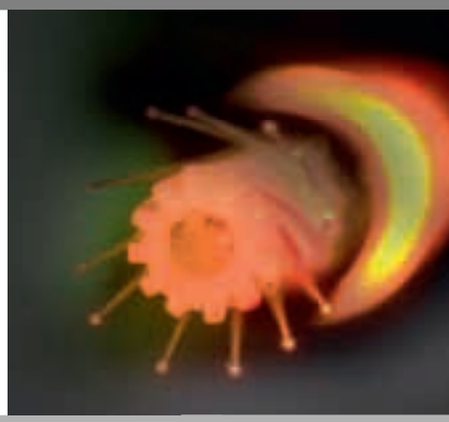
A global chemical player, Arkema consists of 3 coherent and balanced business segments: Vinyl Products, Industrial Chemicals, and Performance Products.
Present in over 40 countries with 18,600 employees, Arkema achieves sales of 5.2 billion euros. With its 6 research centers in France, the United States and Japan, and internationally recognized brands, Arkema holds leadership positions in its principal markets.

Continuously developed by Arkema for more than fifty years, Rilsan® PA11 is a reference in the world of performance polyamides.

Produced from a renewable source (castor oil), Rilsan® PA11 is used in a large number of applications thanks to its outstanding properties: excellent resistance to chemicals (particularly hydrocarbons), ease of processing, a wide range of working temperatures (-40°C / +130°C), high dimensional stability and low density, to name a few. Many industries around the world (automotive, transport, textile, oil and gas, wire & cables, electronics) have used Rilsan® PA11 for decades.

Rilsan® PA11 is easy to process, using most processing technologies (extrusion, extrusion-blow molding, injection molding and rotomolding).
The PA11 matrix accommodates countless additives and filling agents, such as plasticisers, stabilisers, colorants, lubricants, impact modifiers, glass fiber, carbon fiber, etc.
In total, over 100 different grades are available, packaged in sealed bags or containers ready for use.
Rilsan® PA11 is produced in France (Serquigny) and in the USA (Birdsboro, PA).

2 Applications



Rilsan® PA11 is used around the world in many demanding industries:

AUTOMOTIVE

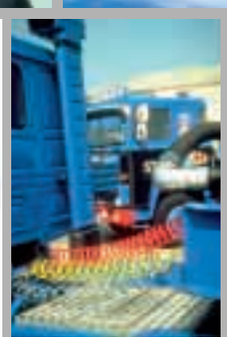
Specific properties:

- Cold impact resistance
- Ageing resistance
- Resistance to hydrocarbons
- Resistance to zinc chloride
- Flexibility

Applications:

- Fuel lines
- Fluid transfer lines (brake, clutch, cooling)
- Quick connectors, fittings, fasteners and clips
- Friction parts

INDUSTRIAL VEHICLES



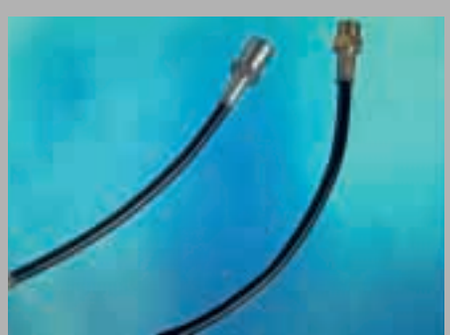
Specific properties:

- Cold impact resistance
- Chemical stability
- Flexibility
- Ageing resistance

Applications:

- Air brake tubing for trucks
- Hydraulic hoses
- Fuel lines, clutch lines
- Quick connectors, fittings
- Fasteners and clips

PNEUMATICS



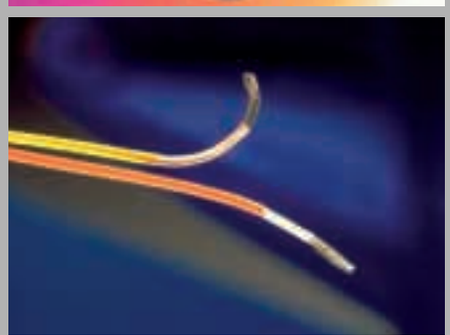
Specific properties:

- Flexibility
- Chemical resistance
- Burst strength

Applications:

- Pneumatic hoses, air lines
- Hydraulic hoses

AEROSPACE

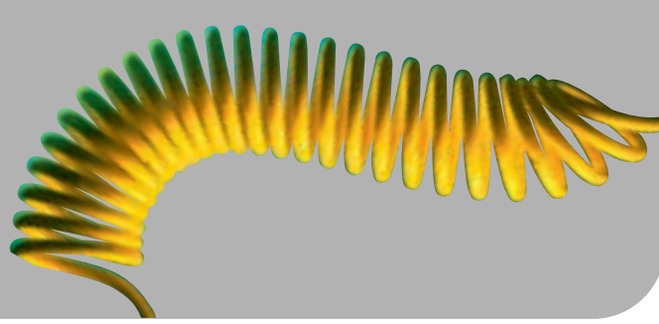


Specific properties:

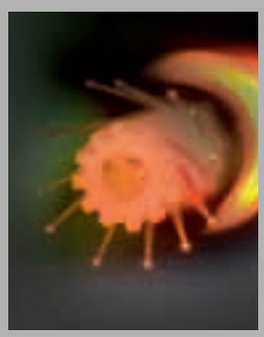
- Temperature resistance
- Dimensional stability
- Resistance to fuel

Applications:

- Electrical cable sheathing
- Hydraulic hoses
- Oil tanks
- Air-conditioning hoses & ducts



EE/CABLE INDUSTRY



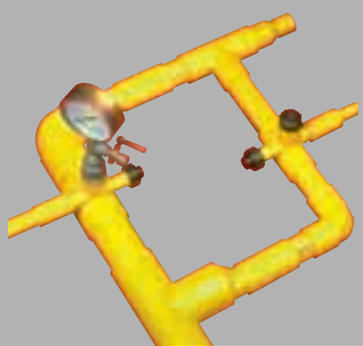
Specific properties:

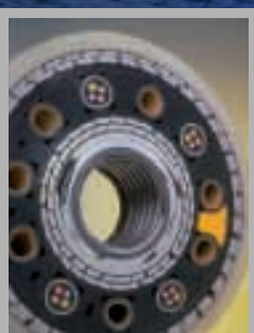
- Chemical resistance
- Easy processing
- Very smooth surface finish
- Resistance to termites
- Abrasion resistance

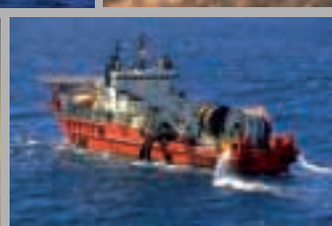
Applications:

- Optical cable sheathing
- Copper cable sheathing
- Connectors
- Housings
- Fasteners and clips

OIL AND GAS







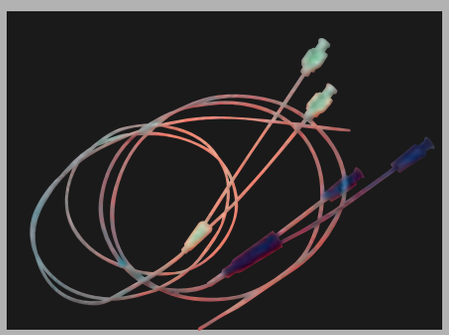
Specific properties:

- Resistance to hydrocarbons
- Ageing resistance
- Flexibility
- Easy processing

Applications:

- Flexibles, umbilical lines and cables,
- Umbilical hoses
- Gas pipes and fittings (T-fittings, valves, reducers)
- Flexibles (flow-lines, risers)
- Flexible liners for offshore & on-shore applications

MEDICAL AND FOOD PACKAGING



Specific properties:

- Food & medical approved grades (Europe, FDA, USP Class VI)
- Chemical stability
- Low gas permeation (O_2, CO_2)

Applications:

- Medical equipment
- Catheters
- Nutriment & solution bags
- Food casing
- Beverage tubing

SPORTS

Specific properties:

- Light weight
- High hardness
- Abrasion & scratch resistance
- Dimensional stability
- Transparency
- Sublimation printing
- Impact resistance
- Ability to withstand surface treatment techniques

Applications:

- Racket eyelets & bumpers
- Badminton shuttlecocks
- Ski top layers
- Shoes soles
- Mechanical parts (footwear, rackets, ski industry)

TEXTILE & MONOFILAMENTS

Specific properties:

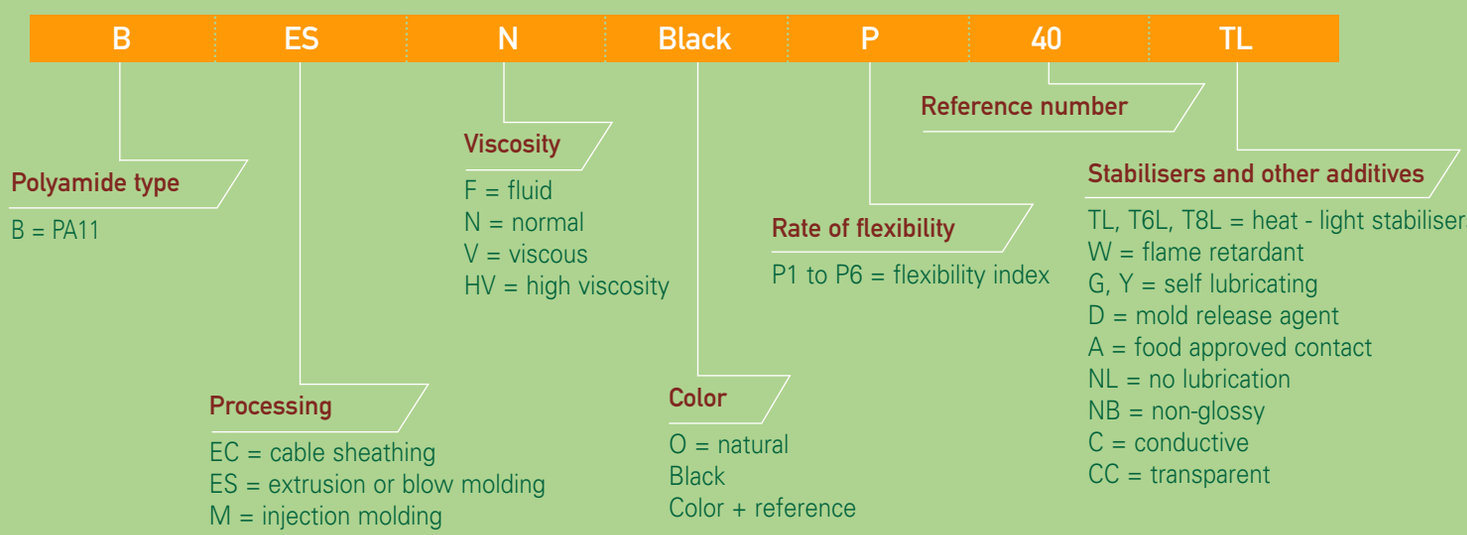
- Chemicals resistance
- Dimensional stability
- Abrasion resistance
- Flex fatigue resistance
- Easy extrusion

Applications:

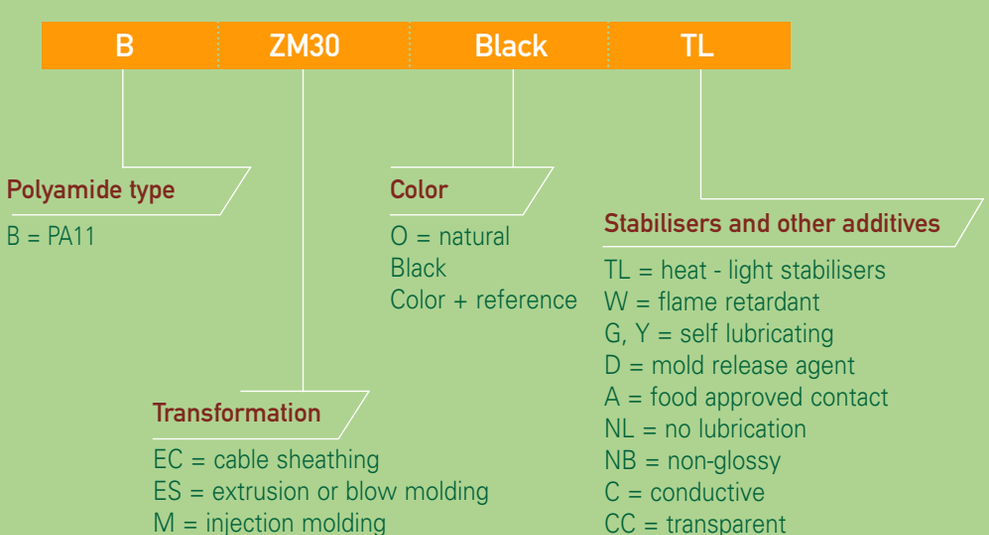
- Technical & high-end fabrics
- Brushes
- Industrial woven fabrics
- Filters

3 Nomenclature

Designation of standard rigid and plasticised grades:



Designation of standard reinforced molding grades:



Designation of new grades in initial marketing phase:

M designation is used (e.g. M-BESN BLACK P 212 CTL)

A few examples of Rilsan® PA11 grades designations:

Rigid	BMN0 TLD; BESNO TL; BESVO A FDA
Semi-rigid	BESNO P20 TL
Flexible	BESNO P40 TL
Reinforced	BZM 23 black TL

Special grades can be developed to fulfill specific customers requirements.

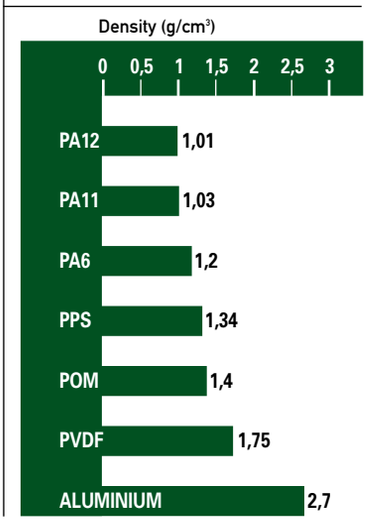
4 Material properties

Physical properties

Density

Compared to other high performance polymers, the Rilsan® family and more specifically Rilsan® PA11 offers very low density, some 3 to 6 times lighter than metal. This is a significant economic advantage when studying the cost versus performance aspect of using Rilsan® PA11.

Comparative density of Rilsan® PA11 and PA12 vs various engineering polymers and aluminium, per ISO 1183 standard



Moisture pick-up

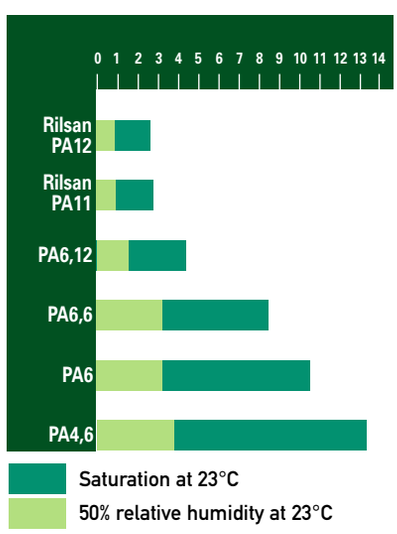
Among all performance polyamides, the Rilsan® family and more specifically Rilsan® PA11 has very low moisture pick-up. Other polyamides feature a more hydrophilic behaviour resulting from the polarity of the amide functions. Thanks to its low concentration of amide groups, Rilsan® PA11 can be used in a wide range of humidity environments. This low moisture pick-up results in outstanding dimensional stability of final parts made out of Rilsan® PA11.

The absorption characteristics of Rilsan® PA11 are similar when it is exposed to other polar liquids such as alcohols, acids and esters.

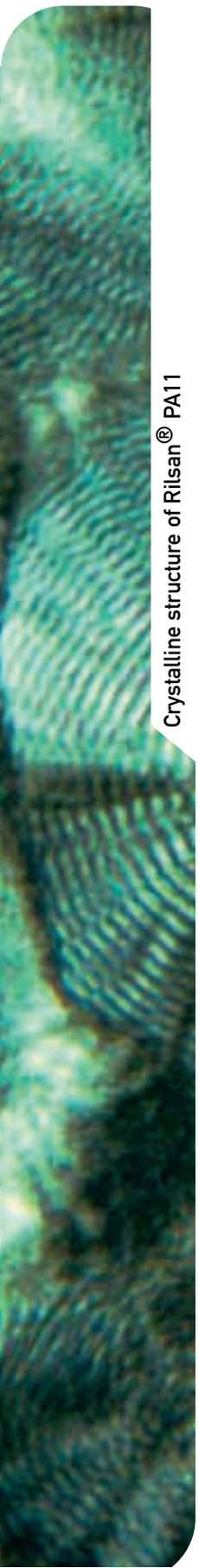
The following table shows the dimensional stability of Rilsan® PA11 and PA6 after 25 weeks of immersion in water at 20°C.

	LENGTH VARIATION	WEIGHT VARIATION
Rilsan® PA11	0,2 – 0,5%	1,9%
PA 6	2,2 – 2,7%	9,5%

Water absorption based on relative moisture rate of Rilsan® PA11 and PA12 vs various polyamides, as per ISO 62 standard



Thermo-mechanical properties


Crystalline structure of Rilsan® PA11

Phase transition

Rilsan® PA11 is a semi-crystalline thermoplastic polymer featuring 2 phase transitions:

• Melting range between 180°C and 189°C (depending on the grade), which corresponds to fusion of the crystalline phase. It occurs 10°C higher than Rilsan® PA12, due to a greater density of hydrogen bonds.

• A glass transition temperature (Tg) of around 45°C, corresponding to transition of the amorphous phase, approximately 5°C higher than for Rilsan® PA12.

The following table provides the melting ranges of several Rilsan® PA11 and PA12 grades, per the ISO 11357 standard.

		Standard molding grades		Standard extrusion flexible grades	
	UNIT	AMNO TLD	BMNO TLD	AESNO P40TL	BESNO P40TL
Melting range	°C	178	189	171	182

Thermal stability

Rilsan® PA11 offers greater thermal stability than Rilsan® PA12, and can be used continuously at 125°C under certain conditions. Additionally, it can withstand intermittent peaks of up to 150°C.
It can also withstand cold temperatures, and maintains its impact resistance at -40°C. For extreme climatic conditions, a special grade is available which can withstand temperatures down to -60°C. Rilsan® PA11 is the only polyamide in the world capable of performing in such harsh environments.

The table below features the typical service temperatures for Rilsan® PA11 and PA12 compared to PA6 and PA66.

	UNIT	RILSAN® PA11	RILSAN® PA12	PA6	PA 66
Operating temperature	°C	100	90	100	110

The following table features the continuous service and temperature peaks for Rilsan® PA11 and PA12 per a major car OEM standard for a 1,000-hour continuous test with temporary 16-hours temperature peaks.

	UNIT	RILSAN® PA11	RILSAN® PA12
Continuous	°C	125	100
Temperature peaks	°C	150	125

Heat distortion temperature under load

As a result of its inherent cohesion forces Rilsan® PA11 features high heat distortion temperatures under load, in excess of those of Rilsan® PA12.
The values obtained show that at high temperatures, Rilsan® PA11 retains its mechanical properties and exhibits higher creep resistance.

The following table features the heat distortion temperature (HDT) under load for various Rilsan® PA11 and PA12 grades, as per ISO 75 standard.

	UNIT	BMNO TLD	AMNO TLD	BESNO P40TL	AESNO P40TL	BZM30 OTL	AZM30 OTLD
HDT under 0,46 Mpa	°C	145	130	130	125	180	175
HDT under 1,85 Mpa	°C	50	45	45	45	175	170

Vicat temperature

For any given formulation, Rilsan® PA11 boasts a higher Vicat softening temperature than Rilsan® PA12.
This temperature, which depends on molding conditions, varies significantly based on the flexural modulus of Rilsan® PA11 grades.

The following table features the Vicat points for Rilsan® PA11 vs Rilsan® PA12, per the ISO 306 standard.

		Standard molding grades	
	UNIT	BMNO type (PA11)	AMNO type (PA12)
Vicat point under 1 daN	°C	180	170
Vicat point under 5 daN	°C	160	140

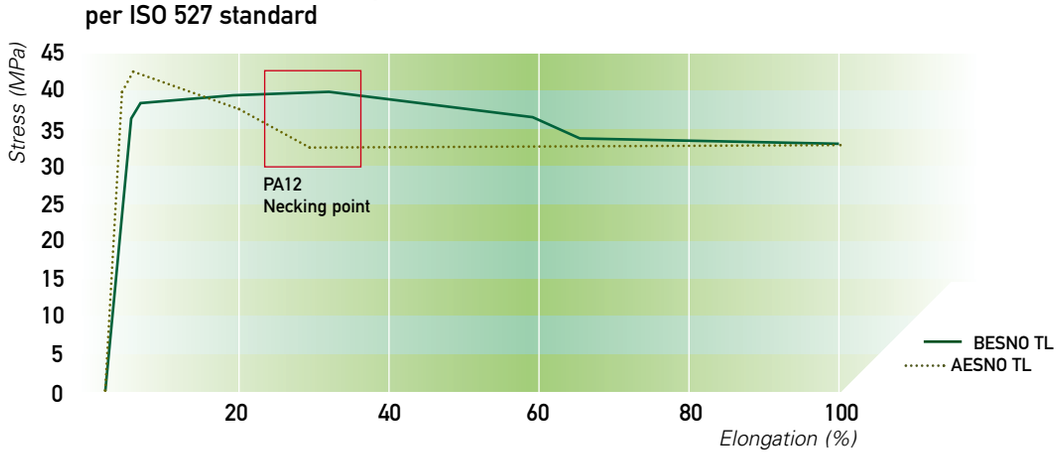
Mechanical properties

Tensile strengh

Rilsan® PA11 exhibits excellent mechanical properties over a wide temperature range. It has high elongation at break and high tensile strength at break and at yield. It is one of the toughest high-performance polymers and is therefore used extensively in engineering applications.

At ambient temperature, the tensile strength of rigid (unmodified) Rilsan® PA12 leads to noticeable necking at around 20% elongation. In the same conditions, rigid Rilsan® PA11 first produces "diffuse necking", up to 40% elongation, beyond which necking occurs. As shown by the graph below, Rilsan® PA11 provides a significant safety factor in mechanical stress over PA12.

Comparative tensile strength curves for Rilsan® AESNO TL and BESNO TL at 23°C, per ISO 527 standard

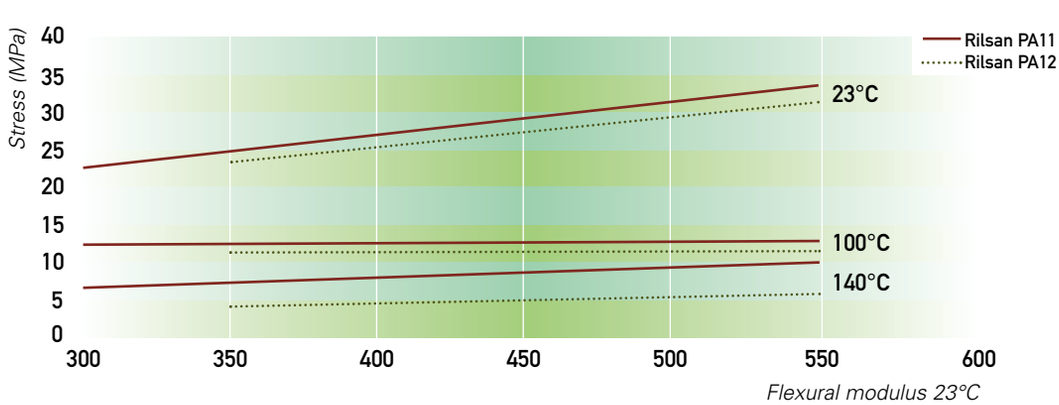


This very different performance can be attributed to the greater strength of the Rilsan® PA11 crystallites (triclinic/hexagonal) compared to the Rilsan® PA12 crystallites (monoclinic).

This better stability of Rilsan® PA11 compared to Rilsan® PA12, observed above with rigid grades also applies to plasticised grades across the entire temperature range from 23°C to the melting point. The difference increases with temperature.

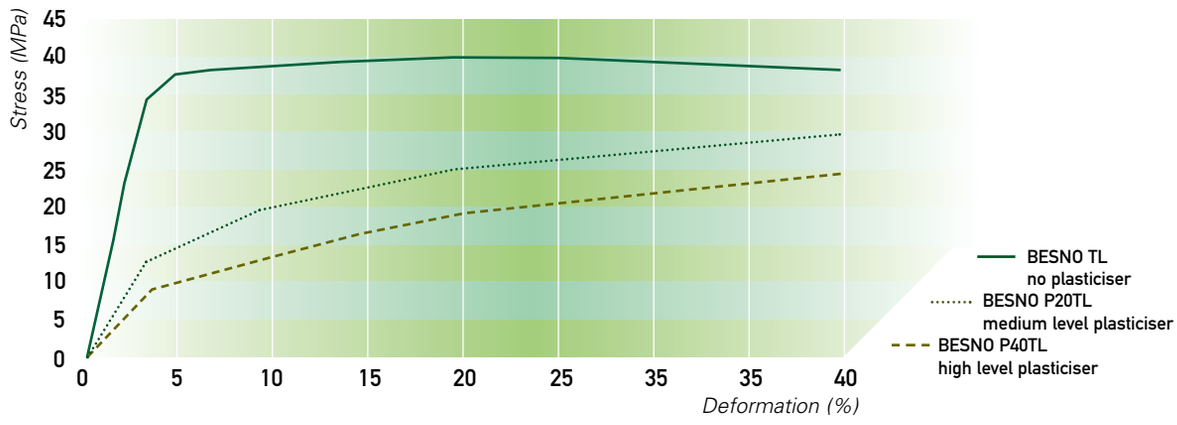
A very significant consequence of this difference in behaviour in actual use is that, at equivalent modulus, a Rilsan® PA11 plasticised tube exhibits a higher burst pressure than its Rilsan® PA12 counterpart.

Comparative burst pressure of plasticised Rilsan® PA11 and PA12 tubes at 23, 100 and 140°C



The increase in plasticiser content significantly changes the tensile behaviour of Rilsan® grades as shown in the following graph.

Comparative tensile curves of various Rilsan® PA11 grades, per ISO 527 standard



	YOUNG'S MODULUS AT 23°C DRY STATE (MPa)	STRESS AT YIELD (MPa)	ELONGATION AT YIELD (%)	TENSILE STRENGH AT BREAK (MPa)	ELONGATION AT BREAK (%)
BESNO TL	1450	40	6	53	300
BESNO P20TL	500	32	20	52	300
BESNO P40TL	335	27	30	48	300

The influence of temperature on the tensile strength of Rilsan® PA11 is typical of the performance of thermoplastics.
The Young's modulus of BESNO P40 TL at various temperatures is detailed in the following table:

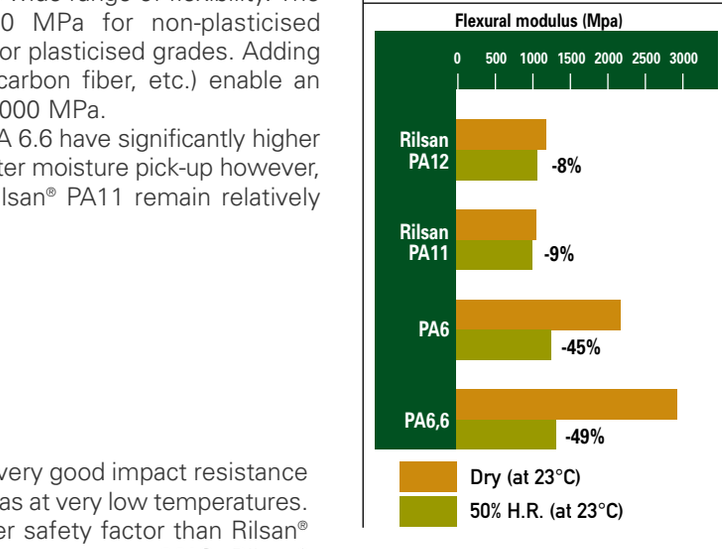
Temperature (°C)	23	60	80	100
Young's modulus (Mpa)	335	173	166	160

Mechanical properties

Flexural modulus

Rilsan® PA11 is available in a wide range of flexibility. The modulus varies from 1200 MPa for non-plasticised grades to around 150 MPa for plasticised grades. Adding specific fillers (glass fiber, carbon fiber, etc.) enable an increase in modulus up to 8000 MPa.
In dry conditions, PA 6 and PA 6.6 have significantly higher rigidity than Rilsan® PA11. After moisture pick-up however, the flexural properties of Rilsan® PA11 remain relatively stable.

Effect of ambient conditions on the flexural modulus of Rilsan® PA11 and PA12 vs PA6 and PA6.6.
Tests conducted per ISO 178 standard

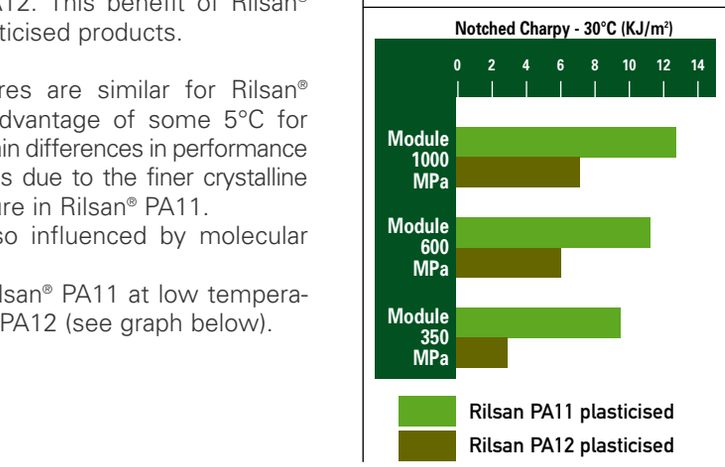


Impact resistance

Rilsan® PA11 demonstrates very good impact resistance at room temperature as well as at very low temperatures. It offers a significantly higher safety factor than Rilsan® PA12. In Charpy notched impact test at -30°C, Rilsan® PA11 is twice as resilient as Rilsan® PA12.
Its fragile/ductile transition is around 35°C versus around 50°C for Rilsan® PA12. This benefit of Rilsan® PA11 is equally seen in plasticised products.

Glass transition temperatures are similar for Rilsan® PA11 and PA12 (a slight advantage of some 5°C for Rilsan® PA11) and do not explain differences in performance between the products. This is due to the finer crystalline grid and spherolitical structure in Rilsan® PA11.
Its impact resistance is also influenced by molecular weight and polydispersity.
The impact resistance of Rilsan® PA11 at low temperature is twice that of Rilsan® PA12 (see graph below).

Comparative impact resistance of Charpy notched plasticised Rilsan® PA 11 and PA12 (-30°C), per ISO 179/1eA standard



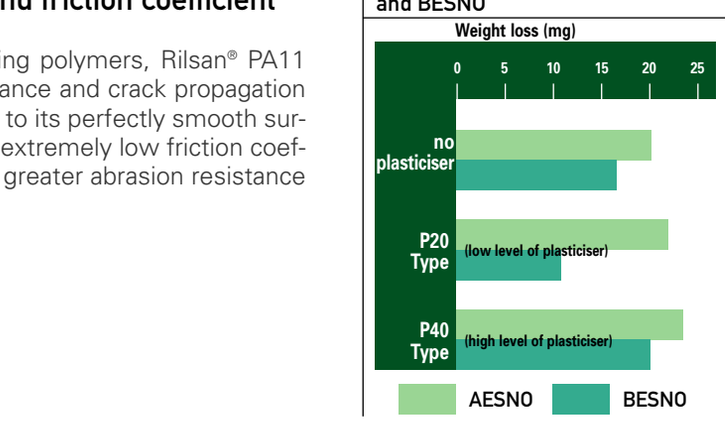
Comparative table of impact resistance of unnotched Charpy Rilsan® PA11 vs PA6, PA6.6 and PBT.

	STANDARD	UNIT	RILSAN PA 11	PA 6	PA 6,6	PBT
Unnotched at +23°C	ISO 179/1eU	$KJ.m^{-2}$	No break	75	50	NC
Unnotched at -30°C	ISO 179/1eU	$KJ.m^{-2}$	No break	40	40	36

Abrasion resistance and friction coefficient

Compared to other engineering polymers, Rilsan® PA11 features good abrasion resistance and crack propagation resistance. This is largely due to its perfectly smooth surface finish, which induces an extremely low friction coefficient. Rilsan® PA11 features greater abrasion resistance than Rilsan® PA12.

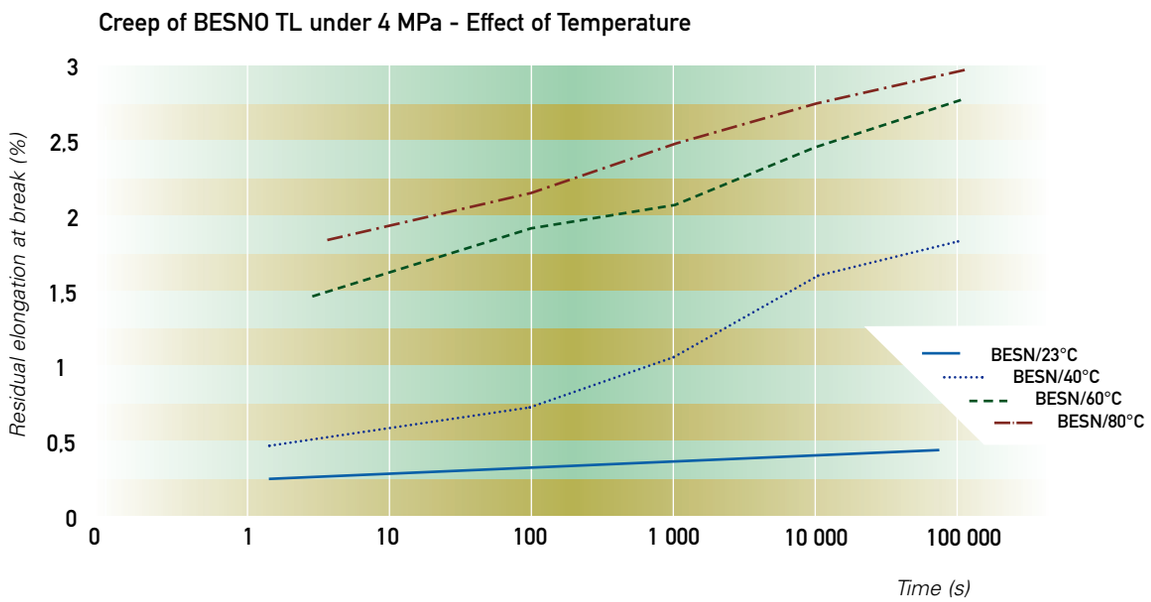
Comparative TABER (methode CS17: 1000 revolutions under 1000 grams) abrasion resistance of Rilsan® AESNO and BESNO



Creep resistance

The notion of a material's lifetime is an important factor when designing components requiring long-term performance in specific operating conditions.
As a general rule, Rilsan® PA11 features visco-elactic behaviour at ambient temperature. However, under permanent stress, above a certain limit, Rilsan® PA11 undergoes plastic deformation.

Our material specialists have developed significant in-house expertise in predicting the long-term performance of parts made out of Rilsan® PA11. Our sales and development network will be pleased to provide further information.

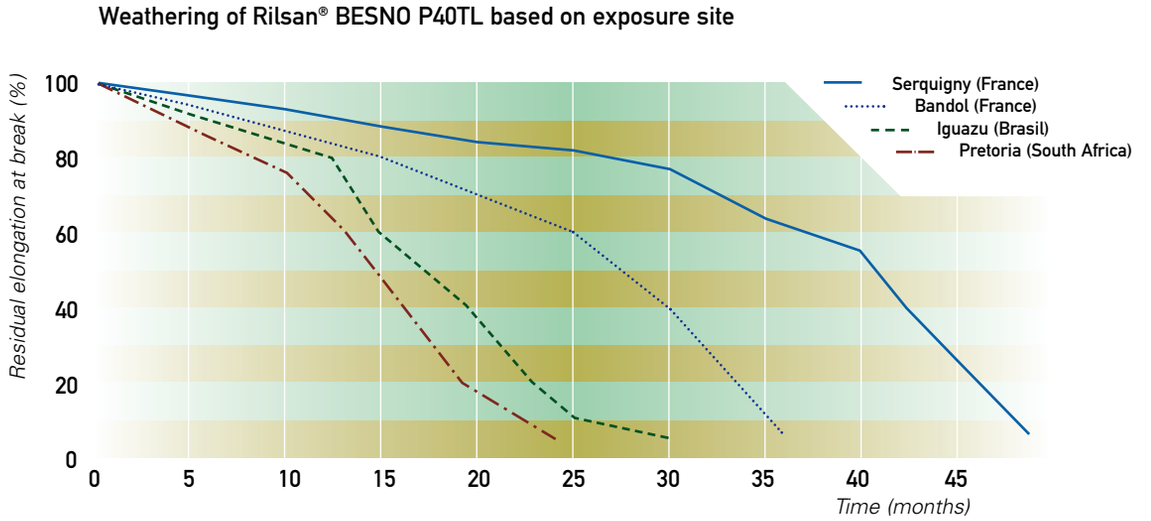


Weathering resistance

Parts made from Rilsan® PA11 perform very well in a wide variety of climates around the world. Rilsan® PA11 is particularly resistant to degradation from the combined effect of the sun's rays and rainwater. The use of stabiliser packages also help to further increase the weathering resistance of natural and colored grades.

The following diagram shows the influence of the exposure site on the residual elongation at break of Rilsan® BESNO P40TL.

- Serquigny (France): temperate and humid climate, typical of Central Europe
- Bandol (France): hot and humid, typical Mediterranean climate
- Iguazu (Brazil): tropical climate
- Pretoria (South Africa): hot and dry climate



Chemical resistance

Rilsan® PA11 offers an ideal balance between the resistance of polyamides to grease and hydrocarbons and the resistance to acids, bases and salts of polyolefines. The excellent chemical resistance of Rilsan® PA11 is reflected both in high dimensional stability under harsh conditions and in the non-degradation of the polymer matrix. Additionally, Rilsan® PA11 features greater resistance to hydrocarbons than Rilsan® PA12, making it the ideal material for highly demanding applications in the oil and gas industry, such as offshore flow-lines.

Rilsan® PA11 features outstanding resistance to oils, hydraulic fluids, and fuels. Compared to polyester-based thermoplastic elastomers and other polyamides, Rilsan® PA11 offers the best combination of properties:

- The best compromise in mechanical properties.
- Excellent dimensional stability due to a lower absorption rate. This is significant in the case of tubing carrying fluids, as any risk of leakage at the connections is minimised.
- Excellent inherent flexibility.
- Very low permeability to hydrocarbons.

The following tables feature the resistance of Rilsan® PA11 to main chemical reagents following 18-months of exposure.

G = Good
L = Limited (swelling of Rilsan® PA11 – suitability depends on specific use and duration)
P = Poor

* slight browning; ** swelling action

CHEMICAL AGENT	CONCENTRATION	PERFORMANCE			
	(100%)	20°C	40°C	60°C	90°C
Mineral acids					
Hydrochloric acid	1%	G	L	P	P
	10%	G	L	P	P
Sulphuric acid	1%	G	L	L	P
	10%	G	L	P	P
Phosphoric acid	50%	G	L	P	P
Nitric acid	any concentration	P	P	P	P
Chromic acid	10%	P	P	P	P
Sulphur dioxide		L	P	P	P
Mineral salts					
Calcium arsenate	concentrated or boiled solutions	G	G	G	
Soda carbonate	"	G	G	L	P
Baryum chloride	"	G	G	G	G
Potassium nitrate	"	G*	L*	P	P
Di-ammonium phosphate	"		G	G	L
Trisodic phosphate	"	G	G	G	G
Alumina sulphate	"	G	G	G	G
Ammonium sulphate	"	G	G	L	
Copper sulphate	"	G	G	G	G
Potassium sulphate	"	G	G	G	G
Sodium sulphide	"	G	L	L	
Calcium chloride	"	G	G	G	G
Magnesium chloride	50 %	G	G	G	G
Sodium chloride	satured	G	G	G	G
Zinc chloride	satured	G	G	L	P

CHEMICAL AGENT	CONCENTRATION	PERFORMANCE			
	(100%)	20°C	40°C	60°C	90°C
Mineral bases					
Soda	50%	G	L	P	P
Potash	50%	G	L	P	P
Ammonia	concentrated	G	G	G	G
Ammonia solution	liquid or gas	G	G		
Other mineral bodies					
Water		G	G	G	G
Sea water		G	G	G	G
Carbonated water		G	G	G	G
Bleach		L	P	P	P
Hydrogen peroxide		G	L		
Oxygen	20 vol.	G	G	L	P
Hydrogen		G	G	G	G
Ozone		L	P	P	P
Sulphur		G	G		
Mercury		G	G	G	G
Fluorine		P	P	P	P
Chlorine		P	P	P	P
Bromine		P	P		
Agricultural spray solution			G	G	
Potassium permanganate	5%	P	P		
Organic bases					
Aniline	Pure	L	P	P	P
Pyridine	Pure	L	P	P	P
Urea		G	G	L	L
Diethanolamine	20%	G	G**	G**	L
Organic acids and anhydrides					
Acetic acid		L	P	P	P
Acetic anhydride		L	P	P	P
Citric acid		G	G	L	P
Formic acid		G	P	P	P
Lactic acid		G	G	G	L
Oleic acid		G	G	G	L
Oxalic acid		G	G	L	P
Picric acid		L	P	P	P
Stearic acid		G	G	G	L
Tartaric acid	satured solution	G	G	G	L
Uric acid		G	G	G	L
Hydrocarbons					
Methane		G	G	G	
Propane		G	G	G	
Butane		G	G	G	
Acetylene		G	G	G	
Benzene		G	G**	L	
Toluene		G	G**	L	L
Xylene		G	G**	L	L
Styrene		G	G**		
Cyclohexane		G	G	L	
Naphtalene		G	G	G	L
Decaline		G	G	G	L
FORANE® 12		G	G	G	
FORANE® 22		G	G	G	
Alcohols					
Methyl alcohol	pure	G	G	G	
Ethyl alcohol	pure	G	G	G	
Butyl alcohol		G	G	G	
Glycerin	pure	G	G	G	P
Glycol		G	G	G	P
Benzyl alcohol		L	P	P	P

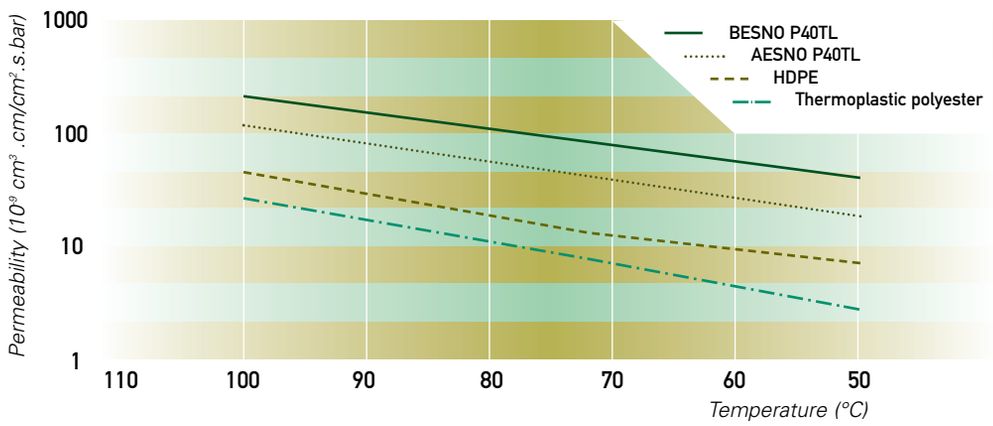
CHEMICAL AGENT	CONCENTRATION	PERFORMANCE			
	(100%)	20°C	40°C	60°C	90°C
Aldehydes and ketones					
Acetone	pure	G	G**	L	P
Acetaldehyde		G	L	P	
Formaldehyde	technical	G	L	P	
Cyclohexanone		G	L	P	
Methylethylketone		G	G	L	P
Methylisobutylketone		G	G	L	P
Benzaldehyde		G	L	P	
Chlorinated solvents					
Methyl bromide		G	P		
Methyl chloride		G	P		
Trichloroethylene		L	P		
Perchloroethylene		L	P		
Carbon tetrachloride		P			
Trichloroethane		L	P	P	P
Phenols		P	P	P	P
Various organic bodies					
Anethol		G			
Glycol chlorhydrine		P	P		
Ethylene oxide		G	G	L	P
Carbon sulphide		G**	L*	P	
Furfurol		G	G**	L	P
Tetraethyle lead		G			
Glucose		G	G	G	G
Salts, esters, ethers					
Methyl acetate		G	G	G	
Ethyl acetate		G	G	G	
Butyl acetate		G	G	G	L
Amyle acetate		G	G	G	L
Tributyl phosphate		G	G	G	L
Tricresyl phosphate		G	G	G	L
Dioctyl phosphate		G	G	G	L
Dioctyl phtalate		G	G	G	
Sulfuric ether		G			
Fatty acid esters		G	G	G	G
Methyl sulfate		G	L		
Miscellaneous products					
Coal gas		G	G		
Oil		G	G	G	G
Grease		G	G	G	G
Beer		G			
Wine		G			
Fruit juice		G	G		
Regular grade gasoline		G	G	G**	
Premium grade gasoline		G	G	G**	
Naphtha solvent		G	G	G**	
Kerosene		G	G	G**	
Crude oil		G	G	G**	
Milk		G	G	G	G
Cider		G			
Stearine		G	G	G	
Mustard		G			
2,4-D Lindane		G			
Oxyquinoleine (agricultural spray)		G			
Turpentine		G	G	G**	
Soap cleanser		G			
Vinegar		G			
Linseed cake		G	G	G	G

Permeability

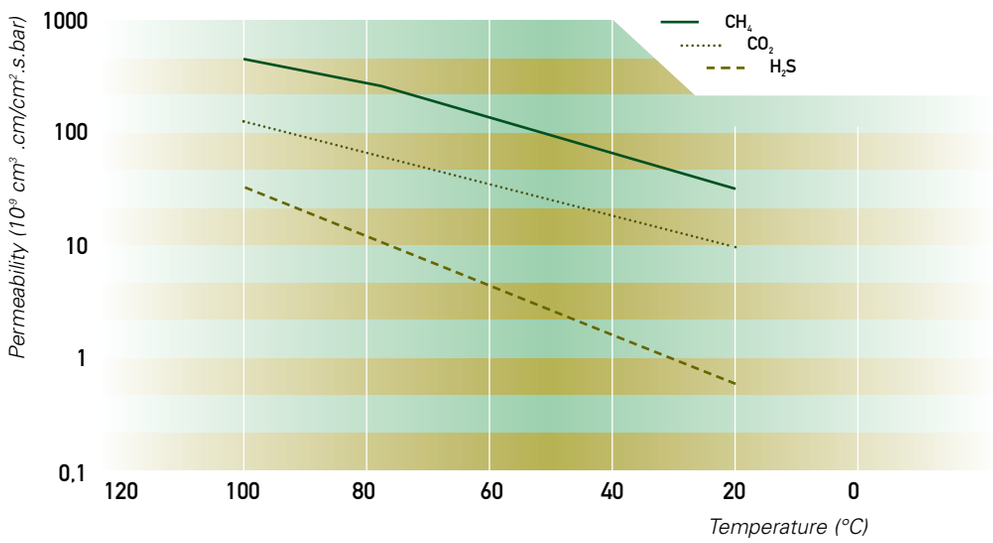
Arkema can offer multi-material solutions for applications requiring low or very low permeability, maintaining the main physical and chemical properties of Rilsan® PA11 in finished components.

As a general rule, Rilsan® PA11 offers better barrier properties to gases and liquids than other flexible thermoplastics or rubbers. In particular, it is twice as impermeable to fuels and hydrocarbons versus PA 12.

Permeability of Rilsan® BESNO P40TL to various gases and at different temperatures



Permeability of various polymers to natural gas (85% CH_4 – 8% C_2H_6 – 3% C_3H_8 – 2% C_4H_{10}) at different temperatures



The following tables feature the permeability to various gases of various Rilsan® grades at 20°C.

Rilsan® BESNO TL

GAS	PERMEABILITY 10^{-9} $cm^3.cm/cm^2.s.bar$)
H_2	7
N_2	0.15
O_2	2
CO_2	7
CH_4	0.15

Rilsan® BESNO P40TL

GAS	PERMEABILITY 10^{-9} $cm^3.cm/cm^2.s.bar$)
H_2	15
CO_2	6
H_2O	0.04
H_2S	30
CH_4	0.6
C_2H_4	2.3
C_3H_8	0.75
C_4H_{10}	5.4

Rilsan® AESNO P40TL

GAS	PERMEABILITY 10^{-9} $cm^3.cm/cm^2.s.bar$)
CH_4	1.6
CO_2	12

Rilsan® PA11 also offers very low permeation to fuels compared to rubber.
The following table compares the fuel permeability of tubing made from Rilsan® BESNO P40TL, versus plasticised PVC and rubber.

PRODUCT	DIMENSION OF PIPE Inner diameter (mm)	Thickness (mm)	PERMEABILITY (g/m².day) 20°C	40°C
Rilsan® BESNO P40TL	6	0.5	2	4
Plasticised PVC	6	2	60	120
Rubber	6	3	60	120

5 Processing

With a relatively low melting temperature, good melt fluidity and a high speed of recrystallisation, Rilsan® PA11 is well-suited to a wide range of processing technologies: extrusion, extrusion-blow molding, injection molding, injection-blow molding and rotomolding. To ensure optimum suitability for each of these processing technologies, Rilsan® PA11 is available in a wide range of viscosities.

Rheological properties of Rilsan® PA11

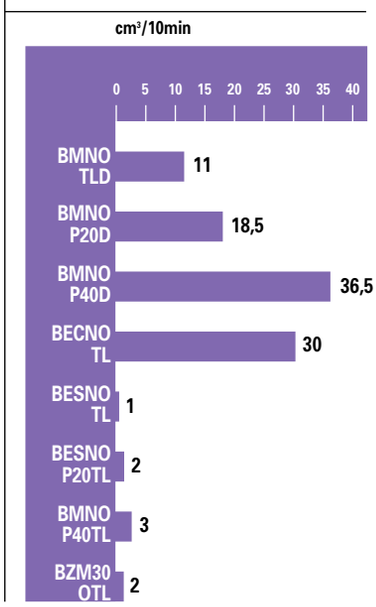
The rheological properties of molten Rilsan® PA11, reflecting their flow capacity, are measured using two types of parameters:

>Melt Volume Index (MVI)
>Melt Viscosity

Melt Volume Index (MVI)

The melt volume index is measured per ISO 1133; it corresponds to the quantity of material at 235°C which can flow in 10 minutes through a 2 mm diameter die under a 2.16 kg load. The melt volume index provides a specific image of the viscosity at a given temperature and shear rate. It also depends upon moisture content.

Comparative melt volume indices of various Rilsan® PA11 grades, per ISO 1133 standard

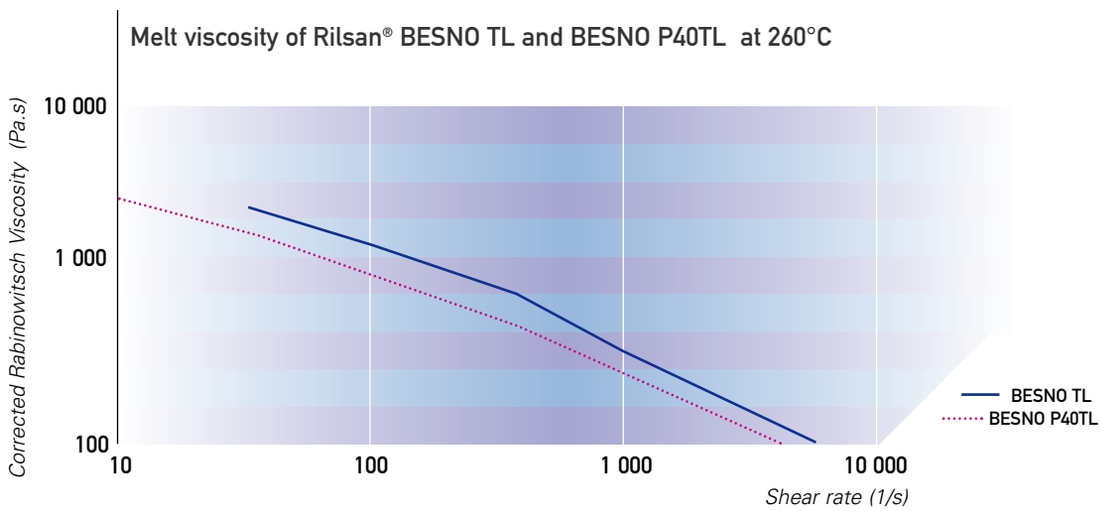


Melt Viscosity

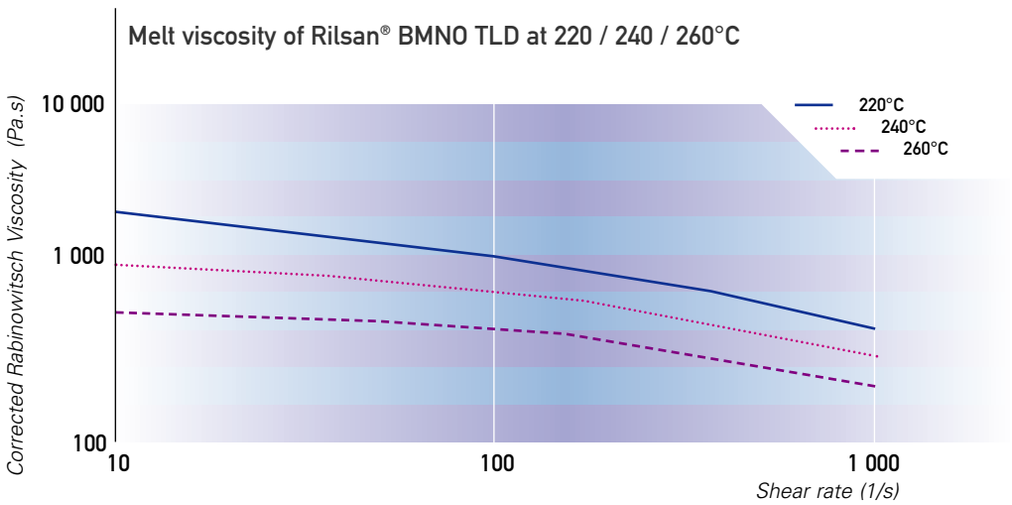
The rheological behaviour of Rilsan® PA11 can be measured more accurately with a capillary rheometer equipped with tooling having a L/D ratio of 20. As illustrated in the following diagrams, the viscosity of Rilsan® PA11 varies according to shear rate and temperature.

Rilsan® PA11 grades for pipe extrusion

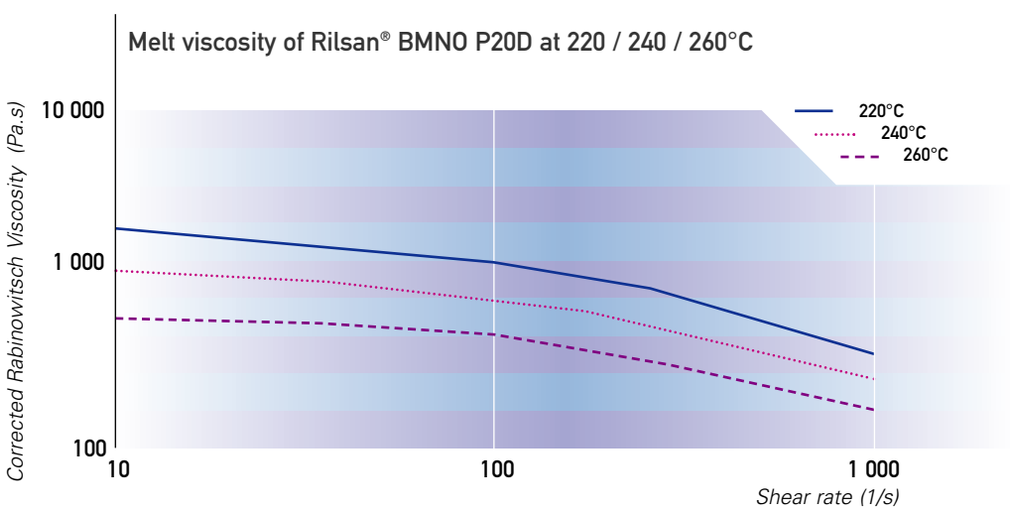
Melt viscosity of Rilsan® BESNO TL and BESNO P40TL at 260°C



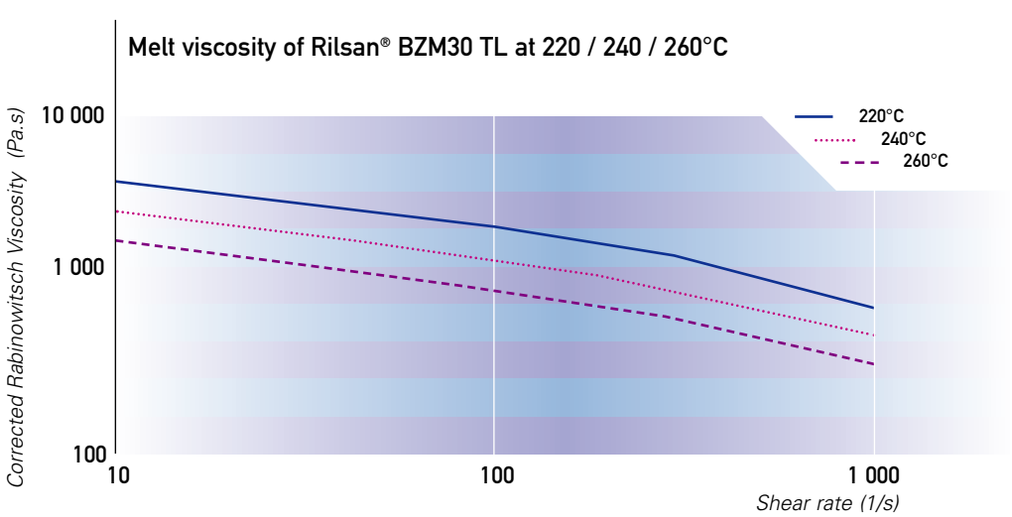
Standard viscosity Rilsan® PA11 grade for injection molding

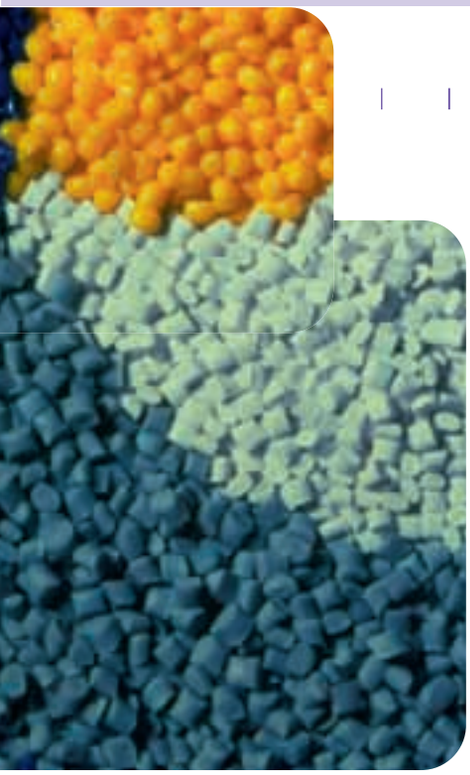


Rilsan® PA11 plasticised grade for injection molding



Reinforced Rilsan® PA11 grade for injection molding





Preparation of Rilsan® PA11

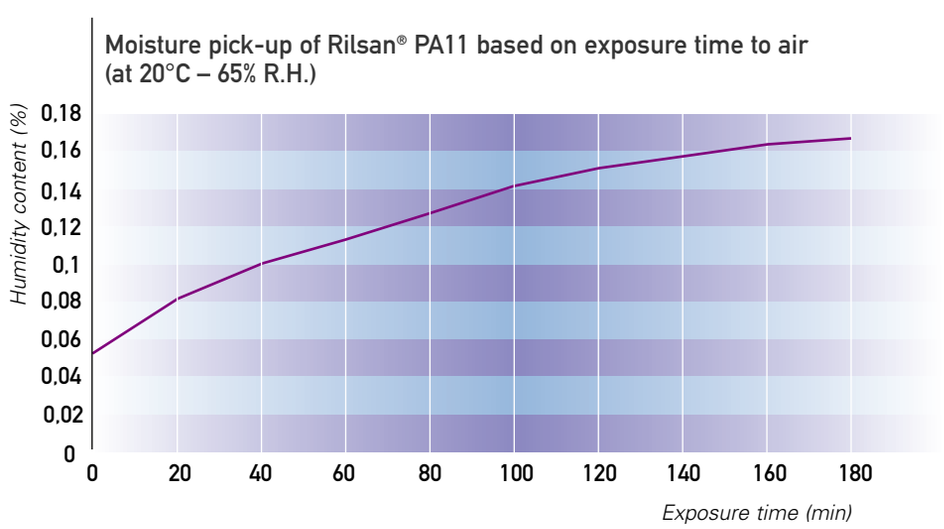
Rilsan® PA11 grades are supplied in the form of granules in moisture proof sealed bags or octabins. Rilsan® PA11 granules do not require pre-drying before use. However, if the packaging has been left open and exposed to air for more than two hours, the product will need to be re-dried under specific conditions.

Moisture pick-up of Rilsan® PA11

Due to its chemical structure, Rilsan® PA11 has lower moisture pick-up than other polyamides (PA 6, PA 66, etc.). This low water absorption provides excellent dimensional stability and causes only minimum variations in its mechanical and electrical properties.
Rilsan® PA11 is produced by the polycondensation of amino acid. As a result, it undergoes an equilibrium reaction with water as shown by the following simplified formula:

$$(PA\ 11)_{m+n} + H_2O \underset{\text{(polycondensation) 2}}{\overset{\text{(hydrolysis) 1}}{\rightleftharpoons}} (PA\ 11)_m + (PA\ 11)_n$$

The presence of excess water promotes hydrolysis by reducing the length of the molecular chains. This change will result in a significant drop in mechanical properties but may not always be evident in the form of surface blemishes such as frosting or bubbles. Since excess moisture can pose problems during the processing of Rilsan® PA11, it is important for the granules to be kept dry at all times. Necessary precautions should be taken to prevent any moisture pick-up during processing.



Drying of Rilsan® PA11

To prevent moisture pick-up, Rilsan® PA11 should first be brought up to the temperature of the plant to prevent any condensation of the ambient moisture as the bags are opened. Additionally, it is essential for the product to be processed within two hours of opening the bag.
If either of these conditions is not fulfilled, Rilsan® PA11 granules should be vacuum-dried for at least 4 hours at a temperature between 80°C and 90°C.
The migration speed of the moisture to the surface of the granules determines drying time. Raising the temperature does not significantly reduce drying time and presents a risk of oxidation.

Storage of dried Rilsan® PA11

After drying, the granules should be stored immediately in sealed containers, which should be filled to the maximum to keep the volume of air to a minimum. The size of storage containers should correspond to the equivalent of 2 hours operation in the molding machine.

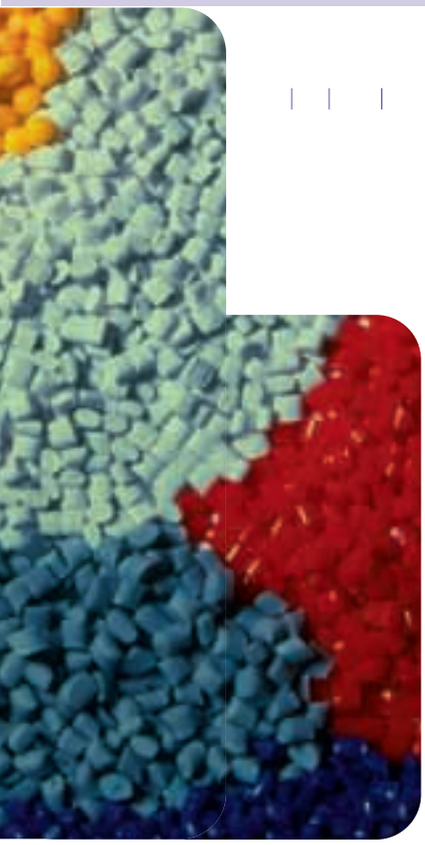
Coloration of Rilsan® PA11

The suitability of Rilsan® PA11 for coloration means that an extensive range of colors can be obtained in addition to black and natural.
Increasingly, processors are required to produce their own color using masterbatches in order to fulfill specific needs or to reduce stocks of colored product. This normally requires adjustments to the injection-molding machine (plastification time, rotation of the screw, back pressure, use or otherwise of mixing adapter, etc.).

Using processing scraps and recycling

The recycling of scraps requires a number of good practices in order to prevent contamination during the various storage and grinding phases.
As long as the material is free of all traces of oxidation and contamination, it is perfectly possible to recycle it in any production process, which does not specifically require 100% virgin product. The proportion of recycled material should be adjusted on the basis of the mechanical properties of the end-component, but should not generally exceed 20% by weight.

Recycling product requires specific precautions to prevent drop-off in performance or changes of the color or the appearance of the component. Our technical team will be pleased to assist you further in this regard.



Processing of Rilsan® PA11

Injection molding

With its melt flow characterictics, Rilsan® PA11 is ideally suited to injection molding, using commercially available equipment.

Injection unit

Screw

Standard screws supplied by equipment manufacturers are suitable for Rilsan® PA11. These screws consist of 3 zones with a non-return valve.
The length of the screw should be at least 15 times its diameter, with a minimum compression ratio of 2.5.

Injection nozzle

The high melt fluidity of Rilsan® PA11 requires the use of a shut-off nozzle. If this is not fitted, molten polymer will leak out between two injection cycles, thereby producing visible blemishes on the finished article (oxidation, cold slug, flow break, etc.).

Mold temperatures

The use of temperature-regulated tooling is highly recommended for the injection molding of Rilsan® PA11. By controlling mold temperatures, one can affect the appearance of the finished article, the ease of filling, mold release, and shrinkage.
Except for a few specific cases, non-glassfiber-reinforced Rilsan® PA11 grades require cold molds (30 to 40°C). However, when injection molding thin-walled articles, or with large surface areas or intricate shapes, higher temperatures can be used to fill the mold cavity more easily.
Glass fiber-reinforced grades require hot molds (90 – 100°C) to produce an even and glossy surface finish.

Injection temperatures

Whichever Rilsan® PA11 grade is used, the temperature should rise from the upstream feed zone to the downstream zone to produce a sufficiently homogeneous melt.

RILSAN® PA11 GRADE	TEMPERATURE (°C)			
	Hopper	Central section	Outlet	Nozzle
BMN	210	225	240	230
BZM30	240	260	270	270

The outstanding thermal stability of Rilsan® PA11 allows much higher temperatures to be used (up to 300°C). However, these temperature levels should be used only when needed.

Shrinkage of Rilsan® PA11

Understanding and controlling shrinkage is key for producing high quality molded parts.
Shrinkage is defined as the dimensional variation between the cold mold and the cooled molded part, measured after 24 hours. It is normally expressed as a percentage of the mold dimensions. The various parameters which can affect shrinkage are as follows:

Holding pressure and time	↑	**Shrinkage** ↓
Temperature of the mold	↑	**Shrinkage** ↑
Temperature of the material	↑	**Shrinkage** ↑
Cooling time	↑	**Shrinkage** ↓
Injection speed	↑	**Shrinkage** ↓

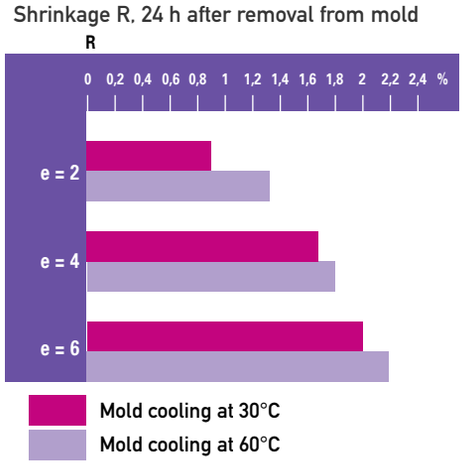
- Design of the article, location and dimension of feed system
- Injection pressure and holding pressure
- Effective duration of holding pressure (before threshold setting)
- Mold temperature and cooling time
- Temperature of the material injected
- Injection speed

An evaluation of the shrinkage of BMNO and BZM30 grades was conducted on injected test samples with thicknesses of 2 mm, 4 mm and 6 mm, whilst maintaining an injection threshold equal to 25% of the nominal thickness (e.g. 0.5 mm layers for a 2 mm sheet).

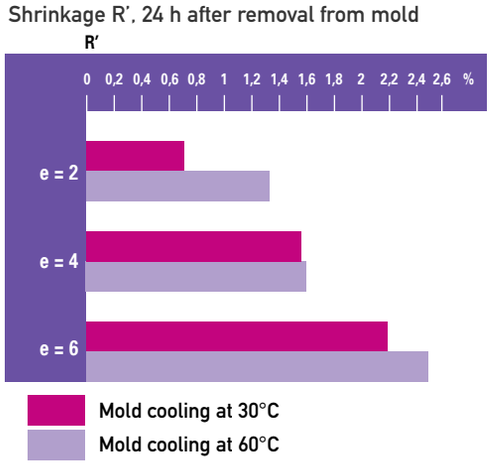
Shrinkage, measured 24 hours after mold release and after thermal treatment, was determined from the following two measurements:
- shrinkage R, in flow direction
- shrinkage R', perpendicular to flow direction.

Shrinkage of BMNO non-reinforced grades

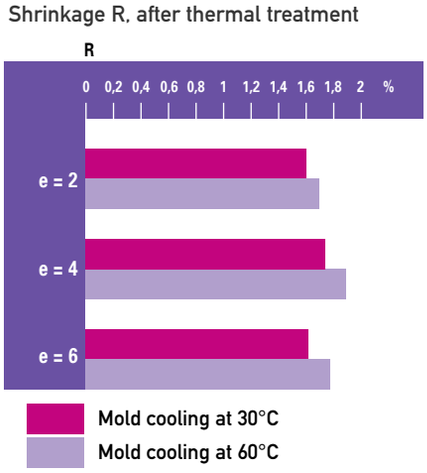
Shrinkage R, 24 h after removal from mold



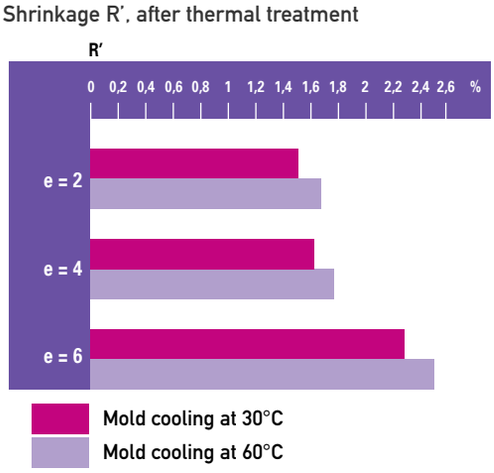
Shrinkage R', 24 h after removal from mold



Shrinkage R, after thermal treatment

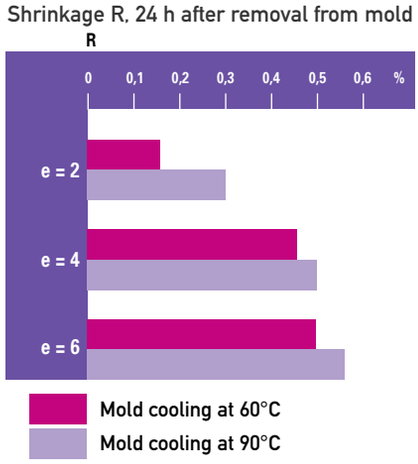


Shrinkage R', after thermal treatment

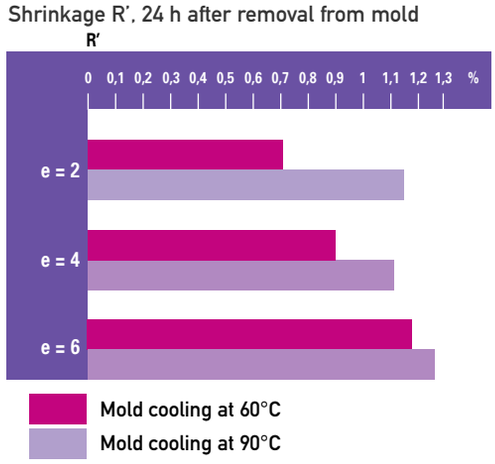


Shrinkage of BZM glass fiber reinforced grades

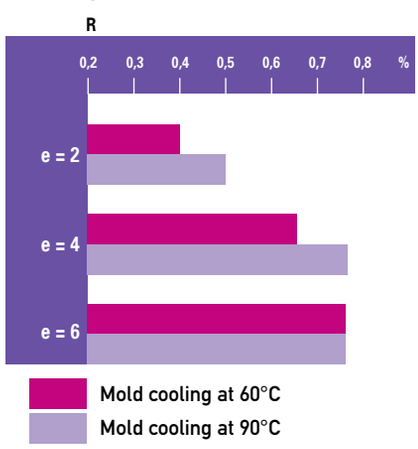
Shrinkage R, 24 h after removal from mold



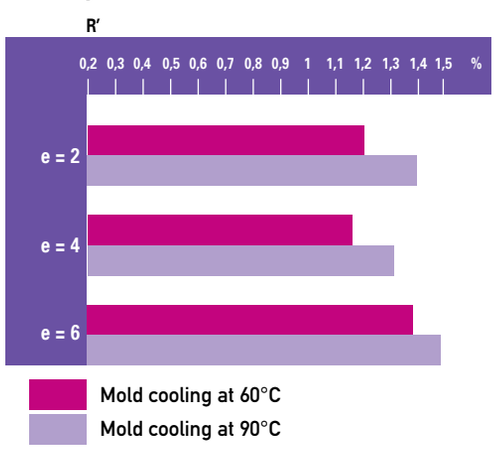
Shrinkage R', 24 h after removal from mold



Shrinkage R, after thermal treatment



Shrinkage R', after thermal treatment



Note

In the case of unfilled grades, shrinkage 24 hours after removal from the mold occurs preferentially in the direction of the melt flow, which is also the main direction of the fibers, hence R > R'.
The presence of oriented fibers generally limits shrinkage following the melt flow, whilst increasing shrinkage across the flow, hence R' > R. Even though these effects are generally acceptable for fiber-reinforced polymers, they depend to a large extent on the thickness of the article (skin effects), the degree of orientation of the fibers (anisotropia) and their length, the type of feed and geometry factors.

Back-pressure

Rilsan® PA11 can be plasticised easily, and back-pressure is not necessary. However, it is advisable for example when masterbatch coloration is used, as this ensures good dispersion of the colorant.

Injection pressure and speed

Injection pressures normally range between 400 and 700 bars for Rilsan® PA11 non-reinforced grades and 700 and 1000 bars for reinforced grades. The choice of value will generally be determined by the processor on the basis of other factors such as temperature of the material and the mold. Where possible, it is advisable to use lower pressure and higher temperatures to achieve optimum properties for articles molded from Rilsan® PA11.

Extrusion (film & pipe)

For extrusion, it is essential to use Rilsan® PA11 granules with a moisture level below 0.1%, to prevent bubbles and other defects in the wall section, and to ensure a steady feed of the granules and a constant mechanical energy absorbed by the material.

Screw: functions and profiles

Screws suitable for the processing of Rilsan® PA11 should fulfill the following functions:
- Consistent feed of granules;
- Efficient melting and de-gassing of the product;
- Excellent homogenisation of the melt through sufficient back-pressure.

Screws with a long compression zone help minimise variations in the pressure reached at the end of this zone and any resulting variations in the flow rate.
Together with the compression rate, the clearance between the screw and the barrel is the most important parameter when choosing the right screw for Rilsan® PA11.

Temperatures profile

The specific temperature profile required can vary considerably from one machine to another. The following information is therefore given as an indication.
It will also depend on the extrusion speed and the type of Rilsan® PA11 grade chosen, i.e whether lubricated or not. Non-lubricated Rilsan® PA11 grades require higher temperatures, especially in the first zone of the extruder.

GRADE	TEMPERATURE (°C)					
	Hopper	Feeding zone	Compression zone	Metering zone	Extrusion head	Die
BESNO P40TL	60	175	220	235	230	220
BESNO P20TL	60	180	225	240	230	220

Extrusion of Rilsan® PA11 tubing

The extrusion of Rilsan® PA11 tubing requires a water tank whose two main functions are to form the shape of the tube in a calibrator under vacuum and to cool efficiently the pipe through continuously circulating water in the tank. The level of vacuum can be varied from 50 to 400 mbars and is used to adjust the outer diameter of the tube.

Rilsan® PA11 features unique extrusion properties versus Rilsan® PA12, due to its viscosity kick during the extrusion process. This is a key benefit for large diameter extrusion, where its melt strength is a real advantage.

Rotomolding

The rheological properties (fluidity) of Rilsan® PA11 make it suitable for applications using the rotomolding technique and in particular the manufacture of articles which include metal inserts.

Rotational molding does not induce residual stress in the material such as that found in injection molded articles. This is because during the rotomolding process, the material is not subject to mixing or compacting to the same degree as in an extrusion screw or an injection molding machine. Rotomolding is also suitable for articles with a more intricate design or with larger dimensions than those produced by injection molding.

Mold technology

The rotomolding of specific Rilsan® PA11 grades requires molds of a traditional construction (steel, aluminium, copper plate, etc.). It is important for vents to be present. Although removing Rilsan® PA11 articles from the mold is easy, it is advisable, where problems do occur, to treat the surface of the mold cavity, either by applying a fluorinated coating or a thermoset varnish, or by spraying the walls of the mold cavity with silicone or other similar products.

Heating temperature and duration

To achieve optimum molding of Rilsan® PA11 articles, it is preferable to heat the product to between *260°C and 300°C*.

The duration of the heating is governed by the temperature of the oven, the thickness and thermal conductivity of the mold, and finally the required Rilsan® PA11 thickness.

Rotation speed

The mold rotation speed along the two axes is based on the dimensions and design of the mold. The choice of these parameters governs the consistency of the material thickness. They should be determined on a case-by-case basis.

Cooling

This obeys the same parameters as heating time (temperature of air and water, thermal conductivity and thickness of the mould). In order to prevent distortion or surface defects on the articles, the temperature should not be allowed to drop too quickly in the first phase. For this reason, preliminary cooling with air is advisable. An air-water-air cooling cycle gives optimum results. Additionally, it ensures longer life for the molds by preventing excessively sudden thermal shocks.

Converting semi-finished products

Machining

Rilsan® PA11 is suitable for the various machining processes: drilling, tapping, sawing, milling, turning, grinding and polishing. It is available on the market in the form of semi-finished products such as profiled bars, pipes, sheets and rough mold blocks. Heat up should be avoided during machining.

Coloration

Rilsan® PA11 is highly suitable for coloration using a number of methods: in the matrix (i.e. during the production of the polymer), through the addition of pigments, by using masterbatches, or by liquid colorants.
References for the most suitable colorants for PA11 are available from us.

Multimaterial structures

Arkema offers a wide range of glues, adhesives and tie layers, making the Company a world leader for the design of multimaterial structures.

Bonding

Rilsan® PA11 can be bonded using either polymeric resins or adhesives onto virtually any type of substrate (e.g, wood, paper, cement, leather, glass, thermosets or thermoplastic resins).

Welding

Rilsan® PA11 can be welded using the wide variety of techniques suitable for polyamide 11: high frequency, induction, friction and ultrasonic welding.

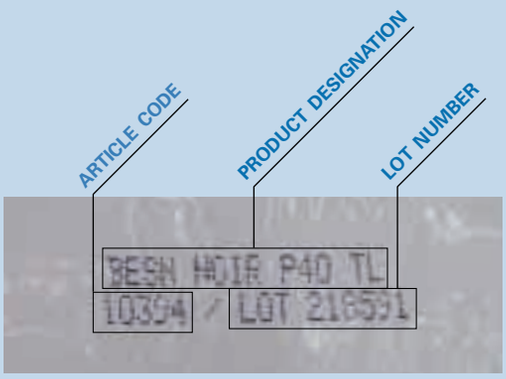
Other techniques for assembly multimaterials

Rilsan® PA11 can be combined with many other thermoplastics or materials by insert-molding, over molding co-injection, coextrusion, etc.

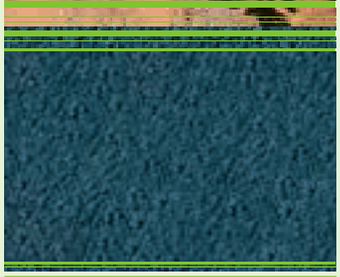
6 Packaging

Rilsan® PA11 25 kg bags feature highly specific properties. They consist of a high performance multilayer structure (PE/PA/Aluminium/PE), which ensures high mechanical properties, efficient palletization, and high barrier to moisture.

Every Rilsan® PA11 bag carries appropriate labels with all essential data (product name, article code, batch number) for the purposes of traceability.



7 Environmental issues



The protection of the environment: yet another benefit of Rilsan® PA11

Rilsan® PA11 has many positive features in terms of environmental protection, following Arkema's global initiatives on sustainable development:

Produced from castor oil, Rilsan® PA11 is a polymer of 100% renewable origin. Through its ongoing purchases of castor oil in the world market, Arkema contributes to the development of several regions (South America, India, South-East Asia, China).

Rilsan® PA11 applications afford an unrivalled balance of technical and economic benefits throughout the industrial supply chain to the end-use consumer.
The use of Rilsan® PA11 in automotive fuel lines, for example, combines light weight, low permeation of hydrocarbons (even lower when several polymers are used in a multilayer solution) as well as ease of processing and assembly for carmakers.

8 A global service

Marketed by Arkema's Technical Polymers Division, Rilsan® PA11 boasts a global and integrated organisation in terms of marketing, technical support, and development network. At every stage of a project involving the use of Rilsan® PA11 (design, industrial development, market launch), the Technical Polymers Division will be pleased to provide you with any assistance you may require.

Our technical teams specialised in high-performance polyamides (choice of polymer, processing, application development), can help you develop high technology solutions.

Finally, as a long-standing partner to high-tech industries (oil, aerospace, automotive, industrial vehicles, etc.), the Technical Polymers Division can oversee complex developments involving the end-user and the industrial supply chain (processor and original equipment manufacturer).

9 Index

Our worldwide sales network can assist you in opening up new markets.

Sales offices:

Asia:

- Kuala Lumpur
- Manilla
- Taipei
- Beijing
- Seoul
- Shanghai
- Tokyo
- Kyoto
- Saïgon
- Bangkok
- Singapore
- Melbourne
- Jakarta
- Mumbaï

Europe:

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- Birmingham
- Düsseldorf
- Amsterdam
- Milan
- Copenhagen
- Barcelona
- Zürich
- Moscow
- Praha
- Warsaw

USA:

- Philadelphia

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