

ultra-high molecular weight polyethylene (PE-UHMW)



- excellent wear resistance
- outstanding impact strength
- very good chemical resistance

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1. Introduction

This brochure contains information on the GUR®/GHR® product portfolio, properties and applications. For processing and machining of these materials, separate publications are available.

GUR®

GUR is the trademark for a group of ultrahigh-molecular-weight polyethylene products (PE-UHMW) produced by Ticona.

The extremely high molecular weight of GUR products imparts properties to this plastic that limit the processing of the virgin material powder to ram extrusion and compression molding processes.

As the molecular weight of polyethylene increases, higher values are obtained for a number of technically important properties:

- notched impact strength
- wear resistance
- energy absorption capacity at high stress rates
- heat deflection temperature
- stress crack resistance.

This combination of properties opens up a wide range of applications for GUR, primarily in the engineering sector.

GHR®

GHR is the trademark for a high-molecular-weight polyethylene (PE-HMW), also supplied in powder form. This material is suitable mainly for compression molding but also for extrusion of sheets, profiles and blocks, and for porous products.

With the addition of heat stabilizers, both GHR and GUR can be used in the manufacture of prosthesis.

Quality system ISO 9001

The GUR product group unit has introduced a quality management system based on ISO 9001. It covers all functions, including development, purchasing, production, analysis, sales and customer service. The global GUR product group unit obtained ISO 9001 certification from the DQS, Deutsche Gesellschaft zur Zertifizierung von Managementsystemen mbH, (German Association for the Certification of Quality Systems) in March 1998.

® = registered trademark

Both GUR and GHR are protected trademarks.

Introduction

1

Physical properties

2

Effect of the service environment

3

Applications – photo documentation

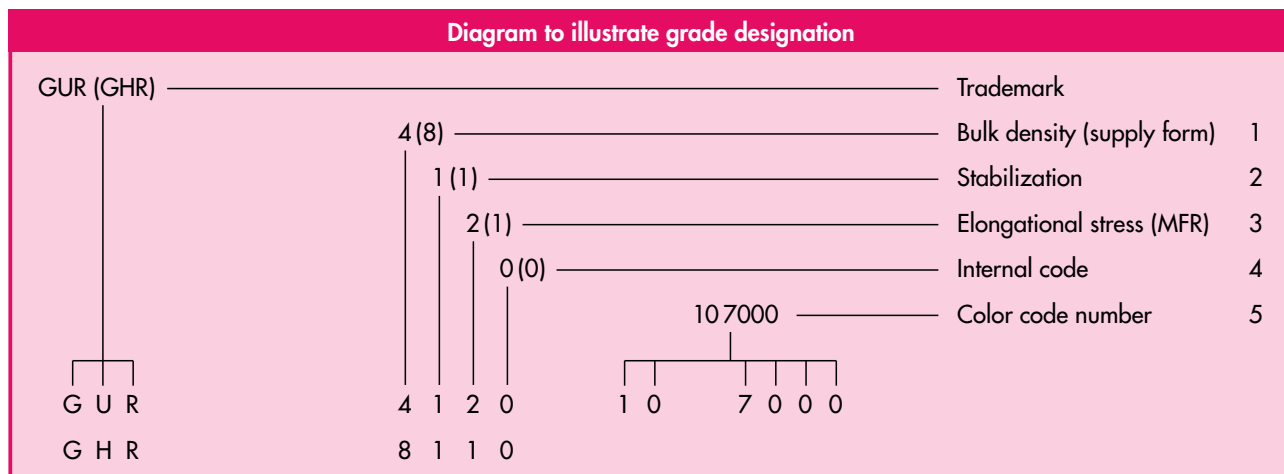
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Subject index

5

1.1 Nomenclature, grade portfolio, supply form

The Ticona ultra high-molecular-weight and high-molecular-weight polyethylenes are coded by a four-digit number, a color number and in some cases by a letter.



1 Bulk density

Code number	Bulk density in g/l
2	200
4	400
5	pellets/granules
8	powder
9	granules

GUR

GHR

2 Stabilizer, Additive

Code number	Stabilizer, additive
0	without additive
1	corrosion stabilizer (CS)
2	CS + heat stabilizer
3	CS + extrusion stabilizer
4	CS + UV stabilizer
5	CS + lubricant

3 Elongational Stress

GUR		GHR	
Code number	Elongational Stress in MPa	Code number	MFR 190/21.6 and 5 in g/10 min
0	< 0.1	0	21.6 < 1.0
1	0.1 – 0.2	1	21.6 1 – 2
2	0.2 – 0.3	2	21.6 > 2 – 20
3	0.3 – 0.5	3	5 1 – 3
5	0.5 – 0.7	4	5 > 3 – 15
7	> 0.7	5	5 > 15 – 40
9	not specified	6	5 > 40 – 100

4 Internal Code

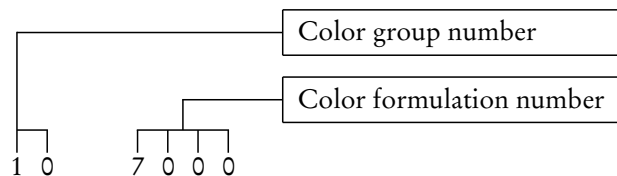
Special code to identify the particular grade.

5 Color code number

The color code number has 6 digits.

Natural grades have no color code number.

The color code number is compressed as follows: color group number, two-digit, for the color, color formulation number, four-digit, for the color formulation.



Code	Color group number	Color formulation number
black	10	7000
white	20	1000
gray	30	8000
gray	30	8100
red	40	2200
yellow	50	4000
green	70	5000
blue	80	3000
blue	80	3200
blue	80	3300
blue	80	5329

Table 1: Basic grades of GUR® and GHR®

Grade	Special properties	Processing/Typical applications
Average molecular weight (determined by viscometry) ¹⁾ about 5.0 million g/mol		
GUR 4020	without additives	compression molding
GUR 4120	excellent property spectrum	compression molding
GUR 4220	GUR 4120 with heat stabilizer	skived film
GUR 4022	coarser particle size, narrower molecular weight distribution than GUR 4020	porous products, battery separators
GUR 2122	GUR 4120 with lower bulk density (0.20 to 0.25 g/cm ³)	suitable for blending with high filler contents, porous products
Average molecular weight (determined by viscometry) ¹⁾ about 6.8 million g/mol		
GUR 4130	higher wear resistance than GUR 4120	compression molding, ram extrusion, battery separators
GUR 4032	coarser particle size, narrower molecular weight distribution than GUR 4130	compression molding, ram extrusion
Average molecular weight (determined by viscometry) ¹⁾ about 9.2 million g/mol		
GUR 4150	higher wear resistance than GUR 4130	compression molding, ram extrusion, battery separators
GUR 4152	coarser particle size, narrower molecular weight distribution than GUR 4150	compression molding, ram extrusion
Average molecular weight (determined by viscometry) ¹⁾ about 10.5 million g/mol		
GUR 4170	higher wear resistance than GUR 4150	compression molding, ram extrusion
Average molecular weight (determined by viscometry) ¹⁾ about 3.9 million g/mol		
GUR 4113	properties similar to those of GUR 4120	thin sheet compression molding
Average molecular weight (determined by viscometry) ¹⁾ about 600 000 g/mol		
GHR 8110	high-molecular-weight PE grade (PE-HMW), particle size distribution approximately the same as for GUR 4120/4150	compression molding, porous products

¹⁾ For further details, see table 2

Special formulations are identified by special letters, for example

AST antistatic material
ALGRA thermally conductive material

Other modifications, such as formulations containing glass fibers, glass microspheres, bronze etc., can be supplied on request for special applications.

Basic grades of GUR® and GHR® are supplied as natural-colored powders.

2. Properties

Table 2: Physical properties

This data was determined on powder or test specimens prepared from compression molded sheet.
Depending on the conditions of specimen preparation, individual measurements may deviate from these values.

Properties	Unit	Test method	Test specimen	GHR 8110	GUR 4113
Density	g/cm ³	ISO 1183 test method A	sheet	0.95	0.94
Viscosity number (VN)	ml/g	ISO 1628 part 3, concentration in decahydro-naphthalene 0.001 g/ml for GHR 8110, 0.0002 g/ml for GUR grades	powder	600	2000
Intrinsic viscosity [η] ¹⁾	ml/g			510	1785
Average molecular weight ²⁾	g/mol			$6.1 \cdot 10^5$	$3.9 \cdot 10^6$
Melt Index MFR 190/21.6 ³⁾	g/10 min	ISO 1133	powder	1.4 ± 0.3	–
Elongational stress F (150/10)	MPa	ISO 11542-2	dumbbell specimen	–	0.13 ± 0.02
Bulk density	g/cm ³	DIN 53 466	powder	≥ 0.4	≥ 0.4
Mechanical properties measured under standard conditions, ISO 291-23/50					
Yield stress	MPa	ISO 527 parts 1 and 2		≥ 21	≥ 17
Elongation at yield	%	testing rate		10	≤ 20
Nominal elongation at break	%	50 mm/min	Multipurpose	> 50	> 50
Tensile modulus	MPa	testing rate 1 mm/min	specimen acc. to ISO 3167	1060	750
Tensile creep modulus 1 h value 1000 h value	MPa MPa	ISO 899 part 1, elongation $< 0.5\%$		680 340	450 250
Ball indentation hardness 30 s value, test load 358 N	N/mm ²	ISO 2039 part 1	sheet, 4 mm	49	38
Shore hardness D, 15 s value	–	ISO 868	sheet, 6 mm	63	62
Charpy notched impact strength (with 14° V-notch on both sides)	kJ/m ²	ISO 11542, part 2	120 x 15 x 10 mm	≥ 25	≥ 170
Wear by the sand slurry method (based on GUR 4120 = 100)		internal test method	76.2 x 25.4 x 6.35 mm	250	110

¹⁾ Calculated using Martin's equation:
 $\log \eta = \log [\eta] + K \cdot [\eta] \cdot c$
 where η viscosity number
 $[\eta]$ intrinsic viscosity in dl/g
 $K = 0.139$ g constant
 $c = 0.02$ g/dl for GUR grades
 $c = 0.1$ g/dl for GHR 8110

²⁾ Calculated molecular weight using Margolies' equation:
 $M = 5.37 \cdot 10^4 [\eta]^{1.49}$
 where η is in dl/g

³⁾ Only for GHR 8110; not measurable with grades of GUR because of their extremely high melt viscosity

Basic grades					GUR® special formulations	
GUR 2122	GUR 4120	GUR 4130	GUR 4150	GUR 4170	ALGRA ⁴⁾	AST ⁵⁾
0.93	0.93	0.93	0.93	0.93	1.25	0.96
2200	2400	3050	3850	4300	–	–
1945	2100	2585	3150	3450	–	–
$4.5 \cdot 10^6$	$5.0 \cdot 10^6$	$6.8 \cdot 10^6$	$9.2 \cdot 10^6$	$10.5 \cdot 10^6$	–	–
–	–	–	–	–	–	–
0.22 ± 0.05	0.22 ± 0.05	0.34 ± 0.07	0.51 ± 0.09	0.7 ± 0.09	–	–
≤ 0.25	≥ 0.4	≥ 0.4	≥ 0.4	≥ 0.4	–	–
≥ 17	≥ 17	≥ 17	≥ 17	≥ 17	≥ 15	≥ 17
≤ 20	≤ 20	≤ 20	≤ 20	≤ 20	≤ 20	≤ 20
> 50	> 50	> 50	> 50	> 50	> 50	> 50
790	720	680	680	570	1350	840
550 270	460 230	430 230	430 220	370 180	1060 600	530 280
38	36	35	35	35	52	38
60	60	60	61	60	–	–
≥ 120	≥ 210	≥ 180	≥ 130	≥ 90	≥ 50	≥ 130
–	100	90	80	70	200	110

4) Graphite-aluminium-filled (thermally conductive material)

5) Antistatic-modified

Table 2: Physical properties (continued)

Thermal Properties	Unit	Test method	Test specimen
Heat deflection temperature HDT/A (1.8 MPa)	°C	ISO 75 parts 1 and 2	80 x 10 x 4 mm
Vicat softening point VST/B/50	°C	ISO 306	10 x 10 x 4 mm
Melting point DSC, 10 K/min	°C	ISO 3146 method C	powder
Coefficient of linear thermal expansion between 23 and 80 °C ¹⁾	°C ⁻¹	ISO 11359, part 1/2	30 x 10 x 4 mm
Thermal conductivity at 23 °C	$\frac{W}{m \cdot K}$	resistance wire method	sheet, 10 mm
Specific heat at 23 °C	$\frac{kJ}{kg \cdot K}$	adiabatic calorimeter	powder
Electrical properties measured under standard conditions, ISO 291-23/50			
Volume resistivity	$\Omega \cdot m$	IEC 60093	
Surface resistivity	Ω		
Dielectric strength	kV/mm	IEC 60243 part 1	
relative permittivity ϵ_r at 100 Hz at 1 MHz	– –	IEC 60250	sheet, 1 mm
Dissipation factor $\tan \delta$ at 100 Hz at 1 MHz	– –		
Tracking CTI ²⁾ CTIM ³⁾	– –	IEC 60112	15 x 15 x 4 mm
Arc resistance	rating	VDE 0303, part 5	120 x 120 x 10 mm

¹⁾ Measured on annealed specimens²⁾ Test solution A³⁾ Test solution B

GUR Specialty Products

Ticona offers a full range of GUR specialty products.
The specific description is located at page 20.

Ultrahigh-molecular-weight Polyethylene (PE-UHMW)

		GUR® special formulations	
GHR 8110	GUR basic grades ⁴⁾	ALGRA ⁵⁾	AST ⁶⁾
44	42	46	42
80	80	101	88
130 – 135	130 – 135	130 – 135	130 – 135
$\approx 2 \cdot 10^{-4}$	$\approx 2 \cdot 10^{-4}$	$\approx 1.5 \cdot 10^{-4}$	$\approx 2 \cdot 10^{-4}$
0.41	0.41	1.6	0.41
1.84	1.84	1.56	–
$> 10^{12}$	$> 10^{12}$	$< 10^7$	$< 10^4$
$> 10^{12}$	$> 10^{12}$	$< 10^9$	$< 10^9$
40	45	–	–
2.9 2.9	2.1 3.0	– –	– –
$2 \cdot 10^{-4}$ $4 \cdot 10^{-4}$	$3.9 \cdot 10^{-4}$ –	– –	– –
600 600	600 600	– –	– –
L 4	L 4	–	–

⁴⁾ The thermal and electrical properties of all basic grades are the same

⁵⁾ Graphite-aluminium-filled (thermally conductive material)

⁶⁾ Antistatic-modified

2.1 Basic definitions

2.1.1 Density and molecular weight

The most important values characterizing the properties of polyethylene are density and molecular weight. A whole range of mechanical properties, including yield stress and flexural and torsional rigidity, depend particularly on density, while toughness (notched impact strength), especially at low temperatures, wear resistance, heat deflection temperature and resistance to stress cracking all depend on molecular weight.

Despite the fact that GUR – according to infrared spectroscopy findings – is a largely linear polyethylene, the density of moldings produced from it attains values of only around 0.93 g/cm³. This is due to the high melt viscosity of the product, which considerably restricts ordering mechanisms such as crystallization. Annealing has only a limited influence on density.

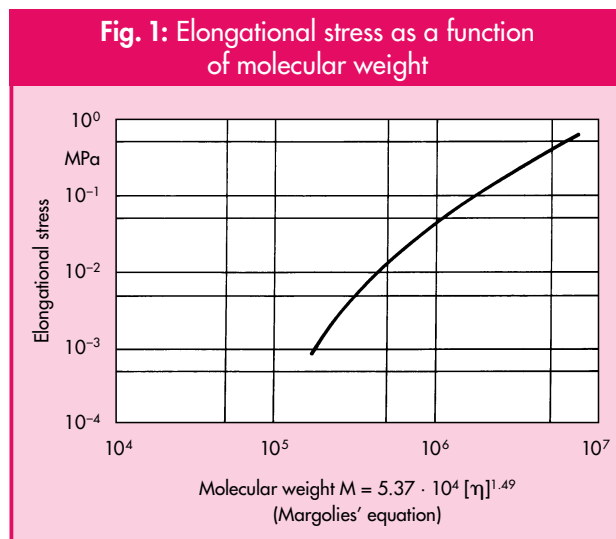
For many technological properties of GUR, the molecular weight is of crucial importance. In the case of higher molecular weight polymers, in contrast with low-molecular-weight substances such as water or benzene, the molecular weight is not a uniformly defined magnitude but an average value, analogous – since individual polymer molecules generally possess quite different chain lengths – to the “average age” of a population. This average value can be defined in various ways. Frequently, molecular weight is determined viscometrically by measuring intrinsic viscosity $[\eta]$ and converting this value by means of the Mark-Houwink equation $M = K [\eta]^\alpha$, where K and α are empirically determined constants. For the different grades of GUR, $[\eta]$ ranges from approx. 1600 – 3500 ml/g and the values for K and α are $5.37 \cdot 10^4$ and 1.49 respectively. From these values a typical molecular weight of about 5.0 million g/mol is obtained for GUR 4120, for example.

2.1.2 Elongational stress as a method of characterizing melt viscosity and molecular weight

A number of mechanical and physical properties of ultrahigh-molecular-weight polyethylenes are dependent on molecular weight. Semi-finished product manufacturers are also interested in processing behavior and the selection of suitable PE-UHMW grades for particular processing methods and property requirements.

For thermoplastics there is a direct correlation between melt viscosity and molecular weight. With ultrahigh-molecular-weight polyethylene such as GUR it is not possible to employ the conventional methods of measurement because of their extremely high melt viscosity. A determination of what is termed the elongational stress provides a practical alternative. The procedure used is as follows: dumbbell test pieces, each with a different weight attached, are suspended in silicone oil heated to 150 °C. Under the test loading, the specimens undergo elongation. The length of time required for 600 % elongation is recorded, and plotted on a log-log scale against the stress applied to each specimen (load per initial cross section of test specimen). A straight line between the points plotted is obtained and the stress which would be required for an elongation time of 10 min is interpolated. This result is known as the elongational stress. The elongational stress values determined for the different grades of GUR range between 0.1 and 0.7 MPa.

Fig. 1 shows the elongational stress as a function of the viscometrically determined molecular weight. This indicates clearly that the yield value determination method provides a good means of differentiating between the various degrees of polymerization of the polymer molecules.



Ultrahigh-molecular-weight Polyethylene (PE-UHMW)

If an attempt is made to carry out the elongational stress determination at a temperature higher than 150 °C, it can be observed that the test specimens do not stretch uniformly but break off after a short, uneven, initial elongation. The same behavior is shown by test pieces subjected to a tensile test at temperatures above 150 °C in a heating cabinet. They do not undergo stretching in the usual manner for polyethylene but break off after a short time under the test stress. This behavior is important in determining the proper conditions for the thermoforming of moldings from GUR. The process must not be carried out at a too high temperature, and low operational rates must be employed to prevent crack formation.

Tensile strength at elevated temperature (120 °C)

The standard method of elongational stress determination cannot be used for moldings made from GUR, since during processing (e.g. compression molding, extrusion) certain crosslinking processes occur in the polymer which prevent uniform stretching of the specimen. For such cases, a different test method known as the tensile test at 120 °C has been developed. In this measurement, a specimen is tested to failure on a horizontal tensile testing machine in a special heating cabinet. It is known that the tensile strength of polyethylene increases with increasing molecular weight. At normal temperatures this effect is masked by the wide range of scatter due to internal stresses in the material. When the determination is carried out at elevated temperature (120 °C has proved a suitable test temperature), reproducible results are obtained. This method is used particularly to determine whether, or to what extent, a decrease in molecular weight has taken place through degradation during processing of GUR.

2.2 Mechanical properties

2.2.1 Properties under short-term stress

The behavior of materials under dynamic, short-term stress is examined in the tensile test according to ISO 527. This test enables the tensile strength and elongation at break to be determined. Fig. 2 shows the stress-strain behavior of GUR at different temperatures.

Fig. 3 shows yield stress as a function of temperature.

Fig. 2: Stress-strain curves for GUR 4120, measured at different temperatures

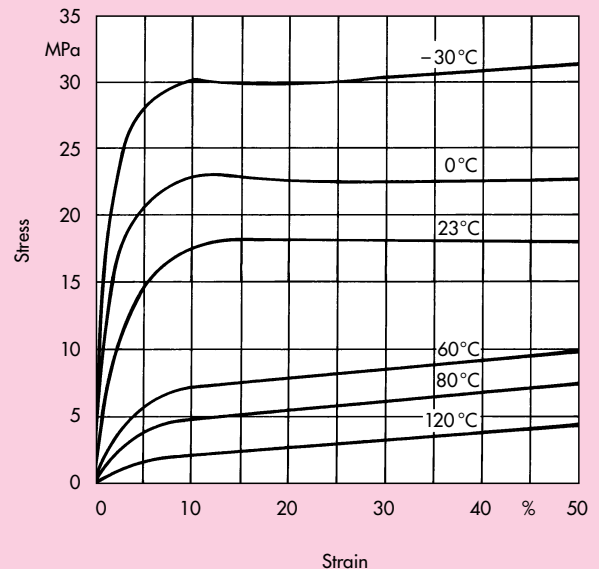
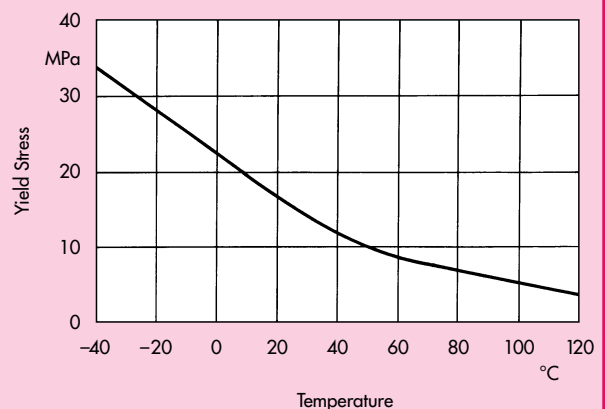


Fig. 3: Yield Stress of GUR 4120 as a function of temperature (measured according to ISO 527, testing rate 5 mm/min)



Other properties determined under short-term stress are the various elastic moduli, i. e. the tensile and flexural moduli measured according to ISO 527 and ISO 178, and the initial values for the flexural creep modulus according to ISO 899, part 2. These values provide an indication of rigidity and are used not only to characterize plastics but for strength calculations and the design of molded parts.

2.2.2 Properties under long-term stress

The results of long-term tests carried out under various conditions provide design engineers with a basis for calculation when designing components subjected to prolonged stress.

The properties of plastics under long term tensile stress are tested by two basic methods:

- creep rupture test according to ISO 899 (deformation increase in specimen held under constant stress)
- stress relaxation test according to DIN 53 441 (stress decay in specimen held under constant strain).

The first test gives the creep strength, i. e. the time to rupture of a test bar loaded with a specified stress under defined environmental conditions. These tests are carried out on tensile test bars (uniaxial stress condition) in air or another medium.

The strain values and creep moduli determined in the creep rupture test under tensile stress also serve as a good approximation for the values to be expected under flexural and compressive stress.

The deformation of a plastic component is not only time- and temperature-dependent but is also a function of the type of stress. Strictly speaking, separate characteristic values should be determined for each type of stress. However, with low deformation the variation between the characteristic values is negligible, so that, for example, the time-dependent compression of a component under compressive stress may be calculated with sufficient accuracy using the flexural creep modulus (determined under flexural stress).

The results of creep tests under uniaxial stress have only limited applicability to the multiaxial stress state.

Creep tests show the behavior of a material under constant stress; the strain originally caused by the stress increases with time, i. e. the material “creeps”.

Fig. 4: Characteristic values for the creep behavior of GUR 4120 under tensile stress, 23 °C and a stress of 1 MPa

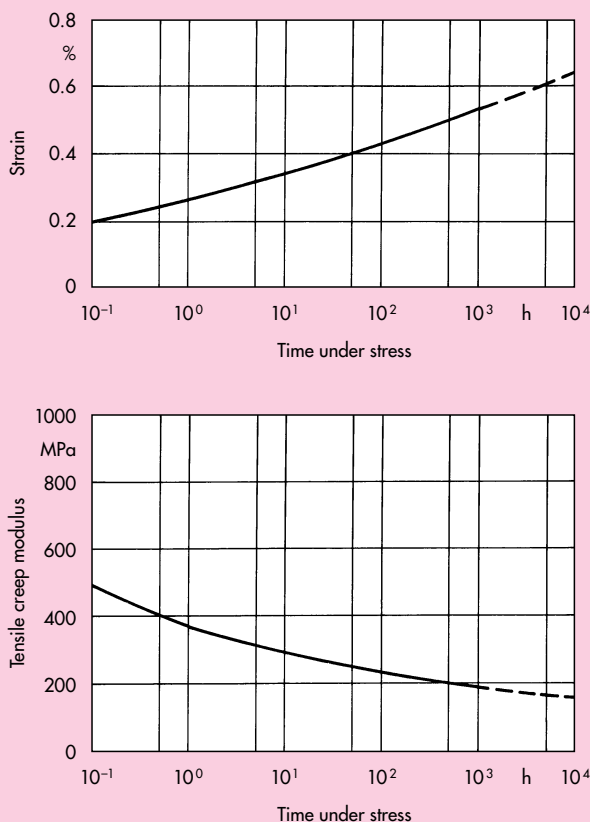
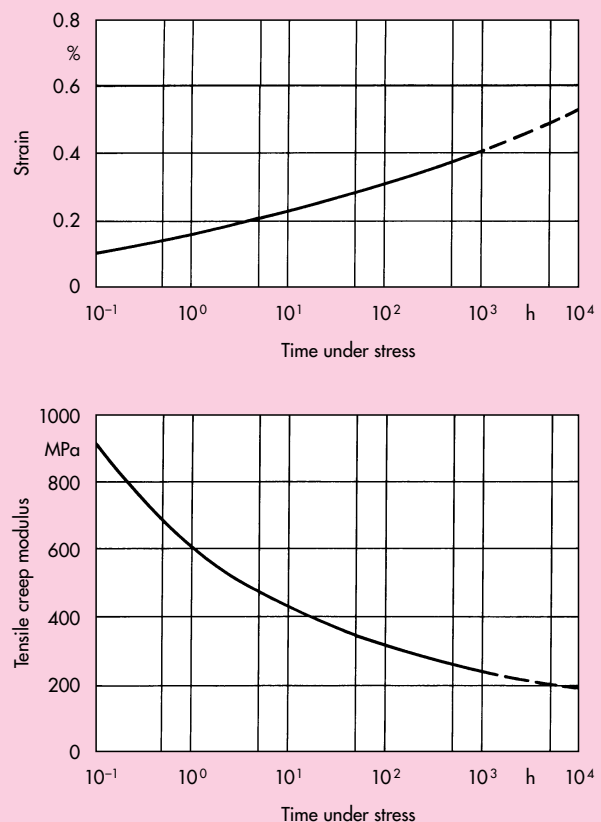


Fig. 5: Characteristic values for the creep behavior of GUR 4152 under tensile stress, 23 °C and a stress of 1 MPa



Ultrahigh-molecular-weight Polyethylene (PE-UHMW)

Creep (cold flow) is a typical property of thermoplastics. This is evident in Figs. 4 to 6, which show important characteristic functions for the creep behavior of GUR 4120, GUR 4152 and GHR 8110 under tensile stress at 23 °C. The required creep tests under tensile stress were continued up to a stress time of 10^3 h and extrapolated to 10^4 h.

Similar behavior is apparent in the creep test under compressive stress. Values measured at 23, 50 and 80 °C at varying compressive stress levels show the increase in compression in the course of about 8 weeks (figs. 7 to 9). When the stress is removed from the test specimens, partial recovery takes place. Table 3 shows the permanent deformation after a stress-free period of 24 hours.

Fig. 6: Characteristic values for the creep behavior of GUR 8110 under tensile stress, 23 °C and a stress of 1 MPa

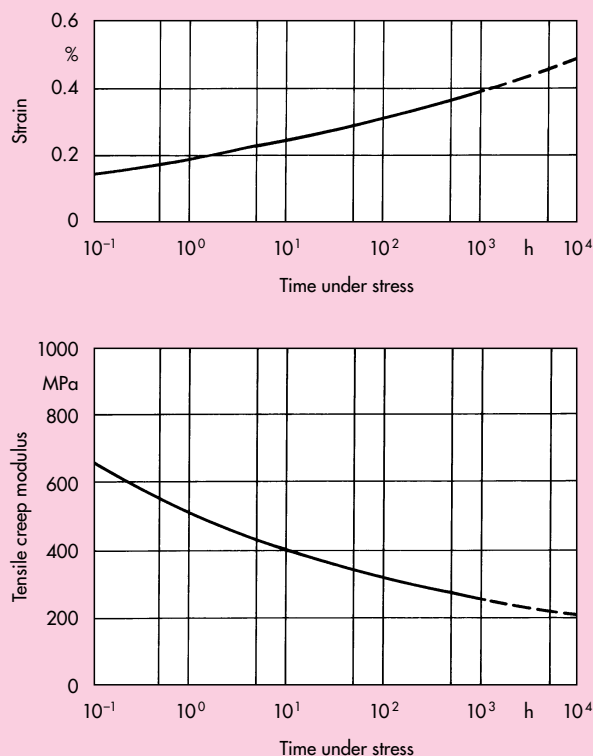


Fig. 7: Creep behavior of GUR under varying compressive stress (measured at 23 °C)

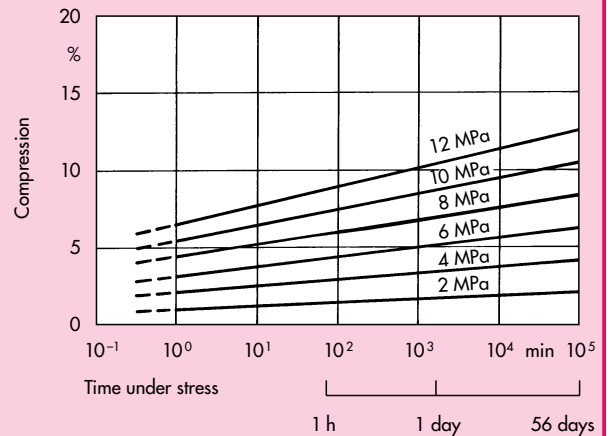


Fig. 8: Creep behavior of GUR under varying compressive stress (measured at 50 °C)

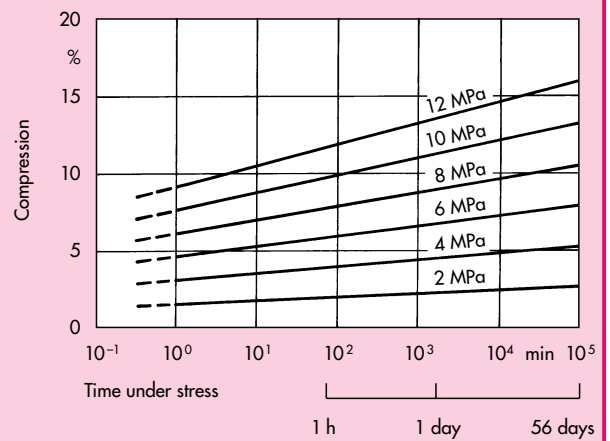


Fig. 9: Creep behavior of GUR under varying compressive stress (measured at 80 °C)

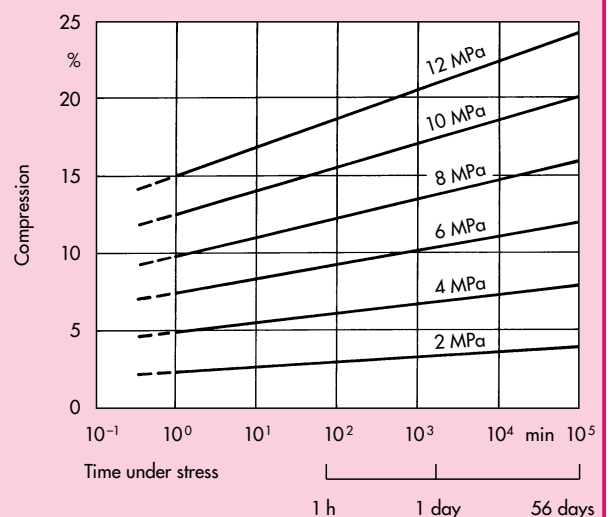


Table 3: Compression and permanent deformation after stress removal

Tem- perature	Compres- sive stress	Compression 1 min after stress removal	Permanent deformation 24 hours after stress removal
°C	MPa	%	%
23	2	0.9	0.6
	4	1.8	1.2
	6	2.7	1.8
	8	3.6	2.4
	10	4.5	2.9
	12	5.4	3.5
50	2	1.3	0.8
	4	2.7	1.5
	6	4.1	2.3
	8	5.5	3.1
	10	6.9	3.9
	12	8.2	4.7
80	2	1.6	1.1
	4	3.2	2.3
	6	4.8	3.5
	8	6.4	4.6
	10	8.1	5.8
	12	9.7	6.9

2.2.3 Impact strength properties

An important property of GUR is its high impact strength, which retains good values down to very low temperatures. Even very severe impact stresses do not lead to specimen failure. In the notched impact test according to ISO 179, no specimen fracture is obtained. For this reason, the notched impact test for GUR has been modified (14° V-notch on both sides) and standardized as ISO 11542-2 for PE-UHMW.

Fig. 10 shows the notched impact strength as a function of temperature.

Because of its exceptional toughness, GUR withstands some impact stress without cracking, even at the temperature of liquid helium (−269 °C).

2.3 Surface properties

GUR exhibits particularly good surface properties (abrasion, low friction and wear behavior) – an important advantage in many technical applications.

2.3.1 Sliding properties and friction coefficients

GUR is an excellent material for sliding applications. Tests in which GUR was compared with other plastic materials have shown that GUR possesses self-lubricating properties, particularly in dry sliding movement against metal surfaces such as steel, brass or copper. These properties are invaluable in dry running conditions; thus, for example, bushings made from GUR, in which metal shafts rotate, can tolerate extraneous materials (such as dust, sand etc.) or misalignment. These conditions do not cause seizing of the shaft. It is important, however, to make adequate provision for the dissipation of frictional heat in order to ensure troublefree performance of the bushings.

It should be remembered that sliding properties are always characteristic of a particular system. In other words, coefficients of friction are not material constants but depend on the sliding partner, surface pressure loading, sliding speed and measuring equipment used, i. e. they are a function of the whole system.

Figs. 11 and 12 show the dependence of the dynamic friction coefficient μ on surface pressure loading and sliding speed. The values were measured on ring-shaped test specimens in which a hardened and polished steel shaft with an average roughness height of $R_z = 2$ to $2.5 \mu\text{m}$ was rotated.

Fig. 10: Notched impact strength of GUR 4120 as a function of temperature, measured according to ISO 11542-2, test specimen with 14° notch on both sides

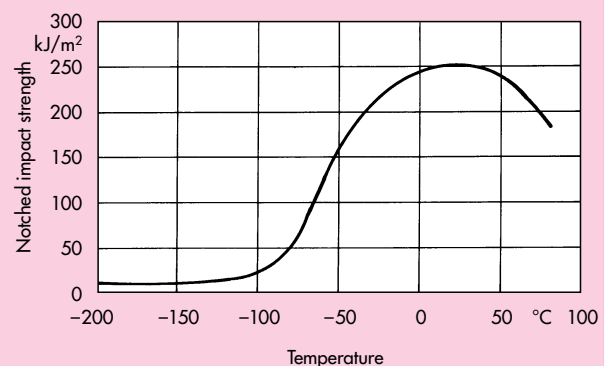


Fig. 11: Dynamic friction coefficient μ of GUR as a function of mean surface pressure loading p_m (at constant sliding speed $v = 10$ m/min)

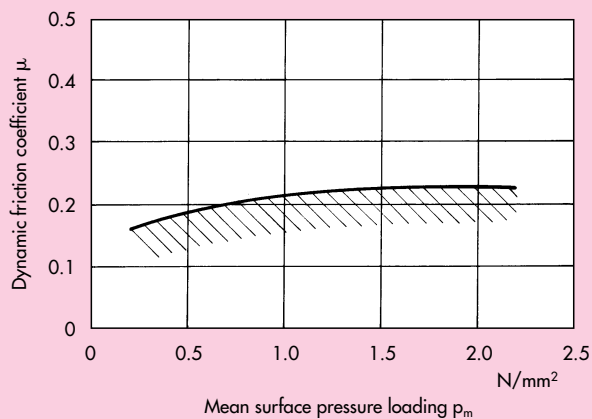


Fig. 12: Dynamic friction coefficient μ of GUR as a function of sliding speed (at mean surface pressure loadings $p_m = 0.26$ and 1.24 N/mm²)

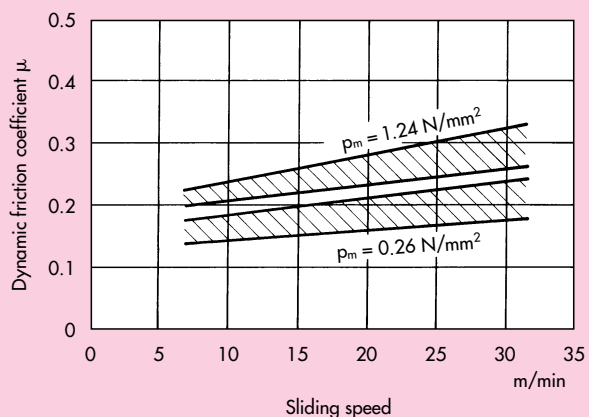
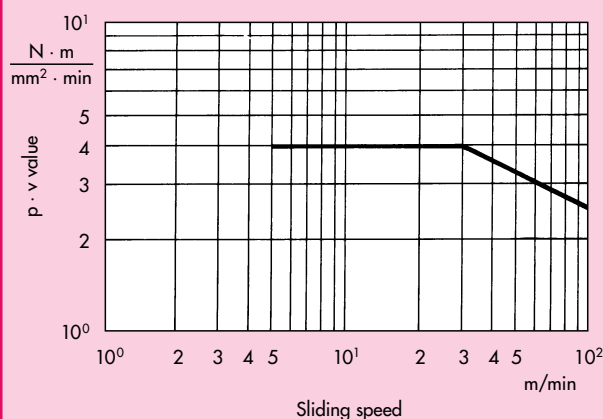


Fig. 13: Load limit for unlubricated bearings made from GUR

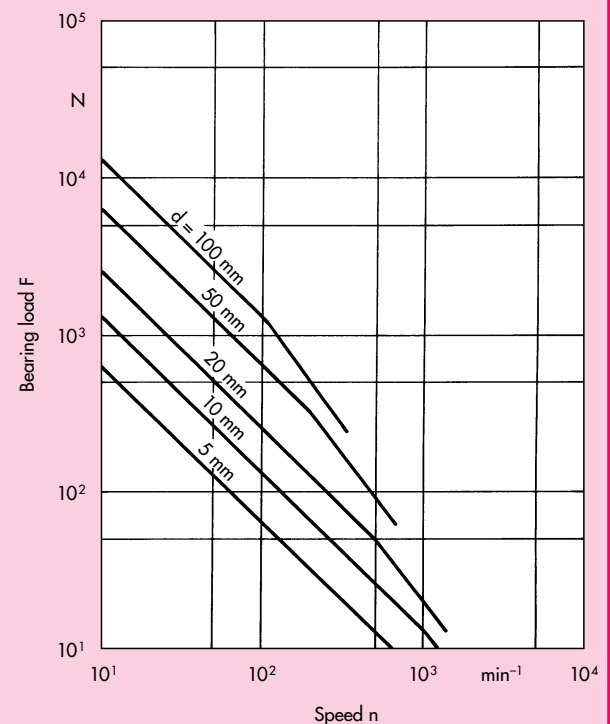


The permissible $p \cdot v$ values for bearing bushings made from GUR are about $4 \text{ N/mm}^2 \cdot \text{m/min}$ for dry running and about $6\text{--}7 \text{ N/mm}^2 \cdot \text{m/min}$ for lubricated operation. These limiting values are, however, affected by a number of other factors, including bearing dimensions, bearing clearance, the material and surface quality of the rotating partner and the effectiveness of frictional heat removal. The maximum permissible surface pressure loading for bearings made from GUR is in the region of 10 N/mm^2 . It has been found in practice that the limiting $p \cdot v$ values do not remain constant over the whole loading range. At higher sliding speeds they should be set somewhat lower and at low speeds somewhat higher. It is difficult to give an estimate for speed in excess of $2 \text{ m/sec} = 120 \text{ m/min}$, and for creep rates. Under such conditions, bearing performance is determined by other criteria.

The dependence of the $p \cdot v$ value on sliding speed may be seen from Fig. 13, while Fig. 14 shows the permissible bearing load as a function of the shaft speed for a bearing ratio b/d (width/diameter) of 1.0. The average roughness height R_z of the hardened and polished steel shaft in this study had a maximum value of $2.5 \mu\text{m}$.

Bearings made from the special GUR formulation ALGRA dissipate heat more effectively and permit higher sliding speeds.

Fig. 14: Permissible bearing load for unlubricated bearings made from GUR (bearing ratio $b/d = 1.0$)



Ultrahigh-molecular-weight Polyethylene (PE-UHMW)

The paraffin-wax-like surface characteristics of molded parts made from GUR prevents caking or freezing on the surface by many, especially moist, bulk materials.

2.3.2 Wear resistance

The amount of wear exhibited by GUR is very slight and, as comparative measurements show, depends on the extent to which optimum manufacture of the product can be achieved and on the nature and surface finish of the sliding partner. For this reason, wear tests in the laboratory are of only limited value in predicting actual performance. Reliable information on wear properties of parts made from GUR is obtainable only from practical trials.

A suitable test method for the purposes of comparison, that is sensitive both to differences in molecular weight and to defective sintering, is the sand-water slurry test (J. Berzen, *Chemie-Technik* 4/1974, pp. 129–134).

The data in Fig. 15 clearly indicate the excellent wear resistance of GUR/GHR against other materials.

The excellent wear resistance of GUR is retained at extremely low temperatures. Gaskets, sleeves and packings produced from GUR have performed so satisfactorily in piston pumps for liquid hydrogen (-253°C), that in a large European nuclear research center the high-alloy CrNi steel pistons (which at this operating temperature had previously showed severe wear and fall-off in efficiency) were sheathed with GUR. After the pumps had run for a year at -253°C ,

it was noted that no decline in performance was apparent. Up on dismantling the pumps, it was evident that GUR, even at these very low temperatures, possesses excellent sliding and abrasion properties. The wear was so slight that it was possible to refit the same pistons.

GUR has also proved to be a very good slip and antiwear modifier for POM. For this reason, Ticona supplies two Hostaform® grades with GUR as an additive.

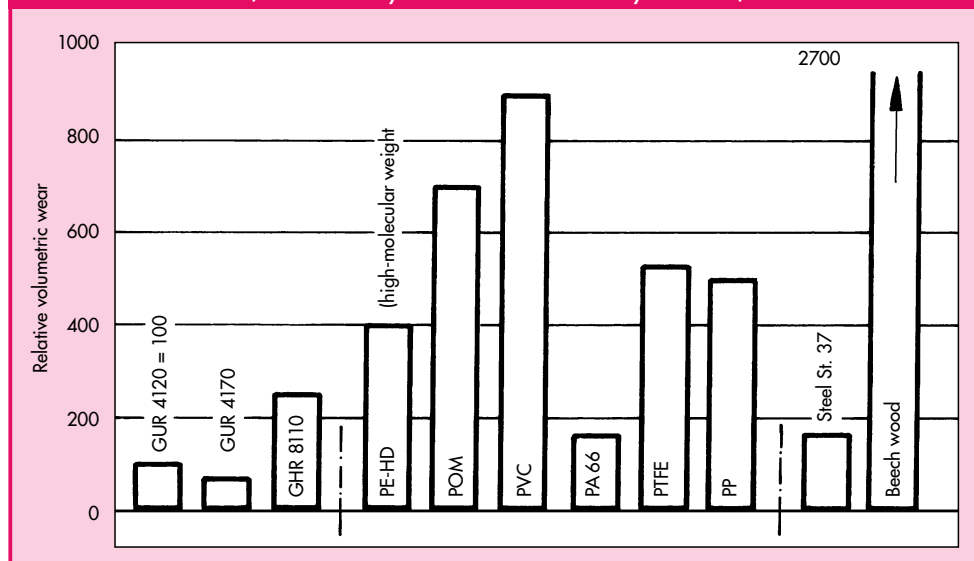
2.4 Thermal properties

2.4.1 Heat resistance

GUR has a higher heat resistance than polyethylenes with lower molecular weight. For example, a pipe section made from GUR placed in an oven at 150°C retains its shape for a long period, while a similarly dimensioned pipe made from a polyethylene of lower molecular weight very quickly collapses. At low mechanical stress levels, the material can be employed at temperatures in the region of 80 to 100°C without any substantial deformation taking place. These temperature limits may be exceeded for short periods without any adverse results. Even at temperatures of around 200°C , GUR by virtue of its viscoelastic properties shows remarkably high dimensional stability under heat, although long-term thermal stress must be avoided because of the risk of thermal degradation and resulting embrittlement.

Thermal degradation can be delayed by using the heat-stabilized grade GUR 4220.

Fig. 15: Relative volumetric wear of various materials, GUR 4120 = 100 (measured by the sand-water slurry method)



2.4.2 Coefficient of linear thermal expansion

In designing close-tolerance components of GUR that are to be exposed to fluctuating temperatures, thermal expansion has to be specially considered. The expansion of semi-crystalline moulded forms under temperature depends not only on the polymer properties but also on the conversion conditions and the resulting internal stress as well as on the geometry of a component and its thermal history. Annealing can significantly reduce stresses. Fig. 16 shows the coefficient of linear thermal expansion of GUR 4120 unannealed and Fig. 17 annealed as a function of temperature. Annealing was carried out for 3 hrs at 90 °C. In critical cases the thermal expansion of a component should be determined under practical oriented test conditions. In the 50 to 80 °C-temperature range, annealing produces a significant reduction in the coefficient of linear thermal expansion.

2.4.3 Thermal conductivity

The thermal conductivity of GUR, as for all thermoplastics, is very low (0.41 W/m · K at 23 °C for the basic grades).

In many applications, however, the rapid dissipation of frictional heat is very important. By adding thermally conducting additives, the thermal conductivity of GUR can be considerably improved.

Example: GUR ALGRA has a thermal conductivity of 1.6 W/m · K at 23 °C.

2.4.4 Specific heat and heat capacity (enthalpy)

The specific heat and heat capacity (enthalpy) of GUR are shown as functions of temperature in Figs. 18 and 19.

2.5 Electrical properties

The most important electrical properties are listed in table 2. The electrical properties of GUR, like its mechanical properties, are unaffected by immersion in water.

The surface resistivity of GUR, as with all insulating materials, is dependent on surface contamination and to a lesser extent on humidity. Dielectric strength is measured according to the standard under short-term, high-voltage stress. It is not, therefore, a measure of maximum permissible continuous stress. In dielectric strength tests, the voltage ($f = 50$ Hz) is steadily increased at a rate of 1 kV/s until insulation breakdown occurs.

The low dissipation factors of GUR and GHR preclude the use of high-frequency heating and welding for these materials.

Fig. 16: Coefficient of linear thermal expansion of GUR 4120 as a function of temperature, measured according to DIN 53 752 method A, test specimen unannealed

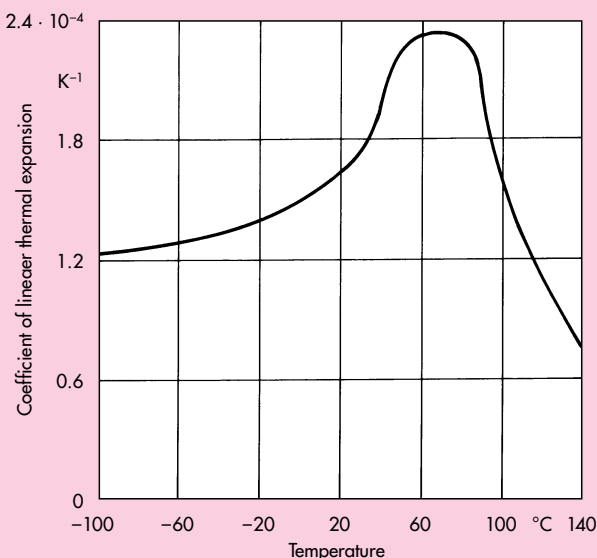


Fig. 17: Coefficient of linear thermal expansion of GUR 4120 as a function of temperature, measured according to DIN 53 752 method A, test specimen annealed for 3 h at 90 °C

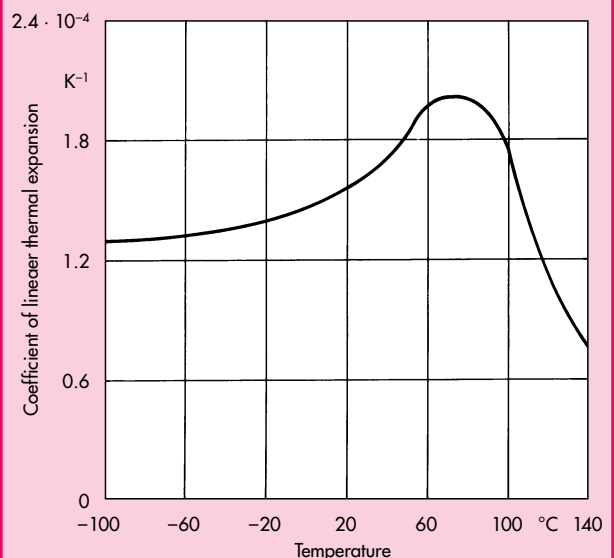
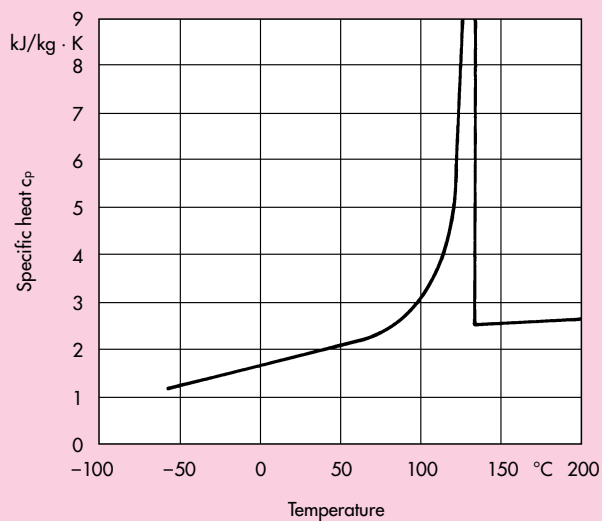
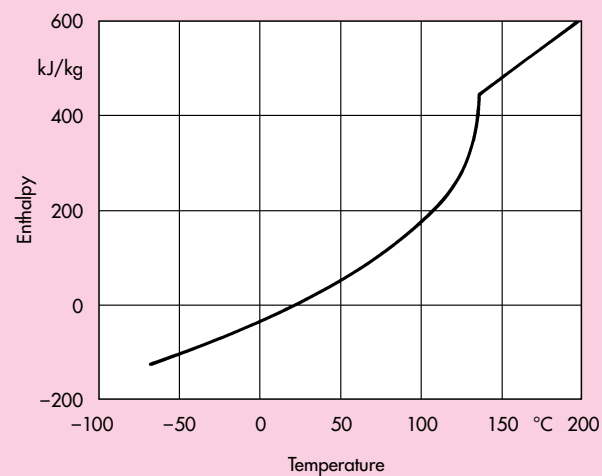


Fig. 18: Specific heat of GUR as a function of temperature**Fig. 19:** Heat capacity (enthalpy) of GUR as a function of temperature (reference temperature 20 $^{\circ}\text{C}$)

3. Effect of the service environment

3.1 Chemical properties

GUR, like all polyethylenes, has very good resistance to aggressive media, except for strong oxidizing acids (for details see the brochure “Resistance to chemicals and other media”, order no. B 206 BR E). Aromatic and halogenated hydrocarbons, which dissolve polyethylenes of lower molecular weight (e. g. decahydro-naphthalene), cause only slight surface swelling in contact with GUR at moderate temperatures.

It is known that the stress cracking resistance of polyethylenes increases with increasing molecular weight. Because of its extremely high molecular weight, GUR can be used in conditions where low-molecular-weight grades would more rapidly fail.

3.2 Water absorption

Like all polyethylenes, GUR is water-repellent and does not swell. In contrast to polymer materials such as the polyamides, which absorb moisture, the properties of GUR are maintained in the finished part regardless of environmental humidity.

If GUR resin is formulated to contain carbon black attention should be paid to moisture absorption by the carbon black. The formulation can, for example, be dried at temperatures of up to 110 °C in a turbo-mixer with a venting device.

3.3 Flammability

Polyethylene ignites in contact with flame, burning with a faintly luminous flame. It continues to burn when the ignition source is removed and melts with burning drips.

3.4 Light and weathering resistance

Semi-finished and finished products made from GUR exhibit surface embrittlement within about 3 months when used in outdoor applications under central European climatic conditions. Through the addition of light stabilizers, outdoor service life can be extended to about 3½ years, depending on the concentration of the UV absorber in GUR.

If GUR is modified with 2.5 % w/w carbon black, for example, then no oxidative degradation is evident even after 5 years' outdoor weathering.

3.5 Assessment under food legislation

The GUR and GHR standard grades, in natural color, when used in accordance with recommendations given in our product literature and in accordance with 21 CFR 177.1520, the applicable FDA polyolefin regulation, meet the requirements of specifications 2.1 and 2.2 of that regulation.

GUR 4120, 4130 and 4150 are also chemically acceptable as per USDA as a material in direct contact with meat or poultry prepared under Federal inspection.

In Recommendation (Empfehlung) III “Polyethylenes”, the German Federal Institute for Consumer Health Protection and Veterinary Medicine (BgVV) regulates the use of polyethylene for the manufacture of consumer articles as defined in Article 5, Para. 1, No. 1 of the German “Food and Consumer Articles Law” (LMBG).

The BgVV Recommendations lay down in accordance with the present state of science and technology under what conditions a consumer article made from plastics satisfies the requirements of Article 31, Para. 1 of the LMBG. The Recommendations state that articles must be suitable for their intended application and should not impart odor or taste to food.

All basic grades (see section 1.1) comply with Recommendation III. There are therefore no objections on health grounds to the use of these materials for the production of consumer articles for food contact applications.

These materials also conform in composition to the Recommendation for the drinking water sector (KTW-Empfehlung 1.3.2 “Polyethylene”). The additional requirements specified in this Recommendation relate to the suitability of end products and it is the manufacturer’s responsibility to demonstrate compliance with these requirements.

Health assessment of plastics under food legislation varies somewhat from one country to another. The basic grades meet the requirements of virtually all countries that have set up regulations.

The European Commission regulations in this area are 90/128/EEC, 92/39/EEC, 93/9/ELOG, 95/3/EEC and 96/II/EEC. These specify which monomers used in the manufacture of plastics are permitted for food contact applications. Work is proceeding on regulations governing additives and polymerization aids.

All formulations of GUR complying with BgVV Recommendation III are also approved for food contact applications within the EU in accordance with Annex II of Directives 90/128/EEC, 92/39/EEC, 93/9/ELOG, 95/3/EEC and 96/II/EEC.

4. Applications – photo documentation

(Arranged according to processing technologies and market segments/industries with appropriate cross references to detailed information provided in the GUR® Topics publications, order no. B..., as indicated below)

4.1 Sheets, profiles (semi-finished and finished products)

(For parts and application examples, semi-finished product specification DIN 16 972 and GUR Topics B 300).

Semi-finished products are the starting point for a large number of finished articles and functional elements fabricated by machining that are used virtually throughout the entire machine and plant construction sector.

GUR can be used to produce compression molded sheets in many different sizes (e. g. 2000 x 1000 mm, 3000 x 2000 mm, 6000 x 2000 mm, 10 000 x 1000 mm etc.), thicknesses (e. g. 4 – 250 mm) and modifications (e. g. antistatic, reinforced etc.), a wide range of skived films (e. g., thicknesses from 0.05 – 3 mm) plus solid and hollow rods. The availability of diverse products and its good machining properties have made PE-UHMW a versatile engineering material that is very much in demand.

Extruded and milled profiles used as chain and belt guides, slideways and guide rails widen the scope of application.

4.1.1 Machine and plant construction

(see GUR Topics B 325 and B 329)

In packaging and filling plants, the food industry, transport, conveying and storage technology, assembly systems, the printing and textile industries etc., wear-, impact- and chemical-resistant components (e.g. profiles for chain/belt drives, curved guides, chain and belt deflecting and tensioning devices, bearing bushes, rail track disks and impact-absorbing elements etc.) can provide a trouble-free operation with low maintenance.

4.1.2 Linings, fenders

(see GUR Topics B 324)

Sheets of GUR (e.g. 8 – 20 mm thickness) are often ideal for lining silos, bunkers, chutes, truck loading platforms/dump trucks, rail wagons, ships' holds etc. because of their non-stick properties and excellent resistance to chemicals, low temperatures and abrasive wear. They permit good material flow, i. e. minimal caking with critical bulk solids/powder products. Dock fender systems made from GUR exploit the good slip properties, resistance to sea water and high abrasion resistance of the material.

Photo 1 Machining: See GUR Topics B 325, pages 20 and 21



Photo 2
Various Chain and belt guides



4.1.3 Paper and pulp industry

Wear-resistant suction box and screen covers, doctor blades, sealing strips, stripping elements, foils, filter plates, etc. of GUR have proved highly successful in papermaking machines (wire section) and the pulp industry.

4.1.4 Chemical industry, electroplating, ceramics industry

(see GUR Topics B 320)

Pumps: centrifugal, diaphragm, metering, eccentric; valves: butterfly valves, ball valves, slide valves; seals and gaskets, electroplating drums, bearing systems, gear-wheels, bellows, bearing bushes, slide and guide rollers, nozzles, doctor blades, stripping elements etc. are widely used throughout these industries because of the excellent chemical, corrosion and wear resistances of GUR.

4.1.5 Electrical industry, refrigeration/ cryogenic technology

Because of its low dissipation factor, which especially at high frequencies remains virtually constant over a wide temperature range, GUR is used for plug-in connectors, cable clamps, contact breakers and insulating components for current collectors in subways, e. g. London, Hamburg.

The remarkably high toughness of GUR, even at extremely low temperatures (down to -265°C), enables it to be used for dynamic seals, sleeves, piston rings, pump packings and many other components in refrigeration/cryogenic technology.

4.1.6 Sport, leisure

Sliding surfaces made from sintered GUR have become successfully established worldwide for Alpine and cross-country skis and snowboards, ice skating rinks and bowling alleys.

4.1.7 Prosthesis

Because of its excellent resistance to heat deformation at around 150°C GUR and GHR resins offer a fast, straightforward route to the manufacture of these products.

4.2 GUR specialty products

The GUR Ticona Business Unit offers a full range of specialty ultra-high molecular weight polyethylene (PE-UHMW) and very-high molecular weight polyethylene (PE-VHMW) grades, in powder forms, tailored for specific functional properties. With our unique polymerization and powder manipulation technology, the GUR specialty products provide:

Photo 3

GUR 2122, scanning electron micrograph of a particle. Product suitable for absorption of high filler quantities (e. g. active carbon)

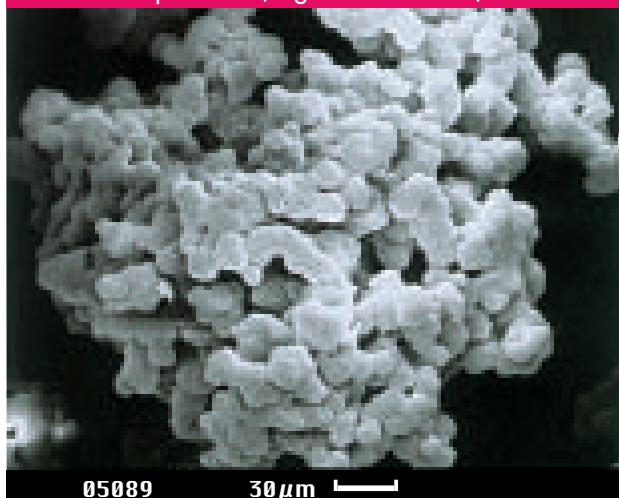
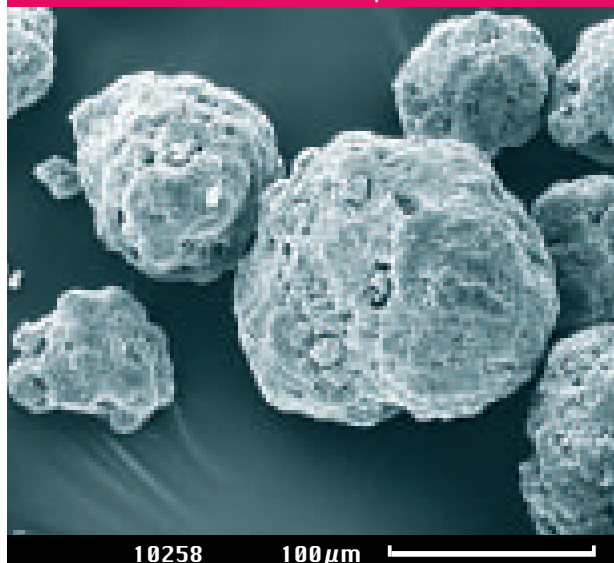


Photo 4 Scanning electron micrograph of a GUR 4120/4150 particle



Ultrahigh-molecular-weight Polyethylene (PE-UHMW)

- Unique particle morphology
- Various particle size distributions
- Fine micropowder
- Ultra-fine micropowder
- Coarse particle structures
- Engineered processibility and performance
- Excellent quality consistency

4.2.1 GUR specialty products for porous applications

GUR specialty products have well defined molecular weights, specifically engineered particle morphologies and precisely controlled particle size distributions. During sintering, the surface of individual polymer particles fuse at their contact points forming a porous structure (Photo 3). Porous parts fabricated with GUR products are used in various applications. Some typical application examples are:

- Absorbent wicking
- Aeration
- Analytical or diagnostic support and reservoirs
- Fluidizing sheets
- Industrial dust collection filters
- Pneumatic mufflers
- Water purification filters

Some of the typical processing performance benefits that may be achieved with the GUR specialty products are:

- Well controlled porosity and flow resistance
- Improved damping behavior
- Excellent raw material uniformity for large volume manufacturing

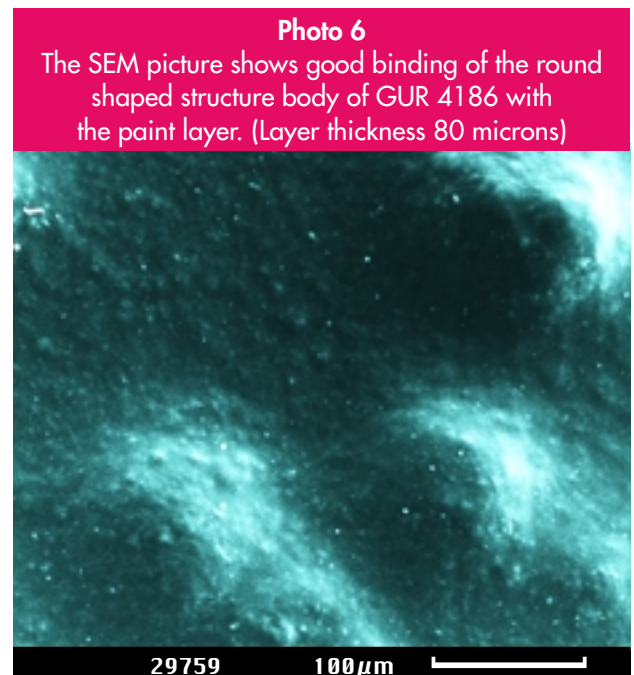
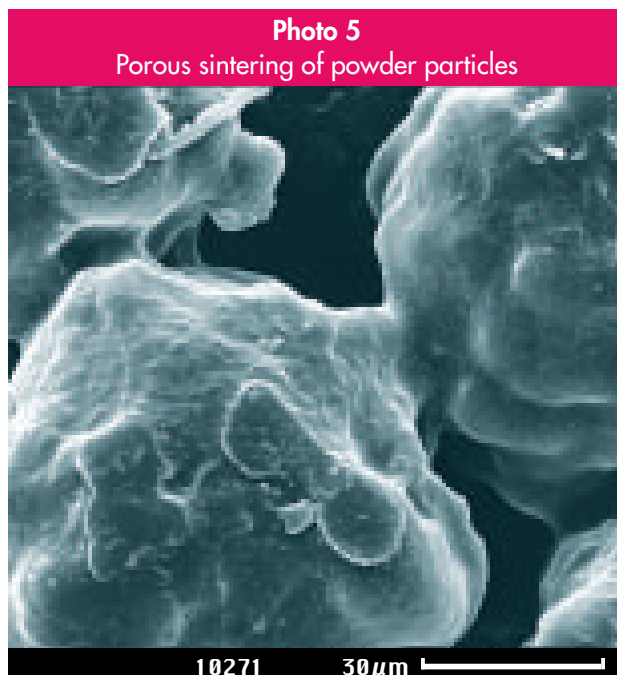
- High consistency of powder properties and quality
- Good compatibility with other filtration media such as activated carbon
- Good mechanical strength
- Excellent processing flexibility
- Outstanding chemical resistance
- FDA, USDA and NSF certified grades

Photo 4 shows a typical morphology of GUR standard grade. Photo 5 demonstrates one example of what GUR specialty products can offer for porous and filtration applications. With its unique particle morphology, porous parts made with GUR 2122 have low flow resistance, high flow uniformity and good compatibility with other functional media.

4.2.2 GUR specialty products for additives and coating applications

Within the GUR specialty products, there are products, such as GUR Micropowders, specifically engineered for additives and coating applications. Our technology expertise enables us to tailor our GUR specialty products with engineered particle sizes, particle size distributions and particle morphologies to meet individual performance needs. Some of the typical benefits that can be achieved with the GUR specialty products are:

- Improved scratch resistance
- Surface effects
- Higher impact strength
- Better abrasion resistance
- Better chemical resistance



Ultrahigh-molecular-weight Polyethylene (PE-UHMW)

The Photo 6 shows good binding of the round shaped structure body of a GUR polymer with the paint layer. (Layer thickness 80 microns)

4.2.3 PE-UHMW high-modulus filaments

Gel spinning technology makes it possible to produce extremely high-tenacity, low-stretch filament yarns, which can then be used as, e.g. cut-resistant, protective gloves in the meat trade or in handling metal sheets. Braided fishing lines, nets, rope, ballistic fabric and many other products are now manufactured from these special fibers produced from PE-UHMW.

4.3 Battery separators of GUR

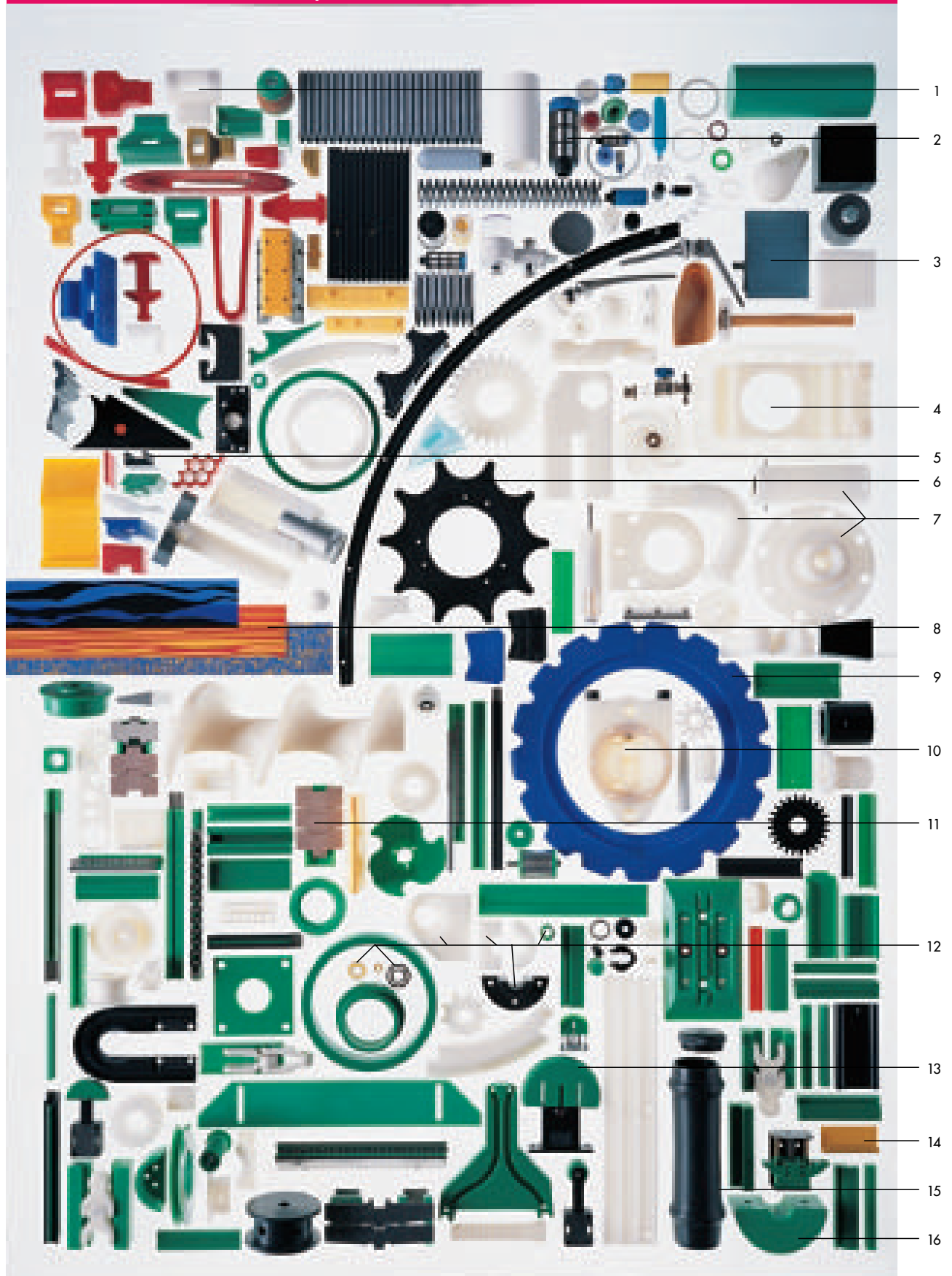
From a mixture of silicic acid, GUR, oil and additives, a 150–250 µm thick film is extruded. A subsequent solvent treatment removes part of the oil and in this way a microporous film is produced (pore size about 0.1–0.7 µm).

From this film, separator envelopes are produced that insulate the lead electrode grids from each other in modern car batteries and prevent short circuits between the electrodes over a long battery service life.

Captions for GUR Poster on page 23

1. *Textile industry, looms: picker, shuttle, picker head, lug strap, heald strap, heald frame guide*
2. *Porous products: lamellar filter (dust filtration), oil filter, silencer, pen tips*
3. *Battery separator envelope*
4. *Valve lining (slide valve)*
5. *Paper industry: doctor blades, foils, suction box cover*
6. *Beverage filling lines: transport starwheel, curved guide*
7. *Electroplating technology: drum bearing, bellows*
8. *Soles for ski and snowboard*
9. *Drive deflection wheel (rake in sewage treatment plant)*
10. *Side piece for diaphragm pump*
11. *Drive and conveying technology: belt profiles for roller chains, flat-top chains (steel, plastic)*
12. *Various bearing designs: split bearings, roller bearings, flanged bearing bushes etc.*
13. *Chain and belt tensioner*
14. *Profiles for railing guides*
15. *“Rabbit” for radioactive samples*
16. *Deflecting rollers: split design for conveyor chains*

GUR poster (size 1000 x 700 mm, B 313 E)



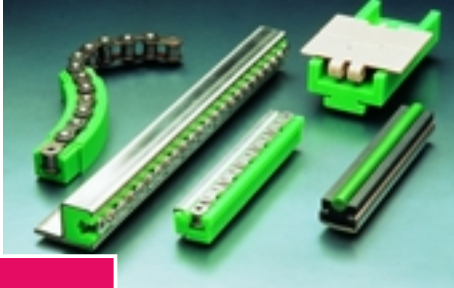


Photo 7
Chain and belt guides

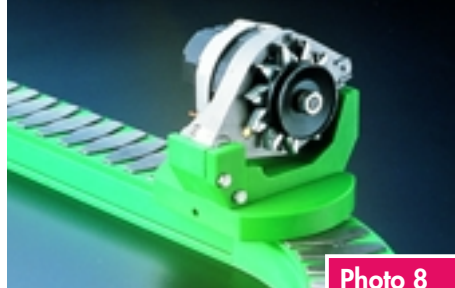


Photo 8
Car alternator assembly



Photo 9
Starter motor assembly conveyor

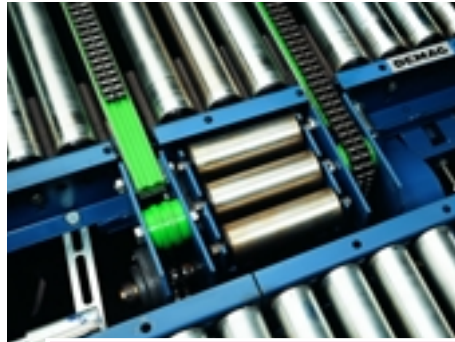


Photo 10
Roller conveyor, chain guide and deflecting roller



Photo 11
Curve guide for POM chains (with return)

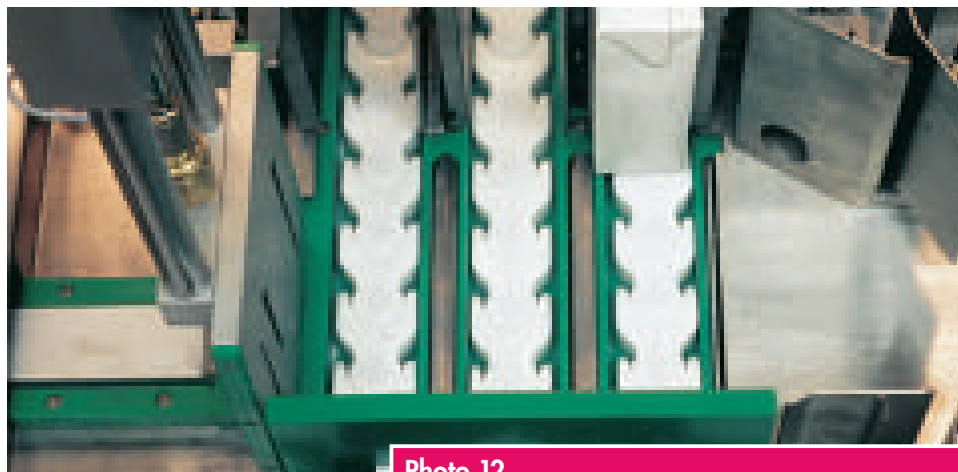


Photo 12
Three guides with POM transport chain (curved sprocket chain)



Photo 13
Guide groove control in a packaging machine

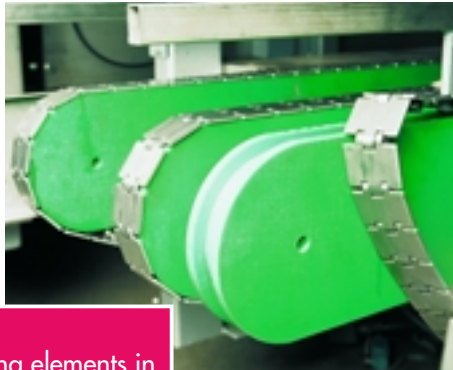


Photo 14
Self-supporting elements in
a conveyor unit for crates



Photo 15
Self-supporting belt guides



Photo 16
Curved guide/guide curve for
a bottle-packaging machine



Photo 17
Curved guide profile in a bottle-filling plant

Photo 18

Pharmaceutical inspection unit
(starwheel, screw, various guides)

**Photo 20**

Cardboard box set-up unit (chain guides)

**Photo 21**

Bottle-filling plant for cleaning substances
(multi-stage starwheel, screw, flat-top chain guide)

**Photo 19**

Food packaging/bagging unit

**Photo 22**

Bag wrapping unit (chain guides – open – closed)



Photo 23
Various bearing designs (open, closed)



Photo 24
Holders for textile bobbin packaging

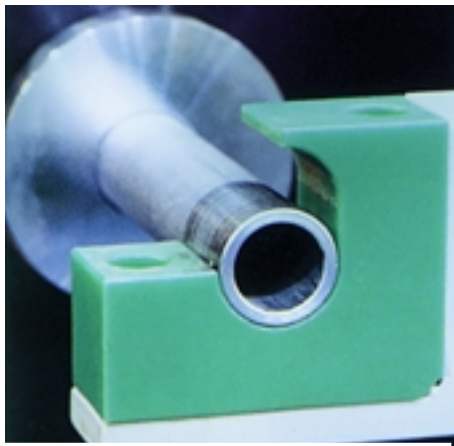


Photo 25
Payoff unit bearing for a blister packaging machine

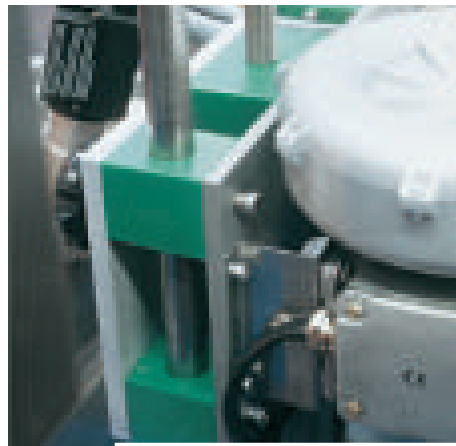
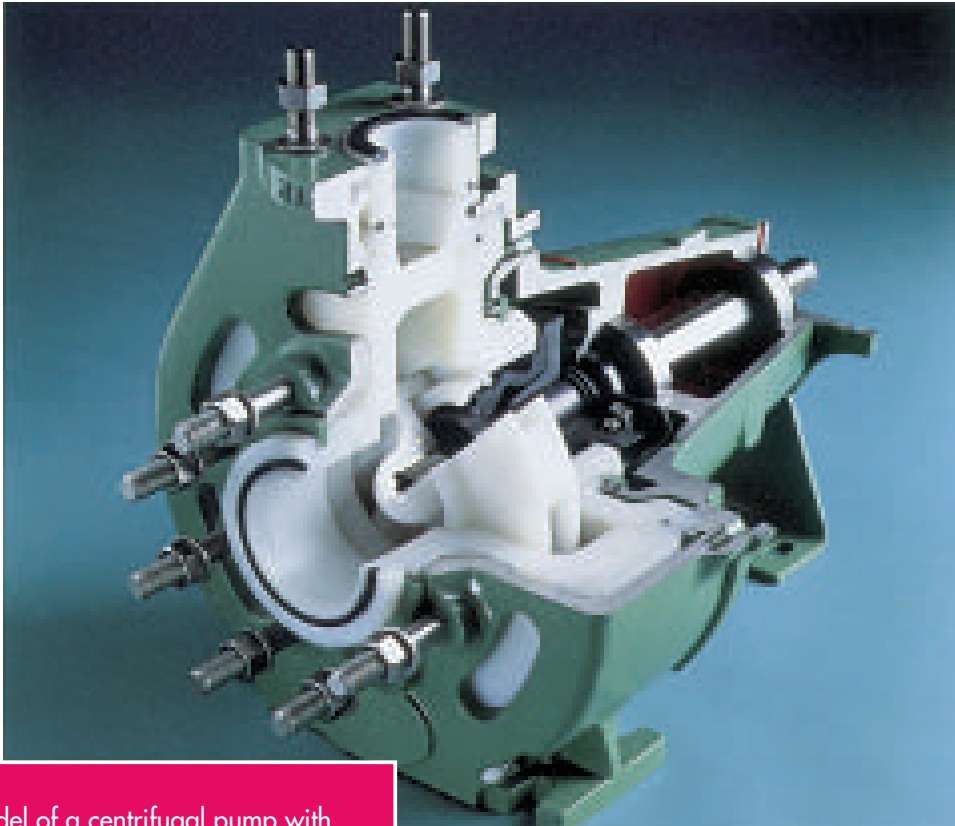


Photo 26
Lifting unit with spindle and bearing guides



Photo 27
Guide rollers in a film wrapping unit

**Photo 28**

Cutaway model of a centrifugal pump with enclosed impeller used in the chemical industry

**Photo 29**

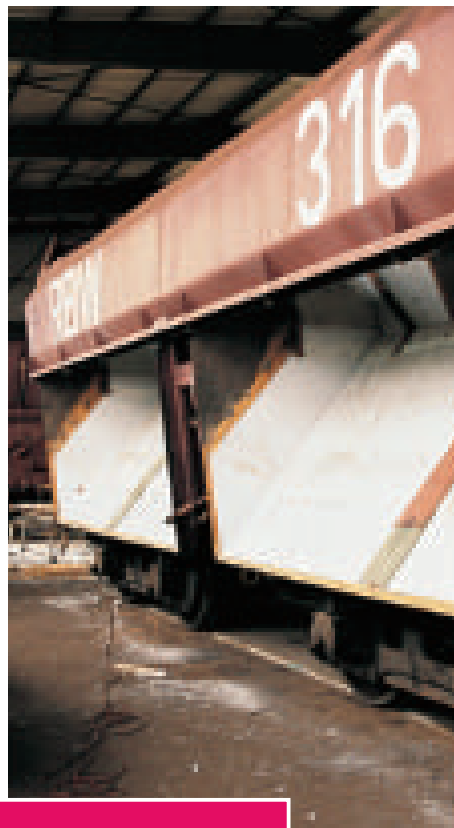
Heald frame guide in a gripper shuttle loom

**Photo 30**

Insulators for subway current collectors

**Photo 31**

Shaping elements in a bread roll-making machine



Photos 32 + 33
Lining on a bucket wheel excavator and coal wagon

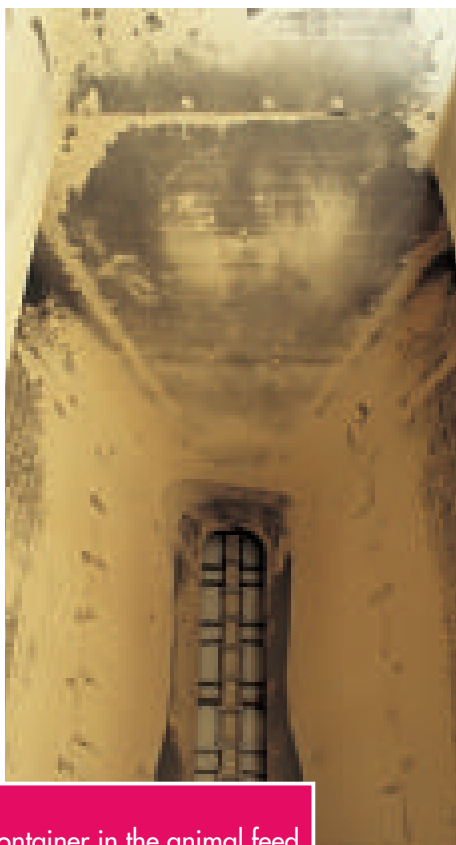


Photo 34
Weigh-mix container in the animal feed industry lined with sheets of GUR

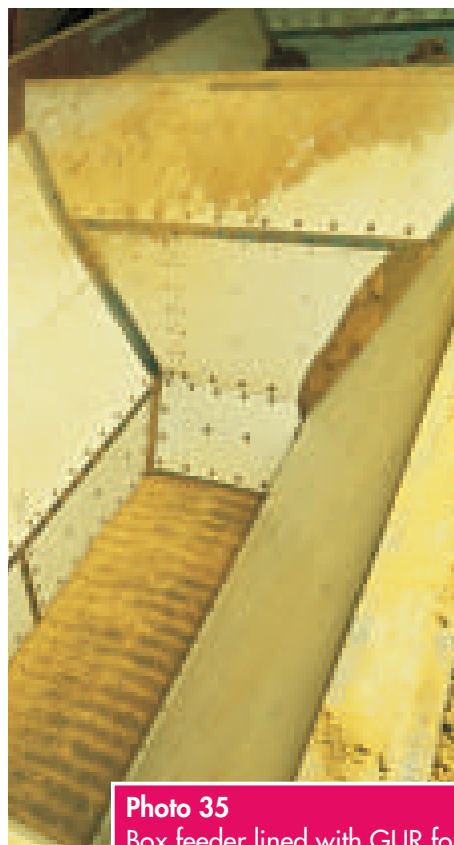


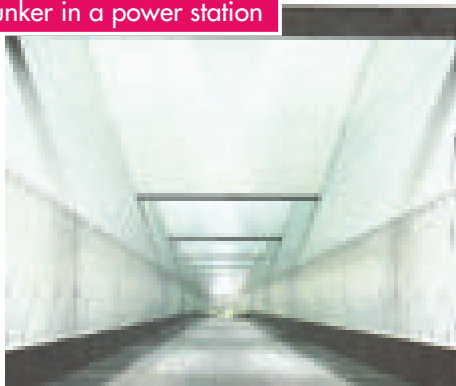
Photo 35
Box feeder lined with GUR for intermediate storage of clay in the pottery industry

Photo 36

Coal loading station with chute of GUR

**Photo 37**

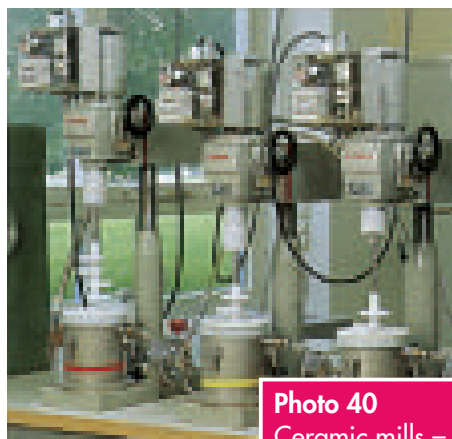
Lined coal bunker in a power station

**Photo 38**

Cargo hold of coal ship lined with GUR

Photo 39

Mixer lined with GUR for mixing ash into a paste

**Photo 40**

Ceramic mills – container and disk stirrer made from GUR



Photo 41
Fenders made from GUR

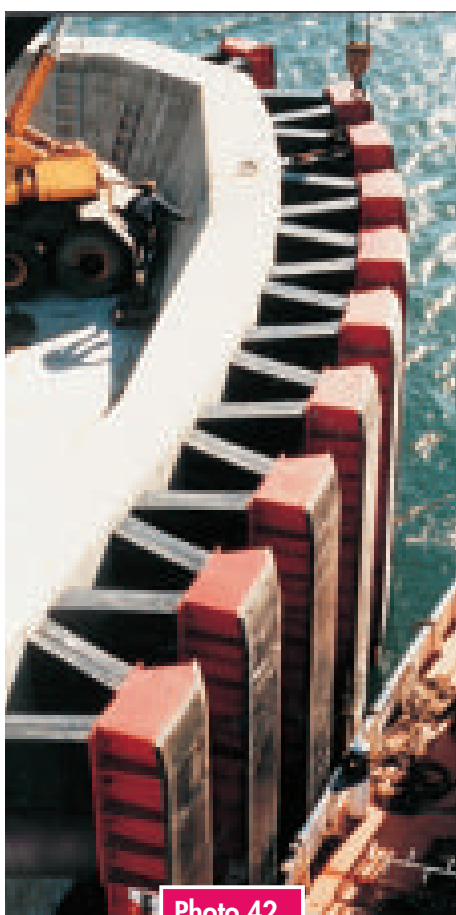


Photo 42
Fendering

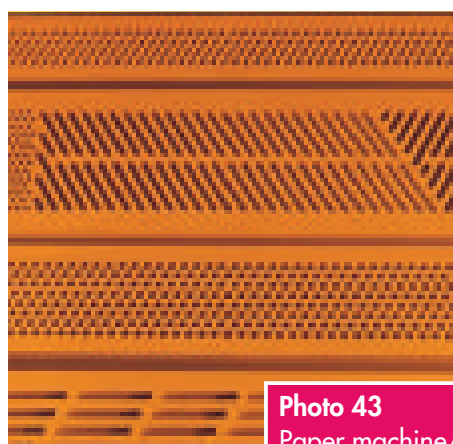


Photo 43
Paper machine/papermaking
– various suction box covers



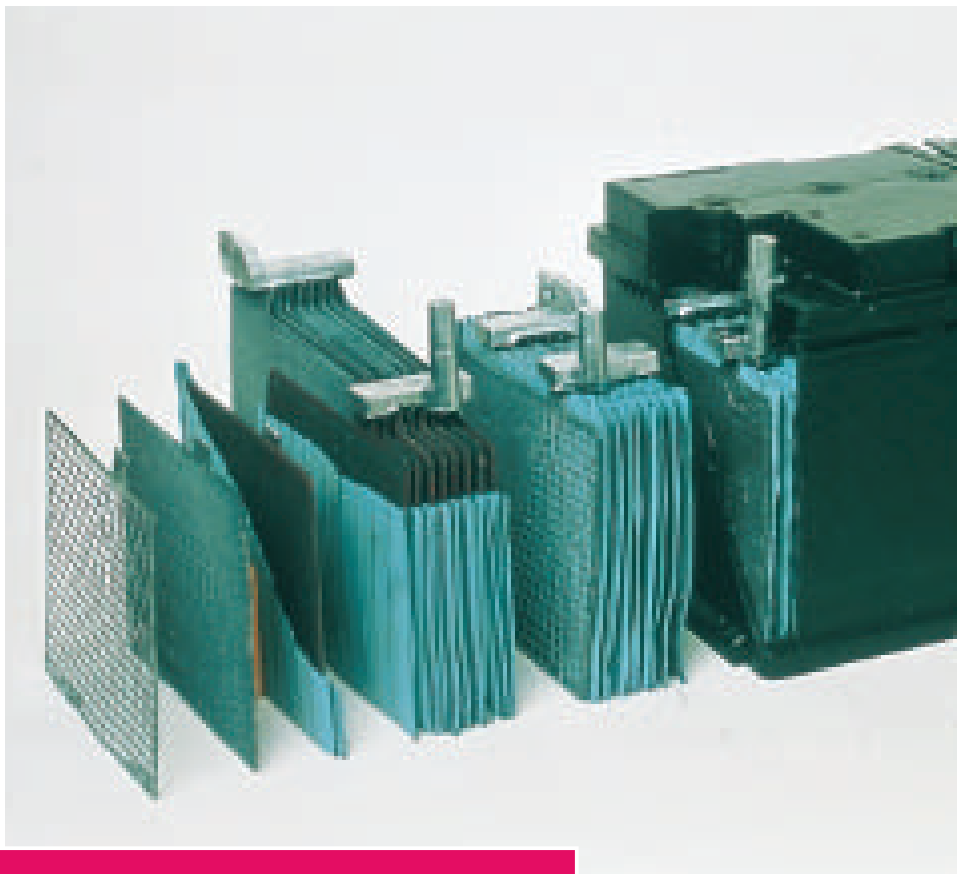
Photo 44
Alpine ski soles made from GUR

Photo 45

Protective glove made from
PE-UHMW high-modulus filaments

**Photo 46**

Fishing line made from PE-UHMW filaments

**Photo 47**

Section through a car battery with envelope separators of GUR

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