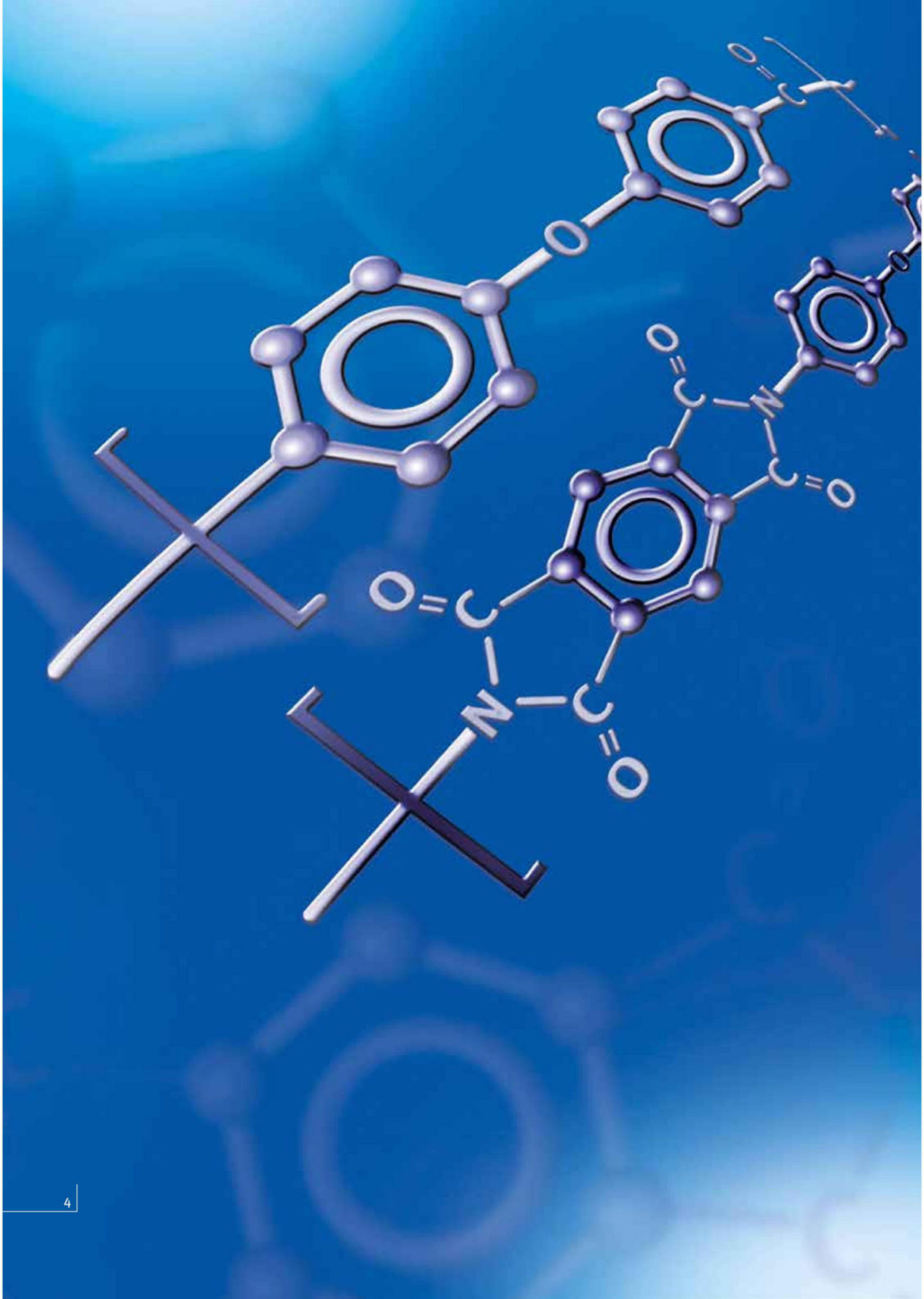


PTFE – Cost-Effective and Versatile Special Plastics

Thanks to their exceptional properties PTFE and modified PTFE as well as the compounds made from these materials offer new technical problem-solving approaches to design engineers.

These unusual properties make PTFE perfectly suited for use as a special-purpose plastic material for a wide range of applications.

Despite higher material costs compared to conventional, mass-produced plastics, PTFE parts may well be the more cost-effective alternative.

When used in critical applications, PTFE offers longer service life, higher reliability and improved functionality to give you a greater competitive edge in difficult markets.

Typical Uses

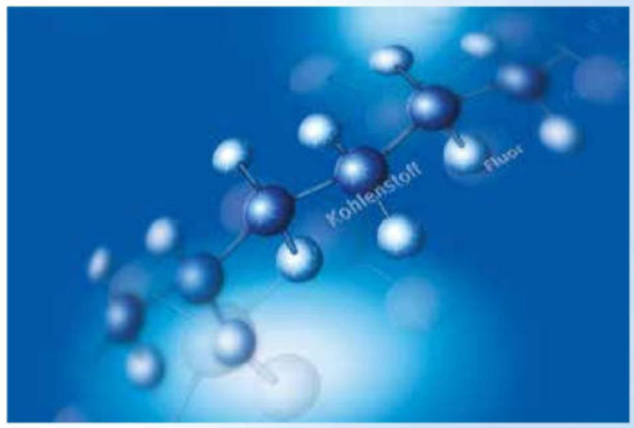
- Sealing and anti-friction elements for mechanical and automotive engineering
- Corrosion protection in the chemical industry based on unfilled PTFE, compounds or laminates
- Insulation material for electronics and electrical engineering
- Seals for automotive fuel supply and fuel injection systems
- Automotive exhaust gas sensor components
- Sealing and anti-friction elements for aircraft
- Coatings for pistons, heating elements, rolls, membranes, etc.
- Medical apparatus engineering
- Use of PTFE products in the food processing industry
- Use of PTFE hoses in the chemical, pharmaceutical and automotive industries
- Large seals for oil and gas production (offshore plants)
- Seals and anti-friction elements for wind turbine generator systems

Synthesis

Polytetrafluoroethylene (PTFE) is a partially crystalline substance obtained from the monomer tetrafluoroethylene (TFE) by polymerization. The macro-molecules created in this process have a linear structure. PTFE's chain structure has two interesting characteristics:

PTFE

The carbon chain is almost completely shielded by fluorine atoms, thus being protected from external influences. The carbon-fluorine combination is one of the strongest bondings in organic chemistry (dissociation energy: 460 KJ/mol). This gives PTFE its exceptionally high chemical and thermal resistance.



Modified PTFE

Modified PTFE is obtained from the monomer, tetrafluoroethylene (TFE) and a modifier (which is perfluorinated as well), perfluoropropylvinylether (PPVE). The shorter molecular chains (compared to PTFE) have a higher tendency to crystallize. This would degrade the mechanical properties of the material. The modifier effectively inhibits crystallization. This means that with modified PTFE it is possible to combine thermoplastic property components – due to the shorter molecular chains – with the good mechanical properties of standard PTFE.

Physical and Chemical Properties of Unfilled PTFE

Special Characteristics

This material is characterized by a concentration of outstanding properties which is unique in the family of plastics:

- An exceptionally wide thermal application range from -260°C up to +260°C (short-term up to 300°C)
- Virtually universal chemical resistance
- Light and weather resistance
- Hot water vapor resistance
- Very good sliding properties
- Anti-adhesive behavior
- Non-combustible ; LOI > 95
- Good electric and dielectric properties
- No absorption of water
- Physiologically harmless (BgVV, EU and FDA approvals for use with foodstuffs)

Benefits of Modified PTFE

While retaining the positive properties that are typical for PTFE, modified PTFE has additional benefits:

- Cold flow reduced by the factor of 3
- Reduced permeation of chemicals and gases down to half of the PTFE value
- Porosity reduced to half of PTFE's porosity
- Minimum tendency for pore formation during drawing processes
- Suitable for welding, using special methods

Shortcomings

Besides these benefits, unfilled PTFE has a few shortcomings as well:

- Cold flow behavior
- Relatively low wear resistance
- Low resistance to high-energy radiation
- Poor adhesion behavior of PTFE
- PTFE is not suitable for injection or welding processes

Compounds Based on PTFE and Modified PTFE

Fillers are incorporated into PTFE for the following reasons:

- **Wear resistance is increased significantly**
- **Cold flow under load is significantly reduced**
- **Depending on the type of filler used, thermal conductivity may increase by a multiple**
- **Thermal expansion is reduced**
- **If required, the electric properties of the PTFE matrix may be modified by the selection of appropriate fillers**
- **In addition, the choice of filler influences wear behavior of the mating surface**

The influences on the ultimate properties of the compound, which may be influenced by both the PTFE matrix and the filler, have been summarized in the following table:

Influencing parameter	*Mechanical property*	*Cold flow*	*Friction coefficient*	*Wear*	*Chemical resistance*	*Expansion coefficient*	*Thermal conductivity*
Effects when exchanging PTFE for mod. PTFE	→ (Neutral)	↘↘ (Positive)	→ (Neutral)	→ (Neutral)	→ (Neutral)	→ (Neutral)	→ (Neutral)
Influence of fillers on the product properties of compounds	↘ (Negative)	↘ (Positive)	↗ (Negative)	↘↘ (Positive)	↘ (Negative)	↘ (Positive)	↗ (Positive)

Trends: → *Positive*
→ *Neutral*
→ *Negative*

The direction of the arrows indicates the decrease or increase of the parameter. The color of the arrows describes the influences on the ultimate properties of the compound.

The Most Commonly Used Fillers and their Influences on Compound Properties:

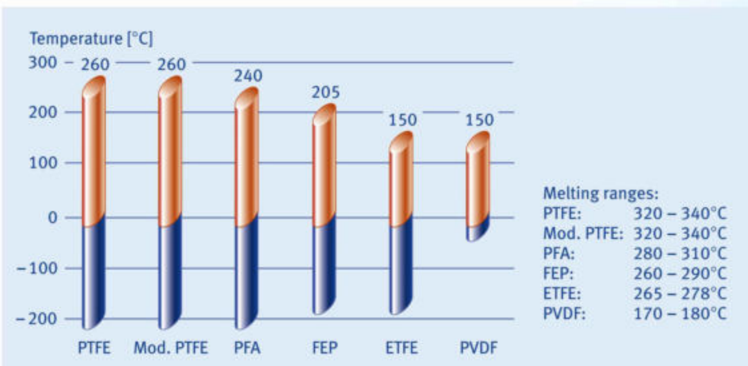
PTFE-Type	*Influence of Fillers*	*Filler Content in % of Weight*	*Limits of Use*
PTFE filled with glass fibers	• higher pressure and wear resistance as well as better thermal conductivity • very good chemical resistance • good dielectric properties	up to 40%	resistant to organic solvents, non-resistant to alkaline solutions and acids
PTFE filled with carbon fibers	• very low deformation under load • good wear resistance, even in water • higher thermal conductivity and lower thermal expansion than glass fibers • very good chemical resistance	up to 25%	carbon fibers are chemically inert
PTFE filled with carbon	• high pressure resistance and hardness • good sliding properties and wear behavior • good thermal conductivity • good chemical resistance • low volume and surface resistivity • electrically conductive	up to 35%, also in combination with graphite	compound is brittle, filler may be attacked by oxidizing media
PTFE filled with graphite	• good lubricating effect • low friction coefficient • no static charging • good thermal conductivity • very good chemical resistance	typically up to 5%, in exceptional cases up to 15%, also in combination with glass fibers or carbon	high abrasion when used with hard metals, is attacked by oxidizing media
PTFE filled with molybdenum disulfite (MoS_2)	• good sliding properties and wear behavior • good no-lube operation in combination with bronze	up to 10%, also in combination with glass fibers or bronze	not resistant when used with hot, concentrated sulfuric acid
PTFE filled with bronze	• good sliding properties and wear behavior • low cold flow • good thermal conductivity • lower chemical resistance • high pressure resistance	up to 60%, also in combination with MoS_2	may be attacked by acids and water
PTFE filled with organic fillers (high-performance thermoplastics)	• outstanding sliding properties and wear behavior • good chemical resistance • high pressure resistance in some cases • suitable for soft mating surfaces, e.g. aluminum • non-abrasive	up to 20%, may be higher in combination with different fillers	depending on the respective filler

Thermal Properties

Thermal Resistance

The thermal resistance of PTFE ranges from -260°C up to +260°C, with short-term resistance up to +300°C. (e.g. no brittling in boiling helium at -269°C). This temperature range is not achieved by any other plastic. Permanent service temperatures, however, depend on the respective load and stress factors. With regard to field applications, this means that PTFE exposed to moderate mechanical stress can be used at temperatures from -200°C up to +260°C.

***Temperature Limits of Selected Fluoroplastics*[2]**



Thermal Expansion of PTFE and Modified PTFE

When designing assembly components the relatively high thermal expansion of these materials must be taken into consideration:

10 – 30°C: $\alpha = 21 \times 10^{-5}$ 1/K
30 – 100°C: $\alpha = 11 \times 10^{-5}$ 1/K
30 – 200°C: $\alpha = 13 \times 10^{-5}$ 1/K
30 – 300°C: $\alpha = 19 \times 10^{-5}$ 1/K

If PTFE assembly components are cooled down from +20°C to -260°C this will result in an app. 2% shrinkage in length.

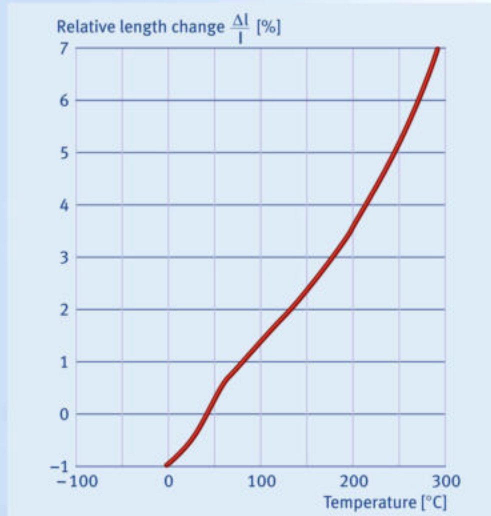
The development of the linear expansion coefficient shows two conspicuous ranges:

- At 19°C there is a transformation within the crystal lattice (‹19°C triclinic, ›19°C hexagonal).
- At app. 327°C there is an even higher degree of unsteadiness, the crystal melting point

Note

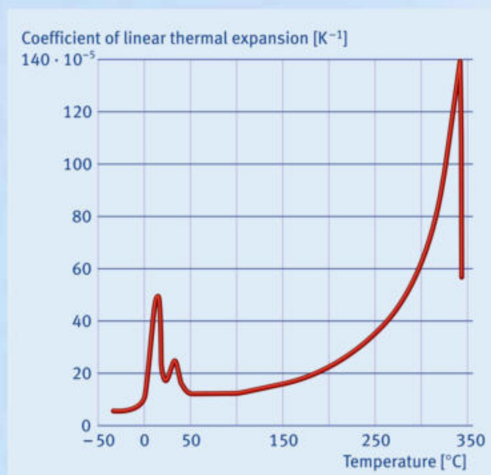
- When performing accurate measurements of PTFE components with narrow tolerance specifications it is imperative to perform the measurements at a temperature of 23 +/- 2°C.
- PTFE compounds generally have a lower thermal expansion. The correlation between temperature and thermal expansion is shown below (see graph on the following page).

Relative change in length of unfilled PTFE depending on temperature[2]



Crystallite transformation at 19°C (triklinc -› hexagonal)

Linear expansion coefficient of unfilled PTFE depending on temperature[2]



Crystallite transformation at 19°C (triklinc -› hexagonal)

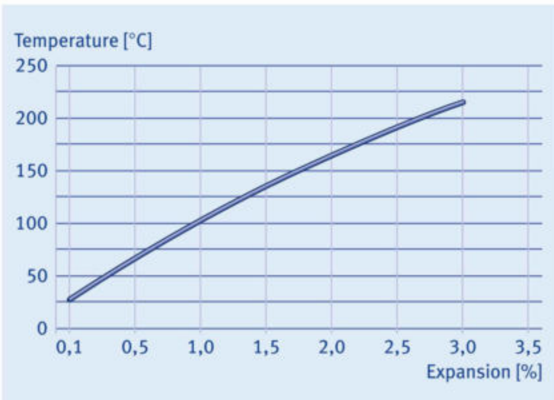
Thermal Properties

Thermal expansion of unfilled PTFE and PTFE compounds, measured lengthwise and crosswise to the pressing direction[2]

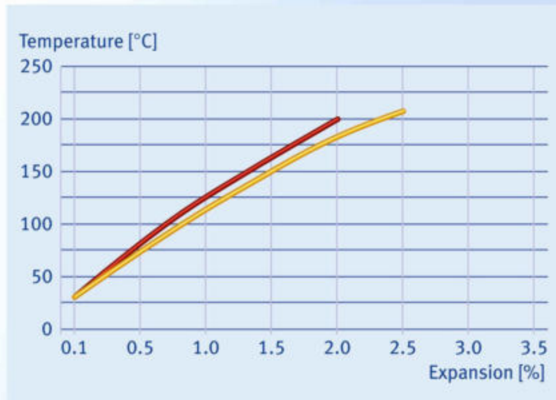
Test piece: diameter 16 mm, length 40 mm

crosswise *lengthwise* *crosswise = lengthwise*

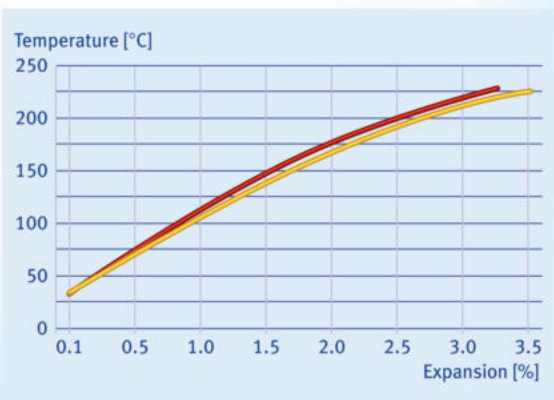
PTFE virgin



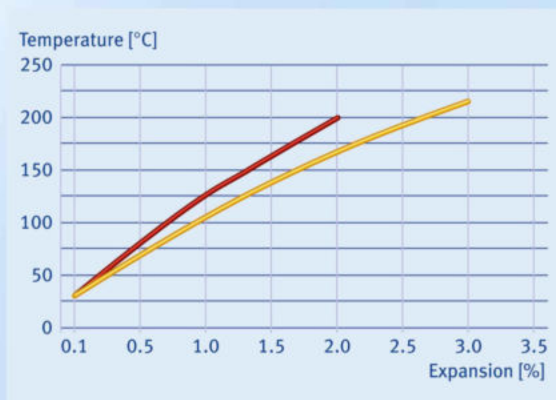
PTFE with 60% bronze



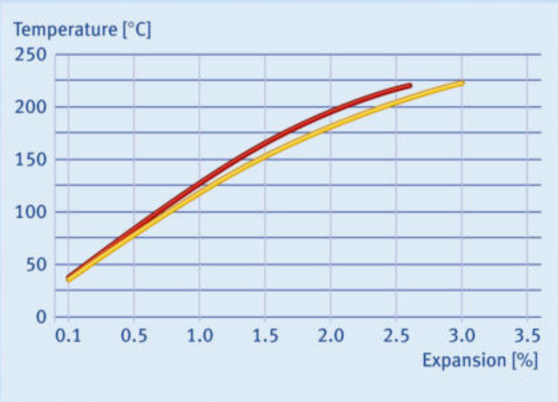
Compound HS 21059



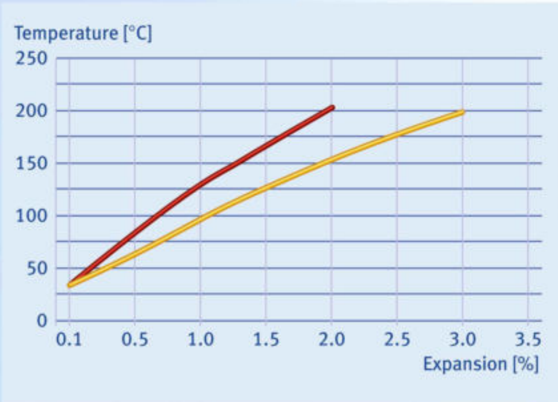
PTFE with 25% glass fibers



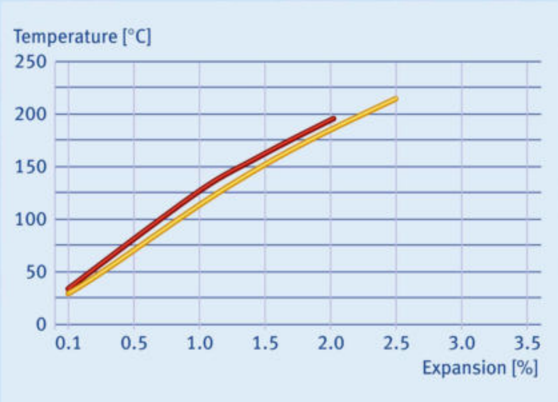
Compound HS 21037



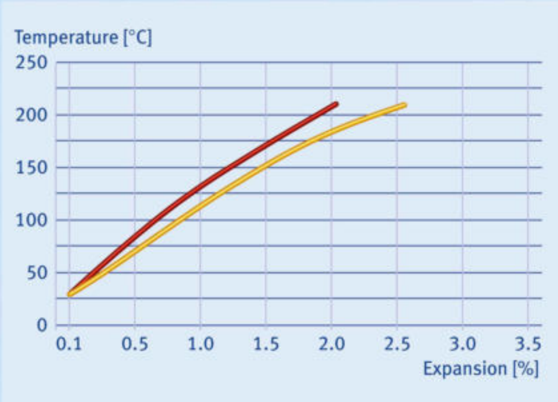
PTFE with 10% glass fibers and 10% graphite



PTFE with 25% carbon



PTFE with 30% carbon and 3% graphite



Chemical and Physical Behavior

Chemical Resistance

The strong fluorine-carbon bonding and the almost complete shielding of the C-atoms by fluorine give PTFE and modified PTFE compounds virtually universal chemical resistance.

- Neither solvents like alcohols, esters and ketones nor aggressive acids (such as fuming sulfuric or nitric acid, hydrofluoric acid, etc.) change the properties of PTFE
- Merely when used in coolants (e.g. Freon (R-12), dichlorodifluoromethanes) a reversible 4 – 10% increase in weight has been measured
- A chemical reaction (browning) of PTFE only occurs with melted or dissolved alkali metals
- At higher temperatures and pressures PTFE reacts with elementary fluoro- and chlorotrifluoride
- Monomers like styrene, butadiene or acrylonitrile can penetrate PTFE or modified PTFE in small amounts, and in the event of conditions triggering a spontaneous polymerization, this may lead to swelling of the material

For these reasons, extensive tables and chemical resistance lists are not required for PTFE.

Light and Weather Resistance

PTFE has outstanding light and weather resistance.

Consequently, PTFE is suitable for outdoor use and use in extreme weather conditions without limitation and without any notable changes to its mechanical or electrical properties.

High-Energy Radiation

PTFE is not radiation-resistant. Consequently, this plastic material should not be used in areas exposed to radiation. An extremely high dose of radiation may result in the decomposition of PTFE: Due to ruptures in the molecular chain the polymeric properties of the material successively deteriorate. This disintegration can ultimately lead to the release of the monomer and thus the release of gaseous TFE in addition to other corrosive and toxic combinations.

- With an absorbed radiation dose of 102 J/kg the polymeric properties begin to change
- With a radiation dose of 5 · 104 J/kg: reduction of tensile strength by 50-90%. Reduction of ultimate elongation by › 90%

Combustibility

Combustion tests have shown that of all plastic materials fluoro-polymers are the most difficult to inflame. The gaseous disintegration products will only ignite within the range of an external flame. After removing the igniting flame the combustion process stops immediately. The ignition temperature measured on semi-finished PTFE products according to ASTM D 1929 are within the range of 500 to 560°C, the LOI index (oxygen index) is 95%. According to Underwriters Laboratories (UL) the various PTFE types are listed in fire class V-0. The relative electrical and mechanical temperature index (RTI) for PTFE is generally at 180°C.

If a higher value is required for a particular application, a special measurement must be performed.

Water Absorption

PTFE absorbs practically no water. Even after storage in water according to DIN 53472/8.2 no absorption of water has been noted.

Physiological Properties

Unfilled PTFE is physiologically inert. FDA, EU and BgVV approvals have been granted.

For glass fiber compounds as well as for fillers PEEK and $PPSO_2$ FDA compliance statements are available.

Cyto-toxicity tests have been performed successfully. Consequently, the use of this material is permissible in both medical and food technology applications.

A highly positive characteristic in this respect is the material's resistance to hot vapor, which means that PTFE components used in the medical, pharmaceutical and food industries are well suited for sterilization.

Sliding Properties

Among other factors, the very low intermolecular forces result in PTFE having the lowest coefficient of friction of all solid materials. With PTFE, the static and dynamic coefficient of friction is virtually identical. This means that there is no »stick-slip effect«.

Even at temperatures below 0°C these favorable sliding properties are retained. Starting at 20°C, PTFE's friction coefficient shows a slight increase. Unfilled PTFE and modified PTFE show roughly the same abrasion behavior. With dynamic seals of the same design made from modified PTFE, the surface compression (⇨ radial force) is often higher than with the same seals made from regular PTFE. The reason is that due to lower cold flow the modified PTFE seal does not back away as much nor drops off over time as much as the regular PTFE seal. While this characteristic may result in higher compound abrasion on one hand, it often guarantees effective sealing over a longer period of time on the other.
The addition of fillers tends to increase the coefficient of friction; abrasion, however, is significantly reduced.

Friction coefficients PTFE/cast perlite in no-lube operation[1] ($p = 0.2$ N/mm², $T = 30$°C, $R_{z\,cast\,perlite} \leq 1.5$ µm)

PTFE Type	*Sliding Speed* $v =$ 0.5 m/s	*Sliding Speed* $v =$ 1.0 m/s
PTFE unfilled	0.25	0.27
PTFE +25% glass fibers	0.15	0.15
PTFE +15% graphite	0.14	0.14
PTFE +25% carbon	0.22	0.21
PTFE +60% bronze	0.20	0.22

Wear Behavior

The wear resistance of pure PTFE is relatively low. The reason is that PTFE molecules, due to their complete enclosure by fluorine atoms, are capable of developing merely minimal intermolecular interaction. In the crystalline regions of the material the molecular layers, similar to graphite, can be pushed off layer by layer under tribological load. In the amorphous areas the polymer composite is more stable due to intermolecular interlooping, however, this accounts for no more than roughly 30 vol % of the polymer.

A significant improvement of wear resistance is achieved by fillers such as carbon, graphite, glass and carbon fibers, bronze or organic fillers.

Compared to PTFE with mineral or metallic fillers, the newly developed special compounds, HS 21059, HS 21037 and HS 10300, even in absolutely dry-running operations have clearly improved wear behavior and very low abrasion tendency on the mating surface, even if the mating surface is unhardened.

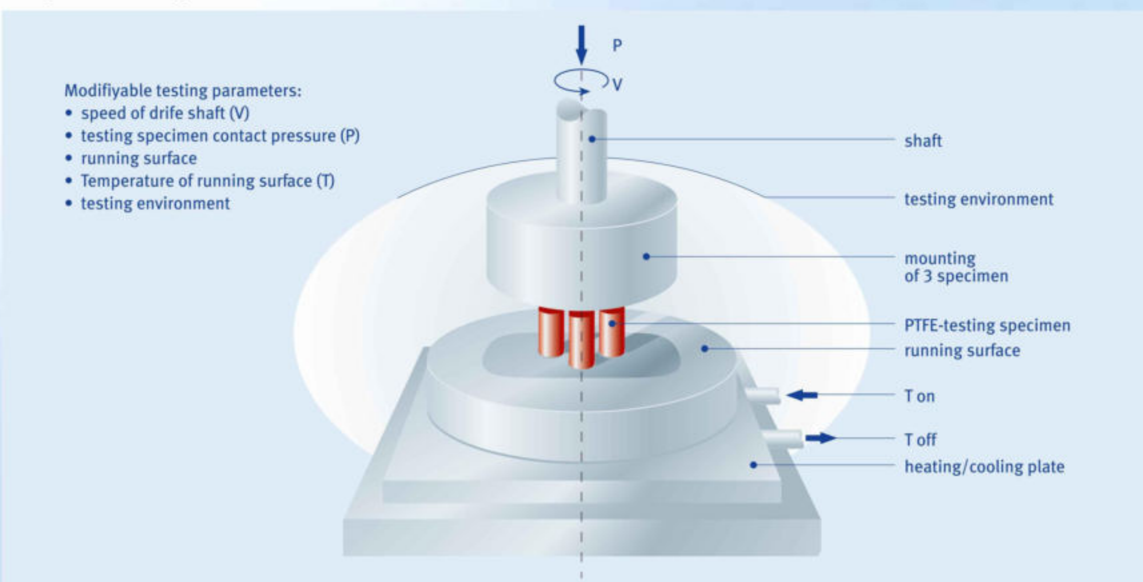
The sliding friction coefficients of the respective mating surfaces are of lesser importance for abrasion behavior. Rather, wear is much more dependent on operating conditions (medium, pressure, speed, temperature, lubrication, surface roughness). Since no PTFE compound is able to meet all requirements, the PTFE compound type best suiting the particular application must be determined.

When performing wear tests the fact that every testing method provides its own set of data must be taken into account.

A direct compound comparison therefore is only possible within each particular test method – using identical or similar testing parameters.

The objective should always be to test materials under conditions resembling actual field applications as closely as possible. ElringKlinger's development labs provide such capabilities.

Long-time test rig



Wear of Unfilled PTFE Compared to Various PTFE-Compounds

Long-term wear in dry-running (oil-free) conditions[2]

Test conditions:

Test atmosphere: air

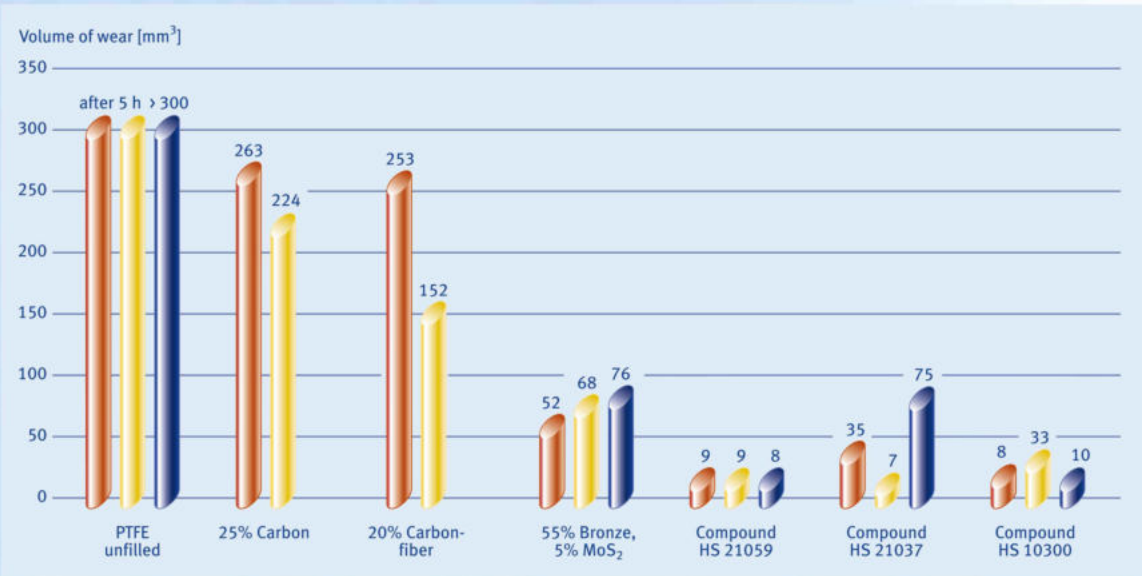
T = 100°C

v = 4 m/s

p = 0.42 N/mm²

Rz = 2 µm

Test period: 100 h



X210 Cr12 *GG25* *Alu hard-anodized*