Fortron®

Polyphenylene sulphide (PPS)

- continuous service temperature up to +240 °C
- inherently flame retardant
- high hardness and rigidity
- low creep
- very good chemical resistance

Fortron® *Polyphenylene sulphide (PPS)*

Ticona

Contents

1.	**Introduction**	2
2.	**Grades, supply forms, colour range, quality management**	2
2.1	Fortron grade range	3
2.2	Colour masterbatches, coloration	4
2.3	Quality management	4
3.	**Properties**	6
3.1	Mechanical properties	6
3.1.1	Properties under short-term stress	6
3.1.2	Properties under long-term stress	7
3.1.3	Fluctuating stress	15
3.2	Thermal properties	17
3.3	Electrical properties	21
3.4	Surface properties	21
3.4.1	Hardness	21
3.4.2	Sliding and abrasion properties	21
3.5	Specification listings	22
3.5.1	MIL specifications	22
3.5.2	Potable water regulations	22
3.5.3	Automotive specifications	22
4.	**Resistance to service environment effects**	23
4.1	Heat ageing	23
4.2	Water absorption	23
4.3	Chemical resistance	23
4.4	UV resistance	29
4.5	Flammability	29

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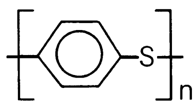
5.	**Processing, finishing**	30
5.1	Injection moulding	30
5.1.1	Machine conditions	30
5.1.2	Shrinkage	31
5.1.3	Mould wall temperatures	33
5.1.4	Mould design, design notes, sprue and gate	33
5.1.5	Changing from another thermoplastic to Fortron	36
5.1.6	Changing from Fortron to another thermoplastic	36
5.1.7	Safety notes	37
5.1.7.1	Thermal stress of the material	37
5.1.7.2	Extraction at the processing machine	37
5.1.7.3	Fire precautions	37
5.2	Extrusion processing	37
5.3	Annealing	37
5.4	Machining	38
5.4.1	General information on machining	38
5.4.2	Tool recommendations for machining	39
5.5	Assembly of Fortron mouldings	39
5.5.1	Welding	39
5.5.2	Snapfit joints	41
5.5.3	Adhesive bonding	41
5.5.4	Assembly with screws	41
5.6	Laser marking	42
5.7	Painting	42
5.8	Printing	42
5.9	Metallisation	42
6.	**Use of recyclates**	43
7.	**UL cards**	44
8.	**Photo supplement showing typical applications**	48
9.	**Subject index**	52
10.	**Literature**	54

Tables (selection):

1	Physical properties
3	Status of Fortron in UL tests
4	CSA rating
6	Resistance to chemicals

1. Introduction

Fortron® is a linear, partially crystalline polyphenylene sulphide. A phenylene ring and sulphur atom form the backbone of the macromolecule and give Fortron a number of unusual properties [1], [2]:



- continuous service temperatures up to 240°C, short-term exposure up to 270°C,
- inherently flame-retardant (UL 94: V-0, some grades 5 VA),
- very good chemical and oxidation resistance,
- high hardness and rigidity,
- very low water absorption,
- low creep, even at elevated temperatures.

This combination of properties places Fortron in the category of a high-performance thermoplastic.

Fortron is suitable for the manufacture of mouldings with good mechanical properties and thermal stability.

The most important applications for Fortron are in the electrical and electronics industries (e. g. plugs and multipoint connectors, bobbins, relays, switches, encapsulation of electronic components). Fortron is being employed increasingly in the automotive industry (air intake systems, pumps, valves, gaskets, components for exhaust gas recirculation systems). Fortron is also used to produce components for mechanical and precision engineering.

For many components exposed to high service stresses, Fortron is the preferred alternative to light-metal alloys, thermosets and many other thermoplastics.

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2. Grades, supply forms, colour range, quality management

Fortron is supplied in powder and pellet form. The current range of grades is described in section 2.1.

By compounding Fortron with glass fibres and glass fibre/mineral filler blends, its rigidity, strength and heat resistance can be considerably increased.
The Fortron range includes extrusion and injection moulding grades with different types and levels of additive and different melt viscosities. Specially easyflowing grades 1140L6, 4184L6, 6850L6 and 6165A6 are available for thinwalled mouldings with unfavourable flow length/wall thickness ratios. Their properties are comparable with those of the corresponding grades with medium viscosity.

The powder grades offer a variety of possibilities for use in powder technology, e. g. as heat-resistant binders or additives in PTFE compounds.

The unreinforced pellet grades are used mainly for fibre manufacture (monofilaments and multifilaments) and for special applications in extrusion (e. g. pipes, semi-finished products, films). Section 2.1 provides an overview.

The range of grades is currently being expanded. Further details are available on request.

2.1 Fortron grade range

Reinforced grades (pellets)	**Fillers**	**Description**
1131L4	30% (w/w) glass fibres	injection moulding grade, medium-range melt viscosity, permits flash-free production of complicated mouldings
1140L4	40% (w/w) glass fibres	injection moulding grade, medium-range melt viscosity with little tendency to form flash
1140L6	40% (w/w) glass fibres	injection moulding grade, like 1140L4 but with lower melt viscosity
1140E7	40% (w/w) glass fibres	improved injection moulding grade, low melt viscosity with little tendency to form flash
4184L4	50% (w/w) glass fibres/mineral	injection moulding grade, comes between 1140L4 and 6165A4 in terms of properties
4184L6	50% (w/w) glass fibres/mineral	injection moulding grade, like 4184L4 but with lower melt viscosity
4665B6	65% (w/w) glass fibres/mineral	injection moulding grade, like 6165A4/A6 but with better tracking resistance and very low warpage
6160B4	60% (w/w) glass fibres/mineral	injection moulding grade, lower density, low corrosion, specially suitable for electronic components
6165A4	65% (w/w) glass fibres/mineral	injection moulding grade, medium-range melt viscosity, lower shrinkage and warpage than glass-fibre-reinforced grades
6165A6	65% (w/w) glass fibres/mineral	injection moulding grade, like 6165A4 but with lower melt viscosity
6850L6	50% (w/w) glass fibres/mineral	injection moulding grade, low melt viscosity, very low warpage
1140L0	40% (w/w) glass fibres	extrusion grade

Unreinforced grades (powder and pellets)	**Supply form**	**Description**
0203B6	coarse powder (average particle size ≧ 300 μm), good free-flowing properties	very low melt viscosity
0203P6	pellets	very low melt viscosity (can be supplied on request)
0205B4	coarse powder (average particle size ≧ 300 μm), good free-flowing properties	low melt viscosity
0205B4/20 μm	finely ground powder (average particle size ≈ 20 μm)	for powder technology, e. g. as heat-resistant binder, as additive in PTFE compounds
0205P4	pellets	low melt viscosity
0214B1	coarse powder (average particle size ≧ 300 μm), good free-flowing properties	medium-range melt viscosity
0214C1	pellets	medium-range melt viscosity
0320B0	coarse powder (average particle size ≧ 300 μm), good free-flowing properties	high melt viscosity
0320C0	pellets	high melt viscosity

2.2 Colour masterbatches, coloration

The reinforced grades are supplied in natural, black and brown colours and the unreinforced grades in natural colour.

In-house coloration of Fortron is possible and serves to identify and distinguish components.

For this purpose, a range of Fortron colour masterbatches with a high pigment content is available. Colour masterbatches are supplied as granules and are used to colour natural Fortron grades. The recommended concentrations are ≦ 40 : 1 for black and brown, ≦ 20 : 1 for the other colours.

If processors wish to use their own colorants, only pigments which can resist the processing temperatures of Fortron (up to 350°C) without decomposition or colour change may be employed. The pigment content should not exceed 1.5% (w/w). Higher pigment contents may cause a reduction in mechanical properties and flowability.

The following colour masterbatches are currently available:

SD3002 K40	black	SJ3013 K20	green
SY3004 K40	brown	SN3012 K20	orange
SC3010 K20	dark grey	SL3017 K20	yellow
SC3011 K20	pale grey	SS3006 K20	red
SG3005 K20	blue		

All colour masterbatches are cadmium-free.

Mechanical properties such as tensile strength and elongation at break may be slightly altered by the addition of colorants.

It should be noted that formulations cannot be expected to give a permanently true colour match. This is because photooxidative reactions taking place under light and heat lead to colour changes in very thin edge layers of components. No change in mechanical properties has been detected in such cases.

2.3 Quality management

Within the Ticona Group in Europe the Fortron Product Team has obtained registration acc. to ISO 9001 and QS-9000 (DOS [German Association for the Certification of Quality Systems], reg. no. 2719). This indicates that the quality system meets the requirements of this international standard. The use of SPC methods to monitor product quality is part of this quality system (see also the brochures “Quality Assurance Polymer Material” and “Statistical Process Control”).

By regular self-assessment in accordance with the automotive requirements of QS-9000 we are constantly developing our quality system to meet the needs of our customers.

To foster effective partnerships with our customers we offer to conclude quality agreements and also to issue test certificates. These agreements document the specifications for our products. In addition, we can agree to issue an inspection certificate in accordance with EN 10 204-3.1B. This contains measured values relating to the batch of which the delivery is part.

DQS

CERTIFICATE

DQS Deutsche Gesellschaft zur Zertifizierung von Managementsystemen mbH
Qualitäts- und Umweltgutachter

hereby certifies that the company

Ticona

Ticona GmbH
Strategic Business Unit Performance Polymers
D-65926 Frankfurt am Main
with the locations as listed in the annex

for all activities in Europe
of Design, Production, Marketing, Distribution and Service for Engineering Plastics

has implemented and maintains a

quality system.

A quality audit, conducted in accordance with QS-9000, appendix B, 'Code of Practice', and documented in an audit report, has verified that this quality system fulfills the requirements of the following standards:

DIN EN ISO 9001 August 1994 edition	**QS-9000** Quality System Requirements Second edition February 1995

This certificate is valid until	2001-12-01
Certificate Registration No.:	2719-03/428
Issued in Frankfurt am Main, Germany	1998-12-02

Dr.-Ing. K. Petrick   Dipl.-Ing. J. Pärsch

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DQS is member of:
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3. Properties

This section discusses the important characteristic properties of Fortron. They have been determined largely by standard test methods.

The physical property values of Fortron are given in table 1 on pages 8 and 9. This table is also available as a pull-out leaflet (B 260 FB E).

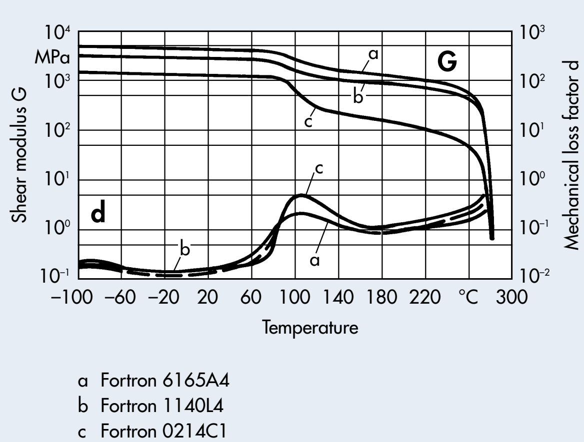
Descriptions of the Fortron grades and their properties are available on the ®CAMPUS 4.1 data base diskette. This diskette can be used on IBM-compatible PCs; the diskette can be ordered by telephoning (++ 49-69) 305 70 63.

The property values determined on test specimens by standard test methods are guide values and can be used as a basis for comparing different materials. However they have only limited applicability to finished parts. The strength of a component depends to a great extent on its design and hence design strength is the criterion used to assess loadbearing capacity.

3.1 Mechanical properties

To characterize the dependence of the mechanical properties of a plastic on temperature, the shear modulus G and the mechanical loss factor d are used, fig. 1.

Fig. 1 · Shear modulus G and loss factor d of some Fortron grades as function of temperature, measured in the torsion pendulum test according to ISO 6721-1,2



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3.1.1 Properties under short-term stress

The behaviour of materials under dynamic short-term stress can be examined in the tensile test according to ISO 527-1, 2. This test enables important properties as tensile strength and strain at break to be determined.

Figs. 2 and 3 show the stress-strain properties of Fortron 1140L4 and 6165A4 at different temperatures. In the upper temperature range (150, 200°C), the values for strain at break are relatively high; this is most marked with the 40% glass-reinforced grade Fortron 1140L4.

Fig. 2 · Stress/strain curves for Fortron 1140L4, measured at different temperatures

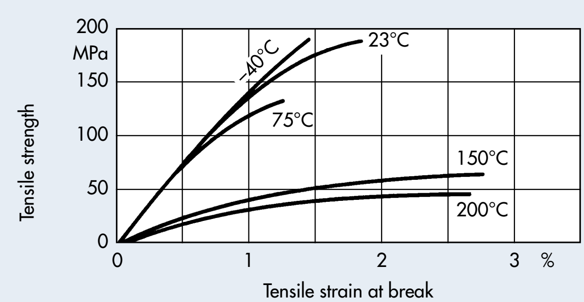
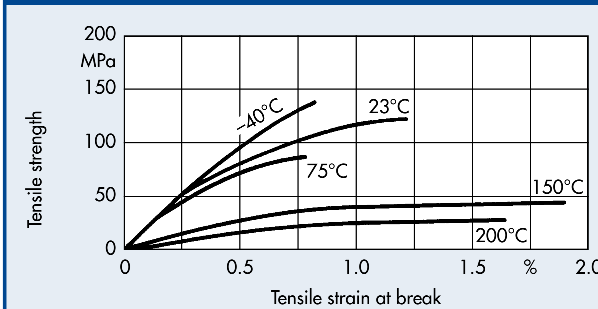


Fig. 3 · Stress/strain curves for Fortron 6165A4, measured at different temperatures



Other properties measured under short-term stress are the different elastic moduli, i. e. the tensile modulus and flexural modulus, determined according to IO 527-1, 2 and ISO 178. The values provide an indication of rigidity and are used not only to characterize plastics but also for strength calculation and the design of moulded parts.

The high tensile and flexural moduli of the reinforced Fortron grades should be noted, see figs. 4 and 5. In these two properties, Fortron 6165A4, containing 65% filler blend, is superior to the grades with 40% glass fibres.

Fig. 4 · Tensile modulus of the most important Fortron Grades as a function of temperature, measured according to ISO 527-1,2

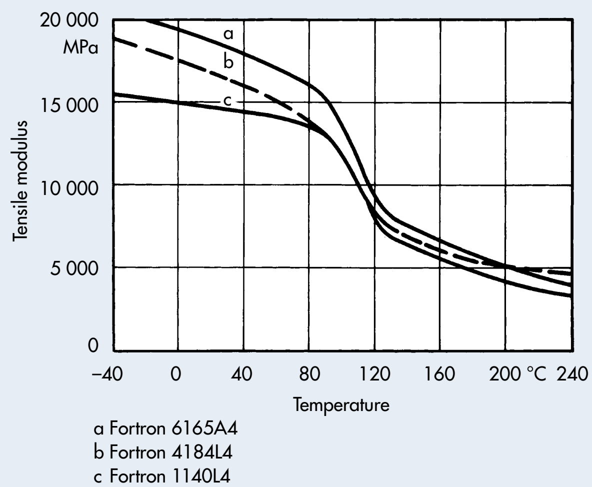
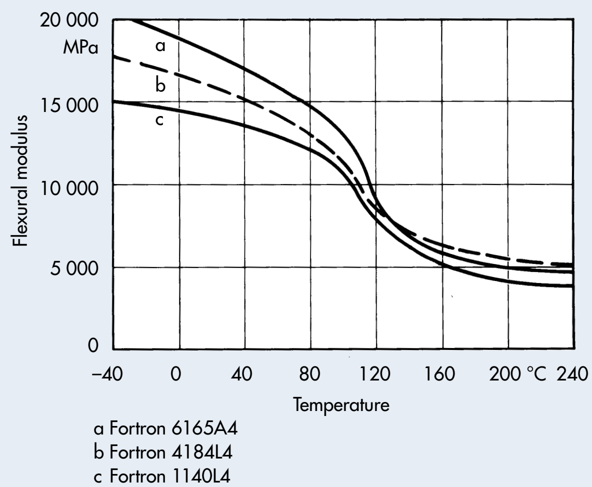


Fig. 5 · Flexural modulus of the most important Fortron grades as a function of temperature, measured according to ISO 178



3.1.2 Properties under long-term stress

The results of long-term tests carried out under various conditions provide the design engineer 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 899-1 (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, for relatively small 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 condition.

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

This property of thermoplastic materials is exhibited only to a very limited extent in the case of the reinforced Fortron grades. This can be seen in the following figs. 6 – 13, which show important characteristic functions for the creep behaviour of Fortron 1140L4 and 6165A4 under tensile stress and at temperatures of 23, 120, 150 and 200°C. The required tensile creep tests were carried out up to a time under load of 10^3 h and extrapolated to 10^4 h.

Table 1 · Physical properties of Fortron (PPS)

Property		Unit	Test method
Reinforcement level (rounded-off)		% (w/w)	–
Density		g/cm^3	ISO 1183
Water absorption (24 h immersion at 23°C)		%	ASTM D 570
Moulding shrinkage (p_c = 500 bar, h = 2 mm)		%	ISO 294-4
(Typical values) [1]) (p_c = 500 bar, h = 4 mm)		%	ISO 294-4
Mechanical properties, measured at 23°C, 50% relative humidity			
Tensile strength[2])		MPa	ISO 527 parts 1 and 2
Strain at break[2])		%	ISO 527 parts 1 and 2
Tensile modulus		MPa	ISO 527 parts 1 and 2
Flexural strength		MPa	ISO 178
Flexural modulus		MPa	ISO 178
Compressive strength		MPa	ISO 604
Compressive modulus		MPa	ISO 604
Impact strength (Charpy)		kJ/m^2	ISO 179/1eU
Notched impact strength (Charpy)		kJ/m^2	ISO 179/1eA
Notched impact strength (Izod)		kJ/m^2	ISO 180/1A
Ball indentation hardness, 30 sec. value		N/mm^2	ISO 2039 part 1
Rockwell hardness, scale M		–	ASTM D 785
Thermal properties			
Heat deflection temperature	HDT/A at 1.8 MPa	°C	ISO 75 parts 1 and 2
	HDT/C at 8.0 MPa	°C	
Coefficient of linear thermal expansion[1])	(between –50 and 90°C)	$°C^{-1}$	ISO 11359-2
	(between 90 and 250°C)	$°C^{-1}$	ISO 11359-2
Electrical properties, measured at 23°C, 50% relative humidity			
Relative permittivity ε_r	at 10 kHz	–	IEC 60250
	at 1 MHz	–	
Dissipation factor tan δ	at 10 kHz	–	
	at 1 MHz	–	
Electric strength		kV/mm	IEC 60243 part 1[3])
Comparative tracking index CTI		–	IEC 60112
	CTI M	–	
Volume resistivity		Ω · m	IEC 60093[4])
Surface resistivity		Ω	
Ball indentation test		°C	IEC 60089 (Sec) 82 March 1993
Fire behaviour			
Flammability		Class	UL 94
Hot wire test (at 1, 2 and 4 mm wall thickness)		°C	IEC 60695 part 1 and 2

[1]) Values from longitudinal transverse directions
[2]) Testing speed 5 mm/min
[3]) P 25/P 75 in transformer oil according to IEC 60296, 1 mm thick sheet
[4]) Measured with sticking electrodes
[5]) Only for 4665B6 black

p_c = cavity pressure

(The data quoted are typical values)

pellets reinforced with glass fibres			unreinforced pellet grades	powder grades	extrusion grades
1131L4	**1140L4*)**	**1140E7**	****)**	*****)**	**1140L0**
30	40	40	–	–	40
1.56	1.65	1.65	1.35	1.35	1.65
0.02	0.02	0.02	0.01	0.01	–
0.3/0.7	0.2/0.6	0.2/0.6	1.2/1.5	–	–
0.5/0.8	0.4/0.6	0.4/0.6	1.5/1.8	–	–
165	195	150	75	75	185
1.9	1.9	1.2	–	–	1.9
12 200	14 700	15 700	3 700	3 700	–
255	285	230	130	130	280
12 000	14 500	–	3 800	3 800	14 000
–	265	–	–	–	–
–	15 000	–	–	–	–
42	53	28	–	–	–
8	10	7	–	–	10
8	10	7	–	–	–
–	322	–	190	–	–
–	100	100	93	–	–
265	270	270	110	110	–
205	215	215	–	–	202
–	$26 \cdot 10^{-6}$	–	–	–	–
–	$48 \cdot 10^{-6}$	–	–	–	–
–	4.0	–	–	–	–
–	4.1	–	–	–	–
–	$0.2 \cdot 10^{-3}$	–	–	–	–
–	$2.0 \cdot 10^{-3}$	–	–	–	–
–	28	–	–	–	–
–	125	–	100	–	–
–	100	–	–	–	–
$> 10^{13}$	$> 10^{13}$	–	–	–	–
$> 10^{15}$	$> 10^{15}$	$> 10^{15}$	$> 10^{15}$	$> 10^{15}$	–
–	260	–	–	–	–
V-0	V-0	V-0	–	–	–
(0.38 mm)	(0.38 mm)	(0.85 mm)	–	–	–
960	960	–	–	–	–

*) The properties of 1140L6 are comparable to those of 1140L4
**) The properties apply to all unreinforced pellet grades
***) The properties were determined on injection moulded specimens and apply to all powder grades

3

Table 1 · Physical properties of Fortron (PPS)			
Property		**Unit**	**Test method**
Reinforcement level (rounded-off)		% (w/w)	–
Density		g/cm^3	ISO 1183
Water absorption (24 h immersion at 23°C)		%	ASTM D 570
Moulding shrinkage (p_c = 500 bar, h = 2 mm)		%	ISO 294-4
(Typical values) [1]) (p_c = 500 bar, h = 4 mm)		%	ISO 294-4
Mechanical properties, measured at 23°C, 50% relative humidity			
Tensile strength[2])		MPa	ISO 527 parts 1 and 2
Strain at break[2])		%	ISO 527 parts 1 and 2
Tensile modulus		MPa	ISO 527 parts 1 and 2
Flexural strength		MPa	ISO 178
Flexural modulus		MPa	ISO 178
Compressive strength		MPa	ISO 604
Compressive modulus		MPa	ISO 604
Impact strength (Charpy)		kJ/m^2	ISO 179/1eU
Notched impact strength (Charpy)		kJ/m^2	ISO 179/1eA
Notched impact strength (Izod)		kJ/m^2	ISO 180/1A
Ball indentation hardness, 30 sec. value		N/mm^2	ISO 2039 part 1
Rockwell hardness, scale M		–	ASTM D 785
Thermal properties			
Heat deflection temperature	HDT/A at 1.8 MPa	°C	ISO 75 parts 1 and 2
	HDT/C at 8.0 MPa	°C	
Coefficient of linear thermal expansion[1])	(between –50 and 90°C)	$°C^{-1}$	ISO 11359-2
	(between 90 and 250°C)	$°C^{-1}$	ISO 11359-2
Electrical properties, measured at 23°C, 50% relative humidity			
Relative permittivity ε_r	at 10 kHz	–	IEC 60250
	at 1 MHz	–	
Dissipation factor tan δ	at 10 kHz	–	
	at 1 MHz	–	
Electric strength		kV/mm	IEC 60243 part 1[3])
Comparative tracking index CTI		–	IEC 60112
	CTI M	–	
Volume resistivity		$\Omega \cdot m$	IEC 60093[4])
Surface resistivity		Ω	
Ball indentation test		°C	IEC 60089 (Sec) 82 March 1993
Fire behaviour			
Flammability		Class	UL 94
Hot wire test (at 1, 2 and 4 mm wall thickness)		°C	IEC 60695 part 1 and 2

[1]) Values from longitudinal transverse directions
[2]) Testing speed 5 mm/min
[3]) P 25/P 75 in transformer oil according to IEC 60296, 1 mm thick sheet
[4]) Measured with sticking electrodes
[5]) Only for 4665B6 black

p_c = cavity pressure

(The data quoted are typical values)

pellets reinforced with glass fibres and mineral filler				
4184L4*)	**4665B6**	**6160B4**	**6165A4**)**	**6850L6**
50	65	60	65	50
1.80	2.03	1.90	1.95	1.80
0.02	0.02	0.02	0.02	0.02
0.3/0.6	0.2/0.6	0.2/0.6	0.2/0.6	0.3/0.6
0.4/0.7	0.3/0.7	0.3/0.7	0.3/0.7	0.4/0.7
165	110	145	130	125
1.4	1.2	1.0	1.2	1.0
16 600	17 300	17 300	19 000	18 500
250	180	220	210	190
16 200	16 000	16 700	18 800	16 800
245	200	220	230	230
16 200	–	–	18 500	–
29	18	27	20	16
7	6	7	7	4
7	5	6	6	4
365	459	403	428	–
–	–	–	100	–
270 215	270 215	270 220	270 215	270 215
$24 \cdot 10^{-6}$ $46 \cdot 10^{-6}$	– –	– –	$19 \cdot 10^{-6}$ $36 \cdot 10^{-6}$	$23 \cdot 10^{-6}$ $46 \cdot 10^{-6}$
4.7 4.7	– 5.3	– 4.9	5.4 5.6	– –
$0.8 \cdot 10^{-3}$ $2.0 \cdot 10^{-3}$	– $2.0 \cdot 10^{-3}$	– $1.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$ $2.0 \cdot 10^{-3}$	$1.0 \cdot 10^{-3}$ $1.0 \cdot 10^{-3}$
27	25	–	25	25
150 150	≧ 250 [5]) –	175 –	175 200	– –
$> 10^{13}$	$> 10^{13}$	$> 10^{13}$	$> 10^{13}$	–
$> 10^{15}$	$> 10^{15}$	$> 10^{15}$	$> 10^{15}$	$> 10^{15}$
–	260	260	275	–
V-0 (0.75 mm)	V-0 (0.45 mm)	V-0 (0.81 mm)	V-0 (0.75 mm)	V-0 (0.38 mm)
960	960	960	960	–

*) The properties of 4184L6 are comparable to those of 4184L4
**) The properties of 6165A6 are comparable to those of 6165A4

Fig. 6 · Characteristic values for the creep behaviour of Fortron 1140L4 under tensile stress (standard climatic conditions 23/50)

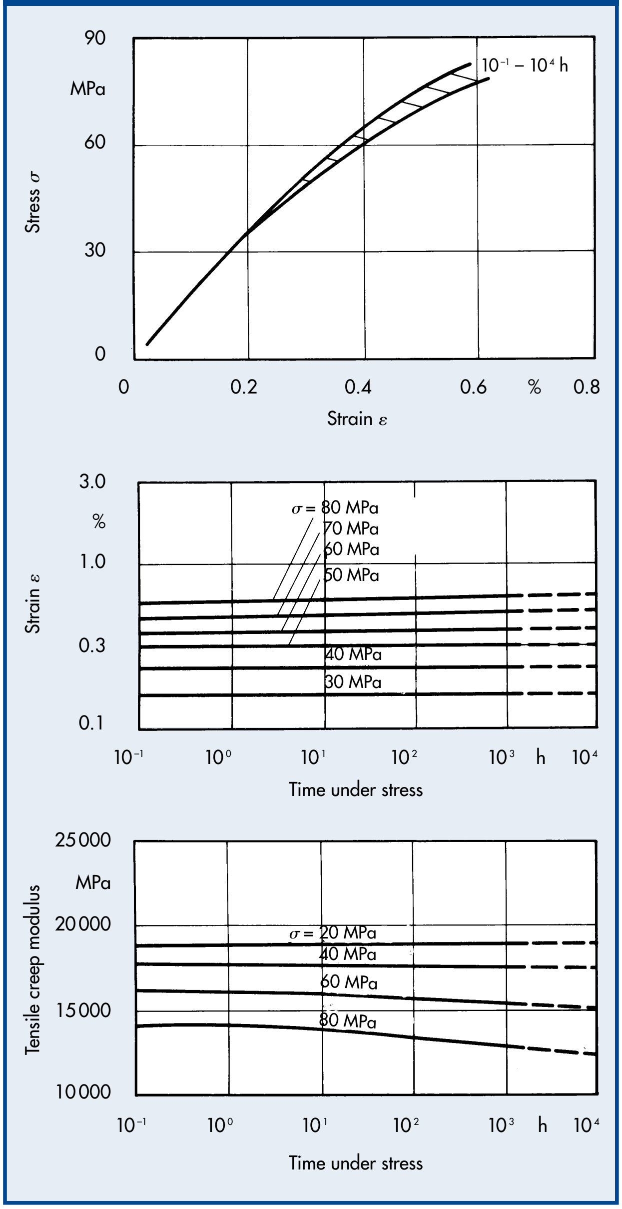


Fig. 7 · Characteristic values for the creep behaviour of Fortron 6165A4 under tensile stress (standard climatic conditions 23/50)

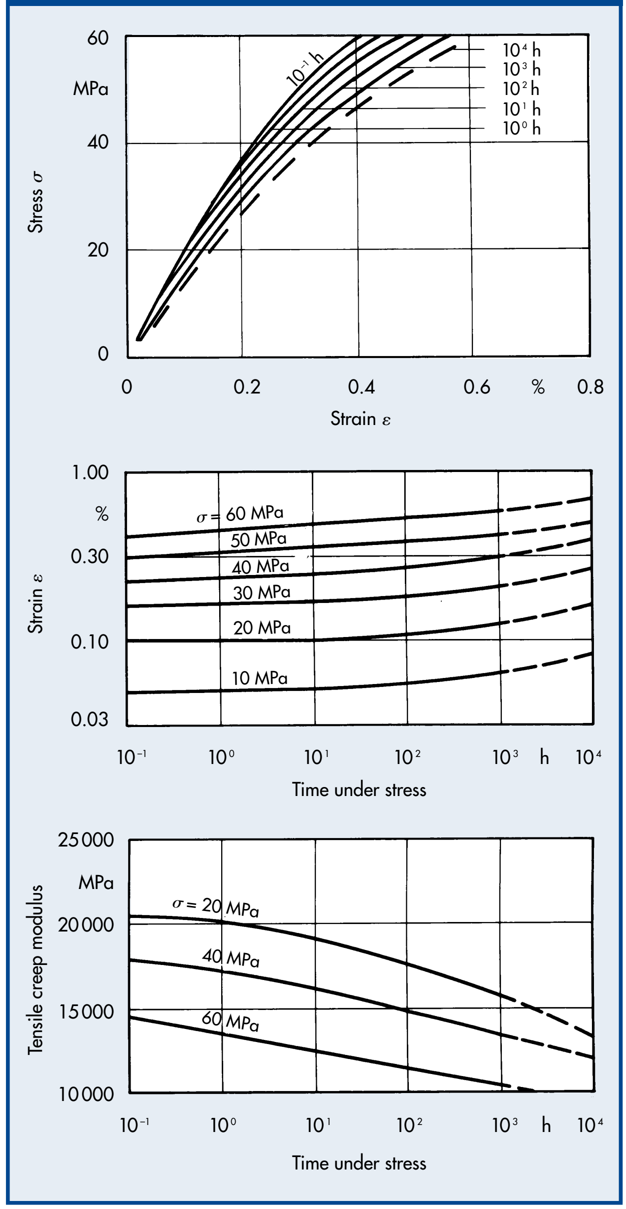


Fig. 8 · Characteristic values for the creep behaviour of Fortron 1140L4 under tensile stress at a temperature of 120°C

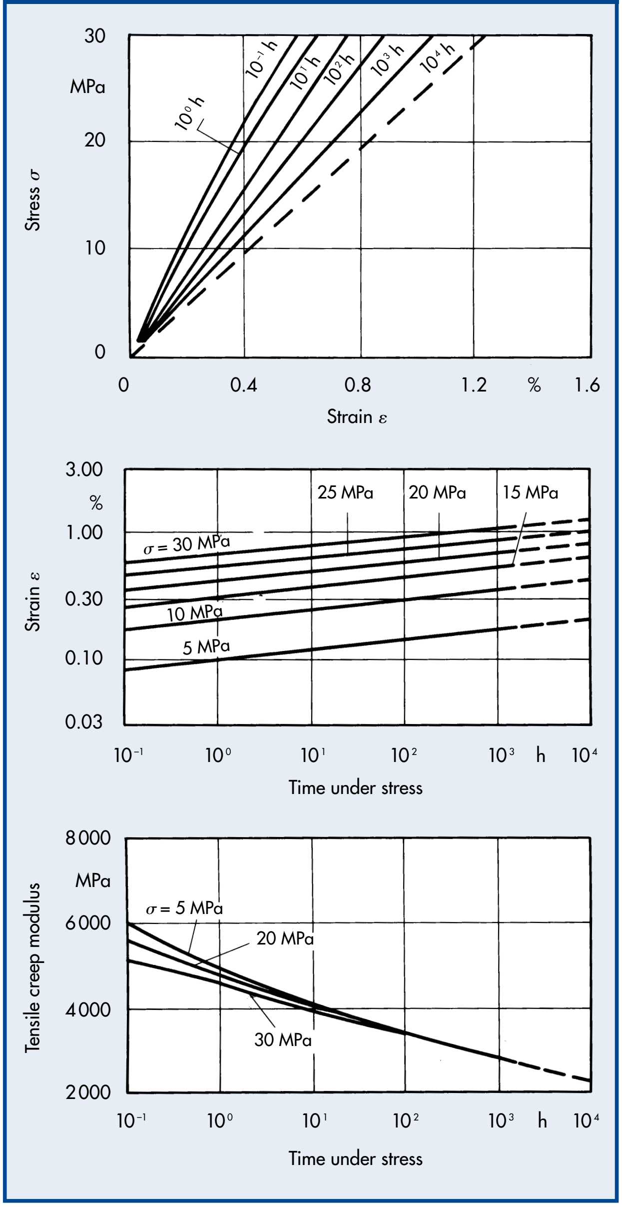


Fig. 9 · Characteristic values for the creep behaviour of Fortron 6165A4 under tensile stress at a temperature of 120°C

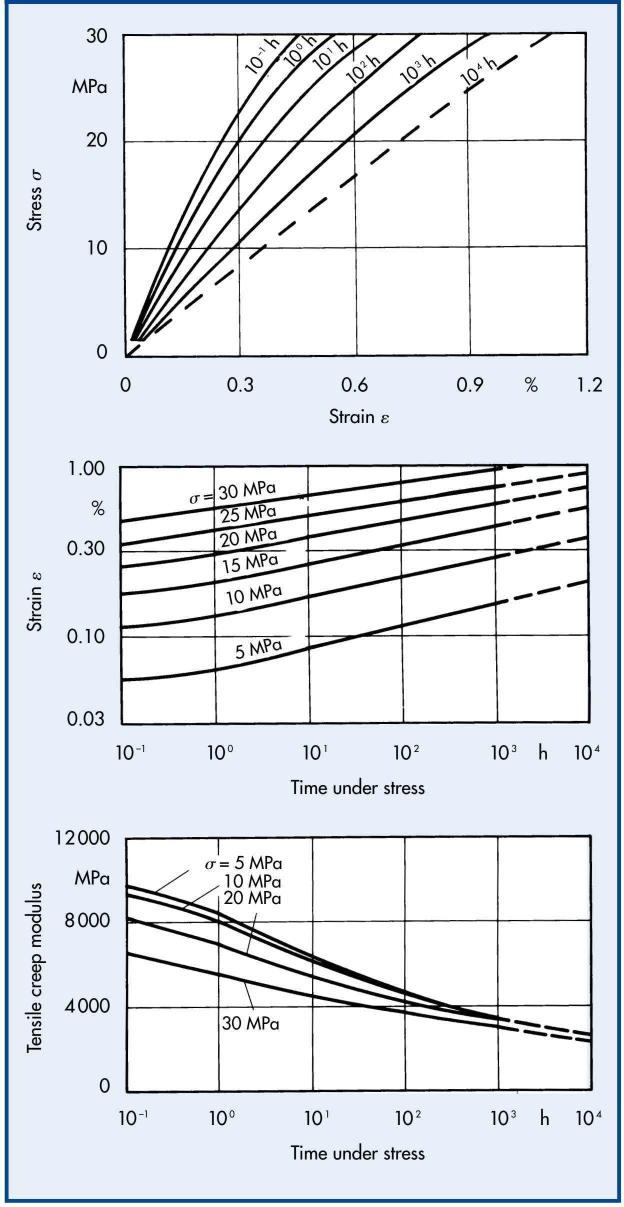


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Fig. 10 · Characteristic values for the creep behaviour of Fortron 1140L4 under tensile stress at a temperature of 150°C

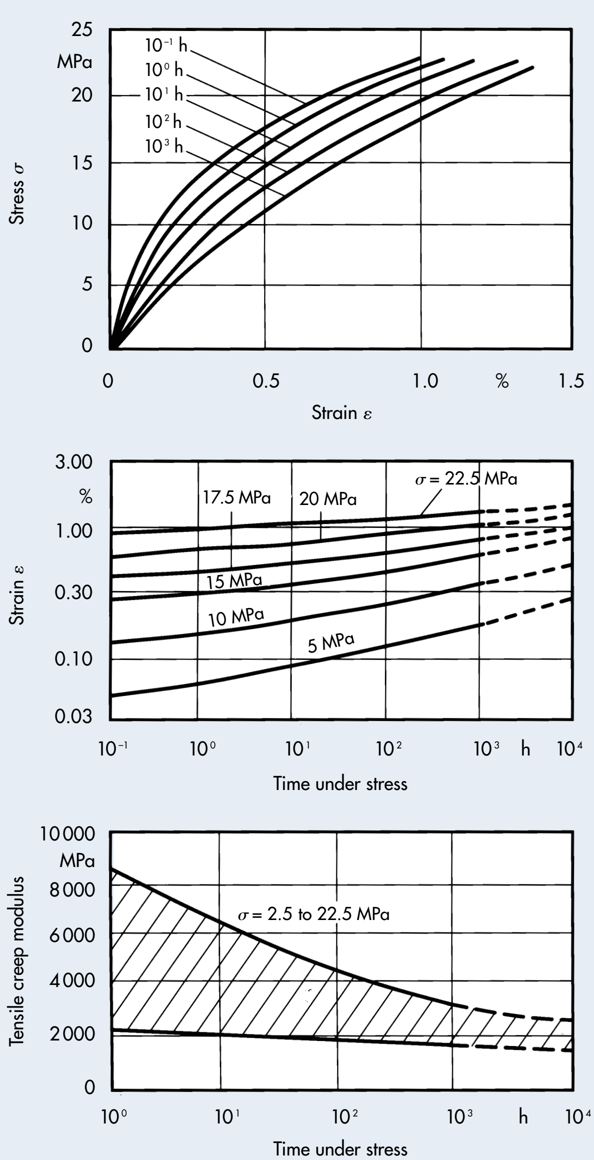


Fig. 11 · Characteristic values for the creep behaviour of Fortron 6165L4 under tensile stress at a temperature of 150°C

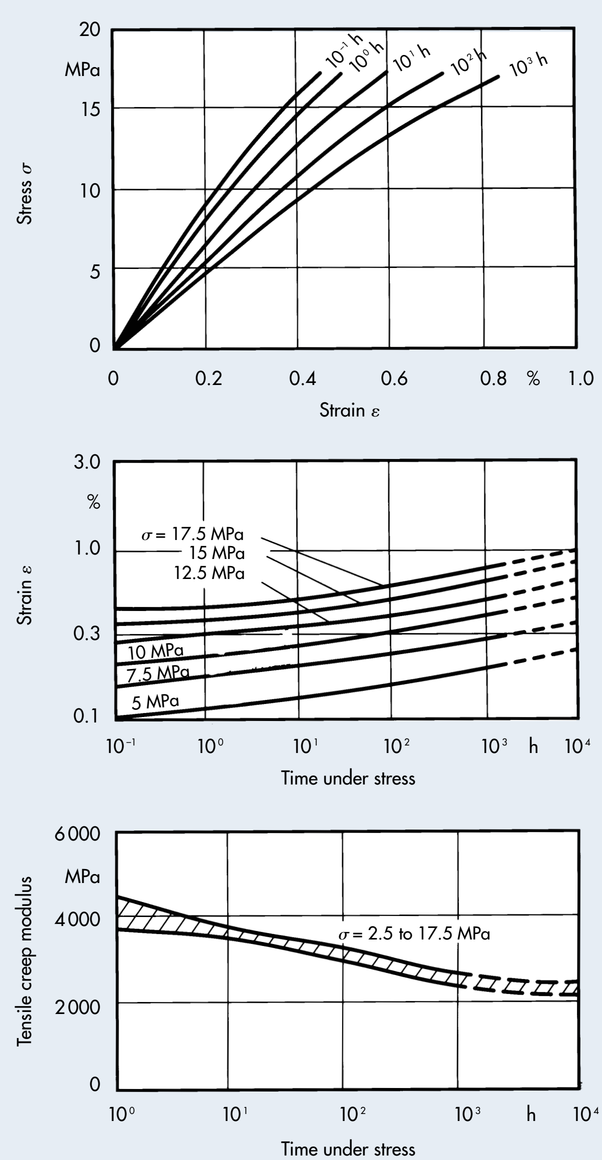


Fig. 12 · Characteristic values for the creep behaviour of Fortron 1140L4 under tensile stress at a temperature of 200°C

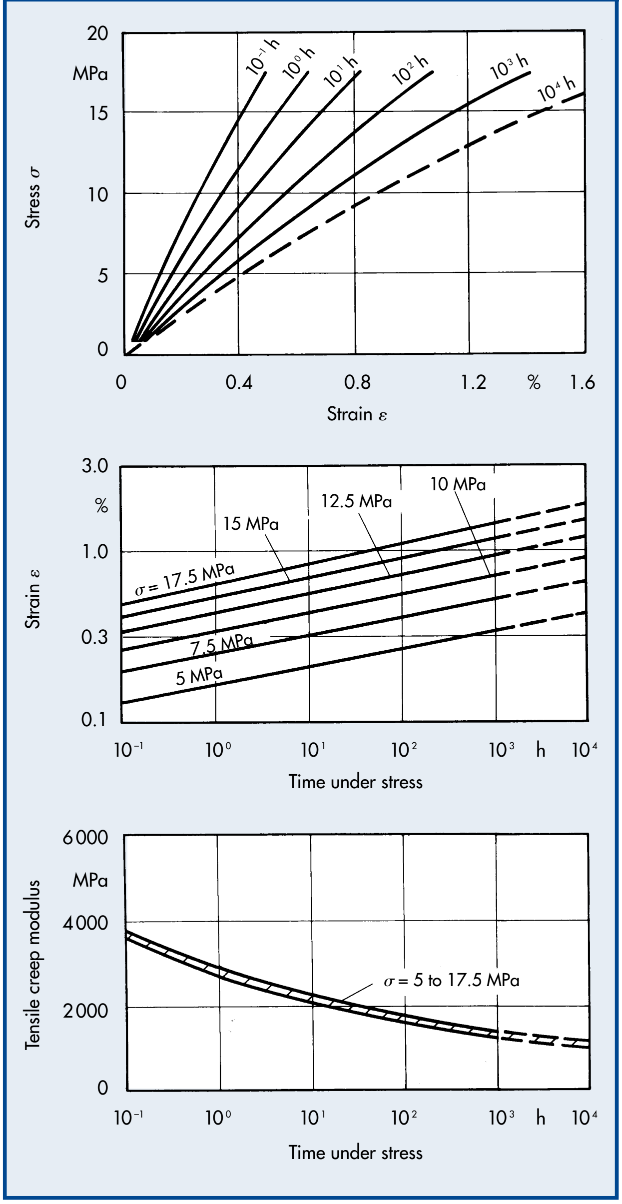
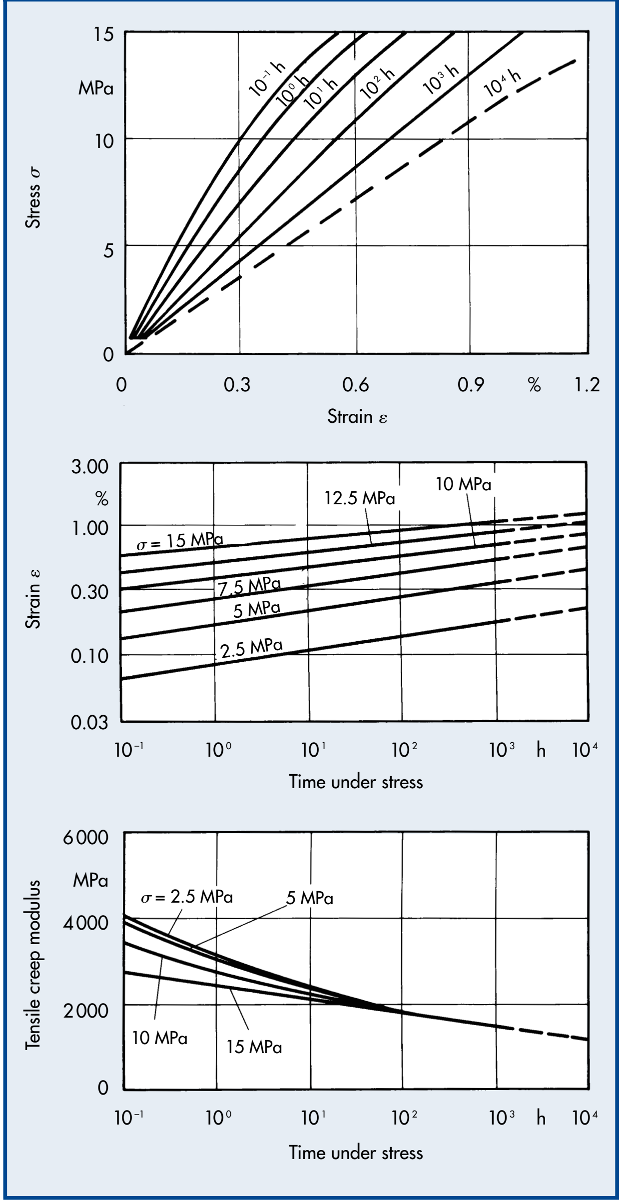


Fig. 13 · Characteristic values for the creep behaviour of Fortron 6165A4 under tensile stress at a temperature of 200°C



Besides the creep tests under tensile stress described above, behaviour under flexural stress is important in designing many structural components. Figs. 14 and 15 show the flexural creep modulus curves for Fortron 1140L4 and 6165A4 at 80, 120 and 200°C.

3.1.3 Fluctuating stress

Design parts subject to periodic loading must be designed on the basis of the fatigue strength. This is defined as the stress amplitude σ_a determined in the fatigue test – with a specified average stress σ_m – that a specimen withstands without failure for a specific number of load cycles, for example 10^7 ("Wöhler curve"). The various stress ranges in which such tests are carried out are shown in fig. 16.

For Fortron the fatigue strength at 10^7 load cycles is about 15 to 30% of the tensile strength determined in the tensile test. For fairly brittle products with high strength and low elongation the tensile strength is identical to the tensile stress at break.

Fig. 17 shows the behaviour of Fortron 1140L4 and 6165A4 in the fluctuating tensile stress range at 23°C; fig. 18 shows the same at 90°C.

The fatigue strength falls with increasing temperature (fig. 18) and load cycle frequency as well as with the existence of stress peaks in notched components.

The Wöhler curves for fluctuating flexural stress for four Fortron grades are shown in fig. 19.

Fig. 14 · Flexural creep modulus of Fortron 1140L4 and 6165A4 at 80 and 120°C (measured with an outer-fibre stress σ_b = 50 MPa)

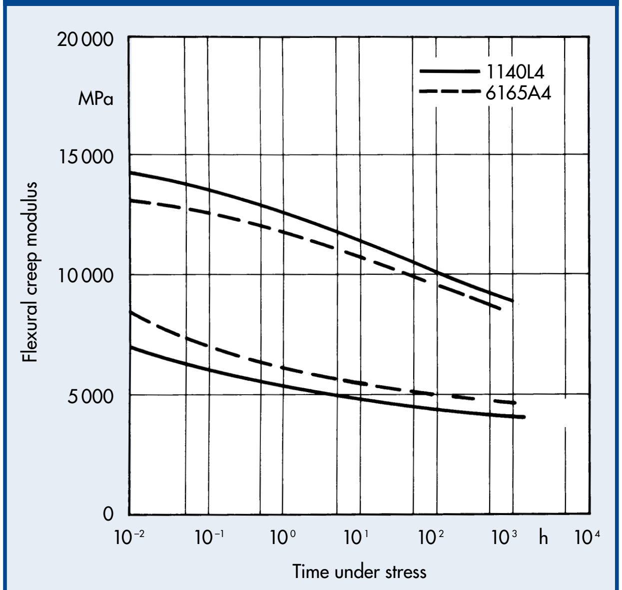


Fig. 15 · Flexural creep modulus of Fortron 1140L4 and 6165A4 at 200°C (measured with an outer-fibre stress σ_b = 30 MPa)

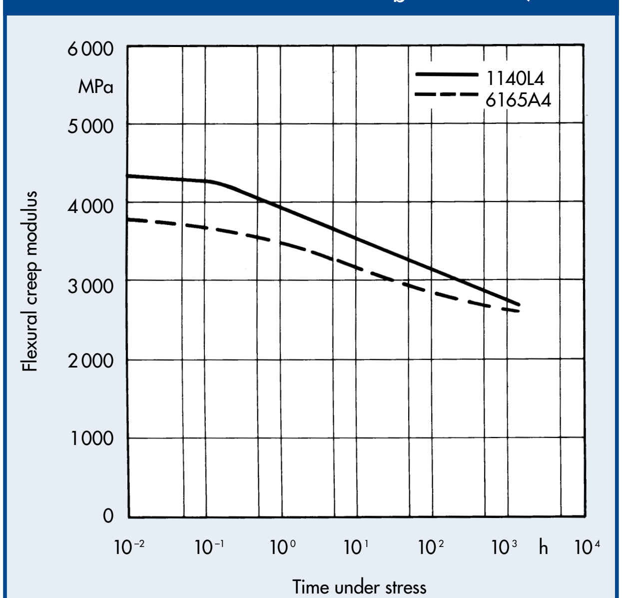


Fig. 16 · Stress ranges in fatigue tests

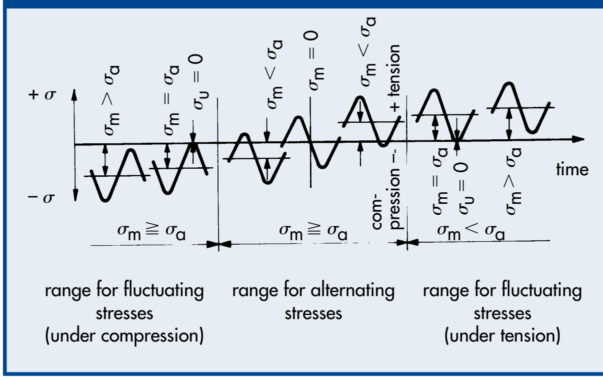


Fig. 17 · Wöhler curve for Fortron 1140L4 and 6165A4, determined in the fluctuating tensile stress range at 23°C

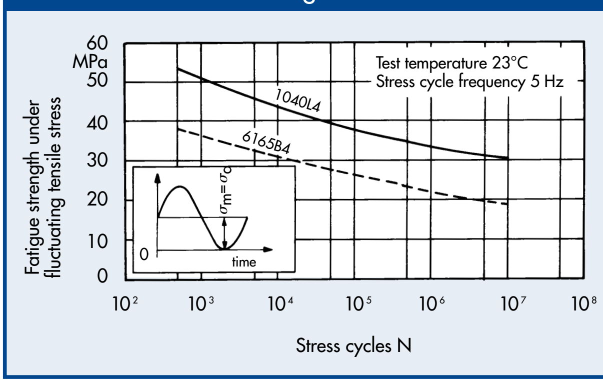


Fig. 18 · Wöhler curve for Fortron 1140L4 and 6165A4, determined in the fluctuating tensile stress range at 90°C

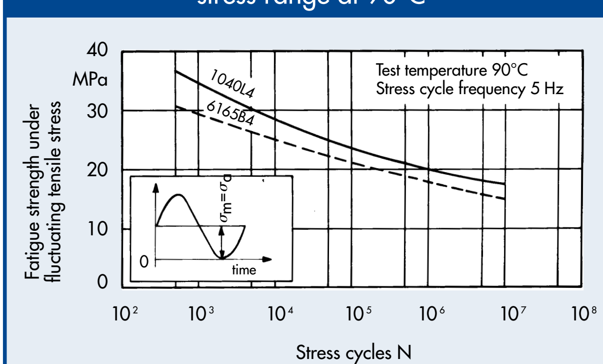
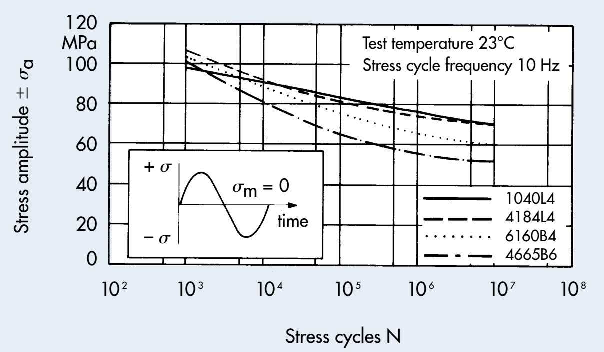


Fig. 19 · Wöhler curve for Fortron 1140L4, 4184L4, 6160B4 and 4665B6, determined in the fluctuating flexural stress range at 23°C



3.2 Thermal properties

Fortron is a semi crystalline material with pronounced thermal transition ranges:

glass temperature T_g:	85 – 100°C
post-crystallization temperature T_{c1}:	110 – 135°C
recrystallization temperature T_{c2}:	around 245°C
crystalline melting range T_m:	280 – 285°C

These temperatures should be taken into account when selecting processing conditions. In injection moulding particularly, it is important to set the mould wall temperature above the post-crystallization temperature T_{c1} (see also section 5.1.3).

Caloric value

The calorific value in accordance with DIN 51 900 Parts 1 and 3 indicates how much energy is liberated when a material burns. The calorific value of Fortron 1140L4 is 18090 J/g and of Fortron 6165A4 9750J/g.

Table 2 · Thermal conductivity

Typical values for the thermal conductivity λ of Fortron are given in the table below:

Temperature	Fortron with 40% GF	Fortron with 65% GF/MIN
25°C	0.20 W/mK	0.30 W/mK
125°C	0.20 W/mK	0.35 W/mK
230°C	0.25 W/mK	0.35 W/mK
300°C	0.25 W/mK	0.35 W/mK

Heat deflection temperature

The heat deflection temperature (HDT) as determined in accordance with ISO 75-1, 2 with different test stresses A, B and C gives designers initial guidance on the continuous service temperature of a plastic. Fig. 20 provides data in accordance with ISO 75-1, 2, method A. Further comparisons are given in fig. 21.

By compounding Fortron with reinforcing materials the heat deflection temperature can be increased up to the region of the crystalline melting point, a property that other polymers (e. g. polyamide) also known to exhibit. The reinforced Fortron grades achieve heat deflection temperatures of 270°C (ISO 75 Parts 1 and 2, 1.8 MPa) or up to 220°C (ISO 75 Parts 1 and 2, 8 MPa). These are some of the highest values attained by thermoplastics (figs. 20 and 21 [6]).

Fig. 20 · Heat deflection temperature of Fortron 1140L4, Fortron 6165A4 and various glass-fibre-reinforced thermoplastics (data from the literature)

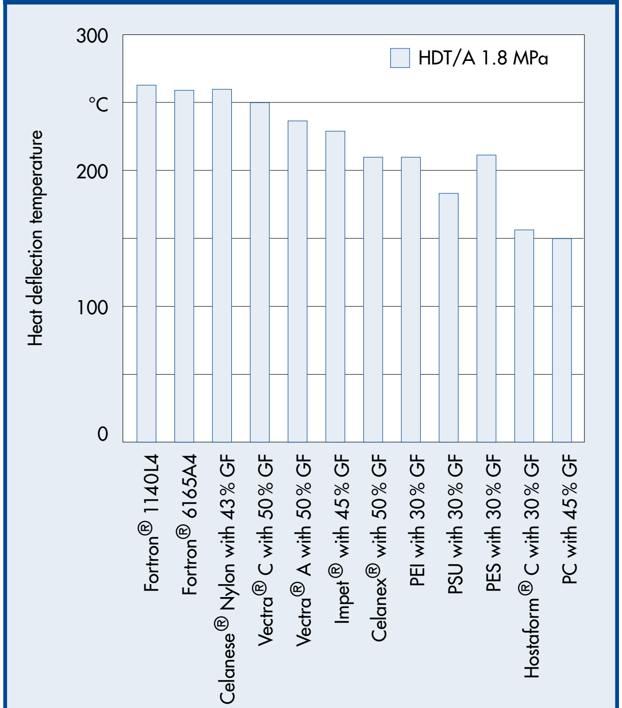


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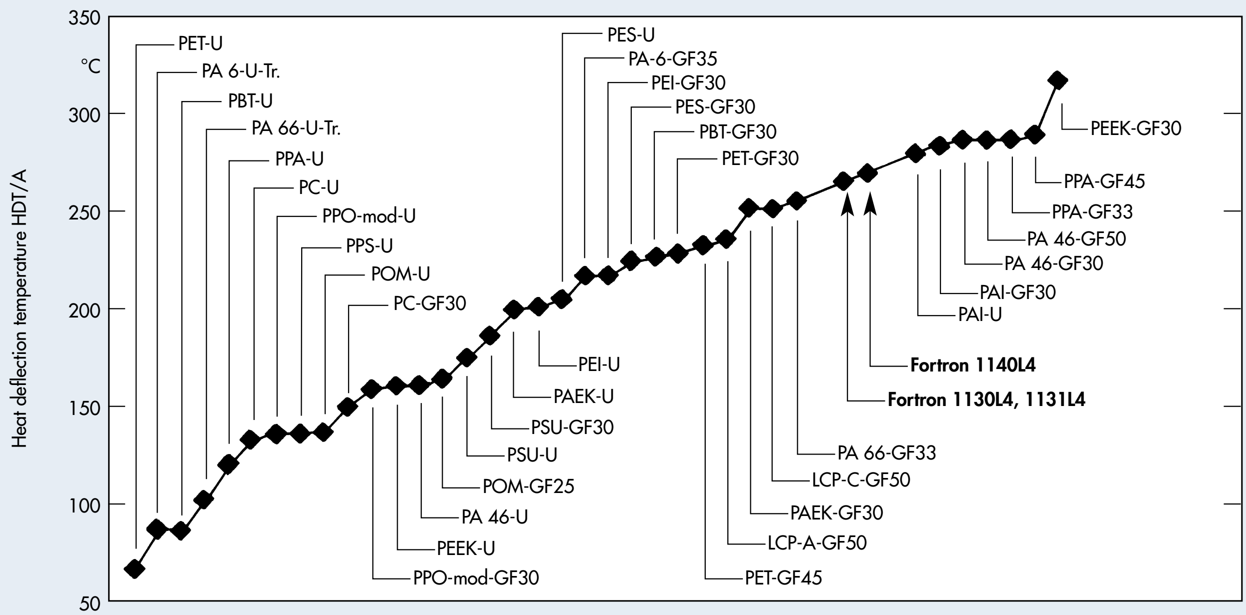
Fig. 21 · Comparison of heat deflection temperatures HDT/A (1.8 MPa) of engineering and high-performance plastics in accordance with ISO 75-1,2 [6]



UL and CSA listings

The Underwriters Laboratories' temperature index values for Fortron grades are shown in table 3. The relative temperature index (RTI) is determined in accordance with UL 746 B for 100,000 h (approximately 11.5 years). The RTI is the temperature after a period of 100,000 h when the tested properties have 50% of the initial value. The ratings in the three columns are based on the following tested properties:

Electrical applications	– dielectric strength (ASTM)
With impact stress	– Izod impact strength (ASTM)
Without impact stress	– tensile strength (ASTM).

Table 4 lists the CSA (Canadian Standards Association) ratings for Fortron grades.

IEC 60216

The preliminary treatment of test specimens as well as the selection of ageing temperatures conform to the requirements of IEC 60216. The thermal properties were tested in accordance with ASTM D 638. The usage of these property values for the determination of time to end-point was done in the case of Fortron. The tested properties are characteristic properties of Fortron and are based on IEC 60216. This temperature index (TI) for 20,000 hours of Fortron 1140L4 was calculated with determined time to end-points in accordance with IEC 60216.

Grade: Fortron 1140L4
Property: tensile strength
TI (20,000 hours) at 0.8 mm: 215°C
TI (20,000 hours) at 1.6 mm: 225°C

Coefficient of linear thermal expansion

The coefficient of linear thermal expansion α of Fortron 1140L4, 4184L4, 6165A4 and 6850L6 is shown in table 5. The test specimens used for the measurements were taken from injection moulded plates produced in a mould with a lateral film gate and so, owing to orientation of the reinforcing fibres, the expansion coefficients show marked directional dependency. In mouldings with superimposed filling directions, an average of "longitudinal" and "transverse" values will be obtained.

3.3 Electrical properties

Fortron has good electrical insulating properties and a low dissipation factor, which makes it a valuable insulating material, particularly in the high-temperature range.

Volume resistivity

The volume resistivity of all Fortron grades at 23°C is $\rho_D > 10^{13}\,\Omega \cdot m$; however the value diminishes with increasing temperature. This temperature dependence is shown in fig. 22 for Fortron 1140L4.

Surface resistivity

Surface resistivity gives an indication of the insulation resistance across the surface of a material. The dependence of this value on humidity and surface contamination must be taken into account. The surface resistivity of all Fortron grades is > $10^{15}\,\Omega$.

Electrically conductive formulations

Electrically conductive formulation with a volume resistivity ≦ 5 Ω · m and a surface resistivity ≦ 500 Ω are being developed. Sample quantities of the trial products can already be supplied on request. These products also have significantly better thermal conductivity, which opens up new application opportunities, e. g. in the electronics sector.

Tests are currently being carried out to determine whether these electrically conductive development products are also suitable for the production of components with electromagnetic shielding properties (EMS).

Relative permittivity, dissipation factor

The relative permittivity ε_r of the Fortron grades ranges between 4.0 and 5.4 at 10 kHz and between 4.1 and 5.6 at 1 MHz. ε_r increases slightly with rising temperature.

The dissipation factor tan δ is a measure of the energy loss in the dielectric by conversion into heat.

The values for Fortron range from $0.2 \cdot 10^{-3}$ to $1.0 \cdot 10^{-3}$ at 10 kHz and from $1.0 \cdot 10^{-3}$ to $2.0 \cdot 10^{-3}$ at 1 MHz. The dependence on frequency and temperature of the dissipation factor tan δ of Fortron 1140L4 and 6165A4 is shown in fig. 23 and Fortron 6160B4 black in fig. 24.

Fig. 22 · Volume resistivity ρ_D of Fortron 1140L4 as a function of temperature

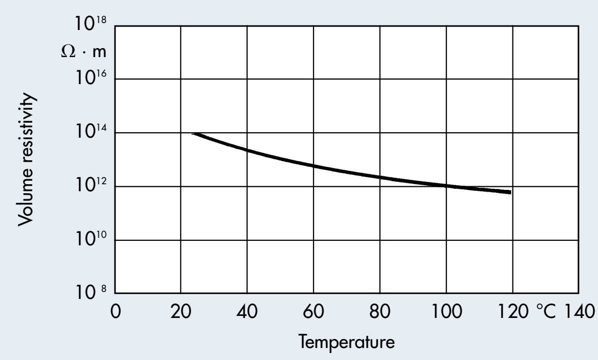


Fig. 23 · Effect of frequency and temperature on the dissipation factor tan δ of Fortron 1140L4 and 6165A4

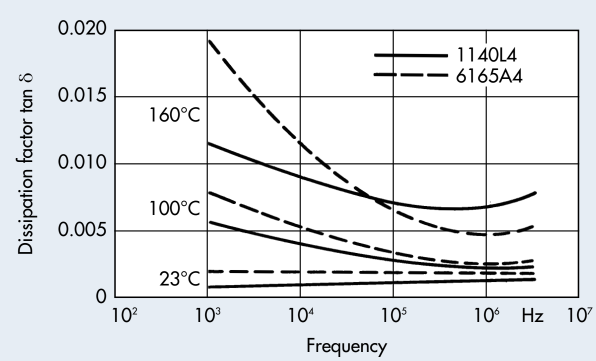


Fig. 24 · Dissipation factor tan δ of Fortron 6160B4 black as a function of frequency at different temperatures

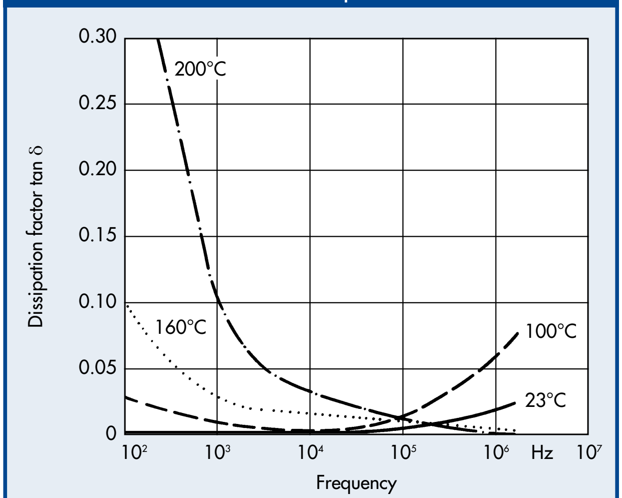


Table 3 · Status in relation to UL tests

Grades	s [mm]	UL 94	Relative temperature index (UL 746B for 100,000 h, RTI) [°C] electrical applications	with impact stress	without impact stress
1131L4 all colours	0.38 0.80 1.50 3.00	V-0 V-0 V-0 V-0	– 220 220 220	– 130 130 200	– 130 130 200
1140L4, 1140L6, all colours	0.38 0.81 1.50 3.00	V-0 V-0 V-0 V-0, 5 VA	130 220 220 220	180 200 200 200	200 200 220 220
1140L4, 1140L6, with 1 to 50% w/w recyclate, all colours	0.38 1.50	V-0 V-0	– –	– 160	– –
1140E7	0.85 1.50 3.00	V-0 V-0 V-0	220 220 220	200 200 200	200 220 220
4184L4, 4184L6, all colours	0.75 1.50 3.00	V-0 V-0 V-0, 5 VA[1])	220 220 220	200 200 200	200 220 220
4665B6, black	0.45 0.82 1.50 3.00	V-0 V-0 V-0 V-0	130 220 220 220	130 180 200 200	130 200 220 220
6160B4, all colours	0.81 1.50 3.00	V-0 V-0 V-0	220 220 220	200 200 200	200 220 220
6165A4, 6165A6, all colours	0.75 1.50 3.00	V-0 V-0 V-0, 5 VA[2])	240 240 240	200 220 220	220 240 240
6850L6, black	0.38 0.86 1.50 3.00	V-0 V-0 V-0 V-0	130 220 220 220	130 180 200 200	130 200 220 220

[1]) At present only for 4184L4 in black
[2]) At present only for 6165A4 in natural, black and brown

UL = Underwriters Laboratories, Inc., USA
s = Specimen thickness

Tests were carried out on products of the Hoechst Celanese Corporation, Chatham, NJ, USA. UL-File Number: E 107854 (M).

The actual data you find also on the UL-homepage: www.UL.com

Table 4 · Canadian Standards Association (CSA) listing for Fortron

Grade	Method	CSA rating for Fortron Colour	Material thickness	CSA/UL rating
1140L4	A	black	1.80	A00
	A	brown	1.86	A00
	A	natural	1.82	A00
	F	black	0.84	0.6 V-0
	F	brown	0.84	0.6 V-0
	F	natural	0.83	0.6 V-0
1140L6	A	black	1.71	A00
	A	brown	1.71	A00
	A	natural	1.78	A00
	F	black	0.78	0.6 V-0
	F	brown	0.86	0.6 V-0
	F	natural	0.81	0.6 V-0
4184L4	A	black	1.88	A00
	F	black	0.87	0.6 V-0
6165A4	A	black	1.62	A00

CSA-File Number LS 66 993, CSA Component Acceptance Plastic Recognition

Table 5 · Coefficient of linear thermal expansion [$°C^{-1}$]

	– 50 to + 90°C		+ 90 to + 250°C		– 50 to + 250°C	
	longitudinal	transverse	longitudinal	transverse	longitudinal	transverse
Fortron 1140L4	$12 \cdot 10^{-6}$	$40 \cdot 10^{-6}$	$7 \cdot 10^{-6}$	$90 \cdot 10^{-6}$	$9 \cdot 10^{-6}$	$65 \cdot 10^{-6}$
Fortron 4184L4	$13 \cdot 10^{-6}$	$36 \cdot 10^{-6}$	$12 \cdot 10^{-6}$	$80 \cdot 10^{-6}$	$13 \cdot 10^{-6}$	$60 \cdot 10^{-6}$
Fortron 6165A4	$14 \cdot 10^{-6}$	$25 \cdot 10^{-6}$	$13 \cdot 10^{-6}$	$60 \cdot 10^{-6}$	$13 \cdot 10^{-6}$	$45 \cdot 10^{-6}$
Fortron 6850L6	$17 \cdot 10^{-6}$	$30 \cdot 10^{-6}$	$25 \cdot 10^{-6}$	$70 \cdot 10^{-6}$	$20 \cdot 10^{-6}$	$50 \cdot 10^{-6}$

Electric strength

Electric strength describes behaviour under short-term, high-voltage stress. It is not a measure for permissible continuous stress. In electric strength tests, the voltage (f = 50 Hz) is steadily increased at a rate of 1 kV/s until insulation breakdown occurs.

In tests according to IEC 60243-1, the Fortron grades showed electric strength values of 25 to 28 kV/mm.

3.4 Surface properties

3.4.1 Hardness

The very high values for ball indentation hardness in accordance with ISO 2039 Part 1 and for Rockwell hardness in accordance with ASTM D 785 are shown in table 1.

3.4.2 Sliding and abrasion properties

It should be noted that the sliding properties are always a characteristic property of the tribological system. Coefficients of friction are therefore not material properties but are dependent on sliding partner, surface pressure, sliding speed and the measuring equipment used, i. e. they are linked to the system. Trials carried out at 23°C and fairly high surface pressure to determine the coefficient of dynamic friction between various Fortron grades and steel gave an average value of 0.4.

In developing mouldings subject to abrasion the behaviour of the various Fortron grades must be determined by in-house tests under simulated service conditions.

Trial products that are characterized by improved sliding and wear properties in selected fields of application are being developed. Sample quantities can be supplied on request.

3.5 Specification listings

3.5.1 MIL specifications

Fortron 1140L4 and 1140L6 have been tested in accordance with US Military Specifications MIL-M-24519 C (Navy) and MIL-M-24519 D (SH) and classified as GST-40-F materials. Both grades are included in the Qualified Products List (QPL-24519).

3.5.2 Potable water regulations

Various Fortron grades and colour masterbatches based on Fortron are listed in the British WRc-Water Byelaws Scheme and are therefore suitable for applications involving contact with potable water up to a temperature of 85°C. Further information can be requested directly by quoting File No. 9112502 for reinforced Fortron grades and 9303504 for colour masterbatches in the series "Water fittings and materials" (Richard Joseph Publishers Ltd, Farnham, Surrey, UK).

In the USA, the Fortron grades 1140L4 and 1140L6 are listed by Underwriters Laboratories as satisfying the requirements of ANSI/NSF-Standard 61 and are thus classified as suitable applications involving contact with potable water.

In Germany the Fortron grade 1140L4 black passed the KTW-tests (KTW, Kunststoffe im Trinkwasserbereich) done on sheets by the TZW (Technologiezentrum Wasser in Karlsruhe), one of the authorized test instituts in Germany. The test sheets have been successfully subjected to the cold and hot water (90°C) tests. The KTW test certificate has been issued and is available on request.

The monomers used for the manufacturing of Fortron 1140L4 are listed in the EU-Directives 90/128/EEC, 92/39/EEC, 93/9/EEC, 95/3/EC, 96/11/EC and the new edition of the German "Bedarfsgegenstände-verordnung" of December 23, 1997. Restriction exists for 1,4-Dichlorobenzene (SML = 12 mg/kg food). Additives employed are listed in EU-Directive 96/11/EC. The above mentioned restriction and the global migration have to be checked on the finished article by the manufacturer or seller.

3.5.3 Automotive specifications

Fortron is specified by leading automotive manufacturers and their suppliers, e. g. in the worldwide Ford-ISO specifications (WSL-M4D 807-A for Fortron 1140L4 and 1140L6, WSF-M4D 803-A2 for Fortron 6165A4 and 6165A6), by Chrysler (MS-DB CPN No. 3502 for Fortron 1140L4, 4184L4 and 6165A4), by General Motors and subsidiaries (GMP.PPS.001 for Fortron 1140L4 and 1140L6, GMP.PPS.002 for Fortron 6165A4 and 6165A6, GMP.PPS.004 for Fortron 4184L4 and 4184L6, Saginaw 26027224 for Fortron 4184L4), by Delco (10702-03 for Fortron 1140L4, 10702-04 for Fortron 6164A4 black, 10702-05 for Fortron 6165A4 natural, 10702-06 for Fortron 4184L6), by Delco Products (DPM 4425 for Fortron 1140L4), by Delco Remy (M-6033 for Fortron 1140L4), by Delco Electronics (M-10702-4 for Fortron 6165A4) and AC Rochester (MS 8755 for Fortron 6165A4) and by Valeo (NVB 10045).

Some Fortron grades are also listed by the Bosch Group and Lucas Varity. We will be pleased to provide information on the latest specification status in the automotive industry.

4. Resistance to service environment effects

4.1 Heat ageing

Fortron is extremely resistant to degradation by thermal oxidation. Finished parts made from Fortron are therefore resistant to high thermal stress. Numerous service environment influences have different effects on the course of heat ageing. Consequently, terms such as "heat resistance", "continuous service temperature" etc. do not describe material properties but should be regarded solely in the context of particular requirements. Experience has shown that upper service temperatures of 270°C under short-term stress (a few hours) and up to 240°C under constant stress (months to years) are permissible.

Figs. 25 and 26 show the change in tensile strength and impact strength of Fortron 1140L4 compared with competition materials when stored in hot air as a function of time [7]. The test specimens were not subject to mechanical load during their time under stress. A striking feature is the very good ageing resistance of Fortron 1140L4, which is unexcelled above about 5000 h.

4.2 Water absorption

Fortron has very low water absorption which is reversible, i. e. on subsequent storage in dry air the absorbed moisture is released again. In processing pellets which have absorbed atmospheric moisture, no molecular degradation occurs but surface defects may be caused on injection moulded parts.

Resistance to hydrolysis is good. With glass-fibre-reinforced grades, a decline in mechanical properties is observed after several months' immersion in water at 95°C. This can be explained – as with many other glass-fibre-reinforced plastics – by chemical attack on the glass fibres and capillary action at the glass fibre/polymer interfaces.

4.3 Chemical resistance

Table 6 indicates the behaviour of Fortron on exposure to the wide range of different chemicals so far tested. Additions are constantly being made to this list.

The test results were rated as follows:

+ resistant, weight increase < 3% or
  weight loss < 0.5 and/or
  decrease in tensile strength < 15%

/ limited resistance, weight increase 3 to 8% or
  weight loss 0.5 to 3% and/or
  decrease in tensile strength 15 to 30%

– not resistant, weight increase > 8% or
  weight loss > 3% and/or
  decrease in tensile strength > 30%

Fortron has excellent chemical resistance. There is no known solvent that will dissolve Fortron below 200°C. A decline in mechanical properties is observed in aqueous solutions of HCl and HNO_3 at 80°C, which can be attributed to chemical attack by the hot water on the glass fibres, as mentioned above.

According to tests carried out by the DVGW research centre at the Engler-Bunte Institute of the University of Karlsruhe, Fortron is resistant to gaseous fuels and is thus suitable for use in gas fittings.

It is important to stress the very good resistance of Fortron to all types of fuel including methanol and to hot engine oils and greases, see table 6. In automotive applications resistance to fuels, oils and antifreezes is of crucial importance. A number of tests with these substances were carried out on Fortron 1140L4 at elevated and high temperatures and different test durations, figs. 27 to 34.

Mechanical properties and dimensions of the test specimens were tested. Fortron 1140L4 demonstrated its excellent resistance. In this connection fig. 35 shows a comparative test with PA 46, reinforced with 30% by weight glass fibres, in an antifreeze.

Fig. 25 · Change in tensile strength (ASTM D 638). Heat ageing properties of Fortron 1140L4, PA46-GF40 and PPA-GF33 after storage in air at 150°C [7]

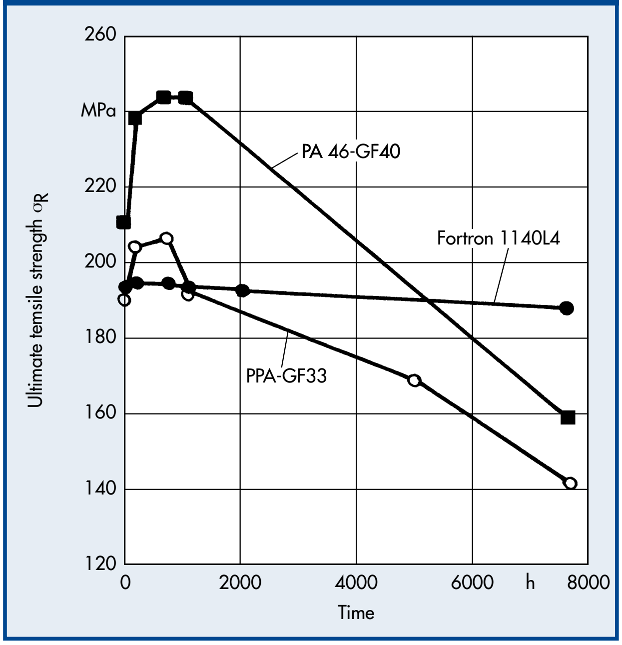


Fig. 26 · Change in Izod impact strength (ASTM D 4812). Heat ageing properties of Fortron 1140L4, PA46-GF40 and PPA-GF33 after storage in air at 150°C [7]

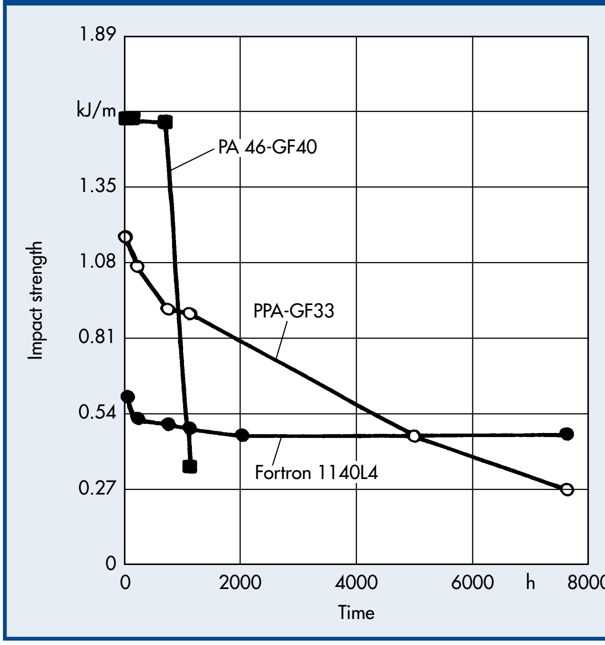


Table 6 · Chemical resistance of Fortron

The tests were conducted on 4 mm-thick injection moulded tensile test bars. The test specimens were immersed in the listed substances under the specified test conditions and were not subjected to external stresses.

Substance	Test conditions (time, temperature)	Fortron grade[1])	Rating
acetone	180 d/55 °C	1140L4	+
antifreeze ®Genantin	180 d/120 °C	1140L4	+
antifreeze ®Toyota Castel	40 d/120 °C	1140L4	+
antifreeze/water mixture (3 : 1 % v/v, antifreeze ®Genantin Super)	180 d/120 °C 180 d/120 °C	1140L4 6165A4	+ +
antifreeze OT 314 Dow Chemicals, long life coolant	9 d/140 °C 9 d/140 °C	1140L4 6165A4	+ /
brake fluid (Fuchs, Stopred)	180 d/150 °C 180 d/150 °C	1140L4 6165A4	+ +
brake fluid (®Toyota Brake Fluid 2500 H)	40 d/80 °C	1140L4	+
n-butanol (butyl alcohol)	170 d/80 °C 180 d/80 °C	6165A4 1140L4	+ +
butanone-2 (methyl ethyl ketone)	180 d/60 °C	1140L4	+

[1]) Other Fortron grades may yield different test results. Where there is any uncertainty, please contact us.

Table 6 · Chemical resistance of Fortron continued

Substance	Test conditions (time, temperature)	Fortron grade[1])	Rating
n-butyl acetate	170 d/80 °C 180 d/80 °C	6165A4 1140L4	+ +
calcium chloride (saturated)	40 d/80 °C	1140L4	+
diethyl ether	40 d/23 °C	1140L4	+
®Frigen 113 (trichlorotrifluoroethane)	40 d/23 °C	1140L4	+
Frigen R 12 + 5 % Aral Alur EE 32 (dichlorodifluoromethane)	60 d/100 °C	1140L4	+
Frigen R 134 A + 5 % Aral Alur EE 32 (tetrafluoroethane)	60 d/100 °C	1140L4	+
hydrochloric acid (10%)	180 d/80 °C 30 d/80 °C 180 d/80 °C 40 d/23 °C 30 d/80 °C 180 d/80 °C	0214C1 6165A4 6165A4 1140L4 1140L4 1140L4	+ / – + / –
nitric acid (10%)	40 d/23 °C 40 d/80 °C	1140L4 1140L4	+ –
sodium chloride (saturated)	40 d/80 °C	1140L4	+
sodium hydroxide (30%)	170 d/80 °C 80 d/80 °C	6165A4 1140L4	– /
sodium hypochlorite (5%)	170 d/80 °C 80 d/80 °C	6165A4 1140L4	– –
sulphuric acid (10%) (10%) (30%)	40 d/23 °C 40 d/80 °C 180 d/80 °C 170 d/80 °C	1140L4 1140L4 1140L4 6165A4	+ + / –
tetrafluorodichloroethane (Frigen 114)	50 d/23 °C 10 d/50 °C	6165A4 1140L4 6165A4 1140L4	+ + + +
toluene	180 d/80 °C	0214C1 6165A4 1140L4	– + /
1,1,1-trichloroethane	180 d/75 °C	1140L4	+
water	180 d/95 °C 30 d/95 °C 30 d/95 °C	0214C1 6165A4 1140L4	+ / /
xylene	180 d/80 °C	1140L4	+
zinc chloride (saturated)	40 d/80 °C	1140L4	+

[1]) Other Fortron grades may yield different test results. Where there is any uncertainty, please contact us.

Table 6 · Chemical resistance of Fortron continued

Substance	Test conditions (time, temperature)	Fortron grade[1])	Rating
Fuels and oils:			
diesel fuel	180 d/80 °C 166 d/100 °C	1140L4 1140L4	+ +
kerosene	40 d/60 °C	1140L4	+
methanol	180 d/60 °C	1140L4	+
methyl-tert.-butyl ether	4 d/100 °C *) 4 d/100 °C *)	1140L4 6165A4	+ +
rape methyl ester	166 d/100 °C	1140L4	+
ethanol	60 d/30 °C	1140L4	+
test fuel FAM-DIN 51 604-A 50% toluene 30% isooctane 15% diisobutylene, 5% ethanol	180 d/80 °C	0214C1 1140L4 6165A4	+ + +
test fuel FAM-DIN 51 604-B 84.5% FAM-DIN 51 604-A 15% methanol 0.5% water	180 d/65 °C 4 d/150 °C *)	1140L4 1140L4	+ +
test fuel FAM-DIN 51 604-C 40% FAM-DIN 51 604-A 58% methanol 2% water	180 d/55°C	1140L4	+
aircraft hydraulic fluid, Mobil, AVREX S Turbo 256	180 d/120 °C 180 d/120 °C	1140L4 6165A4	+ +
ASTM test oil no. 3, according to ASTM D-471	180 d/150 °C 180 d/150 °C	1140L4 6165A4	/ +
automatic transmission fluid, Mobil ATF 220 D-22187	180 d/150 °C 180 d/150 °C	1140L4 6165A4	+ +
spent engine oil heavily used (10 000 km)	180 d/150 °C 180 d/150 °C	1140L4 6165A4	+ +
engine oil, Fuchs Titan Universal HD SAE 30	180 d/150 °C 4 d/180 °C *) 180 d/150 °C	1140L4 1140L4 6165A4	+ + +
engine oil ®Toyota Castel Clean Royal II SE	40 d/50 °C	1140L4	+
transformer oil, Fuchs, Renolin E7, conforming to DIN 53370 and VDE 0370	180 d/100 °C 180 d/100 °C	1140L4 6165A4	+ +

[1]) Other Fortron grades may yield different test results. Where there is any uncertainty, please contact us.
*) Short-time test in an autoclave

Fig. 27 · Change in mechanical properties and dimensions of tensile test bars; testing in the following conditions: 90 and 180 days in engine oil (Titan Universal HD SAE 30) at 150°C, test specimens produced from Fortron 1140L4

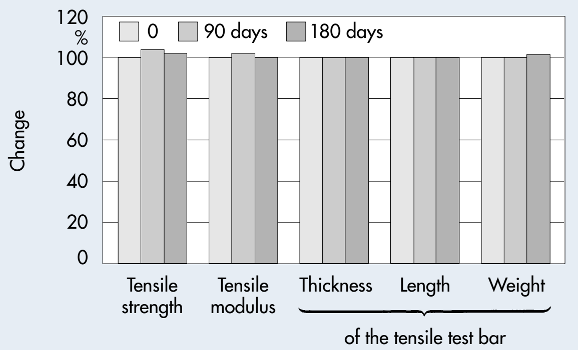


Fig. 30 · Change in tensile strength and dimensions of tensile test bars; testing in the following conditions: 90 and 180 days in test fuel (FAM-DIN 51604-B) at 65°C, test specimens produced from Fortron 1140L4

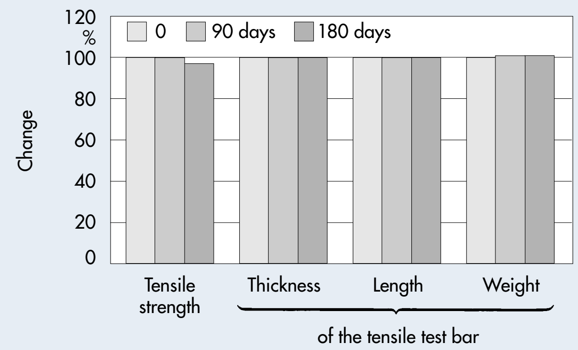


Fig. 28 · Change in mechanical properties and dimensions of tensile test bars; testing in the following conditions: 90 and 180 days in Automatic Transmission Fluid (ATF 220 D-22187) at 150°C, test specimens produced from Fortron 1140L4

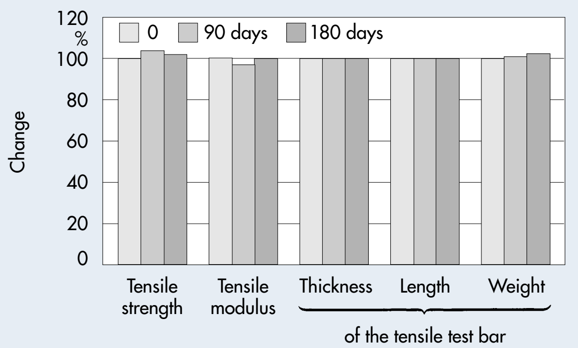


Fig. 31 · Change in tensile strength and dimensions of tensile test bars; testing in the following conditions: 90 and 180 days in test fuel (FAM-DIN 51604-C) at 55°C, test specimens produced from Fortron 1140L4

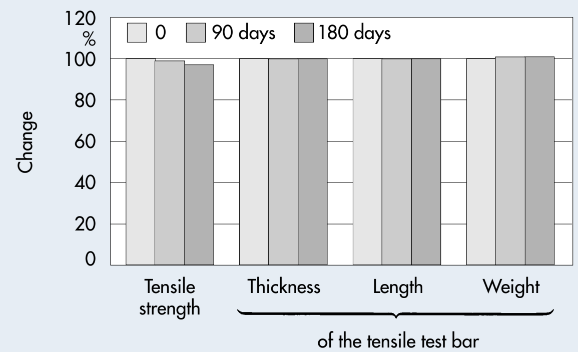


Fig. 29 · Change in tensile strength and dimensions of tensile test bars; testing in the following conditions: 90 and 180 days in test fuel (FAM-DIN 51604-A) at 80°C, test specimens produced from Fortron 1140L4

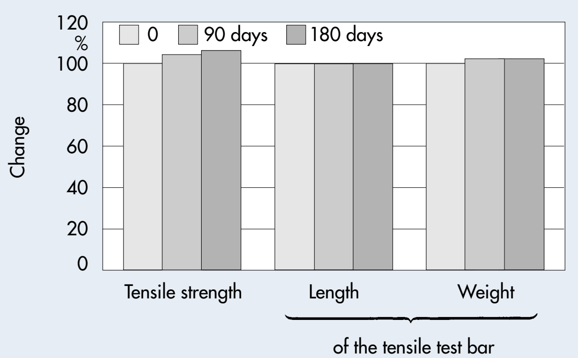


Fig. 32 · Change in tensile strength and dimensions of tensile test bars; testing in the following conditions: 90 and 180 days in diesel fuel at 80°C, test specimens produced from Fortron 1140L4

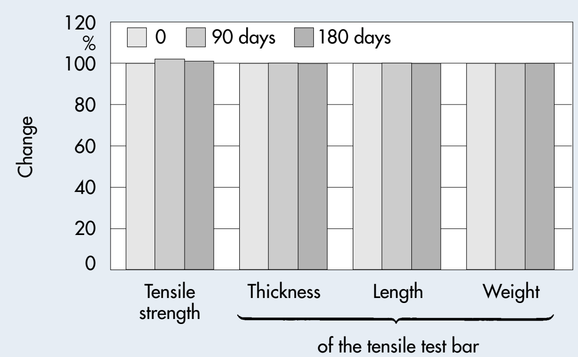


Fig. 33 · Change in mechanical properties and dimensions of tensile test bars; testing in the following conditions: 4 days in an autoclave in methyl-tert.-butyl ether at 100°C, test specimens produced from Fortron 1140L4

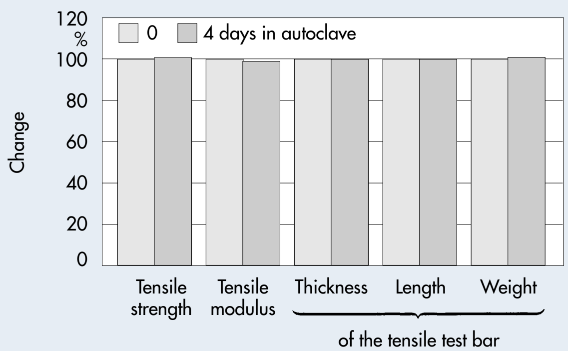


Fig. 34 · Change in mechanical properties and dimensions of tensile test bars; testing in the following conditions: 90 and 180 days in an anti-freeze (Genantin®/water mixture in the ratio 3:1) at 120°C, test specimens produced from Fortron 1140L4

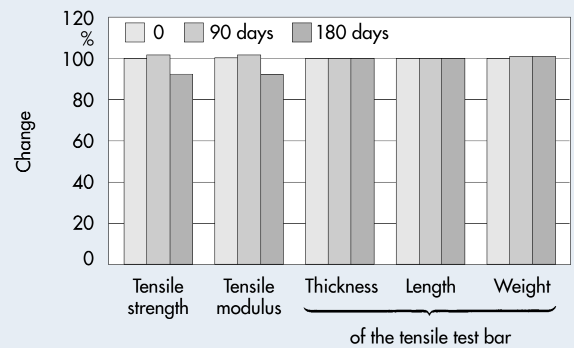
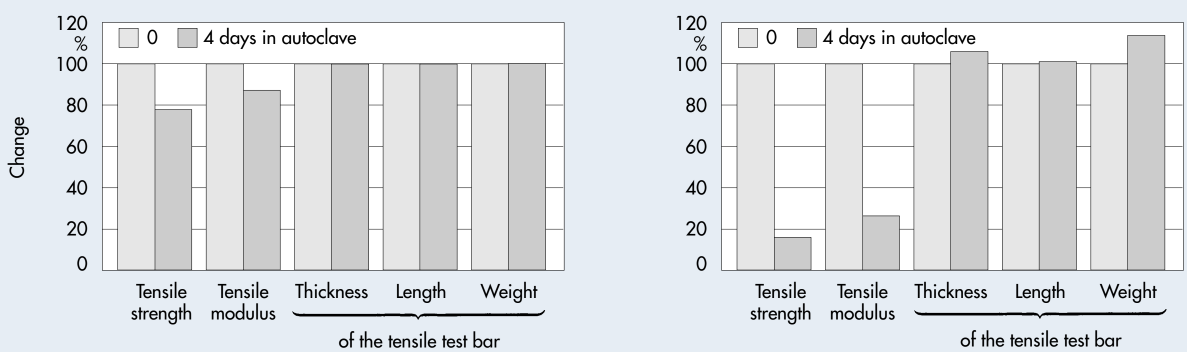


Fig. 35 · Change in mechanical properties and dimensions of tensile test bars; testing in the following conditions: 4 days in an autoclave in an antifreeze (glycol water mixture in the ratio 1:1) at 150°C, test specimens produced from Fortron 1140L4 (A) and PA 46 with 30% glass fibres, heat stabilized (B)



A: Fortron 1140L4

B: PA 46 with 30% glass fibres, heat-stabilized

The usual chemical resistance test involving immersion of test bars in glass flasks with reflux condensers is increasingly being replaced in industry by short-term tests. In these short-term tests in an autoclave testing is carried out at higher temperatures. It is thus possible to utilize the time-lapse effect of raising the temperature.

Rule of thumb: A 10°C rise in temperature doubles the reaction rate of chemical processes. Results of the short-term tests are given in table 6 and indicated by*).

A detailed summary of the results of chemical resistance tests with Fortron grades is provided in the Fortron Chemical Resistance Guide Version 3.0 [10].

4.4 UV resistance

Fortron has good resistance to the effects of ultraviolet radiation. The results of laboratory Weather-O-meter trials on unpigmented and pigmented injection moulded test specimens are shown in table 7.

4.5 Flammability

Fortron is inherently flame retardant i. e. without additives (UL 94 V-0, some grades 5 VA).

Results of tests by the Underwriters Laboratories (UL) are shown in table 3; table 4 contains the CSA listing.

The hot wire test according to IEC 60695 part 2-1 (1 mm, 2 mm and 4 mm) yielded the value 960°C in each case for the following Fortron grades: 1140L4, 4184L4, 4665B6, 6160B4 and 6165A4.

The Fortron grade 1140L4 natural fulfill the requirements of the building class B2 in accordance to DIN 4102, part 1 at wall thicknesses of 3 and 6 mm. The tests were conducted in accordance to DIN 50 050 part 1 (1/88) at application of flame to the edge.

The Fortron grades 1140L4, 4184L4, 4665B6, 6160B4, 6165A4 and 6850L6 were tested in accordance with the US Vehicle Safety Standard FMVSS 302.
No flaming was observed after a flame application time of 15 s. It is therefore not possible to specify a burning rate.

Table 7
Change in the mechanical properties of Fortron after UV exposure in an Atlas Weather-Ometer

Fortron grade	Exposure time [h]	Tensile test according to ASTM D 638: Tensile strength [MPa]	Strain at break [%]	Tensile modulus [MPa]	Notched impact strength (Izod) [J/m] according to ASTM D 256
1140L4 natural	0	181	1.7	15 200	85
	200	181	1.7	15 200	85
	500	179	1.6	15 200	85
	1 000	177	1.7	14 500	85
	2 000	176	1.6	14 500	85
1140L4 brown	0	185	1.7	15 900	91
	200	184	1.7	15 200	85
	500	184	1.7	15 200	91
	1 000	183	1.7	15 200	85
	2 000	183	1.6	15 200	91
1140L4 black	0	176	1.7	13 800	80
	200	176	1.7	14 500	75
	500	178	1.6	15 200	80
	1 000	176	1.7	14 500	80
	2 000	175	1.6	15 200	80

Tested on injection moulded test specimens, apparatus according to ASTM G 23, method 3, without water spray, black standard temperature 60°C, radiation intensity 0.35 $W/m^2 \cdot nm$, 30% relative humidity, under a xenon arc lamp according to ASTM G 26. Mechanical properties tested according to ASTM standards.

None of the test specimens showed any sign of erosion.

5. Processing, finishing

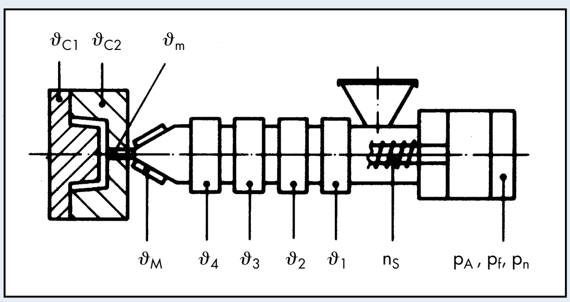
The preferred method of processing for Fortron is injection moulding. Extrusion of mono- and multifilaments, solid rods, sheets and pipes is also possible.

5.1 Injection moulding

Fortron should be fed completely dry to the injection moulding machine. Predrying is recommended despite the low water absorption (see section 4.2). It is advisable to dry the material for 3 and 4 hours at 140°C in a circulating air drying oven, but this requires a homogenous drying of pellets

Molecular degradation is unlikely to occur if Fortron is processed without predrying. But parts produced from such material may have intrusive streaks in the vicinity of the gate and voids which mouldings from predried Fortron do not exhibit.

Fig. 36 · Processing conditions for reinforced** and unreinforced* Fortron



Cylinder temperatures:	ϑ_1: 300*–320°C**
	ϑ_2: 310*–330°C**
	ϑ_3: 320*–340°C**
	ϑ_4: 320*–340°C**
	ϑ_M: 320*–340°C**
	ϑ_m: 310*–340°C**
Max. res. time in cylinder	< 60 min (at 320 – 340°C)
Injection pressure p_f:	500–1000 bar (spec.)
Holding pressure p_h:	300– 700 bar (spec.)
Back pressure p_A:	≦ 30 bar
Screw speed n_S:	low, e. g. 40–100 min^{-1}
Injection rate:	medium to high
Mould wall temperatures ϑ_{C1}, ϑ_{C2}:	140–145°C
Nozzle:	free-flow nozzle, preferably shut-off nozzle

Note:
Tool steel, hardened and corrosion-resistant.
Bimetallic cylinder and screw hardened and corrosion-resistant.

5.1.1 Machine conditions

A survey of processing conditions is given in fig. 36.

PM steels used for screw and cylinder are more and more common. If steels with lower hardness take place, for the screws is a surface treatment such as boriding or facing with refractory hard metals like titanium nitride (TiN) recommended. In addition, hard facing of the screw flights (based on Co/Cr/W) has proved successful. Internal hard facing of the cyclinder is also recommended although generally speaking the cylinder has a longer life than the screw.

The cylinder size should be geared to shot weight in such a way that 30 to 70% of shot capacity is utilized.

A heatable shut-off nozzle is preferred to a free-flow nozzle. If a free-flow nozzle is in use, the flow channel should have a diameter < 4 mm.

Melt temperatures of 320 – 340°C are recommended. If the moulding geometry requires it, e. g. with very low wall thickness, melt temperatures up to about 350°C are possible. The injection pressure should be between 500 and 1000 bar. The holding pressure is normally set at 300 to 700 bar (as specific pressure, to be converted to hydraulic pressure).

The back pressure acting on the screw during plasticization should be low. In most cases no back pressure is required. High back pressure accelerates screw wear. If however back pressure is necessary to achieve better plasticization, 30 bar should not be exceeded.

The optimum screw speeds are between 40 and 100 min^{-1}, depending on screw diameter.

The optimum filling speed should be determined for each individual mould. Over-rapid injection encourages flash formation, excessively slow injection can cause filling problems. A medium injection rate is normally preferred.

The necessary holding pressure time is a function of the wall thickness of the moulding and the melt and mould wall temperatures. To find the optimum value, holding pressure time is increased at the expenses of cooling time, with the cycle otherwise constant, and the corresponding moulding weight is determined, see fig. 37.

Fig. 37 · Determination of optimum holding pressure time t_{No}

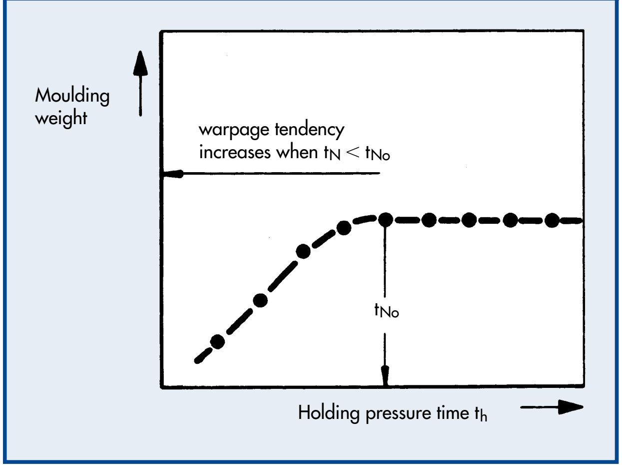
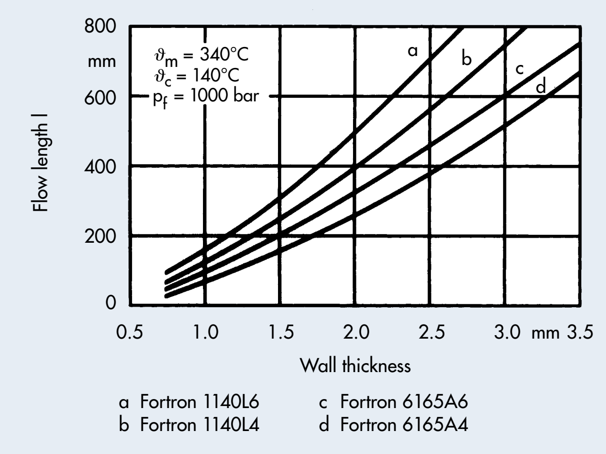


Fig. 38 · Flow length of some Fortron grades as a function of wall thickness



t_{No} is the optimum holding pressure time. Extending this time produces no further increase in moulding weight.

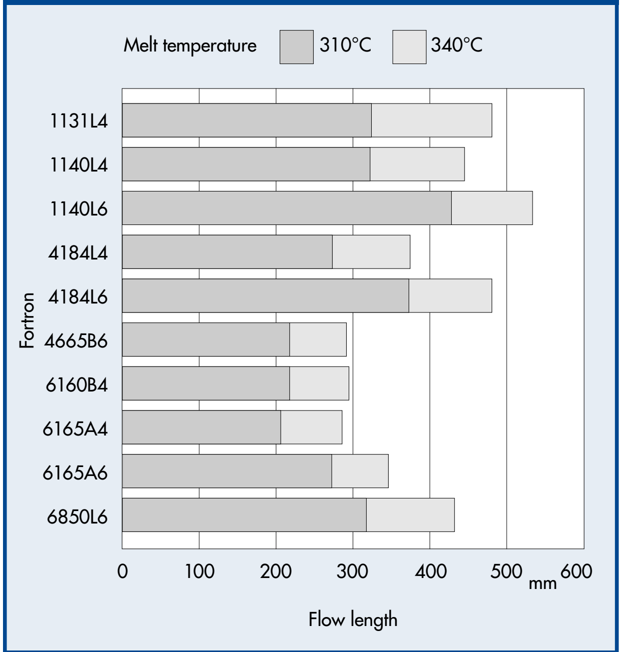
This optimization procedure is recommended if extremely low-warp mouldings are to be produced, particularly from glass-fibre-reinforced grades. Insufficient holding pressure time increases the tendency to warpage.

The residence time in the cylinder should not exceed 60 min (at melt temperatures of 320°C), as otherwise thermal degradation will occur. This is manifested in a fall in viscosity and associated decline in mechanical properties.

The Fortron grades have good flowability. Their flow behaviour was studied in a spiral flow test. In this tests, the length of a spiral injection moulded under defined conditions is used to characterize flow behaviour.

Fig. 38 shows the achievable flow length of some Fortron grades as a function of wall thickness, in each case at melt temperatures of 340°C. This graph can be used for grade selection. Fig. 39 shows the flow lengths achieved by different Fortron grades with a spiral section thickness of 2 mm (at melt temperatures of 310 and 340°C). With this data, it is possible to estimate the extent to which flowability can be improved by increasing melt temperature.

Fig. 39 · Flow length of various Fortron grades, rectangular spiral section (thickness: 2 mm, width: 6 mm), mould temperature: 140°C, specific injection pressure: 1000 bar



5.1.2 Shrinkage

The glass fibres contained in the reinforced Fortron grades are generally oriented in the melt flow direction during injection moulding. This reduces shrinkage in the direction of orientation, i. e. in the flow direction, very considerably while transverse to the direction of orientation shrinkage is greater. The resultant differential shrinkage between the longitudinal and transverse directions can lead to warpage problems, which can frequently be minimized by relocating the gate and by correct moulding design for plastics.

It should also be noted that in weld lines, re-orientation of the fibres takes place and hence a change in shrinkage direction. This can lead to shape deviations, particularly in long mouldings, which can be reduced by altering the melt flow.

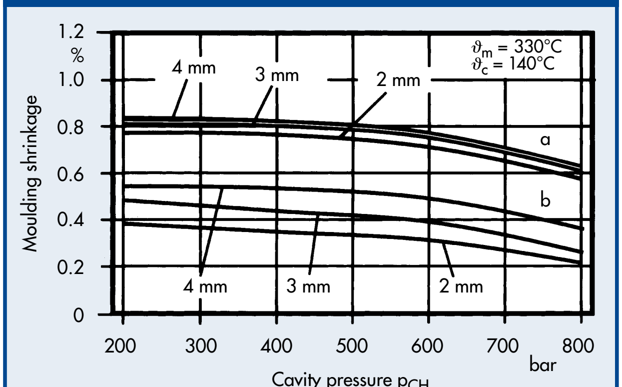
In this connection, reference should be made to methods of fill simulations (e. g. Moldflow) which enable mould filling operations with the preferred flow directions to be selected.

Longitudinal and transverse shrinkage values measured on test plates (60 x 60 x 2 or 3 or 4 mm) are plotted against cavity pressure in figs. 40 to 43. Values of the test plates (60 x 60 x 2 mm) are in accordance with ISO 294-4.

The typical shrinkage behaviour of the following Fortron grades are comparable with each other:
Fortron 1140L4 with 1140L6 and 1140E7
Fortron 4184L4 with 4184L6 and 6850L6
Fortron 6165A4 with 6165A6, 4665B6 and 6160B4.

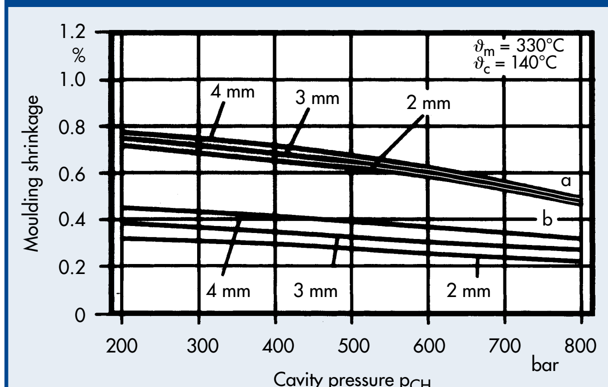
In the case of Fortron 4184L4, 6850L6 and especially 6165A4, the directional dependency of shrinkage is less pronounced than with Fortron 1131L4 and 1140L4. This can be attributed to the effect of mineral fillers contained in 4184L4 and 6165A4, in addition to the glass fibres.

Fig. 40 · Shrinkage of Fortron 1131L4 as a function of wall thickness and cavity pressure



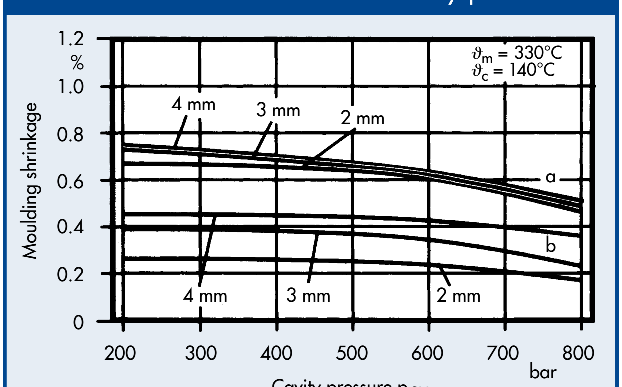
a Shrinkage transverse to the flow direction
b Shrinkage in the flow direction

Fig. 42 · Shrinkage of Fortron 4184L4 as a function of wall thickness and cavity pressure



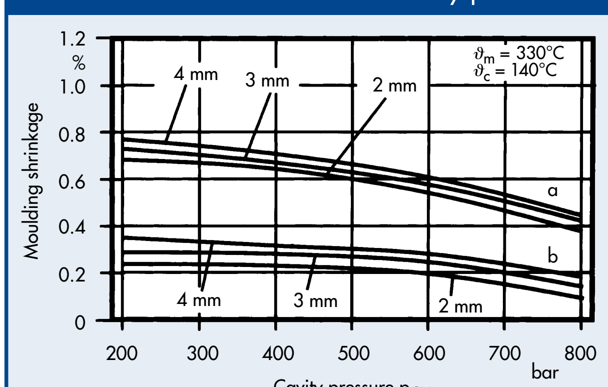
a Shrinkage transverse to the flow direction
b Shrinkage in the flow direction

Fig. 41 · Shrinkage of Fortron 1140L4 as a function of wall thickness and cavity pressure



a Shrinkage transverse to the flow direction
b Shrinkage in the flow direction

Fig. 43 · Shrinkage of Fortron 6165A4 as a function of wall thickness and cavity pressure



a Shrinkage transverse to the flow direction
b Shrinkage in the flow direction

5.1.3 Mould wall temperatures

Mould wall temperature is particularly important in injection moulding of Fortron. It should be above the glass transition and post-crystallization temperatures. Mould wall temperatures of at least 140°C are recommended. These permit a sufficiently high crystallization rate and degree of crystallinity. It should be remembered that the properties of Fortron mouldings depend largely on the crystallinity achieved during processing.

It is advisable to employ circulating-oil systems. Electric systems for heating should be used only in experimental moulds. Hot water systems are only suitable if they can achieve at least a temperature of 150°C. When using electric heating, a power density of 40 to 50 W/kg is recommended.

5.1.4 Mould design, design notes, sprue and gate

Moulds

For experimental moulds or short-runs the steels listed in table 8 are sufficient. If moulds for series production with high production volumes are in use, steels with a surface hardness ≥ 56 HRc (table 9) are necessary. These steels prolong the endurance life of the cavaties and help to hold tight tolerances.

If moulds made from steels < 56 HRc should be used for a longer production time, the surface can be protected against wear. This can be effected by the usual hard-facing methods. In these, the processing temperature of the treatment should never reach the annealing temperature of the steel.

Chromium-containing facing materials such as chromium nitride offer better protection against wear than titanium nitride.

The wear stress caused especially by the high filler content of Fortron is most effectively countered with high surface hardness values of ≧ 56 HRc.

Care must be taken not to increase the hardness of tool steels by nitriding since this will reduce their resistance to corrosive attack.

Highly wear-resistant, corrosion-resistant refractory hard metal alloys such as “Ferro-Titanit S” are suitable. These can be used, for example, for inserts in the gate region where increased wear occurs.

When Fortron is processed in hot runner moulds, externally heated systems with good thermal homogeneity should be used. Since Fortron tends to drool because of its low melt viscosity, shut-off systems or nozzle with tips are preferable.

Effective thermal separation must be ensured between the cavity and the hot runner nozzle. It is advisable to install the hot runner nozzle in air-insulated or temperature-regulated bushing. Furthermore, the hot runner nozzles should be provided with protection against wear.

Table 8 · Recommended steels for Fortron, tool steels, steels of limited suitability with inadequate wear resistance and for a production volume i.e. < 50 000 injection moulding cycles

Type of steel	Designation in accordance with DIN 17 006	Material Nr.	Surface hardness HRc	Comments
Case-hardening steels	X 6CrMo 4 21 MnCr 5	1.2341 1.2162	55 55	not corrosion-resistant, low dimensional stability
Through-hardening steels	X 210Cr 12 X 38CrMoV 51 X 40CrMoV 51 X 45NiCrMo4 90 MnCrV 8	1.2080*) 1.2343*) 1.2344*) 1.2767*) 1.2842	54 53 55 42 43	not corrosion-resistant, very good dimensional stability, high compressive strength
Corrosion-resistant steels	X 42CrMo13 X 36CrMo17	1.2083 1.2316	51 46	still inadequate corrosion resistance and hardness

*) Steel also available as electroslag remelting process grades with a more homogeneous structure and higher corrosion and wear resistance

Venting the moulds

All mould cavities must be effectively vented. An insufficiently vented mould can lead to burn marks on the moulded part caused by high compression of trapped air. Corrosive wear of the mould is also encouraged by unsatisfactory venting.

Effective venting can be provided by, for example, channels in the parting line. The vent channel depth of the land zone should not exceed 0.006 to 0.007 mm as otherwise flashing is likely to occur owing to the good flowability of Fortron. The width of the channel will depend on moulding size. It is recommended to polish the surface of the land zone and the surface opposite (Fig. 44).

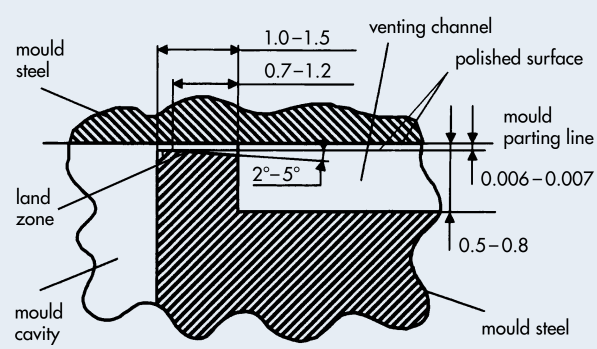
Venting may be achieved or improved via suitably machined ejector pins. Venting of the runners has also proved successful.

Weld lines

It is advisable to pay attention to the following general note, which also applies to Fortron.

Weld lines represent a weak point in any moulding made from reinforced plastic. In the region of the weld line, the fibrous reinforcing materials are oriented largely parallel to the weld line. The reinforcement is thus interrupted. For this reason, weld lines should be placed in areas of low stress, the location of which is primarily determined by the position of the gate. With suitable design measures, weld strength can be increased, for example by increasing wall thickness in the region of the weld line.

Fig. 44 · Proposal for an effective mould venting for Fortron parts



width of channel: dependent on shape of part
depth of channel: at junction of venting channels and at length of channel > 150–200 mm: 0.8–1.2 mm

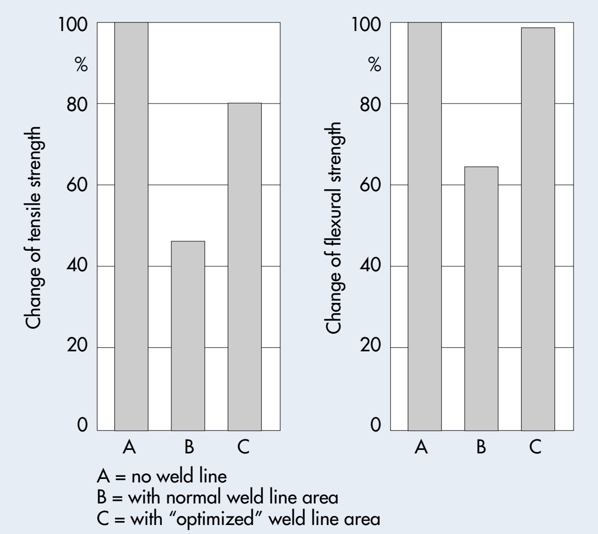
Table 9 · Recommended steels for Fortron, tool steels with adequate wear resistance for a production i.e. volume > 50 000 injection moulding cycles

Type of steel	Designation in accordance with DIN 17 006 or trade name	Material Nr.	Surface hardness HRc	Comments
Through-hardening steels	X 155CrVMo 121	1.2379	58	polishable, not corrosion-resistant
	Böhler "M 340"	–	> 56	additionally corrosion-resistant
Maraging steels (PM steels group)	Uddeholm "Elmax" Böhler "K 190" Böhler "M 390" Zapp CPM T420V	– – – –	57 60 – 63 56 – 62 57	highly wear- and corrosion-resistant highly dimensionally stable very easily polishable
	Zapp CPM 3 V Zapp CPM 9 V	– –	57 – 63 57 – 67	additionally high toughness and not corrosion-resistant
Hard metal alloys	Ferro-Titanit S WST "G25"	– –	66 – 70 64 – 66	extremely high wear and corrosion resistance

Figure 45 compares the tensile strength and flexural strength of Fortron 4184L4 (50% GF/MIN) concerning different levels of weld line strength. It should be added that the absolute level of weld line strength [N/mm²] can be optimized with different steps, e. g. an effective venting, tap and others.

Mouldings from linear PPS (Fortron) have substantially higher weld strength than mouldings from cross-linked PPS.

Fig. 45 · Comparsion of weld line strength of Fortron 4184L4 with no weld line, normal weld line and optimized process



Sprue and gate

Sprues and runners should have a taper of 2 to 3°. A sprue diameter of 4 mm has proved successful. The sprue bushings, runners and gate channels should be polished. Gates should be as large as possible to minimize wear. Undercuts should be avoided.

Injection moulding with pinpoint or tunnel gates is possible but the pinpoint gate should be ≧ 1 mm. With tunnel gates, it is an advantage to provide an ejector pin at the position of the gate to assist ejection. The usage of rectangular sprue is very common, as is the diaphragm sprue for single cavity concentric mouldings of ring shape with medium or small internal diameter.

Ribs, radii, draft angles

Ribs should if possible be the same thickness as the adjacent wall section.

If sink marks occur in a wall opposite the rib then the thickness of the rib must be restricted to 0.5 to 0.7 times the adjacent wall thickness.

The junctions between ribs and adjacent walls must be radiused. Radii of 0.1 to 0.2 times the thickness of the adjacent wall are usual. To avoid notch stresses in parts exposed to high mechanical stress, radii of at least 0.5 mm should be provided.

Similarly, changes in section, corners and edges must be provided with generous radii.

A draft of ≧ 1° should be provided on the moulding to facilitate ejection. Smaller draft angles are possible but alternative measures must then be taken to assist ejection, such as providing a larger number of ejector pins. In each case, a brushed finish in the ejection direction is recommended. For grained cavity surfaces, larger drafts are required depending on the type of grain effect and grain depth (about 1° draft for each 1/100 mm grain depth).

Tolerances

With a nominal dimension of greater 10 mm three different groups of tolerance areas are defined:
General purpose injection moulding $T_f < 1.0\%$
Injection moulding of technical polymers $T_f < 0.6\%$
Injection moulding of precision components $T_f < 0.3\%$.

The particular properties of Fortron make it suitable for precision injection moulding which means a tolerance of IT 11 down to IT 8, fig. 46. For nominal dimensions < 10 mm, the linear relationship between tolerance and nominal dimension no longer applies. The percentage tolerance thus increases very rapidly below about 3 mm, fig. 47 (see also DIN 16 935). Given a sufficiently high level of technical investment (mould, processing and part design), tolerances of < 0.3% are also possible (mould-dependent linear dimension). The preferred Fortron grades for these extremely tight tolerances are highly glass- and mineral reinforced. The achievement of these tolerances presupposes correct plastics design and a higher investment in mould construction and the injection moulding process. Subsequent corrections of the mould may be necessary.

5

Fig. 46 · Tolerance classes for the injection moulded dimensions of components (IT 8 to IT 13 = in accordance to DIN 16901 basic tolerances)

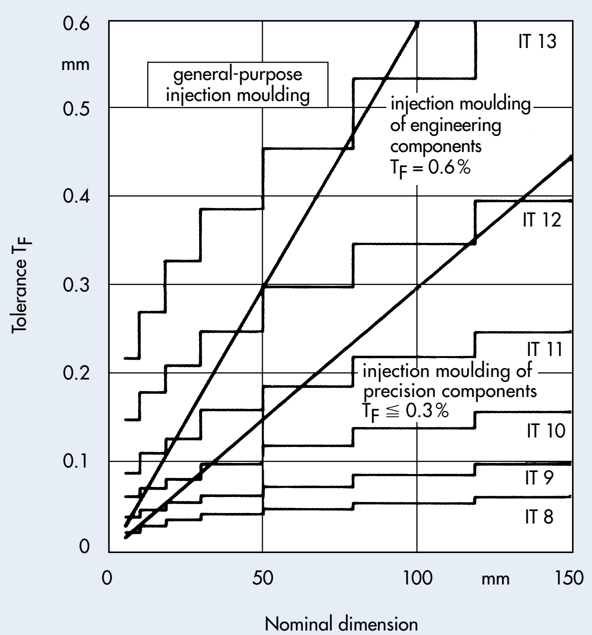
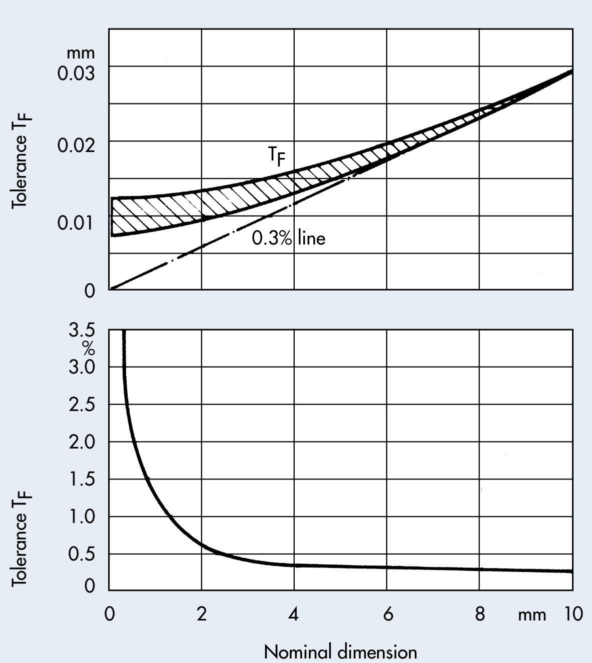


Fig. 47 · Production tolerance for injection moulded precision components with small nominal dimensions



In addition to dimensional tolerances, shape and positional tolerances are generally also important in component specifications. These tolerances restrict the permissible deviation of the shape elements of a component from the geometrically ideal shape and position. Since shape and dimensional tolerances are additionally dependent on warpage, they can only be approximately predicted. For this reason, possibilities for correction should be provided in the mould.

5.1.5 Changing from another thermoplastic to Fortron

Since many other plastics are thermally unstable at the processing temperatures of Fortron, they must be completely removed from the machine. For purging, materials such as polyamide (PA) or cross-linked polymethyl methacrylate (PMMA) are suitable. These materials are ejected at the appropriate melt temperatures in rapid shot sequence with the cylinder disconnected from the mould. As soon as the previous material has been completely expelled, the cylinder temperatures are brought up to the settings recommended for Fortron. Then the purging material (i. e. PA or PMMA) can be ejected.

When the cylinder temperatures required for Fortron are reached, Fortron is fed into the injection moulding machine and the purging material is thus expelled. Injection moulding of parts cannot begin until the purging material has been fully removed.

5.1.6 Changing from Fortron to another thermoplastic

Fortron is expelled from the cylinder with the injection unit disconnected using one of the purging materials mentioned (e. g. PA or PMMA). As soon as the melt is free of all traces of Fortron, the cylinder temperatures are reduced to a level suitable for the purging material, while the melt continues to be injected into the open. When the required temperatures are reached, the purging operation is completed.

5.1.7 Safety notes

5.1.7.1 Thermal stress of the material

In processing Fortron the melt temperature (taking into account permissible residence times in the cylinder) should not exceed 370°C. On exposure to excessive thermal stress Fortron degrades to form sulphur dioxide and carbonyl sulphide.

If thermal degradation in the cylinder is suspected or established, the material should be pumped out with the cylinder heating switched off. Thermally degraded material should preferably be immersed in water to avoid unpleasant odours.

5.1.7.2 Extraction at the processing machine

According to the literature p-dichlorobenzene and phenol can be formed when PPS is processed.

On the basis of this information a series of trials was conducted at Ticona to determine values. Three Fortron grades were processed (two basic grades and one grade with 40% glass fibre) on a Werner & Pfleiderer ZSK 25 extruder at 340°C. The measurements were taken under very unfavourable conditions, i. e. with the extraction system switched off, direct at the points of emission.

- For p-dichlorobenzene the maximum value was 10.3 mg/m^3 (the maximum allowable workplace concentration is 300 mg/m^3);
- for phenol the maximum value was < 0.2 mg/m^3 (the maximum allowable workplace concentration is 19 mg/m^3).

In this series of tests (extrusion with the extraction system switched off) gas samples of all three Fortron grades were taken at the nozzle and analysed for sulphur-containing compounds.

Result: no sulphur-containing compounds were detected in gas chromatographic analysis using a sulphur-specific detector.

Note: the occurrence of p-dichlorobenzene and phenol – even if slight – in normal processing makes it essential to install extractor hoods above the processing machines. Gases that arise as a result of possible overheating of the material must also be collected and removed.

5.1.7.3 Fire precautions

The raw material polyphenylene sulphide is inherently flame-retardant. Nevertheless it is in the interest of the processor when storing, processing or fabricating the material to take the necessary fire prevention measures. Particular care should be taken to observe specific regulations in individual countries.

Certain end products and fields of application may be subject to special fire prevention requirements. It is the responsibility of the raw material processor to ascertain and observe such requirements.

EU safety data sheets for the individual Fortron grades are available.

5.2 Extrusion process

The preferred processing method for Fortron is still injection moulding. Various extrusion processes are developed and can be done with Fortron. Manufacturing of monofilaments and multifilaments, films, wire coating and non wovens etc. is possible.

Extrusion of glass fibre reinforced and unfilled grades for semi-finished products (i. g. rod and slab production) also is possible for applications like prototyping or small production series.

For extrusion processes standard and developmental grades are available. More detailed information is available on request.

5.3 Annealing

If Fortron is processed at the recommended mould wall temperatures (≧ 140°C), mouldings with high crystallinity are obtained which exhibit minimal post-shrinkage, even on exposure to high temperatures.
A test of post-shrinkage effects on parts with a wall thickness of 3 mm produced at mould temperatures of 140°C showed the following results:

Dimensional change [%] after annealing

	Annealing conditions	
	2 h at 230°C	24 h at 230°C
Fortron 1140L4	0.09%	0.10%
Fortron 6165A4	0.10%	0.12%

These dimensional changes are slight and so annealing of Fortron mouldings to counter post-shrinkage effects is not required, see also fig. 48.

Generally speaking, Fortron may also be processed at mould wall temperatures of < 140°C. However this reduces or certainly does not increase the mechanical and thermal stress resistance of such mouldings. If these parts are annealed, stress resistance increases but warpage may also be caused. Annealing can therefore only be recommended if parts are mechanically fixed during the annealing treatment.

Figs. 49, 50 and 51 show the tensile strength, strain at break and heat deflection temperature (HDT/C) of annealed and non-annealed samples of Fortron 1140L4 as functions of mould wall temperature, annealing conditions: 3 h, 200°C.

5.4 Machining

5.4.1 General information on machining

Fortron parts are usually produced by injection moulding, generally speaking, mechanical finishing is not required. For certain purposes, however, machining may be necessary, e. g. if:

– certain contours are too uneconomic or too difficult to produce by injection moulding or cannot be moulded with sufficient precision,
– critical welds can be avoided by subsequent machining.

1. The tools should be sharp, since otherwise an excessive amount of heat will be produced and the surface will be meared.

Fig. 48 · Shrinkage of Fortron 1140L4 tensile test bars (ISO 3167) as a function of mould wall temperature, annealing conditions: 3 h, 200°C

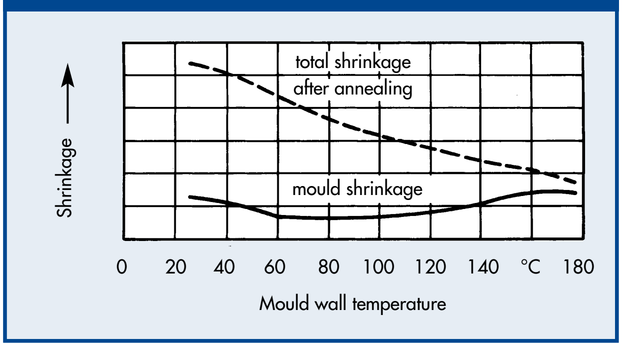


Fig. 50 · Relation between strain at break and mould wall temperature of annealed and non-annealed samples of Fortron 1140L4

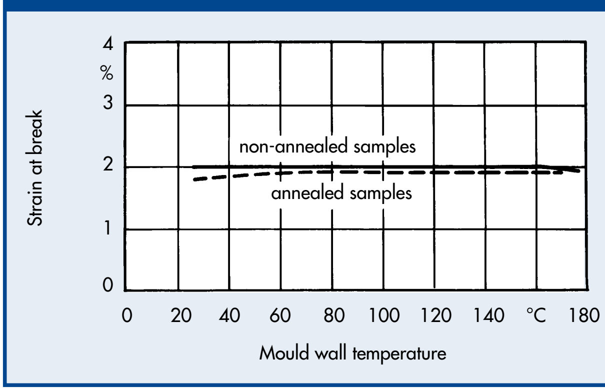


Fig. 49 · Relation between tensile strength and mould wall temperature of annealed and non-annealed samples of Fortron 1140L4

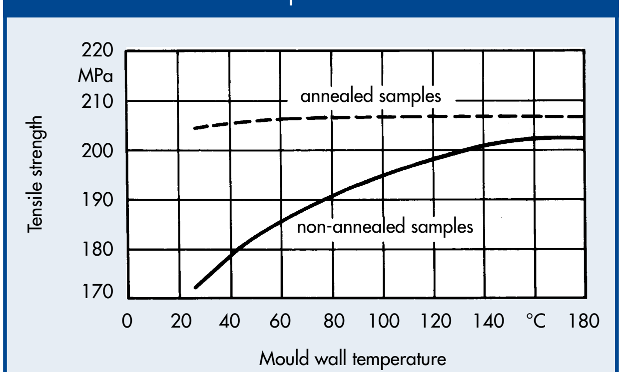
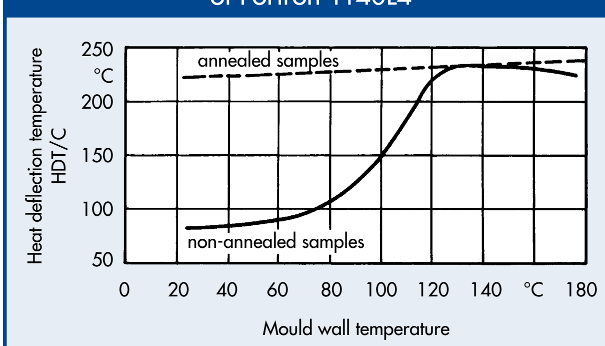


Fig. 51 · Relation between heat deflection temperature HDT/C and mould wall temperature of annealed and non annealed samples of Fortron 1140L4



2. In selecting machining conditions the low thermal conductivity of Fortron – in comparison with metals – must be taken into account. At high cutting speeds tools can be cooled with compressed air or, if necessary, with the usual cutting fluids (e. g. ethylene glycol).

3. Good chip removal gives the best cooling. Fortron is normally reinforced or filled and therefore the chips are fairly short and can be removed easily.

4. Different cutting speeds (drilling: 50 to 200 m/min; turning and milling: 250 to 500 m/min; sawing 500 to 800 m/min) and feed rates (turning: 0.1 to 0.5 mm/rev, drilling: 0.1 to 0.3 mm/rev) are recommended for the various machining processes. Tool wear must be expected with lower feed rates and could impair the quality of the cut surfaces.

5. Burr formation in thread cutting can be avoided by using double-toothed chasers. Cutting dies are not recommended because cutting is likely to continue on the return. A diameter-dependent overmeasure should be used with screw taps.

5.4.2 Tool recommendations for machining

Tools

For machining glass-fibre-reinforced or mineral-filled Fortron grades it is an advantage to use carbide- or diamond-tipped tools. Tools made from high-speed steel are likely to have a shorter service life.

For turning, clearance angles of 6 to 8°, rake angles of 0 to 5° and cutting edge angles of 45 to 60° are recommended. To achieve a smooth cut the cutting profile should be radiused by at least 0.5 mm.

For milling, the usual milling cutters can be used. Cutters with few teeth are preferred because of the larger chip space. This permits a large chip volume, enabling the heat generated to be removed with the chips. Clearance angles of 5 to 15° and rake angles of 6 to 10° have proved successful.

Twist drills for metalworking can also be used to drill Fortron. Twist angles of 12 to 16°, clearance angles of 5 to 10°, rake angles of 10 to 30° and cutting edge angles of 90° are advisable. For deep holes it is particularly important to ensure adequate chip removal e. g. with very smooth helical grooves. Pilot drilling of fairly large diameters is recommended.

Unnecessary heat build-up due to friction should be avoided in sawing because it is mostly thick-walled parts that are machined with the fairly thin saw blade. A favourable tooth geometry is achieved with a clearance angle of 15 to 30° and a rake angle of 0 to 5°. The tooth pitch should be 3 to 5 mm.

5.5 Assembly of Fortron mouldings

With the present drive towards efficient, low-cost manufacture of plastics assembles, the actual technique of assembly has become increasingly important. For manufacturing and fabrication reasons, it is often an advantage to produce the component parts separately and then assemble them as required. Various assembly methods are suitable.

5.5.1 Welding

In low-cost mass production of plastics components, it is often necessary for design, processing and assembly reasons to weld parts together.

The following welding methods are suitable for Fortron mouldings:

– ultrasonic welding
– spin welding
– vibration welding
– hot-plate welding
– induction welding
– laser welding.

All the DVS guidelines mentioned can be obtained from Deutscher Verlag für Schweißtechnik, Düsseldorf, Germany.

In all welding methods, high-quality production of the components to be joined is essential for good weld strength:

– correct part design and moulding conditions for the material and grade,
– high dimensional stability,
– good dimensional accuracy (close tolerances).

The design and geometry of the joint must be appropriate to the welding method used. The processing and specific welding characteristics of Fortron should be taken into account. The choice of method for the particular application will be governed by:

– joint shape and design,
– Fortron grade,
– part requirement profile.

The following points should be taken into account in welding Fortron.

Ultrasonic welding

Fortron mouldings can be joined by the usual ultrasonic assembly methods (welding, riveting) [3]. Joints produced by ultrasonic welding have high strength.

Ultrasonic welding machines can be integrated smoothly and efficiently into mass production processes. Ultrasonic assembly offers the advantage of the shortest cycle times of all the welding methods used for Fortron.

Fortron is suitable for both near- and far-field ultrasonic welding. However, because of the relatively brittle-hard behaviour of the material, it should be borne in mind that the alternating strains which have to be absorbed by the parts being joined can lead to localized damage. To avoid, special precautions need to be taken in terms of correct component design for the material and weld and correspondingly optimized machine settings (amplitude, welding time, welding pressure etc).

Pinch-off welds are the most suitable for this method of welding, employing a frequency of 20 to 40 kHz. Tapered pinch welds with a welding distance of over 1 mm can be made gas-tight.

Additions of up to 40% reinforcing materials still permit good welding results. Under mechanical load fracture usually occurs outside the weld (fig. 52). With higher additions, however, weldability deteriorates.

Spin welding

For Fortron mouldings with rotationally symmetrical joint faces, spin welding is a suitable assembly method to obtain gas-tight, high-strength joints. The most suitable welding conditions, such as surface speed, contact pressures and rotational speeds, will depend on the Fortron grade and part geometry and must be determined by optimizing trials.

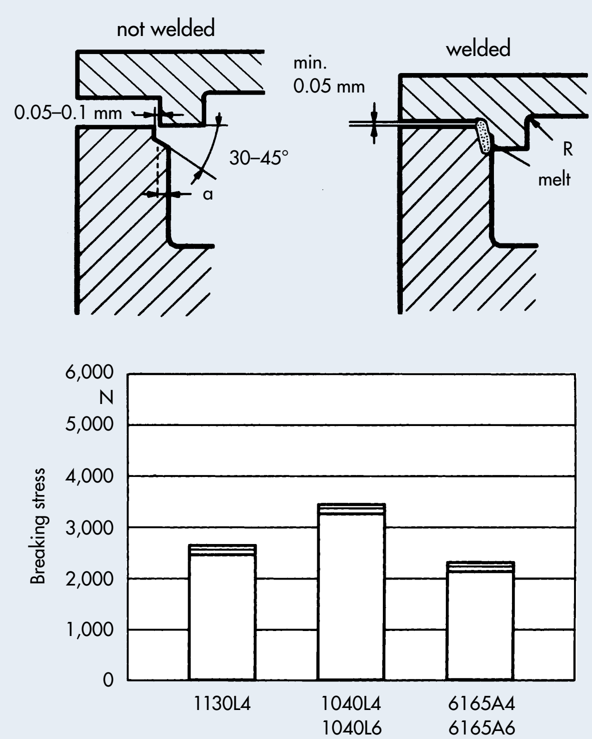
Vibration welding

This method should preferably be used when short cycle times are required and an alternative to ultrasonic or spin welding is necessary because of part geometry or size.

Hot-plate welding

This method is preferably employed for joints exposed to mechanical stress in service, large joint surfaces or part geometries that preclude the use of other welding methods. It is important to ensure that the hot tools used are designed for the high temperatures required.

Fig. 52 · Load bearing capacity of ultrasonically welded test specimens produced from various Fortron grades



Frequency	20 kHz	Welding time	0.8 s
Amplitude	30 µm	Weld design	single pinch weld
Welding force	400 N	Generator output	700 W

Induction welding (electromagnetic welding)

Induction welding can be used to produce gas-tight, high-strength welded joints and for insertion of metal parts. This method, which works on the principle of inductive heating, is unlike the other methods in that it enables joints to be produced which can later be detached (recycling). Induction welding can be used for difficult joints where other techniques fail.

Laser welding

In the laser welding process the laser beam has to be transmitted through the first welding part and absorbed by the second one. Trials with Fortron grades showed that reinforced ones have a good absorption behaviour. The wall thickness for the first (laser-permeable) part made of unfilled Fortron should be less than 2 mm.

Further trials to weld two reinforced Fortron parts are scheduled.

Close contact with the manufacturer of laser welding systems is always recommended when carrying out trials.

5.5.2 Snapfit joints

Fortron is a rigid-hard engineering plastic for which the low-cost, snapfit assembly technique can be used. For this method to be successful, it is important to ensure that the snapfit elements are correctly designed:

- The equations for calculating snapfit joints given in B.3.1 [4] are fully applicable to Fortron, provided the dependence of permissible outer-fibre strain on the wall thickness of the moulding and orientation of the glass fibres is taken into account. The following guide values for outer-fibre strain $\varepsilon_{perm.}$ should be regarded as an upper limit:

Fortron 1131L4, 1140L4, 1140L6:	1.3%
Fortron 4184L4, 4184L6:	1.1%
Fortron 6165A4, 6165A6:	0.8%

The friction factor which is necessary for the calculation depends on the sliding partners, surface roughness and surface pressure. Typical with Fortron are:

Sliding partner:	Fortron/Fortron	0.3 up to 0.4
	Fortron/steel	0.4

Trial products that are characterized by improved sliding and wear properties in selected fields of application are being developed. Sample quantities and more detailed information can be supplied on request.

- Snapfit hooks in which the height uniformly increases over the length up to the cross section where the base of the hook meets the main body of the component (fixed support point) have proved successful. This design, in contrast to the variant with constant hook height, permits greater hook deflection, i. e. a deeper undercut.

Practical trials are recommended in each individual case.

5.5.3 Adhesive bonding

The high solvent resistance of Fortron permits only contact adhesion.

Depending on the application, two-pack adhesives based on epoxy resin, methacrylate or polyurethane, one-pack adhesives based on cyanoacrylate or hot melt adhesives may be used.

Selection of a suitable adhesive is determined by the continuous service temperature to which the bonded joint will be exposed. Close contact with the adhesives industry is always recommended when carrying out trials.

5.5.4 Assembly with screws

Due to the low expansibility in comparison with other polymers, Fortron cannot compensate stress peaks in the same way and is very sensitive to notches. For these reasons, part shapes with a very high stress should be designed with more attention.

For parts made of Fortron, the following screw methods have been used:

- Moulded threads
- moulded-in inserts,
- bolting with:
  - through bolts
  - direct bolts, e. g. self-tapping screws.

The kind of screw method that could be used depends on the requirements and the part design. Close contact with the manufacturers, e. g. screws for plastics, inserts, is always recommended when carrying out trials.

5.6 Laser marking

Noncontact marking of text, patterns, symbols and codes on Fortron surfaces is possible with a laser beam. Laser marking on Fortron can be carried out with an Nd:YAG laser (1064 nm). Nd:YAG lasers produce dark, matt marks on Fortron.

5.7 Painting

Articles made from Fortron can be painted after pretreatment with fluor or primers. Conventional topcoat systems are used and the choice of system depends on the paint properties required, e. g. weathering resistance, chemical resistance and scratch resistance. It is particularly important to ascertain the temperatures to which the painted parts will be exposed and ensure that the paint system can cope with the thermal stresses involved.

5.8 Printing

For the coding of Fortron articles, printing also is possible. A pretreatment to achieve a surface which is free from grease or a method depending on the printing ink is necessary. Depending on the application, inks based on epoxy resin, acrylic resin, cellulose ester or two-pack inks based on urethane may be used.

5.9 Metallisation

Surfaces of parts made of Fortron compounds can be metallized by different methods. Possible technologies are wet- or electro analysis and vacuum metallising. An important condition for metallisation is a flawless part surface. To ensure this, importance should be attached to an effective mould venting.

6. Use of recyclates

Fortron can be recycled by remelting and repelletizing.

Sprues, rejects and post-consumer parts which are clean and not thermally degraded can be reprocessed as regrind in blends with virgin material.

It is particularly important to ensure that these parts are properly sorted, thoroughly dry and clean.

If different grades or contaminated regrind are processed together with virgin material, decomposition of the melt must be expected.

To minimize damage to fillers and reinforcing materials in Fortron compounds as a result of the granulation process, post-consumer parts should be ground under the gentlest possible conditions.

The addition of regrind can impair feed behaviour. It is therefore advisable to match the particle size of the regrind to the pellet size of the virgin material.

If the addition level of regrind is too high, a deterioration in the properties of the moulded parts may be expected. Regrind additions of 25 to 30% should therefore not be exceeded, figs. 53, 54.

If the same material has passed through the recycling loop several times, some decline in physical properties will occur, fig. 55.

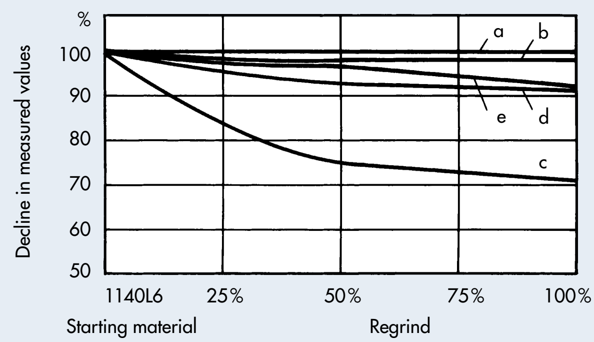
Polymer recycling of Fortron

When Fortron components have reached the end of their useful life, the question of recycling arises, as it does with other thermoplastics. Our own commitment to sustainable development as well as to meeting the needs of our customers and supporting our long-term marketing strategy has led us to develop a recycling process for Fortron that can be used for all grades supplied.

The process of material recycling affords the possibility of returning single-polymer waste and the sprues and runners that occur in processing for re-use. The quality of the recyclate obtained enables it to be re-used in typical Fortron applications.

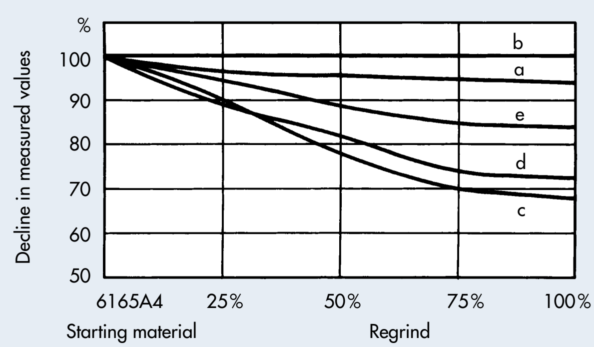
The implementation of this technology on the industrial scale is currently being tested in a specially designed pilot plant. The plant has been in operation since October 1996 and can be inspected by interested customers on request.

Fig. 53 · Behaviour of some mechanical properties as a function of regrind addition, example: Fortron 1140L6



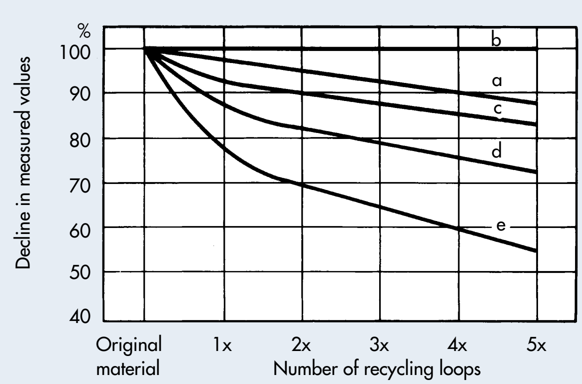
a tensile modulus
b strain at break
c notched impact strength (Charpy)
d impact strength (Charpy)
e tensile strength

Fig. 54 · Behaviour of some mechanical properties as a function of regrind addition, example: Fortron 6165A4



a tensile modulus
b strain at break
c notched impact strength (Charpy)
d impact strength (Charpy)
e tensile strength

Fig. 55 · Behaviour of some mechanical properties as a function of multiple processing, example: Fortron 1140L4



a tensile modulus
b strain at break
c tensile strength
d damage force
e damage energy

5

6

7. UL cards[1)]

1) Updated data are listed in table 3, page 20.

QMFZ2 March 23, 1998
Component - Plastics

TICONA **E107854**

(A005 – cont. from A card)

1120(a)#	NC	0.38	94V-0	130	130	130	—	—	—	—	—
	All	0.80	94V-0	220	130	130	3	4	—	—	—
		1.5	94V-0	220	130	130	2	4	—	—	—
		3.0	94V-0	220	200	200	1	4	3	5	4
1130(a)#	NC	0.38	94V-0	130	130	130	—	—	—	—	—
	All	0.80	94V-0	220	130	130	3	4	—	—	—
		1.5	94V-0	220	130	130	2	4	—	—	—
		3.0	94V-0	220	200	220	1	4	3	5	4
1131L4	BK	0.38	94V-0	130	130	130	—	—	—	—	—
		0.80	94V-0	220	130	130	3	4	—	—	—
		1.5	94V-0	220	130	130	2	4	—	—	—
		3.0	94V-0	220	200	220	1	4	3	5	4

Reports: **December 3, 1996; December 3, 1996; December 3, 1996; December 3, 1996.**

Replaces E107854A005 dated November 12, 1997. **(Cont. on A010 card)**
412775001 N7047 **Underwriters Laboratories Inc.®** D1I/0221149

QMFZ2 March 23, 1998
Component - Plastics

TICONA **E107854**

(A010 – cont. from A005 card)

1140(a)#	All	0.38	94V-0	130	130	130	—	—	—	—	—
		0.81	94V-0	220	200	200	3	4	—	—	—
		1.5	94V-0	220	200	220	1	4	—	—	—
		3.0	94V-0	220	200	220	1	4	3	5	4
1140E#++	All	0.85	94V-0	220	200	200	3	4	—	—	—
		1.5	94V-0	220	200	220	1	4	—	—	—
		3.0	94V-0	220	200	220	1	4	3	5	4
1140L#+	All	0.38	94V-0	130	130	130	—	—	—	—	—
		0.81	94V-0	220	200	200	3	4	—	—	—
		1.5	94V-0	220	200	220	1	4	—	—	—
		3.0	94V-0	220	200	220	1	4	3	5	4
1140L#(f1)	BN,	1.5	94V-0	220	200	220	1	4	—	—	—
	BK	3.0	94V-0	220	200	220	1	4	3	5	4

Reports: **December 3, 1996; December 3, 1996; December 3, 1996; December 3, 1996.**

Replaces E107854A010 dated November 12, 1997. **(Cont. on A015 card)**
412775001 N7047 **Underwriters Laboratories Inc.®** D1I/0221150

QMFZ2 March 23, 1998
Component - Plastics

TICONA **E107854**

(A015 – cont. from A010 card)

1140L4	All	1.5	94V-0	220	200	220	1	4	—	—	—
		3.0	94V-0, 94-5VA	220	200	220	1	4	—	—	—
1160(a)#	NC	0.38	94V-0	130	130	130	—	—	—	—	—
	All	0.80	94V-0	200	130	130	0	4	—	—	—
		1.5	94V-0	200	130	130	0	4	—	—	—
		3.0	94V-0	200	180	220	0	4	3	4	4
1342L4	NC	0.84	94V-0	130	130	130	2	1	—	—	—
		1.5	94V-0	130	130	130	1	1	—	—	—
		3.0	94V-0	130	130	130	1	0	0	4	4
4184(a)#+++	All	0.75	94V-0	220	200	200	3	4	—	—	—
		1.5	94V-0	220	200	220	1	4	—	—	—
		3.0	94V-0	220	200	220	1	4	3	5	4
4184L4	BK	1.5	94V-0	220	200	220	1	4	—	—	—
		3.0	94V-0, 94-5VA	220	200	220	1	4	—	—	—

Reports: **December 3, 1996; December 4, 1996; January 22, 1998; December 4, 1996; December 4, 1996.**

Replaces E107854A015 dated January 20, 1998. **(Cont. on A020 card)**

412775001 N7047 **Underwriters Laboratories Inc.®** D1I/0221151

QMFZ2 March 23, 1998
Component - Plastics

TICONA **E107854**

(A020 – cont. from A015 card)

4332L6	NC	0.38	94V-0	130	130	130	—	—	—	—	—
	All	0.75	94V-0	220	130	200	3	4	—	—	—
		1.5	94V-0	220	130	220	1	4	—	—	—
		3.0	94V-0	220	180	220	1	4	3	5	4
4665B6	BK	0.45	94V-0	130	130	130	—	—	—	—	—
	NC,BK	0.82	94V-0	220	180	200	3	4	—	—	—
		1.5	94V-0	220	200	220	0	4	—	—	—
		3.0	94V-0	220	200	220	0	4	0	4	2
6160(a)#	All	0.81	94V-0	220	200	200	3	4	—	—	—
		1.5	94V-0	220	200	220	1	4	—	—	—
		3.0	94V-0	220	200	220	1	4	3	5	4
6165(a)#	All	0.75	94V-0	240	200	220	3	4	—	—	—
		1.5	94V-0	240	220	240	0	4	—	—	—
		3.0	94V-0	240	220	240	1	4	0	4	2

Reports: **December 4, 1996; Decmber 5, 1996; December 4, 1996; December 5, 1996.**

Replaces E107854A020 dated November 12, 1997. **(Cont. on A025 card)**

412775001 N7047 **Underwriters Laboratories Inc.®** D1I/0314479

QMFZ2 March 23, 1998

Component - Plastics

TICONA **E107854**

(A025 – cont. from A020 card)

6165(a)4	All	0.75	94V-0	240	200	220	3	4	—	—	—
	NC, BK, BN	1.5	94V-0	240	220	240	0	4	—	—	—
		3.0	94V-0, 94-5VA	240	220	240	1	4	0	4	2
6850L6	BK	0.38	94V-0	130	130	130	—	—	—	—	—
		0.86	94V-0	220	180	200	0	4	—	—	—
		1.5	94V-0	220	200	220	0	4	—	—	—
		3.0	94V-0	220	200	220	0	4	0	5	4

Reports: **December 4, 1996; December 6, 1996.**

Replaces E107854A025 dated December 22, 1997. **(Cont. on A030 card)**

412775001 N7047 **Underwriters Laboratories Inc.®** D1I/0314482

QMFZ2 September 16, 1998

Component - Plastics

TICONA **E107854**

(A030 – cont. from A025 card)

Polyphenylene sulfide (PPS), designated "Fortron" furnished in the form of pellets.

8580A#	NC (BK)	0.35	94V-0	130	130	130	—	—	—	—	—
		0.75	94V-0	160	160	160	—	—	—	—	—
		1.5	94V-0	170	160	170	—	—	—	—	—
8885A#	BK	0.35	94V-0	130	130	130	—	—	—	—	—
		0.75	94V-0	160	160	160	2	2	—	—	—
		1.5	94V-0	170	160	170	2	2	—	—	—
		3.0	94V-0	170	160	170	2	2	0	3	2
8861A#	BK	0.81	94V-0	130	130	130	—	—	—	—	—
IGM	NC,BK	0.87	94V-0	130	130	130	—	—	—	—	—

Reports: **December 30, 1997; December 30, 1997; December 30, 1997; March 16, 1998.**

Replaces E107854A030 dated June 19, 1998. **(Cont. on B card)**

412775001 N7047 **Underwriters Laboratories Inc.®** D1I/0336221

QMFZ2 November 12, 1997
Component - Plastics

TICONA **E107854**
(B – cont. from A030 card)

(a)May be followed by an A, B or L to indicate lubricity.
(f1)Suitable for outdoor use with respect to exposure to ultraviolet light, water exposure and immersion in accordance with UL 746C.
+Virgin and regrind from 1 to 50% by weight inclusive have the same basic material characteristics except RTIs are 160 degrees C at a minimum thickness of 1.5 mm for the mechanical with impact property for regrind 26 to 50 % by weight inclusive.
++Virgin and regrind from 1 to 50% by weight inclusive have the same basic material characteristics except RTIs are generic 105 C at a minimum thickness of 0.85 mm, and RTIs are 180 C at a minimum thickness of 1.5 mm for the mechanical with impact property for regrind 26 to 50% by weight inclusive.

Replaces E107854B dated October 28, 1997. (Cont. on C card)
412775001 **Underwriters Laboratories Inc.®** D1I/0143973

QMFZ2 March 23, 1998
Component - Plastics

TICONA **E107854**
(C – cont. from B card)

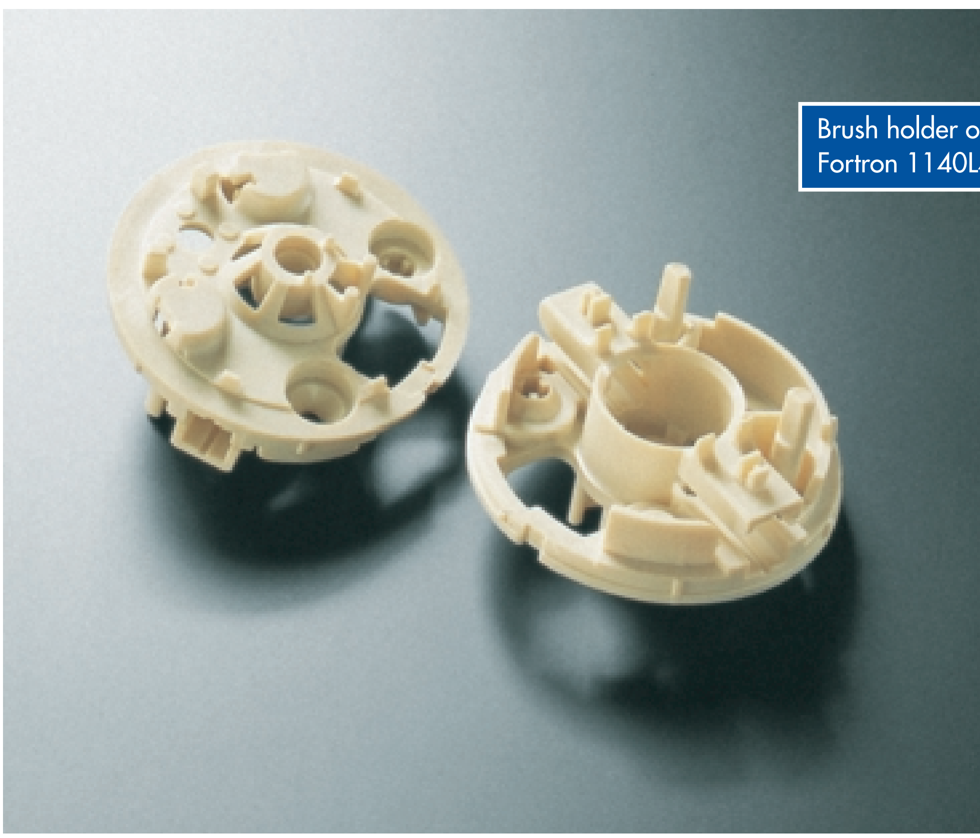
+++Virgin and regrind from 1 to 50% by weight inclusive have the same basic material characteristics except for the unaged tensile impact property.
#May be followed by a one digit number 0-9 incl. to indicate molecular weight.
NOTE: The generic RTI for PPS is 130 C.
Marking: Company name or trademark "FORTRON" and material designation on container, wrapper or molded on finished part.

See General Information Preceding These Recognitions.
UL94 small-scale test data does not pertain to building materials, furnishings and related contents. UL94 small-scale test data is intended solely for determining the flammability of plastic materials used in the components and parts of end-product devices and appliances, where the acceptability of the combination is determined by ULI.

Replaces E107854C dated November 12, 1997.
412775001 **Underwriters Laboratories Inc.®** D1I/0251348

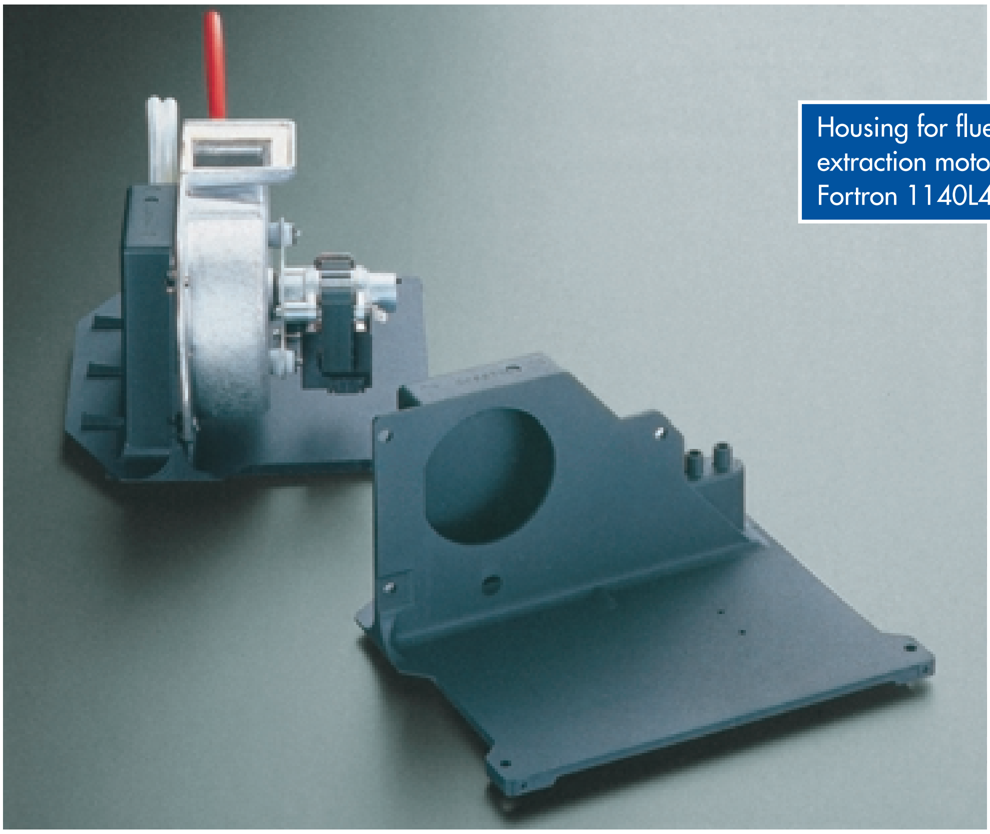
8. Photo supplement showing typical applications

Ceiling light,
Fortron 6165A4 (painted)

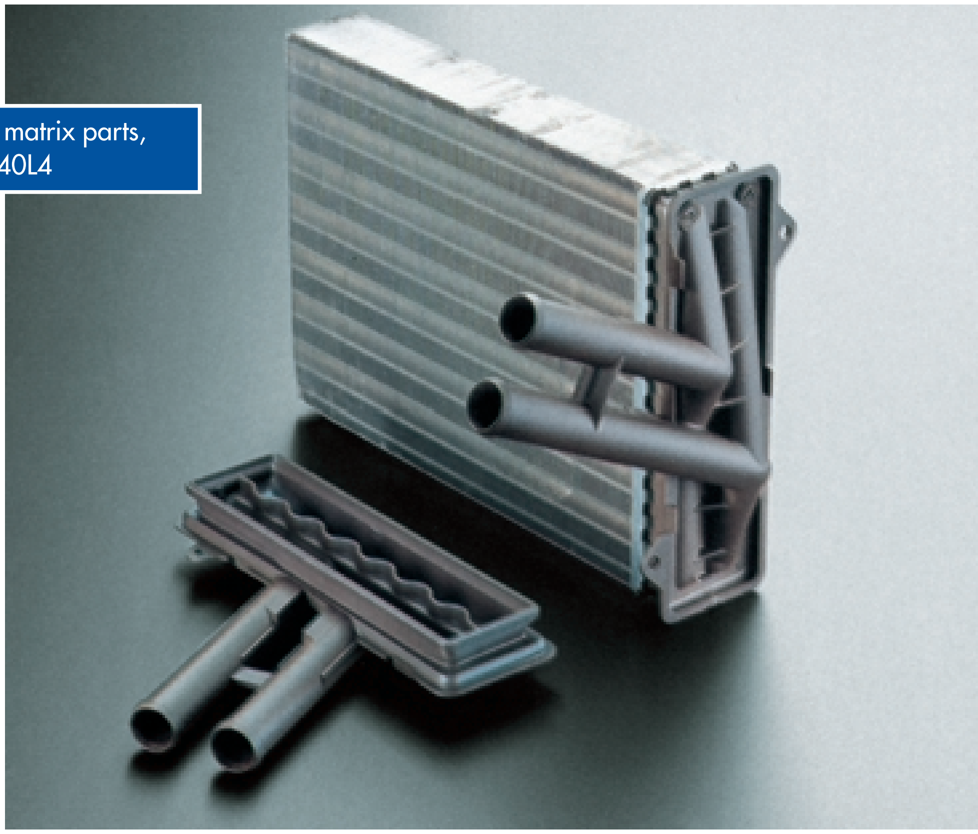


Brush holder of fuel pump,
Fortron 1140L4

Adapter for halogen spotlight, Fortron 6165A4



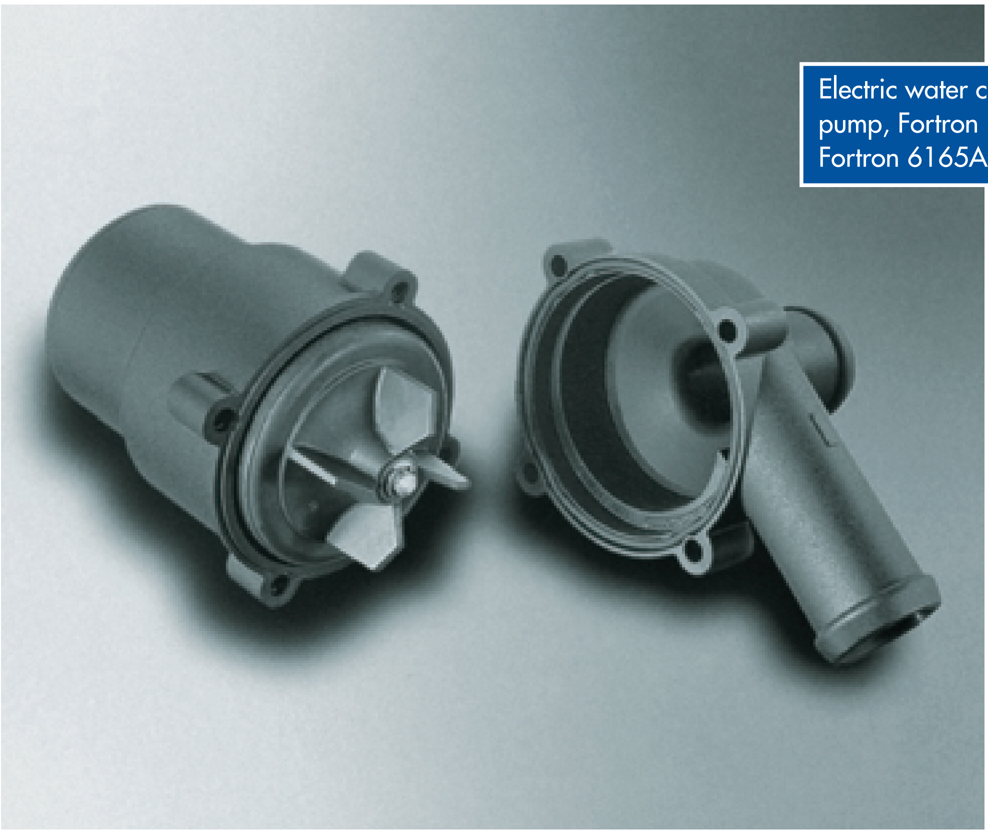
Housing for flue gas extraction motor, Fortron 1140L4



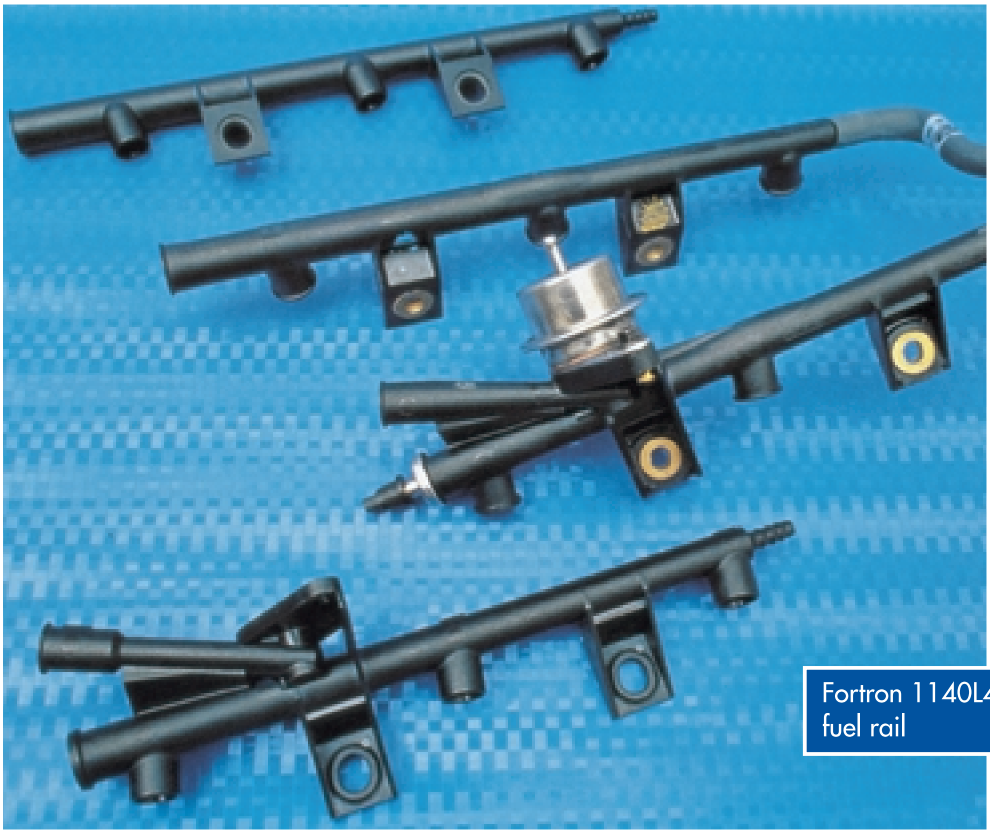
Car heater matrix parts, Fortron 1140L4

Car sunroof frame, gas injection moulded, Fortron 1140L6

Air outlet grille for a microscope, Fortron 1140L4



Electric water circulating pump, Fortron 1140L6, Fortron 6165A6



Fortron 1140L4 for the fuel rail

9. Subject index

Abrasion properties 22
Adhesive bonding 41
Annealing 37
Assembly 39 – 41
Assembly with screws 41
Automotive specifications 22

Back pressure 30
Ball indentation hardness 8 – 11
Bonding, adhesive 41
Building class B2 29

Caloric value 17
CAMPUS (data base) 6
Chemical resistance 23 – 28
Chemical resistance guide 28, 54
Coefficient of thermal expansion 8 – 11, 18, 21
Coloration 4
Coloration, in-house 4
Colour masterbatches 4
Comparativ tracking index CTI 8 – 11
Conductivity 19
Creep properties 7, 12 – 16
Crystalline melting range 17
Crystallinity 17, 33, 37
CSA tests 21
CSA/UL rating 21
Cylinder size (injection moulding) 30
Cylinder temperatures (injection moulding) 30

Degradation, thermal 31, 37
Density 8 – 11
Design notes (mouldings) 33
Dissipation factor 8 – 11, 19
Draft 35
Drilling 39
Drying, see predrying 30
DVS guidelines 39

Ejection taper 35
Electrical properties 8 – 11, 18
Electric strength 8 – 11, 21
Electromagnetic welding 41
Environment, service (resistance to effects of) 23
Extraction at the processing machines 37
Extrusion 30, 37

Fire precautions 37
Flame retardancy, inherent 2, 29
Flammability 29
Flexural creep modulus 16
Flexural modulus 6 – 11
Flexural strength 8 – 11
Flow path length 31
Flowability 31
Fluctuating stress 15
FMVSS 302 29
Friction coefficient, dynamic 22

Gaseous fuels 23
Gate 33
Glass transition temperature 17, 33
Grade range 3

Hardness 8 – 11, 22
Heat ageing 23, 24
Heat deflection temperature 8 – 11, 17, 18, 38
Holding pressure 30
Holding pressure time 30, 31
Hot runner moulds 33
Hot wire test 28
Hot-plate welding 40
Hydrolysis, resistance to 23

IEC 60216 18
Impact strength 8 – 11
Impact strength, notched 8 – 11, 29
Induction welding 41
In-house coloration 4
Injection moulding 30 – 36
Injection moulding, precision 35, 36
Injection pressure 30
Injection rate 30
ISO 9001 certificate 5

Jointing 39 – 41

KTW recommendations 22

Laser marking 42
Laser welding 41
Literature 54
Loss factor, mechanical 6

Machine conditions (injection moulding) 30
Machining 38
Masterbatches, colour 4
Material changes at processing 36
Mechanical loss factor 6
Mechanical properties 6 – 16
Melt temperatures 30, 36
Metallisation 42

Military specifications 22
Milling 39
Moldflow 32
Mould design (injection moulding) 33
Moulding shrinkage 8 – 11
Mould venting 34
Mould wall temperature 17, 30, 33, 38
Moulding, injection 30

Notched impact strength 8 – 11, 29
Nozzle (injection moulding) 30, 33

Painting 42
Pellet grades 3
Physical properties 8 – 11
Pinpoint gate 35
Polymer recycling 43
Post-crystallization temperature 17, 33
Post-shrinkage 37
Potable water regulations 22
Powder grades 3
Precision injection moulding 35
Predrying 30
Pressure, back 30
holding 30
injection 30
Printing 42
Processing 30
Processing conditions (injection moulding) 30
Properties, electrical 8 – 11, 18
mechanical 6 – 16
thermal 8 – 11, 17

Quality management 4

Radii (section changes) 35
Recrystallization temperature 17
Recyclates, use of 43
Regrind addition 43
Relative permittivity 8 – 11, 19
Residence time (max.) in cylinder 30, 31
Ribs 35
Rockwell hardness 8 – 11

Safety data sheet 37
Safety notes 37
Safety precautions in processing 37
Screw speeds 30
Screws 30
Service temperatures 2, 17
Shear modulus G 6
Shrinkage 31, 32
Shut-off nozzle 30
Sliding properties 22
Snapfit joints 41
Specification listings 22
Spin welding 40
Sprue 35
Steels, tool 33, 34
Strain at break 6, 8 – 11, 29, 38, 43
Stress-strain curves 6
Supply forms 2
Surface resistivity 8 – 11, 19

Temperature index (UL-RTI) 20
Tensile creep modulus 12 – 15
Tensile modulus 6 – 11, 29
Tensile strength 6, 8 – 11, 38
Tensile test 6
Thermal conductivity 17
Thermal degradation 31, 37
Thermal expansion, coefficient of 8 – 11, 18, 21
Thermal properties 8 – 11, 17
Tolerances 35, 36
Tool steels 33, 34
Tools (for machining) 39
Tracking CTI 8 – 11
Transition ranges 17
Tunnel gate 35
Turning 39

UL cards 44 – 47
UL rating 20
UL tests 18
Ultrasonic welding 40
Unreinforced grades 3
Undercuts 30, 35
UV light, resistance to 29

Vent channels (injection mould) 34
Venting (of moulds) 34
Vibration welding 40
Volume resistivity 8 – 11, 19

Water absorption 8 – 11, 23
Weld lines 34
Welding 39
Welding, hot-plate 40
induction 41
spin 40
ultrasonic 40
vibration 40
“Wöhler curves” 15 – 17

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