Design guide

Engineering Thermoplastics

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Mitsubishi Chemical Advanced Materials

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With more than 80 years of experience, 46 branch offices in 19 countries, and a team of technical service experts, engineers, and application development managers, the Advanced Materials division of the Mitsubishi Chemical Group (MCG) is the global leader for researching, developing, and manufacturing high-performance engineered polymer materials. Our products make the world a safer place by providing solutions across many industries — Aerospace, Automotive, Renewable Energy, Advanced Fluid Management, Food & Pharma, Heavy Equipment, Linings, Medical & Life Science, Semiconductor & Electronics, Transportation.

Giving back more than we take

For the MCG Advanced Materials division, sustainability is more than just a slogan. It is woven into our company mission and underpins our corporate vision for the future.

Everything we do as a company, a partner and an industry leader is guided by the principles of the vision of our holding company Mitsubishi Chemical Group Corporation (MCGC).

It is this philosophy that allows us to fully focus on addressing global social and environmental demands, while also creating new and sustainable value for our stakeholders.

Realizing our sustainability vision means meeting our own needs without compromising the ability of future generations to meet theirs. More than ever before, we believe achieving excellence means taking decisive action in the present to lay the groundwork for an equally beneficial future.

Table of contents

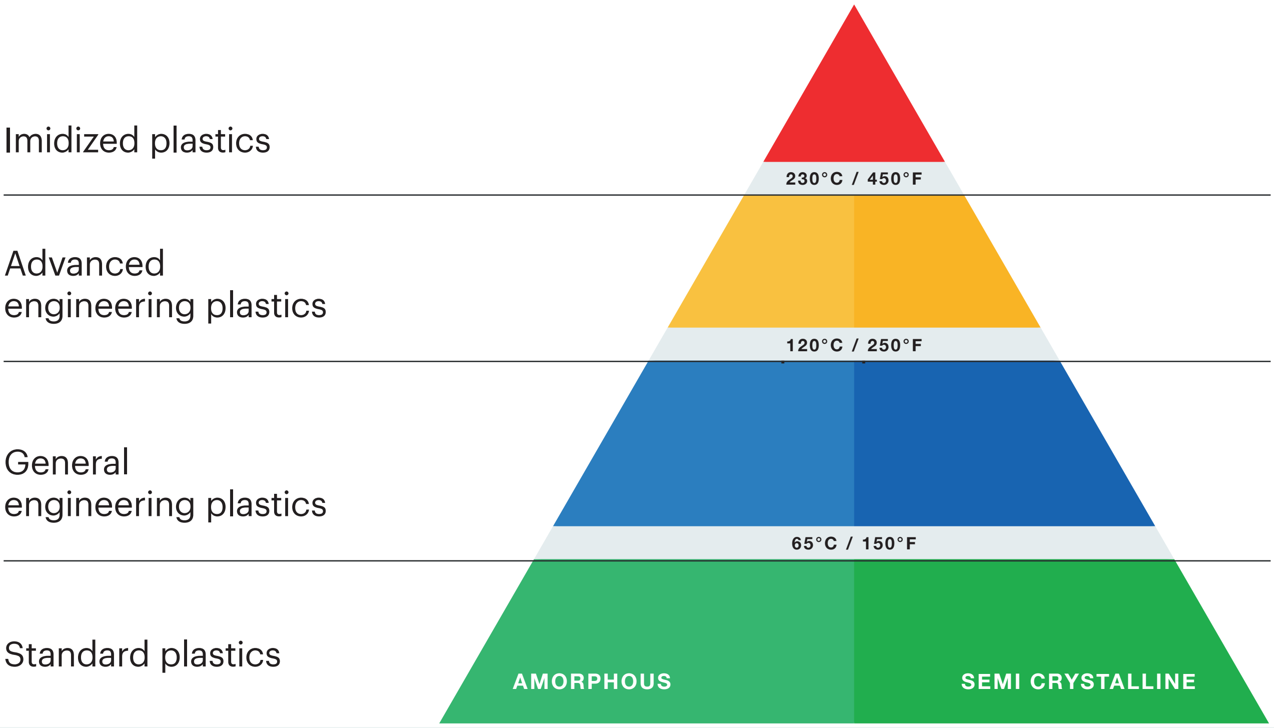
Advanced engineering plastic innovations

As a leader in the plastics industry, we continuously create new materials that outperform traditional metals and ceramics. Our materials are engineered with your industry needs in mind. Whether your needs include reduced weight, smaller carbon footprint, longer part life, higher purity, higher strength or lower costs we have a material that will bring you closer to your goals.

Designing with plastics

1

Thermoplastics materials triangle



Plastics improve components and systems

There are now more than 50 grades of machinable plastic stock shapes (sheet, rod, and tubular bar), spanning the performance/price range of both ferrous and non-ferrous metals to specialty ceramics.

A comparison of typical properties for common engineering materials is shown in *Figure 1.*

Plastics capable of long term service up to 800°F (425°C), with short term exposures to 1,000°F (540°C) are now available. As the number of material options has increased, so has the difficulty of selecting the right material for a specific application. This overview will help you to understand basic categories of plastic materials.

Why plastics?

- Reduce weight
- Improve wear life
- Eliminate lubrication
- Improve inertness
- Reduce noise
- Insulate thermally/electrically

Figure 1: Plastics vs metal — Typical properties

PROPERTIES	UNITS	NYLATRON® PA 66	DURATRON® PAI	BRONZE (SAE 660)	STEEL (A36)	ALUMINUM (1050-H18)
Density	g/cm^3	1.14	1.41	8.80	7.84	2.70
Tensile strength	MPa / psi	90 / 13,000	150 / 21,000	138 / 20,000*	250 / 36,000*	145 / 31,000*
Relative strength to weight	Steel = 1.0	2.48	3.34	0.49	1.0	1.68
Coefficient of linear thermal expansion	μin. / in. K	55	21	10	6.1	13.3
Coefficient of linear thermal expansion	μm / m. K	80	40	18	11	24

* Yield numbers given for metals

Thermoplastics and thermosets

Plastics are classified as being either thermoplastic (meltable) or thermoset (non meltable). Thermoset materials such as phenolics and epoxies were developed during the early 20th century making them some of the earliest engineering plastics. Thermoplastics soon followed with the development of nylon first as a textile but later leading to unprecedented growth of a wide range of engineering plastic chemistries. Both thermoplastic and thermoset semifinished shapes are available for machined parts, although thermoplastic stock shapes are much more widely used today. Their ease of fabrication, self-lubricating characteristics, and broad size and shape availability make thermoplastics ideal for bearing and wear parts as well as structural components.

Figure 2: Reference guide engineering plastics

	PERFORMANCE FAMILY	MATERIAL	TRADENAME	PERFORMANCE PROFILE
Imidized plastics Heat resistance to 800°F (425°C) (HDT)	Imidized	Polybenzimidazole (PBI)	Duratron® PBI	Highest heat resistance and strength to 690°F (365°C)
		Polyimide (PI)	Duratron® PI	High heat resistance and strength to 680°F (365°C) (HDT), wear resistance, dimensional stability
		Polyamide-imide (PAI)	Duratron® PAI Semitron® ESd PAI	Highest strength to 500°F (260°C), extremely low temperature toughness
Advanced engineering plastics Heat resistance to 450°F (230°C) (HDT)	Bearing & wear - high performance	Polyetheretherketone (PEEK)	Ketron® PEEK	Chemical resistance, strength, and wear resistance
		Polytetrafluoroethylene (PTFE)	Fluorosint® PTFE	Chemical resistance, dimensional stability, wear resistance
		Polyphenylene sulfide (PPS)	Techtron® PPS	Chemical resistance, dimensional stability, electrical insulating
	Structural - high performance	Polyetherimide (PEI)	Duratron® PEI	Electrical insulator, dimensional stability, heat resistance and strength to 310°F (210°C) (HDT)
		Polyphenylsulfone (PPSU)	Sultron® PPSU	High strength, steam and impact resistance
		Polysulfone (PSU)	Sultron® PSU	High strength and heat resistance to 340°F (170°C) (HDT)
General engineering plastics Heat resistance to 250°F (120°C) (HDT)	Bearing & wear - engineering	Polyethylene Terephthalate (PET)	Ertalyte® PET	Dimensional stability and wear resistance
		Polyoxymethylene (POM) - Acetal	Acetron®/Ertacetal® POM	Machinability and dimensional stability
		Polyamide (PA) - Nylon	MC™ or Nylatron®/ Ertalon® PA	Toughness, wear resistance and strength
		Ultra high molecular wt. Polyethylene (UHMW-PE)	TIVAR® UHMW-PE	Toughness and abrasion resistance
	Structural - engineering	Polycarbonate (PC)	Altron™ PC	Impact and heat resistance to 260°F (130°C) (HDT)
Standard plastics Heat resistance to 150°F (65°C) (HDT)	Standard engineering	Polypropylene (PP)	Proteus® PP	Chemical resistance, medium strength steam resistance

Basic performance understanding

Elastic behavior

The stress/strain behavior of a plastic differs from that of a metal in several respects, as seen in *Figure 3*.
This includes materials where:

- The yield stress is lower
- The yield strain is higher
- The slope of the stress/strain curve may not be constant below the yield point

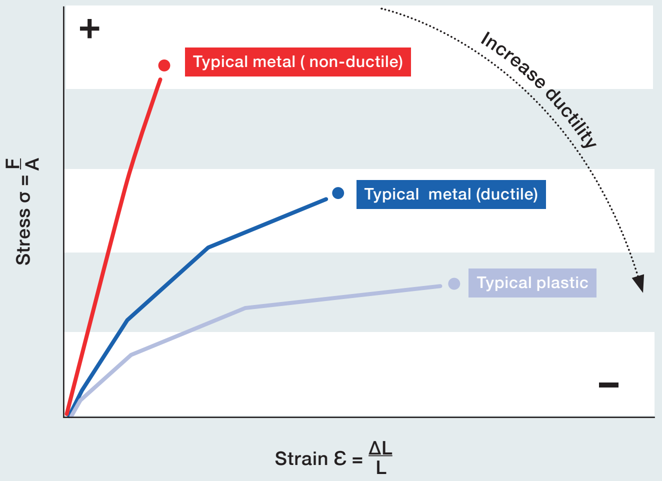
The modulus, as determined using standard tests, is generally reported as the ratio of stress to strain within the elastic portion of the stress strain curve. When designing with thermoplastics, the impact of time, temperature and strain rate generally require consideration. Plastics are considered viscoelastic meaning they exhibit both linear elasticity and time dependent deformation while under load.

To simplify design analysis, strains below 1% are assumed to remain within the elastic limits of most engineering plastics allowing for analysis based upon the assumption that the material is linearly elastic, homogeneous, and isotropic. Another common simplification is to design components so that the maximum working stress is 25% of the material's strength. Both simplifications minimize the time dependent stress/strain behavior of plastics.

Impact strength

Although a number of plastics are well suited for high impact applications, most parts made from rigid engineering plastics require minor design modifications. The relative notch sensitivity or impact resistance of plastics is commonly reported using Izod or Charpy impact strength. Materials with higher Izod/ Charpy impact strengths are more impact resistant. Tensile elongation can also provide insight into a materials ductility.

Figure 3: Stress vs strain



Even parts made from materials exhibiting high impact strength and elongation benefit from radius corners and chamfered edges (see design tip on this page).

Sharp interior corners, thread roots and grooves should be broadly radiused (0.040"/ 1 mm min.) to minimize the notch sensitivity of these materials.

Thermal properties

One should evaluate two important thermal properties when designing plastic components for elevated temperature service.

Continuous Service Temperature
This temperature represents the temperature above which significant and permanent degradation occurs with long exposure. The most commonly used criteria is the temperature at which the original tensile strength decreases by 50% after a 10 year exposure due to thermal oxidative degradation.

Heat Deflection Temperature
The temperature at which a test specimen strains under a specified load as defined in ISO 75 / ASTM D648. It is commonly interpreted as the maximum service temperature for a highly stressed, unconstrained part.

Note: The strength and stiffness of plastics can be significantly affected by relatively small changes in temperature.

Dynamic Modulus Analysis (DMA) curves can be used to predict the effects of temperature change on the modulus of a given material. DMA testing can also factor in the variable of time thereby generating isometric creep curves or apparent modulus values for a given material at a specific temperature over a specific time period.

Dimensional stability

Plastics, may expand and contract 10 times more than many metals. A material's dimensional stability is affected by temperature, moisture absorption, and stress. Assemblies, press fits, adhesive joints, and machined tolerances must reflect these differences. Certain plastics such as nylons are hygroscopic – absorbing up to 7% water (by weight, when submerged).This can result in a dimensional change of up to 2%. Plastics' inherently lower modulus of elasticity can lead to dimensional change, including part distortion during and after machining.

Using the dynamic modulus curve

Dynamic modulus data for material selection

Dynamic Modulus Analysis (DMA) curves show the elastic response (stiffness) of a material to a short duration force (load) at various temperatures. These curves are very important to design engineers who need an understanding of how a material will soften, or lose stiffness, with temperature. Consider the concept of elastic behavior. When a force (stress) is applied to an elastic material, the material stretches by a certain amount.

The modulus or stiffness of a plastic material is temperature dependent. For traditional thermoplastics, understanding this relationship between stiffness and temperature is critical. The curves detailed here show the elastic response (stiffness) of our materials across a wide temperature range. Dynamic Modulus Analysis (DMA) curves can be used to predict the effects of temperature change on a given material.

Dynamic modulus analysis data is a valuable material selection tool

How do you use DMA curves?

Suppose an application requires a highly stress part to operate at a temperature of 175°F (80°C) in a dry environment.
You are considering:
Nylatron® / Ertalon® PA66, Acetron® GP / Ertacetal® POM-C, and Ertalyte® PET.

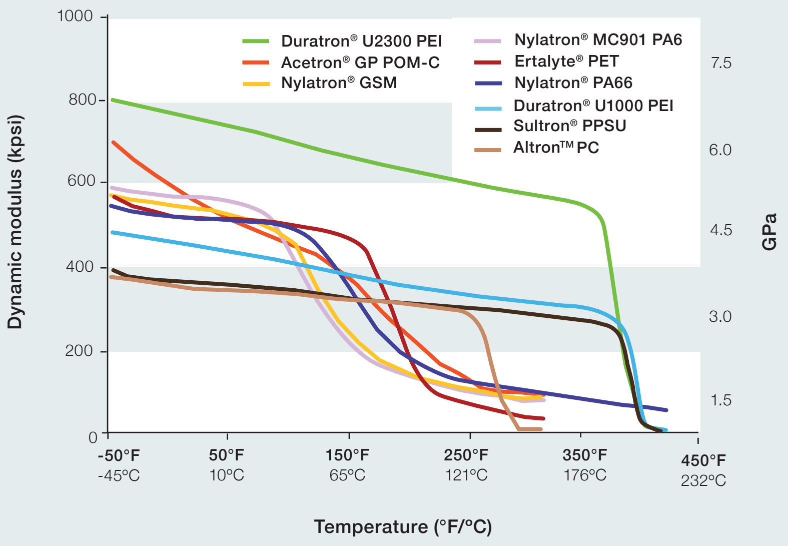
Upon reviewing each material's datasheet their strength/stiffness at room temperature appear similar. You also note that all 3 materials also have Heat Deflection Temperatures (HDTs) over 175°F (80°C). Which material will be the strongest/stiffest? (See *Figure 4*)

The stiffness between room temperature and the HDT are unknown. Using the DMA curves, you see that at 175°F (80°C), the dynamic modulus of the three materials are:

- Nylatron® PA66
  325,000 psi (2240MPa)
- Acetron® GP POM-C
  375,000 psi (2585MPa)
- Ertalyte® PET
  500,000 psi (3447MPa)

At the application temperature of 175°F (80°C), Ertalyte® PET is over 30% stiffer than Acetron® GP POM-C or Nylatron® PA66. If minimizing deflection at this temperature is important in the application, then Ertalyte® PET is the superior choice.

Figure 4: Stiffness vs. temperature (as measured by DMA)



DMA vs. creep data

When a force is applied to a perfectly elastic material, it expands until the force is removed. The material then returns back to its original length. No material is perfectly elastic, and thermoplastics are actually viscoelastic. Although Hooke's Law can be used to approximate their response to a load (the provided strain is low, generally 1% or less), the stiffness of the material will actually depend on how long the material is under load. A viscoelastic material will have a higher modulus (stiffness) when a load is applied for a short period of time than when it is applied over a long duration. This loss of stiffness under load over time is known as creep. A load which causes a minor deflection when applied for a few minutes may cause a larger deflection when left on for several days. Again, understanding creep of a thermoplastic material is important and creep data is available from Mitsubishi Chemical Advanced Materials' Technical Service Department.
technicalsupport@mcam.com

Processing differences – DMA curves

Ketron® CA30 PEEK (extruded) and Ketron® CM CA30 PEEK (compression molded) are produced with the same resin, yet yield different mechanical properties due to their processing.

Much of the difference is explained by the length and orientation of the carbon fiber during processing. In this case and most cases melt processed materials have superior mechanical properties

Figure 5: Bearing & wear advanced engineered materials

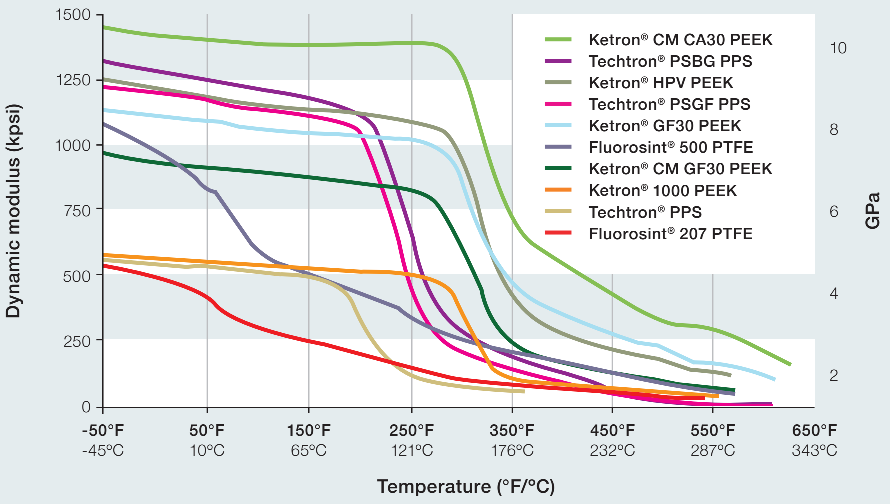


Figure 6: Imidized materials

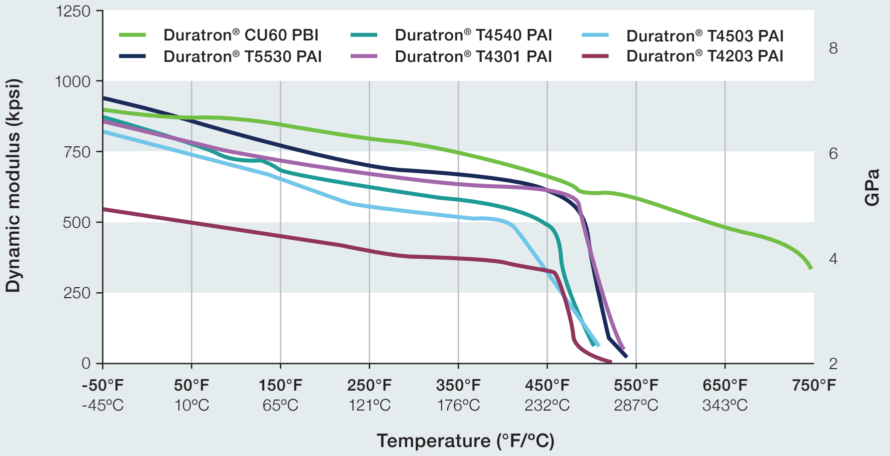
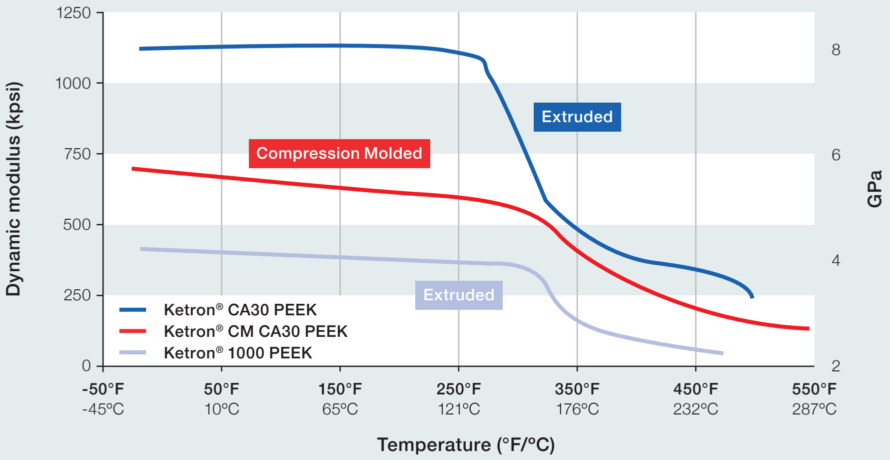
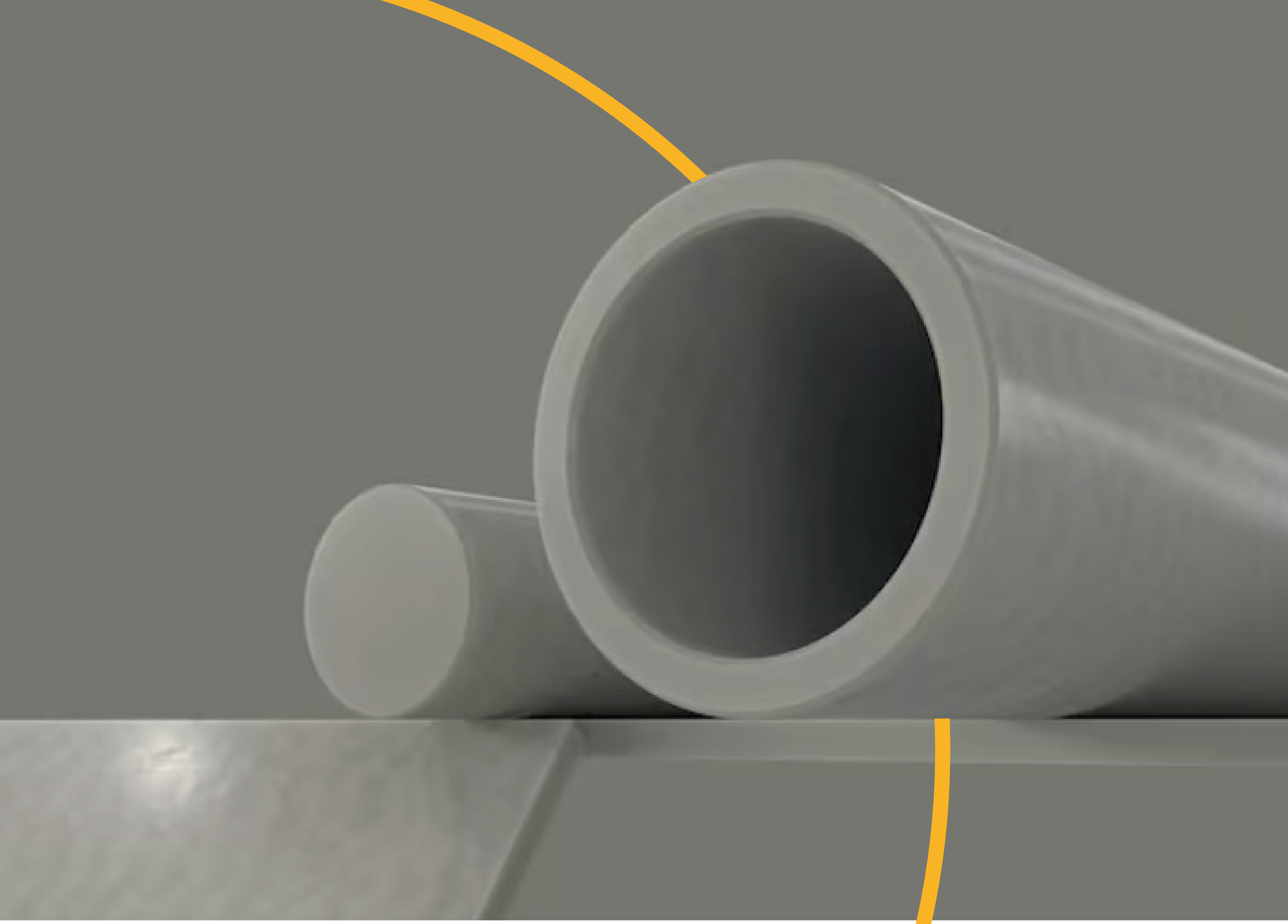


Figure 7: Stiffness vs. temperature





Our commitment to data reliability

The broadest range of engineering oriented plastics for both structural applications and bearing and wear components

Material selection

2

Advanced engineering plastics material guide

Imidized plastics

Duratron® CU60 PBI
Unfilled PBI
compression molded

Duratron® D7000 PI
Unfilled PI
compression molded

Duratron® D7015G PI
Bearing grade PI
compression molded

Duratron® T4203 PAI
Electrical grade PAI
extruded

Duratron® T4301 PAI
Bearing grade PAI
extruded

Duratron® T4501 PAI
Bearing grade PAI
compression molded

Duratron® T4503 PAI
Electrical grade PAI
compression molded

Duratron® T5530 PAI
30% Glass Filled PAI
compression molded

Semitron® ESd 520HR PAI
Static dissipative PAI
compression molded

Advanced engineering plastics

Duratron® U1000 PEI
Unfilled PEI
extruded

Fluorosint® 207 PTFE
FDA compliant Mica filled PTFE
compression molded

Fluorosint® HPV PTFE
FDA Mica filled PTFE
compression molded

Fluorosint® 500 PTFE
Mica filled PTFE
compression molded

Fluorosint® MT01 PTFE
Carbon fiber & proprietary filled PTFE
compression molded

Fluorosint® 135 PTFE
Proprietary filled PTFE
compression molded

Ketron® 1000 PEEK
Unfilled PEEK
extruded

Ketron® CA30 PEEK
30% carbon fiber filled PEEK
extruded

Ketron® GF30 PEEK
30% glass filled PEEK
extruded

Ketron® HPV PEEK
Premium, solid lubricant filled PEEK
extruded

Ketron® VMX Food Grade PEEK
Visual, metal and X-ray detectable PEEK
extruded

Sultron™ PSU
Unfilled PSU
extruded

Semitron® ESd 410C PEI
Static dissipative PEI
compression molded

Semitron® ESd 420 PEI
Static dissipative PEI
compression molded

Semitron® ESd 420V PEI
Static Dissipative PEI
compression molded

Semitron® MDS 100 PEEK
Modified PEEK
compression molded

Semitron® ESd 480 PEEK
Static dissipative PEEK
compression molded

Semitron® ESd 490HR PEEK
Static dissipative PEEK
compression molded

Semitron® ESd 500 HR PTFE
Static dissipative PTFE
compression molded

Semitron® HPV ESd PEEK
Static dissipative PEEK for wear and friction applications
extruded

Semitron® MPR 1000 PAI
Plasma resistant material
extruded and compression molded

Semitron® MP-370 PEEK
Ceramic filled modified PEEK
extruded

Techtron® 1000 PPS
Unfilled PPS
extruded

Techtron® HPV PPS
Premium, solid lubricant filled PPS
extruded

General engineering plastics

Acetron® GP / Ertacetal® C POM-C
Premium porosity-pree
POM-C
extruded

Acetron® VMX Food Grade POM-C
Visual, metal and X-ray
detectable POM-C
extruded

Semitron® ESd 225 POM
Static dissipative POM
extruded

Acetron® / Ertacetal® H POM-H
Unfilled POM-H
extruded

Acetron® AF Blend / Ertacetal® H-TF POM-H
PTFE filled POM-H
extruded

Nylatron® / Ertalon® 4.6
Heat resistant PA46
extruded

Nylatron® MC907 / Ertalon® 6PLA PA6
FDA compliant,
unfilled PA6
cast

Nylatron® GSM PA6
MoS_2 filled PA6
cast

Nylatron® NSM PA6
Premium, solid lubricant
filled PA6
cast

Nylatron® 703 XL PA6
Premium, solid lubricant
filled PA6
cast

Nylatron® 101/ Ertalon® 66 SA PA66
Unfilled PA66
extruded

Nylatron® / Ertalon® 66 GF30 PA66
30% glass filled PA66
extruded

Nylatron® GS PA66
MoS_2 Filled PA66
extruded

Ertalyte® PET
Semi-Crystalline PET
extruded

Ertalyte® TX PET
Premium, solid lubricant
filled PET-P
extruded

Quicksilver® UHMW-PE Premium Truck Liner
Premium, virgin UHMW-PE
extruded

TIVAR® 1000 Virgin UHMW-PE
Natural UHMW-PE
Compression molded/
ram extrusion

TIVAR® 1000 UHMW-PE colors
Colored UHMW-PE
compression molded/
ram extrusion

TIVAR® ESD / TIVAR® 1000 antistatic UHMW-PE
Static Dissipative UHMW-PE
compression molded

TIVAR® 1000 EC UHMW-PE
Natural UHMW-PE
Compression molded/ram
extruded

TIVAR® ECO ESD / TIVAR® ECO black antistatic UHMW-PE
Premium re-processed
industrial UHMW-PE,
antistatic and electrostatic
dissipative
compression molded

TIVAR® 88 UHMW-PE
Modified UHMW-PE
compression molded

TIVAR® 88 W/BurnGuard UHMW-PE
Modified UHMW-PE
compression molded

TIVAR® CERAM P UHMW-PE
Modified UHMW-PE
compression molded

TIVAR® CleanStat™ UHMW-PE
FDA/EU Food compliant,
dissipative UHMW-PE
compression molded

TIVAR® DrySlide UHMW-PE
Modified UHMW-PE
compression molded

TIVAR® H.O.T. UHMW-PE
Modified UHMW-PE
compression molded

TIVAR® HPV UHMW-PE
Bearing grade UHMW-PE
with built in dry lubricant
compression molded, ram
extrusion

TIVAR® Oil Filled UHMW-PE
Modified UHMW-PE
compression molded

TIVAR® Polysteel UHMW-PE
Special UHMW-PE grade
for paper mill applications
compression molded

TIVAR® SuperPlus UHMW-PE
Wear optimized, partially
cross-linked UHMW-PE
compression molded

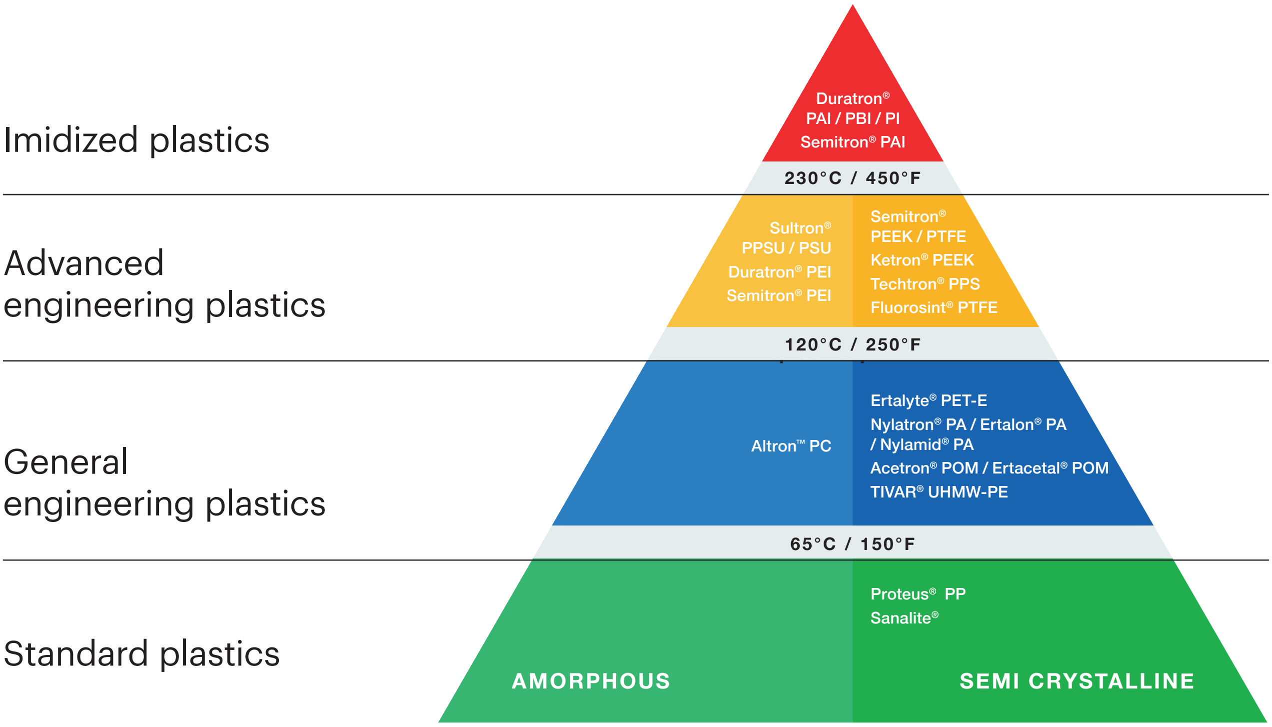
TIVAR® VMX Food Grade UHMW-PE
Premium visual, metal and
x-ray detectable UHMW-PE
food grade
compression molded, ram
extrusion

Altron™ PC
Unfilled PC
extruded

Standard plastics

Proteus® White Homopolymer PP White
Polypropylene extruded/
compression molded

Thermoplastics materials triangle



Material selection outline

01 APPLICATION: What is the primary function of the part?

☐ Structural
If structural, start by choosing a material from the left side or top of the triangle.

☐ Bearing and wear
If bearing and wear, choose a material from the right side or top of the triangle.

02 TEMPERATURE: What is the maximum "No Load" continuous service temperature (in air)?

Continuous use temp. ________________________

Also consider a material's heat deflection temperature (HDT) when selecting a material. Travel up and down the triangle to find a family of materials that offers the ideal temperature resistance.

03 LOAD: Determine the pressure or stress of the application required at temperature.

Working stress required ______________________

Max working stress of a material is estimated using compressive strength, DMA, and creep data along with a safety factor.

04 CHEMICALS: What chemicals will be encountered during service/cleaning?

☐ Strong acids (pH 1-3)
☐ Hot H_2O or steam
☐ Strong alkalies (pH 9 -14)
☐ Chlorine (aqueous)

Semi-crystalline materials (right side) as a general rule offer improved chemical resistance vs. amorphous materials. If on left side of the triangle, you may need to move to semi-crystalline side for improved chemical resistance.

05 FOR BEARING and WEAR APPLICATIONS: To determine the LPV: multiply the pressure by the velocity.

Limiting PV = P(psi / MPa) x V (FPM/ m/s) = _______
Also, choose a material with the lowest wear factor (k) to ensure optimum wear performance. Consider materials with a LPV higher than the calculated value.

06 COMPLIANCE: NSF, FDA, 3A Dairy, USP VI, EU10/2011 etc.

☐ Yes ☐ No
For food applications, consider FDA or EU10/2011 compliant materials. For medical applications, consider our biocompatible Life Science Grade (LSG) materials. Please consult our experts and services teams.

07 DIMENSIONAL STABILITY: Is this important?

☐ Yes ☐ No
Consider a material with a lower CLTE (Coefficient of Linear Thermal Expansion). Materials higher on the triangle offer improved stability versus temperature.

08 IMPACT: Is toughness or impact resistance critical in use?

Consider Izod/Charpy Impact __________________
A higher impact value means improved toughness. Also, consider designs with radiused corners.

09 SIZE: What size stock shape is required for machining?

☐ Rod ☐ Sheet ☐ Tube ☐ Other

Contact Mitsubishi Chemical Advanced Materials for rod, sheet, tube and stock shape availability.

10 RELATIVE COST: What materials meet performance requirements and offer the best value?

FINALLY: Remember to use the proper Mitsubishi Chemical Advanced Materials name call-out on specification, to ensure quality and consistency in your material.

ASTM data

Advanced Engineering Plastics

		ASTM / QTM test method	Units	Duratron® CU60 PBI	Duratron® D7000 PI	Duratron® D7015G PI	Duratron® T4203 PAI	Duratron® T4503 PAI	Duratron® T4301 PAI	Duratron® T4501 PAI	Duratron® T5530 PAI	Semitron® ESd 520HR PAI
MECHANICAL												
1	Specific gravity	ASTM D792	-	1.30	1.40	1.45	1.41	1.40	1.45	1.45	1.61	1.58
2	Tensile strength, ultimate	ASTM D638	psi	16,000	16,000	11,000	20,000	16,000	15,000	9,000	11,500	10,000
3	Elongation at break	ASTM D638	%	2	4	3	10	3	3	3	3	2
4	Tensile modulus	ASTM D638	ksi	850	583	650	600	500	900	500	900	800
5	Flexural strength	ASTM D790	psi	32,000	20,000	16,500	24,000	18,000	23,000	12,000	20,000	17,000
6	Compressive strength	ASTM D695	psi	50,000	24,000	25,000	24,000	22,000	22,00	20,000	27,000	29,000
7	Izod impact, notched	ASTM D256	ft-lb/in	0.50	1.40	0.80	2.00	1.50	0.80	0.50	0.70	0.80
TRIBOLOGICAL												
8	Coefficient of friction (dynamic)	QTM 55007	-	0.24	0.23	0.25	0.35	0.30	0.20	0.20	0.20	0.24
9	Limiting pressure velocity	QTM 55007	psi-ft/ min	37,500	32,500	40,000	12,000	4,000	40,000	22,500	20,000	27,000
10	K (wear) factor, x 10^{-10}	QTM 55010	in^3-min/ ft-lb-hr	60	50	10	35	500	10	150	-	300
11	Sand slurry	ASTM D4020	-	-	-	-	-	-	-	-	-	-
DIMENSIONAL STABILITY												
12	CLTE (-40 - 300°F)	ASTM E831	µin/ in-°F	13	27	25	21	15	14	20	26	28
13	Water absorption at saturation in water	ASTM D570	%	5	1.3	3	1.7	1.7	1.5	1.5	1.5	4.6
THERMAL												
14	Heat deflection temperature at 1.8 MPa (264 psi)	ASTM D648	°F	800	680	690	532	532	534	534	520	520
15	Maximum service temperature, air	-	°F	600	580	580	500	500	500	500	500	500
ELECTRICAL												
16	Dielectric strength	ASTM D149	kV/in	550	700	186	580	600	-	-	700	475
17	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E12	10E12	10E3	10E15	10E12	10E12	10E12	10E12	10E9- 10E11
CHEMICAL RESISTANCE												
18	Acids, weak	-	-	L	A	A	A	A	A	A	A	A
19	Acids, strong (pH 1-3)	-	-	L	U	A	L	L	L	L	L	L
20	Alkalies, weak	-	-	L	U	A	L	L	L	L	L	L
21	Alkalies, strong (pH 11-14)	-	-	U	U	A	U	U	U	U	U	U
22	Hydrocarbons - aromatic	-	-	A	U	U	A	A	A	A	A	A
23	Hydrocarbons - aliphatic	-	-	A	U	U	A	A	A	A	A	A
24	Ketones, esters	-	-	A	U	U	A	A	A	A	A	A
25	Chlorinated solvents	-	-	A	U	U	A	A	A	A	A	A
26	Alcohols	-	-	A	U	A	A	A	A	A	A	A
27	Inorganic salt solutions	-	-	A	A	A	A	A	A	A	A	A
28	Hot Water / steam	-	-	L	L	L	L	L	L	L	L	L

A = Acceptable service | L = Limited service | U = Unacceptable

ASTM data

Advanced Engineering Plastics

		ASTM / QTM test method	Units	Duratron® U1000 PEI	Fluorosint® 207 PTFE	Fluorosint® HPV PTFE	Fluorosint® 500 PTFE	Fluorosint® MT-01 PTFE	Fluorosint® 135 PTFE	Ketron® 1000 PEEK	Ketron® CA30 PEEK	Ketron® GF30 PEEK
MECHANICAL												
1	Specific gravity	ASTM D792	-	1.28	2.30	2.06	2.32	2.27	1.91	1.31	1.41	1.51
2	Tensile strength, ultimate	ASTM D638	psi	17,000	1,500	1,450	1,000	2,100	1,300	16,000	19,000	14,000
3	Elongation at break	ASTM D638	%	60	50	90	30	40	3	40	5	2
4	Tensile modulus	ASTM D638	ksi	500	250	210	300	326	370	630	1,100	1,000
5	Flexural strength	ASTM D790	psi	20,000	2,000	2,500	2,200	4,000	2,500	25,000	25,750	23,000
6	Compressive strength	ASTM D695	psi	22,000	3,800	3,000	4,000	3,400	7,000	20,000	29,000	22,000
7	Izod impact, notched	ASTM D256	ft-lb/in	0.50	1.00	1.80	0.90	-	0.50	0.60	1.03	0.80
TRIBOLOGICAL												
8	Coefficient of friction (dynamic)	QTM 55007	-	0.42	0.10	0.15	0.15	0.18	0.15	0.32	0.20	-
9	Limiting pressure velocity	QTM 55007	psi-ft/ min	1,875	8,000	20,000	8,000	4,500	14,300	8,500	25,000	-
10	K (wear) factor, x 10^{-10}	QTM 55010	in^3-min/ ft-lb-hr	2,900	85	38	600	200	32	375	150	-
11	Sand slurry	ASTM D4020		-	-	-	-	-	-	-	-	-
DIMENSIONAL STABILITY												
12	CLTE (-40 - 300°F)	ASTM E831	µin/ in-°F	31	57	49	25	30	25	26	10	12
13	Water absorption at saturation in water	ASTM D570	%	1.25	0.2	0.43	0.3	-	0.3	0.5	0.3	0.3
THERMAL												
14	Heat deflection temperature at 1.8 MPa (264 psi)	ASTM D648	°F	400	210	180	270	200	220	320	518	450
15	Maximum service temperature, air	-	°F	340	500	500	500	600	500	480	482	480
ELECTRICAL												
16	Dielectric strength	ASTM D149	kV/in	830	-	-	-	-	-	-	32	500
17	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E12	-	-	-	-	-	-	10E4	10E12
CHEMICAL RESISTANCE												
18	Acids, weak	-	-	A	A	A	A	A	A	A	A	A
19	Acids, strong (pH 1-3)	-	-	L	A	U	A	L	A	L	U	L
20	Alkalies, weak	-	-	L	A	L	A	A	A	L	A	A
21	Alkalies, strong (pH 11-14)	-	-	U	A	U	A	A	A	U	U	A
22	Hydrocarbons - aromatic	-	-	A	U	A	U	L	U	A	U	U
23	Hydrocarbons - aliphatic	-	-	A	U	A	U	A	U	A	L	A
24	Ketones, esters	-	-	A	U	A	U	U	U	A	U	L
25	Chlorinated solvents	-	-	A	U	L	U	U	U	A	U	A
26	Alcohols	-	-	A	A	L	A	L	A	A	A	A
28	Inorganic salt solutions	-	-	A	A	A	A	A	A	L	A	A
29	Hot Water / steam	-	-	L	L	L	L	A	A	L	A	L

A = Acceptable service | L = Limited service | U = Unacceptable

ASTM data

Advanced Engineering Plastics

		ASTM / QTM test method	Units	Ketron® HPV PEEK	Ketron® VMX Food Grade PEEK	Sultron® PSU	Semitron® ESd 410C PEI	Semitron® ESd 420 PEI	Semitron® ESd 420V PEI	Semitron® MDS 100 PEEK	Semitron® ESd 480 PEEK	Semitron® ESd 490HR PEEK
	MECHANICAL											
1	Specific gravity	ASTM D792	-	1.44	1.45	1.24	1.41	1.34	1.51	1.51	1.47	1.50
2	Tensile strength, ultimate	ASTM D638	psi	11,000	15,000	10,200	9,000	11,500	10,000	14,700	14,500	14,000
3	Elongation at break	ASTM D638	%	2	6	30	2	2	1.5	1.5	1.5	2.3
4	Tensile modulus	ASTM D638	ksi	850	600	390	850	640	910	1,500	940	940
5	Flexural strength	ASTM D790	psi	27,500	23,000	15,000	12,000	14,500	15,800	20,500	21,000	21,000
6	Compressive strength	ASTM D695	psi	20,000	20,000	13,000	19,500	23,800	22,300	24,400	26,500	26,000
7	Izod impact, notched	ASTM D256	ft-lb/in	0.70	1.00	1.30	0.80	1.00	0.50	0.40	1.00	1.00
	TRIBOLOGICAL											
8	Coefficient of friction (dynamic)	QTM 55007	-	0.21	0.32	-	0.18	0.28	-	-	0.20	0.20
9	Limiting pressure velocity	QTM 55007	psi-ft/ min	20,000	12,000	-	12,000	9,500	-	-	36,000	17,000
10	K (wear) factor, x 10^{-10}	QTM 55010	in^3-min/ ft-lb-hr	100	350	-	125	100	-	-	200	-
11	Sand slurry	ASTM D4020	-	-	-	-	-	-	-	-	-	-
	DIMENSIONAL STABILITY											
12	CLTE (-40 - 300°F)	ASTM E831	µin/ in-°F	17	25	31	18	19,5	15	11	17	28
13	Water absorption at saturation in water	ASTM D570	%	0.3	0.21	0.6	1.1	2.9	1.4	0.58	1.65	1.65
	THERMAL											
14	Heat deflection temperature at 1.8 MPa (264 psi)	ASTM D648	°F	383	320	340	410	410	420	410	500	500
15	Maximum service temperature, air	-	°F	482	480	300	338	340	340	-	475	475
	ELECTRICAL											
16	Dielectric strength	ASTM D149	kV/in	-	-	425	-	-	-	-	-	-
17	Surface resistivity	EOS/ESD S11.11	ohm/sq	-	-	10E12	10E3 - 10E5	10E5- 10E8	10E5- 10E8	10E12	10E5- 10E8	10E9- 10E11
	CHEMICAL RESISTANCE											
18	Acids, weak	-	-	A	A	A	A	A	A	A	A	A
19	Acids, strong (pH 1-3)	-	-	L	U	L	L	A	L	L	L	L
20	Alkalies, weak	-	-	A	A	A	A	A	A	A	A	A
21	Alkalies, strong (pH 11-14)	-	-	A	U	A	A	A	A	A	A	U
22	Hydrocarbons - aromatic	-	-	U	U	A	U	U	U	U	U	U
23	Hydrocarbons - aliphatic	-	-	A	L	A	A	U	A	A	A	A
24	Ketones, esters	-	-	L	U	A	L	U	L	L	L	L
25	Chlorinated solvents	-	-	A	U	A	A	U	A	A	A	A
26	Alcohols	-	-	A	A	A	A	A	A	A	A	A
27	Inorganic salt solutions	-	-	A	A	A	A	A	A	A	A	A
28	Hot Water / steam	-	-	L	L	A	L	L	L	L	L	L

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ASTM data

Advanced Engineering Plastics

		ASTM / QTM test method	Units	Semitron® ESd 500 HR PTFE	Semitron® HPV ESd PEEK	Semitron® MPR-1000 PAI	Semitron® MP-370 PEEK	Techtron® 1000 PPS	Techtron® HPV PPS
MECHANICAL									
1	Specific gravity	ASTM D792	-	2.30	1.46	1.48	1.51	1.35	1.43
2	Tensile strength, ultimate	ASTM D638	psi	1,500	8,600	15,000	11,500	13,500	10,900
3	Elongation at break	ASTM D638	%	50	4	5	2	15	4
4	Tensile modulus	ASTM D638	ksi	250	775	1000	640	500	540
5	Flexural strength	ASTM D790	psi	2,200	15,000	25,000	16,750	21,000	10,500
6	Compressive strength	ASTM D695	psi	3,800	17,500	24,000	18,200	21,500	15,500
7	Izod impact, notched	ASTM D256	ft-lb/in	1.00	1.00	1.30	0.40	0.60	1.40
TRIBOLOGICAL									
8	Coefficient of friction (dynamic)	QTM 55007	-	0.10	-	-	-	0.40	0.20
9	Limiting pressure velocity	QTM 55007	psi-ft/min	6,000	-	6,000	2,200	3,000	8,750
10	K (wear) factor, x 10^{-10}	QTM 55010	in^3-min/ft-lb-hr	30	-	-	-	2400	62
11	Sand slurry	ASTM D4020	-	-	-	-	-	-	-
DIMENSIONAL STABILITY									
12	CLTE (-40 - 300°F)	ASTM E831	µin/in-°F	57	35	15	25	28	33
13	Water absorption at saturation in water	ASTM D570	%	2	0.18	3.4	0.5	0.03	0.09
THERMAL									
14	Heat deflection temperature at 1.8 MPa (264 psi)	ASTM D648	°F	210	383	534	300	250	240
15	Maximum service temperature, air	-	°F	500	482	-	-	-	500
ELECTRICAL									
16	Dielectric strength	ASTM D149	kV/in	-	-	570	375	540	500
17	Surface resistivity	EOS/ESD S11.11	ohm/sq	-	10E5-10E8	10E12	10E12	10E12	10E12
CHEMICAL RESISTANCE									
18	Acids, weak	-	-	A	A	A	A	A	A
19	Acids, strong (pH 1-3)	-	-	A	L	L	L	L	L
20	Alkalies, weak	-	-	A	A	L	A	A	L
21	Alkalies, strong (pH 11-14)	-	-	U	A	U	A	A	U
22	Hydrocarbons - aromatic	-	-	U	U	A	U	U	A
23	Hydrocarbons - aliphatic	-	-	U	A	A	A	A	A
24	Ketones, esters	-	-	L	L	A	L	L	A
25	Chlorinated solvents	-	-	U	A	A	A	A	A
26	Alcohols	-	-	U	A	A	A	A	A
28	Inorganic salt solutions	-	-	A	A	A	A	A	A
29	Hot Water / steam	-	-	L	L	L	L	L	L

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ASTM data

General Engineering Plastics

		ASTM / QTM test method	Units	Acetron® GP POM-C/ Ertacetal® C POM-C	Acetron® VMX Food Grade POM-C	Semitron® ESd 225 POM-C	Acetron® POM-H / Ertacetal® H POM-H	Acetron® AF Blend POM-H / Ertacetal® H-TF POM-H	Nylatron® 4.6 PA4.6 / Ertalon® 4.6 PA4.6	Nylatron® MC® 907 PA6 / Ertalon® 6PLA PA6	Nylatron® GSM PA6	Nylatron® NSM PA6
	MECHANICAL											
1	Specific gravity	ASTM D792	-	1.41	1.47	1.33	1.41	1.50	1.19	1.15	1.16	1.15
2	Tensile strength, ultimate	ASTM D638	psi	9,500	9,000	5,400	11,000	8,000	15,000	12,000	11,000	11,000
3	Elongation at break	ASTM D638	%	30	15	15	30	15	25	20	30	20
4	Tensile modulus	ASTM D638	ksi	400	415	200	450	435	470	400	400	410
5	Flexural strength	ASTM D790	psi	12,000	12,000	7,300	13,000	12,000	17,000	16,000	16,000	16,000
6	Compressive strength	ASTM D695	psi	13,500	13,200	8,000	15,000	14,000	16,000	15,000	14,000	14,000
7	Izod impact, notched	ASTM D256	ft-lb/in	1.00	0.80	1.50	1.00	0.70	0.60	0.40	0.50	0.50
	TRIBOLOGICAL											
8	Coefficient of friction (dynamic)	QTM 55007	-	0.25	0.30	0.29	0,.25	0.19	-	0.20	0.20	0.18
9	Limiting pressure velocity	QTM 55007	psi-ft/ min	2,700	4,000	2,000	2,700	8,300	2,700	3,000	3,000	15,000
10	K (wear) factor, x 10^{-10}	QTM 55010	in^3-min/ ft-lb-hr	200	400	30	200	60	100	100	90	12
	DIMENSIONAL STABILITY											
11	CLTE (-40 - 300°F)	ASTM E831	µin/ in-°F	54	71	93	47	50	50	50	50	55
12	Water absorption at saturation in water	ASTM D570	%	0.9	-	8	0.9	1	7	7	7	7
	THERMAL											
13	Heat deflection temperature at 1.8 MPa (264 psi)	ASTM D648	°F	220	280	225	250	244	320	200	200	200
14	Maximum service temperature, air	-	°F	180	180	210	180	450	210	200	220	-
	ELECTRICAL											
15	Dielectric strength	ASTM D149	kV/in	420	-	-	450	400	-	500	400	400
16	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E12	10E12	10E8- 10E9	10E12	10E12	10E12	10E12	10E12	10E12
	CHEMICAL RESISTANCE											
17	Acids, weak	-	-	L	L	L	L	L	L	L	L	L
18	Acids, strong (pH 1-3)	-	-	A	A	L	L	A	L	U	L	U
19	Alkalies, weak	-	-	A	A	A	A	A	A	L	A	L
20	Alkalies, strong (pH 11-14)	-	-	A	A	A	A	A	A	U	A	U
21	Hydrocarbons - aromatic	-	-	U	U	U	L	U	A	A	A	A
22	Hydrocarbons - aliphatic	-	-	U	U	A	L	U	A	A	A	A
23	Ketones, esters	-	-	U	U	L	U	U	A	A	A	A
24	Chlorinated solvents	-	-	U	U	A	L	U	A	L	A	L
25	Alcohols	-	-	A	A	A	A	A	A	L	A	L
26	Inorganic salt solutions	-	-	A	A	A	A	A	A	A	A	A
27	Hot water / steam	-	-	L	L	L	L	L	A	L	A	L

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ASTM data

General Engineering Plastics

		ASTM / QTM test method	Units	Nylatron® 703 XL PA6	Nylatron® 101 PA66 / Ertalon® 66 SA PA66	Nylatron® GF30 PA66 / Ertalon® 66 GF30 PA66	Nylatron® GS PA66	Ertalyte® PET	Ertalyte® TX PET	Altron™ PC
MECHANICAL										
1	Specific gravity	ASTM D792	-	1.11	1.15	1.29	1.16	1.41	1.44	1.20
2	Tensile strength, ultimate	ASTM D638	psi	9,000	12,000	13,500	12,500	12,400	10,500	10,500
3	Elongation at break	ASTM D638	%	15	50	5	25	20	5	100
4	Tensile modulus	ASTM D638	ksi	400	425	675	480	460	500	320
5	Flexural strength	ASTM D790	psi	13,000	15,000	21,000	17,000	18,000	14,000	13,000
6	Compressive strength	ASTM D695	psi	10,000	12,500	18,000	16,000	15,000	15,250	11,500
7	Izod impact, notched	ASTM D256	ft-lb/in	0.70	0.60	-	0.50	0.50	0.40	1.50
TRIBOLOGICAL										
8	Coefficient of friction (dynamic)	QTM 55007	-	0.14	0.25	-	0.20	0.20	0.19	-
9	Limiting pressure velocity	QTM 55007	psi-ft/min	17,000	2,700	-	3,000	2,800	6,000	-
10	K (wear) factor, x 10^{-10}	QTM 55010	in^3-min/ft-lb-hr	26	80	-	90	60	35	-
DIMENSIONAL STABILITY										
11	CLTE (-40 - 300°F)	ASTM E831	µin/in-°F	49	55	20	40	33	45	39
12	Water absorption at saturation in water	ASTM D570	%	7	7	5.5	7	0.9	0.47	0.4
THERMAL										
13	Heat deflection temperature at 1.8 MPa (264 psi)	ASTM D648	°F	200	200	400	200	240	180	290
14	Maximum service temperature, air	-	°F	210	220	220	300	-	-	210
ELECTRICAL										
15	Dielectric strength	ASTM D149	kV/in	-	400	350	350	385	533	400
16	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E11	10E12	10E12	10E12	10E12	10E12	10E12
CHEMICAL RESISTANCE										
17	Acids, weak	-	-	L	L	L	L	A	A	A
18	Acids, strong (pH 1-3)	-	-	L	U	L	L	A	A	L
19	Alkalies, weak	-	-	A	L	A	A	A	A	L
20	Alkalies, strong (pH 11-14)	-	-	A	U	A	A	A	A	U
21	Hydrocarbons - aromatic	-	-	A	A	A	A	U	U	A
22	Hydrocarbons - aliphatic	-	-	A	A	A	A	U	U	A
23	Ketones, esters	-	-	A	A	A	A	U	U	A
24	Chlorinated solvents	-	-	A	L	A	A	U	U	A
25	Alcohols	-	-	A	L	A	A	A	A	A
26	Inorganic salt solutions	-	-	A	A	A	A	A	A	A
27	Hot water / steam	-	-	A	L	A	A	L	L	L

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ASTM data

Polyethylene Grades

		ASTM / QTM test method	Units	TIVAR® 1000 natural UHMW-PE	TIVAR® 1000 UHMW-PE colors	TIVAR® ESD UHMW-PE / TIVAR® 1000 antistatic UHMW-PE	TIVAR® 1000 EC UHMW-PE	TIVAR® ECO ESD UHMW-PE / TIVAR® ECO black antistatic UHMW-PE	TIVAR® 88 UHMW-PE	TIVAR® 88 W/BurnGuard UHMW-PE / TIVAR® Burnguard UHMW-PE	TIVAR® CERAM P UHMW-PE	TIVAR® CleanStat™ UHMW-PE
	MECHANICAL											
1	Specific gravity	ASTM D792	-	0.93	0.93	0.94	0.93	0.93	0.93	1.00	0.96	0.94
2	Tensile strength, ultimate	ASTM D638	psi	5,800	5,800	5,800	5,800	4,000	5,800	3,600	5,500	5,200
3	Elongation at break	ASTM D638	%	300	300	300	300	200	300	120	300	200
4	Elongation at yield	ASTM D638	%	-	-	-	-	-	-	-	-	-
5	Tensile modulus	ASTM D638	ksi	80	80	87	80	98	61	87	83	94
5	Flexural strength	ASTM D790	psi	3,500	-	3,700	-	2,000	3,200	2,900	3,700	2,700
7	Compressive strength	ASTM D695	psi	3,000	3,000	3,300	3,000	2,800	3,000	2,800	3,000	3,100
8	Izod impact, notched	ASTM D256	ft-lb/in	No Break	No Break	No Break	No Break	No Break	No Break	No Break	No Break	No Break
9	Izod impact, double notched	ASTM D4020	ft-lb/in	28.60	47.6	38.10	110	-	47.60	-	-	45.20
	TRIBOLOGICAL											
10	Coefficient of friction (dynamic)	QTM 55007	-	0.12	0.12	0.12	0.12	0.14	0.12	0.09	0.12	0.12
11	Limiting pressure velocity	QTM 55007	psi-ft/min	3,000	3,000	3,000	3,000	3,000	4,000	-	3,000	3,000
12	K (wear) factor, x 10^{-10}	QTM 55010	in^3-min/ft-lb-hr	-	-	-	-	-	-	-	-	-
13	Sand slurry	ASTM D4020	-	10	10	10	10	18	8	15	8.5	13
	DIMENSIONAL STABILITY											
14	CLTE (-40 - 300°F)	ASTM E831	µin/in-°F	110	110	110	110	110	110	90	110	110
15	Water absorption at saturation in water	ASTM D570	%	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	THERMAL											
16	Heat deflection temperature at 1.8 MPa (264 psi)	ASTM D648	°F	116	116	116	116	116	116	116	116	116
17	Maximum service temperature, air	-	°F	180	180	180	180	180	180	180	180	180
	ELECTRICAL											
18	Dielectric strength	ASTM D149	kV/in	1,150	1,150	-	1,150	-	2,300	-	2,300	-
19	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E14	10E14	10E4	10E14	10E5	10E14	10E11	10E14	10E6
	CHEMICAL RESISTANCE											
20	Acids, weak	-	-	A	A	A	A	A	A	A	A	A
21	Acids, strong (pH 1-3)	-	-	A	A	A	A	A	A	A	A	A
22	Alkalies, weak	-	-	A	A	A	A	A	A	A	A	A
23	Alkalies, strong (pH 11-14)	-	-	A	A	A	A	A	A	A	A	A
24	Hydrocarbons - aromatic	-	-	A	A	A	A	A	A	A	A	A
25	Hydrocarbons - aliphatic	-	-	A	A	A	A	A	A	A	A	A
26	Ketones, esters	-	-	A	A	A	A	A	A	A	A	A
27	Chlorinated solvents	-	-	A	A	A	A	A	A	A	A	A
28	Alcohols	-	-	A	A	A	A	A	A	A	A	A
29	Inorganic salt solutions	-	-	A	A	A	A	A	A	A	A	A
30	Hot water / steam	-	-	L	L	L	L	L	L	L	L	L

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ASTM data

Polyethylene Grades

		ASTM / QTM test method	Units	TIVAR® DrySlide UHMW-PE	TIVAR® H.O.T. UHMW-PE	TIVAR® HPV UHMW-PE	TIVAR® Oil Filled UHMW-PE	TIVAR® SuperPlus UHMW-PE	TIVAR® VMX Food Grade UHMW-PE	Proteus® White Homopolymer PP White
MECHANICAL										
1	Specific gravity	ASTM D792	-	0.94	0.94	0.93	0.94	0.96	0.95	0.91
2	Tensile strength, ultimate	ASTM D638	psi	5,100	6,800	5,900	6,500	5,300	6,100	4,800
3	Elongation at break	ASTM D638	%	200	300	390	280	300	380	400
4	Elongation at yield	ASTM D638	%	-	-	-	-	-	-	12
5	Tensile modulus	ASTM D638	ksi	87	72.5	56	43.5	61	100	173
5	Flexural strength	ASTM D790	psi	2,600	3,800	3,000	2,500	3,100	4,200	4,800
7	Compressive strength	ASTM D695	psi	2,900	3,000	3,000	2,700	3,000	3,000	5,000
8	Izod impact, notched	ASTM D256	ft-lb/in	No Break	No Break	No Break	No Break	No Break	No Break	1.90
9	Izod impact, double notched	ASTM D4020	ft-lb/in	-	46.20	-	-	-	28.60	-
TRIBOLOGICAL										
10	Coefficient of friction (dynamic)	QTM 55007	-	0.08	0.12	0.09	0.14	0.15	0.13	0.25
11	Limiting pressure velocity	QTM 55007	psi-ft/min	4,000	3,000	6,000	4,000	2,000	-	-
12	K (wear) factor, x 10^{-10}	QTM 55010	in^3-min/ft-lb-hr	-	-	20	-	-	-	-
13	Sand slurry	ASTM D4020		10	10	16.5	13	-	11	-
DIMENSIONAL STABILITY										
14	CLTE (-40 - 300°F)	ASTM E831	µin/in-°F	110	110	80	110	67	110	43
15	Water absorption at saturation in water	ASTM D570	%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
THERMAL										
16	Heat deflection temperature at 1.8 MPa (264 psi)	ASTM D648	°F	116	116	116	116	116	116	-
17	Maximum service temperature, air	-	°F	180	180	180	180	180	275	180
ELECTRICAL										
18	Dielectric strength	ASTM D149	kV/in	-	2,300	-	2,300	2,300	-	-
19	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E8	10E12	10E13	10E14	10E14	10E13	10E14
CHEMICAL RESISTANCE										
20	Acids, weak	-	-	A	A	A	A	A	A	A
21	Acids, strong (pH 1-3)	-	-	A	A	A	A	A	A	A
22	Alkalies, weak	-	-	A	A	A	A	A	A	A
23	Alkalies, strong (pH 11-14)	-	-	A	A	A	A	A	A	A
24	Hydrocarbons - aromatic	-	-	A	A	A	A	A	A	A
25	Hydrocarbons - aliphatic	-	-	A	A	A	A	A	A	A
26	Ketones, esters	-	-	A	A	A	A	A	A	A
27	Chlorinated solvents	-	-	A	A	A	A	A	A	A
28	Alcohols	-	-	A	A	A	A	A	A	A
29	Inorganic salt solutions	-	-	A	A	A	A	A	A	A
30	Hot water / steam	-	-	L	L	L	L	L	L	L

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ISO data

Advanced Engineering Plastics

		ISO / ASTM test method	Units	Duratron® CU60 PBI	Duratron® D7000 PI	Duratron® D7015G PI	Duratron® T4203 PAI	Duratron® T4503 PAI	Duratron® T4301 PAI	Duratron® T4501 PAI	Duratron® T5530 PAI	Semitron® ESd 520HR PAI
							MECHANICAL					
1	Density	ISO 1183-1	g/cm^3	1,3	1,38	1,46	1,41	1,41	1,45	1,45	1,61	1,58
2	Tensile strength	ISO 527-1/-2	MPa	130	115	67	150	150	110	110	125	83
3	Tensile strain at break	ISO 527-1/-2	%	3	4	2	20	20	5	5	3	3
4	Tensile strain at yield	ISO 527-1/-2	%	-	-	-	9,0	9,0	-	-	-	-
5	Tensile modulus of elasticity	ISO 527-1/-2	MPa	6.000	3.700	4.900	4.200	4.200	5.500	5.500	6.400	5.500
5	Flexural strength	ISO 178	MPa	160	185	100	178	178	155	155	170	105
7	Compressive stress at 1/ 2/ 5% nominal strain	ISO 604	MPa	58 / 118 / 280	35 / 69 / 145	44 / 81 / 145	34 / 67 / 135	34 / 67 / 135	39 / 72 / 130	39 / 72 / 130	55 / 104 / 190	42 / 82 / 145
8	Charpy impact, notched	ISO 179-1/1eA	kJ/m^2	2,5	4,5	1,5	15,0	15,0	4,0	4,0	3,5	4,0
							TRIBOLOGICAL					
9	Coefficient of friction (Dynamic)	ISO 7148-2		0,3-0,5	0,3-0,5	0,25-0,4	0,35-0,6	0,35-0,6	0,25-0,4	0,25-0,4	0,35-0,6	-
10	Limiting pressure velocity at 0,1 m/s	-	MPa. m/s	1,8	0,46	1,2	0,32	0,32	1,1	1,1	-	-
11	Limiting pressure velocity at 1 m/s	-	MPa. m/s	1,14	0,29	0,44	0,2	0,2	0,69	0,69	-	-
12	K (wear) factor	ISO 7148-2	μm/km	3,0	12,0	55,0	5,0	5,0	1,0	1,0	-	-
							DIMENSIONAL STABILITY					
13	CLTE (23-150 °C)	ASTM E831 (TMA)	μm/ (m.K)	25	42	38	40	40	35	35	35	-
14	CLTE (>150 °C)	ASTM E831 (TMA)	μm/ (m.K)	35	52	47	50	50	40	40	40	-
15	Water absorption at saturation in water	-	%	14,00	4,00	3,00	4,4	4,4	3,8	3,8	3,2	4,6
							THERMAL					
16	Heat deflection temperature at 1.8 MPa (264 psi)	ISO 75 -1/-2	°C	425	355	365	280	280	280	280	280	280
17	Maximum service temperature, air	-	°C	310	260	260	250	250	250	250	250	250
							ELECTRICAL					
18	Dielectric strength	ISO 60243-1	kV/mm	28	28	13	24	24	-	-	28	-
19	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E12	10E12	10E3	10E15	10E12	10E12	10E12	10E12	10E9-10E11
							CHEMICAL RESISTANCE					
20	Acids, weak	-	-	L	A	A	A	A	A	A	A	A
21	Acids, strong (pH 1-3)	-	-	L	U	A	L	L	L	L	L	L
22	Alkalies, weak	-	-	L	U	A	L	L	L	L	L	L
23	Alkalies, strong (pH 11-14)	-	-	U	U	A	U	U	U	U	U	U
24	Hydrocarbons - aromatic	-	-	A	U	U	A	A	A	A	A	A
25	Hydrocarbons - aliphatic	-	-	A	U	U	A	A	A	A	A	A
26	Ketones, esters	-	-	A	U	U	A	A	A	A	A	A
27	Chlorinated solvents	-	-	A	U	U	A	A	A	A	A	A
28	Alcohols	-	-	A	U	A	A	A	A	A	A	A
29	Inorganic salt solutions	-	-	A	A	A	A	A	A	A	A	A
30	Hot water / steam	-	-	L	L	L	L	L	L	L	L	L

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ISO data

Advanced Engineering Plastics

		ISO / ASTM test method	Units	Duratron® U1000 PEI	Fluorosint® 207 PTFE	Fluorosint® HPV PTFE	Fluorosint® 500 PTFE	Fluorosint® MT-01 PTFE	Fluorosint® 135 PTFE	Ketron® 1000 PEEK	Ketron® CA30 PEEK	Ketron® GF30 PEEK
	MECHANICAL											
1	Density	ISO 1183-1	g/cm^3	1,27	2,3	2,06	2,32	2,27	1,89	1,31	1,4	1,51
2	Tensile strength	ISO 527-1/-2	MPa	129	10	10	7	14	11	115	144	80
3	Tensile strain at break	ISO 527-1/-2	%	13	> 50	> 50	15	20	3	17	3,5	4,5
4	Tensile strain at yield	ISO 527-1/-2	%	7,0	4,0	6,0	5,0	6,0	3,0	5,0	-	3,5
5	Tensile modulus of elasticity	ISO 527-1/-2	MPa	3.500	1.450	1.200	1.750	1.900	1.238	4.300	9.200	7.000
5	Flexural strength	ISO 178	MPa	167	14	18	13	20	-	170	220	155
7	Compressive stress at 1/ 2/ 5% nominal strain	ISO 604	MPa	31 / 61 / 137	10.5 / 15 / 20	10 / 14.5 / 19	12 / 19 / 25	11 / 17 / 29	19/ 25 / 30	38 / 75 / 140	69 / 125 / 170	54 / 103 / 155
8	Charpy impact, notched	ISO 179-1/1eA	kJ/m^2	3,5	7,5	12,0	4,5	4,0	3,5	3,5	5,0	3,0
	TRIBOLOGICAL											
9	Coefficient of friction (Dynamic)	ISO 7148-2	-	0,3-0,4	0,15-0,25	0,2-0,3	0,2-0,3	0,15-0,25	-	0,3-0,5	0,2-0,3	0,3-0,45
10	Limiting pressure velocity at 0,1 m/s	-	MPa. m/s	-	0,4	0,4	0,4	-	-	0,33	-	-
11	Limiting pressure velocity at 1 m/s	-	MPa. m/s	-	0,25	0,25	0,25	-	-	0,21	-	-
12	K (wear) factor	ISO 7148-2	μm/km	1.325,0	5,0	2,5	12,0	6,0	-	28,0	2,0	7,0
	DIMENSIONAL STABILITY											
13	CLTE (23-150 °C)	ASTM E831 (TMA)	μm/(m.K)	50	90	80	55	65	55	55	25	30
14	CLTE (>150 °C)	ASTM E831 (TMA)	μm/(m.K)	60	155	135	85	100	85	130	55	65
15	Water absorption at saturation in water	-	%	1,30	1 - 2	0,5 - 1	1,5 - 2,5	1,5 - 2,5	-	0,45	0,35	0,35
	THERMAL											
16	Heat deflection temperature at 1,8 MPa (264 psi)	ISO 75 -1/-2	°C	195	100	80	130	95	100	160	260	230
17	Maximum service temperature, air	-	°C	170	260	260	260	260	-	250	250	250
	ELECTRICAL											
18	Dielectric strength	ISO 60243-1	kV/mm	27	8	-	11	-	-	24	-	24
19	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E12	10E12	10E12	10E12	10E5	10E4	10E12	10E4	10E12
	CHEMICAL RESISTANCE											
20	Acids, weak	-	-	A	A	A	A	A	A	A	A	A
21	Acids, strong (pH 1-3)	-	-	L	A	U	A	L	A	L	U	L
22	Alkalies, weak	-	-	A	A	L	A	A	A	L	A	A
23	Alkalies, strong (pH 11-14)	-	-	A	A	U	A	A	A	U	U	A
24	Hydrocarbons - aromatic	-	-	U	U	A	U	L	U	A	U	U
25	Hydrocarbons - aliphatic	-	-	A	U	A	U	A	U	A	L	A
26	Ketones, esters	-	-	L	U	A	U	U	U	A	U	L
27	Chlorinated solvents	-	-	A	U	L	U	U	U	A	U	A
28	Alcohols	-	-	A	A	L	A	L	A	A	A	A
29	Inorganic salt solutions	-	-	A	A	A	A	A	A	A	A	A
30	Hot water / steam	-	-	L	L	L	L	A	A	L	A	L

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ISO data

Advanced Engineering Plastics

		ISO / ASTM test method	Units	Ketron® HPV PEEK	Ketron® VMX Food Grade PEEK	Sultron® PSU	Semitron® ESd 410C PEI	Semitron® ESd 420 PEI	Semitron® ESd 420V PEI	Semitron® MDS 100 PEEK	Semitron® ESd 480 PEEK	Semitron® ESd 490HR PEEK
	MECHANICAL											
1	Density	ISO 1183-1	g/cm^3	1,45	1,44	1,24	1,41	1,32	1,48	1,51	1,46	1,5
2	Tensile strength	ISO 527-1/-2	MPa	78	114	88	62	57	70	118	55	48
3	Tensile strain at break	ISO 527-1/-2	%	3	5	10	2	2	1,5	2	1	1
4	Tensile strain at yield	ISO 527-1/-2	%	-	4,0	5,0	-	-	-	-	-	-
5	Tensile modulus of elasticity	ISO 527-1/-2	MPa	5.900	4.900	2.850	5.850	640	910	11.000	5.900	6.350
5	Flexural strength	ISO 178	MPa	125	-	120	80	-	-	-	-	-
7	Compressive stress at 1/ 2/ 5% nominal strain	ISO 604	MPa	46 / 80 / 120	45 / 86 / 144	25 / 49 / 101	44 / 76 / 114	33 / 68 / 147	44 / 89 / 169	73 / 125 / 125	42 / 83 / 141	49 / 91 / 146
8	Charpy impact, notched	ISO 179-1/1eA	kJ/m^2	3,0	3,2	3,5	4,0	2,0	2,0	2,0	1,0	1,0
	TRIBOLOGICAL											
9	Coefficient of friction (Dynamic)	ISO 7148-2		0,15-0,25	-	0,5-0,6	-	-	-	-	-	-
10	Limiting pressure velocity at 0,1 m/s	-	MPa. m/s	0,66	-	-	-	-	-	-	-	-
11	Limiting pressure velocity at 1 m/s	-	MPa. m/s	0,42	-	-	-	-	-	-	-	-
12	K (wear) factor	ISO 7148-2	µm/km	2,0	-	6400,0	-	100	-	-	-	-
	DIMENSIONAL STABILITY											
13	CLTE (23-150 °C)	ASTM E831 (TMA)	µm/(m.K)	40	50	55	40	38	30	20	40	36
14	CLTE (>150 °C)	ASTM E831 (TMA)	µm/(m.K)	85	75	70	45	40	30	20	-	63
15	Water absorption at saturation in water	-	%	0,35	-	0,80	1,10	2,9	1,4	-	1,65	1,65
	THERMAL											
16	Heat deflection temperature at 1.8 MPa (264 psi)	ISO 75 -1/-2	°C	195	-	170	200	210	215	-	-	-
17	Maximum service temperature, air	-	°C	250	-	150	170	170	170	-	250	250
	ELECTRICAL											
18	Dielectric strength	ISO 60243-1	kV/mm	-	-	30	-	-	-	-	-	-
19	Surface resistivity	EOS/ESD S11.11	ohm/sq	-	-	10E12	10E3 - 10E5	10E5 - 10E8	10E5 - 10E8	10E12	10E5-10E8	10E9-10E11
	CHEMICAL RESISTANCE											
20	Acids, weak	-	-	A	A	A	A	A	A	A	A	A
21	Acids, strong (pH 1-3)	-	-	L	U	L	L	A	L	L	L	L
22	Alkalies, weak	-	-	A	A	A	A	A	A	A	A	A
23	Alkalies, strong (pH 11-14)	-	-	A	U	A	A	A	A	A	A	A
24	Hydrocarbons - aromatic	-	-	U	U	A	U	U	U	U	U	U
25	Hydrocarbons - aliphatic	-	-	A	L	A	A	U	A	A	A	A
26	Ketones, esters	-	-	L	U	A	L	U	L	L	L	L
27	Chlorinated solvents	-	-	A	U	A	A	U	A	A	A	A
28	Alcohols	-	-	A	A	A	A	A	A	A	A	A
29	Inorganic salt solutions	-	-	A	A	A	A	A	A	A	A	A
30	Hot water / steam	-	-	L	L	A	L	L	L	L	L	L

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ISO data

Advanced Engineering Plastics

		ISO / ASTM test method	Units	Semitron® ESd 500 HR PTFE	Semitron® HPV ESd PEEK	Semitron® MPR-1000 PAI	Semitron® MP-370 PEEK	Techtron® 1000 PPS	Techtron® HPV PPS
	MECHANICAL								
1	Density	ISO 1183-1	g/cm³	2,3	1,45	1,47	1,65	1,35	1,42
2	Tensile strength	ISO 527-1/-2	MPa	10	78	99	78	102	78
3	Tensile strain at break	ISO 527-1/-2	%	> 50	3	4	2	3,5	3,5
4	Tensile strain at yield	ISO 527-1/-2	%	4,0	-	-	-	12,0	-
5	Tensile modulus of elasticity	ISO 527-1/-2	MPa	1.450	5.900	6.050	4.450	4.000	4.000
5	Flexural strength	ISO 178	MPa	14	125	-	-	155	118
7	Compressive stress at 1/ 2/ 5% nominal strain	ISO 604	MPa	10,5 / 15 / 20	46 / 80 / 120	47/ 79/ 130	38 / 72 / 72	39 / 77 / 122	33 / 65 / 105
8	Charpy impact, notched	ISO 179-1/1eA	kJ/m²	7,5	3,0	5,0	0,4	2,0	4,0
	TRIBOLOGICAL								
9	Coefficient of friction (Dynamic)	ISO 7148-2		-	0,15-0,25	-	-	0,4-0,6	0,2-0,35
10	Limiting pressure velocity at 0,1 m/s	-	MPa. m/s	-	0,66	-	-	-	0,43
11	Limiting pressure velocity at 1 m/s	-	MPa. m/s	-	0,42	-	-	-	0,27
12	K (wear) factor	ISO 7148-2	µm/km	-	2,0	-	-	70,0	5,0
	DIMENSIONAL STABILITY								
13	CLTE (23-150 °C)	ASTM E831 (TMA)	µm/ (m.K)	90	40	30	49	80	60
14	CLTE (>150 °C)	ASTM E831 (TMA)	µm/ (m.K)	155	85	36	51	145	100
15	Water absorption at saturation in water	-	%	1 - 2	0,35	3,4	0,5	0,10	0,20
	THERMAL								
16	Heat deflection temperature at 1.8 MPa (264 psi)	ISO 75 -1/-2	°C	100	195	278	148	115	115
17	Maximum service temperature, air	-	°C	260	250	-	-	-	260
	ELECTRICAL								
18	Dielectric strength	ISO 60243-1	kV/mm	-	-	-	-	18	24
19	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E9-10E11	10E5-10E8	10E12	10E12	10E12	10E12
	CHEMICAL RESISTANCE								
20	Acids, weak	-	-	A	A	A	A	A	A
21	Acids, strong (pH 1-3)	-	-	U	L	L	L	L	L
22	Alkalies, weak	-	-	A	A	L	A	A	L
23	Alkalies, strong (pH 11-14)	-	-	U	A	C	A	A	U
24	Hydrocarbons - aromatic	-	-	U	U	A	U	U	A
25	Hydrocarbons - aliphatic	-	-	L	A	A	A	A	A
26	Ketones, esters	-	-	U	L	A	L	L	A
27	Chlorinated solvents	-	-	U	A	A	A	A	A
28	Alcohols	-	-	A	A	A	A	A	A
29	Inorganic salt solutions	-	-	A	A	A	A	A	A
30	Hot water / steam	-	-	L	L	L	L	L	L

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ISO data

General Engineering Plastics

		ISO / ASTM test method	Units	Acetron® GP POM-C/ Ertacetal® C POM-C	Acetron® VMX Food Grade POM-C	Semitron® ESd 225 POM-C	Acetron® POM-H / Ertacetal® H POM-H	Acetron® AF Blend POM-H / Ertacetal® H-TF POM-H	Nylatron® 4.6 PA4.6 / Ertalon® 4.6 PA4.6	Nylatron® MC® 907 PA6 / Ertalon® 6PLA PA6	Nylatron® GSM PA6	Nylatron® NSM PA6
	MECHANICAL											
1	Density	ISO 1183-1	g/cm^3	1,41	1,46	1,33	1,43	1,5	1,19	1,15	1,16	1,14
2	Tensile strength	ISO 527-1/-2	MPa	66	66	38	78	55	105	88	82	80
3	Tensile strain at break	ISO 527-1/-2	%	40	15	15	25	10	25	25	25	25
4	Tensile strain at yield	ISO 527-1/-2	%	15,0	14,0	-	-	-	18,0	5,0	5,0	5,0
5	Tensile modulus of elasticity	ISO 527-1/-2	MPa	3.000	2.950	1.500	3.700	3.100	3.400	3.600	3.400	3.150
5	Flexural strength	ISO 178	MPa	91	93	50	106	-	138	121	111	109
7	Compressive stress at 1/ 2/ 5% nominal strain	ISO 604	MPa	23 / 40 / 72	25 / 44 / 76	14 / 25 / 38	29 / 49 / 85	26 / 44 / 77	31 / 60 / 102	34 / 64 / 93	33 / 62 / 91	31 / 59 / 87
8	Charpy impact, notched	ISO 179-1/1eA	kJ/m^2	8,0	5,0	8,0	10,0	3,0	8,0	3,0	3,0	3,5
	TRIBOLOGICAL											
9	Coefficient of friction (dynamic)	ISO 7148-2		-	-	-	-	0,2-0,3	0,4-0,6	0,4-0,6	0,35-0,55	0,2-0,35
10	Limiting pressure velocity at 0,1 m/s	-	MPa. m/s	-	-	-	-	0,26	0,16	0,13	0,13	0,39
11	Limiting pressure velocity at 1 m/s	-	MPa. m/s	-	-	-	-	0,16	0,1	0,08	0,08	0,25
12	K (wear) Factor	ISO 7148-2	µm/km	-	-	-	-	8	18,0	12,0	11,0	4,5
	DIMENSIONAL STABILITY											
13	CLTE (23-100 °C)	ASTM E831 (TMA)	µm/ (m.K)	125	130	150	110	120	90	90	90	95
14	CLTE (23-60 °C)	ASTM E831 (TMA)	µm/ (m.K)	110	115	-	95	105	80	80	80	80
15	Water absorption at saturation in water	-	%	0,80	0,75	10,00	0,80	0,72	9,5	6,5	6,7	6,3
	THERMAL											
16	Heat deflection Temperature at 1.8 MPa (264 psi)	ISO 75 -1/-2	°C	100	100	-	110	100	160	80	80	75
17	Maximum service temperature, air	-	°C	100	90	90	90	90	130	90	90	90
	ELECTRICAL											
18	Dielectric strength	ISO 60243-1	kV/mm	20	-	-	20	20	25	25	24	25
19	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E12	10E12	10E8-10E9	10E12	10E12	10E12	10E12	10E12	10E12
	CHEMICAL RESISTANCE											
20	Acids, weak	-	-	L	L	L	L	L	L	L	L	L
21	Acids, strong (pH 1-3)	-	-	A	A	L	L	A	L	U	L	U
22	Alkalies, weak	-	-	A	A	A	A	A	A	L	A	L
23	Alkalies, strong (pH 11-14)	-	-	A	A	A	A	A	A	U	A	U
24	Hydrocarbons - aromatic	-	-	U	U	U	L	U	A	A	A	A
25	Hydrocarbons - aliphatic	-	-	U	U	A	L	U	A	A	A	A
26	Ketones, esters	-	-	U	U	L	U	U	A	A	A	A
27	Chlorinated solvents	-	-	U	U	A	L	U	A	L	A	L
28	Alcohols	-	-	A	A	A	A	A	A	L	A	L
29	Inorganic salt solutions	-	-	A	A	A	A	A	A	A	A	A
30	Hot water / steam	-	-	L	L	L	L	L	A	L	A	L

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ISO data

General Engineering Plastics

		ISO / ASTM test method	Units	Nylatron® 703 XL PA6	Nylatron® 101 PA66 / Ertalon® 66 SA PA66	Nylatron® GF30 PA66 / Ertalon® 66 GF30 PA66	Nylatron® GS PA66	Ertalyte® PET	Ertalyte® TX PET	Altron™ PC
				MECHANICAL						
1	Density	ISO 1183-1	g/cm^3	1,11	1,14	1,29	1,15	1,39	1,44	1,2
2	Tensile strength	ISO 527-1/-2	MPa	60	90	85	95	90	76	74
3	Tensile strain at break	ISO 527-1/-2	%	15	50	5	20	15	5	> 50
4	Tensile strain at yield	ISO 527-1/-2	%	6,0	5,0	-	5,0	4	4	6,0
5	Tensile modulus of elasticity	ISO 527-1/-2	MPa	2.750	3.550	5.000	3.600	3.500	3.500	2.400
5	Flexural strength	ISO 178	MPa	0	135	-	128	135	122	103
7	Compressive stress at 1/ 2/ 5% nominal strain	ISO 604	MPa	26 / 48 / 69	32 / 62 / 100	43 / 77 / 112	32 / 62 / 100	33 / 64 / 107	31 / 60 / 102	21 / 40 / 80
8	Charpy impact, notched	ISO 179-1/1eA	kJ/m^2	4,0	4,5	6,0	4,0	2,0	2,5	9,0
				TRIBOLOGICAL						
9	Coefficient of friction (dynamic)	ISO 7148-2		0,12-0,18	0,4-0,6	0,25-0,4	0,35-0,55	0.15-0.25	0.15-0.22	NR
10	Limiting pressure velocity at 0,1 m/s	-	MPa. m/s	0,48	0,13	0,18	0,13	0,15	0,26	NR
11	Limiting pressure velocity at 1 m/s	-	MPa. m/s	0,3	0,08	0,12	0,08	0,09	0,16	NR
12	K (wear) Factor	ISO 7148-2	μm/km	2,5	14,0	11,0	12,0	3	2	NR
				DIMENSIONAL STABILITY						
13	CLTE (23-100 °C)	ASTM E831 (TMA)	μm/(m.K)	100	95	60	90	80	85	65
14	CLTE (23-60 °C)	ASTM E831 (TMA)	μm/(m.K)	85	80	50	80	60	65	65
15	Water absorption at saturation in water	-	%	6,3	8,00	5,5	7,8	0,50	0,47	0,40
				THERMAL						
16	Heat deflection Temperature at 1.8 MPa (264 psi)	ISO 75 -1/-2	°C	70	85	150	85	80	75	130
17	Maximum service temperature, air	-	°C	90	80	110	80	100	100	120
				ELECTRICAL						
18	Dielectric strength	ISO 60243-1	kV/mm		27	27	26	22	21	28
19	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E11	10E12	10E12	10E12	10E12	10E12	10E12
				CHEMICAL RESISTANCE						
20	Acids, weak	-	-	L	L	L	L	A	A	A
21	Acids, strong (pH 1-3)	-	-	L	U	L	L	A	A	L
22	Alkalies, weak	-	-	A	L	A	A	A	A	L
23	Alkalies, strong (pH 11-14)	-	-	A	U	A	A	A	A	U
24	Hydrocarbons - aromatic	-	-	A	A	A	A	U	U	A
25	Hydrocarbons - aliphatic	-	-	A	A	A	A	U	U	A
26	Ketones, esters	-	-	A	A	A	A	U	U	A
27	Chlorinated solvents	-	-	A	L	A	A	U	U	A
28	Alcohols	-	-	A	L	A	A	A	A	A
30	Inorganic salt solutions	-	-	A	A	A	A	A	A	A
31	Hot water / steam	-	-	A	L	A	A	L	L	L

A = Acceptable service | L = Limited service | U = Unacceptable

ISO data

Polyethylene Grades

		ISO / ASTM test method	Units	TIVAR® 1000 natural UHMW-PE	TIVAR® 1000 UHMW-PE colors	TIVAR® ESD UHMW-PE / TIVAR® 1000 antistatic UHMW-PE	TIVAR® 1000 EC UHMW-PE	TIVAR® ECO ESD UHMW-PE / TIVAR® ECO black antistatic UHMW-PE	TIVAR® 88 UHMW-PE	TIVAR® 88 W/BurnGuard UHMW-PE / TIVAR® Burnguard UHMW-PE	TIVAR® CERAM P UHMW-PE	TIVAR® CleanStat™ UHMW-PE
MECHANICAL												
1	Density	ISO 1183-1	g/cm^3	0,93	0,93	0,935	0,945	0,94	0,93	1,01	0,96	0,945
2	Tensile strength	ISO 527-1/-2	MPa	19	19	20	21	20	19	16	18	21
3	Tensile strain at break	ISO 527-1/-2	%	> 50	> 50	> 50	> 50	> 50	> 50	25	> 50	> 50
4	Tensile strain at yield	ISO 527-1/-2	%	15	15	15,0	15,0	15,0	21,0	15,0	15,0	15,0
5	Tensile modulus of elasticity	ISO 527-1/-2	MPa	750	750	790	825	775	790	1.000	750	825
5	Flexural strength	ISO 178	MPa	17	17	18	20	18	18	18	17	20
7	Compressive stress at 1 / 2/ 5% nominal strain	ISO 604	MPa	6,5 / 10,5 / 17	6,5 / 10,5 / 17	7 / 11 / 17,5	7,5 / 12 / 19	7 / 11 / 17,5	7 /10 / 16	7 / 11 / 17	7 / 11 / 17,5	7,5 / 12 / 19
8	Charpy impact, notched	ISO 179-1/1eA	kJ/m^2	115P	115P	110P	105P	90P	96,0	70P	105P	105P
9	Charpy impact, double notched	ISO 21304-2, double notch 14°	kJ/m^2	170	170	140	110	100	-	70	125	110
TRIBOLOGICAL												
10	Coefficient of friction (dynamic)	ISO 7148-2		0,15-0,30	0,15-0,30	0,15-0,30	0,15-0,30	0,15-0,30	0,20-0,35	0,15-0,30	0,15-0,30	0,15-0,30
11	Limiting pressure velocity at 0,1 m/s	-	MPa. m/s	0,08	0,08	0,08	0,08	0,08	-	0,08	0,08	0,08
12	Limiting pressure velocity at 1 m/s	-	MPa. m/s	0,05	0,05	0,05	0,05	0,05	-	0,05	0,05	0,05
13	K (wear) factor	ISO 7148-2	µm/km	8,0	8,0	8,0	8,0	15,0	3,5	14,0	4,0	8,0
14	Sand slurry	ISO 15527	Relative Index TIVAR® 1000 = 100	100	100	105	100	200	80	130	75	100
DIMENSIONAL STABILITY												
15	CLTE (23-100 °C)	ASTM E831 (TMA)	µm/ (m.K)	200	200	200	200	200	200	180	200	200
16	Water absorption at saturation in water	-	%	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1	< 0,2	< 0,1	< 0,1
THERMAL												
17	Heat deflection temperature at 1.8 MPa (264 psi)	ISO 75 -1/-2	°C	42	42	42	42	42	42	42	42	42
18	Maximum service temperature, air	-	°C	80	80	80	80	80	80	80	80	80
ELECTRICAL												
19	Dielectric strength	ISO 60243-1	kV/mm	45	45	-	-	-	-	-	45	-
20	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E14	10E14	10E4	10E4	10E5	10E14	10E11	10E14	10E6
CHEMICAL RESISTANCE												
21	Acids, weak	-	-	A	A	A	A	A	A	A	A	A
22	Acids, strong (pH 1-3)	-	-	A	A	A	A	A	A	A	A	A
23	Alkalies, weak	-	-	A	A	A	A	A	A	A	A	A
24	Alkalies, strong (pH 11-14)	-	-	A	A	A	A	A	A	A	A	A
25	Hydrocarbons - aromatic	-	-	A	A	A	A	A	A	A	A	A
26	Hydrocarbons - aliphatic	-	-	A	A	A	A	A	A	A	A	A
27	Ketones, esters	-	-	A	A	A	A	A	A	A	A	A
28	Chlorinated solvents	-	-	A	A	A	A	A	A	A	A	A
29	Alcohols	-	-	A	A	A	A	A	A	A	A	A
30	Inorganic salt solutions	-	-	A	A	A	A	A	A	A	A	A
31	Hot water / steam	-	-	L	L	L	L	L	L	L	L	L

A = Acceptable service | L = Limited service | U = Unacceptable

ISO data

Polyethylene Grades

		ISO / ASTM test method	Units	TIVAR® DrySlide UHMW-PE	TIVAR® H.O.T. UHMW-PE	TIVAR® HPV UHMW-PE	TIVAR® Oil Filled UHMW-PE	TIVAR® SuperPlus UHMW-PE	TIVAR® VMX Food Grade UHMW-PE	Proteus® White Homopolymer PP White
	MECHANICAL									
1	Density	ISO 1183-1	g/cm^3	0,935	0,93	0,95	0,93	0,96	0,995	0,91
2	Tensile strength	ISO 527-1/-2	MPa	18	19	20	16	17	19	34
3	Tensile strain at break	ISO 527-1/-2	%	> 50	> 50	>50	> 50	> 50	> 50	>25
4	Tensile strain at yield	ISO 527-1/-2	%	20,0	15,0	16,0	40,0	20,0	15,0	6
5	Tensile modulus of elasticity	ISO 527-1/-2	MPa	650	700	800	375	600	775	1.800
5	Flexural strength	ISO 178	MPa	16	16	0	11	14,5	18	50
7	Compressive stress at 1 / 2/ 5% nominal strain	ISO 604	MPa	6 / 10 / 16	6 / 10 / 16	6.8 / 10,7 / 17,2	4 / 6 / 10,5	5 / 8,5 / 14,5	7 / 11,5 / 18	18 / 24 / 27
8	Charpy impact, notched	ISO 179-1/1eA	kJ/m^2	100P	100P	106P	80P	90P	90P	12,0
9	Charpy impact, double notched	ISO 21304-2, double notch 14°	kJ/m^2	130	130	-	140	115	105	-
	TRIBOLOGICAL									
10	Coefficient of friction (dynamic)	ISO 7148-2		0,15-0,30	0,15-0,30	-	0,15-0,30	0,15-0,30	0,15-0,30	-
11	Limiting pressure velocity at 0,1 m/s	-	MPa. m/s	0,08	0,08	-	0,08	0,08	0,08	-
12	Limiting pressure velocity at 1 m/s	-	MPa. m/s	0,05	0,05	-	0,05	0,05	0,05	-
13	K (wear) factor	ISO 7148-2	μm/km	6,0	6,0	-	6,0	4,0	6,0	-
14	Sand slurry	ISO 15527	Relative Index TIVAR® 1000 = 100	85	80	-	95	80	75	-
	DIMENSIONAL STABILITY									
15	CLTE (23-100 °C)	ASTM E831 (TMA)	μm/ (m.K)	200	200	200	200	200	200	150
16	Water absorption at saturation in water	-	%	< 0,1	< 0,1	<0,1	< 0,1	< 0,1	< 0,1	-
	THERMAL									
17	Heat deflection temperature at 1.8 MPa (264 psi)	ISO 75 -1/-2	°C	42	42	-	42	42	42	60
18	Maximum service temperature, air	-	°C	80	110	80	80	80	80	90
	ELECTRICAL									
19	Dielectric strength	ISO 60243-1	kV/mm	-	45	-	-	-	-	-
20	Surface resistivity	EOS/ESD S11.11	ohm/sq	10E8	10E12	10E13	10E14	10E14	10E13	10E14
	CHEMICAL RESISTANCE									
21	Acids, weak	-	-	A	A	A	A	A	A	A
22	Acids, strong (pH 1-3)	-	-	A	A	A	A	A	A	A
23	Alkalies, weak	-	-	A	A	A	A	A	A	A
24	Alkalies, strong (pH 11-14)	-	-	A	A	A	A	A	A	A
25	Hydrocarbons - aromatic	-	-	A	A	A	A	A	A	A
26	Hydrocarbons - aliphatic	-	-	A	A	A	A	A	A	A
27	Ketones, esters	-	-	A	A	A	A	A	A	A
28	Chlorinated solvents	-	-	A	A	A	A	A	A	A
29	Alcohols	-	-	A	A	A	A	A	A	A
30	Inorganic salt solutions	-	-	A	A	A	A	A	A	A
31	Hot water / steam	-	-	L	L	L	L	L	L	L

A = Acceptable service \| L = Limited service \| U = Unacceptable

Understanding the core properties of engineering plastics

At the MCG Advanced Materials division, we are generating mechanical property values using specimens machined from extruded, compression molded, cast or injection molded shapes. These values help avoid the bias that exists with data generated using injection molded test specimens where fiber orientation skews both stiffness and strength of reinforced grades.

Property basics 3

Tensile strength (ASTM D638/ ISO 527)

Ultimate tensile strength (ASTM D638) is the force per unit area required to break a material under tension. It is expressed in pounds per square inch (psi). The force that is required to pull apart one square inch of plastic may range from 1,000 to 50,000 lbs. or higher. Steel and other structural alloys have much higher tensile strengths, such as SS304 at 84 kpsi.

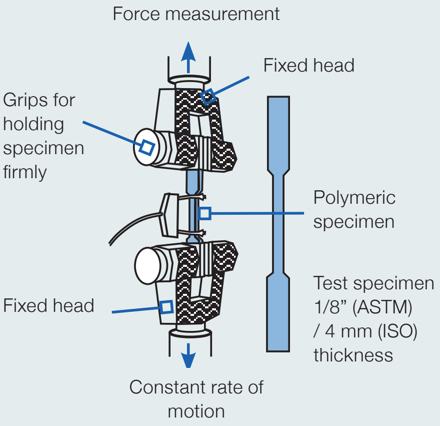
The tensile strength (ISO 527) is one of the most important and widely measured properties of materials used in structural applications. Tensile strength is always reported as psi or MPa. This may also be the stress at which the specimen yields or breaks. A test schematic is shown in *Figure 9*.

Elongation (strain) (ASTM D638/ ISO 527)

Tensile elongation (strain) is the increase in length at break or at yield as noted and expressed as a percentage of original length. For example, a strip of writing paper can be pulled apart with almost no visual stretching or elongation. On the other hand, a rubber band may be stretched several times its original length before breaking and / or yielding.

Figure 9: ASTM D638/ ISO 527

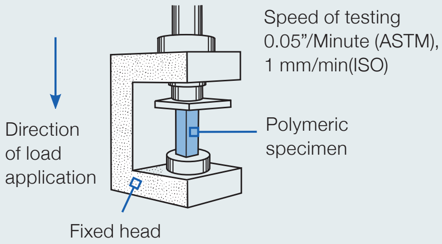
For this test, samples are either machined from stock shapes or injection molded. The tensile testing machine pulls the sample from both ends and measures the force that is necessary to pull the specimen apart (tensile strength), and how much the material stretches before breaking (elongation).



Tensile strength and elongation are both important when toughness is required. A material with high tensile strength and high elongation such as Sultron® PPSU, is a tougher material than one having high tensile strength and low elongation.

Figure 10: ASTM D695/ ISO 604

Specimen of 1/2” x 1/2” x 1” (ASTM) or cylindrical specimen of dia. 8 mm x 16 mm long (ISO) is mounted in a compression tool between testing machine heads. An indicator registers the load in psi.



Compressive strength (ASTM D695/ ISO604)

Compressive strength measures a material’s ability to support a compressive force. *Figure 10* details a test schematic. Always reported as psi or MPa, this property may indicate one of the following:

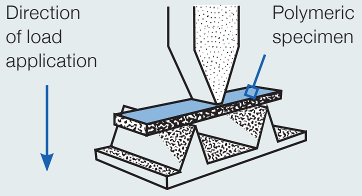
(Ultimate) compressive strength
The maximum stress to rupture a test sample.

Compressive strength at a specific deformation
i.e. 0.1%, 1%, 10% — typically used for materials like plastics that may not rupture.

Compressive yield strength
The stress in psi/MPA measured at the first point on the stress-strain curve at which an increase in strain occurs without an increase in stress.

Figure 11: ASTM D790/ ISO 178

Specimen of 1/8” x 1/2” x 5” (ASTM) or 4x10x80 mm (ISO) is placed on two supports.



Flexural strength (ASTM D79O/ ISO 178)

The flexural strength of a material is defined as its ability to resist deformation (bending) under load. The maximum flexural stress sustained by the test specimen during a bending test is the flexural strength. The test beam is under compressive stress at the concave surface and tensile stress at the convex surface.

See *Figure 11* for test illustration.

Modulus (tensile, compressive, flexural)

The modulus of elasticity (tensile, compressive or flexural) relates an applied stress to a resultant strain. Since plastics do not exhibit perfect elasticity upon loading (a defined constant slope as part of their stress/ strain curve), a tangent modulus is generally reported. Special consideration must be given when designing for continuous or long-term applied stresses due to plastics' time dependent (viscoelastic) behavior under stress. When time dependent strains must be determined, apparent modulus (creep) values must be used. These values are both time and temperature dependent and are generally developed using a Dynamic Modulus Analyzer. DMA curves for MCAM materials can be found on pages 8 and 9.

Figure 12: Indentation hardness test

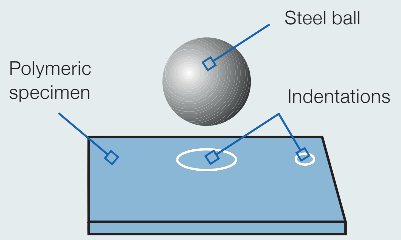


Figure 13: Izod impact test

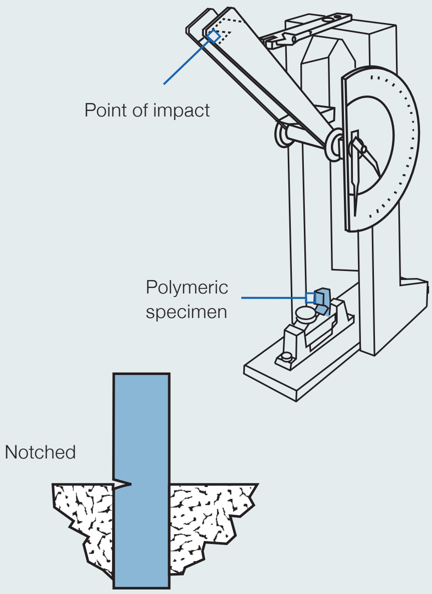
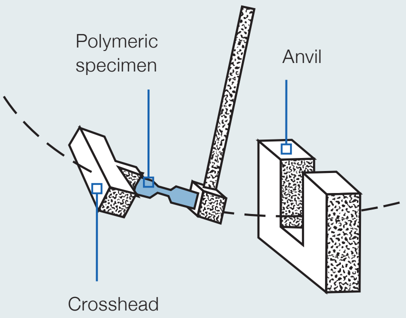


Figure 14: Tensile impact test



Hardness

Hardness is usually reported using one of two test methods – Rockwell (ASTMD 785/ ISO 2039-2) or Indentation Hardness / Durometer (ASTM D 2240 / ISO 868). Rockwell hardness is typically chosen for harder materials such as acetal, nylon, and PEEK, where creep is less of a factor in the test results.

Hardness / Durometer is reported using different scales based on the hardness range of the material. There are no official conversions between scales and unlike metals or steel there is no correlation between hardness and strength.

Impact resistance (toughness)

A material's ability to absorb rapidly applied energy is its impact resistance. Impact resistance will vary based upon the shape, size, thickness, and type of material. Various methods of impact testing are very helpful when comparing the relative impact resistance of different materials. The impact tests most frequently used are Izod, Charpy and tensile impact. Gardner impact tests can also be used to get a complete characterization of a material's toughness.

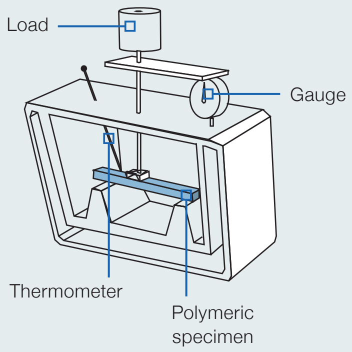
Izod impact (ASTM D256) / Charpy impact (ISO 179)
In this test, a pendulum arm swings to impact a notched, cantilevered beam as shown in *Figure 13* (Izod-sample is placed vertically, Charpy-sample is place horizontally). After fracturing the test specimen, the pendulum continues to travel in the same direction, but with less energy. This loss of energy (measured in ft-lb/in., or J/m or kJ/m^2 for Charpy) of beam thickness, is known as the impact strength. This test can also be done with either an unnotched specimen or with the notch reversed, in which case it is reported as "unnotched" or "reversed notch" impact strength, respectively. This test can also be done with either an unnotched specimen or with the notch reversed (reported as "unnotched" or "reversed notch" impact strength) or as a "double notched" respectively.

Tensile impact (ASTM D1822)
This test uses a swinging pendulum similar to that used in the Izod impact test. The sample specimen is a tensile bar that is mounted, as shown in *Figure 14*, to measure the energy required to fracture it (pull it apart) due to rapid tensile loading.

Heat deflection temperature

The heat deflection temperature is the temperature at which a 1/2” (ASTM) or 4mm (ISO) thick test bar, loaded to a specified bending stress, deflects by 0.010 in. (ASTM) or 0.34mm (ISO) (*Figure 15*). It is often referred to as the “heat deflection temperature” (HDT). This value is used as a relative measure of the ability of various materials to perform at elevated temperatures short term, while supporting loads.

Figure 15: Heat deflection temperature



Continuous service temperature

This value is most commonly defined as the maximum ambient service temperature (in air) that a material can withstand and retain at least 50% of its initial physical properties after long term service (approximately 10 years). Most thermoplastics can withstand short-term exposure to higher temperatures without significant deterioration. When selecting materials for high temperature service, both HDT and continuous service temperature must be considered.

Glass transition temperature (TG, DMA tan delta)

The glass transition temperature (Tg) is the temperature above which an amorphous polymer becomes soft and rubbery. It is critical that an amorphous polymer is used below its Tg if reasonable mechanical performance is expected. Thermoforming processing is typically conducted at or just above the Tg. Semicrystalline materials also exhibit a Tg but this is not generally reported. The HDT reflects this softening point of the amorphous phase. The Tg can be readily observed on the DMA curves as the temperature at which the material’s modulus significantly decreases with small changes in temperature.

Melting point

The temperature at which a semi-crystalline thermoplastic changes from a solid to a highly viscous phase.

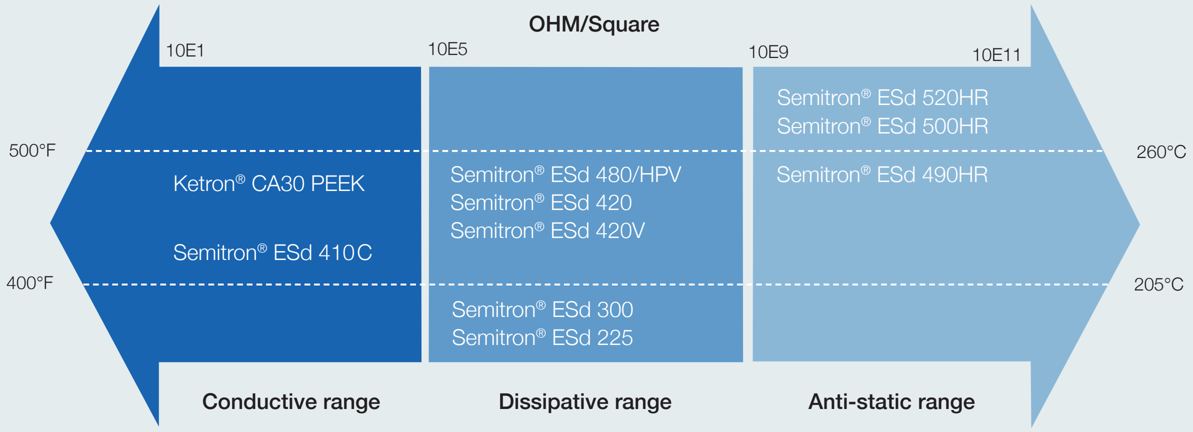
Coefficient of linear thermal expansion (ASTM E 831 (TMA))

The coefficient of linear thermal expansion (CLTE), is the ratio of the change in a linear dimension to the original dimensions of the material for a unit change of temperature. It is usually measured in units of µin./in. °F or µm/ (m.K). The CLTE is important to consider if dissimilar materials are going to be assembled in applications involving large temperature changes. A thermoplastic’s CLTE can be decreased (making it more dimensionally stable) by reinforcing it with glass fibers or other additives. The CLTE may be influenced by resin flow and the orientation of reinforcements. Reinforcements like glass fiber will reduce CLTE in the oriented direction. The CLTE of plastics vary widely, and the most stable plastics approach the CLTE of aluminum but exceed that of steel by up to ten times.

Flammability

In applications (where plastic constitutes a significant percentage of an enclosed space), the consequences of exposure to an actual flame must be considered (i.e. plastic panels used in the interior of an aircraft cabin). Flammability tests measure combustibility, smoke generation, and ignition temperatures of materials.

Figure 16: Resistivity continuum



UL 94 flammability class (HB, V-2, V-1, V-O, 5V)

In this test, specimens are subjected to a specified flame exposure, and the relative ability to continue burning after the flame is removed is the basis for classification. In general, more favorable ratings are given to materials that extinguish themselves rapidly and do not drip flaming particles. Each rating is based on a specific material thickness (i.e. UL94 - V1 @ 1/8” (0.125mm) thick). The UL rating scale from highest burn rate to most flame retardant is HB, V-2, V-1, V-0, 5V (*Figure 17*).

Figure 17: Flammability classes

Surface resistivity (EOS / ESD STM 11.11)

This test measures the ability of electric current to flow over the surface of a material and is expressed in ohms per square area. The more readily the current flows, the lower the surface resistivity as resistivity continuum (*Figure 16*) indicates. The test electrodes are both placed on the same side of the test specimen, and to measure current flow, one must consider that the surface resistivity may be affected by environmental changes such as moisture absorption. Surface resistivity is used to evaluate and select materials for testing when static charge dissipation or other surface characteristics are critical.

Dielectric strength (ASTM D149 / IEC 60243)

When an insulator is subjected to increasingly high voltages, it eventually carbonizes and arcs creating a conductive path. The voltage reached before break down, divided by the sample thickness is the dielectric strength of the material, measured in (Volts/mm). It is generally measured by putting electrodes on either side of a test specimen and increasing the voltage at a controlled rate. Factors that affect dielectric strength in applications include: temperature, sample thickness, conditioning of the sample, rate of increase in voltage, and duration of test. Contamination or internal voids in the sample also affect dielectric strength.

Duratron® U1000 PEI features the highest short term dielectric strength of 830 Volts/mil - 32 kV/mm, making it the most suitable for insulators of all engineered plastics.

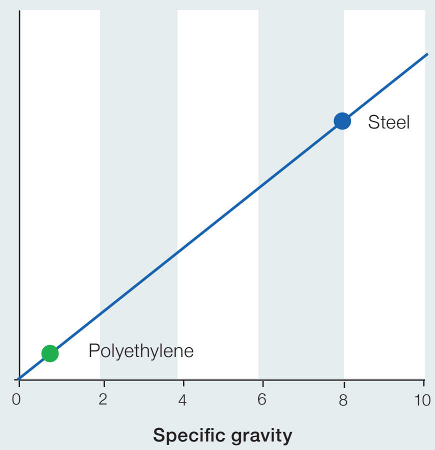
Dielectric constant (ASTM D15O / IEC 62631)

The dielectric constant, or permitivity, is a measure of the ability of a material to store electrical energy.

Polar molecules and induced dipoles in a plastic will align themselves with an applied electric field. It takes energy to make this alignment occur, and some of the energy is converted to heat in the process. This loss of electrical energy in the form of heat is called dielectric loss, and is related to the dissipation factor. The rest of the electrical energy required to align the electric dipoles is stored in the material. It can be released at a later time to do work.

The higher the dielectric constant, the more electrical energy can be stored. A low dielectric constant is desirable in an insulator, whereas someone wanting to build a capacitor will look for materials with high dielectric constants. Dielectric constants are dependent on factors such as frequency, temperature, moisture, chemical contamination and other factors. The values stated in Mitsubishi Chemical Advanced Materials' literature are measured at 1 MHz using carefully conditioned samples.

Figure 18: Specific gravity of materials



Dissipation factor (IEC 62631, ASTM D150)

The dissipation factor, or dielectric loss tangent, indicates the ease with which molecular ordering occurs under an applied voltage. It is most commonly used in conjunction with dielectric constant to predict power loss in an insulator.

Materials with specific gravities less than 1.0 (such as polyethylene and polypropylene) float in water. This can help with the identification of an unknown plastic.

Specific gravity (ASTM D792) / Density (ISO 1183)

Specific gravity is the ratio of the mass of a given volume of material compared to the mass of the same volume of water, measured at 73°F (23°C). This can also be interpreted as the density of a material divided by the density of water.

Water absorption (ISO 62 / ASTM D570)

Water absorption is the percentage increase in weight of a material due to absorption of water. Standard test specimens are first dried then weighed before and after immersion in 73°F (23°C) water.

Weight gain is recorded after 24 hours, and again when saturation is reached. Both percentages are important since they reflect absorption rate.

Mechanical and electrical properties and dimensional stability are affected by moisture absorption. The amount of dimensional or property change associated with water absorption varies from material to material. It is also reversible meaning parts that have absorbed water can be dried to recover the original dimensions and properties.

Ambient humidity will influence a materials water absorption. Highly hygroscopic materials like nylons will often change dimensionally over time as they absorb moisture from the air.

Tribological properties

Coefficient of friction (ASTM D 3702 / MCAM TM 55007 / Method A: (pin-on-disk), as described in ISO 7148-2)

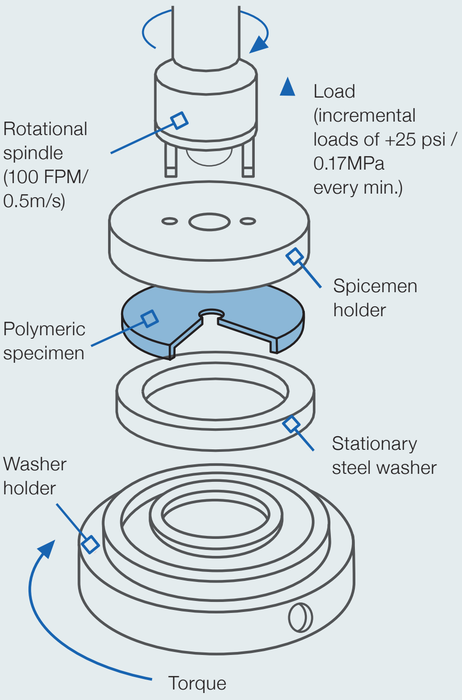
Coefficient of friction (COF) is the measure of resistance to the sliding of one surface over another. Testing can be conducted in a variety of ways. The results do not have a unit of measure associated with them because the COF is the ratio of sliding force to normal force acting on two mating surfaces. Most values are for plastics sliding against polished steel without lubrication. Since the value reflects sliding resistance, the lower the value, the "slicker" the bearing material.

Two values are usually given for COF:

- **"Static"** COF refers to the resistance at initial movement from a bearing "at rest".
- **"Dynamic"** COF refers to the resistance once the bearing or mating surface is in motion at a given speed.

The difference between the static and dynamic COF's indicates "slip-stick". A large difference indicates high slip-stick, and a low (or no) difference indicates low slip-stick. Slip-stick characteristics are important for applications which move intermittently, or require a back-and-forth motion. For a low slip-stick solution, look at Nylatron® GSM Blue PA6, Nylatron® NSM PA6 and Nylatron® 703 XL PA6.

Figure 19: Thrust washer test set-up (TM 55007)



PV and limiting PV (TM 55007)

Two factors that must be considered when reviewing a bearing application:

- **P =** the load or stress acting on the bearing which is reported as lbs./in^2 or MPa
- **V =** the speed or motion between the two contact surfaces which is reported as ft./min. or m/s

The result of multiplying P by V is referred to as the PV for a bearing application. The combination of pressure and velocity causes frictional heat at the bearing surface. This heat can contribute to premature bearing failure due to overheating, if an application PV exceeds the capability of a plastic bearing material.

A material's limiting PV (LPV) is the maximum pressure times velocity (P x V) a material can withstand in an non-lubricated environment. Exceeding this limit typically results in surface melting and rapid bearing failure.

To determine the Limiting PV, a thrust washer test is utilized (*Figure 19*). The plastic sample is rotated at 100 feet per minute (FPM) (0.5m/s), and is exposed to incremental loads of 25 psi (0.17MPa) every 10 minutes while the bearing temperature is measured. The test ends:

- When the system temperature exceeds 300°F / 150°C.
- After excessive deformation.
- When a significant amount of wear of the plastic is detected.

Nylatron® NSM PA6 for bearing applications combines low wear rates with high liimiting PV which allows greater safety and design flexibility.

Wear resistance / “ k” factor (TM 55010 / ISO 7148-2)

The wear rate of a material in a specific application depends on many factors. In order to predict relative part life we measure the wear rate of various materials under standardized test conditions using laboratory test equipment. The variables of pressure, velocity and time are proportional to wear allowing us to calculate a wear factor (“k” factor) for each set of test conditions.

wear (in.) = (k) PVT x 10^{-10} or “k”= wear x 10^{10}

Extreme wear from improper design clearance

The lower the “k” factor, the greater the wear resistance.

Results from this test can vary significantly if different pressure and velocity conditions are used. Consistency of test methods is critical if “k” factors are used to compare various materials.

Figure 20: Wear factor “k” test (TM 55010)

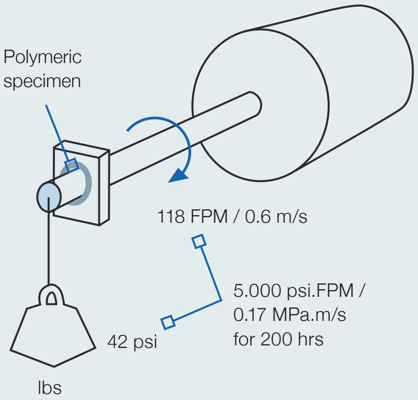
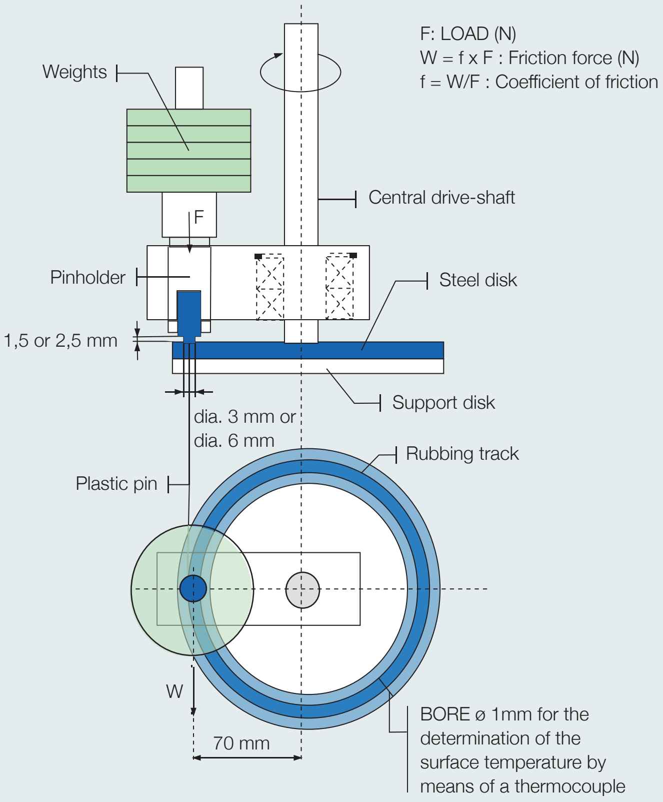


Figure 21: Wear resistance (method A: “pin-on-disk”, as described in ISO 7148-2)



The wear factor relates to the amount of material loss measured over a given distance when two mating parts are sliding over each other.

This test (*Figure 21*) uses a rotating steel disk at a velocity of 0.33 m/s / 65 FPM on which a plastic “pin” is compressed at a pressure of 3MPa 435 PSI = 0.99 MPa.m/s (PV) / 28,275 PSI.FPM. After 28 km of continuous running, the radial wear of the bearing is measured and expressed as µm wear per km rotating distance.

Considerations of bearing application requirements

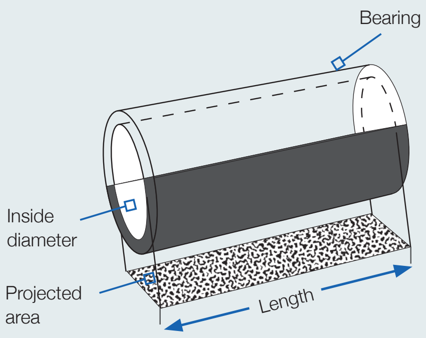
Engineering thermoplastics are commonly used as plane bearings on both newly designed and existing machinery to eliminate the need for external lubrication and maintenance. These materials can replace rolling element bearings and metallic plane bearings made from soft metals such as bronze and lead alloys.

4

Bearing design

Plastics have inherently low friction properties often allowing the designer to eliminate the need for external lubrication while reducing the potential to damage mating surfaces. Selection of an appropriate plastic bearing material requires consideration of an application's unit pressure, linear velocity, ambient temperature and operation cycle time. Other special application requirements such as chemical resistance, dimensional stability and impact resistance must also be considered before final material selection. After choosing an appropriate material, design of the bearing (especially running clearance for any journal bearing) is required.

Figure 22: Bearing contact area



Step 1 : Determine the bearing's operating PV

Application PV = pressure (psi or MPa) x velocity (FPM or m/s)

Determining surface velocity

For sleeve bearings, the formula
V = 0.262 x rpm x D (FPM) or
$V = 5.24^{-5}$ x rpm x D (m/s)
is used to determine the surface velocity "V" in fpm or m/s, from the shaft diameter, "D" (in. or mm) and the shaft revolutions per minute, or rpm. For linear motion, the surface velocity is the speed at which the sliding surface is moving across the mating surface.

Determining unit pressure

For flat bearing surfaces, "P" is simply the total load (lbs. or N) divided by the total contact area ($in.^2$) or (mm^2). For sleeve bearings, "P" is calculated by dividing the total load on the bearing by the projected area of the bearing surface. The projected area of sleeve bearings is calculated by multiplying the bearing inner diameter (inches or mm) by the bearing length (inches or mm).

A thermoplastic material must have enough structural and thermal capability to sustain operation at the given application PV. This capability is measured as a material's Limiting PV (LPV). This term is commonly reported as a single value although it may vary for extremes in velocity and load.

Figure 22a: Bearing and wear properties comparison (Imperial)

MATERIAL	SERVICE TEMP. [degreeF]	CONTINUOUS LIMITING PV [psi.fpm]	"K" FACTOR	COEFFICIENT OF FRICTION (dynamic)	COMPRESSIVE STRENGTH [psi]
TIVAR® 1000 UHMW-PE	180	3,000	111	111	3,000
Acetron® GP POM-C	180	2,700	200	200	15,000
Acetron® POM-H	180	2,700	200	200	16,000
Acetron® AF Blend POM-H	180	8,300	60	60	16,000
Semitron® ESd 225 POM-C	180	2,000	30	30	8,000
Nylatron® 703 XL PA6	200	17,000	26	26	10,000
Nylatron® PA66	200	2,700	80	80	12,500
Nylatron® MC907 PA6	200	3,000	100	100	15,000
Nylatron® GSM PA6	200	3,000	90	90	14,000
Nylatron® GS PA66	200	3,000	90	90	16,000
Nylatron® NSM PA6	200	15,000**	12	12	14,000
Ertalyte® PET	210	2,800	60	60	15,000
Ertalyte® TX PET	210	6,000	35	35	15,250
Nylatron® MC901 PA6	260	3,000	100	100	15,000
Techtron® HPV PPS	430	8,750	62	62	15,500
Ketron® 1000 PEEK	480	8,500	375	375	20,000
Ketron® CA30 PEEK	482	25,000	150	150	29,000
Ketron® HPV PEEK	482	20,000	100	100	20,000
Duratron® T4301 PAI	500	40,000*	10	10	22,000
Duratron® T4501 PAI	500	22,500	150	150	16,000
Fluorosint® 500 PTFE	500	8,000	600	600	4,000
Fluorosint® 207 PTFE	500	8,000	85	85	3,800
Fluorosint® HPV PTFE	500	20,000	38	38	3,000
Duratron® D7015G PI	500	40,000	10	10	25,000
Duratron® CU60 PBI	600	37,500	60	60	50,000

* Value represents the LPV for a machined part with post curing after machining. Post curing parts machined from extruded or injection molded Duratron® PAI significantly increases the LPV.
** At surface speeds below 20 ft./min. the LPV (Basic Limiting PV) may be doubled.

> The maximum unit pressure must always be less than the compressive strength. A good design practice is to divide the compressive strength of a material by 4, and use this value as a maximum "working stress" or maximum unit pressure for a plastic bearing.

Step 2: Select a material and apply the PV correction factors

IMPERIAL:

LPV is the maximum PV that a given material can withstand at 75°F, running continuously without lubrication. *Figure 22a* presents LPV values for various plastic bearing materials. When ambient temperature is approximately 75°F, use H=1 and when bearings are running continuously, C=1. To ensure success, the application PV must be lower than the PV adjusted. Adjustment of LPV is accomplished by multiplying by the correction factors ("H" and "C") obtained from *Figures 23* and *24a*. When ambient temperature is approximately 75°F, use H=1 and when bearings are running continuously, C=1. To ensure success, the application PV must be lower than the PV adjusted.

$PV_{ADJUSTED}$ = Limiting PV of selected material x H x C

Figure 22b: Bearing and wear properties comparison (metric)

	MATERIAL	LIMITING PV at 0,1 m/s at 23°C (MPa. m/s)	LIMITING PV at 1 m/s at 23°C (MPa. m/s)	MAXIMUM ALLOWABLE BEARING TEMPERATURE (°C)	MAXIMUM COMPRESSIVE STRESS BEARING RETAINED (MPa)	MAXIMUM COMPRESSIVE STRESS BEARING NOT-RETAINED (MPa)
Less extreme temp.	Ertacetal® C POM-C	0,16	0,10	90	70	22
	Ertacetal® H POM-H	0,16	0,10	90	75	24
	Ertalon® 4.6 PA4.6	0,16	0,10	120	64	19
	Ertalon® 6 SA PA6	0,12	0,07	80	50	15
	Ertalon® 6PLA PA6	0,13	0,08	90	68	20
	Ertalon® 6 XAU+	0,14	0,09	100	68	20
	Ertalon® 66 SA PA66	0,13	0,08	90	60	18
	Nylatron® 703 XL PA6	0,48	0,30	90	48	14
	Nylatron® GSM PA6	0,13	0,08	90	64	19
	Nylatron® MC 901 PA6	0,13	0,08	90	60	18
	Nylatron® NSM PA6	0,39	0,25	90	58	17
	Nylatron® GS PA66	0,13	0,08	90	60	18
	Ertalyte® PET	0,15	0,09	90	84	40
	Ertalyte® TX PET	0,26	0,16	90	74	35
	Techtron® 1000 PPS	0,15	0,09	220	70	30
	Techtron® HPV PPS	0,44	0,28	200	90	47
	Ketron® 1000 PEEK	0,33	0,21	200	93	49
	Ketron® CA30 PEEK	0,83	0,52	250	110	66
	Ketron® HPV PEEK	0,66	0,42	250	100	57
	Duratron® T4203 PAI	0,60	0,38	200	100	59
	Duratron® T4301 PAI	1,10	0,69	250	115	73
	Fluorosint® 207 PTFE	0,40	0,25	260	48	14
	Fluorosint® 500 PTFE	0,40	0,25	260	60	20
More extreme temp	Fluorosint® HPV PTFE	0,95	0,60	260	48	14
	Fluorosint® MT-01 PTFE	0,22	0,14	260	60	20
	Duratron® D7000 PI	0,46	0,29	240	69	35
	Duratron® D7015G PI	1,70	1,07	250	81	44
	Duratron® CU60 PBI	1,80	1,14	310	100	57

METRIC:

The LPV values for plastic bearing designs, at an operating speed of 0,1 and 1 m/s., can be found in the bearing and wear properties comparison table (*Figure 22b*) for various materials. LPV is the maximum PV that a given material can withstand at 23°C, running continuously without lubrication. The basic LPV taken from this table must be adjusted to compensate for:

1. Ambient temperatures other than 23°C
2. Operating speeds other than 0.1 and/or 1 m/s (use of interpolation or extrapolation)
3. Cycle time if continuous operation is not required.

Adjustment of LPV (for points 1 and 3) is accomplished by multiplying by the correction factors ("H" and "C") obtained from *Figures 23* and *24b*. Be aware, the first step is to calculate the PV at the operating speed in the application (point 2).

Continuous lubrication including oil, grease, and water greatly increase the service life of thermoplastic bearings. Lubrication is usually suggested for velocities greater than 400 FPM (2m/s).

Fig. 23: Ambient temperature correction (H)

When the ambient temperature (surrounding temperature, not heat generated in the bearing from operation) is higher or lower than 75°F, PV capabilities change. Ambient temperatures above or below 75°F affect the allowable temperature rise and load capability of thermoplastic bearings. Refer to the formula below, to compensate PV for variations in ambient temperature.

$PV_{ADJUSTED} = PV \times H$

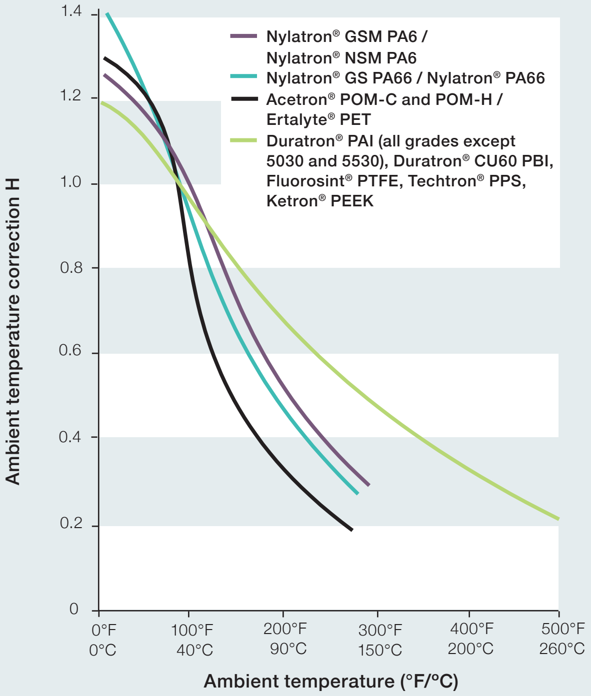


Fig. 24a: Cycle time correction (C)

The rates of heat generation and heat dissipation greatly impact the performance of plastic bearings. If operation is intermittent rather than continuous, the rate of heat generation is reduced, even though the rate of heat dissipation remains constant.

Instructions for use:
Locate the operating period or "on" period on the horizontal scale. Read upwards to intersect with the appropriate curve.

If the off period is the same as the on period, use the (1X) curve. If the off period is two times the on period, use the (2X) curve. If the off period is three and one-half times the on period, use the (3x) curve. If it is four times the on period, use the (4x) curve.

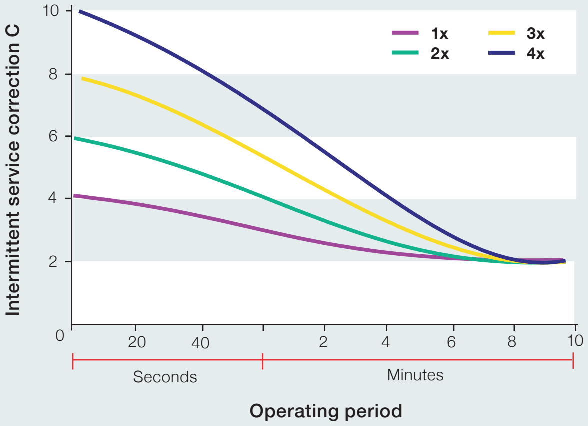


Fig. 24b: Cycle time correction (C)

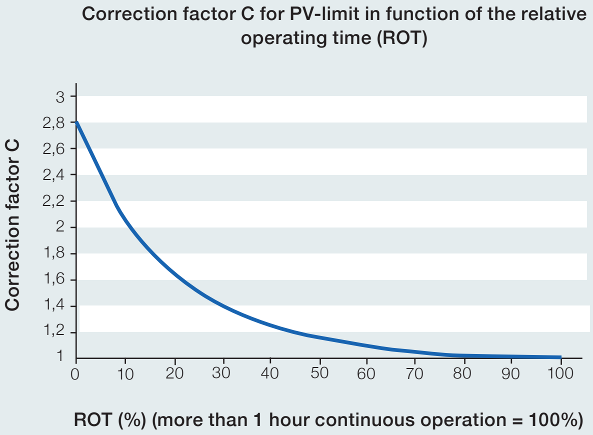
The rates of heat generation and heat dissipation greatly determine the performance of plastic bearings. If operation is intermittent rather than continuous, the rate of heat generation is reduced although the rate of heat dissipation remains constant.

Instructions for use:
The relative operating time (ROT) is calculated by the following equation:

ROT = 100 x OT /BT (%)
BT = basic time = 60 minutes
OT = operating time ("on" – period) in 60 minutes

Locate the calculated ROT (%) in the graph where after the correction factor "C" can be found.

$PV_{ADJUSTED} = PV \times C$



Step 3: Bearing clearance (bearing design imperial)

In most cases, clearance is often understated and is frequently the cause of premature bearing failure. This can be attributed to the fact that most plastic bearing clearances are greater than those recommended for metal bearings.

Metal bearings installed with excessive clearance often result in shaft vibrations, and the scoring (brinnelling) of the bearing and shaft. Plastics, on the other hand, are far more resilient due to their ability to resist scoring, and dampen the shaft vibration.

Total running clearance is obtained by adding three allowances. The total running clearance is then added to the nominal bearing I.D. (shaft diameter) to obtain the actual or design I.D. of the bearing.

Total Running Clearance =
$a_1 + a_2 + a_3$

a_1 = Basic shaft allowance
The basic shaft allowance a_1 is the same for all plastic bearing materials and depends only on the diameter of the shaft to be supported. *Figure 25* was developed from application data on plastic bearings.

a_2 = Wall thickness allowance
(a function of the bearing material, bearing wall thickness, and the ambient operating temperature). Refer to the wall factor from *Figure 26* and multiply by the nominal wall thickness to obtain a_2.

Wall thickness allowance (a_2) is derived from the coefficients of thermal expansion for plastic bearing materials, where each plastic reacts to changing temperatures at a characteristic rate. The thicker the bearing wall, the more material available to expand with higher temperatures. Refer to *Figure 26*, which demonstrates that the higher the ambient temperatures and / or the thicker the bearing walls, the greater the required running clearance.

a_3 = Press fit allowance
Used only when the bearing is to be press fit. It is important to note that a_3 is the same as the recommended press fit interference (see in *Figure 29)*.

When plastic bearings are press fitted into metallic housings or retainers, a recommended interference (*Figure 29*) should be used to ensure that the bushing is adequately secured to resist rotating with the shaft. During press fit, the plastic bearing conforms to the housing I.D. Therefore, the I.D. of the bearing closes-in.

The I.D. close-in will approximately equal the press fit interference. Close-in is compensated with an additional I.D. clearance equal to the interference (a_3).

Fig. 25: (a_1) Basic shaft allowance vs. shaft diameter

SHAFT ALLOWANCE, a_1	SHAFT DIAMETER
.005"	1"
.009"	2"
.012"	3"
.015"	4"
.017"	5"
.020"	6"
.022"	7"
.024"	8"
.026"	9"
.028"	10"
.030"	11"
.032"	12"

Fig. 26: (a_2) Wall factor for plastic bearing materials at various ambient temperatures - for calculation of a_2 (inches)

MATERIAL °F	75°	100°	125°	150°	175°	200°	225°	250°	275°	300°	350°	400°	450°	500°
Nylatron® PA66 / Acetron® POM	.018	.021	.023	.026	.028	.031	.033	.036	.038	-	-	-	-	-
Nylatron® PA6 grades	.015	.016	.018	.019	.021	.023	.024	.026	.026	-	-	-	-	-
Nylatron® GS PA66 / Ertalyte® PET	.013	.015	.016	.018	.020	.022	.023	.025	.027	-	-	-	-	-
Fluorosint® PTFE	.007	.007	.008	.008	.009	.009	.010	.010	.011	.011	.012	.013	.014	.015
Ketron®HPV PEEK / Techtron® HPV PPS	.007	.007	.008	.008	.009	.009	.010	.010	.011	.011	.012	.013	.014	.015
Bearing grade Duratron® PAI	.007	.007	.008	.008	.009	.009	.010	.010	.011	.011	.012	.013	.014	.015
Duratron® CU60 PBI	.007	.007	.008	.008	.009	.009	.010	.010	.011	.011	.012	.013	.014	.015

Note: For temperatures other than given, use the next highest temperature that appears in the table.

Step 3: Bearing clearance (bearing design metric)

In most cases, clearance is often understated and is frequently the cause of premature bearing failure. Most plastic bearing failures are caused by insufficient clearance.

Plastic bearing clearances are much greater than those recommended for metal bearings. Metal bearings installed with excessive clearance often result in shaft vibrations and scoring (brinnelling) of the bearing and shaft. Plastics, on the other hand, are far more resilient, resist scoring and dampen shaft vibration. Total running clearance is obtained by adding three allowances. The total running clearance is then added to the nominal bearing I.D. (shaft diameter) to obtain the actual or design I.D. of the bearing.

Total running clearance =
$a_1 + a_2 + a_3$

a_1 = Basic shaft allowance
The basic shaft allowance a_1 is the same for all plastic bearing materials and depends only on the diameter of the shaft to be supported. *Figures 27, 32a,* and *32b* were developed from application data on plastic bearings.

a_2 = Wall thickness allowance
(a function of the bearing material, bearing wall thickness, and the operating temperature)

First we need to calculate the bearing temperature during use. If the application PV-value is the same as the PV-adjusted, then the bearing would heat up from the temperature at the beginning to the maximum allowable bearing temperature as mentioned in *Figure 22b*. But to ensure a good bearing performance, the application PV should be lower than the PV-adjusted and hence, the bearing temperature during use will be lower than the maximum allowable bearing temperature.

The bearing temperature during use has to be calculated to determine the expansion factor (α). This temperature can be calculated by means of the following equation:

The expansion factor alpha can now be derived from Figure 28 using the bearing temperature calculated before. Use the following equation to obtain a_2.

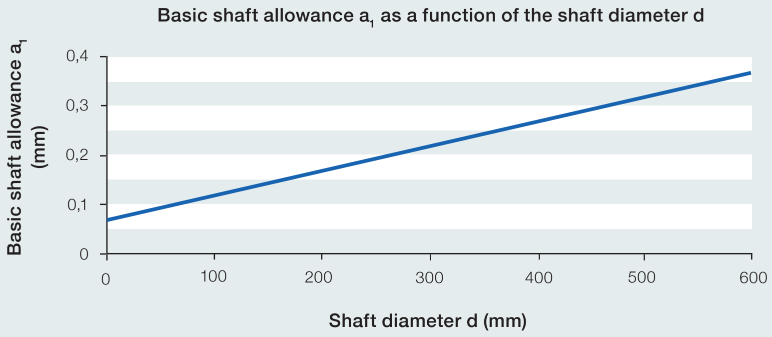
$a_2 = (D^2/d^2 - 1).\alpha.d.$

In which
D = inside diameter of the bearing housing (mm)
d = shaft diameter (mm)
α = expansion factor (-)

The wall thickness allowance (a_2) is derived from the coefficients of thermal expansion for plastic bearing materials. Each plastic reacts to changing temperatures at a characteristic rate. The thicker the bearing wall, the more material there is available to expand with higher temperature. Hence, *Figure 28* demonstrates that the higher the bearing temperature, the greater the required running clearance.

$$\text{Bearing temp} = \text{Start temp} + \left(\text{max temp } (\textit{fig.22b}) - \text{start temp}\right) \times \left(\frac{(\text{Application PV})}{(\text{Adjusted PV})}\right)$$

Figure 27: Basic shaft allowance a_1 versus shaft diameter



$$a_1 = 0.07 + 0.0005 \times d$$

Figure 28: Expansion factor α for plastic bearing materials at various temperatures - for calculation of a_2 (mm)

MATERIAL	23°C	40°C	60°C	80°C	100°C	120°C	150°C	180°C	200°C	220°C	250°C
Ertacetal® C POM-C	0,001	0,003	0,005	0,008	0,011	-	-	-	-	-	-
Ertacetal® H POM-H	0,001	0,003	0,005	0,007	0,01	-	-	-	-	-	-
Ertalon® 46 PA4,6	0,008	0,01	0,0012	0,014	0,016	0,017	-	-	-	-	-
Ertalon® 6 SA PA6	0,008	0,01	0,001	0,014	0,016	-	-	-	-	-	-
Ertalon® 66 SA PA66	0,007	0,009	0,01	0,013	0,014	-	-	-	-	-	-
Ertalon® 66 GF30 PA66	0,005	0,006	0,007	0,009	0,01	-	-	-	-	-	-
Ertalon® 6PLA PA6	0,007	0,008	0,01	0,012	0,014	-	-	-	-	-	-
Ertalyte® PET	0,001	0,002	0,003	0,006	0,007	-	-	-	-	-	-
Ertalyte® TX PET	0,001	0,002	0,003	0,006	0,007	-	-	-	-	-	-
Nylatron® 703 XL PA6	0,006	0,008	0,009	0,012	0,014	-	-	-	-	-	-
Nylatron® GS PA66	0,007	0,009	0,01	0,012	0,014	-	-	-	-	-	-
Nylatron® GSM PA6	0,007	0,009	0,01	0,013	0,014	-	-	-	-	-	-
Nylatron® NSM PA6	0,006	0,008	0,009	0,012	0,014	-	-	-	-	-	-
TIVAR® 1000 UHMW-PE	0	0,004	0,008	-	-	-	-	-	-	-	-
Duratron® CU60 PBI	0,011	0,012	0,012	0,013	0,013	0,014	0,015	0,015	0,016	0,016	0,018
Duratron® D7000 PI	0,003	0,004	0,005	0,006	0,007	0,007	0,009	0,01	0,011	0,012	0,014
Duratron® D7015G PI	0,002	0,003	0,003	0,004	0,005	0,006	0,007	0,008	0,009	0,009	0,01
Duratron® T4203 PAI	0,003	0,003	0,004	0,005	0,006	0,007	0,008	0,009	0,01	0,011	0,013
Duratron® T4301 PAI	0,002	0,003	0,003	0,004	0,005	0,005	0,006	0,008	0,008	0,009	0,01
Fluorosint® 207 PTFE	0	0,002	0,004	0,005	0,007	0,009	0,011	0,014	0,016	0,018	0,027
Fluorosint® 500 PTFE	0	0,001	0,002	0,003	0,004	0,005	0,007	0,008	0,01	0,011	0,016
Fluorosint® HPV PTFE	0	0,002	0,003	0,005	0,006	0,008	0,01	0,013	0,014	0,016	0,022
Fluorosint® MT-01 PTFE	0	0,001	0,003	0,004	0,005	0,006	0,008	0,01	0,011	0,013	0,02
Ketron® 1000 PEEK	0,001	0,002	0,003	0,004	0,005	0,006	0,008	0,009	0,01	0,011	0,021
Ketron® CA30 PEEK	0,001	0,001	0,002	0,002	0,003	0,003	0,004	0,005	0,005	0,006	0,013
Ketron® HPV PEEK	0,001	0,001	0,002	0,003	0,004	0,004	0,005	0,007	0,007	0,008	0,01
Techtron® HPV PPS	0	0,001	0,002	0,004	0,005	0,006	0,007	0,009	0,01	-	-

Note: For temperatures other than given, use interpolation methods to calculate the required expansion factor.

Figure 29: Recommended press-fit interference versus housing inside parameter (a_3)

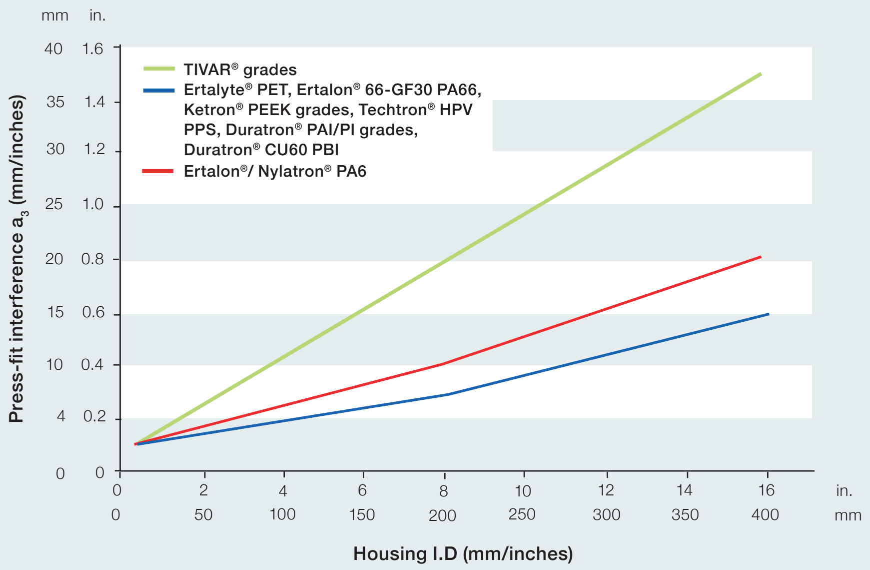
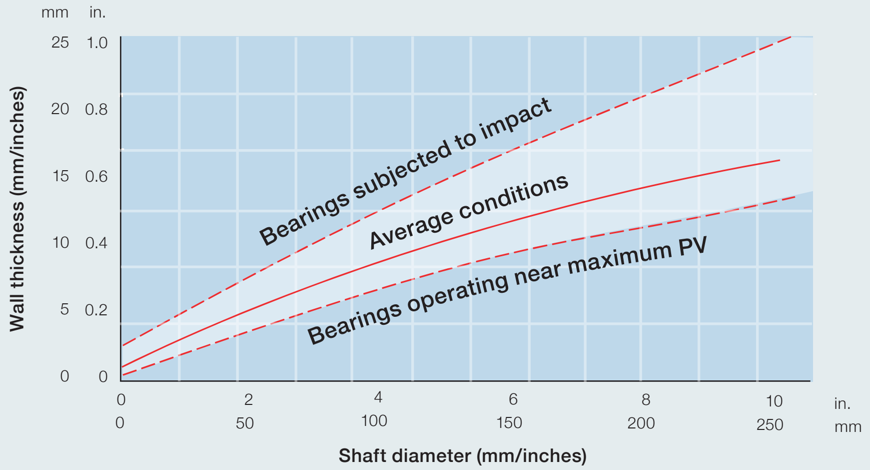


Figure 30: Bearing wall thickness



a_3 = Press-fit allowance:
Used only when the bearing is to be press fit. Note that a_3 is the same as the recommended pressinterferencefit interference (obtain from *Figure 29*). When plastic bearings are press-fit into metallic housings or retainers, a recommended interference (*Figure 29*) should be used to ensure that the bushing is adequately secured to resist rotating with the shaft. During press-fit, the plastic bearing conforms to the housing I.D. Therefore, the I.D. of the bearing closes-in. The I.D. close-in will approximately equal the press-fit interference. Close-in is compensated with an additional I.D. clearance equal to the interference (a_3).

Step 4: Additional design considerations

A) Bearing wall thickness
In many bearing applications, the nominal wall thickness is dictated by the geometry of existing equipment. The plastic bearing is designed from the dimensions of the shaft and the housing. When new equipment is being designed, the engineer is at greater liberty to establish nominal wall thickness.

Figure 30 suggests a range of nominal wall thicknesses for different shaft diameters. Thicker walls are recommended for bearings subjected to severe impact conditions, and minimum walls for bearings operating near the material's maximum recommended PV value.

B) Bearing length / diameter ratio
Bearing length to shaft diameter ratio has a noticeable effect on bearing friction. For a ratio of 1:1 (bearing length equal to the shaft diameter), friction is generally lowest. As the bearing length is increased to two or three times the shaft diameter, there is increased friction and an increased probability of local heating due to out-of-roundness and shaft vibration. On the other hand, very short bearings are often difficult to retain within the bearing housing.

C) Shafts and mating parts
Shafts and mating parts perform best if made from hardened and ground steel. Unhardened steel surfaces will wear quickly in many applications, particularly if unlubricated. Commercial shafting normally is supplied with a surface hardness of Rockwell C-55, although shafting with Rockwell hardnesses as low as C-35 will perform satisfactorily. Shafts and mating parts of stainless steel should be specified in a hardenable grade. In general, harder stainless grades such as 316 are suggested over 303/304 grades.
Mating metal parts should have a smooth surface obtained by grinding or hard plating. Commercial shafting normally is finished to 16 RMS (Ra about 0.35) although a 32 RMS (Ra about 0.8) is usually acceptable. The finish of the plastic bearing is not critical and can be as coarse as 125 RMS (Ra about 3.2).

Nylatron® bearing for wet applications

A) Bearing wall thickness
If your bearing is to be water lubricated and made from nylon, an additional clearance must be added to allow for moisture related expansion of the nylon. Use clearances (*figure 31*) regardless of bearing diameters. Note that as wall thickness increases, moisture clearance increases in progressively smaller amounts. This is due to the increasing resistance of the thicker sections to moisture penetration. Remember to add a moisture factor in your bearing design for water lubricated nylon bearings:

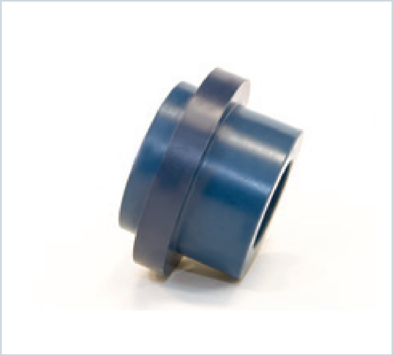
Figure 31: Moisture factor in function of shaft diameter

SHAFT DIAMETER	CLEARANCE (MM)	SHAFT DIAMETER	CLEARANCE (IN)
< 3 mm	0.30	1/8”	0.012
3 - 5 mm	0.43	3/16”	0.017
5 - 6 mm	0.53	1/4”	0.021
6 - 10 mm	0.66	3/8”	0.026
10 - 13 mm	0.76	1/2”	0.03
13 - 25 mm	0.81	3/4”	0.032
		1" and above	0.033

- Non-hygroscopic materials such as Ertalyte® PET and Acetron® GP / Ertaceta®l C POM-C may offer improved wear resistance in wet environments.

Internally lubricated materials such as Nylatron NSM PA6, Nylatron® GSM Blue PA6, Ertalyte® TX PET, Nylatron® LIG PA6 and Ertalon® LFX PA6 provide the lowest cost in use when application PV is less than Limiting PV. Please consult MCAM's team of experts for more information.


Techtron® HPV PPS


Nylatron® GSM Blue PA6

Bearing design metric worksheet

Note: This worksheet applies to sleeve bearings only. Contact us at Technicalsupport@mcam.com with any other bearing related questions.

Information required

Housing bore ________________________ mm

Shaft diameter _______________________ mm

Length ____________________________ mm

Shaft rpm ___________________________

Bearing load _________________________ N

How many bearings per shaft ___________

Ambient temperature __________________ °C

Cycle ☐ Continuous ☐ Intermittent

☐ Time on _____ Time off ______

☐ Is bearing lubricated?

☐ Yes

How?_________________________________

Any chemicals in use?___________________________

How is the bearing retained? _____________________

Type of bearing? ________________________________

Steps 1 & 2: Determine bearings' operating PV, Select material & correction factors

Projected area Bearing ID (mm) __________ x length (mm) ______________ = ____________ mm^2

Pressure Bearing load (N) __________ ÷ projected area (mm^2) __________ = _________ MPa

Velocity 5.24E-5 x ________ rpm x shaft diameter (mm) ____________ = ____________ m/s

(Note: do not exceed 2m/s for velocity for unlubricated applications)

Application PV (imposed PV on bearing)

___________ MPa x ___________ m/s =___________ PV

See (*Figure 21*, page 36) for Limiting PV

☐ Lubricated ☐ Unlubricated

Material selected _________________________________

Corrections for Limiting PV -

See *Figures 22b and 23 (page 41 and 42)*

Figure 22 – Temperature correction H = ______________

Figure 23 – Cycle time correction C = ______________

$PV_{ADJUSTED}$ (Limiting PV for material selected; then adjusted by temperature and cycle corrections)

Limiting PV of material _________ x Temp.(H) ___________

x Cycle (C) _________ = $PV_{ADJUSTED}$

If the application PV is less than the $PV_{ADJUSTED}$ limit for the material selected, the bearing will work.

Steps 3 & 4: Total running clearance

$a_1 + a_2 + a_3$

a_1 = (*Figure 24, page 42*) = ______________ mm

a_2 = (*Figure 25, page 43*)
factor (x), $a_2 = \left(\frac{D^2}{d^2} - 1\right) . \alpha . d$ = ______________ mm

a_3 = (*Figure 26, page 43*)
used if bearing is press fit = ______________ mm

Step 5: Dimension of the bearing

Housing diameter (mm) _______ +a_3 _______ = OD of bearing _______ mm

Shaft diameter (mm)____ + a_1 (mm) _____ + a_2 (mm) _____ + a_3 (mm) _____ = ID of bearing ________ mm

If a nylon bearing is to be used in a water lubricated environment, add moisture factor per *Figure 31* to the ID of the bearing to allow for moisture absorption:

ID of the bearing (mm): _______ + Moisture absorption clearance (mm) _______ = ID of bearing

Length of housing (mm) _______ - calculated expansion factor α used for a_2 (-) _______ x Length of housing (mm) _______ = Length of bearing _______ mm

Note: the length of the bearing should preferably be shorter than the length of the housing to allow for proper expansion in case of a plastic bearing retained in axial direction.

Step 6: Bearings, dimensions and tolerances

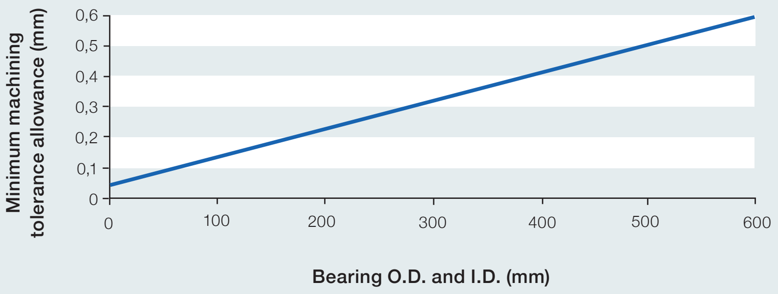
The calculated bearing dimensions need to be adjusted with the machining tolerances as given in the following figure (*Fig. 32a*):

OD = ______________ + Machining tolerances

ID = ______________ + Machining tolerances

Length = ______________ + Machining tolerances

Fig.32a: Minimum machining tolerance versus bearing diameter



Bearing design imperial worksheet

Note: This worksheet applies to sleeve bearings only. Contact us at Technicalsupport@mcam.com with any other bearing related questions.

Information required

Housing bore ________________________ in.

Shaft diameter _______________________ in.

Length _____________________________ in.

Shaft rpm ___________________________

Bearing load _________________________ lbs.

How many bearings/shaft ______________

Ambient temperature __________________ °F

Cycle ☐ Continuous ☐ Intermittent

☐ Time on _____ Time off ______

☐ Is bearing lubricated?

☐ Yes

How?________________________________

Any chemicals in use?____________________________

How is the bearing retained? _____________________

Type of bearing? ________________________________

Steps 1 & 2: Determine bearings’ operating PV, Select material & correction factors

Projected area Bearing ID (in) ___________ x length (in) _______________ = _____________sq. in.

Pressure Bearing load (N) __________ ÷ projected area (mm^2) __________ = ________ v

Velocity 5.24E-5 x ________ rpm x shaft diameter (in) ____________ = ____________ fpm

(Note: do not exceed 400 fpm for velocity for unlubricated applications)

Application PV (imposed PV on bearing)

___________ psi x ___________ fpmi =___________ PV

See (*Figure 21*, page 36) for Limiting PV

☐ Lubricated ☐ Unlubricated

Material selected __________________________________
Corrections for Limiting PV -
See *Figures 22b and 23, (page 41 and 42)*

Figure 22 – Temperature correction H = ______________

Figure 23 – Cycle time correction C = ______________

$PV_{ADJUSTED}$ (Limiting PV for material selected; then adjusted by temperature and cycle corrections)

Limiting PV of material _________ x Temp.(H) ___________

x Cycle (C) _________ = $PV_{ADJUSTED}$

If the application PV is less than the $PV_{ADJUSTED}$ limit for the material selected, the bearing will work.

Steps 3 & 4: Total running clearance

$a_1 + a_2 + a_3$

a_1 = (*Figure 24, page 42*) = ______________ in.

a_2 = (*Figure 25, page 43*)
factor (x), $a_2 = \left(\frac{D^2}{d^2} - 1\right). \alpha.d$ = ______________ in.

a_3 = (*Figure 26, page 43*)
used if bearing is press fit = ______________ in.

Step 5: Dimension of the bearing

Housing diameter (mm) _______ +a_3 _______ = OD of bearing _______ in.

Shaft diameter (mm)____ + a_1 (in.) _____ + a_2 (in.) _____ + a_3 (in.) _____ = ID of bearing ________in.

If a nylon bearing is to be used in a water lubricated environment, add moisture factor per *Figure 31* to the ID of the bearing to allow for moisture absorption:

ID of the bearing (in.): _______ + Moisture absorption clearance (mm) _______ = ID of bearing

Length of housing (in.) _______ - calculated expansion factor α used for a_2 (-) _______ x Length of housing (mm) _______ = Length of bearing _______ in.

Note: the length of the bearing should preferably be shorter than the length of the housing to allow for proper thermal expansion in case of a plastic bearing retained in axial direction.

Step 6: Bearings, dimensions and tolerances

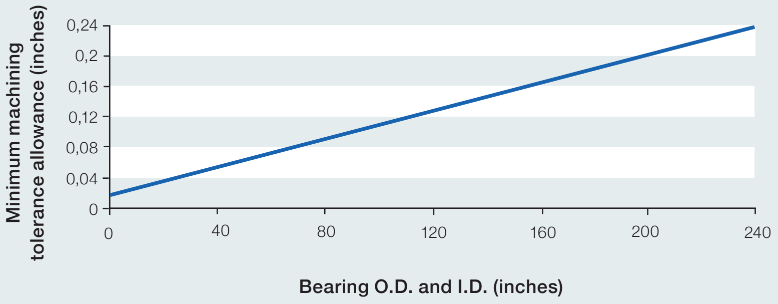
The calculated bearing dimensions need to be adjusted with the machining tolerances as given in the following figure (*Fig. 32a*):

OD = ______________ + Machining tolerances

ID = ______________ + Machining tolerances

Length = ______________ + Machining tolerances

Fig. 32b: Minimum machining tolerance versus bearing diameter



A step-by-step guide to successful roller and wheel performance in demanding work environments

Engineering plastics have many advantages over metals when it comes to applications as rollers or wheels. The abrasion-resistant, vibration-damping and low friction properties of rigid plastic provide quieter, gentler and smoother operation.

Roller and wheel design

5

Fig. 33: Roller configurations

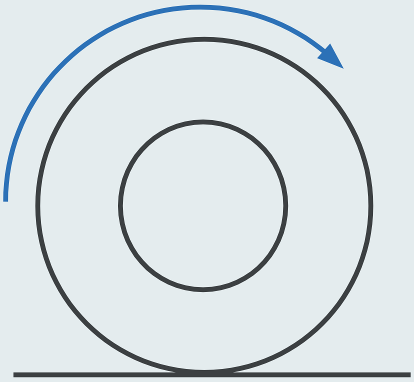


Fig. 33a: Roller on a flat surface

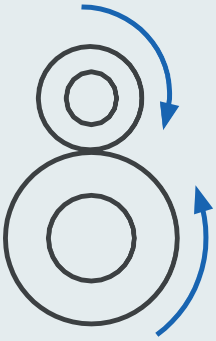


Fig. 33b: Roller on another rolling surface

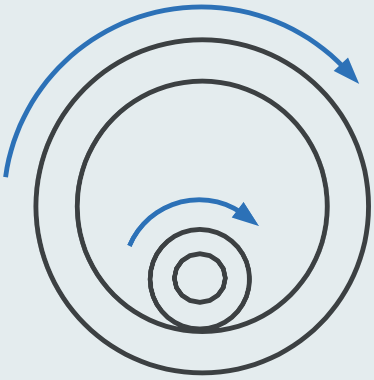


Fig. 33c: Roller in another rolling surface

Rigid plastic rollers and wheels are commonly specified instead of metal. The non-abrasive and vibration dampening characteristics of the plastic rollers / wheels result in a quieter operation environment. Typical rigid plastic roller / wheel material choices are:

- Acetron® POM grades
- Nylatron® PA grades
- Ertalyte® PET-P grades

Rigid plastics can also replace traditional resilient elastomers, such as polyurethane and vulcanized rubber. The rigid plastics are chosen for their lower coefficient of rolling resistance.

To determine the suitability of a rigid plastic roller / wheel, consider the following:

- Load upon the roller / wheel.
- Speed of the roller / wheel.
- Temperature around and on the roller / wheel.

Nylatron® NSM PA6 rollers with Ertalyte® TX bearings.

- Duty cycle of the roller / wheel (whether it is stationary or rotating).
- Creep and fatigue properties of the roller / wheel material.

The creep and fatigue properties play an important role in preventing flat spots, cracking, and softening of the rollers / wheels during their end-use. The first step in calculating their suitability, is to determine the load capacity of the proposed material. The load capacity equation is dependent upon the geometry and configuration of the wheels / rollers.

Step-by-step guide for determining the load capacity of a roller / wheel

1. Select the roller configuration (See *Figure 33*)
32a Roller on a flat surface
32b Roller on another rolling surface
32c Roller in another rolling surface

2. Select the potential roller / wheel material.
For initial material selection, consider environmental temperature & load conditions for the application.

3. Obtain the material stress factor, K (See *Figure 34*)
Note: Separate values are given for stationary vs. rotating situations and a difference between imperial and metric K factors has been given.

4. Using the equation provided for the selected roller configuration (see *Figure 33*), calculate the load capacity of the roller/wheel.

33a Roller on a flat surface

$$W_{MAX} = K (L) \times (D_p)$$

33b Roller on another rolling surface

$$W_{MAX} = K (L) \times \left(\frac{D_p \times D_m}{D_m + D_p} \right)$$

33c Roller in another rolling surface

$$W_{MAX} = K (L) \times \left(\frac{D_p \times D_m}{D_m - D_p} \right)$$

W_{MAX} = Maximum allowable contact load (lbs. or N)
D_p = Diameter of plastic roller (in. or mm)
D_m = Diameter of metal roller (in. or mm)
L = Contact length of roller (in. or mm)
K = Material stress factor (see Figure 34)

Load capacity calculations are purposefully conservative, and are based on a 4x safety factor used to determine K. Designers are encouraged to test all rollers and wheels in conditions similar to those that are anticipated.

Assembly / Fabrication

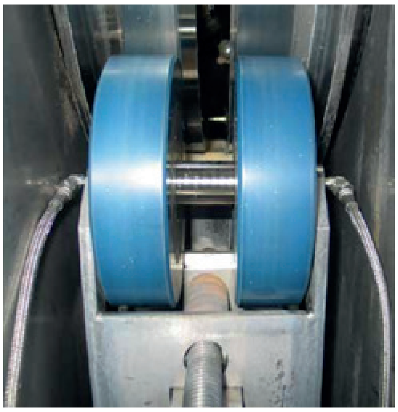
The three common rigid plastic wheel / roller designs include:

- Solid rollers rotating directly on the shaft.
- Solid rollers with ball or roller bearings.
- Plastic sleeves on metal cores.

See *Figure 35* for details on the typical uses, advantages, limitations, and design / fabrication tips for these typical roller designs.

Shrink fitting

Shrink fitting is the most common assembly method. Additionally, shrink fit interference and axial clearance depend upon the roller / wheel's operating temperature. *Figure 36* contains the interference and clearances for four elevated temperatures. To assemble, heat the plastic sleeve to 200°F (90°C) to soften and expand the material sufficiently.



Techtron® HPV PPS rollers in soup processing equipment

Figure 34: Material stress factor (K)*

Lowest performance ↑

MATERIAL	STATIONARY (IMPERIAL)	STATIONARY (METRIC)	ROTATING (IMPERIAL)	ROTATING (METRIC)
TIVAR® 1000 UHMW-PE	5	0.03	12	0.08
Fluorosint® PTFE	5	0.03	17	0.12
Semitron® ESd 225 POM-C	23	0.16	76	0.52
Ertalon® 66 SA / Nylatron® 101 PA66	30	0.21	99	0.68
Nylatron® GSM Blue PA6	32	0.22	106	0.73
Nylatron® GSM PA6	39	0.27	130	0.90
Nylatron® NSM PA6	39	0.27	130	0.90
Ertacetal® / Acetron® POM-H	45	0.31	150	1.03
Ertacetal® H-TF/ Acetron® AF Blend POM-H	45	0.31	149	1.03
Acetron® GP / Ertacetal® POM-C	45	0.31	150	1.03
Ertalon® 6 PLA / Nylatron® MC907 PA6	45	0.31	150	1.03
Ertalyte® PET	46	0.32	142	0.98
Nylatron® GS PA66	49	0.34	162	1.12
Techtron® HPV PPS	70	0.48	170	1.17
Duratron® T4503 PAI	89	0.61	157	1.08
Duratron® T4301 PAI	91	0.63	161	1.11
Duratron® T4501 PAI	96	0.66	170	1.17
Ketron® CM CA30 / HPV PEEK	96	0.66	171	1.18
Ketron® 1000 PEEK	120	0.83	213	1.47
Ketron® HPV PEEK	120	0.83	171	1.18
Duratron® T4203 PAI	168	1.16	298	2.05
Duratron® CU60 PBI	215	1.48	383	2.64

Highest performance

*Based on maximum allowable contact stresses (psi / MPa).

Figure 35: Typical roller / wheel designs

ROLLER / WHEEL DESIGN	TYPICAL USE CONDITIONS	ADVANTAGES	LIMITATIONS	DESIGN / FABRICATION TIPS
Solid rollers rotating directly on the shaft	Intermittent service	Lowest cost	Design must account for moisture and temperature growth	Calculate Limiting PV and required running clearance with bearing design equations. Prevent lateral binding by considering the material's moisture and temperature growth when calculating the axial clearance.
	Low velocity			
	Low load			
Solid rollers with press-fit ball or roller bearings	For operating temperatures up to 120°F (49°C)	Quick and easy assembly	Not suitable for side-loaded wheels / rollers	Press-fit made easier by heating-up the plastic roller.
Solid rollers with mechanically fastened snap rings or metal flanges	For operating temperatures above 120°F (49°C)	Mechanical fastening prevents axial movement		For rolling element bearings: prevent axial and circumferential movement by securing the outer race. Press the bearing into the flanged sleeve. Then press into the wheel / roller. Secure with a bolt through the flange to the roller.
	For side loaded wheels / rollers			
Plastic sleeves on metal cores	High loads	Balances the impact resistance of the plastic sleeve with the heat dissipation of the metal core		Make plastic wall thickness 10 to 15% of metal core OD. Contact Mitsubishi Chemical Advanced Materials for design options.
	High temperatures			
	High speeds			

Figure 36: Interferences and clearances at elevated temperatures

AVERAGE OPERATING TEMPERATURE OF SLEEVE	SHRINK FIT INTERFERENCE AT 68°F (20°C). VALUE IS IN % OF DIAMETER	AXIAL CLEARANCE (B) AT 68°F (20°C). VALUE IS IN % OF SLEEVE WIDTH
100°F (38°C)	0.25	0.05
140°F (60°C)	0.45	0.20
175°F (80°C)	0.65	0.40
200°F (93°C)	0.85	0.60

The MCG Advanced Materials division manufactures cast nylon roll covers for metal cores. To shrink fit the plastic roller onto a metal core, heat the plastic sleeve to 200°F (90°C) and assemble with the (possible) aid of a hydraulic press.

PLASTICS > METALS

Techtron® HPV PPS rollers

Designing sheaves that maximize the lifetime of wire rope while also increasing the lifting capacity

Engineering plastics improve the service life of wire rope life, while also increasing the lifting capacity of most cranes. Their reduced weight and non-corrosive characteristics are also beneficial for applications on land and or sea.

Sheave design

6

Nylatron® GSM PA6 sheaves

Typically, stress on the wire rope, not the sheave, limits the lifting capacity of a system. The point contact pressure for a steel sheave will be much higher than for a Nylatron® PA sheave, and the resilience of Nylatron® PA results in a larger point contact area, and creates support for the wire rope. Lightweight Nylatron® PA sheaves can support cyclical loads equal to steel sheave capabilities.

Reduce weight

Because Nylatron® GSM PA6 nylon is approximately one seventh (1/7) the weight of cast iron or steel, Nylatron® PA sheaves reduce dead weight at the end of the boom. In doing so, mobile cranes have greater stability and lifting capacity, and reduced over-the-road weight.

The reduced weight of Nylatron® GSM PA6 sheaves makes handling, installation, and replacement easier and safer than metal sheaves.

Extend wire rope life

The MCG Advanced Materials division in conjunction with a nationally recognized independent research institute, conducted wire rope endurance tests to obtain a comparison of the fatigue life of wire rope used with Nylatron® GSM PA6 sheaves and hardened steel sheaves under the same conditions.

Test results at stress levels of 10%, 20%, and 28.6% of ultimate wire rope strength indicate dramatic improvements in the endurance life of wire rope, when used with cast Nylatron® sheaves. *Figure 37* summarizes the results of the wire rope life testing. Overall, the tests prove that Nylatron® PA sheaves substantially increased the rope's cycle life.

Additionally, the corrosion resistant properties of Nylatron® PA make these components ideal for marine use.

Nylatron® GSM PA6 sheave on aluminum core.

Figure 37: Wire rope lift test results*

SHEAVE RATIO	ROPE TENSION TEST	DESIGN FACTOR	DURATION OF TEST	INCREASE IN ROPE LIFE**
24/1	10.0% of breaking strength	10.0	136,000 cycles	4.50 times
24/1	20.0% of breaking strength	5.0	68,000 cycles	2.20 times
24/1	28.6% of breaking strength	3.5	70,000 cycles	1.92 times
24/1	28.6% of breaking strength	3.5	39,000 cycles	1.33 times

Sheave ratio = D_p / D_r = Sheave pitch diameter/rope diameter

* Conventional rope retirement criteria based only upon visible wire breaks may prove inadequate in predicting rope failure. Retirement criteria should be established based on the users' experience and demands of the specific applications for users of Nylatron® PA sheaves.

** Increase in rope life attained with Nylatron® GSM PA6 compared to hardened steel sheaves.

Rim dimensions

The rim width (W_r), outside diameters (D_O), and tread diameters (D_t) are typically fixed design dimensions.

The rim flat (F_r - shown in *Figure 38*) between the groove wall and rim edge should be a minimum of 0.12” (3mm), in order to provide adequate side load stability.

Bronze bearings are not recommended for main load applications, and their use should be limited to moderate unit loads. This recommendation is given so that excessive frictional heat build-up, and the possible movement of the bearing in the bore can be avoided.

For lightly loaded applications where pressure-velocity (PV) values are not excessive, it may be possible to plain bore Nylatron® PA sheaves for running directly on the shaft. Contact your local MCG Advanced Materials division representative for appropriate running clearance information.

Groove dimensions

For optimum rope life, the sheave groove profile needs to be correctly matched to the rope diameter (D_r).

If the groove is too small, the rope will be pinched as it is forced into the groove under the influence of load, which will cause damage to the rope and the sheave. If the groove is too large, this could lead to insufficient support for the rope. As a result, the rope could become flattened and distorted under load, which will accelerate the rope's deterioration. The groove radius, R_g, should lie within the range of 0.525xDr to 0.550xDr (with Dr as the rope diameter).

Sheaves should have a smoothly finished groove that is free from machining ridges. Additionally, the groove depth should not be less than 1.5 times the nominal rope diameter (preferred groove depth >1.75 times the rope diameter). The profile at the bottom of the groove should be circular. The angle between the sides of the sheave, Θ_g, (see *Figure 38*) should be between 30° and 60° which is dependent on the fleet angle. The following is recommended:

Fleet angle 0-1°,
groove angle at least 30°

Fleet angle 2-3°,
groove angle at least 45°

Fleet angle 4-5°,
groove angle at least 60°

Fleet angles of >5°
are not recommended

Design strength can be maintained with a minimum web width (W_w), that is at least 20% greater than the rope diameter, or
$W_w \geq 1.20$ x Rope diameter.
The benefit of reducing the web width is weight savings. Additional strength can be obtained by adding ribs to the design.

Hub dimensions

The hub width (W_h) is generally a design requirement specified by the end user. In most cases it should be equal to or greater than the rim width (W_r) for stability of the sheave in use. The minimum hub diameter (D_h) is 1.5 times the bearing outside diameter (D_B), for adequate wall support of the bearing. The wall thickness between the bearing and hub diameter should always be greater than 25mm, or Dh = 25 mm, whichever is greater.

$D_h = 1.5(D_B)$

Bore dimensions

For heavy-duty applications, Nylatron® GSM PA6 sheaves should be installed with anti-friction bearings. Tapered or cylindrical roller bearings are generally recommended, due to their ability to provide maximum contact area across the width of the bore. The choice of bearings is application dependent and should be customer specified. As the coefficient of thermal expansion of Nylatron® is several times that of metal, the press fit allowance must be large enough for the bearing to maintain contact with the bore at temperatures up to 50°C (120°F). This is calculated by:

$d = 0.045/D_b$

d = Press fit allowance (mm)
D_b = Bearing outside diameter (mm)

$d = 0.009/D_b$

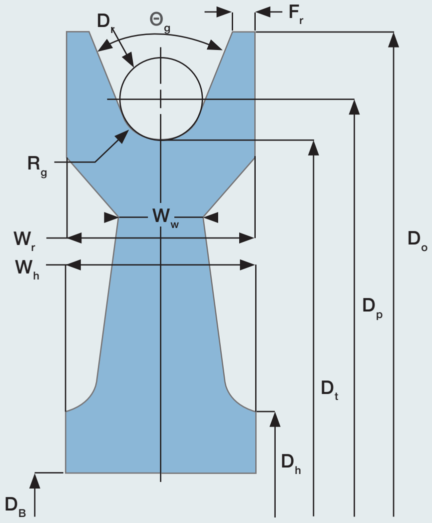
d = Press fit allowance (in)
D_b = Bearing outside diameter (inch)

The diameter of the sheave bore will be the O.D. of the bearing minus the press fit allowance. The tolerance field is +0 and -0.10 mm (+0 and -0.004").

$D_B = D_b - d$ +0/-0.10mm (+0/-0.004")

A sufficient press fit is critical to prevent bearing from moving axially while under load causing the sheave to buckle. For lightly loaded applications where pressure velocity (PV) values are not excessive, it may be possible to plain bore Nylatron® GSM PA6 sheaves for running directly on the shaft. Please consult with your designated MCG Advanced Materials division representative to discuss and calculate these possibilities.

Figure 38: Nomenclature (sheave design)



W_r = Rim width
Θ_g = Groove angle
F_r = Rim flat
D_r = Wire rope dia.
R_g = Groove radius
W_w = Web width

W_h = Hub width
D_t = Tread diameter
D_o = Outside diameter
D_h = Hub diameter
D_B = Bore diameter
D_p = Pitch diameter

Bearing retention

Circumferential bearing retention can be achieved using the press fit allowances (as calculated under bore dimensions), and pressing directly into the bore of the Nylatron® GSM PA6 sheave. A hydraulic press can be used, or the sheave can be heated to 80°-90°C (180° - 200°F). Thrust washers, thrust plates, or snap rings should be placed on either side of the sheave hub to maintain sideways bearing retention. This is necessary, in order to restrict bearing movement which may occur as the result of side forces that are encountered during operation.

There are two exceptions to bearing retention, using the previous procedure:

- Bronze bearings in idler sheaves where the sheave is free to move from side-to-side on a shaft. In this case, positive retention can be accomplished by extending the length of the bearing beyond the hub, and placing external rings on the bearing, on each side of the hub.
- Under conditions where the use of steel inserts are required due to high stress at the sheave bore-bearing interface two retention methods are suggested:
  Option 1
  Press a larger diameter steel sleeve insert in the bore of the sheaves into which the bearing is pressed. The insert is held in the bore by external retaining rings on each side of the hub.
  Option 2
  Use a cast-in aluminum core that is larger than the bearing. contact technical service for more information.

If thrust plates or thrust washers cannot be used, it is critical that other means of retention are found, in order to restrict the bearing from any potential sideways movements. Metal side plates bolted to the hub and overlapping the ends of the bearing can also be used for this purpose.

Fig. 39: Wrap angle factors K

WRAP ANGLE *	K
180°F (82°C)	1.000
170°F (77°C)	0.996
160°F (71°C)	0.985
150°F (66°C)	0.966
140°F (60°C)	0.940
130°F (54°C)	0.906
120°F (49°C)	0.866
110°F (43°C)	0.819
100°F (38°C)	0.766
90°F (32°C)	0.707
80°F (27°C)	0.643
70°F (21°C)	0.573
60°F (16°C)	0.500

* Arc of groove contacted by rope.

Load capability with bearings

The following equations can be used to calculate the maximum groove and bore pressure acting on any sheave.

Equation 1:
Maximum groove pressure

$$P_g = \frac{2\,(LP_{MAX})\,K_2}{D_r \times D_t}$$

Equation 2:
Maximum bore pressure

$$P_b = \frac{2\,(LP_{MAX})\,K_2}{D_B \times W_{bearing}}$$

P_g = Max groove pressure (MPa or PSI)
P_b = Max bore pressure (MPa or PSI)
LP_{MAX} = Max single line pull (N or lb) or wire rope breaking strength divided by design safety factor

D_r = Rope diameter (mm or in)
D_t = Tread diameter / groove base diameter (mm or in)
D_B = Bore diameter (mm or in)
$W_{bearing}$ = total sum of individual bearing width in contact with the sheave (mm or in)

$$K_2 = \text{Wrap factor} = \sin\left(\frac{\text{wrap angle}}{2}\right)$$

Be aware Equation 2 (bore pressure) is only applicable when the fleet angles are 0°, when > 0° one should calculate the loading in axial direction (sideways pull due to fleet angle) as well. Please consult Mitsubishi Chemical Group for further detailed calculations and information.

Load capability of plain bored sheaves

The load capacity for a plain bored Nylatron® PA sheave is based on the capability of the bore to act as a bearing. To determine the recommended load capacity, refer to the "Bearing Design" (pages 39-51) section of this manual, and make the calculations as follows, assuming that the bore of the sheave is a Nylatron® GSM PA6 bearing.

First, obtain the recommended limiting pressure velocity value ($PV_{ADJUSTED}$) for the given operating conditions.

Next, calculate the maximum bore pressure from the equation:

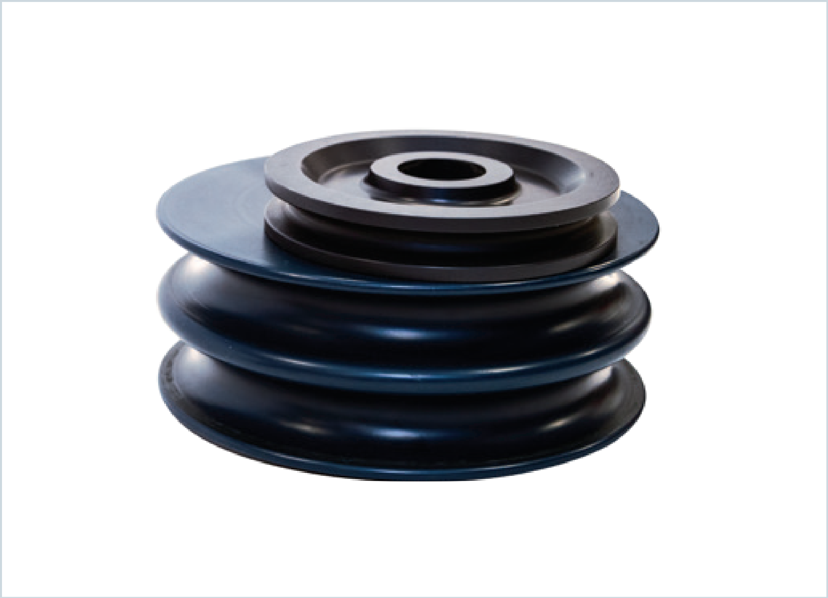
$$P_b = \left(\frac{PV_{ADJUSTED}}{V}\right)$$

P_b = Max bore pressure (PSI)
$PV_{ADJUSTED}$ = Pressure velocity value (PSI x fpm)
V = Shaft surface speed (fpm)
= $0.262 \times$ shaft rpm $\times D_s$ (fpm)
D_s = Shaft diameter (in.)

Bore pressure P_b should not exceed 1,000 psi. Take the calculated value for P_b or 1,000 psi, whichever is less, and substitute in the following equation to obtain the maximum load capacity for the conditions specified:

$$LC = P_b \times D_s \times W_h$$

LC = Max load capacity (lbs.)
W_h = Width of hub in contact with shaft (in.)



Nylatron® GSM PA6 sheaves

The use of nylon thrust washers or plates where they will wear against the Nylatron® PA sheave hub, is not recommended.

Calculating tread pressure is not necessary if the ratio of groove diameter to rope diameter is 18:1 or larger.

Sheave design worksheet

SHEAVE DATA	
Maximum single line pull (load)	Newton (lbs.)
Line speed	m/s (ft./min.)
Fleet angle	°
Temperature low	°F (°C)
Temperature high	°F (°C)
Wrap angle (arc of sheave contacted by rope)	°

Drawing number	
If no drawing is available:	
W_r Rim width:	in (mm)
D_o Outer diameter:	in (mm)
D_t Tread diameter	in (mm)
D_h Center hub O.D.	in (mm)
W_h Hub width	in (mm)
D_B Center bore I.D.	in (mm)
Alignment or access holes required?	
Number	
Pitch Circle	
Grease fittings	
Type	
Location	

WIRE ROPE DATA	
Rope O.D.	in (mm)
Rated breaking strength	
Brand of rope in use	

Design	
Part number	
O.D. of outer race	in (mm)
Bearing width	in (mm)
Method of attachment	

Sheave design - Key takeaways

- The light weight, wear, corrosion, and impact resistance of Nylatron® PA present unique advantages for a variety of wear and structural components.
- The pressure and load capacity limits recommended here, are based on intermittent cyclical loading in typical mobile hydraulic crane operation. If the operation involves continuous cycling or loading, high speed and acceleration, or heavy impact forces, the limits should be reduced, and the application should be thoroughly evaluated.
- Contact the MCG Advanced Materials division for special design requirements including high temperature applications, sheave ratios below 18:1, fleet angles greater than 3°, or severe chemical environments. Industries that use sheaves for power transmission or load lifting applications typically have other bearing and wear requirements that could also benefit from our materials.
- Calculation of tread (groove) pressure is normally not necessary if the ratio of groove diameter to rope diameter is 18:1 or larger.
- Excessive loads and / or speeds may cause distortion of the bore, and a loss of press fit with the bearing. Accelerated groove wear may also occur. For plain bored sheaves, excessive loads and / or speeds may cause accelerated wear and increased clearance in the bore.
- The use of nylon thrust washers or plates where they will wear against the Nylatron® GSM PA6 sheave hub are not recommended.
- The MCG Advanced Materials division has an extensive list of available molds for the manufacturing of Nylatron® GSM PA6 rope sheaves. Please consult the technical sales team to see if one of these “standard” sizes can be used for your intended project.

Successful plastic gear design made right

Engineering plastics provide gear designers many choices for machined gears and similar power transmission components. Our plastics' strength, heat resistance, fatigue properties, impact resistance, inherently low friction and wear resistance provide for lubrication free, quiet operation than all metal gear sets.

Gear design

7

Gear design

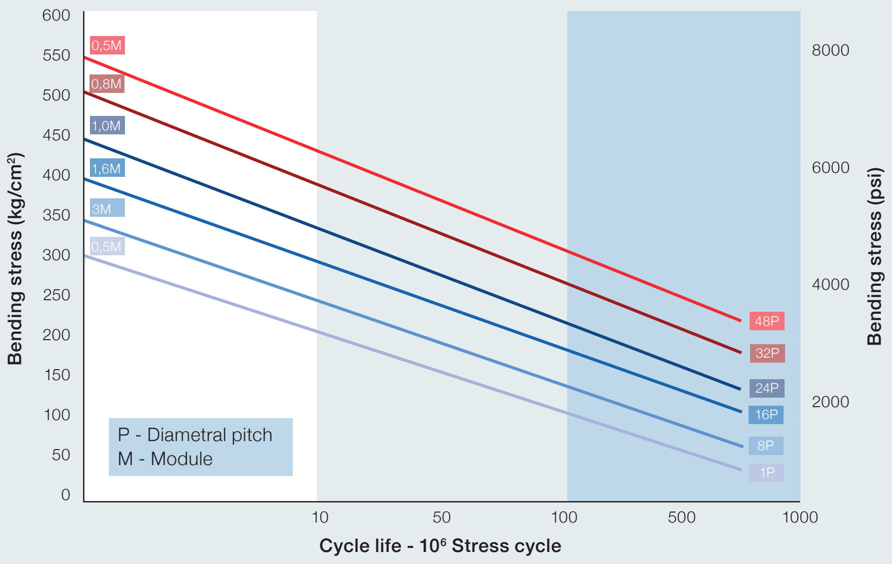
Plastic gears machined out of materials from MCG Advanced Materials division offer the following benefits:

- Exceptional noise abatement
- Ability to run without lubrication
- Corrosion resistance
- Longer wear life and protection of mating gears
- Reduced inertia versus traditional all metal gears

For more than 50 years Nylatron® PA has been used in a variety of industries as gears – spur, worm, bevel, and helical – due to the material's ability to balance strength, heat resistance, fatigue properties, impact resistance, and wear resistance. These characteristics make it the most popular choice for gear components.

Acetron® POM-C acetal, TIVAR® UHMW-PE, Techtron® HPV PPS, Ketron® PEEK, and other higher performance materials offer specific advantages for wet/high humidity conditions, chemically aggressive environments, light duty service, and high temperature applications.

Figure 40: Maximum tooth bending stresses vs. cycle life for nylon gears



Based on pitch line velocity of 2,000 Ft./Min (10 m/s)
P: Diametral Pitch - Ratio of N (number of teeth) to P_d (pitch diameter in in.)
M: Module - is the metric equivalent to P – Ratio of P_d (pitch diameter in mm) to number of teeth.

From the above → P (diametrical Pitch) = 25.4 / M (module)

Designing Nylatron® PA gears

Although nylon has significantly lower strength than a corresponding metal gear, reduced friction and inertia coupled with the resilience (bending) of thermoplastic gear teeth make direct substitution possible in many applications – especially gears made from nonferrous metals, cast iron and unhardened steel.

A step-by-step method for evaluating suitability of nylon spur gears is provided here. This method was developed using gear fatigue test data, and the maximum allowable bending stress of plastic gear teeth (See *Figure 40*). Proper gear design will include calculation of a maximum allowable torque (T_{MAX}) and/or a maximum allowable horsepower (HP_{MAX}) for a given thermoplastic material. Applying a few critical correction factors are also essential to your design. Also provided are calculations for specific correction factors which can be accounted for in your design.

Correction factors

(C_M) Material strength factor
To compare Nylatron® PA gears with other thermoplastic materials, one can multiply the calculated maximum torque (T_{MAX}) and horsepower (HP_{MAX}) values for Nylatron® PA spur gears by the material strength factor (see *Figure 42*) of the material in question to determine appropriate torque and horsepower values.

(C_V) Pitch-line velocity:
Gear velocity can affect the performance capability of a thermoplastic gear. *Figure 43* provides correction factors for various gear speeds. Increased speeds will lower the maximum torque (T_{MAX}) and horsepower (HP_{MAX}) values. Nylatron PA gearing can operate up to pitch-line velocities of 4,000 to 6,000 fpm (20 - 30 m/s) with continuous lubrication to reduce heat build-up.

(C_S) Service life factor
Proper gear design is dependent on not only the application conditions, but how many rotation cycles the gear is expected to achieve. The number of expected gear cycles and the gear pitch will also affect the calculated maximum torque (T_{MAX}) and horsepower (HP_{MAX}) values. Utilize *Figure 44* for this factor.

(C_T) Temperature correction factor
Increased service temperature of the gear application will equate to the material softening, which will also reduce the expected maximum torque (T_{MAX}) and horsepower (HP_{MAX}) values. Apply the correction factor in *Figure 45* to account for this reduced load capability.

Gear design methodology

1: Obtain the required application data

(P) Diametral pitch $P = N/P_d$
→ or

(P) = 25.4 / module (mm)
(N) Number of teeth
(PA) Pressure angle
(F) Face width, inches
(RPM) Input RPMs
(T_I) Input torque (lbf.ft)
→ 1 lbf.ft = 1.36 N.m
(HP_I) Input horsepower
→ 1HP = 745.7 watt

2: Calculate derived data and correction factors

(P_d) Pitch diameter = Pd = N/P
(Y) Tooth form factor (see *Figure 42*)
(S_B) Bending stress (see *Figure 43*)
(C_M) Material strength factor (See *Figure 44*)
(C_V) Velocity factor (see *Figure 45*)
(C_S) Service lifetime factor (see *Figure 46*)
(C_T) Temperature factor (see *Figure 47*)

3: Calculate the maximum torque or horsepower

Calculate the maximum allowable torque or horsepower, then multiply this number by the appropriate correction factors.

Equation 1

$$T_{MAX} = \frac{P_d S_B F Y}{2P} \times C_M C_V C_S C_T$$

Equation 2

$$HP_{MAX} = \frac{P_d S_B F\ Y\ RPM}{126{,}000\ P} \times C_M C_V C_S C_T$$

4: Compare to known input torque or horsepower

Compare the maximum torque (T_{MAX}) and maximum horsepower (HP_{MAX}) above for plastic gears to the known input torque (T_I) and/or horsepower (HP_I).

T_I must be less than or equal to T_{MAX} or HP_I must be less than or equal to HP_{MAX}

If T_I and HP_I exceed the T_{MAX} and HP_{MAX} for the plastic gear, select another material or another pitch diameter and face width, then re-calculate using the new material correction factors.

Figure 41: Gear design

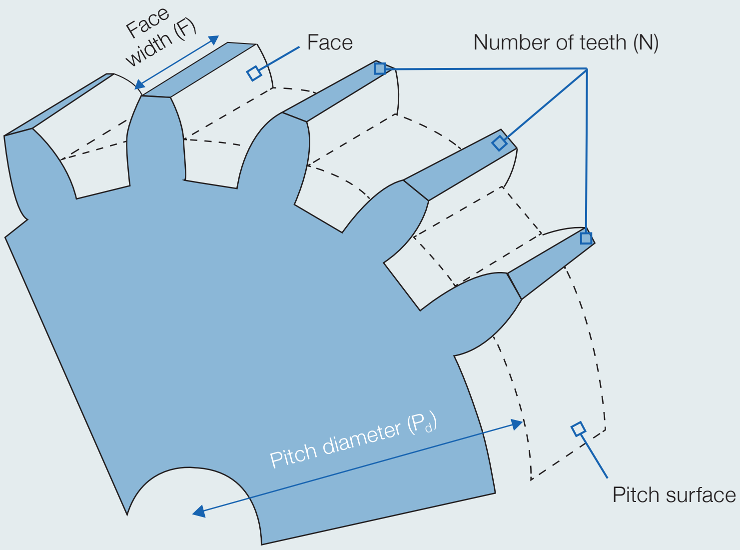


Figure 42: Tooth form factor (Y)

NUMBER OF TEETH	PRESSURE ANGLE		
	$14^{1/2°}$	20° FULL DEPTH	20° STUB
14	-	-	0.540
15	-	-	0.566
16	-	-	0.578
17	-	0.512	0.587
18	-	0.521	0.603
19	-	0.534	0.616
20	-	0.544	0.628
22	-	0.559	0.648
24	0.509	0.572	0.664
26	0.522	0.588	0.678
28	0.535	0.597	0.688
30	0.540	0.606	0.698
34	0.553	0.628	0.714
38	0.566	0.651	0.729
43	0.575	0.672	0.739
50	0.588	0.694	0.758
60	0.604	0.713	0.774
75	0.613	0.735	0.792
100	0.622	0.757	0.808
150	0.635	0.779	0.830
300	0.650	0.801	0.855
Rack	0.660	0.823	0.881

Figure 43: Nylon bending stress (S_B)

PITCH (P)	S_B (PSI)
2	1,994
3	2,345
4	2,410
5	2,439
6	2,675
8	2,870
10	3,490
12	3,890
16	4,630
20	5,005

Figure 44: Material strength factor (C_M)

MATERIAL	OPERATING CONDITIONS		
	NON-LUBRICATION	PERIODIC LUBRICATION	CONTINUOUS LUBRICATION
Ertalyte® PET-P	1.00	1.00	1.20
Nylatron® GS / GSM PA6	0.49	0.94	1.26
Nylatron® MC901 / MC907 PA6	0.49	0.94	1.26
Acetron® GP POM-C	*	*	1.04

*Data not available

Designing for other gear styles

The design formulas for spur gears may be modified when designing for other gear types, which will have differing tooth contact forces. Our recommended corrections for helical and bevel gears are listed below.

Helical gears

The Tooth form factor (Y) must be derived using a calculated formative number of teeth (Nf), based on the following equation. Use this calculated number of teeth with *Figure 42* to determine tooth form factor (Y).

$$N_f = \frac{N_H}{(\cos h)^3}$$

N_f = Formative number of teeth
N_H = Actual number of teeth (helical)
h = Helix angle (degrees)

Additionally, a normalized diametral pitch (P_N) is used, and is calculated from the transverse diametral pitch (P_t). This is the pitch in the plane of rotation.

Use P_N in place of P for pitch diameter (P_d) calculations. This is calculated from:

$$P_N = \frac{P_t}{\cos h}$$

P_N = Normalized diametral pitch
P_t = Transverse diametral pitch
h = Helix angle (degrees)

Figure 45: Velocity factor (C_V)

VELOCITY (FPM)	CORRECTION FACTORS
500	1.38
1,000	1.18
2,000	1.00
3,000	0.93
4,000	0.90
5,000	0.88

Figure 46: Service life factor (C_S)

NUMBER OF CYCLES	16 PITCH	10 PITCH	8 PITCH	5 PITCH
1 million	1.26	1.24	1.30	1.22
10 million	1.00	1.00	1.00	1.00
30 million	0.87	0.88	0.89	0.89

Figure 47: Temperature factor (C_T)

MATERIAL	< 100° F (38°C) C_T =	100°F (38°C) TO 200°F (93°C) CT = 1 / [1 + a (T-100°F (38°C))]
Nylatron® GSM / MC PA6	1.00	a = 0.022
Nylatron® GS PA6 / Nylatron® PA66	1.00	a = 0.004
Acetron® GP POM-C / Ertalyte® PET-P	1.00	a = 0.010

Bevel gears

The tooth form factor (Y) must be derived using a calculated formative number of teeth (Nf) based on the following equation. Use this calculated number of teeth with *Figure 42* to determine the tooth form factor (Y).

$$N_f = \frac{N_B}{\cos ø}$$

ø = Pitch angle (degrees)
N_B = Actual number of teeth (bevel)

It should be noted that diametral pitch (P) and pitch diameter (P_d) refer to the outside or larger tooth dimensions of bevel gears.

Additional gear design concerns

Nylatron® PA gears versus other materials
Nylatron® PA gears are generally superior to other engineering plastics, provided environmental factors such as temperature, humidity, and chemical requirements are within its useable limits.

Mating gear materials
For ideal operating conditions, a Nylatron® PA gear should be mated with a metallic gear, as this arrangement promotes heat dissipation. Another important consideration is that the wear of a plastic gear is largely determined by the counterface, or opposing gear. A minimum surface finish of 12 to 16 µ inches RMS / Ra 0.2 - 0.4 µmeter is recommended on metal gears running against plastic gears.

In general, it is best to avoid making both driven and driving gears from similar plastics. If an all plastic gear system is desired, a combination of dissimilar plastics is recommended, such as Nylatron® PA6 with Acetron® POM-C.

Acetron® POM-C gear

Backlash
The most frequent design error when converting metal gears to plastic gears, is not allowing sufficient backlash. Plastics have a greater thermal expansion than metals, making it critical for sufficient backlash to be designed, in order to compensate for frictional heat and changes in ambient conditions. The suggested backlash (see *Figure 48*) can be calculated using the formulas below.

Backlash should be checked upon installation through a full rotation of the plastic gear.

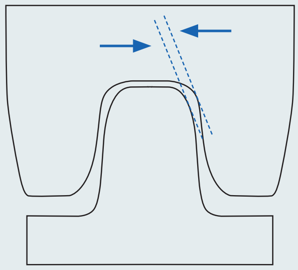
Backlash = 0.100” / P or
0.1 x Module (mm)
P = Diametral pitch

For a more stable material, like Ketron® PEEK:

$$\text{Backlash} = \frac{0.100''}{2P}$$

or backlash = 0.05 x Module (mm)

Figure 48: Backlash



Moisture absorption
Nylatron® PA absorbs moisture in wet environments, and may increase in size slightly. However, many machined gears have thick walls that make moisture pickup very slow eliminating any special consideration when designing the gear. As stated earlier increased backlash generally compensates for growth due to moisture.

Tooth form
Field experience has shown that Nylatron® PA gearing can operate successfully utilizing any of the standard tooth forms. However, when designing new equipment, it is suggested that consideration shall be given to the 20° pressure angle (PA) full depth tooth form (full root radius) to maximize bending strengths of the gear teeth. For Nylatron® PA spur gears, load carrying capacity is approximately 15% greater in a gear designed with a 20° PA versus a 14.5° PA. Also, service life increases by approximately 3.5 times under the same load.

Extended performance
Where the design permits, select the smallest tooth that will carry the load required. This will minimize heat build-up from higher teeth sliding velocities.

Gear assembly

Gears are commonly fastened to shafts using a variety of techniques including:

- Cast or fused over metal cores.
- Press fit over splined and/or knurled shafts for gears transmitting low torques.
- Set screws for low torque gears.
- Bolting a metal hub through the gear width is suitable for drive gears produced in small to intermediate quantities.
- Machined keyways for gears that must remain all plastic.

Keyways

When using a keyway to assemble a gear, radiused keyway corners are always preferred to reduce the stress concentrations, and to provide greater strength. The minimum keyway area is determined from the following formula for Imperial units:

$$A = \frac{63{,}000\ HP}{RPM\ r\ S_k}$$

A = Keyway area (in2)
HP = Horsepower transmitted (hp)
RPM = Gear speed (rpm's)
r = Mean keyway radius (inch)
S_k = Maximum permissible keyway stresses (psi) from *Figure 49*

Use the following formula for metric units:

$$A = \frac{9{,}550\ KW\ (W)}{RPM\ r\ S_k}$$

A = Keyway area (mm^2)
KW = power transmitted
RPM = Gear speed (rpm's)
r = Mean keyway radius (mm)
S_k = Maximum permissible keyway stresses (MPa) from *Figure 49*

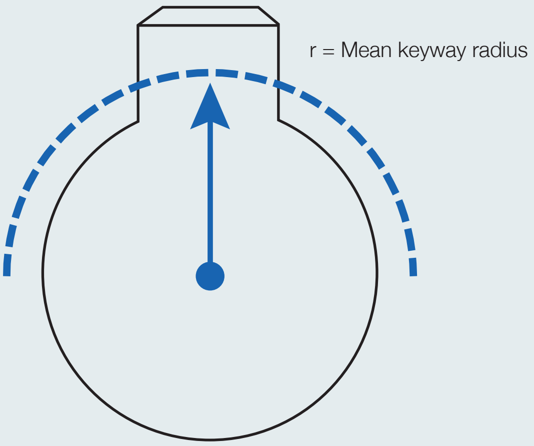
If the keyway size determined from the equation above is impractical, and multiple keyways cannot be used, a keyed flanged hub and check plate bolted through the gear should be used.

Nylatron® PA6 gears

Be sure to design in a .015″ to .030″ radius for keyway corners.

Figure 49: Max keyway stress (S_K)

MATERIAL	S_K (PSI)	S_K (MPA)
Nylatron® GS PA6	1,500	10
Nylatron® PA66	1,500	10
Nylatron® GSM / MC901 PA6	2,000	14
Acetron® POM	2,000	14
Ertalyte® PET	2,000	14

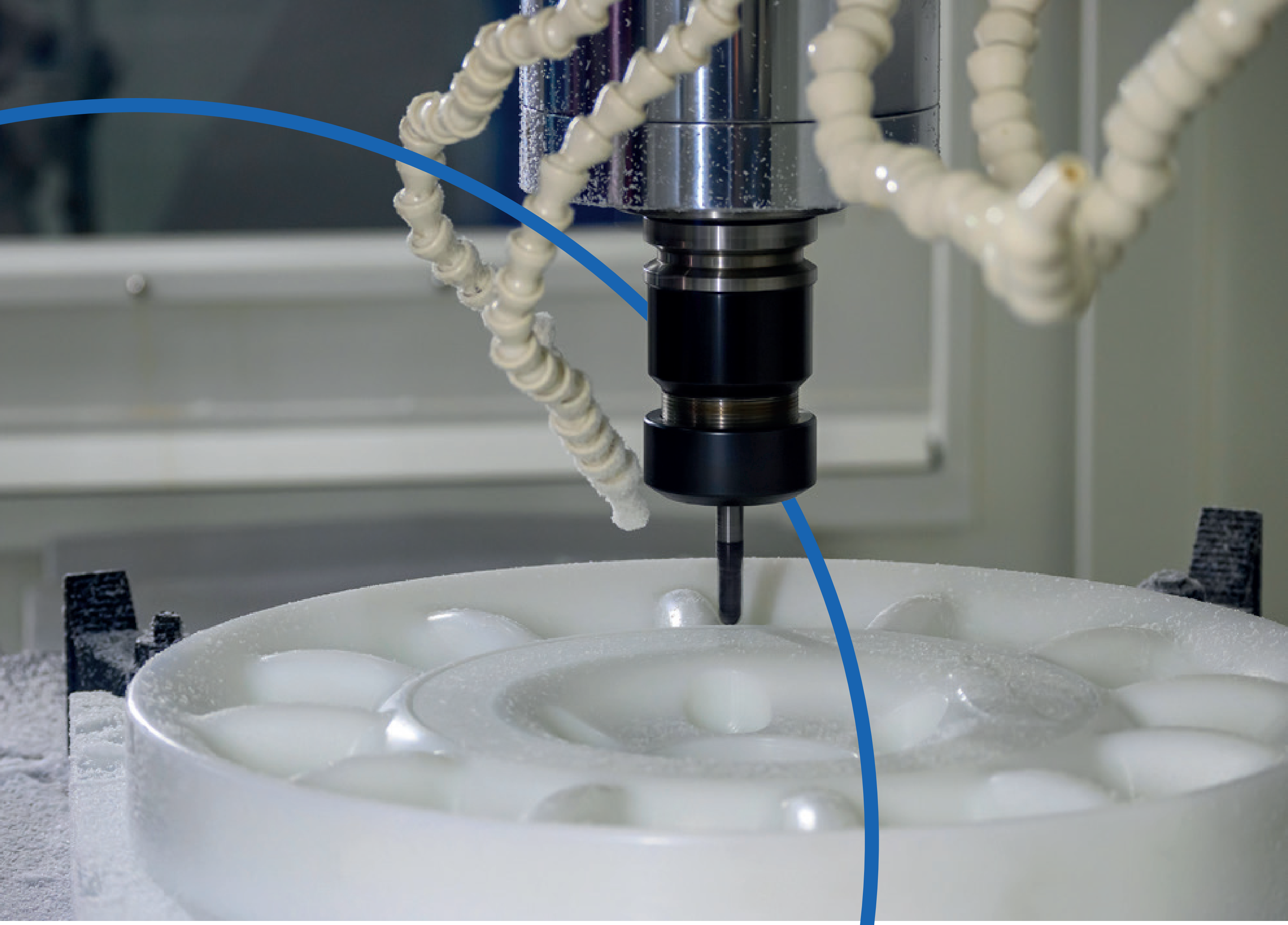


Spur gear design worksheet

STEP 1 – OBTAIN REQUIRED APPLICATION DATA	
P (Diametral pitch: $P = N/P_d$)	
N (Number of teeth)	
PA (Pressure angle)	
F (Face width)	
RPM (Input RPMs)	
T_I (Input torque)	
or HP_I (Input horsepower)	

STEP 2 – CALCULATE DERIVED DATA AND CORRECTION FACTORS	
P_d (Pitch diameter $P_d = N/P$)	
Y (Tooth form factor) see *Figure 42 / page 66*	
S_B (Bending stress) see *Figure 43 / page 66*	
Alternate material	
C_M (Material strength factor) See *Figure 44 / page 66*	
C_V (Velocity factor) see *Figure 45 / page 66*	
C_S (Service life factor) see *Figure 46 / page 66*	
C_T Temperature factor see *Figure 47 / page 66*	
T_{MAX} Maximum torque = $[P_d\ S_B\ F\ Y] / 2\ P \times C_M\ C_V\ C_S\ C_T$	
HP_{MAX} Maximum horsepower = $[P_d\ S_B\ F\ Y\ RPM] / 126{,}000\ P \times C_M\ C_V\ C_S\ C_T$	

STEP 3	
Ensure $T_I < T_{MAX}$ or that $HP_I < HP_{MAX}$	



Designing and manufacturing performance parts that last

It is easy to overlook the importance of product compliance, how machinable a material is and how it will perform in various environments. This section provides information that enables one to fine tune the material selection process and get started machining final parts.

8

Data, compliance & fabrication

Chemical resistance data

	Concentration Weight %	Duratron® CU60 PBI	Duratron® PI	Duratron® PAI	Duratron® U1000 PEI	Fluorosint® PTFE	Ketron® 1000 PEEK	Sultron® PPSU	Techtron® 1000 PPS	Ertalyte® PET	Acetron® GP POM-C	Nylatron® PA6	Nylatron® PA66	Altron™ PC	TIVAR® UHMW-PE	Proteus® PP
Acetaldehyde Aq.	40	*	*	*	A	A	A	D	A	D	A	A	B	*	B	A
Acetamide Aq.	50	*	*	*	*	A	A	*	*	*	A	A	A	*	*	A
Acetic Acid Aq.	10	B	D	A	A	A	A	A	A	B	C	C	C	B	A	A
Acetone	100	A	A	A	C	A	A	D	A	B	A	A	A	D	A	A
Acrylonitrile	100	A	*	A	*	A	A	D	A	B	*	A	A	D	*	A
Alcohols, Aliphatic	100	*	*	A	A	A	A	A	A	A	A	B	B	A	A	A
Allyl Chloride	100	*	*	*	*	A	A	*	*	*	*	*	C	*	A	B
Allyl Alcohol	100	*	*	A	*	A	A	*	A	A	*	B	*	B	A	B
Aluminum Chloride Aq.	10	*	B	A	*	A	A	*	A	A	*	A	A	A	A	A
Aluminum Sulfate Aq.	10	*	B	A	*	A	A	A	A	*	A	A	A	A	A	A
Ammonia Aq.	10	C	D	B	*	A	A	*	A	C	A	A	A	*	A	A
Ammonia Gas	100	C	D	C	*	A	A	B	*	A	D	B	C	D	*	A
Ammonium Carbonate Aq.	10	*	*	A	*	A	A	*	A	A	*	A	A	B	A	A
Ammonium Chloride Aq.	10	*	*	A	*	A	A	A	A	A	A	B	D	A	A	A
Ammonium Chloride Aq.	37	*	*	A	*	A	A	*	A	A	A	B	D	A	A	A
Amyl Acetate	100	*	*	A	B	A	A	D	A	*	A	D	B	D	A	D
Amyl Alcohol	100	*	*	A	*	A	A	A	A	*	*	A	*	B	A	A
Aniline	100	*	D	A	*	A	A	*	A	A	B	C	C	C	A	A
Antimony Trichloride Aq.	10	*	*	*	*	A	A	D	*	*	*	D	D	A	A	A
Barium Chloride Aq	10	*	*	A	*	A	A	A	A	A	A	B	D	A	A	A
Barium Sulfate Aq.	10	*	*	A	*	A	A	*	*	*	A	A	*	*	A	B
Barium Sulfide Aq.	10	*	*	A	*	A	A	*	*	*	*	*	A	*	A	A
Benzaldehyde	100	*	*	A	D	A	A	*	B	A	A	C	A	D	A	A
Benzene	100	*	A	A	D	A	A	D	A	A	A	A	A	D	C	C
Benzenesulfonic Acid	100	*	*	D	*	A	D	*	A	*	C	*	D	D	A	B
Benzyl Alcohol	100	*	*	A	*	A	A	*	A	A	A	D	C	D	A	A
Benzoic Acid Aq.	SAT	*	B	*	*	A	A	*	A	A	*	D	C	D	A	A
Beverages Aq. Alcoholic	100	A	*	A	A	A	A	A	A	A	A	B	B	A	A	A
Beverages Aq. Carbonated	100	A	*	A	A	A	A	A	A	A	A	B	B	A	A	A
Bitumen	100	*	*	*	*	A	A	*	*	*	A	B	B	*	*	*
Bleaching Lye	10	*	*	A	*	A	A	*	*	*	C	B	C	*	A	A
Bleaching Lye	100	*	*	*	*	A	A	*	*	*	C	B	C	*	A	A
Boric Acid Aq.	10	*	B	*	*	A	A	*	A	A	*	D	D	A	A	A
Boron Trifluoride	100	*	*	C	*	*	B	*	*	*	D	D	D	*	*	*
Bromine Aq.	30	*	*	A	*	A	B	A	A	*	D	D	D	D	D	D
Bromine Liq.	100	*	*	B	*	*	D	*	A	*	D	D	D	D	D	D
Butanol	100	A	A	A	A	A	A	B	A	B	A	B	B	A	A	A
Butyl Acetate	100	*	*	A	B	A	A	D	A	A	A	B	A	D	A	B

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Butyl Phthalate	100	*	*	A	*	A	A	*	B	*	*	*	D	*	A	B
Butylene Glycol	100	A	*	*	A	A	A	*	A	B	A	B	A	B	*	*
Butylamine	100	*	*	A	D	A	A	*	B	*	D	*	A	D	*	B
Butyric Acid Aq.	20	*	B	*	*	A	A	*	A	*	A	B	D	D	A	A
Butyric Acid	CONC	*	B	*	*	A	A	*	A	*	*	B	D	D	A	A
Butyrolactone	100	*	*	A	*	A	A	*	*	B	A	A	*	C	*	*
Calcium Chloride Aq.	10	*	B	A	*	A	A	A	A	A	A	A	D	A	A	A
Calcium Chloride (in Alcohol)	20	*	*	*	*	A	A	*	A	*	A	D	D	*	A	A
Calcium Hypochlorite	100	*	*	A	*	A	A	B	A	A	D	D	D	A	A	A
Camphor	100	*	*	*	*	A	A	*	A	*	A	A	A	*	*	C
Carbon Disulphide	100	*	A	*	*	A	A	*	A	*	A	A	A	D	D	D
Carbon Tetrachloride	100	A	*	A	A	A	A	A	A	A	A	A	A	D	C	D
Carbonic Acid Aq.	10	*	A	*	*	A	A	*	A	A	A	*	A	*	A	A
Carnalite Aq.	10	*	*	*	*	A	A	*	*	*	*	A	*	*	*	*
Castor Oil	100	*	*	*	*	A	A	*	*	A	A	*	A	A	A	A
Catechol	100	*	*	*	*	*	A	*	*	*	*	C	*	*	*	*
Chloroacetic Acid Aq.	10	*	C	*	*	A	A	*	A	*	D	C	D	*	D	A
Chloral Hydrate	100	*	*	*	*	A	A	*	*	*	*	D	D	*	A	B
Chlorine Aq.	10	D	*	D	D	A	D	D	B	D	D	D	D	D	B	D
Chlorine Dioxide	100	*	*	*	*	D	D	D	*	*	D	D	D	D	B	C
Chlorine Gas	100	A	A	*	*	A	A	*	*	*	D	D	*	B	B	C
Chlorobenzene	100	*	B	A	*	A	A	D	A	A	A	A	A	D	B	D
Chloroform	100	A	*	A	D	A	A	D	A	D	C	C	A	D	D	C
Chlorosulfonic Acid Aq.	10	*	*	*	*	A	D	*	D	*	D	C	D	*	*	A
Chrome Alum Aq.	10	*	D	*	*	A	A	*	*	*	*	*	A	A	A	A
Chromic Acid Aq.	1	*	A	A	A	A	A	A	A	A	B	C	D	A	A	A
Citric Acid Aq.	10	A	B	A	A	A	A	A	A	A	A	B	B	A	A	A
Citric Acid Aq.	SAT	*	D	B	*	A	A	A	A	A	*	C	C	*	*	*
Coconut Oil	100	*	*	*	*	A	A	*	A	*	*	A	A	*	*	A
Creosote	100	*	*	*	*	A	A	*	*	*	*	*	A	D	*	*
Cresols	100	*	C	*	*	A	A	D	A	*	*	D	D	D	*	D
Cresylic Acid	100	*	*	*	*	A	A	*	*	*	*	*	D	*	A	D
Cupric Chloride Aq.	10	*	*	B	*	A	A	A	A	A	A	*	D	A	*	A
Cupric Sulfate Aq.	0.5	*	*	B	*	A	A	*	A	A	A	B	A	A	*	*
Cupric Sulfate Aq.	10	*	*	B	*	A	A	*	A	*	*	B	B	*	*	*
Cupric Sulfate Aq.	SAT	*	*	B	*	A	A	*	A	*	*	B	B	*	*	*
Cyclohexane	100	A	*	A	A	A	A	B	A	A	A	A	A	B	A	C

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Cyclohexanol	100	A	*	A	A	A	A	A	A	A	A	B	B	C	A	B
Cyclohexanone	100	A	*	A	*	A	A	D	A	A	A	A	A	D	A	D
Decalin	100	A	*	*	A	A	A	A	A	B	B	A	A	A	*	D
Detergents, Organic	100	A	*	A	A	A	A	A	A	A	A	A	A	A	A	A
Dibutylphthalate	100	*	*	A	B	A	A	*	*	*	*	A	A	D	A	A
Dichlorodifluoro Methane	100	A	*	*	D	A	A	D	B	A	A	A	A	D	*	A
Dichloroethylene	100	A	*	A	D	A	A	D	*	B	B	A	A	D	D	A
Diethyleneglycol Aq.	90	*	*	A	*	A	A	B	*	A	A	B	A	A	*	A
Diesel Oil	100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Dimethyl Carbinol	100	*	*	*	*	A	A	*	*	*	*	B	A	*	*	*
Dimethyl Aniline	100	*	*	A	D	A	A	D	A	B	B	*	A	D	*	*
Dimethyl Formamide	100	*	D	*	D	A	A	D	A	A	A	A	A	D	A	A
Dioxane	100	*	*	A	*	A	A	D	A	A	A	A	A	D	*	C
Edible Oils	100	A	A	A	A	A	A	B	A	A	A	A	A	A	A	A
Ethanol, Denatured	96	A	*	A	A	A	A	A	A	A	A	B	B	A	*	A
Ether, Diethyl	100	A	*	A	A	A	A	A	A	A	A	A	A	A	A	D
Ethyl Acetate	100	*	A	A	B	A	A	D	A	A	A	A	A	D	A	A
Ethyl Butyrate	100	*	*	A	B	A	A	D	*	*	*	*	A	D	*	B
Ethyl Chloride	100	*	A	A	*	A	A	*	A	*	*	A	*	*	*	D
Ethylene Chlorohydrin	100	*	*	*	*	A	B	*	A	D	D	D	D	D	*	D
Ethylene Chloride	100	A	A	A	C	A	A	C	A	C	C	B	B	C	B	C
Ethylene Diamine	100	*	*	D	C	A	A	B	D	*	*	A	B	C	A	A
Ethylene Dichloride	100	A	A	A	D	A	A	*	B	D	D	D	B	D	C	B
Ethylene Glycol Aq.	96	A	B	A	D	A	A	A	A	A	A	B	A	B	A	A
Ethylene Propionate	100	*	*	A	*	A	A	*	*	*	*	*	A	*	*	*
Ferric Chloride Aq.	5	*	A	A	*	A	A	A	A	A	A	B	B	A	A	A
Ferric Chloride Aq.	10	*	B	A	*	A	B	A	A	*	*	*	B	A	A	A
Ferric Chloride Aq.	SAT	*	B	A	*	A	B	*	A	*	*	C	C	*	A	A
Ferrous Chloride Aq.	10	*	*	A	*	A	A	*	A	*	*	C	B	*	A	A
Fluorine	100	*	*	C	*	C	D	*	*	C	C	D	D	*	D	D
Fluosilicic Acid Aq.	10	*	*	C	*	B	A	*	A	*	*	C	D	A	A	A
Fluothane	100	*	*	*	*	A	A	*	*	*	*	A	A	*	*	*
Freon 12 (Arcton 12)	100	A	A	*	*	A	A	A	B	A	A	A	A	D	*	C
Formaldehyde Aq.	10	*	B	A	A	A	A	C	A	A	A	B	A	A	A	A
Formic Acid Aq.	3	D	A	C	A	A	B	*	A	B	B	D	D	A	A	A
Formic Acid Aq.	10	D	A	C	A	A	B	D	A	C	C	D	D	B	A	C
Fruit Juices	CONC	A	A	A	*	A	A	A	A	A	A	B	A	A	A	A
Furfural	100	*	*	B	*	A	A	D	A	*	*	B	A	*	A	D

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Gasoline	100	A	A	A	B	A	A	B	A	A	A	A	A	D	A	C
Glycerine	100	*	*	A	*	A	A	B	A	A	A	B	A	A	A	A
Heptane	100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B
Hexane	100	A	*	A	A	A	A	B	A	A	A	A	A	A	A	B
Hydrobromic Acid Aq.	10	*	B	A	*	A	D	B	B	*	*	C	D	*	A	A
Hydrochloric Acid Aq.	0.4	B	B	A	A	A	A	A	A	A	A	B	B	A	A	A
Hydrochloric Acid Aq.	2	D	C	A	A	A	A	A	A	B	B	D	C	A	A	A
Hydrochloric Acid Aq.	10	D	C	A	A	A	A	A	B	C	C	D	D	A	A	A
Hydrofluoric Acid Aq.	4	*	B	*	*	C	D	A	B	B	B	C	D	A	A	A
Hydrogenated Vegetable Oils	100	A	A	A	*	A	A	*	A	A	A	A	A	*	A	A
Hydrogen Peroxide Aq.	0.5	*	*	*	A	A	A	A	A	A	A	*	D	A	A	A
Hydrogen Peroxide Aq.	1	A	*	*	A	A	A	A	A	A	A	C	D	A	A	A
Hydrogen Peroxide Aq.	3	A	*	*	A	A	A	A	A	A	A	C	D	A	A	A
Hydrogen Sulfide Aq.	SAT	*	B	*	*	A	A	*	A	C	C	C	C	A	A	A
Hydroquinone	100	*	*	*	*	A	A	*	*	*	*	B	B	*	A	A
Iodine (in Alcohol)	100	*	*	*	*	A	A	*	*	*	*	D	D	D	A	A
Iodine (in Pt. Iodine) Aq.	3	*	*	*	*	A	A	*	*	*	*	C	D	D	A	A
Iso octane	100	A	*	A	B	A	A	B	A	A	A	A	A	A	A	A
Isopropyl alcohol	100	A	A	A	A	A	A	B	A	A	A	B	B	A	A	A
Isopropyl Ether	100	A	*	A	A	A	A	C	A	A	A	A	A	A	A	B
Lactic Acid Aq.	10	*	A	A	*	A	A	A	A	A	A	A	A	A	A	A
Lactic Acid Aq.	90	*	B	A	*	A	A	*	A	*	*	D	C	*	A	A
Lead Acetate Aq.	10	*	*	A	*	A	A	*	A	*	*	B	B	*	A	A
Lead Stearate	100	*	*	*	*	A	A	*	*	*	*	A	A	*	*	*
Linseed Oil	100	*	*	A	*	A	A	A	A	A	A	A	A	A	A	A
Lithium Bromide Aq.	50	*	*	*	*	A	A	*	*	A	A	D	D	*	*	*
Lubricating Oils (Petroleum)	-	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B
Magnesium Chloride Aq.	10	*	*	A	*	A	A	A	A	A	A	A	A	A	*	A
Magnesium Hydroxide Aq.	10	*	*	D	*	A	A	*	A	B	A	A	A	*	A	A
Magnesium Sulfite Aq.	10	*	*	A	*	A	A	*	A	*	A	A	A	*	A	A
Maleic Acid Aq.	CONC	*	*	*	*	A	A	*	*	*	*	C	*	*	A	A
Malonic Acid Aq.	CONC	*	*	*	*	A	A	B	*	*	*	C	*	*	*	*
Manganese Sulfate Aq.	10	*	*	*	*	A	A	*	*	A	A	A	A	A	*	A
Mercuric Chloride Aq.	6	*	*	*	*	A	A	*	*	*	B	D	C	A	*	A
Mercury	100	*	*	*	*	A	A	*	A	A	A	A	A	A	A	A
Methanol	100	A	*	*	A	A	A	B	A	A	A	B	A	B	A	A
Methyl Acetate	100	*	-	A	B	A	A	*	A	A	A	A	A	D	A	B

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Methyl Ethyl Ketone	100	A	-	A	D	B	A	B	B	A	B	A	A	D	B	A
Methylpyrrolidone	100	*	C	*	*	A	A	D	A	*	*	A	A	*	*	*
Methylene Chloride	100	C	C	A	C	A	A	D	A	D	C	B	B	D	B	C
Methy Phenyl Ether	100	*	*	A	*	A	A	*	A	A	*	*	A	*	A	*
Milk	100	A	*	A	A	A	A	A	A	A	A	A	A	A	A	A
Mineral Oils	100	A	A	A	A	A	A	A	A	*	A	A	A	A	A	A
Naphthalene	100	-	*	*	D	A	A	D	A	A	A	A	A	D	A	A
Nickel Sulfate Aq.	10	-	*	*	*	A	A	*	A	*	*	A	A	A	A	A
Nicotine	100	-	*	*	*	*	A	*	*	*	*	D	D	*	*	A
Nitric Acid Aq.	0.1	B	*	A	A	A	A	A	A	B	D	C	C	A	A	A
Nitric Acid Aq.	10	C	D	A	A	A	A	C	B	C	D	D	D	A	A	A
Nitrobenzene	100	*	C	A	D	A	A	D	A	D	B	B	C	D	A	A
Nitromethane	100	*	*	A	*	A	A	D	A	B	*	B	A	A	A	A
Oleic Acid	100	*	*	*	*	A	A	A	A	A	A	A	A	A	A	B
Oxalic Acid Aq.	10	*	*	*	*	A	A	A	A	*	C	B	C	A	A	A
Ozone	100	*	A	C	*	A	A	A	C	C	C	C	C	D	C	D
Paraffin	100	A	*	A	A	A	A	A	A	A	A	A	A	A	A	A
Perchloroethylene	100	A	A	A	C	A	A	*	A	A	B	B	B	C	B	C
Perchloric Acid Aq.	10	*	*	*	*	A	A	*	*	A	C	C	D	*	A	C
Petroleum Ether	100	-	*	A	*	A	A	*	A	*	A	A	A	A	B	A
Phenol Aq.	6	A	*	*	*	A	B	*	*	A	D	D	D	D	B	B
Phenol Aq.	75	A	*	*	D	A	D	D	*	C	D	D	D	D	B	B
Phenol (Molten)	100	-	*	*	D	A	B	D	*	C	D	D	D	D	B	C
Phosphoric Acid Aq.	0.3	B	*	A	A	A	A	A	A	A	C	B	*	A	A	A
Phosphoric Acid Aq.	3	C	*	A	A	A	A	A	A	A	C	C	D	A	A	A
Phosphoric Acid Aq.	10	C	*	A	A	A	A	A	A	B	D	D	D	A	A	A
Phthalic Acid Aq.	SAT	*	*	*	*	A	A	*	*	*	A	B	B	*	A	C
Phthalic Dioctyl	100	*	*	*	*	A	A	*	A	*	*	A	A	*	*	*
Potassium Acetate Aq.	50	*	*	A	*	A	A	*	*	*	A	A	A	*	A	A
Potassium Bicarbonate Aq.	60	*	*	A	*	A	A	*	A	A	A	A	A	*	A	A
Potassium Bromide Aq.	10	*	*	A	*	A	A	*	A	A	A	A	A	A	A	A
Potassium Carbonate Aq.	60	*	*	A	A	A	A	*	A	A	A	A	A	*	A	A
Potassium Chloride Aq.	90	*	*	A	*	A	A	*	A	A	A	A	A	A	A	A
Potassium Dichromate Aq.	5	*	*	A	*	A	A	*	A	A	A	B	C	A	A	A
Potassium Ferricyanide Aq.	30	*	*	*	*	A	A	*	*	A	*	B	A	*	A	A
Potassium Ferrocyanide Aq.	30	*	*	*	*	A	A	*	*	*	*	B	A	*	A	A

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Potassium Hydroxide Aq.	10	*	D	D	A	B	A	A	A	C	A	A	C	C	A	A
Potassium Hydroxide Aq.	50	*	*	D	*	C	A	B	A	C	D	A	C	D	A	A
Potassium Nitrate Aq.	10	*	*	*	*	A	A	A	A	A	B	A	A	A	A	A
Potassium Permanganate Aq.	1	*	*	A	*	A	A	A	A	A	A	C	D	A	A	B
Potassium Sulfite Aq.	CONC	*	*	A	*	A	A	*	A	*	*	A	A	*	A	A
Potassium Sulfite Aq.	90	*	*	A	*	A	A	*	*	*	*	*	A	*	A	A
Propane Gas	100	A	*	*	*	A	A	*	A	A	A	A	A	A	A	A
Pyridine	100	*	A	D	*	A	A	D	*	*	B	A	A	D	A	A
Resorcinol	100	*	*	*	*	A	A	*	*	*	*	D	D	*	*	A
Salicylic Acid	100	*	*	*	*	A	A	*	*	A	D	A	A	*	A	A
Silicone Fluids	100	A	B	A	*	A	A	*	A	A	A	A	A	A	A	A
Silver Nitrate	100	*	*	A	*	A	A	*	A	A	A	A	A	A	A	B
Soap Solutions	100	A	*	A	A	A	A	A	A	A	A	A	A	A	B	A
Sodium (Molten)	100	*	*	*	*	B	D	*	*	*	C	*	*	*	*	*
Sodium Acetate Aq.	60	*	*	A	*	A	A	*	A	A	A	B	A	*	A	A
Sodium Benzoate Aq.	10	*	*	A	*	A	A	*	*	A	A	*	A	*	A	A
Sodium Bicarbonate Aq.	50	*	*	A	*	A	A	*	A	A	A	A	A	A	A	A
Sodium Bisulphite Aq.	10	*	*	A	*	A	A	*	A	A	D	A	A	A	A	A
Sodium Bromide Aq.	10	*	*	A	*	A	A	*	A	A	A	B	A	*	*	A
Sodium Carbonate Aq.	20	A	*	A	*	A	A	*	A	A	A	B	A	*	A	A
Sodium Carbonate Aq.	50	*	*	A	*	A	A	*	A	*	A	*	A	*	A	A
Sodium Chlorate Aq.	10	*	*	A	*	A	A	*	A	*	A	B	A	A	A	A
Sodium Chloride Aq.	10	*	*	A	*	A	A	A	A	A	A	B	A	A	A	A
Sodium Chloride Aq.	90	*	*	A	*	A	A	*	A	A	A	B	A	A	A	A
Sodium Cyanide Aq.	10	*		*	*	A	A	*	A	*	A	*	A	A	A	A
Sodium Hydroxide Aq.	10	B	*	D	A	B	A	A	A	C	D	D	C	C	A	B
Sodium Hydroxide Aq.	50	C	*	D	D	C	A	C	B	C	D	D	D	D	A	B
Sodium Hypochlorite 15% Cl (Chlorine Bleach)	100	B	*	A	*	A	A	A	A	A	D	C	D	A	A	B
Sodium Nitrate Aq.	50	*	*	*	*	A	A	*	A	A	A	A	A	C	A	A
Sodium Perborate Aq.	10	*	*	*	*	A	A	*	*	*	A	*	B	*	A	A
Sodium Phosphate Aq.	90	*	*	*	*	A	A	*	*	*	*	*	A	*	A	A
Sodium Silicate	100	*	*	*	*	A	A	B	A	A	*	A	A	A	A	A
Sodium Sulfate Aq.	90	*	*	A	*	A	A	*	A	A	*	A	A	A	A	A
Sodium Sulfide Aq.	90	*	*	A	*	A	A	*	A	B	*	*	A	*	A	A
Sodium Thiosulfate Aq.	10	*	*	*	*	A	A	A	A	A	A	A	A	A	A	A
Stannic Chloride Aq.	10	A	*	*	A	A	A	A	A	*	D	*	D	A	*	A

A = No attack, possibly slight absorption. Negligible effect on mechanical properties | B = Slight attack by absorption, some swelling and a small reduction in mechanical properties likely | C = Moderate attack or appreciable absorption; material will have limited life | D = Material will decompose or dissolve in a short time | * = No data available | Aq. = Aqueous Solution | SAT = Saturated Aqueous Solution | CONC = Concentrated Aqueous Solution | NOTE: Where aqueous solutions are shown, the concentration as a percentage of weight is given.

Chemical resistance data

	Concentration Weight %	Duratron® CU60 PBI	Duratron® PI	Duratron® PAI	Duratron® U1000 PEI	Fluorosint® PTFE	Ketron® 1000 PEEK	Sultron® PPSU	Techtron® 1000 PPS	Ertalyte® PET	Acetron® GP POM-C	Nylatron® PA6	Nylatron® PA66	Altron™ PC	TIVAR® UHMW-PE	Proteus® PP
Stannic Sulfate Aq.	10	*	*	*	*	A	A	*	A	*	*	C	D	*	*	*
Stearic Acid	100	*	*	*	*	A	A	*	*	*	A	A	A	*	A	B
Styrene (Monomer)	100	*	*	*	*	A	A	*	A	C	A	A	A	D	B	B
Sulfur	100	*	*	*	*	A	A	*	*	A	A	A	A	A	A	A
Sulfur Dioxide (Dry Gas)	100	*	*	A	*	A	A	*	A	B	D	A	C	A	A	B
Sulfuric Acid Aq.	2	B	B	A	A	A	A	A	A	A	D	C	C	A	A	A
Sulfuric Acid Aq.	5	B	B	A	A	A	A	A	A	A	D	D	D	A	A	A
Sulfuric Acid Conc.	96	*	C	*	D	A	D	D	B	C	D	D	D	D	B	B
Sulfurous Acid Aq.	10	B	*	*	A	A	A	A	A	*	D	*	A	A	A	A
Tallow	100	A	*	A	A	A	A	A	A	*	A	A	A	A	A	A
Tar	100	*	*	A	*	A	A	*	A	*	A	B	B	*	A	A
Tartaric Acid Aq.	10	*	*	*	*	A	A	*	A	*	A	A	B	A	A	A
Tetrachlorethylene	100	*	*	*	A	B	A	D	*	B	A	C	A	D	B	C
Tetrahydrofuran	100	A	*	A	*	A	A	*	A	A	B	A	A	D	B	D
Tetralin	100	*	*	*	*	A	A	*	*	A	A	A	A	*	*	C
Thionyl Chloride	100	*	*	*	*	A	A	*	*	*	B	C	D	*	C	C
Thiophene	100	*	*	*	*	A	A	*	*	*	*	*	A	D	B	B
Toluene	100	A	*	A	D	A	A	D	A	A	B	A	A	D	B	B
Transformer Oil	100	*	A	A	*	A	A	A	A	*	A	A	A	A	B	B
Trichlorethylene	100	*	*	A	D	A	A	D	A	B	D	B	B	D	D	D
Triethanolamine	100	*	*	D	D	A	A	C	A	B	A	A	A	D	A	D
Turpentine	100	*	*	A	*	A	A	C	A	*	A	A	A	B	B	C
Trisodium Phosphate Aq.	95	*	*	*	*	A	A	*	A	A	A	B	*	A	A	A
Urea	100	*	*	*	*	A	A	*	A	A	A	A	A	A	A	A
Vaseline	100	A	*	A	A	A	A	A	A	A	A	A	A	A	A	A
Vegetable Oils	100	A	*	A	A	A	A	A	A	A	A	A	A	A	A	B
Vinegar	100	A	*	A	A	A	A	*	A	A	B	C	C	A	A	A
Vinyl Chloride	100	*	*	*	*	A	A	*	A	*	*	A	A	*	A	A
Water	100	A	*	A	A	A	A	A	A	A	A	A	A	A	A	A
Water (Mildly Chlorinated)	<10	A	A	A	A	A	A	A	A	A	C	A	A	A	A	A
Wax (Molten)	100	A	*	A	A	A	A	A	A	A	A	A	A	A	A	B
White Spirit	100	*	*	*	*	A	A	*	A	*	A	A	A	*	A	A
Wines & Spirits	100	A	*	A	A	A	A	*	A	A	A	B	B	A	A	A
Xylene	100	A	*	A	C	A	A	D	A	A	A	A	A	D	C	B
Xylenol	100	A	*	A	B	A	A	D	*	*	A	D	D	D	*	*
Zinc Chloride Aq.	10	*	*	*	A	A	A	A	A	A	D	B	C	A	A	A
Zinc Oxide	100	*	*	*	*	A	A	*	A	*	C	A	A	*	*	A
Zinc Sulfate Aq.	10	*	*	*	*	A	A	*	A	*	C	*	A	A	A	A

The previous chemicals and fluids are known to attack or be compatible with the materials given. Chemical effects are at room temperature. Use this chart as a general guide only. Contact the Advanced Materials division of MCG for further information. The chemical resistance of plastics can be difficult to predict. It is dependent upon temperature, time of exposure, chemical concentration, and stress on the material. Increases in any of these factors may result in reduced chemical inertness. This table is intended as a guide only, and not intended as an alternative to actual testing. The MCG Advanced Materials division recommends actual testing which represents the only method for evaluating suitability for use.

Product compliance

Our materials are commonly used as components that require global regulatory and compliance approvals. We can work with customers to develop unique product / quality specifications requiring testing, inspection, and certifications.

FDA

FDA (Food and Drug Administration) takes responsibility for determining how the manufactured materials may be used in contact with food products. Definitions for proper use are found in a series of regulations published under Government Regulations CFR 21 or through the FCN (Food Contact Notification) process. The FDA provides certain specifications regarding composition, additives, and properties. A material which meets these standards can then be stated as FDA COMPLIANT. End-users should note that it is their responsibility to use the product in a manner compatible with FDA guidelines.

USDA

USDA (U.S. Department of Agriculture) has jurisdiction over equipment used in federally inspected meat and poultry processing plants, and over packaging materials used for such products. Determining suitability for use of components and the materials from which they are made is the responsibility of the equipment manufacturer. Supporting documentation, as may be required by the Food Safety Inspection Service of USDA, is available.

CFIA

Health Canada and CFIA (Canadian Food Inspection Agency) are agency equivalents to the FDA and USDA. Health Canada, similar to FDA, takes responsibility for determining policies, standards, and regulations for ensuring safe food supply. CFIA, similar to USDA, enforces policies, regulations, and standards set by Health Canada.

CFIA has jurisdiction over federally registered establishments and reviews safety of finished articles used in these facilities.

3A-SSI

3A-SSI (Sanitary Standards, Inc.) is a voluntary organization that provides standards of construction for milk, cheese, butter and ice cream processing equipment.

The organization covers the requirements of plastic materials for multiple-use as product contact surfaces in equipment for production, processing, and handling of food products. The criteria for approval of plastic materials are specified in 3A standard 20, and include: cleanability, bacterial treatment, repeat use conditions, and FDA compliance.

NSF

NSF (National Sanitation Foundation) sets standards for food, water, indoor air and environment. Manufacturers who provide equipment displaying NSF symbol have applied to the NSF for device approval to a specific standard. Approval is issued for the finished product (device) in a specific use (application). To obtain device approval, the device must comply with the appropriate standard by meeting material, design, construction, and performance criteria. The NSF maintains numerous standards. Two standards frequently encountered are:

- 51 Plastics in Food Equipment
- 61 Drinking Water System Components – Health Effects

Ask the MCG Advanced Materials division to help submit your project for NSF review:
regulatorysupport@mcam.com

Sanalite® is the only NSF listed product family.

EU STD

European Commission is responsible for developing regulations for Member States on materials and articles in contact with food. Regulation 1935/2004/EC is the framework regulation that prescribes the requirements to determine if a material or article is acceptable for use in food contact applications. The framework of this regulation requires a declaration of compliance for raw materials which meet EU 10/2011 positive list for monomers and additives, and that products were manufactured in a quality system that meets the requirements of GMP EC 023/2006.

REACH

REACH (EC 1907/2006) is a European regulation designed to increase the protection of human health and the environment by an earlier and better identification of the basic properties of chemical substances. This is done by the four processes of REACH, namely the Registration, Evaluation, Authorization and restriction of Chemicals. The regulation also calls for the progressive substitution of the most dangerous chemicals (referred to as “substances of very high concern”, SVHC) when suitable alternatives have been identified.

CALIF. PROP 65

California Proposition 65, officially known as Proposition 65, officially known as the Safe Drinking Water and Toxic Enforcement Act of 1986, was created in November 1986. The proposition protects the state’s drinking water sources from being contaminated with chemicals known to cause cancer, birth defects or other reproductive harm, and requires businesses to inform Californians about exposures to such chemicals. These warnings come in the form of a “clear and reasonable warning”. While equipment and finished components may require warning labels, the stock shape materials of the MCG Advanced Materials division do not require labels. Required information is detailed on individual PHIS- Product Handling Information Sheet pages.

USP CLASS VI

USP (U.S. Pharmacopoeia) Class VI judges the suitability of plastic material intended for use as containers or accessories for parenteral preparations. Suitability under USP Class VI is typically a base requirement for medical implant device and pharmaceutical equipment manufacturers.
The stock shapes of the MCG Advanced Materials division are no suitable for permanent implant.

The MCG Advanced Materials division offers a line of Life Science Grade (LSG) materials based on medical grade resins in which the stock shape process has been validated and product tested to key USP Class VI and ISO10993 guidelines. These products are appropriate for applications requiring body fluid contact or implantation for up to 24 hours.

RoHS

The original RoHS (Restriction of Hazardous Substances), also known as Directive 2002/95/EC, originated in the European Union in 2002 and restricts the use of six hazardous materials found in electrical and electronic products. All applicable products in the EU market since July 1, 2006 must pass RoHS compliance Directive 2011/65/EU was published in 2011 by the EU, which is known as RoHS-Recast or RoHS 2. Directive 2015/863 was published in 2015 by the EU adds four additional restricted substances (phthalates) to the list of six.

Figure 50: Product compliance

MATERIAL	COLOR	FDA / USDA	(EC) 10/2011 (ONLY FOR FOOD GRADES)	USP CLASS VI (ONLY FOR LSG GRADES)	TYPICAL APPLICATIONS	
					STRUCTURAL	WEAR
Altron™ PC	Nat	N	N	N	✓	-
Acetron® AF Blend POM-H	Brown	N	N	N	✓	✓
Acetron® GP POM-C	Nat/Blk	R	S	N	✓	✓
Acetron® POM-H	Nat	R	N	N	✓	✓
Duratron® U1000 PEI	Nat	R	N	Y	✓	-
	Blk	R	N	Y	✓	✓
Ertalyte® PET-P	Nat	R	S	N	✓	✓
	Blk	R	S	N	✓	✓
Ertalyte® TX PET-P	Grey	R	S	N	✓	✓
Fluorosint® HPV PTFE	Nat	R	N	N	-	✓
Fluorosint® 207 PTFE	Nat	R	N	N	-	✓
Fluorosint® 500 PTFE	Nat	N	N	N	✓	✓
Ketron® 1000 PEEK	Nat/Blk	R	S	Y	✓	✓
Nylatron® GS PA66	Blk	N	N	N	-	✓
Nylatron® GSM PA6	Blk	N	N	N	-	✓
Nylatron® GSM Blue PA6	Dark blue	N	N	N	-	✓
Nylatron® LFG PA6	Nat	S	N	N	-	✓
Nylatron® MC901 PA6	Blue	N	N	N	✓	✓
Nylatron® MC907 PA6	Nat	R	S	N	✓	✓
Nylatron® NSM PA6	Grey	N	N	N	-	✓
Nylatron® PA66	Nat	S	S	N	✓	✓
Proteus® CoPolymer Polypropylene	Nat	S	N	N	✓	-
Proteus® HDPE	Nat	S	N	N	✓	✓
Proteus® Homopolymer Polypropylene	Nat	S	N	N	✓	-
Proteus® LDPE	Nat	S	N	N	✓	-
Proteus® White Polypropylene	White	S	N	N	✓	-
Sanalite® HDPE / PP	Nat	S	N	N	✓	-
Sultron™ PPSU	Nat/Blk	S	N	Y	✓	-
Sultron™ PSU	Nat	S	N	Y	✓	-
Techtron® 1000 PPS	Nat	S	N	N	✓	-
TIVAR® 1000 UHMW-PE	Nat	S	S	N	-	✓
TIVAR® H.O.T. UHMW-PE	White	S	S	N	-	✓
TIVAR® Oil-Filled UHMW-PE	Blk	S	N	N	-	✓
TIVAR® CleanStat UHMW-PE	Blk	S	S	N	-	✓
TIVAR® HPV UHMW-PE	Blue	S	S	N	-	✓

R: tests are performed on resin S: tests are performed on stock shape

This table should be used for reference only. Formal declarations to the various regulations/compliances are available upon request" or something similar.

Fabrication guidelines

The following guidelines are presented for those machinists not familiar with the machining characteristics of plastics. They are intended as guidelines only, and may not represent the most optimum conditions for all parts. The troubleshooting quick reference on *Figure 54 on page 89* should be used to correct undesirable surface finishes or material responses during machining operations. All thermoplastic products of the MCG Advanced Materials division are stress relieved to ensure the highest degree of machinability and dimensional stability. However, the relative softness of plastics (compared to metals) may result in difficulty maintaining tight tolerances during and after machining. A good rule of thumb for tolerances of plastic parts is
+/- .001" per inch of dimension although tighter tolerances are possible with very stable, reinforced materials.

Tips machining MCG Advanced Materials' stock shapes:

- Thermal expansion is up to 10 times greater with plastics than metals.
- Plastics lose heat more slowly than metals, so avoid localized overheating.
- Softening (and melting) temperatures of plastics are much lower than metals.
- Plastics are much more elastic than metals.

Because of these differences, it is suggested to experiment with fixtures, tool materials, angles, speeds and feed rates to obtain optimum results.

Getting started

- Neutral to slightly positive tool geometries with ground peripheries are recommended.
- Carbide tooling with polished top surfaces is suggested for optimum tool life and surface finish. Polycrystalline diamond tooling provides optimum surface finish when machining harder materials like Duratron® and reinforced Ketron® PEEK and Techtron® PPS grades.
- Use adequate chip clearance to prevent clogging.
- Adequately support the material to restrict deflection away from the cutting tool.
- *Figures 51, a, b and c* provide guidance for typical machining parameters.

Coolants

Coolants are generally not required for most turning operations (not including drilling and parting off). However, for optimum surface finishes and close tolerances, non-aromatic, water soluble coolants are suggested. Spray mists and pressurized air are very effective means of cooling the cutting interface. General purpose petroleum based cutting fluids, although suitable for many metals and plastics, may contribute to stress cracking of amorphous plastics such as Altron™ PC, Sultron® PSU, Duratron® U1000 PEI, and Sultron® PPSU.

Coolants are strongly suggested during drilling operations, especially with notch sensitive materials such as Ertalyte® PET, Duratron® PAI, Duratron® CU60 PBI, and glass or carbon reinforced products.
In addition to minimizing localized part heat-up, coolants prolong tool life. Two (flood) coolants suitable for most plastics are Trim E190 and Trim Sol LC SF (Master Chemical Corporation–Perrysburg, OH).

Turning

Most turning and boring should be done with CPG (Type) 422 ground and polished C2 carbide inserts. Turning operations require inserts with positive geometries and ground peripheries. Ground peripheries and polished top surfaces generally reduce material build-up on the insert, improving the attainable surface finish. A fine-grained C-2 carbide is generally best for turning operations.

Drilling

The insulating characteristics of plastics require consideration during drilling operations, especially when hole depths are greater than twice the diameter.

Small diameter holes (1/32" to 1" (0.8 to 25mm) diameter)
High speed steel twist drills are generally sufficient for small holes. To improve swarf removal, frequent pull-out (peck drilling) is suggested. A slow spiral (low helix) drill will allow for better swarf removal.

Typical tolerances achievable for advanced polymers are 0.1 to 0.2% of nominal dimension

Large diameter holes (1" (25mm) diameter & larger)
A slow spiral (low helix) drill or general purpose drill bit ground to a 118° point angle with 9° to 15° lip clearance is recommended. The lip rake should be ground (dubbed off) and the web thinned.
Drill large holes stepwise. A bore diameter of 2" (50 mm) or greater should be made by drilling successively using a Ø 0.5" (12 mm) and Ø 1" (25 mm) drill bit. Further expansion of the hole should be made using a single point boring tool.

Figure 51a: Turning & drilling operations (Imperial)

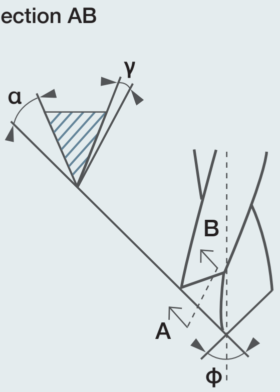
MATERIAL	RELATIVE MACHINABILITY (1-10, 1=EASIEST)	TURNING			DRILLING**	
		DEPTH OF CUT	SPEED (FT./MIN.)	FEED (IN./REV.)	NOMINAL HOLE DIAMETER	FEED (IN./REV.)
TIVAR® UHMW-PE, Nylatron® PA, Acetron® / Ertacetal® POM based materials	1-2	150” deep cut .025” deep cut	500-600 600-700	.010 - .015 .004 - .007	1/16” - 1/4” 1/2” - 3/4” 1” to >2”	.007 - .015 .015 - .025 .020 - .050
Proteus® PP	2-3	.150” deep cut .025” deep cut	500-600 600-700	010 - .015 .004 - .007	1/16” - 1/4” 1/2” - 3/4” 1” to >2”	.007 - .015 .015 - .025 .020 - .050
Altron™ PC						
Sultron® PSU, Sultron® PPSU & Duratron® PEI based materials						
Ertalyte® PET based materials	2	.150”deep cut .025” deep cut	500-600 600-700	.010 - .015 .004 - .007	1/16” - 1/4” 1/2” - 3/4” 1” to >2”	002 - .005 .015 - .025 .020 - .050
Ketron® PEEK based materials	5-7	.150” deep cut .025” deep cut	350-500 500-600	.010 - .015 .003 - .008	1/16” - 1/4” 1/2” - 3/4” 1” to >2”	.002 - .005 .004 - .008 .008 - .012
Fluorosint® PTFE* based materials	1-3	.150”deep cut .025” deep cut	600-1000 600-700	.010 - .016 .004 - .007	1/16” - 1/4” 1/2” - 3/4” 1” to >2”	.007 - .015 .015 - .025 .020 - .050
Techtron® PPS based materials	5	.150” deep cut .025” deep cut	100-300 250-500	.010 - .020 .005 - .010	1/16” - 1/4” 1/2” - 3/4” 1”to >2”	.007 - .015 .015 - .025 .020 - .050
Duratron® PAI & Duratron® PI based materials	5-8	.025” deep cut	300-800	.004 - .007	1/16” - 1/4” 1/2” - 3/4” 1” to >2”	.007 - .015 .015 - .025 .020 - .050
Duratron® CU60 PBI based materials	10	.025” deep cut	150-225	.002 - .006	1/2” or larger	.015 - .025

* For the Fluorosint® MT-01 data, contact technicalsupport@mcam.com

** The recommended speed for drilling operations is 150 to 200 ft./min.

Proper feed rates are most critical to ensure reduced heat generation, tolerance control and good surface finish. Machining speeds can be increased above those listed as long as recommended feed rates are maintained.

Figure 51b: Drilling operations (Metric)

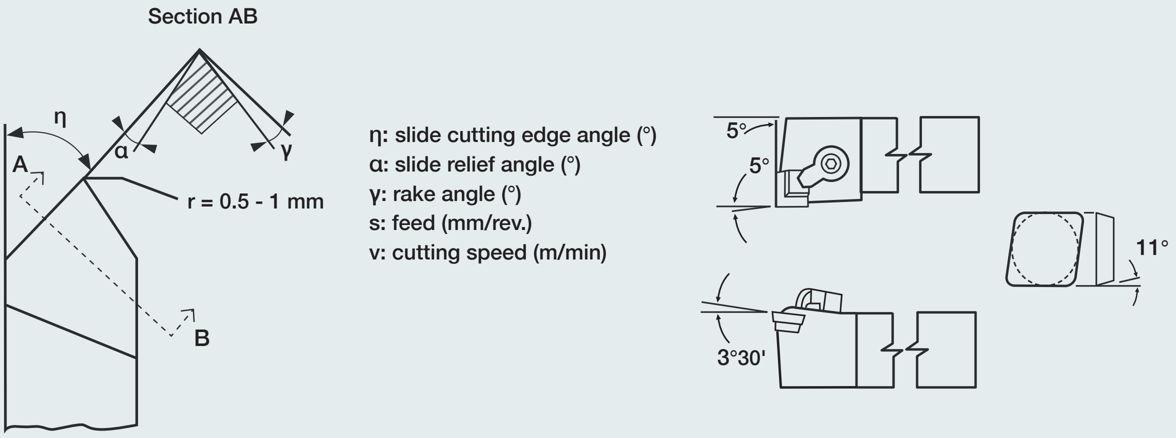


ϕ: top angle (°)
α: relief angle (°)
γ: rake angle (°)
s: feed (mm/rev.)
v: cutting speed (m/min)

	α	γ	ϕ	s	v	MATERIAL TOOL
Ertalon® PA / Nylatron® PA, TIVAR® UHMW-PE	5 - 10	3 - 5	90 – 120	0.1 - 0.3	50 – 100	HSS steel or carbide
Acetron® / Ertacetal® POM Semitron® ESd 225	5 - 10	3 - 5	90 – 120	0.1 - 0.3	50 – 100	HSS steel or carbide
Ertalyte® PET, Duratron® T4203 / 4503 PAI, Ketron® 1000 PEEK, Ketron® TX PEEK	5 - 10	3 - 5	90 – 120	0.1 - 0.3	50 – 80	Carbide
Altron™ PC, Sultron® PPSU, Duratron® U1000 PEI, Sultron® PSU	5 - 10	3 - 5	90 – 120	0.1 - 0.3	50 – 100	Carbide
Ertalon®66 GF30 / Nylatron® GF30 PA66 Duratron® T4301 / T4501 / T5530 / T4501 PAI, Ketron® HPV / GF30 / CA30 / VMX PEEK, Techtron® HPV PPS, Semitron® ESd 410C / 520 HR	5 - 10	3 - 5	90 – 120	0.1 - 0.3	50 – 80	Carbide or PCD/CVD
Duratron® CU60 PBI, Duratron® PI, Fluorosint® MT-01 PTFE	5 - 10	3 - 5	90 – 120	0.1 - 0.3	25 – 50	Carbide or PCD/CVD
Fluorosint® 135 / 207 / 500 PTFE, Semitron® ESd 500HR	5 - 10	3 - 5	90 – 120	0.1 - 0.3	50 - 100	Carbide

When drilling pilot holes for internal threads confirm the actual hole size before tapping. Holes may "close in" after drilling making taps tight.

Figure 51c: Turning operations (Metric)



η: slide cutting edge angle (°)
α: slide relief angle (°)
γ: rake angle (°)
s: feed (mm/rev.)
v: cutting speed (m/min)

	α	γ	η	s	v	MATERIAL TOOL
Ertalon® PA / Nylatron® PA, TIVAR® UHMW-PE	5 – 15	0 - 10	0 - 45	0.05 - 0.5	200 - 500	HSS steel or carbide
Acetron® / Ertacetal® POM Semitron® ESd 225	5 – 15	0 - 10	0 - 45	0.05 - 0.5	200 - 500	HSS steel or carbide
Ertalyte® PET, Duratron® T4203 / 4503 PAI, Ketron® 1000 PEEK, Ketron® TX PEEK	5 – 15	0 - 10	0 - 45	0.05 - 0.5	200 - 400	Carbide
Altron™ PC, Sultron® PPSU, Duratron® U1000 PEI, Sultron® PSU	5 – 15	0 - 10	0 - 45	0.05 - 0.4	200 - 400	Carbide
Ertalon®66 GF30 / Nylatron® GF30 PA66 Duratron® T4301 / T4501 / T5530 / T4501 PAI, Ketron® HPV / GF30 / CA30 / VMX PEEK, Techtron® HPV PPS, Semitron® ESd 410C / 520 HR	5 – 15	0 - 10	0 - 45	0.05 - 0.3	100 - 200	Carbide or PCD/CVD
Duratron® CU60 PBI, Duratron® PI, Fluorosint® MT-01 PTFE	5 – 15	3 - 5	0 - 45	0.05 - 0.2	25 - 100	Carbide or PCD/CVD
Fluorosint® 135 / 207 / 500 PTFE, Semitron® ESd 500HR	8 - 12	0 - 5	0 - 45	0.05 - 0.4	150 - 400	Carbide

The continuous chip stream produced when turning and boring many thermoplastics can be handled using a compressed air powered suction system to avoid the chip wrapping around the chuck, the tool or the workpiece. The suction system can directly dispose the "swarf" into a container for disposal.

Threading and tapping

Threading should be done by single point using a carbide insert and taking four to five 0.001” (0.025mm) passes at the end. Coolant usage is suggested. For tapping, use the specified drill with a two flute coated tap. Remember to keep the tap clean of chip build-up. Use of a coolant during tapping is also suggested.

Milling

Sufficient fixturing allows for fast table travel and high spindle speeds when end milling plastics. When face milling, use positive geometry cutter bodies. Rake angles should be neutral to slightly positive to minimize heat generation. Climb milling is recommended over conventional milling (see Figure 52). To ensure finished part flatness, always machine a plate flat to start. Do not force a plate flat with a vice or vacuum.

> Use of a coated tap will create radii at the root of the threads resulting in a stronger and tougher thread which is less prone to cracking from over-torqueing.

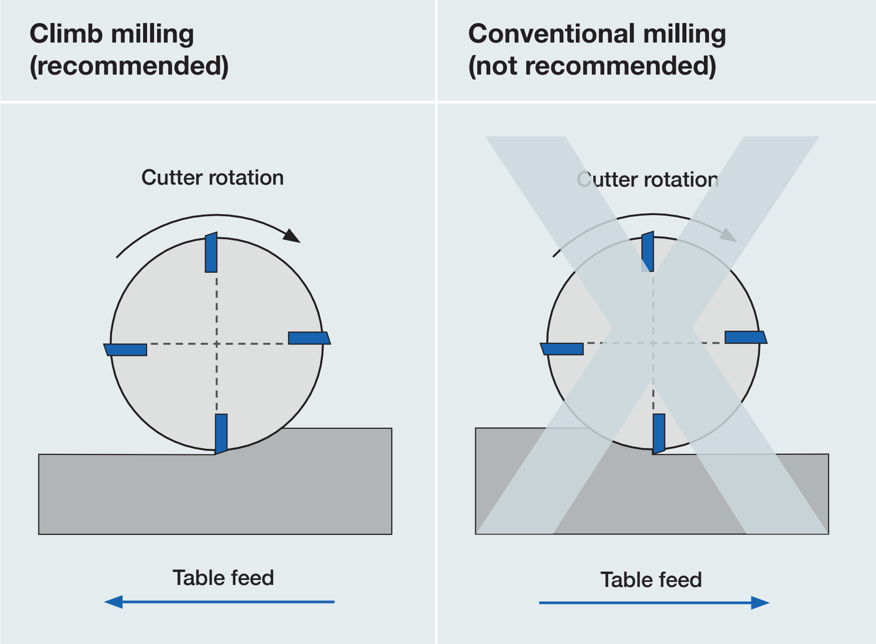
Data, compliance, and fabrication: When removing material in the z-direction, remove equal amounts from the top and bottom surfaces when possible. Parts where more material is removed from one side than the other, may begin to warp or bend, and require an additional starting thickness or rough machining to within .125” of final thickness. This should be followed by a 24-48 hour hold for stress relief before finishing.

Sawing

Band sawing is versatile for straight, continuous curves or irregular cuts. Table saws are convenient for straight cuts and can be used to cut multiple thicknesses and thicker cross sections up to 4” (100mm) with adequate horsepower. Saw blades should be selected based upon material thickness and surface finish desired. Less teeth per inch (per 25.4mm) is typically recommended to generate less heat.

> Rip and combination blades with a 0° tooth rake and 3° to 10° tooth set are best for general sawing in order to reduce frictional heat.
>
> Hollow ground circular saw blades without set will yield smooth cuts up to 3/4” (19mm) thick.
>
> Tungsten carbide blades wear well and provide optimum surface finishes.

Figure 52: Recommended milling



Climb milling (recommended)

Conventional milling (not recommended)

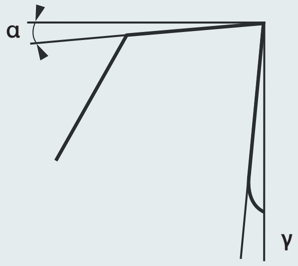
Figure 53a: Milling & sawing (Imperial)

MATERIAL	END MILLING / SLOTTING				FACE MILLING (C-2) CARBIDE TOOL			SAWING			
	HIGH SPEED STEEL (M2, M7)	DEPTH OF CUT	SPEED (RPM)	FEED (IN./MIN.)	DEPTH OF CUT	SPEED (RPM)	FEED (IN./MIN.)	MATERIAL THICKNESS	TOOTH FORM	PITCH (TEETH/ IN.)	BAND SPEEDS (FT./MIN.)
TIVAR® UHMW-PE, Nylatron® PA, Acetron® / Ertacetal® POM based materials	1/4”,1/2” 3/4”, 1”, 2”	0.250	6,500-8,000	35 - 45	0.150	2,500-4,500	30 - 45	< 0.5” 0.5”-1.0” 1.0”- 3.0” >3.0”	Precision “ Buttress “	10-14 6 3 3	3,000 2,500 2,000 1,500
	1/4”,1/2” 3/4”	0.050	7,000-8,500	25 - 30	0.060	2,500-4,500	15 - 20				
Proteus® PP Altron™ PC	1/4”,1/2” 3/4”, 1”, 2”	0.250	2,500–4,000	15 - 25	0.150	2,500-4,500	10 - 15	< 0.5” 0.5”-1.0” 1” - 3” >3”	Precision “ Buttress “	10-14 6 3 3	4,000 3,500 3,000 2,500
Sultron® PSU, Sultron® PPSU & Duratron® PEI based materials	1/4”,1/2” 3/4”	0.050	3,000–4,500	10 - 15	0.060	2,500-4,500	10 - 15				
Ertalyte® PET based materials	1/4”,1/2” 3/4”, 1”, 2”	0.250	2,500–4,000	12 - 15	0.150	2,500-4,000	10 - 12	< 0.5” 0.5”-1.0” 1” - 3” >3”	Precision “ Buttress “	10-14 6 3 3	5,000 4,300 3,500 3,000
	1/4”,1/2” 3/4”	0.050	3,000–4,500	12 - 15	0.060	2,500-4,000	10 - 12				
Ketron® PEEK based materials	1/4”,1/2” 3/4”, 1”, 2”	0.150	2,500–4,000	12 - 15	0.150	2,500-4,000	10 - 12	< 0.5” 0.5”-1.0” 1” - 3” >3”	Precision “ Buttress “	10-14 6-8 3	4,000 3,500 3,000 2,500
	1/4”,1/2” 3/4”	0.060	2,500–4,000	10 - 12	0.060	2,500-4,000	10 - 12				
Fluorosint® PTFE* based materials	1/4”,1/2” 3/4”, 1”, 2”	0.150	6,500 – 8,000	35 - 45	0.150	2,500-4,000	10 - 15	< 0.5” 0.5”-1.0” 1” - 3” >3”	Precision “ Buttress “	10-14 6-8 3 3	3,000 2,500 2,000 1,500
	1/4”,1/2” 3/4”	0.060	7,000 – 8,500	25 - 30	0.060	2,500-4,000	10 - 15				
Techtron® PPS based materials	1/4”,1/2” 3/4”, 1”, 2”	0.150	2,500–4,000	12 - 15	0.150	2,500-4,000	10 - 12	< 0.5” 0.5”-1.0” 1” - 3” >3”	Precision “ Buttress “	10-14 6-8 3 3	5,000 4,300 3,500 3,000
	1/4”,1/2” 3/4”	0.060	3,000 – 4,500	10 - 15	0.060	2,500-4,000	10 - 12				
Duratron® PAI & Duratron® PI based materials	1/4”,1/2” 3/4”, 1”, 2”	0.035	2,500 – 4,000	10 - 15	0.035	2,500-4,000	10 - 12	1/16” - 1/4” 1/2”- 3/4” 1” to >2”	Precision “ Buttress “	10-14 6-8 33	5,000 4,300 3,500 3,000
Duratron® CU60 PBI	1/4”,1/2” 3/4”, 1”, 2”	0.015	2,500 – 3,500	6 - 10	0.015	2,000-3,000	8 - 10	1/2” or larger	Precision “ Buttress “	10 10	3,000 1,500

* For the Fluorosint® MT-01 data, contact Mitsubishi Chemical Advanced Materials.

Proper feed rates are critical to ensure reduced heat generation, tolerance control and good surface finish. Machining speeds can be increased above those listed as long as recommended feed rates are maintained.

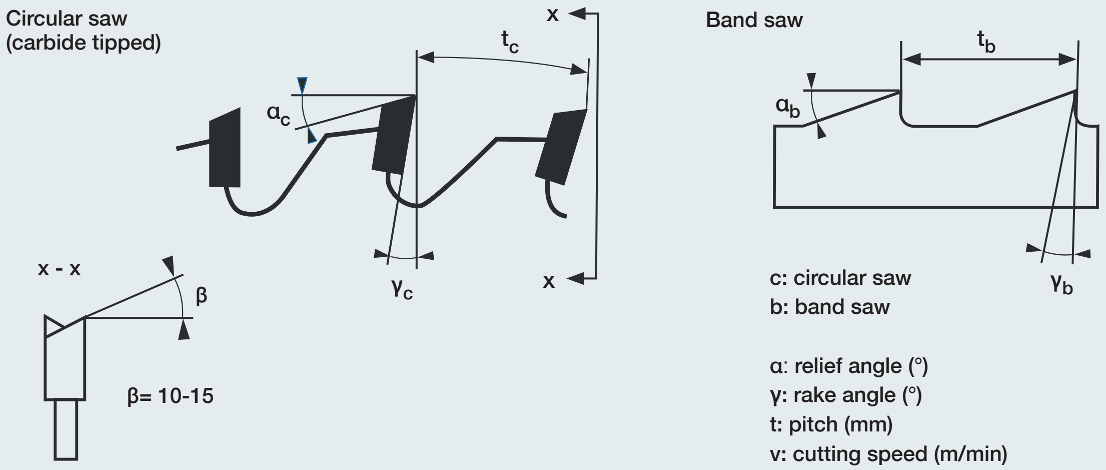
Figure 53b: Milling (Metric)



α: relief angle (°)
γ: rake angle (°)
s: feed (mm/tooth)
v: cutting speed (m/min)

	α	γ	s	v	MATERIAL TOOL
Ertalon® PA / Nylatron® PA, TIVAR® UHMW-PE	5 – 15	0 - 15	≤ 0.5	200 - 500	HSS steel or carbide
Ertacetal® POM, Semitron® ESd 225	5 – 15	0 - 15	≤ 0.5	200 - 400	HSS steel or carbide
Ertalyte® PET, Duratron® T4203 / 4503 PAI, Ketron® 1000 PEEK, Ketron® TX PEEK	5 – 15	0 - 15	≤ 0.4	150 - 300	Carbide
Altron™ PC, Sultron® PPSU, Duratron® U1000 PEI, Sultron® PSU	5 – 15	0 - 15	≤ 0.4	200 - 400	Carbide
Ertalon® 66 GF30 PA6, Duratron® T4301 / T4501 / T5530 / T4501 PAI, Ketron® HPV / GF30 / CA30 / VMX PEEK, Techtron® HPV PPS, Semitron® ESd 410C / 520 HR	5 – 15	0 - 15	≤ 0.3	75 – 150	Carbide or PCD/CVD
Duratron® CU60 PBI, Duratron® PI, Fluorosint® MT-01 PTFE	5 – 15	0 - 15	≤ 0.15	25 - 100	Carbide or PCD/CVD
Fluorosint® 135 / 207 / 500 PTFE, Semitron® ESd 500HR	5 – 15	0 - 15	≤ 0.3	100 - 250	Carbide

Figure 53c: Sawing (Metric)



c: circular saw
b: band saw

α: relief angle (°)
γ: rake angle (°)
t: pitch (mm)
v: cutting speed (m/min)

	α_c	γ_c	t_c	v_c	α_b	γ_b	t_b	v_b
Ertalon® PA / Nylatron® PA, TIVAR® UHMW-PE	10 - 15	0 - 15	8 – 45	1,000-3,000	25 - 40	0 - 8	4 - 10	50 - 500
Ertacetal® POM, Semitron® ESd 225	10 - 15	0 - 15	8 – 45	1,000-3,000	25 - 40	0 - 8	4 - 10	50 - 500
Ertalyte® PET, Duratron® T4203 / 4503 PAI, Ketron® 1000 PEEK, Ketron® TX PEEK	10 - 15	0 - 15	8 – 25	1,000-3,000	25 - 40	0 - 8	4 - 10	50 - 400
Altron™ PC, Sultron® PPSU, Duratron® U1000 PEI, Sultron® PSU	10 - 15	0 - 15	8 – 25	1,000-3,000	25 - 40	0 - 8	4 – 6	50 - 400
Ertalon® 66 GF30 PA6, Duratron® T4301 / T4501 / T5530 / T4501 PAI, Ketron® HPV / GF30 / CA30 / VMX PEEK, Techtron® HPV PPS, Semitron® ESd410C / 520 HR	10 - 15	0 - 15	8 – 25	1,000-3,000	25 - 40	0 - 8	4 – 6	50 - 200
Duratron® CU60 PBI, Duratron® PI, Fluorosint® MT-01 PTFE	10 - 15	0 - 15	8 – 25	1,000-3,000	25 - 40	0 - 8	2 – 3	25 - 100
Fluorosint® 135 / 207 / 500 PTFE, Semitron® ESd 500HR	10 - 15	0 - 15	8 – 25	1,000-3,000	25 - 40	0 - 8	4 – 6	50 - 200

Reinforced materials such as Ertalon® 66 GF30 PA66, Duratron® T4301 PAI, Duratron® T4501 PAI, Duratron® T5503 PAI, Ketron® HPV PEEK, Ketron® GF30 PEEK, Ketron® CA30 PEEK, Techtron® HPV PPS, Semitron® ESd 410C and Semitron® ESd 520HR are preferably cut with a band saw which has a tooth pitch of 4 to 6 mm (Duratron® CU60 PBI, Duratron® PI and Fluorosint® MT-01 PFTE: 2-3 mm). Do not use standard circular saws, as this usually leads to cracks.

Figure 54: Troubleshooting

DRILLING	
DIFFICULTY	COMMON CAUSE
Tapered hole	1. Incorrectly sharpened drill 2. Insufficient clearance 3. Feed too heavy
Burnt or melted surface	1. Wrong type drill 2. Incorrectly sharpened drill 3. Feed too light 4. Dull drill 5. Web too thick 6. Not peck drilling
Chipping of surfaces	1. Feed too heavy 2. Clearance too great 3. Too much rake
Chatter	1. Too much clearance 2. Feed too light 3. Drill overhang too great 4. Too much rake (thin web as described)
Feed marks or spiral lines on inside diameter	1. Feed too heavy 2. Drill not centered 3. Drill ground off-center
Oversized holes	1. Drill ground off-center 2. Web too thick 3. Insufficient clearance 4. Feed rate too heavy 5. Point angle too great
Undersized holes	1. Dull drill 2. Too much clearance 3. Point angle too small
Holes not concentric	1. Feed too heavy 2. Spindle speed too slow 3. Drill enters next piece too far 4. Cut-off tool leaves nib, which deflects drill 5. Web too thick 6. Drill speed too heavy at start 7. Drill not mounted on center 8. Drill not sharpened correctly
Burr at cut-off	1. Dull cut-off tool 2. Drill does not pass completely through piece
Rapid dulling of drill	1. Drill feed too light 2. Spindle speed too fast 3. Insufficient lubrication from coolant

CUTTING OFF	
DIFFICULTY	COMMON CAUSE
Melted surface	1. Dull tool 2. Insufficient side clearance 3. Insufficient coolant supply
Rough finish	1. Feed too heavy 2. Tool improperly sharpened 3. Cutting edge not honed
Spiral marks	1. Tool rubs during its retreat 2. Burr on point of tool
Concave or convex surfaces	1. Point angle too great 2. Tool not perpendicular to spindle 3. Tool deflecting 4. Feed too heavy 5. Tool mounted above or below center
Nibs or burrs at cut-off point	1. Point angle not great enough 2. Dull tool 3. Feed too heavy
Burrs on outside diameter	1. No chamfer before cut-off diameter 2. Dull tool

TURNING & BORING	
DIFFICULTY	COMMON CAUSE
Melted surface	1. Dull tool or heel rubbing 2. Insufficient side clearance 3. Feed rate too slow 4. Spindle speed too fast
Rough finish	1. Feed too heavy 2. Incorrect clearance angles 3. Sharp point on tool (slight nose radius required) 4. Tool not mounted on center
Burrs at edge of cut	1. No chamfer provided at sharp corners 2. Dull tool 3. Insufficient side clearance 4. Lead angle not provided on tool (tool should ease out of cut gradually, not suddenly)
Cracking or chipping of corners	1. Too much positive rake on tool 2. Tool not eased into cut (tool hits work) 3. Dull tool 4. Tool mounted below center 5. Sharp point on tool (slight nose radius required)
Chatter	1. Too much nose radius on tool 2. Tool not mounted solidly 3. Material not supported properly 4. Width of cut too wide (use 2 cuts)

Post machining annealing

When should parts be annealed after machining?

Experience has shown that very few machined plastic parts require annealing during or after machining to meet dimensional or performance requirements. The MCG Advanced Materials division stock shapes are annealed using a proprietary stress relieving cycle to minimize internal stresses that may result from the manufacturing process. This assures that the material will remain dimensionally stable during and after machining.

Machined-in stress can result in poor tolerance control as well as warpage. To prevent machined-in stress, it is important to identify the causes. Machined-in stress is created by:

- Using dull or improperly designed tooling
- Excessive heat generated from inappropriate speeds and feed rates.
- Machining away large volumes of material – usually from one side

Roughing

A simple rough machining step is usually sufficient, and preferred over oven annealing, to achieve even the most critical tolerances on final dimensions.

When milling, rough the parts leaving ~ 0.030” to 0.060” (0.8 – 1.5mm) per side. Once rough machined, let the parts sit for 24 to 48 hours to stabilize; then finish machine. The more material you need to machine away, the more material you should leave on during roughing.
Balanced machining on both sides of the shape centerline should be followed during roughing to help prevent warpage.

When should parts be oven–annealed?

Post annealing, in some cases, may provide additional performance benefits. Oven annealing is used by some to achieve extremely tight tolerances. If using an oven, be sure to follow annealing guidelines below, as shortcuts will actually increase part stress and create more problems holding required dimensions. Oven annealing may help if the following apply.

Tighter tolerance capability
For extremely close tolerance parts, sometimes rough machining alone is not sufficient. Close tolerance parts requiring precision flatness and non-symmetrical contour sometimes require intermediate oven annealing between machining operations.

Improved wear resistance
Extruded or injection molded Duratron® PAI parts that require high pressure velocities (PV) or the lowest possible wear factor will benefit from an additional cure after machining. This curing process optimizes the wear properties. Only Duratron® PAI benefits from such a cycle.

Improved chemical resistance
Altron™ PC, Sultron® PSU, and Duratron® PEI, like many amorphous (transparent) plastics may be annealed to minimize stress cracking. Duratron® PAI also benefits from such a cycle.

Figure 55: Post machining air annealing guidelines*

MATERIAL	HEATING RATE	HOLD TIME	COOLING TIME	ATMOSPHERE
Nylatron® PA grades	60°F (15°C) per hour to 300°F (150°C)	10 minutes per mm (0.04”) thickness	50°F (10°C) per hour	Nitrogen
Ertalyte® PET-E Grades	60°F (15°C) per hour to 300°F (150°C)	10 minutes per mm (0.04”) thickness	50°F (10°C) per hour	Nitrogen
Acetron® GP POM-C	60°F (15°C) per hour to 300°F (150°C)	10 minutes per mm (0.04”) thickness	50°F (10°C) per hour	Nitrogen or air
Acetron® POM-H	60°F (15°C) per hour to 300°F (150°C)	10 minutes per mm (0.04”) thickness	50°F (10°C) per hour	Nitrogen or air
Altron™ PC	60°F (15°C) per hour to 275°F (130°C)	10 minutes per mm (0.04”) thickness	50°F (10°C) per hour	Nitrogen or air
Sultron® PSU	60°F (15°C) per hour to 330°F (165°C)	10 minutes per mm (0.04") thickness	50°F (10°C) per hour	Nitrogen or air
Sultron® PPSU & Duratron® PEI	60°F (15°C) per hour to 390°F (200°C)	10 minutes per mm (0.04”) thickness	50°F (10°C) per hour	Nitrogen or air
Techtron® PPS	60°F (15°C) per hour to 350°F (175°C)	10 minutes per mm (0.04") thickness	50°F (10°C) per hour	Nitrogen or air
Ketron® PEEK	60°F (15°C) per hour to 480°F (250°C)	10 minutes per mm (0.04") thickness	50°F (10°C) per hour	Nitrogen or air
Duratron® PAI (ramp up)	4 hours to 300°F (150°C)	1 day	50°F (10°C) per hour	Nitrogen or air
	4 hours to 420°F (215°C)	1 day	50°F (10°C) per hour	
	4 hours to 470°F (240°C)	1 day	50°F (10°C) per hour	
	4 hours to 500°F (260°C)	3 - 10 days	50°F (10°C) per hour	
Duratron® PI (ramp up)	4 hours to 300°F (150°C)	60 minutes per 1/4” (6mm) thickness	50°F (10°C) per hour	Nitrogen or air
	4 hours to 450°F (230°C)	60 minutes per 1/4” (6mm) thickness	50°F (10°C) per hour	
	4 hours to 600°F (315°C)	60 minutes per 1/4” (6mm) thickness	50°F (10°C) per hour	

* Finish machining of critical dimensions should be performed after annealing. Important: Annealing cycles have been generalized to apply to a majority of machined parts. Changes in heat up and hold time may be possible if cross sections are thin. Parts should be fixtured during annealing to prevent distortion.

Adhesive bonding

The MCG Advanced Materials division has longtime expertise in advising on adhesive bonding of engineering thermoplastics and supporting customers in the selection and application of the right adhesive type, as well as the correct design of the joint and an appropriate surface preparation.

As with every joining method, adhesive bonding has a number of advantages and disadvantages. Users should weigh these against those of other joining methods.

The correct preparation of the surfaces to be bonded and the selection of the suitable adhesive for your application are key to the success of your application. Please make sure to always run tests before you apply adhesive bonding on a larger scale.

The MCG Advanced Materials division holds comprehensive information on adhesives and more. Please feel free to contact us for more details.

Welding

Plastic parts cannot always be made in one piece. Large pieces of special designs require alternative production methods.

Design and tooling considerations sometimes make it more economical and advantageous to produce a part in two or more pieces. We offer welding of panels, sheets, near net shapes or even machined parts in a large variety of dimensions and geometries.

Please consult us for more information to make your project a success.

Mitsubishi Chemical Advanced Materials

North America
Mitsubishi Chemical
Advanced Materials Inc.

2120 Fairmont Avenue
PO Box 14235 — Reading,
PA 19612-4235
Tel: 800 366 0300
+1 610 320 6600

Europe
Mitsubishi Chemical
Advanced Materials NV

Galgenveldstraat 12
8700 Tielt, Belgium
Tel: +32 051 42 35 11

Asia-Pacific
Mitsubishi Chemical
Advanced Materials Asia Pacific Ltd.

Unit 7B, 35/F, Cable TV Tower,
9 Hoi Shing Road,
Tsuen Wan, Hong Kong
Tel: +852 2470 26 83