VESTAKEEP® I grades

PEEK—Polyether Ether Ketone Compounds – Processing guide

VESTAKEEP® I-grades: High Performance Polymers expanded to medical applications

High-Performance Polymers has further expanded its technological lead in the high-performance polymers sector with VESTAKEEP® polyether ether ketone (PEEK[1]) compounds. VESTAKEEP® compounds are particularly suitable for applications in which extremely high mechanical, thermal, chemical and biocompatible requirements must be met.

Evonik markets its VESTAKEEP® compounds worldwide. A proven quality management system ensures a high level of quality for the products introduced on the market, from development through production, and to quality assurance. Our system is ISO 9001:2000 and is continually optimized. A large number of customers have tested this quality system over the years and have attested to its excellence.
For development and production, we have also introduced an environment management system complying with ISO 14001:2005, and this is regularly certified.

This brochure provides an overview of the properties as well as processing.

VESTAKEEP® compounds are particularly characterized by the following material properties:

- very high heat resistance
- high rigidity
- low water absorption and therefore high dimensional stability
- high hardness
- good strength
- excellent sliding friction behavior, minimal abrasion
- good electrical characteristics
- excellent chemical resistance
- excellent hydrolytic stability
- good processability
- low tendency to form stress cracks

Manufacture

VESTAKEEP® is polycondensed from the building blocks hydrochinone and 4,4´-difluorobenzophenone in a multistage process.

The base grades have a melt viscosity of 100-3,000 Pas, measured at 400 °C, and a low shear of 1 sec^{-1}, which is right for injection molding and extrusion applications.

To meet the requirements of different applications, manufacturers can adjust the properties of pure PEEK selectively by adding various additives:

- Processing aids facilitate demolding.

Fillers and reinforcing materials increase rigidity and dimensional stability upon exposure to heat.

[1]PEEK is the official abbreviation for polyether ether ketone according to ISO 1043. In this brochure it will be used only in this context.

Delivery of VESTAKEEP® I grades

As granules: in baskets with a total content of 10 kg, divided into two polyethylene liners each holding 5 kg.
As a powder: in 3 kg baskets with an inner polyethylene liner.

Under normal storage conditions, storage time is practically not limited provided that the packaging has not been damaged. Avoid storing at temperatures above 40°C, in direct sunlight or in high humidity.

Like other partially crystalline polyaryl ether ketones, unmodified VESTAKEEP® I grades appear amber-colored in the melt and grayish in the solid crystalline state (natural colors). VESTAKEEP® I is translucent in its solid, amorphous state and has a characteristic amber color. They are available in two viscosity series, namely VESTAKEEP® I2G with a lower viscosity and VESTAKEEP® I4G with a higher viscosity.

Technical service - CAE support

Our technical service includes comprehensive application engineering advice with the aim of jointly working out technically demanding system solutions with our customers. This also includes support from various CAE methods in the development of molds and molded parts.

We perform processing simulations of the injection-molding process from the filling phase to the holding-pressure phase, including the calculation of shrinkage and distortion, with modern software. This enables us to provide the following data as early as during the product development phase.

- Processing process: e.g., fillability of the mold, resulting process parameters like pressure and temperature distributions, cooling system, influence of various processing parameters
- Component properties: e.g., location of weld lines, air bubbles, shrinkage and distortion, fiber orientation
- Manufacturing costs: required machine size, cycle time, complexity of molded part/mold

As a rule, we require that our customers provide us with an IGES file describing the geometry of the article and, depending on the problem definition, information regarding constraints, such as mold and process requirements. We will enter relevant material properties such as shear viscosity, thermal conductivity and PVT behavior into the calculation.

The results from the simulation calculation support further design and optimization of the molded part and its associated injection mold. This frequently results in a reduction of cost-intensive modifications and in the number of iterative loops on the mold and molded part.

Our qualified teams in Application Technology and Market Development discuss the problem definition and results with the customer and jointly work out solutions.

Overview of VESTAKEEP® I grades and their properties

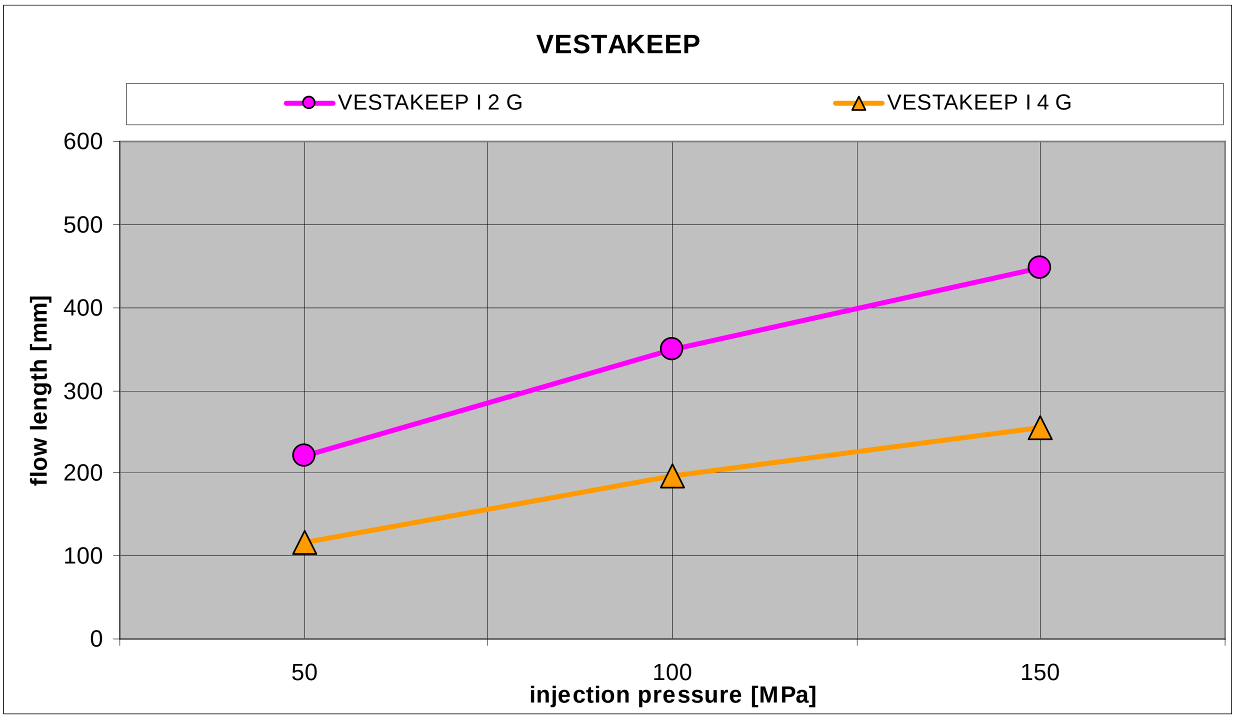
VESTAKEEP	Properties	Processing
I 2 G	unreinforced, medium-viscosity, lubricated	Injection molding, extrusion (film)
I 4 G	unreinforced, high-viscosity, lubricated	Extrusion, (injection molding)

Properties of VESTAKEEP® I grades

Flow behavior

The following illustrations serve as guide for selecting a grade in terms of the flowability of VESTAKEEP®. They show how injection pressure affects the flow length.

The values were obtained at a mold temperature of 180°C and at a processing temperature ranging from 360 to 400°C. The results are based on a flow spiral of 6 by 2 mm.



Tribological properties

Tribology deals with friction, lubrication, and wear to bodies that come into contact with each other. The following table shows the initial results of a tribological test with a slide in form of a pin made of VESTAKEEP® and a rotating disk made of 100Cr6 steel.

The velocity was set at 0.5 m/s, and a total distance of 2,000 m was measured. Additional tests are being conducted with longer total distances. Please ask the indicated contact persons about the current status of these tests.

Tribological properties

	Temperature, load	VESTAKEEP® I 2G	VESTAKEEP® I 4G
Coefficient of sliding friction	23 °C, 1 N	0.4	0.4
	23 °C, 20 N	0.35	0.41
Wear [10^{-6} mm^3/Nm]	23 °C, 1 N	9.1	9.14
	23 °C, 20 N	16.68	10.48

Weld line strength

For the purpose of determining weld line strength, tensile test bars 150 x 10 x 4 mm³ in size were made on an experimental mold. If the runner inserts are replaced, the mold can produce test bars with and without a weld line. The mold surface temperature for all tensile bars was set to 180 °C.

Testing was done under standard conditions according to ISO 527. The results are summarized in the table below. It is obvious for unfilled molding compounds that the weld line leads to practically no decline in the stress at yield.

Weld line strength

VESTAKEEP®	ISO 527-1/-2	Stress at yield [MPa] without weld line	Stress at yield [MPa] with weld line
I 2G	50 mm/min	100	99
I 4G	50 mm/min	96	95

Properties of VESTAKEEP® I grades

Properties		Standard	Unit	VESTAKEEP® I 2G	VESTAKEEP® I 4G
Physical and thermal properties and fire behaviour					
Density	23 °C	ISO 1183	g/cm^3	1.30	1.30
Melting range	DSC, 2nd heating		°C	approx. 340	approx. 340
Melt volume-flow rate (MVR)	380 °C/ 5 kg	ISO 1183	$cm^3/10$ min	70	11
Temperature of deflection under load Method A Method B	 1.8 MPa 0.45 MPa	ISO 75-1/2	 °C °C	 155 205	 155 205
Vicat softening temperature Method A Method B	 10 N 50 N	ISO 306	 °C °C	 335 310	 335 305
Linear thermal expansion longitudinal	23°C-55°C	ISO 11359	 $10^{-4} K^{-1}$	 0.6	 0.6
Oxygen index	3.2 mm	ISO 4589	%	38	38
Flammability acc. UL94	0.8 mm 1.6 mm	IEC 60695		V-0 V-0	V-1 V-0
Glow wire test GWIT GWIT	 2 mm 2 mm	IEC 60695-2- 12/13	 °C °C	 875 960	 850 960
Mold shrinkage in flow direction in transverse direction		ISO 294-4	 % %	 0.7 1.2	 1.1 1.8
Water absorption, saturation	23°C	ISO 62	%	0.5	0.5
Mechanical properties					
Tensile test Stress at yield Strain at yield Strain at break	50 mm/min	ISO 517-1/-2	 MPa % %	 100 5 30	 96 5 30
Tensile test Tensile strength Strain at break	5 mm/min	ISO 527-1/-2	MPa % %	100 5 30	96 5 30
Tensile modulus		ISO 527-1/-2	MPa	3700	3500
CHARPY impact strength	23 °C -30 °C	ISO 179/1eU	kJ/m^2 kJ/m^2	N N	N N
CHARPY notched impact strength	23 °C -30 °C	ISO 179/1eA	kJ/m^2 kJ/m^2	6 C 6 C	7 C 6 C
Electrical properties					
Comperative tracking index Test solution A	 CTI 100 drops value	IEC 60112		 200 175	 200 175
Electric strength	K20 / P50 K20 / K20	IEC 60243-1	kV/mm kV/mm	25 21	25 21
Relative permittivity	50 Hz 1 kHz 1 MHz	IEC 60250		2.8 2.9 2.8	2.8 2.9 2.8
Dissipation factor	1 kHz 1 MHz	IEC 60250		0.003 0.005	0.003 0.005
Volume resistance Volume resistivity Surface resistance Spec. surface resistance		IEC 60093	Ohm Ohm*cm Ohm Ohm	10^{14} 10^{15} 10^{14} 10^{15}	10^{14} 10^{15} 10^{14} 10^{15}

N = no break C = complete break, incl. hinge break H

Processing

General Information

For injection molding and extrusion processing, VESTAKEEP® polymers and compounds are primarily processed in granular form. Most standard screw machines are suitable for this.The plasticating unit should be designed for process temperatures of up to 450 °C. It may also be necessary to modify the controller, band heaters, and temperature sensors. In addition, we recommend that the instructions listed below be observed when processing PEEK.

Drying

VESTAKEEP® leaves the factory with a moisture content of less than 0.25 wt.%. We nevertheless recommend additional drying in order to obtain qualitatively high-grade extrudates.

- **Drying temperature**: 150–160 °C
- **Drying time**: 2–3 hours in the dry-air dryer or vacuum furnace. A drying cabinet is good for base powders.
  We also recommend 4 or more hours for film applications
- **Hopper**: heated or thermally insulated
- **Max. residual moisture:** < 0.02 weight-% is recommended for base powders and granules

Suggestions:

- The saturation temperature of the dryer should be at least -30 °C
- Convey the granules with dried air exclusively
- Use PU hoses for conveying, not PVC hoses

Injection molding

Plasticating Unit

Screw and barrel

Standard screw (three-zone screw) with a length between 18 and 24 D are usually suitable

- Zone breakdown: feed 55–60%, compression 20–25%, metering 20–25%
- Flight depth ratio 2.0–2.5:1

The plasticating unit should be designed so that the required metered volumes lie between 30% and 70% of the maximum possible shot volume. This will produce a homogenous melt quality.

Back flow valve

Commercially available three-piece back flow valves are used. Machine manufacturers provide a wide choice of different designs. Rapid, reproducible closing of the valve during injection is an indispensable requirement for ensuring that quality and weight of the molded part remain constant.

Nozzle

In general, free-flow nozzles are recommended. A slight easing of the decompression of about 3 to 5 mm will counteract the discharge of the melt from the nozzle bore. But decompression distances that are too long will cause air to become trapped, resulting in burned spots and gate marks. Shut-off nozzles are less suitable because loss of injection pressure must be expected because of the poorer melt transport. It is also possible for thermal damage to occur in the existing "dead corners" because of retention times being too long.
In all of the nozzle types used, it is necessary to make sure that the heat output is sufficient. To prevent "freeze-off" of the nozzle and formation of a "cold slug" when the sprue bush is adjacent to the injection unit, the band heater should cover the entire length of the die body.
In order to demold a sprue gate without trouble, the outlet diameter of the machine nozzle should be approximately 0.5 to 1 mm smaller than the bore diameter of the sprue bush.
It is also important that the radius of the machine nozzle is smaller than that of the sprue bush (e.g. nozzle radius = 35 mm, sprue-bush radius = 40 mm).

Injection unit

Screws made of corrosion-protected and wear-protected high-alloy PM steels are usually used to process VESTAKEEP® within the injection cylinder. We recommend a bimetallic design for the injection cylinder.
Since VESTAKEEP® has a strong tendency to adhere to metallic surfaces, it is possible for cracks to form in the nitrided layer of nitrided screw surfaces during cooling. The adhesion can be so strong that the nitride layer can peel off from the steel core.
Metallic areas that come into direct contact with the melt should be highly polished to prevent deposits that could cause thermal decomposition due to the increased retention time. In order to obtain good conveying action by the screw, the friction between the granules and the cylinder wall must be greater than that between the granules and the screw surface.

Cleaning

General
Remove other polymers completely from the plasticating unit before processing VESTAKEEP®. This can be accomplished either by cleaning the cylinder and screw mechanically or by using suitable cleaning materials. These are materials that are thermally stable up to approximately 380 °C.

Material change over to VESTAKEEP®
1. We recommend complete mechanical cleaning of the equipment before VESTAKEEP® is processed.

If cleaning agents are used make sure that they will be completely removed after the cleaning process is finished.

Cleaning while shutting down the injection molding machine
Completely remove the PEEK melt from the cylinder before processing another material. There exists the danger that the melt could solidify with the nitride layer of the cylinder and screw while cooling. Because of the high adhesive forces, this layer could peel and damage the screw (see “Tool steel”). This means that the cylinder may be allowed to cool only after cleaning and careful rinsing.

Cleaning process:
1. Remove material form the injection molding machine (hopper).
2. Introduce the cleaning material and continue rinsing until there are no longer any visible traces of the PEEK material.
3. Reduce cylinder temperatures to a lower temperature (350 °C) that is still acceptable for PEEK.
4. Continue rinsing with the cleaning material until the actual cylinder temperature drops below 300 °C. An even lower temperature (< 250 °C) may be required, depending on cleaning material.
5. Possibility of mechanical cleaning

Clamping unit

Mold clamping force
The required clamping force depends on the size of the expected molding area (sprue area plus article area) and the resulting internal pressure of the mold. An adequate clamping force must be ensured since the injection pressures of 100 to 200 MPa are very high in comparison with other projects.

The production of precision parts and injection molded articles that have large flow-distance/wall-thickness ratios involve pressures in excess of 200 MPa.

Tool

Tool steel
For the cavity, use steel grades that still have a hardness of about 52 to 54 HRC at the high processing temperatures, for example
- 1.2343 ESU (X38CrMoV51) – easy to polish
- 1.2379 (X155CrVMo121) – core hardened
- 1.2083 (X42Cr13) – core hardened, corrosion-resistant
- 1.2316 (X38CrMo16) – non-rusting steel, easy to polish

Wall thickness of molded parts
Minimum wall thickness:
- approx. 1 mm for unfilled PEEK molding compounds
- approx. 1.5 mm for filled PEEK molding compounds

Flow-distance/wall-thickness ratio
Maximum attainable flow distance/wall thickness ratios for unfilled materials and 2 mm wall thickness up to 200 : 1 (conditions: melt temperature 380 °C, mold temperature 180 °C, injection pressure 140 MPa)

Sprue
- Minimum diameter: 4 mm, for direct gating 1 to 1.5 times the thickness of the molded article
- Demolding draft angle: at least 2°
- Ejector claw: special for direct gating
- Manifold: round or trapezoidal (cross section as large as possible for small surface)

Gate
Dependent on melt volume, number of cavities, component geometry; nearly all common systems are suitable; but small tunnel gates freeze off quickly and are preferably used when short holdingpressure times are required; however; thin flow areas should be avoided.
Minimum gate diameter:
- approx. 1.0 mm for unfilled materials
- approx. 2.0 mm for reinforced materials

Hot runner system
We recommend exclusively nozzles that have good external heating with a heatconducting torpedo in the nozzle tip for processing VESTAKEEP® with hot runner systems. These systems generally feature low pressure losses and

clearly defined flow-channel cross sections that enhance flow.
Frequently non-corrosive types of steel with increased chrome content (1.2316, see Mold) are used to process PEEK in hot runner systems. They must permanently maintain process temperatures up to 450 °C.
To achieve an exact thermal separation between nozzle and mold, it is necessary to correctly follow the manufacturer's instructions when implementing the gate geometry. This is important in order to avoid surface defects and unclean separation points.

The feed-point diameter for reinforced compounds should be around 0.2 to 0.3 mm larger than in the case of unreinforced grades.
The hot runner controllers should be able to correct temperature deviations of up to +/- 1 °C.
To keep pressure losses as small as possible, the gate openings should be dimensioned as large as possible.
Many manufacturers can calculate pressure losses in the hot runner based on material data.

Venting
Venting slots in mold parting surface or, in particular, at the end of the runners can generally be incorporated 0.02 mm deep without burr formation. If necessary, the depth may be increased to 0.05 mm but it is then necessary to watch out for burr formation.
Further support of venting by means of appropriately fashioned ejector pins is possible.
Vent packages at critical points of confluence can also help prevent "burnings." Compressed air in the cavity can reach temperatures as high as 1000 °C and result in damage to the molded part.
It is important to provide adequate ventilation in blind holes in particular, because molded articles may otherwise not fill completely. Vent pins that can be easily removed for cleaning are helpful.

Pressure sensor
We recommend the use of an internal pressure sensor to set the switching point precisely.

Temperature control
Since mold surface temperatures can be as high as 220 °C, we recommend the use of oil-operated tempering devices. The devices should be designed for operating temperatures of up to 250 °C. Special hoses that are approved for high operating temperatures should be used. For the mold feed system, tight threaded joints are preferable to plug and coupling systems.
It is also necessary to pay attention to the maximum permissible operating temperatures of all seals (Viton, Kalrez®) within the mold as well as the seals in the hydraulic cylinders of core pullers.
Electrically heated injection molds, in which there is a much slower reaction to temperature changes because no heat is dissipated, can also be used.
The external surfaces of the mold can be covered with insulating plates to minimize loss of heat to the surroundings from thermal radiation. We recommend the use of heat-insulating plates between the machine support plates and mold.

Processing conditions

Cylinder and mold temperatures
We recommend the following melt temperatures to process VESTAKEEP® successfully:

Melt temperatures

VESTAKEEP®	I 2G	I 4G
	[°C]	[°C]
	370	380

Set the cylinder temperature profile slightly rising with the feed temperature 10 to 20 °C lower than the last cylinder heat zone temperature.
The optimum melt temperature depends on various factors, such as the retention time in the plasticizing cylinder and the wall thickness of the molded article. The melt temperatures recommended in the above table can be used as starting temperatures. They can be increased by 10 to 20 °C for short residence times and thin wall thicknesses.

Typical values for cylinder and mold temperatures

	Nozzle [°C]	Zone 3 [°C]	Zone 2 [°C]	Zone 1 [°C]	Hopper [°C]	Mold temp. [°C]
VESTAKEEP®	370–380	360–380	360–370	350–360	70–100	160–200

Select high temperatures to achieve a high degree of crystallization.

Screw speed

Peripheral screw speed	**Rotational speed, e.g., #30 screw**
5–10 m/min	50–100 rpm

Higher speeds are not recommended because of the possibility of thermal overload of the melt caused by frictional heating from large local shear effects.

Back pressure

Back pressures between 2 and 8 MPa improve the melt homogeneity. For reinforced VESTAKEEP® grades, we recommend a lower back pressure in order to process the fillers as gently as possible and obtain the mechanical properties.

Decompression

We recommend a decompression distance of approx. 3 to 5 mm for melt ejection from the nozzle.

Injection speed

The injection speed should be as high as possible and therefore requires injection pressures up to 250 MPa, depending on the prevailing mold conditions (gate dimensioning, flashing, ventilation, etc.). For short filling times, we recommend storage machines.

Injection pressure

The injection molding machine should be designed for injection pressures up to 250 MPa, the required injection pressure essentially depending on the melt and mold temperature and the flow-distance/wall thickness ratio of the component.

Holding pressure

As a rule, holding pressures of up to 120 MPa in combination with an optimized holding-pressure time should be sufficient to produce components without sink marks. A melt cushion of 3 to 5 mm will ensure adequate pressure transmission from the injection cylinder to the cavity. The gating must be dimension large enough to allow the holding pressure to act upon the molded part for a sufficient length of time.

Holding pressure time

Since VESTAKEEP® materials have a high solidification point (T_K approx. 345 °C), gates to the molded article can freeze off prematurely. The optimum holding pressure time must be established by determining the gate seal-off point. Holding pressure times that are too short can result in sink marks and voids because of an insufficient supply of material coming from the plasticizing cylinder.

Production stops

To avoid slow decomposition of the material, we recommend strongly to avoid production stops. If for technical reasons the production has to be stopped for longer than 1 hour, a complete cleaning of the equipment is recommended.

For measures to eliminate defects in injection molded parts see the table on last page

Extrusion

Plasticating unit

Extruder

As mentioned above, most standard screw machines are suitable for PEEK processing provided that they can operate reliably at the required processing temperatures. Standard screws (three-zone screw) with a length between 18 and 24 D are normally suitable: Zone breakdown: feed 12 D, compression 4-6 D, metering 4-6 D

Flight depth ratio: 2-3:1
For screws and barrels, we recommend sufficiently corrosion- and abrasionresistant steels and bimetals.

If conventionally nitrided parts are used, make sure that the VESTAKEEP® melt does not cool on the surface and solidify on the nitride layer. The adhesion can be so strong that cracks will form and the nitride layer can peel off from the steel core.

Processing temperatures

The optimum processing temperatures of PEEK depend on various factors, such as the viscosity of the compound and the technical parameters of the extrusion unit.
The material can be heated in the hopper to improve the melting characteristics of the granules. The recommended temperatures lie in the range 140 °C-180 °C. If it is not possible to heat the hopper, the granules can be fed warm. The temperatures of the feed zone must be chosen on the basis of the viscosity and filler of the material. The first heating zone should be heated to about 350 °C-360 °C. Conventional extrusion exhibits a temperature profile similar to the following:

Typical processing temperatures for VESTAKEEP®

	Nozzle [°C]	Zone 3 [°C]	Zone 2 [°C]	Zone 1 [°C]	Hopper [°C]
VESTAKEEP® G	370-390	360-390	360-370	350-360	140-180

Mold

We recommend that you optimize the heating to achieve a uniformly high temperature distribution (e.g. die heating for flat sheet dies). In order to reach and maintain these temperatures, it is important that thermal radiation be kept low. If this is not possible, the mold should be insulated with appropriate thermal insulation.
Metallic areas that come into direct contact with the melt should be highly polished to reduce the adhesion of the melt to the metal, thus reducing the residence time and less disturbing the flow of the melt.

Downstream unit

It is possible to obtain different properties for the extrudate by tempering the downstream unit (chill roll, calendar and calibration temperatures).
VESTAKEEP® is a semi-crystalline material whose properties (transparency, color, mechanics, etc.) are strongly dependant on the cooling characteristics. If a semi-crystalline structure is to be achieved, it is necessary to temper the extrudate in the downstream unit, possibly up to 240 °C and higher.

Material change-over

For a material change-over from other polymers to PEEK, it is necessary to rinse temperature-unstable materials completely out of the cylinder and downstream units. Decomposition reactions and gas formation could otherwise occur. We recommend mechanical cleaning to avoid any contamination. See the corresponding procedure in the Section "Mechanical cleaning".

Material change-over to VESTAKEEP®

Equipment should be cleaned mechanically to avoid any contamination.

Material change-over of VESTAKEEP® to other polymers

Before another material can be processed, it is necessary to completely remove the PEEK melt from the cylinder. The compound to be processed next should be insensitive to heat in order to avoid decomposition reactions and gas formation.

Cleaning

Remove other polymers completely from the plasticating unit before processing VESTAKEEP®

compounds. This can be accomplished either by cleaning the cylinder and screw mechanically or by using suitable cleaning materials. These are materials that are thermally stable up to approximately 380 °C. One suitable material is a high-viscosity PC containing glass fibers (e.g., MAKROLON® 8345, ASACLEAN®). Other suitable materials include PES, PEI and, with limitations, high-viscosity PP. Since PP decomposes at these temperatures, effective ventilation is important.

Cleaning process

1. Remove the material from the hopper.
2. Run the screw dry.
3. Feed in the cleaning material and continue extruding until there is no longer any visible trace of the PEEK material. Please observe the corresponding processing recommendations of the material manufacturer.
4. Reduce the cylinder temperatures to a lower value that is still acceptable for PEEK (350 °C) and, if necessary, reduce further to the temperatures of the cleaning agent.
5. Continue to rinse with the cleaning material until the typical temperatures of the cleaning material have been attained.
6. If necessary rinse with another material that can be easily removed from the metal before mechanical cleaning.
7. Mechanical cleaning

Other processing instructions

For longer downtimes, the temperature should be dropped to 340 °C. The material possesses adequate melt stability at this temperature. For downtimes exceeding 1 hour cleaning is recommended. See "Cleaning."
If the VESTAKEEP® melt cools down within the cylinder, the compound will harden (similarly as in the case of PC). Because of the high adhesive forces that arise, it is possible, especially in the case of conventionally nitrided surfaces, that cracks will arise or even that the nitride layer will peel off, raising the possibility of damage to the screw (see "Tool steel").

Measures to eliminate defects in PEEK injection molded parts

Defect in the molding	Possible cause	Melt temperature	Mold temperature	Nozzle temperature	Nozzle contact time	Rotational speed of screw	Injection speed	Shot volume	Injection pressure	Holding pressure	Cycle time	Gate cross section	Move the gate position	Improve venting of cavity	Clamping force	Dry the material
Brittleness	Overheating	▼				▼					▼					
	Stresses	▲	▲						▼		▲	▲				
	Flow line	▲	▲				▲						■			
Incompletely filled	Too little injected							▲								
	Insufficient flux	▲	▲				▲		▲							
	Mold design											▲	■	■		
Transparent edges/dark regions	Mold temperature too low		▲													
Cold plugs	Melt transitions within the nozzle			▲	▼											
Sink marks/voids	Inadequate time and pressure conditions	▼							▲	▲						
	Mold design	▼										■	■			
Burn marks	Air trapped in cavity						▼		▼			■	■	■		
Flashing	Clamping force too small/ fitting accuracy of the mold halves	▼	▼				▼		▼	P					▲	
Streaking	Overheated molding compound	▼		▼		▼	▼									
	Humid material															■
Dull surfaces (Reinforced grades)	Insufficient injection speed	▲	▲				▲									
	Shear on the melt too strong					▼										

▲ = increase
▼ = decrease
■ = do
P = profile

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