Wolf Kunststoff-Gleitlager GmbH

COMPOUND DEVELOPMENT
PLASTIC TESTING
DAMAGE ANALYSIS

EN 2.0

Compound development

It requires a number of laboratory experiments to develop a new material, to evolve existing materials more or to modify them. Because of our extensive laboratory equipment and decades of experience we are in the position to perform all relevant tests and to use the determined data as the base for further developments.
We can offer you a product range with a variety of different properties. And if you actually require a material property that our standard range can not perform fully, it is possible for us to influence already existing ZEDEX-plastics in their properties so that the desired property is achieved.

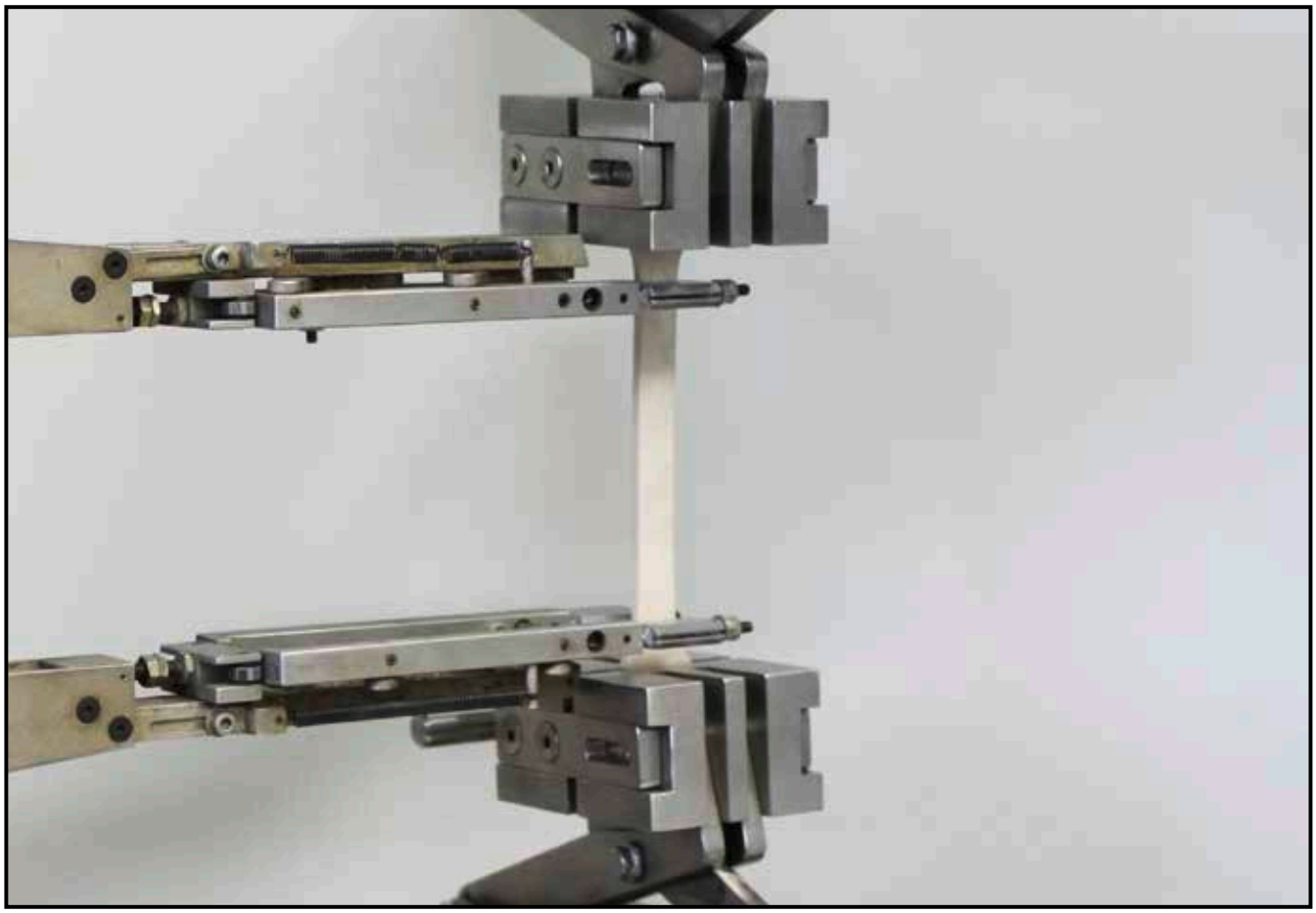
Following modifications are possible:

- Staining in a desired color
- Increasing the toughness or stiffness
- Increasing of the elasticity
- Increasing of the precision
- Increasing of the thermal and electrical conductivity
- Anti micro bacterial effect
- Improvement of the tribological properties

We can prove the successful result by using our laboratory equipment. On the following pages are all material tests described which we can perform in our laboratory.

Foreword

Table of contents



Mechanical tests 6-23

Determining of tensile properties

Standard: DIN EN ISO 527-1

Comparable standard: DIN 53455

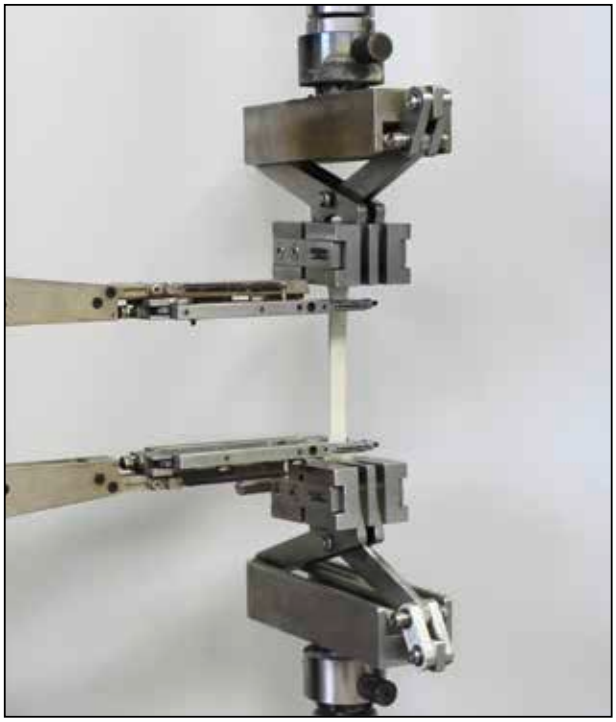
Target

The tensile test is a standardized test and is used to describe the strength and deformation of a material under short-term tension.

Procedure
The experiment is performed on a universal testing machine according to ISO 5893.

Test parameters
Stroke (to 1000 mm)
Strength (up to 10 kN)
Temperature (-100°C to 250°C)
E-Modulus determination 1 mm / min
Tensile strength determination 5 mm/min

Test specimen
Specimen according to DIN EN ISO 3167 type 1A.
5 test specimens are required per test.



Experimental setup

Tensile bars

Parameter specifying

σ_y *Yield strain [MPa]*

σ_m *Tensile strength [MPa]. It is calculated from the maximum tensile force, measured in the test, based on the cross sectional area of the specimen.*

σ_b *Tensile stress at break [MPa]*

σ_x *Stress at x% elongation [MPa]*

ε_y *Yield strain [%] elongation at reaching the yield point*

ε_m *Elongation at tensile strength [%]*

ε_b *Fracture strain [%]*

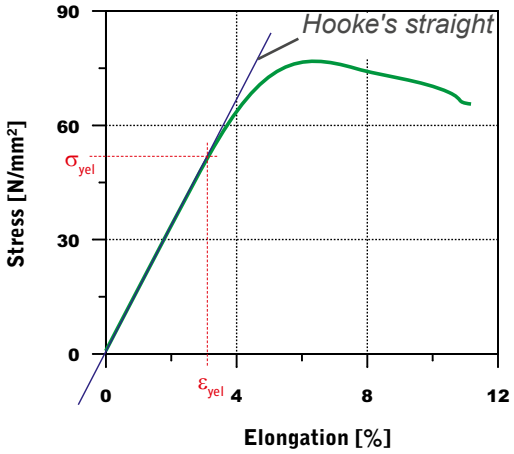
ε_x *Given elongation e.g. 3% -> e3%*

E *E-modulus (tensile modulus) [MPa], determined on the slope of the Hooke's straight at elongations between 0.05- 0.25%.*

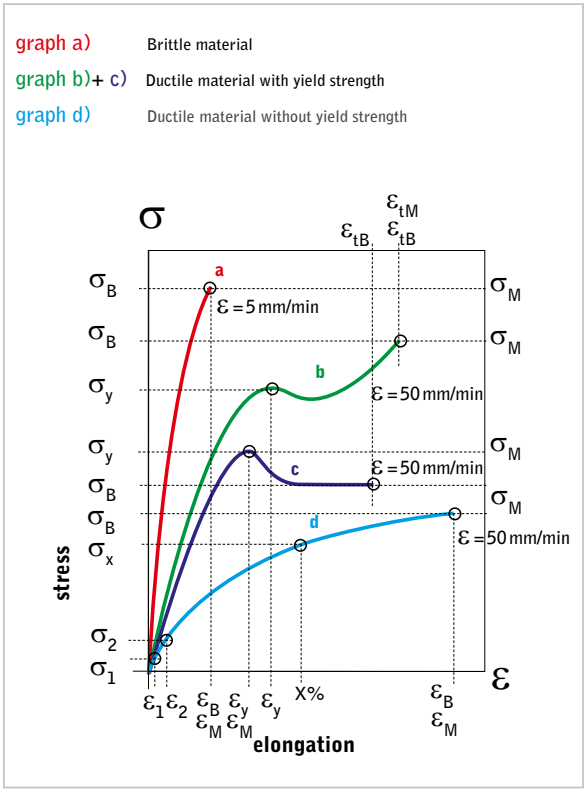
In addition, the Wolf Kunststoff-Gleitlager GmbH specifies following values:

σ_{yel} *Elastic limit [MPa] up to this voltage only purely elastic deformation takes place*

ε_{yel} *Elastic yield point [%] elongation which almost completly disappears , when the specimen gets relieved.*



Elastic limit



Stress-strain diagram

Evaluation

The result is shown in a stress-strain diagram. The following quantities are recorded.

F Test force [N]

ΔL Change in length of the specimen [mm]

The tensile stress is given by:

$$\sigma = \frac{F}{A} \text{ [MPa]}$$

With specimen cross-sectional area A.

The elongation e is calculated as follows:

$$\varepsilon = \frac{\Delta L - L_0}{L_0} \text{ [\%]}$$

With original length L0. With L0 is meant the length of narrow parallel portion of the test specimen.

Determining of presure properties

Standard: DIN EN ISO 604 **Comparable standard:** DIN 53454

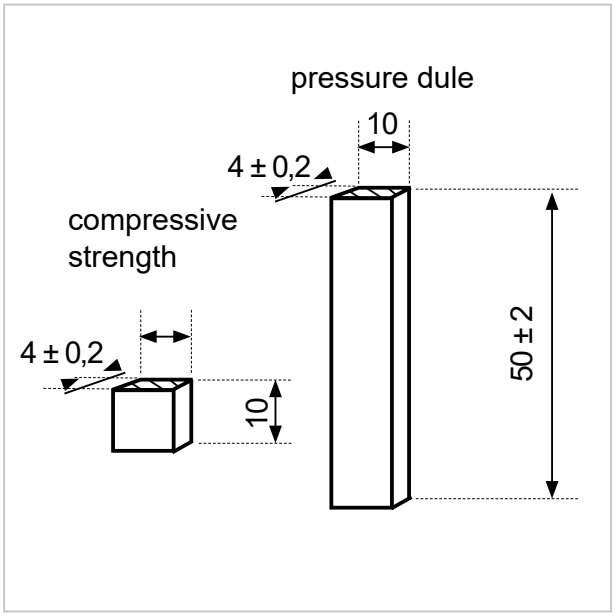
Target
The pressure test is a standardized test and is used to describe the strength and deformation of a material under short-term compressive stress.

Procedure
The experiment is carried out on a universal testing machine (ISO 5893).

Test parameters
> Traverse path (up to 1000 mm)
> Strenght (to 10 kN)
> Temperature (-100°C to 250°C)
> Velocities
> E-modulus determination 1 mm / min
> Compression strength determination 5 mm / min

Test specimen
Specimen according to DIN EN ISO 3167 (see figure right).
5 specimen are needed for each test.

Experimental setup



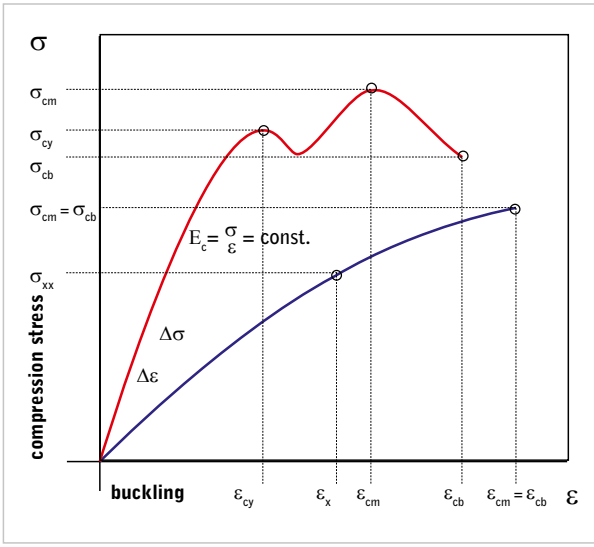
Specimen

Characteristic value

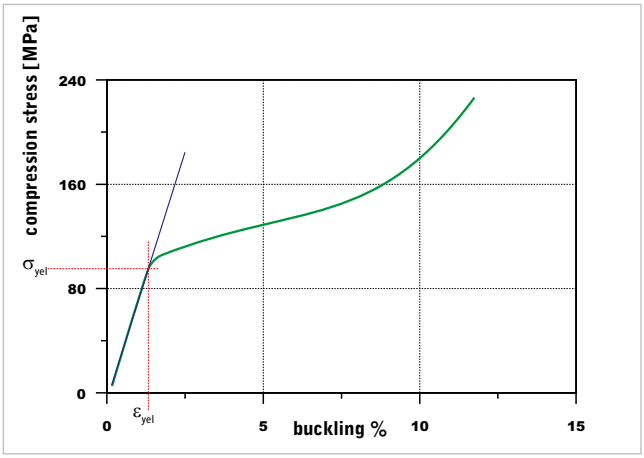
σ_{cy} *Pressure yield stress [MPa]*
σ_{cm} *Compressive strenght, maximum Compressive strenght [MPa]*
σ_{mb} *Compressive stress at break [MPa]*
σ_{cx} *Compressive stress at x% compression [MPa]*
ε_{cy} *Nominal compressive yield strain [%]*
ε_{cm} *Nominal compressive strain at Compresive strenght [%]*
ε_{cb} *Nominal compressive strain at break [%]*
ε_{x} *Predefined compression at x%*
E_c *Compressive modulus [MPa], determined on the slope of the Hooke's straight at elongations between 0,05- 0,25%.*

In addition, the Wolf Kunststoff-Gleitlager GmbH specifies the following values:

σ_{yel} *Elastic limit. Up to this stress only purely elastic deformation takes place.*
ε_{yel} *Elastic yield point [%] elongation which almost completly disappears , when the specimen gets relieved.*



compression stress - buckling



Elastic compression limit

Evaluation
The values are presented in a voltage-buckling-diagram. The following quantities are recorded.

F Test charge [N]
ΔL Change in length of the specimen [mm]

The compression stress is given by

$$\sigma = \frac{F}{A} \text{ [MPa]}$$

Samples with cross-sectional area A

The compression ε is calculated as follows:

$$\varepsilon = \frac{\Delta L - L_0}{L_0} \text{ [\%]}$$

with original length L_0.

Determining of bending properties

Standard: DIN EN ISO 178

Ziel
The 3-point bending test is standardized and used to describe the strength and deformation of a material under short-term bending stress.

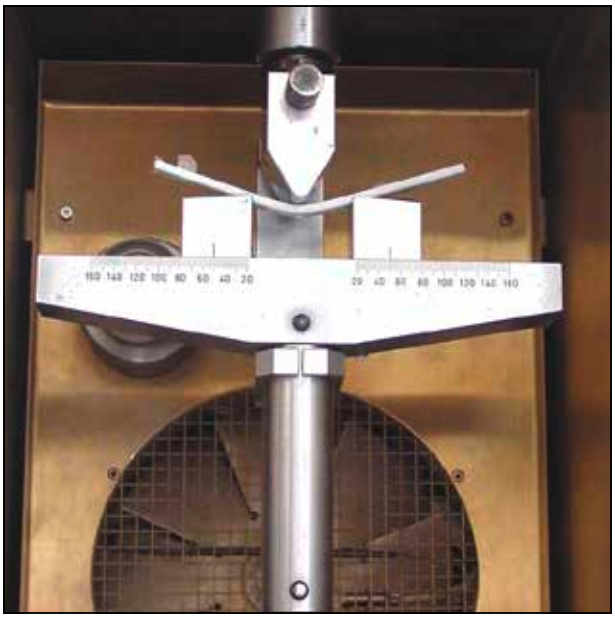
Procedure
The experiment is performed on a universal testing machine according to ISO 5893.

Test parameters
> Stroke (to 1000 mm)
> Strenght (to 10 kN)
> Temperature (-100°C to 250°C)
> Velocities (0,6 mm/min to 600 mm/min)

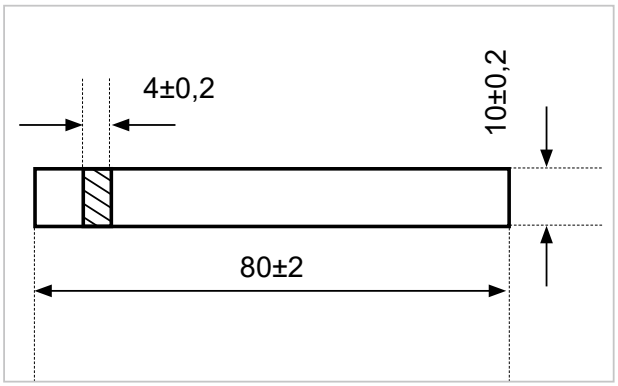
Test specimen
Made of multipurpose test specimens according to DIN EN ISO 3167.
5 specimen are needed for each test

Characteristic value

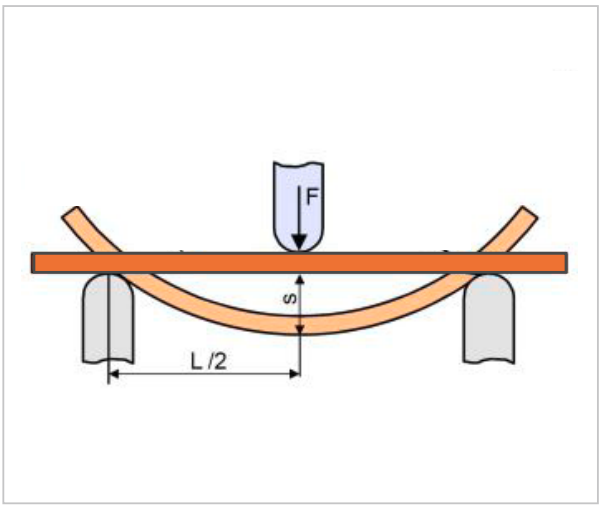
$\sigma_{f,3,5\%}$	*Outer fiber stress at 3,5% outer fiber strain [MPa]*
$\sigma_{f,m}$	*Flexural strength [MPa]*
σ_b	*Flexural stress at break [MPa]*
$\varepsilon_{f,m}$	*Elongation at flexural yield stress [%]*
$\varepsilon_{f,b}$	*Flexural elongation at break [%]*
E_t	*Flexural E-modulus [MPa], determined on the slope of the Hooke's straight at elongations between 0,05- 0,25%.*



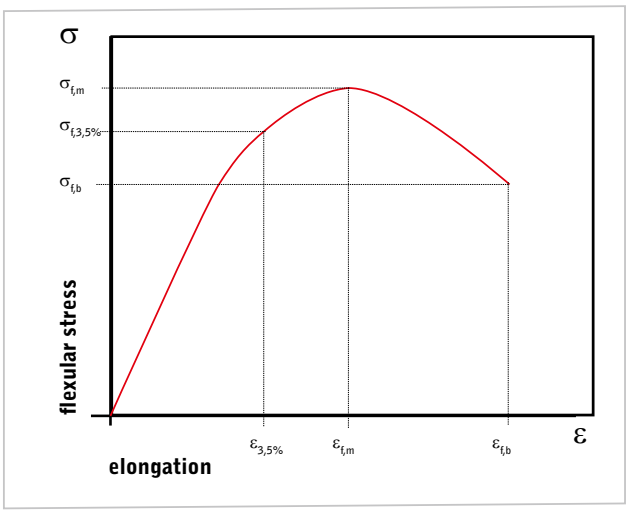
Experimental setup



Specimen



schematic presentation



Flexular stress- outer fiber strain

Evaluation

The bending stress is calculated by using the following formula:

$$\sigma_B = \frac{M_B}{W_B} = \frac{F * L * 1/4}{b * h^2 * 1/6} = \boxed{\frac{3 * F * L}{2 * b * h^2}}$$

Flexural E-modulus E_t is calculated with the deflections s_1 und s_2 accordingly to the Outer fiber strains ε_1=0,05% und ε_2= 0,25% with following formular':

$$E_t = \frac{\sigma_{B1} - \sigma_{B2}}{\varepsilon_1 - \varepsilon_2} \quad \text{whereby} \quad \varepsilon_{1/2} = \frac{600 * s_{1/2} * h}{L^2}$$

F	*Force [N]*
L	*Span [mm]*
h	*Specimen thickness [mm]*
b	*Specimen wideness [mm]*
s	*Deflection [mm]*

Determining of creep behaviour in tensile creep test and creep test at 3-point bending

Standards: DIN EN ISO 899-1
DIN EN ISO 899-2

Comparable standard: DIN 50118

Target
With this test the mechanical properties of plastics get determined under long-term continuous load (creep).

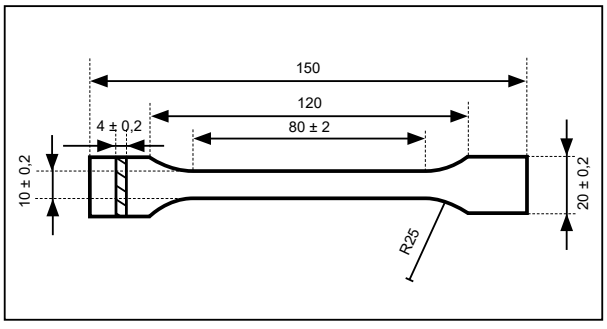
Procedure
The tests are in accordance with DIN EN ISO 899-1 (creep test) or DIN EN ISO 899-2 (creep bending test), performed on a universal testing machine (ISO 5893).

Test parameters
- Stroke (to 1000 mm)
- Strength (to 10 kN)
- Temperature (-100°C to 250°C)
- Velocities (0,6 mm/min to 600 mm/min)
- Trial duration (normally 100 h, in exceptions 1000 h)

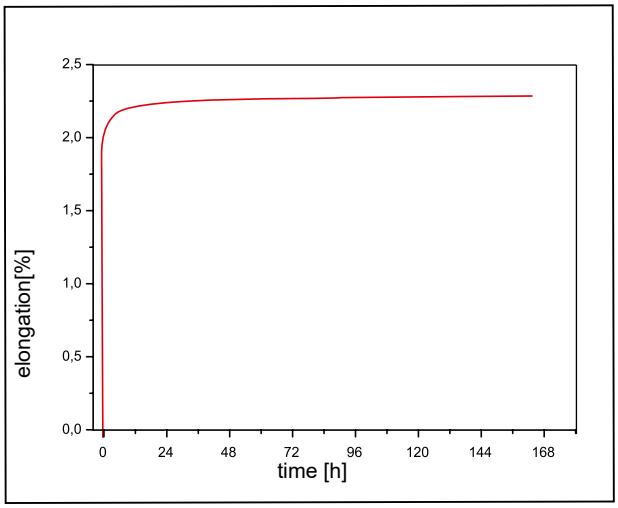
Test specimen
The specimens correspond to those of DIN EN ISO 3167 (multipurpose test body) type 1A.

Characteristic value
The determined isochronous stress-strain diagrams (creep) are used as characteristic values.

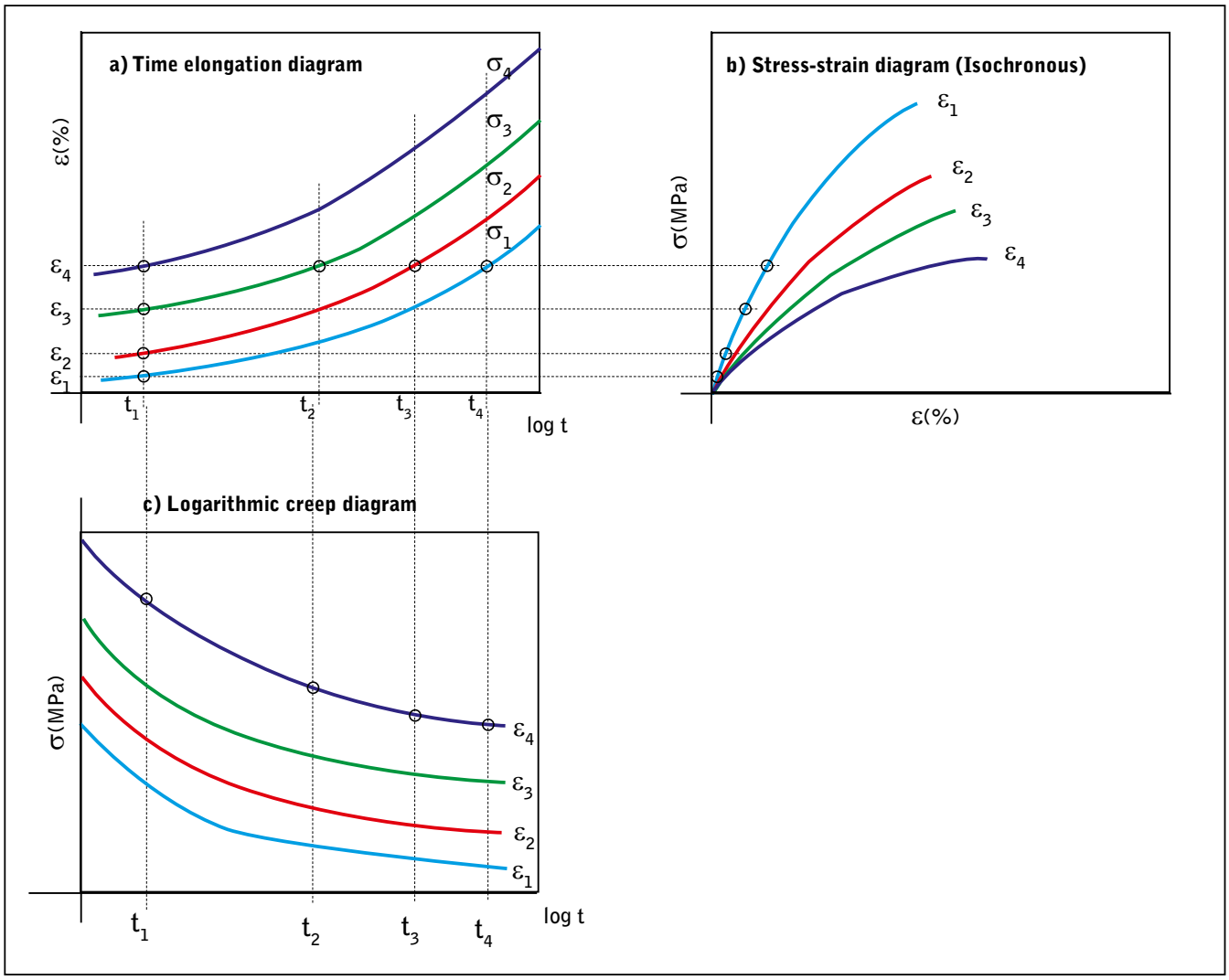
Experimental setup (in this case: tensile creep test)



Testspecimen type 1A



Elongation at constant load



Deformation and stress at different loading times

Evaluation

From the measured values creep curves are created.Those can be converted into isochronous stress-strain diagrams (creep curve), or logarithmic diagramms. Based on the isochronous stress-strain diagrams you will be able to find out the resulting deformation and associated stress at different loading times. Furthermore, it is possible to extrapolate the results projecting over a decade, in order to make predictions about the material behavior.

Determining of ball indentation hardness through ball indentation test

Standard: DIN EN ISO 2039

Target
The Ball indentation hardness gets measured in this test. This value shows the resistance of the tested material to oppose a spherical penetrating body.

Procedure
A hardened steel ball is pressed into the specimen and the depth of penetration gets measured.

Test parameters
The test load may vary depending on the material. It could be varied between 4 power levels (49N / 132N / 358N / 961N). The force must be chosen in a way, that the read depth of measurement is laying between 0.15 and 0.35 mm.

Test specimen
Not closer defined, however it has to have a thickness of at least 4 mm. The contact point must be at least 3 mm away from the edge.

Characteristic value

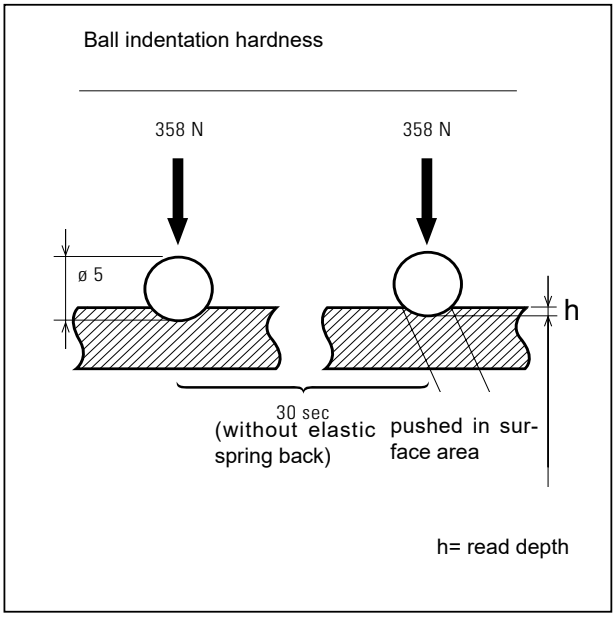
H358 (test force) / 30 (load time) = 125 N/mm² (calculated ball indentation hardness)

Evaluation
The evaluation is carried out according to DIN EN ISO 2039. The penetration depth of the ball can be read on a scale. The ball indentation hardness H could be determinded by reading a table (DIN EN ISO 2039-1 Annex A) or by using the following formula:

$$H = \frac{1}{5\pi} \cdot \frac{F_m}{h_r} \cdot \frac{0{,}21}{(h - h_r) + 0{,}21} -$$

H	Ball indentation hardness [N/mm²]
F_M	Test force [N]
h_r	Reduced penetration depth (= 0,25 mm)
h	Penetration depth [mm]

Experimental setup



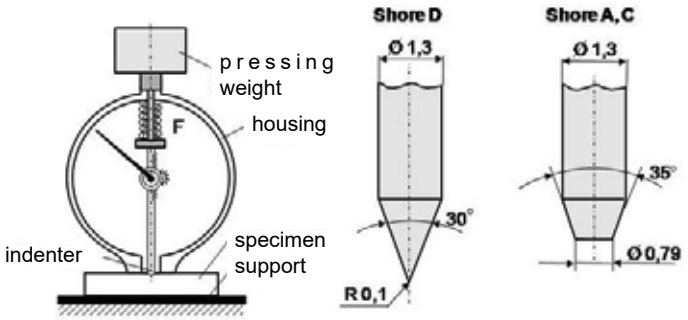
Principle

Determining of indentation hardness with a durometer (Shore-hardnes A / D)

Standard: DIN EN ISO 868 **Comparable standard:** DIN 53505

Target
In this experiment, the shore hardness of plastics get's determined. The shore hardness is a characteristic value for determining the material hardness and is mainly used for elastomers and rubber-elastic plastics.

Procedure
The shore hardness is measured with a shore hardness measuring device through the penetration depth, by pressing in a truncated cone (Shore A) or a truncated cone with spherical cap (Shore D). The truncated cones are preloaded by a spring and exert a force of 12.5 +/- 0.5 N (Shore A) and 50 +/- 0.5N (Shore D) on the specimen. A penetration depth of 2.5 mm corresponds to the value 0 Shore, a penetration depth of 0mm a value of shore 100. The measurement is performed at room temperature. (23°C +/- 2°C)



Test specimen
6 mm (Shore A) and 3 mm (Shore D), respectively. The distance from each body edge must be 12 mm and the surface must be smooth and parallel.

Specification
(Example)

75 ShoreA
read off value procedure

Evaluation
After contact between the test prod with the specimen, the Shore hardness value could be read from the display. The measure of the Shore hardness is defined as follows:

$$\text{shore hardness } (A/B) = 100 - \frac{\text{indenter depth [mm]}}{0{,}025}$$

The indentation hardness can not be calculated from the shore hardness!

Shore hardness measuring device

Determining of the charpy-impact - properties (unnotched / notched)

Standard: DIN EN ISO 179

Target

This test is used to determine the charpy-impact resistance. This means the ability of a material to absorb impact energy without getting broken. The notched charpy impact strength also takes into account the notch sensitivity of the material.

Procedure

The sample is positioned centrally on an abutment and smashed by a tup.Within the DIN EN ISO 179 a distinction between the sub-process has been made.The sub-processes are shown on the following table.

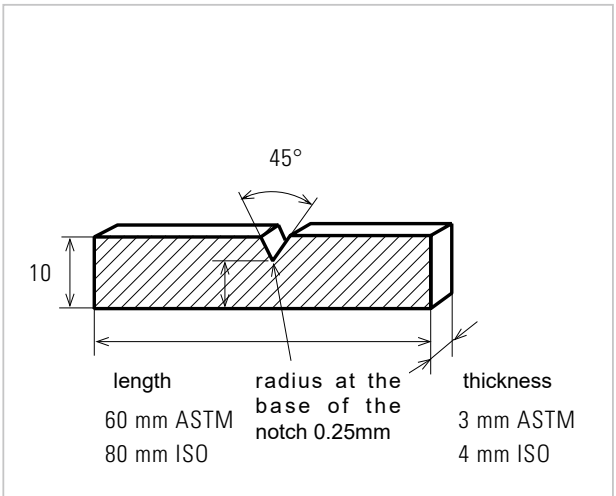
Test parameters

> Temperature (-196°C to 300°C)
> Tup with 0.5J, 1J, 2J, 4J maximum impact work.

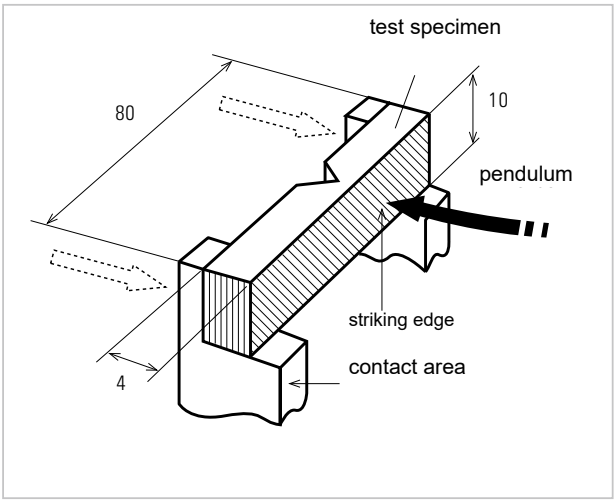
Test specimen

The test specimen is composed of the central part of the multipurpose test specimen according to DIN EN ISO 3167 (tensile bar) and can either be checked notched (notch kind C, impact test) or unnotched.

Procedure	Impact direction	Notch kind	Notching-rounding radius	Remaining width at the notch root
ISO 179-1/1eU	slim sided	unnotched		
ISO 179-1/1eA		single notch		
ISO 179-1/1eB		A	0,25 ± 0,05	8,0 ± 0,2
ISO 179-1/1eC		B	1,00 ± 0,05	8,0 ± 0,2
ISO 179-1/1fU	wide sided	C	0,10 ± 0,02	8,0 ± 0,2



Specimen



Experimental setup

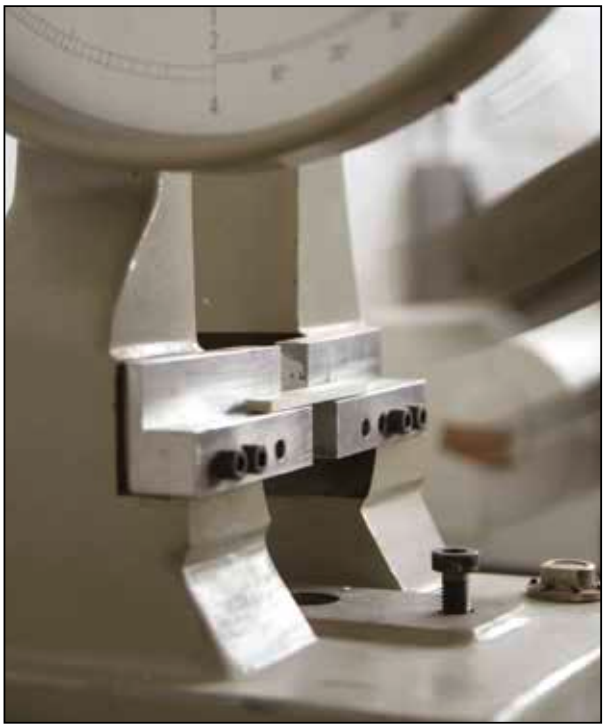
Characteristic value

A_{cU} *Charpy impact strenght [kJ/m²]*
E_c *Impact work [J]*
h *Height of the specimen [mm]*
b *Width of the specimen [mm]*

$$A_{cU} = \frac{E_C * 1000}{h * b}$$

A_{cN} *Charpy notched impact strength [kJ/m²]*
E_c *Impact work [J]*
h *Height of the specimen [mm]*
b_N *Width of the specimen in the notch root [mm]*

$$A_{cN} = \frac{E_C * 1000}{h * b_N}$$



Impact strength testing device

Evaluation
The impact work E_C could be read directly from the scale and is based on the sample cross-section. The result is the impact strength. In notched specimens, the width is determined at the notch root.

Test of resistance property at rapid-deformation (ball drop test)

Standard: modelled after EN ISO 6272-2-2011 and ASTM D 2794

Target

With the falling ball test, it is examined the resistance of a coating to cracking or peeling of from the metal part, when the coating is deformed under standard conditions by a falling body.

Procedure

It will be dropped a ball of 8 mm diameter as a falling weight gradually up to 1 m onto the specimen. Then, the impression will be studied for cracks or separations. If no cracking or peeling can be recognized, this process is repeated for each 25 mm of higher drop height. If cracks are present, the ball will be dropped 5 times from the hight on which the first cracks or peeling off from the substrate could be recognized. The next step is to drop the ball 25 mm lower than the previous height. If no endpoint can be determined, the tests are repeated with all drop heights of 25 mm higher or 25 mm lower chosen to ensure that the end point of the test is in the studied hights.

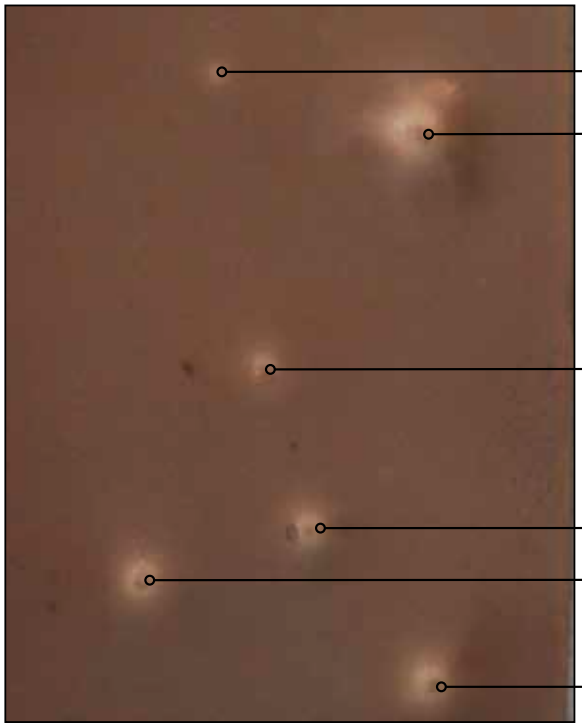
Test parameters

Weight: 1000 g +/- 1 g
Falling body-Ø 8 mm
Falling hight max: 1000 mm

Test specimen

The specimen must be made of metal and has to be in compliance with ISO 1514.
The sample plates must be flat, free from distortion and has to have a thickness of at least 0.25 mm. It must be large enough to have five measuring points which are at least 40 mm apart and at least 20 mm away from the edge of the plate. The thickness shall be measured to 0.01 mm.

Testing device



Example
Stainless steel 1.4301, coatet with
ZX-324V2HTCoat, 80 x 54 x 1 mm

Evaluation
Every drop hight gets tabulated,counted, how often it was successfull and not. The test result is the hight at which the results change from mainly existed to mainly failed.

Determining of the shear / peel hardness at bonded specimens

Standard: Shear/Peel -test DIN EN 1465
factory-standard

Peeltest PVLAB02
factory standard

Target
The shear or peel test is used to obtain a relative comparison of adhesive, which is showing the endurance of the adhesive in dependence of the bonding partners, the surface condition and temperature.

Procedure
The experiments are conducted according to factory standard DIN EN 1465 on a universal testing machine (ISO 5893). The bonding takes place according to application instructions of the adhesive manufacturer.

Test parameters
> Traverse path (to 1000 mm)
> Strenght (to 10 kN)
> Temperature (-100°C to 250°C)
> Time to rupture: 65s +/- 20s
> Adhesive surface
> Adhesive

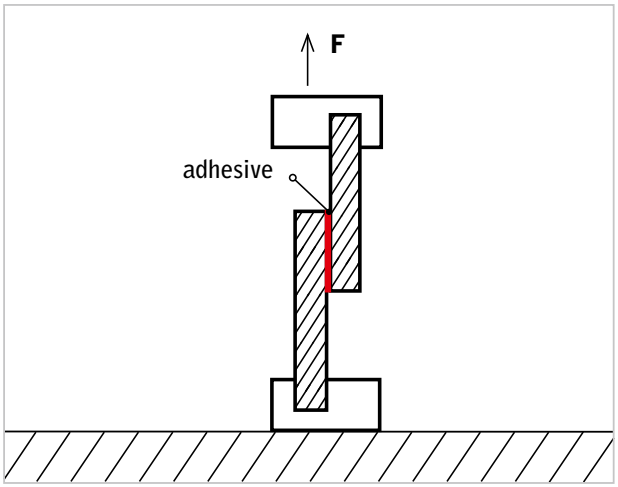
Test specimen
Rectangular specimens with dimensions 100 x 25 x 1,6 are used. The adhesive surface is 312,5 mm² mm² large (Overlap by 12,5 mm).

Characteristic value

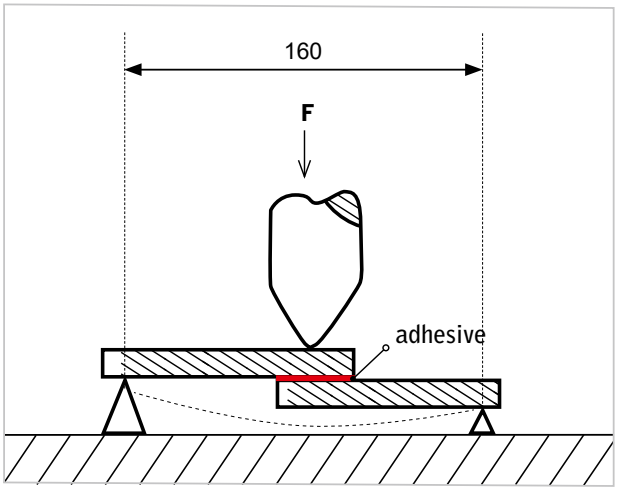
F_{max}	*Force [N] at which the adhesive bond fails*
V	*Crosshead speed [mm / s]*
s_{max}	*Path [mm] at which Fmax is reached*

Type of fracture: Adhesive failure / cohesive failure

The evaluation of the fracture mode allows a statement about the type of failure.
If the adhesive itself or the plastic has failed (cohesive failure), or whether the adhesive failed at the add points.(Adhesive failure)



Shear test
The glued together samples are loaded under shear stress until the adhesive bond fails.



Peel test
The glued together samples are loaded under peel stress until the adhesive bond fails.

Evaluation
The following measured values are recorded during the test:
F Test load [N]
s Traverse path [mm]
The strenght-path curve up to the point the adhesive connection has failed is shown in a diagram.

Conducting of thread pull-out test

Standard: factory standard PVLAB03

Target
The target of this test is to determine the optimal thread parameters for plastic thread.

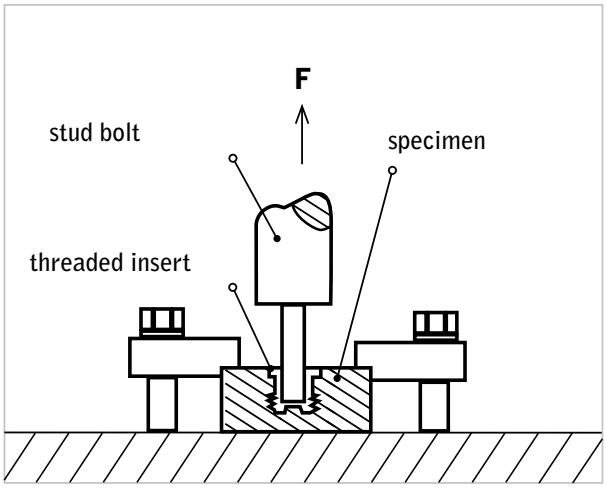
Procedure
For this test, a thread insert is mounted centrally in a specimen.The test specimen is then clamped in a universal testing machine (ISO 5893) and connected to the pulling device by a screw. It is pulled until the thread fails or the power limit of the testing machine (10 kN) has been reached.

Test parameters
> Traverse path (up to 1000 mm)
> Strenght (to 10 kN)
> Temperature (-100°C to 250°C)
> Velocity (0.6 mm / min to 600 mm / min)
> Type and size of the threaded insert

Test specimen
Cylinder Ø 35 x 32 mm is used as a specimen

Characteristic value
Fmax *Maximum measured force [N] during the experiment*
smax *Crosshead travel [mm] at maximum force*

Type of failure:
Brittle fracture, ductile fracture, ripping out



Experimental setup

Evalutation
Based on the force-path diagram, the maximum axial force and the traverse path is getting determined. Subsequently the mode of failure is getting judged.

Determining of tensile, compressive and bending properties with the eplexor

Standards:

tensile test	PVLAB16-1
compressive test	PVLAB16-2
DMA/ 3-point bending test	PVLAB16-3

Target

With the aid of the Eplexor the mechanical (σ, ε and E) as well as the dynamic-mechanical (E′, E′′ and tan(δ)) properties of plastics can be determined in dependence of time, frequency and temperature.

Procedure

For the determining of the mechanical properties specimens get claimed with a quasi-static loading. The determination of the dynamic mechanical values is done in the same way as in a conventional DMA attempt by oscillating dynamic loading.

Test parameters

- Temperature measurement range from -150°C to 500°C
- Heating resp. cooling rate to max. 10 K/min
- Frequency from 0,01 Hz to 100 Hz
- Measuring force to 5000 N
- Amplitude of the load to 9 mm
- Dynamic elongation: from 2 µm to +/- 5 mm
- Static elongation: up to 50mm
- Inert atmosphere N2 or He possible

Test specimen

Compressive: lmax=20 mm; Ø resp.
Cross section: freely selectable
Tensile: prism l=25 mm; a=4; b=4
Bending: prism l=60 mm; a=4 mm; b=10 mm

Characteristic value

Static: Simplified tensile and 3 point bending tests; Relaxation (σ(t)T, ε), retardation (ε(t)T, σ)

Dynamic:
- E‘(T,f) – Memory module function and
- E‘‘(T,f) – Loss modulus function
- E* – complex elastic modulus;
- tan(δ) – Loss resp. damping factor;

Eplexor overall view

Eplexor detailed view

Determination of compression set after constant deformation

Standard: DIN 53517

Target

In this experiment is studied, in what way the elastical properties are remaining, after they had been put under a long-lasting constant compression, at a predetermined temperature.

Procedure

The test is performed with a device consisting of at least 2 plane, polished steel plates (Ra> 4 mm), between which the specimens are compressed. The space of the compression plates can be adjusted to a predetermined value with the aid of spacer. Before starting the experiment, the samples are measured at room temperature with a thickness gauge. The samples and the spacers are placed together on the lower plate and the upper pressure plate is placed above and compressed on the thickness of the spacers by hexagon nuts. After the test the specimens are getting quickly released from the load and after 30 minutes the thickness get's measured. At higher or lower temperatures, the testing device and the samples are remaining in the tempering chamber temperature. The measurements take place at room temperature.

Test parameters

- Temperature [°C]
- Sample thickness [mm]
- Thickness of spacer [mm]
- load duration [h]

Characteristic value

Compression set DVR [%]

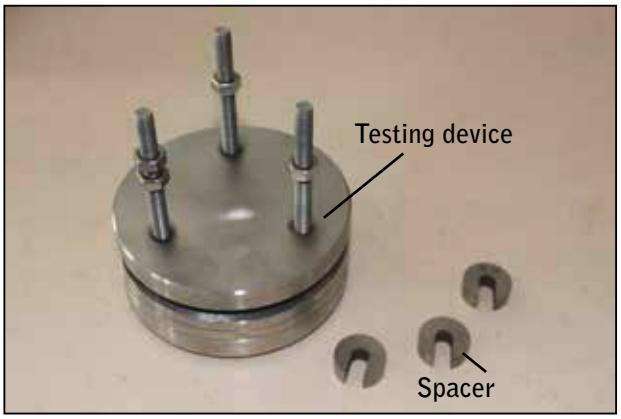
Test specimen

According to the spacers samples are used with the following thicknesses

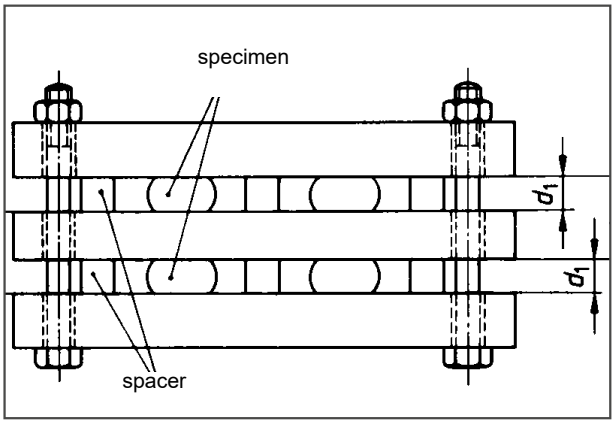
Hardness shore A Description	Specimen 1	Specimen 2	Deformation [%]not stored dimensions
	Thickness of the space piece+/- 0,01 [mm]		
to 80	4,73	9,38	25
>80 to 90	5,36	10,62	15
>90 to 95	5,67	11,25	10

For the investigation of the crystallization behavior from specimen 1, the following spacers need to be used (deformation 25%)

Thickness of test specimen [mm]	Thickness of spacer +/- 0,01 [mm]
6,0 bis 6,19	4,57
6,2 bis 6,39	4,72
6,4 bis 6,60	4,87



Measurings device



Experimental setup

Evaluation

The Compression set [%] is calculated with following formular:

$$DVR = \frac{d_0 - d_2}{d_0 - d_1} * 100$$

d_0 previous sample thickness [mm]
d_1 sample thickness deformed [mm]
d_2 sample thickness relaxed [mm]

Thermal test 26-38

DSC (sifferential scanning calorimeter)

Standard: factory standard PVLAB04

Target
Determination of the glass transition temperature, crystalline melting point, crystallinity, oxidation stability, the characterization of curing reactions and in the measurement of the specific heat.

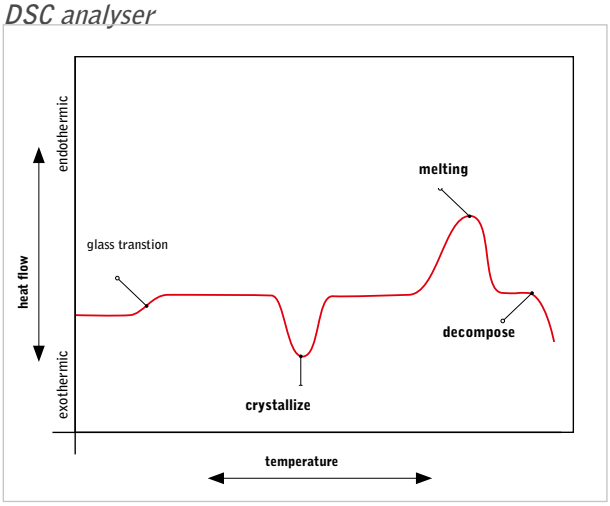
Procedure
In the furnace of the analysis instrument two locked aluminum crucibles are heated with a specific heating or cooling speed.
A crucible contains a sample, and the other crucible is empty (reference). Due to the heat capacity of the sample, the exothermic or endothermic process and phase change such as melting or evaporation, arise the temperature differences between the sample and the reference.

Test parameters
> Start and end temperature (20-600 ° C)
> Heating rate/cooling speed (usual values: 5K/min to 40K/min)
> Inert gas (type, quantity)

Test specimen
The specimen is prepared by cutting with a sharp scalpel of a granular, semi-finished product or component sample and should have a weight of 10-20 mg.

Characteristic value
Tk	*Crystallization temperature [°C]*
Tg	*Glass transition temperature[°C]*
Tm	*Melting temperature [°C]*
DH	*Melting enthalpy [J/g]*
TZer	*Decomposition temperature [°C]*

DSC analyser



Heat flow-temperature history

Evalutation
The characteristic values are determined from the heat flux - temperature gradient.

Thermomechanical analyzer (TMA)

Standard: modelled after DIN 53752

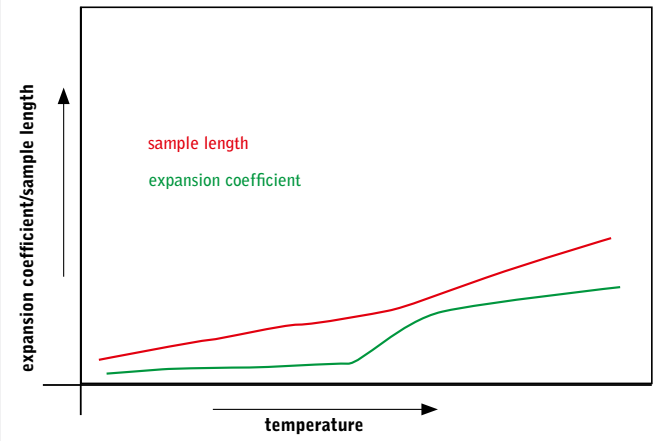
Target
Determination of the average thermal coefficient of linear expansion

Procedure
The test for determining the coefficient of linear expansion is not done like described in DIN 53752 with a dilatometer, but rather performed by the more accurate thermo-mechanical analysis.

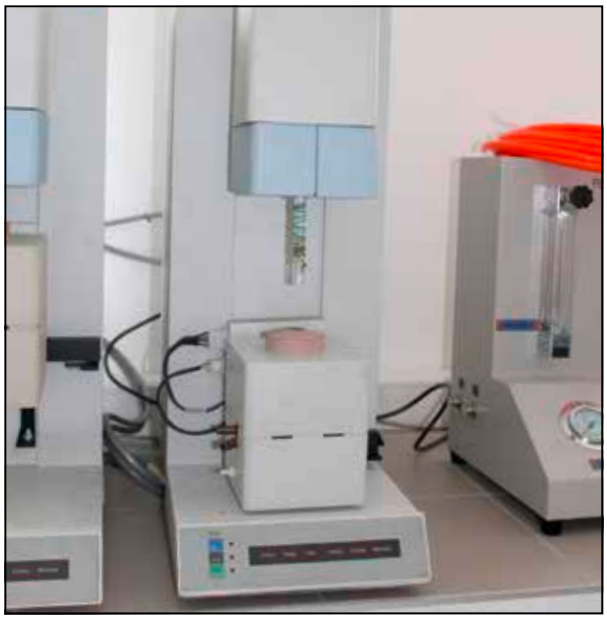
Test parameters
> Temperature (-170°C to 1000°C)
> Heat-/cooling rate
(0,1K/min to 100K/min)
> Measured force

Test specimenpecimen
Cylindrical specimen Ø 6 x 10 mm.

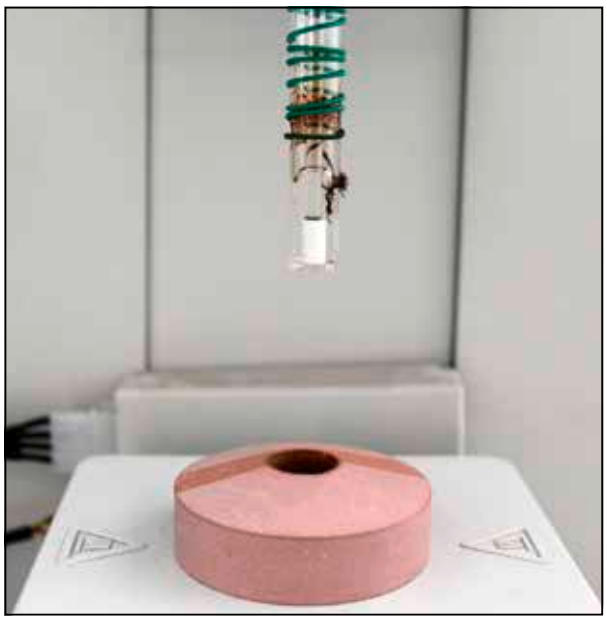
Characteristic value
α *Coefficient of linear expansion [1/°K]*
T_g *Glass transition temperature [°C]*



Sample length in dependence of temperature



TMA analyzer



TMA analyzer

Evaluation
The evaluation is based on the measurement data. In addition to the linear expansion coefficient is also the determination of the glass transition temperature Tg from the sample length-temperature diagram with this method possible.

Thermogravimetric analyzer (TGA)

Standard: factory standard PVLAB06

Target
Target of this test is the determination of decomposition temperature and components of volatile substances or fillers.

Procedure
There is a sample crucible which is coupled to a weighing.The sample crucible is subjected to a temperature program. In dependency of the temperature and time it comes to a mass loss of the sample due to evaporation, decomposition or chemical reactions.

Test parameters
> Temperature (20°C - 850°C)
> Heating rate
> Inert gas purge

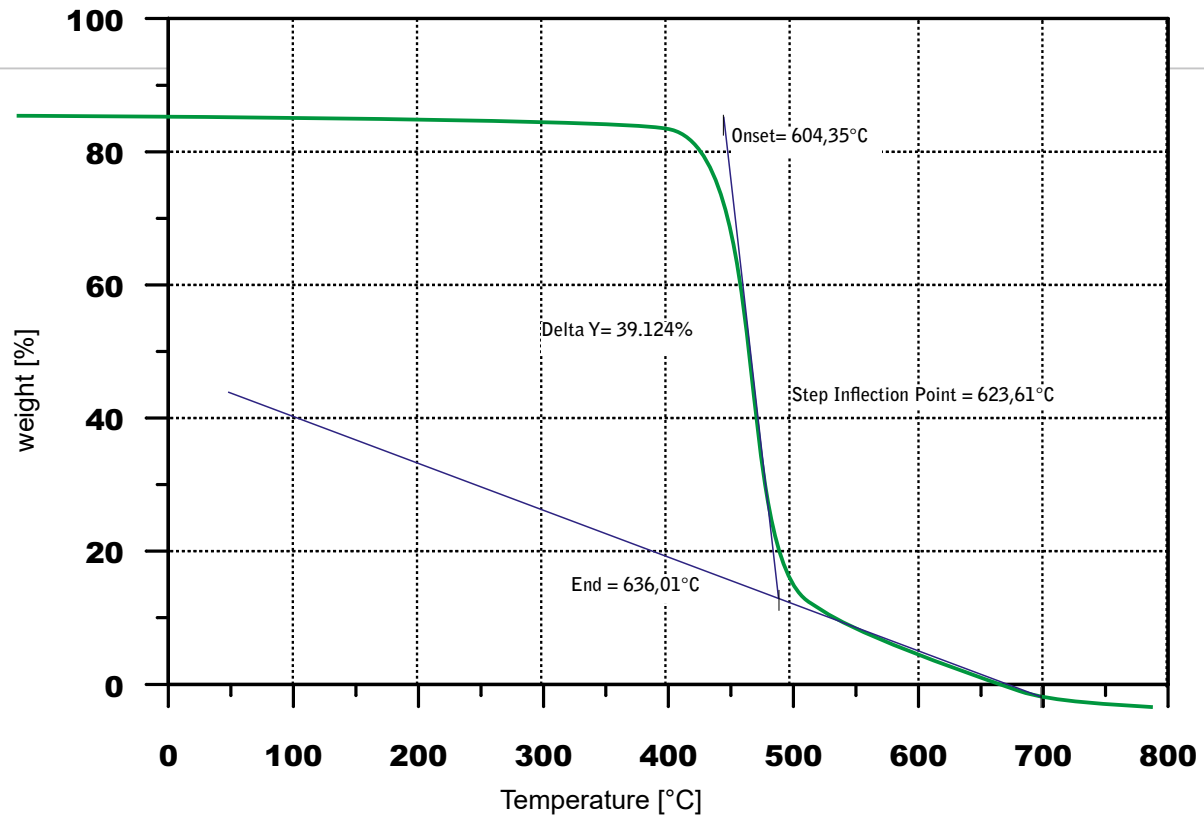
Test specimen
Not further specified. Sample weight 10-20 mg.

Characteristic value
mL1,2... Quantified material components respectively filler content [mg]
TA, TB Decomposition behavior
TC, Beginning, end and middle temperature [° C]
t Decomposition rate [min]

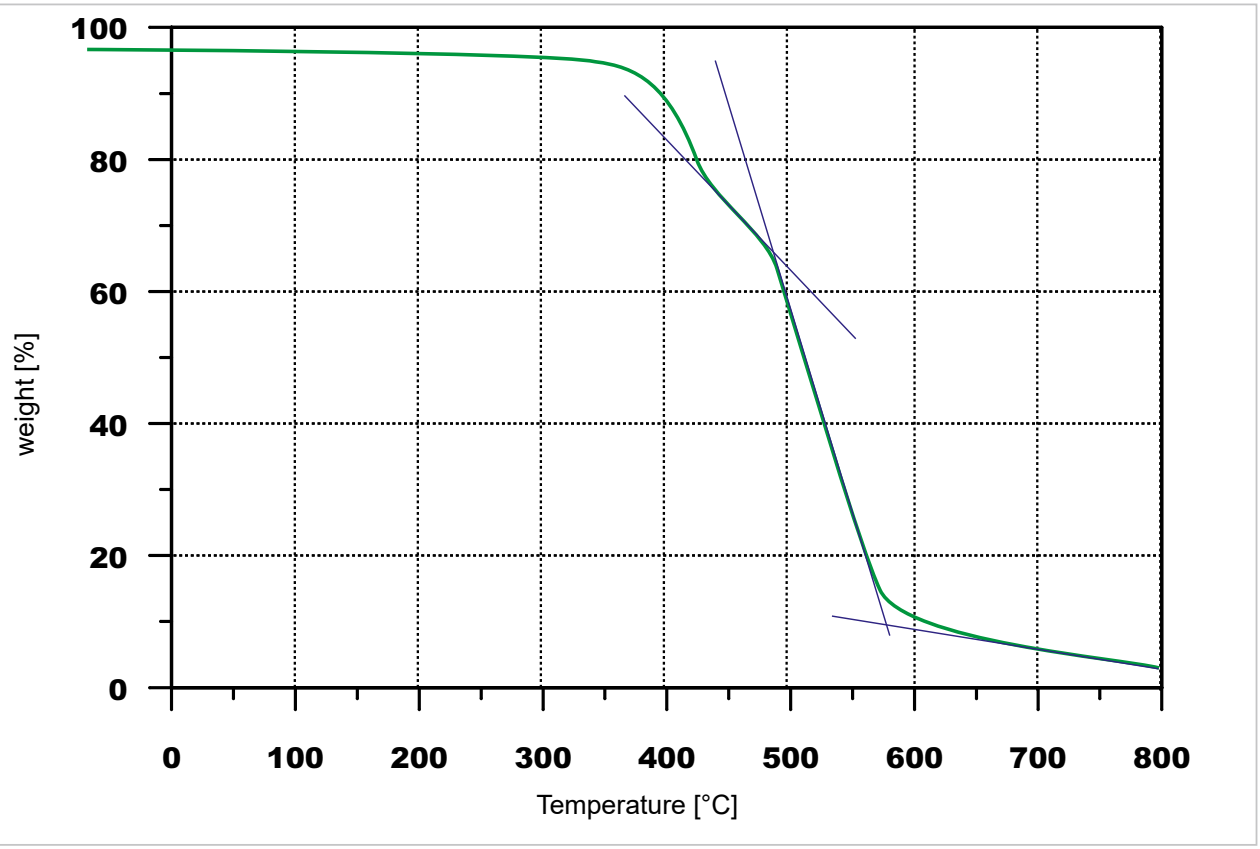
Evaluation
Based on the sample weight-temperature curve (see figure on the following page) the parameters are determined.

TGA analyzer

TGA analyzer (sample holder)



Sample weight-temperature history



Sample weight-temperature history, two components

Dynamic Mechanical Analzyer (DMA)

Standard: PVLAB05

Target
Determine the complex modulus and the mechanical loss factor tan (δ), as well as the glass transition temperature at dynamic (sinusoidal) and thermal stress.

Procedure
The specimen is placed on 2 supporting surfaces. The test specimen is stressed by a test stamp centered with an adjustable frequency and amplitude, subjected to bend.This process takes place at a specific temperature program.

Test parameters
> Temperature (from –170°C to 500°C)
> Heat-/cooling rate
> (0,01 K/min to 100 K/min)
> Frequency (0,01 Hz to 51 Hz)
> Measuring force
> Amplitude of the load

Specimen
Rectangular strips of 22 x 3 x 1 mm

DMA analyzer

DMA analyzer

Characteristic value

*E** *Complex modulus [N/mm²], indicator for the material stiffness, with E*=E‘+iE“*

E’ *Memory module[N/mm²], r eal part of the complex modulus, rigidity of a viscoelastic material. It is proportional to the stored work during a period of burden work.*

E’’ *Loss modulus [N / mm ²], imaginary part of the complex modulus is proportional to work, during one loading period "lost" is(inter alia heat).*

tan (δ) *Loss factor characterizes the Relationship between loss and memory module having the formula:*

$$\tan(\delta) = \frac{E''}{E'} = \frac{1}{2\pi} \cdot \frac{W_{irrev}}{W_{rev}}$$

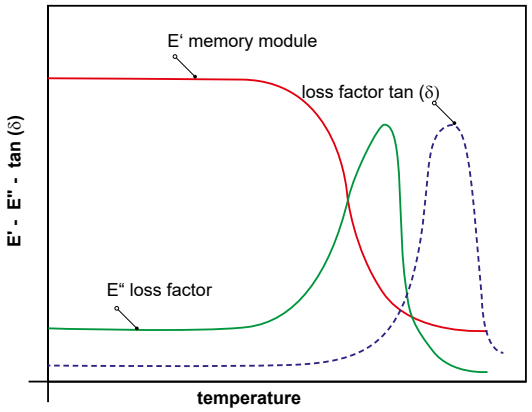
It further characterizes the mechanical damping of a system. A very low value indicates a system with a high elastic fraction.

T_g *Glass transition temperature [°C]*

Additional variables for explaining:

W_{irrev} *Energy [J], which is irretrievably lost (as heat energy)*

W_{rev} *Energy [J], which can be stored during the vibration stress.*



Characteristic value determination

Evaluation

The following measured variables are recorded:

- Temperature
- Frequency
- Complex modulus
- Loss factor tan (d)
- Dynamic force
- Static force
- Viscosity

From the modulus-temperature curve, the parameters can be determined. The characteristic value determination is then carried out graphically in the diagram, or by automatic calculation of the software.

Determination of heat distortion resistance

Standard: DIN EN ISO 75-1/-2 **Comparable standard:** DIN 53461

Target
Determining the temperature at which a predetermined deflection is reached. The HDT (Heat Deflection Temperature) is not to be understood as maximum operating temperature, but it only provides information about the shape retention of plastics. It can be used for rough selection of certain applications.

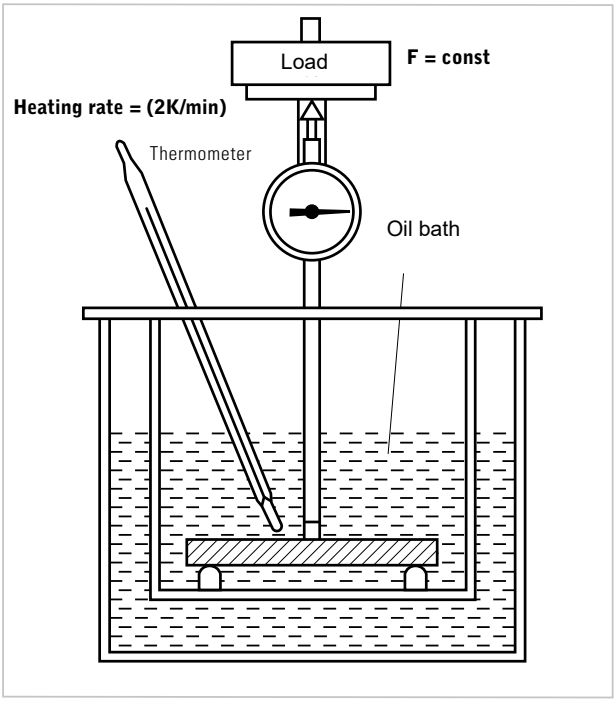
Procedure
The experiment is performed on a universal testing machine (ISO 5893), whereby the specimen is charged according to the 3-point bending principle. Under constant load, the temperature get's increased at a constant rate until the fixed deflection (outer fiber strain 0.2%) is achieved.

Test parameters
> Heating rate 2K/min
> Procedure HDT A: Bending stress s = 1,8 N/mm²
> Procedure HDT B: Bending stress s = 0,45 N/mm²
> Procedure HDT C: Bending stress s = 8,0 N/mm²

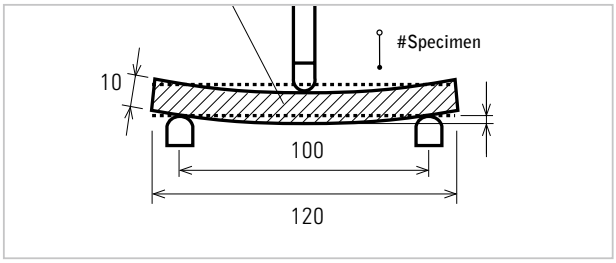
Test specimen
according to standard: DIN EN ISO 75-1/-2.
L x B x H: >110 x 3-4,2 x 9,8-12,8 mm

Characteristic value
Characteristic value is the heat distortion temperature. It is expressed as follows:

Example:
HDT/A = 85°C
A = Procedure A
ϑ = 85°C temperature at which the prescribed deflection is reached.
Heating rate =2 K/min



Experimental setup



(HDT) Heat Deflection Temperature

Evaluation
It is recorded a deflection temperature diagram. From this, the heat distortion temperature can be determined graphically.

Determining the max. Bearing interference fit temperature of pressed bushings

Standard: Factory standard PVLAB10

Target
Determination of the temperature at which a sliding bearing bush made of plastic loses its tightness, when it is pressed into a housing.

Scientific background:
If a plastic bushing with oversize gets pressed into a ring of metal, in the cross-section of the bushing will arise tangential stresses. Because of the frictional engagement will be ensured that the bushings "sit tight" in the steel ring. If the ring is heated with the pressed-in bearings made of plastic, the two materials expand. Because the expansion coefficient of plastics is by a factor of 10 larger than the metal , the plastic bushing would extend more than the steel ring. It means that the compression of the plastic bushing to the outside, is hindered by the metal ring. Thereby the bushing undergoes a compression of the material in the area of the wall. In consequence the tangential stresses on the wall-area will increase.

If the appeared stress is bigger than the allowable stress, it means, that the appeared compression exceeds the allowable compression, the material undergoes an irreversible deformation and the tangential stresses reduces. During cooling of the plain bearing bushing and the metal ring, they pull themselves together. The steel ring assumes its original size while the plastic bushing will shrink on a dimension which will be smaller than the initial dimension. That happens because of the irreversible deformation.
This shrinkage might be so strong that the plain bearing bush in cold state will fall out of the steel ring.

Procedure
A plain bearing is pressed into a metal ring (steel or aluminum) and subjected to a temperature program in the oven.

Test parameters
Type of temperature program:
> Constant temperature / cyclic program.
> Stepless adjustable temperature 25-300 ° C
> Duration of test: max. 7 days

Test specimen
Bushing $Ød_a$=16 mm, $Ød_i$=10 mm, L=9 mm
Bushing obliquely slotted - glued.

Characteristic value
T_{los} *The temperature [°C], at which the bearing interference fit dissolves*

Evaluation
The dimensional changes get documented and then decided, if the bushing has passed the test or not.

The following criterias are examined to assess the solid:
- Press fit is lost
- Dimension changes, $Ød_{aBushing}$= $Ød_{iHousing}$ in cold state
- Bearing clearance of 0.03 mm and more
- Too big length change

Temperature measurement using thermal imaging camera

Standard: none

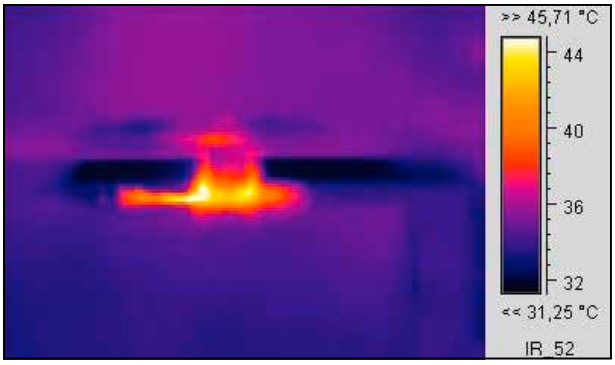
Target

Through the aid of the IR camera, the temperature gradient of an object or group of objects can be picked up and the temperature determined with an accuracy of +/- 2 ° C at any point of the IR image.

Test parameters
Temperature measurement range:-20...+600°C

Evaluation
The analysis of the thermal images is carried out with the appropriate software

Thermal imaging camera



Thermal imaging of a material sample for tribological investigation

Determine the thermal conductivity

Standard: DIN EN ISO 75-1/-2

Target
In this test the thermal conductivity of workpieces should be determined.

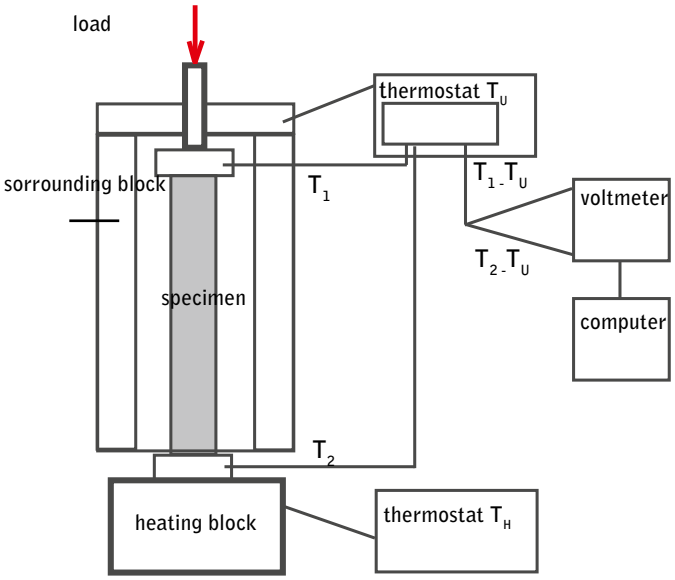
Procedure
The test is carried out using a thermal conductivity measuring device, which is consisting of a heating block and a surrounding block. The specimen is located in the heat-insulated surrounding block. Trough a weight in the lid, the sample get's pressed flat above and below on copper plates , which are each provided with thermocouples. The lower surface is heated one sided by the heating block. Due to the temperature drop a certain temperature results at the upper copper plate. The difference in temperature from the bottom to the top copper plate is measured by the thermocouples, displayed as a voltage by a voltmeter and converted by aid of the software in the thermal conductivity.

Test parameters
Thermoelectric voltage above / below [mV]
Temperature of surrounding block T_U [°C]
Temperature below T_2 [°C]
Temperature above T_1 [°C]
Temperature heating block T_H [°C]
Test specimen dimensions [mm]
Thermal conductivity λ
Measuring area 0,5 to 250 W/m*K

Test specimen
For thermal conductivity λ>*5 W/m*K*
cylinder with Ø 6 x 35mm
or cuboid with 5 x 5 x 35mm

For thermal conductivity λ<*5 W/m*K*
cylinder with Ø 6 x 20mm
or cuboid with 5 x 5 x 20mm
dimensional tolerance +/- 0,3mm

Characteristic value
Thermal conductivity λ [W/m*K]



Evaluation
With the aid of the software a temperature distribution curve get's created graphically, which is showing the course of the temperature between the upper and lower copper plates.

Determining the oxygen index (Limiting Oxygen Index - LOI)

Standard: IEC 695-2-1

Target
In this experiment, the concentration of oxygen in a homogeneous oxygen-nitrogen mix get's determined, which must be at least present so that a material just barely burns.

Procedure
The specimen is getting treated by flames in a fuel container with controlled oxygen content until the specimen begins to burn at the upper end. After 3 minutes, or after burning of 50 mm of the sample length, the oxygen concentration is gradually getting reduced.

Specimen
There are at least 10 test specimens with the following dimensions required:
l = 70-150mm; b = 6,5mm; s = 3,0mm
l = 70-150mm; b = 6,5mm; s = 2,0mm
l = 125-150mm; b = 12,5mm; s = 12,5mm
l = 140mm ; b = 52mm

Test parameters
> Burning time 3 min, burning lenght < 50 mm
or
> Burning time < 3 min, burning lenght 50 mm

Characteristic value
Limiting oxygen index LOI (accurate to 0.5%)

Measuring device

Evaluation

The oxygen concentration get's determined, at which the specimen barely burns.
The result is the limiting oxygen index LOI [%]

Determination of the melt mass-flow rate and melt volume-flow rate

Standard: DIN EN ISO 1133 **Comparable standard:** ASTM D-1238

Target
Determination of melt flow rate and the thermal degradation of plastics. Incorrect processing of the material is resulting in deterioration of the melt viscosity. This allows conclusions on the molecular chain length.

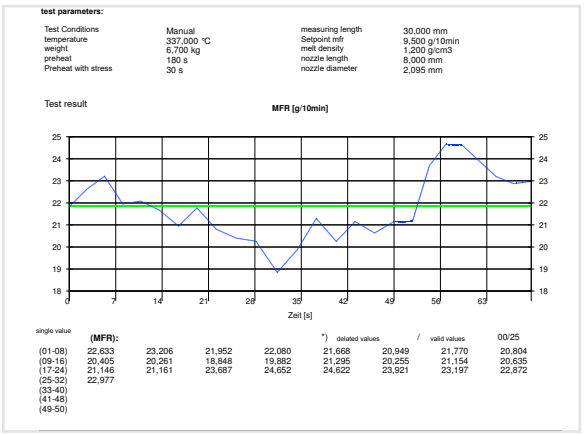
Procedure
A sample of material in granular form is placed in a heated cylinder under constant load and get´s melted. The melt then flows in a set period of time through a nozzle with a known geometry. The distance traveled by the melt is measured with a displacement transducer. Thereby the volume and the mass
(when the melt density is known) of the sample can be determined

Test parameters
> Test temperature
> Load (usually 2.16 kg to 5 kg)
> Number of severed strands (usually: 15 to 20)
> Drying state of the sample material
> Nozzle diameter / - length (2,095mm Ø, L = 8mm

> Test specimen
Granule or in special cases, fragments of semi-finished products, about 6-8 g.

Characteristic value
> MVR - Melt volume flow rate [cm³/ 10min]
> MFR - Melt mass flow rate. [g / 10min]
> Viscosity η [Pa*s)
> Shear velocity γ [1/s]
> Calculated melt density ρ_m [g/cm³]

Viscometer



Excerpt from the test report

Evaluation
A software automatically analyzes the data. To determine the MFR value the individual markdowns of the measurement must be weighed to determine the melt density. In the test record the MVR and the MFR values are diagrammed in function of time

Rheological measurments

Standard: Factory standard PVEXT04

Target
With the aid of the measuring extruder the viscosity of the plastic melt at different temperatures and shear velocities can be measured. Thus, processing close conditions can be simulated and important process parameters can be determined.

Test parameters
> Screw diameter: 19 mm
> L/D: 25
> Operating pressure: max. 700 bar
> Operating temperature: max. 450°C
> Torque: max. 300 Nm
> Rotational speed: max. 200 U/min
> Screws:
Conical screws, compression ratio 1:2 bis 1:5
3 zone screws, compression ratio 1:2 bis 1:5,
Metering screw, compression ratio 1:1,5 bis 1:3
Compression screws, compression ratio 1:1, bis 1:3

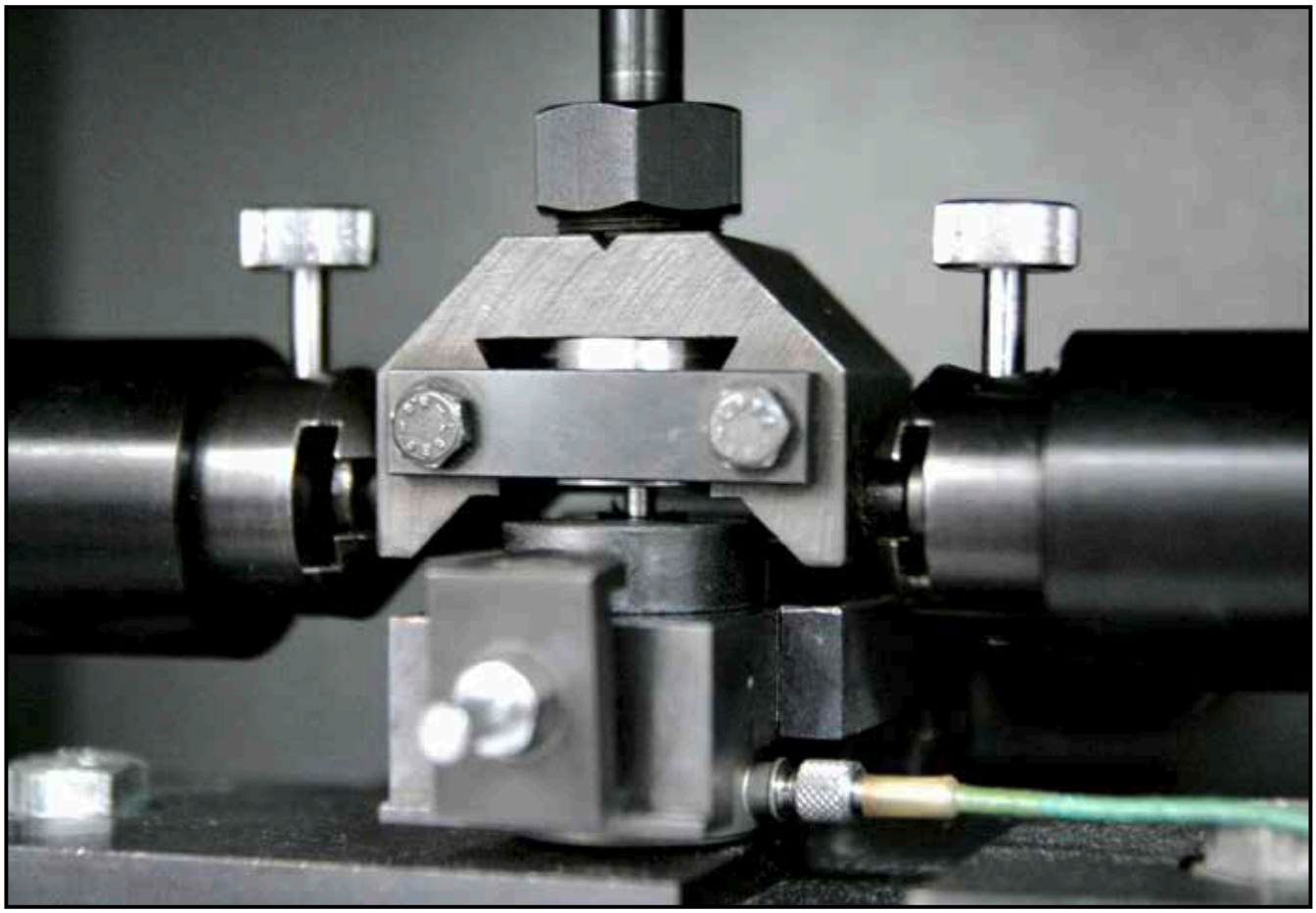
Testing options
> Investigation of the rheological behavior
> Determination of the dynamic viscosity in function of shear rate
> Identification of critical process parameters such as pressure, temperature, viscosity, shear rate, residence time, cooling rate and investigation of the melting behavior.
> Investigation of the degradation behavior, gelation behavior, and crosslinking behavior
> Determination of processing properties and parameters for finding new compounds.
> Determination of additive dispersion and homogenization.
> Determination of the optimal screw geometry and mixed elements

Test specimen
Granules

Manufacturable products and dimensions
Granule wtih Ø3 and 6mm
Rods with Ø1,75; 2; 3; 4; 5; 6 and 8mm
Tubes with $Ø_{outer}$ 8 - 15mm and wall thickness from 0,5 to 2mm

Measuring extruder

Evaluation
The evaluation and creating of a test report takes place through a special software.



Tribological tests 40-51

Determination of friction values, dry, water- and oil-lubricated at various Temperatures

Standard: Factory standard PVLAB08

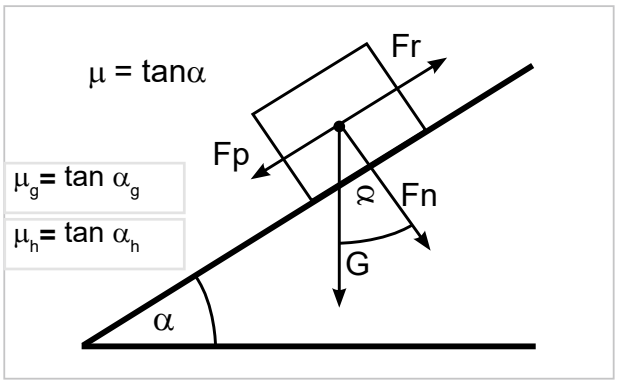
Target
The experiment is based on the principle of the inclined plane and is used to determine static and sliding friction coefficients of tribological systems at translational sliding.

Procedure
To determine the Coefficient of static friction a carriage with 4 samples get layed to the extreme end of an inclinable steel plate. The angle get's detected, at which the carriage starts moving. For the sliding friction value the angle of the plate get's reduced until a sliding of a moved carriage is no longer possible. Both tests get repeated 3 times

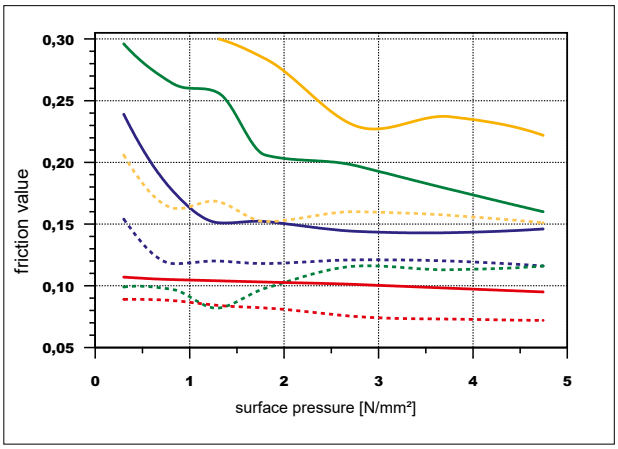
Test parameters
> Temperature
> Loading (94-900 N)
> Lubrication (dry/ water/oiled)

Test specimen
> 4 rectangular specimens, which are stuck on a sliding carriage with the dimensions 10 x 5 x 2 mm. However, the sample can be up to 5 mm thick.

Characteristic value
The tangent of the measured angle delivers the coefficients



Principle



friction value diagram

Evaluation
The angle get's measured, at which the carriage begins to slide. (Coefficient of static friction) resp. the angle at which a sliding carriage stops it's movement (sliding friction coefficient).
The friction coefficients are shown in diagrams, in dependency of the surface pressure, the temperature and the type of lubrication.

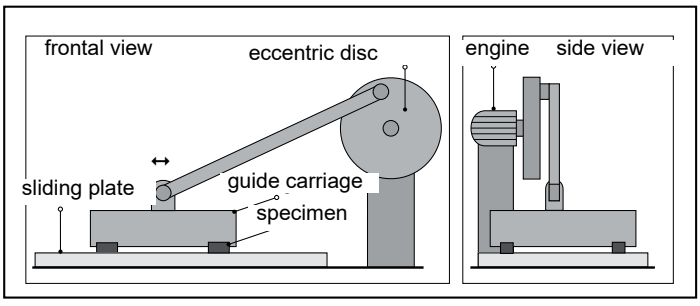
Determination of wear at translational sliding movement

Standard: Factory standard PVLAB11

Target
In this test the wear value (dry, wet, oil lubricated at high temperatures and with nitrogenous cooling at low temperatures) while a running track of 100 km (about 162 h duration) get's determined.

Procedure
For the wear investigation four specimens are placed in a carriage and driven via an eccentric, moved translationally on a running plate. The eccentric disc has a speed of about 35 rev / min. There are two running surfaces provided: A heatable and one for testing at room temperature. The running plate for elevated temperatures can be stepless varied to 280 ° C. In regular intervals the test will be interrupted in order to investigate the initial wear. At the end of the term the wear of the specimens get's measured again.

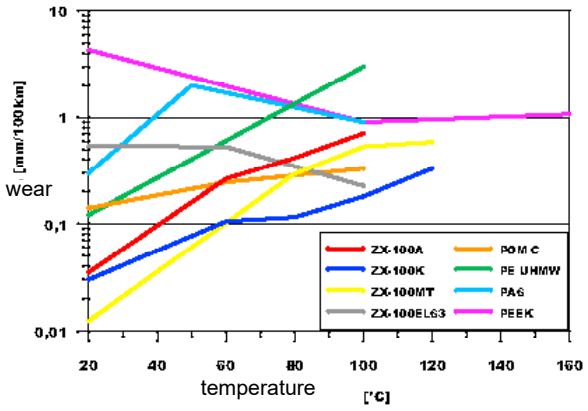
Test parameters
>Temperature:	Min. -100°C, max. 280°C
>Surface pressure:	0,3 N/mm²
>median sliding velocity:	10,3 m/min
>counterpart:	X5CrNi189
surface roughness:	4 µm Rz, sliding surface hard chrome plated, layer thickness 30 µm.



test bench principle

Test specimen
Test specimens dimensions:
10 x 5 x 3 mm to max. 10 x 5 x 4 mm

Characteristic value
wear [mm/100 km]



wear curves

Evaluation
The removal of material is determined in mm after a running distance of 100 km. The results are shown in a graph in function of the temperature

Determination of abrasion resistance - Taber abrasion tester ("Taber Abraser")

Standard: modelled after DIN 53754 and ISO 5470-1

Target
This test is used to assess the resistance of plastics against grain sliding wear (friction wheel procedure).

Procedure
The abrasion is produced by two load friction wheels which are pressed with a defined test force onto the rotating sample. The friction wheel Ø new is 52-53 mm. The wheels will be reworked after each test, that means the abrasion by blowing away and max. 0.1 mm of diameter removed. However, the diameter must be at least 44 mm, otherwise the wheels need to be replaced.
Test duration: 2 x 1000 revolutions.
A weight measurement is performed per 1000 revolutions.
The abrasion is aspirated during the test with a suction device.

Test parameters
> Torgue: 72 U/min
> Load: standard 10 N, other charges possible
> Grain size: adjustable over the standardized friction wheels.
Standard Wolf: CS-17 (caoutchouc with sand grains, springy), alternative H-18 (sintered, not springy)

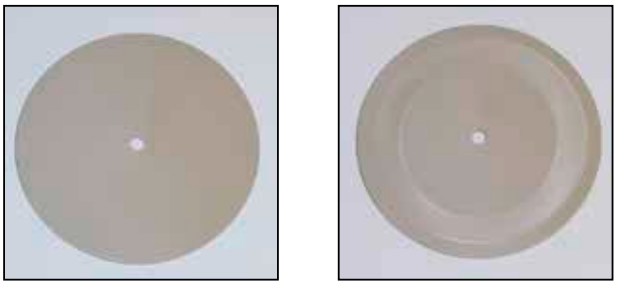
Test specimen
Disc with hole in center
Dimensions Ø100 / 6,5 x 3 mm

Characteristic value
Abrasion amount, by weight [mg]
Dm= m before- m after

Abrasion amount volumetrically [mm3]
DV=Dm / rplastic

Evaluation
The result is the "Taber index" whose amount corresponds to the weight loss in mg (after 1000 cycles).

Taber Abraser


Test specimen (left is new, right is worn)

Test discs
CS-17 (caoutchouc with sand grains, springy, medium coarse), alternative H-18 (sintered, not springy, sharp abrasive effect).


CS-17


H-18

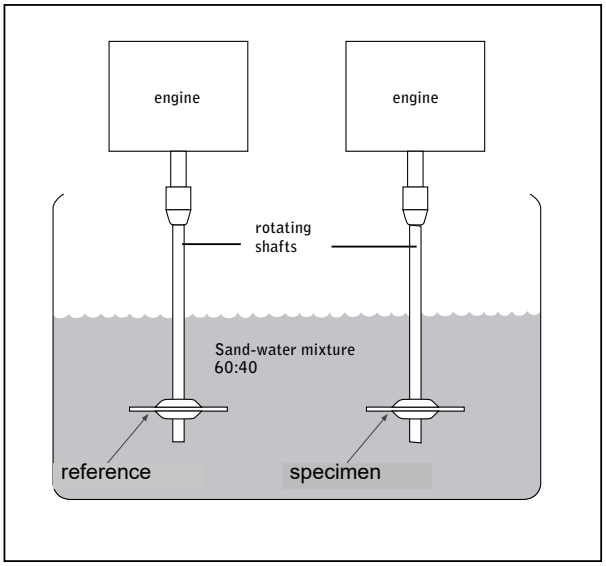
Determination of abrasion wear with the sand slurry method

Standard: modelled after ISO 15527:2007

Target
The sand-slurry test is used to assess the resistance of plastics to abrasive wear in a sand-water mixture.

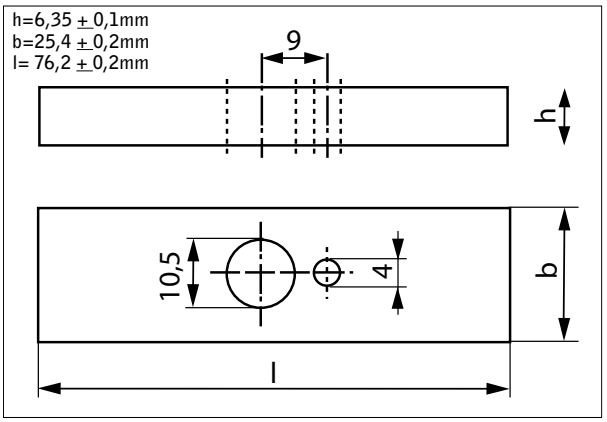
Procedure
The test is performed by two rotating spindles in a pot with the abrasive wear medium (sand-water mixture, 60:40). On the test specimen recorder of one of those spindles a reference specimen from ST-37 get's screwed, on the other spindle the sample body. The spindle distance is 113mm, the distance from the sample to the ground: 40 mm

Dimensions of wear pot:
Inside Ø 210 mm;
outside Ø = 260 mm;
internal height = 300 mm



test device

Test parameters
- > Number of revolutions [1/min]: 1200
- > Duration [h] 7,5 in 2 intervals
- > 1 interval at n= 1200 3 h,
- > 2 interval at n= 1750 4,5 h
- > Abrasive mixture: Silicate sand, grain size0,2 to 1mm,
- > Mixing ratio: (3:2) = 60 weight % sand + 40 weight. % water)



Specimen

Test specimen
There are used by machining manufactured and conditioned specimens, as shown on the adjacent figure.

Characteristic value
Dimensions of the specimens
Surrounding temperature
Temperature of the abrasive medium
Mixing ratio sand : water
Conditioning
Mass of the samples before and after the experiment
Mass and volume loss
Level of abrasion= $\Delta m_{Specimen} - \Delta m_{Reference}$

Evaluation
The mass loss of the samples is evaluated in relation to the mass loss of the reference body, from this the degree of abrasion is determined

Determination of wear and friction values („Pin on Disk")

Standard: Factory standard PVLAB14 **Comparable standard:** ASTM G 99

Target
Determining the wear and friction coefficients depending on the load, sliding speed and temperature of tribological systems with rotary motion

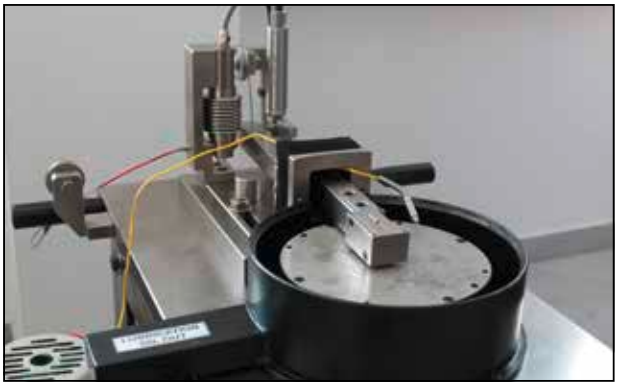
Procedure
The test is performed according to factory standard PVLAB14.

Test parameters
> Contact ratio (point level)
> Motion (rotary / from 0.025 to 15 m / s)
> Force (5 - 200 N), surface pressure: 0,05 - 28 N/mm²)
> Medium (lubrication with oil or water)
> Environment (air, inert gas)
> Temperature
> Material (Surface, Coatings)

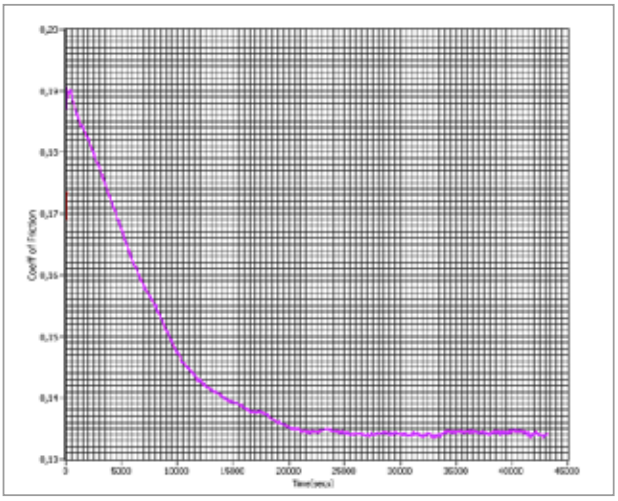
Test specimen
Pin: Ø 4/8 x 25mm
Counterface: steel, Rz 3µm
Radius: 40mm

Characteristic value
μ_g *coefficient of sliding friction*
V_{spez} *Specific wear volume = Wear volume / sliding distance*

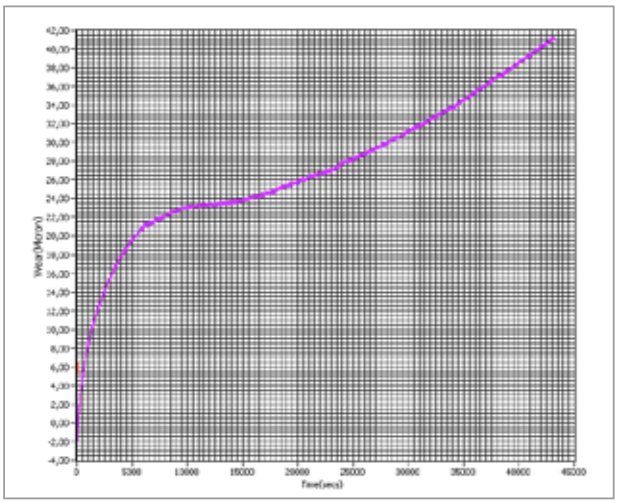
Evaluation
The wear track is calculated from the digitally recorded wear depth. Friction and temperature profile are digitally recorded and then taken from the respective graphs. Additionally, a visual inspection is getting accomplished.



Test bench



Coefficient of friction as a function of time



Wear in function of time

Determination of wear and friction values with the aid of SRV

Standard: factory standard

PVLAB13(friction)

PVLAB13-2 (wear)

Target
Determining the wear and friction coefficients depending on the load, sliding speed, lubricant, temperature of tribological systems.

Procedure
A counter body (eg pen) is oscillatingly with a certain amplitude and frequency moved against a clamped specimen. In the course of the experiment a material removal takes place.

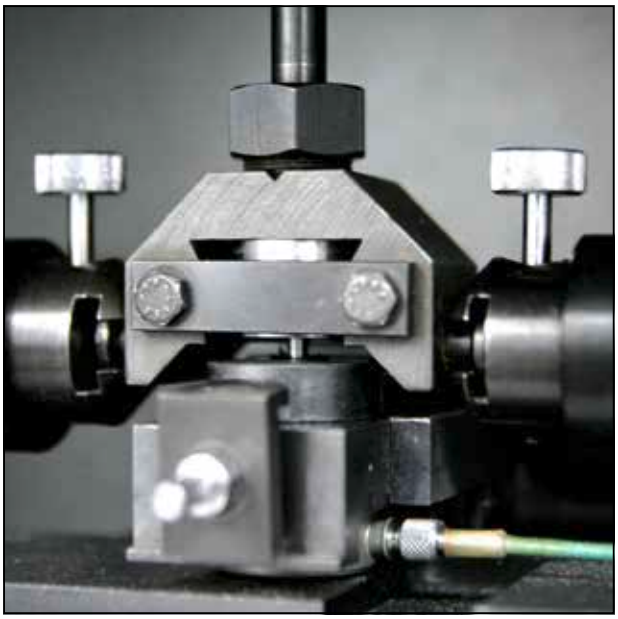
Test parameters
> Contact ratio
(Point-level, level-level, line-level)
> Motion (hub to 3 mm amplitude, frequency to 500 Hz)
> Force (to 1200 N)
> Medium (lubrication with oil or water ...)
> Environment (air, inert gas ...)
> Temperature (250 ° C)
> Material
(Surface roughness, coating ...)

Test specimen
slice of Ø 24 x 8 mm.

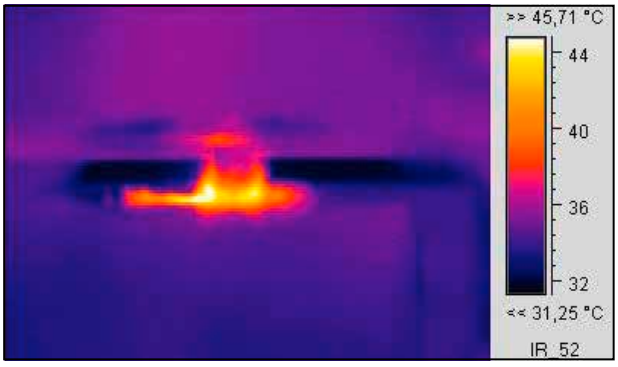
Characteristic value

$\mu_{H,G}$ *Adhesion, coefficient of sliding friction. Higher resolution with SRV method, and larger variation possibilities of the test parameters.*

V_{spez} *Specific wear volume = volume of wear / sliding distance*

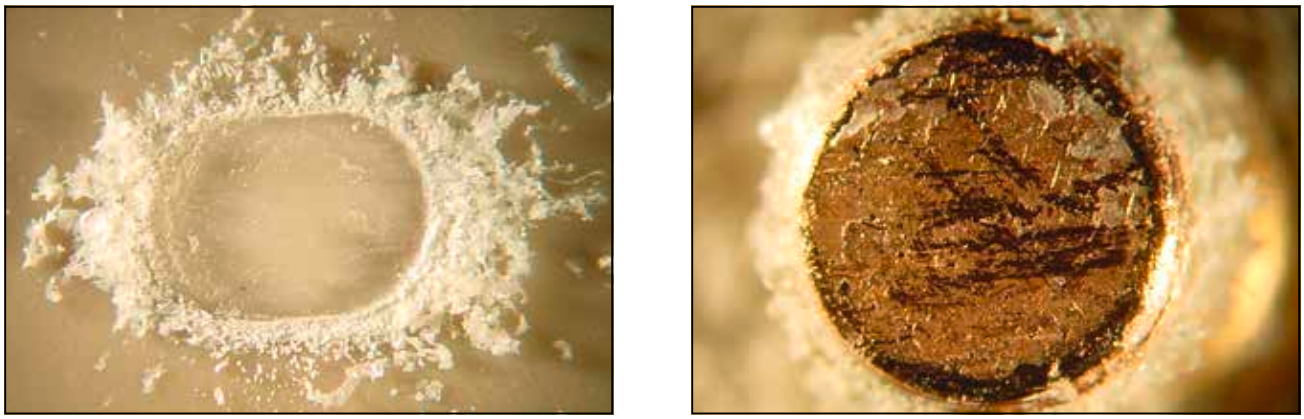


Oscillation block with test specimen

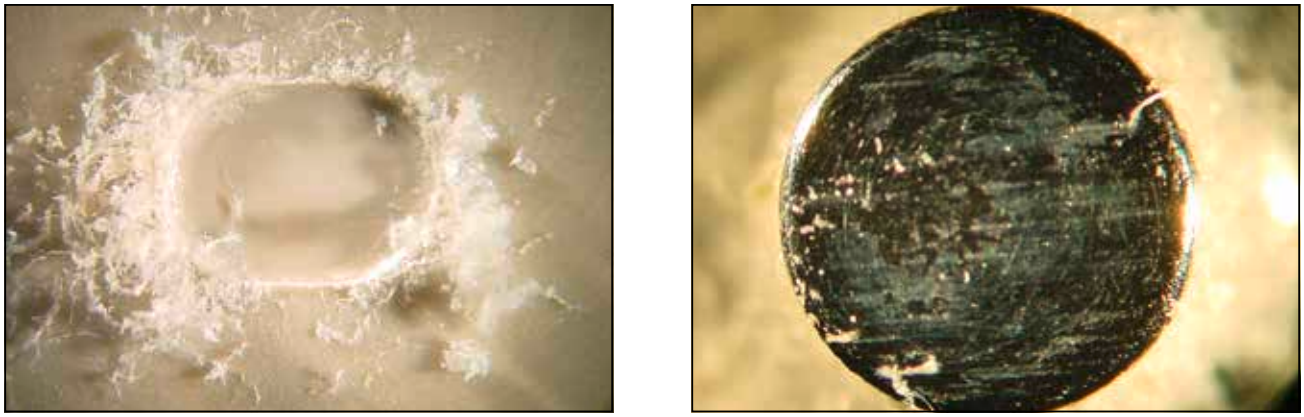


Detail view with IR camera

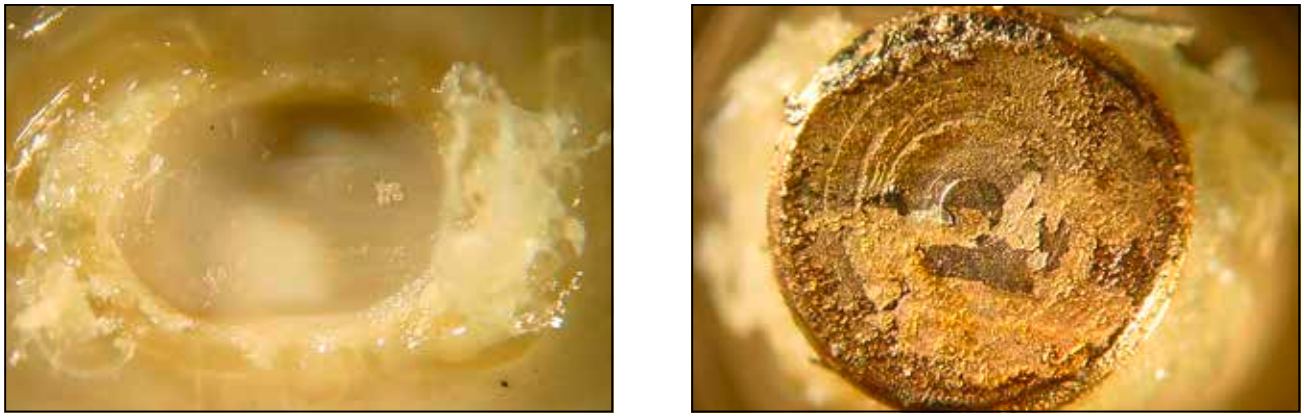
Evaluation
The wear mark gets measured. Friction coefficients are digitally recorded and then taken from friction charts. Additionally, a visual inspection.



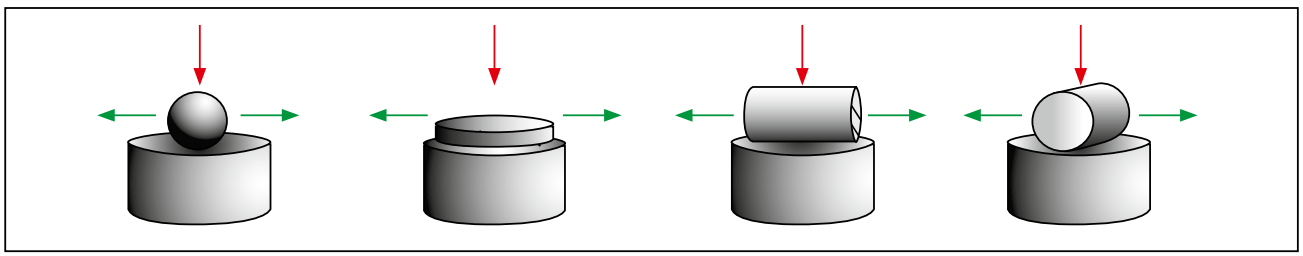
Covering material and specimens with oscillation-wear track.



Covering material after 120 min. 6x magnification, specimen with oscillating wear track.



Covering material after 30 min. 6x magnification, specimen with oscillating wear track.



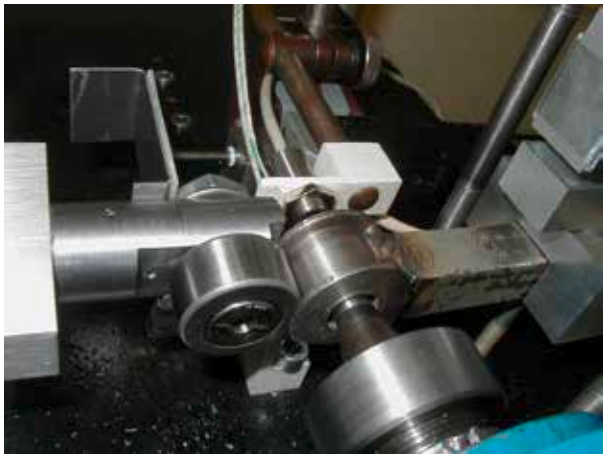
Contact conditions are point, line, or contact surfaces of the specimens.

Conduction of plain bearing tests (Determining of pv-limit values)

Standard: Factory standard PVLAB07

Target
With this test, the PV value of plain bearing bushes is determined. The PV value is an important parameter for the design of bearings. In it the influences of wear, temperature, surface pressure and sliding speed are already included. The result is a limit curve, from which the respective maximum surface pressure at certain sliding velocities can be read. Those values are at a point, where just barely no failure during operation is threatening.

Procedure
The test specimen (bushing) is getting pressed into a housing and loaded in radial or axial direction while the shaft is rotating. The test duration is predetermined. After the test duration will be decided on the basis of defined criteria, whether the bearing has withstood the loads (P, V, T).
The regulation, measurement reporting and the evaluation is carried out by computer.



Test facility (detailed view)

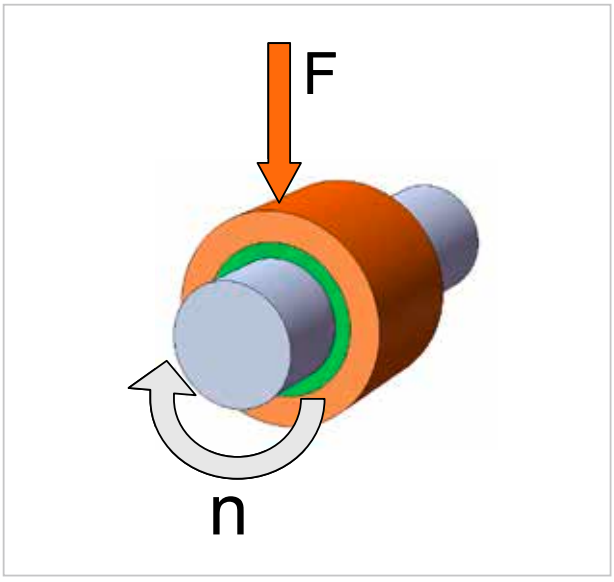
Test parameters
- Lubrication (dry/oiled/water)
- Test duration (normally 3 h)
- Temperature
- Direction of load (Axial/Radial)
- Value of load
- Sliding velocity
  (0.5, 1, 3, 10, 40, 100, 200, 250, 300 m/ min)

Test specimen
Radial: Cylindric plastic bushing with
Øa= 16, Øi =12 mm, L= 9 mm
Øa= 50, Øi= 45 mm, L= 24 mm

Axial: Flanged bushes with
Øa= 18, Øi= 12, $Ø_{Flange}$= 24 mm, L=10 mm, L_{Flange}=3 mm

Characteristic value
pv-value = Surface pressure x sliding velocity

$$\left[\frac{N}{mm^2} \cdot \frac{m}{\min}\right]$$



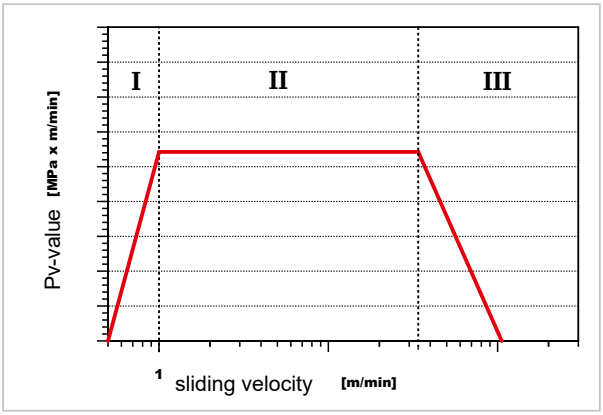
Principle (radial load)

Distinctive sections
The PV value is a measure for into the system introduced power per unit area, which must be absorbed by the sliding bearing. Typical curves are divided into three areas, whose main causes are different (see figure at right).

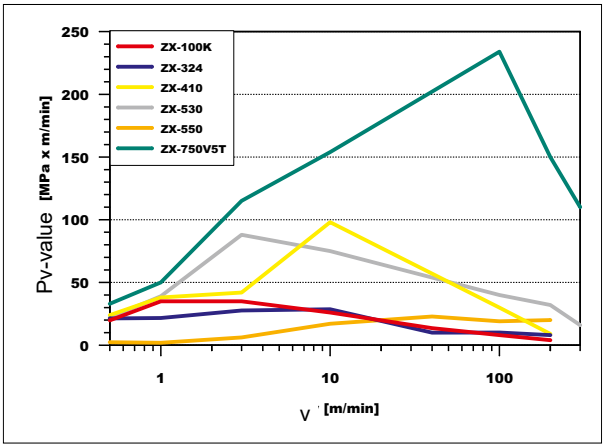
Section I
Slow sliding velocities are leading to deformations because of reaching the maximum permissible surface pressure.

Section II
Section II is a hybrid from the sections I and III.

Section III
At high sliding speeds and larger sliding distances it first comes to increased wear. Additionally the operating temperature rises. The plastics are losing a significant part of their strength. Through further increasing of the sliding velocity it might be caused a melting of the material and higher friction values. Reasons for this may be too low bearing clearance and differential thermal expansion. The PV value is an important design criterion for plain bearings.



typical pv value-curve



pv limit values

Evaluation
The PV limit value curve is graphically displayed on a graph, based on max. 9 support points (0.5 - 300 m / min)

Conducting of lifetime tests (Wear in dependence of the sliding partner)

Standard: Factory standard PVLAB09

Target
The aim of the lifetime test is to determine the wear of plastics at the maximum possible running distance, depending on the sliding partners. Based on this, the optimal sliding partner for plastics is getting determined.

Procedure
A rotating shaft, having a different hardness and surface roughness is mounted in a socket which is charged through a pressure cylinder with radial force.

The bearing tight fit seat get's checked during the test. If it get's lost the test is prematurely terminated. It also ends, when the bearing melts or an enlargement of the inner diameter of more than 0.5mm is determined. The inner diameter is measured 3 times a day.

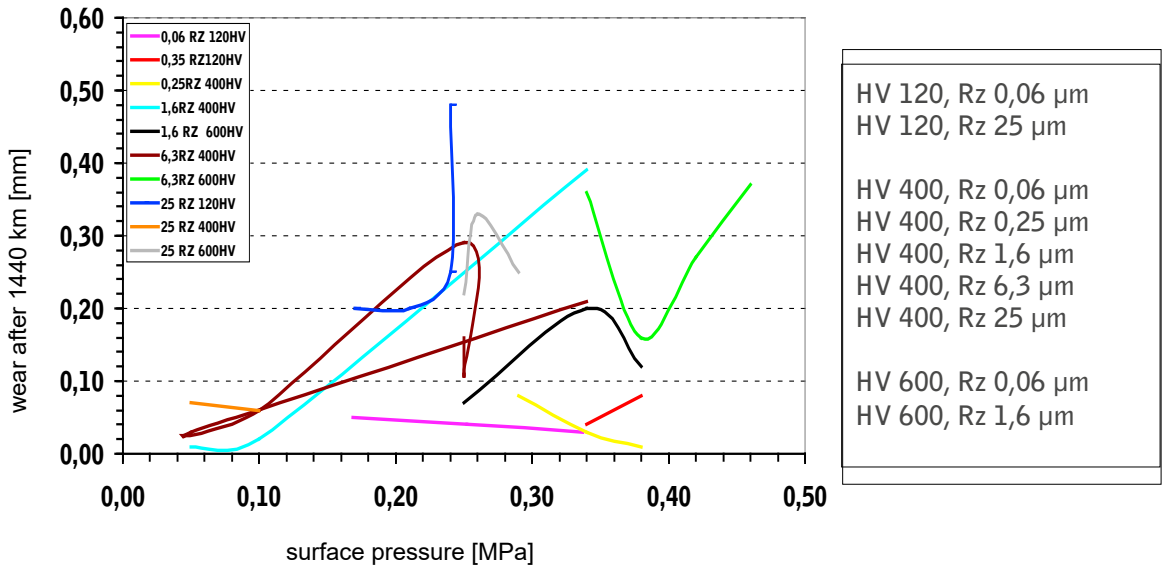
Test parameters
> Radial force (5,4N and 10,8N)
> Peripheral speed (97,3 m/min and 192,3 m/min
> Lubrication (dry/water/oiled)
> Sliding partner (shafts), characterized by surface roughness and vickers hardness.

Test specimen
Sockets, molded or turned in the same dimension and quality.

$Ød_a$ = (16,08-16,12) mm
$Ød_i$ = 12,08 mm
L = 9 mm

Characteristic value
The wear is shown graphically in variation of hardness and roughness in function of the surface pressure. On the basis of this, the optimum sliding partner get's determined.

Evaluation
The wear is shown in a graph, in function of surface pressure, surface roughness and hardness of the sliding partner.



Performing of spindle nut tests (determining of the max. axial force)

Standard: Factory standard PVLAB01

Target
With the aid of a test bench, the maximum axial movement of a plastic nut with trapezoidal thread (Tr 18 x 4) is getting determined at a certain rotational speed.

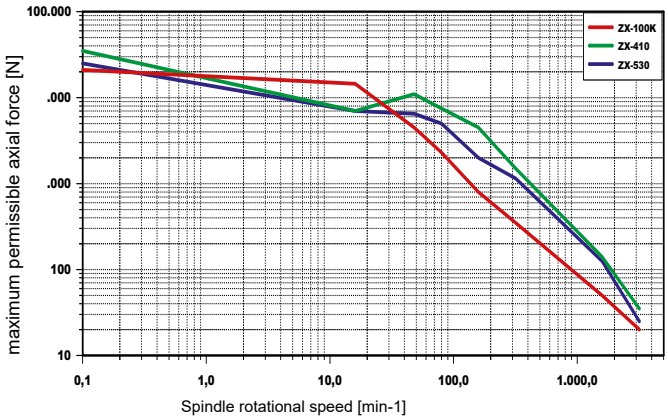
Procedure
In this experiment, a spindle nut is charged by a crossbar with a weight. A motor drives a threaded spindle resulting in a upward and downward movement of the spindle nut.

Test parameters
> Load (1000 - 6000 N)
> Peripheral speed of the spindlel (max. 19,9 m/ min with a translation of 1:4 resp. max. 5,32 m/ min, at a translation of1:16)
> rotational speeds: gear 1:4 -> 0-353 min^{-1}; gear 1:16 -> 0-94 min^{-1}
> Max. axial velocity: gear 1:4 -> 1,4 m/min; gear 1:16 -> 0,376 m/min
> Peripheral velocity for tests: 5; 10; 20; 33 mm/min
> Lubrication (dry/oiled)
> Duty cycle (100% = 5 Std.)

Test specimen
The specimens are plastic spindle nuts with a trapezoidal thread TR 18 x.4

Specimen

Evaluation
The evaluation is based on the recorded values. The results are shown in axial load diagrams and temperature-time-diagrams. From the former, the maximum axial load can be determined, which a moving nut might tolerate.



Axial force in depence of the spindle rotational speed

Electrical tests 54-55

Determining the electrical surface resistance

Standard: modelled after DIN IEC 60093

Target
By means of a probe with two concentric ring electrodes, which can be connected to different measuring devices, the surface resistance can be measured. The surface resistance is the electrical resistance of a test specimen between two electrodes. The value depends on humidity, impurities, specimen size, electrode shape and arrangement of the electrodes .

Procedure
The probe is pushed on the speciman, then a test voltage is applied and the surface resistance can be taken of the device's display.

Test parameters
> El. surface resistance: 50Ω– 1TΩ depended on measuring device

Test specimen
Independend of the thickness, but min. Diameter 70mm

Characteristic value
From the individual measurements we obtain the average surface resistance R_o [TΩ].

Surface resistance measuring electrode

Evaluation
The surface resistance could be read directly from the display of the measuring devise. The several measurements get builded to an average value.

Determination of electrical breakdown resistance

Standard: modelled after DIN IEC 60243

Description
The electrical breakdown resistance is the resistance of an Insulator against electrical breakdown.
It is dependent from the material thickness and sample thickness

Procedure
The experiment is carried out according to DIN IEC 60243. A specimen is clamped between two contacts and dipped in an oil bath (elec. Insulation). The voltage is increased at a constant adjustable speed until it comes to the punch. That means the electric current flows from one contact, by destruction of the sample material, to the other contact.

Test parameters
> Amperage (5 mA to 20 mA)
> Speed of the voltage increase (0,5kV/sec to 3kV/sec)

Test specimen
80 x 80 mm or Ø80 mm, 1-3mm thickness

Characteristic value
From the individual measurements the average penetration resistance could be calculated.

electrical breakdown resistance $= \frac{U_d\ [kV]}{s\ [mm]}$

U_d = *Penetration voltage in kV*
s = *Thickness of the specimen in mm*

Experimental setup

Evaluation
The break down voltage, which is shown in kV directly on the scale gets divided by the thickness of the sample.

Other tests 55-66

Colorimetric determination of colourimetric numbers and color differences in the CIELAB color space

Standard: DIN 6174

Target
Determining of the color tone in the CIE L*a*b* color space and conversion into the RAL-colorsystem.

Procedure
The measuring device operates according to the principle of a spectrophotometer. This means that it measures the remission values of the visible light in the entire spectrum (Infrared to ultraviolet).

Test specimen
Not further specified. at least Ø 6 mm.

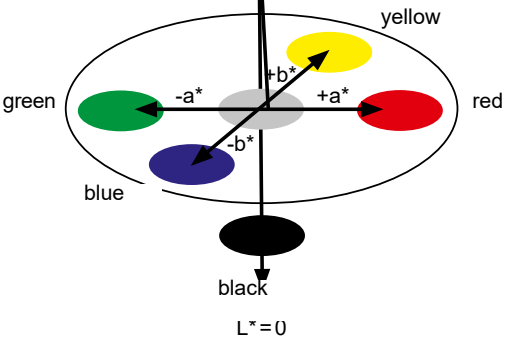
Characteristic value

*L**	*Luminance,*
*a**	*Red-green-parameter*
*b**	*Yellow-blue-parameter*

With these three parameters, the result can be clearly shown in the CIE L * a * b * color space

Evaluation
Measurement results are recorded digitally and stored in a database. The conversion into other colorsystems like for example the RAL-colorsystem is done by the corresponding program.

Color measuring device



*CIE L*a*b* colour space*

Determining of the specific density

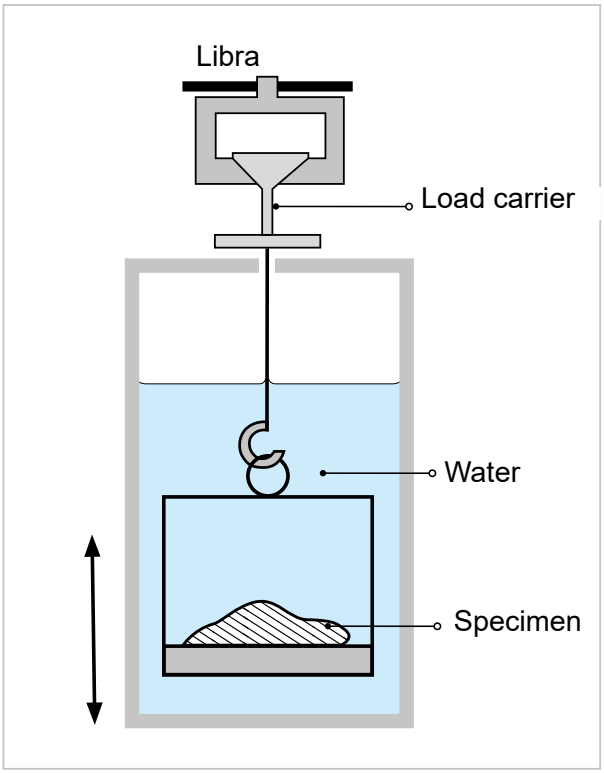
Standard: Factory standard PVEXT03

Target
The specific density of plastic can be measured with the aid of this test. With density is meant the mass of a workpiece refered to it's volume.

Procedure
The test is performed according to the archimedes principle. The mass of the test specimen is first determined in air. This is followed by weighing the specimen in water.The difference between the two weighings corresponds to the buoyancy (= Weight force of the displaced water, because water=1 kg/ dm^3).

Test specimen
Not further specified. Deburred, void-free sample up to 5 g, or 20 x 10 x 5 mm.

Characteristic value
ρ *Denisity [kg/dm^3]*
m *Weight [kg]*
V *Volume [dm^3]*



Density measurement, archimedes principle

Evaluation
With the known density of water (1.0 kg / dm^3) the volume of displaced water can be determined and thereby the volume of the test specimen.
Thereby the density of the specimen can be determined.

Density = Weight/ Volume

FT-IR-spectroscopy

Standard: factory standard PVLAB12

Target

With the aid of infrared spectroscopy, it is possible to examine the type and composition of materials.

Procedure

Means of an interferometer light beams are separated, spatially displaced from each other and superimposed again. Thereby the material-specific IR spectra could be calculated with mathematical algorithms.

Specimen

Solid or liquid samples. Solid samples may also be in powder form. Otherwise, the samples must be free of burrs and grease. Minimum dimensions about 3 mm diameter (corresponds to diameter of the crystal).

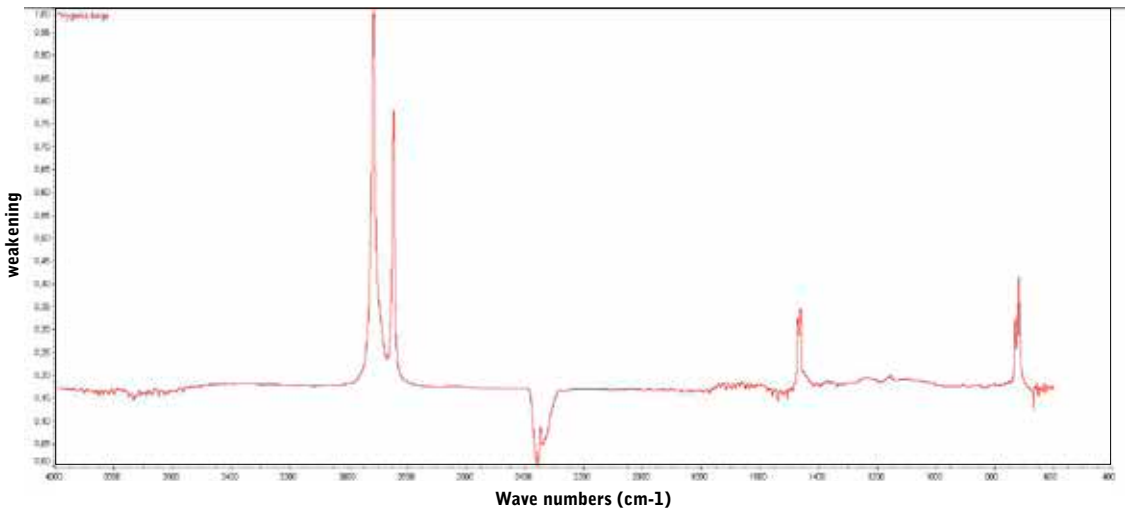
Characteristic value

Characteristic values are significant bands. They are unique for each material in their combination and therefore characteristic. Listed will be the location (wave numbers) and intensity (weakening) of the bands.

FT-IR spectrometer

Evaluation

With the aid of infrared spectroscopy, it is possible to examine the type and composition of materials. The recorded spectra can then be compared with a reference stored in a database. Therefore, the statement can be made about which material it is



infrared Spectroscopy

Determining the residual moisture

Standard: Factory standard PVEXT08

Target
The experiment is used to determine the water content in solids by the combined methods of thermal analysis and coulometry.

Procedure
With a defined temperature profile, a sample is heated in the oven of the device. Due to the heating the surface water and capillary water is evaporating. The leaked moisture is transported by air flow (nitrogen) from the sample to the electrochemical sensor. The other substances, such as plasticizers or residual monomers, may also escape during the measurement, but they are not counted by the sensor.The sensor enables the selective and quantitative detection of the leaked water, without the other substances.

Test parameters
> Temperature measuring area: 25-400°C
> Measurement sensitivity: 0,001-15% water content
> Measuring time:< 25min (usually)
> Inert atmosphere: measured in dry, nitrogen possible

Test specimen
2-2000mg (granule/powder)

Characteristic value
Absolute and relative water content of the samples, amount of water emerging at any time during the measurement.

Humidity measuring instrument

Evaluation
The evaluation is carried out using the appropriate software.

Determination of water absorption

Standard: DIN EN ISO 175 **Comparable standard:** DIN 53476

Target
The test is used to determine the material properties of plastics after storage in a liquid, mass and volume increase.

Procedure
A test specimen is stored in a test specimen liquid for a certain period of time at defined climatic conditions.

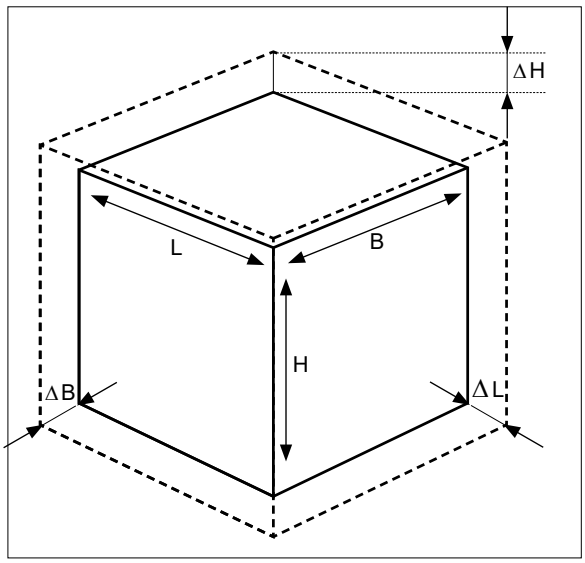
Test parameters
> Type of liquid
> Storage period
> Temperature

Test specimen
according to DIN EN ISO 175:
Rectangular prism with 60 mm edge length, or rod with Ø 60 and l = 60 mm.

Characteristic value

$\Delta m_{\%}$	*Mass increase in percent*
m_1	*Mass at test beginning*
m_2	*Mass directly after test ending*
m_3	*Mass after test ending and drying*
Q'	*Volume increase in percent*

After the end of the test qualitative statements are obtained.



No change
Properties haven't changed.

Barely measurable
Individual characteristics might have changed, but have no further influence.

Slight change
Changes are detectable, but have no serious influence on the material properties.

Mean change
Significant changes in the material properties.

Substantial
Fatal changes.

Evaluation
It is determined the percentage increase in mass (volume increase).Before and after the mechanical, physical, thermal and other properties can be determined.

Ultrasound examination

Standard: Factory standard PVEXT09

Target
The ultrasound examination enables a nondestructive identification of voids and cavities in semi-finished plastics.

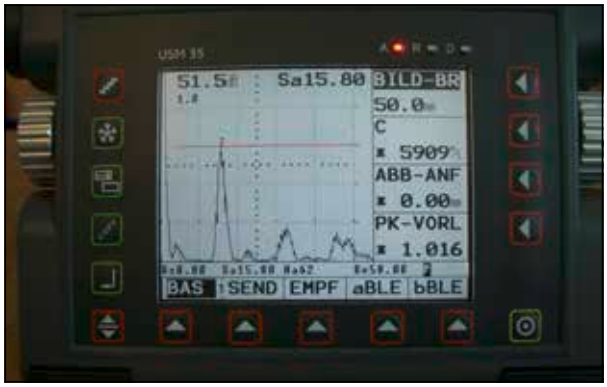
Procedure
In the ultrasonic examination a test-head is positioned on the material surface.Between the test-head and the semifinished product a coupling agent is applied. The test-head sends out an ultrasonic pulse which gets reflected at the fault point. (echo) The returning sonic pulse gets then registered by the test-head. The position of voids and cavities can be detected from the transit time of the sonic pulse, when the sonic velocity has been determinded previously and is known.

Test parameters
> Checked material
> Shape and dimensions of the sample
> Fillers, dyes, pigments
> Sonic velocity [m/s]

Test specimen
There are no specified specimen prescribed. The test can be performed on semifinished products during the running extrusion process or on sawed-off sections.

Characteristic value
Detected voids [number / m] depth [mm]

Ultrasonic test-head



Display of measuring instrument

Evalutation
The position of the echo is shown on the display of the measuring instrument

Determining the surface quality with the aid of a perthometer

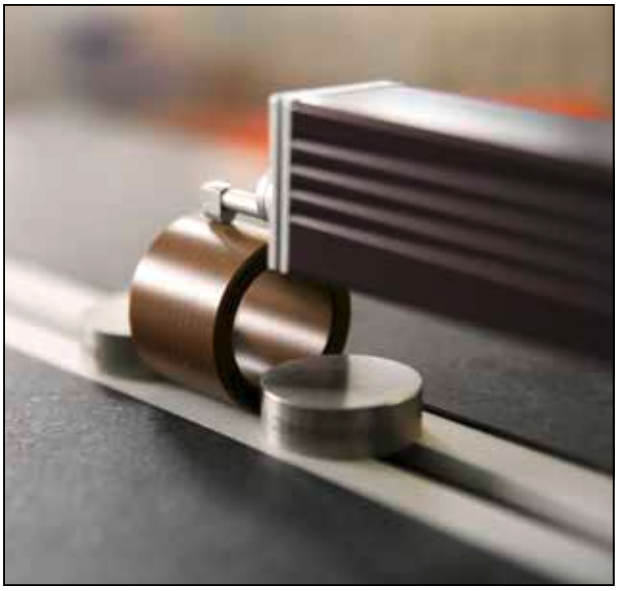
Standard: DIN EN ISO 4287

Target
Determination of surface roughness and the surface profile of finished plastic parts.

Procedure
The measurement is performed with a Perthometer. The filtered roughness profile (R-profile), and the unfiltered P-profile can be measured.

Test parameters
> Test speed
> Filtering
> Length and number of sampling lengths
> Optional parameters (characteristic value)

Test specimen
Not further specified



Measuring device

Evaluation
The recorded profile is created directly in digital format by the Perthometer. The Parameters get calculated automatically.

Kennwertangaben

Ra Arithmetic average of the profile deviations
Rq Quadratic average of the profile deviations
Rz Maximum height of the profile
Rp Height of the largest profile peak
Rv Depth of the the deepest profile valley
Rt Total height of the profile
Da Average of the profile rising
Rsm Average groove wide of the profile elements
Rsk Skewness of the profile,
sk-value>0 -> abrasive
sk-value<0 -> abrasion resistant
sk-value=0 -> same number of peaks /valleys
Rk Core roughness depth
Rku Steepness of the profile
(=1-> smooth, >1->pointed)
RPc Peak counting
S Mean distance of the local peaks
HSC Count High Tops
Mr1 Material ratio (upper limit)
Mr2 Material ratio (lower limit)
Rmax Rt the measuring length
Rc Mean height of profile elements
mrc Material ratio of the profile
A1 Tip surface
A2 Valley surface
Vo Volume measurement
Rvk Average depth of the under the core profile projecting tips
Rpk Average depth of the over the core profile projecting tipsn

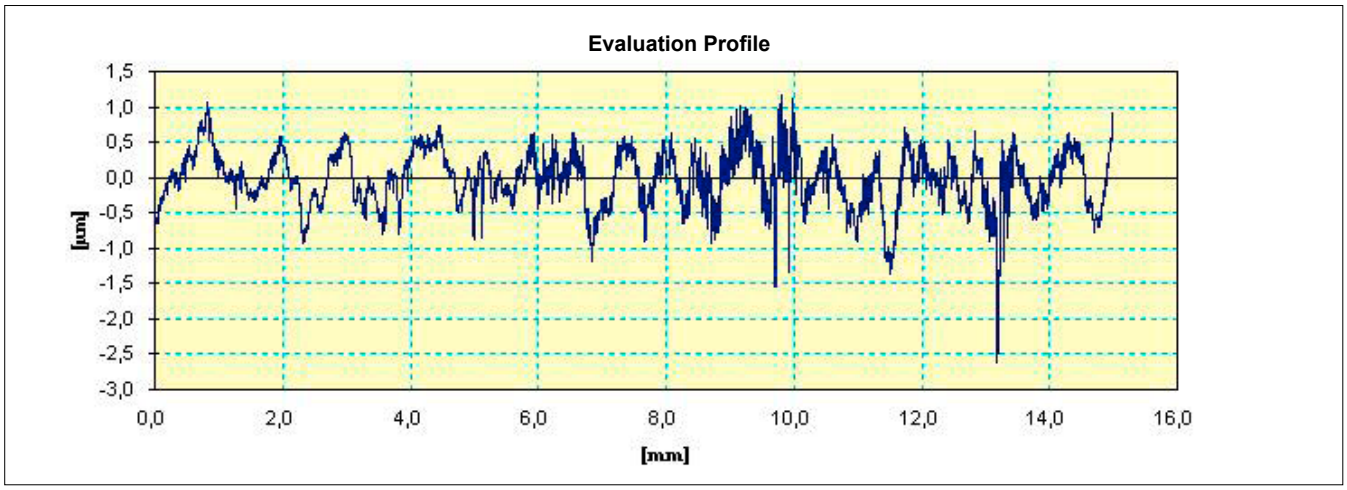


Diagram surface quality

Work Name	Test 1	User	Mitutoyo
Measuring Tool	Surf Test SJ-210	Comment	Version 1.00

Standard	FREE	N	6
Profile	R	Cut-Off	2,5 mm
λs	NONE	Filter	GAUSS

Ra	0,314 µm	S	93,6 µm
Rq	0,398 µm	HSC	81,85 /cm
Rz	2,311 µm	RzJIS	L1,492 um
Ry	2,311 µm	Rppi	53,42 /E
Rp	0,888 µm	RDa	0,031
Rv	1,423 µm	RDq	0,043
R3z	1,263 µm	RIr	1,001
Rsk	-0,566	Rmr	0,040 %
Rku	3,908	Rmr(c)	11,140 %
Rc	1,269 um	Rmr(c)	23,521 %
RPc	21,03 /cm	Rdc	0,193 um
RSm	475,5 µm	Rt	3,786 um
Rpm	0,888 µm	Mr1	6,26 %
Rku	1,035 µm	Mr2	89,99 %
Rpk	0,326 µm	A1	1,02
Rvk	0,512 µm	A2	2,56
		Vo	0,0026

Table surface quality

Examination of the wettability (surface tension with the aid of test inks Method)

Standard: modelled after ASTM D 2578-84

Target
The experiment is used to evaluate the wettability of surfaces, which is for example very important when the workpiece needs to be glued or painted. We carry out the test after the principle of the test inks method. Therefore we have several test inks with different surface tensions to select from.

Procedure
After a thorough cleaning of the test specimens surface the test ink get's applied with a brush stroke. It will be started with the test ink which has the highest surface tension. If the line is not shrinking together on the edges within 3 seconds, it does mean, that the surface is well wettable.
The surface tension of the test body corresponds then to at least the same value of the test ink. If the line is shrinking together, the surface tension of the specimens lay beneath the value of the test ink.
The next step is to approach gradually to the surface tension of the specimen. The process get's repeated with the next lower test ink, until the surface tension of the specimen is at least equal with the value of the test ink.

Test parameters
Test ink with 18-48 mN/m

Test specimen
There are no prescribed specific specimen dimensions. However, the surface must be clean (free of grease) and flat.

Characteristic value
The characteristic value is the surface tension in mN/m.

Test ink method

Evaluation
The flow together of the different test inks get compared. This gives a comparison of the surface tension from the test specimen with the surface tension of the test ink.

Costumer specific tests 68-70

Workpiece analysis

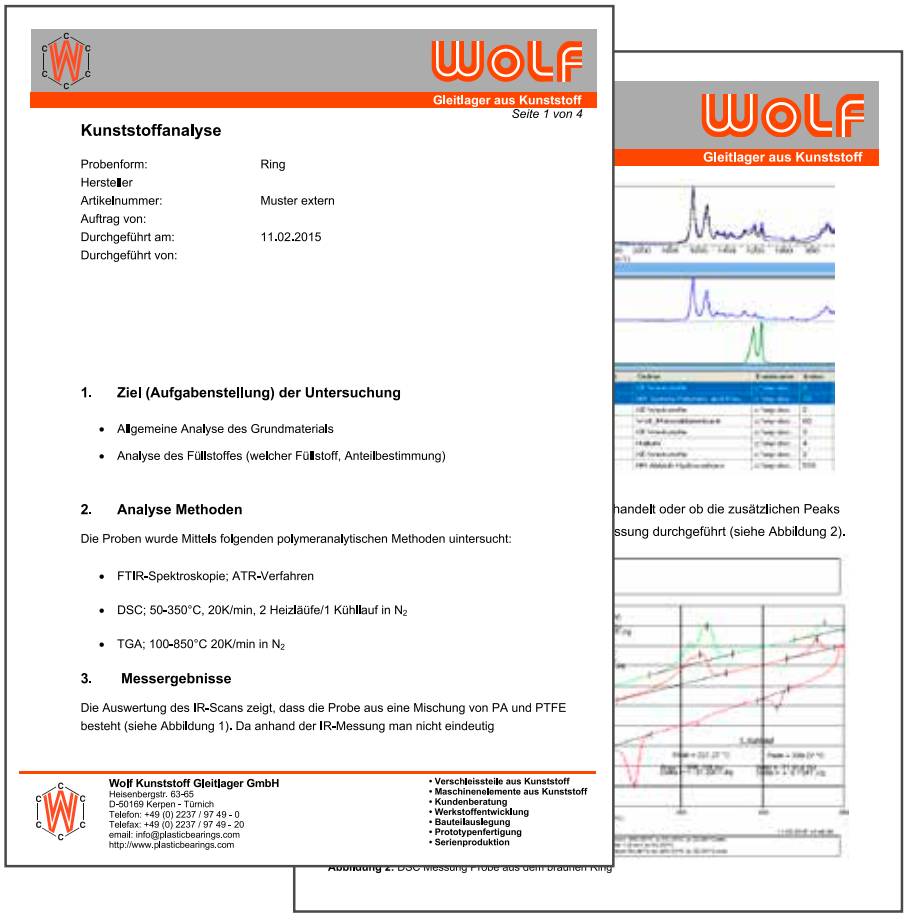
Determination of the material at unknown samples

In a combination of several individual tests we can determine unknown specimens made of plastic and make statements of the base polymer, which components and fillers are included and in what proportions.

Normally the following analytical methods for material analysis are sufficying:

> FT-IR for the determination of the base polymer
> DSC to determine the melting temperature and the glass transition temperature
> TGA for determining the proportions of components and to detect fillers
> If necessary, the test series is complemented by microscopic examinations.

Send us a material sample - we'll tell you then, which material it is and can recommend you on request a suitable alternative material from our program.
You will receive from us a detailed report with the results and evaluations of all individual tests. The test report is available in german and in english language.



WOLF
Gleitlager aus Kunststoff
Seite 1 von 4

Kunststoffanalyse

Probenform: Ring
Hersteller
Artikelnummer: Muster extern
Auftrag von:
Durchgeführt am: 11.02.2015
Durchgeführt von:

1. Ziel (Aufgabenstellung) der Untersuchung

- Allgemeine Analyse des Grundmaterials
- Analyse des Füllstoffes (welcher Füllstoff, Anteilbestimmung)

2. Analyse Methoden

Die Proben wurde Mittels folgenden polymeranalytischen Methoden uintersucht:

- FTIR-Spektroskopie; ATR-Verfahren
- DSC; 50-350°C, 20K/min, 2 Heizläufe/1 Kühllauf in N_2
- TGA; 100-850°C 20K/min in N_2

3. Messergebnisse

Die Auswertung des IR-Scans zeigt, dass die Probe aus eine Mischung von PA und PTFE besteht (siehe Abbildung 1). Da anhand der IR-Messung man nicht eindeutig

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- Verschleissteile aus Kunststoff
- Maschinenelemente aus Kunststoff
- Kundenberatung
- Werkstoffentwicklung
- Bauteilauslegung
- Prototypenfertigung
- Serienproduktion

WOLF
Gleitlager aus Kunststoff

handelt oder ob die zusätzlichen Peaks
ssung durchgeführt (siehe Abbildung 2).

Excerpt from a test report

Damage analysis

Determination of failure causes / Analysis of material errors

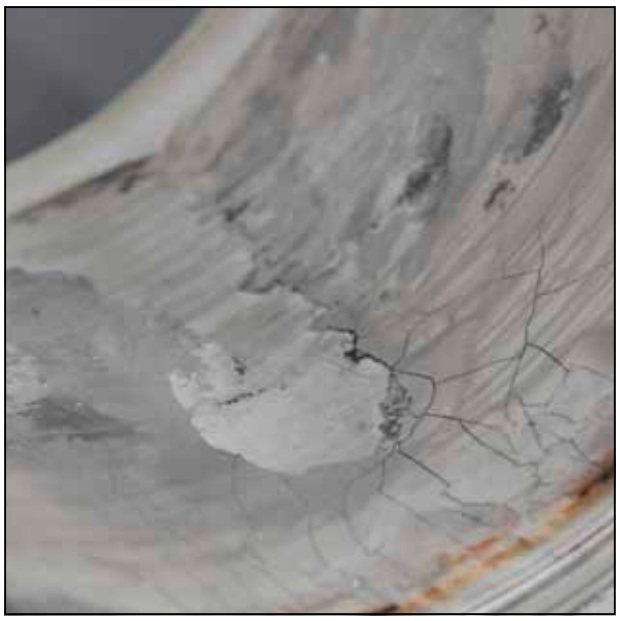
Failures of components made of plastic can have different causes, eg

> Mechanical or thermal overloading
> Influence of chemicals
> Material error
> Processing error
> Environmental influences (e.g. UV radiation)

External indications can be:

> Discoloration
> Cracks, breakage
> Wear is too high
> Plastic deformation, arrears
> Melted areas

With the help of our testing and analysis capabilities, we can determine the cause of failure in most cases, and propose necessary measures to remedy or prevent.

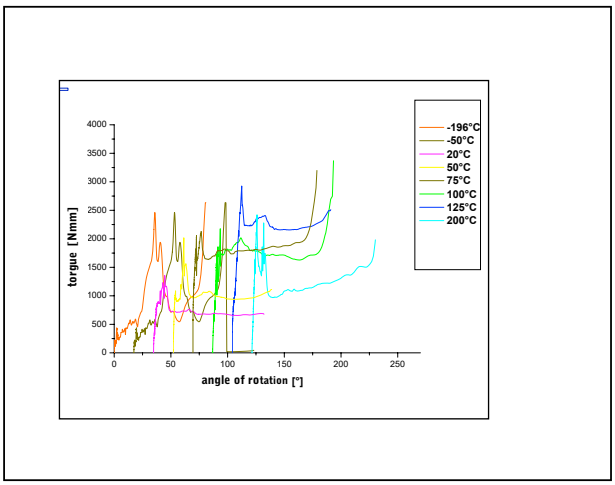


Example:
Molten areas because of too high surface speed and simultaneously too high mechanical load.

Customized component tests

On request we perform tests for you, specially tailored to your application and component stress

Example: Pressure test on sealing rings from ZX-324 (axial and radial). It was determined, in which force a permanent deformation occurs respectively at which force the rings break



Example: Determination of switching torque of a ball valve with ball seals from ZX-324 at extreme temperatures from -196 to + 200 ° C

Minimum amount of sample

To perform a meaningful test series following amounts of semi-finished products are required, depending on the experiment.

Attempt	Standard	Specimen quantity	Semifinished product minimum amount (if no test specimen present)
Mechanical tests			
Determining of tensile properties	DIN EN ISO 527-1	5	Rod Ø 22 x 2000 mm or plate 250 x 500 x 4 mm
Determining of presure properties	DIN EN ISO 604	5	Rod Ø 8, length: Compressive strength: 200 mm, compressive modulus: 1000 mm
Determining of bending properties	DIN EN ISO 178	5	Rod Ø 15 x 500 mm or plate 100 x 80 x 4 mm
Determining of creep behaviour part1:in tensile creep test part2:creep test at 3-point bending	DIN EN ISO 899-1DIN EN ISO 899-2	5	See tensile test (899-1)resp. 3-point bending (899-2)
Determining of ball indentation hardness through ball indentation test	DIN EN ISO 2039PVEXT06	5	Rod Ø 30 x 400 mm or plate 20 x 400 x 4 mm
Determining of indentation hardness with a durometer (Shore-hardnes A / D)	DIN EN ISO 868	5	Ø 10 x 25 mm or plate 12 x 12 x 6 mm
Determining of the charpy-impact - properties (unnotched / notched)	DIN EN ISO 179PVEXT06	10	Ø 15 x 500 mm or plate 100 x 80 x 4 mm
Determination of tensile shear strength and fatigue strength of bonded specimens.	DIN EN 1465 PVLAB02	5	5 plates, format for at least. 5 pieces 100 x 25 x 2 mm for each both adherends.
Conducting of thread pull-out test	PVLAB03	5	Rod Ø 35 x 250 mm or plate 120 x 70 x 32 mm
Determining of tensile, compressive and bending properties with the Eplexor	PVLAB16	5	5 rectangular stripes 70 x 10 x 2mm
Determination of compression set after constant deformation	DIN 53517	3	round rod Ø30 x200mm
Thermical tests			
DSC (differential scanning calorimeter)	PVLAB04	1	5 g granule
Thermomechanical analyzer (TMA)	DIN EN ISO 53752	1	Rod Ø 8 x 125 mm
Thermogravimetric analyzer (TGA)	PVLAB06	1	10 mg (powder oder granule grain)
Dynamic mechanical analzyer (DMA)	PVLAB05	1	Rod Ø 6 x 150 mm, plate 25 x 100 x 2 mm
Determination of heat distortion resistance	DIN EN ISO 75-1/2	3	see 3 point bending test
Determining the max. Bearing interference fit temperature of pressed bushings	PVLAB10	1	See slide bearing experiments (PV limits values)
Determining the thermal conductivity	DIN EN ISO 75-1/2	1	Ø6 x 35mm or 4 x 5 x 35mm
Determining the oxygen index	IEC 695	10	150 x 8 x 4mm
Determination of the melt mass-flow rate and melt volume-flow rate	DIN EN ISO 1133	1	Component or 30 g granule / fragments
Rheological measurments	PVEXT04		Granules

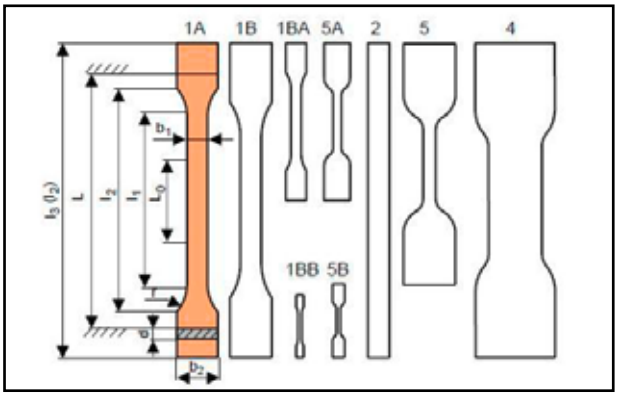
Tribological tests			
Determining of friction value at 25°C, dry	PVLAB08	4	Rod Ø 15 x 60 mm or plate 10 x 40 x 4 mm (per temperature stage)
Determination of wear at translational sliding movement	PVLAB11	4	Rod Ø 15 x 60 mm or plate 10 x 40 x 4 mm (per temperature stage)
Determination of abrasion resistance - Taber Abrasion Tester ("Taber Abraser")	DIN EN ISO 5470-1	1	Disc with > Ø100mm, 3mm thickness or plate with > 100 x 100 mm, 2mm thickness
Determination of abrasion wear with the sand slurry method	In Anlehnung an ISO 15527	1	plate 80 x 30 x 7mm
Determination of wear and friction values („Pin on Disk")	PVLAB14ASTM G99	1	Pin: Ø 3 -12 x 400mm, disc Ø20 -165 x 100
Determination of wear and friction values with the aid of SRV	PVLAB13	1	Pin: Ø 20 x 70 mm, disc: Ø 25 x 60 mm
Conduction of plain bearing tests (determining of pv-limit values)	PVLAB07	50	Ø 18 (55), length: 600 mm (1250) mm
Conducting of lifetime tests (wear in dependence of the sliding partner)	PVLAB09	50	See slide bearing tests
Performing of spindle nut tests (determining of the max. axial force)	PLAB01	50	Ø 55 mm, length: 3500 mm
Electrical tests			
Determining the electrical surface resistance	DIN EN ISO 60093	1	Rod >Ø 70 mm or plate > 70 x 70mm
Determination of electrical breakdown resistance	DIN EN ISO 60243	1	Rod Ø 70 x 75 mm or plate 300 x 200 x 2 mm
Other tests			
Colorimetric determination of colourimetric numbers and color differences in the CIELAB color space	DIN EN ISO 6174PVEXT10	1	Component or about 100 g of granules
Determining of the specific density	PVEXT03	3	3x Ø 15 x 20 mm, plate 10 x 10 x 10 mm
FT-IR-spectroscopy	PVLAB12	1	Chip 4 x 4 x 1 mm or granule grain or small amount of powder
Determining the residual moisture	PVEXT08	1	55 g Granule / powder
Determination of water absorption	DIN EN ISO 175	1	Dice 60 x 60 x 60mm or rod Ø60 x 60mm
Determining the surface quality with the aid of a perthometer	DIN EN ISO 4287	1	Disc Ø20 mm, oder Plättchen ca. 20 x 20 mm
Examination of the wettability (surface tension with the aid of test inks Method)	ASTM D 2578-84	1	Component

From tension rods we can also create test specimens for other tests. The following table shows the dimensions and possible use of the tensile bars.

Specimen type	1A	1B	1BA	1BB	5A	5B	2	5	4
Total length l_3	≥ 150		≥ 75	≥ 30	≥ 75	≥ 35	≥ 150	≥ 115	≥ 152
Initial distance of the terminals	115 ± 1	l2 + 0 bis 5	l2 + 0 bis 2	l2 + 0 bis 1	50 ± 2	20 ± 2	100 ± 5	80 ± 5	98
Distance between the wide parallel parts l_2	104 bis 113	106 bis 120	58 ± 2	23 ± 2	-	-	-	-	-
Length of narrow parallel part l_1	80 ± 2	60 ± 0,5	30 ± 0,5	12 ± 0,5	25 ± 1	12 ± 0,5	-	33 ± 2	-
Measuring length L_0	50 ±0,5		25 ± 0,5	10 ± 0,2	20 ± 0,5	10 ± 0,2	50 ± 0,5	25 ± 0,25	50 ± 0,5
Width of narrow part b_1	10 ± 0,2		5 ± 0,5	2 ± 0,2	4 ± 0,1	2 ± 0,1	-	6 ± 0,4	25,4 ± 0,1
Width at the ends b_2	20 ± 0,2		10 ± 0,5	4 ± 0,2	12,5 ± 1	6 ± 0,5	10 bis 25	25 ± 1	38
Preferred thickness d	4 ± 0,2		≥ 2	≥ 2	≥ 2	≥ 1	≤ 1	≤ 1	≤ 1
Radius r	20 bis 25	≥ 60*	≥ 30	≥ 12	-	-	-	-	-
small Radius r_1	-	-	-	-	8	3 ± 0,1	-	14 ± 1	22
large Radius r_2	-	-	-	-	12,5	3 ± 0,1	-	25 ± 2	25,4
Usage	Tensile test normal, tensile test 3D printing, 3-point bending test, Charpy, DMA, compression test, HDT, ball indentation hardness		Tensile test special size, DMA	Tensile test special size	Tensile test special size, tensile test 3D printing, DMA	Tensile test special size	Tensile test special size, [DMA if d=1mm]	Tensile test special size, [DMA if d=1mm]	Tensile test special size, [DMA if d=1mm]

*r=[(l2-l1)2 + (b2-b1)2] / 4 (b2 - b1)

Dimensions in mm



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Consulting

If you have problems with plastic components, we support you from the problem analysis to the solution over to the delivery of the products.

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Assistance in problem analysis
Phone support
Analysis through questionnaires
Personal consulting
Training courses and presentations
Calculation software for customers

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