SIMPLY NO SUBSTITUTE

DESIGN & FAB GUIDE

QUADRANT ENGINEERING PLASTIC PRODUCTS:

The global leader in engineering plastics for machining

QUADRANT

Plastics are continuously evolving and replacing metals all over the world in extreme high tech markets like Aerospace, Alternative Energy, Automotive, Chemical, Oil & Gas Processing, Defense, Food Processing & Packaging, Heavy & Industrial Equipment, Medical & Life Sciences, Semiconductor & Electronics, and Transportation.

PLASTICS IMPROVE COMPONENT AND SYSTEM EFFICIENCY BY:

PLASTICS > METALS

- REDUCING WEIGHT
- ELIMINATING CORROSION
- IMPROVING WEAR PERFORMANCE IN UNLUBRICATED CONDITIONS
- REDUCING NOISE
- INSULATING & ISOLATING
- INCREASING PART LIFE

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

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. 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 understand basic categories of plastic materials.

FIG 1 PLASTICS VS METAL - TYPICAL PROPERTIES

Property	Units	Nylatron® PA	Duratron® PAI	Bronze	Steel (A36)	Aluminum
Density	g/cm3	1.15	1.41	8.80	7.84	2.70
Tensile Strength	psi	12,000	20,000	22,000*	36,000*	30,000*
Modulus of Elasticity	psi	0.4×10^6	0.6×10^6	16×10^6	30×10^6	10×10^6
Relative Strength to Weight	Steel =1.0	2.27	2.78	0.54	1.0	2.41
Coefficient of Linear Thermal Expansion	in./in./°F	50×10^{-6}	17×10^{-6}	10×10^{-6}	6.3×10^{-6}	12×10^{-6}

* Yield numbers given for metals

THERMOPLASTICS AND THERMOSETS

Plastics are commonly described as being either a thermoplastic (meltable) or a thermoset (non meltable). Thermoset materials such as phenolic and epoxy were developed as early as 1900 and were some of the earliest "high volume" plastics. Both thermoplastic and thermoset stock shapes are available for machined parts, although thermoplastic stock shapes are much more commonly 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.

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FIG 2 QUADRANT EPP PLASTICS

	Performance Family	Material	Tradename	Performance Profile
Imidized	Imidized	Polybenzimidazole (PBI)	Duratron® PBI	Highest heat resistance and strength
		Polyimide (PI)	Duratron® PI	High heat resistance to 600°F
		Polyamide-imide (PAI)	Duratron® PAI	Highest strength to 500°F, dimensionally stable
Advanced Engineering Plastics	Semi-Crystalline High Performance	Polyetherether ketone (PEEK)	Ketron® PEEK	Chemical, wear and heat resistance
		Polyphenylene sulfide (PPS)	Techtron® PPS	Chemical resistance, strength, and wear resistance
		Filled Polytetrafluoroethylene (PTFE)	Fluorosint® PTFE	Chemical resistance and dimensional stability
	Amorphous High Performance	Polyetherimide (PEI)	Duratron® PEI	High strength and heat resistance to 400°F
		Polyphenylsulfone (PPSU)	Quadrant® PPSU	High strength, steam and impact resistance
		Polysulfone (PSU)	Quadrant® PSU	High strength and heat resistance to 300°F
Engineering Plastics	Semi-Crystalline Engineering	Polyethylene Terephthalate (PET-P)	Ertalyte® PET–P	Dimensional stability and wear resistance
		Polyoxymethylene (POM) - Acetal	Acetron® POM	Machinability and dimensional stability
		Polyamide (PA) - Nylon	MC® or Nylatron®	Toughness, wear resistance and strength
		Ultra high molecular wt. Polyethylene (UHMW-PE)	TIVAR® UHMW-PE	Toughness and abrasion resistance
	Amorphous Engineering	Polycarbonate (PC)	Quadrant® PC 1000	Impact and heat resistance to 250°F
		Polyphenylene oxide, modified (PPO)	Quadrant® PPO	Heat resistance, toughness and thermoformability
		Polymethyl methacrylate (PMMA) - Acrylic		Clarity and formability
Standard Plastics	Standard Engineering	Acrylonitrile butadiene styrene (ABS)		Medium strength, toughness and thermoformability
		Polystyrene (PS)		Rigid, light weight, thermoformable
		Polyvinyl chloride (PVC)	Quadrant® PVC	Light weight, easily processed
		Polypropylene (PP)	Proteus® PP	Chemical resistance, medium strength
		High Density Polyethylene (HDPE)	Proteus® HDPE	Chemical resistance, low cost
		Low Density Polyethylene (LDPE)	Proteus® LDPE	Chemical resistance, formability, low cost

1

DESIGNING WITH PLASTICS

PLASTICS > METALS

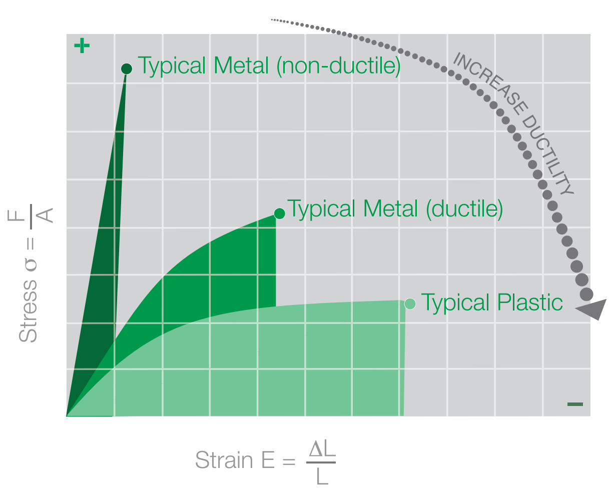
ELASTIC BEHAVIOR

The stress/strain behavior of a plastic differs from that of a metal in several respects, as can be seen in **Figure 3**.

- **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 at the origin of loading up to 0.2% strain. The effects of time, temperature and strain rate generally require consideration due to the viscoelasticity of plastics. Strains below 1% remain within the elastic limits of most engineering plastics and therefore allow analysis based upon the assumption that the material is linearly elastic, homogeneous, and isotropic. Another common practice is to design components so that the maximum working stress is 25% of the material's strength. This also minimizes plastics' time-dependent stress/strain behavior.

FIG 3 STRESS VS. STRAIN



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 impact strength. Materials with higher Izod impact strengths are more impact resistant.

THERMAL PROPERTIES

Two important thermal properties for designing plastic components are:

TIPS

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

- **Continuous Service Temperature**

The temperature above which significant and permanent degradation of the plastic occurs with long exposure.

- **Heat Deflection Temperature**

The softening temperature of a plastic as defined by the ASTM test method (D 648). It is commonly referred to as the maximum service temperature for a highly stressed, unconstrained component.

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 a given material.

DIMENSIONAL STABILITY

Plastics expand and contract 10 times more than many metals. A material's dimensional stability is affected by temperature, moisture absorption and load. 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 also contribute 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 an amount defined as:

$$\Delta = \text{original length} \times \frac{\text{[Force per unit area (stress)]}}{\text{stiffness (modulus)}}$$

This expression can be rewritten in engineering terms as:

$$\varepsilon = \sigma / E \text{ (strain = stress / modulus)}$$

The modulus or stiffness of a 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.

HOW DO YOU USE DMA CURVES?

Suppose your application involves a temperature of 175ºF in a dry application and you are considering Nylatron® PA66, Acetron® GP POM-C, and Ertalyte® PET-P. You would probably first look at each material's datasheet. Their stiffness at room temperature is pretty similar. Also, all of them have Heat Deflection Temperatures (HDT) well over 175ºF. Which one would be best? **(See Figure 4)**

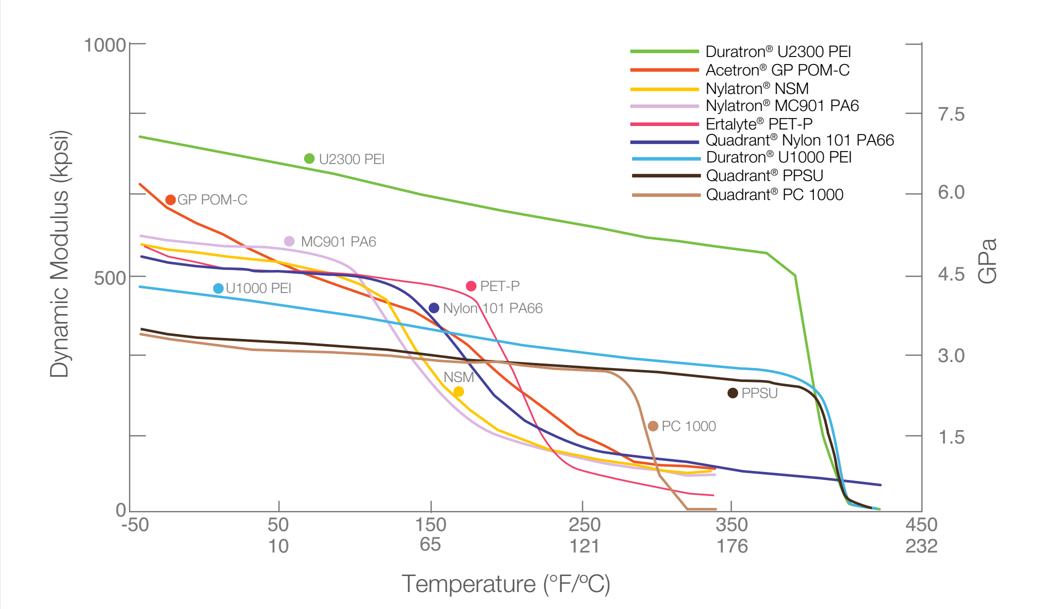
HDT tells you nothing more than the temperature at which the material softens under a given load (264 psi). All three materials have HDTs greater than 200ºF. What you don't know is what the stiffness looks like between room temperature and the HDT. Using the DMA curves, you see that at 175ºF, the dynamic modulus of the three materials are:

Nylatron® PA66	**325,000 psi**
Acetron® GP POM-C	**375,000 psi**
Ertalyte® PET-P	**500,000 psi**

At the application temperature of 175º F, Ertalyte® PET-P is over 30% stiffer than either nylon or acetal. If limiting deflection at this temperature is important in the application, then Ertalyte® is the better choice.

FIG 4

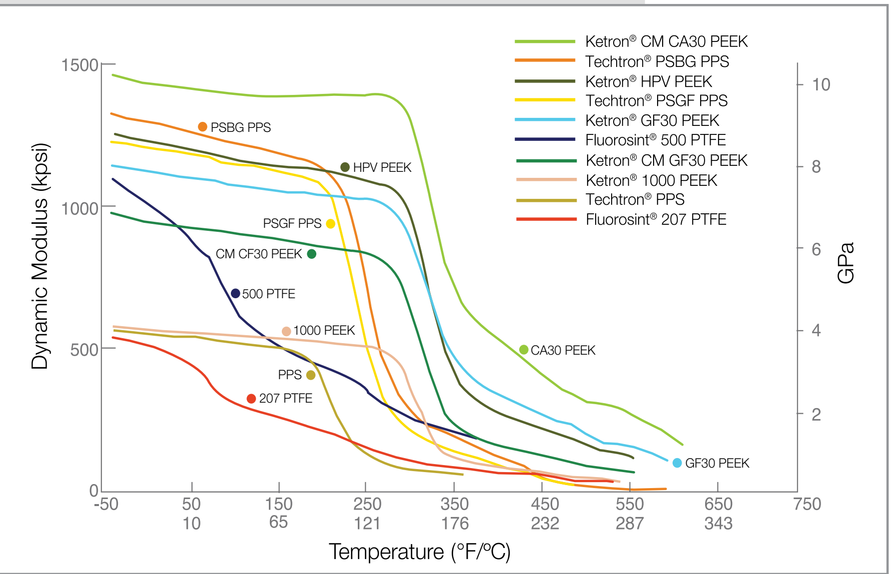
GENERAL ENGINEERED SEMI-CRYSTALLINE MATERIALS & AMORPHOUS ADVANCED ENGINEERED MATERIALS



USING THE DYNAMIC MODULUS CURVE

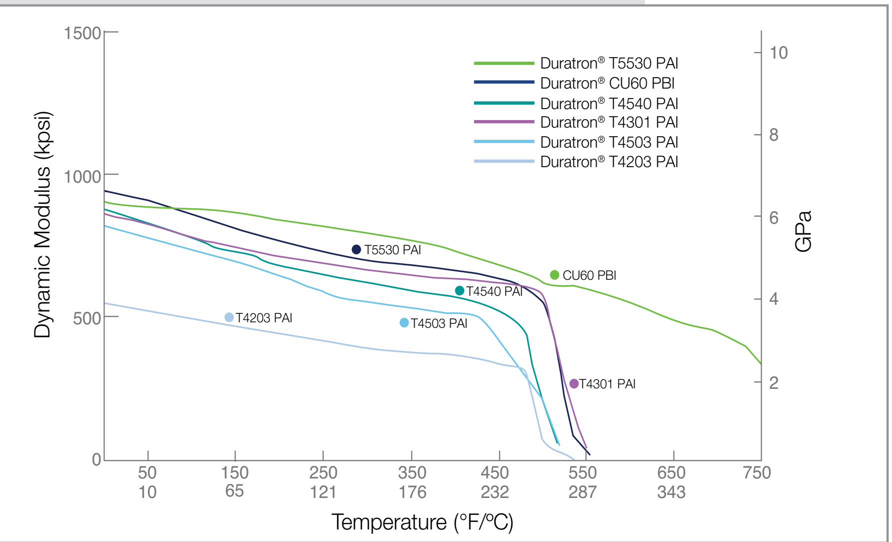
SEMI-CRYSTALLINE ADVANCED ENGINEERED MATERIALS

FIG 5



IMIDIZED MATERIALS

FIG 6



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 methods.

DYNAMIC MODULUS ANALYSIS DATA IS A VALUABLE MATERIAL SELECTION TOOL

See example on previous page to understand a material's stiffness at a given temperature.

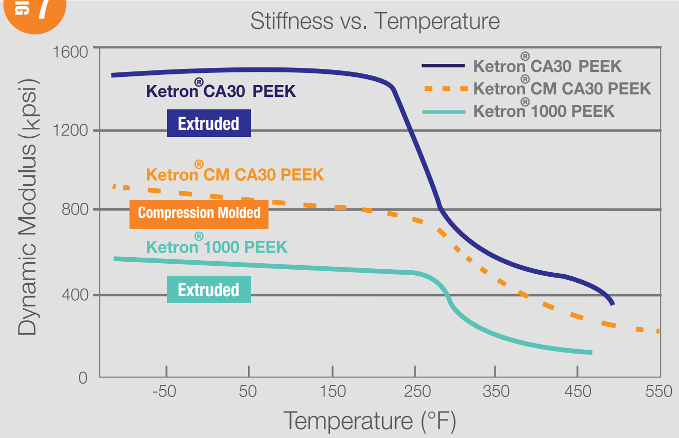
DMA VS CREEP DATA:

When a force is applied to a perfectly elastic material, it stretches a set amount 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 the equations previously mentioned can be used to approximate their response to a load (provided the 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. Creep data is available from Quadrant Engineering Plastic Products' Technical Service Department.

TIPS

Processing method will affect material properties.

FIG 7



MATERIAL SPECIFICATION...

THINGS TO CONSIDER

Confusion around plastics is common considering all the different materials, manufacturers, and trade-names. Added into the confusion is the fact that plastics can be processed in different ways resulting in different physical properties. When writing a material specification, a basic understanding of these effects is critical to avoid confusion and application failure.

RESIN DATA COMES FROM INJECTION MOLDING

Quadrant stock shapes are processed via extrusion, compression molding or some other melt-processable method. Regardless of the conversion method, the base raw material for the stock shape was resin pellets or powder. Material datasheets for resins are based on injection molded dog-bones or test sample plaques. Injection molding these test samples will yield different mechanical properties versus other conversion methods.

Injection molding a test sample results in alignment of the polymer chains that you may not get in other processes like extrusion or compression molding. If the polymer is a fiber filled material, like a glass or carbon filled resin, the fibers will also align. This alignment within injection molded test samples (i.e. dog bones) will result in higher mechanical values compared to other processes like extrusion and compression molding, where the alignment is much less or non-existent.

SHAPE MANUFACTURING

Extrusion is a conversion process where resin is slowly pushed through a die and has time to slowly cool while it comes out of the extruder. While there is some alignment of the polymer chains and the filler while it moves through the die opening, it is much less, compared to that of injection molding. When test samples are machined from extruded shapes, the properties are typically lower compared to injection molded properties. This is especially true for fiber filled polymers.

Compression molding will yield even lower properties than either injection molding or extrusion, as there is no specific orientation of the material and its fillers.

See **Figure 8** showing the same resin manufactured three different ways and the resulting mechanical properties. **Figure 7** represents a DMA curve showing material stiffness versus temperature. Curves for both compression molded and extruded carbon filled PEEK (both utilizing the same resin) are shown. In both the table and the graph, despite the same resin being used, the data and the curves are very different because of the processing differences.

EFFECTS ON MATERIAL SPECIFICATIONS:

A common pitfall in material specification writing is not specifying the origin of the mechanical property call-outs. Often times resin properties are specified, yet the finished part is to be machined from a stock shape. If not clearly defined, the resulting confusion can lead to delays and added costs.

The processing method for the desired plastic is often driven by the size of the component required, or even by the volume of parts required. Clear definition of the origin of the mechanical properties on the material specification is critical to eliminate any certification confusion.

When writing a material specification, consider how the finished component will be sourced and clearly define your material property call-outs.

FIG 8

MECHANICAL PROPERTY COMPARISON – 30% CARBON FILLED PEEK MATERIAL

Mechanical Property	Test Method	Victrex® PEEK 450 CA30	Ketron® CA30 PEEK	Ketron® CM CA30 PEEK
Samples Converted via		Injection Mold	Extrusion	Compression Mold
	SAME BASE RESIN USED			
Ultimate Tensile Strength @73°F	ASTM D 638	32,480	19,000	16,000
Tensile Modulus (psi) @73°F	ASTM D 638	1,885,000	1,100,000	1,400,000
Flexural Strength (psi) @73°F	ASTM D 790	51,475	25,750	23,000
Flexural Modulus of Elasticity (psi) @73°F	ASTM D 790	2,929,000	1,250,000	1,000,000
Compressive Strength @73°F	ASTM D 695	34,800	29,000	28,000

SHAPE DATA

KEY: A = Acceptable Service L = Limited Service U = Unacceptable QTM = Quadrant Test Method

NOTE: Property data shown are typical average values. A dash (-) indicates insufficient data available for publishing.

		PRODUCT DESCRIPTION	UNIT	TEST METHOD	Quadrant® PVC	Proteus® Natural Homopolymer Polypropylene	Proteus® Natural Co-Polymer Polypropylene	Proteus® White Homopolymer Polypropylene	Proteus® Natural O & P Homopolymer Polypropylene	Proteus® HDPE - Natural Polyethylene
MECHANICAL	1	Specific Gravity, 73°F	-	ASTM D792	1.4	0.91	0.90	0.91	0.91	0.96
	2	Yield Point, 73°F	psi	ASTM D638	8,350	4,800	3,400	4,000	4,800	4,600
	3	Tensile Elongation (at yield), 73°F	%	ASTM D638	5	14	11	12	14	12
	4	Tensile Break, 73°F	psi	ASTM D638	8,350	4,800	4,800	4,800	4,800	4,600
	5	Tensile Elongation (at break), 73°F	%	ASTM D638	20	400	300	300	400	400
	6	Tensile Modulus of Elasticity, 73°F	psi	ASTM D638	465,000	190,000	152,000	173,000	190,000	200,000
	7	Flexural Modulus of Elasticity, 73°F	psi	ASTM D790	398,000	195,000	180,000	180,000	195,000	174,000
	8	Hardness, Durometer D	-	ASTM D2240	89	78	72	78	78	70
	9	Izod Impact (notched) 73°F	ft. lb./in.	ASTM D256 Type "A"	0.4	1.2	8	1.9	1.2	1.3
THERMAL	10	Heat Deflection Temperature (HDT)	°F	ASTM D648	-	205	212	210	210	-
	11	Melt Point	°F	ASTM D3418	-	324	305	327	327	260
	12	Continuous Service Temp in Air (max) (1)	°F	-	140	180	180	180	180	180
	13	Surface Resistivity	Ohm-cm	ASTM D257	$> 10^{12}$	$> 10^{15}$	$> 10^{15}$	$> 10^{15}$	$> 10^{15}$	$> 10^{15}$
	14	Volume Resistivity	Ohm	ASTM D257	$> 10^{12}$	$> 10^{15}$	$> 10^{15}$	$> 10^{15}$	$> 10^{15}$	$> 10^{15}$
	15	Flammability (5)	-	-	V0	HB	HB	HB	HB	HB
CHEMICAL (3)	16	Water Absorption	% by wt.	ASTM D570 (2)	-	-	-	-	-	< .01
	17	Acid, Weak	@73°F	-	A	A	A	A	A	A
	18	Acid, Strong	@73°F	-	L	A	A	A	A	A
	19	Alkalies, Weak	@73°F	-	A	A	A	A	A	A
	20	Alkalies, Strong	@73°F	-	A	A	A	A	A	A
	21	Hydocarbons, Aromatic	@73°F	-	U	U	U	U	U	U
	22	Hydocarbons, Aliphatic	@73°F	-	L	U	U	U	U	U
	23	Ketones, Esters	@73°F	-	U	U	U	U	U	U
	24	Ethers	@73°F	-	U	U	U	U	U	U
	25	Chlorinated Solvents	@73°F	-	U	U	U	U	U	U
	26	Alcohols	@73°F	-	A	A	A	A	A	A
	27	Inorganic Salt Solutions	@73°F	-	A	A	A	A	A	A
	28	Sunlight	@73°F	-	U	U	U	U	U	U

(1) Data represents Quadrant's estimated maximum long term service temperature based on practical field experience.

(2) Specimens 1/8" thick x 2" dimeter or square.

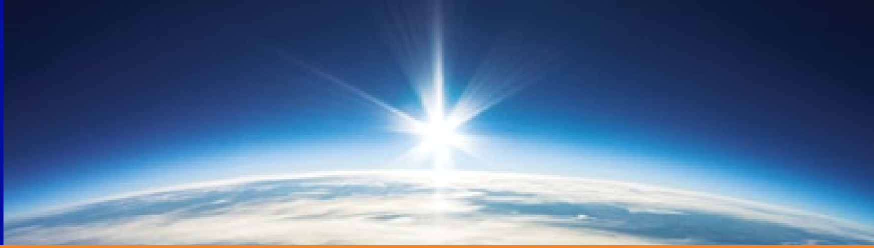
(3) Chemical resistance data are for little or no applied stress. Increased stress, especially localized, may result in more severe attack. Examples of common chemicals also included.

(4) Estimated rating based on available data. The UL 94 Test is a laboratory test and does not relate to actual fire hazard.
Contact Quadrant at TechServices@qplas.com for specific UL "Yellow Card" recognition number.

Distributed by: Polymershapes

	Sanalite® HDPE Polyethylene	Borotron® Borated PE (HDPE)	Proteus® LDPE
1	0.96	1.01	0.92
2	4,900	-	1,500
3	12	-	100
4	4,900	-	1,700
5	350	3.9	400
6	176,000	111,200	57,000
7	170,000	126,500	29,000
8	70	71	54
9	1.3	0.9	No Break
10	-	-	-
11	260	260	230
12	180	180	160
13	> 10^{15}	> 10^{12}	> 10^{15}
14	> 10^{15}	> 10^{12}	> 10^{15}
15	HB	HB	HB
16	< .01	< .01	< .01
17	A	A	A
18	A	A	A
19	A	A	A
20	A	A	A
21	U	U	U
22	U	U	U
23	U	U	U
24	U	U	U
25	U	U	U
26	A	A	A
27	A	A	A
28	U	U	U

SHAPE DATA



		PRODUCT DESCRIPTION	UNIT	TEST METHOD	TIVAR® 1000 UHMW-PE	TIVAR® ECO UHMW-PE	TIVAR® UV UHMW-PE	ARMOR-X ™ UHMW-PE	TIVAR® ESD UHMW-PE	TIVAR® EC UHMW-PE
MECHANICAL	1	Specific Gravity, 73°F	-	D792	0.93	0.93	0.94	1.0	0.94	0.94
	2	Tensile Strength, 73°F	psi	ASTM D638	5,800	4,000	5,800	3,200	5,800	5,800
	3	Tensile Modulus of Elasticity, 73°F	psi	ASTM D638	80,000	98,000	116,000	51,500	87,000	101,000
	4	Tensile Elongation (at break), 73°F	%	ASTM D638	300	200	300	100	300	300
	5	Flexural Strength, 73°F	psi	ASTM D790	3,500	2,000	3,800	2,200	3,700	3,200
	6	Flexural Modulus of Elasticity, 73°F	psi	ASTM D790	87,000	81,000	116,000	44,000	87,000	101,000
	7	Shear Strength, 73°F	psi	ASTM D732	4,800	-	-	-	-	-
	8	Compressive Strength, 10% Deformation, 73°F	psi	ASTM D695	3,000	2,800	3,300	3,900	3,300	3,300
	9	Compressive Modulus of Elasticity, 73°F	psi	ASTM D695	80,000	60,000	100,000	34,000	100,000	100,000
	10	Hardness, Rockwell, Scale as Noted, 73°F	-	ASTM D785	R56	N/A	N/A	N/A	N/A	N/A
	11	Hardness, Durometer, Shore "D" Scale, 73°F	-	ASTM D2240	66	67	66	50	66	66
	12	Izod Impact (notched), 73°F	ft. lb./in. of notch	ASTM D256 Type "A"	No Break	No Break	No Break	No Break	No Break	No Break
	13	Izod Impact (double notch), 73°F	ft. lb. / in.^{2} of notch	ASTM D4020	47.6	38.1	47.6	-	46.2	28.6
	14	Coefficient of Friction (Dry vs. Steel) Dynamic	-	QTM 55007	0.12	0.14	0.12	0.20	0.12	0.12
	15	Limiting PV (with 4:1 safety factor applied)	ft. lbs./in.^{2} min	QTM 55007	3,000	3,000	3,000	-	3,000	3,000
	16	Sand Slurry	1018 Steel=100	ASTM D4020	10	18	10	-	10	10
THERMAL	17	Coefficient of Linear Thermal Expansion (-40°F to 300°F)	in./in./°F	ASTM E-831 (TMA)	1.1×10^{-4}	1.1×10^{-4}	1.1×10^{-4}	-	1.1×10^{-4}	1.1×10^{-4}
	18	Heat Deflection Temperature 264 psi	°F	ASTM D648	116	116	116	116	116	116
	19	Tg-Glass Transition (amorphous)	°F	ASTM D3418	N/A	N/A	N/A	N/A	N/A	N/A
	20	Melting Point (semi-crystalline) Peak	°F	ASTM D3418	275	260	275	275	275	275
	21	Continuous Service Temperature in Air (Max.) (1)	°F	-	180	180	180	180	180	180
	22	Thermal Conductivity	BTU in./hr. ft.^{2} °F	ASTM F433	2.84	N/A	N/A	N/A	N/A	N/A
ELECTRICAL	23	Dielectric Strength, Short Term	Volts/mil	ASTM D149	1,150	N/A	N/A	N/A	N/A	N/A
	24	Surface Resistivity	ohm/square	D257	$>10^{15}$	$<10^{15}$	$>10^{15}$ (UV Colors) $<10^{14}$ (UV Black)	$>10^{15}$	10^5 - 10^9	$<10^5$
	25	Dielectric Constant, 10^6 Hz	-	D150	2.3	N/A	N/A	N/A	N/A	N/A
	26	Dissipation Factor, 10^6 Hz	-	D150	-	N/A	N/A	N/A	N/A	N/A
	27	Flammability @ 3.1 mm (1⁄8 in.) (5)		UL 94	HB	HB	HB	HB	HB	HB
CHEMICAL (3)	28	Water Absorption Immersion, 24 Hours	% by wt.	ASTM D570 (2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	29	Water Absorption Immersion, Saturation	% by wt.	ASTM D570 (2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	30	Acids, Weak, acetic, dilute hydrochloric or sulfuric acid	@73°F		A	A	A	A	A	A
	31	Acids, Strong, conc. hydrochloric or sulfuric acid	@73°F		A	A	A	A	A	A
	32	Alkalies, Weak, dilute ammonia or sodium hydroxide	@73°F		A	A	A	A	A	A
	33	Alkalies, Strong, strong ammonia or sodium hydroxide	@73°F		A	A	A	A	A	A
	34	Hydrocarbons-Aromatic, benzene, toluene	@73°F		L	L	L	L	L	L
	35	Hydrocarbons-Aliphatic, gasoline, hexane, grease	@73°F		A	A	A	A	A	A
	36	Ketones, Esters, acetone, methyl ethyl ketone	@73°F		A	A	A	A	A	A
	37	Ethers, diethyl ether, tetrahydrofuran	@73°F		L	L	L	L	L	L
	38	Chlorinated Solvents, methylene chloride, chloroform	@73°F		L	L	L	L	L	L
	39	Alcohols, methanol, ethanol, anti-freeze	@73°F		A	A	A	A	A	A
	40	Continuous Sunlight	@73°F		L	L	A	A	A	A
OTHER	41	FDA Compliance			Y	N	N	N	N	N
	42	Relative Cost (4)			$	$	$ +	$ +	$ +	$ +
	43	Relative Machinability (1-10, 1=Easier to Machine)			2	3	3	3	3	3

KEY: A = Acceptable Service L = Limited Service U = Unacceptable QTM = Quadrant Test Method

NOTE: Property data shown are typical average values. A dash (-) indicates insufficient data available for publishing.

(1) Data represents Quadrant's estimated maximum long term service temperature based on practical field experience.

(2) Specimens 1/8" thick x 2" diameter or square.

(3) Chemical resistance data are for little or no applied stress. Increased stress, especially localized, may result in more severe attack. Examples of common chemicals also included.

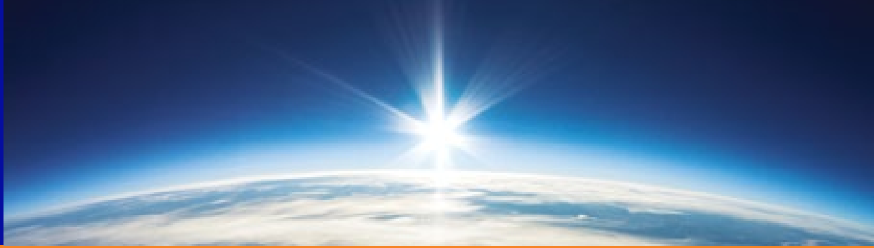
(4) Relative cost of material profiled in this brochure ($ = Least Expensive and $$$$$$ = Most Expensive).

(5) Estimated rating based on available data.The UL 94 Test is a laboratory test and does not relate to actual fire hazard.

Contact Quadrant at TechServices@qplas.com for specific UL "Yellow Card" recognition number.

	TIVAR® DrySlide UHMW-PE	TIVAR® CleanStat UHMW-PE	TIVAR® Oil Filled UHMW-PE	TIVAR® Ceram P UHMW-PE	TIVAR® H.O.T. UHMW-PE	TIVAR® 88 UHMW-PE	TIVAR® 88 UHMW-PE w/BurnGuard	TIVAR® 88-2 UHMW-PE	TIVAR® 88 ESD UHMW-PE	TIVAR® 88-2 ESD UHMW-PE
1	0.94	0.94	0.94	0.96	0.94	0.93	1	0.933	0.945	0.94
2	5,100	5,200	6,500	5,500	6,800	5,800	3,600	5,500	4,800	4,800
3	87,000	94,000	43,500	83,000	72,500	61,000	87,000	97,000	124,000	116,000
4	200	200	280	300	300	300	120	200	250	200
5	2,600	2,700	2,500	3,700	3,800	3,200	2,900	3,000	3,300	3,100
6	72,000	87,000	58,000	94,000	80,000	72,500	94,000	105,000	112,000	106,000
7	-	-	-	-	4,800	-	-	4,800	4,800	4,800
8	2,900	3,100	2,700	3,000	3,000	3,000	2,800	2,900	3,000	2,900
9	80,000	77,750	42,000	94,000	80,000	70,000	65,000	80,000	87,000	80,000
10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
11	64	66	64	68	68	69	64	64	67	64
12	No Break	No Break	No Break	No Break	No Break	No Break	No Break	No Break	No Break	No Break
13	33.3	28.6	36.2	50.0	28.6	34.3	41.9	45.2		
14	0.08	0.12	0.14	0.12	0.12	0.12	0.09	0.08	0.14	0.08
15	4,000	3,000	4,000	3,000	3,000	4,000	-	4,000	4,000	4,000
16	10	13	13	8.5	10	8	15	11	8	10
17	1.1×10^{-4}	1.1×10^{-4}	1.1×10^{-4}	1.1×10^{-4}	1.1×10^{-4}	1.1×10^{-4}	9.0×10^{-5}	1.1×10^{-4}	1.1×10^{-4}	1.1×10^{-4}
18	116	116	116	116	116	116	116	116	116	116
19	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
20	275	275	275	275	275	275	275	275	275	275
21	180	180	180	180	275	180	180	180	180	180
22	N/A	N/A	2.84	2.84	2.84	2.84	-	2.84	N/A	N/A
23	N/A	N/A	-	-	-	-	-	-	N/A	N/A
24	$10^5 - 10^9$	$10^7 - 10^{10}$	$>10^{15}$	$>10^{15}$	$>10^{15}$	$>10^{15}$	$>10^{12}$	$>10^{15}$	$10^5 - 10^9$	$10^5 - 10^9$
25	N/A	N/A	2.3	2.3	2.3	2.3	-	2.3	N/A	N/A
26	N/A	N/A	0.005	0.005	0.005	0.005	-	0.005	N/A	N/A
27	HB	HB	HB	HB	HB	HB	V0	HB	HB	HB
28	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
29	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
30	A	A	A	A	A	A	A	A	A	A
31	A	A	A	A	A	A	A	A	A	A
32	A	A	A	A	A	A	A	A	A	A
33	A	A	A	A	A	A	A	A	A	A
34	L	L	L	L	L	L	L	L	L	L
35	A	A	A	A	A	A	A	A	A	A
36	A	A	A	A	A	A	A	A	A	A
37	L	L	L	L	L	L	L	L	L	L
38	L	L	L	L	L	L	L	L	L	L
39	A	A	A	A	A	A	A	A	A	A
40	A	L	L	L	L	A	L	A	A	A
41	N	Y	Y	N	Y	N	N	N	N	N
42	$$	$$	$$	$$	$$	$$	$$	$$	$$	$$
43	3	3	2	3	2	3	4	2	3	3

SHAPE DATA



		PRODUCT DESCRIPTION	UNIT	TEST METHOD	Quadrant® Nylon 101	Nylatron® GS	Nylatron® GF30	Nylatron® MC907	Nylatron® MC901	Nylatron® GSM
					Unfilled PA66	MoS_2 Filled PA66	30% Glass Filled PA66	Unfilled PA6	Blue, Heat Stabilized PA6	MoS_2 Filled PA6
					Extruded	Extruded	Extruded	Cast	Cast	Cast
MECHANICAL	1	Specific Gravity, 73°F.	-	ASTM D792	1.15	1.16	1.29	1.15	1.15	1.16
	2	Tensile Strength, 73°F.	psi	ASTM D638	12,000	12,500	13,500	12,000	12,000	11,000
	3	Tensile Modulus of Elasticity, 73°F.	psi	ASTM D638	425,000	480,000	675,000	400,000	400,000	400,000
	4	Tensile Elongation (at break), 73°F.	%	ASTM D638	50	25	5	20	20	30
	5	Flexural Strength, 73°F.	psi	ASTM D790	15,000	17,000	21,000	16,000	16,000	16,000
	6	Flexural Modulus of Elasticity, 73°F.	psi	ASTM D970	450,000	460,000	650,000	500,000	500,000	500,000
	7	Shear Strength, 73°F.	psi	ASTM D732	10,000	10,500	10,000	11,000	11,000	10,500
	8	Compressive Strength, 10% Deformation, 73°F.	psi	ASTM D695	12,500	16,000	18,000	15,000	15,000	14,000
	9	Compressive Modulus of Elasticity, 73°F.	psi	ASTM D695	420,000	420,000	600,000	400,000	400,000	400,000
	10	Hardness, Rockwell, Scale as noted, 73°F.	-	ASTM D785	M85 (R115)	M85 (R115)	M75	M85 (R115)	M85 (R115)	M80 (R110)
	11	Hardness, Durometer, Shore "D" Scale, 73°F.	-	ASTM D2240	D80	D85	-	D85	D85	D85
	12	Izod Impact (notched), 73°F.	ft. lb./in. of notch	ASTM D256 Type "A"	0.6	0.5	-	0.4	0.4	0.5
	13	Coefficient of Friction (Dry vs. Steel) Dynamic	-	QTM 55007	0.25	0.2	-	0.2	0.2	0.2
	14	Limiting PV (with 4:1 safety factor applied)	ft. lbs./in.^{2} min	QTM 55007	2,700	3,000	-	3,000	3,000	3,000
	15	Wear Factor "k" x 10^{-10}	in.^{3}-min/ft. lbs. hr.	QTM 55010	80	90	-	100	100	90
THERMAL	16	Coefficient of Linear Thermal Expansion (-40°F to 300°F)	in./in./°F	ASTM E-831 (TMA)	5.5 x 10^{-5}	4 x 10^{-5}	2.0 x 10^{-5}	5.0 x 10^{-5}	5.0 x 10^{-5}	5.0 x 10^{-5}
	17	Heat Deflection Temperature 264 psi	°F	ASTM D648	200	200	400	200	200	200
	18	Tg-Glass transition (amorphous)	°F	ASTM D3418	N/A	N/A	N/A	N/A	N/A	N/A
	19	Melting Point (crystalline) peak	°F	ASTM D3418	500	500	500	420	420	420
	20	Continuous Service Temperature in Air (Max.) (1)	°F	-	210	220	220	200	260	200
	21	Thermal Conductivity	BTU in./hr. ft.^{2} °F	E 1530-11	1.7	1.7	1.7	-	2.37	-
ELECTRICAL	22	Dielectric Strength, Short Term	Volts/mil	ASTM D149	400	350	350	500	500	400
	23	Surface Resistivity	ohm/square	EOS/ESD S11.11	>10^{13}	>10^{13}	>10^{13}	>10^{13}	>10^{13}	>10^{13}
	24	Dielectric Constant, 10^6 Hz	-	D150	3.6	-	-	3.7	3.7	3.7
	25	Dissipation Factor, 10^6 Hz	-	D150	0.02	-	-	-	-	-
	26	Flammability @ 3.1 mm (1/8 in.) (5)		UL 94	V-2	V-2	V-2	HB	HB	HB
CHEMICAL (3)	27	Water Absorption Immersion, 24 Hours	% by wt.	ASTM D570 (2)	0.3	0.3	0.3	0.6	0.6	0.6
	28	Water Absorption Immersion, Saturation	% by wt.	ASTM D570 (2)	7	7	5.5	7	7	7
	29	Acids, Weak, acetic, dilute hydrochloric or sulfuric acid	@73 °F		L	L	L	L	L	L
	30	Acids, Strong, conc. hydrochloric or sulfuric acid	@73 °F		U	U	U	U	U	U
	31	Alkalies, Weak, dilute ammonia or sodium hydroxide	@73 °F		L	L	L	L	L	L
	32	Alkalies, Strong, strong ammonia or sodium hydroxide	@73 °F		U	U	U	U	U	U
	33	Hydrocarbons-Aromatic, benzene, toluene	@73 °F		A	A	A	A	A	A
	34	Hydrocarbons-Aliphatic, gasoline, hexane, grease	@73 °F		A	A	A	A	A	A
	35	Ketones, Esters, acetone, methyl ethyl ketone	@73 °F		A	A	A	A	A	A
	36	Ethers, diethyl ether, tetrahydrofuran	@73 °F		A	A	A	A	A	A
	37	Chlorinated Solvents, methylene chloride, chloroform	@73 °F		L	L	L	L	L	L
	38	Alcohols, methanol, ethanol, anti-freeze	@73 °F		L	L	L	L	L	L
	39	Continuous Sunlight	@73 °F		L	L	L	L	L	L
OTHER	40	FDA Compliance			Y	N	N	Y	N	N
	41	Relative Cost (4)			$$	$$	$$	$$	$$	$$
	42	Relative Machinability (1-10, 1=Easier to Machine)			1	1	4	1	1	1

KEY: A = Acceptable Service L = Limited Service U = Unacceptable QTM = Quadrant Test Method

NOTE: Property data shown are typical average values. A dash (-) indicates insufficient data available for publishing.

(1) Data represents Quadrant's estimated maximum long term service temperature based on practical field experience.

(2) Specimens 1/8" thick x 2" diameter or square.

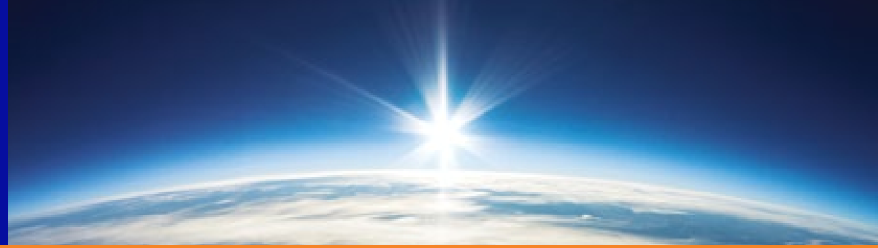
(3) Chemical resistance data are for little or no applied stress. Increased stress, especially localized, may result in more severe attack. Examples of common chemicals also included.

(4) Relative cost of material profiled in this brochure ($ = Least Expensive and $$$$$$ = Most Expensive).

(5) Estimated rating based on available data.The UL 94 Test is a laboratory test and does not relate to actual fire hazard.
Contact Quadrant at TechServices@qplas.com for specific UL "Yellow Card" recognition number.

	Nylatron® LIG / LFG	Nylatron® GSM Blue	Nylatron® NSM	Nylatron® 703XL	Nylatron® 4.6	Acetron® GP POM-C	Acetron® POM-H	Acetron® AF POM-H	Quadrant® PC 1000	Semitron® ESd 225	Ertalyte® PET-P	Ertalyte® TX
	Oil Filled PA6 LFG is FDA Compliant	MoS$_2$ and Oil Filled PA6	Premium, Solid Lubricant Filled PA6	Premium, Solid Lubricant Filled PA6	Heat Resistant PA46	Premium Porosity-free POM-C	Unfilled POM-H	PTFE Filled POM-H	Unfilled PC	Static Dissipative POM	Semi-crystalline PET	Premium, Solid Lubricant Filled PET
	Cast	Cast	Cast	Cast	Extruded	Extruded	Extruded	Extruded	Extruded	Extruded	Extruded	Extruded
1	1.14	1.15	1.15	1.11	1.19	1.41	1.41	1.5	1.2	1.33	1.41	1.44
2	9,900	10,000	11,000	9,000	15,000	9,500	11,000	8,000	10,500	5,400	12,400	10,500
3	465,000	500,000	410,000	400,000	470,000	400,000	450,000	435,000	320,000	200,000	460,000	500,000
4	50	30	20	15	25	30	30	15	100	15	20	5
5	15,000	15,000	16,000	13,000	17,000	12,000	13,000	12,000	13,000	7,300	18,000	14,000
6	525,000	500,000	475,000	360,000	450,000	400,000	450,000	445,000	350,000	220,000	490,000	360,000
7	9,300	-	10,000	-	-	8,000	9,000	7,600	9,200	6,000	8,000	8,500
8	13,500	13,000	14,000	10,000	16,000	15,000	16,000	16,000	11,500	8,000	15,000	15,250
9	330,000	425,000	400,000	360,000	325,000	400,000	450,000	350,000	300,000	175,000	420,000	400,000
10	M85 (R120)	M80 (R117)	M80 (R110)	M65	M97	M88 (R120)	M89 (R122)	M85 (R115)	M75 (R126)	M50 (R108)	M93 (R125)	M94
11	-	-	D85	-	-	D85	D86	D83	D80	D76	D87	D80
12	1.0	0.9	0.5	0.7	0.6	1	1	0.7	1.5	1.5	0.5	0.4
13	0.14	0.18	0.18	0.14	-	0.25	0.25	0.19	-	0.29	0.2	0.19
14	6,000	5,500	15,000	17,000	2,700	2,700	2,700	8,300	-	2,000	2,800	6,000
15	72	65	12	26	100	200	200	60	-	30	60	35
16	5.6×10^{-5}	5.5×10^{-5}	5.5×10^{-5}	4.9×10^{-5}	5.0×10^{-5}	5.4×10^{-5}	4.7×10^{-5}	5×10^{-5}	3.9×10^{-5}	9.3×10^{-5}	3.3×10^{-5}	4.5×10^{-5}
17	200	200	200	200	320	220	250	244	290	225	240	180
18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	293	N/A	N/A	N/A
19	420	420	420	420	554	335	347	347	N/A	320	491	491
20	220	200	200	200	300	180	180	180	250	180	210	210
21	-	-	-	-	2.1	1.6	2.5	-	1.29	-	2	1.9
22	-	-	400	-	-	420	450	400	400	-	385	533
23	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{12}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	$10^{9} - 10^{10}$	$>10^{13}$	$>10^{13}$
24	-	-	-	-	-	3.8	3.7	3.1	3.17	4.31	3.4	3.6
25	-	-	-	-	-	0.005	0.005	0.01	0.0009	0.036	0.02	0.02
26	HB	HB	HB	HB	-	HB	HB	HB	HB	HB	HB	HB
27	0.3	0.3	0.3	0.47	0.6	0.2	0.2	0.2	0.2	2	0.07	0.06
28	6	6	7	7	7	0.9	0.9	1	0.4	8	0.9	0.47
29	L	L	L	L	L	L	L	L	A	L	A	A
30	U	U	U	U	U	U	U	U	U	U	L	L
31	L	L	L	L	L	A	A	A	A	A	A	A
32	U	U	U	U	U	U	U	U	U	U	U	U
33	A	A	A	A	A	A	A	A	U	A	A	A
34	A	A	A	A	A	A	A	A	L	A	A	A
35	A	A	A	A	A	A	A	A	U	A	A	A
36	A	A	A	A	A	A	A	A	U	A	A	A
37	L	L	L	L	L	L	L	L	U	L	U	U
38	L	L	L	L	L	A	A	A	A	A	A	A
39	L	L	L	L	L	L	L	L	L	L	L	L
40	N / Y	N	N	N	N	Y	Y	N	N	N	Y	Y
41	$$	$$	$$ +	$$ +	$$	$$	$$	$$$	$$ +	$$ +	$$ +	$$ +
42	1	1	1	1	1	1	1	1	3	1	2	2

SHAPE DATA



Category	No.	PRODUCT DESCRIPTION	UNIT	TEST METHOD	Techtron® PPS	Techtron® HPV	Techtron® PSBG PPS	Techtron® PSGF PPS	Fluorosint® MT01	Fluorosint® 207	Fluorosint® 135
					Unfilled PPS	Premium, Solid Lubricant Filled PPS	Bearing Grade PPS	40% Glass Filled PPS	Carbon Fiber & Proprietary Filled PTFE	FDA Compliant, Mica Filled PTFE	Propietary Filled PTFE
					Extruded	Extruded	Compression Molded	Compression Molded	Compression Molded	Compression Molded	Compression Molded
MECHANICAL	1	Specific Gravity, 73°F.	-	ASTM D792	1.35	1.43	1.52	1.7	2.27	2.3	1.91
MECHANICAL	2	Tensile Strength, 73°F.	psi	ASTM D638	13,500	10,900	5,000	5,000	2,100	1,500	1,300
MECHANICAL	3	Tensile Modulus of Elasticity, 73°F.		ASTM D638	500,000	540,000	920,000	730,000	326,000	250,000	370,000
MECHANICAL	4	Tensile Elongation (at break), 73°F.	%	ASTM D638	15	4	1	1	40	50	3
MECHANICAL	5	Flexural Strength, 73°F.	psi	ASTM D790	21,000	10,500	10,000	23,000	4,000	2,000	2,500
MECHANICAL	6	Flexural Modulus of Elasticity, 73°F.	psi	ASTM D970	575,000	535,000	820,000	1,000,000	485,000	350,000	300,000
MECHANICAL	7	Shear Strength, 73°F.	psi	ASTM D732	9,000	-	-	-	2,600	1,700	-
MECHANICAL	8	Compressive Strength, 10% Deformation, 73°F.	psi	ASTM D695	21,500	15,500	15,000	24,000	3,400	3,800	7,000
MECHANICAL	9	Compressive Modulus of Elasticity, 73°F.	psi	ASTM D695	430,000	342,000	800,000	1,300,000	250,000	225,000	200,000
MECHANICAL	10	Hardness, Rockwell, Scale as noted, 73°F.	-	ASTM D785	M95 (R125)	M84	M93 (R126)	M94 (R125)	R74	R50	R80
MECHANICAL	11	Hardness, Durometer, Shore "D" Scale, 73°F.	-	ASTM D2240	D85	-	D86	D86	-	D65	D74
MECHANICAL	12	Izod Impact (notched), 73°F	ft. lb./in. of notch	ASTM D256 Type "A"	0.6	1.4	1	1	-	1	0.5
MECHANICAL	13	Coefficient of Friction (Dry vs. Steel) Dynamic	-	QTM 55007	0.4	0.2	0.2	-	0.18	0.1	0.15
MECHANICAL	14	Limiting PV (with 4:1 safety factor applied)	ft. lbs./in.^{2} min	QTM 55007	3,000	8,750	25,000	-	4,500	8,000	14,300
MECHANICAL	15	Wear Factor "k" x 10^{-10}	in.^{3}-min/ft. lbs. hr.	QTM 55010	2,400	62	800	-	200	85	32
THERMAL	16	Coefficient of Linear Thermal Expansion (-40°F to 300°F)	in./in./°F	ASTM E-831 (TMA)	2.8 x 10^{-5}	3.3 x 10^{-5}	1.7 x 10^{-5}	2.5 x 10^{-5}	3.0 x 10^{-5}	5.7 x 10^{-5}	2.5 x 10^{-5}
THERMAL	17	Heat Deflection Temperature 264 psi	°F	ASTM D648	250	240	490	490	200	210	220
THERMAL	18	Tg-Glass transition (amorphous)	°F	ASTM D3418	N/A	N/A	N/A	N/A	N/A	N/A	N/A
THERMAL	19	Melting Point (semi-crystalline) peak	°F	ASTM D3418	540	536	540	540	-	621	621
THERMAL	20	Continuous Service Temperature in Air (Max.) (1)	°F	-	425	430	450	450	600	500	500
THERMAL	21	Thermal Conductivity	BTU in./hr. ft.^{2} °F	E 1530-11	2	2.1	1.77	1.42	-	3.05	-
ELECTRICAL	22	Dielectric Strength, Short Term	Volts/mil	ASTM D149	540	500	-	385	-	200	-
ELECTRICAL	23	Surface Resistivity	ohm/square	EOS/ESD S11.11	$>10^{13}$	$>10^{13}$	$<10^{5}$	$>10^{13}$	$<10^{6}$	$>10^{13}$	$>10^{5}$
ELECTRICAL	24	Dielectric Constant, 10^6 Hz	-	D150	3	-	-	-	-	2.65	-
ELECTRICAL	25	Dissipation Factor, 10^6 Hz	-	D150	0.0013	-	-	-	-	0.008	-
ELECTRICAL	26	Flammability @ 3.1 mm (1⁄8 in.) (5)		UL 94	V-0	V-0	V-0	V-0	V-0	V-0	V-0
CHEMICAL (3)	27	Water Absorption Immersion, 24 Hours	% by wt.	ASTM D570 (2)	0.01	0.01	0.02	0.02	0.1	0.03	0.1
CHEMICAL (3)	28	Water Absorption Immersion, Saturation	% by wt.	ASTM D570 (2)	0.03	0.09	0.03	0.03	-	0.2	0.3
CHEMICAL (3)	29	Acids, Weak, acetic, dilute hydrochloric or sulfuric acid	@73°F		A	A	A	A	A	A	A
CHEMICAL (3)	30	Acids, Strong, conc. hydrochloric or sulfuric acid	@73°F		L	L	L	L	A	A	A
CHEMICAL (3)	31	Alkalies, Weak, dilute ammonia or sodium hydroxide	@73°F		A	A	A	A	A	A	A
CHEMICAL (3)	32	Alkalies, Strong, strong ammonia or sodium hydroxide	@73°F		A	A	A	A	U	U	U
CHEMICAL (3)	33	Hydrocarbons-Aromatic, benzene, toluene	@73°F		A	A	A	A	A	A	A
CHEMICAL (3)	34	Hydrocarbons-Aliphatic, gasoline, hexane, grease	@73°F		A	A	A	A	A	A	A
CHEMICAL (3)	35	Ketones, Esters, acetone, methyl ethyl ketone	@73°F		A	A	A	A		A	A
CHEMICAL (3)	36	Ethers, diethyl ether, tetrahydrofuran	@73°F		A	A	A	A	A	A	A
CHEMICAL (3)	37	Chlorinated Solvents, methylene chloride, chloroform	@73°F		A	A	A	A	A	A	A
CHEMICAL (3)	38	Alcohols, methanol, ethanol, anti-freeze	@73°F		A	A	A	A	A	A	A
CHEMICAL (3)	39	Continuous Sunlight	@73°F		L	L	A	A	A	A	A
OTHER	40	FDA Compliance			Y	Y	N	N	N	Y	N
OTHER	41	Relative Cost (4)			$$$$	$$$$	$$$$$	$$$$$	$$$$	$$$$	$$$
OTHER	42	Relative Machinability (1-10, 1=Easier to Machine)			3	3	5	7	5	1	2

KEY: A = Acceptable Service L = Limited Service U = Unacceptable QTM = Quadrant Test Method

NOTE: Property data shown are typical average values. A dash (-) indicates insufficient data available for publishing.

(1) Data represents Quadrant's estimated maximum long term service temperature based on practical field experience.

(2) Specimens 1/8" thick x 2" diameter or square.

(3) Chemical resistance data are for little or no applied stress. Increased stress, especially localized, may result in more severe attack. Examples of common chemicals also included.

(4) Relative cost of material profiled in this brochure ($ = Least Expensive and $$$$$$ = Most Expensive).

(5) Estimated rating based on available data.The UL 94 Test is a laboratory test and does not relate to actual fire hazard.
Contact Quadrant at TechServices@qplas.com for specific UL "Yellow Card" recognition number.

	Fluorosint® 500	Fluorosint® HPV	Ketron® 1000 PEEK	Ketron® GF30 PEEK	Ketron® CM GF30 PEEK	Ketron® CA30 PEEK	Ketron® CM CA30 PEEK	Ketron® HPV PEEK	Ketron® CM HPV PEEK	Semitron® MDS 100	Semitron® MP 370	Semitron® ESd 480
	Mica Filled PTFE	Mica Filled PTFE	Unfilled PEEK	30% Glass Filled PEEK	30% Glass Filled PEEK	30% Carbon Fiber Filled PEEK	30% Carbon Fiber Filled PEEK	Premium, Solid Lubricant Filled PEEK	Bearing Grade PEEK	Modified PEEK	Ceramic Filled Modified PEEK	Static Dissipative PEEK
	Compression Molded	**Compression Molded**	**Extruded**	**Extruded**	**Compression Molded**	**Extruded**	**Compression Molded**	**Extruded**	**Compression Molded**	**Compression Molded**	**Extruded**	**Compression Molded**
1	2.32	2.06	1.31	1.51	1.59	1.41	1.42	1.44	1.44	1.51	1.62	1.47
2	1,100	1,450	16,000	14,000	7,400	19,000	16,000	11,000	7,900	14,700	11,500	14,500
3	300,000	210,000	630,000	1,000,000	850,000	1,100,000	1,400,000	850,000	530,000	1,500,000	640,000	940,000
4	30	90	40	2	1.0	5	3	2	2	1.5	3	1.5
5	2,200	2,500	25,000	23,000	12,000	25,750	23,000	27,500	13,000	20,500	16,750	21,000
6	500,000	165,000	600,000	1,000,0000	900,000	1,250,000	1,000,000	1,100,000	700,000	1,420,000	625,000	1,000,000
7	2,100	2,500	8,000	14,000	-	15,000	11,000	10,000	-	12,000	11,300	-
8	4,000	3,000	20,000	22,000	19,000	29,000	28,000	20,000	20,000	24,400	18,200	26,500
9	250,000	110,000	500,000	550,000	500,000	-	580,000	500,000	400,000	1,100,000	600,000	570,000
10	R55	R44	M100 (R126)	M103 (R126)	M103 (R124)	M102	M108 (R125)	M85	-	R121	M98	M107 (R122)
11	D70	D64	D85	D89	D86	D93	D91	-	-	-	-	-
12	0.9	1.8	0.6	0.8	1.0	1.03	1.4	0.7	1.0	0.4	0.4	1.0
13	0.15	0.15	0.32	-	-	0.2	0.24	.21	.20	-	-	0.20
14	8,000	20,000	8,500	-	-	25,000	17,000	20,000	35,000	-	2,200	36,000
15	600	38	375	-	-	150	102	100	130	-	>500	200
16	2.5×10^{-5}	4.9×10^{-5}	2.6×10^{-5}	1.2×10^{-5}	1.4×10^{-5}	1×10^{-5}	2.3×10^{-5}	1.7×10^{-5}	2.7×10^{-5}	1.1×10^{-5}	2.5×10^{-5}	1.7×10^{-5}
17	270	180	320	450	450	518	450	383	480	410	300	500
18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-	N/A	N/A	N/A
19	621	621	644	644	644	644	644	644	-	644	644	644
20	500	500	480	480	480	482	480	482	480	480	-	475
21	5.3	-	1.75	2.98	3.06	6.4	6.37	1.7	-	1.73	2.36	2.36
22	275	-	480	500	550	32	-	-	-	-	376	-
23	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	$<10^{5}$	$<10^{5}$	$<10^{13}$	$<10^{13}$	$>10^{13}$	$>10^{13}$	$10^{6} – 10^{9}$
24	2.85	-	3.3	-	-	-	-	-	-	3.37	4.13	10.9
25	0.008	-	0.003	-	-	-	-	-	-	0.007	0.004	.518
26	V-0	V-0	V-0	V-0	V-0	V-0	V-0	V-0	-	-	V-0	V-0
27	0.1	0.15	0.1	0.1	0.15	.06	0.15	.05	0.07	0.10	0.11	0.18
28	0.3	0.43	0.5	0.3	0.5	0.3	0.5	0.3	-	0.58	0.50	1.65
29	A	A	A	A	A	A	A	A	A	A	A	A
30	A	A	L	L	L	L	L	L	L	L	L	L
31	A	A	A	A	A	A	A	A	A	A	L	A
32	U	U	A	A	A	A	A	A	A	A	U	A
33	A	A	A	A	A	A	A	A	A	A	A	A
34	A	A	A	A	A	A	A	A	A	A	A	A
35	A	A	A	A	A	A	A	A	A	A	A	A
36	A	A	A	A	A	A	A	A	A	A	A	A
37	A	A	A	A	A	A	A	A	A	A	A	A
38	A	A	A	A	A	A	A	A	A	A	A	A
39	A	A	L	L	L	A	A	A	A	L	A	A
40	N	Y	Y	N	N	N	N	N	N	N	N	N
41	$$$$	$$$	$$$$$	$$$$$	$$$$$	$$$$$	$$$$$	$$$$$	$$$$$	$$$$$	$$$$$	$$$$$
42	2	2	5	7	7	7	7	7	5	5	5	4

SHAPE DATA

		PRODUCT DESCRIPTION	UNIT	TEST METHOD	Quadrant® PSU	Duratron® U1000 PEI	Duratron® U2300 PEI	Semitron® ESd 410C	Semitron® ESd 420	Semitron® ESd 420V	Quadrant® PPSU
					Unfilled PSU	Unfilled PEI	30% Glass Filled PEI	Static Dissipative PEI	Static Dissipative PEI	Static Dissipative PEI	Unfilled PPSU
					Extruded	Extruded	Extruded	Compression Molded	Compression Molded	Compression Molded	Extruded
MECHANICAL	1	Specific Gravity, 73°F.	-	ASTM D792	1.24	1.28	1.51	1.41	1.34	1.51	1.29
	2	Tensile Strength, 73°F.	psi	ASTM D638	10,200	17,000	17,000	9,000	11,500	10,000	11,000
	3	Tensile Modulus of Elasticity, 73°F.	psi	ASTM D638	390,000	500,000	800,000	850,000	640,000	910,000	340,000
	4	Tensile Elongation (at break), 73°F.	%	ASTM D638	30	60	3	2	2	1.5	30
	5	Flexural Strength, 73°F.	psi	ASTM D790	15,000	20,000	27,000	12,000	14,500	15,800	15,500
	6	Flexural Modulus of Elasticity, 73°F.	psi	ASTM D970	400,000	500,000	850,000	850,000	650,000	910,000	345,000
	7	Shear Strength, 73°F.	psi	ASTM D732	9,000	14,000	14,000	9,000	8,020	-	9,000
	8	Compressive Strength, 10% Deformation, 73°F.	psi	ASTM D695	13,000	22,000	32,000	19,500	23,800	22,300	13,400
	9	Compressive Modulus of Elasticity, 73°F.	psi	ASTM D695	375,000	480,000	625,000	600,000	370,000	545,000	280,000
	10	Hardness, Rockwell, Scale as noted, 73°F.	-	ASTM D785	M82 (R128)	M112 (R125)	M114 (R127)	M115 (R125)	M118	M110 (E78)	M80 (R120)
	11	Hardness, Durometer, Shore "D" Scale, 73°F.	-	ASTM D2240	D80	D86	D86	D85	D85	-	D80
	12	Izod Impact (notched), 73°F	ft. lb./in. of notch	ASTM D256 Type "A"	1.3	0.5	1	0.8	1	0.5	2.5
	13	Coefficient of Friction (Dry vs. Steel) Dynamic	-	QTM 55007	-	0.42	-	0.18	0.28	-	-
	14	Limiting PV (with 4:1 safety factor applied)	ft. lbs./in.^{2} min	QTM 55007	-	1,875	-	12,000	9,500	-	-
	15	Wear Factor "k" x 10^{-10}	in.^{3}-min/ft. lbs. hr.	QTM 55010	-	2,900	-	125	100	-	>1,000
THERMAL	16	Coefficient of Linear Thermal Expansion (-40°F to 300°F)	in./in./°F	ASTM E-831 (TMA)	3.1×10^{-5}	3.1×10^{-5}	1.1×10^{-5}	1.8×10^{-5}	1.95×10^{-5}	1.5×10^{-5}	3.1×10^{-5}
	17	Heat Deflection Temperature 264 psi	°F	ASTM D648	340	400	410	410	410	420	405
	18	Tg-Glass transition (amorphous)	°F	ASTM D3418	374	410	410	410	410	420	428
	19	Melting Point (semi-crystalline) peak	°F	ASTM D3418	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	20	Continuous Service Temperature in Air (Max.) (1)	°F	-	300	340	340	338	340	340	300
	21	Thermal Conductivity	BTU in./hr. ft.^{2} °F	E 1530-11	1.8	1.23	1.56	2.45	1.6	-	2.42
ELECTRICAL	22	Dielectric Strength, Short Term	Volts/mil	ASTM D149	425	830	770	N/A	-	-	360
	23	Surface Resistivity	ohm/square	EOS/ESD S11.11	$>10^{13}$	$>10^{13}$	$>10^{13}$	$10^4 - 10^6$	$10^6 - 10^9$	$10^6 - 10^9$	$>10^{13}$
	24	Dielectric Constant, 10^6 Hz	-	D150	3.14	3.15	3.7	3	5.63	-	3.44
	25	Dissipation Factor, 10^6 Hz	-	D150	0.0008	0.0013	0.0015	0.0013	.266	-	0.0017
	26	Flammability @ 3.1 mm (1⁄8 in.) (5)		UL 94	HB	V-0	V-0	V-0	V-0	V-0	V-0
CHEMICAL (3)	27	Water Absorption Immersion, 24 Hours	% by wt.	ASTM D570 (2)	0.3	0.25	0.18	0.3	0.5	0.21	0.37
	28	Water Absorption Immersion, Saturation	% by wt.	ASTM D570 (2)	0.6	1.25	0.9	1.1	2.9	1.4	1.1
	29	Acids, Weak, acetic, dilute hydrochloric or sulfuric acid	@73°F		A	A	A	A	A	A	A
	30	Acids, Strong, conc. hydrochloric or sulfuric acid	@73°F		U	U	U	U	U	U	L
	31	Alkalies, Weak, dilute ammonia or sodium hydroxide	@73°F		A	A	A	A	A	A	A
	32	Alkalies, Strong, strong ammonia or sodium hydroxide	@73°F		U	U	U	U	U	U	A
	33	Hydrocarbons-Aromatic, benzene, toluene	@73°F		U	U	U	U	U	U	L
	34	Hydrocarbons-Aliphatic, gasoline, hexane, grease	@73°F		L	L	L	L	L	L	A
	35	Ketones, Esters, acetone, methyl ethyl ketone	@73°F		U	U	U	U	U	U	U
	36	Ethers, diethyl ether, tetrahydrofuran	@73°F		L	A	A	A	A	A	L
	37	Chlorinated Solvents, methylene chloride, chloroform	@73°F		U	U	U	U	U	U	U
	38	Alcohols, methanol, ethanol, anti-freeze	@73°F		A	A	A	A	A	A	L
	39	Continuous Sunlight	@73°F		L	A	A	A	A	A	L
OTHER	40	FDA Compliance			Y	Y	N	N	N	N	Y
	41	Relative Cost (4)			$$$	$$$	$$$	$$$$	$$$$$	$$$$$	$$$
	42	Relative Machinability (1-10, 1=Easier to Machine)			3	3	7	4	4	4	3

KEY: A = Acceptable Service L = Limited Service U = Unacceptable QTM = Quadrant Test Method

NOTE: Property data shown are typical average values. A dash (-) indicates insufficient data available for publishing.

(1) Data represents Quadrant's estimated maximum long term service temperature based on practical field experience.

(2) Specimens 1/8" thick x 2" diameter or square.

(3) Chemical resistance data are for little or no applied stress. Increased stress, especially localized, may result in more severe attack. Examples of common chemicals also included.

(4) Relative cost of material profiled in this brochure ($ = Least Expensive and $$$$$$ = Most Expensive).

(5) Estimated rating based on available data.The UL 94 Test is a laboratory test and does not relate to actual fire hazard.
Contact Quadrant at TechServices@qplas.com for specific UL "Yellow Card" recognition number.

	Duratron® T4203 PAI	Duratron® T4503 PAI	Duratron® T4301 PAI	Duratron® T4501 PAI	Duratron® T4540 PAI	Duratron® T5530 PAI	Duratron® T5030 PAI	Duratron® T7130 PAI	Duratron® T7530 PAI	Semitron® ESd 520HR	Duratron® D7000 PI	Duratron® D7015G PI	Duratron® CU60 PBI
	Electrical Grade PAI	Electrical Grade PAI	Bearing Grade PAI	Bearing Grade PAI	Bearing Grade PAI	30% Glass Filled PAI	30% Glass Filled PAI	30% Carbon Fiber Filled PAI	Carbon Fiber Filled PAI	Static Dissipative PAI	Unfilled PI	Bearing Grade PI	Unfilled PBI
	Extruded	Compression Molded	Extruded	Compression Molded	Compression Molded	Compression Molded	Extruded	Extruded	Compression Molded	Compression Molded	Compression Molded	Compression Molded	Compression Molded
1	1.41	1.4	1.45	1.45	1.46	1.61	1.60	1.47	1.51	1.58	1.4	1.45	1.3
2	20,000	18,000	15,000	9,000	13,000	11,500	23,000	22,000	12,500	12,000	16,000	11,000	16,000
3	600,000	500,000	900,000	500,000	575,000	900,000	1,000,000	1,200,0000	730,000	800,000	583,000	650,000	850,000
4	10	8	3	3	3	3	4	2.5	2.6	3	4	3	2
5	24,000	18,000	23,000	12,000	12,000	20,000	30,000	-	18,000	20,000	20,000	16,500	32,000
6	600,000	560,000	800,000	550,000	550,000	900,000	980,000	-	1,000,000	850,000	600,000	640,000	950,000
7	16,000	18,000	16,400	-	-	-	-	-	-	12,600	-	13,000	-
8	24,000	22,000	22,000	20,000	20,000	27,000	40,000	37,000	43,000	30,000	24,000	25,000	50,000
9	478,000	350,000	950,000	395,000	350,000	600,000	700,000	1,000,000	971,000	600,000	450,000	360,000	900,000
10	E80 (M120)	E80 (M119)	E70 (M106)	E70 (M106)	E66 (M107)	E85 (M125)	E90	E91	E90	M108	M110	R126	E105 (M125)
11	-	D90	-	D90	D90	D90	-	-	-	-	-	D87	D94
12	2	1.5	0.8	0.5	1.1	0.7	1.0	0.9	0.7	0.8	1.4	0.8	0.5
13	0.35	0.3	0.2	0.2	0.2	0.2	-	.30	.22	0.24	0.23	0.25	0.24
14	4,000 12,000*	7,500 40,000*	22,500	22,500	7,500	20,000	-	14,000	43,000	27,000	32,500	40,000	37,500
15	>1,000 35*	300 10*	10	4.5	315	-	-	75	112	300	50	10	60
16	1.7×10^{-5}	1.5×10^{-5}	1.4×10^{-5}	2×10^{-5}	2×10^{-5}	2.6×10^{-5}	0.9×10^{-5}	0.5×10^{-5}	0.9×10^{-5}	2.8×10^{-5}	2.7×10^{-5}	2.5×10^{-5}	1.3×10^{-5}
17	532	532	534	534	534	520	530	540	-	520	680	690	800 (DMA)
18	527	527	527	527	527	527	527	527	527	527	660	660	750 (DMA)
19	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
20	500	500	500	500	500	500	500	500	500	500	580	580	600
21	1.8	1.8	3.7	3.7	2.81	2.5	2.5	3.6	3.6	2.48	1.53	2.7	2.8
22	580	600	-	-	-	700	700	-	-	475	700	186	550
23	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	-	-	-	$10^{10} - 10^{12}$	$>10^{13}$	$<10^{4}$	$>10^{13}$
24	4.2	4.2	5.4	5.4	-	6.3	4.4	-	-	5.76	3.41	5.42	3.2
25	0.026	0.031	0.037	0.042	-	0.05	0.05		-	0.182	0.0038	0.007	0.003
26	V-0	V-0	V-0	V-0	V-0	V-0	V-0	V-0	V-0	V-0	V-0	V-0	V-0
27	0.4	0.35	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.6	0.4	0.5	0.4
28	1.7	1.7	1.5	1.5	1.5	1.5	1.5	1.5	1.5	4.6	1.3	3.0	5
29	A	A	A	A	A	A	A	A	A	A	A	A	L
30	L	L	L	L	L	L	L	L	L	L	L	L	U
31	L	L	L	L	L	L	L	L	L	L	L	L	L
32	U	U	U	U	U	U	U	U	U	U	U	U	U
33	A	A	A	A	A	A	A	A	A	A	A	A	A
34	A	A	A	A	A	A	A	A	A	A	A	A	A
35	A	A	A	A	A	A	A	A	A	A	A	A	A
36	A	A	A	A	A	A	A	A	A	A	A	A	A
37	A	A	A	A	A	A	A	A	A	A	A	A	A
38	A	A	A	A	A	A	A	A	A	A	A	A	A
39	L	L	A	A	A	L	A	A	A	L	L	L	L
40	N	N	N	N	N	N	N	N	N	N	N	N	N
41	$$$$$	$$$$$	$$$$$	$$$$$	$$$$$	$$$$$	$$$$$$	$$$$$$	$$$$$$	$$$$$	$$$$$	$$$$$	$$$$$
42	5	6	5	6	6	8	8	8	8	4	5	5	10

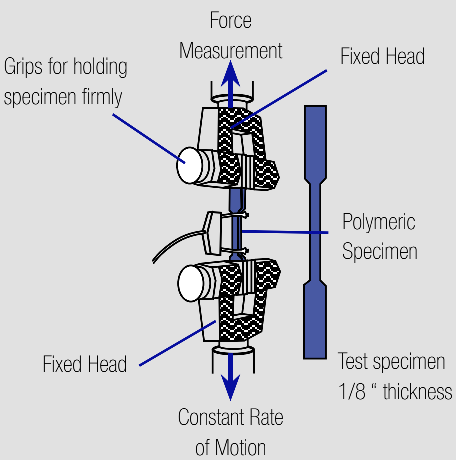
* Extruded PAI materials can benefit from a post-machine cure cycle.

2 PROPERTY BASICS

PROPERTY BASICS

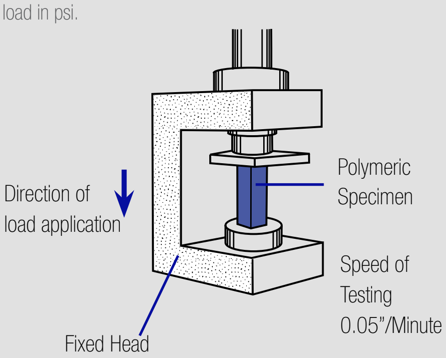
ASTM D 638: For this test, samples are either machined from stock shapes or injection molded. The tensile testing machine pulls the sample from both ends and measures the force necessary to pull the specimen apart (tensile strength), and how much the material stretches before breaking (elongation).

FIG 9



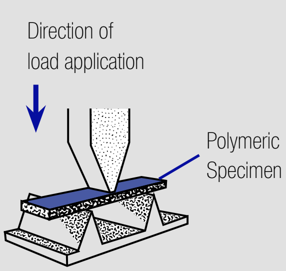
ASTM D 695: Specimen of 1/2" x 1/2" x 1" is mounted in a compression tool between testing machine heads. An indicator registers the load in psi.

FIG 10



ASTM D 790: Specimen of 1/8" x 1/2" x 5" is placed on two supports.

FIG 11



TENSILE STRENGTH (ASTM D 638)

Ultimate tensile strength is the force per unit area required to break a material under tension. It is expressed in pounds per square inch (psi). The force required to pull apart 1 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. A test schematic is shown in **Figure 9**.

ELONGATION (ASTM D 638)

Elongation (which is always associated with tensile strength) is the increase in length at fracture, 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.

TIPS

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

COMPRESSIVE STRENGTH (ASTM D 695)

Compressive strength measures a material's ability to support a compressive force. **Figure 10** details a test schematic. Always reported as pounds per square inch (psi), 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 as measured at the point of permanent yield, zero slope, and on stress-strain curve)

FLEXURAL STRENGTH (ASTM D 790)

Flexural properties measure a material's resistance to bending under load. The load at yield is the flexural strength of the material and is typically expressed in psi. For plastics, the data is usually calculated at 5% deformation/strain (the loading necessary to stretch the outer surface 5%). 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 all 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 data are both time and temperature dependent and generally developed using a DMA (Dynamic Modulus Analyzer). DMA curves for Quadrant materials can be found on pages 7 - 8.

HARDNESS

Hardness is usually reported by one of two test methods – Rockwell (ASTM D 785) or Indentation Hardness / Durometer (ASTM D 2240). The Rockwell test is typically chosen for hard materials such as acetal, nylon, and PEEK where creep is less of a factor in the test results. A test schematic is shown in **Figure 12**.

The Durometer is reported for softer materials such as urethane. The two scales do not correlate and cannot be compared. Data from a single scale is best used to compare hardness for one material versus another. Hardness data is best used to compare materials. By itself the test is not an indication of strength, wear performance or abrasion resistance.

IMPACT/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 and Tensile impact. Charpy and Gardner impact tests can also be used to get a complete characterization of a material's toughness.

Izod Impact (ASTM D 256)

In this test, a pendulum arm swings to impact a notched, cantilevered beam as shown in **Figure 13**. After fracturing the test specimen, the pendulum continues to travel in the same direction, but with less energy. This loss of energy, measured in foot-pounds per inch (ft-lb/in., or J/m) of beam thickness, is known as the Izod 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 Izod" impact strength, respectively.

Tensile Impact (ASTM D 1822)

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

FIG 12 HARDNESS TEST

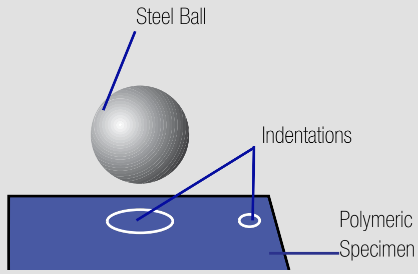


FIG 13 IZOD IMPACT TEST

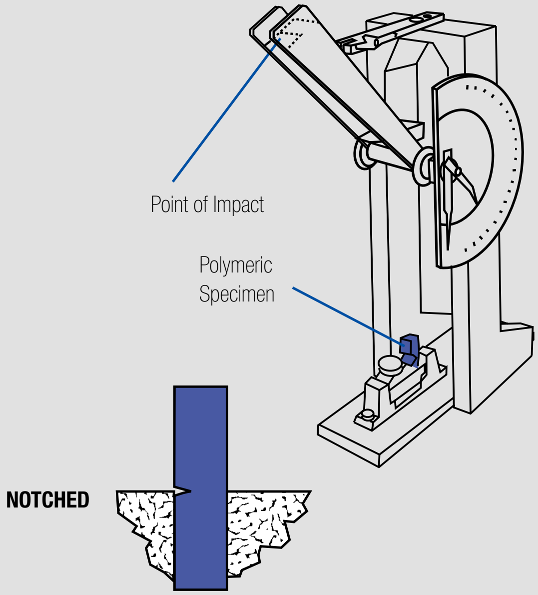
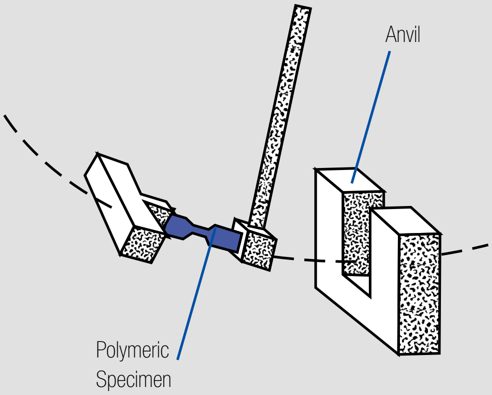
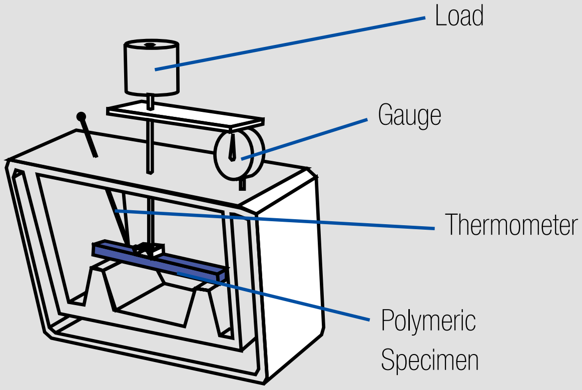


FIG 14 TENSILE IMPACT TEST



HEAT DEFLECTION TEMPERATURE FIG 15



HEAT DEFLECTION TEMPERATURE (ASTM D 648)

The heat deflection temperature is the temperature at which a 1/2" thick test bar, loaded to a specified bending stress, deflects by 0.010 in. **(Figure 15)**. It is sometimes called the "heat distortion 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.

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 need to be considered.

TG (ASTM D 3418)

The glass transition temperature (Tg) is the temperature above which an amorphous polymer becomes soft and rubbery. It is important to ensure that an amorphous polymer is used below its Tg if reasonable mechanical performance is expected, except when thermoforming.

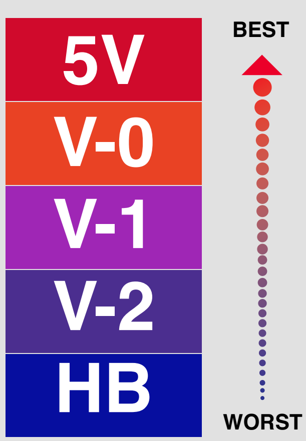
MELTING POINT (ASTM D 3418)

The temperature at which a semi-crystalline thermoplastic changes from a solid to a liquid.

COEFFICIENT OF LINEAR THERMAL EXPANSION (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 in./in./°F. CLTE is a very important consideration if dissimilar materials are 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 of plastics vary widely. The most stable plastics approach the CLTE of aluminum but exceed that of steel by up to ten times.

FLAMMABILITY CLASSES FIG 16



FLAMMABILITY

In electrical applications (or any 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.

UL 94 FLAMMABILITY CLASS (HB, V -2, V -1, V -0, 5V)

In this test, specimens are subjected to a specified flame exposure. The relative ability to continue burning after the flame is removed is the basis for classification. In general, the 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" thick). The UL rating scale from highest burn rate to most flame retardant is HB, V-2, V-1, V-0, 5V **(Figure 16)**.

SURFACE RESISTIVITY (EOS/ESD S 11.11)

This test measures the ability of electric current to flow over the surface of a material and is expressed in ohms/square area. The more readily the current flows, the lower the surface resistivity as resistivity continuum **(Figure 17)** indicates. The test electrodes are both placed on the same side of the test specimen. 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.

- Insulators exhibit resistivities of 10^{12} and higher ohm/square
- Antistatic/partially conductive products exhibit resistivities of 10^5 to 10^{12} ohm/square
- Conductive products exhibit resistivities of 10^{-6} to 10^5 ohm/square

DIELECTRIC STRENGTH (ASTM D 149)

When an insulator is subjected to increasingly high voltages, it eventually breaks down and allows a current to pass. The voltage reached before break down divided by the sample thickness is the dielectric strength of the material, measured in volts/mil. 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.

DIELECTRIC CONSTANT (ASTM D 150)

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. 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 Quadrant's literature are measured at 10^6 Hertz in carefully conditioned samples.

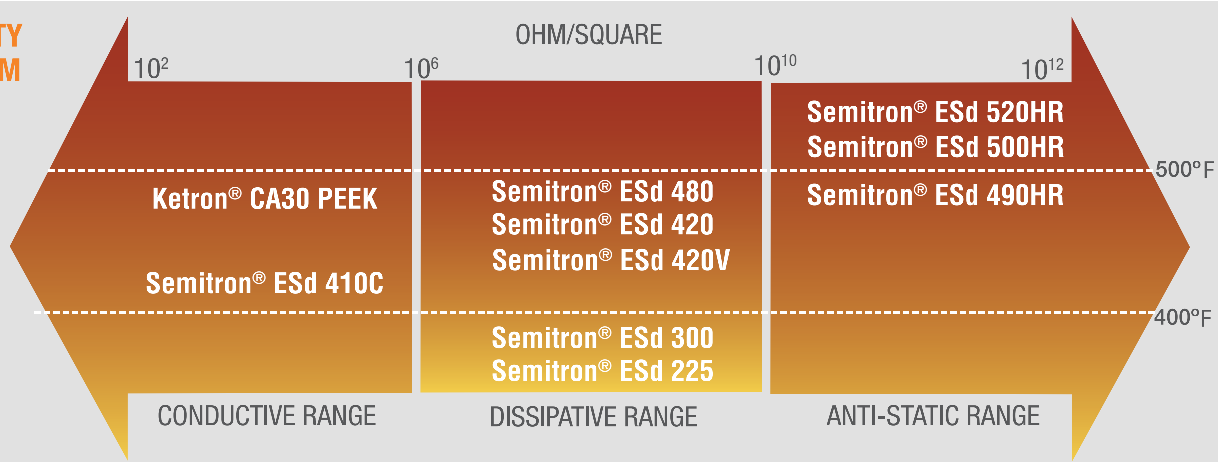
DISSIPATION FACTOR (ASTM D 150)

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.

TIPS

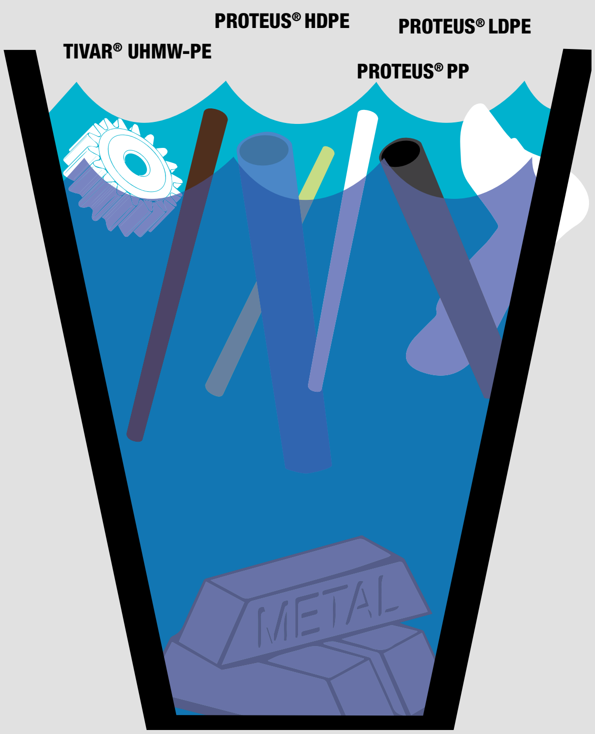
Duratron® U1000 PEI has the highest short term dielectric strength of Quadrant's engineering plastics. The value is 830 Volts/mil. This makes Duratron® U1000 PEI a material favorite for insulators.

FIG 17 **RESISTIVITY CONTINUUM**



PROPERTY BASICS

SPECIFIC GRAVITY OF MATERIALS FIG 18



SPECIFIC GRAVITY (ASTM D 792)

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). (Density of a material divided by the density of water.) Since it is a dimensionless quantity, it is commonly used to compare materials. Specific gravity is used extensively to determine part cost and weight.

TIPS

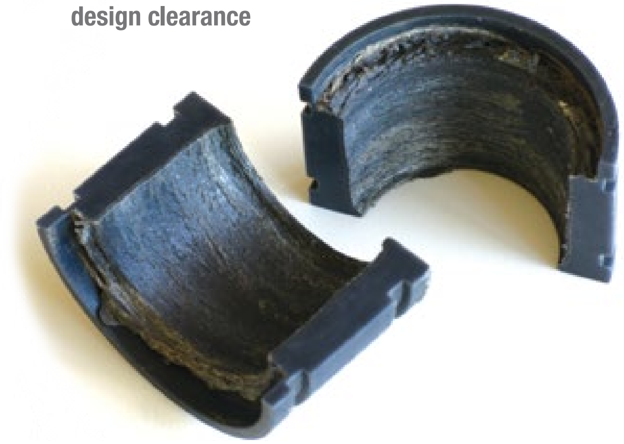
Materials with specific gravities less than 1.0 (such as polyethylene and polypropylene) float in water. This can help with identification of an unknown plastic.

WATER ABSORPTION (ASTM D 570)

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.

TRIBOLOGICAL PROPERTIES

Extreme wear from improper design clearance



COEFFICIENT OF FRICTION (ASTM D 3702/ QTM 55007)

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 although thrust washer testing is most common. The results do not have a unit of measure associated with them since the COF is the ratio of sliding force to normal force acting on two mating surfaces. COF values are useful to compare the relative "slickness" of various materials, usually run unlubricated over or against polished steel. 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.

TIPS

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 plastic, look to Nylatron® GSM Blue PA6 and Nylatron® 703XL PA6.

PV AND LIMITING PV (QTM 55007)

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

- **P =** the load the bearing will be subjected to (measured as pressure (lbs./in^2))
- **V =** the speed of the contact surfaces (velocity (ft./min.))

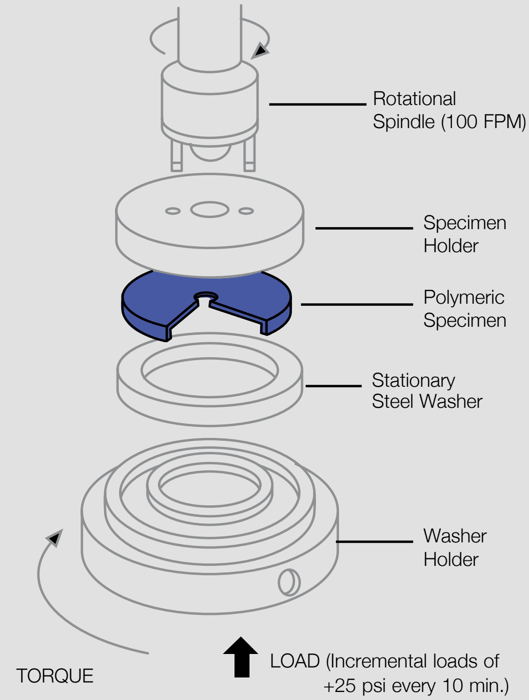
The result of multiplying P by V is referred to as the PV for a bearing application. The combination of pressure and velocity causes the generation of frictional heat at the bearing surface. This heat can contribute to premature bearing failure due to overheating if an application PV exceeds the capability of a plastic bearing material. Limiting PV is the maximum PV to which a bearing material should be subjected in unlubricated conditions. A material subjected to a PV in excess of its Limiting PV may fail prematurely due to surface melting or excessive wear.

To test for Limiting PV, a thrust washer set-up is utilized **(Figure 19)**. The plastic sample is rotated at 100 feet per minute (FPM) and is exposed to incremental loads of 25 psi every 10 minutes while bearing temperature is measured. The test has ended when the system temperature exceeds 300°F, or excessive deformation, or rapid wear of the plastic is detected. The resulting PxV combination is determined and divided by a safety factor of 4.

TIPS

Enhanced bearing and wear materials, such as Nylatron® NSM PA6 nylon, combine a low wear rate (12) with high Limiting PV capabilities (15,000 psi-FPM dry) – allowing much wider design flexibility and greater safety factors.

FIG 19 THRUST WASHER TEST SET-UP (QTM 55007)



WEAR RESISTANCE / "K" FACTOR (QTM 55010)

The wear factor ("k" factor) relates bearing surface wear rate to the variables of pressure, velocity and time.

This test uses a "journal bearing" set-up **(Figure 20)** with an actual bearing exposed to a constant load and speed (118 FPM, 42 psi = 5,000 PV). After 200 hours (T=hours) of continuous running, the radial wear of the bearing is measured and (k) is calculated.

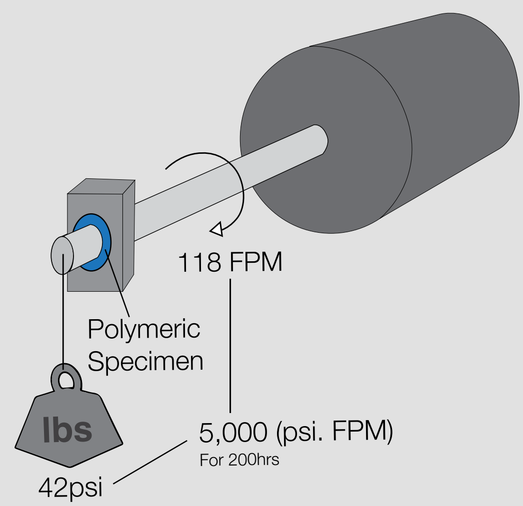
$$\text{"k"} = \frac{\text{wear}}{PVT} \times 10^{10}$$

$$\text{or wear (in.)} = (k)\ PVT \times 10^{-10}$$

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.

For application specific K-factor testing, contact Quadrant at TechServices@qplas.com or via our live chat feature at quadrantplastics.com.

FIG 20 WEAR FACTOR (K) TEST (QTM 55010)



3
MATERIAL SELECTION

STRUCTURAL

	2		3			4				6		7	8	10
			Max Compressive Working Stress (psi)			Chemical				Compliance**		CLTE	Izod	Relative Cost
	HDT	CUT	73°F	150°F	300°F	Acid	Alkali	Steam	Chlorine (Aqueous)	FDA	LSG	in./in./°F	ft.lb/in. of notch	
Duratron® PBI	800°F	650°F	12,500	11,500	10,500	Not OK	Not OK	Not OK	Not OK	No	No	1.3×10^{-5}	.5	75.0
Duratron® PI	680°F	580°F	6,750	6,200	5,670	Fair	Not OK	Not OK	Not OK	No	No	2.7×10^{-5}	.8 - 1.4	80.0
Duratron® PAI*	540°F	500°F	5,000	4,500	3,000	Fair	Not OK	Not OK	Not OK	No	No	1.7×10^{-5}	.5 - 2	28.0
Semitron® ESd	*For Static Dissipative needs, numerous material options are available.													
Duratron® PEI*	410°F	340°F	3,800	2,700	1,700	Fair	Fair	OK	Not OK	Yes	Yes	3.1×10^{-5}	.5 - 1	4.0
Quadrant® PPSU	400°F	300°F	3,000	2,200	1,500	Fair	OK	OK	Not OK	Yes	Yes	3.1×10^{-5}	2.5	9.0
Quadrant® PSU	340°F	300°F	3,000	2,200	1,000	Fair	Fair	OK	Not OK	Yes	Yes	3.1×10^{-5}	1.3	4.0
Quadrant® PC	290°F	250°F	2,000	1,200	–	Fair	Fair	Not OK	Not OK	Yes	Yes	3.9×10^{-5}	1.5	1.7
Quadrant® PPO	200°F	200°F	3,000	1,200	–	Fair	Fair	Not OK	Not OK	No	No	3.56×10^{-5}	–	1.5
PVC	140°F	140°F	2,500	1,000	–	Fair	OK	Not OK	–	No	No	6.1×10^{-5}	–	1.0

*Available in Semitron® static dissipative grades.

HOW TO SELECT THE IDEAL MATERIAL...

1 **APPLICATION: What is the primary function of the part?**

- ❑ Structural
- ❑ Bearing & Wear

If structural, start by choosing a material from the amorphous side of the triangle (left side).
If bearing and wear, choose a material from the semi-crystalline side of the triangle (right side).

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

- Continuous Use Temp __________

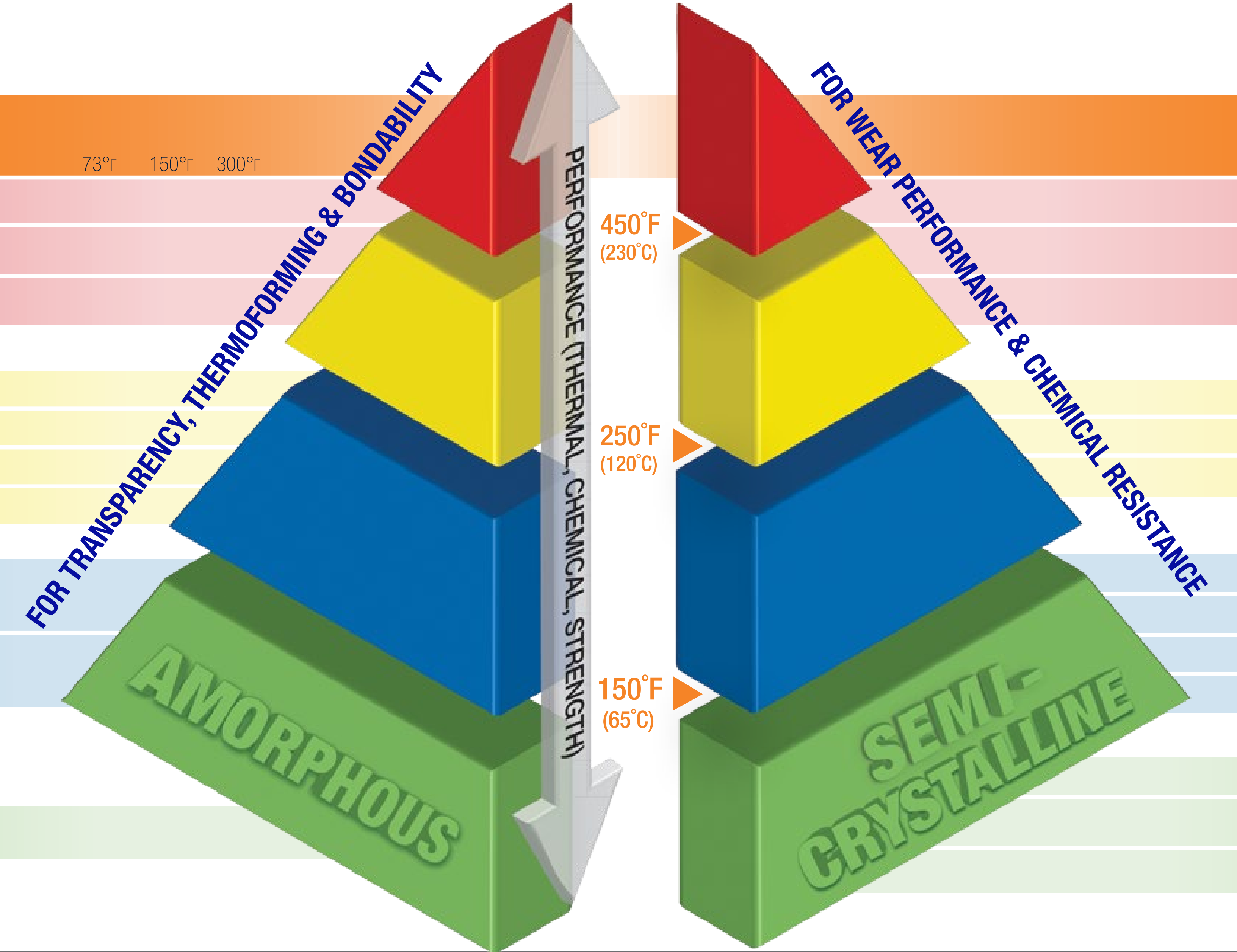
Also consider a material's heat deflection temperature (HDT) when selecting a material.

Travel up and down the triangle to find a family of materials that offers the ideal temperature resistance.

3 **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.



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

- ❑ Strong Acids (pH 1-3)
- ❑ Strong Alkalies (pH 9 -14)
- ❑ Hot H_2O or Steam
- ❑ 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.

5 FOR BEARING & WEAR APPLICATIONS: To determine the LPV: multiply the pressure by the velocity.

Limiting PV = P(psi) x V (FPM) = ______________________

Consider materials with a LPV higher than calculation.

Also, choose a material with the lowest wear factor (k) to ensure optimum wear performance.

6 COMPLIANCE: (NSF, FDA, 3A Dairy, USP VI, etc.) required?

❑ Yes ❑ No

For food applications, consider FDA compliant materials. For medical applications, consider Quadrant's biocompatibility tested Life Science Grade (LSG) materials.

BEARING & WEAR

	2		3			4				5		6		7	8	10	
	HDT	CUT	Max Compressive Working Stress (psi)			Chemical				Wear		Compliance**		CLTE	Izod	Relative Cost	
			73°F	150°F	300°F	Acid	Alkali	Steam	Chlorine (Aqueous)	K-Factor	LPV	FDA	LSG	in./in./°F	ft.lb/in. of notch		
	800°F	650°F	12,500	11,500	10,500	Not OK	Not OK	Not OK	Not OK	60	37,500	No	No	1.3x10^{-5}	.5	75.0	Duratron® PBI
	680°F	580°F	6,750	6,200	5,670	Fair	Not OK	Not OK	Not OK	10	40,000	No	No	2.7x10^{-5}	.8 - 1.4	80.0	Duratron® PI
	540°F	500°F	5,000	4,500	3,000	Fair	Not OK	Not OK	Not OK	10	40,000	No	No	1.7x10^{-5}	.5 - 2	28.0	Duratron® PAI*
	320°F	480°F	3,500	1,750	750	OK	OK	OK	Not OK	100	20,000	Yes	Yes	2.6x10^{-5}	.6 - 1	20.0	Ketron® PEEK*
	250°F	340°F	2,100	2,000	500	OK	OK	OK	Not OK	62	8,750	Yes	No	2.8x10^{-5}	.5 - 1	16.0	Techtron® PPS
	270°F	500°F	1,500	1,000	500	OK	Fair	OK	OK	38	20,000	Yes	No	2.5x10^{-5}	.9 -1.8	12.0	Fluorosint® PTFE*
	240°F	210°F	2,300	2,000	-	Fair	Fair	Not OK	Not OK	35	6,000	Yes	No	3.3x10^{-5}	.5	2.0	Ertalyte® PET-P
	200°F	200°F	2,000	1,200	-	Fair	Not OK	Not OK	Not OK	12	15,000	Yes	No	5.5x10^{-5}	.4 -1	1.0	Nylatron® PA
	250°F	180°F	2,200	1,800	-	Fair	Not OK	Not OK	Not OK	200	2,700	Yes	Yes	5.4x10^{-5}	1.5	1.2	Acetron® POM*
	116°F	180°F	1,800	400	-	OK	Fair	Not OK	OK	-	4,000	Yes	No	11x10^{-5}	.7 - 1	0.5	TIVAR® UHMW-PE
	140°F	180°F	500	250	-	OK	OK	Not OK	Not OK	-	-	Yes	Yes	4.6x10^{-5}	1.5	0.3	Proteus® PP
	140°F	180°F	1,000	500	-	OK	OK	Not OK	Not OK	-	-	Yes	No	6.7x10^{-5}	1.5	0.3	Proteus® HDPE
	140°F	160°F	500	250	-	OK	OK	Not OK	Not OK	-	-	Yes	No	-	-	0.3	LDPE

**Available in material grades that meet compliance requirements.

7 **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.

8 **IZOD IMPACT: Is toughness or impact resistance critical in use?**

- Consider Izod Impact ____________________

A higher Izod impact value means improved toughness. Also, consider designs with radiused corners.

9 **SIZE:** What size **stock shape** is required for machining?

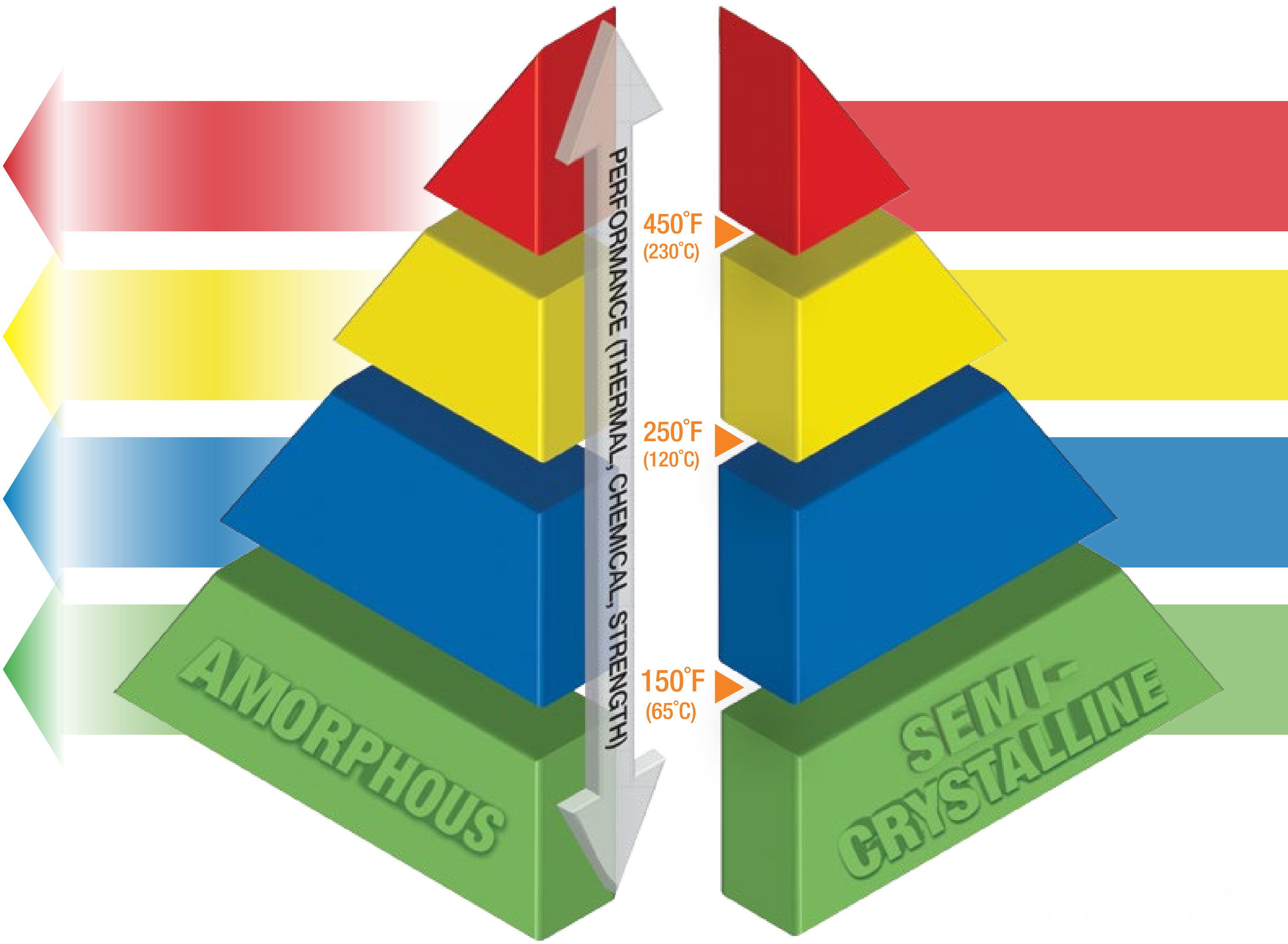
❑ Rod ❑ Sheet ❑ Tube ❑ Other

Contact Quadrant for rod, sheet, tube & stock shape availability.

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

FINALLY: Remember to use proper Quadrant name call-out on specification to ensure quality and consistency in your material.

OPEN HERE FOR A MATERIAL SELECTION GUIDE



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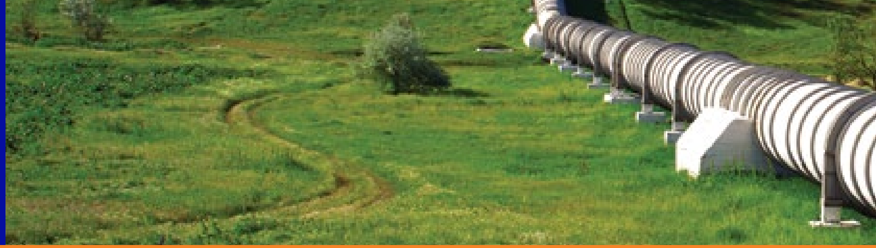
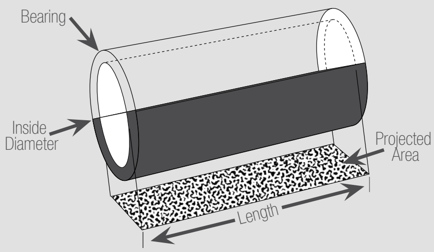
4 BEARING DESIGN

BEARING DESIGN



BEARING CONTACT AREA

FIG 21



Engineering thermoplastics are commonly used as bearings on newly designed and existing machinery, replacing:

- **Rolling element bearings**
- **Metallic plane bearings**
- **Slide pads**
- **Soft metals such as bronze and lead alloys**

PLASTICS > METALS

With plastics' inherently low friction properties, designers often eliminate the need for external lubrication while reducing potential damage to mating surfaces. Selection of an appropriate plastic bearing material requires consideration of an application's unit pressure, calculated 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.

BEARING AND WEAR PROPERTIES COMPARISON

FIG 22

LESS EXTREME TEMP. ↔ MORE EXTREME TEMP.

Material	Service Temp.	Continuous Limiting PV	"k" Factor	Coefficient Friction of (Dynamic)	Compressive Strength	Cost Factor
TIVAR® 1000 UHMW-PE	180	3,000	111	0.12	3,000	0.5
Acetron® GP POM-C	180	2,700	200	0.25	15,000	1.2
Acetron® POM-H	180	2,700	200	0.25	16,000	1.2
Acetron® AF Blend POM-H	180	8,300	60	0.19	16,000	3.5
Semitron® ESd 225 POM-C	180	2,000	30	0.29	8,000	3.3
Nylatron® 703XL PA6	200	17,000	26	0.14	10,000	1.5
Nylatron® GSM Blue PA6	200	5,500	65	0.18	13,000	1.0
Quadrant® Nylon 101 PA66	200	2,700	80	0.25	12,500	1.0
Nylatron® MC 907 PA6	200	3,000	100	0.20	15,000	1.0
Nylatron® GSM PA6	200	3,000	90	0.20	14,000	1.0
Nylatron® GS PA66	200	3,000	90	0.20	16,000	1.0
Nylatron® NSM PA6	200	15,000**	12	0.18	14,000	1.4
Ertalyte® PET-P	210	2,800	60	0.20	15,000	1.6
Ertalyte® TX PET-P	210	6,000	35	0.19	15,250	1.8
Nylatron® LIG/LFG PA6	220	6,000	72	0.14	13,500	1.0
Nylatron® MC® 901 PA6	260	3,000	100	0.20	15,000	1.0
Techtron® HPV PPS	430	8,750	62	0.20	15,500	22
Techtron® PSBG PPS	450	25,000	800	0.20	15,000	17
Ketron® 1000 PEEK	480	8,500	375	0.32	20,000	19
Ketron® CA30 PEEK	482	25,000	150	0.20	29,000	55
Ketron® HPV PEEK	482	20,000	100	0.21	20,000	30
Duratron® T4301 PAI	500	40,000*	10	0.20	22,000	28
Duratron® T4501 PAI	500	22,500	150	0.20	16,000	28
Fluorosint® 500 PTFE	500	8,000	600	0.15	4,000	12
Fluorosint® 207 PTFE	500	8,000	85	0.10	3,800	12
Fluorosint® HPV PTFE	500	20,000	38	0.15	3,000	12
Duratron® D7015G PI	500	40,000	10	0.25	25,000	63
Duratron® CU60 PBI	600	37,500	60	0.24	50,000	76

* 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.

STEP 1: DETERMINE BEARINGS' OPERATING PV

Application PV = Pressure (psi) x Velocity (FPM)

Determining Surface Velocity

For sleeve bearings, the formula **V = 0.262 x rpm x D** is used to determine the surface velocity "V" in fpm, from the shaft diameter, "D" (in.) 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.

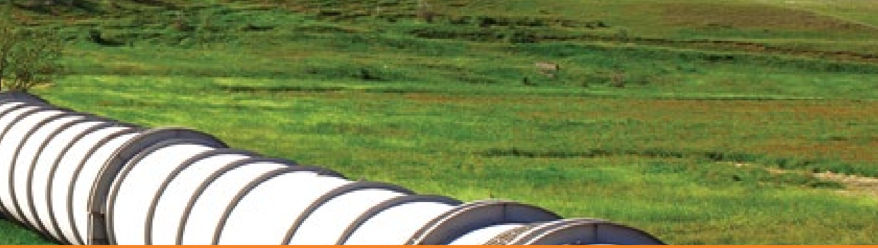
Determining Unit Pressure

For flat bearing surfaces, P is simply the total load (lbs.) divided by the total contact area expressed in square inches (in.^{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 I.D. (inches) by the bearing length (inches), as seen in **Figure 21**.

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.

TIPS

The maximum unit pressure must always be less than the compressive strength of a selected material. 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 & APPLY THE PV CORRECTION FACTORS

Figure 22 presents LPV values for various Quadrant plastic bearing materials. LPV is the maximum PV that a given material can withstand at 75°F, running continuously without lubrication. The basic LPV taken from this table must be adjusted to compensate for ambient temperatures other than 75°F, and for the cycle time, if continuous operation is not required. Adjustment of LPV is accomplished by multiplying by the correction factors ("H" and "C") obtained from **Figures 23 and 24**. 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.

$$PV_{ADJUSTED} = \text{Limiting PV of Quadrant Material Selected} \times H \times C$$

FIG 23

AMBIENT TEMPERATURE CORRECTION (H)

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

$$PV_{ADJUSTED} = PV \times H$$

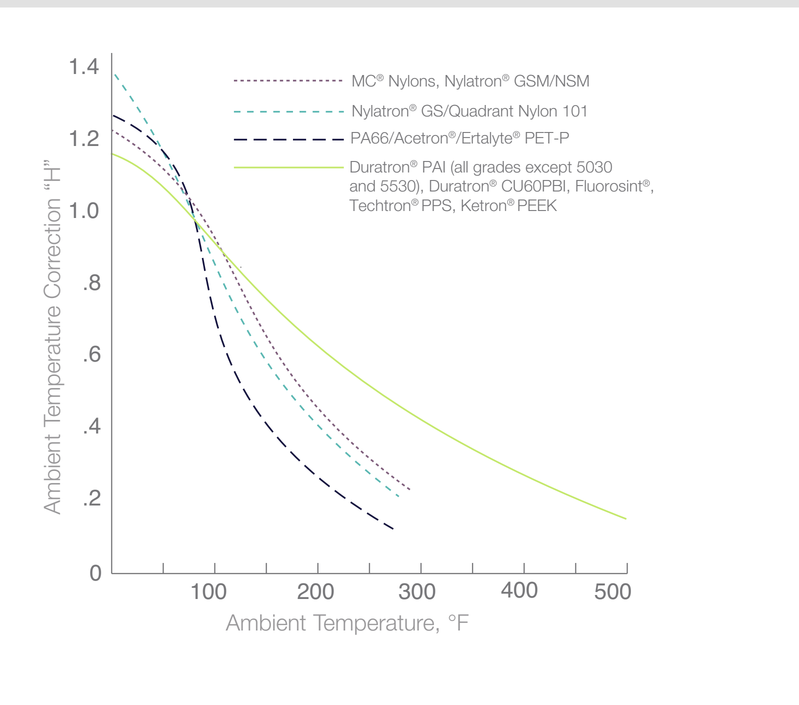


FIG 24

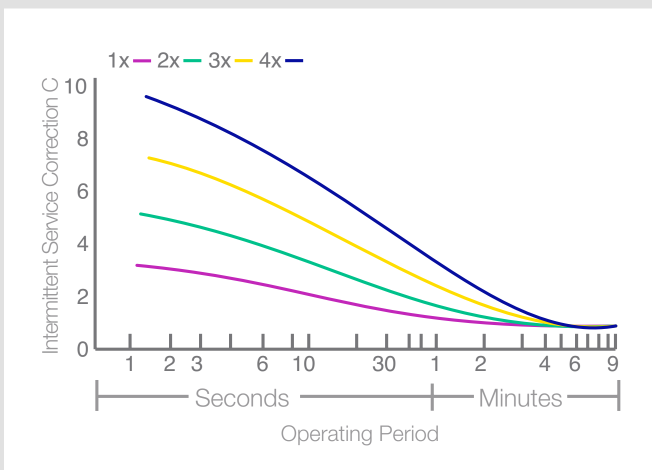
CYCLE TIME CORRECTION (C)

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:

Locate operating period or "on" period on 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. Interpolate conservatively. For example, if off period is three and one-half times the on period, use the (3X) curve.

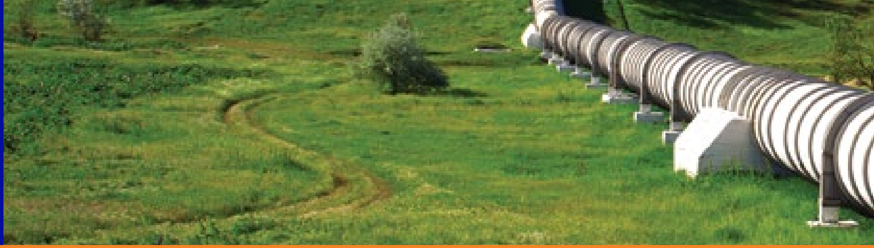
$$PV_{ADJUSTED} = PV \times C$$



TIPS

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.

BEARING DESIGN



(a_1) BASIC SHAFT ALLOWANCE VERSUS SHAFT DIAMETER

FIG 25

Shaft Allowance, a_1 (inches)	Shaft Diameter (inches)
.005	1"
.009	2"
.012	3"
.015	4"
.017	5"
.020	6"
.022	7"
.024	8"
.026	9"
.028	10"
.030	11"
.032	12"

STEP 3: BEARING CLEARANCE

Clearance has been the least understood and most frequently encountered problem in the design of plastic bearings. 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. **Figure 25** was developed from application data on plastic bearings.

FIG 26

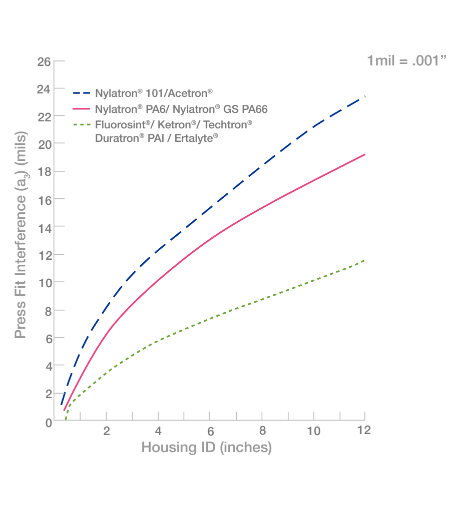
(a_2) Wall factor for plastic bearing materials at various ambient temperatures - for calculation of a_2 (inches)

	75°	100°	125°	150°	175°	200°	225°	250°	275°	300°	350°	400°	450°	500°
Quadrant® Nylon 101 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, Ertalyte® PET-P	.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.

(a_3) RECOMMENDED PRESS FIT INTERFERENCE VERSUS HOUSING INSIDE DIAMETER

FIG 27



a_2 = Wall thickness allowance (a function of the bearing material, bearing wall thickness, and the ambient operating temperature) **Obtain 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 the 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 26** demonstrates that the higher ambient temperatures and/or thicker bearing walls, the greater the required running clearance.

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 press fit interference **(obtain from Figure 27)**.

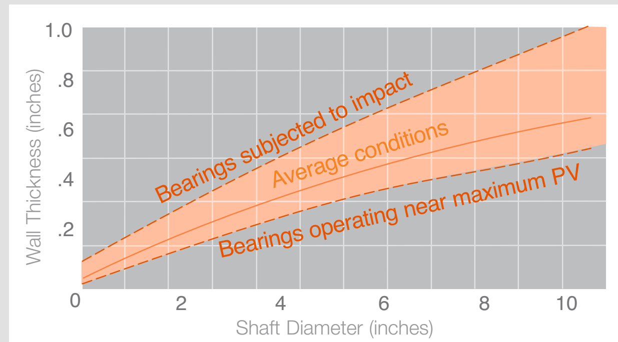
When plastic bearings are press fit into metallic housings or retainers, a recommended interference **(Figure 27)** should be used to ensure that the bushing is adequately secured to resist rotating with the shaft. During press fit, the plastic bearing conforms to the housing I.D. Therefore, the I.D. 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 28** suggests a range of nominal wall thicknesses for different shaft diameters. Maximum walls are recommended for bearings subjected to severe impact conditions, and minimum walls for bearings operating near the material's maximum recommended PV value.

FIG 28 BEARING WALL THICKNESS



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 although a 32 RMS is usually acceptable. The finish of the plastic bearing is not critical and can be as coarse as 125 RMS.

TIPS

TIVAR® UHMW-PE materials have a lower mechanical strength than other traditional thermoplastic bearings. As a result, please review TIVAR® Bushing/Bearing Design Specifications below.

D) TIVAR® UHMW-PE BUSHING/BEARINGS DESIGN SPECS

Press Fitting TIVAR® UHMW-PE Bearings:

- Add .8 to 1.0% to the nominal OD on bearing:

  $(OD_b - ID_h) / ID_h \times 100 = .8\%$ to 1.0%

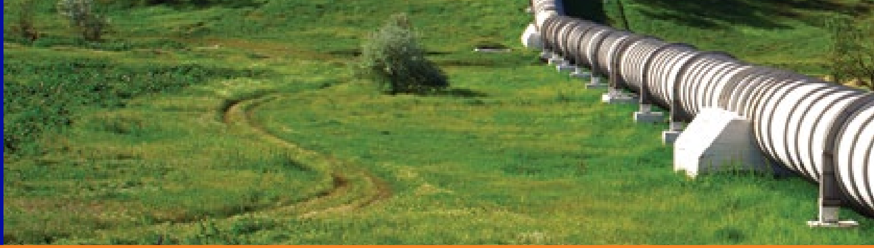
  OD_b = Bearing OD

  ID_h = Mating Housing ID
- Bearing length to diameter ratio should be equal to or less than 1.5: $L/OD_b \leq 1.5$
- For each .004" or .10mm added to the nominal bushing O.D. for press fitting into a housing, the bushing I.D. will close in .001" or .03mm

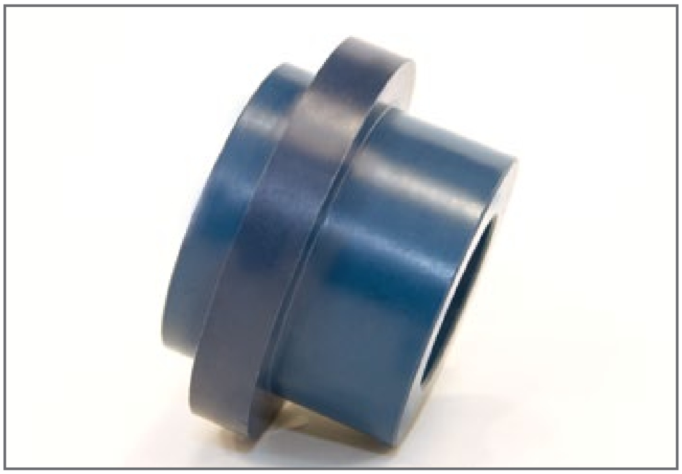
Shaft Diameters/TIVAR® UHMW-PE Bearings:

- To produce a running fit, increase the nominal bearing I.D. by .001" or .03mm for shaft diameters less than 1" or 25mm in size.
- To produce a running fit on shafts 1" or 25mm and larger, increase the nominal bearing I.D. by .003" or .07mm for each 1" or 25mm in size.
- Recommended bearing wall thickness is one tenth of shaft diameter when designing a TIVAR® bearing.
- Increase the wall thickness for shock load conditions and decrease the wall thickness for applications near the limiting PV value.
- It is recommended that the length of a TIVAR® UHMW-PE bearing be equal to the shaft diameter unless under a high load, where more surface area is required to resist creep.

BEARING DESIGN



Duratron® CU60 PBI bushing next to the steel bearing it replaced due to shaft galling.



Techtron® HPV PPS

Nylatron® GSM Blue PA6

NYLATRON® BEARING FOR WET APPLICATIONS

If your bearing is to be water lubricated and made from a Quadrant Engineering Plastic Products' nylon, an additional clearance must be added for moisture expansion of the nylon. Use clearances below 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. Add a moisture factor in your bearing design for water lubricated nylon bearings per table below:

Moisture Factor

1/8"	clearance in inches is	0.012"
3/16"	clearance in inches is	0.017"
1/4"	clearance in inches is	0.021"
3/8"	clearance in inches is	0.026"
1/2"	clearance in inches is	0.030"
3/4"	clearance in inches is	0.032"
1" +	clearance in inches is	0.033"

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

TIPS

Internally lubricated materials such as Nylatron® NSM PA6, Nylatron® GSM Blue PA6 nylon and Ertalyte® TX provide the lowest cost in use when application PV is less than Limiting PV.

BEARING DESIGN WORKSHEET

Note: This worksheet applies to sleeve bearings only. Contact Quadrant at TechServices@qplas.com or via our live chat feature at quadrantplastics.com with any questions.

INFORMATION REQUIRED

Housing bore ______________________ in.

Shaft diameter______________________ in.

Length ______________________ in.

Shaft rpm ______________________

Bearing load______________________ lbs.

How many bearings/shaft ____________

Ambient temperature ____________ °F

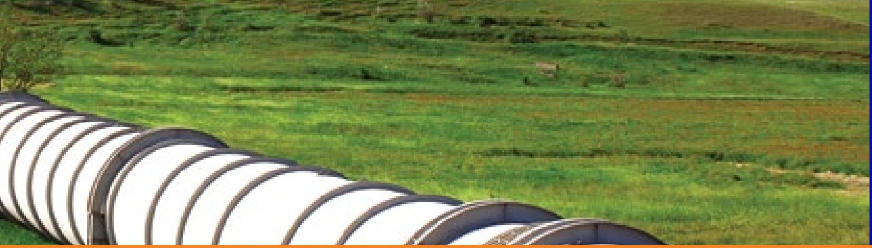
Cycle ❑ Continuous

❑ Intermittent

Time on ______ Time off ______

❑ Is bearing lubricated?

How? ______________________



STEPS 1 & 2: DETERMINE BEARINGS' OPERATING PV, SELECT MATERIAL & CORRECTION FACTORS

Projected area

Bearing ID ______________ x Length_________________ = __________ sq. in.

Pressure

Bearing load _____________ ÷ Projected area __________ = __________ psi

Velocity

0.262 x ______________ rpm x Shaft diameter __________ = __________ fpm

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

Application PV (imposed PV on bearing)

_____________ psi x ______________ fpm = __________ PV

See (Figure 22, page 34) for Limiting PV

Lubricated ❑ Unlubricated ❑

Material Selected _______________________________________

Corrections for Limiting PV - See **(Figures 23 and 24, page 35)**

Figure 23 – Temperature Correction H = __________

Figure 24 – 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 25, page 36)** = ________

a_2 = **(Figure 26, page 36)**

Bearing wall $\frac{(OD - ID)}{2}$ x Temp. factor for material

= ________

a_3 = **(Figure 27, page 36)** – used if bearing is press fit

= ________

STEP 5: DIMENSION OF THE BEARING

Housing dia.: ________ $+a_3$ ________ = OD of bearing ________

Shaft dia.: _____ + a_1 _____ + a_2 _____ + a_3 = ID of bearing ________

If a nylon bearing is to be used in a water lubricated environment, add moisture factor per **page 38** *to the ID of the bearing to allow for moisture absorption:*

ID of bearing: ________ + Moisture absorption clearance ________ = ID of bearing

Length of housing _____________

STEP 6: BEARINGS, DIMENSIONS AND TOLERANCES

OD = _____________ ±0.004 in. or ± 0.001 in./in. of dia.

ID = _______________ +0.008 / -0.000 in. or +0.002/ -0.000 in./in. of dia.

Length = _______________ ±0.010 in. or ± 0.001 in./in. of length

**The greater of the tolerances will apply.*

5

ROLLER/WHEEL DESIGN

ROLLER/WHEEL DESIGN

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 quieter operation. Typical rigid plastic roller/wheel material choices are:

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

PLASTICS > METALS

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

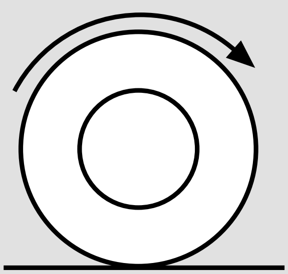
To determine the suitability of a rigid plastic roller/wheel, consider:

- Load upon the roller/wheel
- Speed of the roller/wheel
- Temperature around and on the roller/wheel
- Duty cycle of the roller/wheel – whether it is stationary or rotating
- Creep and fatigue properties of the roller/wheel material

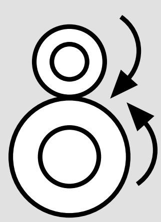
The creep and fatigue properties play an important role in preventing flat spots, cracking and softening of the rollers/wheels in end-use. The first step in calculating suitability is to determine the load capacity of the proposed material. The load capacity equation is dependent upon the geometry and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

(1) roller on a flat surface (Figure 29 a.)
(2) roller on another rolling surface (Figure 29 b.)
(3) roller in another rolling surface (Figure 29 c.)

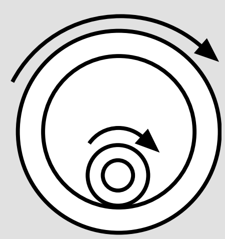
FIG 29



Roller on a flat surface (Figure 29 a.)



Roller on another rolling surface (Figure 29 b.)



Roller in another rolling surface (Figure 29 c.)

ROLLER/WHEEL DESIGN

DETERMINING THE LOAD CAPACITY OF A ROLLER/WHEEL

1: Select the roller configuration.

1. Roller on a flat surface
2. Roller on another rolling surface
3. Roller in another rolling surface **(See Figure 29)**

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

3: From **Figure 30**, obtain the material stress factor, K.
Note: Separate values are given for stationary vs. rotating situations.

4: Using the equation provided for the selected roller configuration, calculate the load capacity of the roller/wheel.

(1) Roller on a flat surface **(Figure 29 a.)**

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

(2) Roller on another rolling surface **(Figure 29 b.)**

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

(3) Roller in another roller surface **(Figure 29 c.)**

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

Where:
W_{MAX} = Maximum allowable contact load (lbs.)
D_p = Diameter of plastic roller (in.)
D_m = Diameter of metal roller (in.)
L = Contact length of roller (in.)

TIPS

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 anticipated.

FIG 30 MATERIAL STRESS: FACTOR (K)*

LESS EXTREME ↕ MORE EXTREME

Material	Stationary	Rotating
TIVAR® 1000 UHMW - PE	5	12
Fluorosint® PTFE	5	17
Semitron® ESd 225 POM-C	23	76
Quadrant® Nylon 101 PA66	30	99
Nylatron® GSM Blue PA6	32	106
Nylatron® GSM PA6	39	130
Nylatron® NSM PA6	39	130
Techtron® PSBG PPS	42	75
Acetron® POM-H	45	150
Acetron® AF Blend POM-H	45	149
Acetron® GP POM-C	45	150
Nylatron® MC901 / 907 PA6	45	150
Ertalyte® PET–P	46	142
Nylatron® GS PA66	49	162
Techtron® HPV PPS	70	170
Duratron® T4503 PAI	89	157
Duratron® T4301 PAI	91	161
Duratron® T4501 PAI	96	170
Duratron® T4540 PAI	95	170
Ketron® CM CA30/HPV PEEK	96	171
Ketron® 1000 PEEK (Extruded)	120	213
Ketron® HPV PEEK	120	171
Ketron® CA30 PEEK	132	234
Duratron® T4203 PAI	168	298
Duratron® CU60 PBI	215	383

Based on maximum allowable contact stresses (psi).

ASSEMBLY/FABRICATION

The three commmon rigid plastic wheel/roller designs are:

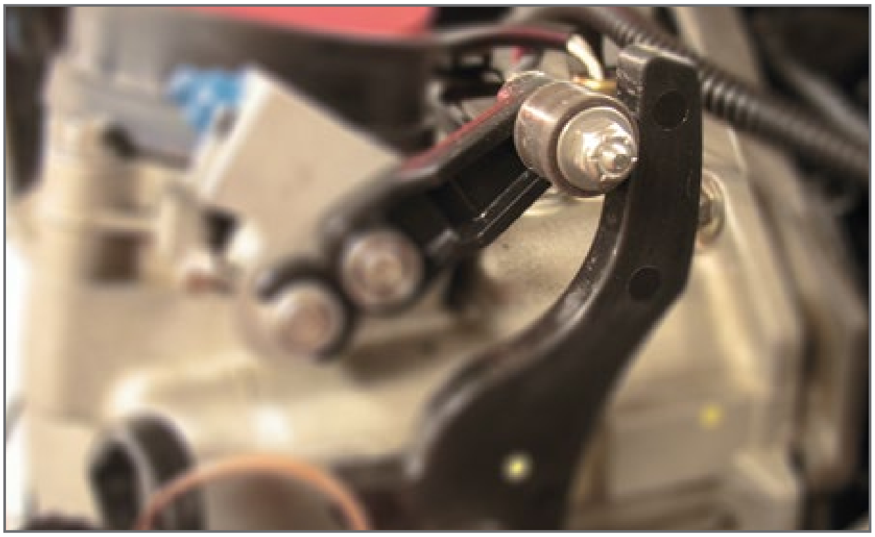
- **Solid rollers rotating directly on the shaft**
- **Solid rollers with ball or roller bearings**
- **Plastic sleeves on metal cores**

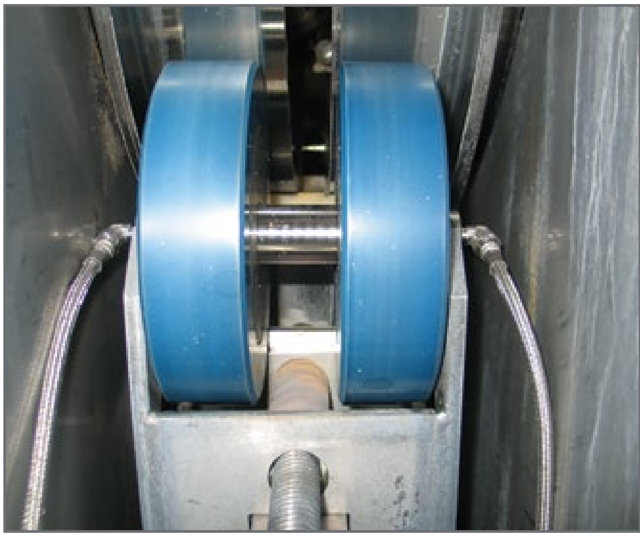
See **Figure 31** for details on the typical uses, advantages, limitations, and design/fabrication tips for these typical roller designs.

FIG 31

TYPICAL ROLLER/WHEEL DESIGNS

Roller/Wheel Design	Typical Use Conditions	Advantages	Limitations	Design/Fabrication Tips
Solid rollers rotating directly on the shaft	Intermittent service Low velocity Low load	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.
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) For side loaded wheels/rollers	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.
Plastic sleeves on metal cores	High loads High temperatures High speeds	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 Quadrant for design options.





SHRINK FITTING

Shrink fitting is the most common assembly method. Shrink fit interference and axial clearance depends upon the roller/wheel's operating temperature. **Figure 32** contains the interference and clearances for four elevated temperatures. To assemble, heat the plastic sleeve to 200°F.

Quadrant manufactures cast nylon roll covers for shrinking onto metal cores. Cast nylon roll covers are available in diameters up to 25" and in lengths up to 84". To shrink onto core, simply heat the plastic sleeve and metal core to 200°F and assemble with the aid of a hydraulic press.

CASTING PLASTIC SLEEVE ONTO METAL CORE

Directly casting the nylon plastic sleeve onto the metal core is the most efficient assembly method. It also eliminates slippage between the plastic sleeve and the metal core – the most common issue for shrink fits. Casting on the metal core is ideal for wheels/rollers with face widths less than 1".

FIG 32

INTERFERENCES & 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

6 SHEAVE DESIGN

NYLATRON® GSM PA6 SHEAVES

SUPPORT THE SAME LOAD AS METAL

Stress on the wire rope – not the sheave – commonly limits the lifting capacity of a system. The point contact pressure for a steel sheave will be much higher than for a Nylatron® nylon sheave, and the resilience of nylon results in a larger point contact area and creates support for the wire rope. Lightweight Nylatron® nylon 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 conventionally used cast steel, Nylatron® nylon sheaves reduce dead weight at the end of the boom. This provides mobile cranes with greater stability and lifting capacity and lowers over-the-road weight.

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

EXTEND WIRE ROPE LIFE

Quadrant Engineering Plastic Products, 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 33** summarizes results of the wire rope life testing. The tests prove Nylatron® nylon sheaves substantially increase rope cycle life.

RESISTS CORROSION

The corrosion resistant properties of nylon make these plastic parts ideal for marine use.

PLASTICS > METALS

For many years, manufacturers and operators of heavy-duty lifting equipment have sought ways to increase wire rope endurance life. Early attempts included lining the grooves of metal sheaves with resilient materials and mounting rims made of these materials on metal hubs.
Growth in manufacturing of mobile lifting equipment now requires designers to consider reducing the dead weight of metal sheaves on the boom or mast, and improving lift and over-the-road performance. Expansion in offshore exploration has also generated a need for lifting equipment with corrosion resistant parts.

With the development of Nylatron® GSM PA6 cast nylon sheaves, the search for improved wire rope life, reduced weight, and corrosion resistance has been resolved. Nylatron® nylon sheaves are widely used on both mobile and offshore lifting equipment.

TIPS

- **Bronze bearings are not recommended for main load applications. Their use should be limited to moderate unit loads to avoid excessive frictional heat build-up and possible movement of the bearing in the bore.**
- **For lightly loaded applications where pressure-velocity (PV) values are not excessive, it may be possible to plain bore Nylatron® nylon sheaves for running directly on the shaft. Contact Quadrant at TechServices@qplas.com or via our live chat feature at quadrantplastics.com for appropriate running clearance information.**

FIG 33 **WIRE ROPE LIFT TEST RESULTS***

Sheave Ratio	Rope Tension for Test	Approximate Design Factor (Fd)	Duration of Test	Increase in Rope Life Attained with Nylatron® GSM PA6 Sheaves*
24/1	10.0% of breaking strength	10.0	136,000 cycle	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
18/1	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® nylon sheaves.

SHEAVE DESIGN

DESIGN GUIDELINES

When designing with custom or standard sheaves, certain considerations should be observed by equipment engineers. Of special importance are groove configuration, bore configuration, bearing retention, and load capacity **(See Figure 35 - Page 50)**.The basic design of any sheave should conform to the appropriate minimum pitch diameter/rope diameter sheave ratios of 18/1 and 24/1 for the mobile crane industry. The 18/1 ratio conforms to the Power Crane and Shovel Associations and American National Standards Institute (ANSI) minimums for load hoisting cranes. The 24/1 ratio complies with most European standards and should be considered for export requirements.

RIM DIMENSIONS

The rim width (W_r), outside diameters (D_0), and tread diameters (D_T) are typically fixed design dimensions. The rim flat (F_r - shown in **Figure 35**) between the groove wall and rim edge should be a minimum of 1/8" to provide adequate side load stability.

GROOVE DIMENSIONS

The groove radius (R_g) for a Nylatron® nylon sheave should be a minimum of 5% greater than the nominal rope diameter divided by 2 to accommodate rope tolerances while giving adequate rope support.

$$R_g = 1.05\ (D_r /2)$$

Experience indicates that a groove angle Θ_g of 30° will generally provide optimum rope support for mobile crane sheaves.
Fleet angles $\geq$ 2° up to 4% generally require a 45° groove angle.
Typical American and European practice requires that the depth of the rope groove for mobile crane sheaves be made a minimum of 1.75 times the rope diameter.

WEB DIMENSIONS

Practical experience with crane sheaves has shown that the required design strength can be maintained with a minimum web width that is 10% greater than the rope diameter or:

$$W_w = 2.2\ (R_g)$$

Where: W_w = 1.1 • Groove Diameter
R_g = 1.05 • D_r / 2

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 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 1".

$$D_h = 1.5(D_b)$$

The transitions from the hub diameter to the web and the web diameter to the rim must be tapered and radiused as appropriate based upon the design thicknesses and diameters.

BORE DIMENSIONS

Nylatron® nylon sheaves for heavy-duty applications should be installed with antifriction bearings. Needle roller bearings are generally recommended, as they provide a continuous contact area across the width of the bore. As the coefficient of thermal expansion of nylon 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 140°F.

$$d = .009\sqrt{D_b}$$

Where: d = Press fit allowance (in.)
D_b = Bearing outside diameter (in.)

The diameter of the sheave bore will be the O.D. of the bearing minus the press fit allowance. $D_B = D_b - d$

Sufficient press fit is critical to prevent buckling of a loaded sheave.

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® nylon sheave. A hydraulic press can be used, or the sheave can be heated to 180°-200°F and the bearing dropped into the expanded bore. Thrust washers or thrust plates should be placed on either side of the sheave hub to maintain sideways bearing retention. This is necessary to restrict bearing movement which may occur as the result of side forces encountered during operation.

There are two exceptions to bearing retention using the above procedure:

- **Two-row double-cup tapered roller bearings in heavy-duty sheave applications**
- **Bronze bearings in idler sheaves where the sheave is free to move from side-to-side on a shaft**

Since thrust washers or thrust plates cannot be used, other means of retention must be found to restrict sideways movement of the bearing.

A positive retention method for two-row double-cup tapered roller bearings is to place a steel sleeve insert in the bore of the Nylatron® sheaves into which the cup is pressed. The insert is held in the bore by external retaining rings on each side of the hub.

Positive retention of bronze bearings in Nylatron® idler sheaves can be accomplished by extending the length of the bushing beyond the hub on both sides, and placing external retaining rings on each side of the hub. Metal side plates bolted to the hub and overlapping the ends of the bearing can also be used for this purpose.

A steel sleeve insert, held in the bore by external retaining rings, is recommended with the use of two-row double-cup tapered roller bearings.

SHEAVE DESIGN

1: LOAD CAPABILITY OF NYLATRON® NYLON SHEAVES (WITH BEARINGS)

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

$$P_g = \frac{2\,(LP_{MAX})\,K_\Theta}{D_r \bullet D_t} \qquad (1)$$

$$P_b = \frac{2\,(LP_{MAX})\,K_\Theta}{D_b \bullet W_h} \qquad (2)$$

Where:

- P_g = Max groove pressure (psi)
- P_b = Max bore pressure (psi)
- LP_{MAX} = Max single line pull (lb.) or wire rope breaking strength divided by design safety factor
- D_r = Rope diameter (in.)
- D_t = Tread diameter (in.)
- D_b = Bore diameter (in.)
- W_h = Hub width (in.)
- K_Θ = Wrap factor = $\sin\left(\frac{\text{wrap angle}}{2}\right)$
- Θ = Wrap angle

FIG 34 **WRAP ANGLE FACTORS** K_Θ

Wrap Angle Θ *	K_Θ
180°	1.000
170°	0.996
160°	0.985
150°	0.966
140°	0.940
130°	0.906
120°	0.866
110°	0.819
100°	0.766
90°	0.707
80°	0.643
70°	0.573
60°	0.500

** Arc of groove contacted by rope.*

Maximum service pressure can safely reach 8,600 psi for short term loads (a few minutes). Maximum service pressure for static loads (>100 hours) should not exceed 3,500 psi. Equations (1) and (2) can be rewritten to calculate the maximum line pull for a Nylatron® sheave:

$$Lp_{MAX} = \frac{1750\,(D_r \bullet D_t)}{K_\Theta}$$

$$Lp_{MAX} = \frac{1750\,(Wh \bullet D_b)}{K_\Theta}$$

2.LOAD CAPABILITY OF PLAIN BORED SHEAVES

The load capacity for a plain bored Nylatron® nylon sheave is based upon the ability of the bore to act as a bearing. To determine the recommended load capacity, refer to the Bearing Design section of this manual, and make calculations as follows, assuming that the bore of the sheave is a Nylatron® GSM PA6 nylon 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:

$$P_b = \frac{PV_{ADJUSTED}}{V}$$

Where:

- P_b = Maximum bore pressure (psi)
- PV_a = Pressure velocity value (psi • fpm)
- V = Shaft surface speed (fpm)
  = 0.262 x shaft rpm x Ds (fpm)
- D_s = Shaft diameter (in.)

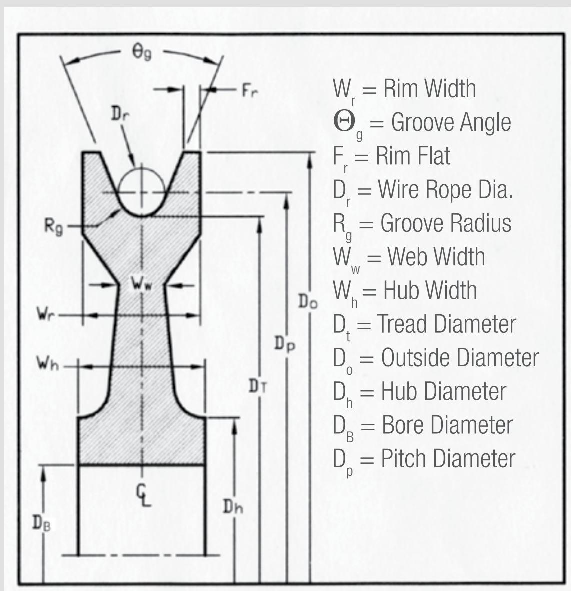
Bore pressure Pb should not exceed 1,000 psi. Take the calculated value for Pb or 1,000 psi, whichever is less, and substitute in the following equation to obtain the maximum load capacity for the conditions specified:

$$LC = P_b \bullet D_s \bullet W_h$$

Where:

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

FIG 35 **SHEAVE NOMENCLATURE**



SHEAVE DESIGN

INFORMATION REQUIRED

Maximum single line pull (Load) ________________ lbs.
Line speed ________________ ft./min.
Fleet angle ________________ degrees
Temperature low ___________°F high ___________°F

Wrap Angle (Arc of sheave contacted by rope) ___________°

SHEAVE DATA

Drawing Number? ____________________
If no drawing is available...
W_r Rim width ____________________ inches
D_o Outer diameter ____________________ inches
D_t Tread diameter ____________________ inches
D_h Center hub O.D. ____________________ inches
W_h Hub width ____________________ inches
D_b Center bore I.D. ____________________ inches
Alignment or access holes required?

____

Number? ____________________________
Pitch Circle? _________________________
Grease fittings? _______________________
Type? ______________________________
Location? ___________________________

WIRE ROPE DATA

Rope O.D.___________ inches
Rated breaking strength ________
Brand of rope in use ______________________________

BEARING SPECIFICATIONS

Design ____________________________
Mfr / Part Number __________________
O.D. of outer race ___________inches
Bearing width ___________inches
Method of attachment ______________________________

If you require any further assistance or a quote, contact Quadrant at TechServices@qplas.com or via our live chat feature at quadrantplastics.com for more information.

TIPS

- **Contact Quadrant at TechServices@qplas.com or via our live chat at quadrantplastics.com for special design requirements including underwater cable systems, V-belt applications, high temperature, 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 the use of Quadrant's products.**
- **Nylatron's® wear and impact resistance, light weight, and corrosion resistance present unique advantages in a wide variety of wear and structural components (i.e. slide bearings, wire guides, bushings, rollers and roll covers).**
- **The pressure and load capacity limits recommended here are based on intermittent cyclical loading as in typical mobile hydraulic crane operation. If operation involves continuous cycling or loading, high speed and acceleration, or heavy impact forces, the limits should be reduced and the application thoroughly evaluated.**
- **Excessive loads and/or speeds may cause distortion of the bore and loss of press fit with the bearing. Accelerated groove wear may also result. For plain bored sheaves, excessive loads and/or speeds may cause accelerated wear and increased clearance in the bore.**

TIPS

- **The use of nylon thrust washers or plates where they will wear against the Nylatron® nylon sheave hub is not recommended.**
- **Calculation of tread pressure is not necessary if the ratio of groove diameter to rope diameter is 18:1 or larger.**

7 GEAR DESIGN

ENGINEERING PLASTIC GEARS OFFER:

PLASTICS > METALS

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

Nylatron® has been the standard material of choice. It has been successfully used in a variety of industries for spur, worm, bevel, and helical gears for well over 40 years. All over the world, thermoplastic gears continue to replace traditional materials like steel, cast iron, bronze, phenolic, and even wood. Nylatron® balances strength, heat resistance, fatigue properties, impact resistance, and wear resistance; making it the most popular choice for gearing. Acetron® POM-C acetal, TIVAR® UHMW-PE, Techtron® HPV PPS, Ketron® PEEK, and new higher performance materials offer specific advantages for wet/high humidity conditions, chemically aggressive environments, light duty service, or high temperature applications.

DESIGNING NYLATRON® 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 Quadrant's gear fatigue test data, and the maximum allowable bending stress of plastic gear teeth **(See Figure 36)**. 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

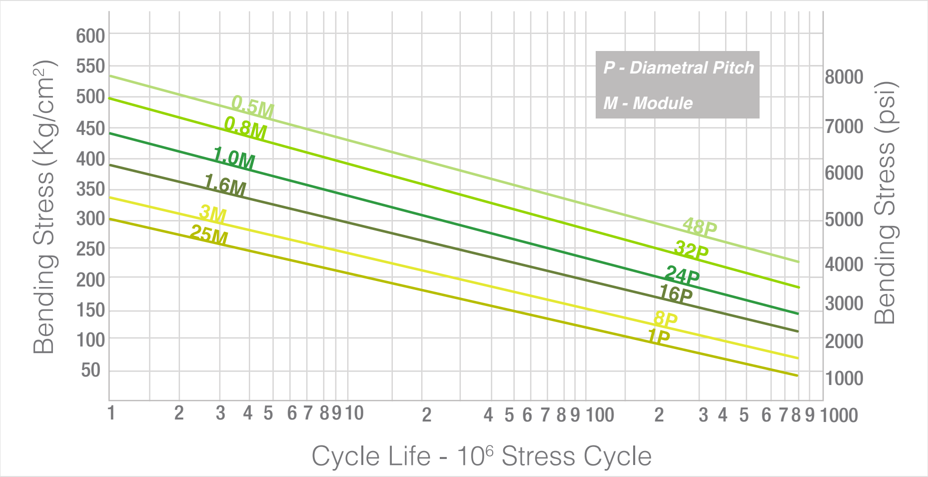
- (C_M) **Material Strength Factor:** To compare Nylatron® gears with other thermoplastic materials, one can multiply the calculated maximum torque (T_{MAX}) and horsepower (HP_{MAX}) values for Nylatron® spur gears by the Material Strength Factor **(See Figure 40)** of the material in question to determine appropriate torque and horsepower values.

- (C_V) **Pitch-line Velocity:** Gear velocity can affect the performance capability of a thermoplastic gear. **Figure 41** provides correction factors for various gear speeds. Increased speeds will lower the maximum torque (T_{MAX}) and horsepower (HP_{MAX}) values. Nylatron gearing can operate up to pitch-line velocities of 4,000 to 6,000 fpm 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 42** for this factor.

- (C_T) **Temperature Correction Factor:** Increased service temperature of the gear application will equate to some amount of material softening, which also reduces expected maximum torque (T_{MAX}) and horsepower (HP_{MAX}) values. Apply the correction factor per **Figure 43** to account for this reduced load capability.

FIG 36 **MAXIMUM TOOTH BENDING STRESSES VS. CYCLE LIFE FOR NYLON GEARS**



Based on Pitch Line Velocity of 2,000 Ft./Min

P Diametral Pitch - Ratio of N (number of teeth) to P_d (pitch diameter)

M Module - is the metric equivalent to P

GEAR DESIGN METHOD

1: OBTAIN THE REQUIRED APPLICATION DATA:

(P) Diametral Pitch **P= N/P_d**
(N) Number of Teeth
(PA) Pressure Angle
(F) Face Width, inches
(RPM) Input RPMs
(T_I) Input Torque
(HP_I) Input Horsepower

2: CALCULATE DERIVED DATA AND CORRECTION FACTORS

(P_d) Pitch Diameter = **P_d = N/P**
(Y) Tooth Form Factor - **From Figure 38**
(S_B) Bending Stress - **From Figure 39**
(C_M) Material Strength Factor - **From Figure 40**
(C_V) Velocity Factor - **From Figure 41**
(C_S) Service Lifetime Factor - **From Figure 42**
(C_T) Temperature Factor - **From Figure 43**

FIG 37 GEAR DESIGN

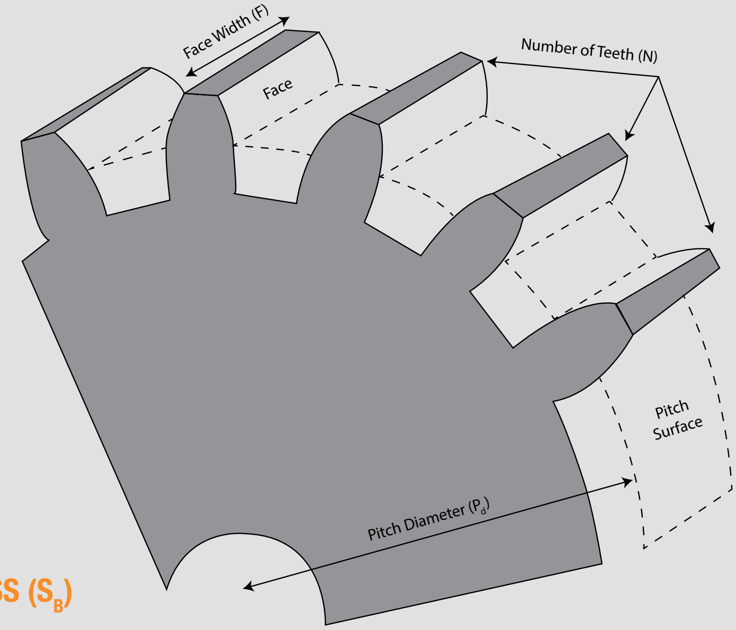


FIG 38 TOOTH FORM FACTOR (Y)

Number of Teeth	14 1/2°	20° Full Depth	20° Stub
	Pressure Angle		
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

FIG 39 NYLON BENDING STRESS (S_B)

Pitch	S_B
2	1994
3	2345
4	2410
5	2439
6	2675
8	2870
10	3490
12	3890
16	4630
20	5005

FIG 40 MATERIAL STRENGTH FACTOR (C_M) Operating Conditions

Material	Non-Lubrication	Periodic Lubrication	Continuous Lubrication
Nylatron® NSM PA6	1.00	1.00	1.20
Nylatron® GS, GSM PA6	0.49	0.94	1.26
Nylatron® MC901/907 PA6	0.49	0.94	1.26
Acetron® GP POM-C	*	*	1.04
Phenolic	*	0.96	1.13
TIVAR® UHMW-PE	*	*	0.75

** Data not available*

FIG 41 VELOCITY FACTOR (C_V)

Velocity-fpm	Correction Factors
500	1.38
1000	1.18
2000	1.00
3000	0.93
4000	0.90
5000	0.88

FIG 42 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

FIG 43 TEMPERATURE FACTOR (C_T)

Materials	< 100°F C_T =	100°F to 200°F $C_T = 1 / [1 + \alpha (T\text{-}100°F)]$
Nylatron® GSM, NSM, and MC Nylons	1.0	$\alpha = 0.022$
Nylatron® GS and Quadrant® Nylon 101 PA66	1.0	$\alpha = 0.004$
Acetron® GP POM-C	1.0	$\alpha = 0.010$

3: CALCULATE THE MAXIMUM TORQUE OR HORSEPOWER

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

$$T_{MAX} = \frac{P_d\, S_B\, F\, Y}{2P} \times C_M\, C_V\, C_S\, C_T \quad \text{(Equation 1)}$$

$$HP_{MAX} = \frac{P_d\, S_B\, F\; Y\, RPM}{126{,}000\, P} \times C_M\, C_V\, C_S\, C_T \quad \text{(Equation 2)}$$

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.

DESIGN 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. Detailed here are corrections for helical and bevel gears.

HELICAL GEARS

The Tooth Factor (Y) must be derived using a calculated Formative Number of Teeth (N_f) based on the following equation. Use this calculated number of teeth with Table 1 to determine Tooth Form Factor (Y).

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

Where:

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

In addition, a Normalized Diametral Pitch (P_N) is used which is calculated from the transverse diametral pitch (P_t) which 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:

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

P_N = Normalized Diametral Pitch
P_t = Transverse Diametral Pitch
ψ = Helix angle (degrees)

BEVEL GEARS

The Tooth Form Factor (Y) must be derived using a calculated Formative Number of Teeth (N_f) based on the following equation. Use this calculated number of teeth with **Figure 38** to determine Tooth Form Factor (Y).

$$N_f = \frac{N_B}{\cos \varnothing}$$

Where:

$\varnothing$ = 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.

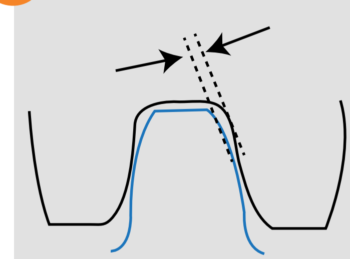
ADDITIONAL GEAR DESIGN CONCERNS:

Nylatron® Gears versus other materials – Nylatron® gears are generally superior to other engineering plastics, provided environmental factors such as temperature, humidity, and chemicals are within its useable limits. The choice of material depends on both environmental and operating running conditions.

Mating Gear Materials – For best operation, a Nylatron® gear should be mated with a metallic gear, as this arrangement promotes heat dissipation. Consider that the wear of a plastic gear is largely determined by the counterface, or opposing gear. A surface finish of 12 to 16 μ in. minimum 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 (e.g. Nylatron® PA6 with Acetron® POM-C).

Backlash – The most frequent design error when converting metal to plastic gears is not allowing sufficient backlash. Plastics have a greater thermal expansion versus metals, and thus sufficient backlash must be designed in to compensate for frictional heat and changes in ambient conditions. The suggested backlash can be calculated using **Figure 44**:

FIG 44 BACKLASH



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

Backlash = 0.100" / P
where P = Diametral Pitch

For a more stable material, like Ketron® PEEK:

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

ADDITIONAL GEAR DESIGN CONCERNS (CONT.):

Moisture Absorption – Nylatron® does absorb some moisture, and will therefore increase slightly in size. However, most gears are of such a heavy cross-section that moisture pickup is extremely slow and does not require any special consideration when designing the gear. Again, increased backlash compensates for growth due to moisture.

Tooth Form – Field experience has shown that Nylatron® gearing can operate successfully utilizing any of the standard tooth forms in use today. However, when designing new equipment, it is suggested that consideration 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® 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 will be seen under the same load.

Extended Performance – Where design permits, select the smallest tooth that will carry the load required. This will minimize heat build-up from higher teeth sliding velocities. Also, for higher torque capability, consider nylon gear blanks cast directly over machined steel inserts.

GEAR ASSEMBLY

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

- Press fit over splined and/or knurled shafts for gears transmitting low torques
- Set screws for economical 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 carrying higher torques

KEYWAYS

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

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

Where:
- A = Keyway area
- HP = Horsepower transmitted
- RPM = Gear speed (rpm's)
- r = Mean keyway radius
- S_k = Maximum permissible keyway stresses from **Figure 45**

FIG 45

MAX KEYWAY STRESS (S_K)

Materials	S_k (psi)
Nylatron® GS PA66	1,500
Nylatron® PA66	1,500
Nylatron® GSM/MC901 PA6	2,000
Acetron® POM	2,000
TIVAR® UHMW-PE	300

If the keyway size determined from the equation below is impractical and multiple keyways cannot be used, then a keyed flanged hub and check plate bolted through the gear should be used. The required number of bolts and their diameters at a particular pitch circle radius is calculated from a modified form of the equation:

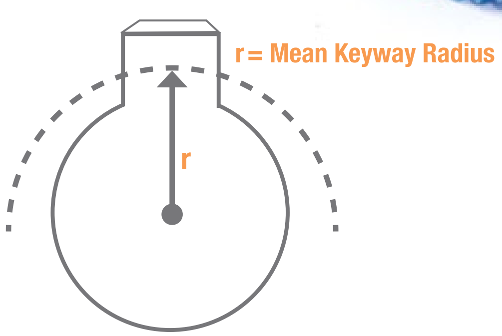
$$\text{Minimum Number of Bolts} = \frac{63{,}000\ HP}{RPM\ r_1\ A_1\ S_k}$$

Where:
- r_1 = Pitch circle radius of bolts
- A_1 = Projected area of bolts (bolt diameter x gear width in contact with bolts)

Raise fractional values to the next highest number of bolts. Do not excessively tighten bolts during assembly to avoid the risk of gear distortion or bolt shearing due to material expansion during normal running. Consequently, the use of cup washers or similar are recommended where practical, although nylon washers provide a satisfactory alternative.

TIPS

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



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, inches	____________
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 **(From Figure 38)**	____________
S_B	Bending Stress **(From Figure 39)**	____________
Alternate Material		______________________________
C_M	Material Strength Factor **(From Figure 40)**	____________
C_V	Velocity Factor **(From Figure 41)**	____________
C_S	Service Life Factor **(From Figure 42)**	____________
C_T	Temperature Factor **(From Figure 43)**	____________

T_{MAX} Maximum Torque (in lbs) $= [P_d\, S_B\, F\, Y] / 2P \quad x \quad C_M\, C_V\, C_S\, C_T$ ________

HP_{MAX} Maximum Horsepower $= [P_d\, S_B\, F\, Y\, RPM] / 126{,}000\, P \quad x \quad C_M\, C_V\, C_S\, C_T$ ________

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

ADDITIONAL GEAR
DESIGN TIPS

TIPS

- Heat dissipation and therefore performance is optimized by running plastic gears against metal gears. When running an all plastic gear system, dissimilar materials are suggested (e.g. nylon with acetal).
- Where design permits, select the smallest tooth that will carry the load required. This will minimize heat build-up from higher teeth sliding velocities.
- For higher torque capability, consider gear blanks cast directly over machined steel inserts.
- Nylatron® nylon gears are generally superior to other engineering plastics provided environmental factors such as temperature, humidity and chemicals are within its usable limits. The choice of material depends on both environmental and operational running conditions.
- The wear of a plastic gear is largely determined by the counterface, or opposing gear. In general, it is best to avoid making both driven and driving gears from similar plastics. Most plastic gears wear well against metal. A surface finish of 12-16 μ in. minimum is recommended on metal gears running against plastic gears.
- If the Nylatron® gear is to be completely immersed in water, it is suggested that you contact Quadrant at TechServices@qplas.com or via our live chat feature at quadrantplastics.com for design assistance.

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DATA, COMPLIANCE & FABRICATION

CHEMICAL
RESISTANCE DATA

KEY:

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

(Where aqueous solutions are shown, the concentration as a percentage of weight is given.)

CHEMICAL	Concentration Weight, %	Proteus® PP	Proteus® HDPE / LDPE	TIVAR® UHMW-PE	Nylatron® PA66	Nylatron® PA6	Acetron® GP POM-C, Acetron® POM-H	Ertalyte® PET-P Ertalyte® TX PET-P	Quadrant® PC 1000	Quadrant® PSU/PPSU	Duratron® U1000 PEI	Fluorosint® PTFE	Techtron® PPS	Ketron® 1000 PEEK	Duratron® PAI	Duratron® PI	Duratron® CU60 PBI
Acetaldehyde Aq.	40	B	A	B	B	B	A	A	D	*	D	A	A	A	A	*	*
Acetamide Aq.	50	A	A	*	A	A	A	*	*	*	*	A	*	A	*	*	*
Acetic Acid Aq.	10	A	A	A	C	C	C	B	B	A	A	A	A	A	A	D	B
Acetone	100	A	D	A	A	A	A	B	D	D	C	A	A	A	A	A	A
Acrylonitrile	100	A	A	*	A	A	*	B	D	D	*	A	A	A	A	*	A
Alcohols, Aliphatic	100	A	A	A	B	B	A	A	A	A	A	A	A	A	A	*	*
Allyl Chloride	100	B	B	A	C	*	*	*	*	*	*	A	*	A	*	*	*
Allyl Alcohol	100	B	B	A	*	B	*	A	B	*	*	A	A	A	A	*	*
Aluminum Chloride Aq.	10	A	A	A	A	A	*	A	A	*	*	A	A	A	A	B	*
Aluminum Sulfate Aq.	10	A	A	A	A	A	A	*	A	A	*	A	A	A	A	B	*
Ammonia Aq.	10	A	A	A	A	A	A	C	*	*	*	A	A	A	B	D	C
Ammonia Gas	100	A	A	*	C	B	D	A	D	B	*	A	*	A	C	D	C
Ammonium Carbonate Aq.	10	A	A	A	A	A	*	A	B	*	*	A	A	A	A	*	*
Ammonium Chloride Aq.	10	A	A	A	D	B	A	A	A	A	*	A	A	A	A	*	*
	37	A	A	A	D	B	A	A	A	*	*	A	A	A	A	*	*
Amyl Acetate	100	D	A	A	B	D	A	*	D	D	B	A	A	A	A	*	*
Amyl Alcohol	100	A	A	A	*	A	*	*	B	A	*	A	A	A	A	*	*
Aniline	100	A	A	A	C	C	B	A	C	*	*	A	A	A	A	D	*
Antimony Trichloride Aq.	10	A	A	A	D	D	*	*	A	D	*	A	*	A	*	*	*
Barium Chloride Aq	10	A	A	A	D	B	A	A	A	A	*	A	A	A	A	*	*
Barium Sulfate Aq.	10	B	A	A	*	A	A	*	*	*	*	A	*	A	A	*	*
Barium Sulfide Aq.	10	A	A	A	A	*	*	*	*	*	*	A	*	A	A	*	*
Benzaldehyde	100	A	A	A	A	C	A	A	D	*	D	A	B	A	A	*	*
Benzene	100	C	C	C	A	A	A	A	D	D	D	A	A	A	A	A	*
Benzenesulfonic Acid	100	B	D	A	D	*	C	*	D	*	*	A	A	D	D	*	*
Benzyl Alcohol	100	A	A	A	C	D	A	A	D	*	*	A	A	A	A	*	*
Benzoic Acid Aq.	SAT	A	A	A	C	D	*	A	D	*	*	A	A	A	*	B	*
Beverages Aq. Alcoholic	100	A	A	A	B	B	A	A	A	A	A	A	A	A	A	*	A
Beverages Aq. Carbonated	100	A	A	A	B	B	A	A	A	A	A	A	A	A	A	*	A
Bitumen	100	*	A	*	B	B	A	*	*	*	*	A	*	A	*	*	*
Bleaching Lye	10	A	A	A	C	B	C	*	*	*	*	A	*	A	A	*	*
	100	A	A	A	C	B	C	*	*	*	*	A	*	A	*	*	*
Boric Acid Aq.	10	A	A	A	D	D	*	A	A	*	*	A	A	A	*	B	*
Boron Trifluoride	100	*	A	*	D	D	D	*	*	*	*	*	*	B	C	*	*
Bromine Aq.	30	D	D	D	D	D	D	*	D	A	*	A	A	B	A	*	*
Bromine Liq.	100	D	D	D	D	D	D	*	D	*	*	*	A	D	B	*	*
Butanol	100	A	A	A	B	B	A	B	A	B	A	A	A	A	A	A	A
Butyl Acetate	100	B	D	A	A	B	A	A	D	D	B	A	A	A	A	*	*
Butyl Phthalate	100	B	A	A	D	*	*	*	*	*	*	A	B	A	A	*	*
Butylene Glycol	100	*	A	*	A	B	A	B	B	*	A	A	A	A	*	*	A
Butylamine	100	B	*	*	A	*	D	*	D	*	D	A	B	A	A	*	*
Butyric Acid Aq.	20	A	B	A	D	B	A	*	D	*	*	A	A	A	*	B	*
Butyric Acid	CONC	A	B	A	D	B	*	*	D	*	*	A	A	A	*	B	*
Butyrolactone	100	*	*	*	*	A	A	B	C	*	*	A	*	A	A	*	*
Calcium Chloride Aq.	10	A	A	A	D	A	A	A	A	A	*	A	A	A	A	B	*
Calcium Chloride (in Alcohol)	20	A	A	A	D	D	A	*	*	*	*	A	A	A	*	*	*
Calcium Hypochlorite	100	A	A	A	D	D	D	A	A	B	*	A	A	A	A	*	*
Camphor	100	C	C	*	A	A	A	*	*	*	*	A	A	A	*	*	*
Carbon Disulphide	100	D	B	D	A	A	A	*	D	*	*	A	A	A	*	A	*
Carbon Tetrachloride	100	D	B	C	A	A	A	A	D	A	A	A	A	A	A	*	A
Carbonic Acid Aq.	10	A	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	*	A	*	*	*
Catechol	100	*	*	*	*	C	*	*	*	*	*	*	*	A	*	*	*
Chloroacetic Acid Aq.	10	A	B	D	D	C	D	*	*	*	*	A	A	A	*	C	*
Chloral Hydrate	100	B	A	A	D	D	*	*	*	*	*	A	*	A	*	*	*
Chlorine Aq.	10	D	D	B	D	D	D	D	D	D	D	A	B	D	D	*	D
Chlorine Dioxide	100	C	D	B	D	D	D	*	D	D	*	D	*	D	*	*	*
Chlorine Gas	100	C	D	B	*	D	D	*	B	*	*	A	*	A	*	A	A
Chlorobenzene	100	D	D	B	A	A	A	A	D	D	*	A	A	A	A	B	*
Chloroform	100	C	D	D	A	C	C	D	D	D	D	A	A	A	A	*	A
Chlorosulfonic Acid Aq.	10	A	A	*	D	C	D	*	*	*	*	A	D	D	*	*	*
Chrome Alum Aq.	10	A	A	A	A	*	*	*	A	*	*	A	*	A	*	D	*
Chromic Acid Aq.	1	A	A	A	D	C	B	A	A	A	A	A	A	A	A	A	*
Citric Acid Aq.	10	A	A	A	B	B	A	A	A	A	A	A	A	A	A	B	A
	SAT	*	*	*	C	C	*	A	*	A	*	A	A	A	B	D	*

CHEMICAL RESISTANCE DATA (CONTINUED)

CHEMICAL	Concentration Weight, %	Proteus® PP	Proteus® HDPE / LDPE	TIVAR® UHMW-PE	Nylatron® PA66	Nylatron® PA6	Acetron® GP POM-C, Acetron® POM-H	Ertalyte® PET-P Ertalyte® TX PET-P	Quadrant® PC 1000	Quadrant® PSU/PPSU	Duratron® U1000 PEI	Fluorosint® PTFE	Techtron® PPS	Ketron® 1000 PEEK	Duratron® PAI	Duratron® PI	Duratron® CU60 PBI
Coconut Oil	100	A	A	*	A	A	*	*	*	*	*	A	A	A	*	*	*
Creosote	100	*	B	*	A	*	*	*	D	*	*	A	*	A	*	*	*
Cresols	100	D	B	*	D	D	*	*	D	D	*	A	A	A	*	C	*
Cresylic Acid	100	D	D	A	D	*	*	*	*	*	*	A	*	A	*	*	*
Cupric Chloride Aq.	10	A	A	*	D	*	A	A	A	A	*	A	A	A	B	*	*
Cupric Sulfate Aq.	0.5	*	A	*	A	B	A	A	A	*	*	A	A	A	B	*	*
	10	*	A	*	B	B	*	*	*	*	*	A	A	A	B	*	*
	SAT	*	A	*	B	B	*	*	*	*	*	A	A	A	B	*	*
Cyclohexane	100	C	A	A	A	A	A	A	B	B	A	A	A	A	A	*	A
Cyclohexanol	100	B	A	A	B	B	A	A	C	A	A	A	A	A	A	*	A
Cyclohexanone	100	D	B	A	A	A	A	A	D	D	*	A	A	A	A	*	A
Decalin	100	D	A	*	A	A	B	B	A	A	A	A	A	A	*	*	A
Detergents, Organic	100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	*	A
Dibutylphthalate	100	A	A	A	A	A	*	*	D	*	B	A	*	A	A	*	*
Dichlorodifluoro Methane	100	A	B	*	A	A	A	A	D	D	D	A	B	A	*	*	A
Dichloroethylene	100	A	C	D	A	A	B	B	D	D	D	A	*	A	A	*	A
Diethyleneglycol Aq.	90	A	A	*	A	B	A	A	A	B	*	A	*	A	A	*	*
Diesel Oil	100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Dimethyl Carbinol	100	*	*	*	A	B	*	*	*	*	*	A	*	A	*	*	*
Dimethyl Aniline	100	*	*	*	A	*	B	B	D	D	D	A	A	A	A	*	*
Dimethyl Formamide	100	A	A	A	A	A	A	A	D	D	D	A	A	A	*	D	*
Dioxane	100	C	C	*	A	A	A	A	D	D	*	A	A	A	A	*	*
Edible Oils	100	A	A	A	A	A	A	A	A	B	A	A	A	A	A	A	A
Ethanol, Denatured	96	A	A	*	B	B	A	A	A	A	A	A	A	A	A	*	A
Ether, Diethyl	100	D	B	A	A	A	A	A	A	A	A	A	A	A	A	*	A
Ethyl Acetate	100	A	B	A	A	A	A	A	D	D	B	A	A	A	A	A	*
Ethyl Butyrate	100	B	C	*	A	*	*	*	D	D	B	A	*	A	A	*	*
Ethyl Chloride	100	D	D	*	*	A	*	*	*	*	*	A	A	A	A	A	*
Ethylene Chlorohydrin	100	D	B	*	D	D	D	D	D	*	*	A	A	A	*	*	*
Ethylene Chloride	100	C	C	B	B	B	C	C	C	C	C	A	A	A	A	A	A
Ethylene Diamine	100	A	B	A	B	A	*	*	C	B	C	A	D	A	D	*	*
Ethylene Dichloride	100	B	D	C	B	D	D	D	D	*	D	A	B	A	A	A	A
Ethylene Glycol Aq.	96	A	A	A	A	B	A	A	B	A	D	A	A	A	A	B	A
Ethylene Propionate	100	*	*	*	A	*	*	*	*	*	*	A	*	A	A	*	*
Ferric Chloride Aq.	5	A	A	A	B	B	A	A	A	A	*	A	A	A	A	A	*
	10	A	A	A	B	*	*	*	A	A	*	A	A	B	A	B	*
	SAT	A	A	A	C	C	*	*	*	*	*	A	A	B	A	B	*
Ferrous Chloride Aq.	10	A	A	A	B	C	*	*	*	*	*	A	A	A	A	*	*
Fluorine	100	D	B	D	D	D	C	C	*	*	*	C	*	D	C	*	*
Fluosilicic Acid Aq.	10	A	A	A	D	C	*	*	A	*	*	B	A	A	C	*	*
Fluothane	100	*	*	*	A	A	*	*	*	*	*	A	*	A	*	*	*
Freon 12 (Arcton 12)	100	C	C	*	A	A	A	A	D	A	*	A	B	A	*	A	A
Formaldehyde Aq.	10	A	A	A	A	B	A	A	A	C	A	A	A	A	A	B	*
Formic Acid Aq.	3	A	A	A	D	D	B	B	A	*	A	A	A	B	C	A	D
	10	C	B	A	D	D	C	C	B	D	A	A	A	B	C	A	D
Fruit Juices	CONC	A	A	A	A	B	A	A	A	A	*	A	A	A	A	A	A
Furfural	100	D	D	A	A	B	*	*	*	D	*	A	A	A	B	*	*
Gasoline	100	C	A	A	A	A	A	A	D	B	B	A	A	A	A	A	A
Glycerine	100	A	A	A	A	B	A	A	A	B	*	A	A	A	A	*	*
Heptane	100	B	D	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hexane	100	B	D	A	A	A	A	A	A	B	A	A	A	A	A	*	A
Hydrobromic Acid Aq.	10	A	A	A	D	C	*	*	*	B	*	A	B	D	A	B	*
Hydrochloric Acid Aq.	0.4	A	A	A	B	B	A	A	A	A	A	A	A	A	A	B	B
	2	A	A	A	C	D	B	B	A	A	A	A	A	A	A	C	D
	10	A	A	A	D	D	C	C	A	A	A	A	B	A	A	C	D
Hydrofluoric Acid Aq.	4	A	A	A	D	C	B	B	A	A	*	C	B	D	*	B	*
Hydrogenated Vegetable Oils	100	A	A	A	A	A	A	A	*	*	*	A	A	A	A	A	A
Hydrogen Peroxide Aq.	0.5	A	A	A	D	*	A	A	A	A	A	A	A	A	*	*	A
	1	A	A	A	D	C	A	A	A	A	A	A	A	A	*	*	A
	3	A	A	A	D	C	A	A	A	A	A	A	A	A	*	*	A
Hydrogen Sulfide Aq.	SAT	A	A	A	C	C	C	C	A	*	*	A	A	A	*	B	*
Hydroquinone	100	A	A	A	B	B	*	*	*	*	*	A	*	A	*	*	*
Iodine (in Alcohol)	100	A	B	A	D	D	*	*	D	*	*	A	*	A	*	*	*
Iodine (in Pt. Iodine) Aq.	3	A	B	A	D	C	*	*	D	*	*	A	*	A	*	*	*
Iso octane	100	A	A	A	A	A	A	A	A	B	B	A	A	A	A	*	A
Isopropyl alcohol	100	A	A	A	B	B	A	A	A	B	A	A	A	A	A	A	A
Isopropyl Ether	100	B	B	A	A	A	A	A	A	C	A	A	A	A	A	*	A
Lactic Acid Aq.	10	A	A	A	A	A	A	A	A	A	*	A	A	A	A	A	*
	90	A	A	A	C	D	*	*	*	*	*	A	A	A	A	B	*
Lead Acetate Aq.	10	A	A	A	B	B	*	*	*	*	*	A	A	A	A	*	*
Lead Stearate	100	*	*	*	A	A	*	*	*	*	*	A	*	A	*	*	*
Linseed Oil	100	A	B	A	A	A	A	A	A	A	*	A	A	A	A	*	*
Lithium Bromide Aq.	50	*	A	*	D	D	A	A	*	*	*	A	*	A	*	*	*

CHEMICAL RESISTANCE DATA (CONTINUED)

CHEMICAL

	Concentration Weight, %	Proteus® PP	Proteus® HDPE / LDPE	TIVAR® UHMW-PE	Nylatron® PA66	Nylatron® PA6	Acetron® GP POM-C, Acetron® POM-H	Ertalyte® PET-P Ertalyte® TX PET-P	Quadrant® PC 1000	Quadrant® PSU/PPSU	Duratron® U1000 PEI	Fluorosint® PTFE	Techtron® PPS	Ketron® 1000 PEEK	Duratron® PAI	Duratron® PI	Duratron® CU60 PBI
Lubricating Oils (Petroleum)		B	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Magnesium Chloride Aq.	10	A	A	*	A	A	A	A	A	A	*	A	A	A	A	*	*
Magnesium Hydroxide Aq.	10	A	A	A	A	A	A	B	*	*	*	A	A	A	D	*	*
Magnesium Sulfite Aq.	10	A	A	A	A	A	A	*	*	*	*	A	A	A	A	*	*
Maleic Acid Aq.	CONC	A	B	A	*	C	*	*	*	*	*	A	*	A	*	*	*
Malonic Acid Aq.	CONC	*	*	*	*	C	*	*	*	B	*	A	*	A	*	*	*
Manganese Sulfate Aq.	10	A	A	*	A	A	A	A	A	*	*	A	*	A	*	*	*
Mercuric Chloride Aq.	6	A	A	*	C	D	B	*	A	*	*	A	*	A	*	*	*
Mercury	100	A	A	A	A	A	A	A	A	*	*	A	A	A	*	*	*
Methanol	100	A	A	A	A	B	A	A	B	B	A	A	A	A	*	*	A
Methyl Acetate	100	B	C	A	A	A	A	A	D	*	B	A	A	A	A		*
Methyl Ethyl Ketone	100	A	B	B	A	A	B	A	D	B	D	B	B	A	A		A
Methylpyrrolidone	100	*	A	*	A	A	*	*	*	D	*	A	A	A	*	C	*
Methylene Chloride	100	C	C	B	B	B	C	D	D	D	C	A	A	A	A	C	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	*	A
Mineral Oils	100	A	A	A	A	A	A	*	A	A	A	A	A	A	A	A	A
Naphthalene	100	A	A	A	A	A	A	A	D	D	D	A	A	A	*	*	
Nickel Sulfate Aq.	10	A	A	A	A	A	*	*	A	*	*	A	A	A	*	*	
Nicotine	100	A	A	*	D	D	*	*	*	*	*	*	*	A	*	*	
Nitric Acid Aq.	0.1	A	A	A	C	C	D	B	A	A	A	A	A	A	A	*	B
	10	A	A	A	D	D	D	C	A	C	A	A	B	A	A	D	C
Nitrobenzene	100	A	A	A	C	B	B	D	D	D	D	A	A	A	A	C	*
Nitromethane	100	A	A	A	A	B	*	B	A	D	*	A	A	A	A	*	*
Oleic Acid	100	B	B	A	A	A	A	A	A	A	*	A	A	A	*	*	*
Oxalic Acid Aq.	10	A	A	A	C	B	C	*	A	A	*	A	A	A	*	*	*
Ozone	100	D	*	C	C	C	C	C	D	A	*	A	C	A	C	A	*
Paraffin	100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	*	A
Perchloroethylene	100	C	C	B	B	B	B	A	C	*	C	A	A	A	A	A	A
Perchloric Acid Aq.	10	C	C	A	D	C	C	A	*	*	*	A	*	A	*	*	
Petroleum Ether	100	A	C	B	A	A	A	*	A	*	*	A	A	A	A	*	
Phenol Aq.	6	B	B	B	D	D	D	A	D	*	*	A	*	B	*	*	A
	75	B	B	B	D	D	D	C	D	D	D	A	*	D	*	*	A
Phenol (Molten)	100	C	B	B	D	D	D	C	D	D	D	A	*	B	*	*	
Phosphoric Acid Aq.	0.3	A	A	A	*	B	C	A	A	A	A	A	A	A	A	*	B
	3	A	A	A	D	C	C	A	A	A	A	A	A	A	A	*	C
	10	A	A	A	D	D	D	B	A	A	A	A	A	A	A	*	C
Phthalic Acid Aq.	SAT	C	A	A	B	B	A	*	*	*	*	A	*	A	*	*	*
Phthalic Dioctyl	100	*	*	*	A	A	*	*	*	*	*	A	A	A	*	*	*
Potassium Acetate Aq.	50	A	A	A	A	A	A	*	*	*	*	A	*	A	A	*	*
Potassium Bicarbonate Aq.	60	A	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	A	*	*
Potassium Carbonate Aq.	60	A	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	A	*	*
Potassium Dichromate Aq.	5	A	A	A	C	B	A	A	A	*	*	A	A	A	A	*	*
Potassium Ferricyanide Aq.	30	A	A	A	A	B	*	A	*	*	*	A	*	A	*	*	*
Potassium Ferrocyanide Aq.	30	A	A	A	A	B	*	*	*	*	*	A	*	A	*	*	*
Potassium Hydroxide Aq.	10	A	A	A	C	A	A	C	C	A	A	B	A	A	D	D	*
	50	A	A	A	C	A	D	C	D	B	*	C	A	A	D	*	*
Potassium Nitrate Aq.	10	A	A	A	A	A	B	A	A	A	*	A	A	A	*	*	*
Potassium Permanganate Aq.	1	B	A	A	D	C	A	A	A	A	*	A	A	A	A	*	*
Potassium Sulfite Aq.	CONC	A	A	A	A	A	*	*	*	*	*	A	A	A	A	*	*
Potassium Sulfite Aq.	90	A	A	A	A	*	*	*	*	*	*	A	*	A	A	*	*
Propane Gas	100	A	A	A	A	A	A	A	A	*	*	A	A	A	*	*	A
Pyridine	100	A	C	A	A	A	B	*	D	D	*	A	*	A	D	A	*
Resorcinol	100	A	B	*	D	D	*	*	*	*	*	A	*	A	*	*	*
Salicylic Acid	100	A	B	A	A	A	D	A	*	*	*	A	*	A	*	*	*
Silicone Fluids	100	A	A	A	A	A	A	A	A	*	*	A	A	A	A	B	A
Silver Nitrate	100	B	B	A	A	A	A	A	A	*	*	A	A	A	A	*	*
Soap Solutions	100	A	A	B	A	A	A	A	A	A	A	A	A	A	A	*	A
Sodium (Molten)	100	*	*	*	*	*	C	*	*	*	*	B	*	D	*	*	*
Sodium Acetate Aq.	60	A	A	A	A	B	A	A	*	*	*	A	A	A	A	*	*
Sodium Benzoate Aq.	10	A	A	A	A	*	A	A	*	*	*	A	*	A	A	*	*
Sodium Bicarbonate Aq.	50	A	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	A	*	*
Sodium Bromide Aq.	10	A	A	*	A	B	A	A	*	*	*	A	A	A	A	*	*
Sodium Carbonate Aq.	20	A	A	A	A	B	A	A	*	*	*	A	A	A	A	*	A
	50	A	A	A	A	*	A	*	*	*	*	A	A	A	A	*	*
Sodium Chlorate Aq.	10	A	A	A	A	B	A	*	A	*	*	A	A	A	A	*	*
Sodium Chloride Aq.	10	A	A	A	A	B	A	A	A	A	*	A	A	A	A	*	*
	90	A	A	A	A	B	A	A	A	*	*	A	A	A	A	*	*
Sodium Cyanide Aq.	10	A	A	A	A	*	A	*	A	*	*	A	A	A	*		*
Sodium Hydroxide Aq.	10	B	B	A	C	D	D	C	C	A	A	B	A	A	D	*	B

CHEMICAL RESISTANCE DATA

CHEMICAL RESISTANCE DATA (CONTINUED)

CHEMICAL	Concentration Weight, %	Proteus® PP	Proteus® HDPE / LDPE	TIVAR® UHMW-PE	Nylatron® PA66	Nylatron® PA6	Acetron® GP POM-C, Acetron® POM-H	Ertalyte® PET-P Ertalyte® TX PET-P	Quadrant® PC 1000	Quadrant® PSU/PPSU	Duratron® U1000 PEI	Fluorosint® PTFE	Techtron® PPS	Ketron® 1000 PEEK	Duratron® PAI	Duratron® PI	Duratron® CU60 PBI
Sodium Hydroxide Aq.	50	B	B	A	D	D	D	C	D	C	D	C	B	A	D	*	C
Sodium Hypochlorite 15% Cl (Chlorine Bleach)	100	B	B	A	D	C	D	A	A	A	*	A	A	A	A	*	B
Sodium Nitrate Aq.	50	A	A	A	A	A	A	A	C	*	*	A	A	A	*	*	*
Sodium Perborate Aq.	10	A	A	A	B	*	A	*	*	*	*	A	*	A	*	*	*
Sodium Phosphate Aq.	90	A	A	A	A	*	*	*	*	*	*	A	*	A	*	*	*
Sodium Silicate	100	A	A	A	A	A	*	A	A	B	*	A	A	A	*	*	*
Sodium Sulfate Aq.	90	A	A	A	A	A	*	A	A	*	*	A	A	A	A	*	*
Sodium Sulfide Aq.	90	A	A	A	A	*	*	B	*	*	*	A	A	A	A	*	*
Sodium Thiosulfate Aq.	10	A	A	A	A	A	A	A	A	A	*	A	A	A	*	*	*
Stannic Chloride Aq.	10	A	A	*	D	*	D	*	A	A	A	A	A	A	*	*	A
Stannic Sulfate Aq.	10	*	*	*	D	C	*	*	*	*	*	A	A	A	*	*	*
Stearic Acid	100	B	A	A	A	A	A	*	*	*	*	A	*	A	*	*	*
Styrene (Monomer)	100	B	B	B	A	A	A	C	D	*	*	A	A	A	*	*	*
Sulfur	100	A	A	A	A	A	A	A	A	*	*	A	*	A	*	*	*
Sulfur Dioxide (Dry Gas)	100	B	A	A	C	A	D	B	A	*	*	A	A	A	A	*	*
Sulfuric Acid Aq.	2	A	A	A	C	C	D	A	A	A	A	A	A	A	A	B	B
	5	A	A	A	D	D	D	A	A	A	A	A	A	A	A	B	B
Sulfuric Acid Conc.	96	B	B	B	D	D	D	C	D	D	D	A	B	D	*	C	*
Sulfurous Acid Aq.	10	A	A	A	A	*	D	*	A	A	A	A	A	A	*	*	B
Tallow	100	A	B	A	A	A	A	*	A	A	A	A	A	A	A	*	A
Tar	100	A	A	A	B	B	A	*	*	*	*	A	A	A	A	*	*
Tartaric Acid Aq.	10	A	A	A	B	A	A	*	A	*	*	A	A	A	*	*	*
Tetrachlorethylene	100	C	B	B	A	C	A	B	D	D	A	B	*	A	*	*	*
Tetrahydrofuran	100	D	D	B	A	A	B	A	D	*	*	A	A	A	A	*	A
Tetralin	100	C	C	*	A	A	A	A	*	*	*	A	*	A	*	*	*
Thionyl Chloride	100	C	C	C	D	C	B	*	*	*	*	A	*	A	*	*	*
Thiophene	100	B	C	B	A	*	*	*	D	*	*	A	*	A	*	*	*
Toluene	100	B	B	B	A	A	B	A	D	D	D	A	A	A	A	*	A
Transformer Oil	100	B	B	B	A	A	A	*	A	A	*	A	A	A	A	A	*
Trichlorethylene	100	D	D	D	B	B	D	B	D	D	D	A	A	A	A	*	*
Triethanolamine	100	D	D	A	A	A	A	B	D	C	D	A	A	A	D	*	*
Turpentine	100	C	D	B	A	A	A	*	B	C	*	A	A	A	A	*	*
Trisodium Phosphate Aq.	95	A	A	A	*	B	A	A	A	*	*	A	A	A	*	*	*
Urea	100	A	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	*	A
Vegetable Oils	100	B	B	A	A	A	A	A	A	A	A	A	A	A	A	*	A
Vinegar	100	A	A	A	C	C	B	A	A	*	A	A	A	A	A	*	A
Vinyl Chloride	100	A	A	A	A	A	*	*	*	*	*	A	A	A	*	*	*
Water	100	A	A	A	A	A	A	A	A	A	A	A	A	A	A	*	A
Water (Mildly Chlorinated)	<10	A	A	A	A	A	C	A	A	A	A	A	A	A	A	A	A
Wax (Molten)	100	B	A	A	A	A	A	A	A	A	A	A	A	A	A	*	A
White Spirit	100	A	A	A	A	A	A	*	*	*	*	A	A	A	*	*	*
Wines & Spirits	100	A	A	A	B	B	A	A	A	*	A	A	A	A	A	*	A
Xylene	100	B	C	C	A	A	A	A	D	D	C	A	A	A	A	*	A
Xylenol	100	*	*	*	D	D	A	*	D	D	B	A	*	A	A	*	A
Zinc Chloride Aq.	10	A	A	A	C	B	D	A	A	A	A	A	A	A	*	*	*
Zinc Oxide	100	A	A	*	A	A	C	*	*	*	*	A	A	A	*	*	*
Zinc Sulfate Aq.	10	A	A	A	A	*	C	*	A	*	*	A	A	A	*	*	*

The previous chemicals and fluids are known to attack or be compatible with the Quadrant materials given. Chemical effects are at room temperature. Use this chart as a general guide only. Contact Quadrant at TechServices@qplas.com or via our live chat feature at quadrantplastics.com 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. Quadrant recommends actual testing which represents the only method for evaluating suitability for use.

PRODUCT COMPLIANCE

Quadrant materials are commonly used in processing equipment and products requiring various types of regulatory agency compliance. We routinely work with these agencies to assure the widest variety of our products are recognized as being compliant – giving designers the broadest selection of candidate materials. A brief overview of the six most common agencies is provided below. Additionally, we have specific product listings with Underwriters Laboratories (UL), American Bureau of Shipping (ABS), ASTM and many global manufacturers. Quadrant can work with customers to develop unique product / quality specifications requiring testing, inspection and certifications. Such requests should be directed to TechServices@qplas.com.

FDA

FDA (Food & Drug Administration) takes responsibility for determining whether and how manufactured materials may be used in contact with food products. Definitions for proper use are found in a series of regulations published annually 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. Plastic materials are approved per material for a group of related applications, such as Acetron® GP POM-C acetal (material) for meat and poultry processing (application).

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. Materials are tested for compliance by the material supplier. Supporting documentation must be available as required by a food inspector.

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 which we frequently encounter and to which some of our products have been tested, are:

51 Plastics in Food Equipment

61 Drinking Water System Components – Health Effects

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 regulation requires a declaration of compliance, raw materials which meet EU 10/211 positive list for monomers and additives, and a quality system that meets GMP EC 2023/2006 requirements.

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 device manufacturers.

Quadrant stock shapes are not suitable for permanent implant.

Quadrant produces a line of Life Science Grade (LSG) materials for which the stock shape has been tested to USP Class VI and ISO 10993 guidelines. These products are appropriate for applications requiring implant for up to 24 hours.

PRODUCT COMPLIANCE

MATERIAL	PRODUCT FAMILY	COLOR	FDA / USDA	NSF	3A-DAIRY	CFIA	USP CLASS VI	TYPICAL APPLICATIONS Structural or Wear
Acetron® AF Blend PTFE	Acetal	Brown	NO	NO	NO	NO	NO	Bearing & Wear
Acetron® GP POM-C	Acetal	Nat / Blk	YES	* STD 51 & 61 (Natural Only)	YES	YES	NO	Both
Acetron® POM-H	Acetal	Natural	YES	* STD 61 & 51	NO	YES	NO	Both
Duratron® U1000 PEI	PEI	Natural	YES	* STD 51	NO	NO	YES	Structural
Duratron® U1000 PEI	PEI	Black	YES	NO	NO	YES	YES	Structural
Ertalyte® PET–P	Polyester	Natural	YES	NO	YES	YES	NO	Both
Ertalyte® PET–P	Polyester	Black	YES	NO	NO	NO	NO	Both
Ertaltye® TX PET-P	Polyester	Grey	YES	NO	NO	NO	NO	Both
Fluorosint® HPV PTFE	PTFE	Natural	YES	NO	NO	NO	NO	Bearing & Wear
Fluorosint® 207 PTFE	PTFE	Natural	YES	NO	NO	NO	NO	Bearing & Wear
Fluorosint® 500 PTFE	PTFE	Natural	NO	NO	NO	NO	NO	Both
Ketron® 1000 PEEK	PEEK	Nat / Blk	YES	NO	YES	NO	YES	Both
Nylatron® GS PA66	Nylon 66	Black-Grey	NO	NO	NO	NO	NO	Bearing & Wear
Nylatron® GSM PA6	Nylon 6	Black-Grey	NO	NO	NO	NO	NO	Bearing & Wear
Nylatron® GSM Blue PA6	Nylon 6	Dark Blue	NO	NO	NO	NO	NO	Bearing & Wear
Nylatron® LFG PA6	Nylon 6	Natural	YES	NO	YES	NO	NO	Bearing & Wear
Nylatron® MC 901 PA6	Nylon 6	Blue	NO	NO	NO	NO	NO	Both
Nylatron® MC 907 PA6	Nylon 6	Natural	YES	NO	YES	NO	NO	Both
Nylatron® NSM PA6	Nylon 6	Grey	NO	NO	NO	NO	NO	Bearing & Wear
Proteus® CoPolymer Polypropylene	CO-PP	Natural	YES	NO	NO	NO	NO	Structural
Proteus® HDPE	HDPE	Natural	YES	NO	NO	NO	NO	Both
Proteus® Homopolymer Polypropylene	PP	Natural	YES	NO	YES	NO	NO	Structural
Proteus® LDPE	LDPE	Natural	YES	NO	NO	NO	NO	Structural
Proteus® White Polypropylene	PP	White	YES	NO	NO	NO	NO	Structural
Quadrant® CPVC	CPVC	Grey	NO	* STD14 & 61	NO	NO	NO	Structural
Quadrant® Nylon 101 PA66	Nylon 66	Natural	YES	* STD 61	YES	NO	NO	Both
Quadrant® PC 1000	PC	Natural	NO	NO	NO	NO	NO	Structural
Quadrant® PPO	PPO	Black	NO	NO	NO	NO	NO	Structural
Quadrant® PPSU	PPSU	Nat / Blk	YES	NO	NO	NO	YES	Structural
Quadrant® PSU	PSU	Natural	YES	* STD 61	YES	NO	YES	Structural
Sanalite® Cutting Board-HDPE or PP	HDPE PP	Natural	YES	(APPROVED) STD 51	NO	YES	NO	Structural
Techtron® 1000 PPS	PPS	Natural	YES	NO	YES	NO	NO	Structural
TIVAR® 1000 UHMW-PE	UHMW-PE	Natural	YES	NO	YES	YES	NO	Bearing & Wear
TIVAR® H.O.T. UHMW-PE	UHMW-PE	White	YES	NO	YES	NO	NO	Bearing & Wear
TIVAR® Oil-Filled UHMW-PE	UHMW-PE	Brown/Grey	YES	NO	NO	NO	NO	Bearing & Wear
TIVAR® CleanStat UHMW-PE	UHMW-PE	Black	YES	NO	YES	NO	NO	Bearing & Wear
TIVAR® HPV UHMW-PE	UHMW-PE	Blue	YES	NO	NO	NO	NO	Bearing & Wear

* NSF COMPLIANT - Ask Quadrant to help submit your project for NSF review.

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 **Page 72** should be used to correct undesirable surface finishes or material responses during machining operations. All Quadrant materials are stress relieved to ensure the highest degree of machinability and dimensional stability. However, the relative softness of plastics (compared to metals) generally results in greater 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.

WHEN MACHINING QUADRANT STOCK SHAPES, REMEMBER...

- 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, you may wish 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® CU60 PBI.
- Use adequate chip clearance to prevent clogging
- Adequately support the material to restrict deflection away from the cutting tool

COOLANTS

Coolants are generally not required for most machining 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 Quadrant® PC 1000, Quadrant® PSU, Duratron® U1000 PEI, and Quadrant® PPSU.

TURNING

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.

TIPS

- **Coolants are strongly suggested during drilling operations, especially with notch sensitive materials such as Ertalyte® PET-P, 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).**

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" 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.

LARGE DIAMETER HOLES (1" 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.

It is generally best to drill a pilot hole (maximum 1/2" diameter) using 600 to 1,000 rpm and a positive feed of 0.005" to 0.015" per revolution. Avoid hand feeding because of the drill grabbing which can result in microcracks forming. Secondary drilling at 400 to 500 rpm at 0.008" to 0.020" per revolution is required to expand the hole to larger diameters.

A two step process using both drilling and boring can be used on notch sensitive materials such as Ertalyte® PET–P and glass reinforced materials. This minimizes heat build-up and reduces the risk of cracking.

1. Drill a 1" diameter hole using an insert drill at 500 to 800 rpm with a feed rate of 0.005" to 0.015" per revolution.
2. Bore the hole to final dimensions using a boring bar with carbide insert with 0.015" to 0.030" radii at 500 to 1,000 rpm and a feed rate of 0.005" to 0.010" per revolution.

TIPS

Typical tolerances achievable for advanced polymers are 0.1 to 0.2%.

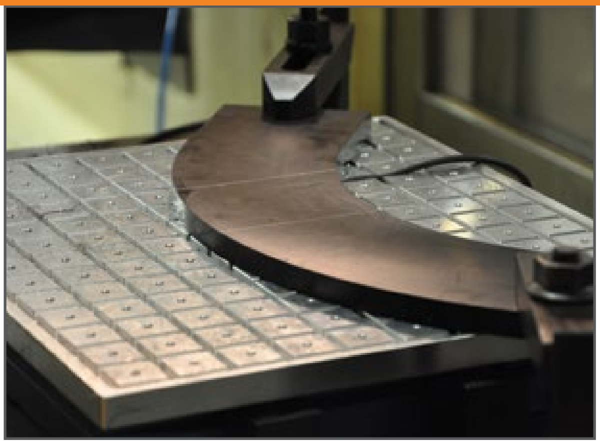
FIG 46 TURNING & DRILLING OPERATIONS

Material	Relative Machinability (1 to 10 1= easiest)	Turning			Drilling**	
		Depth of Cut	Speed Feet/Min.	Feed In./Rev.	Nominal Hole Diameter	Feed In./Rev.
TIVAR® UHMW-PE Nylatron® PA, Acetron® 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, Quadrant® PC 1000, Quadrant® PSU, Quadrant® PPSU & Duratron® PEI based materials	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
Ertalyte® PET-P 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 Quadrant at TechServices@qplas.com or via our live chat feature at quadrantplastics.com.
** The recommended speed for drilling operations is 150 to 200 ft./min.

TIPS

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.



THREADING AND TAPPING

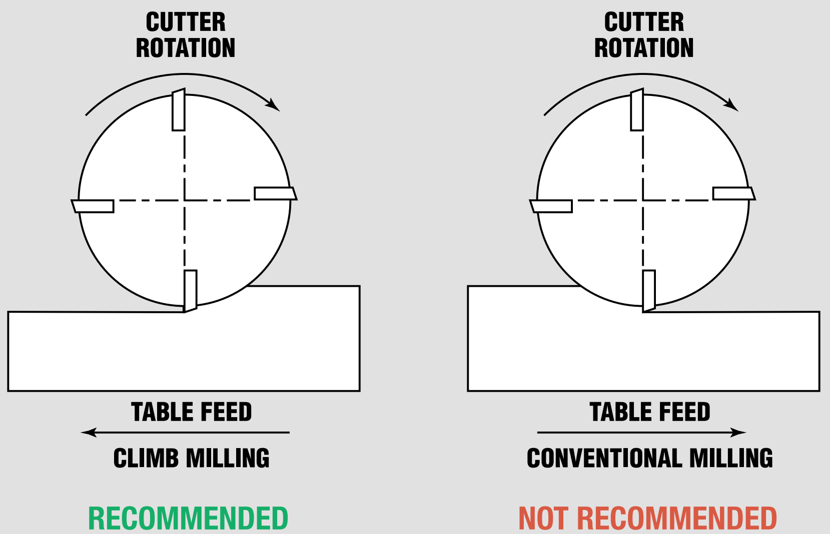
Threading should be done by single point using a carbide insert and taking four to five 0.001" passes at the end. Coolant usage is suggested. For tapping, use the specified drill with a two flute coated tap. Remember to keep the tap clean of chip build-up. Use of a coolant during tapping is also suggested.

TIPS

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-torquing.

MILLING

Sufficient fixturing allows fast table travel and high spindle speeds when end milling plastics. When face milling, use positive geometry cutter bodies. Climb milling is recommended over conventional milling. To ensure finished part flatness, always machine a plate flat to start. Do not force a plate flat with a vice or vacuum.



CORRECT
Neutral to slightly positive tool geometry

INCORRECT
High positive or negative tool geometry

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" with adequate horsepower. Saw blades should be selected based upon material thickness and surface finish desired. Less teeth per inch is typically recommended to generate less heat.

TIPS

- **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" thickness.**
- **Tungsten carbide blades wear well and provide optimum surface finishes.**

FIG 47 MILLING & SAWING

	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® 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 " Butress "	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, Quadrant® PC 1000, Quadrant® PSU, Quadrant® PPSU, & Duratron® PEI based materials	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 " Butress "	10-14 6 3 3	4,000 3,500 3,000 2,500
	1/4",1/2" 3/4"	0.050	3,000 – 4,500	10 - 15	0.060	2,500-4,500	10 - 15				
Ertalyte® PET-P 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 " Butress "	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 " Butress "	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 " Butress "	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 " Butress "	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	< 0.5" 0.5"-1.0" 1" - 3" >3.0"	Precision " Butress "	10-14 6-8 3 3	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	< 0.375 -1" 1" - 2"	Precision Butress	10 10	3,000 1,500

* For the Fluorosint® MT-01 data, contact Quadrant at TechServices@qplas.com or via our live chat feature at quadrantplastics.com.

TIPS

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.

FIG 48 TROUBLE SHOOTING

DRILLING	
Drilling	**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 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
Oversize holes	1. Drill ground off-center 2. Web too thick 3. Insufficient clearance 4. Feed rate too heavy 5. Point angle too great
Undersize 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. Feed too light of drill 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
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 cut-off point enough 2. Tool dull 3. Feed too heavy
Burrs on outside diameter	1. No chamfer before cut-off diameter diameter 2. Dull tool
TURNING & BORING	
Melted surface	1. Tool dull 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 after machining to meet dimensional or performance requirements.

Most Quadrant 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.

However, machined-in stress can result in poor tolerance control and premature part failure. 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 of the stock shape.**

ROUGHING - RECOMMENDED ANNEALING TECHNIQUE

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

When machining with a mill, rough the parts leaving ~ 0.030” to 0.060” per side. For rounds, rough the diameter oversized by ~ 0.125”. 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. Also, 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 machine oven annealing may provide additional performance benefits in a few rare cases. Also, 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 be used for the following rare cases.

- **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**
  Quadrant® PC, Quadrant® PSU, Duratron® PEI, like many amorphous (transparent) plastics may be annealed to minimize stress cracking. Duratron® PAI also benefits from such a cycle.

FIG 49 POST MACHINING AIR ANNEALING GUIDELINES*

Material	Heat Up*	Hold*	Cool Down*	Environment
Nylatron® PA6	4 hours to 300°F	30 minutes per 1/4” thickness	50°F per hour	Nitrogen
Nylatron® PA66	4 hours to 350°F	30 minutes per 1/4” thickness	50°F per hour	Nitrogen
Ertalyte® PET–P Grades	4 hours to 350°F	30 minutes per 1/4” thickness	50°F per hour	Nitrogen
Acetron® GP POM-C	4 hours to 310°F	30 minutes per 1/4” thickness	50°F per hour	Nitrogen or Air
Acetron® POM-H	4 hours to 320°F	30 minutes per 1/4” thickness	50°F per hour	Nitrogen or Air
Quadrant® PC 1000	4 hours to 275°F	30 minutes per 1/4” thickness	50°F per hour	Air
Quadrant® PSU	4 hours to 330°F	30 minutes per 1/4” thickness	50°F per hour	Air
Quadrant® PPSU, Duratron® PEI	4 hours to 390°F	30 minutes per 1/4” thickness	50°F per hour	Nitrogen or Air
Techtron® PPS	4 hours to 350°F	30 minutes per 1/4” thickness	50°F per hour	Nitrogen or Air
Ketron® PEEK (ramp up)	4 hours to 300°F 4 hours to 375°F	60 minutes per 1/4” thickness 60 minutes per 1/4” thickness	50°F per hour	Nitrogen or Air
Duratron® PAI (ramp up)	4 hours to 300°F 4 hours to 420°F 4 hours to 470°F 4 hours to 500°F	1 day 1 day 1 day 3 to 10 days	50°F per hour	Air
Duratron® PI (ramp up)	4 hours to 300°F 4 hours to 450°F 4 hours to 600°F	60 minutes per 1/4” thickness 60 minutes per 1/4” thickness	50°F per hour	Air

Finish machining of critical dimensions should be performed after annealing.

* Temperatures +/- 10°F and times within 10 minutes

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.

GLOBAL CAPABILITIES

AMERICAS

- Engineering plastic shape production:
  - Extrusion
  - Compression Molding
  - Casting
- Plastics machining shop for NPI support & process optimization

EUROPE

- Full engineering plastic shape production
- Four state-of-the-art machining centers for part production
- Fluoropolymer plate & sheet production
- Injection molding

ASIA

- Local customer service & warehousing in:
  - China
  - South Korea & Japan
  - Singapore & SEA
- Manufacturing in Japan, Korea & China
- Technical & engineering support

KEY INDUSTRIES

- Aerospace
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- Alternative Energy
- Medical / Life Sciences
- Automotive
- Semiconductor / Electronics
- Chemical / Oil & Gas Processing
- Transportation
- Food Processing & Packaging
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