Quadrant Engineering Plastic Products

global leader in engineering plastics for machining

Design And Fabrication Reference Guide

QUADRANT

PLASTICS OVERVIEW

QUADRANT

The World's Leading Manufacturer of Plastic Stock Shapes.

The Quadrant Design & Fabrication Reference Guide was developed to assist materials specifiers, designers, and fabricators in the use of engineering plastics. Although the content of this guide is primarily intended to facilitate the use of engineering plastic stock shapes for machined parts, much of the information presented here may be applied to plastic parts processed via alternative methods such as injection molding.

This reference is divided into four sections. The first section provides an overview of plastics as engineering materials, basic design considerations, and an introduction to commonly used physical properties.

The material selection section is a step-by-step guide to selecting plastics based upon specific application requirements, including the need for chemical resistance and FDA, or other regulatory agency approval. The component design section contains guidelines for designing plastic bearings, wheels, sheaves and gears. The final section discusses fabrication guidelines to facilitate machining of plastic stock shapes, and answer frequently asked fabrication questions.

This brochure does not include detailed Quadrant product descriptions or physical property data. That information is contained in our *Product and Applications Guide, (LIT.Quadrant)* which may be requested by contacting Quadrant at 1-800-366-0300, or on our website at *www.quadrantepp.com.*

Plastics increasingly replace traditional materials such as bronze, stainless steel, cast iron and ceramics. They are chosen for improved performance and cost reduction. Plastics can:

- **Reduce Weight**
- **Eliminate Corrosion**
- **Improve Wear Performance in Unlubricated Conditions**
- **Reduce Noise**
- **Increase Part Life**
- **Insulate & Isolate, Both Thermally and Electrically**

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

Typical applications for engineering plastics range from semiconductor processing equipment components to heavy equipment wear parts, to food processing industry components.

Machinable plastic stock shapes (sheet, rod, and tubular bar) are now available in more than 50 grades, 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.

The Materials Positioning Triangle shown on page 4 (Figure 1) includes the most common thermoplastics grouped according to general performance characteristics. Materials within a specific group have similar general characteristics as defined by the group positioning statement. The materials are ranked according to heat resistance.

Table 1 : **Typical Properties of Engineering Materials**

Property	Units	Nylon	Torlon* PAI	Bronze	Steel (A36)	Aluminum
Density	g/cm^3	1.15	1.41	8.80	7.84	2.70
Tensile Strength	psi	12,000	18,000	22,000	36,000	30,000
Modulus of Elasticity	psi	0.4 x 10^6	0.6 x 10^6	16 x 10^6	30 x 10^6	10 x 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 x 10^{-6}	14 x 10^{-6}	10 x 10^{-6}	6.3 x 10^{-6}	12 x 10^{-6}

Dark blue columns are plastics.

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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.

>> CONTINUED

PLASTICS OVERVIEW

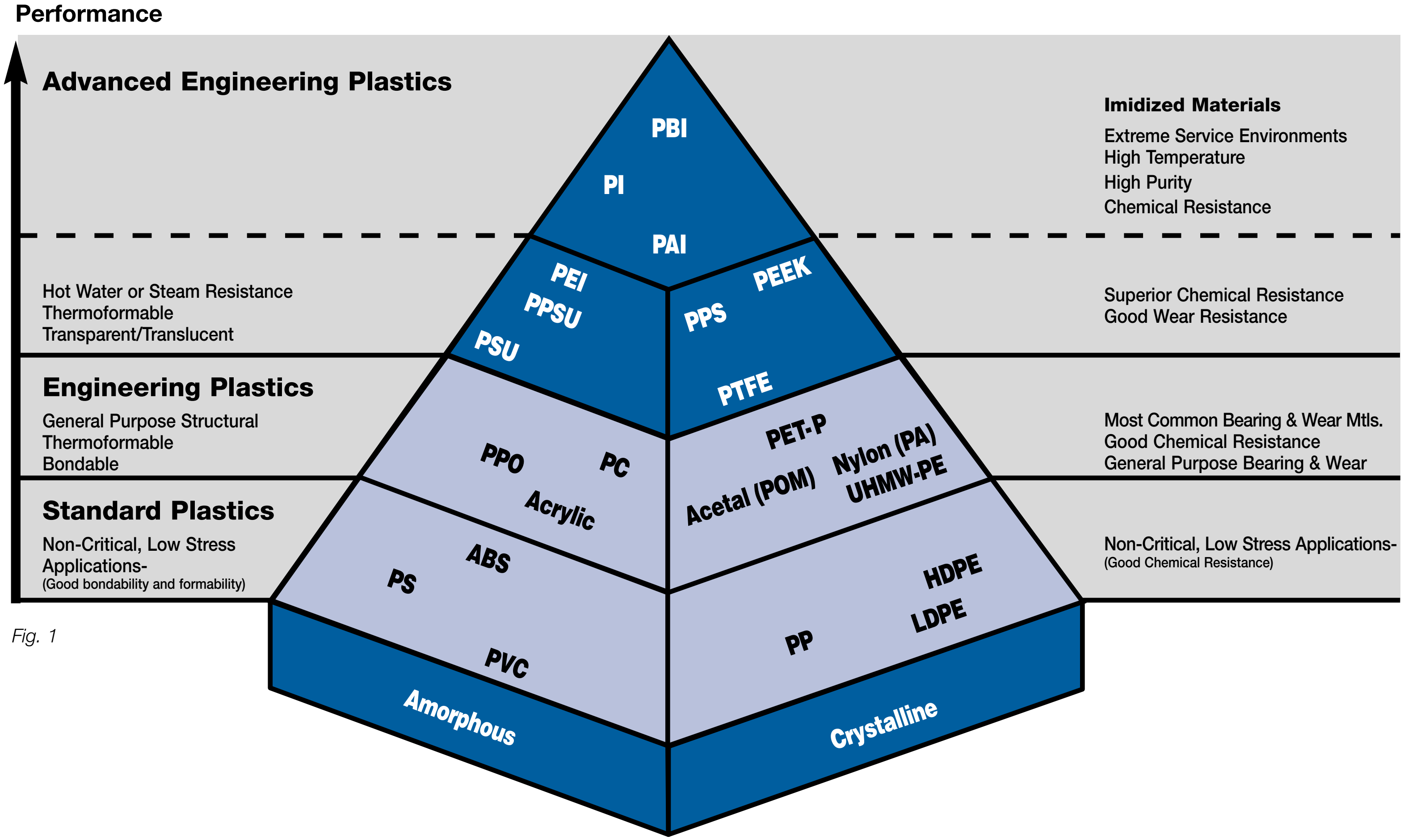


Fig. 1

	Performance Family	Material	Tradename	Performance Profile
Advanced Engineering Plastics	Imidized	Polybenzimidazole (PBI)	Celazole* PBI	Highest heat resistance and strength
		Polyamide-imide (PAI)	Torlon* PAI	Highest strength to 500°F, dimensionally stable
	Crystalline High Performance	Polyetheretherketone (PEEK)	Ketron® PEEK	Chemical, wear and heat resistance
		Polyphenylene sulfide (PPS)	Techtron® or Ryton* PPS	Chemical resistance, strength, and wear resistance
		Filled PTFE	Fluorosint®	Chemical resistance and dimensional stability
		Polytetrafluoroethylene (PTFE)	Teflon* PTFE	Excellent dielectric properties, chemical resistance
	Amorphous High Performance	Polyetherimide (PEI)	Ultem* PEI	High strength and heat resistance to 400°F
		Polyphenylsulfone (PPSU)	Radel* R PPSU	High strength, steam and impact resistance
		Polysulfone (PSU)	PSU 1000 Polysulfone	High strength and heat resistance to 300°F
Engineering Plastics	Crystalline Engineering	Polyethylene Terephthalate (PET-P)	Ertalyte® PET–P	Dimensional stability and wear resistance
		Polyoxymethylene (POM) - Acetal	Acetron® or Delrin* Acetal	Machinability and dimensional stability
		Polyamide (PA) - Nylon	MC® or Nylatron®	Toughness, wear resistance and strength
		Ultra high mole. wt. Polyethylene (UHMW-PE)		Toughness and abrasion resistance
	Amorphous Engineering	Polycarbonate (PC)	PC 1000 Polycarbonate	Impact and heat resistance to 250°F
		Polyphenylene oxide, modified (PPO)	Noryl*	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)		Light weight, easily processed
		Polypropylene (PP)		Chemical resistance, medium strength
		High Density Polyethylene (HDPE)		Chemical resistance, low cost
		Low Density Polyethylene (LDPE)		Chemical resistance, formability, low cost

Table 2

DESIGNING WITH PLASTICS

Designing machined plastic components follows the approach used for metals but requires special consideration of:

- **Elastic Behavior**
- **Impact Strength**
- **Thermal Properties**
- **Dimensional Stability**

ELASTIC BEHAVIOR

The stress/strain behavior of a plastic differs from that of a metal in several respects as can be seen in Figure 2.

- **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 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.

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

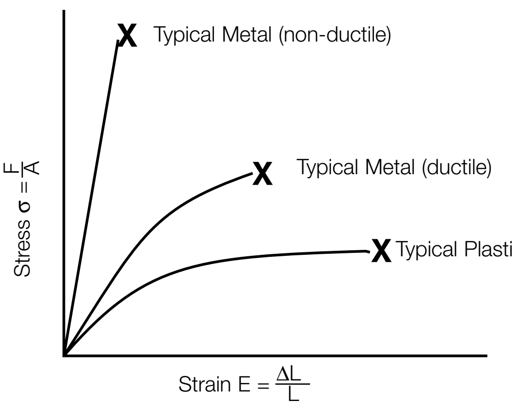
THERMAL PROPERTIES

Two important thermal properties for designing plastic components are:

- **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.

Fig. 2 - **STRESS VS. STRAIN**



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 8% water (by weight, when submerged). This can result in a dimensional change of up to 3%. Plastics' inherently lower modulus of elasticity can also contribute to dimensional change including part distortion during and after machining.

The following five pages provide an introduction to common physical properties and terms used to characterize materials and design plastic components. Physical property values for specific materials can be found in our *Products and Applications Guide (LIT.Quadrant).*

>> MECHANICAL

PROPERTY BASICS

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 3.

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.

DESIGN TIP

Tensile strength and elongation are both important when toughness is required. A material with high tensile and high elongation such as Radel* R 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 4 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, on stress-strain curve)

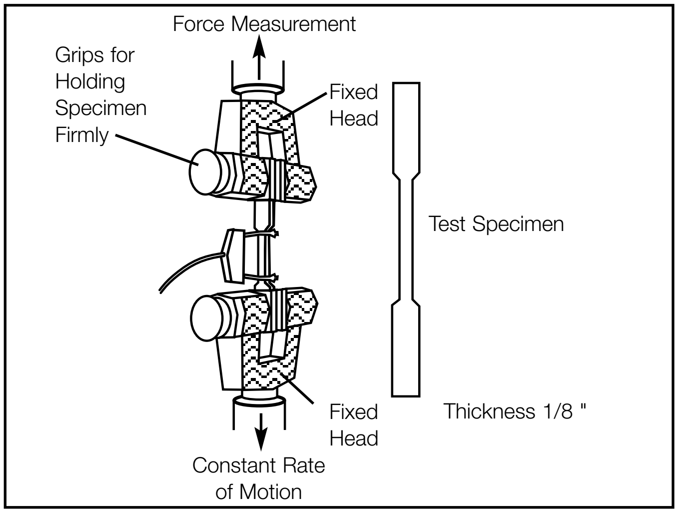
Flexural Strength (ASTM D 790)

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 5 for test illustration.

Hardness

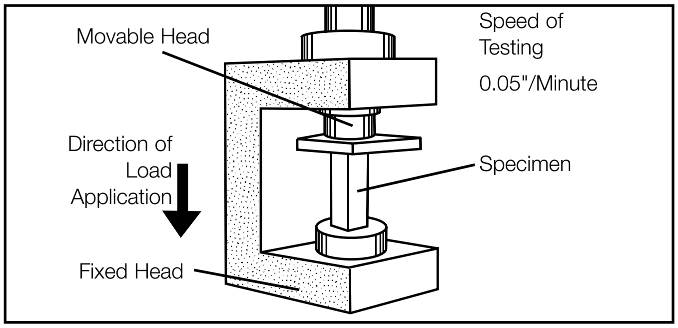
Hardness is usually reported by one of two test methods – Rockwell (ASTM D 785) or Indentation Hardness/Durometer (ASTM D 2240). The Rockwell test is typically chosen for hard materials such as acetal, nylon, and PEEK where creep is less of a factor in the test results. A test schematic is shown in Figure 6.

Fig. 3



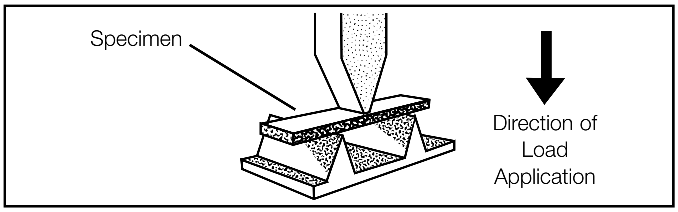
ASTM D 638: *For this test, samples are either machined from stock shapes or injection molded. The tensile testing machine pulls the sample from both ends and measures the force necessary to pull the specimen apart (Tensile Strength), and how much the material stretches before breaking (Elongation).*

Fig. 4



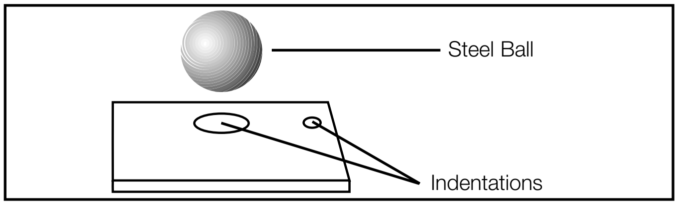
ASTM D 695: *Specimen of 1/2" x 1/2" x 1" is mounted in a compression tool between testing machine heads. An indicator registers the load in psi.*

Fig. 5



ASTM D 790: *Specimen of 1/8" x 1/2" x 5" is placed on two supports and a load is applied in the center. The load at yield is a material's flexural strength.*

Fig. 6



PROPERTY BASICS

The Durometer is reported for softer materials such as Urethane and PVC. The two scales do not correlate and cannot be compared. Hardness data is best used to compare materials. By itself the test is no indication of strength, wear performance or abrasion resistance.

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.

Due to plastics' time dependent (viscoelastic) behavior under stress, special consideration must be given when designing for continuous or long-term applied stresses. 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 page 9, 10 and 11 of the *Products and Applications Guide*.

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 do not provide results that are of immediate use to a designer, but are very helpful when comparing the relative impact resistance of various 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.

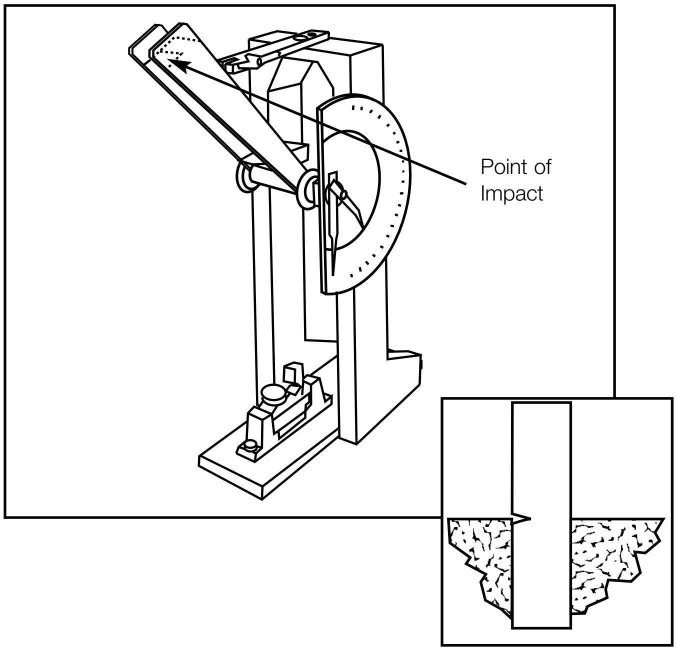
IZOD IMPACT (ASTM D 256)

One of the most widely used methods for measuring impact strength is the Izod impact test. In this test, a pendulum arm swings to impact a notched, cantilevered beam (See Figure 7). After fracturing the test specimen, the pendulum continues to travel in the same direction, but with less energy due to the impact with the specimen. 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 a notched or 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)

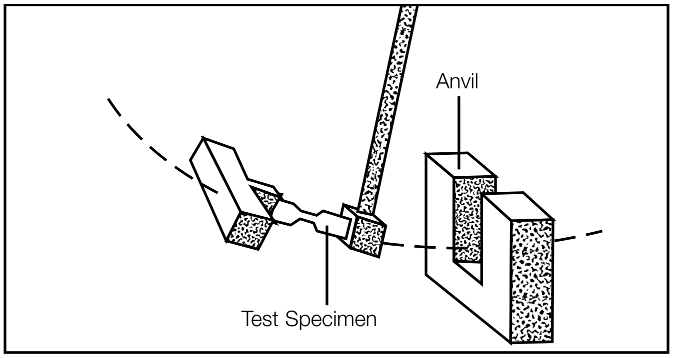
This test uses a swinging pendulum similar to that used in the Izod impact test, except the sample specimen is a tensile bar. It is mounted, as shown in Figure 8, to measure the energy required to fracture it (pull it apart) due to rapid tensile loading.

Fig. 7 - **IZOD IMPACT TEST**



NOTCHED

Fig. 8 - **TENSILE IMPACT TEST**



>> THERMAL & ELECTRICAL

PROPERTY BASICS

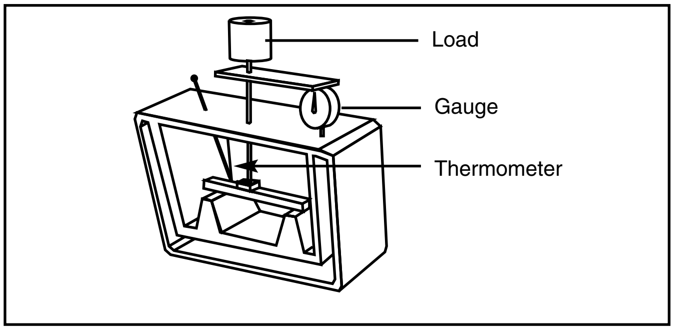
Coefficient of Linear Thermal Expansion (E 831 TMA)

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.

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. (see Figure 9). 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.

Fig. 9



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. Except when thermoforming, it is important to ensure that an amorphous polymer is used below its Tg if reasonable mechanical performance is expected.

Melting Point (ASTM D 3418)

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

Fig. 10 - **RESISTIVITY CONTINUUM**

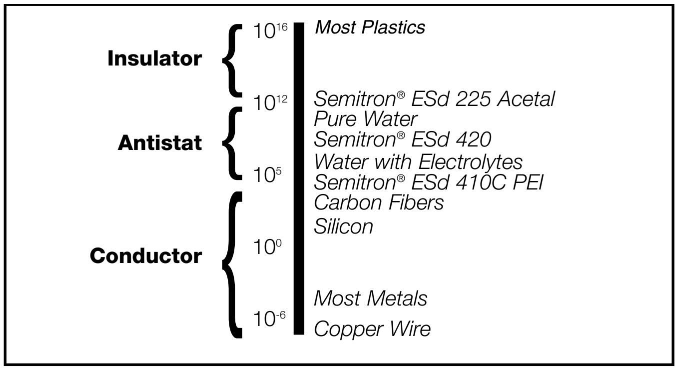
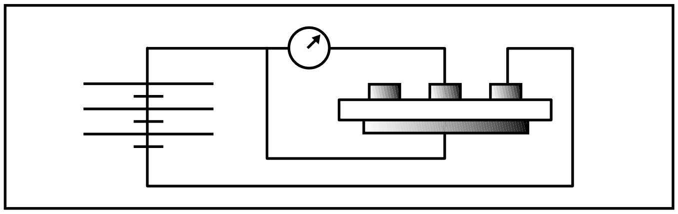


Fig. 11 - **SURFACE RESISTIVITY**



Volume Resistivity (ASTM D 257)

The volume resistivity of a material is its ability to resist the flow of electricity, expressed in ohms-cm. The more readily the current flows, the lower the volume resistivity. Volume resistivity can be used to predict the current flow from an applied voltage as demonstrated by Ohm's Law.

$$V = IR$$

Where:

V = Applied voltage (volts)
I = Electrical current (Amperes)
R = Resistance of the wire (ohms)

As the Resistivity Continuum in Figure 10 indicates:

- ➜ **insulators exhibit resistivities of 10^{12} and higher**
- ➜ **antistatic/partially conductive products exhibit resistivities of 10^{5} to 10^{12}**
- ➜ **conductive products exhibit resistivities of 10^{-6} to 10^{5}**

For details concerning Quadrant's line of static dissipative plastics, please consult the *Advanced Engineering Plastics for the Semiconductor Industry brochure.*

Surface Resistivity (EOS/ESD S11.11)

This test measures the ability of current to flow over the surface of a material. Unlike the volume resistivity test, the test electrodes are both placed on the same side of the test specimen (see Figure 11). However, like volume resistivity, surface resistivity is 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.

PROPERTY BASICS

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 (see Figure 12). 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.

DESIGN TIP

Ultem* 1000 PEI has the highest short term dielectric strength of Quadrant's engineering plastics. The value is 830 Volts/mil. For more information concerning Ultem 1000's electrical performance, see page 43 of Quadrant's *Products and Applications Guide*.

Dielectric Constant (ASTM D 150(2))

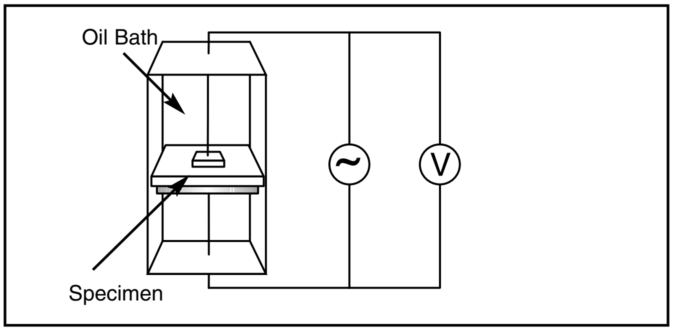
The Dielectric Constant, or permitivity, is a measure of the ability of a material to store electrical energy. Polar molecules and induced dipoles in a plastic will align themselves with an applied electric field. It takes energy to make this alignment occur. Some of the energy is converted to heat in 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.

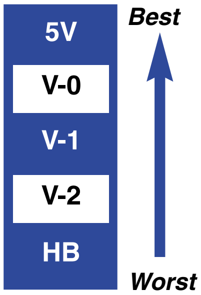
The higher the dielectric constant, the more electrical energy can be stored. A low dielectric constant is desirable in an insulator, whereas someone wanting to build a capacitor will look for materials with high dielectric constants. Dielectric constants are dependent on frequency, temperature, moisture, 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.

Fig. 12





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.

MATERIAL SELECTION

What is the Primary Function of the Part?

BEARING & WEAR

☐Celazole* PBI	650°F
☐Fluorosint® filled PTFE's	500°F
☐Torlon* PAI (4301,4501, 4540, 4347,4XCF)	500°F
☐Ketron® PEEK	480°F
☐Ketron® PEEK HPV	480°F
☐Ketron® 30% CF PEEK	480°F
☐Ryton* Bearing Grade PPS	450°F
☐Techtron® HPV	430°F
☐MC® 901 nylon	260°F
☐Ertalyte® PET-P / Ertalyte® TX	210°F
☐Nylon 101	210°F
☐Nylatron® GS nylon	210°F
☐Nylatron® NSM nylon	200°F
☐Nylatron® GSM Blue nylon	200°F
☐Nylatron® GSM nylon	200°F
☐MC® 907 nylon	200°F
☐Acetron® GP Acetal / Delrin* 150	180°F
☐Delrin* AF Blend	180°F
☐UHMW-PE	160°F

Limiting PV (at Room Temperature) psi-fpm with 4:1 safety factor applied

☐Celazole* PBI	37,500
☐Ketron® 30% CF PEEK	25,000
☐Ryton* Bearing Grade PPS	25,000
☐Torlon* PAI (4301,4501, 4540, 4347, 4XCF)	22,500
☐Techtron® HPV	17,000
☐Nylatron® NSM Nylon	15,000
☐Ketron® PEEK HPV	35,000
☐Delrin* AF Blend	8,300
☐Fluorosint® 500 filled PTFE	8,000
☐Fluorosint® 207 filled PTFE	8,000
☐Ertalyte® TX	6,000
☐Ketron® PEEK	5,500
☐Nylatron® GSM Blue nylon	5,500
☐Nylatron® GS / GSM nylons	3,000
☐MC® 901 / MC® 907 nylon	3,000
☐Ertalyte® PET-P	2,800
☐Nylon 101	2,700
☐Acetron® GP Acetal / Delrin* 150	2,700
☐UHMW-PE	2,000

Quadrant Engineering Plastic Product's material selector is designed to help simplify the sometimes difficult task of choosing an appropriate thermoplastic stock shape material using application design criteria. This selector should only serve as a guide, and not a fail safe substitute for thorough design engineering.

Any material selection should be reviewed and thoroughly tested prior to actual use.

What is the Maximum "No Load" Continuous Service Temperature? (in air)

Select only materials rated above.

To Convert from °C:
(°C x 1.8) + 32 = °F

For Bearing and Wear Applications, Determine the Pressure (or Stress) and Velocity

P=

V=

PV=

Select only materials rated above service PV

For Structural Applications, Determine the Pressure (or Stress)

Select only materials rated above service pressure

STRUCTURAL

☐Celazole* PBI	650°F
☐Torlon* PAI grades	500°F
☐Fluorosint® filled PTFE	500°F
☐Semitron® ESd 500HR	500°F
☐Teflon* PTFE	500°F
☐Ketron® PEEK	480°F
☐Ketron® 30% GF or 30% CF PEEK	480°F
☐Ryton* 40% GF PPS	450°F
☐Techtron® PPS	425°F
☐Techtron® CM PPS	425°F
☐Semitron® ESd 410C	410°F
☐Ultem* 1000 PEI , Ultem* 2300 PEI	340°F
☐Radel* R PPSU	300°F
☐PSU 1000 Polysulfone	300°F
☐Polycarbonate	250°F
☐Ertalyte® PET-P	210°F
☐30% GF Nylon	210°F
☐Nylon 101 / Nylatron® GS Nylon	210°F
☐MC® 901 / MC® 907 Nylons	200°F
☐Semitron® ESd 225	180°F
☐Acetron® GP Acetal / Delrin* 150	180°F
☐UHMW-PE	160°F

Maximum Working Stress (Continuous Load - psi)

	73°F	150°F	300°F
☐Celazole* PBI	12,500	11,500	10,500
☐Ultem* 2300 PEI	6,200	4,600	3,000
☐Ketron® 30% GF PEEK	6,000	4,000	2,000
☐Ketron® 30% CF PEEK	6,000	4,000	2,000
☐Torlon* PAI grades	5,000	4,500	3,000
☐Ryton* 40% GF PPS	5,000	4,000	750
☐Semitron® ESd 410C	4,000	3,000	2,000
☐Radel* R PPSU	3,000	2,200	1,500
☐Ultem* 1000 PEI	3,800	2,700	1,700
☐30% GF Nylon	3,500	2,500	—
☐Ketron® PEEK	3,500	1,750	750
☐PSU 1000 Polysulfone	3,000	2,200	1,000
☐Ertalyte® PET-P	2,300	2,000	—
☐Acetal / Delrin* 150	2,200	1,800	—
☐Techtron® PPS	2,100	2,000	500
☐Techtron® CM PPS	2,100	2,000	500
☐Polycarbonate	2,000	1,200	—
☐Nylons	2,000	1,200	—
☐Semitron® ESd 225	1,800	1,500	—
☐UHMW-PE	1,800	400	—
☐Fluorosint® PTFE	1,500	1,000	500
☐Semitron® ESd 500HR	1,500	1,000	500
☐Teflon* PTFE	500	250	100

DIRECTIONS

After determining whether your application is primarily bearing and wear or structural in nature, follow that specific column to determine candidate materials. Materials that meet all of your criteria should be considered candidates for further evaluation and testing. If you have any questions about using this selector, contact Quadrant at 1-800-366-0300.

BEARING & WEAR

FDA Compliant Materials

☐Fluorosint® 207 filled PTFE
☐Ertalyte® TX
☐Ertalyte® PET-P (Natural & Black)
☐Nylon 101
☐MC® 907 nylon
☐Acetron® GP Acetal (Natural)
☐Delrin* 150 Acetal (Natural)
☐UHMW-PE

Chemical Environment

Strong Acids

BEST

Fluorosint®
UHMW-PE
Ketron® PEEK
Ketron® PEEK 30% CF
Ketron® PEEK HPV
Techtron® HPV
Ryton* BG PPS

Strong Alkalies

Fluorosint®
UHMW-PE
Ketron® PEEK
Ketron® 30% CF PEEK
PEEK HPV
Techtron® HPV
Ryton* BG PPS

Steam

BEST

Fluorosint®
Ketron® PEEK
PEEK 30% CF
Techtron® HPV
Ryton* BG PPS
PEEK HPV
Acetron® GP Acetal

Chlorine (Aqueous)

Fluorosint®
UHMW-PE
Ketron® PEEK
Ketron® 30% CF PEEK
PEEK HPV
Ertalyte® PET–P
Ertalyte® TX

Size Capability

	ROD (DIAMETERS)	PLATE (THICKNESS)
☐Acetal / Delrin* 150	.062" – 8"	.031" – 4.5"
☐Celazole* PBI$^{\Delta}$	.375" – 3.75"	.500" – 1.5"
☐Delrin* AF Blend	.250" – 6"	.250" – 2"
☐Ertalyte® PET-P	.375" – 7.08"	.250" – 4"
☐Ertalyte® TX	.375" – 7.88"	.315" – 3.94"
☐Fluorosint® PTFE	.500" – 8.75"	.250" – 3"
☐Ketron® PEEK	.125" – 4"	.250" – 2"
☐MC® 901 / 907 nylon	2" – 38"	.187" – 4"
☐Nylatron® GS nylon	.062" – 2"	.031" – 2"
☐Nylatron® GSM Blue	2" – 38"	.187" – 4"
☐Nylatron® GSM nylon	2" – 38"	.187" – 4"
☐Nylatron® NSM nylon	2" – 38"	.187" – 4"
☐Nylon 101	.062" – 6"	.031" – 3"
☐Ketron® PEEK 30% CF$^{\Delta}$	1" – 3.75"	—
☐Ketron® PEEK HPV	.236" – 3.94"	.197" – 1.97"
☐Ryton* BG PPS$^{\Delta}$	1" – 5"	.375" – 1.75"
☐Techtron® HPV	.236" – 3.94"	.197" – 3.15"
☐Torlon* 4301 PAI	.250" – 2"	.250" – 1.25"
☐Torlon* 4540$^{\Delta}$	1" – 15"	.375" – 1.5"
☐Torlon* 4501	1.5" – 15"	.375" – 1.5"

Note:
CF = Carbon fiber reinforced
GF = Glass fiber reinforced
BG = Bearing grade
ESD = Electrostatic dissipative
CM = Compression molded

Is FDA/USDA/ NSF / 3A Dairy Compliance Required?

Yes__ No__

See the Regulatory Compliance Chart on page 36 of this manual for complete details on all materials.

What Chemicals will be Encountered During Service or Cleaning?

___Strong Acids (pH 1-3)
___Strong Alkalies (pH 9-14)
___Hot Water / Steam
___Chlorine (aqueous)

For resistance to other chemicals, see pages 32 through 35 of this manual, or contact Quadrant's Technical Service.

What Size Stock Shape is Required for Machining?

Rod____
Plate____

(Custom sizes including disc and tubular bar are also available in cast and compression molded materials.)

Δ Products are compression molded and typically available in rod, plate, tubular bar and discs. Rod and tube lengths range from 3" to 12". Plate sizes are 12" x 12", 13-1/4" x 14-1/4", and 14" x 28".

ΔΔ FDA compliant by special order only.

STRUCTURAL

FDA Compliant Materials

☐Fluorosint® 207 filled PTFE
☐Ketron® PEEK (Natural)
☐Ultem* 1000 PEI
☐PSU 1000 Polysulfone
☐PC 1000 PolycarbonateΔΔ
☐Ertalyte® PET-P (Black & Natural)
☐Nylon 101 (Natural)
☐MC® 907 Nylon
☐Acetron® GP Acetal/Delrin* 150 (Natural)
☐UHMW-PE

Chemical Environment

Strong Acids

BEST

Teflon* PTFE
Fluorosint®
UHMW-PE
Ketron® PEEK
Techtron® PPS
Ryton* 40% GF PPS
Radel* R PPSU
Ultem* 1000 PEI
PC 1000 Polycarbonate
PSU 1000 Polysulfone

Strong Alkalies

Teflon* PTFE
Fluorosint®
UHMW-PE
Ketron® PEEK
PPS products
Radel* R PPSU
PSU 1000 Polysulfone

Steam

BEST

Teflon* PTFE
Fluorosint® 500
Ketron® PEEK
Techtron® PPS
Radel* R PPSU
Ultem* 1000 PEI
PSU 1000 Polysulfone

Chlorine (Aqueous)

Teflon* PTFE
Fluorosint® 500
UHMW-PE
Ketron® PEEK
PPS products
Ertalyte® PET-P
Radel* R PPSU
Ultem* 1000 PEI

Size Capability

	ROD (DIAMETERS)	PLATE (THICKNESS)
☐Celazole* PBI$^{\Delta}$	.375" – 3.75"	.500" – 1.5"
☐Delrin* 150	.250" – 8"	.250" – 3"
☐Ertalyte® PET-P	.375" – 7.08"	.250" – 4"
☐Fluorosint® PTFE	.500" – 8.75"	.250" – 3"
☐Ketron® 30% CF PEEK	1" – 3.75"	——
☐Ketron® 30% GF PEEK	.375" – 2"	——
☐Ketron® PEEK	.125" –4"	.250" – 2"
☐MC® 901 / 907 nylon	2" – 38"	.187" – 4"
☐Nylon 101	.062" – 6"	.031" – 3"
☐PC 1000 Polycarbonate	.062" – 6"	.250" – 3"
☐PSU 1000 Polysulfone	.250" – 6"	.250" – 3"
☐Radel* R PPSU	.250" – 6"	.250" – 3"
☐Ryton* 40% GF PPS$^{\Delta}$	1" – 4"	.375" – 2"
☐Semitron® ESd 225	.187" – 4"	.250" – 2"
☐Semitron® ESd 410C	.375" – 3"	.375" – 2"
☐Semitron® ESd 500HR	——	.250" – 2"
☐Techtron® PPS	.250" – 4"	.250" – 2"
☐Techtron® CM PPS$^{\Delta}$	1" – 3.5"	.375" – 1.5"
☐Torlon* 4301	.250" – 2"	.250" – 1.25"
☐Torlon* 5530, 4503$^{\Delta}$	.375" – 15"	.375" – 2"
☐Ultem* 2300 PEI	.500" – 6"	.375" – 2"
☐Ultem* 1000 PEI	.125" – 6"	.250" – 2"
☐30% GF Nylon	.315" – 7.88"	.394" – 3.94"
☐Torlon* 4203	.062" – 2"	.250" – 1.25"
☐Nylatron* GS	.062" – 2"	.031" – 2"

MATERIAL SELECTION

BEARING AND WEAR

Stability

		CLTE	H_2O Absorp. (Saturation)
BEST	Ryton* BG PPS	1.2×10^{-5}	0.03
	Celazole* PBI	1.3×10^{-5}	15.00*
	Torlon* PAI grades	1.4×10^{-5}	1.50
	Ketron® 30% CF PEEK	1.7×10^{-5}	0.50
	Ketron® PEEK HPV	1.7×10^{-5}	0.30
	Fluorosint® 500	2.1×10^{-5}	3.00
	Ketron® PEEK	2.6×10^{-5}	0.50
	Techtron® HPV	3.3×10^{-5}	0.10
	Ertalyte® PET-P	3.3×10^{-5}	0.90
	Ertalyte® TX	4.5×10^{-5}	0.50
	Delrin* 150 Acetal	4.7×10^{-5}	0.90
	Delrin* AF Blend	5.0×10^{-5}	1.00
	Acetron® GP Acetal	5.4×10^{-5}	0.90
	Fluorosint® 207	5.7×10^{-5}	2.00
	MC® 901 / 907 nylon	3.5×10^{-5}	7.00
	Nylatron® GSM nylon	3.5×10^{-5}	7.00
	Nylatron® GS nylon	4.0×10^{-5}	7.00
	Nylatron® NSM nylon	5.0×10^{-5}	7.00
	Nylon 101	5.5×10^{-5}	7.00
	Nylatron® GSM Blue	5.9×10^{-5}	7.00
	UHMW-PE	9.2×10^{-5}	0.01

Toughness or Impact Resistance

Tough Materials
MC® 901 / MC® 907 nylon
Nylatron® GSM nylon
Nylatron® GSM Blue nylon
UHMW-PE

Average Toughness
Nylon 101 Nylatron® NSM nylon
Acetron® GP Acetal
Delrin* 150 Acetal
Delrin* AF Blend
Ertalyte® TX
Fluorosint® filled PTFE
Ketron® PEEK
Torlon* PAI

Notch Sensitive Materials
Nylatron® GS nylon
Ertalyte® PET–P
Ketron® PEEK HPV
Ketron® 30% CF PEEK
Techtron® HPV
Ryton* BG PPS
Celazole* PBI

Is Dimensional Stability Over a Temperature Range Critical?

Select a material with the lowest coefficient of linear thermal expansion (in. / in. / °F) or lowest water absorption.

***Applications requiring Celazole* PBI are typically dry due to high temperatures.**

Is Toughness or Impact Resistance Critical in Use?

Select the most impact resistant material if toughness is critical.

STRUCTURAL

Stability

	CLTE	H_2O Absorp. (Saturation)	
Celazole* PBI	1.3×10^{-5}	15.00*	BEST
Torlon* PAI grades	1.7×10^{-5}	1.50	
Ultem* 2300 PEI	1.1×10^{-5}	0.90	
Ketron® 30% GF PEEK	1.4×10^{-5}	0.50	
Semitron® ESd 410C	1.8×10^{-5}	1.25	
Fluorosint® 500	2.1×10^{-5}	3.00	
Ryton* 40% GF PPS	2.5×10^{-5}	0.03	
Ketron® PEEK	2.6×10^{-5}	0.50	
Techtron® PPS	2.8×10^{-5}	0.03	
30% GF Nylon	3.1×10^{-5}	7.00	
Radel* R PPSU	3.1×10^{-5}	1.10	
Ultem* 1000 PEI	3.1×10^{-5}	1.25	
PSU 1000 Polysulfone	3.1×10^{-5}	0.60	
Ertalyte® PET-P	3.3×10^{-5}	0.90	
PC 1000 Polycarbonate	3.9×10^{-5}	0.40	
Acetal / Delrin* 150	4.7×10^{-5}	0.90	
MC® 901/ 907 nylon	3.5×10^{-5}	7.00	
Nylatron® GS nylon	4.0×10^{-5}	7.00	
Nylon 101	5.5×10^{-5}	7.00	
Fluorosint® 207	5.7×10^{-5}	0.03	
Semitron® ESd 500HR	5.7×10^{-5}	2.00	
UHMW-PE	9.2×10^{-5}	0.01	
Semitron® ESd 225	9.3×10^{-5}	2.00	
Teflon* PTFE	10.0×10^{-5}	0.01	

Toughness or Impact Resistance

Tough Materials
MC® 901 / MC® 907 nylon
Radel* R PPSU
PC 1000 Polycarbonate
Teflon* PTFE
UHMW-PE

Average Toughness
Nylon 101
Semitron® ESd 225
Acetron® GP Acetal / Delrin* 150
Fluorosint® filled PTFEs
Torlon* PAI grades
Ketron® PEEK
Ultem* 1000 PEI
Techtron® PPS
PSU 1000 Polysulfone
Techtron® CM PPS
Semitron® ESd 500HR

Notch Sensitive Materials
Nylatron® GS nylon
Ertalyte® PET-P
30% GF Nylon
Semitron® ESd 410C
Ultem* 2300 PEI
Ketron® 30% GF or CF PEEK
Ryton* 40% GF PPS
Celazole* PBI

What Materials Meet Performance Requirements and Offer the Best Value?

All costs are estimates relative to Nylon 101. Please note that size availability and near net shapes can reduce material cost.

BEARING AND WEAR

Relative Cost Factor

Celazole* PBI	76.4
Ketron® 30% CF PEEK	55.0
Ketron® PEEK HPV	30.3
Torlon* PAI grades	28.1
Techtron® HPV	22.0
Ketron® PEEK	19.8
Ryton* BG PPS	17.8
Fluorosint® filled PTFE	12.1
Delrin* AF Blend	3.5
Ertalyte® PET-P	1.6
Ertalyte® TX	1.8
Nylatron® NSM nylon	1.4
Acetron® GP Acetal / Delrin*	1.2
Nylatron® GSM Blue nylon	1.2
Nylatron® GS nylon	1.2
Nylatron® GSM nylon	1.0
MC® 901/MC® 907 nylon	1.0
Nylon 101	1.0
UHMW-PE	0.5

Note:
CF = Carbon fiber reinforced
GF = Glass fiber reinforced
BG = Bearing grade
ESd = Electrostatic dissipative
CM = Compression molded

STRUCTURAL

Relative Cost Factor

Celazole* PBI	76.4
Ketron® 30% CF PEEK	55.0
Semitron® ESd 500HR	45.8
Semitron® ESd 520HR	36.4
Ketron® 30% GF PEEK	34.0
Torlon* PAI grades	28.1
Ketron® PEEK	19.8
Techtron® CM PPS	18.5
Semitron® ESd 410C	17.3
Techtron® PPS	15.9
Fluorosint® 500 filled PTFE	12.1
Radel* R PPSU	9.0
Ryton* 40% GF PPS	8.1
Ultem* 2300 PEI	7.0
30% GF Nylon	4.5
PSU 1000 Polysulfone	4.0
Ultem* 1000 PEI	3.9
Semitron® ESd 225	3.3
Teflon* PTFE	3.0
PC 1000 Polycarbonate	1.7
Ertalyte® PET-P	1.6
Acetal/Delrin* 150	1.2
Nylatron® GS nylon	1.2
Nylon 101	1.0
MC® 901/MC® 907 nylon	1.0
UHMW-PE	0.5

Material Selection:
1.______________ (1st choice)
2.______________ (Alternate)
3.______________ (Alternate)

For other special environmental conditions (i.e. Radiation, Static Dissipation, etc.), please call Quadrant's Technical Service Group at 1-800-366-0300

BEARING DESIGN

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**

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.

Measuring Operating PV

Determining Surface Velocity

For sleeve bearings, the formula **V = 0.262 x rpm x D** is used to determine the surface velocity 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.

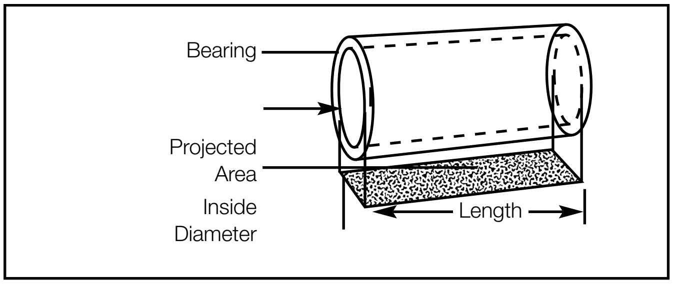
Determining Unit Pressure

The unit pressure "P" is quickly calculated for flat wear surfaces and sleeve bearings. 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), see Figure 14.

DESIGN TIP

The maximum unit pressure must always be less than the compressive strength of a selected material. A good design practice is to use the "working stress" listed on page 12 of this manual as the maximum unit pressure for a plastic bearing.

Fig. 14



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.

Table 3 : **Basic Limiting PV (LPV) for Quadrant's Bearing Material**

Operating without lubrication and with ambient temperature of 75°F. Units of LPV are (PSI)(FPM). (4:1 Safety Factor applied)

Material	**PV_L Unlubricated**
30% Carbon-filled Ketron® PEEK	41,000
Celazole* PBI	37,500
PEEK HPV	35,000
Bearing Grade Ryton* PPS	25,000
Torlon* 4301 and 4501 PAI	22,500Δ
Techtron® HPV	17,000
Nylatron® NSM Nylon	15,000ΔΔ
Ketron® PEEK	8,500
Delrin* AF Blend	8,300
Fluorosint® 207/500	8,000
Ertalyte® TX	6,000
Nylatron® GSM Blue Nylon	5,500
MC® Nylons/Nylatron® GS/GSM	3,000
Ertalyte® PET–P	2,800
Nylon 101/Acetal	2,700

Δ **Value represents the LPV for a machined part without post curing after machining. Post curing parts machined from extruded or injection molded Torlon* PAI significantly increases the LPV to as high as 45,000.**

ΔΔ **At surface speeds below 20 ft./min. the LPV (Basic Limiting PV) may be doubled.**

Applying the PV Factor

Table 3 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 modified to compensate for ambient temperatures other than 75°F., and for the cycle time, if continuous operation is not required.

Modification of LPV is accomplished by multiplying by the correction factors ("H" and "C") obtained from Figures 15 and 16. When ambient temperature is approximately 75°F., H=1 and when bearings are run continuously, C=1. Therefore LPV as listed in Table 3 can be used as PVa.

DESIGN TIP

Continuous lubrication including oil, grease and water greatly increase the service limits of thermoplastic bearings. Lubrication is usually suggested for velocities greater than 400 fpm.

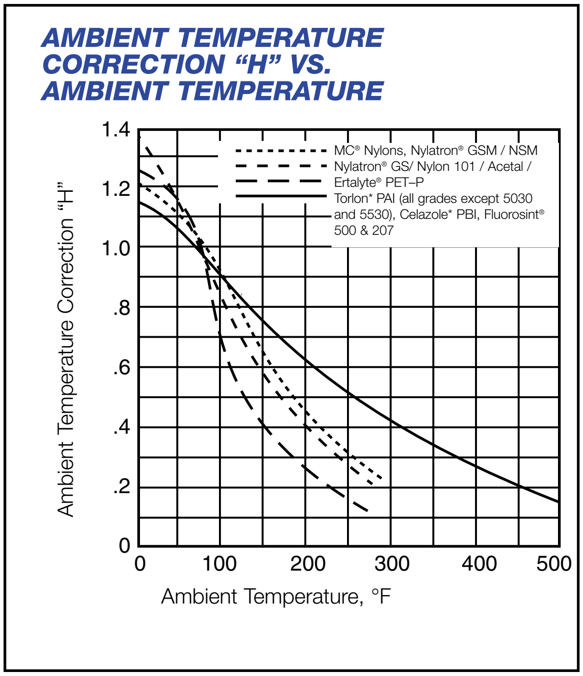
Ambient Temperature Correction (H)

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 Figure 15 to compensate PV for variations in ambient temperature.

PVa = PV x H

Fig. 15


AMBIENT TEMPERATURE CORRECTION "H" VS. AMBIENT TEMPERATURE

Cycle Time Correction (C)

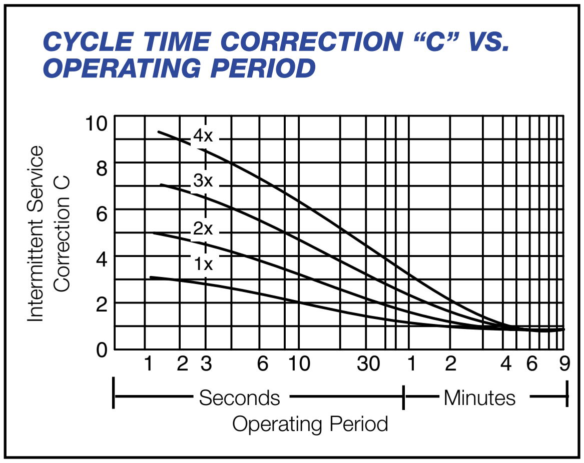
The rates of heat generation and heat dissipation greatly determine the performance of plastic bearings. If operation is intermittent rather than continuous, the rate of heat generation is reduced although the rate of heat dissipation remains constant.

Instructions for use of Figure 16

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.

PVa = PV x C

Fig. 16


CYCLE TIME CORRECTION "C" VS. OPERATING PERIOD

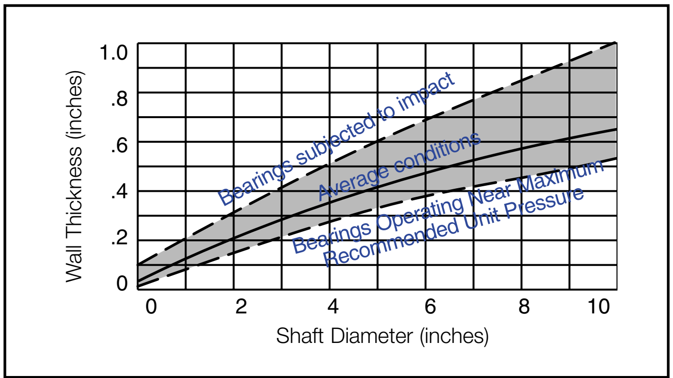
BEARING DESIGN

Nominal 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 17 suggests a range of nominal wall thicknesses for different shaft diameters. Maximum walls are recommended for bearings subjected to severe impact conditions, minimum walls for bearings operating near the material's maximum recommended PV.

Fig. 17 - **SUGGESTED NOMINAL WALL THICKNESS**



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.

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 = $a_1 + a_2 + a_3$, where:

a_1 = Basic shaft allowance– obtain value from Figure 18.

a_2 = Wall thickness allowance (a function of the bearing material, bearing wall thickness, and the ambient operating temperature)– obtain wall factor from Table 4 and multiply by the nominal wall thickness to obtain a_2.

a_3 = 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 19.

Fig. 18 - **SHAFT ALLOWANCE (a_1) VERSUS SHAFT DIAMETER**

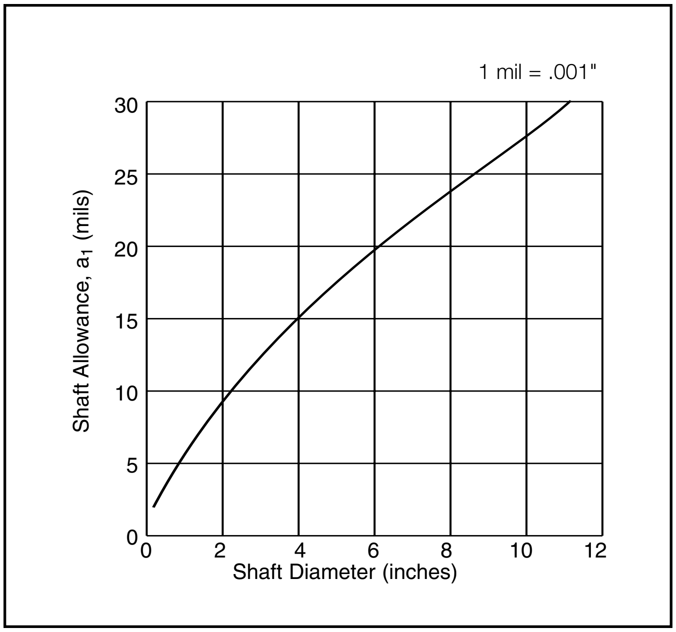
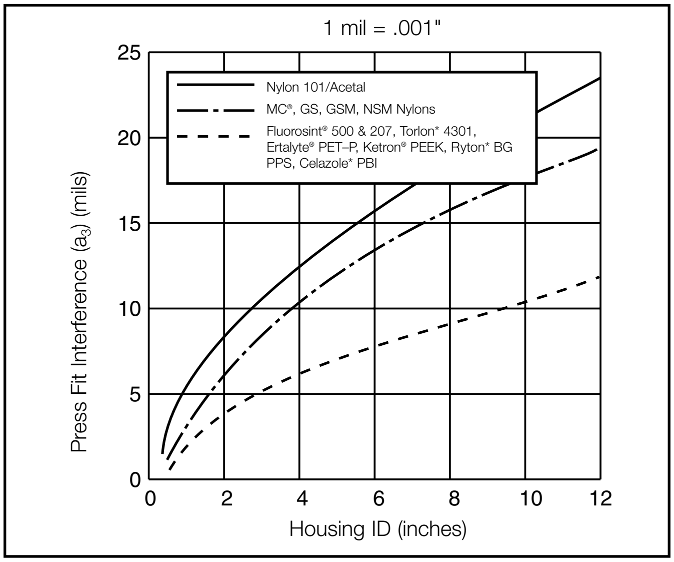


Table 4 : **Wall factor for plastic bearing materials at various ambient temperatures - for calculation of (a_2) (inches)**

	75°	100°	125°	150°	175°	200°	225°	250°	275°	300°	350°	400°	450°	500°
Nylon 101/Acetal	.018	.021	.023	.026	.028	.031	.033	.036	.038					
Cast nylon 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® 500 and 207	.007	.007	.008	.008	.009	.009	.010	.010	.011	.011	.012	.013	.014	.015
Ketron® PEEK, Techtron® PPS,	.007	.007	.008	.008	.009	.009	.010	.010	.011	.011	.012	.013	.014	.015
Bearing grade Torlon* PAI,	.007	.007	.008	.008	.009	.009	.010	.010	.011	.011	.012	.013	.014	.015
Celazole* 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.

Fig. 19 - **RECOMMENDED PRESS FIT INTERFERENCE (A_3) VERSUS HOUSING INSIDE DIAMETER**



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 18 was developed from application data on plastic bearings.

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, Table 4 demonstrates that with higher ambient temperatures and/or thicker bearing walls the greater the required running clearance.

Press Fit into Metallic Housing

When plastic bearings are press fit into metallic housings or retainers, a recommended interference (Figure 19) should be used to ensure 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 OD clearance equal to the interference (a_3).

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 or coarser finish will work in many applications. The finish of the plastic bearing is not critical and can be as coarse as 125 RMS.

DESIGN TIP

•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.

Moisture expansion clearance (only if water-lubricated nylon bearing)
If bearing wall thickness in inches is:

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 Acetal may offer improved wear resistance in wet environments.

•Internally lubricated materials such as Nylatron® NSM nylon, Nylatron® GSM Blue nylon and Delrin* AF provide the lowest cost in use when PV is less than PV_L.

Bearing and Wear Properties Comparison

Material	Continuous Service Temp.	Limiting PV	"k" Factor	Coefficient of Friction (Dynamic)	Compressive Strength	Cost Factor
Nylatron® GSM Blue Nylon	-	5,500	65	0.18	13,000	1.2
UHMW-PE	160	2,000	111	0.12	4,000	0.5
Acetron® GP Acetal	180	2,700	150	0.25	15,000	1.2
Acetron® NS Acetal	180	8,750	48	0.20	15,000	3.0
Delrin* AF Blend Acetal	180	8,300	57	0.19	16,000	3.5
Nylatron® NSM Nylon	200	15,000	9	0.18	14,000	1.4
Nylatron® GSM Nylon	200	3,000	100	0.20	14,000	1.0
Nylon 101	210	2,700	75	0.25	12,500	1.0
Ertalyte® TX PET-P	210	6,000	35	0.19	15,250	-
Ertalyte® PET-P	210	2,800	60	0.20	15,000	1.6
Nylatron® GS Nylon	220	3,000	70	0.20	16,000	1.2
Techtron® HPV	430	17,000	85	0.16	-	22.0
BG Ryton* PPS	450	25,000	575	0.20	15,000	17.8
30% CF Ketron® PEEK	480	25,000	150	0.24	25,000	55.0
Ketron® PEEK(extruded)	480	25,000	235	0.40	20,000	19.8
Ketron® PEEK HPV	482	35,000	100	0.21	26,700	30.3
Torlon* 4301 PAI (extruded)	500	22,500	350	0.20	24,000	28.1
Fluorosint® 500	500	8,000	600	0.15	4,000	12.1
Fluorosint® 207	500	8,000	35	0.10	3,800	14.5
Celazole* PBI	600°F	37,500	53	0.24	50,000	76.4

>> DESIGN WORKSHEET

BEARING DESIGN

This worksheet applies to sleeve bearings only. If the bearing has another configuration, sketch and note all dimensions and fax to Quadrant Technical Service at (610) 320-6866.

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? ____________
____
____

PV Determination

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)

PV - imposed PV on bearing

____________ psi x ____________ fpm ____________
= ____________ PV

See Table 3 on page 16 for Limiting PV

Lubricated ____________
Unlubricated ____________

Material Selected ____________

Corrections for Limiting PV - See page 17 (Figures 15 and 16)
Figure 15 – Temperature Correction H = ____________
Figure 16 – Cycle Time Correction C = ____________

PV Correction

Limiting PV ____________ x Temp. (H) ____________ x Cycle (C) ____________
= ____________ PV Limit

If the imposed PV is less than the PV limit for the material selected, the bearing will work.

Total Running Clearance

$a_1 + a_2 + a_3$
a_1 = Figure 18 (page 18)
a_2 = Table 4 (page 18) for ambient temp. to 90°F
= Bearing wall $\left(\frac{(OD - ID)}{2}\right)$ x Temp. factor for material
a_3 = Figure 19 (page 19) – used if bearing is press fit

Dimension 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 factor given in Design Tips on page 19 to the ID of the bearing to allow for moisture absorption –

____________ + Moisture absorption clearance ____________
= ____________ ID of bearing

Length of housing ____________

Dimensions and Tolerances

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

OD = ____________ ±

ID = ____________ $^{+0.008}_{-0.000}$ or + 0.002/-0.000 in./in. of dia.

ID = ____________ ± 0.000”

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

Length = ____________ ±

The greater of the tolerances will apply.

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:

- Acetal
- Nylon
- Polyester

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.

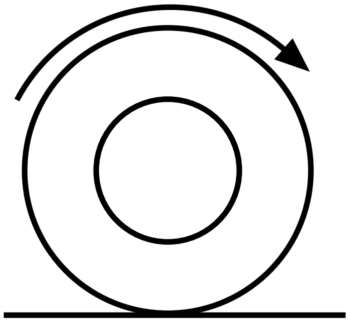
The first step in calculating suitability is to determine the load capacity of the proposed material. The load capacity equation is dependent upon the geometry and configuration of the wheels/rollers. Load capacity equations are provided on page 22 for three configurations:

(1) roller on a flat surface (Figure 20a.)

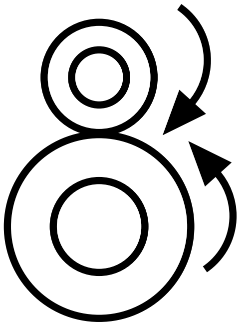
(2) roller on another rolling surface (Figure 20b.)

(3) roller in another rolling surface (Figure 20c.)

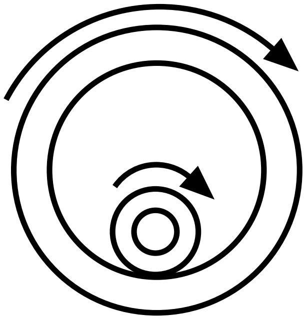
Fig. 20



a. Roller on flat surface



b. Roller on roller



c. Roller in roller

>> CONTINUED

ROLLER/WHEEL DESIGN

Determining the Load Capacity of a Roller/Wheel

Step 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 20)

Step 2

Select the potential roller/wheel material.

Step 3

From Table 5, obtain the material stress factor, K.

Note: Separate values are given for stationary vs. rotating situations.

Step 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 20a.)

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

(2) Roller on another rolling surface (Figure 20b.)

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

(3) Roller in another roller surface (Figure 20c.)

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

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.)

DESIGN TIP

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.

Table 5 : **Maximum Allowable Contact Stresses (psi)**

	Material Stress Factor K	
Material	**Stationary**	**Rotating**
Semitron® ESd 500HR	5	17
Fluorosint® 207	5	17
Fluorosint® 500	5	17
Semitron® ESd 225	23	76
Nylon 101	30	99
Nylatron® GSM Blue Nylon	32	106
Nylatron® GSM Nylon	39	130
Nylatron® NSM Nylon	39	130
Delrin* AF Blend	45	149
Acetron® GP Acetal	45	150
MC® 901/MC® 907 Nylons	45	150
Ertalyte® PET–P	46	142
Delrin* Acetal	46	151
Nylatron® GS Nylon	49	162
Torlon* 4503 PAI	89	157
BG Ryton* PPS	42	75
Torlon* 4501 PAI	96	170
Torlon* 4540 PAI	96	170
Ketron® PEEK (CM)	96	171
Ketron® PEEK (Extruded)	120	213
30% CF Ketron® PEEK	132	234
Torlon* 4301 PAI	91	161
Torlon* 4203 PAI	168	298
Celazole* PBI	215	383

Assembly / Fabrication

The three common 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 Table 6 for details on the typical uses, advantages, limitations and design/fabrication tips for these typical roller designs.

Fabrication Methods for Plastic Sleeves on Metal Cores

Shrink fitting

Shrink fitting is the most common assembly method. Shrink fit interference and axial clearance depends upon the roller/wheel's operating temperature. Table 7 contains the interference and clearances for four elevated temperatures. To assemble, heat both the plastic sleeve and metal core to 200°F.

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

Casting plastic sleeve on to metal core

Directly casting the nylon plastic sleeve on to 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".

Table 7 : **Interferences and Clearances at Elevated Temperatures**

Average Operating Temperature of Sleeve	Shrink Fit Interference at 68°F (20°C) Value is in % of d	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

Table 6 : **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 temperature 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 in to 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.

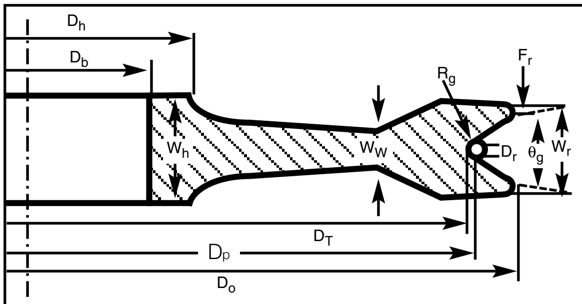
SHEAVE DESIGN

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 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.

Fig. 21



Where:

W_r = Rim width
θ_g = Groove angle
F_r = Rim flat
D_r = Wire rope diameter
R_g = Groove radius
W_w = Web width
W_h = Hub width
D_T = Tread diameter
D_o = Outside diameter
D_h = Hub diameter
D_b = Bore diameter
D_p = Pitch diameter

NYLATRON® GSM NYLON 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 created support for the wire rope. Light weight Nylatron nylon sheaves can support cyclical loads equal to steel sheave capabilities.

➜ Reduce Weight

Because Nylatron GSM 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 lower over-the-road weight.

The reduced weight of Nylatron GSM 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 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. Table 8 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.

Table 8 : **Wire Rope Lift Test Results***

Sheave Ratio	Rope Tension for Test	Design Factor (F_d)	Approximate Duration of Test	Increase in Rope Life Attained with Nylatron® GSM Sheaves*
24/1	10.0% of breaking strength	10.0	136,000 cycles	4.50 times
24/1	20.0% of breaking strength	5.0	68,000 cycles	2.20 times
24/1	28.6% of breaking strength	3.5	70,000 cycles	1.92 times
18/1	28.6% of breaking strength	3.5	39,000 cycles	1.33 times
Sheave Ratio = D_T/D_r = Sheave pitch diameter/rope diameter				

*Conventional rope retirement criteria based only upon visible wire breaks may prove inadequate in predicting rope failure. **The user of Nylatron nylon sheaves is therefore cautioned that a retirement criteria should be established based on the users' experience and demands of the specific applications.**

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. Figure 21 should help to clarify important parameters. The basic design of any sheave should conform with 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) and outside tread diameters (D_O and D_T) are typically fixed design dimensions. The rim flat (Fr-shown in Figure 21) 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 (Rg) 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.

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

Experience indicates that a groove angle (θg) of 30° will generally provide optimum rope support for mobile crane sheaves. Unless otherwise specified, Nylatron nylon sheaves are supplied with a 30° groove angle. Fleet angles 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. Nylatron nylon sheaves are supplied with a corresponding groove depth unless otherwise specified.

Web Dimensions

Practical experience with crane sheaves has shown that the required design strength can be maintained with a minimum web width that is 20% greater than the rope diameter or :

$$Ww = 2.2(R_g)$$

Where:

W = 1.1 • Groove Diameter

Rg = 1.05 • Dr / 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 (Dh) 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".

$$Dh = 1.5(Db)$$

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.

$$D_B = D_b - d$$

The press fit allowance may be reduced somewhat for light duty thin-walled bearings to prevent possible close-in of the bearing on the shaft. Sufficient press fit is critical to prevent buckling of a loaded sheave.

DESIGN 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 for appropriate running clearance information.

SHEAVE DESIGN

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.

DESIGN TIP

- 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.

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.

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.

$$P_g = \frac{2(LP_{MAX})K_\Theta}{Dr \bullet Dt} \qquad (1)$$

$$P_b = \frac{2(LP_{MAX})K_\Theta}{Db \bullet Wh} \qquad (2)$$

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

Dr = Rope diameter (in.)

Dt = Tread diameter (in.)

Db = Bore diameter (in.)

Wh = Hub width (in.)

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

Θ = Wrap angle

Table 9 : **Wrap Angle Factors**

Wrap Angle	*(Included angle)	K_Θ
180°	(0°)	1.000
170°	(10°)	0.996
160°	(20°)	0.985
150°	(30°)	0.966
140°	(40°)	0.940
130°	(50°)	0.906
120°	(60°)	0.866
110°	(70°)	0.819
100°	(80°)	0.766
90°	(90°)	0.707
80°	(100°)	0.643
70°	(110°)	0.573
60°	(120°)	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:

$$L_{pMAX} = \frac{1750\,(Dr \bullet Dt)}{K_\Theta}$$

$$L_{pMAX} = \frac{1750\,(Wh \bullet Db)}{K_\Theta}$$

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 nylon bearing.

First, obtain the recommended limiting pressure velocity value (PVa) for the given operating conditions. Next, calculate the maximum bore pressure from the equation:

$$P_b = \frac{PV_a}{V}$$

Where:

P_b = Maximum bore pressure (psi)
PV_a = Pressure velocity value (psi • fpm)
V = Shaft surface speed (fpm)
$= 0.262 \times$ shaft rpm $\times D_s$ (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.)

DESIGN TIPS

Contact Quadrant 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 products from Quadrant. Nylatron nylon'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).

Sheave Design Worksheet

INFORMATION REQUIRED

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

Arc of sheave contacted by rope _________°

SHEAVE DATA

Drawing Number? ________________
If no drawing is available...
Wr Rim width ________________ inches
Do Outer diameter ________________ inches
Dt Tread diameter ________________ inches
Dh Center hub O.D. ________________ inches
Wh Hub width ________________ inches
Db 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, PLEASE FAX THIS SHEET OR YOUR APPLICATION INFORMATION TO QUADRANT TECHNICAL SERVICES AT 610-320-6866.

GEAR DESIGN

Engineering plastics gears offer:

- **quiet operation**
- **ability to run without lubrication**
- **reduced inertia versus traditional all metal gears**
- **corrosion resistance**

Nylatron® and MC® nylons have been successfully used for spur, worm, bevel and helical gears for 25 years. Today, in a variety of industries, plastic gears continue to replace:

- **steel**
- **cast iron**
- **wood**
- **phenolic**
- **bronze**

Nylatron nylon balances strength, heat resistance, fatigue properties, impact resistance and wear resistance, making it the most popular choice for gearing. Acetal, UHMW-PE and new higher performance materials offer specific advantages for wet/high humidity conditions, chemically aggressive environments, light-duty service or high temperature applications.

Nylatron® Nylon as a Replacement for Metal 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.

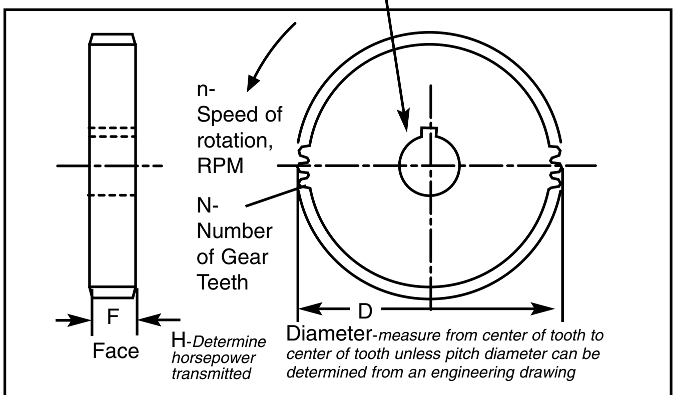
A step-by-step method for evaluating suitability of nylon spur gears is provided here.

This method was developed using Quadrant's gear fatigue test data, and the maximum allowable bending stress of plastic gear teeth (see Figure 23). In addition, four correction factors are provided which account for:

- **Material strength and the presence or absence of lubrication**
- **Pitch line velocity**
- **Required service life**
- **Ambient temperature under service conditions**

Fig. 22

Note: *Be sure to design in an .015" to .030" radius for keyway corners.*



Diametral Pitch (DP) is the ratio of N (number of teeth) to PD (pitch diameter) DP=N/PD. The Module (M) is the metric equivalent to DP.

Gear Design Method

Step 1

Obtain the Required Application Data
- Diametrical Pitch, P
- Number of Teeth, N
- Pressure Angle, PA
- Face Width, inches, f
- Input RPMs, n
- Input Torque, T_i

OR Input Horsepower, HP_i

Fig. 23 - **MAXIMUM TOOTH BENDING STRESSES VS. CYCLE LIFE FOR NYLON GEARS**

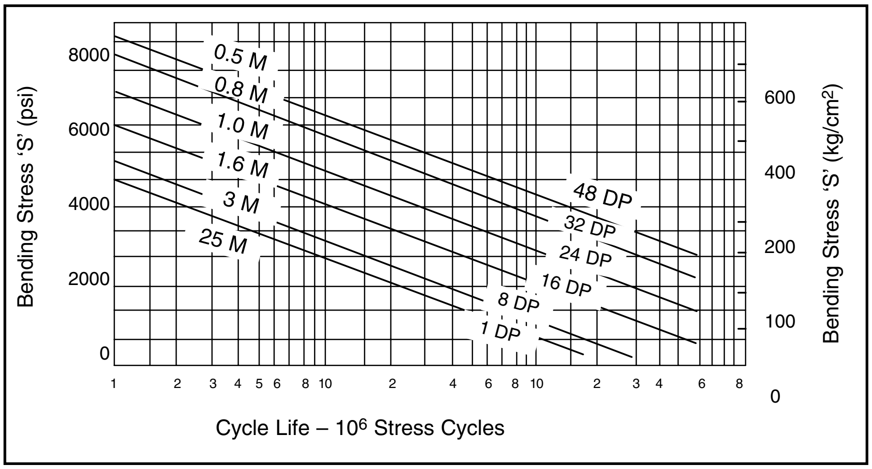


Table 10 : **Tooth Form Factor**

Number of Teeth	14 1/2°	20° Full Depth	20° Stub
14	–	–	0.540
15	–	–	0.566
16	–	–	0.578
17	–	0.512	0.587
18	–	0.521	0.603
19	–	0.534	0.616
20	–	0.544	0.628
22	–	0.559	0.648
24	0.509	0.572	0.664
26	0.522	0.588	0.678
28	0.535	0.597	0.688
30	0.540	0.606	0.698
34	0.553	0.628	0.714
38	0.566	0.651	0.729
43	0.575	0.672	0.739
50	0.588	0.694	0.758
60	0.604	0.713	0.774
75	0.613	0.735	0.792
100	0.622	0.757	0.808
150	0.635	0.779	0.830
300	0.650	0.801	0.855
Rack	0.660	0.823	0.881

Step 2

Obtain the Derived Data and Correction Factors

Pitch Diameter, $D_P = N/P$
Tooth Form Factor, y - From Table 10
Bending Stress, S_b - From Table 11
Service Lifetime Factor, C_s - From Table 12
Velocity Factor, C_v - From Table 13
Material Strength Factor, C_m - From Table 14
Temperature Correction Factor, C_T

- For ambient temperature <100ºF, $C_T = 1$
- For ambient temperature between 100ºF and 200ºF,

$$C_T = 1/(1 + \alpha\,(T-100^{\circ}F))$$

Where $\alpha = 0.022$ for Nylatron® GSM, NSM, and MC® nylons
$\alpha = 0.004$ for Nylatron® GS and Nylon 101
$\alpha = 0.010$ for Acetron® GP Acetal

Step 3

Calculate the Maximum Torque or Horsepower using Equations (1) and (2)

Maximum Torque

$$T_{MAX} = \frac{D_p\, S_b\, fy}{2P}\, C_s C_v C_m C_t \qquad \text{(Equation 1)}$$

$$HP_{MAX} = \frac{D_p\, S_b\, f\, y\, n}{126{,}000\, P}\, C_s C_v C_m C_t \qquad \text{(Equation 2)}$$

Table 11 : **Bending Stresses**

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

Table 12 : **Life Factors for Nylatron® Nylon Spur Gears**

Number of Cycles	16 pitch	10 pitch	8 pitch	5 pitch
1 million	1.26	1.24	1.30	1.22
10 million	1.0	1.0	1.0	1.0
30 million	0.87	0.88	0.89	0.89

Table 13 : **Velocity Correction Factors**

Velocity-fpm	Correction Factors
500	1.38
1000	1.18
2000	1
3000	0.93
4000	0.90
5000	0.88

Table 14 : **Material Strength Factor**

	Operating Conditions		
Material	Non-Lubrication	Periodic Lubrication	Continuous Lubrication
Nylatron® NSM	1.00	1.00	1.20
Nylatron® GS, GSM	0.49	0.94	1.26
MC® 901/907 Nylon	0.49	0.94	1.26
Acetron® GP Acetal	*	*	1.04
Phenolic	*	0.96	1.13
UHMW-PE	*	*	0.75

* Data not available.

Step 4

Compare the maximum torque (T_{MAX}) and maximum horsepower (H_{MAX}) values for the plastic gear with the known input torque (T_I) and/or horsepower (H_I).

T_I must be less than or equal to T_{MAX}
or
H_I must be less than or equal to H_{MAX}

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

GEAR DESIGN

Helical Gears

To determine the stress on plastic helical gears, spur gear design equations 1 and 2 are modified to compensate for the differing tooth contact forces. The tooth form factor Y is calculated from the formative number of teeth rather than the actual number using the equation:

$$N_f = \frac{N}{(\cos U)^3}$$

Where:

N_f = Formative number of teeth

N = Actual number of teeth

U = Helix angle (degrees)

In addition, the normal diametral pitch is used rather than the diametral pitch used for spur gears in equations (1) and (2). This is calculated from:

$$PN = \frac{P}{\cos U}$$

Where:

PN = Normal diametral pitch

It can be seen from these equations that the effect is more pronounced as the helix angle increases. Metal helical gears are often specified to reduce noise and vibration and it should be noted that the equivalent plastic spur gears will achieve these reductions more efficiently.

Bevel Gears

For bevel gears, the tooth form factor y is calculated using the formative number of the teeth using the equation:

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

Where:

$\varnothing$ = Pitch angle, degrees

It should be noted that Diametral Pitch and Pitch Diameter used in equations (1) and (2) refer to the outside or larger tooth dimensions of bevel gears.

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 an economical low torque gear**
- **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. The use of radiused keyways is preferred to square to reduce the stress concentration at the corners. The minimum corners keyway area is determined from the formula:**

$$A = \frac{63{,}000\ H}{n\ r\ Sk}$$

Where:

A = Keyway area

H = Horsepower transmitted

n = Gear speed (rpm's)

r = Mean keyway radius

Sk = Maximum permissible keyway stresses from Table 15

Table 15 : **Maximum Permissable Keyway Stress (Sk) for Continuously Running Gears**

Material	Sk (psi)
Nylatron® GS nylon	1,500
Nylatron® GSM/MC901	2,000
Nylon 6/6	1,500
Acetal	2,000
UHMW-PE	300

If the keyway size determined from the equation above 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.

Minimum number of bolts =

$$\frac{63{,}000\ HP}{n\ r_1\ A_1\ Sk}$$

Where:

r1 = Pitch circle radius of bolts

A1 = Projected area of bolts (bolt diameter x gear width in contact with bolts)

Raise fractional values to the next highest number of bolts. Should not be excessively tightened during assembly of the gear in order 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.

DESIGN 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).
- Sufficient backlash is required for plastic gears to accommodate the greater thermal expansion of plastic versus metal due to frictional heating and changes in ambient conditions. The suggested backlash can be calculated using:

$$\text{Backlash} = \frac{0.100}{P} \quad \text{(diametrical pitch)}$$

- A 20° pressure angle with a full root radius maximizes the bending strength of gear teeth over 14-1/2° pressure angles. This increases the load carrying capability by 15% over 14-1/2° pressure angle, or increases service life 3.5 times at the same load.
- 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 directly cast 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. min. is recommended on metal gears running against plastic gears.

CHEMICAL DATA

The following 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 for further information.

		Nylons											
Chemical	Concentration Weight, %	Nylon 101, Nylatron® GS	MC® 901, MC® 907, Nylatron® GSM, GSM Blue, Nylatron® NSM	Acetron® GP Acetal, Delrin*	Ertalyte® PET-P Ertalyte® TX	PC 1000 Polycarbonate	PSU 1000 Polysulfone	Ultem* 1000 PEI	Fluorosint® PTFE	Techtron® PPS	Ketron®, PEEK	Torlon* PAI	Celazole* Polybenzimidazole
Acetaldehyde Aq.	40	B	B	A	A	D	*	D	A	A	A	A	*
Acetamide Aq.	50	A	A	A	*	*	*	*	A	*	A	*	*
Acetic Acid Aq.	10	C	C	C	B	B	A	A	A	A	A	A	B
Acetone		A	A	A	B	D	D	C	A	A	A	A	A
Acrylonitrile		A	A	*	B	D	D	*	A	A	A	A	A
Alcohols, Aliphatic		B	B	A	A	A	A	A	A	A	A	A	*
Allyl Chloride		C	*	*	*	*	*	*	A	*	A	*	*
Allyl Alcohol		*	B	*	A	B	*	*	A	A	A	A	*
Aluminum Chloride Aq.	10	A	A	*	A	A	*	*	A	A	A	A	*
Aluminum Sulfate Aq.	10	A	A	A	*	A	A	*	A	A	A	A	*
Ammonia Aq.	10	A	A	A	A	*	*	*	A	A	A	B	C
Ammonia Gas		C	B	D	A	D	B	*	A	*	A	C	C
Ammonium Carbonate Aq.	10	A	A	*	A	B	*	*	A	A	A	A	*
Ammonium Chloride Aq.	10	D	B	A	A	A	A	*	A	A	A	A	*
	37	D	B	A	A	A	*	*	A	A	A	A	*
Amyl Acetate		B	D	A	*	D	D	B	A	A	A	A	*
Amyl Alcohol		*	A	*	*	B	A	*	A	A	A	A	*
Aniline		C	C	B	A	C	*	*	A	A	A	A	*
Antimony Trichloride Aq.	10	D	D	*	*	A	D	*	A	*	A	*	*
Barium Chloride Aq	10	D	B	A	*	A	A	*	A	A	A	A	*
Barium Sulfate Aq.	10	*	A	A	*	*	*	*	A	*	A	A	*
Barium Sulfide Aq.	10	A	*	*	*	*	*	*	A	*	A	A	*
Benzaldehyde		A	C	A	A	D	*	D	A	B	A	A	*
Benzene		A	A	A	A	D	D	D	A	A	A	A	*
Benzenesulfonic Acid		D	*	C	*	D	*	*	A	A	D	D	*
Benzyl Alcohol		C	D	A	A	D	*	*	A	A	A	A	*
Benzoic Acid Aq.	SAT	C	D	*	A	D	*	*	A	A	A	*	*
Beverages Aq. Alcoholic		B	B	A	A	A	A	A	A	A	A	A	A
Beverages Aq. Carbonated		B	B	A	A	A	A	A	A	A	A	A	A
Bitumen		B	B	A	*	*	*	*	A	*	A	*	*
Bleaching Lye	10	C	B	C	*	*	*	*	A	*	A	A	*
	100	C	B	C	*	*	*	*	A	*	A	*	*
Boric Acid Aq.	10	D	D	*	A	A	*	*	A	A	A	*	*
Boron Trifluoride		D	D	*	*	*	*	*	*	*	*	*	*
Bromine Aq.	30	D	D	D	*	D	A	*	*	A	B	A	*
Bromine Liq.		D	D	D	*	D	*	*	*	A	D	*	*
Butanol		B	B	A	B	A	B	A	A	A	A	A	A
Butyl Acetate		A	B	A	A	D	D	B	A	A	A	A	*
Butyl Phthalate		D	*	*	*	*	*	*	A	B	A	A	*
Butylene Glycol		A	B	*	B	B	*	A	A	A	A	*	A
Butylamine		A	*	D	*	D	*	D	A	B	A	A	*
Butyric Acid Aq.	20	D	B	A	*	D	*	*	A	A	A	*	*
Butyric Acid	CONC	D	B	*	*	D	*	*	A	A	A	*	*
Butyrolactone		*	A	A	B	C	*	*	A	*	A	A	*
Calcium Chloride Aq.	10	D	A	A	A	A	A	*	A	A	A	A	*
Calcium Chloride (in Alcohol)	20	D	D	A	*	*	*	*	A	A	A	*	*
Calcium Hypochlorite		D	D	D	A	A	B	*	A	A	A	A	*
Camphor		A	A	A	*	*	*	*	A	A	A	*	*
Carbon Disulphide		A	A	A	*	D	*	*	A	A	A	*	*
Carbon Tetrachloride		A	A	A	A	D	A	A	A	A	A	A	A
Carbonic Acid Aq.	10	A	*	A	A	*	*	*	A	A	A	*	*
Carnalite Aq.	10	*	A	*	*	*	*	*	A	*	A	*	*
Castor Oil		A	*	A	A	A	*	*	A	*	A	*	*
Catechol		*	C	*	*	*	*	*	*	*	A	*	*
Chloroacetic Acid Aq.	10	D	C	D	*	*	*	*	A	A	A	*	*
Chloral Hydrate		D	D	*	*	*	*	*	A	*	A	*	*
Chlorine Aq.	10	D	D	D	*	D	D	*	A	*	D	*	*
Chlorine Gas	100	*	D	D	*	B	*	*	A	*	A	*	A
Chlorobenzene		A	A	A	A	D	D	*	A	A	A	A	*
Chloroform		A	C	C	D	D	D	D	A	A	A	A	A
Chlorosulfonic Acid Aq.	10	D	C	D	*	*	*	*	A	D	D	*	*
Chrome Alum Aq.	10	A	*	*	*	A	*	*	A	*	A	*	*
Chromic Acid Aq.	1	D	C	B	A	A	A	A	A	A	A	A	*
Citric Acid Aq.	10	B	B	A	A	A	A	A	A	A	A	*	A
	SAT	C	C	*	A	*	A	*	A	A	A	*	*

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.

		Nylons											
Chemical	Concentration Weight, %	Nylon 101, Nylatron® GS	MC® 901, MC® 907, Nylatron® GSM, GSM Blue, NSM	Acetron® GP Acetal, Delrin*	Ertalyte® PET-P Ertalyte® TX	PC 1000 Polycarbonate	PSU 1000 Polysulfone	Ultem* 1000 PEI	Fluorosint® PTFE	Techtron® PPS	Ketron®, PEEK	Torlon* PAI	Celazole* Polybenzimidazole
Coconut Oil		A	A	*	*	*	*	*	A	A	A	*	*
Creosote		A	*	*	*	D	*	*	A	*	A	*	*
Cresols		D	D	*	*	D	D	*	A	A	A	*	*
Cresylic Acid		D	*	*	*	*	*	*	A	*	A	*	*
Cupric Chloride Aq.	10	D	*	A	A	A	A	*	A	A	A	*	*
Cupric Sulfate Aq.	0.5	*	B	A	A	A	*	*	A	A	A	*	*
	10	B	*	A	*	*	*	*	A	A	A	*	*
	SAT	*	B	*	*	*	*	*	A	A	A	*	*
Cyclohexane		A	A	A	A	B	B	A	A	A	A	A	A
Cyclohexanol		B	B	A	A	C	A	A	A	A	A	A	A
Cyclohexanone		A	A	A	A	D	D	*	A	A	A	A	A
Decalin		A	A	A	*	A	A	A	A	A	A	*	A
Detergents, Organic		A	A	A	A	A	A	A	A	A	A	*	A
Dibutylphthalate		A	A	A	*	D	*	B	A	*	A	A	*
Dichlorodifluoro Methane		A	A	A	A	D	D	D	A	B	A	*	A
Dichloroethylene		A	A	D	B	D	D	D	A	*	A	A	A
Diethyleneglycol Aq.	90	A	B	A	A	A	B	*	A	*	A	A	*
Diesel Oil		A	A	A	A	A	A	A	A	A	A	A	A
Dimethyl Carbinol		A	B	A	*	*	*	*	A	*	A	*	*
Dimethyl Aniline		A	*	*	B	D	D	D	A	A	A	A	*
Dimethyl Formamide		A	A	A	A	D	D	D	A	A	A	*	*
Dioxane		A	A	A	A	D	D	*	A	A	A	A	*
Edible Oils		A	A	A	A	A	B	A	A	A	A	A	A
Ethanol, Denatured	96	B	B	A	A	A	A	A	A	A	A	A	A
Ether, Diethyl		A	A	A	A	A	A	A	A	A	A	A	A
Ethyl Acetate		A	A	C	A	D	D	B	A	A	A	A	*
Ethyl Butyrate		A	*	*	*	D	D	B	A	*	A	A	*
Ethyl Chloride		*	A	A	*	*	*	*	A	A	A	A	*
Ethylene Chlorohydrin		D	*	*	*	D	*	*	A	*	A	*	*
Ethylene Chloride		B	B	A	C	C	C	C	A	A	A	A	A
Ethylene Diamine		B	A	A	*	C	B	C	A	D	A	D	*
Ethylene Dichloride		B	*	B	*	D	*	D	A	B	A	A	A
Ethylene Glycol Aq.	96	A	B	A	A	B	A	D	A	A	A	A	A
Ethylene Propionate		A	*	*	*	*	*	*	A	*	A	A	*
Ferric Chloride Aq.	5	B	B	A	A	A	A	*	A	A	A	A	*
	10	B	*	A	*	A	A	*	A	A	B	A	*
	SAT	C	C	*	*	*	*	*	A	A	B	A	*
Ferrous Chloride Aq.	10	B	C	A	*	*	*	*	A	A	A	A	*
Fluorine		D	D	D	*	*	*	*	C	*	D	*	*
Fluosilicic Acid Aq.	10	D	C	*	*	A	*	*	B	A	*	*	*
Fluothane		A	A	*	*	*	*	*	A	*	A	*	*
Freon 12 (Arcton 12)		A	A	A	A	D	A	*	A	B	A	*	A
Formaldehyde Aq.	10	A	B	A	A	A	C	A	A	A	A	A	*
Formic Acid Aq.	3	D	D	D	B	A	*	A	A	A	B	C	D
	10	D	D	D	C	B	D	A	A	A	B	C	D
Fruit Juices	CONC	A	B	A	A	A	A	*	A	A	A	A	*
Furfural		A	B	A	*	*	D	*	A	A	A	B	*
Gasoline		A	A	A	A	D	B	B	A	A	A	A	A
Glycerine		A	B	A	A	A	B	*	A	A	A	A	*
Heptane		A	A	A	A	A	A	A	A	A	A	A	A
Hexane		A	A	A	A	A	B	A	A	A	A	A	A
Hydrobromic Acid Aq.	10	D	C	D	*	*	B	*	A	B	D	A	*
Hydrochloric Acid Aq.	0.4	B	B	C	A	A	A	A	A	A	A	A	B
	2	C	D	D	B	A	A	A	A	A	A	A	D
	10	D	D	D	C	A	A	A	A	B	A	A	D
Hydrofluoric Acid Aq.	4	D	C	D	B	A	A	*	C	B	D	*	*
Hydrogenated Vegetable Oils		A	A	A	A	*	*	*	A	A	A	A	*
Hydrogen Peroxide Aq.	0.5	D	*	A	A	A	A	A	A	A	A	*	A
	1	D	C	B	A	A	A	A	A	A	A	*	A
	3	D	C	B	A	A	A	A	A	A	A	*	A
Hydrogen Sulfide Aq.	SAT	C	C	C	C	A	*	*	A	A	A	*	*
Hydroquinone		B	B	*	*	*	*	*	A	*	A	*	*
Iodine (in Alcohol)		D	D	*	*	D	*	*	A	*	A	*	*
Iodine (in Pt. Iodine) Aq.	3	D	C	*	*	D	*	*	A	*	A	*	*
Iso octane		A	A	A	A	A	B	B	A	A	A	A	A
Isopropyl alcohol		B	B	A	A	A	B	A	A	A	A	A	A
Isopropyl Ether		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	*
	90	C	D	*	*	*	*	*	A	A	A	A	*
Lead Acetate Aq.	10	B	B	A	*	*	*	*	A	A	A	A	*
Lead Stearate		A	A	*	*	*	*	*	A	*	A	*	*
Linseed Oil		A	A	A	*	A	A	*	A	A	A	*	*
Lithium Bromide Aq.	50	D	D	A	*	*	*	*	A	*	A	*	*

The following 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 for further information.

		Nylons											
Chemical	Concentration Weight, %	Nylon 101, Nylatron® GS	MC® 901, MC® 907, Nylatron® GSM, GSM Blue, Nylatron® NSM	Acetron® GP Acetal, Delrin*	Ertalyte® PET-P Ertalyte® TX	PC 1000 Polycarbonate	PSU 1000 Polysulfone	Ultem* 1000 PEI	Fluorosint® PTFE	Techtron® PPS	Ketron®, PEEK	Torlon* PAI	Celazole* Polybenzimidazole
Lubricating Oils (Petroleum)		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	*
Magnesium Hydroxide Aq.	10	A	A	A	B	*	*	*	A	A	A	D	*
Magnesium Sulfite Aq.	10	A	A	A	*	*	*	*	A	A	A	A	*
Maleic Acid Aq.	CONC	*	C	*	*	*	*	*	A	*	A	*	*
Malonic Acid Aq.	CONC	*	C	*	*	*	B	*	A	*	A	*	*
Manganese Sulfate Aq.	10	A	A	A	A	*	*	*	A	*	A	*	*
Mercuric Chloride Aq.	6	C	D	B	*	A	*	*	A	*	A	*	*
Mercury		A	A	A	A	A	*	*	A	A	A	*	*
Methanol		A	B	A	A	B	B	A	A	A	A	*	A
Methyl Acetate		A	A	A	A	D	*	B	A	A	A	A	*
Methyl Ethyl Ketone		A	A	B	A	D	B	D	B	B	A	A	A
Methylpyrrolidone		A	A	*	*	*	D	*	A	A	A	*	*
Methylene Chloride		B	B	C	D	D	D	C	A	A	A	A	C
Methy Phenyl Ether		A	*	*	A	*	*	*	A	A	A	A	*
Milk		A	A	A	A	A	A	A	A	A	A	A	A
Mineral Oils		A	A	A	*	A	A	A	A	A	A	A	A
Naphthalene		A	A	A	A	D	D	D	A	A	A	*	
Nickel Sulfate Aq.	10	A	A	*	*	A	*	*	A	A	A	*	
Nicotine		D	D	*	*	*	*	*	*	*	A	*	
Nitric Acid Aq.	0.1	C	C	D	B	A	A	A	A	A	A	A	B
	10	D	D	D	C	A	C	A	A	B	A	A	C
Nitrobenzene		C	B	B	D	D	D	D	A	A	A	A	*
Nitromethane		A	B	*	B	A	D	*	A	A	A	A	*
Oleic Acid		A	A	A	A	A	A	*	A	A	A	*	*
Oxalic Acid Aq.	10	C	B	C	*	A	A	*	A	A	A	*	*
Ozone		C	C	C	A	D	A	*	A	*	A	*	*
Paraffin		A	A	A	A	A	A	A	A	A	A	A	A
Perchloroethylene		B	B	B	A	C	*	C	A	A	A	A	A
Perchloric Acid Aq.	10	D	C	C	A	*	*	*	A	*	A	*	
Petroleum Ether		A	A	A	*	A	*	*	A	A	A	A	
Phenol Aq.	6	D	D	D	A	D	*	*	A	*	B	*	A
	75	D	D	D	C	D	D	D	A	*	D	*	A
Phenol (Molten)		D	D	D	C	D	D	D	A	*	B	*	
Phosphoric Acid Aq.	0.3	*	B	C	A	A	A	A	A	A	A	A	B
	3	D	C	C	A	A	A	A	A	A	A	A	C
	10	D	D	D	B	A	A	A	A	A	A	A	C
Phthalic Acid Aq.	SAT	B	B	A	*	*	*	*	A	*	A	*	*
Phthalic Dioctyl		A	A	*	*	*	*	*	A	A	A	*	*
Potassium Acetate Aq.	50	A	A	A	*	*	*	*	A	*	A	A	*
Potassium Bicarbonate Aq.	60	A	A	A	A	*	*	*	A	A	A	A	*
Potassium Bromide Aq.	10	A	A	A	A	A	*	*	A	A	A	A	*
Potassium Carbonate Aq.	60	A	A	A	A	*	*	A	A	A	A	A	*
Potassium Chloride Aq.	90	A	A	A	A	A	*	*	A	A	A	A	*
Potassium Dichromate Aq.	5	C	B	A	A	A	*	*	A	A	A	A	*
Potassium Ferricyanide Aq.	30	A	B	*	A	*	*	*	A	*	A	*	*
Potassium Ferrocyanide Aq.	30	A	B	*	*	*	*	*	A	*	A	*	*
Potassium Hydroxide Aq.	10	C	A	A	C	C	A	A	B	A	A	D	*
	50	C	A	D	C	D	B	*	C	A	A	D	*
Potassium Nitrate Aq.	10	A	A	B	A	A	A	*	A	A	A	*	*
Potassium Permanganate Aq.	1	D	C	A	A	A	A	*	A	A	A	A	*
Potassium Sulfite Aq.	CONC	A	A	*	*	*	*	*	A	A	A	A	*
Potassium Sulfite Aq.	90	A	*	*	*	*	*	*	A	*	A	A	*
Propane Gas		A	A	A	A	A	*	*	A	A	A	*	A
Pyridine		A	A	B	*	D	D	*	A	*	A	D	*
Resorcinol		D	D	*	*	*	*	*	A	*	A	*	*
Salicylic Acid		A	A	D	A	*	*	*	A	*	A	*	*
Silicone Fluids		A	A	A	A	A	*	*	A	A	A	A	A
Silver Nitrate		A	A	A	A	A	*	*	A	A	A	A	*
Soap Solutions		A	A	A	A	A	A	A	A	A	A	A	A
Sodium (Molten)		*	*	C	*	*	*	*	B	*	D	*	*
Sodium Acetate Aq.	60	A	B	A	A	*	*	*	A	A	A	A	*
Sodium Benzoate Aq.	10	A	*	A	A	*	*	*	A	*	A	A	*
Sodium Bicarbonate Aq.	50	A	A	A	A	A	*	*	A	A	A	A	*
Sodium Bisulphite Aq.	10	A	A	D	A	A	*	*	A	A	A	A	*
Sodium Bromide Aq.	10	A	B	A	A	*	*	*	A	A	A	A	*
Sodium Carbonate Aq.	20	A	B	A	A	*	*	*	A	A	A	A	A
	50	A	*	A	*	*	*	*	A	A	A	A	*
Sodium Chlorate Aq.	10	A	B	A	*	A	*	*	A	A	A	A	*
Sodium Chloride Aq.	10	A	B	A	A	A	A	*	A	A	A	A	*
	90	A	B	A	A	A	*	*	A	A	A	A	*
Sodium Cyanide Aq.	10	A	*	A	*	A	*	*	A	A	A	*	*
Sodium Hydroxide Aq.	10	C	D	D	C	C	A	A	B	A	A	D	B

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.

		Nylons											
Chemical	Concentration Weight, %	Nylon 101, Nylatron®GS	MC® 901, MC® 907, Nylatron® GSM, GSM Blue, NSM	Acetron® GP Acetal, Delrin*	Ertalyte® PET-P Ertalyte® TX	PC 1000 Polycarbonate	PSU 1000 Polysulfone	Ultem* 1000 PEI	Fluorosint® PTFE	Techtron® PPS	Ketron®, PEEK	Torlon* PAI	Celazole* Polybenzimidazole
Sodium Hydroxide Aq.	50	D	D	D	C	D	C	D	C	B	A	D	C
Sodium Hypochlorite 15% Cl (Chlorine Bleach)		D	C	D	A	A	A	*	A	A	A	A	B
Sodium Nitrate Aq.	50	A	A	A	A	C	*	*	A	A	A	*	*
Sodium Perborate Aq.	10	B	*	A	*	*	*	*	A	*	A	*	*
Sodium Phosphate Aq.	90	A	*	*	*	*	*	*	A	*	A	*	*
Sodium Silicate		A	A	*	A	A	B	*	A	A	A	*	*
Sodium Sulfate Aq.	90	A	A	*	A	A	*	*	A	A	A	A	*
Sodium Sulfide Aq.	90	A	*	*	B	*	*	*	A	A	A	A	*
Sodium Thiosulfate Aq.	10	A	A	A	A	A	A	*	A	A	A	*	*
Stannic Chloride Aq.	10	D	*	D	*	A	A	A	A	A	A	*	A
Stannic Sulfate Aq.	10	D	C	*	*	*	*	*	A	A	A	*	*
Stearic Acid		A	A	A	*	*	*	*	A	*	A	*	*
Styrene (Monomer)		A	A	A	C	D	*	*	A	A	A	*	*
Sulfur		A	A	A	A	A	*	*	A	*	A	*	*
Sulfur Dioxide (Dry Gas)	100	C	A	D	B	A	*	*	A	A	A	A	*
Sulfuric Acid Aq.	2	C	C	D	A	A	A	A	A	A	A	A	B
	5	D	D	D	A	A	A	A	A	A	A	A	B
Sulfuric Acid Conc.		D	D	D	C	D	D	D	A	B	D	*	*
Sulfurous Acid Aq.	10	A	*	D	*	A	A	A	A	A	A	*	B
Tallow		A	A	A	*	A	A	A	A	A	A	A	A
Tar		B	B	A	*	*	*	*	A	A	A	A	*
Tartaric Acid Aq.	10	B	A	A	*	A	*	*	A	A	A	*	*
Tetrachlorethylene		A	C	A	B	D	D	A	B	*	A	*	*
Tetrahydrofuran		A	A	B	A	D	*	*	A	A	A	A	A
Tetralin		A	A	A	A	*	*	*	A	*	A	*	*
Thionyl Chloride		D	C	B	*	*	*	*	A	*	A	*	*
Thiophene		A	*	*	*	D	*	*	A	*	A	*	*
Toluene		A	A	B	A	D	D	D	A	A	A	A	A
Transformer Oil		A	A	A	*	A	A	*	A	A	A	A	*
Trichlorethylene		B	B	D	B	D	D	D	A	A	A	A	*
Triethanolamine		A	A	A	B	D	C	D	A	A	A	D	*
Turpentine		A	A	A	*	B	C	*	A	A	A	A	*
Trisodium Phosphate Aq.	95	*	B	A	A	A	*	*	A	A	A	*	*
Urea		A	A	A	A	A	*	*	A	A	A	*	*
Vaseline		A	A	A	A	A	A	A	A	A	A	A	A
Vegetable Oils		A	A	A	A	A	A	A	A	A	A	A	A
Vinegar		C	C	B	A	A	*	A	A	A	A	A	A
Vinyl Chloride		A	A	*	*	*	*	*	A	A	A	*	*
Water		A	A	A	A	A	A	A	A	A	A	A	A
Wax (Molten)		A	A	A	A	A	A	A	A	A	A	A	A
White Spirit		A	A	A	*	*	*	*	A	A	A	*	*
Wines & Spirits		B	B	A	A	A	*	A	A	A	A	A	A
Xylene		A	A	A	A	D	D	C	A	A	A	A	A
Xylenol		D	D	A	*	D	D	B	A	*	A	A	A
Zinc Chloride Aq.	10	C	B	D	A	A	A	A	A	A	A	*	*
Zinc Oxide		A	A	C	*	*	*	*	A	A	A	*	*
Zinc Sulfate Aq.	10	A	*	C	*	A	*	*	A	A	A	*	*

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.

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 Quadrant Engineering Plastic at 1-800-366-0310.

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. 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. Materials used in this equipment are approved on an individual basis. Determining suitability for use of components and the materials from which they are made is the responsibility of the equipment manufacturer. On request, Quadrant will supply a "letter of guarantee" for a Quadrant product listed as USDA compliant. This letter certifies that the material meets applicable FDA criteria. Supporting documentation as may be required by the Food Safety Inspection Service of USDA, is also available.

Canada AG

Agriculture Canada (Food Production and Inspection Branch of the Canadian Government) is the Canadian government agency equivalent to the USDA. As with the USDA, plastic materials are approved per material for a group of related applications, such as Acetron® GP acetal (material) for meat and poultry processing (application).

3A-Dairy

3A-Dairy 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 milk and milk products. The criteria for approval of plastic materials are specified in 3A standard 20-18, 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 all direct and indirect drinking water additives. Manufacturers who provide equipment displaying the NSF symbol have applied to the NSF for device approval to a specific standard. The approval is issued for the finished product (device) in a specific use (application). To obtain device approval, all components within the device must comply with the Standard. Establishing compliance of the equipment's components can be accomplished in one of two ways:

1. The component has been tested to the Standard by the component supplier and is certified as such.
2. The equipment manufacturer must supply documentation that the component meets the Standard. If any testing is required, it must be completed by the equipment manufacturer.

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

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.

No Quadrant material is suitable for implantable medical devices.

MATERIAL	Product Family	COLOR	FDA	USDA	NSF	3A–DAIRY	CANADA AG	USP CLASS VI[Δ]	Typical Applications (Structural or Wear)
Acetron® GP	Acetal	Natural	YES	YES	STD 51 & 61	YES	YES	NO	Both
Delrin*	Acetal	Natural	YES	YES	STD 61	NO	YES	NO	Both
Delrin* AF Blend	Acetal	Brown	NO	NO	NO	NO	NO	NO	Bearing & Wear
Ertalyte® PET–P	Polyester	Natural	YES	YES	NO	YES	YES	NO	Both
Ertalyte® PET–P	Polyester	Black	YES	YES	NO	NO	NO	NO	Both
Ertaltye® TX	Polyester	Gray	YES	YES	NO	YES	NO	NO	Both
Fluorosint® 207	PTFE	Natural	YES	YES	NO	NO	NO	NO	Bearing & Wear
Fluorosint® 500	PTFE	Natural	NO	NO	NO	NO	NO	NO	Both
Ketron® PEEK	PEEK	Natural	YES	YES	NO	YES	NO	NO	Both
MC® 901	Nylon 6	Blue	NO	NO	NO	NO	NO	NO	Both
MC® 907	Nylon 6	Natural	YES	YES	NO	YES	NO	NO	Both
Nylatron® GS	Nylon 66	Black-Grey	NO	NO	NO	NO	NO	NO	Both
Nylatron® GSM	Nylon 6	Black-Grey	NO	NO	NO	NO	NO	NO	Bearing & Wear
Nylatron® GSM Blue	Nylon 6	Dark Blue	NO	NO	NO	NO	NO	NO	Bearing & Wear
Nylatron® NSM	Nylon 6	Grey	NO	NO	NO	NO	NO	NO	Bearing & Wear
Nylon 101	Nylon 66	Natural	YES	YES	STD 61	YES	NO	NO	Both
Polycarbonate	PC	Natural	NO	NO	NO	NO	NO	NO	Structural
Polysulfone	PS	Natural	YES	YES	STD 61	YES	NO	YES	Structural
Radel* R	PPSU	Natural	NO	NO	NO	NO	NO	YES	Structural
Techtron®	PPS	Natural	NO	NO	NO	NO	NO	NO	Structural
Ultem* 1000	PEI	Natural	YES	YES	STD 51	NO	NO	YES	Structural

Celazole* PBI, Torlon* PAI and all fiber-reinforced (i.e. glass, carbon) materials available from Quadrant are neither FDA, USDA nor 3A-Dairy compliant.

[Δ] No Quadrant Engineering Plastic Products' materials are suitable for implantable devices.

Table 16

[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 42 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

- ➜ **Positive tool geometries with ground peripheries are recommended**
- ➜ **Carbide tooling with polished top surfaces is suggested for optimum tool life and surface finish. Diamond coated or polycrystalline tooling provides optimum surface finish when machining Celazole* 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 PC 1000 Polycarbonate, PSU 1000 Polysulfone, Ultem* 1000 PEI, and Radel* R PPSU.

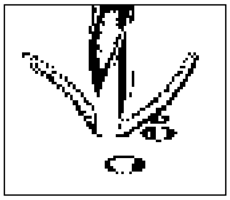
MACHINING TIPS

- Coolants are strongly suggested during drilling operations, especially with notch sensitive materials such as Ertalyte® PET-P, Torlon* PAI, Celazole* 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 9106CS (Master Chemical Corporation–Perrysburg, OH) and Polycut (Tullco – Savannah, GA). A generally suitable mist coolant is Astro-Mist 2001A (Monroe Fluid Technology–Hilton, NY).

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.

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 and 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.

Table 17 : **Fabrication Guidelines for All Quadrant Materials Turning and Drilling Operations**

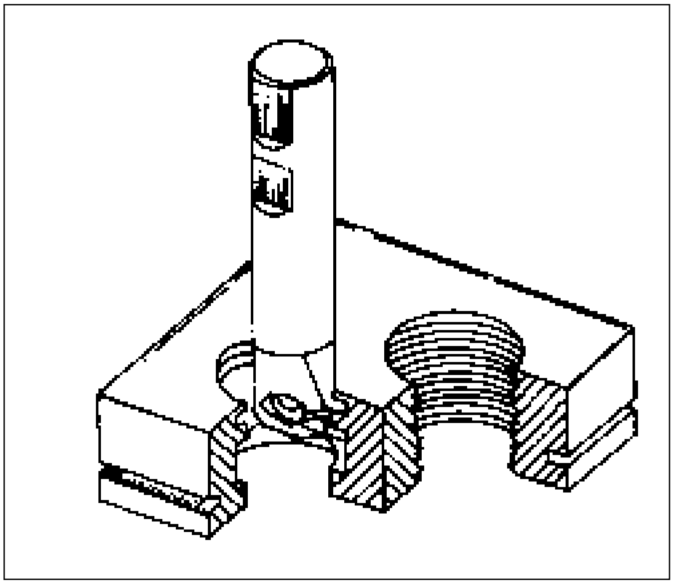
Material	Relative Machinability (1 to 10 1=easiest)	Turning			Drilling**	
		Depth of Cut	Speed Feet/Min.	Feed, In./Rev.	Nominal Hole Diameter	Feed, In./Rev.
Acetron® GP	1	.150” deep cut	500-600	.010-.015	1/16"	.007-.015
Delrin*, Delrin* AF	1	.025” deep cut	600-700	.004-.007	1/8"	"
Delrin* AF Blend	1				1/4"	"
Nylon 101	1				1/2"	.015-.025
Nylatron® GS, GSM	1				3/4"	"
Nylatron® GSM Blue	1				1"	.020-.050
Nylatron® NSM	1				1 1/2"	"
MC® 901, MC® 907 Nylon	1				2" or larger	"
PC 1000 Polycarbonate	3					
PSU 1000 Polysulfone	3					
Ultem* 1000 & 2300 PEI	7					
Fluorosint® 500	1	.150” deep cut	350-500	.010-.015	1/16"	.007-.015
Fluorosint® 207	1	.025” deep cut	500-600	.003-.008	1/8"	"
					1/4"	"
					1/2"	.015-.025
					3/4"	"
					1"	.020-.050
					1 1/2"	"
					2" or larger	"
Ketron® PEEK	5	.150” deep cut	600-1000	.010-.016	1/16"	.002-.005
Ketron® PEEK 30% GF	7	.025” deep cut	600-700	.004-.007	1/8"	"
Ketron® PEEK 30% CF	7				1/4"	"
Ketron® PEEK HPV					1/2"	.004-.008
					3/4"	"
					1"	.008-.012
					1 1/2	"
					2" or larger	"
Ertalyte® PET-P	2	.150” deep cut	500-600	.010-.015	1/16"	.002-.005
Ertalyte® TX		.025” deep cut	600-700	.004-.007	1/8"	"
					1/4"	"
					1/2"	.015-.025
					3/4"	"
					1"	.020-.050
					1 1/2"	"
					2" or larger	"
Techtron® PPS	3	.150” deep cut	100-300	.010-.020	1/16"	.007-.015
Techtron® HPV	6	.025” deep cut	250-500	.005-.010	1/8"	"
Ryton* PPS	5				1/4"	"
Ryton* BG PPS					1/2"	.015-.025
					3/4"	"
					1"	.020-.050
					1 1/2"	"
					2" or larger	"
Torlon* 4203 PAI	5	.025” deep cut	300-800	.004-.025	1/16"	.007-.015
Torlon* 4301 PAI	5				1/8"	"
Torlon* 4501 PAI	6				1/4"	"
Torlon* 4503 PAI	6				1/2"	.015-.025
Torlon* 4540 PAI	6				3/4"	"
Torlon* 5530 PAI	8				1"	.020-.050
					1 1/2"	"
					2” or larger	"
Celazole* PBI	10	.025” deep cut	150-225	.002-.006	1/2" or larger	.015-0.25

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

FABRICATION GUIDELINES

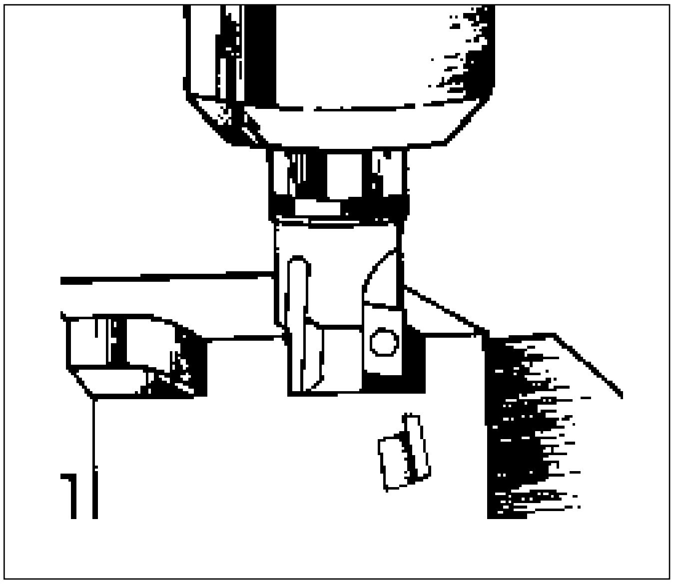
Threading and Tapping

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 tap. Remember to keep the tap clean of chip build-up. Use of a coolant during tapping is also suggested.



Milling

Sufficient fixturing allows fast table travel and high spindle speeds when end milling plastics. When face milling, use either high positive or high shear geometry cutter bodies.



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.

MACHINING 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.

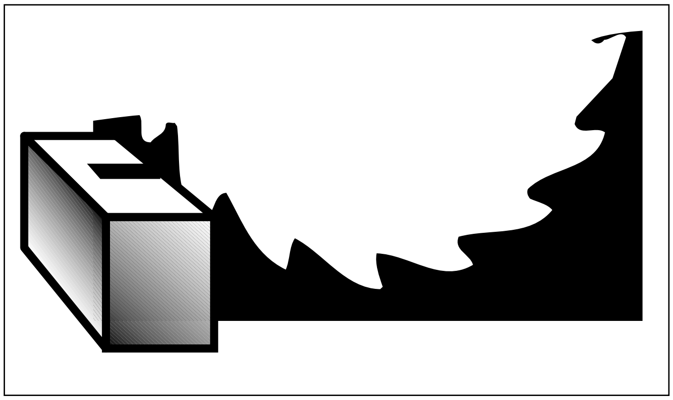


Table 18 : **Fabrication Guidelines–Milling and Sawing**

	End Milling / Slotting				Face Milling (C-2) Carbide Tool			Sawing			
	High Speed Steel (M2, M7)	Depth of Cut	Speed, Ft./Min.	Feed, In./Tooth	Depth of Cut	Speed, Ft./Min.	Feed, In./Tooth	Material Thickness	Tooth Form	Pitch Teeth/In.	Band Speeds Ft./Min.
Acetron® GP Acetal	1/4"	0.250	270-450	0.002	0.150	1300-1500	0.020	<1/2"	Precision	10-14	3,000
Delrin* 150 Acetal, Delrin* AF	1/2"	"	"	0.003	0.060	1500-2000	0.005	1/2"-1"	"	6	2,500
Delrin* AF Blend	3/4"	"	"	0.005				1"-3"	Butress	3	2,000
Nylon 101, Nylatron® GS	1", 2"			0.008				3"	"	"	1,500
Nylon, Nylatron® GSM, GSM Blue	1/4"	0.050	300-500	0.001							
Nylatron® NSM	1/2"	"	"	0.002							
MC® 901 Nylon, MC® 907 Nylon	3/4"	"	"	0.004							
PC 1000 Polycarbonate	1/4"	0.250	270-450	0.002	0.150	1300-1500	0.020	<1/2"	Precision	10-14	4,000
PSU 1000 Polysulfone	1/2"	"	"	0.003	0.060	1500-2000	0.005	1/2"-1"	"	6	3,500
Ultem* 1000 PEI	3/4"	"	"	0.005				1"-3"	Butress	3	3,000
Ultem* 2300 PEI	1", 2"	"	"	0.008				3"	"	"	2,500
	1/4"	0.050	300-500	0.001							
	1/2"	"	"	0.002							
	3/4"	"	"	0.004							
Ketron® PEEK	1/4"	0.250	270-450	0.002	0.150	500-750	0.020	<1/2"	Precision	8-14	4,000
Ketron® PEEK HPV	1/2"	"	"	0.003	0.060	"	0.005	1/2"-1"	"	6-8	3,500
	3/4"	"	"	0.005				1"-3"	Butress	3	3,000
	1", 2"	"	"	0.008				3"	"	"	2,500
	1/4"	0.050	300-500	0.001							
	1/2"	"	"	0.002							
	3/4"	"	"	0.004							
Fluorosint® 500	1/4"	0.250	270-450	0.002	0.150	500-700	0.010	<1/2"	Precision	8-14	3,000
Fluorosint® 207	1/2"	"	"	0.003	0.060	550-750	0.005	1/2"-1"	"	6-8	2,500
	3/4"	"	"	0.005				1"-3"	Butress	3	2,000
	1", 2"	"	"	0.008				3"	"	"	1,500
	1/4"	0.050	300-500	0.001							
	1/2"	"	"	0.002							
	3/4"	"	"	0.004							
Techtron® PPS	1/4"	0.250	270-450	0.002	0.150	1300-1500	0.020	<1/2"	Precision	8-14	5,000
Techtron® HPV	1/2"	"	"	0.003	0.060	1500-2000	0.005	1/2"-1"	"	6-8	4,300
Ryton* PPS	3/4"	"	"	0.005				1"-3"	Butress	3	3,500
	1", 2"	"	"	0.008				3"	"	"	3,000
	1/4"	0.050	300-500	0.001							
	1/2"	"	"	0.002							
	3/4"	"	"	0.004							
Torlon* PAI	1/4"	0.50	270-450	0.002	0.035	500-800	.006-.035	<1/2"	Precision	8-14	5,000
	1/2"	"	"	0.003				1/2"-1"	"	6-8	4,300
	3/4"	"	"	0.005				1"-3"	Butress	3	3,500
	1", 2"	"	"	0.008				3"	"	"	3,000
	1/4"	0.050	300-500	0.001							
	1/2"	"	"	0.002							
	3/4"	"	"	0.004							
Ertalyte® PET-P	1/4"	0.250	270-450	0.002	0.150	1300-1500	0.020	<1/2"	Precision	10-14	5,000
Ertalyte® TX	1/2"	"	"	0.003	0.060	1500-2000	0.005	1/2"-1"	"	6	4,300
	3/4"	"	"	0.005				1"-3"	Butress	3	3,500
	1", 2"	"	"	0.008				3"	"	"	3,000
	1/4"	0.050	300-500	0.001							
	1/2"	"	"	0.002							
	3/4"	"	"	.004							
Celazole* PBI	1/2"							3/8"-1"	Precision	10	3,000
	3/4"							1"-2"	Butress	10	1,500
	1", 2"										
	1/4"	0.015	250-350	0.002	0.015	250-350	.002-.006				
	1/2"										
	3/4"										

FABRICATION GUIDELINES

Table 19 : **Troubleshooting Quick Reference**

Drilling

Difficulty	Common Cause
Tapered hole	1. Incorrectly sharpened drill 2. Insufficient clearance 3. Feed too heavy
Burnt or melted surface	1. Wrong type drill 2. Incorrectly sharpened drill 3. Feed too light 4. Dull drill 5. Web too thick
Chipping of surfaces	1. Feed too heavy 2. Clearance too great 3. Too much rake (thin web as described)
Chatter	1. Too much clearance 2. Feed too light 3. Drill overhang too great 4. Too much rake (thin web as described)
Feed marks or spiral lines on inside diameter	1. Feed too heavy 2. Drill not centered 3. Drill ground off-center
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 2. Spindle speed too fast 3. Insufficient lubrication from coolant

Cutting Off

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

ANNEALING

When should parts be annealed after machining to ensure optimum part performance?

Experience has shown us that very few machined plastic parts require annealing after machining to meet dimensional or performance requirements.

All Quadrant stock shapes are annealed using a proprietary stress relieving cycle to minimize any internal stresses that may result from the manufacturing process. This assures you that the material will remain dimensionally stable during and after machining.

Machined-in stress can reduce part performance and lead to 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**

To reduce the potential for machined-in stress, review the fabrication guidelines for the specific material. Recognize that guidelines change as the material type changes.

Benefits of Post-Machining Annealing

- **Improved Chemical Resistance**
  Polycarbonate, polysulfone, and Ultem* PEI, like many amorphous (transparent) plastics may be annealed to minimize stress crazing. Torlon* PAI also benefits from post machining annealing. Annealing finished parts becomes more important as machining volume increases. Annealing after machining reduces "machined-in" stresses that can contribute to premature failure.
- **Better Flatness and Tighter Tolerance Capability**
  Extremely close–tolerance parts requiring precision flatness and non-symmetrical contour sometimes require intermediate annealing between machining operations. Improved flatness can be attained by rough machining, annealing and finish machining with a very light cut. Balanced machining on both sides of the shape centerline can also help prevent warpage.
- **Improved Wear Resistance**
  Extruded or injection molded Torlon PAI parts that require high PV's or the lowest possible wear factor benefit from an additional cure after machining. This curing process optimizes the wear properties. Only PAI benefits from such a cycle.

Table 20 : **Post Machining Air Annealing Guidelines**

Material	Heat Up	Hold	Cool Down	Environment
Type 6 Nylons	4 hours to 300°F	30 minutes per 1/4" thickness	50°F per hour	Oil or Nitrogen
Type 6/6 Nylons	4 hours to 350°F	30 minutes per 1/4" thickness	50°F per hour	Oil or Nitrogen
Ertalyte® PET–P	4 hours to 350°F	30 minutes per 1/4" thickness	50°F per hour	Oil or Nitrogen
Acetron® GP Acetal	4 hours to 310°F	30 minutes per 1/4" thickness	50°F per hour	Nitrogen or Air
Delrin*	4 hours to 320°F	30 minutes per 1/4" thickness	50°F per hour	Nitrogen or Air
PC 1000 Polycarbonate	4 hours to 275°F	30 minutes per 1/4" thickness	50°F per hour	Air
PSU 1000 Polysulfone	4 hours to 330°F	30 minutes per 1/4" thickness	50°F per hour	Air
Radel* R PPSU	4 hours to 390°F	30 minutes per 1/4" thickness	50°F per hour	Nitrogen or Air
Ultem* PEI	4 hours to 390°F	30 minutes per 1/4" thickness	50°F per hour	Air
Techtron® PPS	4 hours to 350°F	30 minutes per 1/4" thickness	50°F per hour	Air
Ketron® PEEK	2 hours to 300°F 2 hours to 375°F	60 minutes per 1/4" thickness 60 minutes per 1/4" thickness	50°F per hour	Air
Torlon* PAI	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

Finish machining of critical dimensions should be performed after annealing.

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

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