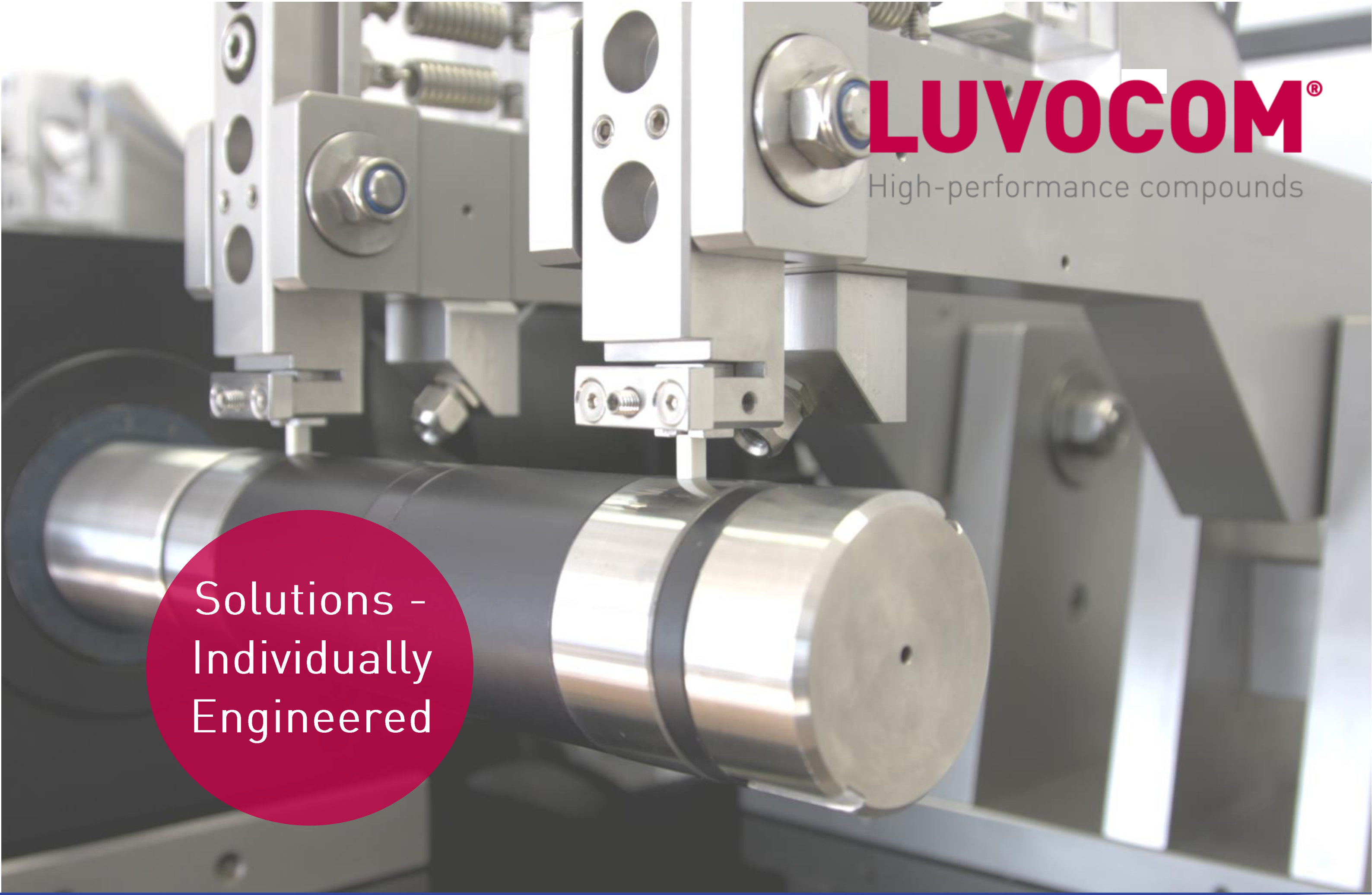


A Guide to Tribology

Customized Polymer Materials

TRIBOLOGICAL

LEHVOSS Group

Contents

Made-to-measure materials

More powerful components with reduced system costs – our thermoplastic LUVOCOM® high-performance compounds make this possible. At the same time, the material properties are precisely matched to the application and the processing technique. Since 1984, our products have stood for quality and reliability around the world. Through its Customized Polymer Materials business unit, the LEHVOSS Group is a partner of industry with regard to material selection, development and manufacture as well as consultancy and support for applications technology, from engineering design through to production.

Tribology – Our topic from the outset

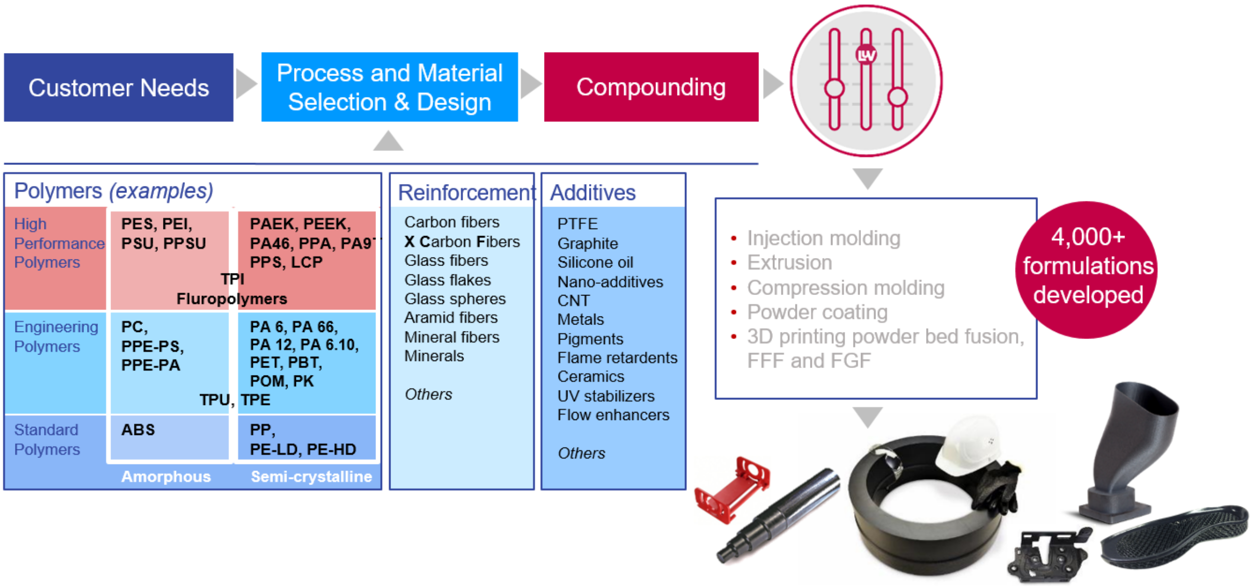
Polymers are the only possible material alternative for many tribological systems, particularly if no additional lubrication is desired. They offer numerous benefits such as low density, good corrosion resistance, low-cost processing and in many cases are also more wear-resistant than classic solutions using metal.

One of our main focuses is on tribologically optimized compounds for moving parts, such as friction bearings, gear wheels, rollers and sliders, in countless applications. Through the integration of lubricants and reinforcing materials, we improve the wear, friction and running-in characteristics of polymers and hence of the tribological system. This makes it possible to achieve systems requiring little or no maintenance that function without additional lubrication. In lubricated assemblies, the dry-running properties of these materials come to the fore and thus increase the safety level for designer and user alike.

We offer extensive capacities in material development, testing and consultancy so that materials can be selected to suit the application. Our decades of experience in this field helps the component developer to achieve the goal more quickly so that the user receives more efficient products.

Our service portfolio

- Made-to-measure materials with application-specific modifications for sophisticated uses
- Selection of polymer, reinforcement and additives according to the demands of the application
- Short material development time and implementation in series production
- A market leader for:
  - Thermoplastics with tribological modification
  - Thermoplastics with carbon fiber reinforcement
  - Compounds based on PAEK (polyaryletherketones, e.g. PEEK)
  - 3D materials for individualized mass production
- Extensive experience with more than 4,000 high-performance compounds already developed, of which some 700 are tribologically optimized
- Recognized development partner of OEMs, system suppliers and processing firms

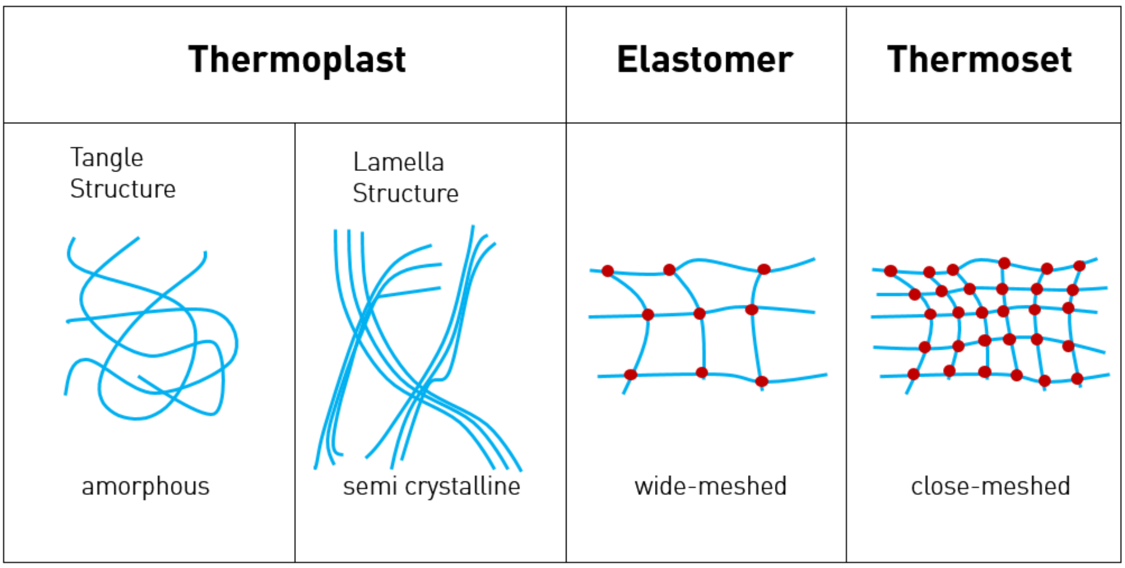


Made-to-measure materials by application and processing requirement

Plastics in tribology

LUVOCOM® compounds are based exclusively on thermoplastic polymers. Typically, they are subdivided according to their thermal properties into standard, technical and high-performance plastics (also high-temperature plastics). The latter are thermoplastics with a continuous service temperature in excess of 140°C. The mechanical strength properties of thermoplastics are dependent upon temperature and, in particular, decrease significantly beyond the glass transition temperature (Tg).

Within the thermoplastics there are the classes of amorphous and partially crystalline polymers. This describes the alignment of the macromolecules in the rigid state.



In tribological terms, the partially crystalline polymers usually exhibit better characteristics. Due to their crystalline structural components, the properties they exhibit include high wear resistance, low coefficients of friction and a generally better chemical resistance. This becomes clear in the following comparison of selected wear factors (K). The wear factor describes the wear of a material that arises under a certain pressure over a frictional path (see Page 11).

Amorphous Polymers		**Semi-crystalline Polymers**	
	Wear factor K		*Wear factor K*
PS	5800	PE	350
SAN	5800	PP	340
ABS	6800	PBT	410
PC	4900	PA6	390
PA amorphous	1200	PA66	390
PSU	2900	PA612	370
PES	2900	PA610	350
PEI	7800	PA11	350
PPE	5900	POM	125
		PPS	1050
		PEEK	390
		TPU	665

Wear factors of various polymers (dependent upon system)

Despite their poorer wear behaviour, amorphous thermoplastics often have to be employed in precision plastic parts and components to be manufactured with narrow tolerances and low warpage due to their better shrinkage isotropy. If tribological stresses occur on these components, modification with lubricants is generally indispensable.

For plastic parts to prove their worth in practice, the temperature resistance and temperature characteristics are frequently decisive factors. A plastic is sufficiently temperature-resistant if, when taking into account the respective intended use with a limited effect of heat and under other environmental conditions close to those in practice, no adverse decrease in the practical value of the part occurs. When thermoplastics are heated, physical and chemical changes take place, with the physical changes generally being reversible and the chemical changes irreversible. With short-term heating, the physical, reversible changes cause a lowering of the mechanical strength values; if the heating process has a longer time to act, irreversible chemical changes may occur as well. The strength values of thermoplastics are temperature-dependent.

The basic considerations on the temperature behaviour of plastics are important because, in components subject to a high load and tribological stress, friction is primarily liberated as heat, which frequently makes it necessary to use HT plastics. Differences between a mechanical and a tribological strain are as follows:

- As distinct from purely mechanical strain, tribological strain mainly takes place in the surface areas of parts being moved against each other.
- In tribological loads material interactions may also occur between the mating friction parts in addition to force-related interactions

A general distinction is made between motional friction (dynamic friction; the friction between bodies moved relatively to each other) and friction of rest (static friction; the friction between two bodies at rest in relation to each other, in which the shear force is not sufficient to cause a relative motion).

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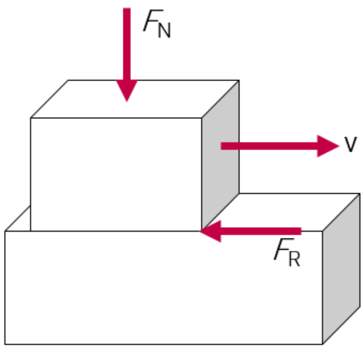
High-performance compounds

Friction force F_N = Normal force F_R x Coefficient of friction f

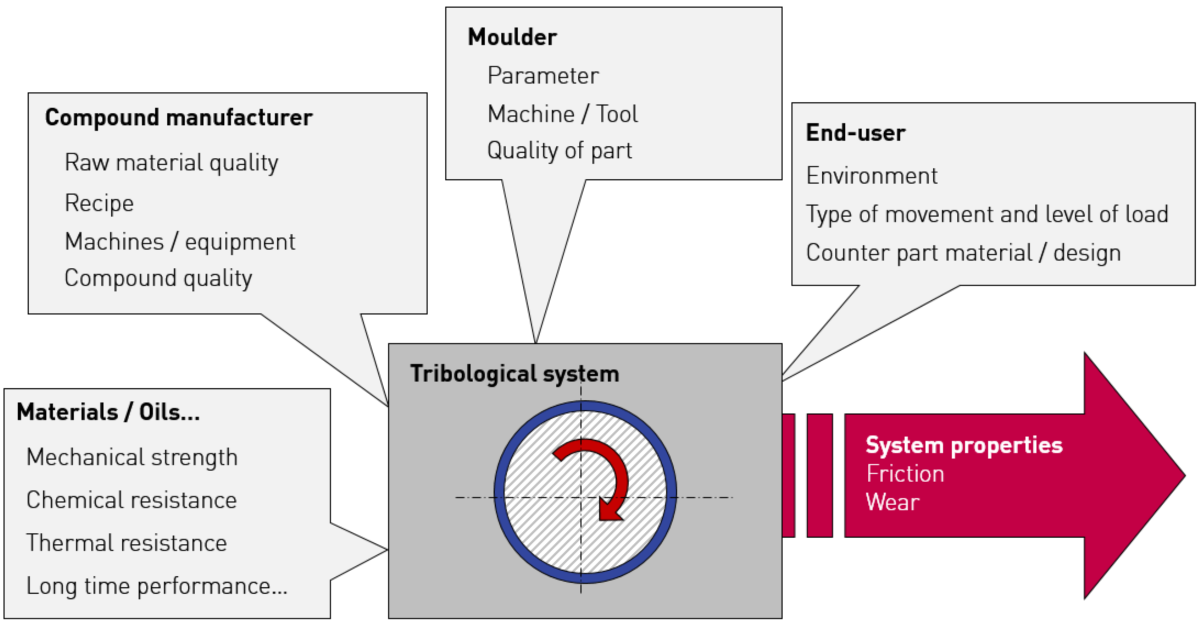


The friction number, f, results from the quotient of the perpendicular force (F_N) and frictional force (F_R),
v= velocity

The wear associated with the frictional process is generally undesirable (exceptions: chalk used in schools and pencils) while the friction number, f, (also called coefficient of friction, μ) may itself vary according to the type of tribological system and is often intended to do so. In the case of tribopolymers in unlubricated systems, it typically lies between 0.1 and 0.5. Here, LEHVOSS supplies compounds with friction numbers starting at 0.04. As a matter of principle, it may be stated that tribological properties are not specific material properties but the properties of a whole system.

The tribological system

A tribological system not only comprises the components in relative motion to each other but also the media that may be between the frictional surfaces, such as lubricants, chemicals and slurry. A stress profile has to be precisely defined for each tribological system. This profile determines the dimensioning and surface structure of the components, the choice of material, the selection of lubrication type and ultimately the flawless and reliable functioning of the component.



The tribological system – The system characteristics depend on the selected parameters and the quality of the materials and the finished component

The following parameters have to be considered in defining the specification for the stress profile.

- Sequence of movements (continuously in one direction, intermittent or oscillating)
- Perpendicular forces and contact pressure
- Level of mechanical stress (static and dynamic)
- Relative velocity between the sliding partners
- Duration of stress (time or distance, permanent or with interruptions)
- Temperatures (ambient temperatures and additionally occurring frictional temperature)
- Any media acting and the environmental conditions to be expected in series use
- Particles occurring between the sliding surfaces, e.g. due to the fracture of protruding fibres
- Type of material and surface hardness of the counteracting part as well as its surface hardness and quality

Furthermore, the following points are also crucial for the performance of the component:

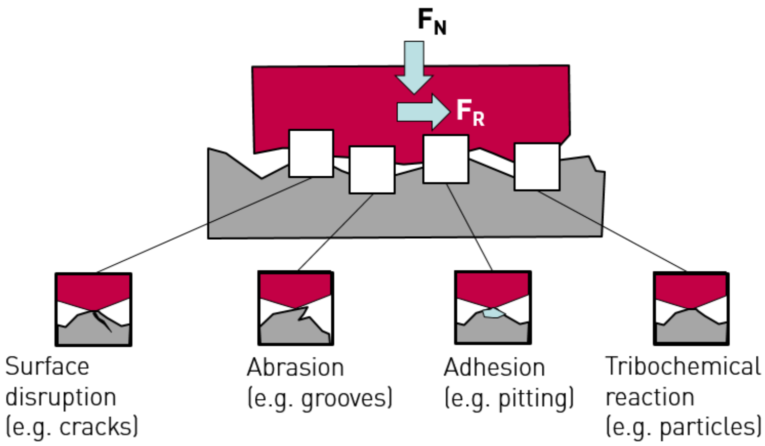
- Material quality (production, use of suitable and approved raw materials)
- Component quality (machining suitable for the material, adapted machine and tool)
- Component design and layout (incl. wall thicknesses, orientation of reinforcing fibres)

The quality and use of adapted raw materials significantly influence the tribological properties of compounds

The functional specification plays a major part in the selection of the polymer and necessary additives. Important factors are viscosity (flowability and durability), temperature resistance and chemical resistance of the base polymer. Experience with the planned application is also very helpful in selecting the material. This may greatly simplify the process of system layout and lead to success more quickly.

Causes of wear and their effect

The processes that take place in the material combinations (polymer/metal, polymer/polymer) in the boundary layers defy recording with measuring technology. The friction force to be applied, F_R, comprises an adhesion and a deformation component and, in the case of correspondingly hard and rough counteracting surfaces a cutting component. Hence the main factors of influence for sliding friction are the adhesion of the boundary layers, the deformation of the micro contact sites and wear as a result of machining.



Adhesion phenomena

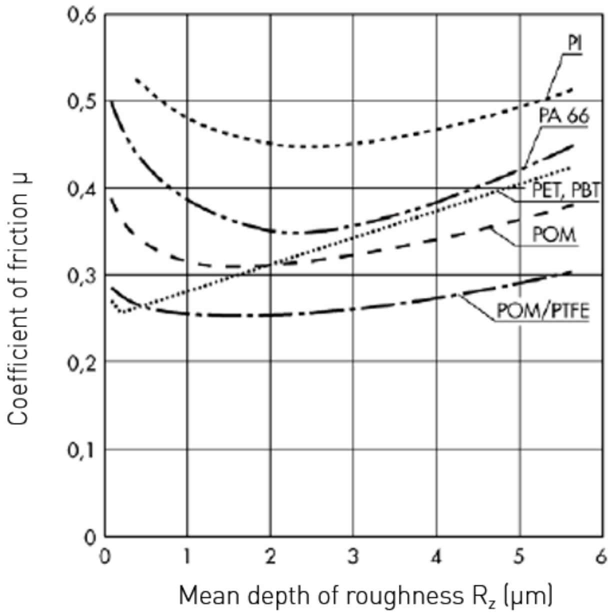
If two bodies with flat surfaces are placed on one another, initially only the peaks of the three highest asperity elevations touch. As the perpendicular force, F_N, increases, the number and dimension of the contacts due to elastic or elastic-plastic deformation grows, the specific compression decreases. In the regions of real contact areas, the surfaces approach to such an extent that atomic or molecular interactions occur (Van der Waals forces).

! In the polymer/polymer sliding pair, physical adhesion forces may additionally occur as well as electrostatic charges. In particular, this effect may arise with a combination of the same polymer. Consequently, different plastics should work against each other in polymer/polymer combinations.

Deformation and cutting phenomena, coefficient of friction

In a metal/polymer combination, firstly the comparatively soft polymer material undergoes elastic deformation according to the level of surface pressure. Secondly, metallic asperity peaks may penetrate into the polymer surface. When the material partners are moved in relation to each other, firstly the energy introduced through deformation will lead to a loss of friction. Secondly, depending on the height of the asperity peaks that have penetrated, abrasion due to wear will occur. Added to these are hysteresis losses that result through deformation processes in the separation of adhesive contacts. In the adhesion range, the sliding procedure is interpreted as a rapid succession of adhesive bonding, distortion, separation and restoration of interlinked molecular areas. If the bonding energy of the polymer is now exceeded in certain positions, fracture and hence molecular degradation of the polymer will occur. This chain degradation is accelerated still further by frictional heat and environmental influences (media, foreign bodies, etc.).

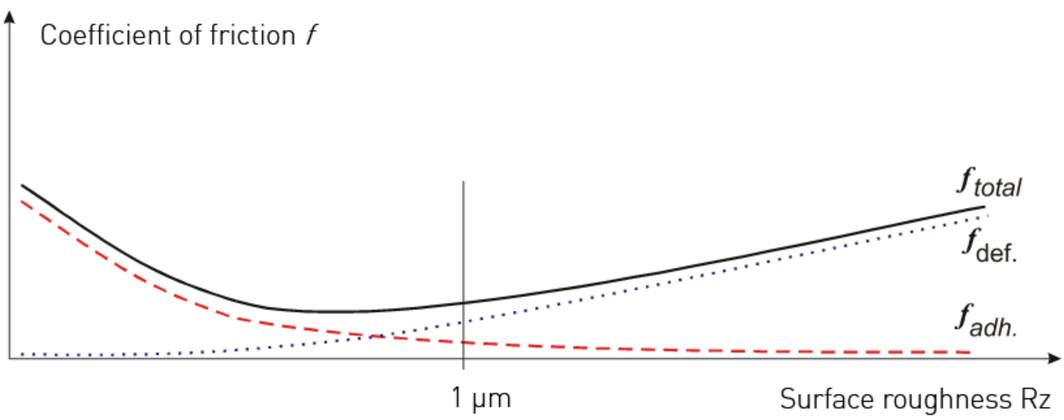
There are polymers in which only individual molecule segments are extracted from the material during the relative movement of the sliding partners, above all if a pronounced molecular orientation is established in the direction of slip. In this case only slipping of the chain occurs and not chain fracture. Cutting phenomena in the polymer/metal combination primarily occur if the roughness of the metal surface is too high. As a general recommendation, a maximum value for the mean surface roughness, R_Z, of 3 µm applies here. In addition, abrasive wear can be reduced if the score marks of the roughness are oriented in the direction of movement by grinding of the surface.



Dependence of the coefficient of friction, μ, on the mean surface roughness, Rz, for various polymers/compounds. General recommendation for surface roughness range: Rz between 1 and 3 μm. Source: VDI 2541

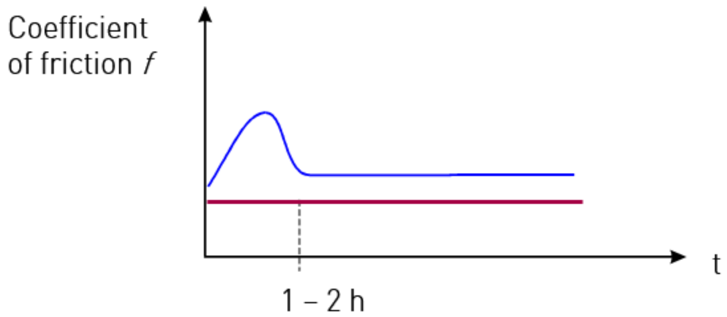
To summarize, it may be stated that energy is introduced into the polymer material surface during the friction process and crack formation together with fracture of the polymer chains may occur. A hard asperity peak will also cause abrasive wear to occur (micro cutting operations). The coefficient of friction is also made up of a deformation and an adhesion/abrasion component. As described, this value is also dependent upon the system. Different recommendations for material and quality of the counteracting partners emerge according to the system and objective.

! A general recommendation is that the surface roughness, Rz, should be between 1 and 3 μm. As a result the level of wear can be maintained at a low level in normal circumstances.



The system-dependent coefficient of friction results from a deformation and an adhesion component

In determining the coefficient of friction, the value first increases during the running-in period, before falling again after a certain smoothing of the partners, and then remains relatively constant over time if the other influential parameters do not change (blue line in next graph). This demand also applies to certain practical applications. In the case of contact washers in clutches, for example, the frictional torque can be adjusted via the spring tension but should remain as constant as possible during the life span even under the influence of the dirt and abraded particles that occur. Furthermore, there is also a requirement for a very short or running-in phase or even no running-in phase at all (red line). This can be implemented by the appropriate modification of polymers.

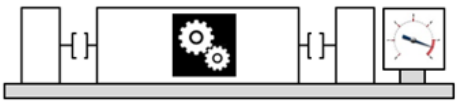
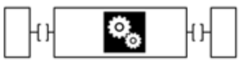
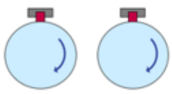
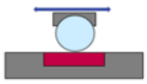


Typical pattern (blue) of the coefficient of friction in a tribological system and ideal pattern (red)

Determination of tribological parameters

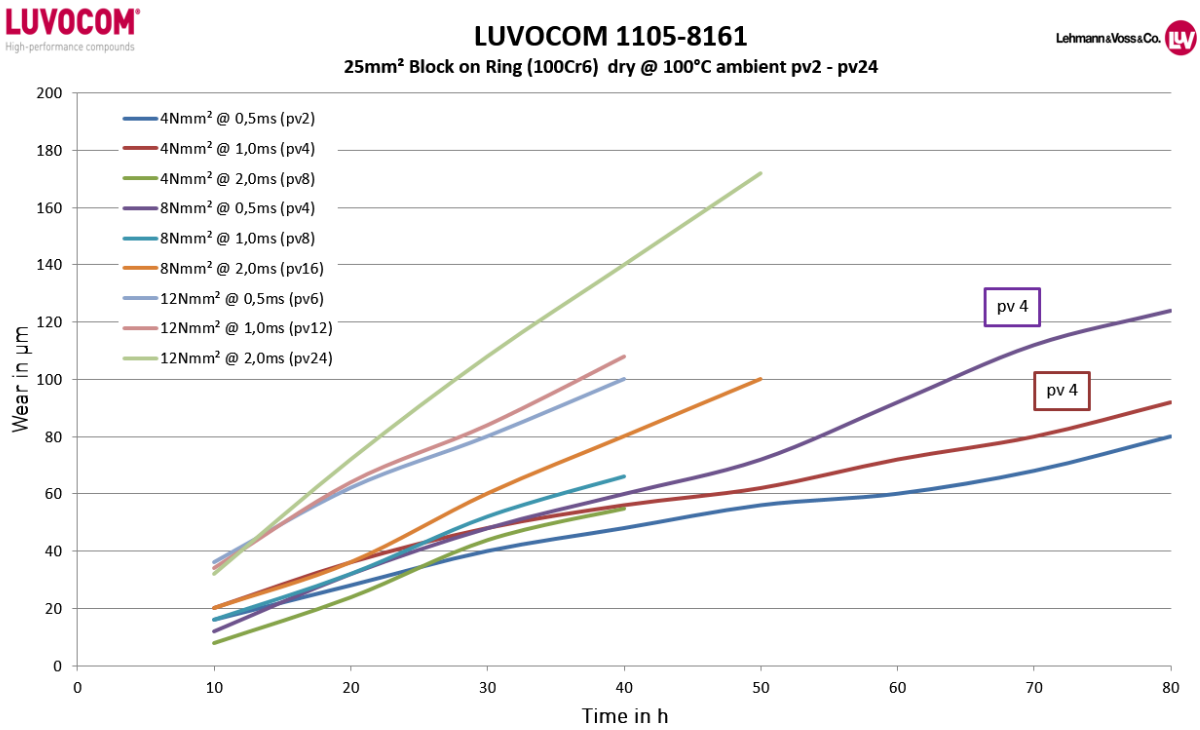
It is also in the designer's interest to obtain the friction and wear values for the thermoplastic materials offered on the market. Yet tribological properties are not specific material properties but instead depend on the tribological system concerned. The material manufacturer cannot avoid indicating tribological reference values. However, in such cases it is necessary to provide precise information on the test parameters and it can only involve a comparison of different materials or material modifications under identical test conditions. On the basis of our many years' of experience and extensive test results determined, it is possible to recommend suitable compounds for the application in question.

Appropriate test apparatus enables an approximation to be achieved to the real assembly in use, but a final inspection and clearance can only take place via experiments on test rigs within the actual system and field trials.

Category	Type of Test	Set-up	
1	Field Test		Simulation / Field test
2	Test stand with serial equipment		
3	Test stand with equipment assembly		
4	Test with real part or downsized assembly		Preliminary tests / Preselection
5	Simulation of operational demands with test specimen		
6	Smale scale test with test specimen		

The sequence of movements will differ according to the structure of the test rig. The methods include continuously rotating the test specimen in one direction (e.g. block-on-ring tribometer) or subject it to oscillation (e.g. SRV tribometer). Various coefficients of friction and specific wear values are established in each case. In practice, it is useful to employ the comparative values for preselection of a material.

One very helpful guide for the designer is the pv value. Here p represents the pressure and v the velocity. In addition to the effective pv value, the accompanying pressure and testing speed should also be stated. The wear characteristics of a material may vary with an identical pv value but different parameters. The following graph includes an example. The pv values of 4 result from a pressure of 4 N/mm² and a speed of 1.0 m/s in one case and from 8 N/mm² and 0.5 m/s in the other.

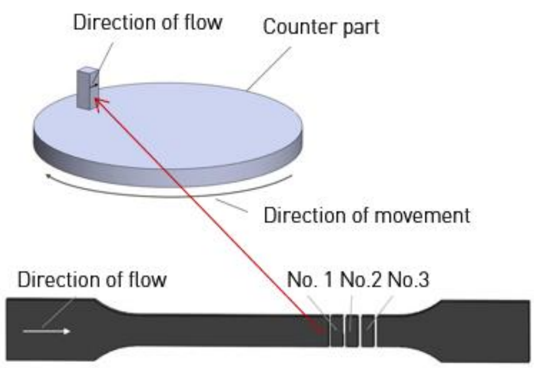


Comparison of the wear characteristics of a tribologically modified PEEK compound at different pressures and speeds. Test: Block-on-ring, counteracting partner 100Cr6, dry, 100 °C ambient temperature.

It is also common to indicate the so-called K value for wear. This is in a certain ratio to the glide path covered and to the perpendicular force. The wear factor K is calculated as follows:

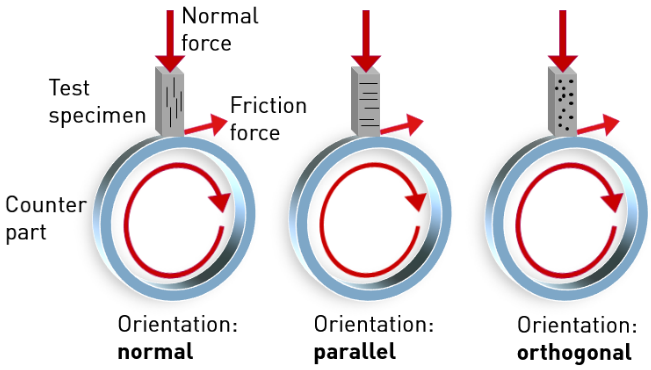
$$K = \frac{\text{measured wear W (mm}^3\text{)}}{\text{perpendicular force (N) x glide path (m)}}$$

The samples under test are obtained either from injected tensile test bars, injected, extruded or pressed plates, semi-finished goods or specially injected test bodies (e.g. for sphere-prism test).

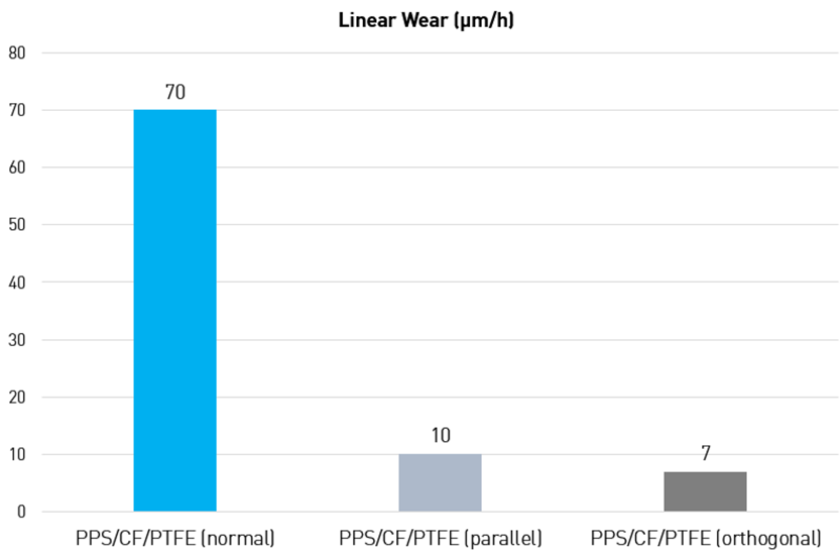


Test body production for pin-on-disc tribometer

In comparative investigations, it is important to make sure that typically the orientation of fillers and fibres is identical. Compared with the specimens, finished parts have a different orientation of fibres and fillers; additives may also be oriented and the polymer may have been partially damaged during processing.



The orientation of fibres and other additives has a decisive influence on the tribological characteristics of a compound and counteracting partner



Influence of fibre orientation on the wear characteristics, illustrated by a PPS/CF/PTFE compound

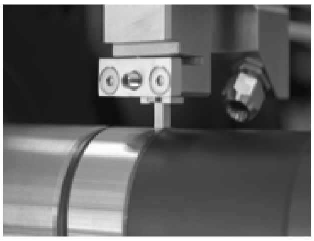
Practically based tribological investigations are generally indispensable in a specific application. In the case of a new design, the following problem has to be considered:

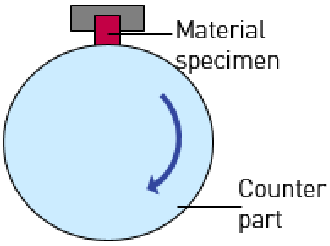
! If the sample is manufactured mechanically from a semi-finished product and later has to be injection-moulded or compression moulded in series use, the results of the tribological investigations will not be identical. In such a case, it is advisable to create a pilot mould for the component to be inspected and this should have approximately the same injection conditions as the series mould intended for later use.

Our test methods

In the development and inspection of our high-performance compounds, we employ the tribological test methods described below. Various parameters, such as speed, pressure, type of movement, time, and temperature can be set to match the application together with, wherever possible, use of the appropriate counteracting partner.

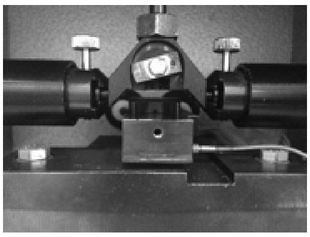
Block-on-ring tribometer

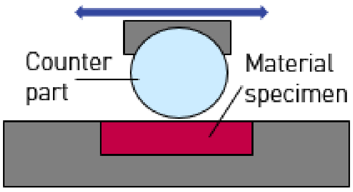




Parameter	
Type of movement	Linear sliding
Speed range	0.01 - 4.0 m/s
Pressure range	0.05 – 200 MPa
Temperature range	23 – 300 °C
Test with fluids	Yes
Counterpart materials	Various

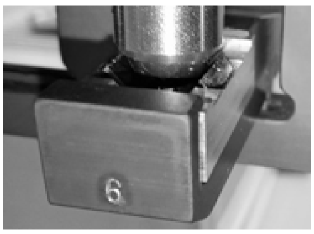
SRV tribometer

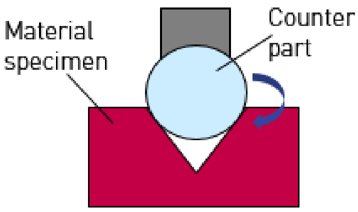




Parameter	
Type of movement	High frequency linear oscillation
Speed range	0.04 - 2.5 m/s
Load	20 – 1200 N
Temperature range	21 – 190°C
Test with fluids	No
Counterpart materials	100Cr6, X5 CrNiMo, AlCu4MgSi

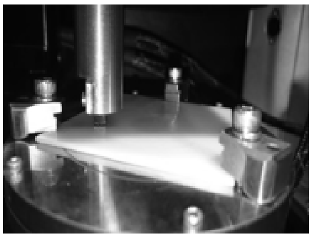
Sphere-prism tribometer

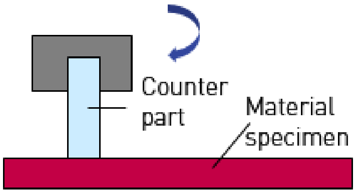




Parameter	
Type of movement	Rotation
Speed range	0.028 m/s
Pressure range	30 N
Temperature range	23°C
Test with fluids	Yes
Counterpart materials	Various

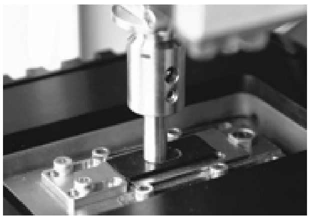
Pin-on-disc tribometer

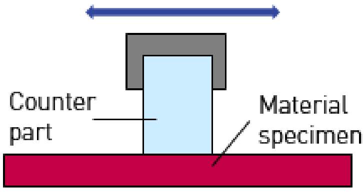




Parameter	
Type of movement	Rotation
Speed range	0.1 – 5000 rpm
Load	0.05 – 1000 N
Temperature range	- 20 – 350°C
Test with fluids	Yes
Counterpart materials	Various

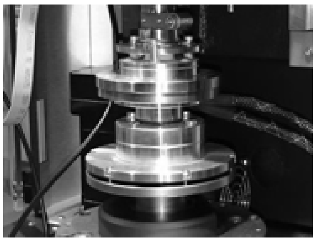
Pin-on-plate tribometer

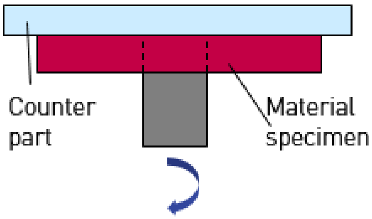




Parameter	
Type of movement	Oscillation 0.75 – 25 mm swing
Speed range	0.1 – 60 Hz
Load	0.05 – 1000 N
Temperature range	-20 – 200°C
Test with fluids	No
Counterpart materials	Various

Thrust washer tribometer





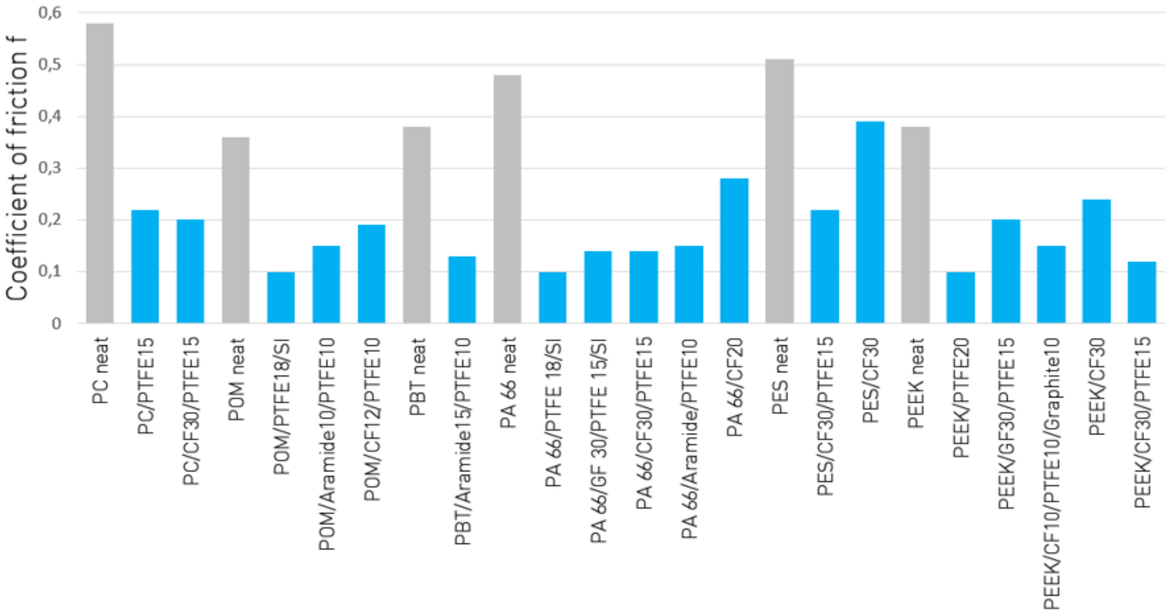
Parameter	
Type of movement	Rotation
Speed range	0.01 – 15 m/s
Load	0.05 – 1000 N
Temperature range	- 40 – 150°C
Test with fluids	Yes
Counterpart materials	Various

TRIBOLOGICAL

LUVOCOM®
High-performance compounds

Improvement of the tribological material properties

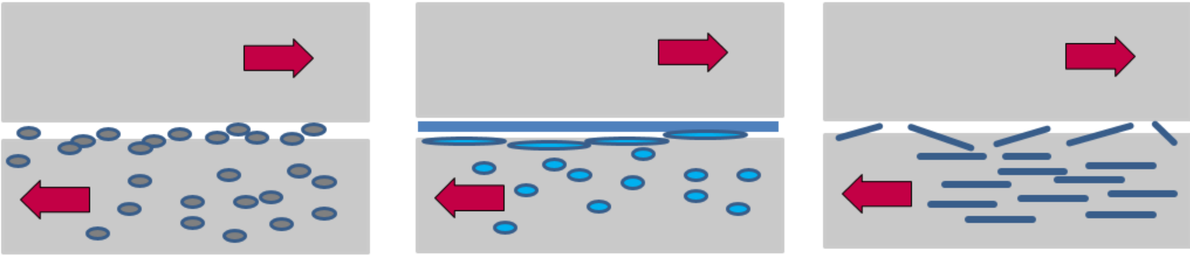
Every polymer has certain inherent tribological properties, which differ fundamentally in amorphous and partially crystalline polymers. Among them, depending on the tribological system, there are also polymers with varying degrees of suitability for a specific application. The addition of fibres, lubricants and additives improves the properties of the polymers. The following chart shows coefficients of friction against steel determined at room temperature. It can be clearly seen how the coefficients of friction are reduced compared with the basic polymers by integrating lubrication.



Comparison of coefficients of friction of neat polymers (grey) with tribologically modified polymers (blue). Measured at room temperature, mating partner steel 100Cr6, UTI frictional wear device (oscillating)

Below are examples of the influence of additives on the compound properties:

- Reinforcing materials (e.g. carbon and glass fibers) → Improvement in mechanical properties (e.g. strength)
- Lubricants (e.g. PTFE, silicone oil) → Increase in wear resistance, reduction in coefficient of friction
- Finely divided additives (e.g. MoS_2, pigments) → Increase in wear resistance due to nucleation
- Minerals (e.g. boron nitride) → Increase in thermal conductivity



Particle
e.g.
- Graphite,
- Molybdenum (MoS_2)

Lubricating film
e.g.
- PTFE
- Silicone oil
- UHMW-PE
- Graft-Copolymers

Reinforcing materials
e.g.
- Carbon fibers
- Aramid fibers
- Glass fibers

Mode of operation of fillers and reinforcing materials

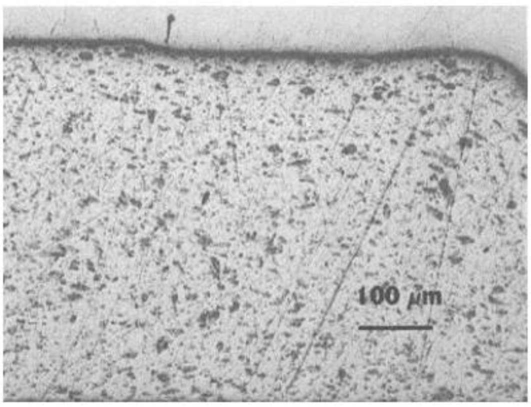
The most important tribologically active additives for polymers

a) Lubricants

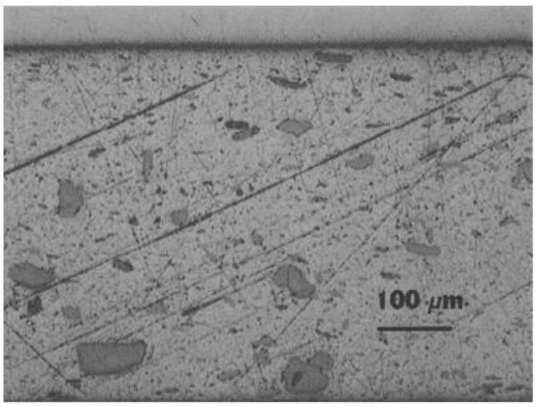
Polytetrafluoroethylene (PTFE)

- Partially crystalline, thermoelastic polymer
- Chemically very resistant
- High temperature resistance
- Forms a lubricating film between the frictional partners, thus reducing coefficient of friction and wear values
- Large selection of different PTFE types for optimum material combination

PTFE, as a tribologically highly effective additive, is incorporated into thermoplastic compounds in powder form. In the case of PTFE, when there is a frictional load, rubbing of the polymer chains occurs and a lubricant film forms between the mating partners. The coefficient of friction falls dramatically as a result and fatigue symptoms of the polymers in the boundary layer can also be reduced, and less wear occurs. The PTFE film brings adhesive and sliding friction into line, thus generally preventing what is known as stick slip. There is a large selection of different PTFE powders with specific properties.



PA 46 with PTFE fine distribution



PA 46 with PTFE coarse distribution

Sectional micrographs of PA 46 with different PTFE distributions

The suitable type is selected to match the polymer and in accordance with the requirements catalogue of the relevant tribological application. An example of a development such as this is our product series LUVOCOM® XTF (Page 27).

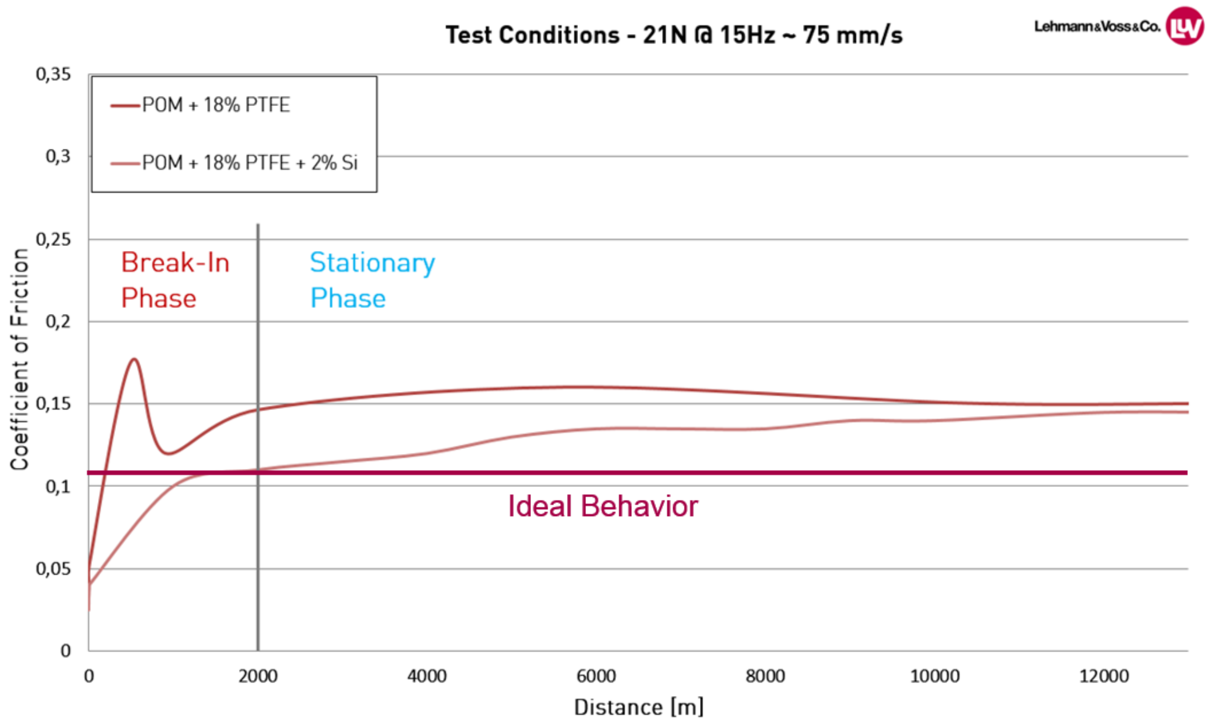
! It is not possible to use materials containing PTFE in production lines of the tobacco-producing industry.

Silicone oil (SI)

- Polymerized siloxane
- Stable to temperature
- Electrically insulating
- Migrates to the surface where its forms a continuous lubricating film
- Dosage approx. 0.5 to 2% by weight
- Combinations of PTFE and silicone oil for better and faster running-in behaviour, reduction of stick-slip and at higher bearing speeds

Highly viscous silicone oils often have only limited compatibility with the polymer matrix and therefore migrate slowly to the surface. The bloom they form here provides a continuous lubricant film. So as not to substantially reduce the mechanics of the polymer material and to avoid delamination in the manufacture of parts, a proportion ranging from 0.5 to 2% is usually added. The combination of PTFE-silicone oil has proven to be particularly effective at high bearing speeds and in the reduction of stick-slip. This combination also ensures optimized running-in of the frictional partners.

! The use of materials containing silicone oil may be critical for electrical and electronic applications and should be examined. This also applies to products for which a paint finish is intended. It is now possible to use special silicone oils.



Coefficient of friction – Typical running-in and stationary phase for two tribological compounds based on POM, modified with PTFE or PTFE and silicone oil

Graphite (GR)

- Organic, grey to black mineral
- High temperature resistance
- Electrical and thermal conductivity
- Good lubricating properties, particularly in contact with water
- Improvement of the shrinkage isotropy of compounds
- Increase in the compressive strength of compounds

Graphite consists of carbon and is a crystalline relatively soft mineral. The crystal structures are organized in layers. These layers slip against each other readily. In combination with moisture, this results in good lubricating properties. In compounds, it is used as a temperature-resistant and tribological additive and can help to improve the shrinkage isotropy as well as increase the compressive strength of the material. Compounds with graphite particularly exhibit tribological advantages when the components function in water or come into contact with water. Graphites also increase the thermal conductivity of compounds. This helps in the dissipation of frictional heat and thus reduces the thermal load of the frictional partners.

Molybdenum sulphide (MoS_2)

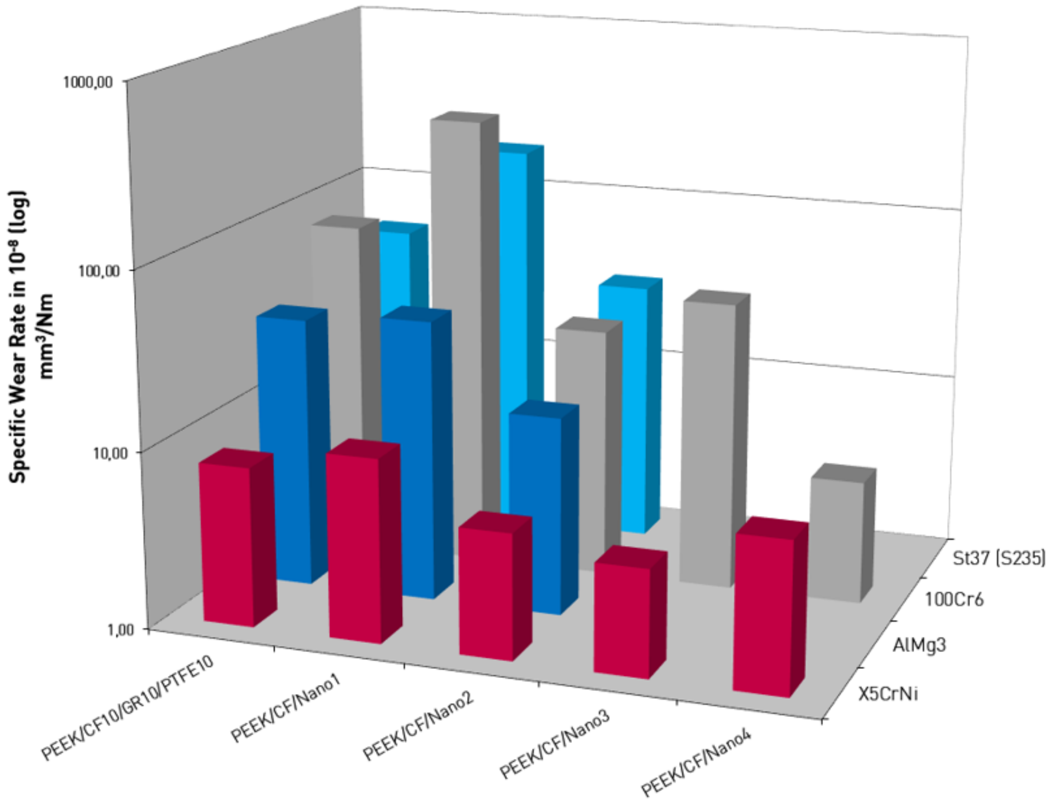
- Greyish black, crystalline mineral
- High temperature resistance
- Low coefficient of friction under dry running conditions
- Functions as a nucleating agent in partially crystalline thermoplastics

Like graphite, MoS_2 is structured in layers, which can easily move against each other. This explains the lubricating effect. In compounds, MoS_2 is able to reduce the coefficients of friction somewhat under dry running conditions. Another advantage with a greater effect is that MoS_2 acts as a nucleating agent in partially crystalline thermoplastics and enhances the fine crystalline structure, reaching into the marginal zones. Fine crystalline regions exhibit higher wear resistance values than amorphous or less crystalline regions.

Nano-additives

- Very finely divided additives in the nanometre range (10^{-9} m) with a mineral or organic base
- Combination of various additives possible
- Wear resistance of compounds is significantly increased
- Low coefficients of friction can be attained
- Running-in characteristics can be significantly optimized

Nanotechnology has already been employed in plastics technology for a considerable time. Lehmann&Voss&Co. has already been using nano-additives for tribological compounds since 2000. Suitable processing is able to ensure a good dispersion within the compound. As a result, the active particles are then present in the surface of the component, which is very important for tribological applications in particular. This makes it possible to achieve especially low wear rates, constant coefficients of friction, high pv values and good running-in characteristics. Combining different nano-additives and reinforcing fibres (mostly CF) leads to very extensive opportunities for made-to-measure compounds. The following chart illustrates this. PEEK/CF with various nano-additives was tested against different counterparts under dry running conditions. Compared with the classical use of additives for PEEK with CF, graphite and PTFE, it is possible to reduce wear in a large number of material combinations.



Wear of tribologically modified PEEK-CF nano-compounds compared to PEEK with CF, graphite and PTFE. Testing conducted with different counteracting partners.

! Nanofillers may also provide a solution if PTFE modification is out of the question. For instance, when used in liquids that flush PTFE out of the material compound or when PTFE causes too great a reduction in the mechanical properties of the compound.

External lubrication

As a matter of principle, there is also the option of employing traditional lubrication even for tribological systems with plastic counteracting partners. This may involve the application of oils or greases, the sliding partners may be immersed in oil emulsions, porous polymeric materials may absorb oils or antifriction lacquers may be applied to the sliding partners.

Special oils and greases are available for plastics that do not chemically attack the polymeric material and do not cause stress cracking even in amorphous plastics. High tribological stresses, in particular, sometimes make traditional lubrication unavoidable. In such cases, a plastic with lubricant additives is not necessary unless deficient lubrication may occur during operation and dry-running properties have to be ensured. Unlike metals, polymeric materials have small surface energies and this results in pronounced spreading of the oils on the contact points, and after a certain period an absence of lubrication may occur at the bearing point. The application of a fluorinated antifriction lacquer may be a solution here.

! Oils and greases with a high viscosity of the base oil have proven particularly useful for tribological systems with plastics. Further information on this matter is available from the lubricant producers. However, in many cases lubrication with oil or grease is not desired because of their tendency to soil.

b) Reinforcement

Here it is important to select the correct fiber types and ensure that they are ideally linked and incorporated in the polymer. In the case of the polymer surface, which in the state of friction is flexed by deformation, there is a danger that small fragments of fibres will break away and come between the sliding partners. Increasing wear is then possible. In tribological applications, lubricants generally have to be added to fiber-reinforced thermoplastics so that the permitted wear of the system and coefficients of friction can be adhered to.

Generally when fiber-reinforced polymers are being used it is important to consider optimum alignment of the fibers in the component design because this is a decisive factor for the mechanical and also the tribological properties (cf. page 12).

Aramid fibers (AF)

- Based on aromatic polyamide
- Low specific weight
- Increased in the compound strength (lower in comparison to GF and CF)
- Increase in the wear resistance of the compound
- Less abrasive than GF and CF

Aramid fibers have good mechanical properties with a low specific weight. Their strength is relatively low perpendicular to the longitudinal axis of the fibers. The opportunities for coupling these fibers to polymers is not optimal. During the processing, fracturing of the fibers occurs so that the mechanical level of compounds reinforced with aramid fibers is not especially high. However, the tribological properties are favourable, above all in combination with soft partner materials such as aluminium or bronze.

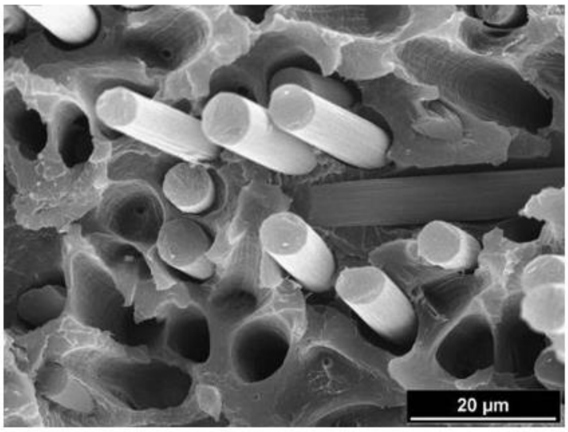
Glass fibers (GF)

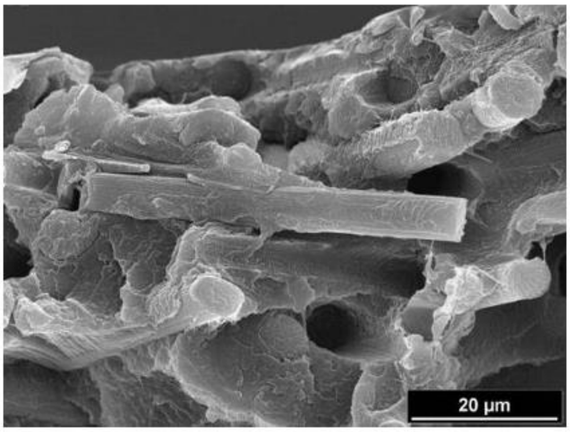
- Amorphous structure with isotropic properties
- High tensile and compressive strength
- Increase in the mechanical properties of polymers
- Higher compound strength at high temperatures
- Increase in the wear resistance of the compound
- Increase in the permissible pv values

Fiber-reinforced thermoplastics permit a higher level of mechanical strength, even under high temperatures and offer a supportive effect in the frictional surface. The reinforced materials have an enhanced creep behaviour, a lower coefficient of thermal expansion and a somewhat enhanced thermal conductivity. The wear can be significantly reduced. This results in an increase in the permissible pv values. This can also be attributed to the high hardness of glass fibers. However, here it is necessary to consider the possible greater wear of the counteracting partner. This applies in particular to soft materials such as unreinforced polymers and metals such as aluminium or brass.

Carbon fibers (CF)

- Generally based on pyrolysed polyacrylonitrile (PAN)
- High tensile strength
- Thermally and electrically conductive
- Low specific weight
- Negative coefficient of thermal expansion
- CF-reinforced thermoplastics offer the maximum mechanical strength level
- CF compounds exhibit good wear characteristics, elevated thermal conductivity, higher pv values, are lighter than GF compounds and are generally electrically conductive





Scanning electron micrographs of PEEK with CF

Carbon fibers make it possible to achieve compounds with high strengths, e.g. LUVOCOM® XCF (page 29), and very tribological properties. The compounds also exhibit low thermal expansion, elevated thermal conductivity, dimensional accuracy, long-term dimensional stability, electrical conductivity and low weight. In contrast to GF, CF exhibit better wear characteristics. The graphite-like layered lattice structure at the surface slides in a defined manner and less wear is caused as a result.

There are a large number of different CF varieties. Here too, of course, the selection of suitable types is important for an optimum tribocompound. In terms of component design, the comments for GF also apply. In CF compounds too, an improvement in tribological properties can be achieved through the addition of lubricants.

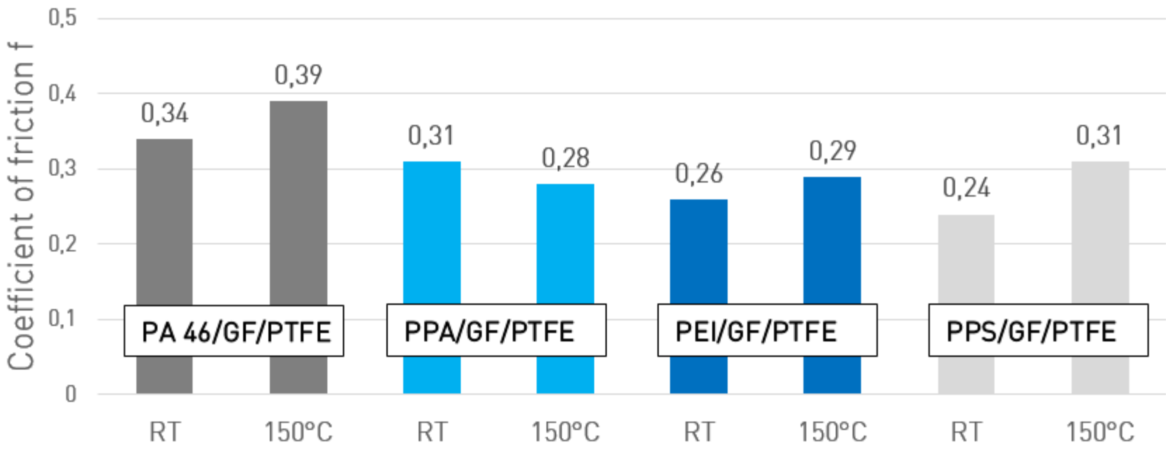
c) Composites with metals

Another opportunity for obtaining efficient components is to combine plastics with metals. This involves either coating metal plates with plastics via hot pressing – e.g. for rolled friction bearings – or metal parts obtain a coating via an electrostatic application process.

The plastics are modified in accordance with the requirements for the specific application and generally contain integrated lubricants and reinforcing materials. The advantages lie in the high strength and the good thermal conductivity of these composites, the permissible pv values of which are in many cases above those of pure unmodified polymers. These solutions make it possible to implement very strong and resistant components. We also offer material solutions for these systems with our LUVOCOM® and LUVOCOM® P product series.

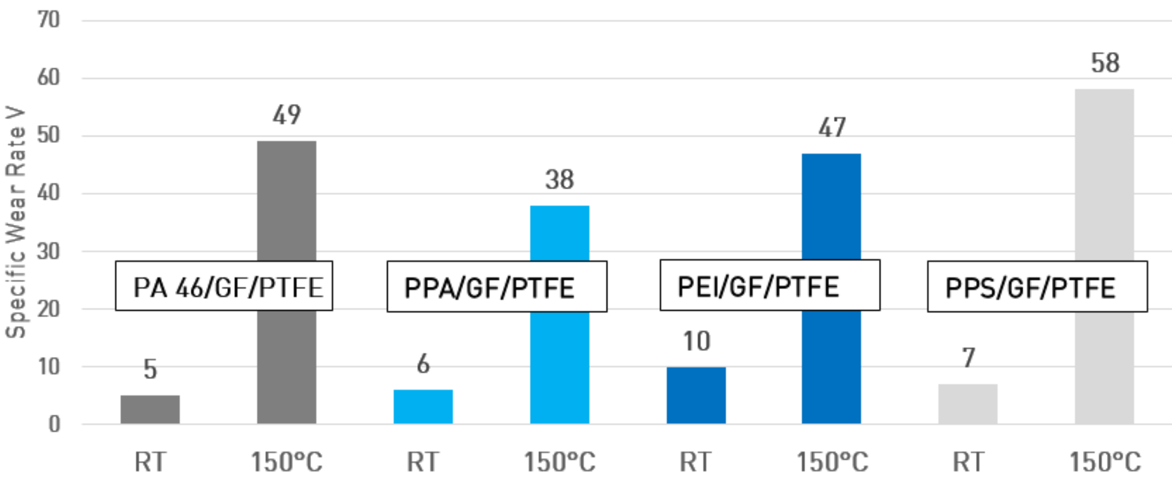
Practical investigations

In practice, the operating temperatures of components are generally below or above room temperature, which is usually the setting for standard tests. Furthermore, the frictional energy is also converted into heat in the sliding surfaces. This is why the tribological material test is also conducted at elevated temperatures. This takes place in temperature-controlled test chambers or a heated environment. The influence of temperature on the coefficient of friction can be seen in the following chart. The example lists four different thermoplastics, each of which has been modified with 30% glass fibres and 15% PTFE. Test temperatures are room temperature and 150 °C.



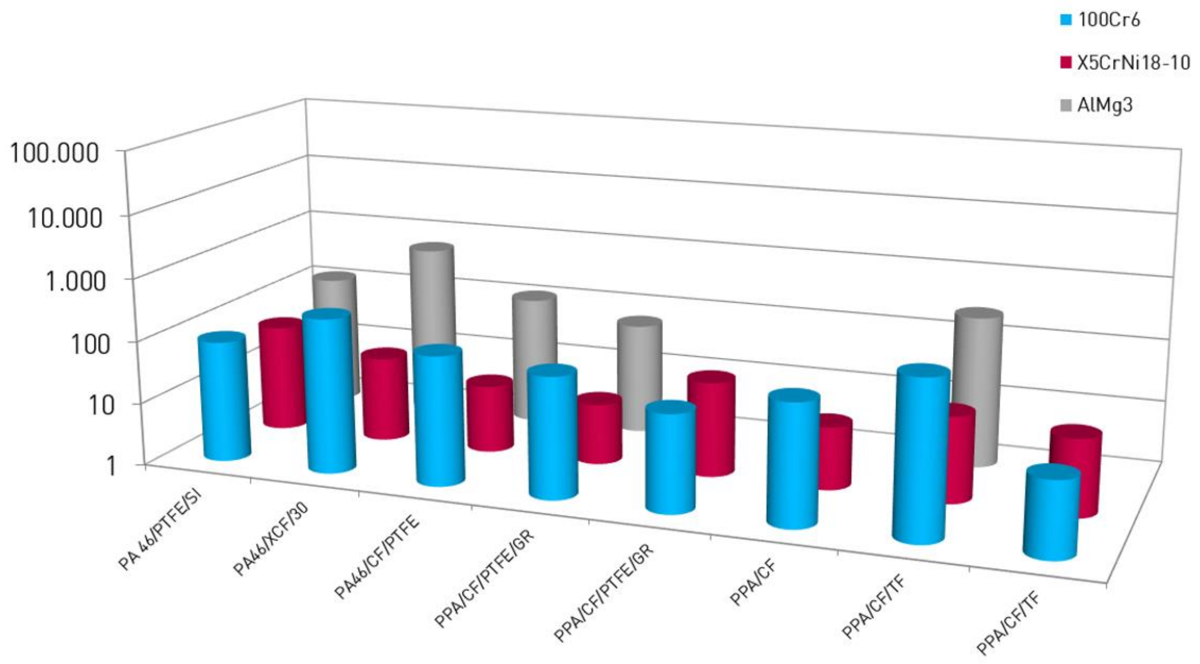
Influence of temperature on coefficients of friction of tribological compounds. Test at room temperature and at 150 °C, mating partner steel 100Cr6, pin-on-disc tribometer, V = 1 m/s, p = 1 MPa, dry running conditions

The temperature also has a considerable influence on the specific wear rate. This can be seen in the next chart.



Influence of temperature on the specific war rate, V, (10^{-7} mm^3/Nm) of tribological compounds. Test at room temperature and at 150 °C, mating partner steel 100Cr6, pin-on-disc tribometer, V = 1 m/s, p = 1 MPa, dry running conditions

The previously described influence of the material of the mating partner becomes clear in the following chart. Under identical test conditions, different metals result in different wear characteristics. It should be noted that the wear is very low for all the compounds listed. The compounds tested were based on PPA and PA46. Counteracting partners are 100Cr6, X5CrNi18-10 and AlMg3.



Principal influence of the counteracting partner on the specific wear rates of tribological compounds. Test at room temperature, sphere-prism tribometer, PA46 and PPA compounds

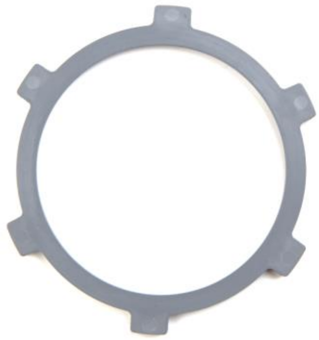
Sample applications

Every industry has specific applications and hence different requirements as well. Plastics are used in a large number of tribological applications. Providing a complete list is almost impossible. In the following, we list a number of examples and describe the most important requirements on typical components.

Application: Friction control disc
Market: Automotive
Requirements:

- Specific coefficients of friction
- Short running-in characteristics
- Low wear

Material in the example: PEEK with CF and nano-additives



Application: Friction bearing
Market: Mechanical engineering
Requirements:

- Low coefficients of friction
- Low wear
- Dry running characteristics

Materials in the example: PEEK, PPS, PA66 with CF and lubricants

Application: Bearing race
Market: Automotive
Requirements:

- Good creep resistance
- Low wear
- Chemical resistance

Material in the example: PBT with GF and lubricants

Application: Glide-ring sealing
Market: Automotive
Requirements:

- Coefficient of friction 0.3
- Short running-in characteristics
- Low wear

Materials in the example: PEEK and PPS with CF and lubricants

Application: Holder for optical lenses
Market: Precision instruments
Requirements:

- Specific coefficients of friction
- Short running-in characteristics
- Low wear

Material in the example: PC with CF and lubricants

Application: Coated pillar loop
Market: Automotive
Requirements:

- Lowest possible coefficients of friction
- High wear resistance
- Environmentally friendly coating

Materials in the example: Metal coated with lubricant-modified POM

Application: Bearing ring for seals
Market: Oil & gas industry
Requirements:

- High tensile strength and good impact strength
- High resistance to temperature and chemicals
- Good gap extrusion strength

Material in the example: PEEK with CF

LUVOCOM® product highlights

The following tables and information describe a selection of special product series and classical modifications of our LUVOCOM® high-performance compounds for tribological applications. The materials are optimized for various tribological systems and offer specific advantages. Application-related material adaptations are possible at any time. Further information, also on additional products and options from our company, is readily available on request.

LUVOCOM® - product series

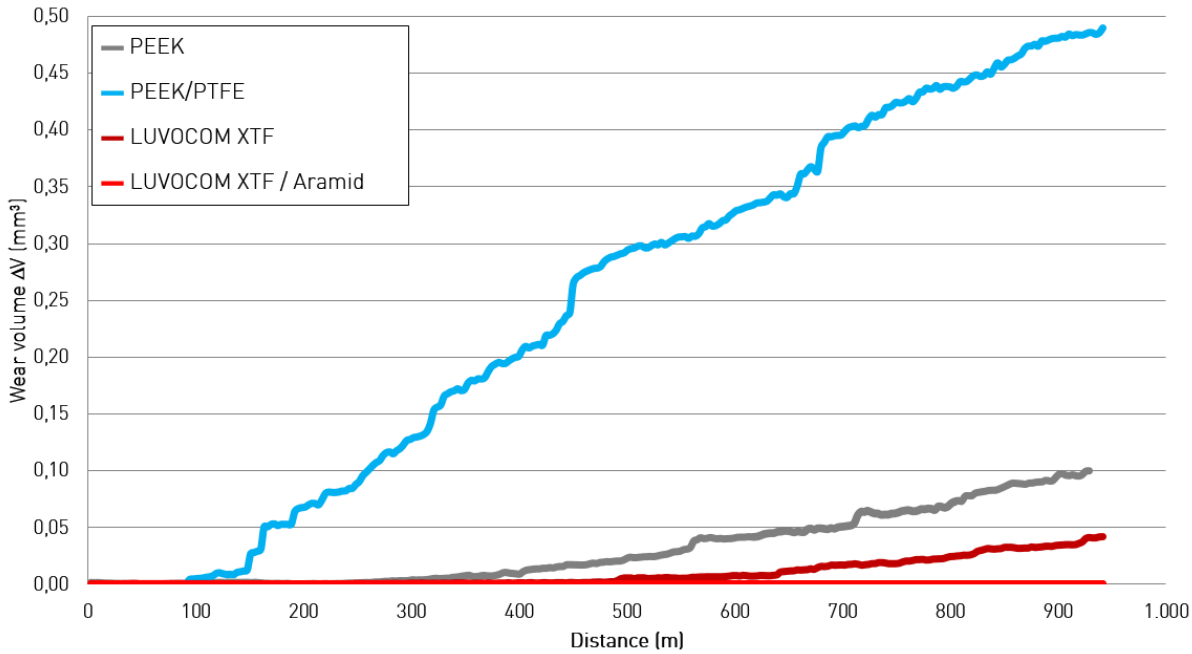
Product series	Main modification	What is optimized?	Typical polymers
LUVOCOM® XTF	Special PTFE	Wear	PPS, PEEK
LUVOCOM® 8000 Series	Nano-additives	Wear, friction	PA, PEEK
LUVOCOM® XSL	Oils	Wear, friction	POM, PA
LUVOCOM® P (coating powder)	PTFE	Wear, friction	POM, PBT
LUVOCOM® EOG	Fibers, lubricant package	Wear, tensile strength and isotropic properties	PAEK
LUVOCOM® XCF	Carbon fibers	Tensile strength, stiffness and impact strength	PA, POM, PPA, PPS, PAEK

LUVOCOM® - Classic modifications

Main modification	Explanatory note	Optimization	Typical polymers
TF	PTFE	Wear, friction	PC, PA, PBT, POM, PAEK
TF/SI	PTFE + SI	Wear, friction	PA, PBT, POM
GF/TF	Glass fibers + PTFE	Mechanical properties, wear, friction	PC, PA, PBT, PPS, PAEK
GF/TF/SI	Glass fibers + PTFE + silicone oil	Mechanical properties, wear, friction	PC, PA, PBT
CF/TF	Carbon fibers + PTFE	Mechanical properties, wear, friction	PA, PPS, PAEK
CF/TF/SI	Carbon fibers + PTFE + silicone oil	Mechanical properties, wear, friction	PC, PA, PBT
AF	Aramid fibers	Wear, tensile strength	PA, POM, PPS, PAEK
AF/TF	Aramid fibers + PTFE	Wear, tensile strength, friction	PA, POM, PPS, PAEK
AF/CF/TF	Aramid fibers + carbon fibres + PTFE	Wear, tensile strength, friction	PA, PPS, PAEK
CF/10/GR/10/ TF/10	10% each of carbon fibers, graphite, PTFE	Wear, friction, tensile strength	PPS, PAEK

LUVOCOM® XTF

With LUVOCOM® XTF we offer a product series that makes it possible to reduce component wear through the use of innovative raw materials and adapted process engineering. This is particularly so in the case of higher pressure and simultaneously lower speeds.



Wear volume of LUVOCOM XTF compounds compared with PEEK natural and PEEK with PTFE. Test: Pin-on-plate (oscillating) against 100Cr6 at room temperature

LUVOCOM® 8000 Series

The use of nano-scale additives now places previously unattainable properties within reach. Among other features, LUVOCOM® compounds of this series exhibit enhanced tribological properties. This is accomplished by using a host of different additives. Combining thermoplastics such as PEEK, PPS or PA 66 with special nano-additives makes it possible to create tribologically modified materials with higher wear resistance while maintaining a low coefficient of friction. Traditional solid lubricants, such as PTFE, are generally avoided in this process. The benefits are that the materials can be better processed and the finished product exhibits enhanced mechanical strength properties.

LUVOCOM® XSL

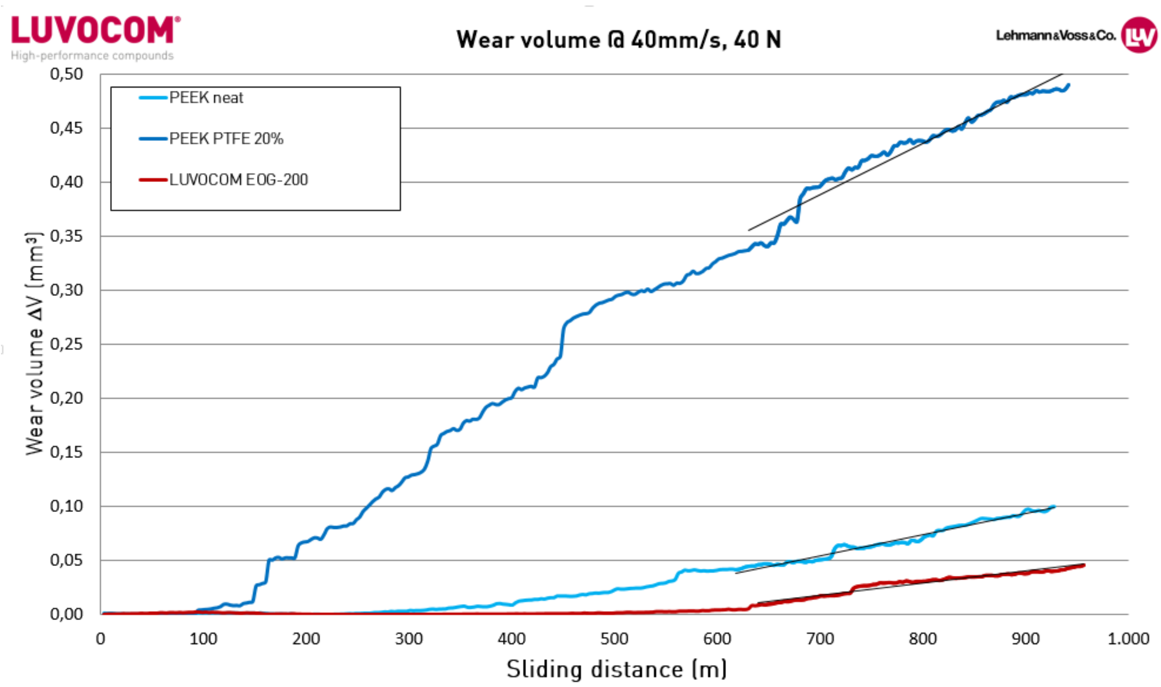
This product series, based on technical polymers such as POM and PA 6, offers especially low coefficients of friction, values down to 0.04 (under dry running conditions) have been achieved so far. This was otherwise only possible with an additional external lubrication. This makes it possible to implement applications in which good slip properties are essential and external lubrication is not desired or possible.

LUVOCOM® P

LUVOCOM® P compounds are powders for electrostatic processing methods. Compared with conventional thermosetting powder paints, thermoplastic materials offer significant advantages in many applications. The focus of LUVOCOM® P is on tribological varieties. It can be used to implement coatings with low coefficients of friction and wear values.

LUVOCOM® EOG

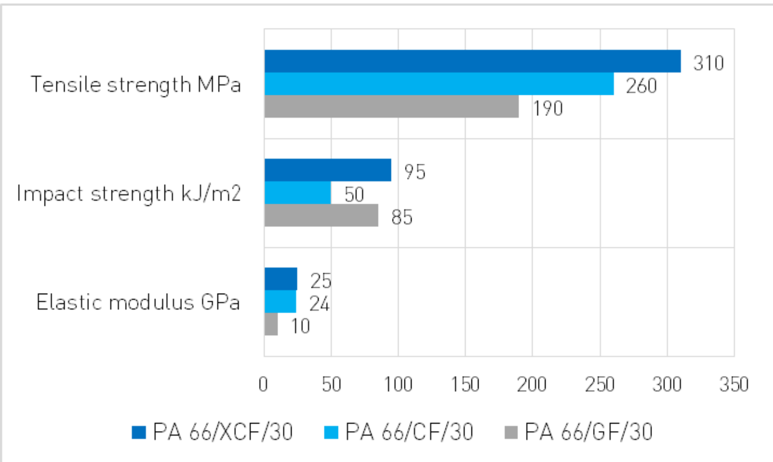
The oil and gas industry needs materials that exhibit a high resistance to temperature and chemicals, good mechanical strength and impact resistance but also excellent tribological properties. Applications include seals and bearing rings. The LUVOCOM® EOG product series has been developed especially for this purpose and exhibits, among other features, good wear resistance and isotropic mechanical characteristics.



Comparison of the wear characteristics of various materials based on PEEK with LUVOCOM EOG. Test at room temperature, SRV tribometer

LUVOCOM® XCF

By using high-performance CF and adapting the production process, we are able to supply LUVOCOM® XCF compounds with especially high strength values. Bending strengths of up to 530 MPa and tensile moduli of up to 52 GPa have been achieved. High strengths are generally an advantage for components in tribological applications. They often lead to higher wear resistance.



Comparison of reinforced PA 66 compounds. LUVOCOM XCF exhibits high strengths combined with high impact resistance compared with classic PA 66 with CF and PA 66 with GF

Summary

The key notes in brief:

- Tribological applications demand materials precisely tuned to the purpose (application-specific development)
- The requirements on the tribological system have to be known
- Material selection is made on the basis of data, investigations, comparison and experience
- Tribological properties indicated in data sheets such as coefficient of friction and wear rate vary according to the system and are only useful for comparing individual materials; they cannot be simply applied in design calculations
- Quality and processing of the material used play a decisive role in the efficiency of the tribological system

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Our expertise in materials

LEHVOSS Group

Further information, brochures and data sheets are available from **www.luvocom.com**

12/2021