TECHNICAL NOTE

Tubing Bend Radius

The question is often raised as to what is the minimum bend radius of a specific size of tubing. The bend radius is established primarily by three different factors: diameter, wall thickness, and resin. YOZONE prides itself in its sample program through which we work with companies to find the right material and perfect size.

As a general guide, however, we have performed a series of bend tests that we hope will guide you in determining the size that is most suitable for you.

The following is a guide to the bend radius of our PTFE Industrial Wall tubing: Based on a minimum of 36″ lengths:

Size	Diameter*
1/32″ Industrial	.660″
1/16″ Industrial	1.375″
3/32″ Industrial	2.00″
1/8″ Industrial	3.25″
3/16″ Industrial	4.00″
1/4″ Industrial	6.50″
5/16″ Industrial	8.00″
3/8″ Industrial	9.00″
7/16″ Industrial	9.50″
1″ Industrial	12.00″

*Please Note: The bend radius is 1/2 the diameter.

Biocompatibility and Certified USP Class VI Approved Resins

YOZONE is proud to offer USP Class VI resin to meet the unique requirements of the medical device manufacturing community.

The following resins are certified USP Class VI approved, used for medical, diagnostic, and analytical applications consisting of extruded tubing, heat shrink tubing, profiles and multi- lumens:

- PTFE - Polytetrafluoroethylene
- FEP - Fluorinatedethylenepropylene
- PFA - Perfluoroalkoxy
- ETFE - Ethylenetetrafluoroethylene
- PEEK™ - Polyetheretherketone

In addition, YOZONE has certified USP Class VI tests for many pigments and compounds used in conjunction with USP Class VI-tested resins.

YOZONE has tested the resins and pigments meet the following USP Plastics Class VI requirements:

Biological Reactivity

- Systemic Injection (Acute Systemic Toxicity, Mice)
- Intracutaneous Test (Intracutaneous Toxicity, Rabbits)
- Implantation Test (Implant, Rabbits)

In addition to the extensive testing YOZONE does on their resins, we offer 100 percent traceability on all your orders. You can be assured that when you purchase your tubing from YOZONE, it will pass subsequent traceability test requirements. Additional testing may also be available for certain resins.

TECHNICAL NOTE

Burst Pressure

YOZONE has been supplying fluoropolymer tubing to manufacturers of high pressure devices since our inception. The innate strength of all fluoropolymers make their use in these kinds of applications an ideal choice. Below, you will find a formula for calculating the maximum burst pressure by using Tensile Strength Values.

The theoretical burst pressure of tubing at ambient temperature can be calculated by using the ID and OD dimensions in inches and the tensile strength at yield in pounds per square inch.

The following formula is to be used as a guide in the design process. It does not consider factors such as steam pressure and elevated temperature, altitude, etc., and it is calculated at ambient room temperature. The burst pressure result is meant as a guideline in design, not a definitive number.

$$P = \frac{T(OD^2 - ID^2)}{OD^2 + ID^2}$$

P= Theoretical Burst Pressure, psi
T= Tensile Strength at Yield, psi

Chemical Compatibility

Fluoropolymer resins are essentially chemically inert. This has long been one of the greatest assets of these plastics. Fluoropolymers are an ideal transport medium for today's highly volatile chemical compounds and exotic fluids. The widespread acceptance within the chemical, environmental, defense, aerospace, and medical industries is a testament to fluoropolymers' unique ability to withstand and resist a wide variety of liquid and gaseous compounds.

There are very few chemicals, such as molten alkali metals, turbulent liquid or gaseous fluorine, chlorine trifluoride, or oxygen difluoride, that are known to react with fluoropolymers.

To a lesser degree, halogenated organic chemicals may be absorbed by fluoropolymer resins. This will cause a very slight change in weight or possibly a slight swelling. This phenomenon is less evident in FEP and PFA extrusions because they are relatively less permeable than PTFE extrusions.

Concentricity Formula

To determine a tube's concentricity use the following formula:

W min is the minimum wall thickness and W max is the maximum wall thickness of the sleeve as taken from any location of the wall of a tubing's cross section. This can be measured using a toolmakers micrometer or optical comparator.

-ASTM D 2671 11.3

$$C = 100 \times \frac{(W\ min)}{(W\ max)}$$

TECHNICAL NOTE

Etching - Technical Questions

Why would I need to etch tubing?

Fluoropolymers such as PTFE, FEP, and PFA (often called Teflon) are very lubricious (slippery). This lubricity and the chemical composition of fluoropolymers reduces their bondability. Etching alters the surface properties of the polymer allowing it to be bonded with conventional adhesives.

How does it work?

Etching is performed by the chemical reaction between a sodium solution and the fluorine molecules on the surface of the tubing. Fluorine molecules are stripped from the carbon backbone of the fluoropolymer. This leaves the carbon atoms with a deficiency of electrons. When the etched material is exposed to air, oxygen molecules, water vapor, and hydrogen allow restoration of the electrons. This restoration process results in a group of organic molecules responsible for adhesion.

Will etching change the properties of my tubing?

The etching process only penetrates to a depth of a few angstroms so the properties of the tubing will remain mostly unaffected. However the etching process will darken the surface of the material, usually to a brown or tan shade. Surface lubricity is also reduced by the etching process.

How should I store etched tubing?

Etched fluoropolymers will "grab" molecules from the air to repair their electron deficiency. This results in a weakening of the surface etching. For this reason, all etched materials should be stored in their original sealed bags. YOZONE ships all etched tubing orders in sealed black protective bags to prevent degradation from UV radiation.

Does a darker color mean a better etch?

Color is not a reliable indicator of etch quality. For this reason YOZONE includes etch certifications with each order shipped.

How is the etch tested?

The etched material is tested using the contact angle method. Contact angle measurements of liquid droplets on substrate surfaces are used to characterize surface wettability. As shown in Figure 1 below, the contact angle is defined as the angle between the substrate support surface and the tangent line at the point of contact of the liquid droplet with the substrate. In this picture, example "B" demonstrates a more effective etch than example "A".

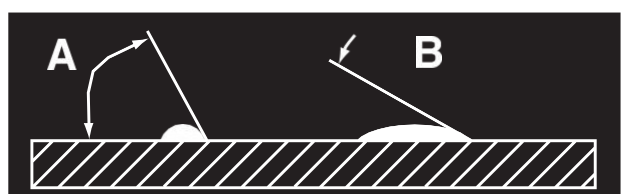

Figure 1

YOZONE performs contact angle tests on all etched tubing orders and includes a
Certificate of Compliance with the material.

TECHNICAL NOTE

Relationship for gaseous permeation is:

P = D S

P is the permeability (cm3(STP)/sec-cm-cm Hg)

D is the diffusion coefficient (sm2/sec)

S is the solubility coefficient (cm3(STP)/cm3-cm Hg)

Sterilization Methods

Please see the following table to select the best material suited for your sterilization method of choice.

Sterilization methods:
ETO, Autoclave, and Gamma

Resin	ETO	Autoclave	Gamma
PTFE	Excellent	Average	Poor
FEP	Excellent	Excellent	Good
PFA	Excellent	Excellent	Poor
ETFE	Excellent	Excellent	Good
PVDF	Excellent	Excellent	Good
PEEK™	Excellent	Excellent	Excellent
Polyethelyne	Excellent	Excellent	**Good***

*High density grades not as stable as medium and low grades

UV Compatibility

YOZONE tubing is virtually unaffected by weather or prolonged exposure to ultraviolet light. Independent testing on samples exposed to virtually all climatic conditions confirm the weather resistant properties of fluoropolymer tubing. Where applications demand complete dependability in these conditions, fluoropolymers are the answer. Resistance to extreme heat, cold, and ultraviolet light encountered in radar and other electronic components, such as antenna bushings, are excellent examples of the value of this material in these applications.

Ultraviolet transmittance can be another useful aspect of fluoropolymer tubing. While levels of UV transmittance vary among the fluoropolymer resin family, YOZONE tubing is used in applications such as water purification with excellent results. Crystallinity and wall thickness also affect the level of transmittance tubing will allow. Contact a YOZONE Technical Account Manager for more information on this very useful property of fluoropolymer tubing.

Summary Of Properties

The information presented in this publication is believed to be accurate and is not intended to constitute a specification. Property characteristics are dramatically impacted by geometry and processing method; therefore the properties of extruded parts may vary. This table is only meant to serve as a general guideline; users should evaluate the material to determine the suitability for their own particular application.

PHYSICAL	**ASTM**	**PTFE**	**FEP**	**PFA**	**THV**	**PVDF**	**EFEP**	**ETFE**	**PEEK**
Density (g/cc)	D792	2.16-2.22	2.12-2.17	2.12-2.17	1.95-2.06	1.76-1.88	1.74	1.7-1.86	1.1-1.48
Water Absorption (%)	D570	0	0.004	<0.03	<0.03	0.01-0.06	0.1 max	0.007	0.1-0.45
Standard Percent Crystallinity (%)		>90	70	48-70	26-29	35-70	10	50	25-35
Refractive Index		1.35	1.33-1.35	1.35	1.3502	1.42	1.338-1.34	1.34	---
Radiation Resistance (MRad)		1	10	1-10	20	1000	---	50	1000
Oxygen Index (%)	D2863	>95	95 min	95 min	65-75	44-80	31	30-46	35
MECHANICAL	**ASTM**	**PTFE**	**FEP**	**PFA**	**THV**	**PVDF**	**EFEP**	**ETFE**	**PEEK**
Hardness, Shore D	D2240	50-65	55-65	55-60	44-58	65-82	75	63-72	>85
Ultimate Tensile Strength (MPa)	D638	20-35	18-34	25-35	20-29	17-48	40-50	37-50	75-97
Elongation at Break (%)	D638	200-550	245-400	250-420	420-600	50-400	420-460	200-550	96-110
Modulus of Elasticity (GPa)	D638	0.39-0.6	0.44-0.64	0.45	0.24	0.5-5	0.490-0.78	0.49-0.78	2.3-4.3
Flexural Modulus (GPa)	D790	0.275-0.7	0.58-0.62	0.6-0.7	0.032-0.52	1.3-7	0.88-1.37	0.7-1.2	3.6-4.1
Coefficient of Friction		0.02-0.2	0.04-0.2	0.04-0.2	0.8	0.14-0.23	0.055-0.078	0.05-0.4	0.34
ELECTRICAL	**ASTM**	**PTFE**	**FEP**	**PFA**	**THV**	**PVDF**	**EFEP**	**ETFE**	**PEEK**
Volume Resistivity (Ω-cm)	D257	1e14-1e19	1e17 - 1e18	1e18	>1e15	1.5-2e14	1e16	1e17	4.9e16
Dielectric Constant 1MHz	D150	2.1	2-2.1	1.9-2.1	2.4-6.6	7	2.6	2.5-2.6	2.8-2.2
Dielectric Strength (V/mil)	D149	189-610	500-2000	500-2000	1220-1570	800-1700	400	400-1800	500
THERMAL	**ASTM**	**PTFE**	**FEP**	**PFA**	**THV**	**PVDF**	**EFEP**	**ETFE**	**PEEK**
Conductivity (W/m-K)	C117	0.167-0.3	0.19-0.25	0.15-0.25	--	0.17-0.19	0.24	0.24	0.25
Maximum Service Temp, Air (°C)		260	200-205	260	150	100-130	150	150	250-260
Minimum Service Temp, Air (°C)		-200-240	-200-240	-200	-50		---	-100-1890	
Melt Temperature (°C)		327-342	265-275	300-315	120-185	172	160-195	230-280	343
Glass Temperature (°C)		127	80	100	5-36	-30-40	-40-50	40-80	143
Decomposition Temperature (°C)	E1131	400-500	380-430	475	420-440	375-400	350	350-380	540
CTE, linear 20° (μm/m-°C)	D696	126-180	100-135	120-140	---	90-144	50-90	50-90	47