DESIGNING WITH ENGINEERING

PLASTICS

with survey tables

Licharz
engineering plastics

DIN EN ISO 9001:2015

Certified quality management
system according

Updated 01/2019
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This list renders all previous versions null and void!

Contents

Foreword

Engineering plastics are becoming increasingly popular in machine and equipment design as design engineers recognise their advantages and economic significance.

The use and development of materials is subject to continuous change. This also applies to plastics. Many machined parts that were manufactured exclusively from conventional metals just ten years ago are now being made from modern engineered plastics.

This change is expected to continue in the future – perhaps at an even faster pace than experienced to date. This change can be attributed to the enormous rise in the number of engineering plastics available along with their many different modifications, characteristics and possible applications. Due to their specific properties, many plastics are equal or superior in countless ways to conventional design materials. In many cases, engineering plastics have already replaced conventional materials due to their superior performance properties.

The main advantages of engineering plastics in comparison to conventional metals are: weight reduction, resistance to wear, good vibration absorption and the fact that plastics are easier to machine. Additionally, their high level of chemical resistance, the increasing thermal strength of several types of plastic and improved recycling possibilities are further positive arguments for deciding on engineering plastics.

The task of design engineers will increasingly be to find an optimal material for a specific application while keeping production costs down.

Often there is a lack of awareness regarding the actual volume prices of plastics compared to conventional metal materials. Even high quality modified polyamides can be less expensive than many types of metals. In addition, the much higher chip removal capacity when plastics are machined is another factor that influences the price/performance ratio in comparison to metals.

The experience that LICHARZ has gained during the last 50 years in manufacturing, machining and utilizing engineering plastics for machine and equipment design, automotive industry applications and other areas has made it one of the leading companies of its kind in Europe. Over the years, we have come to focus on applications that are subject to slide and wear stresses.

The majority of semi-finished products described in this document, in particular all variants of cast polyamides and finished parts, are produced in our plant or manufactured by us on cutting edge CNC controlled machines.

In order to make it easier for design engineers and users to determine which plastic is best for their specific applications, we have summarised our experience in the form of material descriptions and design and machining information in this brochure.

Material overview

The most important engineering plastics are:
Polyamide (PA)
Polyacetal (POM)
Polyethylene terephthalate (PET)

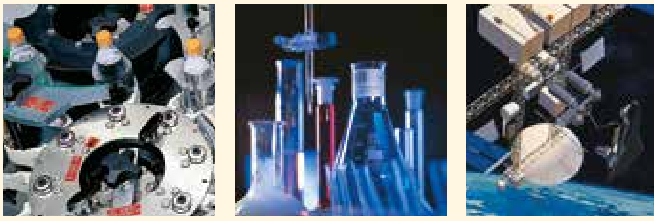
They are used in their diverse material modifications for components that are subject to sliding and wear loads.

A variety of other plastics are only partially suitable for sliding applications. They are used where special requirements such as chemical resistance or transparency are required.

These include:
Polyethylene (PE)
Polypropylene (PP)
Polyvinylchloride (PVC)
Polycarbonate (PC)

High-performance plastics are another group of modern materials that are characterised by their high level of rigidity and strength at high temperatures. The disadvantage is the high price, which in some cases can be as much as 30 times the cost of engineering plastics.

High-performance plastics include:
Polyvinylidene fluoride (PVDF)
Polytetrafluoroethylene (PTFE)
Polyetherketone (PEEK)
Polysulfone (PSU)
Polyetherimide (PEI)



Product overview

Product	Material
LiNNOTAM	PA 6 C
LiNNOTAM MoS	PA 6 C + MoS2
LiNNOTAM CC	PA 6 C-CC
LiNNOTAM HS	PA 6 C-WS
LiNNOTAM*GLiDE*	PA 6 C + Oil
LiNNOTAM*GLiDE PRO T*	PA 6 C + solid lubricant
LiNNOTAM*DRiVE 600 Fe*	PA 6 C + impact modified + steel core
LiNNOTAM*DRiVE 612 Fe*	PA 6/12 G + steel core
LiNNOTAM*DRiVE 1200 Fe*	PA 12 G + steel core
LiNNOTAM*HiPERFORMANCE 600*	PA 6 C + impact modified
LiNNOTAM*HiPERFORMANCE 612*	PA 6/12 G
LiNNOTAM*HiPERFORMANCE 1200*	PA 12 G
Polyamide 6	PA 6
Polyamide 66	PA 66
Polyamide 66 + Glass fibre	PA 66 GF 30
Polyamide 12	PA 12
Polyacetal Copolymer	POM-C
Polyacetal Copolymer glass fibre	POM-C GF 30
Polyethylene terephthalate	PET
Polyethylene terephthalate + Solid lubricant	PET-GL
Polytetrafluoroethylene	PTFE
Polyvinyl difluoride	PVDF
Polyethylene 1,000	PE-UHMW
Polypropylene Homopolymer	PP-H
Polyvinylchloride	PVC-U
Polyetherketone	PEEK
Polyetherketone (modified)	PEEK-GL
Polysulfone	PSU
Polyether amide	PEI

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POLYAMIDES

The competitive edge through engineered components made of plastic

The material

Polyamides are subdivided into various basic types. PA 6, PA 66 and PA 12 have established themselves as the most important for technical applications. Apart from the standard versions there are a large number of polyamides from which the basic types are specifically treated with additives for the requirements of special applications.

In the production of semi-finished products, a distinction is made between the manufacturing processes of extrusion and casting. The performance of extruded polyamide semi-finished products, however, has various disadvantages. The limits of manufacturing size are reached quickly. In addition the properties of the extruded materials are negatively affected because this process remolds the materials under temperature/pressure. The extrusion screw and tooling also cause shearing stress and breaks in the polymer matrix. Polyamides manufactured in monomer casting show a higher degree of crystallinity and thus have much better material properties than the extruded types.

In any case, all polyamides share, independently of their manufacturing process, a large number of basic properties specific to the material.

The key properties of polyamide are:
- High mechanical strength, hardness, rigidity and toughness
- High mechanical damping properties
- Good fatigue resistance
- Very high wear resistance
- Good sliding and emergency running properties
- Good machining properties

Extruded polyamides

Polyamide 6 (PA 6) is the best known extruded polyamide and offers a balanced combination of all typical polyamide material properties. Compared to the cast variants however, it absorbs more moisture, has much lower wear resistance and less dimensional strength. Furthermore, because of the manufacturing process, only a limited size range and unit weight can be produced. This restricts the design possibilities of the user.

The main properties of PA 6 are:
- Good mechanical strength
- high impact resistance
- good damping properties

Typical application examples are:
- Gears
- hammer heads
- impact and shock resistant components

Polyamide 66 (PA 66)

is used in smaller dimensioned applications and offers higher rigidity and wear resistance compared to PA 6. Compared to the cast variants, this material also displays higher water absorption. As regards to the other properties, PA 66 is comparable to the standard cast type **LiNNOTAM**, but is far more expensive. As with PA 6, the manufacturing process limits the size and unit weight which can be produced, and this restricts the user's design possibilities. Therefore PA 66 in practical application is replaced to a large extent by the more economical **LiNNOTAM**, which can also be produced in almost unlimited weights and sizes.

The main properties of PA 6 are:
- Good mechanical strength
- high impact resistance
- good damping properties
- good wear resistance

Typical application examples are:
- Friction bearings
- slide plates
- gears

Polyamide 66 + 30% Glass fibre (PA 66 GF 30)

Compared to unreinforced PA 66 an improved tensile/compressive strength, rigidity and dimensional stability are achieved due to the glass fibre as well as lower water absorption. Glass fibre reinforced Polyamide 66 is therefore particularly suitable for components where higher loads occur and/or increased demands are placed on the dimensional stability.

Polyamide 12

has very good impact behaviour, it is tough and is dimensionally stable due to its very low water absorption. It is available in small quantities as semi-finished products, but is not generally considered for construction applications due to its high price (3-4 times more expensive than PA 6).

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LiNNOTAM

The competitive edge through engineered components made of plastic

Cast polyamides

Cast polyamide is a partially crystalline thermoplastic which is produced by means of anionic polymerisation of the raw material Caprolactam. In a pressureless casting process the liquid monomer is polymerised via a controlled chemical reaction directly to a semi-finished product or mould. **LiNNOTAM** is the new brand name of the exceptionally effective cast polyamides from LICHARZ.

Polyamides from the **LiNNOTAM** brand produced by means of this process
- are mostly free of internal stresses
- display a high degree of crystallinity
- can be manufactured as semi-finished shape or near net shape component
- can be machined to almost any form
- can be manufactured in almost unlimited weights and dimensions

By means of additives, e.g. oil, solid lubricants or heat stabilisers, and modifications to the polymer matrix, the typical properties of cast polyamide can be aligned and adjusted for specific applications. Thus a tailor-made range of material can be offered for a wide scope of applications.

LiNNOTAM is available in four other versions:

LiNNOTAM*GLiDE*: Optimum anti-friction characteristics over the entire service lifetime.

LiNNOTAM*HiPERFORMANCE*: The high-performance triple: dimensionally stable, fatigue-resistant, with excellent damping. Versions designed for special requirements include, for example, low water absorption, good resistance to hydrolysis and high impact strength.

LiNNOTAM*DRIVE:* Ideally suited for the transmission of power and torque.

LiNNOTAM*CUSTOM*: Your requirements are unique and individual. Ask us. We have the technical capabilities, the experience and the capacity to develop the perfect solution.

Further special settings can be made and delivered on request.

LiNNOTAM
Standard quality for high wear demands on parts in machine and plant engineering.
Colours: natural, black, blue

Due to its balanced mechanical properties and its excellent mechanical features this standard quality manufactured in a monomer casting process is the ideal construction material for a wide range of applications.

LiNNOTAM offers compelling advantages compared to extruded polyamide 6 due to

- better mechanical strength
- lower moisture absorption
- better creep resistance
- better dimensional stability
- higher wear resistance

Very good friction characteristics
make **LiNNOTAM** a classic friction bearing material for highly loaded machine parts. These include bushings, slide and guide plates as well as gears and sprockets. Generally, an initial lubrication during assembly is sufficient due to the low coefficient of friction. In many cases lubrication can be dispensed with altogether.

High abrasion and wear resistance
at low to medium speeds, in particular under demanding conditions (e.g. dust or sand in the bearing), complete the scope of **LiNNOTAM** as a friction bearing material. Under demanding conditions a significantly longer service life can be achieved compared to conventional bearing materials such as cast iron, steel or bronze.

Good damping properties
for the reduction of vibration and noise is of particular interest when using ropes and sheaves. **LiNNOTAM** reduces the vibrations that are transferred from metallic rollers via the roller to the bearing, bearing to the shaft and from there to the machine frame. Friction bearings made of **LiNNOTAM** reduce the vibrations affecting the machine frame. This results in the prolongation of the service life of the machine and machine components. Furthermore, measures to reduce the operating noise level of the machine are supported and enhanced.

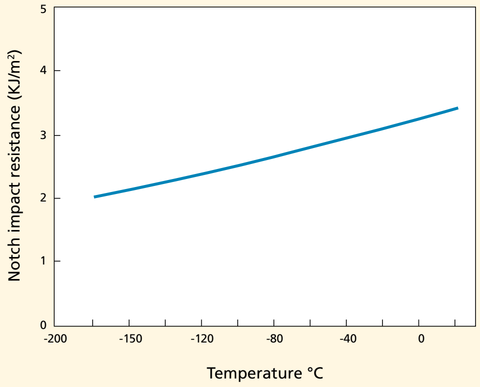
Low specific weight
Component weight is less compared to metallic materials. This is of particular interest when centrifugal forces result from rotating components. These centrifugal forces are considerably reduced due to the lower component weight, resulting in fewer imbalances and accompanying vibrations. Often the significant weight reduction also lessens the required drive power and the handling and assembly of large parts is made much easier.

Good machinability, dimensional stability and low residual stress
enable the manufacture of complex components and the use in all areas of design. Machining can be performed with standard tools and conventional machines for working wood and metal. High feed rates and cutting speeds facilitate cost-effective production.

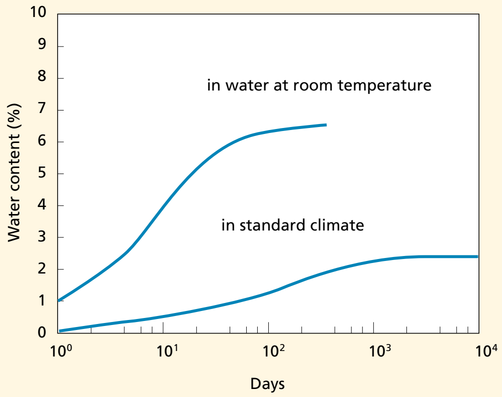
Changes in material properties

due to temperature, environmental conditions and moisture content must be taken into account. An increase in temperature coupled with high moisture content makes the material elastic. Tensile and compressive strength as well as the modulus of elasticity and hardness decrease. Simultaneously, the impact strength and elongation increases. The material assumes a strong, tough, elastic character. The change in length at elevated temperature or increased water content must also be considered. The following charts illustrate the relationship.

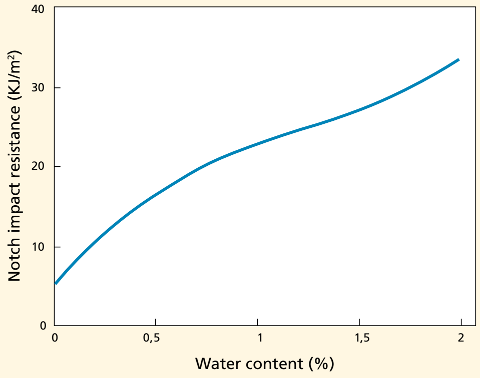
Notch impact resistance
of **LiNNOTAM** at low temperatures



Water absorption
of **LiNNOTAM** in water at room temperature and standard climate (Test piece: standard small rod)



Notch impact resistance
of **LiNNOTAM** with different water contents



LiNNOTAM HS
Primarily comparable to the standard quality but with the heat aging stabiliser it is better protected against thermal-oxidative degradation.
Colour: black.

LiNNOTAM MoS
Primarily comparable to the standard quality, however the molybdenum disulphide gives increased crystallinity.
Colour: black, anthracite.

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LiNNOTAMGLiDE

The competitive edge through engineered components made of plastic

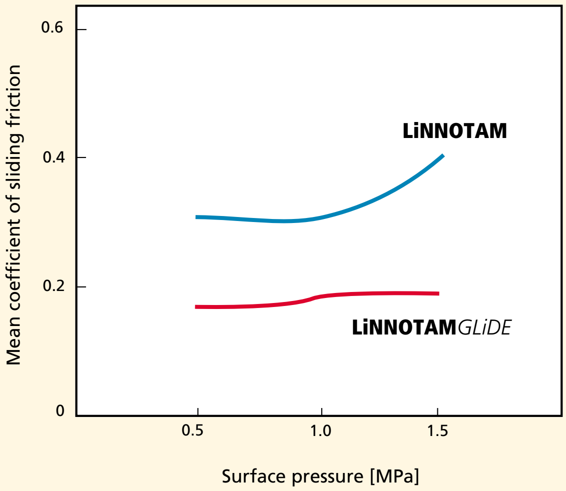
LiNNOTAM*GLiDE* is a high crystalline modification of **LiNNOTAM**, manufactured in the monomer casting process which, through the addition of oil and active lubricating additives, is specially designed for sliding applications. Contrary to the standard quality **LiNNOTAM**, **LiNNOTAM***GLiDE* features a unique combination of properties.

Excellent sliding properties

make **LiNNOTAM***GLiDE* a special friction bearing material for highly loaded slide and wear parts in machines and equipment. Due to the lubrication and additives in the material, a sustainable lubricating effect is achieved for the whole life cycle. A 50% reduction in friction is achieved in comparison to the standard quality, thus producing less frictional heat and considerably higher peak load capacity. Also the undesirable stick-slip tendency is reduced.

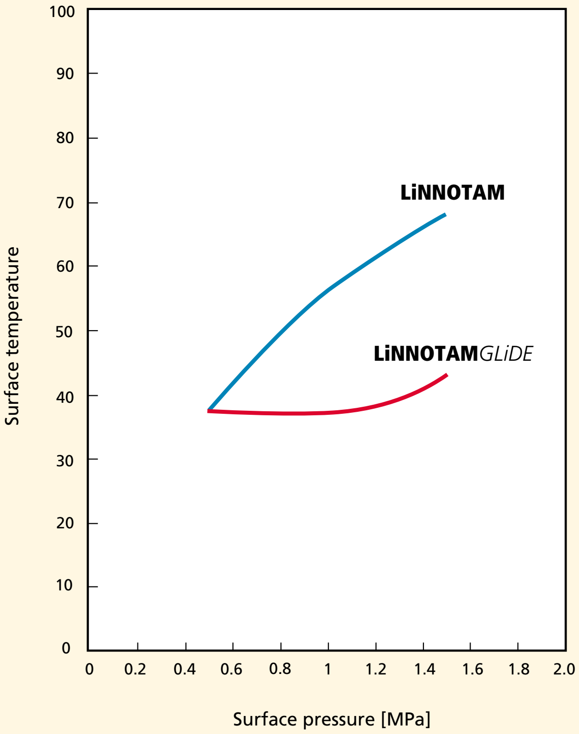
Coefficient of sliding friction of **LiNNOTAM** and **LiNNOTAM***GLiDE*

Friction ring ST 50 K (v = 1m/s)



Surface temperature after 1 hour Sliding friction of **LiNNOTAM** and **LiNNOTAM***GLiDE*

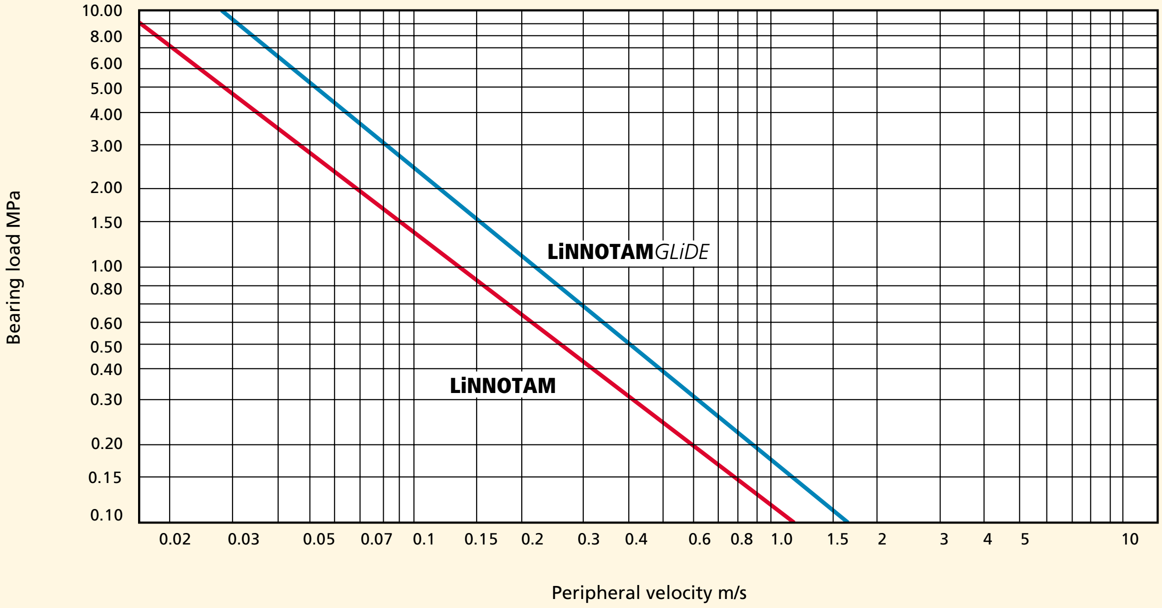
Friction ring ST 50 K (v = 1m/s)



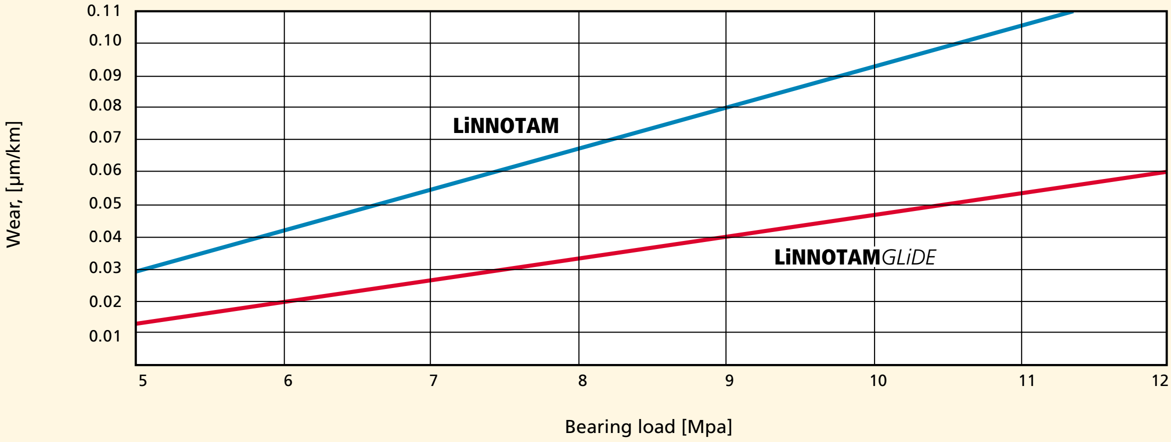
Extraordinary wear resistance

is achieved by the fine crystal microstructure of **LiNNOTAM***GLiDE*. Compared with standard quality, the reduced frictional heat as well as the reduced friction coefficient makes application possible at higher speeds and surface pressures. This applies not only for dry running and lack of lubrication but also for running under emergency conditions.

LiNNOTAM*GLiDE*/**LiNNOTAM** load limit

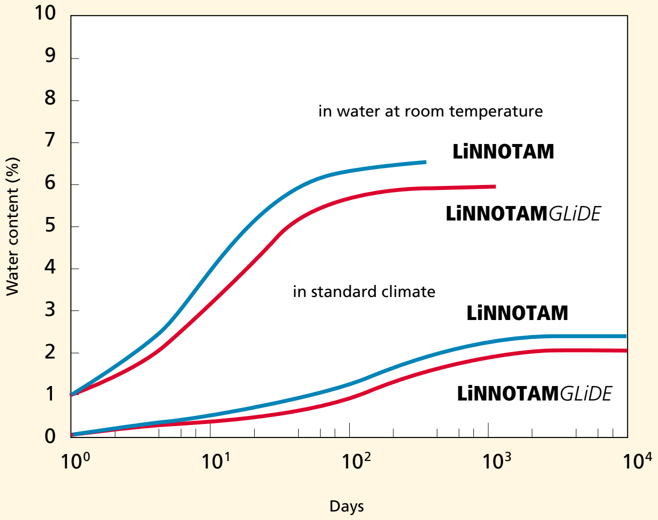


LiNNOTAM*GLiDE*/**LiNNOTAM** wear rate



Reduced moisture absorption and dimensional stability
are achieved with **LiNNOTAM***GLiDE* due to its highly crystalline molecular structure and specific additives. In comparison to standard quality materials the low moisture absorption results in improved dimensional stability and lower moisture related deterioration of mechanical values.

LiNNOTAM*DRiVE*/**LiNNOTAM** water absorption



Applications and examples
The key applications of **LiNNOTAM***GLiDE* are in conveyor and transport technology as well as in machine engineering, equipment design and the automotive industry. **LiNNOTAM***GLiDE* components are of particular advantage in the area of filling, labelling and packaging machines.

LiNNOTAM*GLiDE* meets the requirements of Regulation (EU) No 10/2011 and the requirements of 21 CFR § 177.1500 of the FDA and may be used for the manufacture of consumer goods that come into direct contact with foodstuffs.

Typical applications are:
- Bearings
- Guide rails
- Sprockets and chain guides
- Slide rails
- Feeder wheels
- Actuators
- Curve guides
- Gears

LiNNOTAM*GLiDE*
LiNNOTAM with built-in oil lubrication, self-lubricating effect, improved wear resistance.
Colours: black, yellow, natural.

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LiNNOTAM*GLiDE PRO T*

The competitive edge through engineered components made of plastic

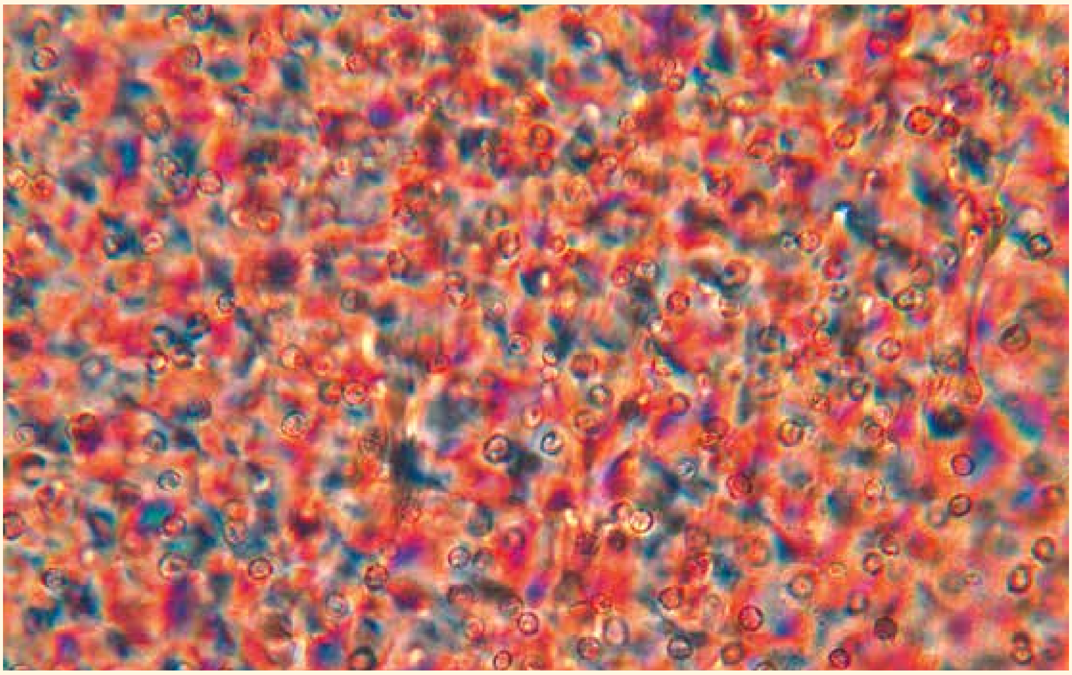
LiNNOTAM*GLiDE PRO T* is a polyamide manufactured in the monomer casting process based on **LiNNOTAM**, and with the addition of solid lubricants and special additives is particularly suitable for sliding applications. It complements the bearing materials product line and has maximum wear resistance and long life.

Exceptionally low sliding friction coefficient

The integrated lubricants in **LiNNOTAM***GLiDE PRO T* are carefully selected with a focus on the sliding properties. The balanced composition of the material formula allows for a friction coefficient of 0.15 µ which is extraordinarily low. Furthermore, the tendency for stick-slip is reliably reduced to a minimum.

Homogeneous structure

The microtome of **LiNNOTAM***GLiDE PRO T* in polarized light magnified 250x illustrates the uniform microstructure.

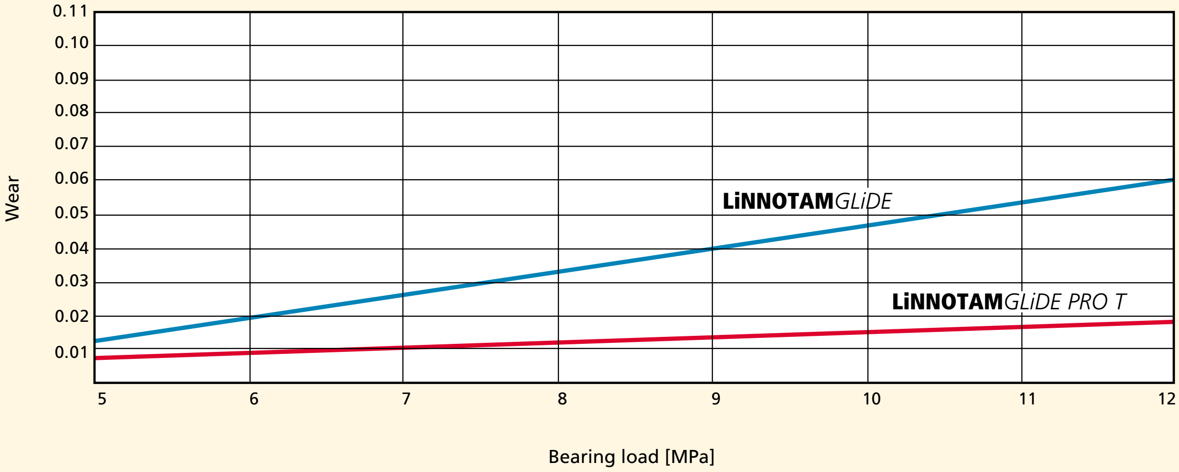


LiNNOTAM*GLiDE PRO T*

Material characteristics

In addition to high strength the fundamental characteristics and performance of this material are of particular importance: the self-lubricating effect and the sliding characteristics remain permanently and uniformly stable throughout the lifetime. Considerably better friction and wear values are realized compared with the unfilled **LiNNOTAM** and the oil-filled variant **LiNNOTAM***GLiDE*. The combination of the properties of **LiNNOTAM***GLiDE PRO T* make this material the first choice for highly loaded sliding and wear parts when lubrication of components is difficult, impossible or undesirable.

LiNNOTAM*GLiDE PRO T*/**LiNNOTAM***GLiDE* wear rate



Application areas

for **LiNNOTAM***GLiDE PRO T* are in particular machine engineering and equipment design as well as drive and conveyor technology. Due to the carefully chosen raw materials **LiNNOTAM***GLiDE PRO T* is available in FDA compliant quality and fulfils the requirements of Regulation (EU) No 10/2011 and the requirements of 21 CFR § 177.1500 of the FDA in almost all applications.

Typical applications:

- Bearing bushes
- Curve guides
- Slide and guide plates
- Castors
- Gears and sprockets

LiNNOTAM*GLiDE PRO T*

The finely dispersed solid lubricant contained in the material ensures self-lubricating properties.
Excellent wear resistance is achieved at very low coefficient of friction.
Colours: grey, green, red.

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LiNNOTAM*HiPERFORMANCE*

The competitive edge through engineered components made of plastic

LiNNOTAM*HiPERFORMANCE 612* (PA 6/12 G) is a co-polyamide mix manufactured by static casting from the raw materials caprolactam and laurinlactam. Compared to pure **LiNNOTAM** it has a higher shock and impact resistance as well as lower tendency to absorb moisture, but retains the same gliding and wear properties. In addition, the material is characterised by improved creep resistance and higher elasticity. **LiNNOTAM***HiPERFORMANCE 612* because of its tough and hard material characteristics is the ideal material for applications where increased shock and vibration load is expected or there are increased demands on fatigue strength or elasticity.

Typical applications are:
- Gears wheels
- Racks
- Pinions
- Rollers with long idle times
- Crane support pads

LiNNOTAM*HiPERFORMANCE 1200* (PA 12 G) is manufactured from the raw material laurinlactam based on the anionic reaction in the unpressurized gravity casting process. The process produces a material with high molecular weight that is highly crystalline and largely stress-free, which gives **LiNNOTAM***HiPERFORMANCE 1200* outstanding properties compared to other polyamides.

The main advantages are:
- extremely low water absorption (max. 0.9% in standard climate conditions 25/50)
- excellent dimensional stability and stable mechanical characteristics
- excellent damping of mechanical vibrations
- high toughness at temperatures as low as -50 °C
- very good wear resistance
- very good friction and dry running properties
- low specific weight
- good chemical and hydrolysis resistance
- resistant to stress cracking

These properties make **LiNNOTAM***HiPERFORMANCE 1200* the ideal partner for applications in conveyor and drive engineering.

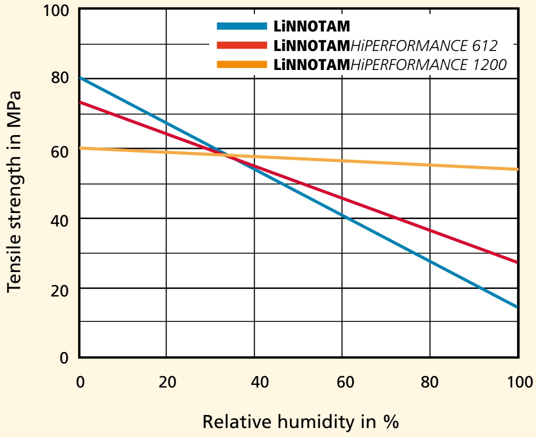
Material characteristics
Due to the highly crystalline molecular structure, material properties are created which are far superior to those of conventional polyamides in many ways. The properties typical for polyamides and appreciated by users are thus mostly retained, e.g. wear resistance/ abrasion resistance and the good sliding properties, and are further supported by the special molecular structure.

The main difference to the conventional polyamides is considered to be the tough material characteristics. The **LiNNOTAM***HiPERFORMANCE* materials exhibit a hardness which is essential for many technical applications, without becoming brittle and breakable. At the same time a high degree of toughness is assured.

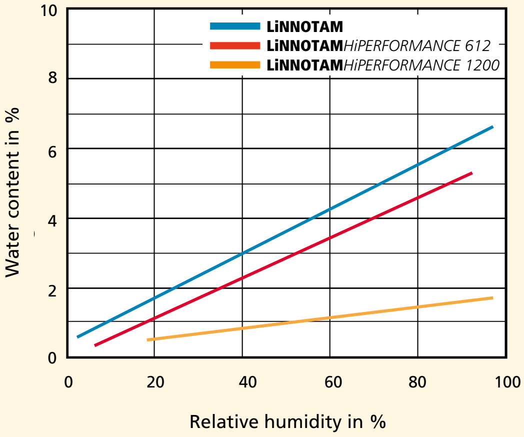
A further important feature is the low moisture absorption from ambient air. Swelling, which is common to polyamides due to moisture from the environment, is minimised, and the dimensional stability of engineered parts is considerably improved. Where **LiNNOTAM***HiPERFORMANCE 1200* is used, dimensional changes due to moisture absorption can even be ignored, since in normal climate conditions 23/50 it absorbs a maximum of 0.9% moisture and only 1.5% to saturation in water. It is also used in many technical applications where hardness is a priority without becoming brittle and prone to breakage. At the same time a high toughness is assured. Furthermore the loss of rigidity due to moisture absorption is insignificant. Thus **LiNNOTAM***HiPERFORMANCE 1200* is extremely suitable for engineered components for which the special properties of polyamide are essential and long term stability is required.

Both materials also feature improved creep resistance, higher elasticity and very good wear resistance. Furthermore their excellent mechanical damping qualities and high degree of toughness even at low temperatures are impressive.

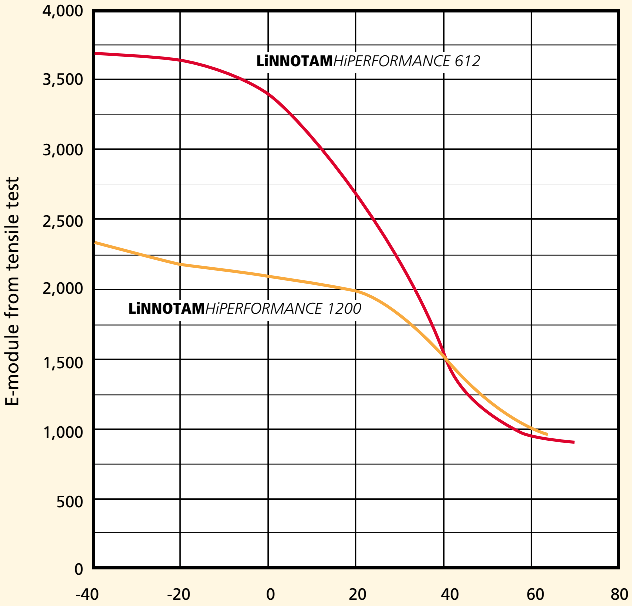
Loss of rigidity due to water absorption



Water absorption when stored in air



E-module at different temperatures



LiNNOTAM*HiPERFORMANCE 612*
Co-polyamide on the basis of PA 6/12 G with greater impact resistance, less water absorption and improved creep resistance compared to pure **LiNNOTAM**.
Colour: natural, black.

LiNNOTAM*HiPERFORMANCE 1200*
Cast polyamide from raw material Laurinlactam. Very good impact resistance, toughness, excellent dimensional stability, lowest water absorption, very good creep resistance, hydrolysis resistance, good chemical resistance.
Colour: natural, black.

Drive elements often transmit high torque, and to generate this high power, loads must be transmitted to the elements via the shaft-hub connection. In principle engineering plastics are suitable for these purposes. However, pure plastic designs often reach their limits in such cases. The allowable surface pressure in the keyway is often exceeded or the hubs become distorted under the high load. Furthermore, plastics are susceptible to notching, so that in extreme situations there is a danger that the groove in the side under load will give way. Further problems often arise when tolerances are required which are not possible with plastic designs.

This is where the material varieties of **LiNNOTAM***DRiVE*, which have been developed for just these applications, come into use. The combination of **LiNNOTAM***DRiVE* materials with a metal core combines the advantages and specific properties of both materials in an unusual design material. The knurled metal core is completely covered with a low viscosity melt generated in the monomer casting process. After casting, the polymer cools down and shrinks onto the metal core. A powerful bond exists between the core and the mantle, which assures optimal and dependable transmission of power.

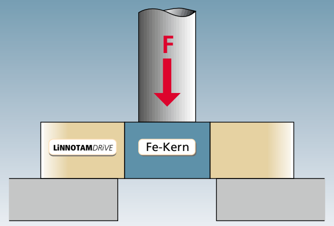
Due to the surface structure of the metal core, a safeguard against radial and lateral slip is assured. The mantle consists of **LiNNOTAM***HiPERFORMANCE 612* or **LiNNOTAM***HiPERFORMANCE 1200*.

Typical applications of **LiNNOTAM***DRiVE* construction materials are:
- Gears:
  - spur gears
  - worm gears
  - bevel gears
- Sprockets
- Castors, guide rollers and sheaves
- Cams
- Agitator blades
- Pump impellers

In addition to the advantages over **LiNNOTAM***HiPERFORMANCE*, these composites are also impressive due to:
- plastic/metal compound
- optimal power and torque transmission
- reliable transmission of high axle power and torque
- calculation and manufacture of the shaft/hub connection with traditional processes and tolerances for metal
- lower momentum mass compared to purely steel constructions
- high level of running accuracy

Practice has shown that with this surface characteristic, power and torque transmission with plastic is successful and sufficiently high power/torque values can be transmitted. Practical results are also supported by the compression and torsion tests shown in fig. 1 and 2.

Axial load experiment



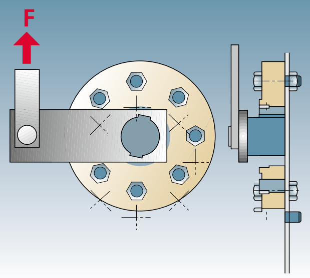
Material:	**LiNNOTAM***DRiVE*
Steel core:	Ø 60 mm x 38 mm
LiNNOTAM*DRiVE*-disk:	Ø 140 mm x 38 mm
Knurl:	Axial and circumferential knurl, DIN 82-RGE 2,5
Material steel:	Machining steel 9 SMn 28K

Result of axial load:

Max. axial load:	**100 kN**

Fig. 1 Axial load test

Torque transmission test



Material:	**LiNNOTAM***DRiVE*
Steel core:	Ø 80 mm x 20 mm
LiNNOTAM*DRiVE*-disk:	Ø 200 mm x 33 mm
Knurl:	Axial and circumferential knurl, DIN 82-RGE 2,5
Material steel:	Machining steel 9 SMn 28K

Result of torque transmission:

Max. torque:	**4,45 kNm**

Fig. 2 Torque transmission test

LiNNOTAM*DRiVE Fe* is equipped as standard with a machining steel 9 SMn 28 K as core material.

Other core materials possible are:

- Stainless steel
  - V2A (1.4305)
  - V4A (1.4571)
- Aluminium
- Brass

Other core materials are possible on request.

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POM/PET

The competitive edge through engineered components made of plastic

Polyacetal (POM)

Polyacetal is a high crystalline thermoplastic with high strength and rigidity as well as good sliding properties and wear resistance with a low level of moisture absorption. Its good dimensional stability, exceptional fatigue resistance as well as excellent machining properties make Polyacetal a versatile design material also for complex components. POM satisfies high surface finish requirements.

Strength, rigidity and dimensional stability can be further improved by adding glass fibres as a filler, although this decreases sliding properties.

A distinction is made between homopolymers (POM-H) and copolymers (POM-C); homopolymers have a higher density, hardness and strength due to their higher degree of crystallinity. However, copolymers have a higher impact resistance, greater abrasion resistance and better thermal/chemical resistance.

The Polyacetal semi-finished products that we offer – from which we also manufacture finished products – are produced from copolymers in an extrusion process.

Main properties

- High strength
- High rigidity
- High hardness
- Good impact resistance, also at low temperatures
- Low level of moisture absorption (at saturation 0.8%)
- Good creep resistance
- High dimensional stability
- Resistant to hydrolysis (up to +60 °C)
- Physiologically safe

Colours

POM-C: natural/black
POM-C + GF: black.

Sliding properties

POM-C has excellent sliding properties and good wear resistance. Combined with its other outstanding properties, POM-C is well suited for use in sliding applications at medium to high loads. This also applies to applications where high levels of humidity or moisture are expected.

Due to the closely spaced static and dynamic coefficient of friction low starting torques can be implemented.
Glass filled types are the exception here as the sliding properties are significantly worse compared to the unfilled types.

Weathering effects

POM-C is not resistant to UV rays. The surface oxidizes when subjected to UV radiation in combination with oxygen and becomes stained or dull. With long-term exposure to UV radiation, the material tends to become brittle.

Chemical resistance

POM is resistant to weak acids, weak and strong alkaline solutions, organic solvents and petrol, benzene, oils and alcohols.

POM-C is not resistant to strong acids (pH < 4) or oxidising materials.

Behaviour in fire

POM-C is rated as normal flammable. When the source of ignition is removed, POM-C continues to burn, forming droplets. During thermal decomposition, formaldehyde can form. The oxygen index (= the oxygen concentration required for combustion) at 15% is very low compared to other plastics.

Areas of use

- General machine engineering
- Vehicle construction
- Precision mechanics
- Electrical industry
- Information technology

Applications

- Spring elements
- Bushes
- Gears
- Sliding elements
- Insulators
- Pump components
- Casing parts
- Valves and valve bodies
- Counter parts
- Precision parts

Machining

POM-C develops a fragmented chip and is thus ideally suited for machining on automatic lathes, but it is also possible to machine it on cutting machine tools. The semi-finished products can be drilled, milled, sawed, planed and turned on a lathe. It is also possible to cut threads or insert threaded parts in the material. Generally no cooling or lubricating emulsion is necessary.

To limit material deformation due to internal residual stress in semi-finished products, the parts should always be machined from the geometrical centre of the semi-finished product, removing an even quantity of material from all sides.

If maximum dimensional stability is demanded from the finished components, the parts to be manufactured should be rough pre-machined and stored for an interim period or heat treated. The parts can then be completed. More detailed information on interim storage and heat treatment, as well as other information about machining, is provided in the chapter on “Machining guidelines”.

Polyethylene terephthalate (PET)

The molecule structure of polyethylene terephthalate can be produced either as an amorphous or semi-crystalline thermoplastic. The amorphous type is crystal clear with lower mechanical stability and inferior sliding properties.

The semi-crystalline types, on the other hand, have a high level of hardness, rigidity and stability with excellent sliding properties and low sliding abrasion. Because of its good creep resistance, low level of moisture absorption and excellent dimensional stability, the material is ideally suited for complex parts with the highest demands on dimensional stability and surface finish. For the reasons mentioned above, only the semi-crystalline type is suitable for sliding applications.

The wear resistance and sliding properties of PET-GL have been improved compared to pure PET by adding a special, homogeneously distributed solid lubricating agent.

The PET semi-finished products that we offer – and from which we also manufacture all finished products – are manufactured from semi-crystalline types in an extrusion process.

Main properties

- High stability
- High rigidity
- High hardness
- Low moisture absorption (at saturation 0.5%)
- Very good creep resistance
- Very high dimensional stability
- Constantly low sliding friction
- Very little sliding abrasion
- Resistant to hydrolysis (up to +70 °C)
- Physiologically safe

Colours

PET: natural, black
PET-GL: light grey.

Sliding properties

PET has excellent sliding properties, very good wear resistance and, in combination with its other properties, is an excellent material for highly loaded sliding applications. This also applies to applications where high levels of humidity or moisture are expected.

The modified type PET-GL is especially suitable for highly loaded sliding applications in dry running operations due to its integrated solid lubricating agent. The solid lubricating agent “self-lubricates” the PET-GL, which gives it excellent sliding properties and highest wear resistance with a much higher load-bearing strength (pv limiting value) compared to pure PET. It also prevents the stick-slip effect. The other properties are equal to those of pure PET.

Weathering effects

PET is not resistant to UV rays. The material surface changes when subjected to UV rays in combination with atmospheric oxygen. If the material is to be subjected to UV rays for longer periods, a black coloured type is recommended.

Chemical resistance

PET is resistant to weak acids and alkaline solutions, salt solutions, perchlorinated and fluorinated hydrocarbons, oils, fuels, solvents and surface-active substances. Strong polar solvents have an irreversible swelling effect. PET is not resistant to strong acids or alkaline solutions, esters, ketones or chlorinated hydrocarbons.

Behaviour in fire

PET is rated as normal flammable. When the source of ignition is removed, PET continues to burn, forming droplets. The oxygen index (the oxygen concentration required for combustion) at 23% is average compared to other plastics.

Areas of use

- General machine engineering
- Vehicle construction
- Precision mechanics
- Electrical industry
- Information technology

Applications

- Ratchet wheels
- Bushes
- Gears
- Sliding elements
- Insulators
- Casing parts
- Counter components
- Precision bearings
- Cam disks

Machining

PET develops a brittle, flowing chip and is suitable for machining on automatic lathes, but it can also be machined on cutting machine tools. The semi-finished products can be drilled, milled, sawed, planed and turned on a lathe. It is also possible to cut a thread into the material or insert a threaded element. Generally no cooling or lubricating emulsion is necessary.

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STANDARD PLASTICS

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Polyethylene (PE)

Polyethylene is a semi-crystalline thermoplastic with high toughness and chemical resistance, but rather low mechanical strength in comparison to other plastics and cannot be used at high temperatures. The different polyethylenes differ in regard to their molar mass (molecular weight), which is important for the respective physical properties. This means that in addition to the common properties that all types have, certain ones have type-specific properties.

The polyethylene finished products that we offer consist of high density polyethylene types produced by extrusion or moulding processes.

Main properties

- Low density compared to other materials (0.94 g/cm^3)
- High impact resistance, also at low temperatures
- Minimum water absorption (< 0.01%)
- Excellent chemical resistance
- High corrosion resistance
- Anti-adhesive
- Very good electrical insulator
- High vibration absorption
- Physiologically safe (does not apply to regenerate semi-finished products)

Colours

PE-HD: natural, black
PE-HMW: natural, green
PE-UHMW: natural, green, black.
Other colours on request.

Sliding properties

PE-HD (PE 300; molar mass approx. 200,000 g/mol) is very suitable for welding due to its relatively low molar mass; however, it is not abrasion resistant and has low strength values. This leads to a high level of sliding abrasion, which excludes its use in sliding applications.

PE-HMW (PE 500; molar mass approx. 500,000 g/mol) has better sliding properties because of its higher molar mass and is also more abrasion resistant than PE-HD. In combination with its good level of toughness, it is suitable for use in low load components that are not subject to any high degree of sliding abrasion.

PE-UHMW (PE 1,000; molar mass approx. 4,500,000 g/mol). Because of its high molar mass it has very good wear resistance, bending strength and impact resistance and good noise absorption. Due to its excellent sliding properties and low sliding abrasion, it is the ideal material for lightly loaded components.

Both PE-HMW and PE-UHMW are also available as regenerated material, although it must be noted that the respective physical properties are slightly reduced.

Chemical resistance

All PE types are resistant to acids, alkaline solutions, salts and salt solutions, alcohols, oils, fats, waxes and many solvents. Aromatics and halogenated hydrocarbons cause swelling. All PE types are not resistant to strong oxidising materials (e.g. nitric acid, chromic acid or halogens), and there is a danger of stress corrosion cracking.

Weathering effects

As a general rule, no PE types are resistant to UV rays. This does not apply to the black coloured types, which are resistant to UV rays also in combination with atmospheric oxygen.

Behaviour in fire

All PE types are rated as normal flammable. When the source of ignition is removed they continue to burn and form droplets. However, apart from carbon dioxide, carbon monoxide and water, only small quantities of carbon black and molecular constituents of the plastic develop as conflagration gases. The oxygen index (the oxygen concentration required for combustion) at 18% is low compared to other plastics.

Areas of use

PE-HD
- Electroplating industry
- Chemical industry
- Chemical apparatus construction

PE-HMW
- Food industry
- Meat processing industry
- Sporting venue construction

PE-UHMW
- Electroplating industry
- General machine engineering
- Coal processing
- Packaging industry
- Conveying technology
- Paper industry
- Electrical industry

Applications

PE-HD
- Component parts in chemical equipment design
- Fittings
- Inserts
- Stacking boxes

PE-HMW
- Cutting table surfaces
- Agitator blades
- Wall linings in refrigeration rooms
- Impact bands
- Knife blocks

PE-UHMW
- Sheaves, guide rollers
- Sprocket wheels and pinions
- Gears
- Chain guides
- Slides
- Suction plates
- Roller knife and scrapers
- Chute linings for silos
- Conveyor trough linings
- Abrasion protection strips

Machining

In addition to the good welding properties of PE-HD and PE-HMW, all PE types can also be machined on machine tools. The semi-finished products can be drilled, milled, sawed, planed and turned on a lathe. It is also possible to cut a thread into the material or insert a threaded element. As a rule, no cooling or lubricating emulsion is necessary.

Polypropylene (PP)

Polypropylene is a semi-crystalline thermoplastic with high rigidity and very good chemical resistance. Characteristic for polypropylene is a CH_3 side-group in the monomer structural unit, which can be aligned in various spatial positions during polymerisation. The various spatial alignments are significant for the physical properties and differ according to the following:

- Isotactic (regular, one-sided alignment in the macromolecule),
- Syndiotactic (regular, double-sided alignment in the macromolecule),
- Atactic (irregular, random alignment in the macromolecule).

Alignment

A distinction is also made between homopolymers and copolymers; copolymers are tougher but have less mechanical and chemical stability.

As the physical properties improve considerably with the increase in the isotactic concentration in the polymer, isotactic polypropylene homopolymers should be the first choice for use in the technical area. The polypropylene finished products that we offer consist of high density polypropylene types produced by extrusion or moulding processes.

Main properties

- Low density compared to other materials (0.91 g/cm^3)
- Minimum water absorption (< 0.01%)
- Excellent chemical resistance, also to solvents
- High corrosion resistance
- Relatively high surface hardness
- Very good electrical insulator
- Physiologically safe

Colours

Natural (white), grey (≈ RAL 7032)
Other colours available on request.

Sliding properties

PP-H is subject to strong sliding abrasion and is thus not suitable for use in sliding applications.

Chemical resistance

PP-H is resistant to acids, alkaline solutions, salts and salt solutions, alcohols, oils, fats, waxes and many solvents. Aromatics and halogenated hydrocarbons cause swelling. PP-H is not resistant to strong oxidising materials (e.g. nitric acid, chromic acid or halogens) and there is a danger of stress corrosion cracking.

Behaviour in fire

PP-H is rated as normal flammable. When the source of ignition is removed PP-H continues to burn, forming droplets. However, apart from carbon dioxide, carbon monoxide and water, only small quantities of carbon black and molecular constituents of the plastic develop as conflagration gases. The oxygen index (the oxygen concentration required for combustion) at 18% is low compared to other plastics.

Weathering effects

PP-H is not resistant to UV rays. UV rays, in combination with atmospheric oxygen, oxidise the surface and discolouration occurs. If the material is exposed to the effects of UV rays for a longer period, this will cause irreparable damage and decomposition of the surface.

Areas of use

- Electroplating industry
- Chemical industry
- Machine engineering
- Stamping/punching plants

Applications

- Pump parts
- Component parts in chemical apparatus construction
- Fittings
- Valve bodies
- Product holders for electroplating processes
- Punching plates

Machining

In addition to its good welding properties, PP-H can also be machined on machine tools. The semi-finished products can be drilled, milled, sawed, planed and turned on a lathe. It is also possible to cut a thread into the material or insert a threaded element. Generally no cooling or lubricating emulsion is necessary.

During cutting, it is very important to ensure that the tools that are used are always adequately sharp. Blunt tools cause the surface to heat, which can cause "smearing" and consequently unacceptable surface finishes.

Polyvinylchloride (PVC)

Polyvinylchloride-hard (PVC-U) is an amorphous thermoplastic with no added plasticiser. It has a high hardness and rigidity. According to DIN 16 927 the material is classified as normal shock resistant, however its toughness values border on being rated as highly shock resistant, which gives it a high degree of safety in regard to the design of components. The polyvinylchloride finished products that we offer consist of high density polyvinylchloride types produced by extrusion or moulding processes.

Main properties

- Hard surface
- High rigidity
- Low water absorption
- Excellent chemical resistance
- Fire resistant (UL 94 V 0)
- Easily thermoformed
- Can be bonded
- Good cutting properties

Colours

grey (≈ RAL 7011), black, red, transparent
Other colours available on request.

Sliding properties

PVC-U is not subject to any major sliding abrasion and is thus suitable for use in sliding applications.

Weathering effects

PVC-U is not resistant to the effects of UV rays. In combination with atmospheric oxygen, the surface oxidises and discolouration occurs. If the material is exposed to UV rays and atmospheric oxygen for longer periods, irreparable damage and decomposition of the surface will occur.

Food law suitability

PVC-U does not comply with the requirements of the European Union regulation 10/2011 or the FDA and may not be used for manufacturing consumer goods that come into direct contact with food.

Chemical resistance

PVC-U is resistant to acids, alkaline solutions, alcohols, oils, fats, aliphatic hydrocarbons and petrol.
PVC-U is not resistant to benzene, chlorinated hydrocarbons, ketones or esters.
In combination with strong oxidising materials (e.g. nitric acid or chromic acid), there is a danger of stress corrosion cracking.

Behaviour in fire

PVC is rated as fire resistant in the highest category, even without additives. When the source of ignition is removed, PVC is self-extinguishing. The oxygen index (the oxygen concentration required for combustion) at 40% is very high compared with other plastics.

Areas of use

- Electroplating industry
- Machine engineering
- Filling plants
- Photo industry

Applications

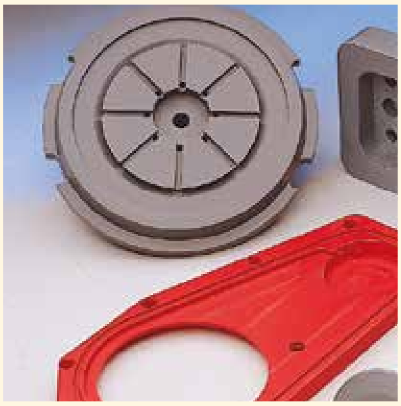
- Pump parts
- Fittings
- Valve bodies
- Component parts in chemical equipment design
- Feed tables
- Machine and equipment covering

Machining

In addition to its good welding properties and the possibility for glueing, PVC-U can also be machined on machine tools. The semi-finished products can be drilled, milled, sawed, planed and turned on a lathe. It is also possible to cut a thread into the material or insert a threaded element. Generally no cooling or lubricating emulsion is necessary.

During machining it is very important to ensure that the tools that are used are always adequately sharp. If this is not the case, the high temperatures caused by the blunt cutting edge can cause the material to degrade and, in combination with atmospheric moisture, can cause small quantities of hydrochloric acid to form as aerosols.

In addition, because of its hard-brittle properties, we recommend that elastomer or thermoplastic washers are used for PVC-U component parts that are to be fastened by screwing. The use of washers such as this reduces the danger of transmitting high stresses by tightening the screws and the stress cracking around the edge of the drilled hole that this causes.



Polycarbonate (PC)

Polycarbonate is an amorphic thermoplastic with high mechanical strength and rigidity as well as good creep qualities. The material is, by virtue of its amorphic molecular structure, translucent and transparent. Particular features are the excellent impact resistance over a large range of temperatures which remain constant even at low temperatures. The combination of impact resistance and transparency make polycarbonate the ideal material for armoured windows, outer casings and safety glass for machines and the building trade. Special types are available for glazing where impact resistance remains almost unchanged for years despite weather conditions. These modified types are considered practically indestructible. The polycarbonate finished products that we offer consist of high density polycarbonate types produced by extrusion or moulding processes.

Main properties

- excellent transparency
- high level of toughness even at low temperatures
- high dimensional stability
- good electrical insulator
- high rigidity
- high creep resistance over a wide range of temperatures
- large temperature range (-100 °C to +120 °C)
- physiologically harmless
- good welding and bonding properties

Colours

natural (clear, transparent)
Colours available on request.

Sliding properties

PC is subject to strong sliding abrasion and is therefore not suitable for sliding applications.

Weathering effects

The PC-standard type is equipped with UV stabilisers and is generally considered UV resistant. However, a product made from this type can only be used indoors. Under constant exposure to direct, strong UV rays and other atmospheric influences there is a risk that the material will become brittle. This may result in stress cracking and breakage. Therefore, we recommend using a type with a special UV protection coating for products intended for outside use. This has been proven in long-term trials and is generally considered as UV-stable and weather resistant.

Chemical resistance

PC is resistant to mineral oils, weak and dilute acids and aliphatic carbohydrates. It is unstable towards strong acids and alkalis, chlorinated and aromatic carbohydrates as well as solvents. It is also not resistant to hydrolysis.

Behaviour in fire

PC is rated as normal flammable without additional fire retardant additives. But there are also modified types available with fire retardant additives, which are classified according to UL-94 test criteria as a flame retardant. After removal of ignition source both the modified and the unmodified types are self-extinguishing. The oxygen index (the oxygen concentration required for combustion) is 26%.

Areas of use

- Optics
- Electrical/Electronics
- Medical
- Vehicle
- Mechanical engineering
- Data Technology
- Construction

Applications

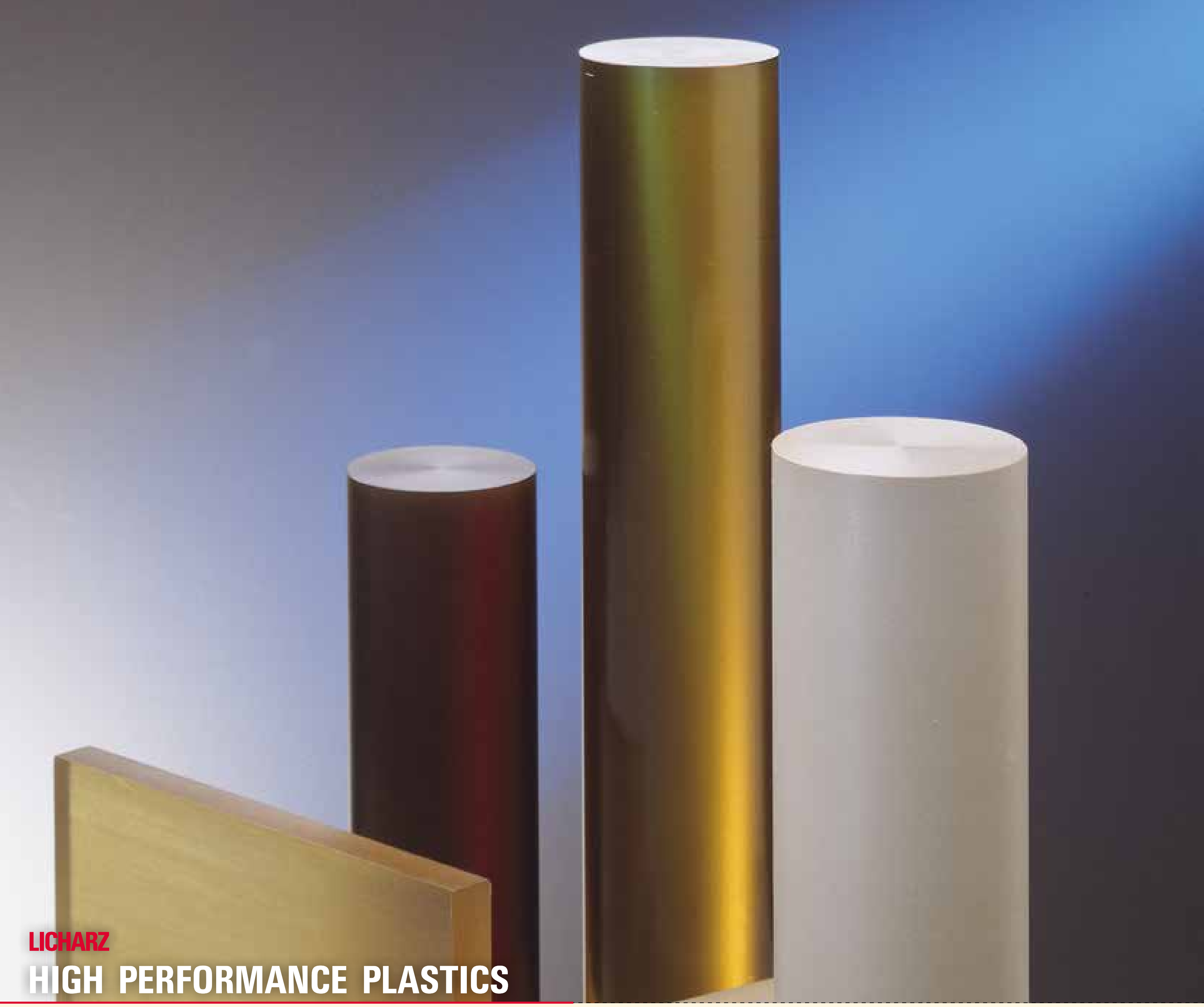
- Machine covers
- Glazing
- Light domes
- Equipment housing
- Sight glasses
- Precision mechanical parts
- Insulators
- Parts for medical technology

Machining

In addition to its good welding properties and bonding ability, PC can be machined without problem. The semi-finished products can be drilled, milled, sawed, planed and turned on a lathe. It can also be tapped or receive threaded inserts. Use of cooling-lubricating emulsions and cutting oils are not recommended as the additives here can cause tension cracks to form. Cooling, is however, generally not necessary. If cooling is required, use of water or oil-free compressed air is recommended.

Semi-finished products of PC can be reshaped by various means. For example machine covers can be given the required form by bending or bevelling (either cold or warm). Light domes, bowl shapes or similar components can be manufactured by vacuum forming, positive forming or pressure forming.

In comparison to other thermoplastics PC is classified as sensitive to stress cracking. For structural parts made of PC, which will be secured by screws, we recommend using elastomeric or thermoplastic washers. These discs reduce the risk of transmission of excessive pressure stresses that can be caused by tightening the screws. Thus, avoiding stress cracks occurring around the edge of the drilled hole.



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HIGH PERFORMANCE PLASTICS

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Polyvinylidenefluoride is a high crystalline thermoplastic with good mechanical, thermal and electrical properties. As a fluoroplastic, polyvinylidene fluoride has excellent chemical resistance without the disadvantages of low mechanical values and difficult workability of other fluoroplastics. The polyvinylidenefluoride finished products that we offer consist of high density polyvinylidenefluoride types produced by extrusion or moulding processes.

Main properties

- Low density in comparison to other fluoroplastics
- Good mechanical stability compared to other fluoroplastics
- Can be used continuously at high temperatures (+140 °C in air)
- Absorbs practically no water
- Good dimensional stability
- High chemical resistance
- Good hydrolytic stability
- Weather resistant
- Radiation resistant
- Good electric insulator
- Fire resistant (UL 94 V 0)
- Physiologically safe
- High abrasion resistance

Colours

natural (white to ivory)

Sliding properties

PVDF has good sliding properties, is resistant to wear and is very suitable for chemically stressed sliding applications that are also subjected to thermal influences. However, in component design, the relatively high coefficient of thermal expansion should be considered.

Resistance to radiation/Weathering effects

PVDF is resistant to both β-rays and γ-rays as well as UV rays in connection with atmospheric oxygen. Hence PVDF is ideal for use in the pharmaceutical and nuclear industries and under weathering effects.

Chemical resistance

PVDF is resistant to acids and alkaline solutions, salts and salt solutions, aliphatic and aromatic hydrocarbons, alcohols and aromatics. PVDF is not resistant to ketones, amines, fuming sulphuric acid, nitric acid or to several hot alkalis (concentration related). Dimethyl formamide and dimethyl acetamide dissolve PVDF.

Behaviour in fire

Even without additives, PVDF is rated in the highest category as fire resistant. When the source of ignition is removed, PVDF extinguishes itself. At 78%, the oxygen index (= the concentration of oxygen required for combustion) is very high compared to other plastics.

Areas of use

- Chemical and petrochemical industries
- Pharmaceutical industry
- Textile industry
- Paper industry
- Food industry

Applications

- Pump parts
- Fittings and fitting components
- Valves and valve components
- Seals
- Friction bearings
- Component parts in plant/apparatus engineering

Machining

In addition to its good welding suitability, PVDF can also be machined on machine tools. With the respective surface treatment, PVDF can be bonded with a special solvent adhesive. Fluoropolymers degrade at temperatures above approx. 360 °C and form highly aggressive and toxic hydrofluoric acid. As polymer dust can form when the material is being machined, smoking should not be permitted at the workplace.

Polytetrafluoroethylene (PTFE)

Polytetrafluoroethylene is a high crystalline thermoplastic with excellent sliding properties, anti-adhesive surfaces, excellent insulation properties, an almost universal chemical resistance and an exceptionally broad temperature deployment spectrum. However, this is offset by low mechanical strength and a high specific weight compared to other plastics. To improve the mechanical properties, polytetrafluoroethylene is compounded with fillers such as glass fibre, carbon or bronze. The polytetrafluoroethylene finished products that we offer consist of high density polytetrafluoroethylene types produced by extrusion or moulding processes.

Main properties

- Excellent sliding properties
- Highest chemical resistance, also to solvents (limited with PTFE + bronze)
- Resistant to hydrolysis (limited with PTFE + bronze)
- High corrosion resistance (limited with PTFE + bronze)
- Broad temperature deployment spectrum (-200 °C to +260 °C)
- Resistant to weathering
- Does not absorb moisture
- Physiologically safe (not PTFE + carbon/ + bronze)
- Good electrical insulator (not PTFE + carbon/+ bronze)
- Good thermal insulator (not PTFE + carbon/+ bronze)
- Anti-adhesive
- Virtually unwettable with liquids
- Fire resistant

Colours

PTFE pure: white
PTFE + glass: light grey
PTFE + carbon: black
PTFE + bronze: brown

Sliding properties

PTFE has excellent sliding properties and because of its very close static and dynamic abrasion values, it prevents the “stick-slip effect”. However, due to its low mechanical strength, PTFE has high sliding abrasion and a tendency to creep (cold flow). Hence, unfilled PTFE is only suitable for sliding applications with low mechanical load. Its load bearing capacity can be constructively improved by equipping the sliding element with several chambers. It must be ensured that the chamber is fully enclosed so that the slip lining cannot escape (“flow out”).

PTFE + glass has worse sliding properties than pure PTFE due to the filler, but it can bear much higher loads. Sliding abrasion and the coefficient of elongation are reduced, while creep resistance and dimensional stability increase. The glass particles embedded in the material cause higher wear on the mating part than pure PTFE.

PTFE + carbon has similarly good slip properties as pure PTFE, but because of the addition of a filler, it has much better mechanical stability. As with glass as a filler, sliding abrasion and the coefficient of elongation are reduced, while creep resistance and dimensional stability increase. Sliding elements filled with carbon can be used for applications that are occasionally or constantly surrounded by water.

PTFE + bronze has the best mechanical values of all filled PTFE types and is very suitable for sliding applications. The filler causes the lowest sliding abrasion of all PTFE types. In addition to this, thermal conductivity, and consequently the dissipation of friction heat from the friction bearing, is considerably improved compared to other sliding materials, which leads to a longer life.

Weathering effects

All PTFE types are very resistant to UV rays, even in combination with atmospheric oxygen. No oxidation or discolouration has been observed.

Chemical resistance

Unfilled PTFE is resistant to almost all media apart from elemental fluorine, chlorotrifluoride and molten or dissolved alkali metals. Halogenated hydrocarbons cause minor, reversible swelling. In the case of filled PTFE, due to the filler one can assume a lower chemical resistance, although it is the filler that forms the reaction partner to the medium, not the PTFE. As a rule, it can be said that the types filled with carbon are not much less resistant than pure PTFE. The types filled with glass are resistant to acids and oxidising agents but less resistant to alkalis. The types filled with bronze have a much lower chemical resistance than pure PTFE. Before using filled PTFE types in chemically burdened environments, their resistance to the respective medium should always be tested.

Behaviour in fire

PTFE is rated as fire resistant in the highest category. It does not burn when an ignition source is added. The oxygen index (the oxygen concentration required for combustion), at 95% is one of the highest compared to other plastics.

Areas of use

- Chemical industry
- Machine engineering
- Precision mechanics
- Electrical industry
- Textile industry
- Paper industry
- Food industry
- Aerospace industry
- Building and bridge construction

Applications

- Friction bearings
- Bearing bushes
- Shaft seals
- Piston rings
- Valve seats/seat rings
- Insulators
- Flat seals
- O-rings
- Test jacks
- Thread guides
- Anti-adhesive liners

Machining

PTFE is difficult to weld and even then only by using a special process. It can be machined on machine tools. The semi-finished products can be drilled, milled, sawed, planed and turned on a lathe. It is also possible to cut a thread into the material or insert a threaded element. PTFE can also be bonded when the surface has been suitably treated by etching with special etching fluid. Up to approx. 19 °C, PTFE is subject to a phase transition which is normally accompanied by an increase in volume of up to 1.2%. This means that finished parts that are dimensionally stable at 23 °C can have considerable dimensional deviations at temperatures below 19 °C. This must be considered in the design and dimensioning of PTFE components. When the material is being machined, attention must be paid that good heat dissipation is guaranteed for parts with minimum tolerances, otherwise the good insulation properties can lead to dimensional deviations in finished parts after cooling because of the heat build-up and thermal expansion. Fluoropolymers degrade above approx. 360 °C forming highly aggressive and toxic hydrofluoric acid. As polymer dust can form when the material is being machined, smoking should not be permitted at the workplace.

Polyetheretherketone (PEEK)

Polyetheretherketone is a semi-crystalline thermoplastic with excellent sliding properties, very good mechanical properties, even under thermal load and an excellent resistance to chemicals. The high continuous working temperature rounds off the profile of this high-performance plastic and makes it a virtually universally useable design material for highly loaded parts. The polyetheretherketone finished products that we offer consist of high density polyetheretherketone types produced by extrusion or moulding processes.

Main properties

- High continuous working temperature (+250 °C in air)
- High mechanical strength
- High rigidity
- High creep resistance, also at high temperatures
- Good sliding properties
- High wear resistance
- High dimensional stability
- Excellent chemical resistance
- Resistant to hydrolysis
- Good electrical insulator
- Radiation resistant
- Physiologically safe
- Fire resistant (UL 94 V 0)

Colour natural (≈ RAL 7032), black

Sliding properties

PEEK ideally combines good sliding properties with high mechanical strength and thermal stability as well as excellent chemical resistance. Because of this, it is suitable for sliding applications. Modified types containing carbon fibre, PTFE and graphite, with highest wear resistance, a low coefficient of friction and a high pv limiting value, are available for component parts that are subject to especially high abrasion and wear.

Weathering effects

PEEK is resistant to x-rays, β-rays and γ-rays. Hence PEEK is ideal for use in the pharmaceutical and nuclear industries. PEEK is not resistant to UV rays in combination with atmospheric oxygen.

Chemical resistance

PEEK is resistant to non-oxidising acids, concentrated alkaline solutions, salt solutions, cleaning agents or paraffin oils. It is not resistant to oxidising agents such as concentrated sulphuric acid, nitric acid or hydrogen fluoride.

Behaviour in fire

PEEK is rated fire resistant in the highest category. When the source of ignition is removed PEEK is self-extinguishing. The oxygen index (the oxygen concentration required for combustion) is 35%.

Areas of use

- Chemical and petrochemical industries
- Pharmaceutical industry
- Food industry
- Nuclear industry
- Aerospace industry
- Defence technology

Applications

- Gears
- Friction bearings
- Bobbins
- Fittings (e.g. casing for hot water meters)
- Valves
- Piston ring
- Parts for car engines (e.g. bearing cages)

Machining

In addition to its good welding and bonding properties PEEK can be easily machined. The semi-finished products can be drilled, milled, sawed, planed and turned on a lathe. It is also possible to cut a thread into the material or insert a threaded element. Generally no cooling or lubricating emulsion is necessary.

Polysulfone (PSU)

Polysulfone is an amorphous thermoplastic with high mechanical strength and rigidity and remarkably high creep resistance across a wide temperature range and high continuous working temperature for an amorphous plastic. In addition, Polysulfone is transparent because of its amorphous molecule structure. Its very good resistance to hydrolysis and very good dimensional stability round off the profile. The polysulfone finished products that we offer consist of high density polysulfone types produced by extrusion or moulding processes.

Main properties

- High continuous working temperature (+160 °C in air)
- Very good resistance to hydrolysis (suitable for repeated steam sterilisation)
- High toughness, also at low temperatures
- High dimensional stability
- Good electrical insulator
- High mechanical stability
- High rigidity
- High creep resistance across a wide temperature range
- Good resistance to radiation
- Physiologically safe
- Fire resistant (UL 94 V 0)

Colour

Natural (honey yellow, translucent)

Sliding properties

PSU is subject to strong sliding abrasion and is thus unsuitable for sliding applications.

Resistance to radiation/weathering effects

PSU is resistant to x-rays, β-rays, γ-rays and microwaves. Hence PSU is ideally suited for use in the pharmaceutical, food and nuclear industries.

Chemical resistance

PSU is resistant to inorganic acids, alkaline solutions and salt solutions, as well as cleaning agents and paraffin oils. It is not resistant to ketones, esters, chlorinated hydrocarbons or aromatic hydrocarbons.

Behaviour in fire

PSU is rated as fire resistant in the highest category. When the source of ignition is removed, PSU is self-extinguishing. The oxygen index (the oxygen concentration required for combustion) is 30%.

Areas of use

- Electro-technology
- Electronics
- Vehicle construction
- Equipment engineering
- Aerospace industry

Applications

- Bobbins
- Inspection glasses
- Sealing rings
- Equipment casing
- Insulating sleeves

Machining

In addition to its good welding and bonding properties PSU can be easily machined. The semi-finished products can be drilled, milled, sawed, planed and turned on a lathe. It is also possible to cut a thread into the material or insert a threaded element. Generally no cooling or lubricating emulsion is necessary.

Polyetherimide (PEI)

Polyetherimide is an amorphous thermoplastic with high mechanical stability and rigidity as well as remarkably high creep resistance across a wide temperature range and high continuous working temperature for an amorphous plastic. In addition, polyetherimide is transparent because of its amorphous molecule structure. Its very good resistance to hydrolysis and very good dimensional stability round out the profile.

The polyetherimide finished products that we offer consist of high density polyetherimide types produced by extrusion or moulding processes.

Main properties

- High continuous working temperature (+170 °C in air)
- High mechanical stability
- High rigidity
- High creep resistance across a broad temperature range
- High dimensional stability
- Very good resistance to hydrolysis (suitable for repeated steam sterilisation)
- Good electrical insulator
- Good resistance to radiation
- Physiologically safe
- Fire resistant (UL 94 V 0)

Colour

Natural (amber, translucent)

Sliding properties

PEI is subject to strong sliding abrasion and is thus unsuitable for sliding applications.

Resistance to radiation/weathering effects

PEI is resistant to x-rays, β-rays and γ-rays as well as UV-rays in combination with atmospheric oxygen. Hence PEI is ideally suited for use in the pharmaceutical and nuclear industries and under weathering effects.

Chemical resistance

PEI's resistance should be tested before it is used with ketones, aromatic hydrocarbons or halogenated hydrocarbons. Alkaline reagents with pH values > 9 should be completely avoided.

Behaviour in fire

PEI is rated as fire resistant in the highest category, also without additives. When the source of ignition is removed, PEI is self-extinguishing. The oxygen index (the oxygen concentration required for combustion), at 47% is very high compared to other plastics.

Areas of use

- Electro-technology
- Electronics
- Vehicle construction
- Equipment engineering

Applications

- Bobbins
- Inspection glasses
- Equipment casing
- Insulating sleeves

LICHARZ

STRUCTURE AND PROPERTIES OF PLASTICS

The competitive edge through engineered components made of plastic

Structure and properties

1. Fundamentals

In general terms, plastics are macromolecular compounds manufactured from existing natural substances by chemical conversion or by synthesising products from the chemical decomposition of coal, petroleum or natural gas. The raw materials produced by conversion or synthesis are usually converted into semi-finished or finished products by applying temperature and pressure.
These processes include, among others, injection moulding and extrusion. Exceptions to this are the polyamide semi-finished products manufactured by Licharz in static and centrifugal moulding processes, as these methods are done without pressure.

2. Structure

2.1 Classification

Usually plastics are classified in two main groups – thermoplastics and duroplastics.

- When they are heated to an adequate degree, **thermoplastics** soften until they are melted and then harden again on cooling. Forming and reforming thermoplastics is based on this repeatable process. Provided the heating does not cause excess thermal stress leading to chemical degradation, there is no change to the macromolecules.
- Because of their molecular structure, **duroplastics** cannot be reformed after they have been originally formed, not even at high temperatures. The original formation is based on a chemical reaction of intermediates, most of which are not macromolecular, to closely cross-linked macromolecules.

In DIN 7724, plastics are classified according to their behaviour when subjected to different temperatures. This leads to the following classification:

- **Plastomers** (= thermoplastics) are non-cross-linked plastics that react energy-elastically (metal elastically) within their service temperature range, and which soften and melt from a material specific temperature onwards.
- **Thermoplastic** elastomers are physically or chemically coarse-meshed, cross-linked plastics or plastic mixtures. In their normal service temperature range they behave entropy-elastically (rubber-elastically) but at high temperatures they soften to the point of melting.
- **Elastomers** are coarse-grained, temperature-stable, cross-linked plastics which are entropyelastic (rubber-elastic) in their service temperature range. They can be formed reversibly and do not flow until they reach their decomposition temperature range.
- **Duromers** (= duroplastics) are close-meshed, cross-linked plastics, which react energy-elastically (metal-elastically) in their service temperature range and which do not flow until they reach their decomposition temperature range.

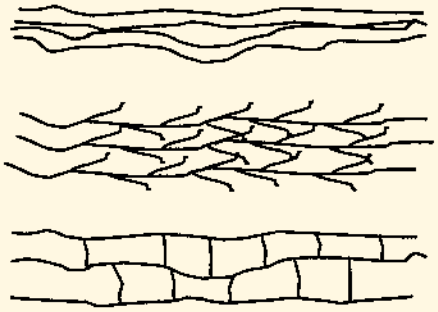
2.2 Structure and form of the macromolecules

Apart from a few exceptions, the plastics that are produced today are generally based on the ability of carbon to form long chains through atomic bonds. As opposed to ion bonds, the outer shell of the carbon atom fills to the noble-gas configuration with eight electrons. Bond partners can be complete atom groups or single atoms such as hydrogen, oxygen, nitrogen, sulphur or carbon.

Through synthesis many individual small molecules (= **mono**mers) of one or more starting products are bonded together chemically into macromolecules (= **poly**mers). As a rule, the resulting chains are between 10^{-6} and 10^{-3} mm long. The size of the macromolecules is expressed by the degree of polymerisation n or by the molecular weight. As it is not possible to achieve a homogeneous distribution of the chain length in polymerisation, the values are given as averages. It is normal to give a measure of the viscosity (e.g. melt index, M.F.I.) instead of the degree of polymerisation or the molecular weight. The higher n is, the higher the viscosity.

In the formation of macromolecules a distinction is made between linear, branched and cross-linked molecule structures:

- If the monomers are bonded with one another at two points (bifunctional) this forms a threadlike, linear macromolecule.
- If the individual monomers are bonded at more than two points this produces molecule branches.
- If monomers are mainly bonded with one another at three points (trifunctional) this forms a spatial, weakly or strongly cross-linked macromolecule.



Linear or branched macromolecules produce thermoplastics, weak cross-linked ones produce elastomers and strongly cross-linked macromolecules produce duromers.

As Licharz has specialised in the manufacture and marketing of semi-finished products and finished parts from thermoplastics (plastomers), we will only consider the thermoplastic group and its various sub-groups in the following. There is adequate literature available that deals with the other groups of plastics.

2.3 Molecular bonding force

The coherence of macromolecules is based on chemical and physical bonding forces.

For polymer materials these are:

- the primary valency forces as a chemical bonding force
- the secondary valency force (van der Waals forces) as a physical bonding force

The primary valency forces are essentially responsible for the chemical properties of the plastic, while the secondary valency forces are responsible for the physical properties and the alignment of the macromolecules.

2.3.1 Primary valency forces

The primary valency forces that are generated by the bond distance and the bonding energy come from the atomic bond of the polymers. The smaller the bond distance between the individual atoms in the polymer chain the higher the bonding energy. The bonding energy is also increased with the number of bonds of the individual atoms.

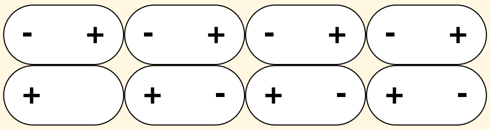
2.3.2 Secondary valency forces (Secondary bonding forces)

The secondary valency forces come from the intermolecular bonds. They consist of three forces:

1.) Dispersion forces are the forces of attraction between the individual molecules in the substance. These are greater the closer the molecules are to one another. In the crystalline ranges of the semi-crystalline plastics, these forces are especially high because of this. This explains their mechanical superiority compared to amorphous plastics.

Increasing the distances between the molecules drastically reduces the forces. One reason for increasing distances could be vibration caused by heating the polymer material. But intercalating foreign atoms between the molecules (e.g. solvent or water) can also increase the distance.

By intercalating plasticisers in the molecule chain, this effect can be used to produce plastics that are rubber-elastic at room temperature.



2.) Dipole forces are not found in all plastics. They only occur if the atomic bond has a strong overweighting to one side due to the alignment of the atoms in the galvanic series. This can only happen if dissimilar partners form a bond. The more electronegative atom of a bond draws the electron pair towards itself (➜ polarisation) and a dipole is formed. The neighbouring polarised groups attract one another because of the unequal electrical charges.

Polymer materials with a dipole character are generally less soluble (with the exception of strong polar solvents) and soften at higher temperatures than polymer materials without a dipole character. PVC is the most significant polymer material with a dipole character.

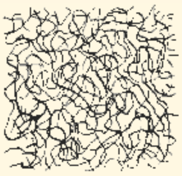
3.) Hydrogen bridges are bonds of opposite oxygen and hydrogen molecules of different molecule chains due to their high affinity to one another. This type of bond is the most stable of all secondary valency bonds. The hydrogen bridges are only dissolved with very strong forces and immediately reform themselves as soon as the displacement forces cease, rather like Velcro. The excellent properties, like a high melting point or extraordinary toughness, of various polymer materials such as polyamides are due to hydrogen bridges.

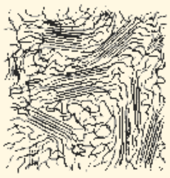
Other purely physical intermolecular bonds are entanglement, looping of chains or bonding in the semi-crystalline ranges. These are described as network points that allow molecule interlocking power transmission.

In very thin and symmetrical molecule chains, the secondary valency powers are generally not so pronounced, apart from molecule parts in the semi-crystalline ranges. The molecule chains of polymer materials such as this can easily slide past one another if they are subject to mechanical load. These materials have very good sliding properties, but at the same time they are subject to high wear due to abrasion, and they have a high tendency to creep. Examples of this are PE-UHMW and PTFE.

2.4 Order of the macromolecules

Thermoplastics are classified in two groups according to the order of their macromolecules. A distinction is made between:





- amorphous thermoplastics with completely disordered macromolecules (wadding-like structure) due to the form of the basic units and /or the alignment of any side groups that exist. Amorphous thermoplastics are hard, brittle and transparent.
- semi-crystalline thermoplastics with some highly ordered, parallel positioned macromolecule chains that form crystallites. A large number of crystallites form so-called spherulites. Complete crystallisation (➜ semi-crystalline plastic) is not possible because of chain looping during polymerisation. Semi-crystalline plastics are tough and opaque to white.

Semi-crystalline plastics have different properties than amorphous plastics due to the higher secondary valency forces. They soften later, can be subjected to more mechanical load, are more resistant to abrasion, are tough-elastic rather than brittle and are generally more resistant to chemicals. Because of this, the semi-crystalline thermoplastics are more significant for engineering plastics.

2.5 Alignment of the molecules in the macromolecule

Basically there are three different alignment possibilities of the substitute “R” in the molecule chain.

1.) Atactic

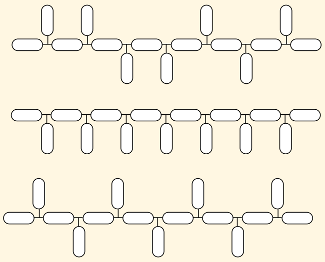
Random alignment in the chain

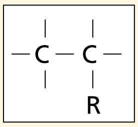
2.) Isotactic

Regular, one-sided alignment in the chain

3.) Syndiotactic

Regularly changing alignment in the chain





$$-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{\underset{R}{|}}{C}}-$$

The polymer material can only have a crystalline structure if a regular chain alignment exists for a specific length of the complete sequence. As a result of this, the molecule alignment has a direct influence on the mechanical properties.

2.6 Homopolymers/copolymers

Plastics that are polymerised from the same monomer units are called homopolymers. Plastics that consist of two or more monomer units are described as copolymers. When copolymers are being produced, the monomer units are not just mixed, but chemically integrated into the molecule chain. With copolymerisation it is possible to improve specific material properties in a targeted manner.

Essentially, a distinction is made between four different types of copolymers:

1.) Statistic chain structure	(random distribution of the different monomer units)
2.) Alternating chain structure	(regular change of the different individual monomer units)
3.) Block-like chain structure	(regularly changing blocks of the different monomer units)
4.) Graft polymers	(homogeneous chain of one unit with grafted side chains of a different unit)

Another alternative to change the properties is to (physically) mix two polymers. The materials produced from this are known as polyblends.

3. Properties

The above-described molecular structure of the plastics produces a range of special properties and unique characteristics. In the following, several of these will be introduced and described in more detail.

3.1 Mechanical properties

The mechanical properties of plastics are primarily determined by the secondary bonding forces. The more pronounced these are, the better the mechanical properties.

Because of the morphological structure of plastics, the properties are dependent on factors such as

- time
- temperature
- moisture
- chemical influences

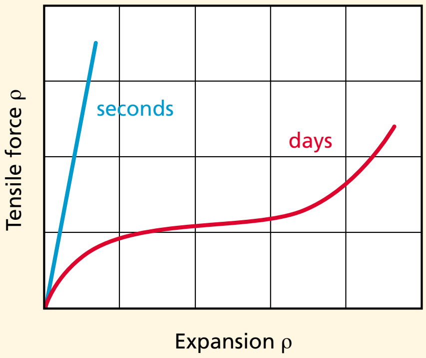
and fluctuate strongly depending on the influence of one of more factors.

3.1.1 Visco-elastic behaviour

All plastics have a more or less pronounced visco-elasticity. Mechanical load dissolves the secondary bonds in the molecule structure, and the molecule chains slide past one another. The longer the load is applied, the further the chains move away from each other.

This means that compared to metallic materials, plastics deform when subjected to high load over a long period (➜ cold flow). When maximum expansion has been reached, the plastic solidifies again and expansion is reduced. The weaker the secondary bonds in the macromolecule are, the more pronounced these properties are.

A simple molecule structure with no entangled side-groups, or a low degree of crystallinity in the plastic, encourages the chains to glide past one another.

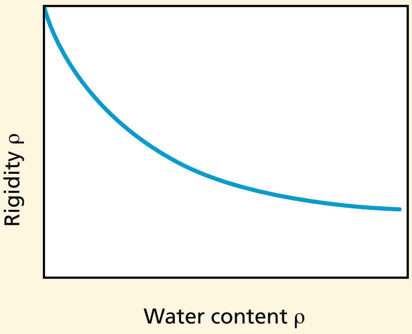


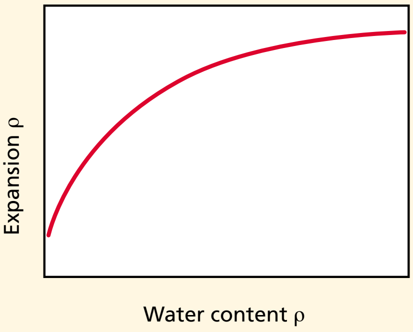
This deformation is further promoted by thermal influences. The molecules are stimulated to vibrate which leads to greater distances between the chains and consequently to weaker secondary bonds. Hence, stability values for dimensioning component parts cannot be used as a single point value, but rather they must be included in the static calculation in relation to load time and thermal effects.

3.1.2 Moisture absorption

In particular plastics produced by polycondensation (➜ polymerisation with the cleavage of water for example) have a tendency to absorb water from the surroundings via inward diffusion. This process is a reversible balanced reaction in which the more water which is available, the more the plastics absorb. The intercalated water molecules increase the distance between the molecule chains and weaken the secondary bonds.

The chains become more mobile, which results in a reduction in mechanical values and an increase in elasticity as well as swelling. In the case of polyamides the hydrogen bridges do not just ensure excellent mechanical properties such as good abrasion resistance, mechanical stability and toughness, they also lead to intercalation of water in the molecule chains. As both water and the polyamide molecules are capable of forming hydrogen bridges when the water has diffused into the molecule chain, it separates the existing hydrogen bridge and occupies the free valences. The water molecules make the polymer chain slightly more mobile which gives room for more water molecules. This process continues until the saturation point has been reached. When the water concentration in the surroundings falls again, the process is reversed. Water absorption is favoured by increasing temperatures and high ambient moisture. By absorbing water, the polyamides become more tough-elastic and less solid and rigid.





For applications in which these properties are required, it is possible to increase the water concentration by storing the materials in hot water (➜ conditioning).

For water absorption through atmospheric moisture, it should be noted that the process in thick-walled component parts only takes place close to the surface and that generally no water absorption, with the described effects, should be expected in the inner area of the component part.

3.1.3 Influence of chemicals

Chemicals can attack and separate the primary and secondary bonds of the molecule chains, which can be seen by swelling or decomposition of the plastic. Swelling of the plastic is caused by the chemical diffusing into the molecule structure, leading to a loss of stability. In a purely chemical attack, the loss of stability can occur with no noticeable increase in volume or weight.
The inward diffusion of the foreign molecules reduces the secondary valency powers to such an extent that the internal stresses in the material or external forces can cause (stress) cracking (➜ stress corrosion cracking).

3.2 Chemical resistance

Compared to metallic materials, plastics have a high resistance to chemicals. This can be attributed to the fact that the molecules are linked through atomic bonding. Because of their physical nature, the secondary valency powers only play a subordinate role. Most plastics are resistant to many acids and alkaline solutions as well as aqueous salt solutions and solvents. However, oxidising acids and organic solvents can be a problem in many cases, but this problem can be resolved by using special plastics. Resistance to chemicals decreases as the temperature and exposure time increase. This can be seen by an increase in weight and volume as well as a decline in mechanical values. A lack of resistance to a specific medium can generally be seen by a swelling of the plastic with no appreciable chemical attack, or in a chemical attack with medium to severe swelling.

3.3 Electrical properties

Because of the atomic bonding of their molecules, plastics, unlike metallic materials with ion bonds, do not have free electrons and are thus classified as non-conductors. However, the insulation properties can be greatly reduced or even completely negated through water absorption and/or the addition of metallic fillers, graphite or carbon black.
Many plastics are suitable for use in high-frequency areas as their dielectric losses are very low and they only heat up a little.

Losses in the area of application should be

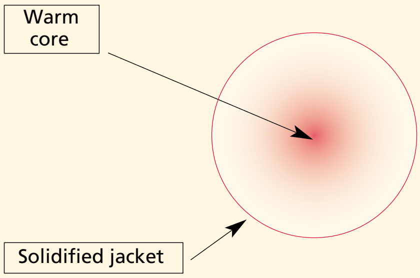
- for high frequency insulators $\epsilon_r \cdot \tan \partial < 10^{-3}$
- for high frequency heating $\epsilon_r \cdot \tan \partial > 10^{-2}$

Plastics generally have a surface resistance of $>10^8\ \Omega$. In the event of friction with a second non-conductor, this leads to electrostatic charging due to electron transfer at the boundary surface. Plastics without any conductance additives are not suitable for use in explosion protected areas as sparks can be caused when they touch grounded objects.

3.4 Dimensional stability

Increasing heat or intercalation of foreign molecules (e.g. water or solvent) in the chain compound of the molecule chains increases the distance between the chains. This causes the volume of the plastic components to change, resulting in a change in its dimensions. Vice versa, as the surroundings become colder, or when the water concentration decreases, the volume is reduced and is accompanied by the corresponding shrinking and size reduction.

Plastics are generally formed or reformed to semi-finished products from the melt. As a rule, the semi-finished products we manufacture are thick-walled products with large volumes, such as solid rods, slabs and blocks. As plastics are poor heat conductors, the edges of the products cool much quicker than the core. However, because of heat expansion, this has greater volume than the edges. The outer area has already solidified with a loss of volume and the associated shrinking. The shrinking of the core causes inner stresses that “freeze” as the product cools. These stresses can be minimised by heat treatment (➜ annealing, similar to stress-free annealing of steel). However, some residual stress can remain. These decrease over a period of time due to the visco-elastic behaviour of the plastics (➜ relaxation).



These residual stresses can be released by one-sided machining or heating and can become obvious through dimensional changes or distortion.

The properties of the plastics described above are more or less pronounced and can be compensated and kept under control relatively easily with proper design. The following chapters deal with special issues such as behaviour in fire, storage, material-compliant tolerances in components and many other factors.

1. Behaviour of plastics in fire and fire ratings

Generally, plastics are organic substances or modifications of organic substances, which, like other organic substances are threatened by chain breakage, cleavage of substitutes and oxidation at high temperatures. Therefore, apart from a few exceptions, plastics are more or less combustible, which is something that can be a serious technical problem in the specific use of plastics.

1.1 Combustibility

If plastics are heated locally or over large surfaces to above their specific decomposition temperature, they release volatile, low molecular constituents. In many cases together with the ambient oxygen, these form a flammable gas mixture which can ignite if an ignition source is added and an adequate supply of oxygen is available.

The amount of heat that is fed in and the volume of the combustible surface that this can affect are both very significant for the evolution of a fire and the course of the fire. Another decisive factor is the atmospheric oxygen concentration.

For instance, it is possible that a large quantity of heat which affects a large volume with a large surface area but a lack of oxygen only leads to pyrolytic cleavage in the beginning (➜ release of highly flammable, volatile and low molecular constituents). If one adds oxygen in the right concentration, under unfavourable conditions this can result in a deflagration or an explosion.

However, with the same volumes and a lower heat input, as well as an adequately high oxygen concentration, the same substance only burns slowly. Because of this behaviour, it is very difficult, if not impossible, to make any fire-technical forecasts.

1.2 Conflagration gases

As with the combustion of other substances, when plastics burn they produce various conflagration gases. As a rule, these are said to be highly toxic. This is not absolutely correct as, on the one hand, the toxicity depends on the type and quantity of the plastic involved in the fire and, on the other, all conflagration gases resulting from a (substance-independent) fire should be regarded as toxic.

One example is the conflagration gases resulting from the incineration of polyethylene, which, in addition to small quantities of soot and low molecular plastic constituents, almost exclusively contain carbon monoxide, carbon dioxide and water. This is comparable with the conflagration gases that occur when wood or stearine are burned.

In contrast, when polyvinyl chloride is burned, there is a danger of chlorine being released, which in combination with atmospheric moisture or extinguishing water forms to hydrochloric acid.

Many plastics produce a lot of soot when they burn, which makes it difficult for the fire brigades to reach the source of the fire. These plastics include the polyolefins PE and PP as well as styrene plastics such as PS and ABS.

This must be considered for designs in fire-critical areas.

1.3 Behaviour in fire

Almost all plastics are combustible. Exceptions to this are PTFE and silicones, which are virtually non-combustible. Most plastics continue to burn after they have been ignited and the source of ignition has been removed. Several extinguish when the ignition source is removed, while others cannot be ignited. In many cases, the plastic melts due to the heat of combustion and forms burning droplets which can promote the spread of the fire. The degree of combustibility can be reduced by adding the corresponding additives. Additives based on the following mechanisms are used:

- **Endothermy**
  The temperature of the plastic is reduced by the decomposition or vaporisation of the additive. This is possible for example with water stores (aluminium hydroxide) or phosphorous compounds being added to the plastic.
- **Radical bonding**
  The radicals that form during the fire are bonded by the additive, which slows down the thermal decomposition and consequently the release of flammable, volatile constituents.
- **Formation of heavy gases**
  Heavy gases are formed through the thermal effects on the additive, preferably halogens, which shield the plastic from atmospheric oxygen and thus prevent oxidation.

But the use of fire retarding additives does not make plastics non-combustible. Only plastics that are regarded as being non-flammable are suitable for applications that demand non-combustibility of the plastic.

1.4 Fire ratings

Often, to assess how plastics behave in fire, imprecise terms such as “highly flammable” or “fire resistant” or “non-combustible” are used. These terms inadequately reflect the actual behaviour of the plastics and only provide a limited inference for the usability of a plastic for a specific application.
To assess how plastics behave in fire in the areas of electro-technology, traffic, building, etc. there are currently approximately 700 national and international test methods. In the electrical sector the method UL 94 HB or UL 94 V from Underwriters Laboratories (USA) has become the most widely accepted. These tests refer to the burning time and the burning behaviour of plastics. In test UL 94 V a distinction is made between classifications V0 to V2, V0 being the most favourable rating.

However, some test methods, such as the UL tests from Underwriters Laboratories (USA), have now obtained worldwide recognition for fire protection rating. Originally intended for electrical engineering, the methods UL 94 HB and UL 94 V are being applied as the most significant. In the meantime, however, other industries are increasingly moving towards test results obtained with this method. Principles for tests in accordance with UL 94 are the flash duration and the burning behaviour of plastics. These are calculated using two different test setups.

Horizontal flame test (UL 94 HB)

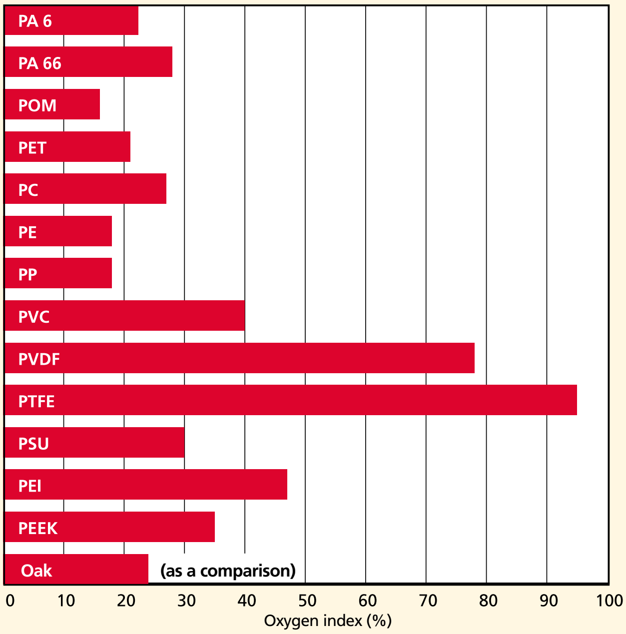
The samples are horizontally clamped to a 45° incline to the horizontal transverse axis in the sample holder and ignited with a Bunsen burner at the free end. Marks are made on the sample at a distance of 25.4 mm and 101.6 mm from the end exposed to the flame. The sample material then corresponds to the classification, if the burning rate between the two measuring marks at sample thicknesses of ≤ 3.05 mm is maximum 76.2 mm/min and a thickness > 3.05 mm is maximum 38.1 mm/min. In addition, the samples must self-extinguish before reaching the 101.6 mm mark.

Vertical flame test (UL 94 V)

The samples are suspended vertically clamped in the sample holder. A piece of cotton wool is placed at a defined distance below the clamped test specimen. A Bunsen burner is placed vertically under the sample and ignites the free end. The flame is applied per sample twice for 10 seconds. The test criterion for classification is the amount of time that elapses between the removal of the burner and the self-extinguishing of the sample. As an additional criterion for the classification it is observed whether parts of the burning sample drip off and ignite the cotton wool placed below. Details to the individual requirements of the different classifications can be found in the table below.

	Classification according to UL 94		
	V0	V1	V2
Number of test pieces	5	5	5
Permissible burning time, per sample, with flame impingement	≤ 10 s	≤ 30 s	≤ 30 s
Total permissible burning time of 5 tests and 2 flame impingements	≤ 50 s	≤ 250 s	≤ 250 s
Permissible formation of burning droplets/ignition of the cotton wool	no	no	yes

Another possibility of comparing the flammability of plastics is the oxygen index. In a controllable O_2/N_2 mixture a vertical plastic sample is ignited and the minimum volume of O_2 required to burn the plastic is measured. This test also allows the effects of flame retardants to be observed. The diagram opposite contains several oxygen indices for comparison. Index values ≤ 21% can lead to continued burning after the source of ignition has been removed. Information regarding other technology standards and test methods applied are available on request.



Resistance to radiation and weathering

1. Plastics' resistance to radiation and weathering

Changes in plastics due to weathering effects and high-energy rays are often described as "aging", with reference to the process of biological degradation. This is quite an accurate description since plastics, as organic materials, do not just have an analogy to natural substances in their constituents but also in their macromolecular structure. The parallels are also obvious by the fact that we often speak of the "life" of a plastic product. The duration is determined by the decomposition of the plastic. It may be relatively long compared to other natural substances, but it is still limited.

1.1 Radiation

The majority of plastics are subject to decomposition or a cross-linking of the macromolecular structure when affected by high-energy radiation. The changes in the molecular structure that actually occur depend on the atmospheric oxygen.

When oxygen is present, generally oxidative decomposition of the plastic occurs. This is especially the case when the dose of radiation is small, the surface area of the product is large and the walls are thin. Under these prerequisites, the atmospheric oxygen has sufficient time to diffuse into the plastic and to occupy the valences that are made free by the radiation.

In the absence of oxygen, the plastic is partially degraded by the main chains breaking up and partially cross-linked. Generally degradation and cross-linking reactions happen at the same time, although one of the reactions is stronger.

In any case, the changes in the plastics caused by radiation are accompanied by a loss of mechanical properties such as mechanical stability, rigidity and hardness or brittleness. Plastics that are subject to cross-linking can experience a change in properties even leading to a rubber-elastic condition. Besides this, during both the cross-linking and decomposition of the plastics, small amounts of gaseous substances such as carbon monoxide or carbon dioxide are released.

Attention should be paid to the fact that the described changes are very gradual and that there is no sudden, unannounced change in properties. The effects of radiation on plastics depend on the geometry of the component, dosage, mechanical load, temperature and the surrounding medium. Therefore, it is not possible to make a generalised statement about the damaging doses for individual plastics.

1.2 Weathering effects

Weathering resistance is mainly evaluated by the visual change of the surface. However, this leaves the question unanswered as to how the mechanical values change. On the one hand, it cannot be ruled out that plastics which are not subject to any great visual changes have a serious loss of mechanical properties and, on the other hand, plastics with considerable visual changes suffer no great loss of mechanical properties. But to evaluate weathering resistance correctly, the mechanical properties must be a measured. Some results of weathering are a decline in stability and hardness as well as an increase in elasticity or brittleness. The surface of the plastic can appear bleached or oxidatively degraded or stress cracks can form.

The changes in plastics as a result of weathering are mainly caused by thermal and photo-oxidative reactions as well as by the intercalation of water molecules in the plastic's chain structure.

UV rays and warming by direct sunlight lead to chain decomposition and free valences that are saturated by oxygen diffusing inwards. The surface becomes yellow or bleached.

In the case of semi-crystalline plastics there could be secondary crystallisation resulting in increased hardness and rigidity. Consequently these plastics are also more brittle and lose a large part of their elasticity. Frozen residual stresses from the manufacturing process can relax and cause deformation through the effects of warming – similar to an annealing process. This is especially serious for thin-walled finished parts.

By absorbing water, the plastics become tough-elastic and stability and rigidity decline, which can also be a problem with thin-walled finished parts. Weathering resistance can be improved with additives – in a similar way that fire retardant additives are used. However, it is not possible to provide a complete protection against degradation caused by the effects of weathering. Unfortunately no valid testing standard or standard parameters are defined regarding artificial weathering and its variables that could be used to compare resistances. However it can be said that plastics that have been coloured with carbon black or stabilised against UV rays with additives are more stable against light and weathering effects than light coloured or natural coloured grades. Exceptions to this are PVDF and PTFE, which have outstanding resistance to light and weathering effects even without colouring or additives.

However, due to their chemical structure even polyamides do not absorb UV radiation and are therefore in principle classified as a weather-resistant plastic. This assessment applies to thick-walled components (wall thickness > 5 mm). Changes in the material characteristics (e.g. embrittlement) are often only observed in extremely thin products (e.g. films and foils) – especially with double-sided weathering. However, changes are also observed in thick-walled components where they are exposed to high-energy radiation (UV rays or similar) whilst being exposed to the effects of oxygen at the same time. Under these conditions surface oxidation may occur which can lead to discoloration of the surface. However, as polyamides also act as an oxygen barrier, the effect of the surface damage remains limited to a depth of 0.2 to 0.3 mm. It forms a ”rind“ under which the core of the part is well protected against further oxidative attack. The effects of UV radiation on the material characteristics of the core material are therefore normally not observed. The phenomenon of rind formation is also valid for thick-walled parts made of polyamides used for water storage. Here, effects on the material characteristics of the core material, (an increase in elasticity with a simultaneous decrease in strength), are generally only observed when the part has reached the end of its service life due to mechanical influences (e.g. wear).

In the evaluation of weather resistance it is clear that not only the type of plastic used is significant, but also the geometry of the part. Changes that are caused by weathering are usually only reflected in the regions near the surface of the products. In general deep-lying layers are not attacked, so that thick-walled parts are less affected by changes than thin-walled parts. Nevertheless, for parts that are used in weather conditions or that are exposed to high-energy rays, it is recommended that resistant materials are used and that the resistance is verified by experimentation (if possible carried out under operating conditions).

Storage information

Information for material-related handling of plastics at receipt and in storage
The material properties and special features of plastics described in the previous sections clearly illustrate that plastic products can suffer unwanted quality losses due to environmental effects.

Therefore to maintain the high quality and functionality of our products – also over longer periods – several factors should be considered when handling and storing them:

1. Plastics become brittle at low temperatures and become hard, less elastic and sensitive to impact. In this condition the danger of breaking or splitting through external forces is very high – especially for finished products. Cold plastic products should never be thrown, shaken or dropped.
2. The properties of plastics can change due to weathering effects. The material properties can suffer irreversible negative effects through sunlight, atmospheric oxygen and moisture (e.g. bleaching and/or oxidation of the surface, water absorption, etc.). If the products are subject to direct sunlight or one-sided heat, there is a danger of permanent deformation through heat expansion and released internal residual stresses. Therefore finished products should not be stored outdoors and semi-finished products should be stored outdoors for as short a period as possible.
3. Plastics have scratch sensitive surfaces. Sharp edges on shelves, nails in pallets, large dirt particles between the products and other sharp objects can cause scratches and/or grooves, which in turn can cause breakage and notching. When transporting and storing plastic products it should be ensured that the surface remains scratch and groove free and that no rough particles are allowed to adhere to the surface.
4. Not all plastics are equally resistant to chemicals, solvents, oils or fats. Several are attacked by these substances, which can lead to surface opacity, swelling, decomposition and permanent changes in the mechanical properties. Therefore, substances that can attack and damage plastics must be kept away from the products during storage.
5. Plastics are subject to reversible dimensional changes when affected by extreme temperature fluctuations due to shrinking or expansion. Dimension checks can only be carried out immediately on receipt of the goods if the products are at room temperature (≈ +23 °C). Products with a higher or lower temperature could produce incorrect measured values due to shrinkage or expansion of the plastic. Too warm/cold products must be stored temporarily in a dry place and be brought up/down to room temperature before dimensions are checked.
6. Because of the production process, plastics, and finished products manufactured from them, can have residual stresses, in spite of annealing. These have a tendency to relax when the products are stored for long periods and subjected to temperature effects (e.g. direct sunlight). Polyamides also tend to absorb water when the humidity is high, which in turn causes the volume to increase. These processes are generally accompanied by dimensional and shape changes due to deformation.

Therefore for long-term storage we recommend closed boxes and constant conditions (≈ standard climate +23 °C/50% RH). The expected dimensional and shape changes are thus kept to a minimum and generally have no effect on the function of the product.

LICHARZ

PLASTIC FRICTION BEARINGS

The competitive edge through engineered components made of plastic

1. Use of thermoplastics for friction bearings

Requirements for a friction bearing material such as

- good sliding and emergency running properties
- wear resistance
- pressure resistance
- long life
- heat deflection temperature

are easily fulfilled by today's modern thermoplastics.

Plastics are especially used where
- dry running or mixed friction occurs
- special plastic-specific properties are required
- low manufacturing costs are advantageous even with low quantities

In particular
- good sliding properties
- low coefficients of friction
- high wear resistance
- good damping properties
- low weight
- good dry and emergency running properties
- corrosion resistance
- chemical resistance
- low maintenance after initial one time lubrication
- physiologically safe in some cases

are valued as plastic-specific properties.

Disadvantages, such as low thermal conductivity, temperature-dependent strength values, relatively high thermal expansion, creep under long-term exposure as well as the partial inclination to moisture absorption are to a large extend controlled by appropriate design.

1.1 Materials

Of the large number of plastics that are available, those with semi-crystalline or high crystalline molecular structures are most suitable for use as sliding elements. Several materials belonging to this group, and how they have been modified for slide applications, are listed in Table 1.

Table1: Friction bearing materials and properties

Product	Material	Property
LiNNOTAM	PA 6 C	High abrasion resistance
LiNNOTAM MoS	PA 6 C + MoS_2	Higher crystallinity than PA 6 C
LiNNOTAM*GLiDE*	PA 6 C + Oil	Highest abrasion resistance, low coefficient of friction
LiNNOTAM*GLiDE PRO T*	PA 6 C + solid lubricant	Very low friction coefficient, low wear
LiNNOTAM*HiPERFORMANCE 1200*	PA 12 G	High abrasion resistance, high load bearing strength
Polyamide 6	PA 6	Medium abrasion resistance
Polyamide 66	PA 66	High abrasion resistance
Polyacetal (Copolymer)	POM	Medium abrasion resistance, compression resistant
Polyethyleneterephthalate	PET	High abrasion resistance, low coefficient of friction
Polyethyleneterephthalate and lubricant	PET-GL	High abrasion resistance, very low coefficient of friction
Polyethylene UHMW	PE-UHMW	Low coefficient of friction, low rigidity, acid-resistant
Polytetrafluoroethylene	PTFE	Very good sliding properties, low rigidity
Polytetrafluoroethylene and glass fibre	PTFE + glass	Partially good sliding properties good rigidity
Polytetrafluoroethylene and carbon	PTFE + carbon	Very good sliding properties, good rigidity
Polyetheretherketone	PEEK	High pv, high loadability, high price
Polyetheretherketone modified	PEEK-GL	Best sliding properties highest pv value and highest price

1.2 Manufacture

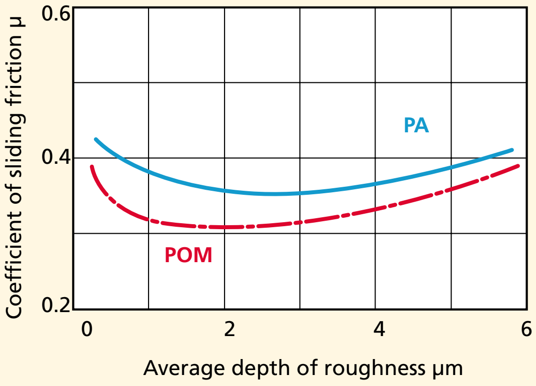
Friction bearings can be manufactured by machining or injection moulding. Polyamide bearings manufactured by injection moulding are much less wear resistant than those produced by machining due to their amorphous proportions in the molecular structure. The fine crystalline structure of the low stress polyamide semi-finished products manufactured by casting guarantees optimum wear resistance.

Compared to injection moulded friction bearings, machined bearings allow high dimensional precision. The high machining performance of conventional machine tools, lathes and CNC machining centres allow the cost-effective manufacturing of individual parts as well as small to medium sized batches. Flexible, almost limitless design possibilities, especially for thick walled parts are another advantage of machined friction bearings.

1.3 Sliding abrasion/mating

Sliding abrasion is primarily dependent on the material and surface properties of the mating component. The most favourable mating component for plastic has proven to be hardened steel with a minimum hardness of 50 HRc. If surfaces with a lower hardness are used there is a danger of rough tips breaking off and causing increased plastic/metal abrasion in friction bearings.

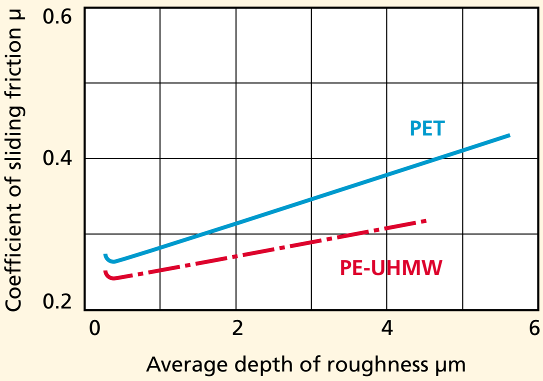
Figure 1



The influence of surface roughness on sliding abrasion and the sliding friction coefficient can be evaluated in different ways. For the more abrasion resistant, less roughness sensitive plastics (e.g. PA and POM) it can be observed that the sliding friction coefficient is relatively high, especially for particularly smooth surfaces (Figure 1).

As the roughness increases, it is reduced to a minimum and then increases again in the further course. The sliding abrasion becomes higher with increasing roughness. On the other hand, the more abrasion susceptible plastics (e.g. PE-UHMW, PTFE) show a steadily increasing sliding friction coefficient with increasing roughness. The range in which the sliding friction coefficient improves with increasing roughness is minimal. The sliding abrasion increases with increasing roughness.

Figure 2



The model idea to explain this behaviour assumes that abrasion in friction bearings takes over a lubricating function. It can be observed that a favourable sliding condition exists when the quantity and form of abrasion are optimum.

With the plastics that are less sensitive to roughness, adhesion forces and adhesive bridges have an effect in the low roughness range of the mating component. Due to the smooth surface, there is no great abrasion that can take over the lubricating function. As roughness increases, the movement hindering forces decrease so that the sliding friction coefficient improves with increasing abrasion. From a specific degree of roughness, the plastic begins to abrade, which requires higher movement forces. The amount of abrasion exceeds the optimum. Because of these mechanisms, the sliding friction coefficient deteriorates.

As the optimum abrasion volume is very small with the plastics that are sensitive to roughness, these plastics only have a very narrow range in which the sliding behaviour can be improved by abrasion. With increasing roughness, the effects of the abrasion become predominant. It is no longer possible to improve the sliding behaviour. By the same token, the sliding behaviour only worsens due to a lack of abrasion on materials that have mating components with an extremely smooth surface.

The surface roughness of the plastics plays no role in this observation, as they are soft compared to the metallic mating component and quickly adapt to its contact pattern. Hence, important for choosing the surface quality of the steel sliding surface is the question whether the functionality of the sliding element is affected by either the amount of sliding abrasion or the sliding friction coefficient. For combination with plastic friction bearings, the mating components in Table 2 with the associated surface grades can be recommended:

Table 2: Recommended surface qualities for mating components

		PA 6 C	**PA 12 G**	**PA 6**	**PA 66**	**PA 12**	**POM**	**PET**	**PE-UHMW**	**PTFE**
Mating component hardened steel	Hardness HRc min.	50	50	50	50	50	50	50	50	50
	R_z [µm]	2-4	2-4	2-4	2-4	2-4	1-3	0.5-2	0.5-2	0.2-1
Mating component thermoplastic	Material	POM	POM	POM	POM	POM	PA	PA/POM	PA/POM	PA/POM/PET
	R_z [µm]	10	10	10	10	10	10	10	10	5

Low surface hardness and smaller/greater surface roughness than those specified promote sliding abrasion in the bearing and thus shorten its useful life.

In addition to the above-mentioned factors, running speed, surface pressure and temperature also have an effect on sliding abrasion. High running speeds, surface pressure and temperatures also increase sliding abrasion. The following table contains guiding values for the sliding abrasion of plastics.

Table 3: Sliding abrasion of plastics 1)

Material	Sliding abrasion in µm/km	Material	Sliding abrasion in µm/km
LiNNOTAM*GLiDE*	0.03	POM-C	8.9
LiNNOTAM*GLiDE PRO T*	0.03	PET	0.35
LiNNOTAM	0.1	PET-GL	0.1
PA 6	0.23	PE-UHMW	0.45
PA 66	0.1	PTFE	21.0
PA 12	0.8		

1) against steel, hardened and ground, P = 0.05 MPa, v = 0.6 m/s, t = 60 °C in the vicinity of the running surface

The stated values depend on the sliding system and can also change due to changes in the sliding system parameters.

1.4 Lubrication/dry running

At present there are no general valid lubrication rules for plastic friction bearings. The same lubricants that are used for metallic friction bearings can also be used for plastic bearings. It is advisable to use a lubricant despite the good dry running properties of plastics, as the lubricant reduces the coefficient of friction and thus the frictional heat. In addition, continuous lubrication also helps dissipate heat from the bearing. Lubricating the friction bearings gives them a higher load bearing capacity and reduces wear, which in turn gives them longer life. However, if the bearings are to be used in a very dusty application it is advisable not to use any lubrication, as the dust particles become bonded in the lubricant and can form an abrasive paste which causes considerable wear. The plastic bearing materials recommended in the table on page 63 are resistant to most commonly used lubricants.

An alternative to external lubrication are plastics with self-lubricating properties such as **LiNNOTAM***GLiDE*, **LiNNOTAM***GLiDE PRO T* or PET-GL. Due to the lubricants that are integrated into the plastic, these materials have the lowest wear rates as well as excellent dry and emergency running properties. When design reasons require to do so, it is also possible to operate plastic friction bearings without lubrication.

However, attention must be paid that the load values are within the pv values stated in Table 4. In any case, a one-time lubrication should be carried out during installation if possible, even if dry running is intended. This considerably improves the start-up behaviour and can prolong the life of the product. It is also possible to lubricate the bearings subsequently at intervals to be determined empirically.

1.5 Contamination/corrosion

The steel shaft of friction bearings that are operated in dry running conditions is in danger of corroding due to migrating moisture. When the surface of the mating component is damaged by corrosion, this increases sliding abrasion and can cause the bearing to malfunction prematurely. This can be prevented by sealing the bearing against moisture. Other effective measures are to plate the mating component with chromium or to manufacture the mating component from stainless steel.

Because of their low coefficients of sliding friction, plastic friction bearings tend to suffer much less from frictional corrosion than metallic bearing materials. Wear caused by frictional corrosion can be reduced even further by lubrication. Compared to metallic bearing materials, wear in plastic friction bearings caused by contamination such as dust or abrasion is much lower, as plastics, and especially polyamides, have the ability to embed dust particles and thus prevent the abrading effects. When operating in environments with high dust levels, it is recommended that the bearing is fitted with lubrication grooves. The lubricant contained there binds the dust particles and keeps them away from the slide zone.

1.6 Load limits

Load limits for thermoplastic friction bearings are defined by the compressive strength and bearing temperature. The bearing temperature is directly related to the running speed and the ambient temperature, and, with dynamically loaded friction bearings, also to the duration of operation. The mating components, their surface quality and the chosen type of operation (lubricated or unlubricated) also have an effect on the bearing temperature of a thermoplastic friction bearing. Table 4 contains guiding values for individual plastics. For statically loaded bearings or friction bearings with very low running speeds, the figures for sustained pressure loading can be applied. For dynamically loaded bearings, usually the pv value (product of surface pressure and average running speed) is used as a characteristic variable. It must be noted that this value is not a material characteristic value, as the load limit of the plastics depends on the above-mentioned variables.

	LiNNOTAM	**LiNNOTAM***GLiDE*	**LiNNOTAM** *HiPERFORMANCE*	**PA 6**	**PA 66**	**PA 12**	**POM-C**	**PET**	**PET-GL**	**PE-UHMW**	**PTFE**	**PTFE + carbon**	**PEEK**	**PEEK-GL**
Sustained pressure load static MPa Not equipped with chambers, Deformation < 2%	23	20	24	15	18	10	22	35	33	5	5	12	57	68
Equipped with chambers; Deformation < 2%	70	60	–	50	60	43	74	80	75	20	20	–	105	120
Coefficient of friction μ (average value) Dry running on steel	0.36 – 0.42	0.18 – 0.23	0.40 – 0.60	0.38 – 0.42	0.35 – 0.42	0.32 – 0.38	0.30	0.25	0.2	0.28	0.08	0.1	0.30 – 0.38	0.11
pv-guiding value MPa · m/s Dry running/ Installation lubrication V = 0.1 m/s V = 1.0 m/s Continuously lubricated	0.13 0.08 0.05	0.23 0.15 0.50	0.12 0.10 0.35	0.11 0.07 0.40	0.13 0.08 0.50	0.08 0.50	0.15 0.10 0.50	0.15 0.10 0.50	0.25 0.15 0.50	0.08 0.05 0.40	0.05 0.40	0.40 0.50	0.34 0.22 1.0	0.66 0.42 1.0
Coefficient of thermal expansion +20 °C to +60 °C in $10^{-5} \cdot K^{-1}$	8	8	10	9	8	10	10	8	8	18	20	11	5	4.5
Maximum permissible bearing temperature in continuous operation (RF< 80%)	+90	+90	+90	+80	+90	+80	+90	+80	+90	+50	+160	+200	+250	+250
Moisture absorption in % at 23 °C/50% RF when saturated in water	2.2 6.5	1.8 5.5	0.9 1.4	2.1 10	3.1 9	0.8 1.5	0.2 0.8	0.2 0.5	0.2 0.4	0 <0.01	0 <0.01	0 <0.01	0.2 0.45	0.14 0.3

Table 4: Material guiding values

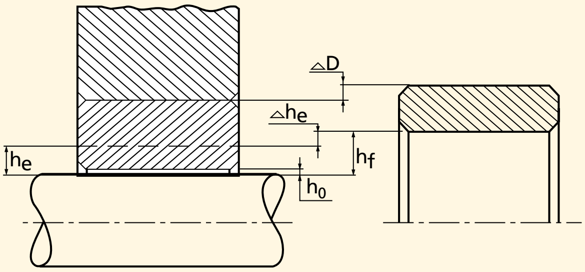
2. Constructional design

2.1 Bearing play

When designing friction bearings, a distinction is made between operating play h_0, installation play h_e and manufacturing play h_f (see Figure 3).

- The operating play (basic play or minimum play) h_0 is the minimum clearance that must exist under the most unfavourable conditions to prevent the bearing from sticking.
- The installation play h_e is the clearance in an installed but not yet warm operating state.
- The manufacturing play h_f is the measure describing the excess size that the internal diameter of the bearing must have compared to the shaft diameter to ensure operating play under operating conditions.

Figure 3: Diagram of different bearing play

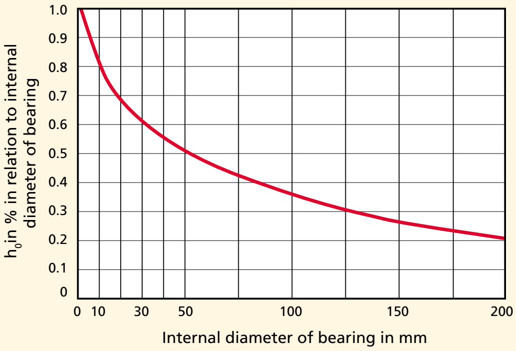


The required operating bearing play h_0 can be seen in Diagram 1. If guiding requirements are higher, the bearing play can be less. Literature recommends the following as a calculation basis.

$h_0 = 0.015\sqrt{d_w}$ where
h_0 = operating bearing play in mm
d_w = spindle diameter in mm

However, for arithmetical determination, the precise operating conditions must be known, as otherwise the temperature and moisture effects cannot be taken fully into account.

Diagram 1: Required operating bearing play

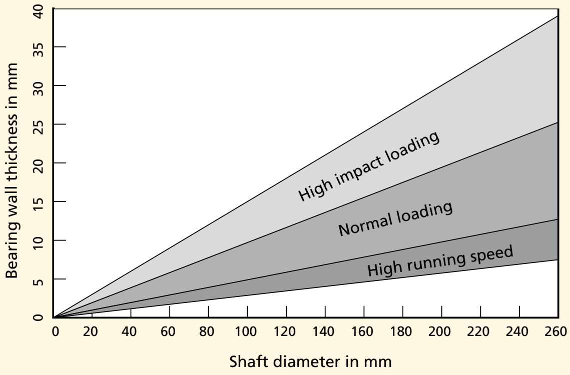


2.2 Wall thickness/bearing width

The wall thickness of thermoplastic friction bearings is very important in regard to the good insulation properties of the plastics. To ensure adequate heat dissipation and good dimensional stability, the friction bearing wall must be thin. However, the bearing wall thickness also depends on the amount and type of load. Bearings with high circumferential speeds and/or high surface pressures should have thin walls, while those with high impact loads should be thicker. Diagram 2 shows the bearing wall thicknesses that we recommend in relation to the shaft diameter and the type of load.

Where thermoplastic friction bearings are to be used as a replacement for bearings made from other materials, the wall thicknesses are generally defined by the existing shafts and bearing housings. In cases such as this, attention should be paid that the minimum wall thicknesses in Diagram 2 are maintained. To prevent a build-up of heat in the centre of the friction bearing it should be ensured that it is in the range of 1-1.5 d_w when the bearing width is being determined. Experience has shown that a bearing width of approx. 1.2 d_w is ideal to prevent an accumulation of heat in the middle of the bearing.

Diagram 2: Recommended bearing wall thickness



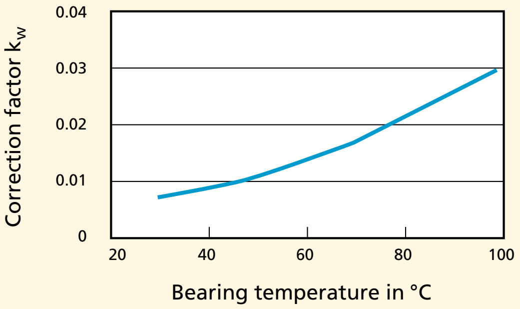
2.3 Allowances

For friction bearings that are to be used in environments with high temperatures, a certain dimensional change due to thermal expansion should be allowed for when the bearing is being dimensioned.

The expected dimensional change is calculated from:

$\Delta l = s_L \cdot k_w$ [mm] where
Δl = dimensional change
s_L = bearing wall thickness
k_W = correction factor for heat expansion

Diagram 3: Correction factor k_W



The correction factor k_W for the respective max. ambient temperatures is shown in Diagram 3. The calculated dimensional change must be added to the operating bearing play.

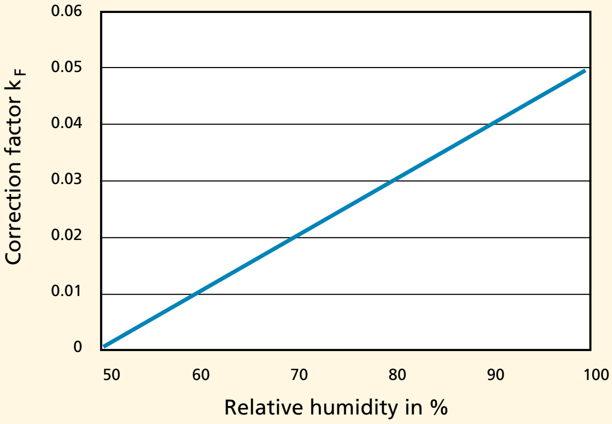
If it is foreseeable that polyamide friction bearings are to be used permanently under conditions with increased humidity or water splashing, an additional dimensional change due to moisture absorption must be taken into account.

The expected dimensional change is calculated from:

$\Delta l = s_L \cdot k_F$ [mm] where
Δl = dimensional change
s_L = bearing wall thickness
k_F = correction factor for moisture absorption

Diagram 4 shows the correction factor k_F for the respective max. humidity. The calculated dimensional change must be added to the operating bearing play.

Diagram 4: Correction factor k_F

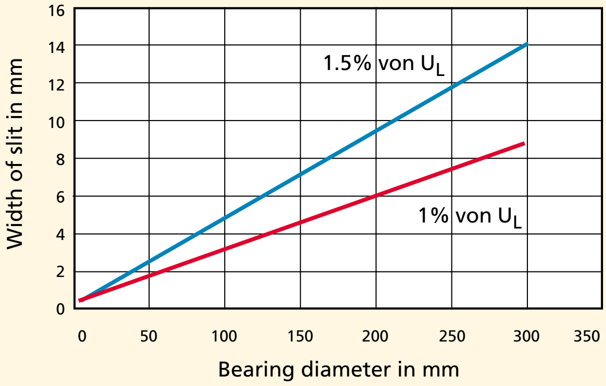


The two values are determined and added for operating conditions that require a correction due to temperature and moisture. The total is the required allowance.

2.4 Design as slit bearing bush

For use in extreme moisture and temperature conditions, a bearing bush with an axial slit running at an angle of 15°-30° to the shaft axis has proven to be the best solution. The slit absorbs the circumferential expansion of the bearing bush so that a diameter change caused by the effects of temperature or moisture does not have to be considered when calculating bearing play. Only the wall thickness change has to be included,

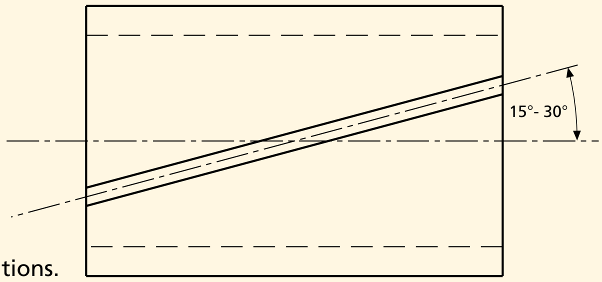
Diagram 5: Width of slit



although this is minor compared to the change in diameter caused by circumferential expansion.

In lubricated bearings, the slit can also fulfil the role of a lubricant depot and collect abrasion particles.

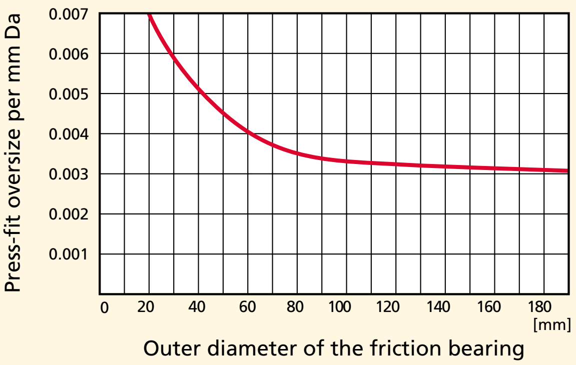
The width of the slit depends on the diameter of the bearing and the requirements of the operating conditions. We recommend a slit approx. 1-1.5% of the circumference of the friction bearing.



2.5 Fixing

In practice it has proved expedient to press over-dimensional friction bearings into a bearing bore. When it is being set in, the bearing bush is compressed by the amount of the oversize. Therefore this oversize must be considered as an allowance to the operating bearing play on the internal diameter of the bush. Diagram 6 shows the required oversize.

Diagram 6: Required press-fit oversize



As a result of temperature increases, the stresses in the bearing become greater and there is a danger of relaxation when it cools. This can lead to a situation where the force of pressure is no longer adequate to keep the friction bearing in the bearing seat under pressure. Because of this we recommend an additional safeguard for temperatures above 50 °C with a securing form-fit element commonly used in machine engineering.

3. Calculating dynamically loaded friction bearings

As opposed to friction bearings that are only burdened by a static normal force, statically loaded friction bearings are also subjected to a tangential force. This leads to an increase in transverse stress in the plastic and consequently to higher material stress.

3.1 Continuous operation

Generally the pv value (the product of the average surface pressure and the average running speed) is used as a characteristic value for the dynamic load bearing capacity of friction bearings. To calculate the dynamic load bearing capacity of radial bearings, it is necessary to determine the $pv_{duration}$ value.

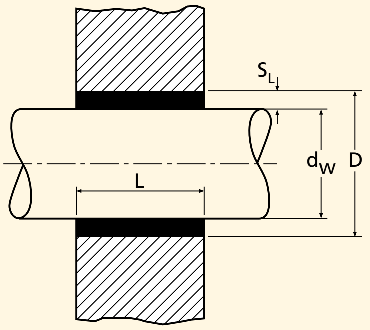
The average surface pressure for radial bearings is

$$p = \frac{F}{d_w \cdot L} \text{ [MPa]}$$

where

F = bearing load in N
d_w = shaft diameter in mm
L = bearing width in mm

Figure 5: Radial bearing



Radial bearing

The average running speed for radial bearings is

$$v = \frac{d_w \cdot \pi \cdot n}{60.000} \quad [m/s]$$

where

d_w = shaft diameter in mm

n = speed in min^{-1}

Hence $pv_{duration}$ for dynamic loading for radial bearings without lubrication is

$$pv_{duration} = \left(\frac{F}{d_w \cdot L}\right) \cdot \left(\frac{d_w \cdot \pi \cdot n}{60.000}\right) \quad [MPa \cdot m/s]$$

The calculated $pv_{duration}$ value should be less or equal to the material-specific pv value shown in Table 4.

3.2 Intermittent operation

The dynamic load bearing capacity of thermoplastic friction bearings is very much dependent on the heat that builds up during operation. Accordingly, friction bearings in intermittent operation with a decreasing duty cycle become increasingly loadable. This is accounted for by using a correction factor for the relative duty cycle (= ED).

Under these conditions, the following applies to radial bearings in intermittent operation

$$pv_{int} = \frac{pv_{duration}}{f}$$

where

f = correction factor for ED

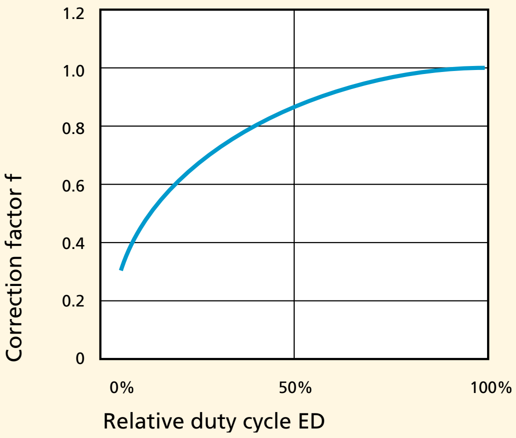
The relative duty cycle ED is defined as the ratio of the load duration t to the total cycle time T in percent.

$$ED = \frac{t}{T} \cdot 100 \quad [\%]$$

For thermoplastic friction bearings, the total cycle time is defined as T = 60 min. The total of all individual loads during these 60 minutes forms the load duration.

This calculated value can then be used to determine the correction factor f from Diagram 7. It should be noted that every load duration t, over and above 60 min. (regardless of whether this only happens once), is to be evaluated as continuous loading.

Diagram 7: Correction factor f



3.3 Determining sliding abrasion

It is a very complex matter to determine the sliding abrasion beforehand in order to determine the expected life of a friction bearing. Generally it is not possible to record the external conditions adequately, or conditions change during operation in a manner that cannot be predetermined. However, it is possible to calculate the expected sliding abrasion sufficiently accurately to provide a rough estimate of the life of a bearing. Roughness, pressure and temperature proportions are aggregated to form an equation based on simplified assumptions.

Hence sliding abrasion ΔS is:

$$\Delta S = 10 p_N \left(S_0 + S_1 \cdot R_V + S_2 \cdot R_V^2\right) \cdot \left(1 - \frac{\vartheta_F}{\vartheta_0} + 400^{\frac{\vartheta_F - \vartheta_0}{\vartheta_0}}\right) \cdot \rho_2 \gamma \quad [\mu m/km]$$

where

S_0 = measured and experience value

S_1 = measured and experience value

S_2 = measured and experience value

ϑ_0 = measured and experience value

ϑ_F = sliding surface temperature in °C

R_V = average depth of roughness in µm

p_N = maximum compression in MPa

ρ_2 = grooving direction factor

γ = smoothing factor

The grooving direction factor ρ_2 is only used in the equation if the sliding direction corresponds to the direction of the machining grooves of the metallic mating component. This takes account of the influence of the different degrees of roughness during the relative movement of the metallic mating component in the same direction and vertically to the direction of the machining grooves.

The smoothing factor γ describes the smoothing of the metallic mating component through the abrasion of rough tips and/or the filling of roughness troughs with abraded plastic material.

Using an approximation equation the maximum compression p_N is

$$p_N = \frac{16}{3\pi} \cdot \frac{F}{d_W \cdot L} \text{ [MPa]}$$

where

F = bearing load in N

d_W = shaft diameter in mm

L = bearing width in mm

where $p_N \geq (0{,}8 \text{ to } 1{,}0) \cdot \sigma_D$ may not exceed σD (compressive strength of the respective plastic).

The measured and experience values can be seen in Table 5, the grooving direction factors in Table 6. We do not have any measured or experience values for materials other than those listed below.

Table 5: Measured and experience values for individual plastics

Material	S_0	S_1	S_2	ϑ_0	γ
PA 6	0.267	0.134	0	120	0.7
PA 66	0.375	0.043	0	120	0.7
PA 12	0.102	0.270	0.076	110	0.7
POM-C	0.042	0.465	0.049	120	0.8
PE-UHMW	1.085	- 4.160	4.133	60	0.7
PET	0.020	0.201	- 0.007	110	0.8
PTFE	1.353	-19.43	117.5	200	0.6

Table 6: Groove direction factors for plastics

R_v vertical to the direction of the machining grooves in µm	PA	POM-C	PET	PE-UHMW
> 0.5	1.0	0.9	0.8	0.8
0.5-1	0.9	0.6	0.6	0.4
1-2	0.8	0.3	0.4	0.2
2-4	0.8	0.2	0.3	–
4-6	0.8	0.2	0.3	–

3.4 Determining the service life of a bearing

As a rule, a plastic friction bearing has reached the end of its service life when the bearing play has reached an unacceptably high level. Bearing play is made up of several factors. On the one hand there is some deformation due to the bearing load, and on the other hand the operating play and the wear resulting from use must be considered. As these can only be arithmetically calculated in advance and since the sliding abrasion calculated approximately at 3.3 is used to calculate the service life, the service life itself should only be regarded as an approximate value for a rough estimate.

Under these prerequisites and in combination with the running speed, the expected service life H is

$$H = \frac{\left(\Delta h_{zul} - \Delta h - \dfrac{h_0}{2}\right)}{\Delta S \cdot v \cdot 3{,}6} \cdot 10^3 \quad [h]$$

where

Δh_{zul} = permissible journal hollow in mm
Δh = journal hollow in mm
h_0 = operating play in mm
ΔS = wear rate in µm
v = running speed in m/sec

To obtain a rough approximation of the actual service life, it is acceptable to leave the journal hollow Δh out of the calculation, as in realistic conditions this is very small and is often within the manufacturing tolerance range.

LICHARZ

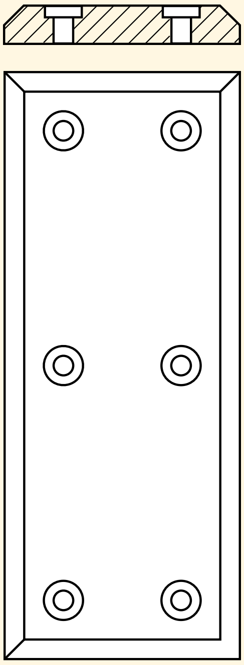
THERMOPLASTIC SLIDER PADS

The competitive edge through engineered components made of plastic

Plastic slider pads

1. Thermoplastic slider pads

In the same way that friction bearing bushes are used to arrange the bearings of a shaft for rotational and up and down movements, the same plastics can of course be used for linear movements in the form of slider pads. Basically all the plastics listed in the “Friction bearings” chapter are suitable for use as slider pads. However, several are especially suitable. These will be described in the following with their advantages.



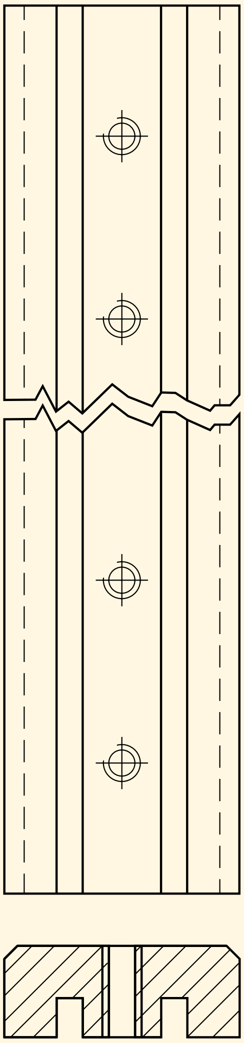
1.1 Materials

Plastics that are used as slider pads require good sliding properties as well as high stability and elasticity and creep resistance. These requirements are fulfilled especially well by **LiNNOTAM**. The high stability compared to other thermoplastics allows higher loads. The good elasticity ensures that deformation is reversed when the material is subjected to impact load peaks. Assuming that the load remains below the permissible limit, this ensures that permanent deformation is avoided to a great extent.

The oil-filled modification **LiNNOTAM***GLiDE* is available for highly loaded slider pads. The oil which is embedded in the molecular structure reduces sliding friction by around 50% and also considerably reduces sliding abrasion.

PET is best suited for applications where a high level of moisture is expected. The material has high mechanical stability, creep resistance, dimensional stability and good sliding properties. Water absorption is low and has virtually no effect on the mechanical or electrical properties.

However, PET is not as wear resistant as polyamides. But PET-GL is available as a modified grade with a solid lubricant. This has improved sliding properties and much better wear resistance.



2. Design information

2.1 Friction heat

As opposed to friction bearings that operate continuously at high speeds, most slider pads and guide rails usually work under conditions that minimise the development of friction heat. The running speeds are relatively slow and operation is more intermittent than continuous. Under these conditions, it is unlikely that friction heat builds up to a level that could cause increased wear or a breakdown in the component.

2.2 Pressure and running speed

As a rule, when dimensioning and designing sliding elements, the design engineers consider the pressure and speed ratio. If the pressure and speed ratios are unfavourable, the resulting friction heat leads to excess wear and even to a premature breakdown of the component. However, experience in the design and operation of slider pads has shown that it is generally unnecessary to calculate the pressure and speed values due to the favourable operating conditions of slider pads. Instead of this, the following limiting pressure values can be used as a basis for most guide rail applications. The values apply at a standard temperature of 23 °C.

PA	PET	Load	Movement	Lubrication
28 MPa	**21 MPa**	interrupted	interrupted	periodic
14 MPa	**10 MPa**	continuous	interrupted	periodic
3.5 MPa	**2.5 MPa**	continuous	continuous	none

2.3 Lubrication

Again the statements regarding dry running and the use of lubricants from the “Friction bearings” chapter apply. Basically it must be said that initial lubrication at installation considerably improves the service life and running behaviour. The materials that have been modified with lubricant, such as **LiNNOTAM***GLiDE* and **LiNNOTAM***GLiDE PRO*, have much longer service lives than all other plastics.

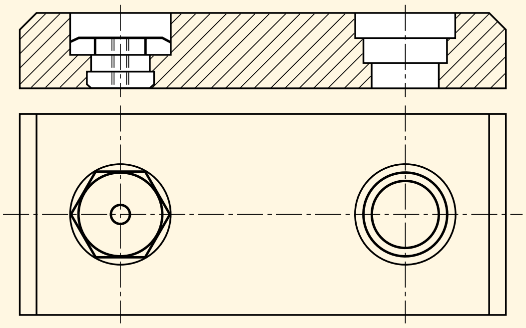
2.4 Mounting

Polyamide slider pads or guide rails with a mechanical sliding function are generally mounted on steel constructions.

Countersunk screws or machine screws can be used without any problem for applications at room temperature and normal climatic conditions (50% RH). For operating conditions with high humidity, we recommend that you consider using PET/PET-GL.

If a higher ambient temperature is expected, the approx.10 times higher linear expansion of plastic compared to steel must be considered. Firmly screwed plastic rails can corrugate due to linear expansion. To prevent this from happening, the mounting points should be less than 100 mm apart. In the case of longer sliding rails, one single fixed point screw is advised. The other screws in oblong holes should be able to absorb the thermal expansion. Instead of oblong holes, the rails can also be held in grooves, T-slots or similar. Changes in length caused by extreme ambient conditions have no effect on the fixing or function.

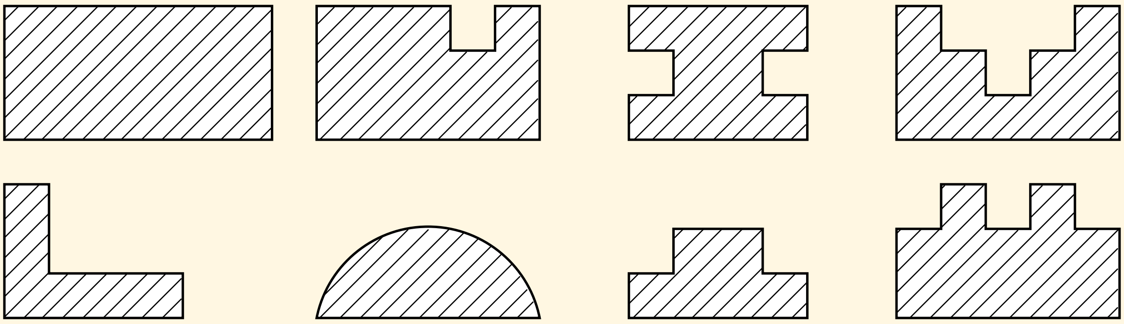
Figure 1: Example of threaded inserts



For polyamide slider pads in high performance applications such as telescopic booms on mobile cranes, we recommend special nuts that are pressed into hexagonal holes on the slider pads.
By pressing the nut into the hexagonal hole it cannot fall out or loosen. The bottom of the slide plate should be absolutely flush.

Under full torque, the polyamide is held under pressure by the threaded insert and the insert sits on the steel support. For mountings such as this, pad thicknesses of 12-25 mm are adequate for optimum performance.

2.5 Applications and examples of shapes
Slide and guide pads in telescopic cranes, garbage presses, car body presses, road and rail vehicles, timber processing machines and plants, packaging and filling plants, transport and conveyor systems, chain guides, etc.



LICHARZ

PLASTIC CASTORS

The competitive edge through engineered components made of plastic

1. Plastics as castor materials

Plastic wheels and castors are increasingly used in plants and material flow systems, replacing conventional materials. This is because of advantages such as

- Cost-effective manufacturing
- Very quiet running
- High wear resistance
- Good vibration and noise damping
- Low weight
- Protection of the tracks
- Corrosion resistance

In addition to the soft-elastic wheels made from polyurethanes, hard elastic wheels and castors made from cast polyamide, POM and PET are popular for higher loads. However, compared to conventional metal wheel and castor materials, several plastic-specific properties must be considered when calculating and dimensioning.

1.1 Materials

LiNNOTAM, **LiNNOTAM***HiPERFORMANCE 612* and **LiNNOTAM***HiPERFORMANCE 1200* have proved to be ideal materials. POM and PET can also be used. However, experience has shown that although these have a similar load bearing capacity to the cast polyamides, they are subject to much more wear. The recovery capacity of these materials is lower than that of polyamides. In dynamic operation, flattening that occurs under static loading does not form back as easily as with polyamide castors.

1.2 Differences between steel and plastic

Plastic has a much lower modulus of elasticity than steel, which leads to a relatively greater deformation of plastic wheels when they are subjected to loads. But at the same time, this produces a larger pressure area and consequently a lower specific surface pressure, which protects the track. If the loading of the wheel remains within the permissible range, the deformation quickly disappears due to the elastic properties of the plastics.

In spite of the larger pressure area, plastic wheels are not as loadable as steel wheels with the same dimensions. One reason for this is that plastic wheels can only withstand much smaller compressive strain (compression) in the contact area, another reason is the transverse strain that occurs due to the very different degrees of rigidity of the castor and track materials. These hinder the wheel from deforming and have a negative influence on the compressive strain distribution in the wheel.

1.3 Manufacture

There are several production processes that can be used to manufacture plastic castors.

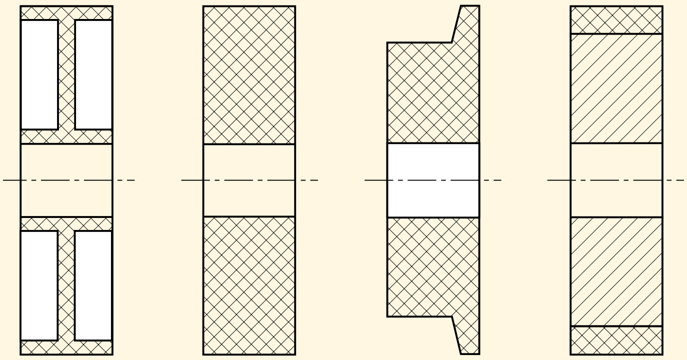
If high volumes of wheels with small dimensions are to be produced, injection moulding is a suitable method. As a rule, for production-engineering reasons, larger dimensions can only be produced by injection moulding as recessed and ribbed profile castors. It must also be noted that these only have half the load bearing capacity of a solid castor with the same dimensions. It is also a very complex procedure to calculate a castor such as this compared to a solid castor, and rolling speeds of more than 3m/s are not recommended because of production-related eccentricity. An economic and technical alternative to injection moulding is to machine semi-finished products. In the small dimensional range up to Ø 100 mm, the castors are manufactured on automatic lathes from rods. Sizes above this are produced on CNC lathes from blanks.

Manufacture by machining from semi-finished products deserves a mention as an economic and technical alternative to injection moulding. In the small dimension range of up to ø 100 mm the castors are produced on automatic lathes from bar stock and for products above this size on CNC lathes from round blanks. The centrifugal casting process can also be employed. In this process the outer contours of the part are cast to size and then the bearing seats or axle bores are machined to the required finished dimensions. This also enables larger dimensions in higher quantities to be produced particularly economically.

With this process a degree concentricity can be achieved that enables the castors to be used with rolling speeds of up to 5 m/s.

1.4 Castor design

In addition to the four basic castor body shapes, castors differ mainly in the type and design of their bearings. Like sheaves, solid castors can also be fitted with friction bearings. A prerequisite is that the material-specific max. loading parameters are not exceeded. How to calculate friction bearings and the significant factors for safe operation of the bearing are contained in the chapter on ”Friction bearings“. If it is not possible to use a friction bearing because the load is too high or because of other factors, the use of antifriction bearings is recommended. The chapter on ”Tolerances“, section 2.5.2 deals with the material related design of bearing seats in detail. Compression-set antifriction bearings used at temperatures above 50 °C can loosen. This can be counteracted by design measures such as pressing the bearing into a steel flange sleeve screwed to the body of the castor.



Alternatively we recommend the use of our **LiNNOTAM***DRiVE* materials (PA with a metal core), which combines the advantages of plastic as a castor material and steel as a bearing seat material. Because of its form and frictional connection of the steel core with the plastic, this material is also recommended for applications where driving torque has to be transferred. For castor diameters > 250 mm, a lined castor design is advantageous.

The plastic lining is fixed to the metallic core of the castor through shrinkage. Details of this design alternative will be described in a separate section.

2. Calculation

When calculating plastic castors, several important points must be remembered. The material has visco-elastic properties, which become visible through decrease in rigidity as the load duration increases. The result of this is that when the contact area of the static wheel is continuously loaded, it becomes larger the longer this load continues. However, as a rule because of the materials’ elastic properties, they are quickly able to return to their original shape when they begin rolling. Hence, no negative behaviour is to be expected during operation. But if the permissible yield stress of the material is exceeded the material can ”flow“ and lead to permanent deformation.

This causes increased start-up forces when the castor or wheel is restarted and eccentricity in the rolling movement. High ambient temperatures and, especially for polyamides, high humidity promote this behaviour, as they reduce the maximum yield stress. An exception to this is **LiNNOTAM***HiPERFORMANCE 1200*, as it has less tendency to absorb water.

It should also be noted that because of the material's good damping properties, the body of the castor can heat up as a result of high running speeds or other loading factors. In extreme cases, temperatures can occur that cause the plastic wheel to malfunction. However, if the loads remain within the permissible limits, plastic castors and wheels will operate safely and reliably.

2.1 Calculation basics

It would appear practical to apply the Hertzian relationships when calculating castors, but plastic wheels do not fulfil all the conditions for this approach. For example, there is no linear connection between stress and expansion, and because of the elasticity of the material, shear stresses occur in the contact area while the wheel is rolling. Nevertheless, it is possible to make an adequately precise calculation on the basis of Hertz' theory. The compression parameter p' is determined with the following calculations. This parameter is generally calculated with short-time modulus of elasticity determined at room temperature and therefore does not reflect the actual compression in the contact area. Because of this, the determined values are only expressive in combination with Diagrams 1 to 4.

The calculated values are usually higher than those that actually occur during operation and therefore contain a certain degree of safety. Still, castors or wheels can malfunction as it is not possible to consider all the unknown parameters that can occur during operation to an adequate extent in the calculation.

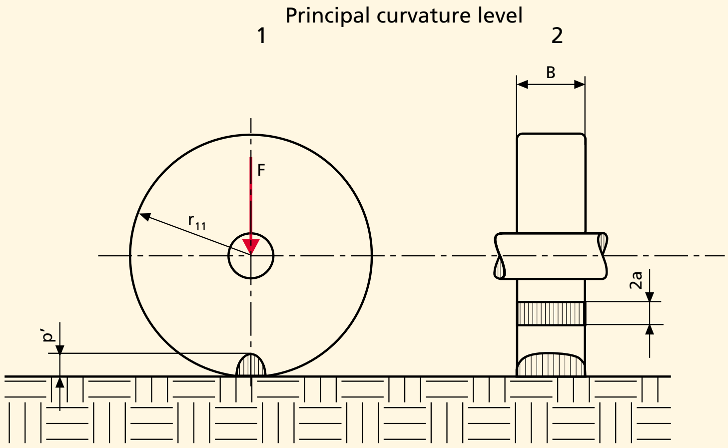
For castors with friction bearings, the load limit of the friction bearing is decisive. As a rule, the full load bearing capacity of the running surface cannot be utilised, as the load limit of the friction bearing is reached beforehand (see chapter "Friction bearings").

2.2 Cylindrical castor/flat track

Under load, a projected contact area is formed with length 2a and width B, with compression distributed over the area in a semi ellipsoidal form. Noticeable is that the stress increases at the edges of the castor. This stress increase is generated by shear stresses that occur across the running direction. These have their origins in the elastic behaviour of the castor material. The stress increases become larger the greater the differences in rigidity between the track and the castor materials. As stress increase in a castor made from hard-elastic plastic is quite small and can therefore be ignored for operating purposes and as the shear stresses cannot be calculated with Hertz' theory, these are not considered.

Assuming that the track material has a much higher modulus of elasticity than the castor material and that the radii in the principal curvature level (PCL) 2 are infinite, the compression parameter p' is

$$p' = f_w \sqrt{\frac{F}{r_{11} \cdot B}} \quad \text{[MPa]}$$



where

F = wheel load in N

r_{11} = castor radius in mm from PCL 1

B = wheel width in mm

f_w = material factor

LiNNOTAM = 25.4

PA 6 = 38

POM = 33.7

If the moduli of elasticity of the castor and track materials are known, the following equations can be used:

$$p' = \sqrt{\frac{F \cdot E_e}{2 \cdot \pi \cdot r_{11} \cdot B}} \quad \text{[MPa]}$$

and

$$\frac{1}{E_e} = \frac{1}{2} \left[\frac{1 - v_1^2}{E_1} + \frac{1 - v_2^2}{E_2} \right]$$

For identical track and castor materials E_e is:

$$E_e = \frac{E}{1 - v^2}$$

where

F = wheel load in N

E_e = replacement module in MPa

r_{11} = castor radius in mm from PCL 1

B = wheel width in mm

E_1 = modulus of elasticity of the castor body in MPa

v_1 = transversal contraction coefficient of the castor body from Table 1

E_2 = modulus of elasticity of the track material in MPa

v_2 = transversal contraction coefficient of the track material from Table 1

Table 1: Transversal contraction coefficients for various materials

	PA 6 LiNNOTAM POM PET	Ferritic steels	Steel with approx. 12% Cr	Austenitic steels	Cast iron				Aluminium alloys	Titanium alloys
					GG 20	GG 30	GG 40	GGG 38 to 72		
Transversal contraction coefficient μ at 20 °C	0.4 up to 0.44	0.3	0.3	0.3	0.25 up to 0.26	0.24 up to 0.26	0.24 up to 0.26	0.28 up to 0.29	0.33	0.23 up to 0.38

The half contact area length required to estimate flattening is calculated from

$$a = \sqrt{\frac{8 \cdot F \cdot r_{11}}{\pi \cdot E_e \cdot B}} \quad [\text{mm}]$$

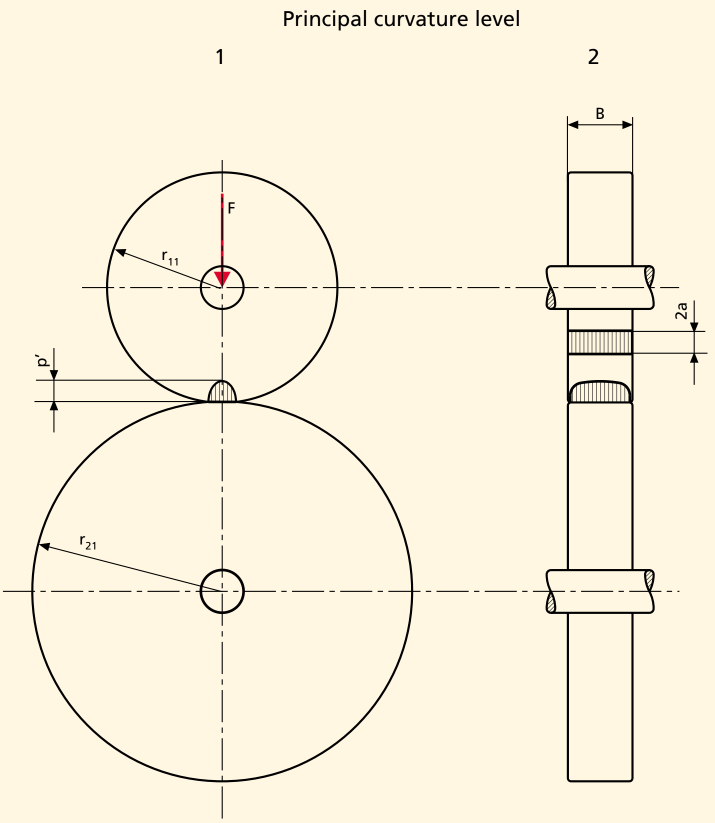
where

F = wheel load in N

E_e = replacement module in MPa

r_{11} = castor radius in mm from PCL 1

B = wheel width in mm



2.3 Cylindrical castor/ curved track

Also in this system a projected contact area is formed with length 2a and width B, with compression distributed over the area in a semi ellipsoidal form. The previously described stress increases also form in the edge zones. The calculation is carried out in the same way as for the "cylindrical castor/flat track" from section 2.2. However, because of the second radius in PCL 1, a replacement radius r_e is formed from the radii r_{11} and r_{21}. This is used in the equation corresponding to relationships of the moduli of elasticity to calculate the compression parameter.
If the castor runs on a curved track the replacement radius is

$$r_e = \frac{r_{11} \cdot r_{21}}{r_{11} + r_{21}} \quad [\text{mm}]$$

For castors running on a curved track the replacement radius is:

$$r_e = \frac{r_{11} \cdot r_{21}}{r_{11} - r_{21}} \quad [\text{mm}]$$

where

r_{11} = castor radius in mm from PCL 1

r_{21} = track radius in mm from PCL 1

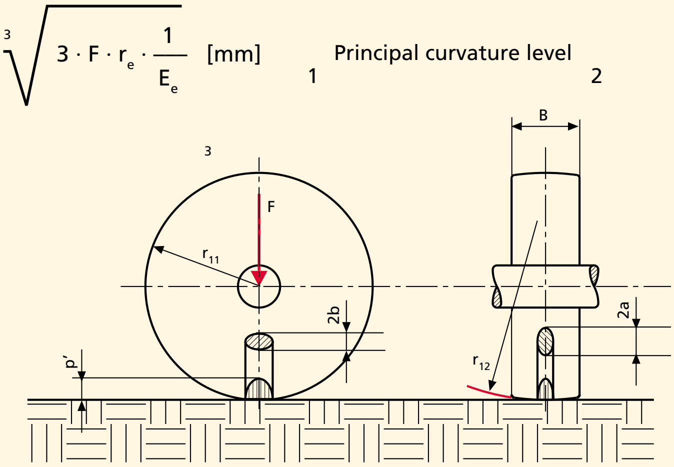
The replacement radius r_e is also used in the equation to calculate half the contact area length a.

2.4 Curved castor/flat track castor system

The phenomenon described in section 2.2, where stress increases at the edges, can be reduced with design changes of the shape of the wheel. If the track is furthermore slightly curved across the rolling direction, only minor stress increases are observed. It has proven practical to use the diameter of the wheel as the radius of the curvature. This measure also counteracts the evolution of excess edge pressure that could arise from alignment errors during assembly.

A castor with curves in PCL 1 and 2 forms an elliptical contact area with axes 2a and 2b across which the compression is distributed in the form of an ellipsoid. The semi axis of the elliptical contact area are calculated from

$$a = s \cdot \sqrt[3]{3 \cdot F \cdot r_e \cdot \frac{1}{E_e}} \ \text{[mm]} \quad \text{und} \quad b = l \cdot \sqrt[3]{3 \cdot F \cdot r_e \cdot \frac{1}{E_e}} \ \text{[mm]}$$



and

$$r_e = \frac{r_{11} \cdot r_{12}}{r_{11} + r_{12}} \ \text{[mm]}$$

where

F = wheel load in N

E_e = replacement module in MPa

s = Hertz correction value from Table 2

r_e = substitute radius

l = Hertz correction value from Table 2

The replacement module is determined as described in section 2.2.

To determine the Hertz correction values s and l the value cos t must be determined mathematically.

$$\cos\tau = \frac{\left(\frac{1}{r_{11}} - \frac{1}{r_{12}}\right)}{\left(\frac{1}{r_{11}} + \frac{1}{r_{12}}\right)}$$

where

r_{11} = castor radius in mm from PCL 1

r_{12} = castor radius in mm from PCL 2

The Hertz correction values in relation to $\cos\tau$ can be taken from Table 2. Intermediate values must be interpolated.

Table 2: Hertz correction values in relation to $\cos\tau$

$\cos\tau$	**1**	**0.985**	**0.940**	**0.866**	**0.766**	**0.643**	**0.500**	**0.342**	**0.174**	**0**
s	∞	6.612	3.778	2.731	2.136	1.754	1.486	1.284	1.128	1
l	0	0.319	0.408	0.493	0.567	0.641	0.717	0.802	0.893	1
ψ	∞	2.80	2.30	1.98	1.74	1.55	1.39	1.25	1.12	1

With these calculated values the compression parameter can be determined as follows:

$$p' = \frac{3 \cdot F}{2 \cdot \pi \cdot a \cdot b} \quad [\text{MPa}]$$

where

F = wheel load in N

a = semi axis of the contact area longitudinally to the running direction

b = semi axis of the contact area transversely to the running direction

2.5 Curved castor/curved track castor system

Both the shape of the contact area and the calculation correspond to section 2.3. However, when the replacement radius r and the value for cos t are being calculated, it should be considered that the track also has curvature radii in PCL 1 and 2.

Consequently the replacement radius for castors that roll on a curved track is

$$\frac{1}{r_e} = \frac{1}{r_{11}} + \frac{1}{r_{12}} + \frac{1}{r_{21}} + \frac{1}{r_{22}} \quad [\text{mm}]$$

and for castors that roll in a curved track

$$\frac{1}{r_e} = \frac{1}{r_{11}} + \frac{1}{r_{12}} + \frac{1}{-r_{21}} + \frac{1}{-r_{22}} \quad [\text{mm}]$$

where

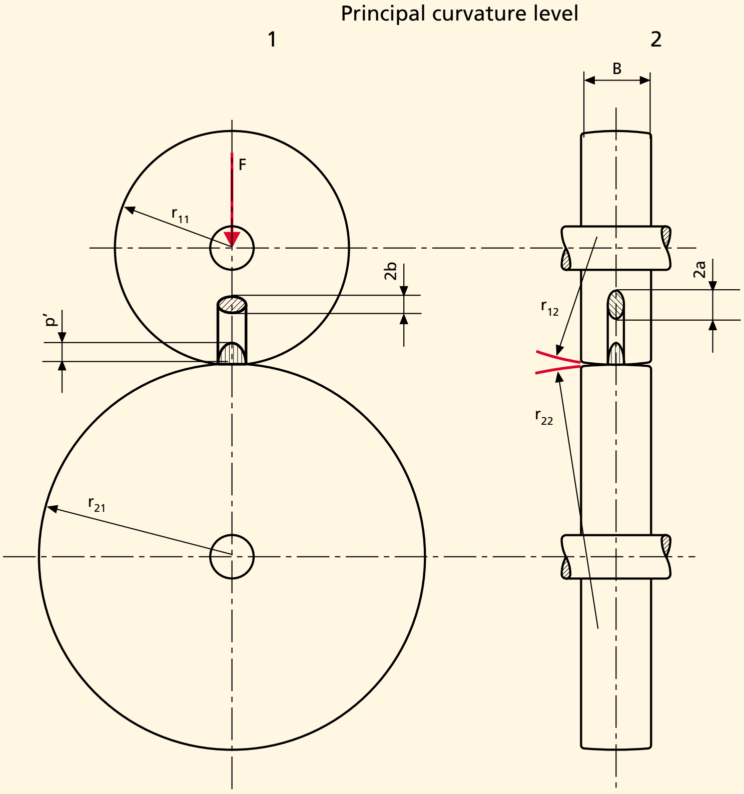
r_{11} = castor radius in mm from PCL 1

r_{12} = castor radius in mm from PCL 2

r_{21} = track radius in mm from PCL 1

r_{22} = track radius in mm from PCL 2

When determining cos τ it should be remembered that the value should be considered independently of whether the castor runs on or in a track. Therefore in the equation a positive value is always used for the radii.



$$\cos \tau = \frac{\left(\frac{1}{r_{11}} - \frac{1}{r_{12}}\right) + \left(\frac{1}{r_{21}} - \frac{1}{r_{22}}\right)}{\left(\frac{1}{r_{11}} + \frac{1}{r_{12}}\right) + \left(\frac{1}{r_{21}} + \frac{1}{r_{22}}\right)}$$

To calculate the semi axis a and b and the compression parameter the method described in section 2.4 can be applied.

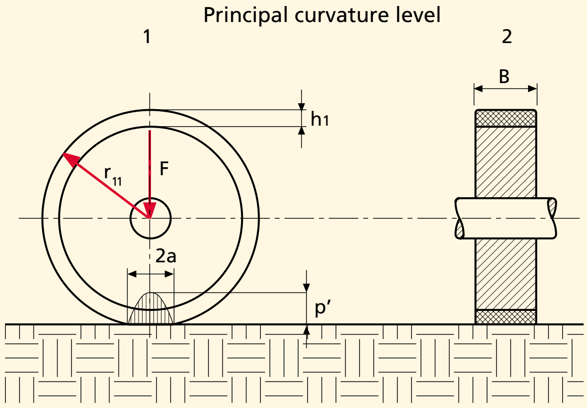
2.6 Cylindrical plastic castor lining

2.6.1 Calculation

Castor linings can only be calculated according to the equations in sections 2.2 to 2.5 if specific ratios between the half contact area length a, the wheel width B and the height of the lining h are fulfilled. The ratios h/a ≥ 5 and B/a ≥ 10 must be fulfilled as a condition. As soon as these limiting values are not met, the evolving contact area is reduced despite the same load and outer wheel dimensions. The result is that the compression of the contact area increases and becomes greater, the smaller the lining thickness. In spite of this, it is possible to determine the compression ratios approximately.

The half contact area length a becomes

$$a = \sqrt[3]{1{,}5 \cdot r_e \cdot \frac{F}{B} \cdot \frac{E'_1 \cdot h_2 + E'_2 \cdot h_1}{E'_1 \cdot E'_2}} \quad \text{[mm]}$$



For castor linings that run on or in a curved track, the replacement radius r_e is determined as described in section 2.3.

The compression parameter then becomes

$$p' = \sqrt[3]{\frac{9}{32} \cdot \frac{1}{r_e} \cdot \left(\frac{F}{B}\right)^2 \cdot \frac{E'_1 \cdot E'_2}{E'_1 \cdot h_2 + E'_2 \cdot h_1}} \quad \text{[MPa]}$$

where

F = wheel load in N
E'_1 = calculation module of wheel material in MPa
E'_2 = calculation module of track material in MPa
r_e = replacement radius in mm
h_1 = castor lining thickness in mm
h_2 = track thickness in mm
B = wheel width in mm

The calculation moduli of the materials must be determined taking account of the transversal contraction coefficients:

$$E'_1 = \frac{E_1}{1 - v_1^2} \cdot \frac{(1 - v_1)^2}{1 - 2v_1} \quad \text{und} \quad E'_2 = \frac{E_2}{1 - v_2^2} \cdot \frac{(1 - v_2)^2}{1 - 2v_2} \quad \text{[MPa]}$$

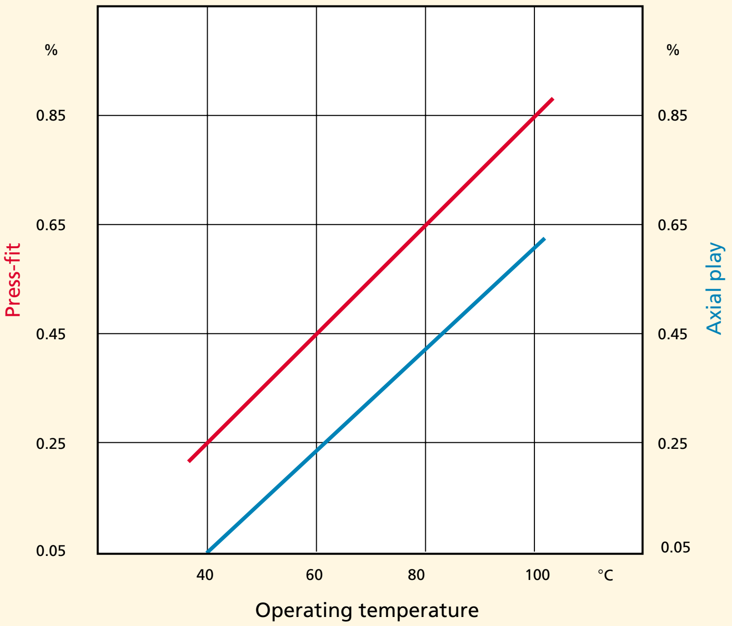
where

E_1 = modulus of elasticity of the castor material in MPa
v_1 = transversal contraction coefficient of the castor material from Table 1
E_2 = modulus of elasticity of the track material in MPa
v_2 = transversal contraction coefficient of the track material from Table 1

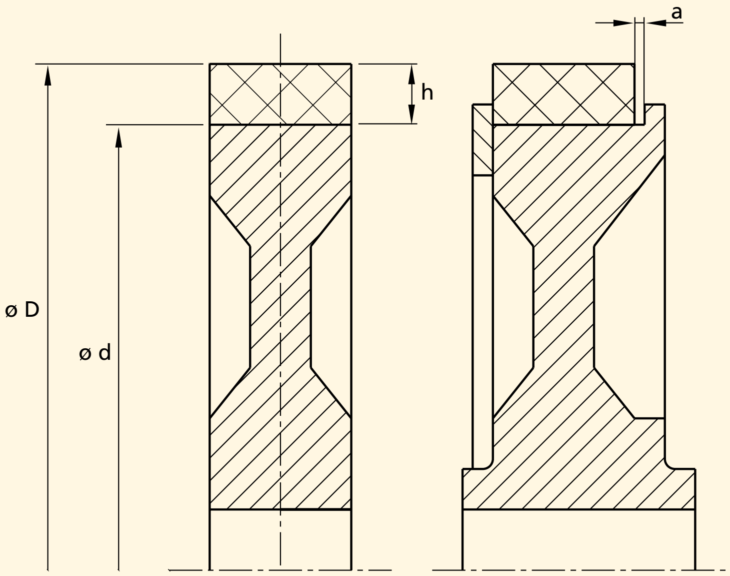
2.6.2 Design and assembly information

The shape of the plastic castor linings and the metallic core is generally dependent on the type of load that the castor will be subjected to. For castors with a low load where no axial shear is expected and where the diameter is < 400 mm, it is possible to choose a core shape with no side support. The operating temperatures may not exceed 40 °C. If it is expected that axial forces may affect the castor, that the lining will be subjected to high pressures or that operating temperatures will exceed 40 °C for short or long periods, the linings must be secured against sliding down by a side collar on the core or with a flange. The same applies for castor diameters ≥ 400 mm.

Diagram 1: Press-fit and axial play in relation to operating temperature



No special demands are placed on the metal core in the area of support for the lining in regard to surface quality and dimensional stability. A cleanly machined surface and a diameter tolerance of d ± 0.05 mm are adequate. Grooves in the axial direction (e.g. knurls with grooves parallel to the axis and broken tips) are permissible. Approximately 0.1 to 0.15 d of d has proven to be a suitable height for the plastic lining. The lining is generally fixed to the metal core by heating it and then shrinking it on to the cold core. The lining can be heated either with circulating hot air (approx. 120 to 140 °C) or in a water bath (approx. 90 to 100 °C). The lining is heated to an extent that it can be easily drawn on to the cold core with a gap between the core and the lining all the way around. This process should be carried out quickly so that the lining does not become cold before it sits properly on the core. Rapid or uneven cooling should be avoided at all costs, as otherwise stresses will form in the lining.



The press-fit for manufacturing the lining depends on the operating temperature and the diameter of the metal core. Diagram 1 shows the proportional press-fit in relation to the diameter of the metal core for castors with a diameter of > 250 mm. For castors with a securing collar/flange a slight axial play must be considered to absorb the changes in width resulting from thermal expansion. The proportional axial play in relation to the width of the lining can also be seen in Diagram 1.

2.7 Maximum permissible compression parameters

Diagrams 2 to 5 show the limit loads of castor materials for various temperatures and in relation to the rolling speed. The results for compression parameters gained from the calculations have to be compared with these limits and may not exceed the maximum values. The curves in relation to the rolling speed reflect the load limits in continuous use. In intermittent operation, higher values may be permitted. Unallowable high loads must be avoided when the castor is stationary, as these could cause irreversible deformation (flattening) of the contact area.

Diagram 2

Load limit for ball bearing solid castors made from **LiNNOTAM**

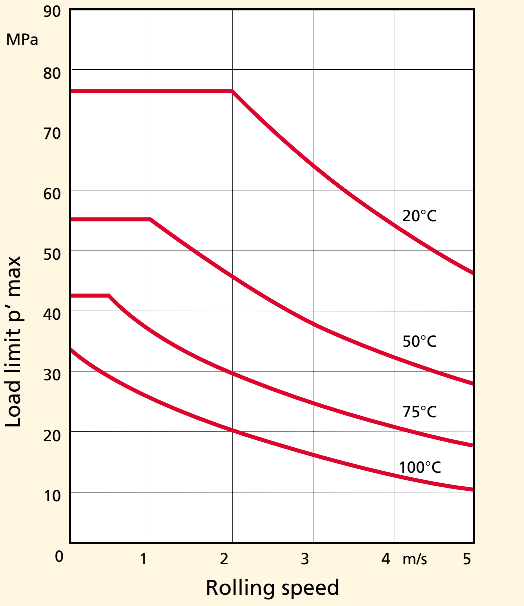


Diagram 3

Load limit for ball bearing solid castors made from POM

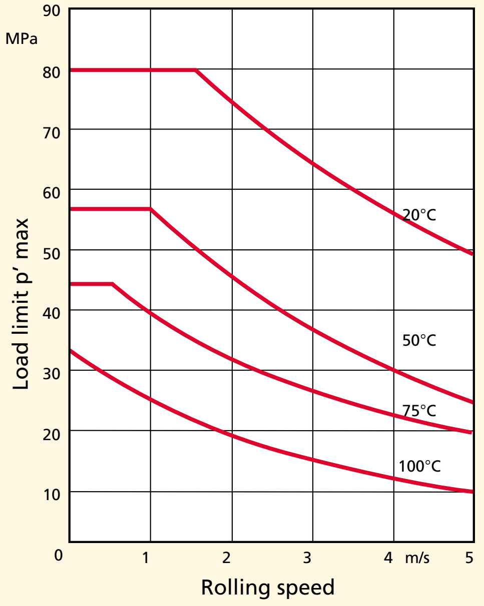


Diagram 4

Load limit for **LiNNOTAM** castors with static loading

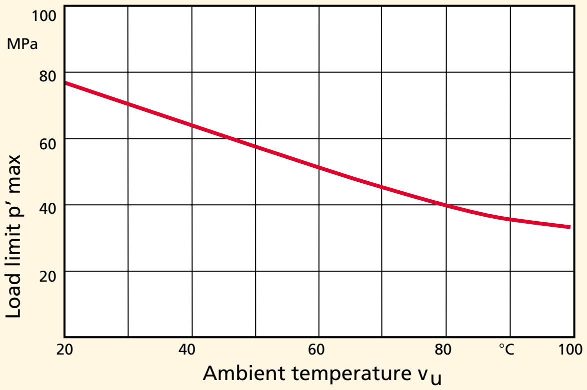
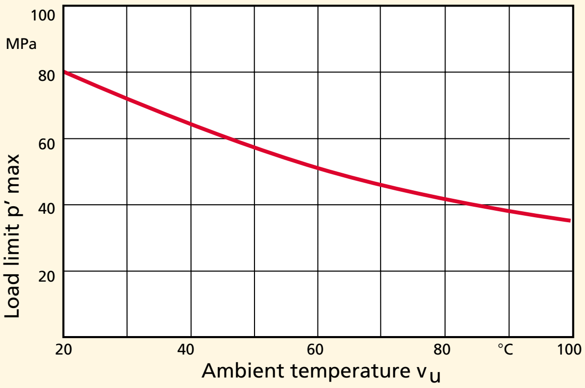


Diagram 5

Load limit for POM castors with static loading



3. Estimating the elastic deformation of the castor body

Often the function of castors and wheels is dependent on the deformation of the running surface (flattening) while the wheel or castor is stationary. This is determined immediately after the load has taken effect with the modulus of elasticity of the material. However, because of the viscoelastic behaviour of the plastic, the time-related deformation behaviour must be determined with the part-specific creep modulus. The creep modulus is determined by carrying out creep experiments with castors and can be seen in Diagrams 6 and 7. On the basis of the values determined in experiments, the time-related flattening can only be estimated with the following equations. It is virtually impossible to make an exact calculation due to the often unknown operating parameters and the special properties of the plastic. But the values obtained from the equations allow the flattening to be determined approximately enough to assess the functioning efficiency. The following is used to estimate the cylindrical castor/cylindrical track:

$$o_A = \frac{1{,}5 \cdot \psi \cdot F}{E_e \cdot a} \quad [\mathrm{mm}]$$

and the cylindrical castor/flat track

$$o_A = \frac{F}{\pi \cdot E_e \cdot B} \cdot \left(2 \cdot \ln \left(\frac{2 \cdot r_{11}}{a} \right) + 0{,}386 \right) \quad [\mathrm{mm}]$$

where

F = wheel load in N

ψ = Hertz correction value from Table 2

E_e = modulus of elasticity or creep modulus in MPa

a = semi axis of the contact area longitudinal to the running direction

B = wheel width in mm

r_{11} = castor radius in mm from PCL 1

Diagram 6

Creep modulus of **LiNNOTAM** at 20 °C

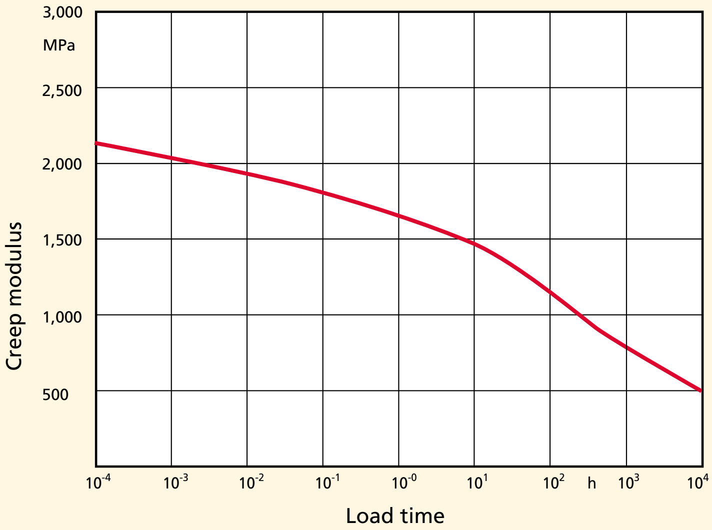
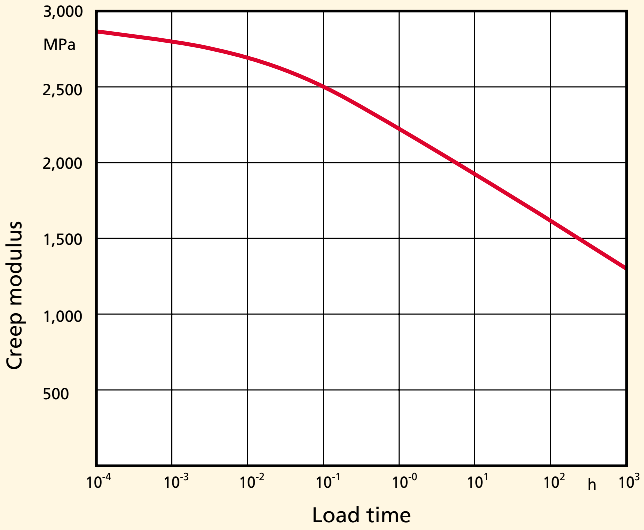


Diagram 7

Creep modulus of POM at 20 °C



As in castor systems with curvature radii quite considerable shear stresses occur in the PCL 2, it is not possible to analytically estimate the systems with curvature radii in the PCL 2. These can only be determined numerically with a three-dimensional FE model.

LICHARZ

PLASTIC SHEAVES

The competitive edge through engineered components made of plastic

1. Use of **LiNNOTAM** as a sheave material

Steel wire ropes are important and highly loaded machine elements in conveying technology. In many cases, large machines depend on their functioning not only for efficiency but also safety. As opposed to other machine elements, they must be replaced before they fail.

The surface pressure that occurs at the point of contact between the sheave and the rope is decisive for the service life and loadability of ropes that run over sheaves. Sheave materials with a low modulus of elasticity lead to low surface pressures and consequently to a longer service life of the rope. For this reason, thermoplastics are used to manufacture sheaves.

The plastics need to offer the following properties:
- Rope conserving elasticity
- Adequate compression fatigue strength
- High wear resistance
- Adequate toughness, also at low temperatures
- Resistance to lubricants
- High resistance to weathering effects

Experience has shown that cast polyamide (**LiNNOTAM**) fulfils these requirements more than adequately. Other plastics such as PE-UHMW or PVC as shock-resistant modifications are only used in special cases due to their low degree of loadability and lower wear resistance. Because of this, we will only deal with **LiNNOTAM** as a sheave material in the following versions.

1.1 Advantages of sheaves made from **LiNNOTAM**

1.1.1 Low rope wear

Ropes that run over sheaves made from metallic materials are subject to high loads due to the surface pressure that occurs between the rope and the groove. When the rope rolls over the sheave, only the outer strands lie on the groove. The result of this is wear in the form of individual strands breaking or, more serious, rope breakage.

Sheaves made from **LiNNOTAM** prevent this due to their elastic behaviour. The pressure between the rope and the roller in the combination steel rope/polyamide roller is around 1:10 compared to steel rope/steel roller. This can be attributed to the visco-elastic behaviour of polyamide. It is not just the outer strands that lie in the groove, but almost the whole projected strand width. This reduces surface pressure between the rope and the roller and considerably extends the life of the rope.

1.1.2 Weight reduction

Polyamides are around seven times lighter than steel. Because of the weight advantage, a considerable weight reduction can be achieved by using polyamide sheaves with a similar load bearing capacity. A mobile crane with up to 18 polyamide sheaves can save approx. 1,000 kg and thus reduce the axle load. The lighter sheave weight also has a positive effect on the crane boom and considerably eases the handling and assembly of the sheaves.

1.1.3 Damping

The good damping properties of **LiNNOTAM** reduce vibration that metallic sheaves transfer from the rope via the sheave to the shaft and bearings. This conserves the rope, shaft and bearings and also reduces running noise.

1.2 Lubricating the rope

The use of viscous and adhesive rope lubricants can cause the rope to stick to the sheave groove. In combination with a dusty environment or dirt particles that are introduced to the sheave system, this forms an abrasive paste that can cause increased wear on the rope and the sheave. Therefore we recommend that the rope is lubricated with a low viscous corrosion protection oil, which keeps the rope and the sheave relatively clean.

1.3 Wear on sheaves made from LiNNOTAM

Essentially, wear is caused on polyamide sheaves through excess mechanical load or wheel slip, whereby the sheave groove is the most loaded point. The sheave groove is subjected to pulsating loads as the rope rolls over it and it becomes warm at high speeds.
Basically, wear on idler sheaves or sheaves that run over a taut rope is less than on driven sheaves. If stranded ropes are used, the individual strands can press into the base of the groove in highly stressed applications. For highly stressed, non-slipping sheaves in combination with an open stranded rope, the circumference of the groove base must not be an integral multiple of the wire strand. Thus, like the combing teeth of a cog wheel, it is prevented that the same points of the groove base are constantly in contact with a rope summit or valley. When closed ropes are used in combination with lubricants, pits can form, which are probably caused in the same way as pits form with gears.
As a rule, under normal environmental conditions and when the limit load values are not exceeded, one can expect groove base wear of ≤ 0.1µm/km.

2. Construction Design information

2.1 Sheave groove profile

The radius of the sheave groove should be approx. 5-10% larger than half the diameter of the rope. This ensures that rope tolerances are adequately considered and that the rope sits well in the groove. The sheave groove depth h is given in DIN 15061 part 1 for steel sheaves as at least $h_{min} = d\sqrt{2}$. We recommend a sheave groove depth of $h \geq 1.5\ d$ for polyamide sheaves. The V angle β is dependent on the lateral fleet angle (max. permissible fleet angle in the groove direction = 4.0°).

The following groove angles in combination with the fleet angle have stood the test:

Fleet angle 0°-2.5° → β =45°
Fleet angle >2.5°-4.0° → β = 52°

A groove angle of < 45° should be avoided. DIN 15061 part 1 recommends the dimensions in Table 1 as guiding values for sheave groove profiles. As a guiding value for the diameter of the rope groove base of rope disks made from cast polyamide, we recommend:
$D_1 = 22 \cdot d_1$ [mm]

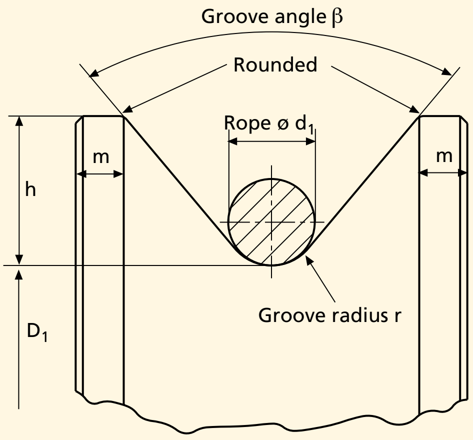


Table 1: Guiding values for rope groove profiles in mm according to DIN 15061 Part 1

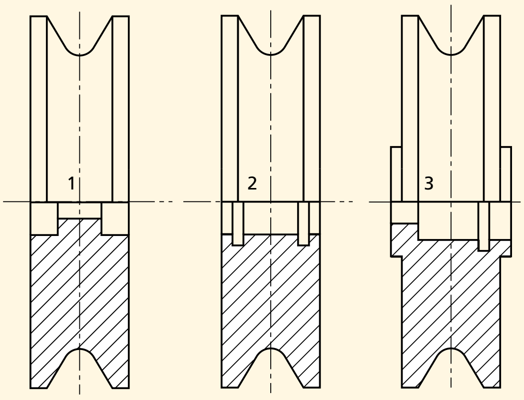
ø d_1	r_1	h	m	ø d_1	r_1	h	m	ø d_1	r_1	h	m
3	1.6	8	2	21	11	35	7	39	21	60	11
4	2.2	10	2	22	12	35	7	40	21	60	11
5	2.7	12.5	2	23	12.5	35	7	41	23	60	11
6	3.2	12.5	3	24	13	37.5	8	42	23	65	11
7	3.7	15	4	25	13.5	40	8	43	23	65	11
8	4.2	15	4	26	14	40	8	44	24	65	12.5
9	4.8	17.5	4.5	27	15	40	8	45	24	65	12.5
10	5.3	17.5	4.5	28	15	40	8	46	25	67.5	12.5
11	6.0	20	5	29	16	45	8	47	25	70	12.5
12	6.5	20	5	30	16	45	8	48	26	70	12.5
13	7.0	22.5	5	31	17	45	8	49	26	72.5	12.5
14	7.5	25	6	32	17	45	8	50	27	72.5	12.5
15	8.0	25	6	33	18	50	10	52	28	75	12.5
16	8.5	27.5	6	34	19	50	10	54	29	77.5	12.5
17	9.0	30	6	35	19	55	10	56	30	80	12.5
18	9.5	30	6	36	19	55	10	58	31	82.5	12.5
19	10.0	32.5	7	37	20	55	11	60	32	85	12.5
20	10.5	35	7	38	20	55	11	–	–	–	–

2.2 Bearings

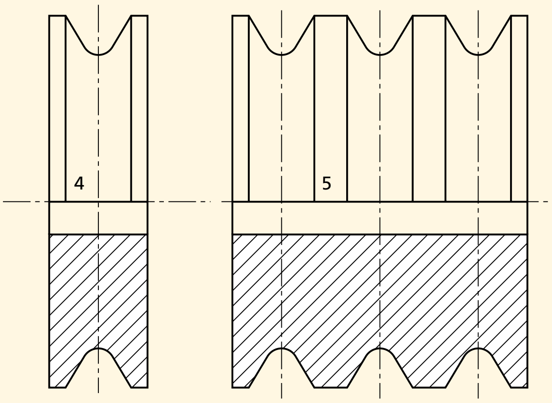
Due to the good sliding properties of **LiNNOTAM**, when sheaves are not subjected to undue stress, friction bearings can be used. Decisive is the pv limiting value. If high degrees of wear are expected on the bearing with an intact sheave groove, the use of a replaceable bearing bush can prevent the sheave having to be replaced prematurely.

For highly loaded sheaves, whose maximum load values are above those for a friction bearing, we recommend the installation of anti-friction bearings. These can be mounted by pressing them into a bearing seat produced according to the dimensions in Diagrams 1 and 2. If axial loads are expected on the anti-friction bearings, we recommend that the bearing is secured against falling out by securing elements commonly used in machine engineering, such as circlips according to DIN 472.

The following diagram shows several possible sheave designs.



Design with bearing seat for antifriction bearings



Design with friction bearings

Diagram 1: Recommended bore undersize for antifriction bearing seats

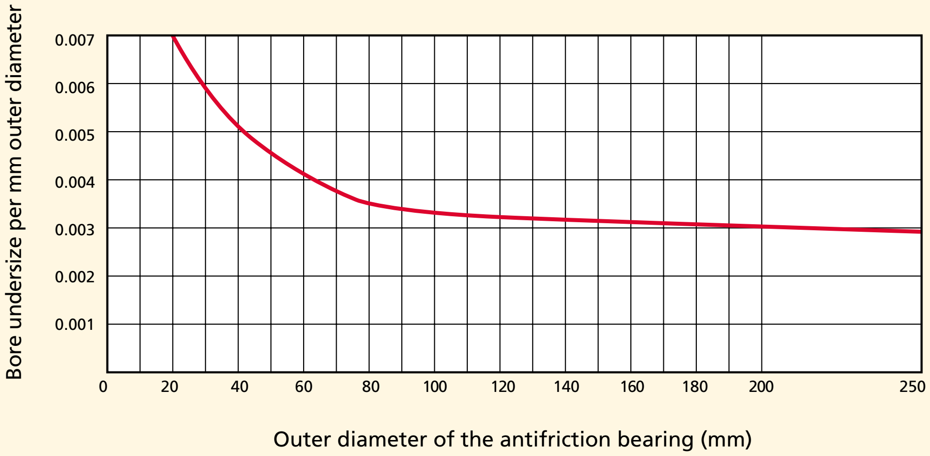
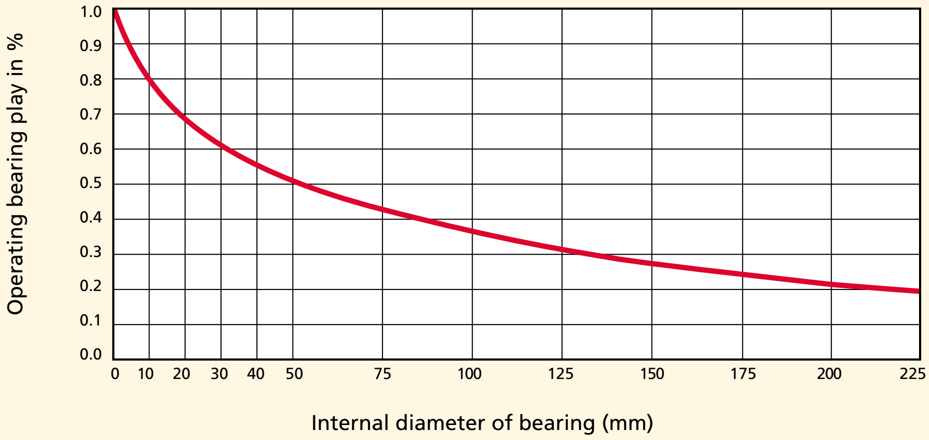


Diagram 2: Recommended operating bearing play for friction bearings



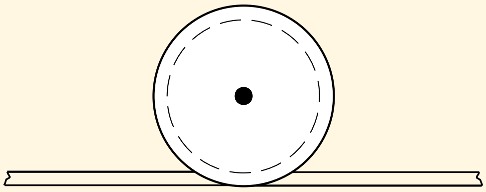
When calculating and dimensioning the bearings, especially friction bearings, attention should be paid that the bearing load for idler sheaves corresponds to the rope tension, but for fixed sheaves the angle of contact forms a force equal to twice the cable tension at 180°. Section 3 »Calculating sheaves« provides more information on this subject.

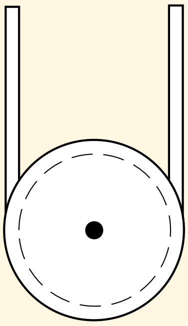
3. Calculating sheaves

For the calculation of sheaves, distinctions must be made regarding the load, the rope used and the type of operation.

A distinction is made between

- Point loading on the sheave
  (the sheave runs on a taut rope)
- Circumferential loading on the sheave
  (rope encircles the sheave)





- The type of rope
  Open wire rope (stranded rope)
  Closed wire rope
- The type of operation
  Loose sheave (e.g. sheave on a cableway)
  Fixed sheave (e.g. deflection sheaves)

These criteria lead to different calculation procedures and force considerations for the individual load cases, rope types and types of operation.

3.1 Calculating the bearing compression

If the roller bearing is to be executed as a friction bearing, the pv values in the bearing must be calculated and compared with the permissible values for **LiNNOTAM**. The friction bearing should be considered in the same way as a press fit bearing bush. In other words, the calculation is the same as for dynamically loaded friction bearings. The expected bearing load is dependent on the type of operation of the sheave. For idler sheaves, the rope tension F_s can be used as the bearing load to calculate the pv value of the rope tension.

Thus the average surface pressure for radial bearings in idler sheaves is

$$p = \frac{F}{d_W \cdot L} \quad [\text{MPa}]$$

where

F = rope tension in N
d_W = shaft diameter in mm
L = bearing width in mm

and the average sliding speed is

$$v = \frac{d_W \cdot \pi \cdot n}{60{,}000} \quad [\text{m/s}]$$

where

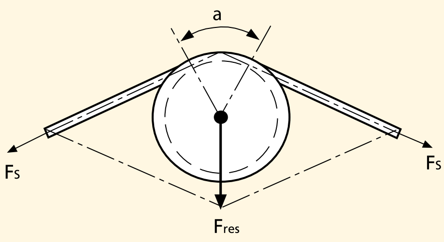
d_W = shaft diameter in mm
n = speed in min^{-1}

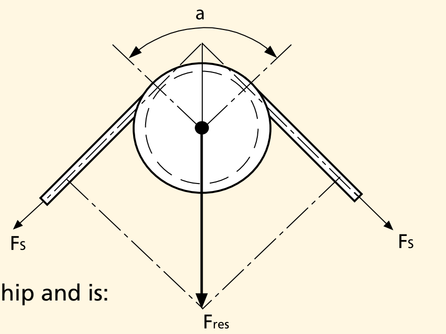
Aggregated $pv_{duration}$ for idler sheaves with dynamic loading becomes:

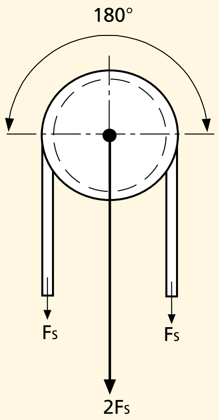
$$pv_{duration} = \left(\frac{F_S}{d_w \cdot L}\right) \cdot \left(\frac{d_w \cdot \pi \cdot n}{60.000}\right) \quad [\mathrm{MPa} \cdot \mathrm{m/s}]$$

In intermittent operation it is possible to correct $pv_{duration}$ by the process described in the section 3.2 of the chapter on »Friction bearings«.

For fixed rollers, the bearing load is dependent on the angle of contact that the rope forms with the sheave. If the sheave is completely encircled (180°), the rope tension is doubled in the calculations. For an angle of contact $\alpha < 180°$, a resulting force F_{res} must be calculated with the help of the angle and the cable tension.







This is calculated from the triangular relationship and is:

$$F_{res} = F_S \sqrt{2 - 2 \cdot \cos \alpha} \quad [N]$$

where
F_S = cable tension in N
α = angle of contact

For sheaves made from **LiNNOTAM**, the determined pv values may not exceed 0.13 Mpa · m/s in dry running applications or 0.5 Mpa · m/s with lubrication. If the calculated values exceed these maximum values, an anti-friction bearing would be advisable.

3.2 Calculating the compression between the rope and the sheave groove

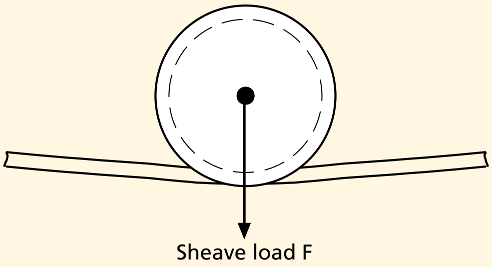
The main criterion for the load bearing capacity of sheaves is the compression between the rope and the sheave. To calculate the compression, the Hertz' equations that have been modified for this case are used. The results of the calculations must be compared with the permissible values for **LiNNOTAM** shown in Diagrams 3 and 4. They must be considered in combination with the speed of the rope and may not exceed these values.

3.2.1 Point contact of closed wire ropes

If closed wire ropes with a small fleet angle are used ($\alpha < 10°$), such as is the case with cableways, this causes concentrated loading. The area of pressure is elliptical.

Under these conditions the compression parameter p' for sheaves made from **LiNNOTAM** is calculated from the equation.

$$p' = \frac{63{,}5}{\xi \cdot \eta} \cdot \sqrt[3]{\left(\Sigma \frac{1}{R}\right)^2 \cdot F} \quad [\mathrm{MPa}]$$



where

ξ = correction value

η = correction value

$\Sigma \frac{1}{R}$ = total of the principle curvatures in mm^{-1}

F = sheave load in N

The sum of the principle curvatures of the bodies that are in contact with one another is calculated from:

$$\Sigma \frac{1}{R} = \frac{2}{d} - \frac{1}{\rho} - \frac{1}{r} + \frac{2}{D} \quad [mm^{-1}]$$

From the sum of the principle curvatures, the correction angle ϑ can be used to determine the correction values ξ and η according to the following formula:

$$\cos \vartheta = \frac{\frac{2}{d} + \frac{1}{\rho} - \frac{1}{r} - \frac{2}{D}}{\Sigma \frac{1}{R}}$$

where

d = rope diameter in mm

ρ = rope curvature radius (generally negligible as it is very large compared to other radii)

r = groove radius in mm

D = groove base diameter

The correction values ξ and η can be found in Table 1. If ϑ lies between the table values, the correction values must be interpolated

Table 1: Correction values ξ and η for different values of ϑ

ϑ	90°	80°	70°	60°	50°	40°	30°	20°	10°	0°
ξ	1.0	1.128	1.284	1.486	1.754	2.136	2.731	3.778	6.612	∞
η	1.0	0.893	0.802	0.717	0.641	0.567	0.493	0.408	0.319	0

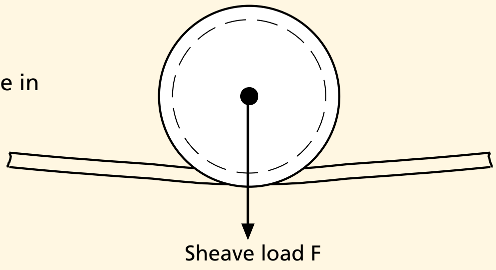
3.2.2 Point contact of open wire ropes

It can be assumed for sheaves made from **LiNNOTAM** that because of the elasticity of the sheave in combination with an open stranded rope, that not one single wire from the strand lies in the groove but rather several wires and that these participate in the transmission of power. Therefore, the entire strand is regarded as a single wire and it is assumed that all loaded strands transmit the same power. In the calculation, a correcting factor is introduced that takes account of the power transmission of several strands (maximum 40%). With this consideration the compression parameter p' becomes:

$$p' = p'_e \cdot \sqrt[3]{\frac{X}{Z}} \quad [\mathrm{MPa}]$$

and the compression parameter p'e for one single wire in combination with a **LiNNOTAM** sheave is

$$p'_e = 42 \cdot \sqrt[3]{\left(1 - \frac{d_1}{2r} + \frac{d_1}{D}\right)^2 \cdot \frac{F}{d_1^2}} \quad [\mathrm{MPa}]$$



where

X = correction factor in relation to p'_e from Table 2

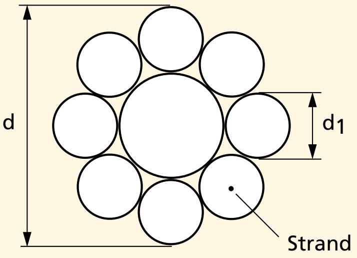
Z = number of outer strands

d_1 = strand diameter in mm

r = groove radius in mm

D = groove base diameter in mm

F = sheave load in N



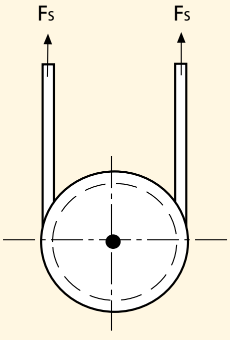
3.2.3 Peripheral load with open wire ropes

In regard to the power transmission between the rope and the sheave, the same applies as to concentrated loading as described in item 3.2.2. The only difference is that the load on a completely encircled sheave is not a point load but a uniform load. Hence, the compression parameter p' becomes:

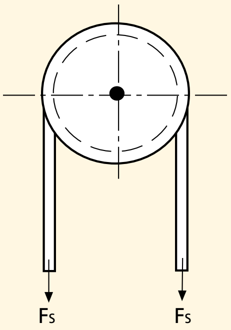
$$p' = p'_e \sqrt{\frac{X}{Z}} \quad [\text{MPa}]$$

and the compression parameter p'_e for a single wire in combination with a **LiNNOTAM** sheave is

$$p'_e = 55 \cdot \sqrt{\frac{(2r - d_1) \cdot Fs}{2r \cdot d_1 \cdot D}} \quad [\text{MPa}]$$



Idler



Fixed sheave

where

X = correction factor in relation to p'_e from Table 2

Z = number of outer strands

d_1 = strand diameter in mm

r = groove radius in mm

D = groove base diameter in mm

F_S = cable tension in N

When determining the correction factor, it should be considered that when X > Z, Z = X must be inserted in the radicand of the correction factor so that the radicand is 1. If the value of p'_e is between the values given in the table, the value for X must be interpolated accordingly.

Table 2: Correction factor X

Surface pressure p'_e in MPa	Correction factor X
≤ 50	Z
150	6
300	4
≥ 450	2.5

3.3 Maximum permissible surface pressures

The results from the calculations must be compared with the maximum permissible load parameters from Diagrams 3 and 4. It is not permissible to exceed these values.

Diagram 3:
Load limit in relation to the rope speed and ambient temperature for sheaves made from **LiNNOTAM** under peripheral loading

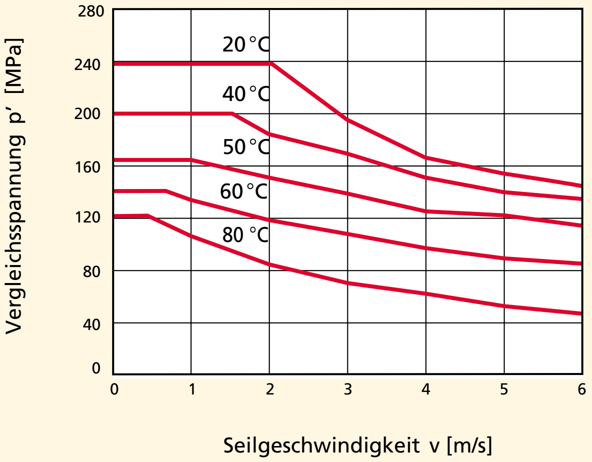
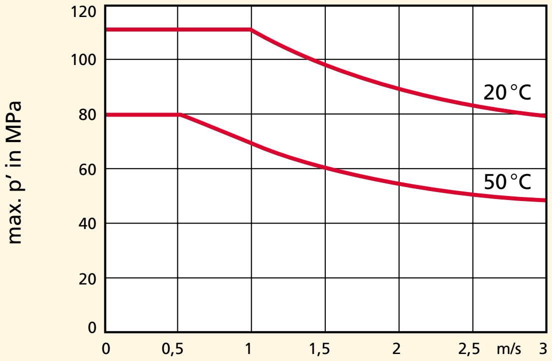


Diagram 4:
Load limit parameter p'max in relation to the rope speed and ambient temperature for sheaves made from **LiNNOTAM** under concentrated loading.



LICHARZ

PLASTIC GEARS

The competitive edge through engineered components made of plastic

1. Use of plastics as a gear material

Although thermoplastic gears are unsuitable for applications in high performance gears and for transmitting high power, they have opened up a broad field of application. The specific material properties allow use under conditions where even high quality metallic materials fail. For instance, plastic gears must be used if the following are the key requirements:

- Maintenance-free
- High wear resistance when used in a dry running application
- Low noise
- Vibration damping
- Corrosion resistance
- Low mass moment of inertia due to low weight
- Inexpensive production

For a plastic to be able to satisfy these requirements, it is absolutely vital that the right material is chosen and that the design is carried out in a material-related manner.

1.1 Materials

Only a few thermoplastics are significant for the manufacture of gears. The plastics are described in detail in the previous chapters, so here we will only describe them in regard to gear teeth.

- **PA 6** Universal gear material for machine engineering; it is wear resistant and impact absorbing even when used in rough conditions, less suitable for small gears with high dimensional requirements.
- **PA 66** Is more wear resistant than PA 6 apart from when it is used with very smooth mating components, more dimensionally stable than PA 6 as it absorbs less moisture, also less suitable for small gears with high dimensional requirements.
- **LiNNOTAM** (PA 6 C) Essentially like PA 6 and PA 66, however, it is especially wear resistant due to its high degree of crystallinity.
- **LiNNOTAM***HiPERFORMANCE 612***/LiNNOTAM***DRiVE 612 Fe* (PA 6/12 G) Tough modified polyamide, suitable for use in areas with impact-like load peaks, wear resistance comparable to **LiNNOTAM**.
- **LiNNOTAM***HiPERFORMANCE 1200***/LiNNOTAM***DRiVE 1200 Fe* (PA 12 G) Tough-hard polyamide with relatively low water absorption, hence, better dimensional stability than other polyamides, especially suitable for use in areas with impact-like load peaks, excellent wear resistance.
- **LiNNOTAM***GLiDE* (PA 6 C + Oil) Self-lubricating properties due to oil in the plastic, hence, excellent for dry running applications and especially wear resistant.
- **LiNNOTAM***GLiDE PRO T* (PA 6 C + solid lubricant) Self-lubricating properties due to solid lubricants contained in the plastic, therefore suitable for dry running and is wear resistant.
- **POM-C** Because of its low moisture absorption it is especially suitable for small gears with high dimensional stability demands, not so loadable in dry running applications due to its hardness, however, if permanently lubricated, POM-C gears are more loadable than polyamide ones.

- **PE-UHMW** Because of its low stability, it can only be used for gears that are not subjected to high loads, good damping properties and chemical resistance, hence mainly suitable for use in applications with mechanical vibration and in chemically aggressive environments.

1.2 Counterparts

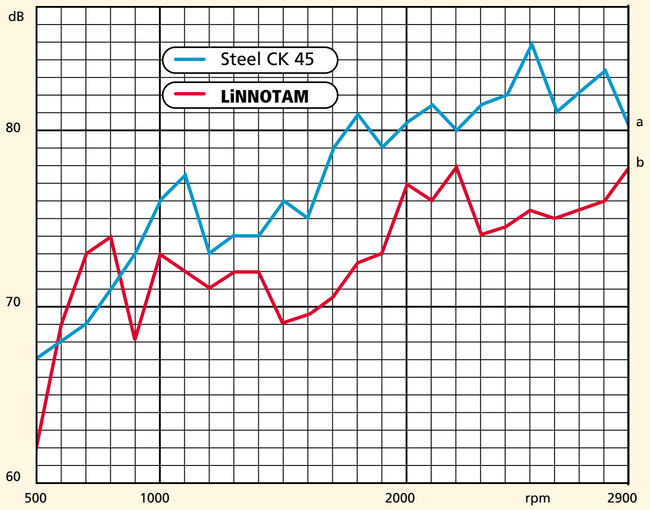
Hardened steel is the most suitable counterpart regarding wear and utilisation of the load carrying capacity, as it ensures very good dissipation of friction heat. In regard to surface properties, the same applies as with friction bearings: the harder the steel the less wear on the wheel and pinions. As a guiding value, we recommend a maximum roughness depth of R_t = 8 to 10 µm both in lubricated operation and in dry running applications. For gears that are not subject to heavy loads, it is possible to mate plastic/plastic. The surface roughness is insignificant for wear. When choosing a material, it should be remembered that the driving pinions are always subjected to a higher level of wear. Consequently, the more wear resistant material should always be chosen for the pinions (➜ pinion: steel, wheel: plastic or pinion: PA, wheel: POM).

1.3 Lubrication

The statements made in the chapter on »Friction bearings« regarding dry running and the use of lubricants also apply here. Basically it should be noted that installation lubrication considerably improves the service life and the running-in behaviour. Materials that are modified with a lubricant, such as **LiNNOTAM***GLiDE*, have much longer service lives than all other plastics, even without lubrication. Continuous lubrication with oil leads to better heat dissipation and consequently to a longer life and higher levels of transmitted power. When the component is lubricated with grease, the circumferential speed should not exceed 5 m/sec, as otherwise there is a danger that the grease will be cast off. Due to polyamide's tendency to absorb moisture, water lubrication is not recommended for polyamide components.

1.4 Noise development

Plastics in general have good damping properties. This considerably reduces noise on plastic gears compared to metal ones. The diagram opposite shows the sound intensity curves of gear mates steel/steel (a) and steel/plastic (b). It shows maximum differences of 9 dB. Hence, steel/steel is up to three times as loud as steel/plastic.



1.5 Manufacture

Plastic gears are manufactured with the same machining process as metal gears. As the cutting forces are very low, the profile can be manufactured in one cycle with high feed rates, which in turn reduces manufacturing costs.

When manufacturing with high feed rates, corrugated surfaces can be produced. At first these give an unfavourable impression. However, in dry running applications the faces of the teeth are quickly smoothed after a short running-in period. In lubricated applications, the corrugated form acts as a lubrication pocket where the lubricant can collect – to the advantage of the gear.
In other words, this corrugation does not display any reduction in quality.
Basically when machining plastic gears, depending on the module, qualities of 9 to 10 can be achieved. Regarding the tooth quality that can be achieved, it should be noted that the rolling tooth flanks of plastic gears easily fit one another. Therefore, greater tolerances are allowed than would be the case with metal gears. This especially applies to power transmitting pinions. For the grade that is exclusively related to tangential composite error F_i" and tangential tooth-to-tooth error f_i" this means that up to two grades more are permitted than for similar gears made from metal. The tooth play is increased by one to two grades compared to steel to compensate for temperature and moisture effects.

2. Design information

The following design information is intended to assist when dimensioning new gear components. Existing data should be used for gear designs that are in use and which have been tried and tested.

2.1 Width of the tooth face

For plastic gears there is basically no problem in extending their width to the same size as the diameter. Determining the smallest width is dependent upon the axial stability of the gear. No test results are available in regard to the connection between the life of the component and the width of the tooth face or regarding a determination of the optimum width of tooth face. Practical experience has, however, shown that the width of the tooth face should be at least six to eight times the module.
For the mating components steel/plastic it is better to design the plastic gear slightly smaller than the steel pinion to make sure that the plastic gear is loaded across the entire width of the tooth face. A similar situation arises with the mating components plastic/plastic, where the dimensions of the gear on which the higher wear is expected should be slightly narrower. This prevents wear on the edges of the teeth, which could affect the running behaviour.

2.2 Module, angle of pressure and number of teeth

The load bearing capacity of plastic gears can be directly affected by the choice of module and angle of pressure. If, while maintaining the same peripheral force, the module/angle of pressure is increased, the root-strength of the teeth increases. However, compared to steel gears, the actual increase is less, as the effective contact ratio factor decreases and it is no longer possible for several teeth to engage simultaneously. A higher contact ratio factor, however, can be better for the load bearing capacity than increasing the root-strength of an individual tooth. We can derive the following connection from this (applies mainly to slow running or impact loaded gears):

- Preferably a small module for tough elastic thermoplastics (increase in the contact ratio factor, ➜ several teeth engaged simultaneously).
- Preferably a large module for hard thermoplastics (increase in the root-strength of the teeth, as a higher contact ratio factor is not possible due to the inferior deformation behaviour).

In the case of gears with a high peripheral speed, attention must be paid that the movement is not affected by the effective contact ratio factor.

The angle of pressure for involute teeth is defined at 20°. Nevertheless, it can occasionally be necessary to change the angle of pressure (e.g. to decrease the number of teeth or reduce running noise). Angles of pressure < 20° lead to thinner and hence less loadable teeth with steep tooth profiles but low running noise. Angles of pressure > 20° produce sharper, thicker teeth with a greater root strength and flatter profiles.
In regard to the number of teeth, it should be noted for higher peripheral speeds that the ratio between the number of teeth may not be an integer multiple. If this is the case, the same teeth always engage, which encourages wear.

2.3 Helical gearing

Experience has shown that helical plastic gears run quieter with a small helix angle than spur toothed types. However, the expected increase in the load bearing ability is smaller than is the case with steel gears. Although the length of the face contact line increases and the load is distributed among several teeth, the load is uneven and the teeth are deformed. This negates the advantage of helical gearing to a certain degree. As with metal gears, helical toothed plastic gears are calculated via a spur toothed spare wheel. $\beta \approx 10°\text{-}20°$.

2.4 Profile correction

Profile corrections are generally necessary when

- a gear pair has to be adapted to suit a specified axle base (positive or negative profile correction)
- the number of teeth is not reached and this causes undercut (positive profile correction)

In the application, attention should be paid that in the case of negative profile correction the undercut is not too great. This would result in greatly minimised root strength of the teeth, which could reduce the life and load bearing capacity of the gear.
Vice versa, in the case of positive profile correction, the thicker tooth root could cause a loss in the deformation capability and a subsequent reduction in the contact ratio factor.

2.5 Flank clearance and crest clearance

Because of the high thermal expansion factors of plastics when dimensioning gears, attention must be paid to the material-related fitting of the flank and crest clearances so that a minimum flank clearance is guaranteed. When plastic gears are used, it has proven practical to maintain a minimum flank clearance of ≈ 0.04 · modulus. The built-in flank clearance is thus

$$S_e = S_{eo} + 2 \cdot l \cdot \sin \alpha \,(k\alpha + k_F) \qquad [\text{mm}]$$

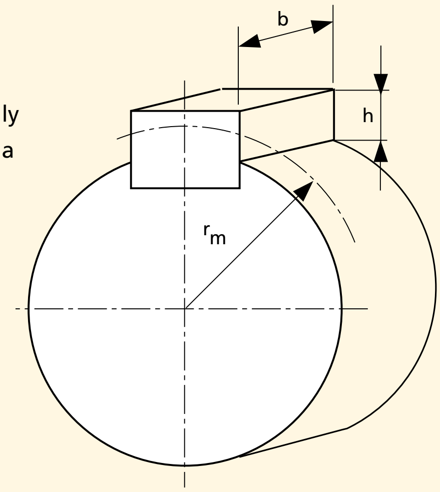
where

S_{eo} = minimum flank clearance in mm
l = total distance consisting of plastic between the two rotational axes in mm
α = angle of pressure
$k\alpha$ = coefficient of elongation
k_F = correction factor for moisture absorption (to be used for polyamides, can be found in the chapter on »Friction bearings«)

For the inbuilt crest clearance, a measure of 0.3 · module has proven to be practical. This takes account of temperature fluctuations of up to ± 20 °C and also makes adequate consideration for any inaccuracies in the toothed gears.

2.6 Power transmission

The feather key and groove type of connection that is generally used in machine engineering is also used for plastic gears. For a connection such as this, the flank of the key groove must be examined to ensure that it does not exceed the permissible surface pressure. The surface pressure is

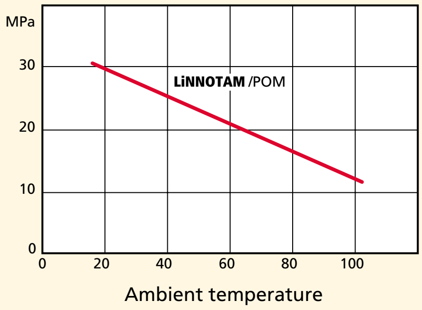


$$p_F = \frac{M_d \cdot 10^3}{i \cdot r_m \cdot h \cdot b} \quad \text{[MPa]}$$

where
M_d = transmitted torque in Nm
i = number of groove flanks
r_m = radius from the centre of the shaft to the centre of the bearing flank in mm
h = height of the bearing flank in mm
b = width of the bearing flank in mm

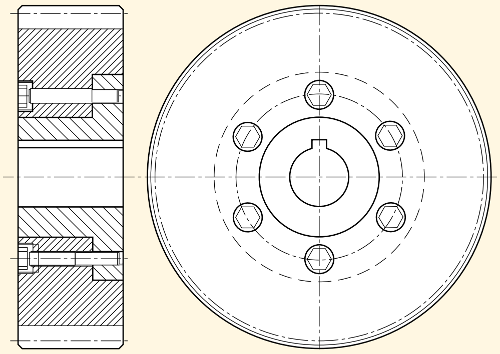
The value produced from the calculation is compared with Diagram 1 and may not exceed the maximum permissible values. However, it should be noted that this value contains no safety factor for shock-type loads or safety reserves. Depending on the load, we recommend a safety factor of 1.5 to 4.

Diagram 1: Guiding value for permissible surface pressure



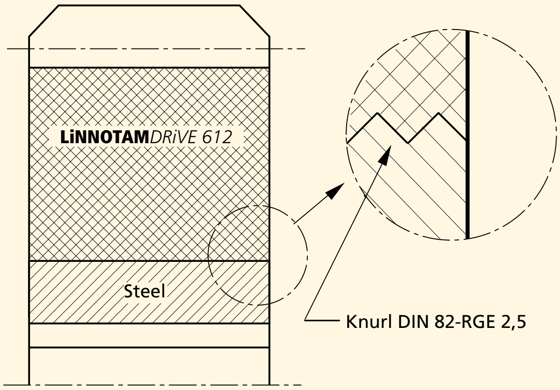
Because of the notch sensitivity of plastics when key grooves are being manufactured, attention should be paid that the edges are designed with a radius. However, this is generally not possible because the usual cutting tools and feather keys are sharp edged. When larger torque is being transmitted this can also cause deformation in the hub.

If the calculation of the flank pressure should produce high pressure values that are not permissible, or if hub deformation is feared, there are several possibilities of power transmission available. One possibility is the non-positive connection of the wheel body with a steel insert. This is screwed to the wheel body. The diagram opposite shows one possible design solution.



For fixing the steel insert we recommend hexagon socket screws according to DIN 912, property class 8.8 or better in the following dimensions.

Tip diameter	Number of screws	Screw size
up to 100 mm	3	M6
up to 200 mm	4	M 8
above 200 mm	6	M8/M 10



For gears with relatively thin walls, it is advisable to use hexagon socket screws with a low head according to DIN 6912, property class 8.8 or better.

One alternative to the use of a screwed steel fitting is to design the gears in **LiNNOTAM***DRiVE 612* or **LiNNOTAM***DRiVE 1200 Fe*. The metallic core which is connected to the plastic both in a form-fit and non-positive manner enables the shaft-hub connection to be calculated and dimensioned like a metallic component as usual. The form-fit and non-positive connection between the plastic casing and the metallic core is created with a knurl.

3. Calculating thermoplastic gears

The reasons for the premature breakdown of thermoplastic gears are generally the same damage aspects and principles that occur in metallic gears. This is why the calculation of plastic gears does not differ in principle from the known methods. The only difference is that the material-specific properties of plastics are included in the calculations in the form of correction factors.

3.1 Torque M_d, peripheral force F_U and peripheral speed v

The torque is:

$$M_d = 9.550 \cdot \frac{P}{n} \quad [\mathrm{Nm}]$$

where
P = power in kW
n = speed in min^{-1}

The peripheral force is:

$$FU = 2 \cdot 10^3 \cdot \frac{M_d}{d_0} \quad [\mathrm{N}]$$

where
M_d = torque in Nm
d_0 = reference diameter in mm

The peripheral speed is calculated as:

$$v = \frac{d_0 \cdot \pi \cdot n}{60 \cdot 10^3} \quad [\mathrm{m/s}]$$

where
d_0 = reference diameter
n = speed in min^{-1}

3.2 Tooth body temperature ϑ_Z and tooth flank temperature ϑ_F in continuous operation

As with all designs made from thermoplastic materials, temperature also plays a major role for gears in regard to the load bearing capacity of the component. A distinction is made between the tooth body temperature ϑ_Z and the tooth flank temperature ϑ_F .

The tooth body temperature is responsible for the permissible tooth root loading and tooth deformation, whereas the tooth flank temperature is used to roughly estimate the level of wear. However, it is very difficult to determine these two temperatures accurately because on a rotating gear the heat transmission coefficient can only be estimated roughly. Consequently, any arithmetical determination of the temperatures is liable to have a certain amount of error. In particular, when the tooth flank temperature is being calculated, quite often high values are produced which, in some cases, are even above the melting temperatures of the plastics. However, in practice no melting of the tooth profile has been observed. Nevertheless, the values can be regarded as characteristic and comparison temperature values. It can be assumed that the excessive calculated values would in any case guarantee a design which is on the safe side.

For the thermal calculation of the gears, the friction heat, the heat dissipated from the gear in the gear room and the heat that is dissipated from the gear room to the outside must be considered. Under these conditions, the following:

$$\vartheta_{1,2} = \vartheta_U + P \cdot \mu \cdot 136 \cdot \frac{i + 1}{z_{1,2} + 5i} \cdot \left(\frac{k_2 \cdot 17100}{b \cdot z_{1,2} \cdot (v \cdot m)^{\frac{3}{4}}} + 7{,}33 \cdot \frac{k_3}{A} \right) \quad [°C]$$

where

Index 1 for the pinion

Index 2 for the wheel

ϑ_U = ambient temperature in °C

P = power in kW

μ = coefficient of friction

z = teeth

i = transmission ratio z_1/z_2 with

z_1 = number of teeth in pinion

b = width of the tooth face in mm

v = peripheral speed in m/sec

m = module in mm

A = surface of the gear casing in m^2

k_2 = material-related factor

k_3 = gear-related factor in m^2 K/W

For factor k_2 the following must be included depending on the temperature to be calculated:

Calculation of flank temperature:

k_2 = 7 for mating components steel/plastic

k_2 = 10 for mating components plastic/plastic

k_2 = 0 in the case of oil lubrication

k_2 = 0 at ≤ 1 m/sec

Calculation of root temperature:

k_2 = 1.0 for mating components steel/plastic

k_2 = 2.4 for mating components plastic/plastic

k_2 = 0 in the case of oil lubrication

k_2 = 0 at ≤ 1 m/sec

For factor k_3 and the coefficient of friction μ, the following must be included independent of the temperature to be calculated:

k_3 = 0 for completely open gear m^2 K/W

k_3 = 0.043 to 0.129 for partially open gear in m^2 K/W

k_3 = 0.172 for closed gear in m^2 K/W

μ = 0.04 for gears with permanent lubrication

μ = 0.07 for gears with oil mist lubrication

μ = 0.09 for gears with assembly lubrication

μ = 0.2 PA/steel

μ = 0.4 PA/PA

μ = 0.25 PA/POM

μ = 0.18 POM/steel

μ = 0.2 POM/POM

3.2.1 Tooth body temperature ϑ_Z and tooth flank temperature ϑ_F in intermittent operation

Analogous to friction bearings, because of the lower amount of heat caused by friction, gears in intermittent operation are increasingly loadable the lower the duty cycle. The relative duty cycle ED is considered in the equation in section 3.2 by introducing a correction factor f.

The relative duty cycle is defined as the ratio between the load duration t and the overall cycle time T as a percentage.

$$ED = \frac{t}{T} \cdot 100 \quad [\%]$$

where

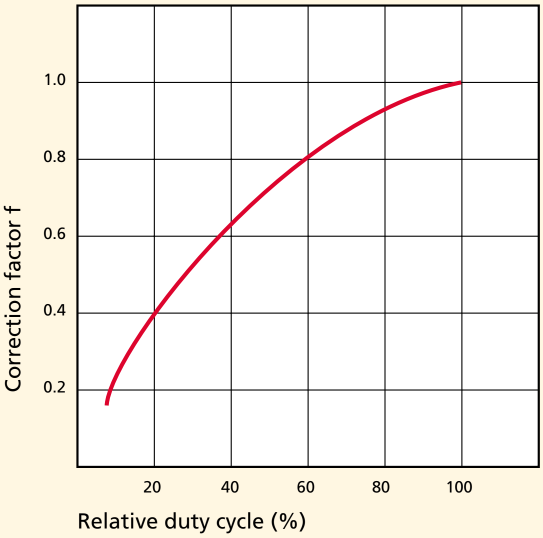
t = total of all load times within the cycle time T in min

T = cycle time in min

For thermoplastic gears, the overall cycle time is defined as T = 75 min. The total of all individual load times occurring within this 75 min forms the load duration t.

With the value that has been calculated in this manner it is now possible to determine the correction factor f from Diagram 2. Attention should be paid that each load duration which exceeds 75 min (regardless of whether this is only once) is evaluated as a continuous load.

Diagram 2: Correction factor for ED



Taking account of the correction factor, the tooth flank temperature and tooth body temperature is

$$\vartheta_{1,2} = \vartheta_U + P \cdot f \cdot \mu \cdot 136 \cdot \frac{i+1}{z_{1,2}+5i} \cdot \left(\frac{k_2 \cdot 17.100}{b \cdot z_{1,2} \cdot (v \cdot m)^{\frac{3}{4}}} + 7{,}33 \cdot \frac{k_3}{A} \right) \quad [°C]$$

The values given in section 3.2 can be used for the factors k_2, k_3 and the coefficient of friction μ.

3.3 Calculating the root strength of teeth

If the tooth root load σ_F exceeds the permissible load σ_{Fper} under loading, it must be assumed that the teeth will break. For this reason the tooth root load must be calculated and compared with the permissible values. If the pinion and gear are constructed from plastic, the calculations must be carried out separately for each of them.

The tooth load is:

$$\sigma_F = \frac{F_U}{b \cdot m} \cdot K_B \cdot Y_F \cdot Y_\beta \cdot Y_\epsilon \quad [MPa]$$

where

F_U = peripheral force in N
b = gear width in mm (where the width of the pinion and gear differ: use the smaller width + m as a calculation value for the wider gear)
m = module in mm
K_B = operating factor for different types of drive operation, from Table 2
Y_F = tooth shape factor from Diagram 3
Y_β = helix factor to take account of the increase in load bearing capacity in helical gearing, as this is the case with plastic gears, this value is to be set as 1.0
Y_ϵ = contact ratio factor from Table 1, where $Y_\epsilon = 1/\epsilon_\alpha$ and $\epsilon_\alpha = \epsilon_{\alpha\ z1} + \epsilon_{\alpha\ z2}$

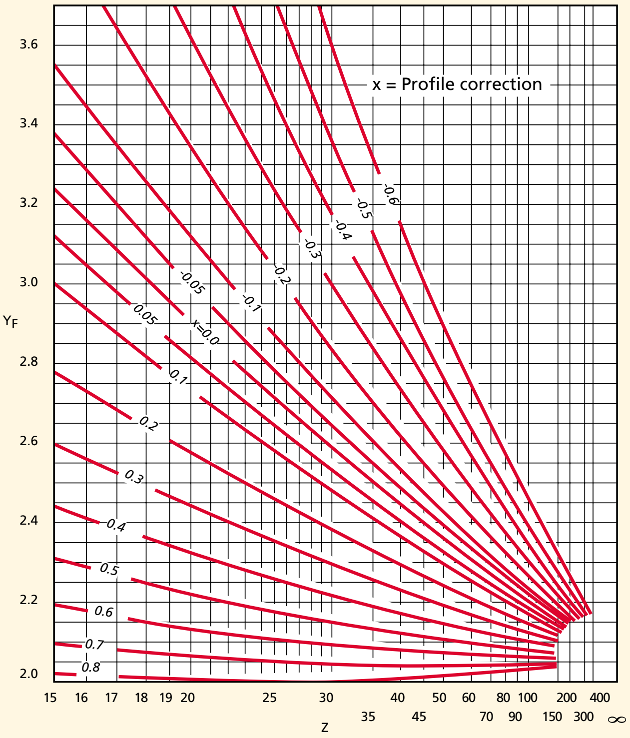
Table 1: Partial transverse contact ratio for gears without profile correction

z	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
$\varepsilon_{\alpha z}$	0.731	0.740	0.749	0.757	0.765	0.771	0.778	0.784	0.790	0.796	0.801
z	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
$\varepsilon_{\alpha z}$	0.805	0.810	0.815	0.819	0.822	0.827	0.830	0.833	0.837	0.840	0.843
z	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**
$\varepsilon_{\alpha z}$	0.846	0.849	0.851	0.854	0.857	0.859	0.861	0.863	0.866	0.868	0.870
z	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**
$\varepsilon_{\alpha z}$	0.872	0.873	0.875	0.877	0.879	0.880	0.882	0.883	0.885	0.887	0.888
z	**58**	**59**	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**
$\varepsilon_{\alpha z}$	0.889	0.891	0.892	0.893	0.895	0.896	0.897	0.989	0.899	0.900	0.901
z	**69**	**70**	**71**	**72**	**73**	**0.74**	**75**	**76**	**77**	**78**	**79**
$\varepsilon_{\alpha z}$	0.903	0.903	0.904	0.906	0.906	0.907	0.909	0.909	0.910	0.911	0.912
z	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**
$\varepsilon_{\alpha z}$	0.913	0.913	0.914	0.915	0.916	0.917	0.917	0.918	0.919	0.919	0.920
z	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**100**	**101**
$\varepsilon_{\alpha z}$	0.920	0.921	0.922	0.922	0.923	0.924	0.924	0.925	0.925	0.926	0.927

Table 2: Operating factor K_B

	Mode of operation of the driven machine			
Mode of operation of the driving machine	**Even**	**Moderate impact**	**Average impact**	**Strong impact**
Even	1.0	1.25	1.5	1.75
Moderate impact	1.1	1.35	1.6	1.85
Average impact	1.25	1.5	1.75	2.0
Strong impact	1.5	1.75	2.0	2.25

Diagram 3: Tooth formation factor Y_F as a function of the number of teeth



In the case of profile corrected toothed gears the factor Yε must be adjusted accordingly.
The following applies:

$$\varepsilon_\alpha = \frac{Z_1}{2 \cdot \pi} \cdot (\tan \alpha_{E1} - \tan \alpha_{A1}) \qquad \text{and} \qquad \tan \alpha_{A1} = \tan \alpha_{tw} \cdot \left(1 + \frac{Z_2}{Z_1} \right) - \frac{Z_2}{Z_1} \tan \alpha_{A2}$$

The value $\tan\alpha_{E1}$ is dependent on the correction value:

$$D_1 = \frac{d_{K1}}{d_{G2}}$$

where
d_{K1} = outside diameter of pinion
d_{G2} = base diameter of large wheel

The value $\tan\alpha_{A2}$ is dependent on the correction value:

$$D_2 = \frac{d_{K2}}{d_{G1}}$$

where
d_{K2} = outside diameter of large wheel
d_{G1} = base diameter of pinion

The values for $\tan \alpha_{E1}$ and $\tan \alpha_{A2}$ can be taken from Diagram 5. The effective pressure angles atw and tan atw are calculated from the profile correction $x_{1,2}$ and the number of teeth $z_{1,2}$ where Index 1 stands for the pinion and Index 2 for the large gear. The effective pressure angles for spur gears are shown in Diagram 4.

Diagram 4: Effective pressure angle α_{tw}, $\tan\alpha_{tw}$

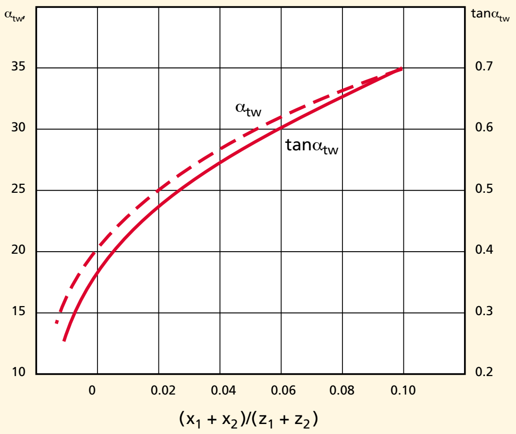
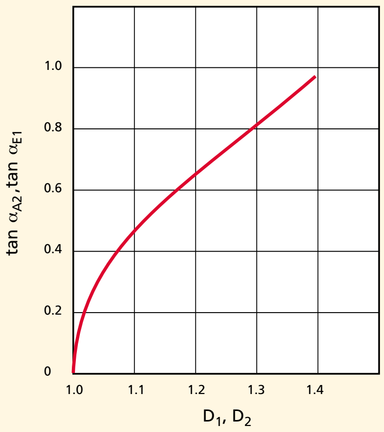


Diagram 5: Correction diagram for transverse contact ratio



3.4 Calculating tooth profile strength

Excessive pressure on the tooth profile can cause pitting or excessive wear. The wear is particularly obvious in the root and crest of the tooth, which changes the tooth formation and consequently leads to uneven transmission of motion. In order to prevent premature failure due to excessive wear or pitting, the tooth flank pressure σ_H must be determined. The pressure occurring on the tooth flank is:

$$\sigma_H = \sqrt{\frac{F_U \cdot (z_1 + z_2)}{b \cdot d_0 \cdot z_2}} \cdot K_B \cdot Z_\varepsilon \cdot Z_H \cdot Z_M \qquad \text{[MPa]}$$

where
F_U = peripheral force in N
z_1 = number of teeth in pinion
z_2 = number of teeth in large gear
b = gear width in mm (where the width of the pinion and gear differ: use the the smaller width + m as a calculation value for the wider gear)
d_0 = reference diameter in mm
K_B = operating factor for different types of drive operation, from Table 2
$Z\varepsilon$ = contact ratio factor
Z_H = zone factor
Z_M = material factor

The contact ratio of several teeth acts like a widening of the tooth. This apparent widening is taken account of with the contact ratio factor Z_ε and equated for spur and helical gears. The contact ratio factor becomes:

$$Z_\varepsilon = \sqrt{\frac{4 - (\varepsilon_{\alpha z^1} + \varepsilon_{\alpha z^2})}{3}}$$

where
$\varepsilon_{\alpha z^1}$ = partial transverse contact ratio of pinion from Table 1
$\varepsilon_{\alpha z^2}$ = partial transverse contact ratio of large wheel from Table 1

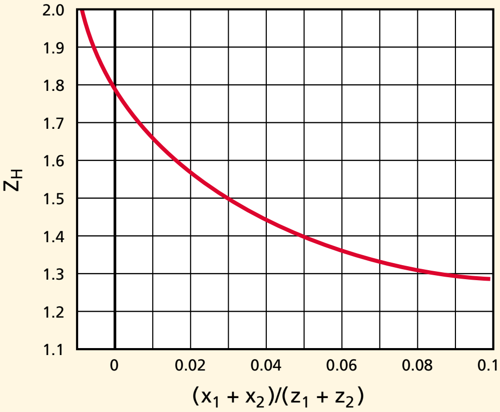


Diagram 6: Zone factor Z_H with profile correction and $\alpha = 20°$

The tooth formation factor Z_H takes account of the tooth flank distortion. In the case of non-profile corrected spur teeth with an angle of pressure of $\alpha = 20°$ the zone factor can be approximated with $Z_H = 1.76$. For profile corrected spur teeth Z_H can be taken from the diagram opposite. For angles of pressure other than 20° the following applies:

$$Z_H = \frac{1}{\cos\alpha} \cdot \sqrt{\frac{1}{\tan\alpha_{tw}}}$$

where
α = normal angle of pressure
$\tan\alpha_{tw}$ = effective pressure angle from Diagram 4

The elasticity of the plastic and consequently the effective contact surface of the tooth profile are considered with the material factor Z_M. It can be said with sufficient accuracy that:

$$Z_M = \sqrt{0{,}38 \cdot E'} \qquad \text{und} \qquad E' = \frac{E_1 \cdot E_2}{E_1 + E}$$

where
E_1 = dynamic modulus of elasticity of the pinion
E_2 = dynamic modulus of elasticity of the gear

The different moduli of different materials for the pinion and gear have been taken into account. For the mating components plastic/steel the corresponding factor for Z_M can be taken from Diagram 8. For the mating components of gears made from the same plastic the following applies:

$$Z_{M(K/K)} = \frac{1}{\sqrt{2}} \cdot Z_{M(K/St)}$$

If the gear and pinion are made from different plastics, the factor Z_M (K/St) for the softer plastic should be used. The tooth flank temperature is determined with the help of the formula in sections 3.2 or 3.2.1.

Diagram 7: Dynamic modulus of elasticity

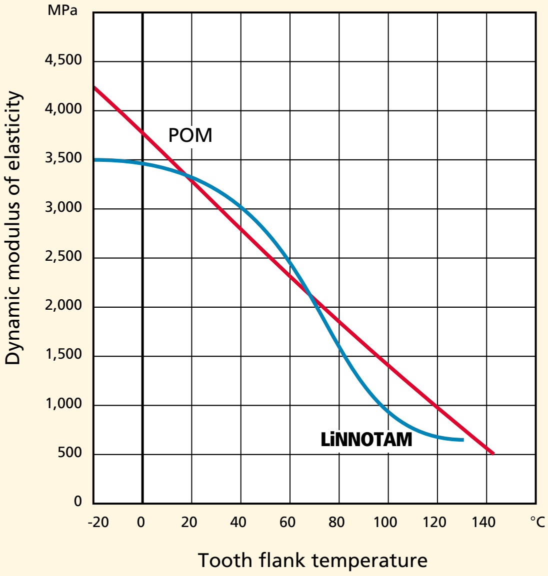
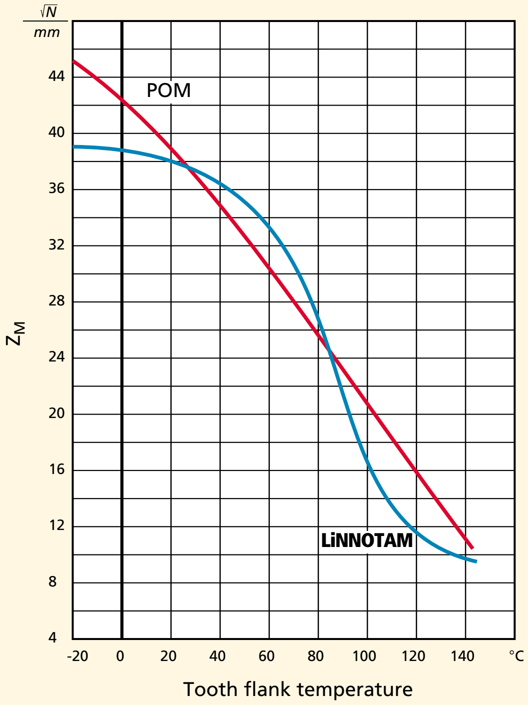


Diagram 8: Material factor for mating components K/St.



3.5 Safety factor S

The results for σ_F and σ_H from the calculations must be compared with the permissible values. As a rule a minimum safety factor of 1.2 to 2 is advisable. The following applies:

$$\sigma_{Fzul} = \frac{\sigma_{Fmax}}{S} \quad \text{and} \quad \sigma_{Hzul} = \frac{\sigma_{Hmax}}{S}$$

where

S = advisable safety factor

σ_{Fmax} = permissible tooth root load from Diagrams 9 and 10 in combination with the tooth temperature

or

S = advisable safety factor

σ_{Hmax} = permissible flank pressure from Diagrams 11 to 14 in combination with the tooth temperature

The following table contains several minimum safety factors in relation to operating conditions.

Type of operation	Minimum safety factor
Normal operation	1.2
High load reversal	1.4
Continuous operation with load reversals ≥ 10^8	≥ 2

The permissible tooth root loads and flank pressures are shown in the following diagrams.

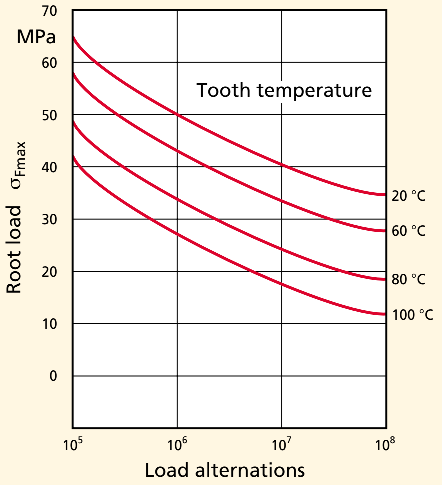


Diagram 9: Root strength of teeth σ_{Fmax} for POM

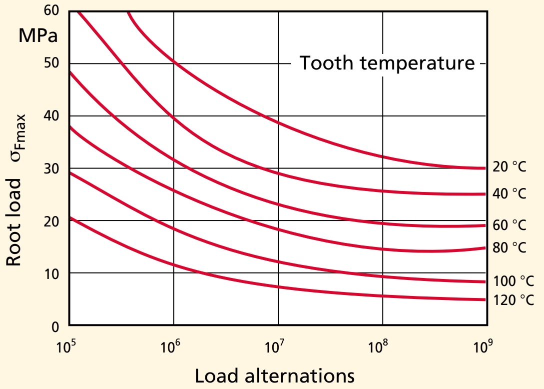


Diagram 10: Root strength of teeth σ_{Fmax} for **LiNNOTAM**

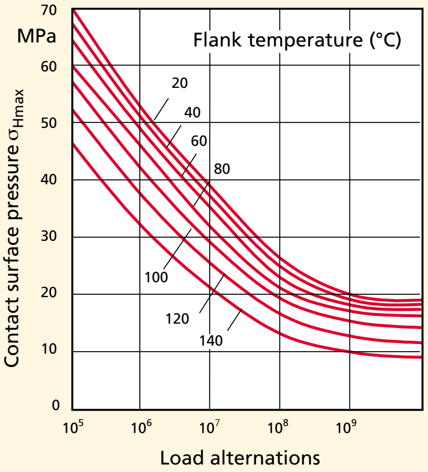


Diagram 11: Contact surface pressure σ_{Hmax},
LiNNOTAM, dry running

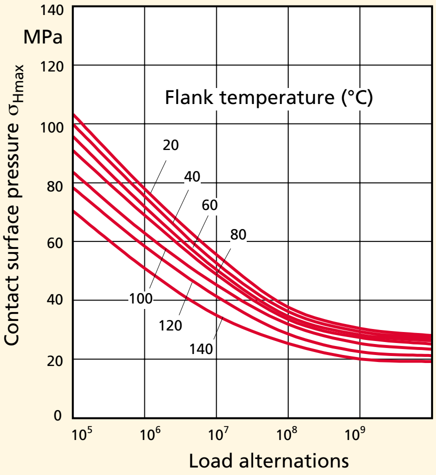


Diagram 12 : Contact surface pressure σ_{Hmax},
LiNNOTAM, grease lubrication

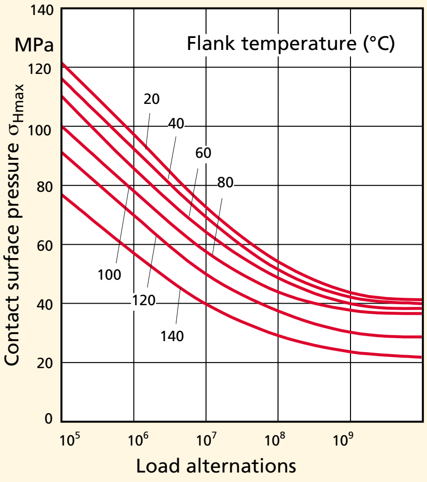


Diagram 13: Contact surface pressure σ_{Hmax},
LiNNOTAM, oil lubrication

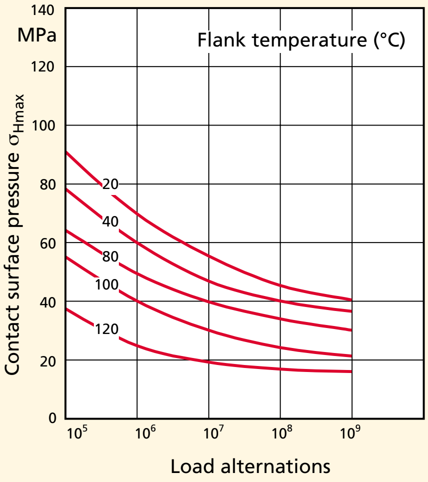


Diagram 14: Contact surface pressure σ_{Hmax},
POM, dry running

3.6 Calculating tooth distortion

The tooth distortion that occurs when a load is applied acts like a pitch error during the transition from the loaded to the unloaded condition of the tooth. As excessive deformation could cause the gear to break down, plastic gears must be examined in regards to their compliance with the maximum permissible tooth distortion.

Tooth distortion f_K as a correction of the crest of the tooth in the peripheral direction becomes:

$$f_K = \frac{3 \cdot F_U}{2 \cdot b \cdot \cos \alpha_0} \cdot \varphi \cdot \left(\frac{\psi_1}{E_1} + \frac{\psi_2}{E_2} \right) \quad [\mathrm{mm}]$$

where

φF = correction value from Diagram 15

$\psi_{1,2}$ = correction values from Diagram 16

$E_{1,2}$ = modulus of elasticity from Diagram 7

For the mating components plastic/steel the following applies:

$$\frac{\psi_{ST}}{E_{ST}} = 0$$

Diagram 15: Correction value φ

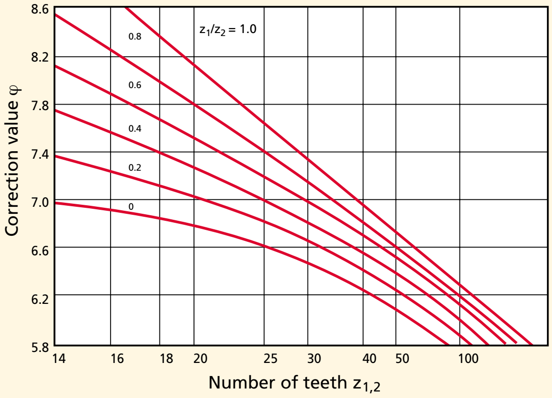
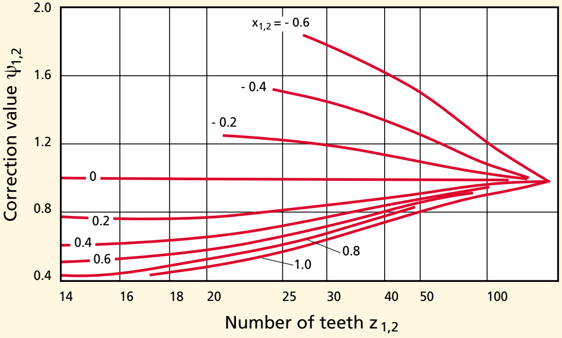


Diagram 16: Correction value $\psi_{1,2}$



The permissible tooth distortion is generally determined by the requirements that are placed on the gears in regard to running noise and life. Practice has shown that the running noises increase considerably from a tooth distortion $f_K = 0.4$ mm. Another parameter is the ratio between tooth distortion and module.

In the form of an equation, the permissible limiting values become:

$$f_{Kzul} \leq 0.4 \quad [\mathrm{mm}]$$

bzw.

$$f_{Kzul} \leq 0.1 \cdot m \quad [\mathrm{mm}]$$

The calculated values should not exceed the limiting values. If, however, this is the case one would have to accept increased running noises and a shorter life.

LICHARZ

PLASTIC SPINDLE NUTS

The competitive edge through engineered components made of plastic

Plastic spindle nuts

1. Plastic as a material for spindle nuts

Spindle nuts, in combination with a threaded spindle, transform a turning motion into a linear motion. Good stability of the nut material, a large thread bearing area and high surface quality are advantages for power transmission. A trapezoidal screw thread design according to DIN 103 is advantageous and practical.

Loading of the thread flanks is the same as on a sliding element which means that in regard to choosing a suitable material for the spindle nut, the main considerations are sliding and wear properties. The stability of the chosen material is decisive for safe power transmission.

It should be noted that glass fibre reinforced plastics are unsuitable for the manufacture of spindle nuts. Compared to other thermoplastics, they exhibit inferior sliding and wear values. In addition, the glass fibres can cause increased wear in the mating component. The relatively high modulus of elasticity of these materials also hinders deformation of the thread during load peaks, so that the load can distribute evenly over all the threads. This results in tears in the thread and a much shorter service life compared to plastics that are not reinforced.

1.1 Materials

For the manufacture of spindle nuts, cast polyamides with and without sliding additives, as well as POM, PET and PET with sliding additives have proven their worth.

In regard to service life, like all other sliding applications, the use of materials with built-in lubrication (such as **LiNNOTAM***GLiDE*, **LiNNOTAM***GLiDE PRO* and PET-GL) is an advantage. Compared to other plastics, they exhibit less wear and thus achieve a longer service life.

1.2 Lubrication

As with all other slide applications, lubrication is not absolutely necessary, but among other things it does considerably prolong the service life of the components. It also counteracts the danger of stick-slip occurring.

Initial installation lubrication is practical, as recommended for friction bearings and sliding pads, with a subsequent empirical lubrication. This especially applies to highly loaded spindle nuts where attention has to be paid that the friction heat is dissipated.

However, graphite should not be used as a lubricant in combination with polyamide spindle nuts, as stick-slip becomes more likely with this combination.

2. Manufacture and design

The threads of spindle nuts can be machined on suitable machine tools. We recommend that they be produced on a lathe with the use of a thread turning tool. In this way, it can be ensured that there is enough play on the flanks of the thread to balance out the effects of heat expansion and moisture absorption.

Generally the spindle nut and housing are connected via a feather key. The load bearing capacity of plastic nuts in this case is oriented to the admissible compression in the feather key groove.

To fully utilise the load bearing capacity of the plastic thread, a form-fit connection between the outer steel housing and the plastic nut is required.

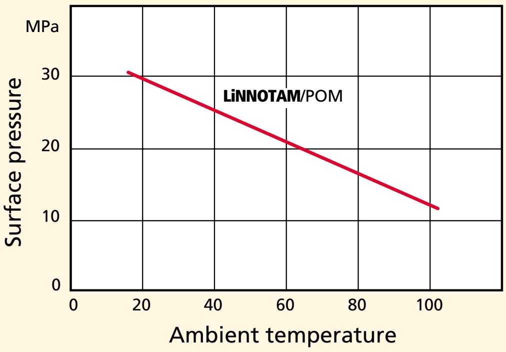
3. Calculating the load bearing capacity

3.1 Surface pressure in the key groove

For a feather key connection, the side of the key groove must be checked to ensure that it does not exceed the permissible surface pressure:

$$P_F = \frac{M_d \cdot 10^3}{i \cdot r_m \cdot h \cdot b} \qquad [\text{MPa}]$$

Diagram 1: Guiding values for permissible surface pressure



where

M_d = transmitted torque in Nm

i = number of groove flanks

r_m = radius from the middle of the shaft to the middle of the bearing flank in mm

h = height of the bearing flank in mm

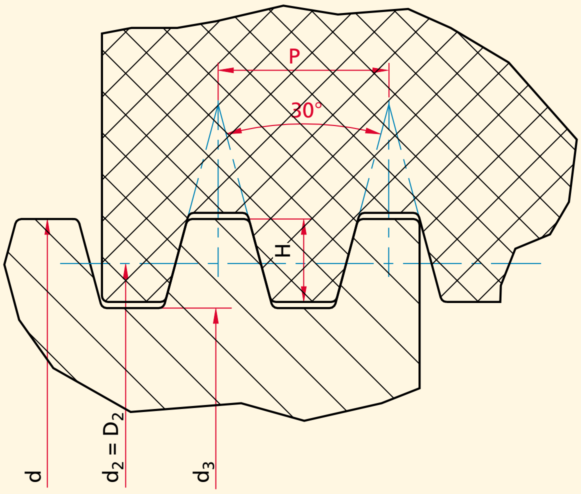
b = width of the bearing flank in mm

The value from the calculation is compared with Diagram 1 and may not exceed the maximum value.

3.2 Surface pressure on the thread flank

If we assume that all thread flanks bear the load equally, the surface pressure on the flanks is:

$$p = \frac{F}{z \cdot H \cdot \sqrt{\left(d_2 \cdot \pi \cdot \frac{l}{P}\right)^2 + l^2}} \qquad [\text{MPa}]$$



where

F = axial load of the spindle in N

P = lead in mm

d_2 = flank diameter in mm

l = length of nut in mm

H = depth for ISO metric trapezoidal screw thread in mm according to Table 1

z = number of screw flights (in case of multiple-flights)

In the case of static loading for spindle nuts made from PA, POM or PET, at 20 °C approx. 12 MPa and at 80 °C approx. 8 MPa can be permitted as the maximum compression.

Table 1: ISO metric trapezoidal screw thread according to DIN 103

Thread diameter d	P	H = 0.5 · P	d_2 = d - H	Thread diameter d	P	H = 0.5 · P	d_2 = d - H	Thread diameter d	P	H = 0.5 · P	d_2 = d - H
8	1.5	0.75	7.25	36	6	3	33	75	10	5	70
10	2	1	9	40	7	3.5	36.5	80	10	5	75
12	3	1.5	10.5	44	7	13.5	40.5	85	12	6	79
16	4	2	14	48	8	4	44	90	12	6	84
20	4	2	18	52	8	4	48	95	12	6	89
24	5	2.5	21.5	60	9	4.5	55.5	100	12	6	94
28	5	2.5	21.5	65	10	25	60	110	12	6	104
32	6	3	29	70	10	5	65	120	14	7	113

3.3 Sliding friction on the thread flank

As the thread flanks can be considered as a sliding element, the pv value can also be used as a guiding value for sliding friction loads for spindle nuts. For the thread flank this is

$$pv = p \cdot \frac{n \cdot \sqrt{(d_2 \cdot \pi)^2 + s^2}}{60{,}000} \qquad [\mathrm{MPa} \cdot \mathrm{m/s}]$$

where

n = number of strokes in 1/min^{-1}
d_2 = flank diameter in mm
s = stroke length in mm

As with friction bearings, the question regarding the permissible sliding friction load is a problem caused by the heat that occurs due to friction. If it can be ensured that the plastic nuts have sufficient time to cool down in intermittent operation, higher values can be permitted than in the case of continuous operation.

However, the determined values may not exceed the maximum values given in Table 2.

Table 2: pv – limiting values for spindle nuts

	Continuous operation					Intermittent operation				
	LiNNOTAM	**LiNNOTAM***GLiDE*	POM-C	PET	PET- GL	**LiNNOTAM**	**LiNNOTAM***GLiDE*	POM-C	PET	PET- GL
Dry running	0.06	0.12	0.06	0.06	0.13	0.08	0.12	0.08	0.08	0.37
Continuous lubrication	0.30	0.30	0.30	0.30	0.50	0.45	0.45	0.45	0.45	0.50

LICHARZ

TOLERANCES

The competitive edge through engineered components made of plastic

1. Material-related tolerances for machined plastic component parts

Plastics are often integrated into existing assemblies to replace conventional materials. As a rule, however, the production drawing is only altered in respect to the new material. Often the tolerances that have been specified for the steel component are not adapted to suit the new material. But even in the case of new designs where plastic is planned as a material, the tolerance fields that are normal for steel are still used. However, the special features of plastics preclude the use of the narrow production tolerances required for steel parts.

The decisive factor is not the possibility of manufacturing the parts, since this is virtually no problem with the use of modern CNC machine tools, but rather the permanent compliance with the tolerances after the manufacturing process. This applies especially to dimensions in a class of tolerances with very narrow fields (< 0.1 mm). These can change immediately after the part is taken from the machine due to the visco-elastic behaviour of the plastics. In particular, the higher level of thermal expansion, volume changes due to the absorption of moisture as well as form and dimensional changes caused by the relaxation of production-related residual stresses are just some of the possible causes.

Another problem is the fact that there is no general standard for machined plastic components. The lack of a common basis for material-related tolerances for parts such as this often leads to disagreement between the customer and the supplier in regard to the classification of rejects and/or defects in delivery. Choosing a tolerance field that is suitable for the respective material can avoid disputes and also ensure that the plastic components function and operate safely as intended.

The following sections of this chapter are based on our many years of experience with different plastics and are intended to assist design engineers in defining tolerances. The aim is to create a standard basis and to avoid unnecessary costs caused by rejects due to off-spec tolerances.

The tolerance fields that we recommend can be achieved with conventional production methods and without any additional expenditure. In general, the functioning and operating safety of the components were not limited because of the increased tolerance. Narrower tolerances than those stated here are possible to a certain extent, but would necessitate unjustifiably high processing expenditure, and the materials would also require intermediate treatment (annealing) during the production process. If component parts require tolerance fields of < 0.1 mm or ISO series IT 9 fits and smaller, we will be happy to advise you in the choice of a technically/economically practical and sustainable tolerance field.

2. Plastic-related tolerances

2.1 General tolerances

The general tolerances for untoleranced dimensions can be chosen according to DIN ISO 2768 T1, tolerance class »m«. In this standard, the tolerances are defined as follows:

Table 1: Limiting dimensions in mm for linear measures (DIN ISO 2768 T1)

Tolerance class	Nominal size range in mm 0,5 up to 3	above 3 up to 6	above 6 up to 30	above 30 up to 120	above 120 up to 400γ	above 400 up to 1000	above 1000 up to 2000	above 2000 up to 4000
f (fine)	± 0.05	± 0.05	± 0.1	± 0.15	± 0.2	± 0.3	± 0.5	–
m (medium)	± 0.1	± 0.1	± 0.2	± 0.3	± 0.5	± 0.8	± 1.2	± 2.0
g (rough)	± 0.15	± 0.2	± 0.5	± 0.8	± 1.2	± 2.0	± 3.0	± 4.0
v (very rough)	–	± 0.5	± 1.0	± 1.5	± 2.5	± 4.0	± 6.0	± 8.0

Table 2: Limiting dimensions in mm for radius of curvature and height of bevel (DIN ISO 2768 T1)

Tolerance class	Nominal size range in mm 0.5 up to 3	above 3 up to 6	above 6
f (fine) m (medium)	± 0.2	± 0.5	± 1.0
g (rough) v (very rough)	± 0.4	± 1.0	± 2.0

Table 3: Limiting dimensions in degrees for angle measurements (DIN ISO 2768 T1)

Tolerance class	Nominal size range of the shorter leg in mm up to 10	above 10 up to 50	above 50 up to 120	above 120 up to 400	above 400 γ
f (fine) m (medium)	± 1°	± 30'	± 20'	± 10'	± 5'
g (rough) v (very rough)	± 1° 30' ± 3	± 1° ± 2°	± 30' ± 1°	± 15' ± 30'	± 10' ± 20'

For length measurements the choice of tolerance class »f« is possible in special cases. The lasting durability of the tolerance, based on the geometry of the workpiece, should be checked with the manufacturer of the component part.

2.2 Shape and position

The general tolerances for untoleranced dimensions can be selected according to DIN ISO 2768 T2, tolerance class »K«. In this standard the tolerances are defined as follows:

Table 4: General tolerances for straightness and evenness (DIN ISO 2768 T2)

Tolerance class	Nominal size range in mm up to 10	above 10 up to 30	above 30 up to 100	above 100 up to 300	above 300 up to 1000 γ	above 1000 up to 3000
H	0.02	0.05	0.1	0.2	0.3	0.4
K	0.05	0.1	0.2	0.4	0.6	0.8
L	0.1	0.2	0.4	0.8	1.2	1.6

Table 5: General tolerances for rectangularity (DIN ISO 2768 T2)

	Nominal size range in mm			
Tolerance class	up to 100	above 100 up to 300	above 300 up to 1000	above 1000 up to 3000
H	0.2	0.3	0.4	0.5
K	0.4	0.6	0.8	1.0
L	0.6	1.0	1.5	2.0

Table 6: General tolerances for symmetry (DIN ISO 2768 T2)

	Nominal size range in mm			
Tolerance class	to 100	above 100 up to 300	above 300 up to 1000	above 1000 up to 3000
H	0.5			
K	0.6		0.8	1.0
L	0.6	1.0	1.5	2.0

The general tolerance for run-out and concentricity for class »K« is 0.2 mm.

In special cases it is possible to choose tolerance class »H«. The general tolerance for run-out and concentricity for class »H« is 0.1 mm.
It is important to check with the manufacturer to make sure the tolerance can be held over the long term.

2.3 Press fit

As described above, it is not possible to apply the ISO tolerance system that is usually applied to steel components. Accordingly, the tolerance series IT 01-9 should not be used. In addition, to determine the correct tolerance series, the machining method and the type of plastic being used must be considered.

2.3.1 Dimensional categories

The different plastics can be classified into two categories according to their dimensional stability. These are shown in Table 7.

Table 7: Dimension categories for plastics

Dimension category	Plastics	Comments
A	POM, PET, PTFE+glass, PTFE+bronze, PTFE+carbon,PC,PVC-U, PVDF, PP-H, PEEK, PEI, PSU, HGW (laminated fabric)	Thermoplastics with or or without reinforcement/fillers (with low moisture absorption)
B	PE-HD, PE-HMW, PE-UHMW, PTFE, PA 6, **LiNNOTAM**, PA 66, PA 12	Soft thermoplastics and polyamides with moisture absorption

2.3.2 Classification of tolerance series for milled parts

Classification for milled parts with tolerances

Dimension A IT 10-12
category: B IT 11-13

Table 8: ISO basic tolerances in µm according to DIN ISO 286

Nominal size range mm		ISO tolerance series (IT)										
		6	7	8	9	10	11	12	13	14	15	16
From up to	1-3	6	10	14	25	40	60	100	140	250	400	600
Above up to	3-6	8	12	18	30	48	75	120	180	300	480	750
Above up to	6-10	9	15	22	36	58	90	150	220	360	580	900
Above up to	10-18	11	18	27	43	70	110	180	270	430	700	110
Above up to	18-30	13	21	33	52	84	130	210	330	520	540	1300
Above up to	30-50	16	25	39	62	100	160	250	390	620	1000	1600
Above up to	50-80	19	30	46	74	120	190	300	460	740	1200	1900
Above up to	80-120	22	35	54	87	140	220	350	540	870	1400	2200
Above up to	120-180	25	40	63	100	160	250	400	630	1000	1600	2500
Above up to	180-250	29	46	72	115	185	290	460	420	1150	1850	2900
Above up to	250-315	32	52	81	130	210	320	520	810	1300	2100	3200
Above up to	315-400	36	57	89	140	230	360	570	890	140	2300	3600
Above up to	400-500	40	63	97	155	250	400	630	970	1550	2500	4000

2.3.3 Classification of tolerance series for turned parts

Classification for turned parts with tolerances

Dimension A IT 10-11
category: B IT 11-12

Table 8: ISO basic tolerances in µm according to DIN ISO 286

Nominal size range mm		ISO tolerance series (IT)										
		6	7	8	9	10	11	12	13	14	15	16
From up to	1-3	6	10	14	25	40	60	100	140	250	400	600
Above up to	3-6	8	12	18	30	48	75	120	180	300	480	750
Above up to	6-10	9	15	22	36	58	90	150	220	360	580	900
Above up to	10-18	11	18	27	43	70	110	180	270	430	700	110
Above up to	18-30	13	21	33	52	84	130	210	330	520	540	1300
Above up to	30-50	16	25	39	62	100	160	250	390	620	1000	1600
Above up to	50-80	19	30	46	74	120	190	300	460	740	1200	1900
Above up to	80-120	22	35	54	87	140	220	350	540	870	1400	2200
Above up to	120-180	25	40	63	100	160	250	400	630	1000	1600	2500
Above up to	180-250	29	46	72	115	185	290	460	420	1150	1850	2900
Above up to	250-315	32	52	81	130	210	320	520	810	1300	2100	3200
Above up to	315-400	36	57	89	140	230	360	570	890	140	2300	3600
Above up to	400-500	40	63	97	155	250	400	630	970	1550	2500	4000

2.4 Surface quality

The degree of surface quality that can be achieved depends on the machining method. Table 9 shows the surface qualities that can be achieved without any additional expenditure for the individual processes.

Table 9: Achievable surface qualities for various machining processes

Form of machining	Max. achievable degree of roughness	Average roughness value R_a (µm)	Averaged depth of roughness R_z(µm)
Milling	N7	1.6	8
Turning	N7	1.6	8
Planing	N8	3.2	12.5
Sawing	N8	3.3	26

It is possible to achieve better surface qualities than those shown in Table 9 in conjunction with higher production expenditure. However, the production possibilities must be discussed with the manufacturer of the component part in regard to the respective plastic and the machining method.

2.5 Tolerances for press fits

2.5.1 Oversize for bushes

To ensure that friction bearing bushes sit properly in the bearing bore, the insertion of an oversized component has proved to be a good method. The oversize for plastic bushes is very large compared to metal bearing bushes. However, due to the visco-elastic behaviour of the plastics, this is especially important because of the effects of heat, as otherwise the bearing bush would become loose in the bore. If the maximum service temperature is 50 °C, it is possible to do without an additional securing device for the bearing bush if the oversizes from Diagram 1 are complied with. In the case of temperatures above 50 °C, we recommend that the bush be secured with a device commonly used in machine engineering (e.g. a retaining ring according to DIN 472, see also the chapter on »Friction bearings« section 2.5).
It should also be considered that when the bearing bush is being inserted, its oversize leads to it being compressed. Consequently the oversize must be considered as an excess to the operating bearing play, and the internal diameter of the bearing must be dimensioned accordingly. Diagram 2 shows the required bearing play in relation to the internal diameter of the bearing. To prevent the bearing from sticking at temperatures above 50 °C, it is necessary to correct the bearing play by the factors shown in the chapter on »Friction bearings« section 2.3.

Diagram 1:
Press-fit oversize for friction bearings

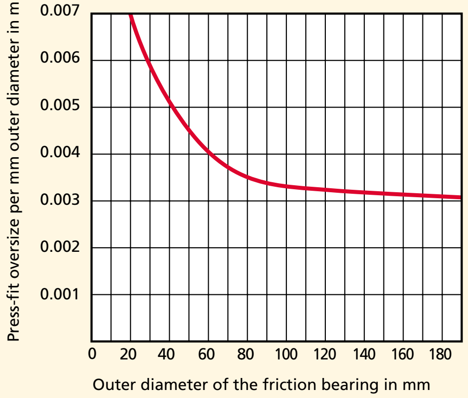
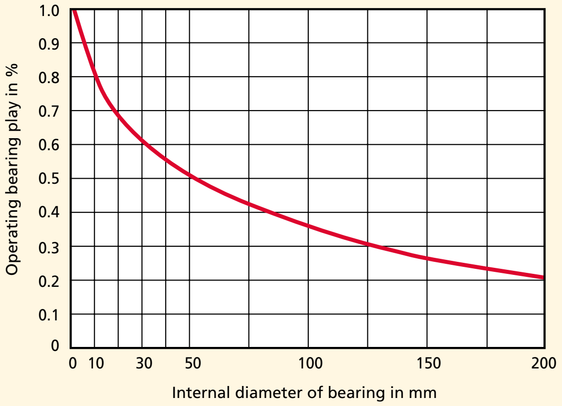


Diagram 2: Operating bearing play



In regard to dimensioning thin walled bearing bushes, rings and similar components, it must be noted that the measuring forces that are applied and the deformation that this causes can result in incorrect measurements. Hence, the tolerances for the outer diameter and wall thickness shown in Figure1 are recommended.

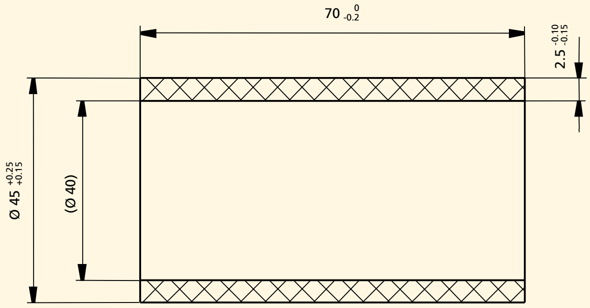
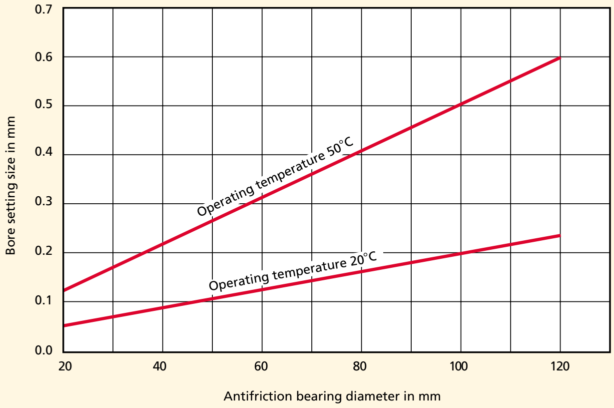


Figure 1: Example of tolerance for a bearing bush

2.5.2 Press-fit undersize for antifriction bearings

Antifriction bearings can be inserted directly into the undersized bearing seat for maximum operating temperatures of up to 50 °C. If low loads and low operating temperatures are expected, no additional securing is required for the bearing, but it is recommended for higher loads and operating temperatures. Again this is because of the visco-elastic behaviour of the plastics which can result in a reduction in the compression force and bearing migration. The bearing can also be secured with devices commonly used in machine engineering (e.g. retaining ring according to DIN 472). If the bearing is to be used in areas where high temperatures or loads are expected, it is also possible to place a steel sleeve in the bearing bore. This steel sleeve is fixed in the bearing bore with additional securing elements, and the bearing is pressed in to this ring. Diagram 3 shows the required temperature-related undersizes for fixing the bearing in the bearing seat by compression.

Diagram 3: Bore setting sizes for bearing seats



For bearing seats into which anti-friction bearings are inserted for operation at normal temperature and load conditions, we recommend the following press-fit undersizes and tolerances:

Bearing seat diameter up to 50 mm	➜	-0,15/-0,25 mm
Bearing seat diameter above 50 up to 120 mm	➜	-0,25/-0,35 mm
Bearing seat diameter above 120 mm	➜	-0,40/-0,50 mm

In our many years of experience, bearing seats manufactured according to the above exhibit no excessive decrease in compression force and are able to keep the anti-friction bearings in position safely and securely. However, if this recommendation is taken, it should be noted that in the case of extremely small ratios between the bearing seat diameter and the outer diameter it is possible that the bearings loosen despite compliance with our recommendations. This can be attributed to the fact that the stresses caused by insertion can result in deformation of the plastic material. As a result of this, the bearing seat diameter becomes larger and the compression force needed to fix the bearing can no longer be maintained. This behaviour is exacerbated by high temperatures and/or flexing that occurs during operation. This can be negated to a certain extent by the securing measures described above.

3. General information

The basic tolerances and dimensions stated above can only be sustainably maintained under normal climatic conditions (23 °C/50% rel. humidity). If the environmental conditions differ, they must be considered by applying the respective correction factors. These can be found for the specific cases in the previous chapters.

3.1 Dimensional and volume changes under the influence of temperature

In general it can be said that elongation caused by temperature is approx. 0.1% per 10 K temperature change. In addition, in the case of polyamides, due to the absorption of moisture a change in volume of 0.15-0.20% per 1% water absorbed must be considered.

Considering the material-specific coefficient of elongation, the expected elongation and volume changes due to fluctuating temperatures can be calculated approximately. Hence, the expected elongation is

$$\Delta l = l \cdot \alpha \cdot (\upsilon_1 - \upsilon_2) \quad [\text{mm}]$$

where
Δl = expected elongation
l = original length in mm
α = material-specific coefficient of elongation
υ_1 = installation temperature in °C
υ_2 = operating temperature in °C

The expected change in volume is calculated – with the assumption that the elongation is not hindered in any direction – from:

$$\Delta V = V \cdot \beta \cdot (\upsilon_2 - \upsilon_1) \quad [\text{mm}^3]$$

and

$$\beta = 3 \cdot \alpha$$

where
ΔV = expected change in volume
V = original volume in mm^3
α = material-specific coefficient of elongation
β = material-specific coefficient of volume expansion
υ_1 = installation temperature in °C
υ_2 = operating temperature in °C

The material-specific coefficients of elongation can be found in Table 10.

Table 10: Linear coefficients of elongation of various plastics

Product	Material	Coefficient of elongation $\alpha\ 10^{-5}\ .\ K^{-1}$
LiNNOTAM	PA 6 C	7
LiNNOTAM CC	PA 6 C -CC	8
LiNNOTAM*GLiDE*	PA 6 C + Oil	7
LiNNOTAM*GLiDE PRO T*	PA 6 C + Solid lubricant	7
LiNNOTAM*HiPERFORMANCE 612*	PA 6/12 G	8
LiNNOTAM*HiPERFORMANCE 1200*	PA 12 G	10
Polyamide 6	PA 6	9
Polyamide 6 + 30% glass fibre	PA 6 C F30	3
Polyamide 66	PA 66	10
Polyamide 12	PA 12	12
Polyacetal	POM-C	10
Polyacetal GF-filled	POM-C-GF30	2.5
Polyethylene terephthalate	PET	7
Polyethylene terephthalate + lubricant additive	PET-GL	8
Polytetrafluoroethylene	PTFE	19
Polytetrafluoroethylene + 25% glass fibre	PTFE-GF25	13
Polytetrafluoroethylene + 25% carbon	PTFE-K25	11
Polytetrafluoroethylene + 40% bronze	PTFE-B40	10
Polyethylene 500	PE-HMW	18
Polyethylene 1000	PE-UHMW	18
Polyetheretherketone	PEEK	4
Polyetheretherketone modified	PEEK-GL	3
Polysulfone	PSU	6
Polyetherimide	PEI	6

3.2 Geometric shapes

The geometric relationships of a workpiece can cause changes in dimensions and shape after the machining process. Therefore, either the geometric shape has to be changed or the recommended tolerance series for workpieces with extreme geometric shape and wall thickness relationships, e.g. extreme one-sided machining, extremely thin walls, extreme wall thickness differences, must be adapted accordingly. If there is any uncertainty in regard to the definition of shape, dimension or position tolerances, we would be pleased to assist.

3.3 Measuring technology

It is very difficult to measure narrow tolerances in plastic workpieces, especially in thin-walled parts. The pressure exerted on the workpiece by the measuring instrument can deform the plastic part, or the low coefficient of friction of plastics can distort the starting torque of micrometre gauges. This inevitably leads to incorrect measured values. Therefore it is recommended that contactless measuring systems are used.

LICHARZ

MACHINING AND POST-MACHINING PROCESSES

The competitive edge through engineered components made of plastic

1. Machining of thermoplastics

With the increasing variety of engineering plastics and the resulting applications, design engineers now have many new horizons that were previously unthinkable with conventional materials. In many cases, in addition to material limitations, the only other limits to design possibilities are the restrictions imposed by the manufacturing process. Particularly if large volume parts are required from cast polyamides and polyacetal (POM) or polyethylene terephthalate (PET), manufacturing processes such as injection moulding cannot be used.
This applies equally to complex parts that require machining from all sides with narrow tolerances.

Fig. 1: Complex component made from POM

In this area, machining has proven to be the best method. Highly precise parts and large components can be manufactured especially economically in small and medium batches by machining.

For the manufacture of high quality products, certain specific features of plastics must be considered when machines and tools are being chosen and used.

1.1 Machining equipment/tools

No special machines or processes are required for machining. The machines that are normally used in the woodworking and metal industries with HSS tools (high speed steel) or hard metal tools can be used. The only thing to consider is that when a circular saw is used to cut plastic, hard metallic saw blades must be used.

The group of glass fibre reinforced plastics is a special case. While it is possible to machine them with hard metal tools, it is very difficult to achieve economic results due to the short service life of the tools. In this case it is advisable to use diamond tipped tools, which are much more expensive than conventional tools but have a much longer service life.

1.2 Machining and clamping the workpiece

Plastics have lower thermal conducting properties than metals, as well as a lower modulus of elasticity. If not handled properly, the workpiece can become extremely warm and thermal expansion can occur. High clamping pressures and blunt tools cause deformation during machining. Dimensional and shape deviations outside the tolerance range are the consequence. Satisfactory results are only achievable if several material-specific guidelines are considered when machining plastics.

In detail, these guidelines are:

- The highest possible cutting speed should be chosen.
- Optimum chip removal must be ensured so that the chips are not drawn in by the tool.
- The tools that are used must be very sharp. Blunt tools can cause extreme heat, which results in deformation and thermal expansion.
- The clamping pressures must not be too high as this would result in deformation of the workpiece and the clamping tool would leave marks in the workpiece.
- Because of the low degree of stiffness, the workpiece must be adequately supported on the machine table and should lie as flat as possible.
- Perfect, high-quality surfaces can only be obtained when the machines operate with low vibration.

Particularly problematic to produce accurately are parts which require high cutting volumes or an uneven depth of cut. In both cases it is advisable to make a preliminary cut leaving an allowance and apply intermediate tempering. That and subsequent 24-hour storage ensure that machining-induced thermal stresses and residual stresses in the semi-finished product are largely relieved. The parts can then be finish machined.

If these guidelines are complied with, it is not difficult to obtain narrow, plastic-oriented tolerances with a high level of reproducibility.

1.3 Cooling during machining

As a rule it is not absolutely necessary to cool the workpiece during machining. If cooling is to be applied it is recommended that compressed air is used. This has the advantage that in addition to the cooling effect, the chips are removed from the working area and cannot be drawn into the workpiece or tool.

Common drilling emulsions and cutting oils can also be used for cooling. The application is particularly recommended when deep holes are to be introduced or a thread is to be cut. It also enables higher feed rates and therefore achieves lower run times. However, it must be kept in mind that some plastics may not be resistant to some ingredients of the drilling emulsions and cutting oils and can be irreversibly damaged. Therefore it is advisable to check the resistance of the plastic before use. Alternatively, the emulsion or oil manufacturers can provide information and advice on any known incompatibilities with plastics. Workpieces with emulsion or cutting oil on them should be thoroughly cleaned after machining. It is important to ensure that any residues are completely removed.
This ensures that any follow-up operations such as gluing or painting remain trouble free. With polyamides particular care must be taken to prevent the water content of the emulsion from causing changes in the parts through moisture absorption.

2. Parameters for the individual machining processes

2.1 Sawing

Plastics can be sawn with a band saw or a circular saw. The choice depends on the shape of the semi-finished product. The use of a band saw is particularly recommended when a “support groove” (prism) is used to cut rods and tubes and also has the advantage that the heat is dissipated via the long saw blade. However, the teeth of the blade must be set adequately so that the blade cannot jam.

Circular saws, on the other hand, are mainly used for cutting sheets and blocks with straight edges. Here, attention should be paid that the feed rate is adequate so that chips are removed, that the saw blade does not jam and that the plastic does not overheat at the point where it is being cut. Table 1 contains guiding values for the cutting geometry of the saw blades.

2.2 Milling

Milling on conventional machining centres is unproblematic. With a high cutting speed and medium feed rate it is possible to achieve high levels of machining performance with good surface quality and accuracy. Care must be taken that tools with sufficiently large chip space are used. It guarantees a reliable chip removal and it avoids heat congestion. We recommend the values given in the Table in regard to the cutter geometry.

2.3 Turning on a lathe

Since most plastics produce unbroken chips, it is important to ensure that the chips are removed, as they would otherwise catch and revolve with the part being turned on the lathe. In addition, because of the low degree of stiffness of plastics, there is a great danger of longer parts sagging, and it is thus advisable to use a steady rest. The values given in the Table apply to the cutter geometry.

2.4 Drilling

Drill holes can be made with a conventional HSS drill. If deep holes are being drilled, it must be ensured that the chips are removed, as otherwise the plastic on the walls of the hole will heat to the point of melting and the drill will “clog”. This especially applies to deep holes. For drilled holes in thin-walled workpieces, it is advisable to choose a high drilling speed and, if applicable, a neutral (0°) effective cutting angle. This prevents the drill from sticking in the workpiece and hinders the associated stripping of the hole or the workpiece being drawn up by the drill. The recommended values for drill cutting geometry are shown in the table.

2.5 Drilling large diameters in sections of round rod

When drilling, high temperatures build up on the cutting edges, especially with highly crystalline materials such as **LiNNOTAM**, which cannot be adequately dissipated because of the good insulation properties of the plastics. The heat causes an internal expansion in the material, which in turn causes compressive stress in the inside of the rod section. This stress can be so high that the rod tears and splits. This can be avoided to a great extent if the material is machined correctly.

It is advisable to pre-drill the hole and complete it with a right side tool. The pre-drilled holes should not exceed 35 mm in diameter. Drilled holes in long sections of rod must only be made from one side, as otherwise an unfavourable stress relationship is created when the drilled holes meet in the middle of the rod, which can lead to the rod section cracking.
In extreme cases it may be necessary to heat the blank to approx. 120-50 °C and pre-drill it in this condition. The hole can then be completed when the rod has cooled down and when an even temperature has set in throughout the blank. Finishing can take place after complete cooling and achieving a uniform temperature level inside the blank.

2.6 Notes on reinforced and filled plastics

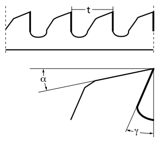
Plastics that are reinforced or filled with glass fibres, carbon fibres, glass beads, mineral substances or other substances have a higher level of residual stress compared to non-reinforced or unfilled plastics. The reinforcement and filler materials also make the products harder and more brittle and reduce impact strength. This makes these products susceptible to cracking. During machining the residual stresses may be relieved, which makes itself noticeable by strong deformation, cracking or full failure. The following notes should therefore be taken into account when machining and manufacturing:

- If possible the semi-finished products should be heated to approximately 120 °C before drilling or sawing. (Suggested exposure time: approx. 5-6 min per mm of cross-section).
- As a minimum a carbide-tipped, but preferably diamond-coated tools should be used for machining.
- When clamping and fixing ensure freedom from deformation and expose the material to the minimum possible bending, tensile or compressive forces.

If the above guidelines are observed the production of complex products from engineering plastics using machining processes can be easily achieved even where the highest quality standards of accuracy and functionality are required.

Machining and post-machining processes

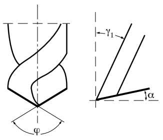
Sawing



α = Clearance angle (°)
γ = Effective cutting anglel (°)
v = Cutting speed (m/min)
t = Number of teeth
Values for circular saw without ()
Values for band saw with ()
Use offset bandsaw blades!

	PA	POM	PET	PE/PP-H	PVC	PVDF	PTFE	PSU	PEI	PEEK	Reinforced materials
α	30 – 40 (10 – 20)	30 – 40 (10 – 20)	30 – 40 (10 – 20)	20 – 30 (20 – 30)	5 – 10 (30 – 40)	30 – 40 (10 – 20)	10 – 15 (10 – 30)	10 – 15 (10 – 30)	10 – 15 (15 – 30)	10 – 15 (15 – 30)	15 – 30 (15 – 30)
γ	0 – 10 (0 – 8)	0 – 10 (0 – 8)	0 – 10 (0 – 8)	6 – 10 (2 – 8)	0 – 6 (0 – 5)	0 – 10 (0 – 8)	0 – 15 (0 – 4)	0 – 15 (0 – 4)	10 – 15 (15 – 30)	0 – 15 (0 – 5)	15 – 30 (10 – 15)
v	1000 – 3500 (200 – 1000)	1000 – 3500 (200 – 1000)	1000 – 3500 (200 – 1000)	1000 – 3500 (500 – 800)	3000 – 4000 (800 – 1200)	1000 – 3500 (200 – 1000)	1800 – 2000 (300 – 500)	1800 – 2000 (300 – 500)	1800 – 2000 (300 – 500)	1800 – 2500 (500 – 800)	500 – 1500 (200 – 300)
t	24 – 80 (3 – 5 / inch)	24 – 80 (3 – 5 / inch)	24 – 80 (3 – 5 / inch)	24 – 80 (3 – 8 / inch)	36 – 80 (3 – 5 / inch)	24 – 80 (3 – 5 / inch)	24 – 80 (2 – 5 / inch)	24 – 80 (3 – 5 / inch)	24 – 80 (3 – 5 / inch)	24 – 80 (3 – 5 / inch)	24 – 80 (3 – 5 / inch)

Drilling

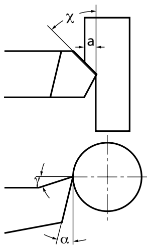


α = Clearance angle (°)
γ = Effective cutting angle (°)
ϕ = Point angle (°)
v = Cutting speed (m/min)
s = Forward feed (mm/rev.)

The angle of twist of the drill should be at least 12-16°

	PA	POM	PET	PE/PP-H	PVC	PVDF	PTFE	PSU	PEI	PEEK	Reinforced materials
α	5 – 15	5 – 10	5 – 10	10 – 20	5 – 10	5 – 15	10 – 15	8 – 15	8 – 15	5 – 15	5 – 10
γ	5 – 10	5 – 15	5 – 15	10 – 15	0 – 5	5 – 20	5 – 20	10 – 20	10 – 20	10 – 15	5 – 10
ϕ	60 – 90	60 – 90	60 – 90	60 – 90	60 – 100	110 – 130	110 – 130	60 – 90	60 – 90	90 – 120	110 – 120
v	50 – 150	50 – 150	50 – 150	50 – 150	30 – 120	100 – 300	100 – 300	50 – 100	50 – 100	50 – 200	80 – 100
s	0.1 – 0.5	0.1 – 0.3	0.1 – 0.3	0.1 – 0.5	0.1 – 0.5	0.1 – 0.3	0.1 – 0.3	0.1 – 0.4	0.1 – 0.4	0.05 – 0.3	0.1 – 0.3

Turning on a lathe

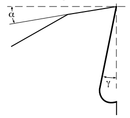


α = Clearance angle (°)
γ = Effective cutting angle (°)
ξ = Setting angle (°)
v = Cutting speed (m/min)
s = Forward feed (mm/rev.)
a = Rate of cut (mm)

The point radius should be at least 0.5 mm

	PA	POM	PET	PE/PP-H	PVC	PVDF	PTFE	PSU	PEI	PEEK	Reinforced materials
α	5 – 15	5 – 10	5 – 10	5 – 10	8 – 10	5 – 15	5 – 10	5 – 10	5 – 10	5 – 10	6 – 8
γ	0 – 10	0 – 5	0 – 5	0 – 5	0 – 5	5 – 15	0 – 5	0 – 5	0 – 5	0 – 5	2 – 8
χ	0 – 45	0 – 45	0 – 45	0 – 60	30 – 60	0 – 45	0 – 45	0 – 45	0 – 45	0 – 45	45 – 60
v	200 – 500	200 – 500	200 – 500	250 – 500	250 – 750	150 – 200	200 – 500	150 – 400	150 – 400	200 – 500	150 – 200
s	0.05 – 0.5	0.05 – 0.5	0.05 – 0.5	0.1 – 0.5	0.3 – 0.5	0.1 – 0.3	0.05 – 0.5	0.1 – 0.3	0.1 – 0.3	0.2 – 0.5	0.1 – 0.5
a	to 15	to 15	to 15	to 15	to 10	to 15	to 15	to 10	to 10	to 15	to 10

Milling



α = Clearance angle (°)
γ = Effective cutting anglel (°)
v = Cutting speed (m/min)
Feed up to 0.5 mm per tooth
Helix angle of the cutter from 0-40°

	PA	POM	PET	PE/PP-H	PVC	PVDF	PTFE	PSU	PEI	PEEK	Reinforced materials
α	5 – 15	5 – 10	5 – 10	5 – 20	5 – 10	5 – 15	10 – 15	10 – 20	10 – 20	5 – 15	15 – 30
γ	0 – 15	0 – 10	0 – 10	5 – 15	0 – 15	5 – 15	15 – 20	5 – 15	5 – 15	5 – 10	5 – 10
v	to 1000	to 1000	to 1000	to 1000	to 1000	to 1000	to 600	to 400	to 400	to 500	to 100

Instructions for cutting:

For the following dimensions/materials we recommend heating

before making the cut:
from Ø 50: PA 66 GF
from Ø 60: PEEK-GF, PEEK-GL, POM-G
from Ø 100: PA 6 GF, PA 12 GF, PE

before drilling in the center:
from Ø 60: PEEK-GF, PEEK-GL, POM-GF
from Ø 80: PA 66 GF
from Ø 100: PA 66, PA 6 GF, PA 12 GF, PET
from Ø 180: **LiNNOTAM**, **LiNNOTAM***HiPERFORMANCE 612*,
LiNNOTAM*HiPERFORMANCE 1200*

Do not use lubricants/oils.
Risk of tension cracks!

Use of carbide and diamond
tools is recommended

Heat semi-finished products to approx.120° C!
Suggested exposure time: approx. 5-6 min
per mm of cross-section

3. Post-machining processes

3.1 Conditioning

The process of conditioning is defined as treatment of dry polyamide products aiming at the fastest possible moisture accumulation. This can be necessary where parts made from polyamides must not change dimensions due to further water absorption, where parts are to be in permanent contact with water or submerged in water, or where specific material changes are should be brought about by water absorption.

Polyamide products are usually distinguished by the following moisture conditions:

• dry	(moisture content <0.2%)
• humid	(constant weight when stored in standard air at 23 °C/50% relative humidity)
• wet	(constant weight even after prolonged immersion in water)

For conditioning, besides the processes that use warm air and humidity, it is also possible to store in hot water (water temperature approx. 80 °C-100 °C max). In terms of effort this is the simplest method, but it does have some significant disadvantages. With thick-walled parts the water first diffuses in the surface regions and saturates them. However, after the conditioning period the lower layers still do not have the desired water content. After removing the parts from the water bath a portion of the absorbed water evaporates back into the air. The water content of the near-surface layers settles at the desired value, but the lower-lying levels fall below the intended value. It is therefore prudent to slightly extend the time in the water bath and then store the part in normal room air for several days of conditioning. After the loss of water from the near-surface layers this achieves virtually uniform water content over the cross section.

3.2 Important factors in the water absorption of polyamides

The process of water absorption is generally only very slow and is influenced by various factors. The most important factors can be illustrated as follows:

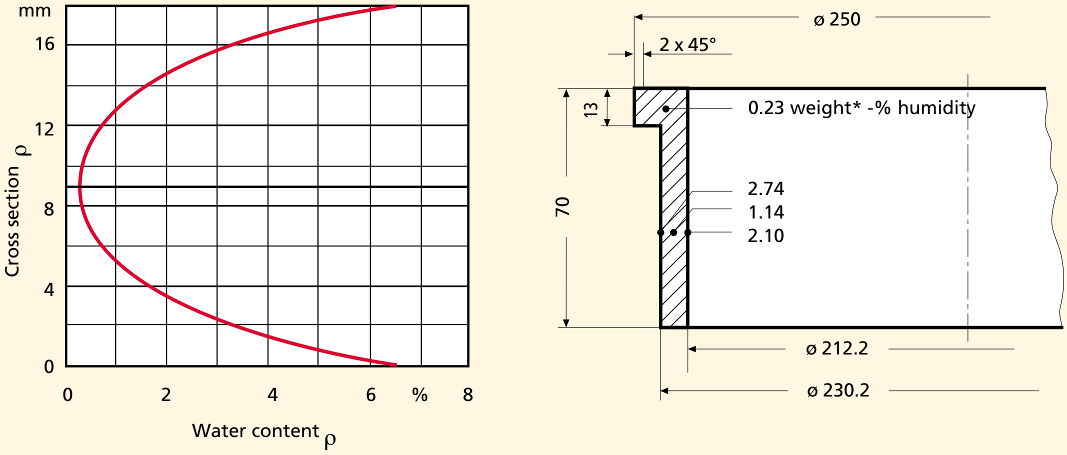
3.2.1 Speed of water absorption

Water or moisture is absorbed very slowly by polyamide until a state of equilibrium is achieved. Once equilibrium is reached moisture content can only be influenced by altering the environmental conditions, such as increasing the moisture content and/or increasing the temperature. The tendency of water molecules to diffuse into a solid increases significantly with increasing temperature. It therefore follows that, with increasing ambient temperature, less time is required to make a defined amount of water penetrate into a part made of polyamide. The size of the specific surface area (surface area per unit volume) is crucial. The larger the specific surface area of a part is, the larger the surface area available for attack by the water molecules and the resulting absorption speed is faster. It may be concluded from the above that for the practical use of polyamides short-term fluctuations in humidity in the environment have only a limited impact on the material properties, but that long-term fluctuations and possibly associated with high temperature can induce the changes in material properties previously described.

3.2.2 Water absorption in air

Water absorption due to humidity is primarily determined by the relative humidity and not the air temperature. It should be noted that the process of water absorption due to humidity only takes place in the near-surface areas of thick-walled components and water absorption in the core of the part with the consequences described is normally not expected. (Fig.2)

Fig. 2 Moisture distribution in thick-walled components from cast polyamide



3.2.3 Influence of the degree of crystallinity

Since water is absorbed only by the amorphous proportions in the polyimide, the water intake also significantly depends on the degree of crystallinity. With increasing crystallinity the saturation concentration (depending on the chemical composition and the type of polyamide) as well as the absorption speed and the absorption capacity also increase. Cast polyamides have a higher degree of crystallinity compared to extruded polyamides. They absorb much less water and require significantly more time.

Machining and post-machining processes

4. Tempering

The tempering process is defined as the heat treatment of parts or semi-finished products in order to

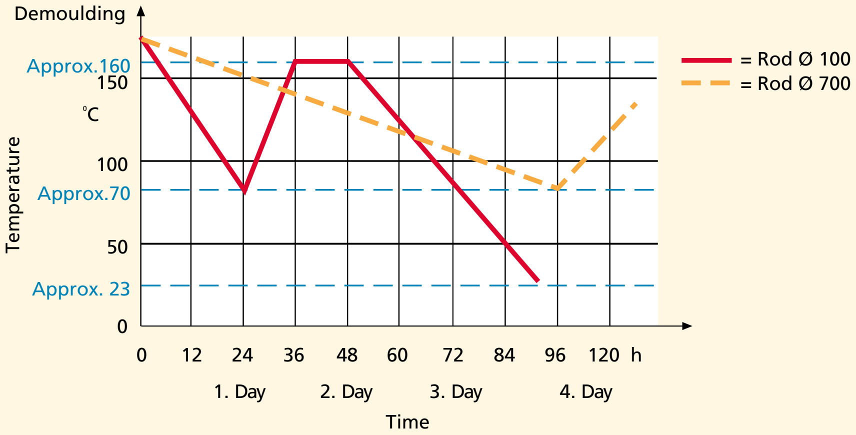
- largely reduce residual stresses from the manufacturing or production process
- increase the crystallinity and thereby to improve the mechanical characteristics of the material
- prevent warping and dimensional changes during or after machining
- improve the permanent dimensional stability

Usually semi-finished products and parts are tempered in an oven using hot circulating air. Hot oil baths using a paraffin or silicone oil base are also commonly used. The process is based on a uniform scheme regardless of the heat transfer medium used. The products are slowly and evenly heated in a heating cabinet (in the media) and brought to the material-specific tempering temperature. Once this is achieved the products are kept at this temperature for several hours. The complete warming through of the products is essential and crucial for tempering to be a success. The holding period required is dependent on the product dimensions and shape as well as its mass and is set based on these parameters. On completion of the holding period ensure that the tempered material cools to room temperature slowly, draught-free and under control. This will ensure the formation of a highly crystalline structure in the material and that only minimum residual stresses result from uneven heat losses during the cooling phase.

The temperature range for common technical plastics is usually between 130 °C and 170 °C. Some materials (such as the high-temperature plastics) require higher temperatures.

In special cases technical plastics can also be tempered at higher temperatures. However, specific process conditions must be complied with and it must be ensured that the maximum temperature is always 30 to 40 °C below the melting point. The general specification of the required heating, holding and cooling times is only possible to a very limited extent. The dependencies on product dimensions, shape and mass of the goods to be tempered are very large. For example, a large mass requires a significantly higher quantity of heat and heating period to reach full and uniform heating than a small mass. It also needs a significantly longer cooling time as the quantity of heat adsorbed is released at a slow rate due to the large mass. The following diagram clearly shows these differences using newly cast solid **LiNNOTAM** rods as an example.

Machining and post-machining processes



It is evident that a solid rod with Ø 100 is cooled enough to be tempered one day after demoulding. However, a solid rod with Ø 700 mm needs at least four days until it is cooled down enough for the tempering process to begin.

But also the product form has a significant influence on the tempering times. Pipes are for example completely warmed faster than solid rods because they offer a greater surface area to heat absorption due to inner and outer diameter. Accordingly these cool down faster again after tempering than solid bars.

If parts are to be intermediately tempered during manufacturing, in addition to the above parameters also the geometric conditions of the construction part as well as the existing wall thicknesses and their distribution on the workpiece are to be considered.

Taking previous versions into consideration the following data can be used as a rough guideline:

Material	Temperature in ° C	Heating in ° C/Hr.	Holding time in min/mm	Cooling in ° C/Hr.
Polyamide (PA):	ap. 160-165	ap. 10-15	ap. 5-6	ap. 15-20
Polyacetal (POM):	ap. 150-152	ap. 10-15	ap. 5-6	ap. 15-20
Polyethylene terephthalate (PET):	ap. 170-175	ap. 10-15	ap. 5-6	ap. 15-20
Polyetheretherketone (PEEK):	ap. 220-225	ap. 10-15	ap. 5-6	ap. 15-20

More exact details for the tempering of our products are available on request.

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MECHANICAL VALUES AND CHEMICAL RESISTANCES OF PLASTICS

The competitive edge through engineered components made of plastic

Information and conditions concerning the table

“Physical Material Guiding Values”

The information in the list is intended to provide an overview of the properties of our products and to allow a quick comparison of materials. They represent our present standard of knowledge and do not claim to be complete. Because of the high level of dependence on environmental influences and machining methods, the values given here should only be regarded as standard values. In no way do they represent a legally binding assurance in regard to the properties of our products nor to their suitability for specific applications. All the values stated here were determined from average values resulting from many individual measurements and refer to a temperature of 23 °C and 50% RH. For specific applications, we recommend that the suitability of the materials be first tested by practical experiments.

The conditions under which the individual values were determined, and any special features in regard to these values, are contained in the following list with the respective footnotes:

Parameter	Condition	Footnote
Impact resistance DIN EN ISO 179	Measured with an impact pendulum testing machine 0.1 DIN 51 222	1
Creep load DIN 53 444	Load that leads to 1% overall expansion after 1,000 h	2
Coefficient of sliding friction	Hardened and ground against steel, P = 0.05 MPa, V = 0.6 m/s, t = 60 °C in vicinity of running area	3
Linear coefficient of elongation	For temperature range from + 23 °C to + 60 °C	4
Temperature range	Experience values, determined on finished parts without load in warmed air, dependent on the type and form of heat, short-term = max. 1 h, long-term = months	5
Dielectric strength IEC 250	at 10^6 Hz	6
Colours	POM-C natural = white PET-natural = white PVDF-natural = white to ivory (translucent) PE-natural = white PP-H natural = white (translucent) PP-H grey ≈ RAL 7032 PVC-grey ≈ RAL 7011 PEEK natural ≈ RAL 7032 PSU-natural = honey yellow (translucent) PEI-natural = amber (translucent)	7
Units and abbreviations	o. B. = without breakage 1 MPa = 1 N/mm^2 1 g/cm^3 = 1,000 kg/m^3 1 kV/mm = 1 MV/m	none

Physical Material Guiding Values

As of 2016

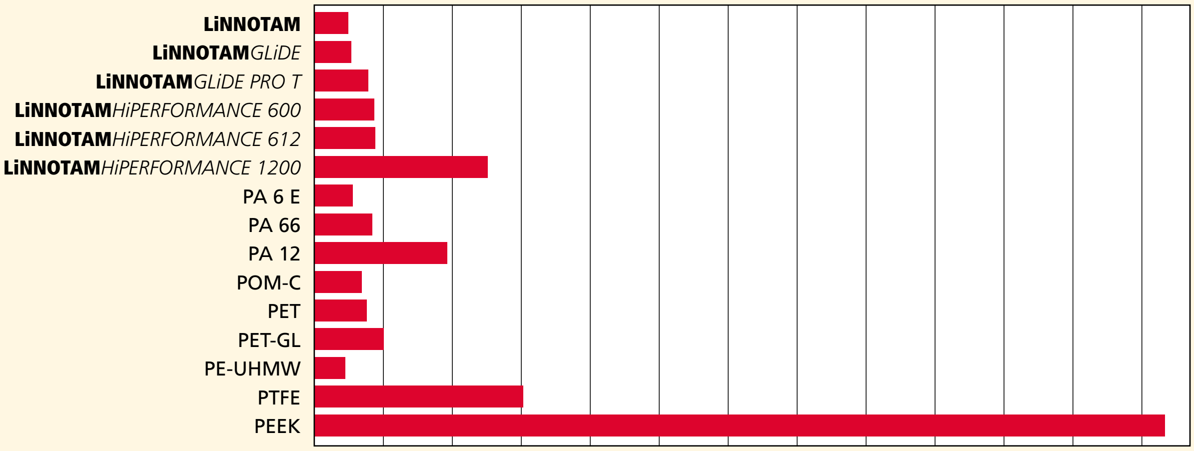
					Mechanical values													
No.	**Product**	**Material**	**Colours (standard)**	**Test specimen condition**	**Density DIN EN ISO 1183**	**Yield stress DIN EN ISO 527**	**Elongation at break DIN EN ISO 527**	**E-Module (tensile) DIN EN ISO 527**	**E-Module (bending) DIN EN ISO 178**	**Flexural strength DIN EN ISO 178**	**Impact strength DIN EN ISO 179**	**Notched-bar impact strength DIN EN ISO 179**	**Ball indentation hardness $H_{358/30}$ DIN EN ISO 2039-1**	**Creep rate stress at 1% elongation DIN EN ISO 899-1**	**Sliding friction coefficient against steel (dry running) [3]**	**Sliding wear against steel (dry running) [3]**	**Melting temperature DIN EN ISO 3146**	**Thermal conductivity DIN 52 612**
					1 ρ g/cm^3	2 σ_{zS} MPa	3 ε_{zR} %	4 E_t MPa	5 E_{B3} MPa	6 σ_{bB} MPa	7 a_{cU} kJ/m^2	8 a_{cN} kJ/m^2	9 H_K MPa	10 $\sigma_{1/1000}$ MPa	11 μ –	12 V µm/km	13 T_m °C	14 λ W/(K·m)
1	**LINNOTAM**	PA 6 C	natural/black/blue	dry/humid	1.15	80/60	40/100	3,100/1,800	3,400/2,000	140/60	o. B.	>4/>15	160/125	>7	0.36/0.42	0.10	+ 220	0.23
2	**LINNOTAM** MoS	PA 6 C + MoS$_2$	black	dry/humid	1.15	85/60	40/100	3,200/1,850	3,300/2,000	130/50	o. B.	>5/>15	150/115	>7	0.32/0.37	0.10	+ 220	0.23
3	**LINNOTAM** HS	PA 6 C-WS	black	dry/humid	1.15	90/60	30/80	2,500/2,000	3,000/2,300	120/40	o. B.	>4/>12	170/130	>7	0.36/0.42	0.10	+ 220	0.23
4	**LINNOTAM***GLiDE*	PA 6 C + Oil	natural/black/yellow green/red	dry/humid	1.14	80/55	50/120	2,800/1,700	3,000/1,900	135/55	o. B.	>5/>15	150/100	>7	0.15/0.20	0.03	+ 220	0.23
5	**LINNOTAM***GLiDE PRO T*	PA 6 C + solid lubricant	grey/red/green	dry/humid	1.14	80/60	40/100	3,100/1,800	3,300/2,000	110/60	o. B.	>4/>15	160/125	>7	0.15/0.23	0.03	+ 220	0.23
6	**LINNOTAM***DRiVE 600 FE*	PA 6 C + impact modified	–	dry/humid	1.15	90	20	2,800	2,500	160/130	o. B.	>15	175	>7	0.36/0.42	–	+ 225	0.23
7	**LINNOTAM** *HiPERFORMANCE 612*	PA 6/12 G	natural	dry/humid	1.12	80/55	55/120	2,500/1,500	2,800/1,800	135/55	o. B.	>12	140/100	>15	0.36/0.42	0.12	+ 220	0.23
8	**LINNOTAM** *HiPERFORMANCE 1200*	PA 12 G	natural	dry	1.03	60/50	55/120	2,200/1,800	2,400	90	o. B.	>15	100	>11	0.4	–	+ 190	0.23
9	**LINNOTAM** CC	PA 6 C-CC	natural/black	dry	1.15	71	>40	2,800	2,700	97	o. B.	–	125	–	0.36/0.42	–	+ 220	0.23
10	Polyamide 6	PA 6	natural/black	dry/humid	1.14	70/45	50/180	2,700/1,800	2,500/1,400	130/40	o. B.	>3/o.B.	160/70	>8	0.38/0.42	0.23	+ 218	0.23
11	Polyamide 66	PA 66	natural/black	dry/humid	1.14	85/65	30/150	3,000/1,900	2,900/1,200	135/60	o. B.	>3/>15	170/100	>8	0.35/0.42	0.1	+ 265	0.23
12	Polyamide 66 + Glass fibre	PA 66 GF 30	black	dry	1.35	160	3	11,000	–	–	50	6	240/200	40	0.45/0.5	–	+ 255	0.3
13	Polyamide 12	PA 12	natural	dry	1.02	50	>200	1,800	1,500	60	o. B.	>15	100	>4	0.32	0.8	+ 178	0.30
14	Polyacetal Copolymer	POM-C	natural[7]/black	dry	1.41	65	40	3,000	2,900	115	o. B.	>10	150	13	0.32	8.9	+ 168	0.31
15	Polyacetal Copolymer Glass fibre	POM-C GF 30	black	dry	1.59	125	3	9,300	9,000	150	30	5	210	40	0.50	–	+ 168	0.40
16	Polyethylenterephtalat	PET	natural[7]/black	dry	1.38	80	40	3,000	2,600	125	82	14	140	13	0.25	0.35	+ 255	0.24
17	Polyethylenterephtalat + solid lubricant	PET-GL	lightgrey	dry	1.38	75	5	2,230	–	–	23	10	–	–	0.2	0.1	+ 245	0.23
18	Polytetrafluorethylen	PTFE	natural	dry	2.18	25	380	750	540	6	o. B.	16	30	1.5	0.08	21.0	+ 327	0.23
19	Polyvinyldifluorid	PVDF	natural[7]	dry	1.78	56	22	2,000	2,000	75	o. B.	>15	120	3	0.3	–	+ 178	0.19
20	Polyethylene 1,000	PE-UHMW	natural[7]/black/green	dry	0.94	22	350	800	800	27	o. B.	o.B.	40	–	0.29	0.45	+ 133	0.38
21	Polypropylene Homopolymer	PP-H	natural[7]/grey[7]	dry	0.91	32	70	1,400	1,400	45	o. B.	7	70	4	0.35	11.0	+ 162	0.22
22	Polyvinylchloride	PVC-U	grey[7]/black/red/ white	dry	1.42	58	15	3,000	–	82	o. B.	4	130	–	0.6	56.0	–	0.156
23	Polyetherketone	PEEK	natural[7]/black	dry	1.32	95	45	3,600	4,100	160	o. B.	7	230	–	0.34	–	+ 340	0.25
24	Polyetherketone (modified)	PEEK-GL	black	dry	1.48	118	2	8,100	10,000	210	25	2.5	215	–	0.11	–	+ 340	0.24
25	Polysulfone	PSU	natural[7]	dry	1.24	75	>50	2,500	2,700	106	o. B.	4	150	22	0.4	–	–	0.26
26	Polyether amide	PEI	natural[7]	dry	1.27	105	>50	3,100	3,300	145	o. B.	–	165	–	–	–	–	0.22

All of these values were calculated as the average of many measurements and refer to a temperature of 23 °C and 50% RF.

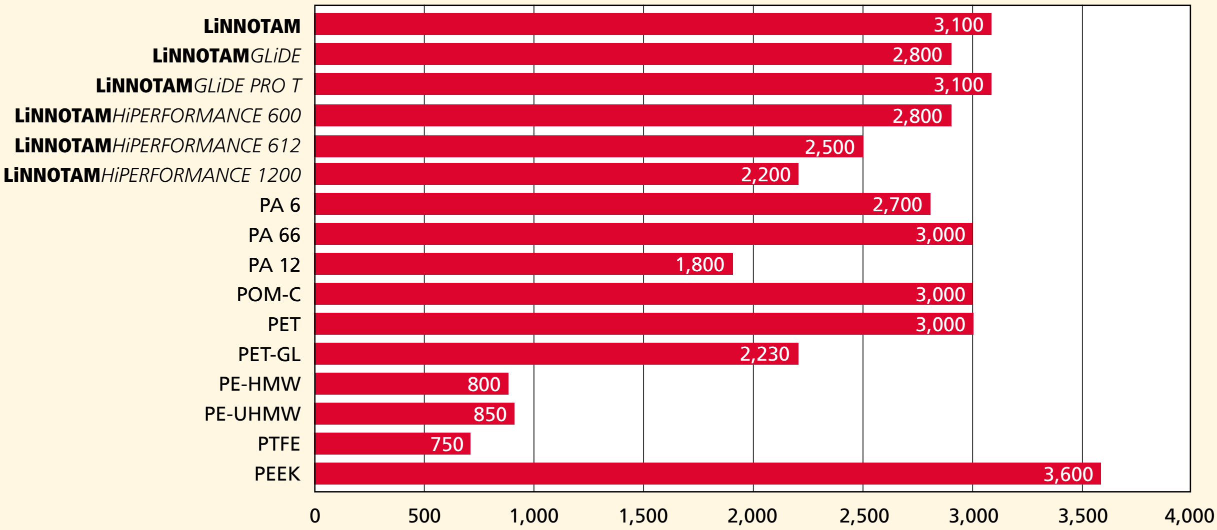
Thermal values					Electrical values						Miscellaneous data			
Specific thermal capacity 15 c J/(g·K)	**Coefficient of linear expansion** 4) 16 α $10^{-5}\cdot K^{-1}$	**Operating temperature range, (long-term)** 5) 17 – °C	**Operating temperature range, (short-term)** 5) 18 – °C	**Fire behaviour after UL 94 IEC 60695** 19 – –	**Dielectric constant** 6) **IEC 60250** 20 ε_R –	**Dielectric loss facto** 6) 21 tan δ –	**Specific volume resistance IEC 60093** 22 ρ_D Ω·cm	**Surface resistance IEC 60093** 23 R_o Ω	**Dielectric strength IEC 60243** 24 E_d kV/mm	**Creep resistance IEC 60112** 25 – –	**Moisture absorption in NK DIN EN ISO 62** 26 $w(H_2O)$ %	**Water absorption until saturated DIN EN ISO 62** 27 W_s %	**Specific properties** 28 –	**No.**
1.7	7-8	-40 to +105	+ 170	HB	3.7	0.03	$10^{15}/10^{12}$	$10^{13}/10^{12}$	50/20	CTI 600	2.2	6.5	hard, pressure and abrasion resistant can be produced in largest dimensions	1
1.7	7-8	-40 to +105	+ 160	HB	3.7	0.03	$10^{15}/10^{12}$	$10^{13}/10^{12}$	50/20	CTI 600	2.2	6.5	as PA 6 C , except increased cristallinity	2
1.7	7-8	-40 to +105	+ 180	HB	3.7	0.03	$10^{15}/10^{12}$	$10^{13}/10^{12}$	50/20	CTI 600	2.2	7	as PA 6 C , except heat ageing resistant	3
1.7	7-8	-40 to +105	+ 160	HB	3.7	0.03	$10^{15}/10^{12}$	$10^{13}/10^{12}$	50/20	CTI 600	1.8	5.5	high abrasion resistance, low sliding friction	4
1.7	7-8	-40 to +105	+ 160	HB	3.7	0.03	$10^{15}/10^{12}$	$10^{13}/10^{12}$	50/20	CTI 600	2.2	6.5	low stick-slip, very slow sliding friction	5
1.7	7-8	-40 to +105	+ 160	HB	3.7	0.03	$10^{15}/10^{12}$	$10^{13}/10^{12}$	50/20	CTI 600	1.9	5.8	high impact and shock resistance, with steel core	6
1.7	7-8	-40 to +105	+ 160	HB	3.7	0.03	10^{15}	10^{13}	50/20	KA 3c	1.9	5.8	as PA 6 C , except set for high impact strength	7
1.7	10-11	-60 to +110	+ 150	HB	3.7	0.03	10^{15}	10^{13}	50/20	CTI 600	0.9	1.4	low water absorption, very good long-term rupture strength	8
1.7	8-9	-40 to +90	+ 150	HB	3.7	0.03	$10^{15}/10^{12}$	$10^{13}/10^{12}$	50/20	KA 3C/KA 3b	2.5	7.5	higher impact strength than PA 6 C	9
1.7	8-9	-30 to +100	+ 140	HB	7	0.3	$10^{15}/10^{12}$	$10^{13}/10^{10}$	50/20	CTI 600	3.0	10.0	tough, good vibration damping	10
1.7	9-10	-30 to +100	+ 150	HB	5.0	0.2	$10^{15}/10^{12}$	$10^{12}/10^{10}$	50/20	CTI 600	2.5	9.0	high abrasion resistance (similar to PA 6 C)	11
1.5	2-3	-30 to +120	+ 180	HB	3.7	0.02	$10^{14}/10^{13}$	$10^{13}/10^{12}$	60/30	CTI 475	1.5	5.5	high strength, low thermal expansion	12
2.09	11-12	-70 to +70	+ 140	HB	3.1	0.03	2×10^{15}	10^{13}	30	CTI 600	0.8	1.5	tough, hydrolysis resistance, negligible moisture absorption	13
1.45	9-10	-30 to +100	+ 140	HB	3.9	0.003	10^{15}	10^{13}	20	CTI 600	0.2	0.8	very high strength, impact resistance, low tendency to creep	14
1.21	3-4	-30 to +110	+ 140	HB	4.8	0.005	10^{15}	10^{13}	65	KA 3C/ KC >600	0.17	0.6	high strength, low thermal expansion	15
1.1	7-8	-20 to +100	+ 160	HB	3.6	0.008	10^{16}	10^{14}	50	CTI 600	0.25	0.5	tough, hard, negligible cold flow, dimensionally stable	16
–	6-7	-20 to +110	+ 160	HB	3.6	0.008	10^{16}	10^{14}	–	CTI 600	0.2	0.5	as PET, plus highest wear resistance	17
1	18-20	-200 to +260	+ 280	V-0	2.1	0.0005	10^{18}	10^{17}	40	CTI 600	0.01	< 0.01	high chemical resistance, low strength	18
0.96	13	-40 to +140	+ 160	V-0	8.0	0.165	5×10^{14}	10^{13}	25	CTI 600	< 0.04	< 0.04	resistant to UV-, b- and λ-Radiation, resistant to abrasion	19
1.84	18	-260 to +50	+ 80	HB	3.0	0.0004	$>10^{16}$	10^{14}	44	CTI 600	0.01	< 0.01	as PE-HMW, but more abrasion resistant at low friction values	20
1.7	16	0 to +80	+ 100	HB	2.25	0.00033	$>10^{16}$	10^{14}	52	CM 600	< 0.01	< 0.01	as PE-HD, but higher thermal strength	21
1.05	8	0 to +50	+ 70	V-0	3.3	0.025	10^{16}	10^{13}	39	KA 3b	< 0.01	< 0.01	good chemical resistance, hard and brittle	22
1.06	4-5	-40 to +250	+ 310	V-0	3.2	0.002	10^{16}	10^{16}	24	CTI 150	0.2	0.45	high temperature resistance, hydrolisis dimensionally stable	23
–	3	-40 to +250	+ 310	V-0	3.2	–	10^{5}	–	24.5	–	0.14	0.3	as PEEK, except higher pv-values, better sliding properties	24
1	5-6	-40 to +160	+ 180	V-0	3.0	0.002	10^{17}	10^{17}	30	CTI 150	0.4	0.8	can be sterilised in steam, hydrolisis resistant, radiation resistant	25
–	5-6	-40 to +170	+ 200	V-0	3.0	0.003	10^{18}	10^{17}	33	CTI 175	0.75	1.35	high strength and rigidity, high thermal resistance	26

Physical Material Guiding Values

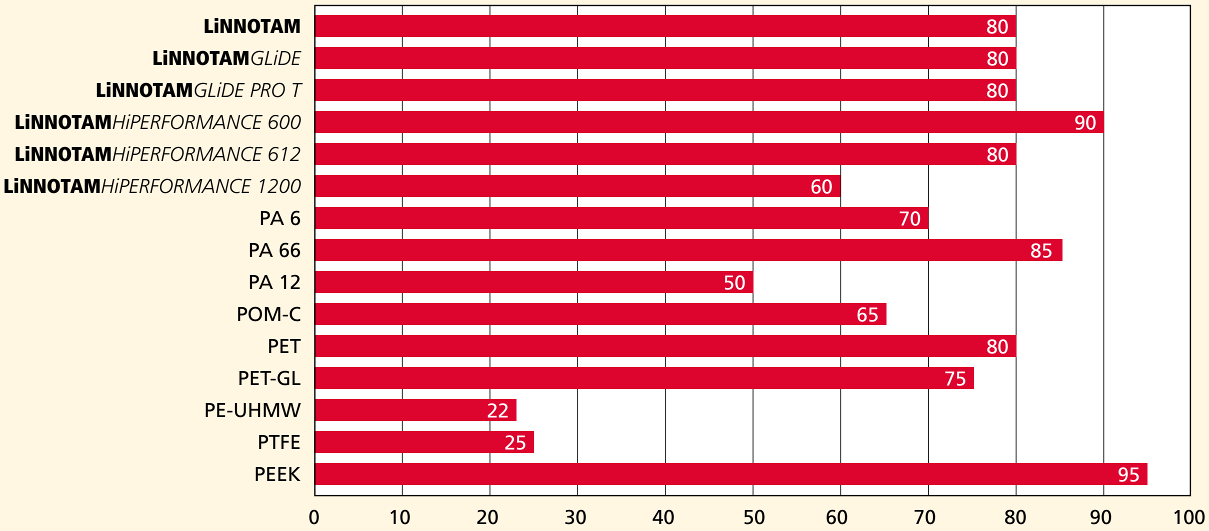
Comparison of material costs (volume prices)



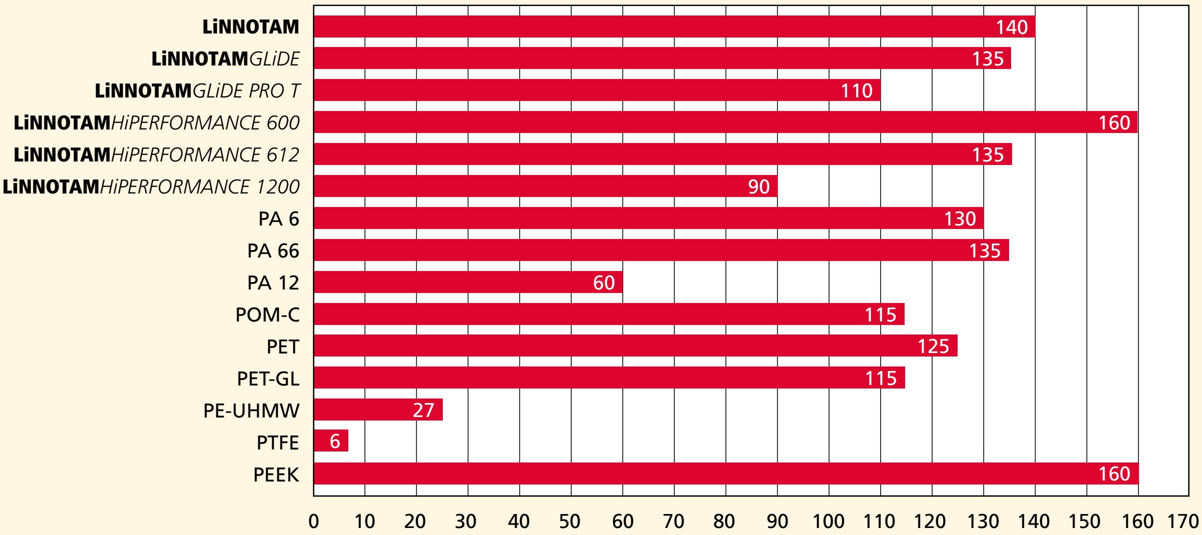
E-modulus from tensile test in MPa (short term value)



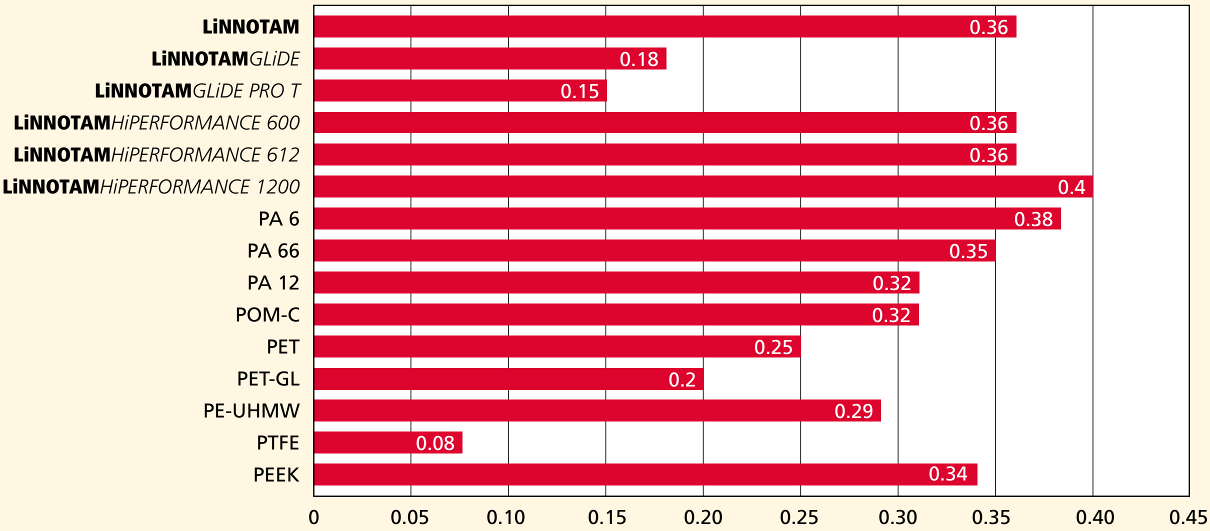
Permissible yield stress in MPa (short term value)



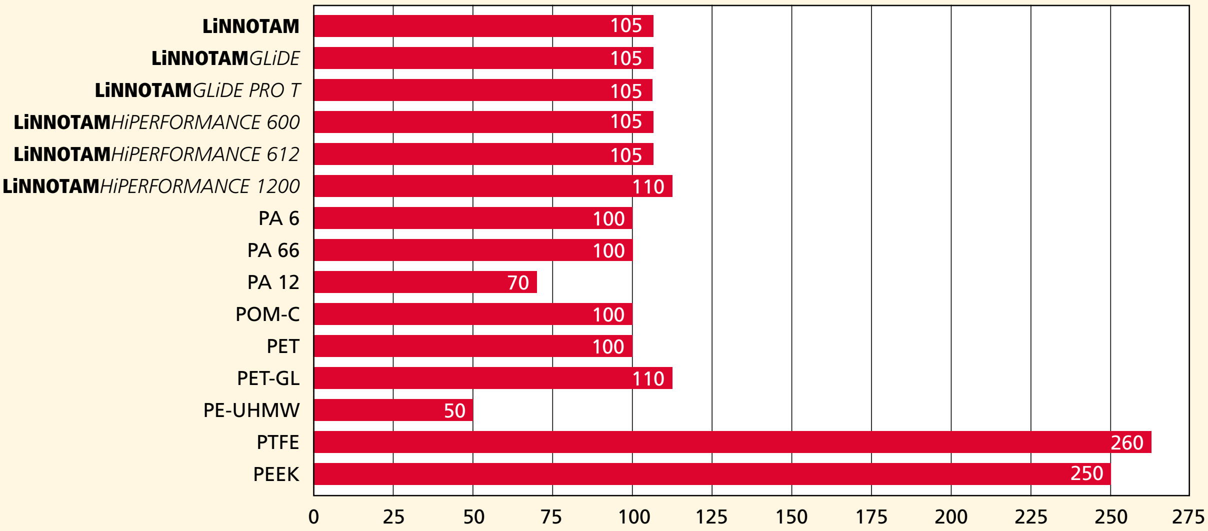
Flexural strength in MPa (short term value)



Coefficient of sliding friction against steel
(hardened and ground, P = 0.05 MPa, v = 0.6 m/s, t = 60 °C in the vicinity of the running surface)

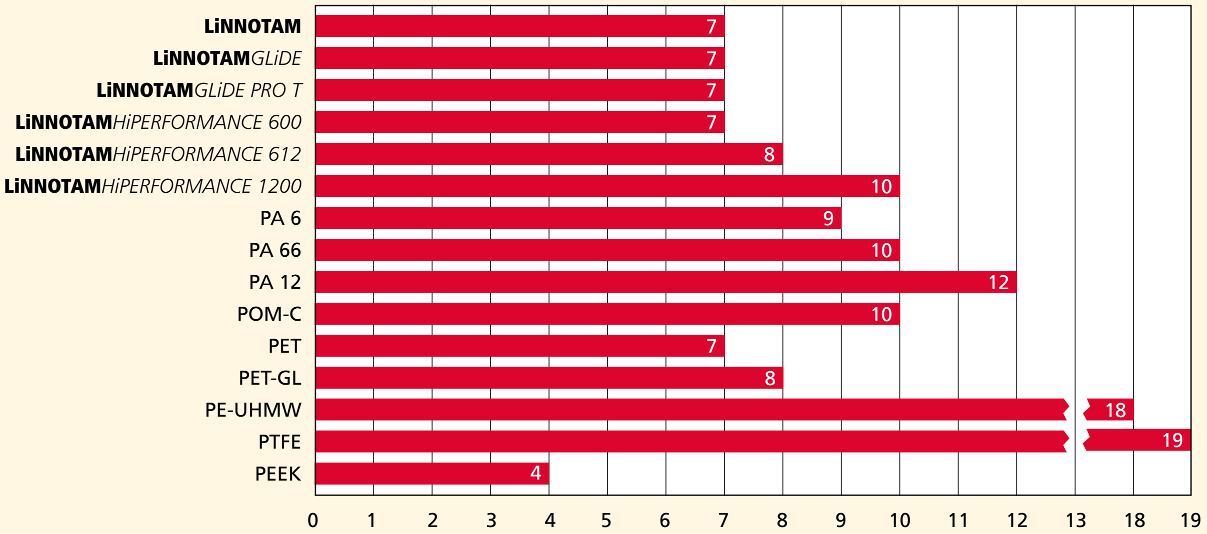


Long term service temperature in °C (in air without static load)

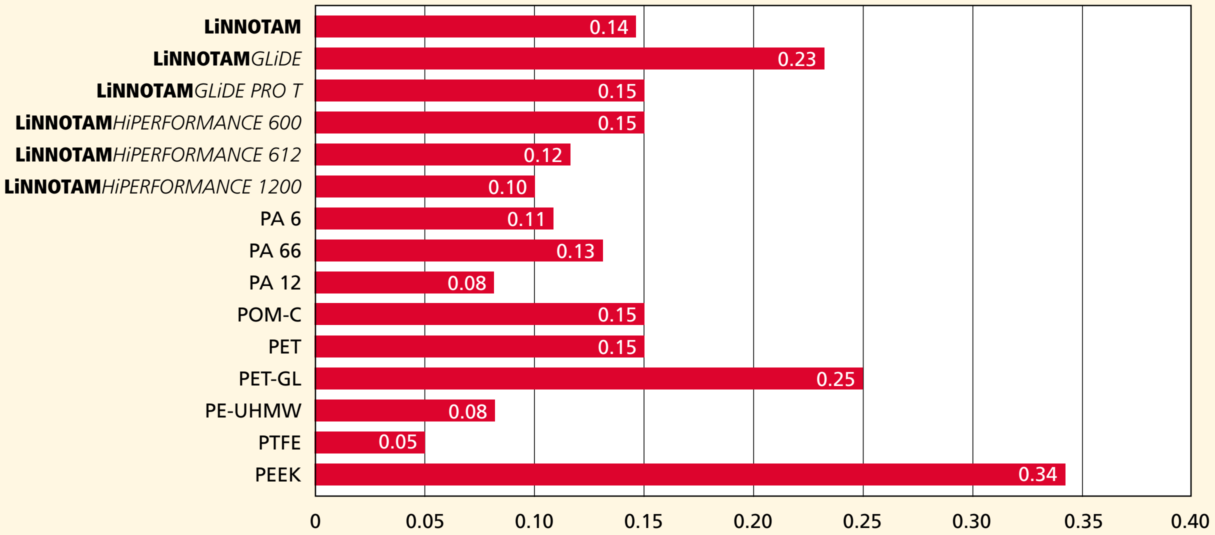


Physical material guiding values

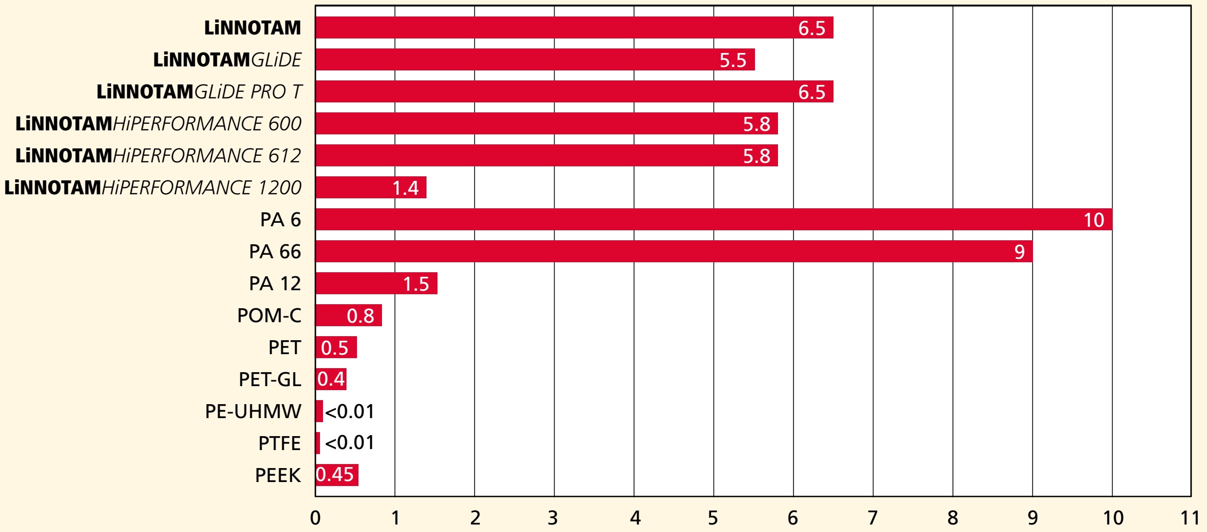
Coefficient of linear expansion ($10^{-5} \cdot K^{-1}$)



pv guiding values in MPa · m/s (dry running with integrated lubrication v = 0.1 m/s)



Water absorption until saturated in %



Information on how to use the list

"Chemical resistance"

The information regarding chemical resistance in the following list relates to experiments in which the samples were subjected to the respective media free of external stress and loading. This is supplemented by our practical experience and, in most cases, many years of using plastics in contact with these media. Due to the variety of media, this list is just an excerpt of the data that is available to us. If the list does not contain the medium that you use, we would be happy to provide information on the resistance of our plastics on request.

When using the list, please remember that factors such as:

- deviating degrees of purity of the medium
- deviating concentration of the medium
- temperatures different to those stated
- fluctuating temperatures
- mechanical load
- part geometries, especially those that lead to thin walls or extreme differences in wall thickness
- stresses that are created by machining
- mixtures that are made up of different media
- combinations of the above factors

can have an effect on the chemical resistance.

Nevertheless, in spite of being rated as a component with »limited resistance«, a plastic component can still be superior to a metal part and can also be more practical from an economic aspect.

In the case of oxidising materials such as nitric acid and polar organic solvents, despite a chemical resistance against the medium, in many thermoplastics there is still a danger of stress cracking. Therefore for the manufacture of parts that come into contact with such media, a process should be chosen that creates as little mechanical stress as possible in the workpiece. An alternative is to decrease the stress by annealing the semi-finished products before and during the manufacturing process.

Generally it is not possible to forecast the level of resistance against mixtures of different media, even if the plastic is resistant to the individual components of the mixture.
Therefore in such a case we recommend that the material is stored and aged with the respective mixed medium under the expected environmental conditions. It is also important to remember that where parts are to be subjected to two or more media there could be an additional temperature load in the area of immediate contact due to the evolving reaction heat.

In spite of the rating »resistant«, in certain cases the surfaces of plastics can become matte or discoloured, and transparent plastics can become opaque when they come into contact with the media. However, the resistance remains intact even after these surface changes.

The information contained in the lists corresponds to our present standard of knowledge and should be regarded as standard values. If in doubt, or in the case of specific applications, we recommend that the material be aged under the expected environmental conditions to test its resistance.

Chemical resistance

		Concentration	Temperature °C	1 **LiNNOTAM**	2 **LiNNOTAM** HS	3 **LiNNOTAM** MoS	4 **LiNNOTAM***GLiDE*	5 **LiNNOTAM***GLiDE PRO T*	6 **LiNNOTAM***HiPERFORMANCE 600*	7 **LiNNOTAM***HiPERFORMANCE 612*	8 **LiNNOTAM***HiPERFORMANCE 1200*	9 **PA 6** – Polyamide 6	10 **PA 66** – Polyamide 66	11 **PA 12** – Polyamide 12	12 **POM-C** – Polyacetal – Copolymer	13 **PET** – Polyethyleneterephtalat	14 **PET-GL** – Polyethylenterephtalat/solid lubricant	15 **PTFE** – Polytetrafluoroethylen	16 **PVDF** – Polyvinyl difluorid	17 **PE-UHMW** – Polyethylene 1,000	18 **PP-H** – Polypropylene	19 **PVC-U** – Polyvinylchloride (hard)	20 **PEEK** – Polyetherketone	21 **PEEK-GL** – Polyetherketone modified	22 **PSU** – Polysulfone	23 **PEI** – Polyether amide
1	Acetal aldehyde	40	20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	+	+	–	+	+	–	+
2	Acetamide	50	20	+	+	+	+	+	+	+	+	+	+	+	+	/	/	+	–	+	+	/	+	+	/	+
3	Acetone	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	○	○	+	–	+	+	–	+	+	–	–
4	Acrylnitrile	UV	RT	+	+	+	+	+	+	+	+	+	+	+	/	/	/	+	+	+	+	/	+	+	–	/
5	Alkyl alkohol	UV	RT	○	○	○	○	○	○	○	○	○	○	○	/	+	+	+	/	+	+	–	+	+	○	/
6	Aluminium chloride	10	RT	+	+	+	+	+	+	+	+	+	+	+	○	+	+	+	+	+	+	+	+	+	+	+
7	Formic acid	2	RT	○	○	○	○	○	○	○	○	○	○	○	+	+	+	+	+	+	+	+	+	+	/	+
8	Formic acid	UV	RT	L	L	L	L	L	L	L	○	L	L	○	–	○	○	+	+	+	+	+	○	○	–	/
9	Ammonia	10	RT	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	○	○	–	–
10	Ammonium hydroxide	30	RT	+	+	+	+	+	+	+	+	+	+	+	–	–	–	+	–	+	+	/	+	+	+	–
11	Ammoniumnitrate	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–
12	Aniline	UV	RT	–	–	–	–	–	–	–	○	–	–	○	○	+	+	+	+	+	○	–	+	+	–	/
13	Antimontrichloride	10	RT	–	–	–	–	–	–	–	–	–	–	–	/	/	/	+	+	+	+	+	+	+	/	/
14	Benzaldehyde	UV	RT	○	○	○	○	○	○	○	○	○	○	○	+	+	+	+	○	+	+	–	+	+	–	–
15	Petrol, super	HÜ	40	+	+	+	+	+	+	+	+	+	+	+	+	/	/	+	+	○	○	–	+	+	○	–
16	Benzene	UV	RT	+	+	+	+	+	+	+	+	+	+	+	○	+	+	+	+	○	○	–	+	+	–	–
17	Benzene acid	UV	RT	–	–	–	–	–	–	–	+	–	–	+	○	+	+	+	+	+	+	+	+	+	/	/
18	Benzyl alcohol	UV	RT	○	○	○	○	○	○	○	○	○	○	○	+	+	+	+	+	+	+	/	+	+	○	–
19	Bleaching lye (12.5% AC)	HÜ	RT	–	–	–	–	–	–	–	○	–	–	○	–	+	+	+	+	+	+	+	+	+	–	+
20	Borax	WL	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	/	/	+	+	/	/
21	Boric acid	10	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
22	Hydrobromic acid	10	RT	–	–	–	–	–	–	–	–	–	–	–	–	○	–	+	+	+	+	+	+	+	+	/
23	Hydrobromic acid	50	RT	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	○	○	/	/
24	Butanol	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	○	+
25	Butyl acetate	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	/	/	+	+	–	○
26	Calcium chloride	5	RT	+	+	+	+	+	+	+	+	+	+	+	○	+	+	+	+	+	+	+	+	+	○	+

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27	Calcium chloride in alcohol	20	RT	–	–	–	–	–	–	–	–	L	L	–	–	+	+	+	+	+	+	/	+	+	○	+
28	Calcium hypochloride	GL	RT	–	–	–	–	–	–	–	–	–	–	–	–	○	○	+	+	+	+	+	+	+	/	/
29	Chlorbenzene	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	○	○	–	+	+	L	–
30	Chloroacetic acid	UV	RT	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	/	+	+	/	/
31	Chloroform	UV	RT	○	○	○	○	○	○	○	○	○	○	○	–	–	–	+	+	○	○	–	+	+	L	–
32	Chromic acid	1	RT	○	○	○	○	○	○	○	○	○	○	○	○	+	+	+	+	+	+	+	+	+	○	+
33	Chromic acid	50	RT	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	○	○	+	+	+	○	/
34	Cyclohexane	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	○	/
35	Cyclohexanol	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	○	–
36	Cyclohexanone	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	○	+	+	+	+	+	L	/
37	Dibutyl phtalate	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	○	○	/	/	+	+	+	○
38	Dichlorethane	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	○	○	–	+	+	L	–
39	Dichlorethylene	UV	RT	+	+	+	+	+	+	+	+	+	+	+	L	L	L	+	+	–	○	–	+	+	/	/
40	Iron(II)chlorid	GL	RT	–	–	–	–	–	–	–	–	–	–	–	○	/	/	+	+	+	+	+	+	+	–	+
41	Iron(III)chlorid	GL	RT	–	–	–	–	–	–	–	–	–	–	–	○	/	/	+	+	+	+	+	+	+	–	+
42	Vinegar	HÜ	RT	–	–	–	–	–	–	–	+	–	–	+	+	+	+	+	○	+	+	+	+	+	/	/
43	Acetic acid	5	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
44	Acetic acid	10	RT	○	○	○	○	○	○	○	+	○	○	+	○	+	+	+	+	+	+	+	+	+	+	+
45	Acetic acid	10	50	–	–	–	–	–	–	–	○	–	–	○	–	+	+	+	+	+	+	+	+	+	+	+
46	Acetic acid	95	RT	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	○	+	+	–	–
47	Acetic acid	95	50	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	○	○	○	–	+	+	–	–
48	Ethylether	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	○	○	–	+	+	○	+
49	Hydrofluoric acid	WL	RT	L	L	L	–	L	L	L	L	L	L	L	–	–	–	+	+	+	+	+	L	L	–	○
50	Formaldehyde	UV	RT	○	○	○	○	○	○	○	○	○	○	○	+	+	+	+	+	+	+	+	+	+	–	–
51	Glycerine	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	○	+
52	Fuel	HÜ	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	/	+	+	+	+	+	+	+

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Chemical resistance

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53 Heptanol	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	○	+	+	+	○	+
54 Hexane	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	○	+
55 Isopropanol	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	○	○	+	+	+	+	+	+	+	○	/
56 Potash lye	10	RT	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+	+	○	+
57 Potash lye	10	80	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+	○	–	+	–	+	+	○	–
58 Potash lye	50	RT	○	○	○	○	○	○	○	+	○	○	+	+	–	–	+	+	+	+	+	+	+	○	–
59 Ketone (aliphatic)	UV	RT	○	○	○	○	○	○	○	○	○	○	○	+	–	–	+	/	+	/	/	+	+	/	/
60 Methanol	50	RT	+	+	+	+	+	+	+	+	+	+	+	+	○	+	+	+	+	+	+	+	+	○	+
61 Methanol	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	○	+	+	+	+	+	+	+	+	○	+
62 Methylene chlorid	UV	RT	–	–	–	–	–	–	–	○	–	–	○	–	–	–	+	+	○	○	L	+	+	L	L
63 Mineral oil	HÜ	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
64 Sodium hypochloride	10	RT	–	–	–	–	–	–	–	–	–	–	–	–	○	○	+	+	+	○	+	+	+	+	/
65 Sodium lye	10	RT	+	+	+	+	+	+	+	+	+	+	+	+	○	○	+	○	+	+	+	+	+	+	○
66 Sodium lye	10	80	–	–	–	–	–	–	–	–	–	–	–	+	–	–	+	○	○	+	○	+	+	+	–
67 Sodium lye	50	RT	○	○	○	○	○	○	○	○	○	○	○	+	–	–	+	○	+	+	+	+	+	+	–
68 Sodium lye	50	80	–	–	–	–	–	–	–	–	–	–	–	+	–	–	+	○	○	+	○	+	+	+	–
69 Nitrobenzene	UV	RT	–	–	–	–	–	–	–	–	–	–	–	○	○	○	+	+	+	+	–	+	+	–	–
70 Nitrotoluene	UV	RT	○	○	○	○	○	○	○	○	○	○	○	○	+	+	+	/	+	+	–	+	+	/	/
71 Oxalic acid	10	RT	○	○	○	○	○	○	○	○	○	○	○	–	+	+	+	+	+	+	+	+	+	+	+
72 Phenol	90	RT	L	L	L	L	L	L	L	L	L	L	L	–	–	–	+	+	+	+	○	+	+	–	–
73 Phenol	UV	40	L	L	L	L	L	L	L	L	L	L	L	–	–	–	+	+	+	+	–	+	+	–	–
74 Phenol	UV	60	L	L	L	L	L	L	L	L	L	L	L	–	–	–	+	○	–	–	–	+	+	–	–
75 Phenol	UV	80	L	L	L	L	L	L	L	L	L	L	L	–	–	–	+	○	–	–	–	+	+	–	–
76 Phosphoric acid	10	RT	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+
77 Phosphoric acid	25	RT	–	–	–	–	–	–	–	–	–	–	–	○	+	+	+	+	+	+	+	+	+	+	+
78 Phosphoric acid	85	RT	L	L	L	L	L	L	L	L	L	L	L	–	+	+	+	+	+	+	+	+	+	○	–
79 Propanol	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
80 Nitric acid	10	RT	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+	+	+	+

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81	Nitric acid	10	60	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	+	+	/	/
82	Nitric acid	50	RT	L	L	L	L	L	L	L	L	L	L	L	–	–	–	+	+	–	–	–	○	○	+	/
83	Nitric acid	80	RT	L	L	L	L	L	L	L	L	L	L	L	–	–	–	+	○	–	–	–	○	○	+	/
84	Hydrochloric acid	10	RT	–	–	–	–	–	–	–	–	–	–	–	–	○	○	+	+	+	+	+	+	+	+	+
85	Hydrochloric acid	20	RT	–	–	–	–	–	–	–	–	–	–	–	–	○	○	+	+	+	+	+	+	+	+	+
86	Hydrochloric acid	30	RT	L	L	L	L	L	L	L	L	L	L	L	–	–	–	+	+	+	+	+	+	+	○	+
87	Sulphuric acid	40	RT	–	–	–	–	–	–	–	–	–	–	–	–	○	○	+	+	+	+	+	○	○	+	+
88	Sulphuric acid	40	60	–	–	–	–	–	–	–	–	–	–	–	–	○	○	+	+	+	+	○	–	–	○	○
89	Sulphuric acid	96	RT	L	L	L	L	L	L	L	L	L	L	L	–	–	–	+	+	○	○	+	L	L	L	–
90	Sulphuric acid	96	60	L	L	L	L	L	L	L	L	L	L	L	–	–	–	+	+	–	–	○	L	L	L	–
91	Carbon tetrachloride	UV	RT	+	+	+	+	+	+	+	+	+	+	+	○	+	+	+	+	–	–	–	+	+	+	+
92	Tolual	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	○	○	–	+	+	–	–
93	Trichlorethylene	UV	RT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	+	+	○	○	–	+	+	L	–
94	Hydrogen peroxide	10	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
95	Hydrogen peroxide	20	RT	–	–	–	–	–	–	–	○	–	–	○	+	+	+	+	+	+	+	+	+	+	+	+
96	Hydrogen peroxide	30	RT	–	–	–	–	–	–	–	–	–	–	–	○	+	+	+	+	+	+	+	+	+	+	+
97	Hydrogen peroxide	30	60	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	/	○	○	○	+	+	/	/
98	Xylene	UV	RT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	○	○	–	+	+	○	○
99	Citric acid	10	RT	○	○	○	○	○	○	○	+	○	○	+	+	+	+	+	+	+	+	+	+	+	○	+
100	Citric acid	10	50	○	○	○	○	○	○	○	○	○	○	○	–	+	+	+	+	+	+	+	+	+	○	+

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Our machining capabilities:

- CNC milling machines, workpiece capacity up to max. 3,000 x 1,000 mm
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- CNC automatic lathes up to 100 mm diameter spindle swing
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- Thickness planers up to 230 mm thickness and 1,300 mm width
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- Gear cutting machines for gears starting at module 0.5 to 1,500 mm
- Parts marking with print, laser, embossing or stamping
- Assembly work
- Annealing ovens for thermal treatment

We machine:

• Polyamide	PA
• Polyacetal	POM
• Polyethylene terephthalate	PET
• Polyethylene 1,000	PE-UHMW
• Polyethylene 500	PE-HMW
• Polyethylene 300	PE-HD
• Polypropylene	PP-H
• Polyvinyl chloride (hard)	PVC-U
• Polyvinylidene fluoride	PVDF
• Polytetrafluoroethylene	PTFE
• Polyetheretherketone	PEEK
• Polysulphon	PSU
• Polyether imide	PEI

Examples of parts:

- Rope sheaves and castors
- Guide rollers
- Deflection sheaves
- Friction bearings
- Slider pads
- Guide rails
- Gears
- Sprocket wheels
- Spindle nuts
- Curved feed tables
- Feed tables
- Feed screws
- Curved guides
- Metering disks
- Curved disks
- Threaded joints
- Seals
- Inspection glasses
- Valve seats
- Equipment casings
- Bobbins
- Vacuum rails/panels
- Stripper rails
- Punch supports

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