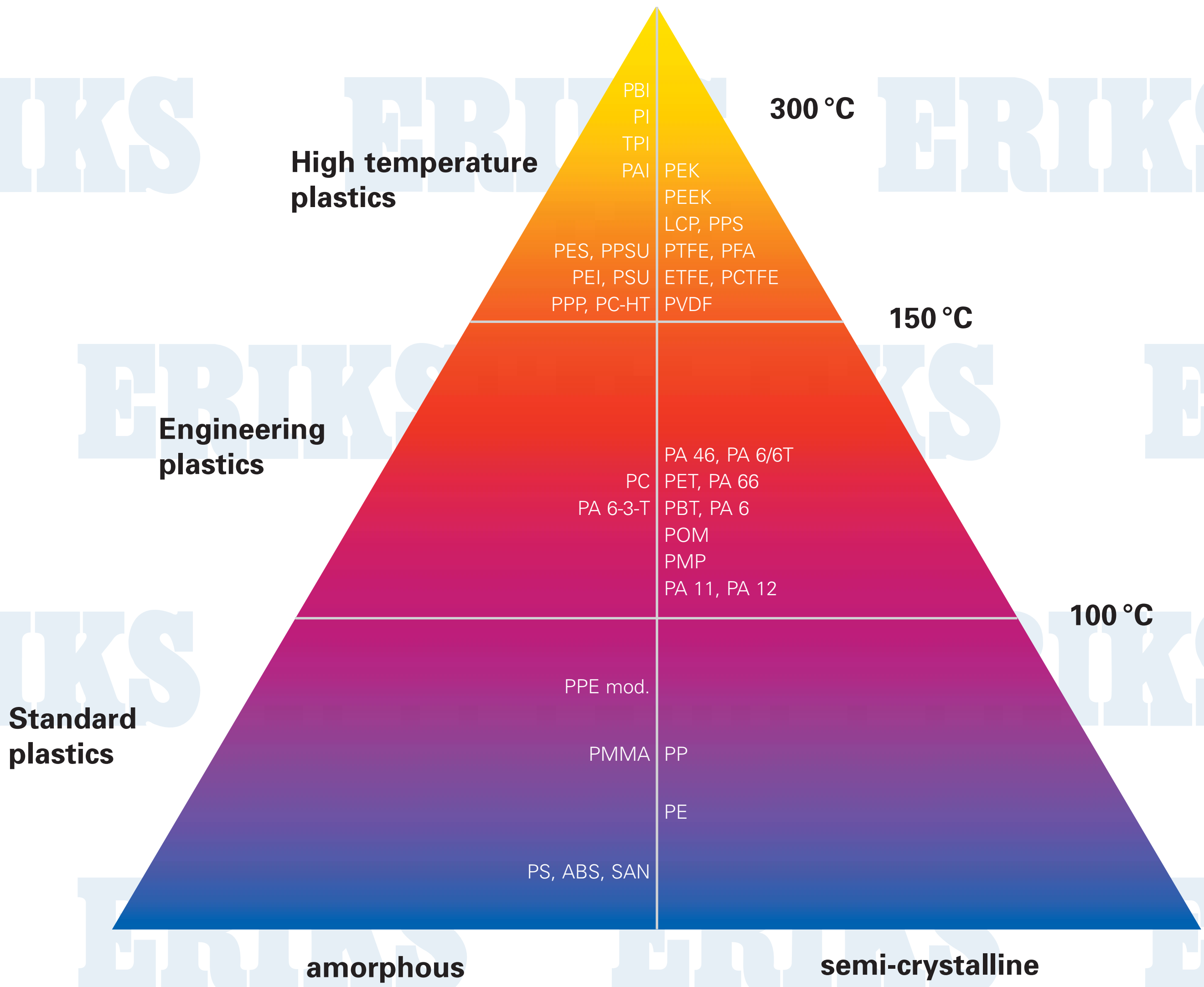
Classification of Plastics



Thermoplastic polymers can be divided into amorphous and semi-crystalline on the basis of their structure.

Polymers with an amorphous structure are normally transparent and tend to be sensitive to stress cracking. They are suitable for making precision parts due to their high dimensional stability.

Semi-crystalline plastics are opaque, mostly tough and show good or very good chemical resistance.

Plastics can also be differentiated according to their temperature resistance:

High-temperature plastics have long term service temperatures of above 150 °C and have a high level of thermo-mechanical properties.

Plastics suitable for the highest application temperatures (PI, PBI, PTFE) cannot be processed using melting processes. Production of parts is carried out by sintering.

Engineering plastics can be used permanently at temperatures between 100 °C and 150 °C. They exhibit good mechanical properties and good chemical resistance.

Standard plastics can be used permanently at temperatures below 100 °C.

The above pyramid of plastic materials shows a detailed overview of thermoplastic polymers on the basis of these criteria.

High Temperature Plastics

VESPEL® and SINTIMID (PI)
Depending upon the type, provide high strength with a low level of creep and good wear-resistance up to 300 °C in continuous use. Dimensional stability, electrical insulation, high purity, low outgassing. Suitable for thermally and mechanically stressed engineering elements and components. Inherently flame resistant.

TECATOR (PAI)
Very good physical stability low level of creep, high chemical resistance. Good wear resistance, low thermal expansion coefficient inherently flame resistant.

TECAPEEK HT (PEK)
Increased level of properties compared to TECAPEEK. Very good abrasion characteristics. Suitable for high load sliding applications. Very good chemical resistance. Inherently flame resistant.

TECAPEEK (PEEK)
Balanced profile of properties; low level of creep, high modulus of elasticity. Excellent tribological properties, especially abrasion resistance. Very good resistance to different media, FDA conformity and physiologically harmless. Very good chemical resistance. Inherently flame resistant.

TECATRON (PPS)
Chemical resistance; low level of creep, high dimensional stability due to low moisture absorption, high modulus of elasticity, inherently flame resistant.

TECASON E (PES)
Inherently flame resistant, good electrical and dielectric properties and thus well suited for use as electrical insulators. Fulfils the foodstuffs requirements.

TECASON P (PPSU)
Good impact strength, chemical resistance and resistance to hydrolysis. Inherently flame resistant. Fulfils the foodstuffs requirements.

TECASON S (PSU)
High strength, rigidity and hardness. Low moisture uptake and very good dimensional stability. Inherently flame resistant. Fulfils the foodstuffs requirements.

TECAPEI (PEI)
Very good mechanical and electrical properties. Inherently flame resistant. Fulfils the foodstuffs requirements.

TECAMAX SRP (PPP)
Stiffer and harder than other non-reinforced thermoplasts. High scratch and abrasion resistance. Good resistance against hot steam and chemicals. Outstanding mechanical properties. Low density.

TECAFLON PTFE (PTFE)
Highest chemical resistance, permanent service temperature of 260 °C. Exceptional sliding characteristics as well as excellent electrical properties. Inherently flame resistant. Fulfils the foodstuffs requirements.

TECAFLON ETFE (E/TFE)
Good kinetic friction properties, very good chemical resistance and very good mechanical properties. Inherently flame resistant. Fulfils the foodstuffs requirements.

TECAFLON PVDF (PVDF)
Very good chemical resistance, good electrical and thermal properties. Very tough even at low temperatures and good mechanical properties. Can be processed as a thermoplastic and physiologically harmless. Inherently flame resistant.

TECAMID 12 (PA 12)
Very high durability, good chemical resistance, lowest water uptake of all polyamides. Fulfils the foodstuffs requirements.

TECAMID 46 (PA 46)
Heat-stabilized, good thermal insulation. Very well suited for sliding and wearing parts which are exposed to raised temperatures. High durability.

TECAMID 66 (PA 66)
Good rigidity, hardness, wear-resistance and dimensional stability, good kinetic friction characteristics, types complying to FDA available. Fulfils the foodstuffs requirements. For parts which are exposed to higher mechanical and heat loads.

TECAMID 6 (PA 6)
Semi-crystalline thermoplastic with good damping capacity, good impact strength and high degree of toughness even at low temperatures, good wear-resistance, especially against rough frictional surfaces.

TECAST 6 (PA 6 G)
Polyamide casting material with similar properties to TECAMID 6. Production of parts with large volumes and large wall thickness possible.

TECAST 12 (PA 12 G)
Polyamide casting material with similar properties to TECAMID 12, production of parts with large volumes and large wall thickness possible.

TECARIM (PA 6 G)
Very tough polyamide 6 block copolymer. Very good strength and toughness to be used advantageously in the low temperature range. Excellent resistance to impact and abrasion, chemical resistance. Appliction specific adjustability of the material properties.

TECANAT (PC)
Amorphous, transparent material with excellent impact strength, permanent service temperature 120 °C, good mechanical strength, low level of creep and very good dimensional stability. Fulfils the foodstuffs requirements.

**TECAPET/
TECADUR PET (PET)**
Good wear properties in moist or dry surroundings, high dimensional stability due to low thermal expansion, low moisture uptake, good dielectric properties, good chemical resistance. Fulfils the foodstuffs requirements.

TECADUR PBT (PBT)
High strength and durability with good dimensional stability, good sliding and wear characteristics, high precision thanks to low water uptake, very high rigidity as well as a low thermal expansion coefficient due to glass-fibre reinforcement.

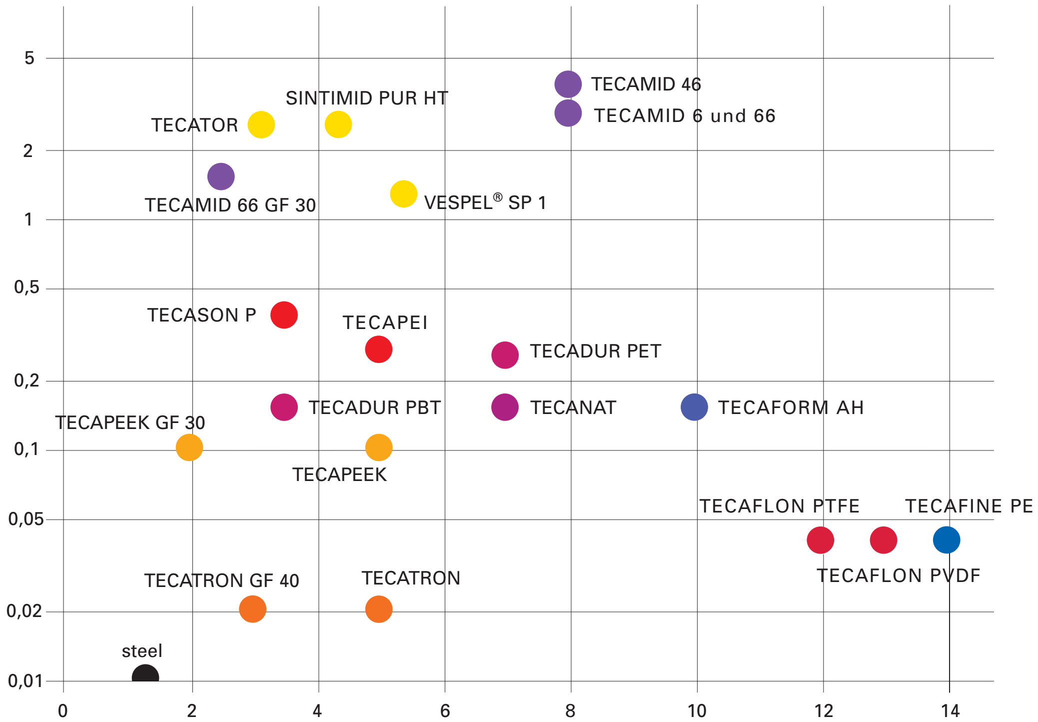
TECAFORM AH (POM-C)
Semi-crystalline POM-copolymer with good physical properties. Low moisture uptake, good fatigue strength and rigidity, very simple machine processing, good shape stability, parts with narrow tolerances. Good sliding characteristics. Fulfils the foodstuffs requirements.

TECAFORM AD (POM-H)
Slightly higher mechanical values in comparison to TECAFORM AH, very good resilience and high surface hardness, very good kinetic friction properties.

TECAFINE (PE, PP)
High chemical resistance, high degree of durability and elongation at break, low tendency to stress corrosion cracking, very low water uptake, good sliding characteristics and low abrasion.

Water Absorption

Moisture uptake until saturation in % in standard climatic conditions



Coefficient of linear thermal expansion (10^{-5} 1/k)

Polyamides show increased water absorption in comparison to other engineering plastics. This leads to dimensional changes to finished parts, to a reduction of the strength factors and also changes the electrical insulating characteristics absorption.

Modification Options

The profile of plastic properties can be modified to the required application by the specific use of fillers.

Reinforcing fibres

Glass fibres are used mainly to increase the mechanical strength, particularly tensile strength. Other values, such as compression strength and temperature-dependent dimensional stability, are also improved.

Carbon fibres may be used as an alternative to glass fibre to increase mechanical strength. Due to the lower density, higher strength values can be achieved using the same proportion by weight. Furthermore, carbon fibres improve the sliding and wear characteristics.

Colour

The incorporation of pigments and colorants into technical plastics allows individually customized colour standards to be produced (e.g. according to RAL, Pantone, etc.), although the choice of pigments with high-temperature plastics is limited.

Light stabilization

Weathering or continual exposure to high temperatures can lead to discolouration or affect the mechanical properties of many plastics. The additi on of **UV** or **thermal stabilizers** helps prevent such effects.

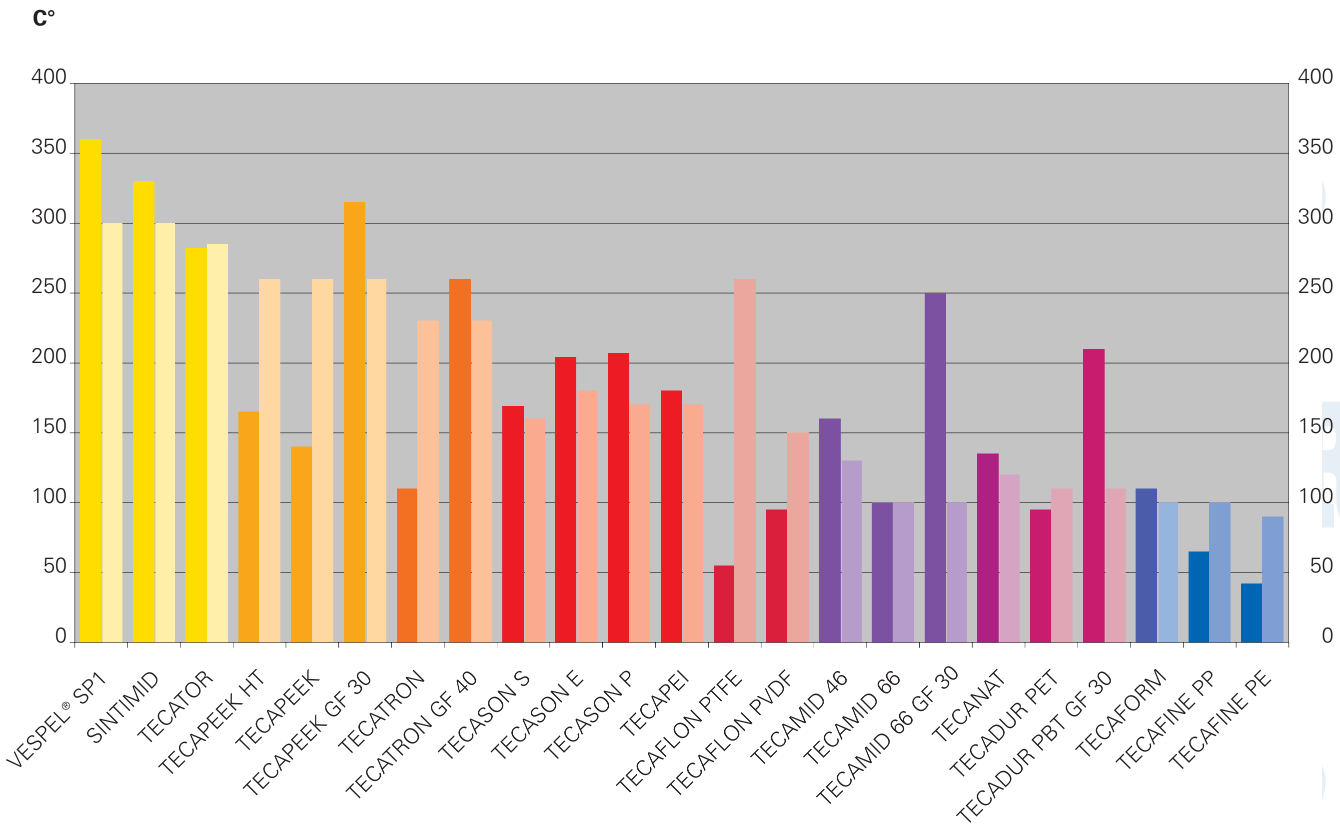
Friction and wear-reducing fillers

Graphite is pure carbon, which in a finely ground state exhibits high lubricating properties. By incorporating it uniformly into a polymer, the coefficient of friction can be lowered.

PTFE is a high temperature fluorinated polymer. Typical of this material is its remarkable non-sticking properties. Under pressure the particles from PTFE filled plastics develop a fine, sliding polymer film on the opposite material surface.

Molybdenum disulphide is used primarily as a nucleating agent and forms a uniform fine crystalline structure even when small amounts are added, with increased abrasion resistance and reduced friction.

Thermal Resistance



Left column: Heat deflection temperature according to the HDT-A procedure
Right column: long term service temperature

The thermal resistance of a plastic is characterised mainly by the heat deflection temperature and the long term service temperature.

The heat deflection temperature (HDT) is described as the temperature under which an extreme fibre elongation of 0.2 % is achieved under a specific bending stress. With the frequently used HDT-A procedure the bending stress used is 1.8 MPa.

The heat deflection temperature provides an indication of the maximum temperature in use for mechanically loaded components.

The long term service temperature represents the temperature above which material decomposition takes place due to thermal stress. It should be noted that the mechanical properties at this temperature differ considerably from those at room temperature.

Characteristic Mechanical Values

Mechanical characteristics in tensile testing

Tensile testing according to DIN EN ISO 527 serves to assess the characteristics of plastics in short-term, single-axle stressing.

Important factors for the choice of a plastic apart from the characteristics under stress and elongation are also the temperature and the time the load is applied.

- **Tensile stress** σ
  σ is the tensile force in relation to the smallest measured initial cross-section of the test specimen at every arbitrary point during the experiment.

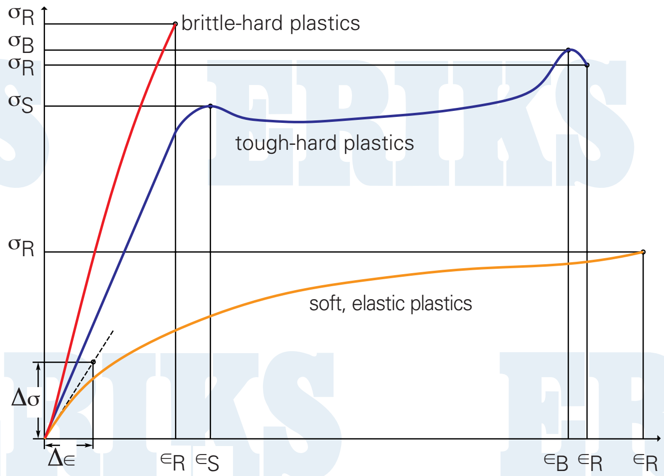
- **Tensile strength** σ_B
  σ_B is the tensile stress at maximum force.

- **Tensile strength at break** σ_R
  is the tensile stress at the moment of break.

- **Tensile strength at yield** σ_S
  is the tensile stress at which the slope of the curve describing the change of force versus length (see graph) equals zero for the first time.

- **Elongation** ϵ
  Is the change in length ΔL in relation to the original length L_0 of the specimen at every arbitrary point during the experiment. The elongation at maximum force is described as ϵ_B, the elongation at break by ϵ_R, the yield stress with ϵ_S.

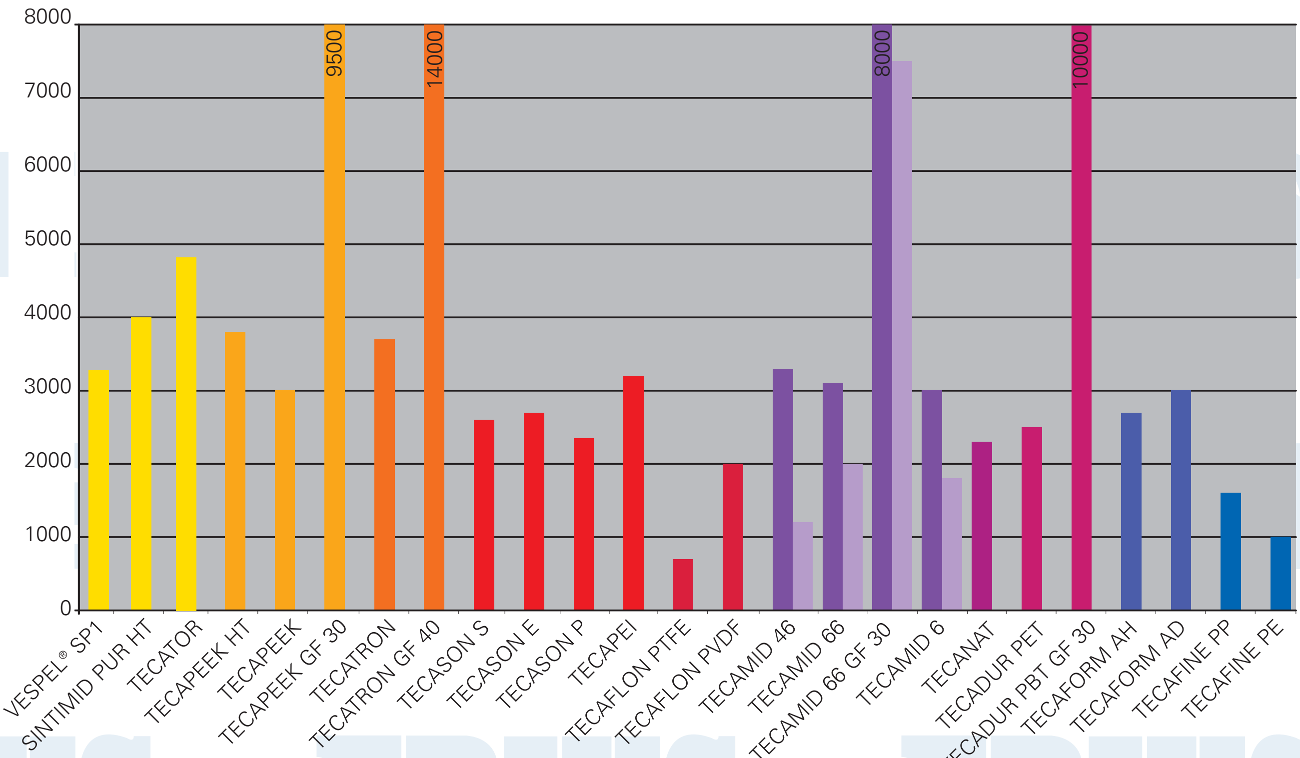
Stress σ MPa



σ_B maximum stress
σ_R tensile strength at break
σ_S tensile strength at yield
ϵ_B elongation at maximum stress
ϵ_R elongation at break
ϵ_S elongation at yield

- **Modulus of elasticity E**
  A linear relationship can only be observed in the lower range of the stress-elongation diagram for plastics. In this range Hooke's law applies, which says that the quotient of the stress and strain (modulus of elasticity) is constant.
  $E = \sigma / \epsilon$ in MPa.

Comparison of E-modulus of different plastics (room temperature) in MPa



***Left column: Dry   Right column: Moist**

Sliding and Abrasive Characteristics

Plastics have proven to be useful in various applications as sliding materials. Particularly advantageous are their dry running properties, low noise and maintenance characteristics, chemical resistance and electrical insulation.

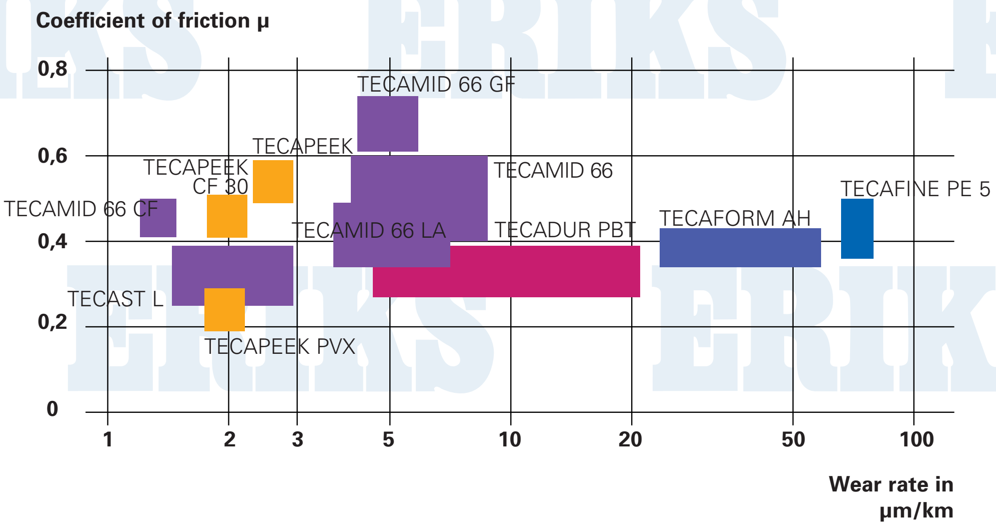
The sliding and abrasive behaviour is in this respect not a material property, but is determined specifically by the tribological system with various parameters such as material combination, surface roughness, lubricant, load, temperature, etc.

The inherently good sliding properties of plastics can also be modified to specific requirements by the use of additives (see section "Modification Options", page 6).

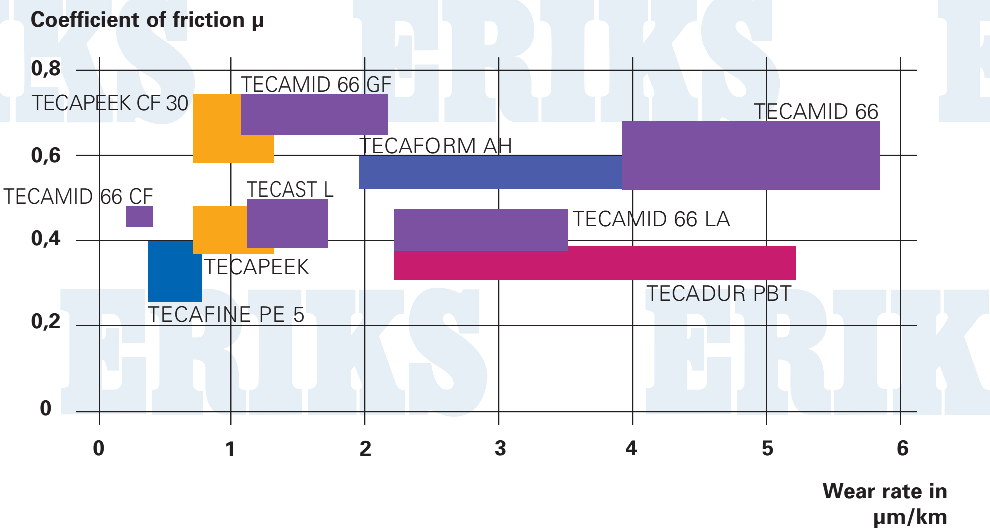
Additives such as glass fibre, glass beads or mineral fillers normally act abrasively on the sliding parts.

Cast polyamides are frequently used for slide bearing applications, which is why a large number of dynamic friction-optimised materials are also available.

If bearings also have to work at high temperatures, high speeds or strong contact pressures, high temperature plastics are used. In the following diagrams, the tribological properties of various materials used for sliding bearings with different degrees of surface roughness are compared.



Conditions:
Load: 1 MPa,
Speed: 0,5 m/s,
against steel with **R_z = 2,5 µm**



Conditions:
Load: 1 MPa,
Speed: 0,5 m/s,
against steel with **R_z = 0,2 µm**

Flame Protection Classification

High standards are set for flame protection in various plastic applications.

The classification of materials is generally made according to the "UL Standard 94” of the Underwriters’ Laboratories.

The classification into different fire classes is achieved using two test set-ups:

Horizontal flame experiment according to UL 94 HB

Material which is classified according to UL 94 HB may not exceed a maximum combustion rate of 76.2 mm/min at a wall thickness of less than 3.05 mm and with horizontal clamping. At a wall thickness of 3.05 – 12.7 mm this value should not exceed maximum 38.1 mm/min.

Materials classified in this way are easily flammable and therefore hardly meet the requirements of other flammability tests.

Vertical flame experiment according to UL 94

In this experiment a flame is held for ten seconds against the vertically clamped test specimen and then removed. The time taken for the last flame to extinguish itself is measured, and this experiment is repeated ten times. Apart from the combustion time, the classification also takes into consideration whether burning droplets are formed. The various criteria are listed in the following table.

Classification according to UL 94

	Classification according to UL 94		
	V-0	V-1	V-2
Burning time after each flaming	≤10 s	≤30 s	≤30 s
Burning time after 10 repetitions	≤50 s	≤250 s	≤250 s
Formation of burning droplets	no	no	yes

Oxygen index according to ASTM D 2863

The oxygen index of a material is defined as the minimum concentration of oxygen, expressed in vol.-% of an oxygen/nitrogen mixture, which maintains combustion of a defined material sample.

Material	DIN Description	Fire class acc. to UL 94	Oxygen index according to ASTM D 2863
VESPEL®	**PI**	V-0 (3,2 mm)	49
SINTIMID	**PI**	V-0 (3,2 mm)	44
TECATOR	**PAI**	V-0 (3,2 mm)	
TECAPEEK HT	**PEK**	V-0 (1,6 mm)	40
TECAPEEK	**PEEK**	V-0 (1,45 mm)	35
TECAFLON PTFE	**PTFE**	V-0 (3,2 mm)	95
TECATRON	**PPS**	V-0 (3,2 mm)	
TECATRON GF 40	**PPS**	V-0 (0,4 mm)	
TECASON E	**PES**	V-0 (1,6 mm)	39
TECASON P	**PPSU**	V-0 (0,8 mm)	
TECASON S	**PSU**	V-0 (4,5 mm)	32
TECAFLON PVDF	**PVDF**	V-0 (0,8 mm)	43
TECANAT	**PC**	V-2 (3,2 mm)	
TECANAT GF 30	**PC**	V-1 (3,2 mm)	
TECADUR PET	**PET**	HB (3,2 mm)	
TECALUBE	**PA 6 G**	V-2	

Radiation Resistance of Plastics

Plastics can come into contact with different types of radiation, depending upon the area of application, which affect the structure of the material.

The spectrum of electromagnetic radiation ranges from radio frequencies, with long wave-lengths, to normal daylight with short wave-length UV radiation to very short wave-length X-rays and gamma radiation.
The shorter the wave-length of the radiation the more easily it can damage the plastic.

An important characteristic value in connection with electromagnetic radiation is the dielectric loss-factor, which describes the amount of energy absorbed by the plastic.

Plastics with high dielectric loss-factors strongly heat up in an alternating electrical field and are therefore not suitable as high frequency and micro-wave insulating materials.

Ultraviolet radiation

UV-radiation from sunlight is particularly effective in unprotected open-air applications.

Plastics which are inherently resistant are to be found in the group of fluorinated polymers, e.g. unsurpassed are PTFE and PVDF. Without respective protective measures, various plastics begin to yellow and become brittle depending upon the level of irradiation.

UV protection is achieved using additives (UV stabilizers) or protective surface coatings (paints, metallization). The addition of carbon black is cost-effective, frequently used and is a very effective method.

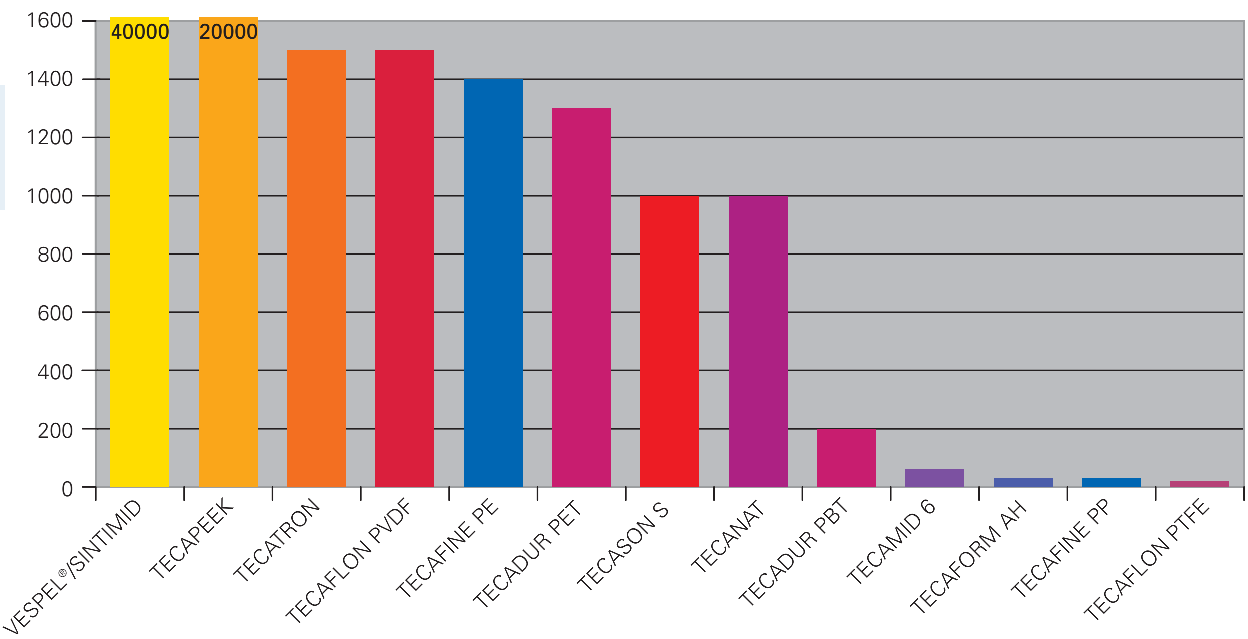
Gamma radiation resistance

Gamma and X-ray radiation are frequently to be found in medical diagnostics, radiation therapy, in the sterilisation of disposable articles and also in the testing of materials and in test instrumentation.

The high energy radiation often leads in these applications to a decrease in the expansion characteristics and the development of brittleness. The overall service life is dependent upon the total amount of radiation absorbed.

PEEK HT, PEEK, PI and the amorphous sulphur-containing polymers, for example, been proved to have very good resistance towards gamma radiation and X-rays. On the other hand, PTFE and POM are very sensitive and therefore are practically unsuitable for this purpose.

Radiation dose in kilograys (kGy) which reduces elongation by less than 25 %.



Applications in Electrical Engineering

It is often required of plastics used in electrical engineering applications that they discharge or conduct static electricity.

This is achieved by the specific addition of electrically active substances, such as special conducting carbon blacks, carbon fibre, conducting micro-fibres with nanostructures or inherently conducting substances.

Conducting carbon blacks are used only for applications outside of clean-room production, where the actual semi-conductor structures are closed and sealed.

Carbon fibres, nanotubes and inherently conducting substances are more abrasion-resistant and tend to lead to considerably less contamination.

The electrical parameters can thus be kept within better definable limits.

A material with a surface resistance of $10^6\,\Omega$ to $10^{12}\,\Omega$ is considered to discharge static electricity. If the surface resistance is smaller than $10^6\,\Omega$, then the material is said to be electrically conducting.

Material	DIN Description	Specific volume resistance in $\Omega \cdot cm$	Surface resistance in Ω
SINTIMID PAI ESD	PI	10^9 - 10^{11}	10^9 - 10^{11}
TECAPEI ESD 7	PEI	10^6 - 10^8	10^8 - 10^{10}
TECANAT ESD 7	PC	10^7 - 10^9	10^8 - 10^{10}
TECAFORM AH SD	POM-C	10^9 - 10^{11}	10^9 - 10^{11}
TECAPEEK ELS	PEEK	10^2 - 10^4	10^1 - 10^3
TECAPEEK CF 30	PEEK	10^5 - 10^7	10^5 - 10^7
TECAFLON PTFE C25	PTFE	10^2 - 10^4	10^2 - 10^4
TECAFLON PVDF AS	PVDF	10^2 - 10^4	10^2 - 10^4
TECAFLON PVDF CF 8	PVDF	10^3 - 10^5	10^5 - 10^7
TECAMID 66 CF 20	PA 66	10^2 - 10^4	10^2 - 10^4
TECAFORM AH ELS	POM-C	10^2 - 10^4	10^2 - 10^4
TECAFINE PP ELS	PP	10^3 - 10^5	10^3 - 10^5

Antistatic

Electrically conducting

Applications in Foodstuffs and Medical Technology

Special requirements are necessary in the areas of foodstuffs and medical technology with regard to physiological suitability and resistance.

FDA conformity

The American Food and Drug Administration (FDA) checks the suitability of materials with regard to their contact with foodstuffs. Raw materials, additives and properties of plastics are specified by the FDA in the "Code of Federal Regulations" CFR 21. Materials which fulfil the respective requirements are considered to conform to FDA.

Biocompatibility

The biocompatibility describes the compatibility of a material to the tissue or the physiological system of the patient. The assessment is performed using various tests according to USP (U.S. Pharmacopoeia) Class VI or according to ISO 10993.

Resistance to different sterilisation procedures and chemicals: multiple-use equipment in medical technology has to have good resistance towards preparatory procedures such as sterilisation and disinfection. These requirements are best met with high-performance plastics.

Material	DIN Description	FDA conformity*	Biocompatibility*	Sterilization	
				Hot steam 137 °C	Gamma radiation
TECAPEEK MT	PEEK	x	x	+	+
TECAFLON PTFE	PTFE	x		+	-
TECATRON MT	PPS		x	+	+
TECASON E	PES	x		o	+
TECASON P	PPSU	x	x	+	+
TECASON S	PSU	x	x	o	+
TECAFLON PVDF	PVDF	x		+	+
TECANAT	PC	x		-	+
TECAMID 66	PA 66	x		-	o
TECADUR PET	PET	x		-	+
TECAFORM AH MT	POM-C	x		o	-
TECAFINE PMP	PMP	x		-	+
TECAFINE PP	PP	x		-	+
TECAFINE PE	PE	x		-	+

x Material corresponds to FDA conformity and biocompatibility
+ Resistant
o Limited resistance
- Not resistant

* FDA conformity and biocompatibility applies to natural materials. Pigments used are checked for their suitability according to FDA regulations.

Biocompatibility is not a material specification and necessitates prior testing, if necessary special production.