Thermoplastic Polyurethane Elastomers
Elastollan® Cable Sheathings

BASF
The Chemical Company

BASF Polyurethanes Worldwide Network Map

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Introduction

Thermoplastic polyurethane (TPU) is well known in the cable industry since the beginning of the sixties. In course of time it has given a good account of itself as material for cable sheathing.

Because of the excellent mechanical properties and resistance against oils and chemicals, TPU is the ideal material for sheathing of flexible high performance cables. TPU can be used under the harshest environmental conditions, e.g. as sheathing for seismic streamer sleeves (also in very cold regions), drag cables and industrial robots. TPU cables are durable even in very demanding conditions found in construction sites and mines.

In 1985 thermoplastic polyurethanes were included as sheathing material in the VDE 0250, part 818 under the abbreviation PUR. This standard has since been replaced, in November 1995 by the VDE 0282, part 10. Now is valid the HD 22.10 S1 standard of “Celenec” (European Committee for Electric Standardisation). All member countries of Celenec have adopted this document in their national standard.

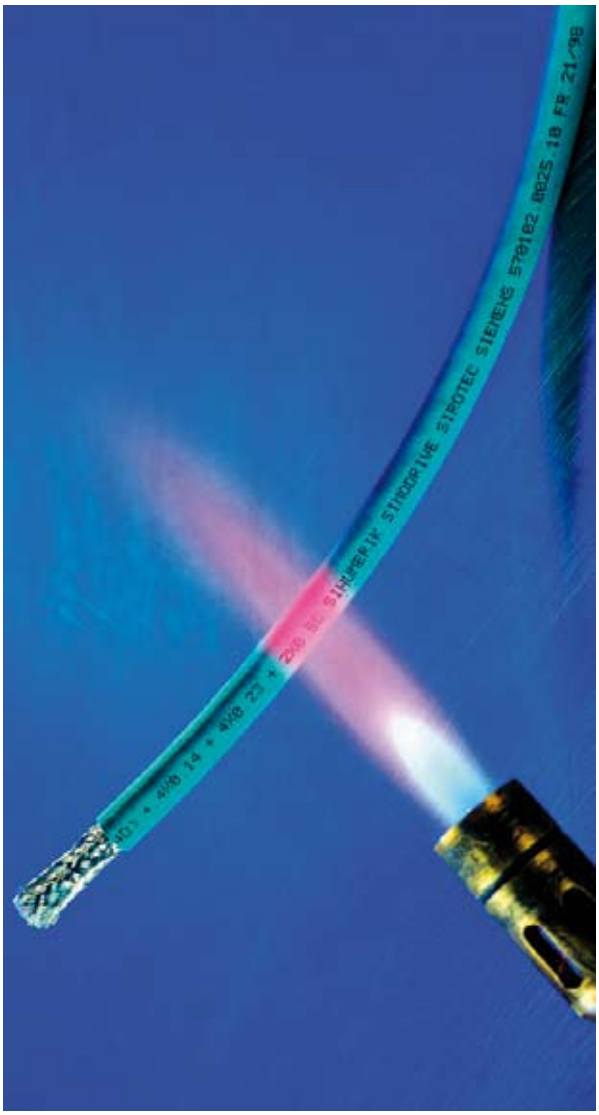
The automotive industry is now the biggest consumer of TPU cables. This development started in 1978 with the introduction of the anti-blocking system (ABS) in vehicles. Then, as now, it was necessary to convey information from the speed sensors out of the danger area of the wheel housing in a secure manner. Highly stringent requirements are placed on the cable used here in terms of low-temperature flexibility, resistance to flying stones and vibration resistance.

Up to now in the numerous applications in cable industry TPU is mainly used as outer sheathing material. Meanwhile TPU is of growing interest as core isolation material.

Outstanding Properties

Following a summary of the properties which make Elastollan® TPU to the ideal material for cable sheathing and insulation:

- Temperature range: -40°C ~125 °C
- Excellent low temperature flexibility
- Ageing resistant
- Environmental resistance (humidity, ozone, UV-radiation, microbes)
- Tear and tear propagation resistant
- Wear resistant
- Chemical resistant
- Oil resistant
- Halogen free
- High flexural fatigue strength
- Sufficient electrical insulation
- Possible gating of watertight plug



Applications

Automotive	■ Sensor- and control cables ■ Battery cables
Mechanical engineering	■ Drag cables for automatic equipment ■ Cables for robots and handling tools
Construction industry	■ Energy cables for construction machines and tools
Others	■ Medicine, railway, airport equipment, off shore, nuclear power stations, domestic articles

The following pictures show typical applications for TPU cable sheathing and connectors in different industrial sectors

Fig. 1: ABS cables require a high reliability of cables. TPU sheathed cables safely transmit information from the wheel sensors in the wheel-case. Water proofness, low temperature flexibility and resistance against stone impact are essential in this.

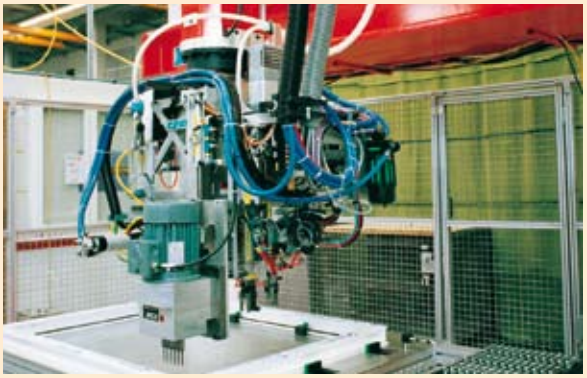


Fig. 2: Cables for robots and automatic devices need to be flexible, abrasion resistant and resistant to long term stress. Sheathed with TPU even with a flame retardant halogen free grade they achieve a long lifetime.

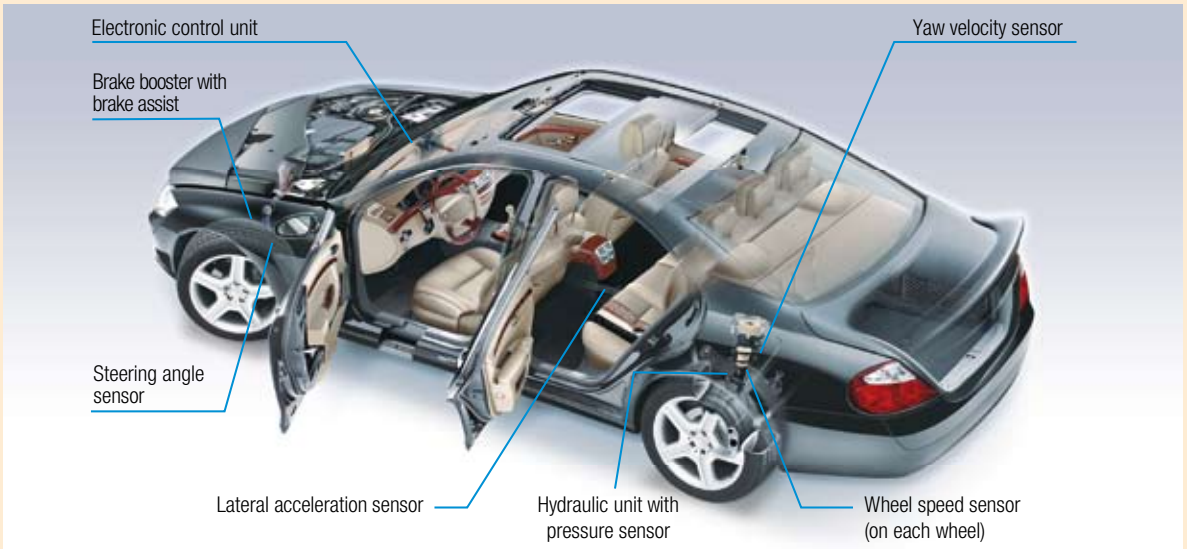


Fig. 3: Electronic stability program (ESP): ESP systems require a high reliability of both cables and plugs. TPU sheathed cables safely transmit information from the sensors to the control unit

Applications

Fig. 4: TPU sheathing for exploration cables

Fig. 5: Energy cable on construction site/open cast mining

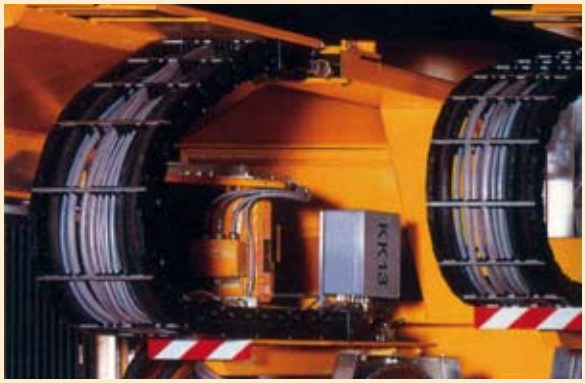


Fig. 6: Robots are often required to move long distances. The entire control and energy supply must be provided by drag cables. These drag cables are stressed with a continuous friction. The wear performance of TPU is outstanding

Fig 7: TPU cable plugs and connectors

Plug connectors are generally subject to the stringent requirements as cables. A high wear resistance and dimensional accuracy is required, together with temperature resistance and resistance to chemicals. Over and above this, a high clamping force, coupled with absolute water tightness, is an essential requirement.

In the ideal case, therefore, TPU should also be used for the plug connector. A watertight bond will be achieved by molding the connector directly onto the TPU sheathing. Also anti-kink sleeves can be molded directly onto the cable.

TPU can be processed on conventional injection moulding machines without any problems in order to produce these plug connectors.

Classification

Thermoplastic polyurethane (TPU) belongs to the family of materials known as thermoplastic elastomers (TPE). It attains virtually the same level of elasticity as crosslinked elastomers (rubber) while simultaneously offering the advantages that it can be processed like a thermoplastic and it is recyclable.

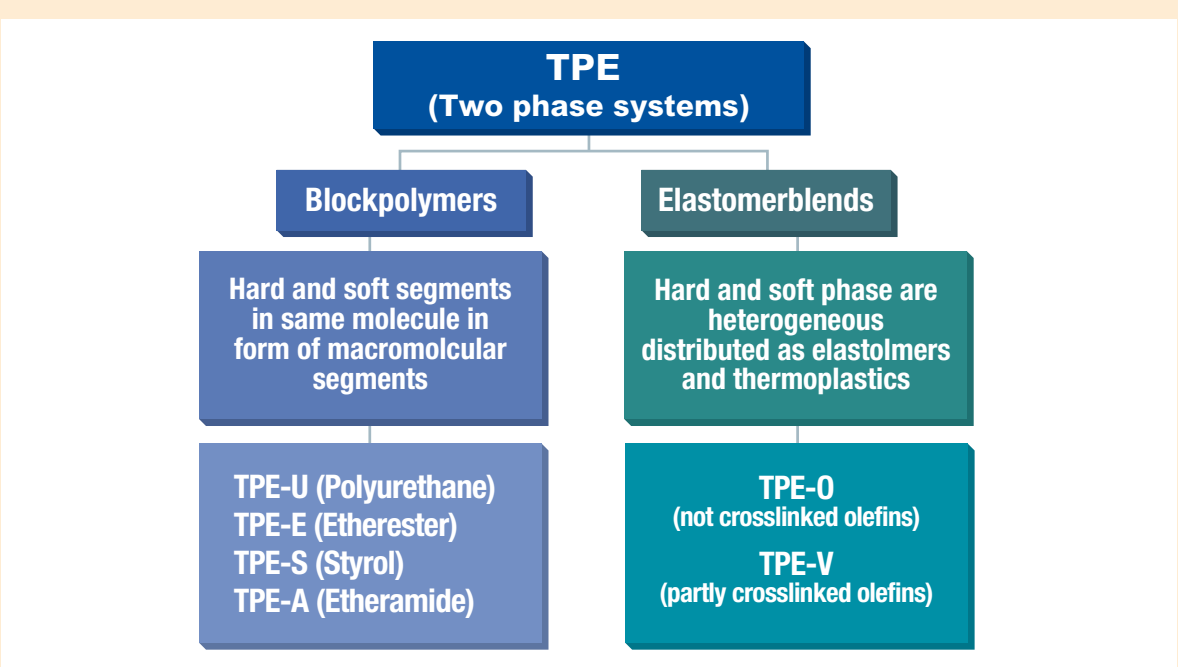


Fig. 12: Classification

Chemical structure

Thermoplastic polyurethane is made up of block copolymer molecules with alternating rigid and flexible segments. It is this combination of flexible, elastic segments with a high extensibility and low glass transition temperature, on the one hand, and rigid crystallising segments with a high melting point, on the other hand, that gives the material its elastomeric nature. By altering the ratio of the rigid phase, it is possible to vary properties such as hardness, strength, rigidity, extensibility and low-temperature flexibility over a broad range. A distinction is drawn between polyether and polyester polyurethane as a function of the polyols employed. The cable industry uses predominantly polyether TPU on account of its good microbe resistance and considerably better hydrolysis resistance. Only polyether TPU is conforming to Celenec.

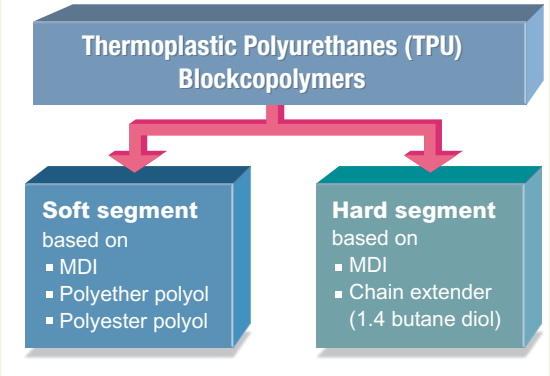


Fig. 13: Chemical structure

Nomenclature

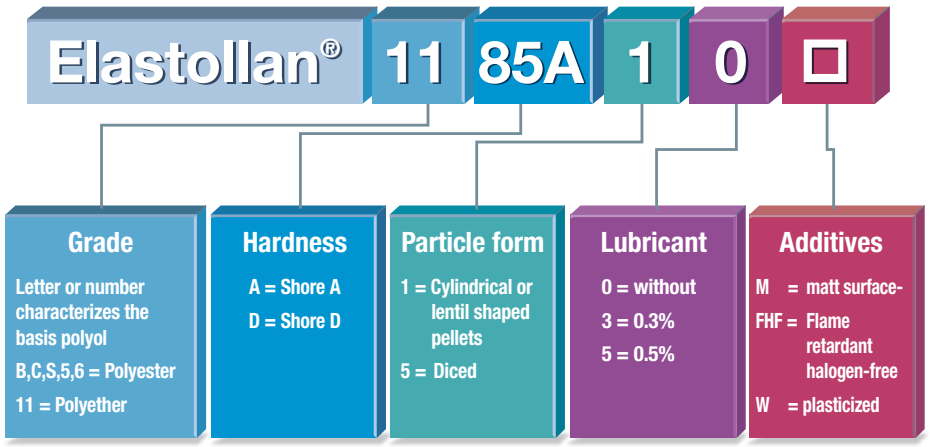


Fig. 14: Nomenclature

Additives

Additive	Function	Percentage
Konz 926	Matt surface	8-10 %
Konz 2877	UV stabilizer	min. 2 %
Konz 950/1	Release agent	min. 2 %
Konz 978	Matt surface	2-4 %
Various color concentrates*	Coloring	min. 2 %

* Minimum order volume for color concentrates is 100Kg

Table 4: Additives

Product Range

Soft grades

Properties	Unit	DIN							
Elastollan®			LP 9232	1175A 10W	1180A 10	1185A 10	1185A 10WM	1185A 10M	1185A 10FHF
Hardness	Shore A Shore D	53505	65	75	80	87 36	87 39	88 39	89 37
Density	g/cm^3	53479	1.04	1.14	1.11	1.12	1.15	1.11	1.23
Tensile strength	MPa	53504	35	40	45	45	35	45	35
Elongation	%	53504	650	700	650	600	600	600	600
Stress at 20% elongation 100% elongation 300% elongation	MPa	53504		 2 4 8	 2 4.5 8	 2.5 6 10	 4 7 13	 3.5 7 12	 3.5 8 13
Tear strength	N/mm	53515	30	40	55	70	55	60	60
Abrasion		53516	45	45	30	25	38	60	35
Compression set at RT at 70°C	%	53517		 20 40	 25 45	 25 45	 20 35	 35 40	 25 45

Table 1: Mechanical properties - Soft grades

Hard grades

Properties	Units	DIN						
Elastollan®			1195A 10	1154D 10	1154D10 FHF	1154D50 10KFFC	1164D 15	1174D11
Hardness	Shore A Shore D	53505	96 48	 53	 58	 62	 64	 73
Density	g/cm^3	53479	1.15	1.17	1.27	1.23	1.18	1.20
Tensile strength	MPa	53504	55	50	30	40	50	50
Elongation	%	53504	500	450	350	400	350	300
Stress at 20% elongation 100% elongation 200% elongation	MPa	53504	 6 10 18	 11 17 38	 13 19 36	 16.5 22 31.5	 16 25 45	 25 30 45
Tear strength	N/mm	53515	100	150	110	250	190	220
Abrasion		53516	25	20	30	30	20	20
Compression set at RT at 70°C	%	53517	 30 45	 40 50	 30 45	 30 45	 40 50	 50 55

Table 2: Mechanical properties - Hard grades

Processing

Extruder screw design

TPU sheathing can be extruded on standard equipment. Single screw extruders with a compression ratio of approx. 2.5 : 1 and a L/D ratio of 25 - 30 : 1 are most suitable. Barrier screws are also recommended to get a highly homogenous TPU melt.

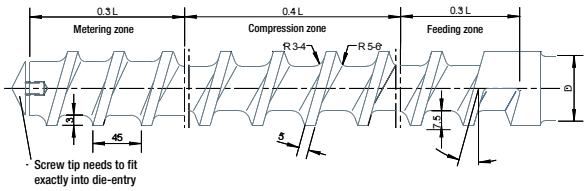


Fig 8: One kind of srew design

Cross head design

Die design should be favorable for flow, that means the melt needs forced conveying all over the die. Die flow should be optimized to avoid dead spots, since stagnation results in thermal degradation of the melt. Thermally degraded particles can cause pimples on the cable surface. Additional to the flow optimization, an uniform temperature distribution is also important. Frozen particles also lead to an irregular surface finish.

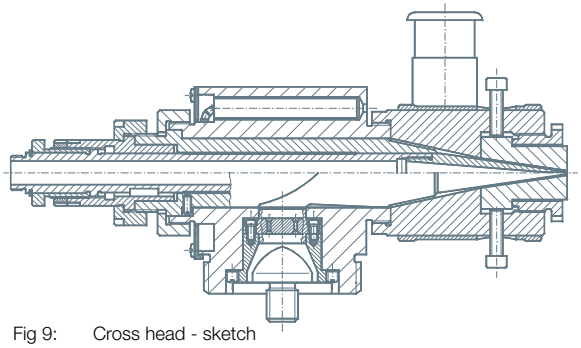


Fig 9: Cross head - sketch

Temperature profile

Processing temperatures guidelines are shown in Table 3. Actual temperatures will be dependent on several factors such as e.g.

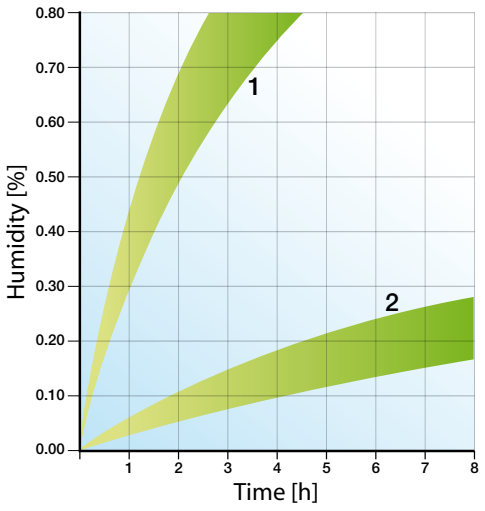
- screw design and
- throughput.

Recommended temperatures [°C] for processing of Elastollan® TPU							
Shore Hardness	Screw				Adapter	Head	Die
	Zone1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
75 A	150	165	180	190	190	190	190
80 A	160	175	190	200	200	200	200
85 A	165	180	195	205	205	205	205
90 A	170	195	200	210	210	210	210
95 A	175	200	205	215	215	215	215
54 D	180	205	210	220	220	220	220
64 D	185	210	215	225	225	225	225
74 D	190	215	220	230	230	230	230

Table 3: Recommended temperatures [°C] for processing of TPU (Elastollan®)

Humidity

Thermoplastic polyurethanes are hygroscopic and drying of the granules before processing is absolutely necessary. Dependent on climatic conditions granulate exposed to the atmosphere can very quickly (in less than half an hour) absorb more than 0.1% moisture. Absorbed moisture can affect processing and results in a reduction of physical properties. The moisture content of TPU should be reduced to at least 0.02% by pre-drying prior to processing.



1 - standard atmosphere 40 °C/92 % rel. humidity
2 - standard atmosphere 23 °C/50 % rel. humidity

Fig. 10: Moisture absorption of polyether TPU

Drying

Excessive moisture content in the granules can lead to processing problems and to reduction in the quality of the extruded cable. Foaming of the plasticized material or the formation of gas bubbles in the melt is an indication that the moisture content is excessively high. Variations in output during extrusion processing are in many cases attributable to insufficient pre-drying.

In order to ensure optimal performance properties, it is necessary that the material is dried before processing. Water content of the granules should not exceed 0.02 %. Conventional circulating -air ovens, vacuum dryer cabinets and dehumified air dryers are suitable for this purpose. Recommended drying parameters:

2 to 3 hours	Circulating-air:	100˚C to 120˚C
	Dehumified air:	80˚C to 120˚C

When using circulating-air ovens, the layer of granulate should not exceed 4 cm in height. With dehumified air dryers, the total available capacity may be utilized. When color masterbatches and additives are used, care must be taken to see that they are also dried. Therefore it is better to pre-mix with the granules before the drying process to make sure that the whole product is dried.

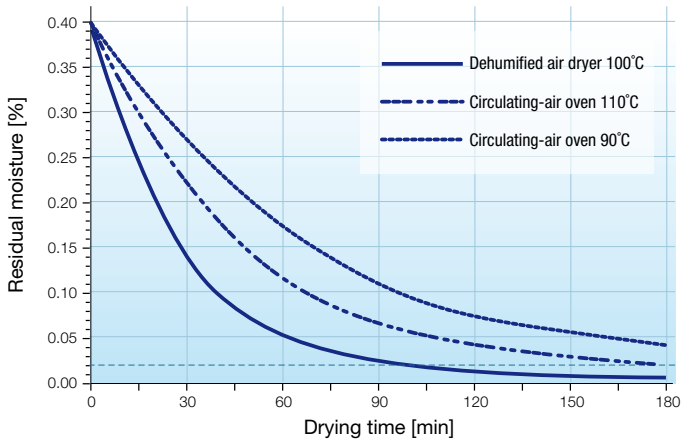


Fig. 11: Drying diagram of Elastollan®

Mechanical properties

Elastollan® TPU is generally supplied with a surface hardness of 80 Shore A to 75 Shore D. Lower hardnesses can be achieved through the addition of plasticizers. Low hardness grades without plasticizer are on development stage. Elastollan® 1185 A FHF is a speciality product that is flame retardant without containing any halogens. More flexible TPUs up to some 95 Shore A are generally employed for cable sheathing on account of their greater elasticity. Harder products as of around 95 Shore A are given preference for the insulation of stranded wires. These are sufficiently flexible with low wall thicknesses and have advantages when it comes to stranding on account of their better antifriction properties. All the different degrees of hardness are used for cable connectors, depending on the flexibility required.

Torsion modulus

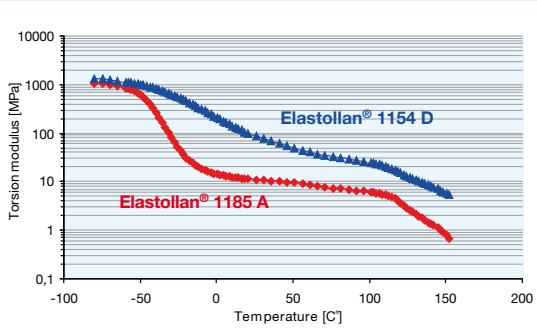


Fig. 15: Torsion modulus - Elastollan® 1185 /1154 D

The course of the torsion modulus shows the better flexibility (even at low temperatures) of softer Elastollan® TPU, whereas the harder Elastollan® TPU remains more form stable at higher temperatures.

Impact strength

	Temperature	1175 A 10 W	1185 A 10	1185 A 10FHF	1195 A 10	1154 D 10	1154 D 10 FHF	1164 D 15
Unnotched specimen	-40°C	KB	KB	KB	KB	KB	48	KB
	-50°C	KB	KB	KB	KB	KB	37	KB
Notched specimen	-10°C	KB	KB	KB	KB	163	9	29
	-20°C	KB	KB	KB	KB	168	5	13
	-30°C	KB	KB	37	180	14	3	9
	-40°C	KB	KB	8	24	11	3	9
	-50°C	KB	KB	4	12	9	3	7

Table 5: Impact strength of Elastollan® according to DIN EN ISO 179 (kJ/m^2); KB = no fracture

The impact strength results shown in table 5 confirm the outstanding flexibility of Elastollan® TPU at low temperatures. Unnotched specimen except the hard flame retardant grade show no fracture till -50 °C. Impact strength tests of notched specimens illustrate the better flexibility with decreasing hardness.

Abrasion

	Double strokes
Elastollan® 1185A	250
Elastollan® 1195A	500
Elastollan® 1154D	2000
Cable: Nominal area : 0.25 mm^2 Wall thickness of insulation : 0.30 mm Outer diameter : 1.30 mm	**Test instrument:** Needle diameter : 0.45 mm Test load : 7N Length : 10 mm

Table 6: Abrasion resistance of Elastollan® ISO TC 22

While the abrasion values of TPU as per DIN 53516 are scarcely dependent on the hardness (Table1, 2), harder versions withstand the typical abrasion test for insulation for an extremely long period of time. Vehicle manufacturers frequently specify at least 150 or 200 double strokes up to the point when insulation wears through. Even soft TPUs exceed these values.

Electrical properties

The volume resistivity of Elastollan® TPU is sufficient for insulations up to 1000 V and exceeds the required 10^8 Ohm cm for insulation by standard ISO 6722 (automotive industry) even at temperatures of 90°C. With increasing hardness the insulation effect of Elastollan® TPU grows.

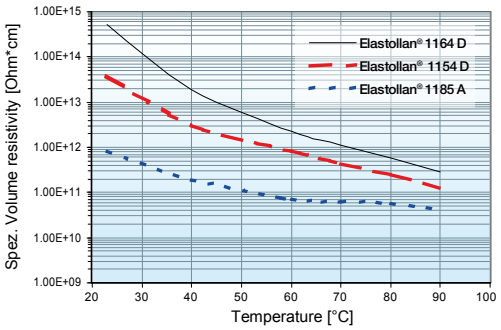


Fig. 16: Volume resistivity - IEC 60093

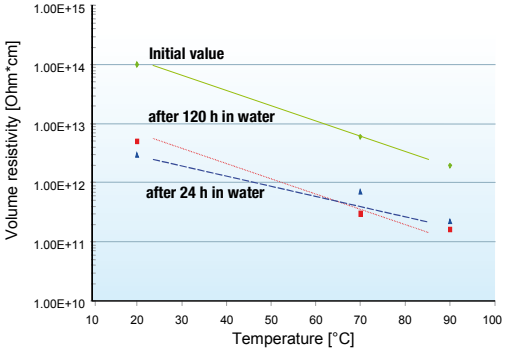


Fig. 17: Volume resistivity - IEC 60093 of Elastollan® 1154 D

After storage in water the volume resistivity is reduced by only some more than one power of ten.

The electric strength is measured according to IEC 60243-1 in transformer oil. Although this leads to relative low values, Elastollan® TPU achieves an electric strength of roundabout 35 kV/mm.

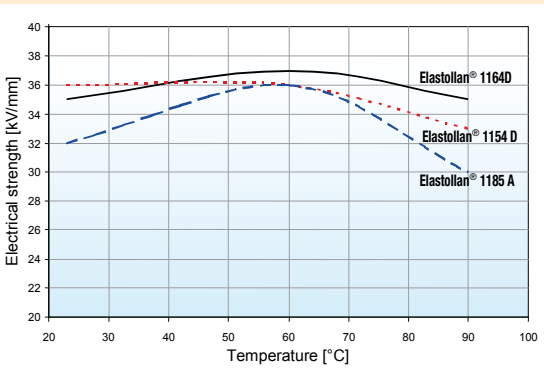


Fig. 18: Electrical strength - IEC 60243-1

	Standard IEC	Elastollan® 1185 A 10	Elastollan® 1154 D 10
Surface resistivity	60093	10^{15} Ohm	10^{15} Ohm
Comparative tracking index	60112	CTI = 600	CTI = 600
Relative permittivity at 100 Hz at 1 MHz	60250	 ca. 7.5 ca. 6	 ca. 7 ca. 5.5
Dissipation factor at 100 Hz at 1 MHz	60250	 0.03-0.5 0.04-0.1	 0.03-0.1 0.05-0.08

Table 7: Electrical properties

The electric properties of Elastollan® TPU are generally perfectly adequate for the insulation of sensor and energy cables up to 1000 V. The exception here is cables for high-frequency transmission, such as antenna cables, where Elastollan® TPU should not be used as the primary insulation on account of the dielectric losses. For the use as cable sheathing the surface resistance is important. The surface resistance of TPU exceeds the required values (VDE - regulations) of at least 10^9 Ohm with roundabout 10^{15} Ohm noticeable.

Thermal properties

Long term thermal behavior is determined according to ISO 2578. The test specimen is permanently conditioned at a selected temperature until a defined test criterion is no longer achieved. The achieved temperature resistance is therefore dependent from the end criterion and the test time.

For Elastollan® TPU the end criterion is usually taken as an elongation at break of 300 % (50 % of original elongation at break), but it is also quite usual to test to an elongation of 50 %. The electrical engineering sector frequently specifies a 20 000 h test (2.3 years) for assessing service life. Elastollan® TPU can be used at 105°C over this period of time still having an elongation of 300 %. If an elongation at break of 50 % is sufficient the temperature resistance is increased to 110 °C over a period of 20 000 h.

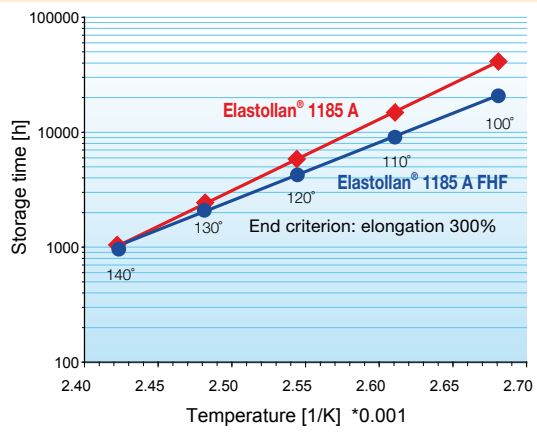


Fig. 19 : Long term air ageing

Standard ISO 6722, which is frequently cited in the automotive industry and was specially compiled for automotive cables with the assistance of the German Automotive Standards Committee (FAKRA), divides insulating materials into six temperature classes. Class C is rated for applications over a range from -40 to +125°C in this standard. The corresponding tests are performed on the insulated cable in each case. Elastollan® TPU passes both the winding test at -40 °C and storage for 3000 h at +125°C. The additional requirements of ISO 6722 are met by appropriate grades of Elastollan® TPU.

Hydrolysis resistance

For outdoor applications the hydrolysis resistance is absolutely necessary. Generally, the rate of hydrolytic degradation of TPU increases with increasing temperatures. A standard ether Elastollan® TPU has a very good hydrolytic resistance as shown in the Arrhenius curve in fig. 20. Even after 20000 h permanent immersion in 80°C hot water this product maintains 300% elongation at break. The requirements set out in the current VDE standards or by the vehicle industry are exceeded by a wide margin. TPU cables can thus be used in hot water at 80°C for 20000 h, for example.

The hydrolysis resistance of the flame retardant halogen free grade is decreased because of the additive. But the reached values of this grade are sufficient for outdoor applications. After storage in 80°C hot water for 5000 h the elongation is still 300 %. Lifetime in 70°C hot water is extended to over 25.000 h.

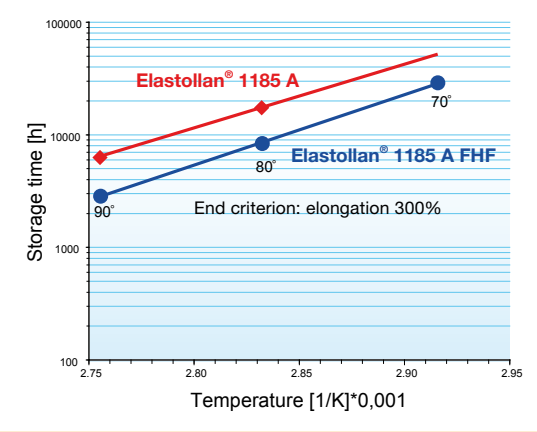


Fig. 20: Long term hydrolysis resistance

Chemical resistance

The chemical resistance is conditioned essentially by the action time, quantity and concentration of the chemical that acts. The influence of the temperature can be estimated as follows: if the temperature is increased by 10°C, then the service life will be reduced by half. As a result, a reduction in the temperature by 10°C will lead to a doubling of the service life.

Swelling and dissolution are governed primarily by the number of effective hydrogen bridges between the molecule chains; this number rises with an increasing hardness. From this it can be established that harder products undergo less swelling and display a greater resistance.

All in all, Elastollan® TPU displays good resistance to a large number of chemicals. Despite this, a check must be conducted on compatibility if contact with chemicals is to be expected. High-polar organic solvents, such as dimethyl formamide (DMF) or tetrahydrofurane (THF) will even dissolve Elastollan® TPU.

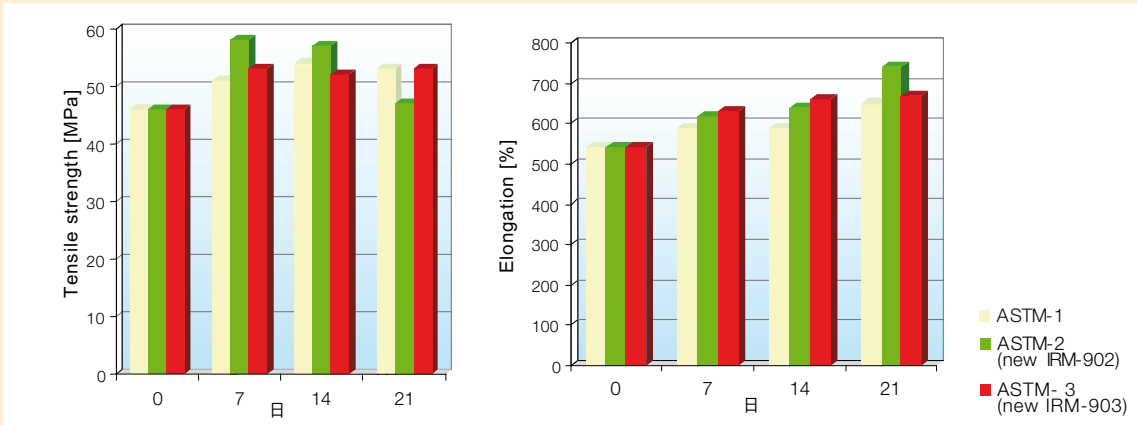


Fig. 21: Resistance of Elastollan® 1185 A in ASTM (IRM)-oils at 100°C

There is no noticeable degradation of Elastollan® 1185 A after 21 days storage in mineral oils at 100°C.

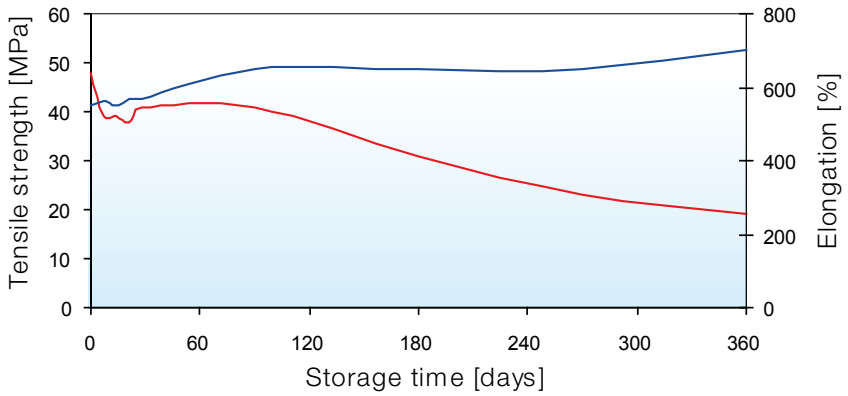


Fig. 22 : Resistance of Elastollan® 1185 A in Biodiesel - RME at 60 °C

The resistance of TPU to mineral oils is generally very good. In the event of contact with water-miscible oils or bio-oils, a resistance test should be conducted on account of the highly different formulations.

Chemical resistance

Ozone resistance

Ozone is highly reactive on account of its structure and readily reacts with organic substances. With non-stabilised elastomers based on rubber, the action of ozone leads to cracking. TPU displays excellent ozone resistance even without additional stabilisation. The test specified in VDE 0472, Part 805-B leads to a rating of crack-free. On the basis of DIN 53509/1-A, TPU achieves a rating of crack-free, step 0. The elasticity is retained in its entirety, the surface hardness does not increase.

UV resistance

UV-radiation causes yellowing and surface embrittlement of MDI based thermoplastic polyurethanes. Mechanical properties are also reduced. Addition of color pigments prevents deep penetration of UV rays and thus mechanical degradation. UV absorbers absorb radiation and dissipate the energy in form of heat; antioxidants deactivate oxidised molecules by decomposing evolved peroxides. Radical absorber, so-called HALS-products, stabilise the molecules by reacting with free radicals from degraded molecules.

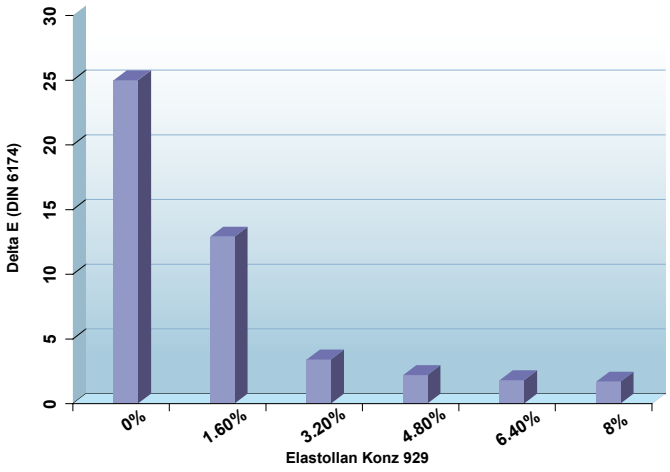


Fig. 23: Discoloration by UV-radiation - Elastollan® 1195 A, DIN 75202, 300 h

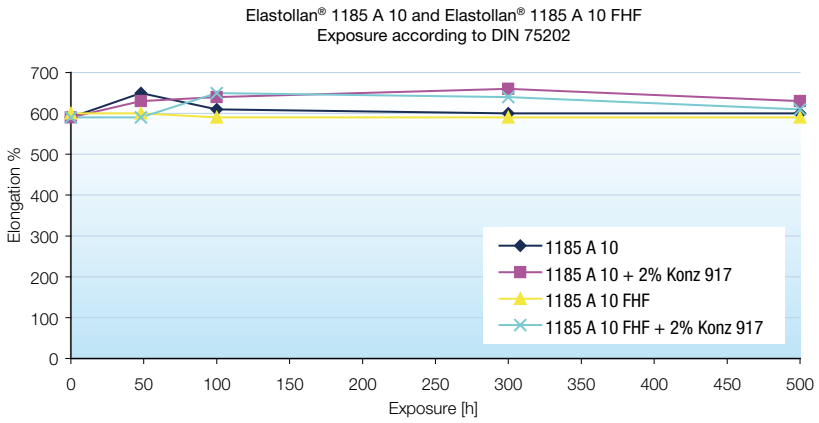


Fig. 24: Effect of exposure and coloring on elongation

Fire behavior

The advantages of TPU cables such as temperature resistance, flexibility, high mechanical resistance, low friction etc. can be combined with self-extinguishing properties. The properties of a halogen free, flame retardant Elastollan® TPU almost achieve the values of a standard TPU.

Elastollan® 1185 A 10 FHF is rated UL94 V-0 for wall thicknesses of 0.75, 1.5 and 3.0 mm. In the cable industry, flame tests are conducted on finished cables. While material-based test certificates stating the results of measurements on the test piece can provide a certain indication, these are no substitute for a test conducted on the cable itself.

The flame resistant halogen-free Elastollan® 1185 A FHF passes the flame test to VDE 0482, Part 265-2 and ULVW 1 as a sheathing material, providing that the cable is of a suitable design. In these tests, a vertically clamped cable must extinguish after a flame has been applied to it (for the ULVW test, the flame must be applied several times over).

Automotive manufactures require the flame retardance test to FMVSS 302 (Federal Motor Vehicle Safety Standard) for plastics. This standard, which permits a maximum burning rate of 101.6 mm/min on the horizontal test piece, is fulfilled by TPU without flame retardants. For certain cables or stranded wire insulation, the self-extinction of a flame on cables clamped vertically or at 45° is required.

Toxicity of combustion gases and smoke density

To estimate the hazards of a possible fire, test procedures for toxicity of combustion gases and smoke density need to be considered. The procedures developed to date are however limited because:

- large amounts of strongly toxic carbon monoxide are released in any fire;
- the generation of smoke depends mainly on the fire condition and air supply.

Standards to assess the toxicity of combustion gases and smoke density exist but are not internationally uniform.

The French standard NF 16-101 considers the composition of combustion gases, smoke density and smoke development. This standard has been adopted for railway vehicles in Spain, Portugal and Belgium.

	NF X 10-702		NF 16-101		
	D_m	VOF 4	CTI (600°C)	IF	Class
E 1185 A	97	190	10.8	12.7	F1
E 1185 A FHF	253	512	32.2	35.7	F2
CR-EM 2	297	578	53.5	49.0	F3
EPDM-EM 3	136	198	4.2	9.5	F1
HFFR-HM 4	195	271	6.0	14.0	F1
PVC-YM 2	693	1458	125.5	118.3	F4

Legend

Dm = maximum optical density
VOF 4 = speed of smoke development during the first 4 minutes
CTI = conventional toxicity index
IF = smoke index
IF = Dm/100 + VOF4/30 + CTI/2
F0…F5 = classification by smoke index

Table 8: Toxicity of combustion gases and smoke density

The whole cable construction has to be considered while applying the material specific values to a complete cable. By the use of the form stable Elastollan® TPU instead of an other material the thickness of the sheathing often can be reduced – the easiest and most effective way for reducing combustion gases and smoke density.

All not modified and plasticed grades fulfill the requirements regarding corrosivness of combustion gases of VDE 0482 part 267.

Quality management

BASF Polyurethane Specialties (China) Co. Ltd has been certified by TUV Rheinland that we have established and apply a quality management system to meet the requirements for production, research & Development, sales and technical service of Polyurethane system (PU) and Thermoplastic Polyurethane (TPU) according to DIN EN ISO 9001:2000.

TÜV CERT

CERTIFICATE

The TÜV CERT Certification Body
of TÜV Rheinland Cert GmbH
certifies in accordance with
TÜV CERT procedures that

BASF Polyurethane Specialties (China) Co., Ltd.
No. 2333 Gang Cheng Road, Pudong, Shanghai 200137, P. R. China

has established and applies a quality management system for

Production, Research & Development, Sales and Technical Service of Polyurethane Systems (PU) and Thermoplastic Polyurethane (TPU)

An audit was performed, Report No. **085596**.
Proof has been furnished that the requirements according to

DIN EN ISO 9001:2000

are fulfilled.
The certificate is valid until **2011-05-26**.
Certificate Registration No. **01 100 085596**

Hong Kong, 2008-05-27

TÜVRheinland®

TÜV CERT Certification Body of
TÜV Rheinland Cert GmbH

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