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PTFE SEMIFINISHED PRODUCTS
AND FINISHED PARTS

TEKU

PTFE - compounds

Properties and characteristic data

The properties of PTFE can be modified by selective additions of special fillers, in order to broaden the scope of application and optimize the material for certain uses.

Material properties of PTFE

PTFE is a partly crystalline polymer of carbon and fluorine having unbranched, linear structure. The carbon-fluorine bond is unusually stable –the carbon chains are surrounded almost completely by a helical arrangement of fluorine atoms. The numerous uses of PTFE rely decisively on the properties resulting from this structural constitution.

Chemical resistance

The extremely strong carbon-fluorine bond and the fact that the carbon chains are shielded fluorine atoms impart universal chemical resistance. Only fluorine-containing hydrocarbon compounds and molten alkali metals are able to swell PTFE or lead to chemical surface reactions.

Thermal properties

The chemical resistance and electrical properties are conserved both in the cryogenic range and at temperatures up to 260°C. Due to the extremely high melt viscosity, PTFE parts retain their shape despite greatly reduced strength. The upper limit for continuous stress and strain is about 260°C, depending on the mechanical properties.
Figure 1 shows an example of how the mechanical properties depend on temperature.

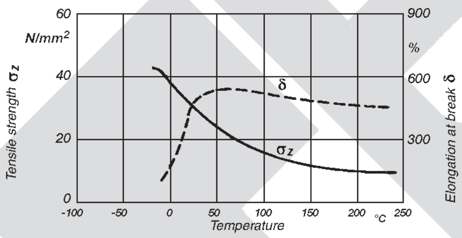

Fig. 1: Tensile strength and elongation at break as a function of temperature

Electrical properties

The dielectric loss factor and the dielectric constant are extremely low and almost independent of frequency in a range from 10 to 10^{10} Hz, and they vary only slightly in a temperature range from -50°C to above +200°C.

Non-stick and sliding properties

By virtue of the weak intermolecular forces, which in turn are due to the high bond energy between carbon and fluorine, PTFE has excellent non-stick behaviour. Even viscous and tacky substances do not adhere. PTFE is difficult to wet – the contact angle with water is 126°. PTFE has a very low coefficient of friction, which is almost constant in the static and dynamic range. With increasing load the coefficient of friction decreases rapidly at first, then more slowly, and is almost constant within a sliding velocity range of 50 m/min and in the temperature range above 20°C.

Thermal expansion

The relative length change of PTFE depends on temperature. The curve of the coefficient of linear expansion is illustrated in Figure 2.
The large expansion at +19°C is due to the crystallite transformation at that temperature.

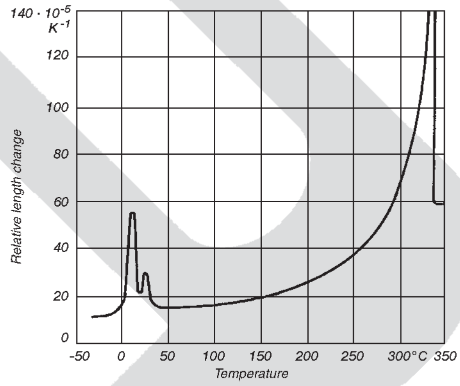

Fig. 2: Coefficient of linear expansion as a function of temperature

Behaviour under long-term stress and strain

In common with other thermoplastic materials, PTFE also undergoes deformation under prolonged load. The deformation depends on the magnitude of the load, on temperature and on duration. Deformation which already begins at room temperature is referred to as "cold flow". As an example of this phenomenon, Figures 3a and 3b show the time yield limits as a function of loading duration.

Figs. 3a and 3b: Time-elongation stresses as a function of loading duration (tested per DIN 53444)

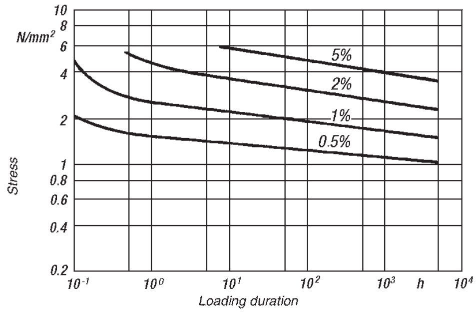

Fig. 3a: at 20°C air temperature

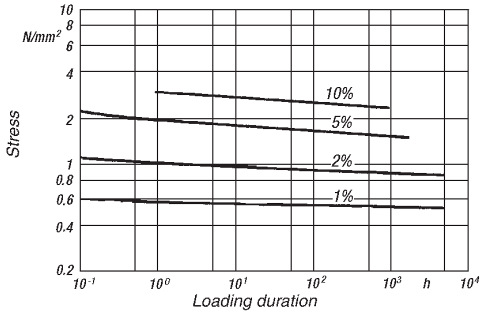

Fig. 3b: at 100°C air temperature

Further properties

A tabular listing of the characteristic data of PTFE, such as mechanical and physical values, thermal and electrical properties, will not be presented here.
Even under extreme climatic conditions, the properties of PTFE do not change. The aging resistance is extremely high.
A further advantage of this plastic is that it is physiologically neutral in the temperature range up to +220°C. Breakdown products must be expected, however, above 300°C, the temperature at which thermal decomposition slowly begins.

PTFE processing

Because of its high melt viscosity above the crystallite melting range of about 320°C, PTFE must be processed by special methods. Processing of the powdered polymer of various particle sizes and hardnesses is achieved by compaction at room temperature followed by sintering at temperatures above the crystallite melting point.
In processing by moulding, PTFE powder is compacted at room temperature, using metal moulds and hydraulic presses, to obtain simple shaped articles such as rods, tubes and sheets for further processing by chip-removing methods, after which it is sintered in hot-air ovens, which in special cases have a nitrogen atmosphere. The sintering cycle depends on the size and dimensions of the shaped parts, and involves monitored heating, controlled holding at temperature and monitored cooling.
Geometrically simple parts can be automatically moulded at correspondingly high output rate with short cycle times. In contrast to processing by moulding as described above, which permits compaction in only one direction, a process of uniform compaction from all directions is possible in isostatic moulding. For this purpose, the PTFE powder is pressed in elastic moulds by a pressure-exerting liquid medium, thus producing geometrically more complex shapes.
A continuous pressure-sintering method is ram extrusion. In this process PTFE powder is processed via a proportioning unit in metal tools, heated to sintering temperature, in order to obtain semifinished products such as rods, tubes and profiled sections from which finished parts are made by chip-removing techniques on lathes and automatic machine tools.
Paste extrusion is another continuous process for pressing ultrafine PTFE powder with lubricant addition, subsequent evaporation of the lubricant and sintering of the extrudate. This process is used to manufacture thin-walled tubes and pipes.

PTFE compounds

Compounds are mixtures of pure, virgin PTFE with inorganic fillers. PTFE compounds broaden the scope of application of PTFE varieties and permit adaptation to specific practical requirements.
In the use of unfilled PTFE types, it must be kept in mind that

- the thermal expansion is about 10% higher than that of metals
- the abrasion resistance is low
- starting from a certain load level, the material becomes deformed by cold flow
- the thermal conductivity is low.

Most of these properties can be modified selectively by admixing fillers. Depending on the type and proportion of such fillers, it is possible

- to increase the compressive strength, especially at higher temperatures
- to reduce cold deformation ("cold flow")
- to improve the wear resistance
- to increase the thermal conductivity
- to reduce the coefficient of linear thermal expansion
- to influence the electrical volume resistance and surface resistance.

It must not be overlooked, however, that the use of fillers will lead to lower tensile strength and poorer elongation at break. The chemical resistance known for unfilled PTFE will also be influenced by the type of filler. In general, the processing conditions will be more difficult.
The most common fillers are glass, carbon black, graphite, bronze, molybdenum disulphide, steel and ceramics.

Table 1 lists the type and proportion of filler additives and the associated improvements in properties.

Table 1 Composition of some PTFE compounds (standard values)

Filler	Filler content wt%	vol%	Improved properties
Glass	15 20 25 40	13 17 22 36	Compressive strength Wear resistance
Carbon black	10 25 35	11 27 37	Compressive strength Wear resistance Thermal conductivity
Graphite	10 15 20	10 15 20	Thermal conductivity Coefficient of friction
Glass + MoS_2	15 + 3	13.5 + 1.5	Wear resistance
MoS_2	3	1.5	Coefficient of friction Wear resistance
Bronze	40 60	14 27	Compressive strength Thermal conductivity
Ceramic	15	9	Compressive strength
V 2 A	25	9.5	Compressive strength Thermal conductivity

Table 2 lists the characteristic data of filled PTFE materials. All values are mean values.

Table 2 Properties of PTFE compounds

	Unit	Test method	Filler					
Filler type	-	-	-	ground glass fibers		electro-carbon	natural graphite	bronze
Filler proportion	wt%	-	-	15	25	25	15	60
Density	g/cm³	ASTM 1457-62 T	2.17	2.21	2.24	2.09	2.17	3.90
Tensile strength	N/mm²	ASTM 1457-62 T	31	16	15	14	14	14
Elongation at break	%	ASTM 1457-62 T	400	300	270	170	160	> 100
Ball indentation hardness	N/mm²	ASTM 1457-62 T	-	29.0	30.0	38.0	32.0	40.0
Deformation under load 14 N/mm², 100 h, 23°C	%	ASTM D 621-59	14	10-17	7-14	6	7.0	5.0
Thermal conductivity	W/m·K	DIN 52612	0.23	0.35	0.35	0.7	0.93	0.7
Coefficient of linear expansion between 30° and 100°C	K^{-1}	DIN 52328 (dilatometer)	$1.6x10^{-4}$	$1.1x10^{-4}$	$1.0x10^{-4}$	$1.0x10^{-4}$	$1.1x10^{-4}$	$0.7x10^{-4}$

The indicated values are mean values from a series of production batches and can be regarded merely as guideline and comparison values.

In Figures 4 to 12, mechanical and physical properties of PTFE compounds are compared with those of unfilled PTFE.
The indicated values are mean values from a series of production batches and can be regarded merely as guideline and comparison values.

Diagrams

(Figs. 4 to 12)

Mechanical properties of PTFE compounds compared with unfilled PTFE

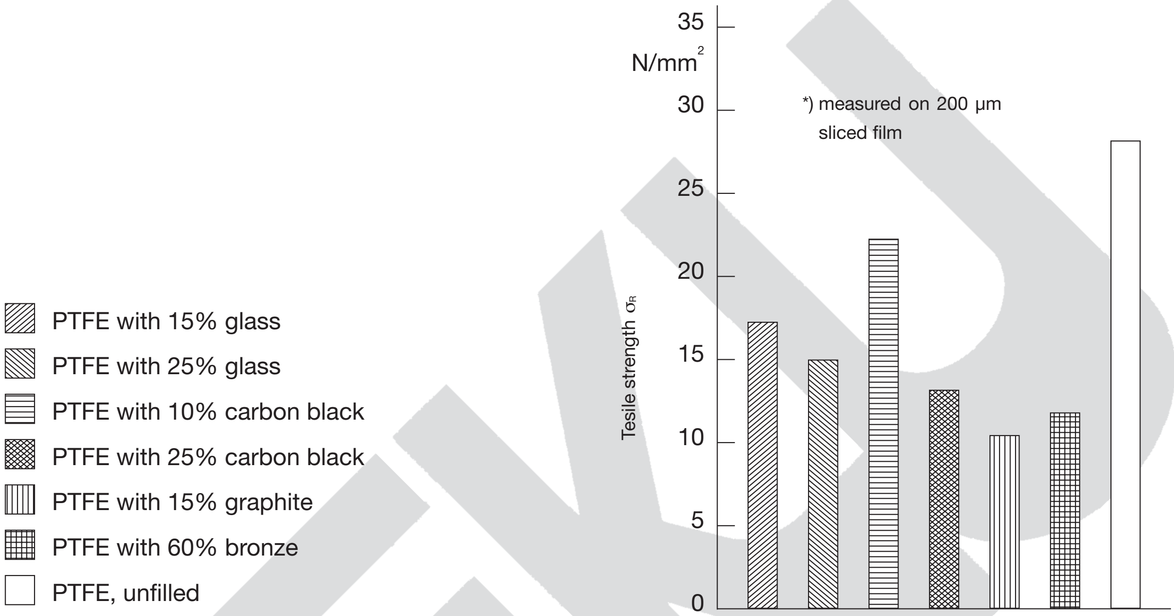

Fig. 4: Tensile strength per ASTM D 1457 (ram-extruded specimens)

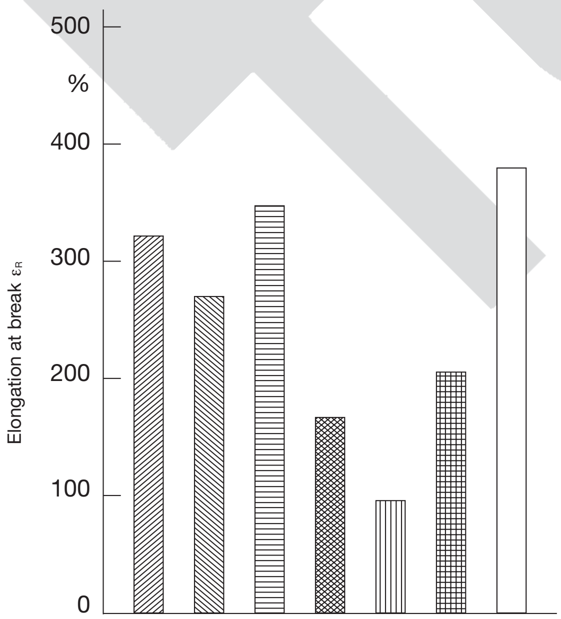

Fig. 5: Elongation at break per DIN EN ISO 527 (ram-extruded specimens)

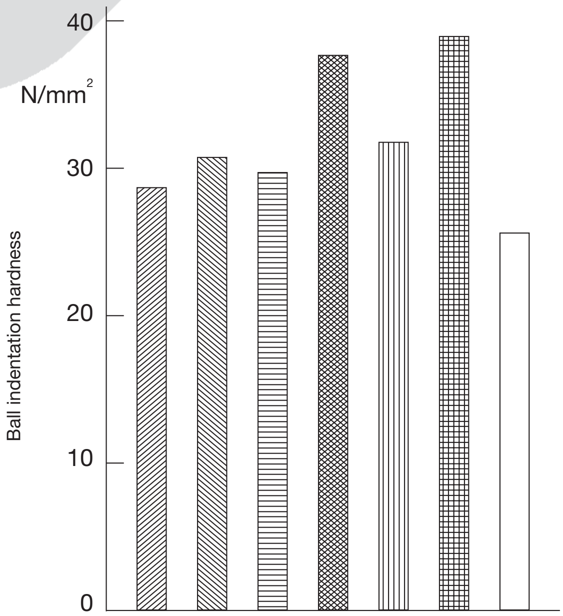

Fig. 6: Ball indentation hardness per DIN 53456 (moulded specimens)

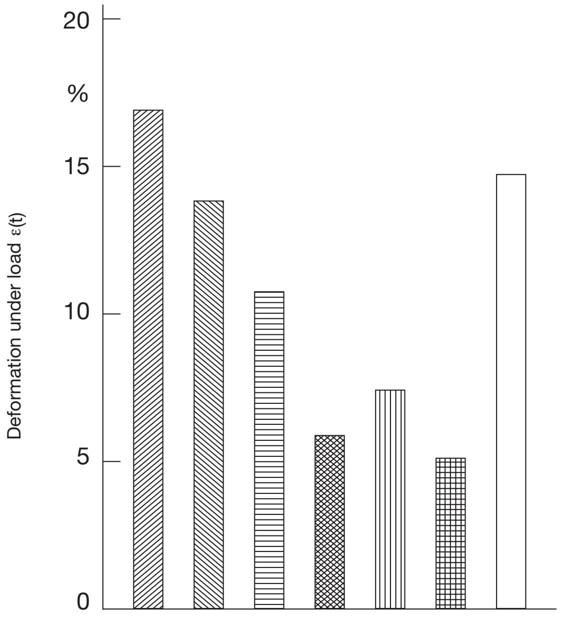

Fig. 7: Deformation under load per ASTM D 621 (15 N/mm², 100 h, 23°C, moulded specimens)

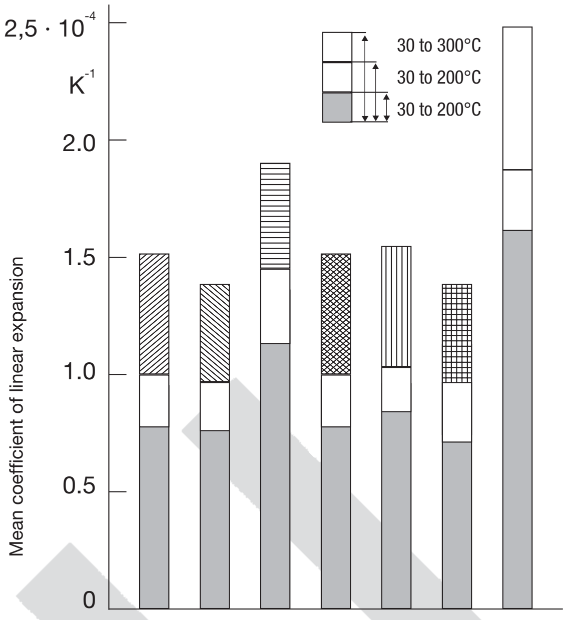

Fig. 8: Mean coefficient of linear expansion perpendicular to the pressing direction

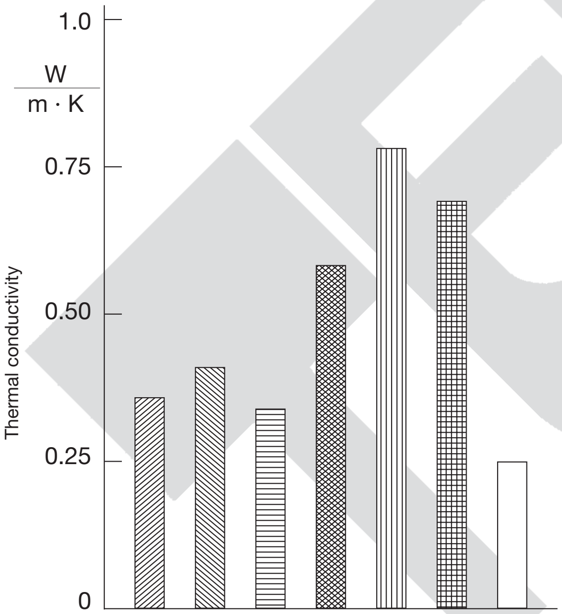

Fig. 9: Thermal conductivity per DIN 52612

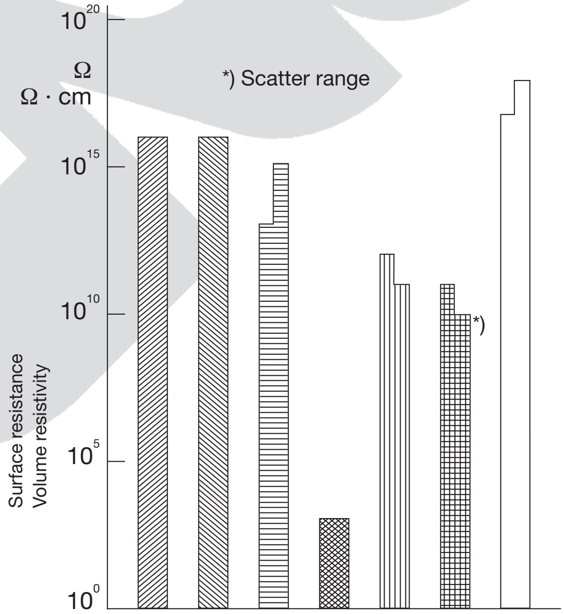

Fig. 10: Surface resistance (left half of bars) and volume resistivity (right half of bars) per DIN 53482

Figs. 11-12: Coefficients of friction of PTFE compounds compared with unfilled PTFE in the 30° to 100°C temperature range at several sliding velocities. Internal test method: partner material was cast pearlite with peak-to-valley height R_t = < 1,5 µm, load 0,2 N/mm².

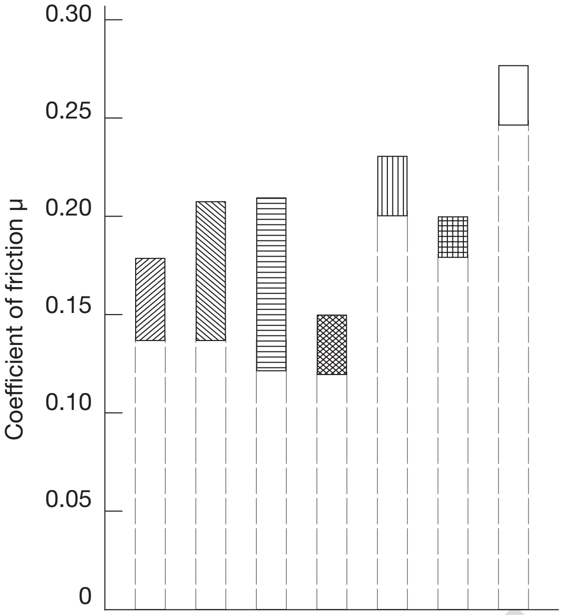

Fig. 11: Coefficients of friction at sliding velocity of v = 1.9 m/s

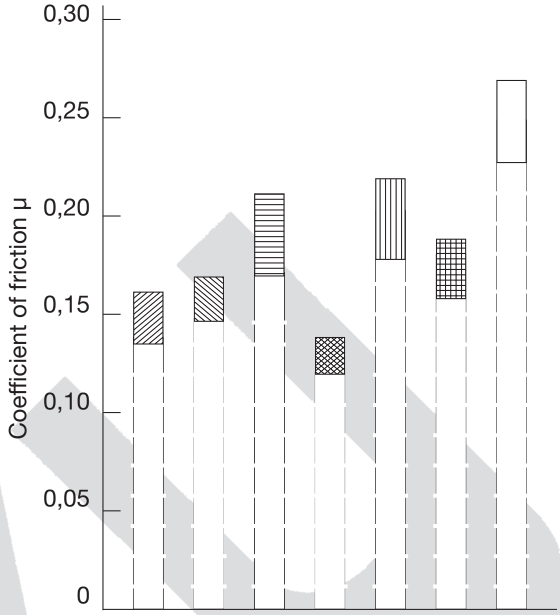

Fig. 12: Coefficients of friction at sliding velocity of v = 1.0 m/s

Figures 13a and 13b show the wear behavior of filled and pure PTFE. The illustrated curves were obtained by employing the same test methods for various loading durations and partner materials.

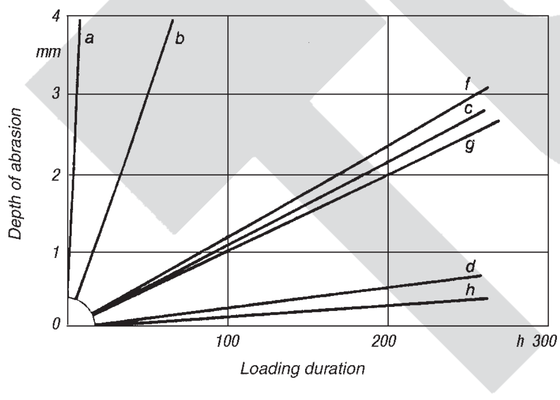

Fig. 13a: Depth of abrasion as a function of loading duration, partner material ST 50

a = PTFE unfilled
b = PTFE with 15% graphite
c = PTFE with 25% glass fibre
d = PTFE with 25% carbon black
f = PTFE with 15% glass fibre
g = PTFE with 20% glass fibre and 5% graphite
h = PTFE with 60% bronze

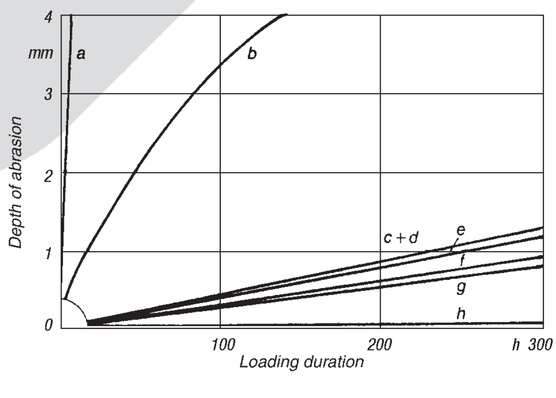

Fig. 13b: Depth of abrasion as a function of loading duration, partner material cast pearlite

a = PTFE unfilled
b = PTFE with 15% graphite
c = PTFE with 25% glass fibre
d = PTFE with 25% carbon black
e = PTFE with 33% carbon black/graphite
f = PTFE with 15% glass fibre
g = PTFE with 20% glass fibre and 5% graphite
h = PTFE with 60% bronze

The processing conditions influence the properties of compounds more than in case of unfilled PTFE.
Out of a large number of factors that may influence the variation of properties (such as preforming pressure, temperature, extrusion velocity, length of the extrusion tool, etc.), the dependence of density and tensile strength on preforming pressure were selected (Figs. 14 and 15).

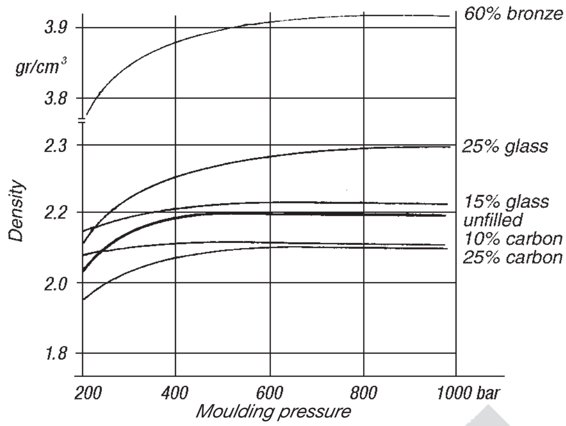

Fig. 14: Dependence of density on preforming pressure

These examples show how important it is exactly to maintain the processing condition defined for each PTFE compound in order to ensure optimization of the properties.
Processing quality is a significant factor in determining whether the selected materials will be suitable and satisfactory in practice.

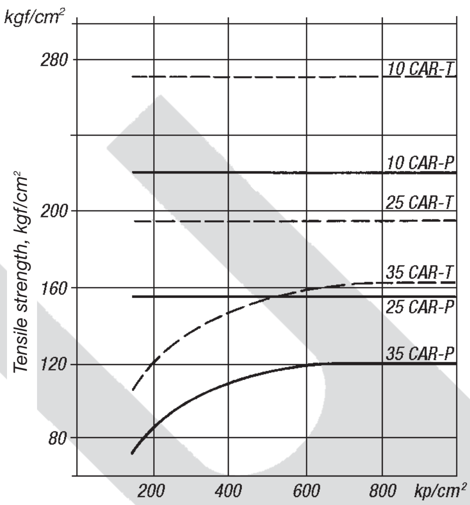

Fig. 15: Dependence of tensile strength on preforming pressure
10 CAR = PTFE with 10% carbon black
25 CAR = PTFE with 25% carbon black
35 CAR = PTFE with 35% carbon black
P = parallel to the pressing direction
T = transverse to the pressing direction

Supply program:

PTFE semifinished products

extruded rods	up to 160 mm ø
extruded, polished rods	up to 60 mm ø
moulded rods	up to 775 mm ø
extruded tubes	up to 205 mm ø
moulded tubes and rings	up to 1440 mm ø
moulded sheets	up to 1400 x 1400 mm
films	up to 1800 mm wide

PTFE finished parts
custom-built:
bellows, expansion joints,
piston and rod seals,
roofing packings, flange seals,
pump cases, impellers,
diaphragms, sliding rings, ball-seat rings,
balls, valve bodies, column plates and
cage trays, support rings, etc.

All products can be made from pure, virgin PTFE or from PTFE compounds.

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