

ARKEMA

RILSAN®

RILSAN® POLYAMIDE 11  
A Proven Legacy, an  
Exciting Future



# Introduction



Developed by Arkema more than 70 years ago, Rilsan® PA11 is a high performance reference in the world of engineering polymers.

Produced from a renewable source (castor oil), Rilsan® PA11 is used in a large number of applications thanks to its outstanding properties, including excellent chemical resistance, easy processing, high and low temperature performance (-40°C / +130°C), high dimensional stability, and low density. Many industries around the world (e.g. automotive, textile, oil & gas, wire & cables, electronics) have used Rilsan® PA11 for many decades for its long-term durability.

Rilsan® PA11 is easy to process using most processing technologies (extrusion, extrusion-blow molding, injection molding, rotomolding, and 3D printing).

The PA11 matrix accommodates countless additives and filling agents, such as plasticizers, stabilizers, colorants, lubricants, impact modifiers, glass fibers, carbon fibers, etc. A variety of grades are available, packaged in sealed bags or containers ready for use. Rilsan® PA11 is produced in Europe, North America, and Asia.

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Rheological Properties of Rilsan® PA11

Preparation of Rilsan® PA11

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# APPLICATIONS

## 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



## ELECTRICAL & ELECTRONICS

- **Specific Properties:**
  - Chemical resistance
  - Easy processing
  - Smooth surface finish
  - Resistance to termites
  - Abrasion resistance
- **Applications:**
  - Optical cable sheathing
  - Copper cable sheathing
  - Connectors
  - Housings
  - Fasteners, clips, and mechanical parts



## SPORTS

- **Specific Properties:**
  - Lightweight
  - Energy return
  - Fatigue resistance
  - Abrasion and scratch resistance
  - Cold impact resistance
- **Applications:**
  - Racket eyelets and bumpers
  - Badminton shuttlecocks
  - Ski top layers
  - Shoe midsoles and outsoles
  - Textiles



## INDUSTRIAL VEHICLES

- **Specific Properties:**
  - Cold impact resistance
  - Chemical resistance
  - Flexibility
  - Ageing resistance
- **Applications:**
  - Air brake tubing for trucks
  - Hydraulic hoses
  - Fuel lines, clutch lines
  - Quick connectors, fittings, fasteners and clips



## OIL & GAS

- **Specific Properties:**
  - Resistance to hydrocarbons
  - Ageing resistance
  - Flexibility
  - Easy processing
- **Applications:**
  - Umbilical lines and hoses
  - Gas pipes and fittings (t-fittings, valves, reducers)
  - Flexibles (flow-lines, risers)
  - Flexible liners for offshore and on-shore applications
  - Cables



## AEROSPACE

- **Specific Properties:**
  - High and low temperature performance
  - Dimensional stability
  - Resistance to fuel
- **Applications:**
  - Electrical cable sheathing
  - Hydraulic hoses
  - Oil tanks
  - Air-conditioning hoses and ducts



## MEDICAL & FOOD PACKAGING

- **Specific Properties:**
  - Food and medical compliant grades (Europe, FDA, USP Class VI)
  - Chemical resistance
  - Low gas permeation (O<sub>2</sub>, CO<sub>2</sub>)
- **Applications:**
  - Nutrient and solution bags
  - Masks, hearing aides
  - Food casing
  - Beverage tubing



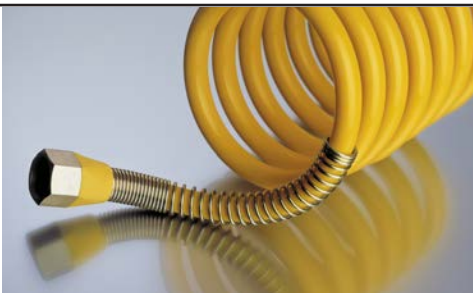
## TEXTILES & MONOFILAMENTS

- **Specific Properties:**
  - Chemical resistance
  - Dimensional stability
  - Abrasion resistance
  - Flex fatigue resistance
  - Easy extrusion
- **Applications:**
  - Technical and high-end fabrics
  - Brushes
  - Industrial woven fabrics
  - Filters



## PNEUMATICS

- **Specific Properties:**
  - Flexibility
  - Chemical resistance
  - Burst strength
- **Applications:**
  - Pneumatic hoses, air lines
  - Hydraulic hoses



# Nomenclature

## Standard Rigid and Plasticized Grades:

B	ES	N	Black	P	40	TL
<b>POLYAMIDE TYPE</b> B,K,F = PA11	<b>PROCESSING</b> EC = Cable Sheathing ES = Extrusion or Blow Molding M = Injection Molding	<b>VISCOSITY</b> F = Fluid N = Normal V = Viscous HV = High Viscosity	<b>COLOR</b> O = Natural Black Color + Reference	<b>RATE OF FLEXIBILITY</b> P1 to P6 = Flexibility Index	<b>REFERENCE NUMBER</b>	<b>STABILIZERS AND OTHER ADDITIVES</b> TL, T6L, T8L = Heat - Light Stabilizers W = Flame Retardant G, Y = Self Lubricating D = Mold Release Agent A = Food Contact Approved NL = No Lubrication NB = Non-glossy C = Conductive CC = Transparent

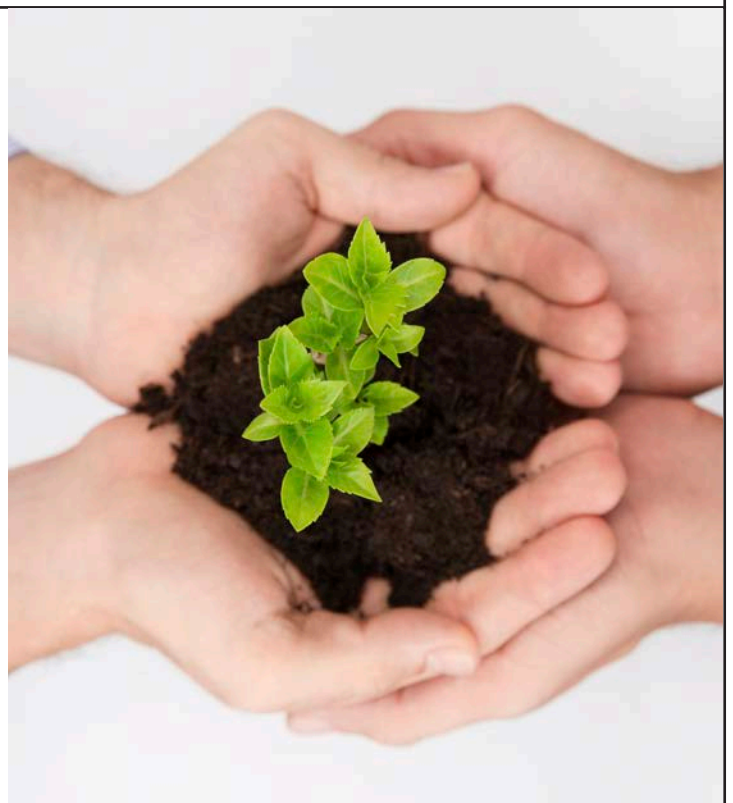
## Standard Reinforced Molding Grades:

B	ZM	30	Black	TL
<b>POLYAMIDE TYPE</b> B,K,F = PA11	<b>REINFORCED GRADES</b> ZM = Glass Fiber UM = Glass Beads SR = Carbon Fiber	<b>REINFORCEMENT AMOUNT</b> # = Filler Amount	<b>COLOR</b> O = Natural Black Color + Reference	<b>STABILIZERS AND OTHER ADDITIVES</b> TL = Heat - Light Stabilizers W = Flame Retardant G, Y = Self Lubricating D = Mold Release Agent

## A few examples of Rilsan® PA11 grades designations:

<b>RIGID</b>	BMNO TLD; BESNO TL; BESVO A FDA
<b>SEMI-RIGID</b>	BESNO P20 TL
<b>FLEXIBLE</b>	BESNO P40 TL
<b>REINFORCED</b>	BZM30 Black TL

Special grades can be developed to fulfill specific customer requirements.



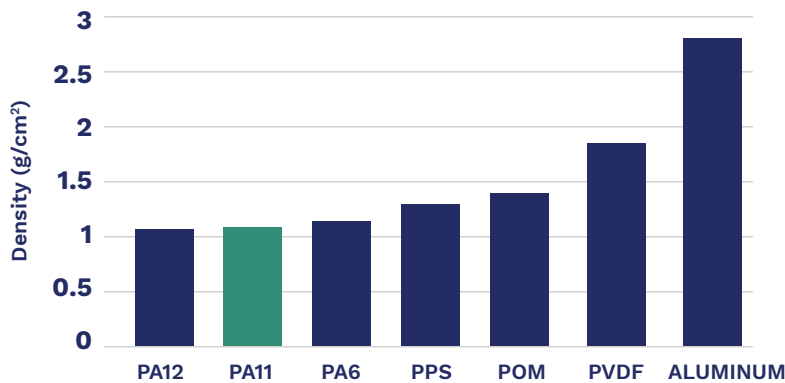
# MATERIAL PROPERTIES

## PHYSICAL PROPERTIES

### Density

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

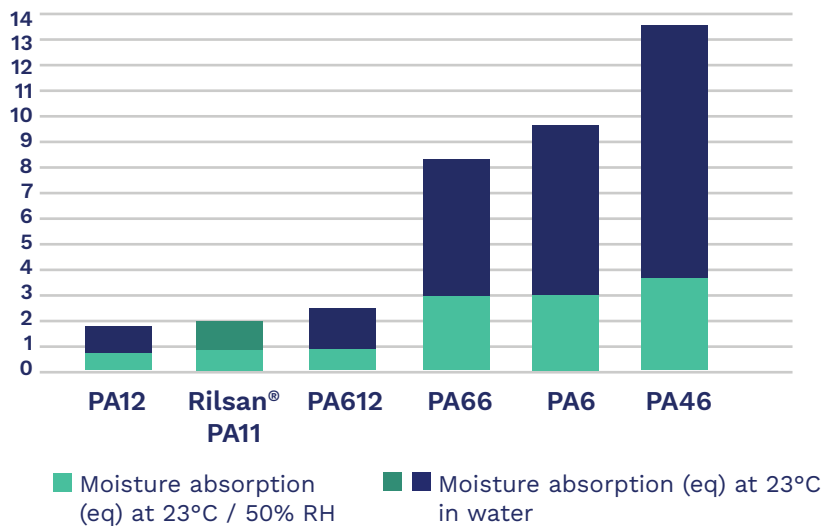
Comparative Densities of Engineering Polymers & Aluminum (g/cm<sup>2</sup>)



### Moisture pick-up

Among all performance polyamides, Rilsan® PA11 has very low moisture pick-up. Other polyamides feature a more hydrophilic behavior resulting from the polarity of the amide group in the backbone. Due to its low concentration of amide groups, Rilsan® PA11 can be used in a wide range of humidity environments. The absorption characteristics of Rilsan® PA11 are similar when it is exposed to other polar liquids such as alcohols, acids and esters. This low moisture pick-up results in outstanding dimensional stability of final parts made with Rilsan® PA11.

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



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%
PA6	2.2 - 2.7%	9.5%

# THERMO-MECHANICAL PROPERTIES

## 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 PA12, due to a greater density of hydrogen bonds.
- A glass transition temperature (Tg) at about 45°C, corresponding to transition of the amorphous phase.

The following table provides the melting ranges of several Rilsan® PA11 and Rilsamid® PA12 grades, per the Tg DSC (ISO 11357-1/-2)

		STANDARD MOLDING GRADES		STANDARD EXTRUSION FLEXIBLE GRADES	
	Unit	AMNO TLD (PA12)	BMNO TLD (PA11)	AESNO P40 TL (PA12)	BESNO P40 TL (PA11)
<b>MELTING RANGE</b>	°C	178	189	174	181



## Thermal Stability

Rilsan® PA11 offers greater thermal stability than PA12 and can be used continuously at 125°C under certain conditions. Additionally, it can withstand intermittent peaks of up to 150°C. For higher temperatures ask our team about the Rilsan® HT range. It can also withstand cold temperatures, and maintains its high impact resistance at -40°C. For extreme climate conditions, a special grade is available that 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 Rilsamid® PA12 compared to PA6 and PA66.

	Unit	Rilsan® PA11	Rilsamid® PA12	PA6	PA66
<b>Operating Temp</b>	°C	100	90	100	110

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

	Unit	Rilsan® PA11	Rilsamid® PA12
<b>Continuous</b>	°C	125	100
<b>Temperature Peaks</b>	°C	150	125

\*\*Best-in-class extrusion PA11 grades can now withstand 170°C for 1000h. At similar composition, PA11 will exhibit 10-20°C greater performance than equivalent PA12 grades.

### Heat Distortion Temperature Under Load

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

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

	Unit	BMNO TLD (PA11)	AMNO TLD (PA12)	BESNO P40 TL (PA11)	AESNO P40 TL (PA12)	BZM30 OTL (PA11)	AZM30 OTLD (PA12)
<b>HDT UNDER 0.46 MPa</b>	°C	145	135	130	90	180	175
<b>HDT UNDER 1.85 MPa</b>	°C	50	55	45	46	175	160

### Vicat Temperature

Rilsan® PA11 boasts a higher vicat softening temperature than PA12. This temperature, which depends on molding conditions, varies significantly based on the flexural modulus of the grade.

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

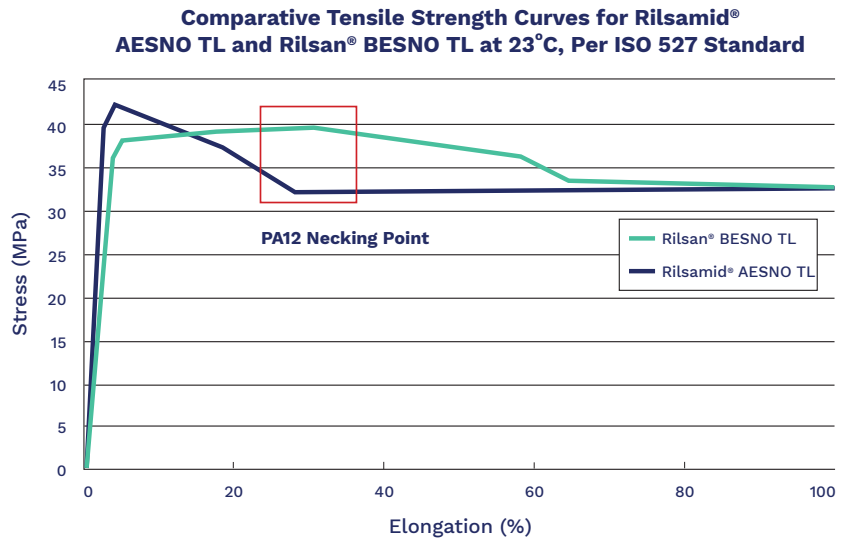
	Unit	PA11 RIGID TYPE P40	PA12 RIGID TYPE P40
<b>VICAT POINT UNDER 1 daN</b>	°C	180	170
<b>VICAT POINT UNDER 5 daN</b>	°C	160	142



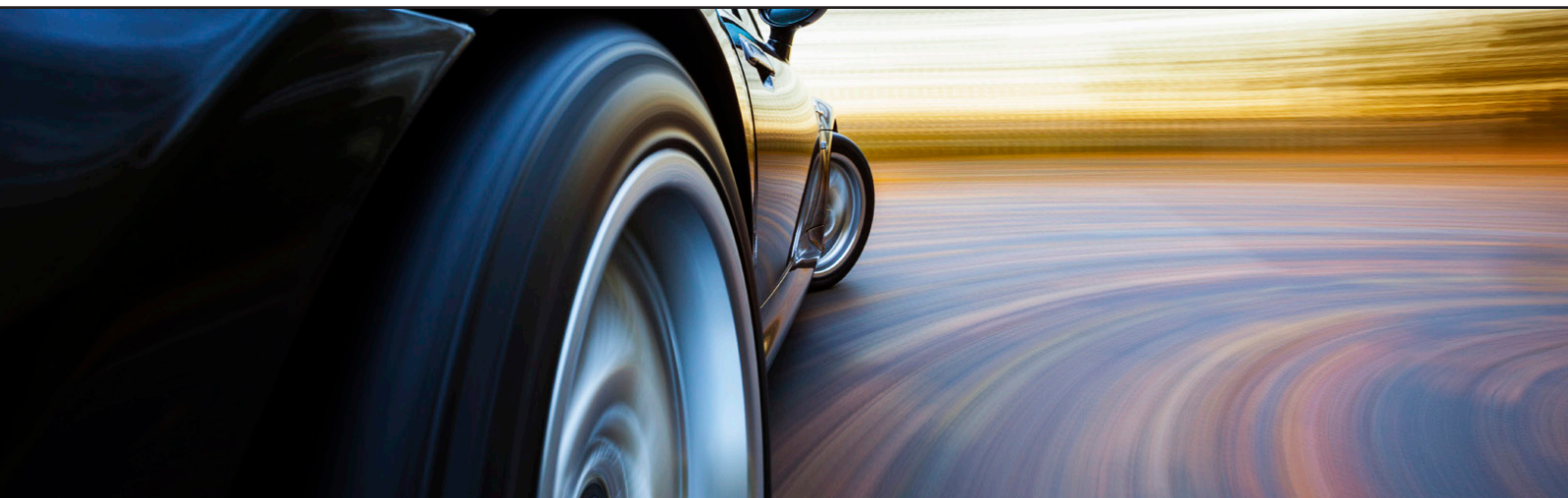
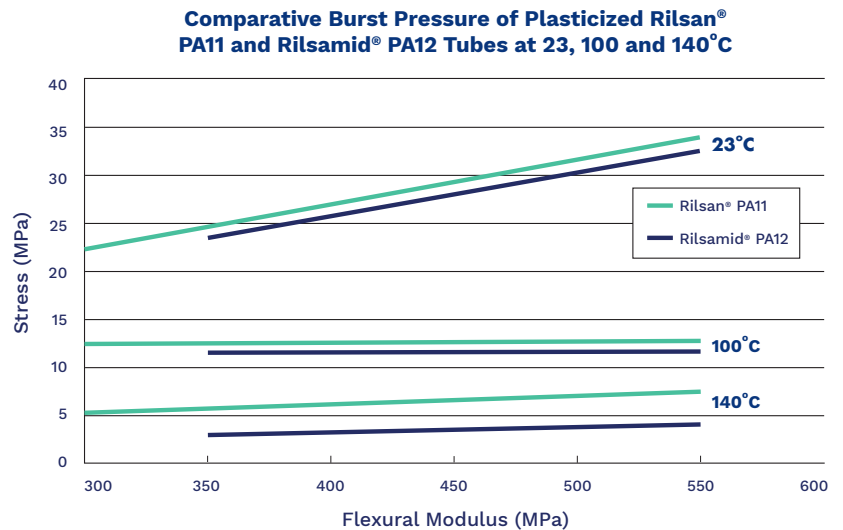
# MECHANICAL PROPERTIES

## Tensile Strength

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 demanding applications. At ambient temperature, the tensile strength of rigid (unmodified) 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.



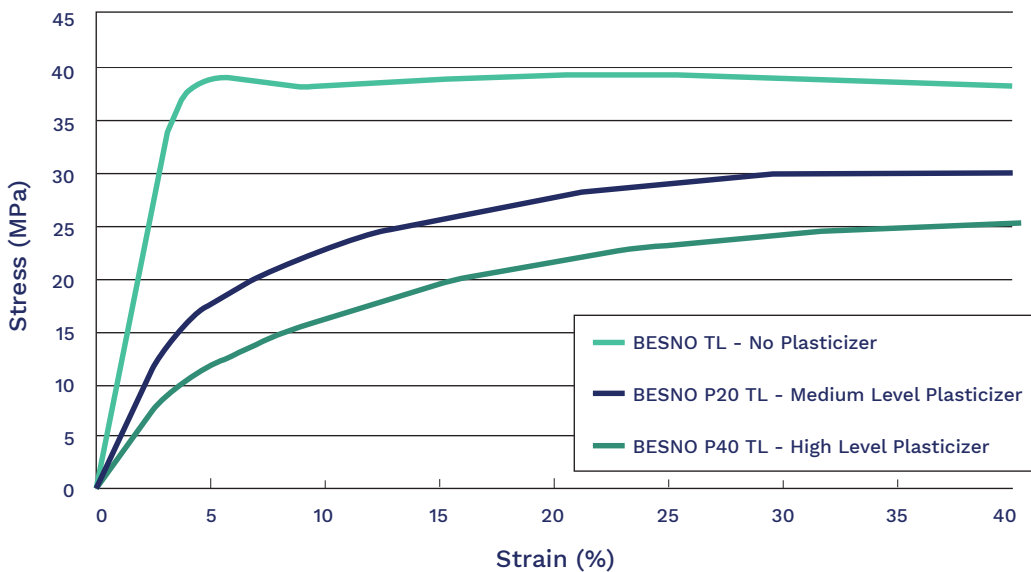
This very different performance can be attributed to the greater strength of the Rilsan® PA11 crystallites (triclinic/hexagonal) compared to the PA12 crystallites (monoclinic). This better stability of Rilsan® PA11 compared to PA12 observed above with rigid grades also applies to plasticized grades from 23°C to the melting point (the disparity increases with temperature). A significant consequence of this difference in behavior in actual use is that, at equivalent modulus, a Rilsan® PA11 plasticized tube exhibits a higher burst pressure than its PA12 counterpart.





The increase in plasticizer content significantly changes the tensile behavior of Rilsan® PA11 grades as shown in the following graph below.

**Comparative Tensile Curves of Various Rilsan® PA11 Grades, Per ISO 527 Standard**



Tensile properties at 23°C *	Tensile modulus (MPa)	Stress at yield (MPa)	Strain at yield (%)	Stress at break (MPa)	Strain at break (%)
<b>BESNO TL</b>	1280	38	5	57	> 50
<b>BESNO P20 TL</b>	510	31	40	45	> 50
<b>BESNO P40 TL</b>	345	26	50	48	> 50

\* ISO 527 1-2 standard (Conditioned sample).

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:

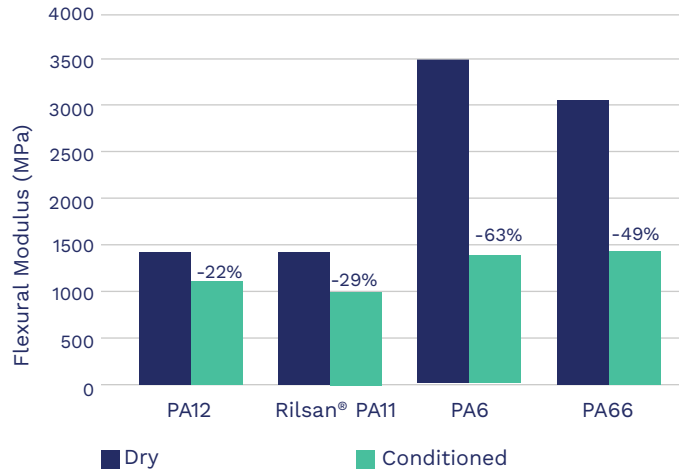
TEMPERATURE (°C)	23	60	80	100
<b>YOUNG'S MODULUS (MPa)</b>	345	180	172	165



## Flexural Modulus

Rilsan® PA11 is available in a wide range of flexibilities. The modulus varies from 1200 MPa for non-plasticized grades to around 150 MPa for plasticized grades. Adding specific fillers (e.g. glass fiber, carbon fiber) enable an increase in modulus up to 8000 MPa. In dry conditions, PA6 and PA66 have significantly higher rigidity than Rilsan® PA11, but after moisture pick-up, the flexural properties of Rilsan® PA11 remain relatively stable.

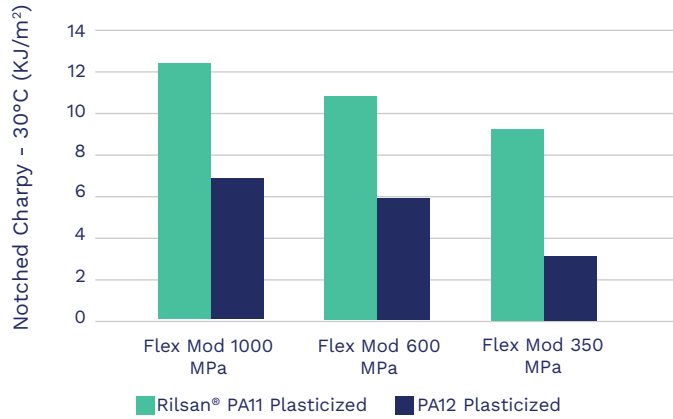
**Effect of ambient conditions on the flexural modulus of Rilsan® PA11 and PA12 vs PA6 and PA66. Tests conducted per ISO 178 standard**



## Impact Resistance

Rilsan® PA11 demonstrates very good impact resistance at room temperature as well as at very low temperatures leading to a significantly higher safety factor than for PA12. In Charpy notched impact test at -30 °C, Rilsan® PA11 is twice as resilient as PA12. Its fragile/ductile transition is ~35 °C versus ~50 °C for PA12. This benefit of Rilsan® PA11 applies to both unplasticized and plasticized grades. Glass transition temperatures are similar for Rilsan® PA11 and PA12 (a slight advantage of 5° C for Rilsan® PA11) and do not explain differences in performance between the products. This is due to the finer crystalline grid and spherulitical 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 PA12 (see graph to the right).

**Comparative impact resistance of Charpy notched plasticized Rilsan® PA11 and PA12 (-30°C), per ISO 179/1eA standard**



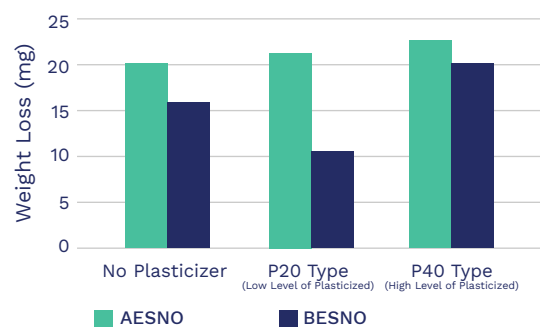
**Comparative table of impact resistance of unnotched Charpy Rilsan® PA11 vs PA6, PA66 and PBT**

	STANDARD	UNIT	Rilsan® PA11	PA6	PA66	PBT
<b>UNNOTCHED AT +23 °C</b>	ISO 179/1eU	KJ.m <sup>2</sup>	No Break	75	50	300
<b>UNNOTCHED AT -30 °C</b>	ISO 179/1eU	KJ.m <sup>2</sup>	No Break	40	40	300

## Abrasion Resistance and Coefficient of Friction

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

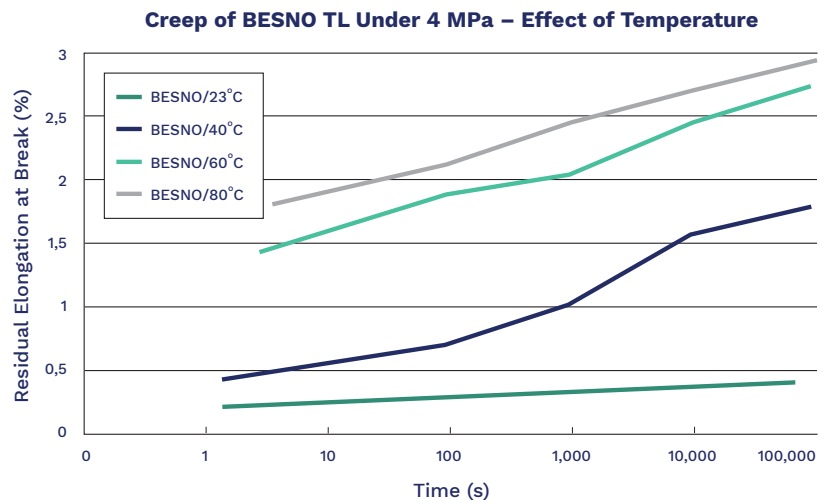
**Comparative TABER(method H18: 1000 revolutions under 1000 grams) abrasion resistance of Rilsamid® AESNO (PA12) and Rilsan® BESNO (PA11)**



# Long-Term Performance

## Creep Resistance

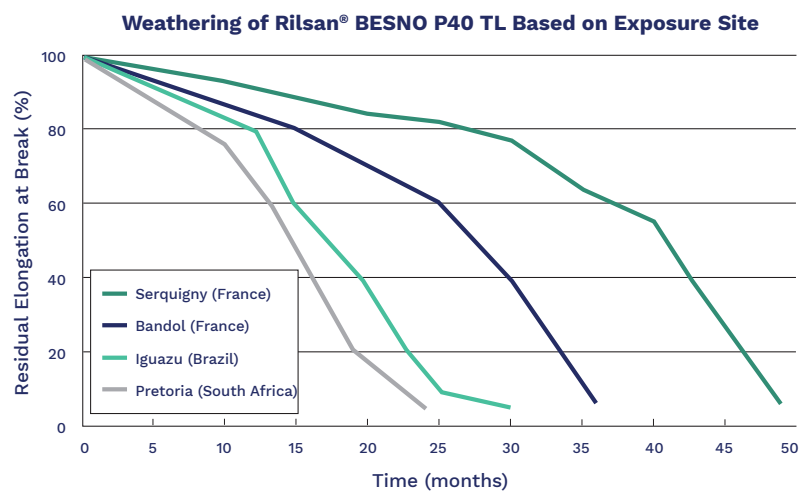
The notion of a material's lifetime is an important factor when designing components requiring long-term performance in specific operating conditions. As a general rule, Rilsan® PA11 features viscoelastic behavior at ambient temperature. However, under permanent stress, above a certain limit, Rilsan® PA11 undergoes plastic deformation. Arkema's 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 team will be pleased to provide further information.



## Weathering Resistance

Parts made with 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 stabilizer 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 P40 TL.



- **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 a great balance between the resistance to grease and hydrocarbons and the resistance to acids, bases and salts. The excellent chemical resistance of Rilsan® PA11 is reflected both in high dimensional stability under harsh conditions and in the nondegradation of the polymer matrix. Additionally, Rilsan® PA11 features greater resistance to hydrocarbons than PA12, making it a preferred 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 a better combination of properties:

- Stability of strong mechanical properties
- Excellent dimensional stability due to a lower absorption rate (significant in the case of tubing carrying fluids, to minimize risk of leakage at the connection sites)
- Excellent inherent flexibility
- Very low permeability to hydrocarbons

The following tables feature the resistance of Rilsan® PA11 to common chemicals after 18-months of exposure.

G = Good

L = Limited (swelling – suitability depends on specific use and duration)

P = Poor

\* Slight Browning

\*\* Swelling Action

CHEMICAL AGENT	CONCENTRATION (100%)	PERFORMANCE			
		20°C	40°C	60°C	90°C
<b>MINERAL ACIDS</b>					
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
<b>MINERAL SALTS</b>					
Calcium Arsenate	Concentration 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	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	Saturated	G	G	G	G
Zinc Chloride	Saturated	G	G	L	P

CHEMICAL AGENT	CONCENTRATION (100%)	PERFORMANCE			
		20°C	40°C	60°C	90°C
<b>MINERAL BASES</b>					
Soda		G	L	P	P
Potash	50%	G	L	P	P
Ammonia	50%	G	G	G	G
Ammonia Solution	Concentrated Liquid or Gas	G	G		
<b>OTHER MINERAL BODIES</b>					
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 Volume	G	G	L	P
Hydrogen		G	G	G	G
Ozone		L	P	P	P
Sulfur		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	G	
Potassium permanganate	5%	P	P		
<b>ORGANIC BASES</b>					
Aniline	Pure	L	P	P	P
Pyridine	Pure	L	P	P	P
Urea		G	G	L	L
Diethanolamine	20%	G	G**	G**	L

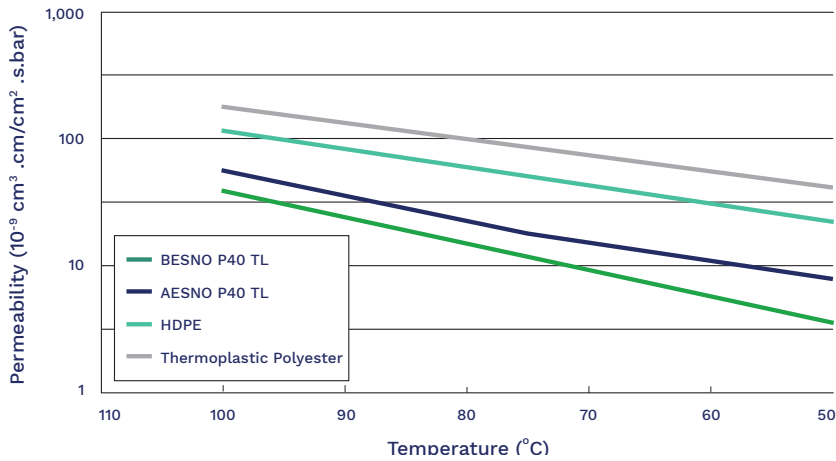
CHEMICAL AGENT	CONCENTRATION (100%)	PERFORMANCE			
		20°C	40°C	60°C	90°C
<b>ORGANIC ACIDS AND ANHYDRIDES</b>					
Acetic Acid		L	P	P	P
Acetic Anhydride		L	P	P	P
Citric Acid		G	G	L	P
Formic Acid		G	P	P	P
Lactic Acid		G	G	G	L
Oleic Acid		G	G	G	L
Oxalic Acid		G	G	L	P
Picric Acid		L	P	P	P
Stearic Acid		G	G	G	L
Tartaric Acid	Saturated Solution	G	G	G	L
Uric Acid		G	G	G	L
<b>HYDROCARBONS</b>					
Methane		G	G	G	
Propane		G	G	G	
Butane		G	G	G	
Acetylene		G	G	G	
Benzene		G	G**	G**	
Toluene		G	G**	G**	L
Xylene		G	G**	G**	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	
<b>ALCOHOLS</b>					
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
<b>ALDEHYDES AND KETONES</b>					
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	
<b>CHLORINATED SOLVENTS</b>					
Methyl Bromide		G	P		
Methyl Chloride		G	P		
Trichloroethylene		L	P		
Perchloroethylene		L	P		
Carbon Tetrachloride		P			

CHEMICAL AGENT	CONCENTRATION (100%)	PERFORMANCE			
		20°C	40°C	60°C	90°C
<b>CHLORINATED SOLVENTS Continued</b>					
Trichloroethane		L	P	P	P
<b>PHENOLS</b>					
Phenols		P	P	P	P
<b>VARIOUS ORGANIC BODIES</b>					
Anethol		G			
Glycol Chlorhydrine		P	P		
Ethylene Oxide		G	G	L	P
Carbon Sulphide		G**	L*	P	
Furfurol		G	G**	L	P
Tetraethyl Lead		G			
Glucose		G	G	G	G
<b>SALTS, ESTERS, ETHERS</b>					
Methyl Acetate		G	G	G	
Ethyl Acetate		G	G	G	
Butyl Acetate		G	G	G	L
Amyl Acetate		G	G	G	L
Tributyl Phosphate		G	G	G	L
Tricresyl Phosphate		G	G	G	L
Diocyl Phosphate		G	G	G	L
Diocyl Phtalate		G	G	G	
Sulfuric Ether		G			
Fatty Acid Esters		G	G	G	G
Methyl Sulfate		G	L		
<b>MISCELLANEOUS PRODUCTS</b>					
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

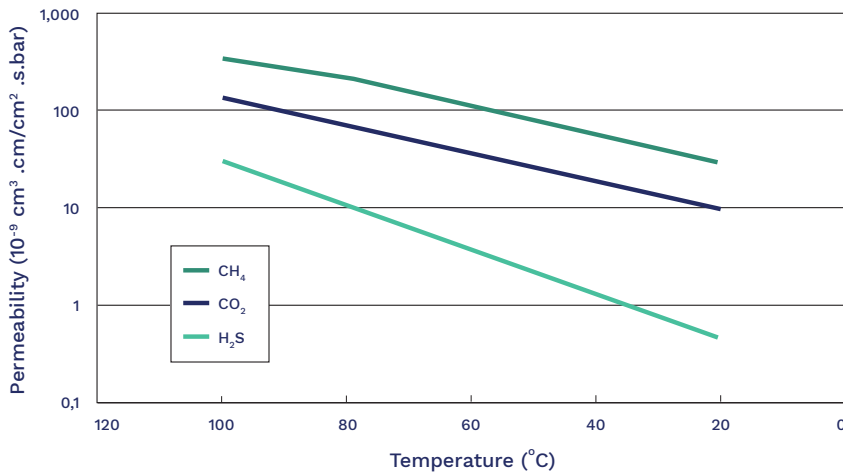
## Permeability

Multi-material solutions are available for applications requiring low or very low permeability. These multilayer solutions maintain the key 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 PA12.

**Permeability of Various Polymers to Natural Gas  
(85% CH<sub>4</sub> - 8% C<sub>2</sub>H<sub>6</sub> - 3% C<sub>3</sub>H<sub>8</sub> - 2% C<sub>4</sub>H<sub>10</sub>) at Different Temperatures**



**Permeability of Rilsan® BESNO P40 TL to Various Gases  
and at Different Temperatures**



Graphs published in «Raveau Simon Polymer in offshore engineering June 1988»



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

**Rilsan® BESNO TL**

Gas	PERMEABILITY (10 <sup>-9</sup> cm <sup>3</sup> .cm/ cm <sup>2</sup> .s.bar)
H <sub>2</sub>	15.00
O <sub>2</sub>	2.00
N <sub>2</sub>	0.15

**Rilsan® BESNO P40 TL**

Gas	PERMEABILITY (10 <sup>-9</sup> cm <sup>3</sup> .cm/ cm <sup>2</sup> .s.bar)
CH <sub>4</sub>	0.60
C <sub>2</sub> H <sub>4</sub>	2.30
C <sub>3</sub> H <sub>8</sub>	0.75
C <sub>4</sub> H <sub>10</sub>	5.40
H <sub>2</sub> O (vap.)	0.04
CO <sub>2</sub>	6.00
H <sub>2</sub> S	30.00

**Rilsamid® (PA12) AESNO P40 TL**

Gas	PERMEABILITY (10 <sup>-9</sup> cm <sup>3</sup> .cm/ cm <sup>2</sup> .s.bar)
CH <sub>4</sub>	1.60
CO <sub>2</sub>	12.00

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 P40 TL, versus plasticized PVC and rubber.

PRODUCT	DIMENSION OF PIPE		PERMEABILITY (g/m <sup>2</sup> .day)	
	INNER DIAMETER (mm)	THICKNESS (mm)	20°C	40°C
<b>RILSAN® BESNO P40 TL</b>	6	0.5	2	4
<b>PLASTICIZED PVC</b>	6	2	60	120
<b>RUBBER</b>	6	3	60	120



# PROCESSING

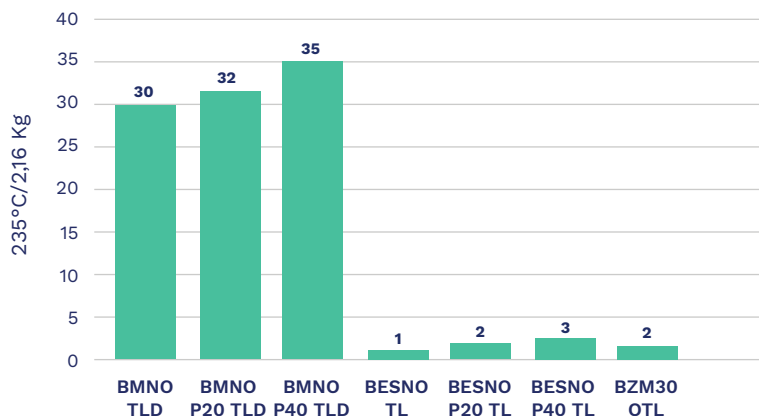
With a relatively low melting temperature, good melt fluidity, and a high speed of recrystallization, Rilsan® PA11 is well-suited to a wide range of processing technologies: extrusion, extrusion-blow molding, injection molding, injection-blow molding, rotomolding, and 3D printing. To ensure optimum suitability for each of these processing technologies, Rilsan® PA11 is available in a wide range of viscosities. 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 that 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. MVI also depends upon moisture content.

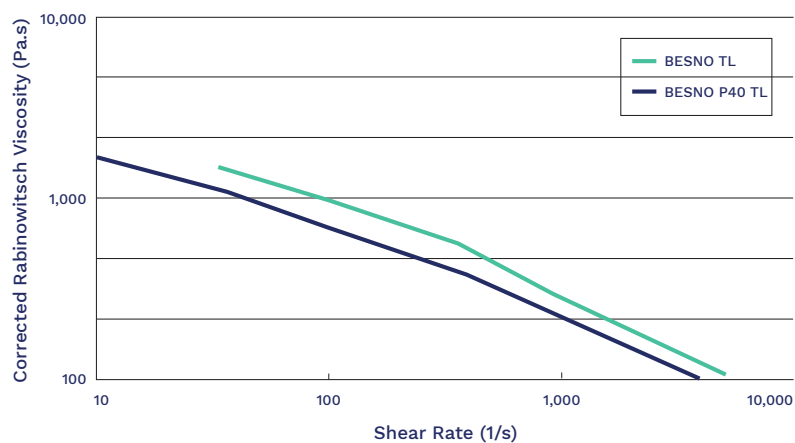
**Comparative Dry Melt Volume Indices of Various Rilsan® PA11 Grades per ISO 1133 standard**



## Melt Viscosity

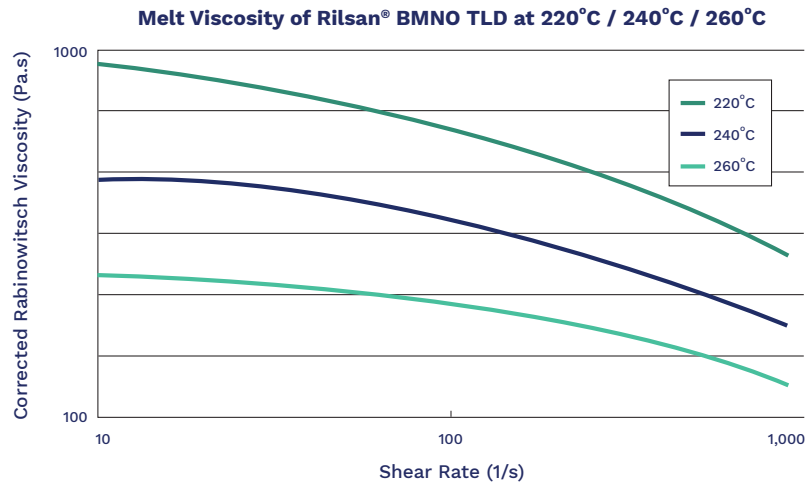
The rheological behavior of Rilsan® PA11 can be measured more accurately with capillary rheometer equipped with tooling having an L/D ratio of 20. As illustrated in the following diagrams, the viscosity of Rilsan® PA11 varies according to shear rate and temperature.

**Melt Viscosity of Rilsan® BESNO TL and BESNO P40 TL at 260°C**

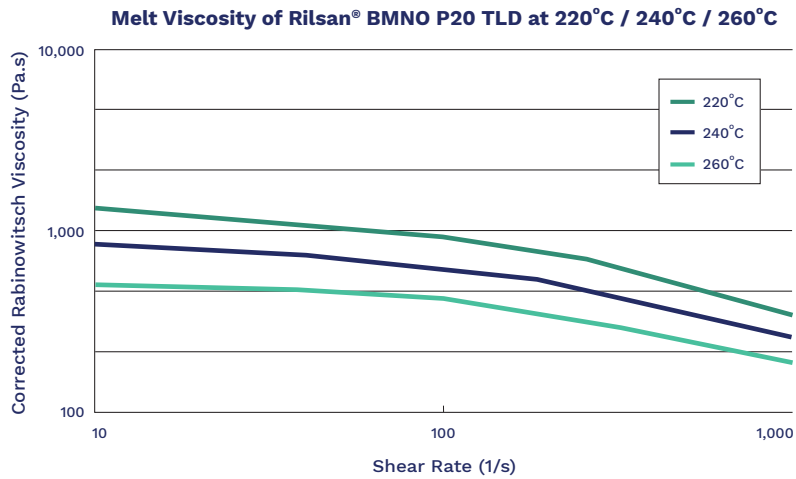




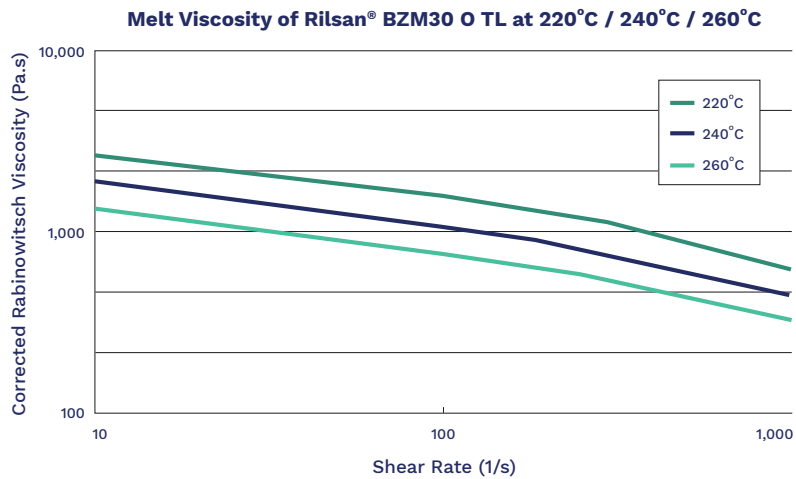
## Rilsan® PA11 Grade for Injection Molding



## Standard Viscosity Rilsan® PA11 Grade for Plasticised Molding



## FG Reinforced Rilsan® PA11 Plasticised Grade for Injection Molding

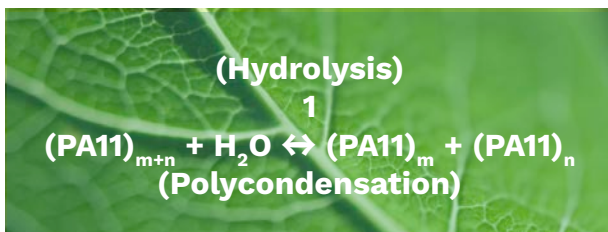


## Preparation of Rilsan® PA11

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 (see below for drying conditions).

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.

Moisture pick-up of Rilsan® PA11 due to its chemical structure, Rilsan® PA11 has lower moisture pick-up than short-chain polyamides (e.g. PA6, PA66). This low water absorption leads to 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:



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 Conditions

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 are 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

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

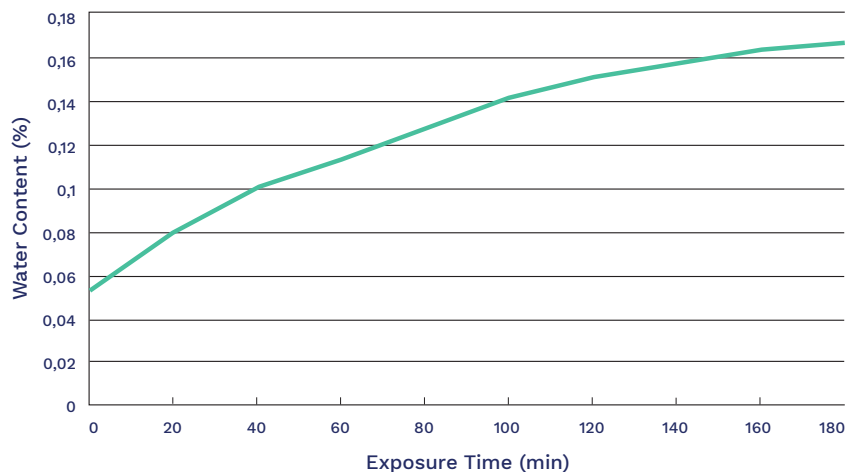
## Coloration

An extensive range of colors can be achieved with Rilsan® PA11. 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 (e.g. plastification time, rotation of the screw, back pressure, use or otherwise of mixing adapter).

## Recycling

The recycling of scraps requires a number of best 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 possible to recycle it in any production process that 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 generally should not exceed 20% by weight.

Moisture Pick-up of Rilsan® PA11 Based on Exposure Time to Air (at 20°C – 65% R.H.)



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 Rilsan® PA11 Injection Molding

With its melt flow characteristics, Rilsan® PA11 is suited for injection molding using commercially available equipment.

#### Injection Unit SCREW

Standard screws 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 18 times its diameter, with a minimum compression ratio of 2.2.

#### INJECTION NOZZLE

If the injection unit moves to the back position at each cycle then operating a shut-off nozzle may be recommended. If this is not fitted, molten polymer will leak out between 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, processors can affect the appearance of the finished article, the ease of filling, mold release, and shrinkage. Except for a few specific cases, Rilsan® PA11 grades require mold temperatures from 40°C to 60°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 molds temperatures up to 90°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.

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:

- 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 Rilsan® BMNO (standard molding grade) and Rilsan® BZM30 (glass

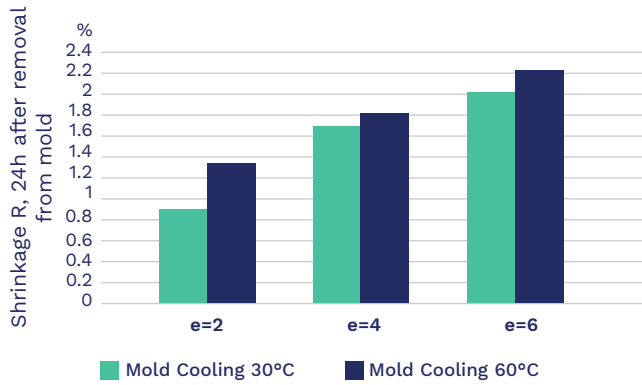
HOLDING PRESSURE AND TIME	↑	SHRINKAGE	↓
TEMPERATURE OF THE MOLD	↑	SHRINKAGE	↑
TEMPERATURE OF THE MATERIAL	↑	SHRINKAGE	↑
COOLING TIME	↑	SHRINKAGE	↓
INJECTION SPEED	↑	SHRINKAGE	↓

fiber reinforced molding grade) was conducted on injected test samples with thicknesses of 2, 4, and 6mm, while maintaining an injection threshold equal to 25% of the nominal thickness (0.5mm layers for a 2mm sheet). Shrinkage, measured 24 hours after mold release and after thermal treatment, was determined from the following two measurements:

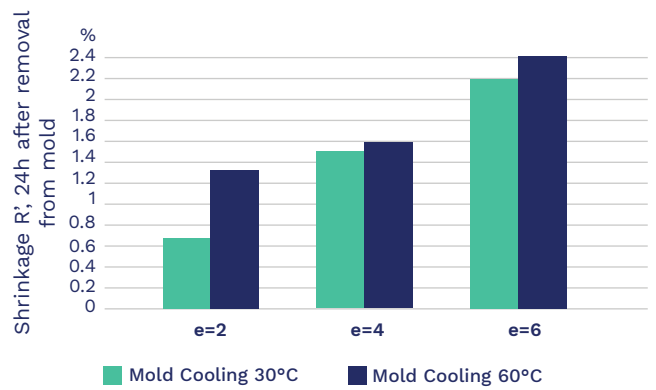
- Shrinkage R, in flow direction
- Shrinkage R', perpendicular to flow direction.

RILSAN® PA11 GRADES	TEMPERATURE (°C)			
	HOPPER	CENTRAL SECTION	OUTLET	NOZZLE
BMNO TLD	210	225	240	230
BZM30 O TL	240	260	270	270

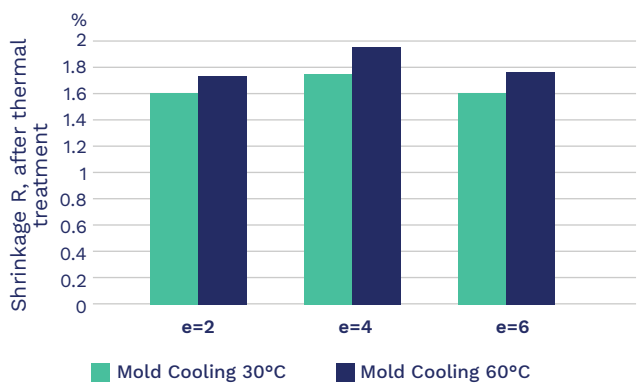
**Shrinkage R, 24h After Removal From Mold**



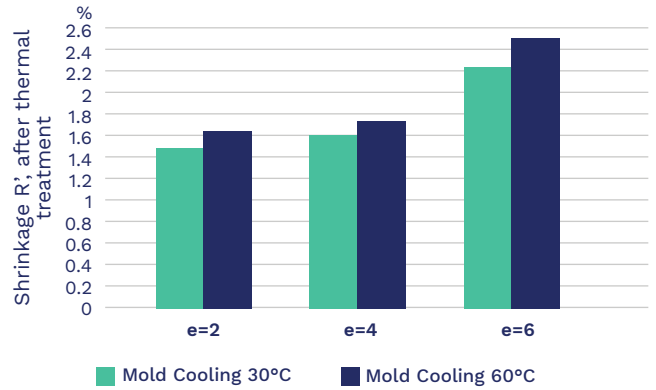
**Shrinkage R', 24h After Removal From Mold**

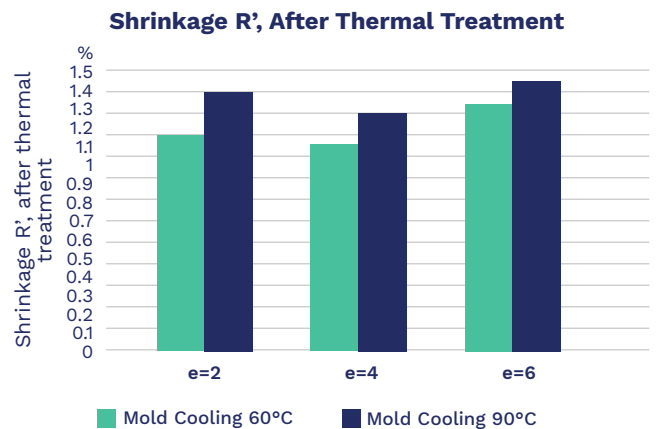
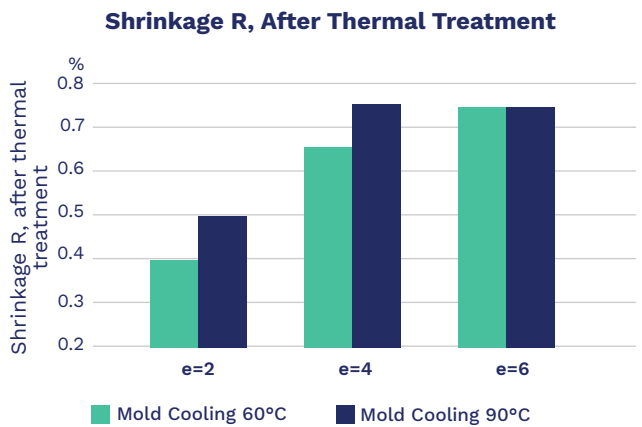
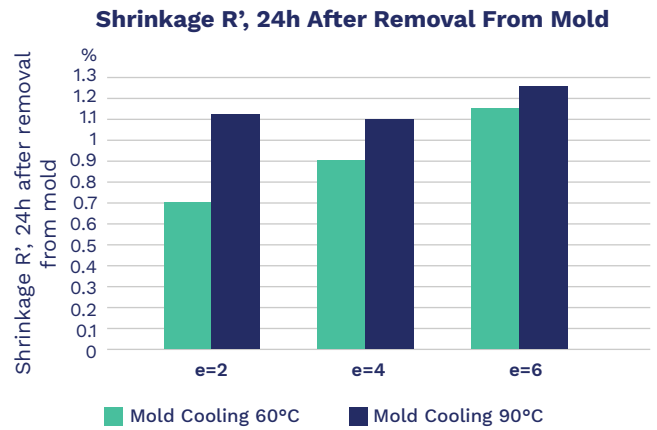
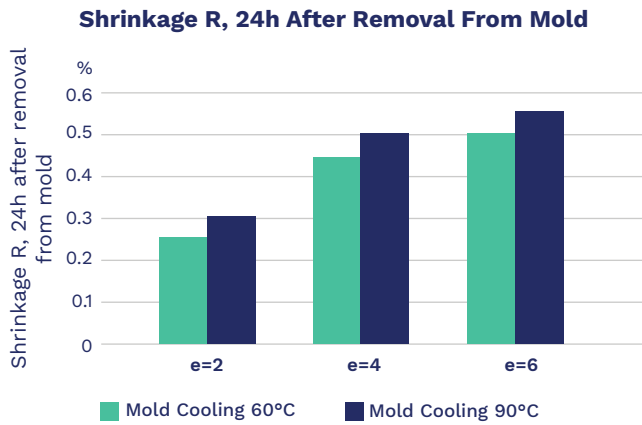


**Shrinkage R, After Thermal Treatment**



**Shrinkage R', After Thermal Treatment**





## Back-pressure

Rilsan® PA11 can be plasticized easily with minimum back-pressure. However, a higher back-pressure is advisable when masterbatch coloration is used, as this ensures good dispersion of the colorant.

## Injection Pressure and Speed

Injection pressure strongly depends on part design such as thickness and flow length. Injection pressure usually ranges between 500 and 900 bars for Rilsan® PA11 non-reinforced grades but it can increase up to 1500 bars for the most viscous Rilsan® PA11 reinforced grades depending on the application.

## 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 (anisotropic) and their length, and the type of feed and geometry factors.

## Extrusion (Film and 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
- Homogenization of the melt through sufficient back-pressure

Screws with a long compression zone help minimize 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.

### Temperature 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 Rilsan® PA11 grade chosen, i.e. whether lubricated or not. For example, non lubricated grades require higher temperatures, especially in the first zone of the extruder.

GRADES	TEMPERATURE ( C )					
	HOPPER	FEEDING ZONE	COMPRESSION ZONE	METERING ZONE	EXTRUSION HEAD	DIE
BESNO P40 TL	60	175	220	235	230	220
BESNO P20 TL	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 efficiently cool 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 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.

### Extrusion blow molding

Thanks its high viscosity Rilsan® PA11 can be processed in extrusion blow molding and suction extrusion blow molding. For instance, Rilsan® BESN P123

Black TL can be extruded into a 15kg parison.

## 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, aluminum, copper plate, etc.). It's advised to use demolding agent.

## Heating temperature and duration

To achieve optimum rotomolding of Rilsan® PA11 articles in order to keep the PIAT (Peak Internal Air Temperature) it is recommended to heat the product no higher than 220°C in the mold. The duration of the heating is governed by the temperature of the oven, the thickness and thermal conductivity of the mold, and 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 mold). 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 typically gives the best results and 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. Heating up the part 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. Contact the Arkema's technical service team for recommendation of the most suitable colorants for PA11.

### **Multi-material structures**

Arkema offers a wide range of glues, adhesives and tie layers, making the company a world leader for the design of multi-material, multi-layer structures. Bostik, a global leader in adhesives is also a subsidiary of the Arkema Group.

### **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, thermoplastic resins).

### **Welding**

Rilsan® PA11 can be welded using a wide variety of techniques: high frequency, induction, friction, and ultrasonic welding, IR, Laser welding.

### **Other Techniques For Assembling Multi-materials**

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

### **Bio-based, Renewable Solutions**

Arkema is a world leader in ultra high performance polymers that are bio-based/renewable. For over 70 years, Arkema has been a leading innovator in both monomer and polymer production from castor oil feedstock. The Group is well known for its flagship amino 11 chemistry and the Rilsan® PA11 and Pebax® Rnew® polymer ranges.

### **Sustainably Sourced**

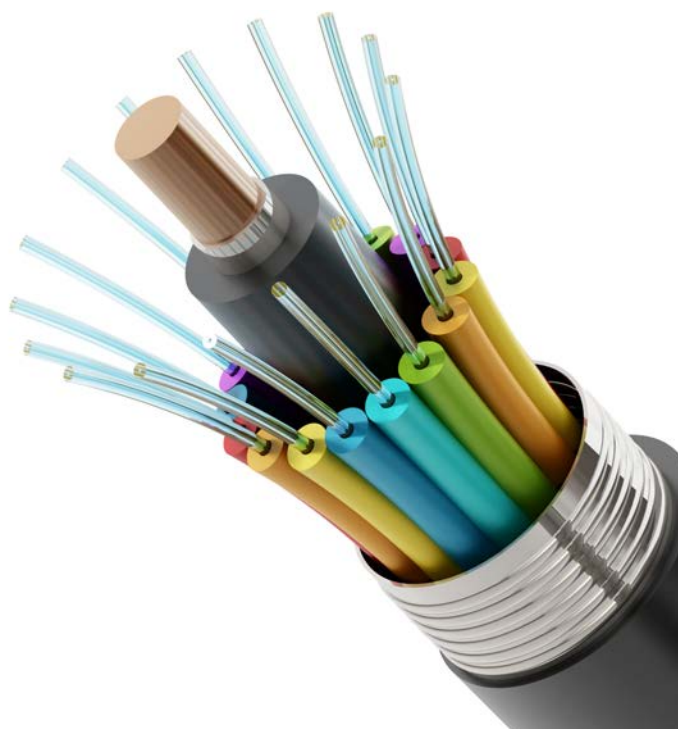
Arkema's amino 11 chemistry is derived from the castor bean, a sustainable, renewable crop that does not compete with food and does not cause deforestation. Arkema is a leading driver of sustainable castor farming in India.

The castor bean is actually a seed. When planted, more seeds grow – the circle of life.

Further, Rilsan® and Pebax® Rnew® grades are generally recyclable. Arkema offers its Virtucycle® program to partner customers.

### **Global Service**

Arkema's High Performance Polymers division boasts a global and integrated organization in terms of production, technical support, and development. At every stage of a project involving the use of Rilsan® PA11 (design, industrial development, market launch), the High Performance Polymers division will be pleased to provide you with any assistance you may require. Our technical teams specialized in high-performance polyamides can help in grade selection, processing parameters, application development, and much more. Finally, as a long-standing partner to high-tech industries (oil and gas, aerospace, automotive, industrial vehicles, electronics etc.), the High Performance Polymers division can oversee complex developments involving the end-user and the industrial supply chain (processors and OEMs).



# MA

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