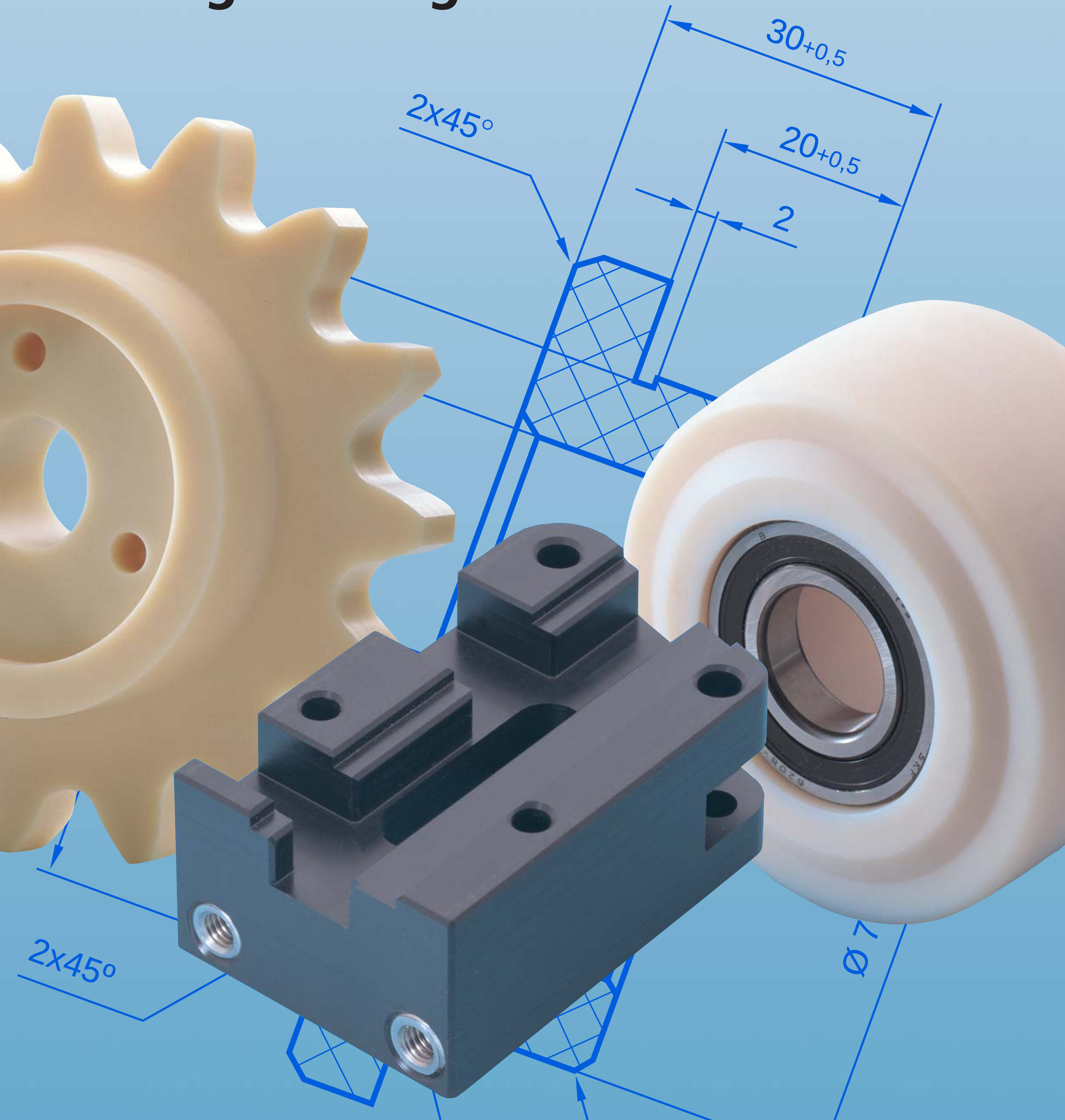
Licharz
engineering plastics

Designing with engineering Plastics



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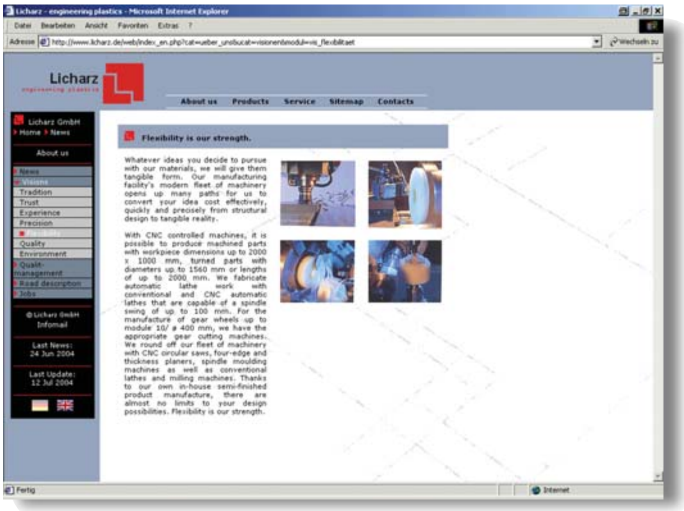

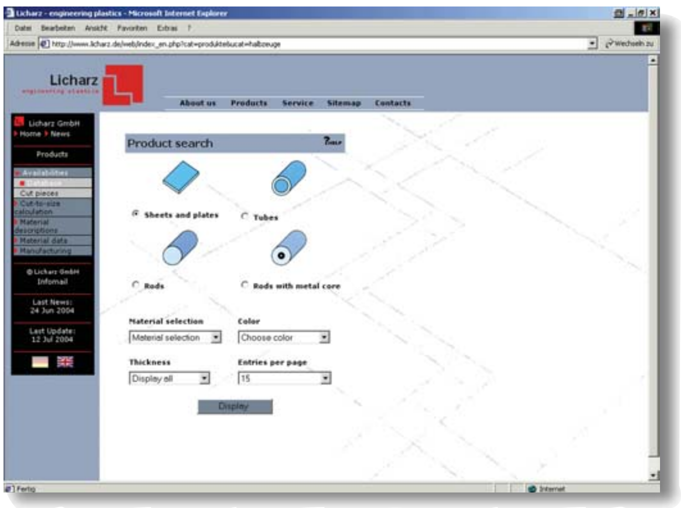

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Plastic castors

Plastic castors

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 1.1 Materials

PA 6 G, PA 6/12 G and PA 12 G 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 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 100mm, the castors are manufactured on automatic lathes from rods. Sizes above this are produced on CNC lathes from blanks.

Another alternative is the centrifugal moulding process. In this process, the outer contours of the castor are moulded to size and then only the bearing seat and axis holes are machined to the required finished size. This allows large quantities of larger dimensions to be manufactured economically.

With this process, running truths are achieved that allow speeds of up to 5 m/s.

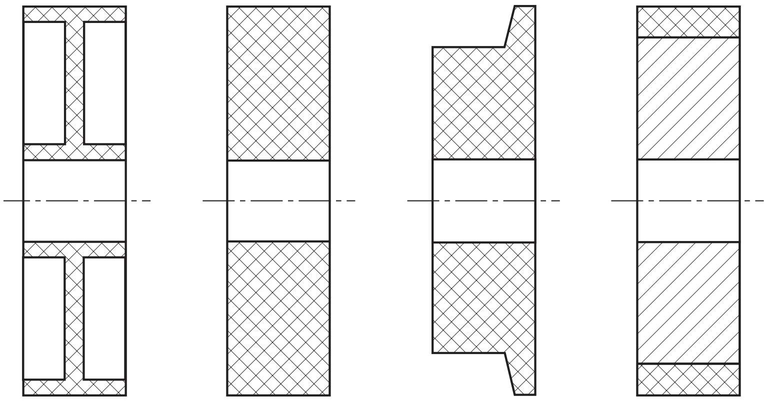
1.4 Castor design

In addition to the four basic castor body shapes, castors differ mainly in the type and design of their bearings. Like rope pulleys, 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 Calaumid-Fe 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.

Figure 1: Basic castor shapes



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 are the PA 12 G polyamides, as they have 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

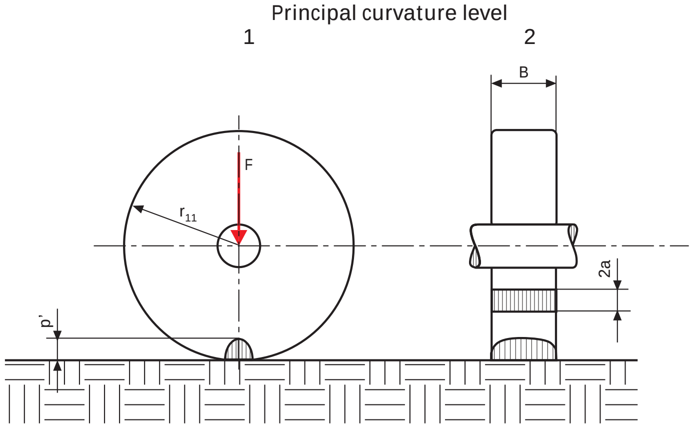
It would appear practical to apply the Hertzian relationships when calculating castors. But plastic wheels do not fulfil all the conditions for this approach. For example, there is no linear connection

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 rather 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 hemiellipsoidal 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
PA 6 G = 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

$$\frac{1}{E_e} = \frac{1}{2} \left[\frac{1 - \nu_1^2}{E_1} + \frac{1 - \nu_2^2}{E_2} \right]$$

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

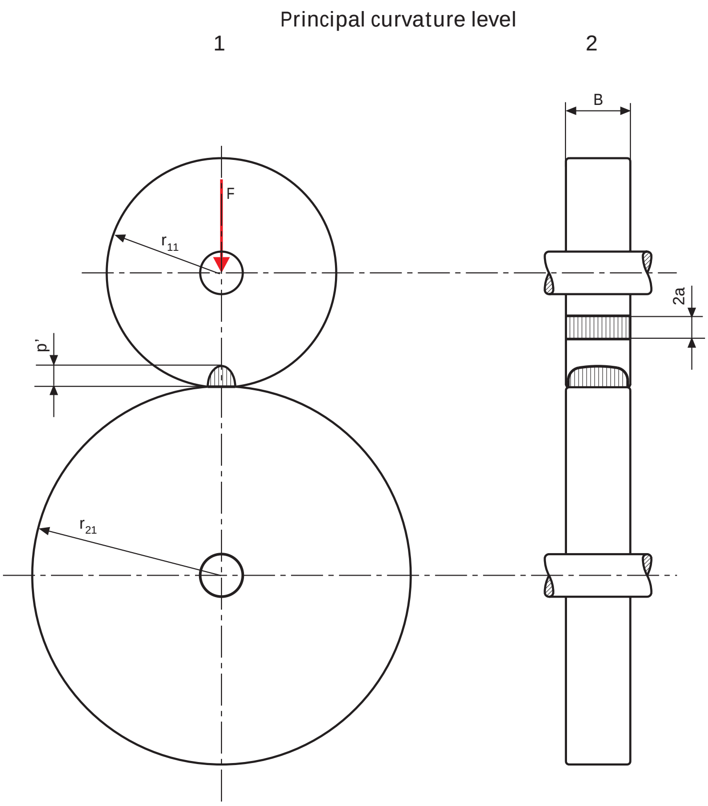
Table 1: Transversal contraction coefficients for various materials

	PA 6 PA 6 G 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 hemiellipsoidal 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

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

For castors running on a curved track the replacement radius is

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

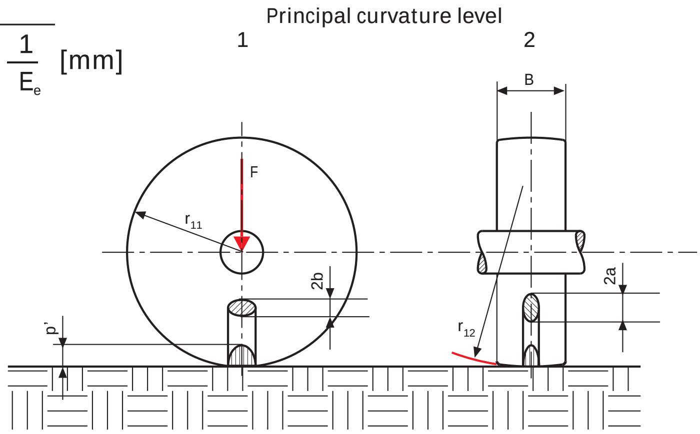
where
r_{11} = castor radius in mm from PCL 1
r_{21} = track radius in mm from PCL 1

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

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



and

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

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 τ must be determined mathmatically.

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

where
r_{11} = castor radius in mm from PCL 1
r_{12} = Rcastor radius in mm from PCL 2

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

Table 2: Hertz correction values in relation to cos τ

cos τ	**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:

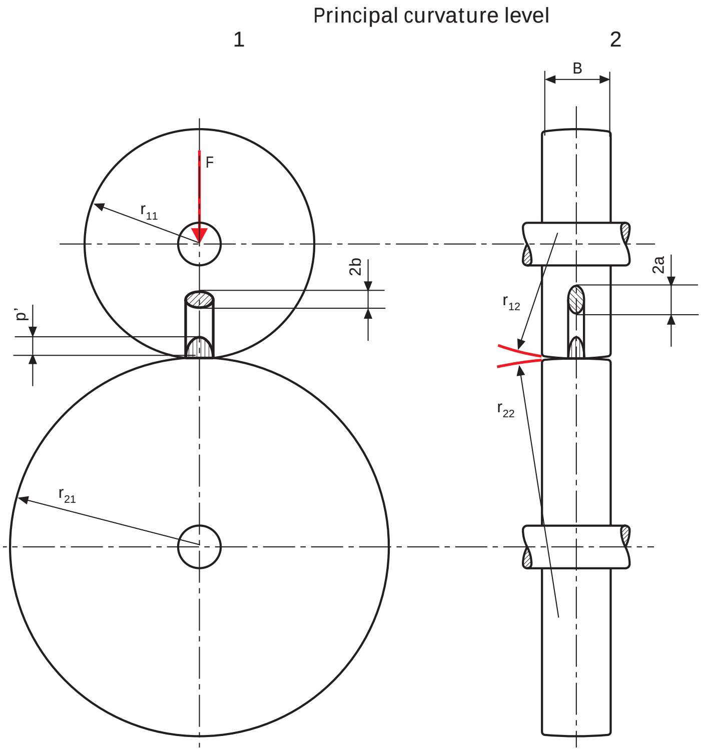
$$p' = \frac{3 \cdot F}{2 \cdot \pi \cdot a \cdot b} \qquad [\text{MPa}]$$

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 τ 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.

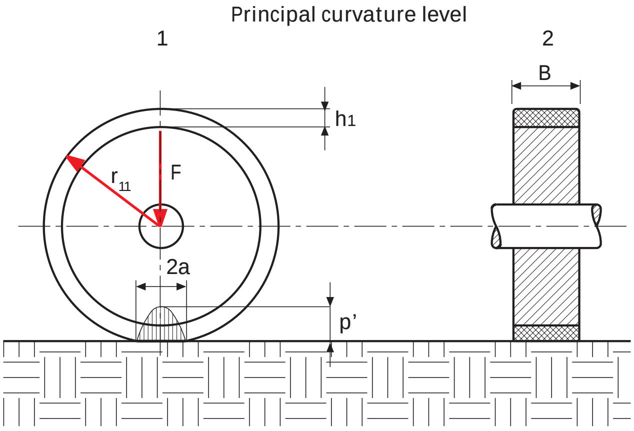
$$\cos \tau = \frac{\left(\frac{1}{r_{11}} - \frac{1}{r_{12}}\right) + \left(\frac{1}{r_{21}} - \frac{1}{r_{22}}\right)}{\left(\frac{1}{r_{11}} + \frac{1}{r_{12}}\right) + \left(\frac{1}{r_{21}} + \frac{1}{r_{22}}\right)}$$

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 $h/a \geq 5$ and $B/a \geq 10$ 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

$$a = \sqrt[3]{1{,}5 \cdot r_e \cdot \frac{F}{B} \cdot \frac{E_1' \cdot h_2 + E_2' \cdot h_1}{E_1' \cdot E_2'}} \quad [\mathrm{mm}]$$

For castor linings that run on a flat track $r_e = r_1$. 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

$$p' = \sqrt[3]{\frac{9}{32} \cdot \frac{1}{r_e} \cdot \left(\frac{F}{B}\right)^2 \cdot \frac{E_1' \cdot E_2'}{E_1' \cdot h_2 + E_2' \cdot h_1}} \quad [\mathrm{MPa}]$$

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.

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

where

E_1 = modulus of elasticity of the castor material in MPa

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

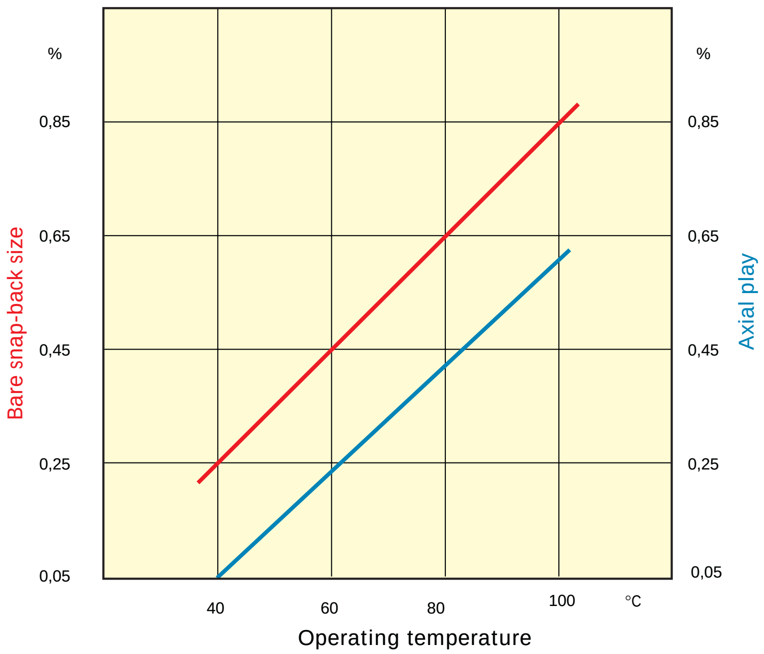
E_2 = modulus of elasticity of the track material in MPa

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

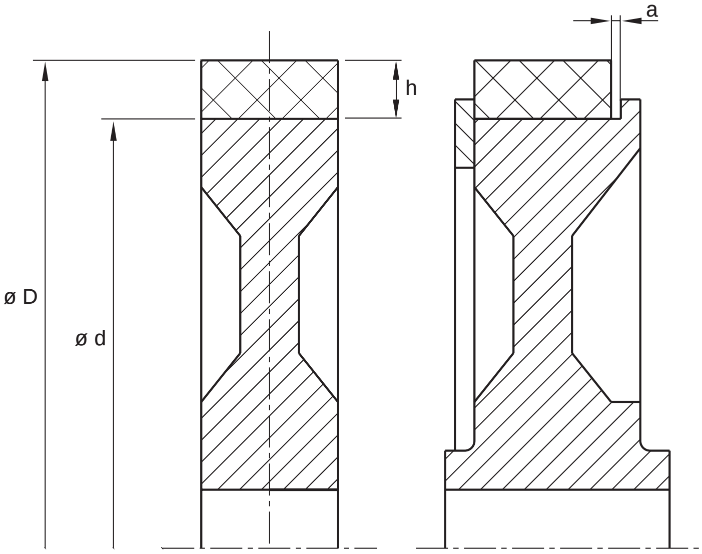
2.6.2 Design and assembly information

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 < 400mm, 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 ≥ 400mm.

Diagram 1: Bare snap-back size 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 ± 0.05mm are adequate. Grooves in the axial direction (e.g. knurls with grooves parallel to the axis and broken tips) are permissible. Approximately 1.0 to 1.5% 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 bare snap-back size for manufacturing the lining depends on the operating temperature and the diameter of the metal core. Diagram 1 shows the proportional bare size in relation to the diameter of the metal core for castors with a diameter of > 250mm. 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 PA 6 G

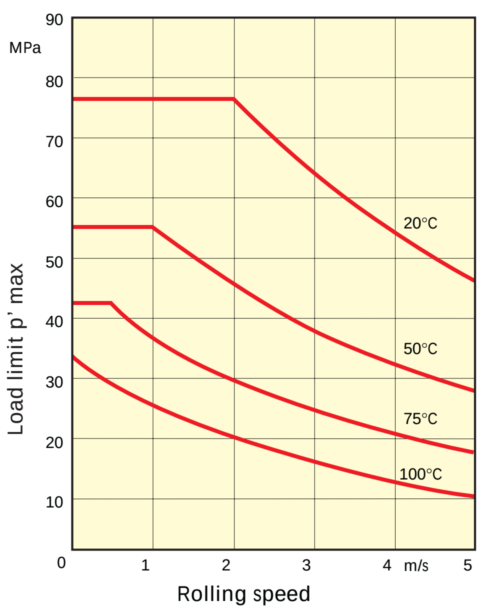


Diagram 3

Load limit for ball bearing solid castors made from POM

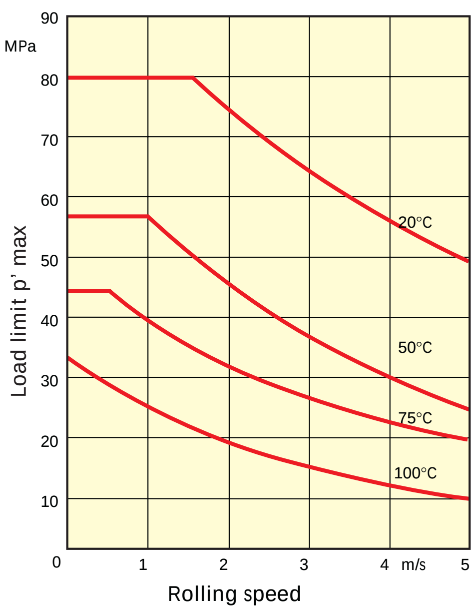


Diagram 4

Load limit for PA 6 G castors with static loading

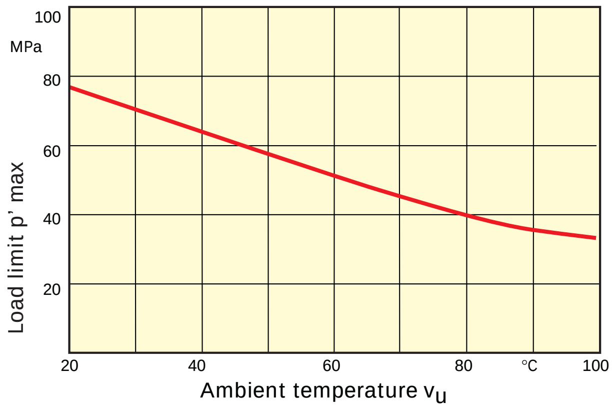
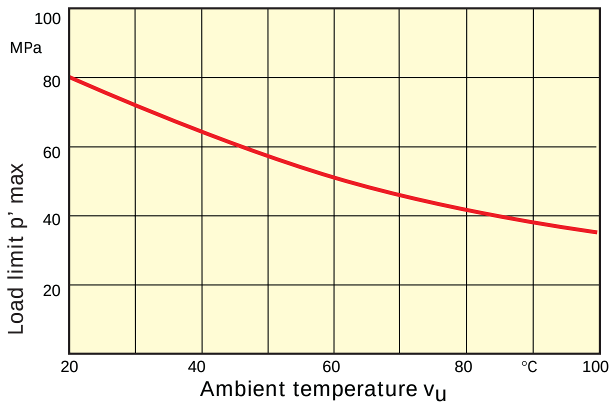


Diagram 5

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 visco-elastic 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

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

and the cylindrical castor/flat track

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

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

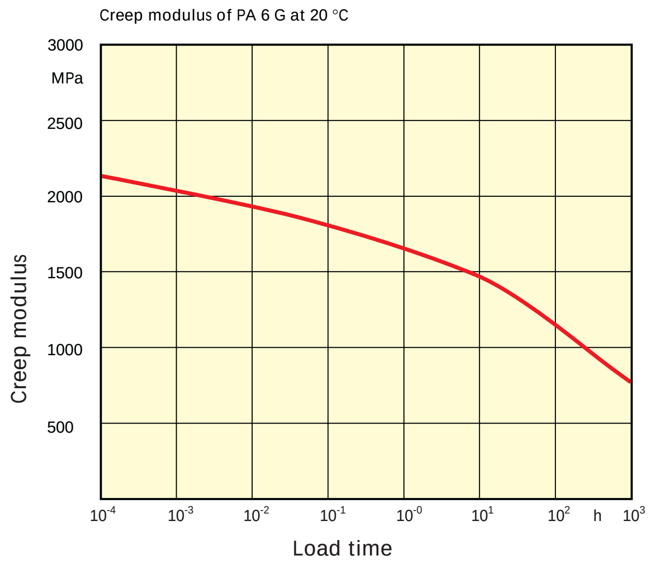
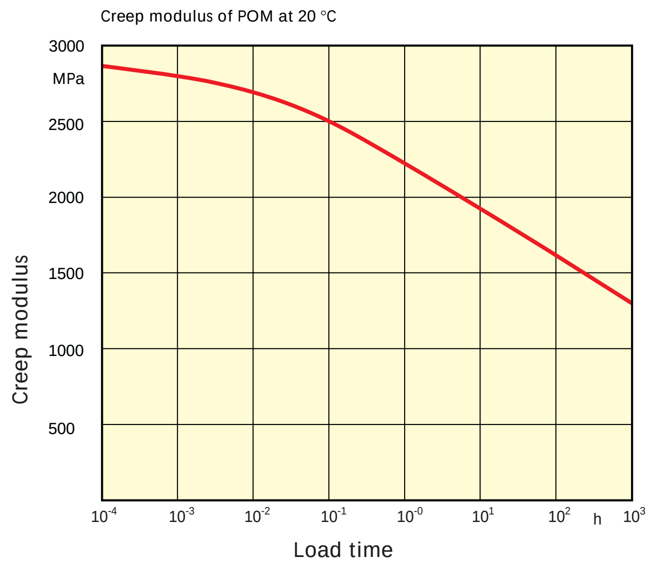


Diagram 7



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.

Plastic castors

Our machining capabilities:

- CNC milling machines, workpiece capacity up to max. 2000 x 1000mm
- 5-axis CNC milling machines
- CNC lathes, chucking capacity up to max. 1560 mm diameter and 2000 mm long
- Screw machine lathes up to 100mm diameter spindle swing
- CNC automatic lathes up to 100mm diameter spindle swing
- Gear cutting machines for gears starting at Module 0,5
- Profile milling (shaping and molding)
- Circular saws up to 170mm cutting thickness and 3100mm cutting length
- Four-sided planers up to 125mm thickness and 225mm width
- Thickness planers up to 230mm thickness and 1000mm width

We process:

- Polyamide PA
- Polyacetal POM
- Polyethylene terephthalate PET
- Polyethylene 1000 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
- Polysulphone PSU
- Polyether imide PEI

Examples of parts:

- Rope sheaves and castors
- Guide rollers
- Deflection sheaves
- Friction bearings
- Slider pads
- Guide rails
- Gear wheels
- 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

Information on how to use this documentation

All calculations, designs and technical details are only intended as information and advice and do not replace tests by the users in regard to the suitability of the materials for specific applications. No legally binding assurance of properties and/or results from the calculations can be deduced from this document. The material parameters stated here are not binding minimum values, rather they should be regarded as guiding values. If not otherwise stated, they were determined with standardised samples at room temperature and 50% relative humidity. The user is responsible for the decision as to which material is used for which application and for the parts manufactured from the material. Hence, we recommend that practical tests are carried out to determine the suitability before producing any parts in series.

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For further information, detailed catalogs are available:

- Information on Licharz machining capabilities of component parts
- Brochure „Material Guiding Values / chemical Resistance“
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