

Introduction

Teflon* FEP (fluorinated ethylene propylene) is chemically a copolymer of hexafluoropropylene and tetrafluoroethylene. It differs from the PTFE (polytetrafluoroethylene) resins in that it is melt-processible using conventional injection molding and screw extrusion techniques. Teflon PFA is a resin very similar to Teflon FEP in use, but Teflon PFA can be used at even higher temperatures.

Teflon FEP can be made into articles having a combination of mechanical, chemical, electrical, temperature, and friction-resisting properties unmatched by articles made of any other material.

The design and engineering data presented in this publication are intended to assist end users in determining where and how Teflon FEP may best be used. As with other products, it is recommended that design engineers work closely with an experienced fabricator, since the method of fabrication may markedly affect not only production costs, but also the properties of the finished article.

All properties presented in this handbook should be considered typical values and are not to be used for specification purposes. The age of this data varies greatly, ranging in origin from the 1960s to the 1990s.

Commercially Available Products

Teflon FEP 100

General-purpose molding and extrusion resin.

Teflon FEP 140

A higher molecular weight (lower melt flow number) resin, used where a combination of improved stress crack resistance with only moderate reduction in processing rates is needed.

Teflon FEP 160

The highest molecular weight (lowest melt flow number) resin, used where the highest level of stress crack resistance is required and where processing rates are of secondary importance.

Teflon FEP 4100

A low molecular weight (high melt flow number) resin, designed for high speed melt extrusion onto fine wire.

Standard colors are available as concentrates from commercial producers for incorporation by the processor.

Other product grades are also available for special processing needs. They include powder and dispersion forms for coating applications and special resins for wire insulation.

Teflon FEP film is also available in a wide range of thicknesses for electrical, chemical, and release applications. These include untreated as well as one or both sides treated for improved cementability.

Specifications

The ASTM material specification covering Teflon FEP is D2116. Teflon FEP is also called out in various industrial and military specifications for tubing, molded parts, and film as well as numerous wire and cable applications.

General Properties of Teflon FEP

Teflon FEP can be described as a fluoropolymer resin having most of the excellent physical, chemical, and electrical properties of Teflon PTFE fluoropolymer resin but with the ability to be processed using conventional thermoplastics processing equipment. The upper continuous use temperature is 200°C (392°F). Teflon FEP is satisfactorily used in cryogenic service at temperatures well below that of liquid nitrogen. It is normally inert to liquid oxygen (LOX) when the surfaces are free of any contamination, pigmentation, or fillers. Resistance to chemicals is excellent as is weathering resistance.

This combination of properties and processibility make Teflon FEP the preferred product in such applications as valve and pump linings, pipe liners, release applications, or similar uses where resistance to chemicals at elevated temperatures is essential or where serviceability at extremely low temperatures is desired.

*DuPont registered trademark for its fluoropolymer resins

Typical Properties of Teflon® FEP Fluoropolymer Resins

A list of typical properties of Teflon FEP is shown in **Table 1**. These data are of a general nature and should not be used for specifications. Because the principal difference among the grades is molecular weight, only those properties affected by molecular weight show

significant differences. These include toughness and stress crack resistance. Minor differences in tensile and compressive properties are sometimes seen due to variations in processing conditions. Electrical properties and resistance to chemicals are generally the same for all grades.

Table 1
Typical Properties of Teflon FEP Fluoropolymer Resins

Property	ASTM Method	Unit	Teflon FEP Grade			
			100	140	160	4100
Mechanical						
Melt Flow Rate	D2116	g/10 min	7	3	1.5	22
Specific Gravity	D792		2.13–2.15	2.13–2.15	2.13–2.15	2.13–2.15
Tensile Strength, 23°C (73°F)	D2116	MPa (psi)	23 (3,400)	28 (4,000)	28 (4,100)	20 (2,950)
Ultimate Elongation, 23°C (73°F)	D2116	%	300	300	300	300
Compressive Strength, 23°C (73°F) at 5% Strain	D695	MPa (psi)	15.2 (2,200)	15.2 (2,200)	15.2 (2,200)	N/A
Impact Strength 23°C (73°F) –60°C (–76°F)	D256	J/m (ft·lb/in)	no break no break	no break no break	no break no break	no break no break
Flexural Modulus, 23°C (73°F)	D790	MPa (psi)	620 (90,000)	620 (90,000)	550 (80,000)	646 (94,000)
Hardness, Durometer, Shore D	D2240		56	56	56	55
Coefficient of Friction	D1894		0.25	0.25	0.25	0.25
Deformation Under Load, 23°C (73°F), 6.9 MPa (1,000 psi), 24 hr	D621	%	0.50	0.50	0.50	N/A
Water Absorption, 24 hr	D570	%	0.004	0.004	0.004	0.004
Linear Coefficient of Expansion	E831					
0 – 100°C		mm/mm·°C × 10 ⁻⁵	13.5	13.9	13.5	N/A
100 – 150°C			20.8	21.2	23.4	
150 – 200°C			26.6	27.0	27.8	
32 – 212°F		(in/in·°F × 10 ⁻⁵)	(7.5)	(7.5)	(7.5)	
212 – 302°F			(11.8)	(11.8)	(11.8)	
302 – 392°F			(14.8)	(14.8)	(14.8)	

(continued)

Table 1 (continued)
Typical Properties of Teflon FEP Fluoropolymer Resins

Property	ASTM Method	Unit	Teflon FEP Grade			
			100	140	160	4100
Electrical						
Surface Resistivity	D257	ohm·sq	10 ¹⁵	10 ¹⁵	10 ¹⁵	10 ¹⁵
Volume Resistivity	D257	ohm·cm	10 ¹⁷	10 ¹⁷	10 ¹⁷	10 ¹⁷
Dielectric Strength 0.254 mm (10 mil) 3.18 mm (1/8 in) sheet	D149	kV/mm (V/mil)	79 (2,000) 21 (530)	79 (2,000) 20.5 (520)	71 (1,800) 20 (510)	
Dielectric Constant, 21°C (70°F) 1 kHz–500 MHz 13 GHz	D1531		2.05 2.04	2.05 2.04	2.05 2.04	2.01 2.02
Dissipation Factor,* 21°C (70°F) 1 kHz 100 kHz 1 MHz 1 GHz 13 GHz	D1531		0.00006 0.0003 0.0006 0.0011 0.0007	0.00006 0.0003 0.0006 0.0011 0.0007	0.00006 0.0003 0.0006 0.0011 0.0007	0.0003
Arc Resistance	D495	sec	165	165	165	165
Thermal						
Melting Point	DTA D3418	°C (°F)	257–263 (495–505)	257–263 (495–505)	257–263 (495–505)	259 (498)
Specific Heat 25°C (77°F) 100°C (212°F) 150°C (302°F)	DSC	kJ/kg·K cal/g·°C	0.240 0.266 0.288	0.242 0.267 0.290	0.268 0.294 0.315	— — —
Heat of Fusion	DSC D3417	kJ/kg (Btu/lb)	10.1 (4.35)	9.8 (4.22)	11.6 (4.97)	— —
Deflection Temperature 455 kPa (66 psi) 1820 kPa (264 psi)	D648	°C (°F)	77 (170) 48 (119)	77 (170) 48 (119)	74 (164) 48 (119)	— —
Oxygen Index	D2863	%	>95	>95	>95	>95
Heat of Combustion	D240	kJ/kg (Btu/lb)	5,114 (2,200)	5,114 (2,200)	5,114 (2,200)	
Upper Service Temperature		°C (°F)	204 (400)	204 (400)	204 (400)	204 (400)
Thermal Conductivity		W/m·K (Btu·in/h·ft ² ·°F)	0.2 ± 0.04 (1.4 ± 0.3)	— (—)	— (—)	— (—)
Heat Capacity		J/kg (Btu/lb)	5.1 (0.28)	— (—)	— (—)	— (—)
Flammability	ANSI/UL 94		V-0	—	—	—
General						
Weather Resistance	Florida Exposure	No significant change in tensile strength; slight increase in elongation, but still high after 25 years.				
Chemical Resistance	D543	outstanding outstanding outstanding outstanding				
Refractive Index	D542-50	1.341–1.347 1.341–1.347 1.341–1.347 1.341–1.347				

*Measurements were made on Teflon FEP 100. The results are shown graphically in **Figure 23**.

Mechanical Properties

Fabricated shapes of Teflon® FEP fluoropolymer resins are tough, flexible in thin sections, and fairly rigid in thick sections. With increasing temperature, rigidity (as measured by flexural modulus) decreases significantly up to the maximum continuous-use temperature of 204°C (400°F). Surfaces of fabricated parts have a very low coefficient of friction, although slightly higher than that of Teflon PTFE. Very little sticks to Teflon FEP, but the surfaces can be specially treated to accept conventional industrial adhesives.

Tensile Properties

Teflon FEP is an engineering material whose performance in any particular application may be predicted by calculation in the same manner as for other engineering materials. From the data presented in this handbook, values can be selected which, with appropriate safety factors, will allow standard engineering formulas to be used in designing parts.

Stress/strain curves for temperatures in the usual design range for Teflon FEP 100 (**Figure 1**) show that yield occurs at relatively low deformations. Elastic response begins to deviate from linearity at strains of only a few percent, as with most plastics. Therefore in designing with Teflon, it is often best to work with acceptable strain and determine the corresponding stress. Typical stress/strain curves that show ultimate tensile strengths at -52°C (-62°F), 23°C (73°F), 100°C (212°F), and 200°C (392°F) for Teflon FEP 100, 140, and 160 are given in **Figures 2, 3, 4, and 5**. Test specimen preparation, geometry, and test conditions affect test results, so these variables must be kept constant when making comparisons.

The effects of temperature on tensile strength and ultimate elongation are summarized in **Figures 6 and 7**.

Of more practical importance is yield strength. With Teflon FEP, elastic response begins to deviate from linearity at strains of only a few percent. This is referred to as yield strength. The effect of temperature on yield strength for Teflon FEP 100 is shown in **Table 2**.

Flexural Modulus

Flexural modulus is a measure of stiffness and is among the properties included in **Table 1**. Teflon FEP retains flexibility to very low temperatures and is useful at cryogenic temperatures. The effect of temperature on flexural modulus is shown in **Figure 8**.

Compressive Stress

Stress/strain curves for compression are similar to those for tension at low values of strain. Typical compression curves for Teflon FEP 100 at three temperatures at low levels of strain are shown in **Figure 9**.

Creep and Cold Flow

A plastic material subjected to continuous load experiences a continued deformation with time that is called creep or “cold flow.” A similar phenomenon occurs with metals at elevated temperatures. With most plastics, however, deformation can be significant even at room temperature or below, thus the name “cold flow.”

Creep is the total deformation under stress after a specified time in a given environment beyond that instantaneous strain that occurs immediately upon loading. Independent variables that affect creep are load or stress level, time under load, and temperature.

Initial strain or deformation occurs instantaneously as a load is applied to Teflon FEP or any other plastic. Following this initial strain is a period during which the part continues to deform but at a decreasing rate. Data can be obtained over a wide range of temperatures using tensile, compressive, or flexural creep. Flexural measurements are more easily made and are the most common. However, tensile and compressive creep data are frequently more useful in designing parts. Typical data for tensile loadings for Teflon FEP 100 at four temperatures are shown graphically in **Figures 10, 11, 12, and 13**.

Typical curves for total deformation versus time under compressive load are shown at two temperatures for Teflon FEP 100 in **Figures 14 and 15**.

Figure 1. Tensile Stress, Based on Original Cross Section, Teflon® FEP 100 Fluoropolymer Resin

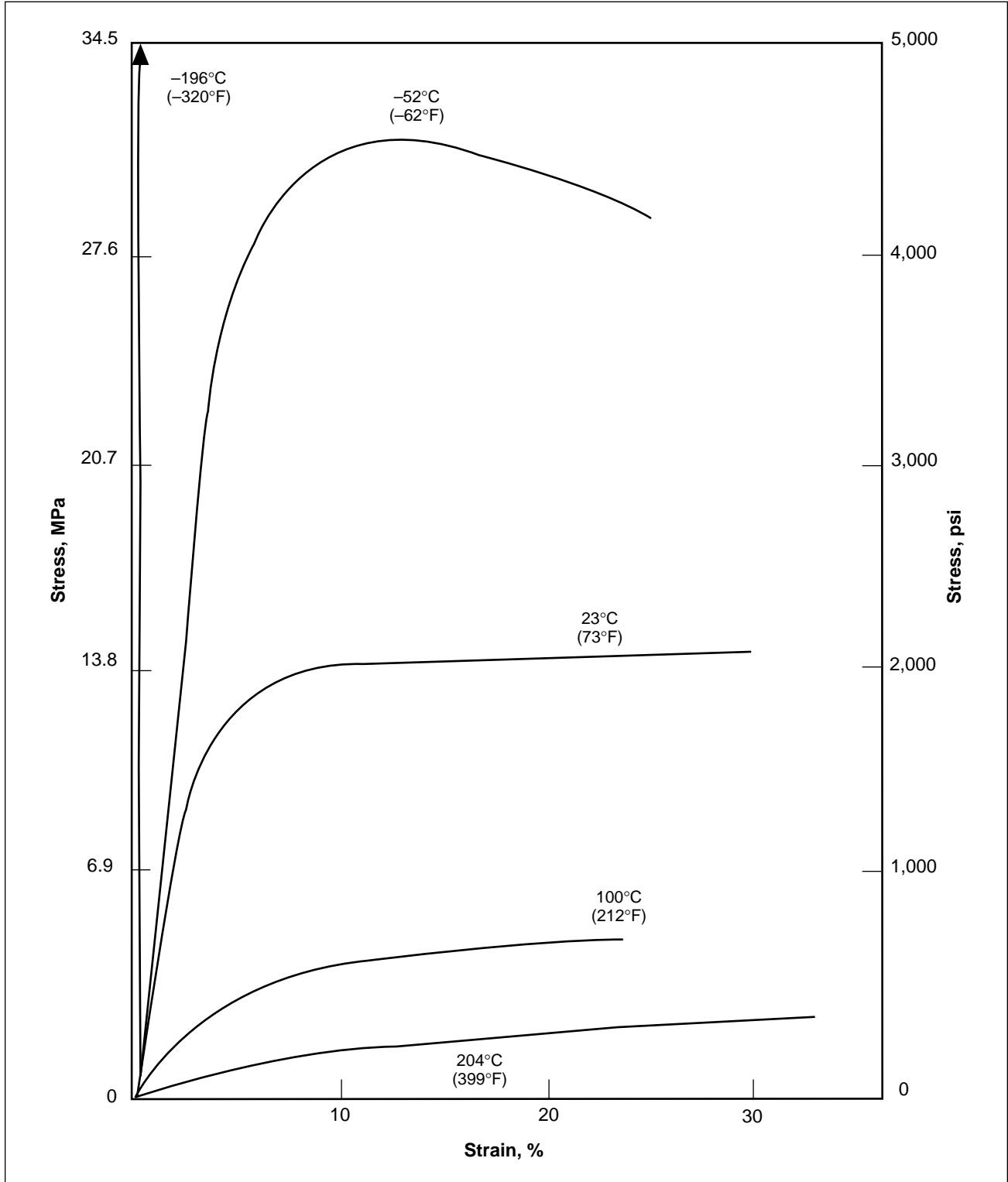


Figure 2. Tensile Stress versus Strain at -52°C (-62°F),* Teflon® FEP 100, 140, and 160 Fluoropolymer Resins

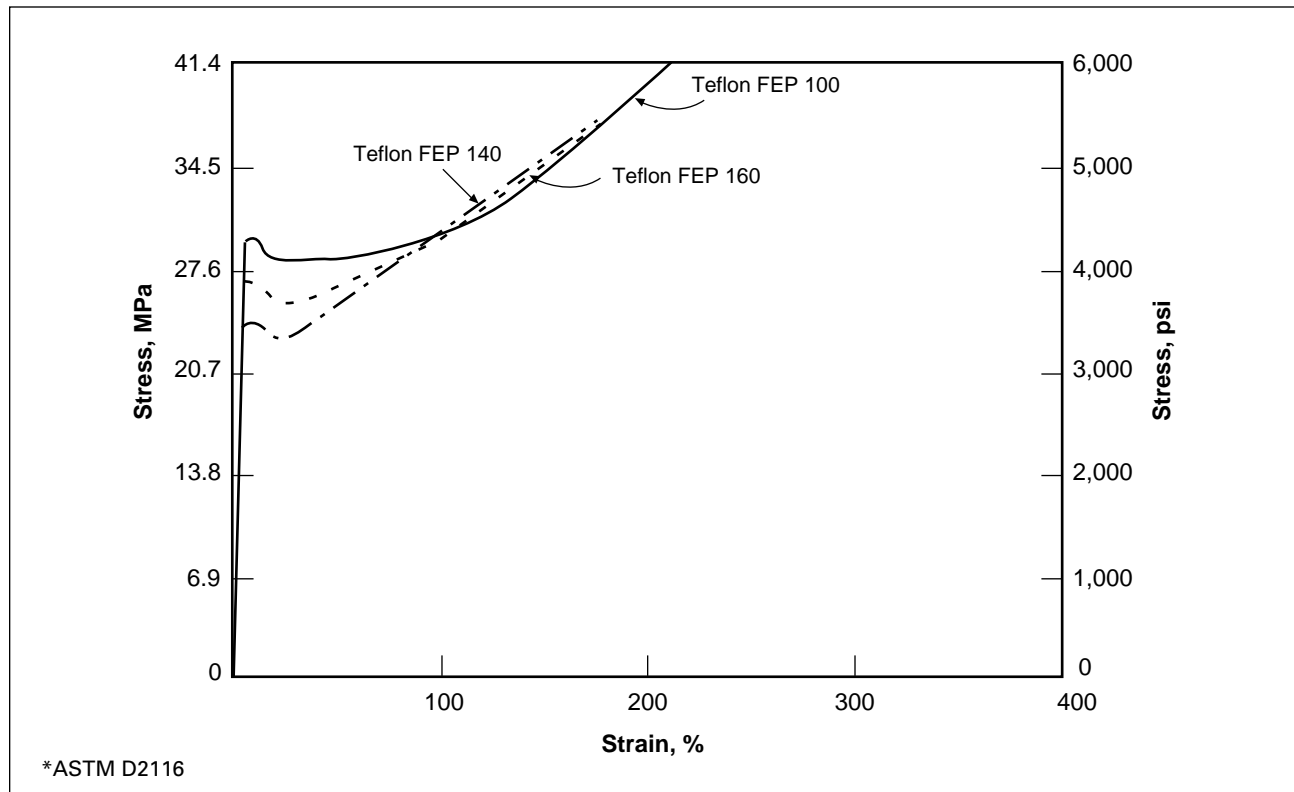


Figure 3. Tensile Stress versus Strain at 23°C (73°F),* Teflon FEP 100, 140, and 160

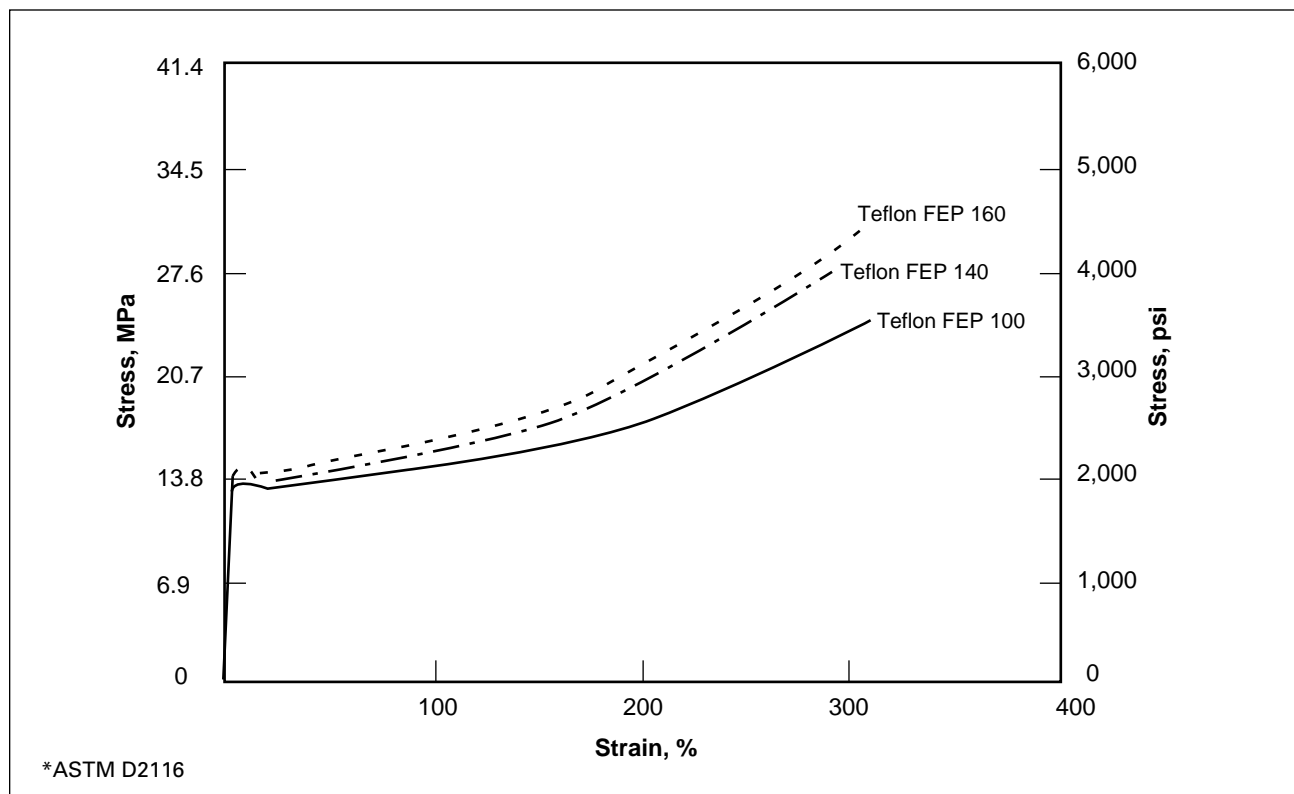


Figure 4. Tensile Stress versus Strain at 100°C (212°F),* Teflon® FEP 100, 140, and 160 Fluoropolymer Resins

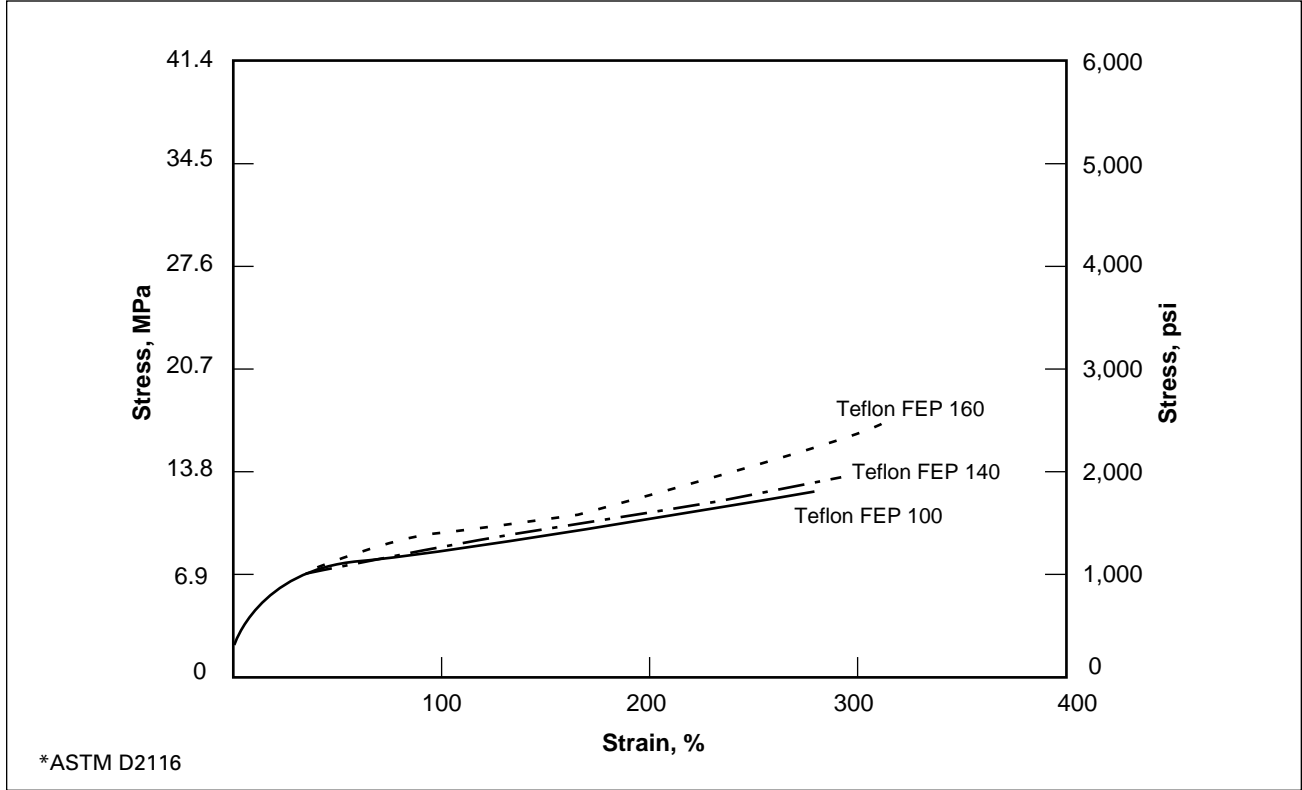


Figure 5. Tensile Stress versus Strain at 200°C (392°F),* Teflon FEP 100, 140, and 160

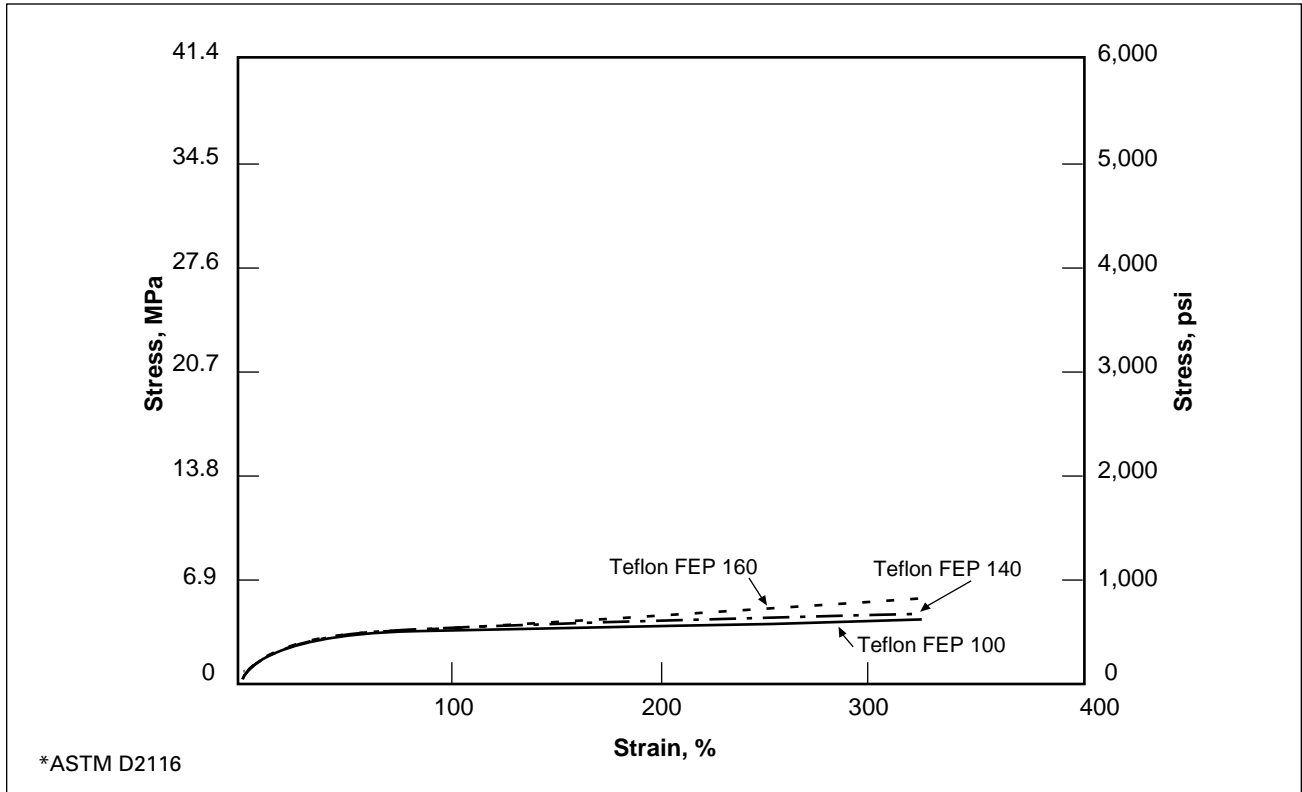


Figure 6. Tensile Strength versus Temperature,* Teflon® FEP 100, 140, and 160 Fluoropolymer Resins

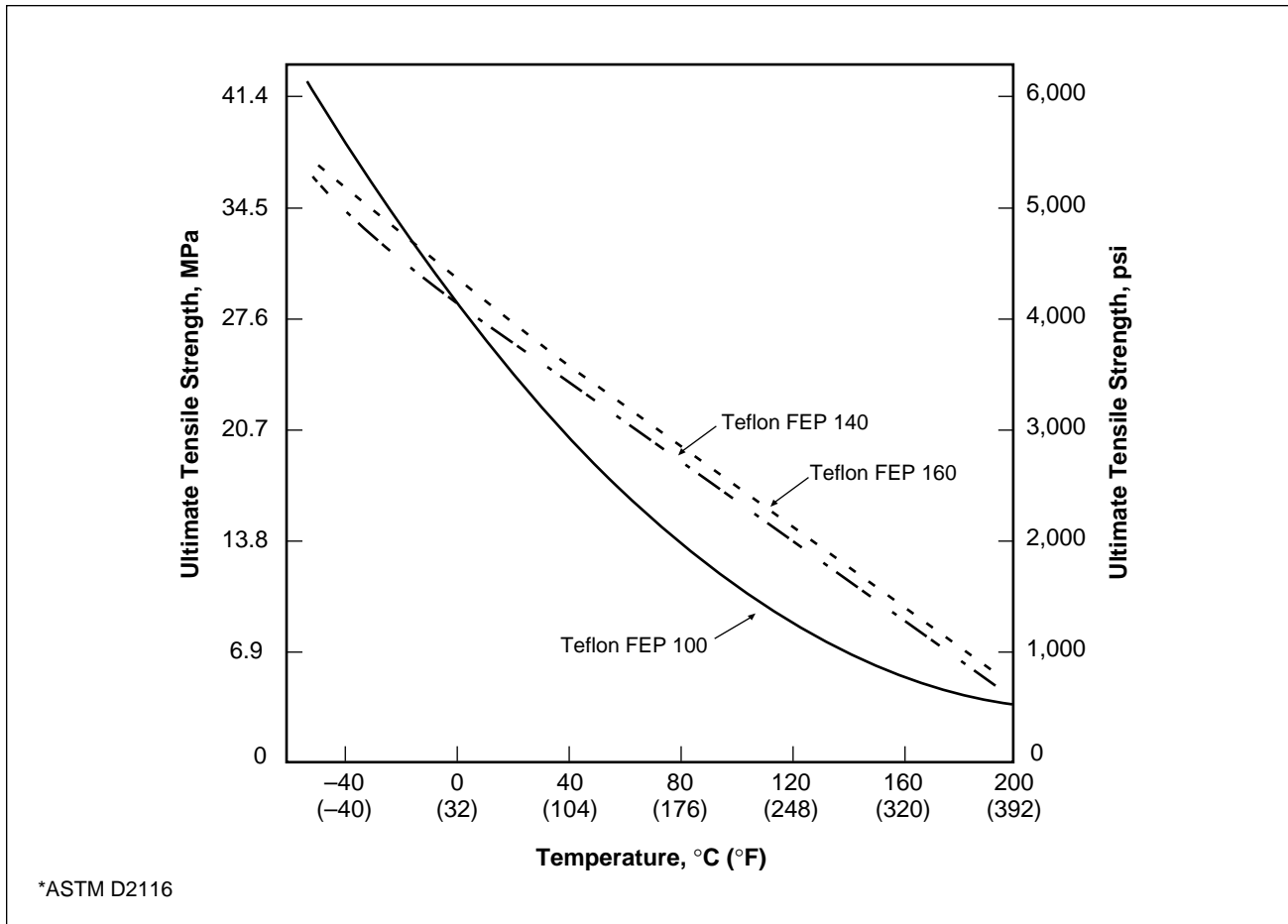


Figure 7. Ultimate Elongation versus Temperature,* Teflon FEP 100, 140, and 160

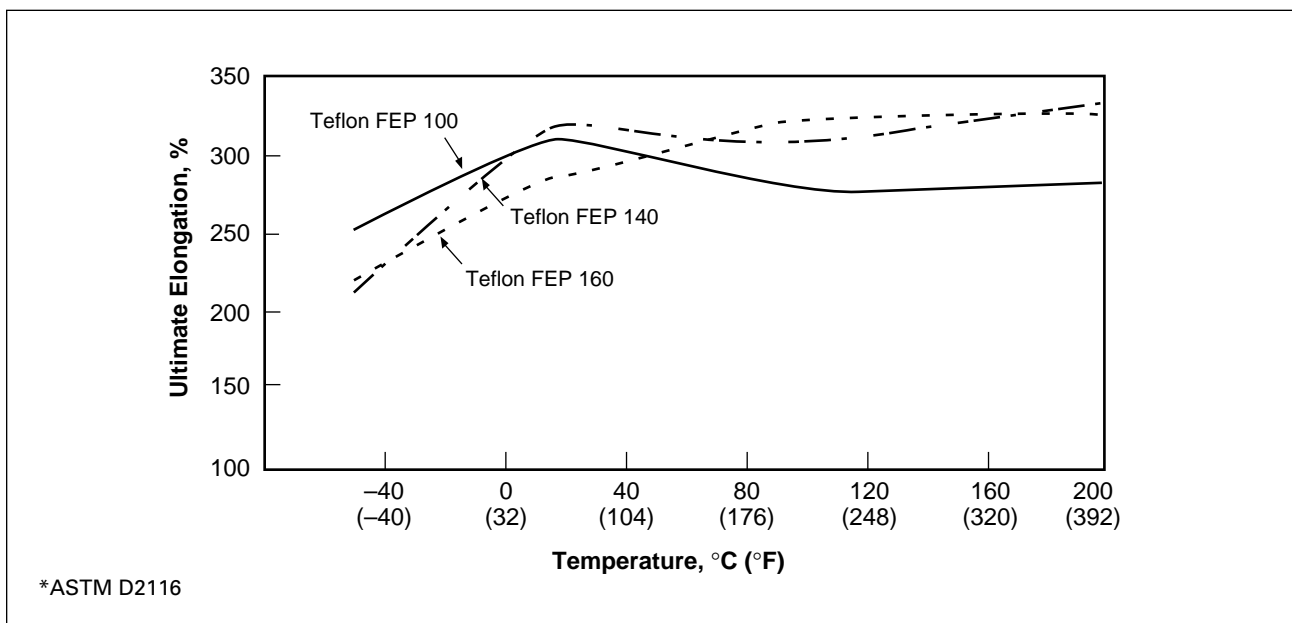


Figure 8. Flexural Modulus versus Temperature, Teflon® FEP 100, 140, and 160 Fluoropolymer Resins

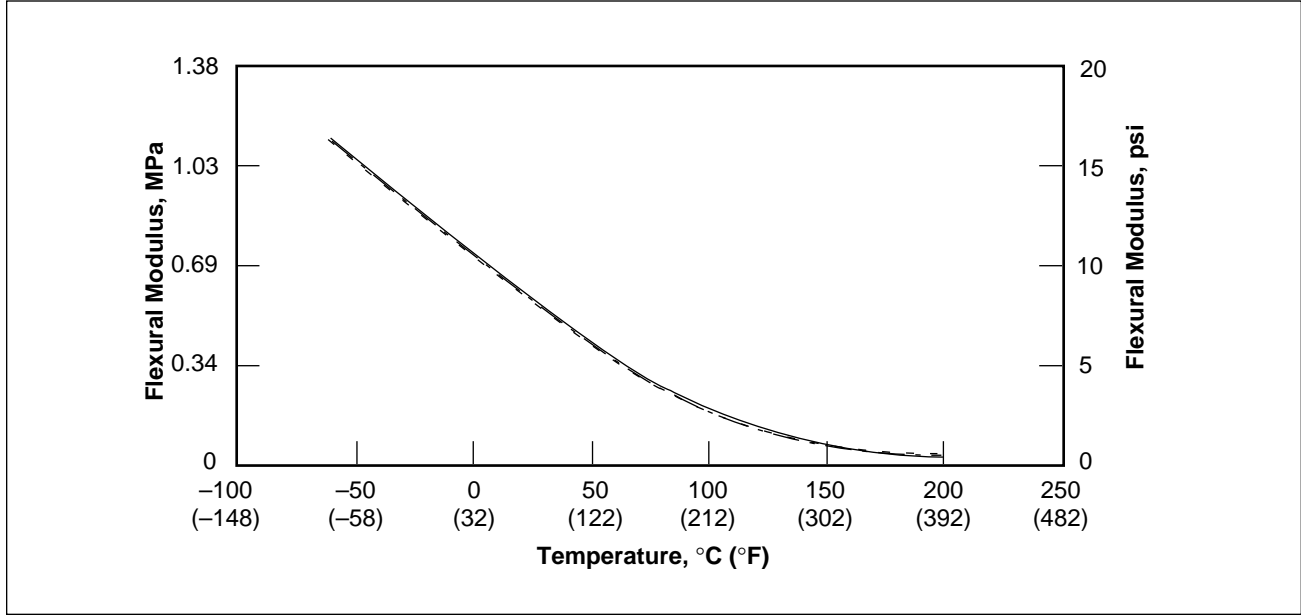
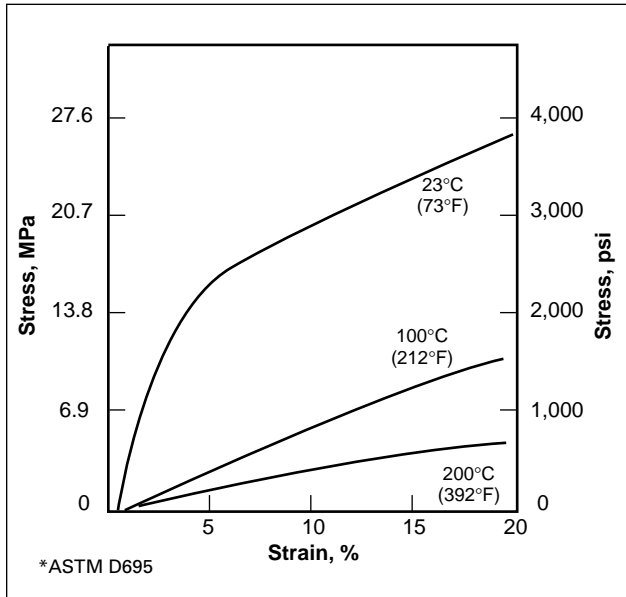


Figure 9. Compressive Stress versus Strain,* Teflon FEP 100



Note: Teflon FEP 140 and 160 have approximately the same curves in compression.

**Table 2
Effect of Temperature on Yield Strength—
Teflon FEP 100**

Temperature		Yield Strength	
°C	°F	MPa	psi
-251	-420	165	24,000
-196	-320	131	19,000
-129	-200	97	14,000
-73	-100	62	9,000
-56	-68	28	4,000
0	32	14	2,000
23	73	12.4	1,800
70	158	6.9	1,000
121	250	3.5	500

Figure 10. Total Deformation versus Time Under Load at -54°C (-65°F), Teflon® FEP 100 Fluoropolymer Resin

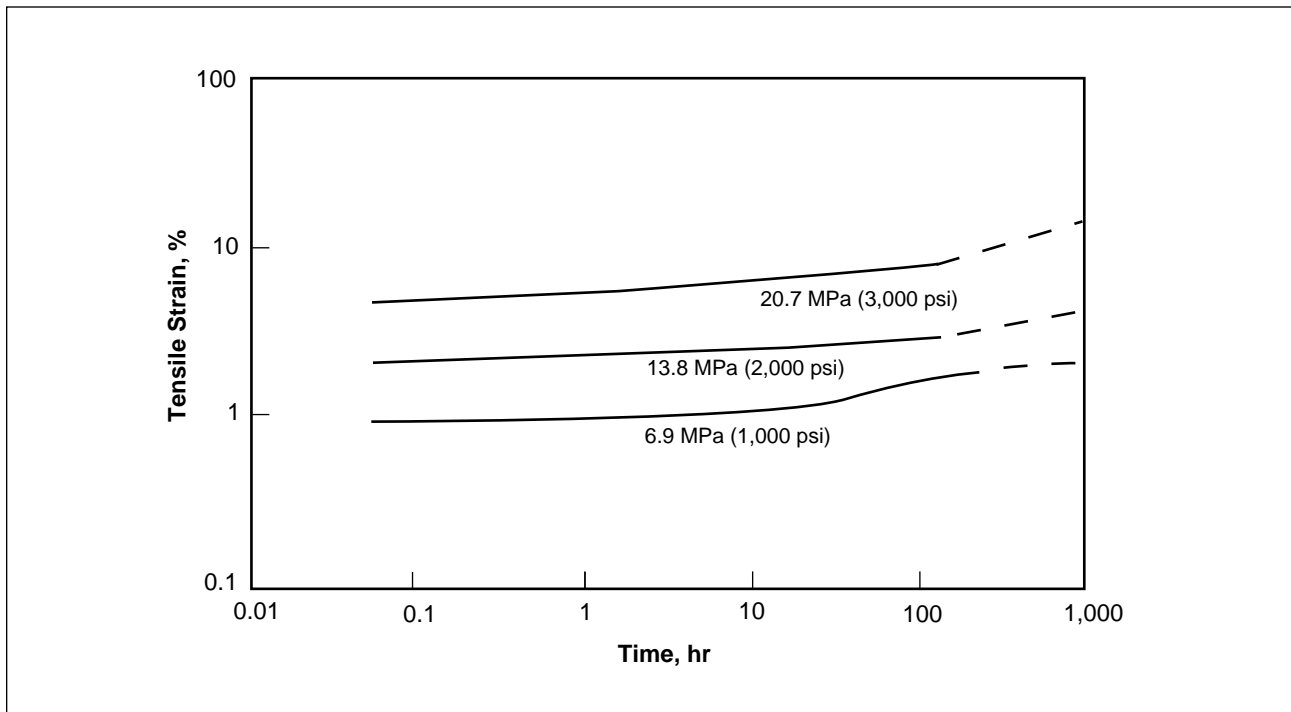


Figure 11. Total Deformation versus Time Under Load at 23°C (73°F), Teflon FEP 100

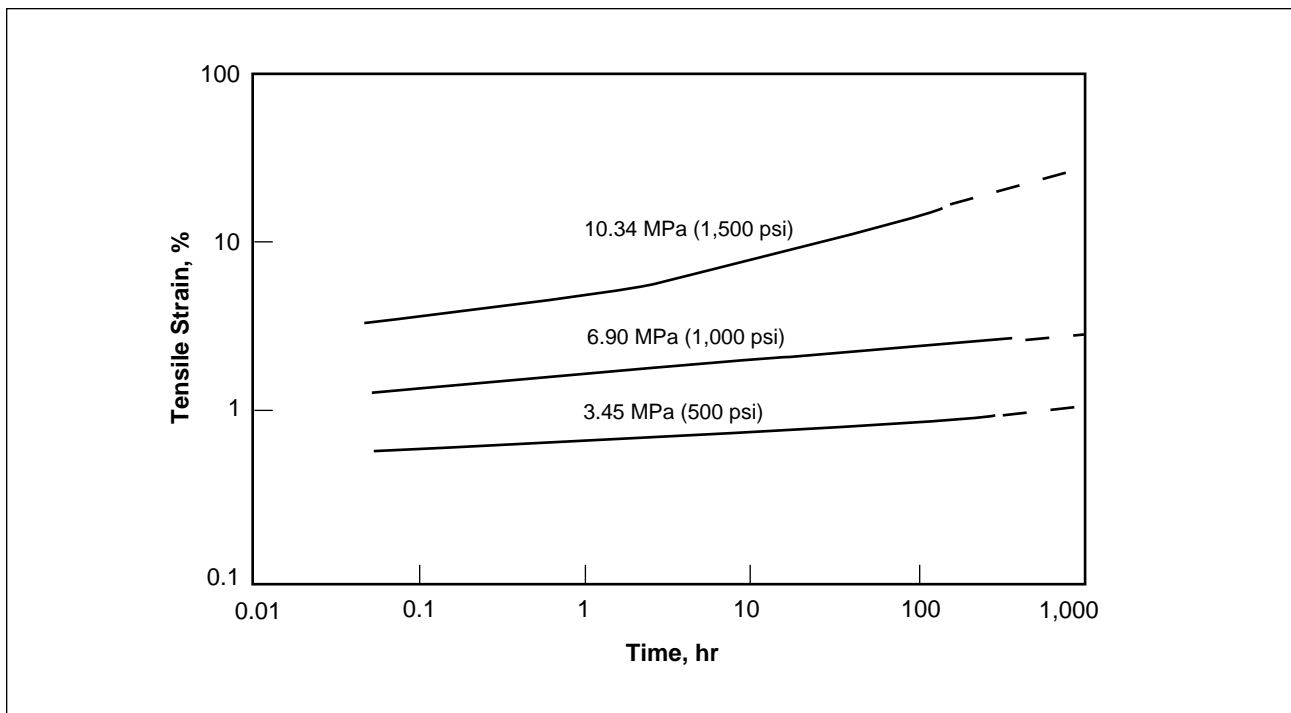


Figure 12. Total Deformation versus Time Under Load at 100°C (212°F), Teflon® FEP 100 Fluoropolymer Resin

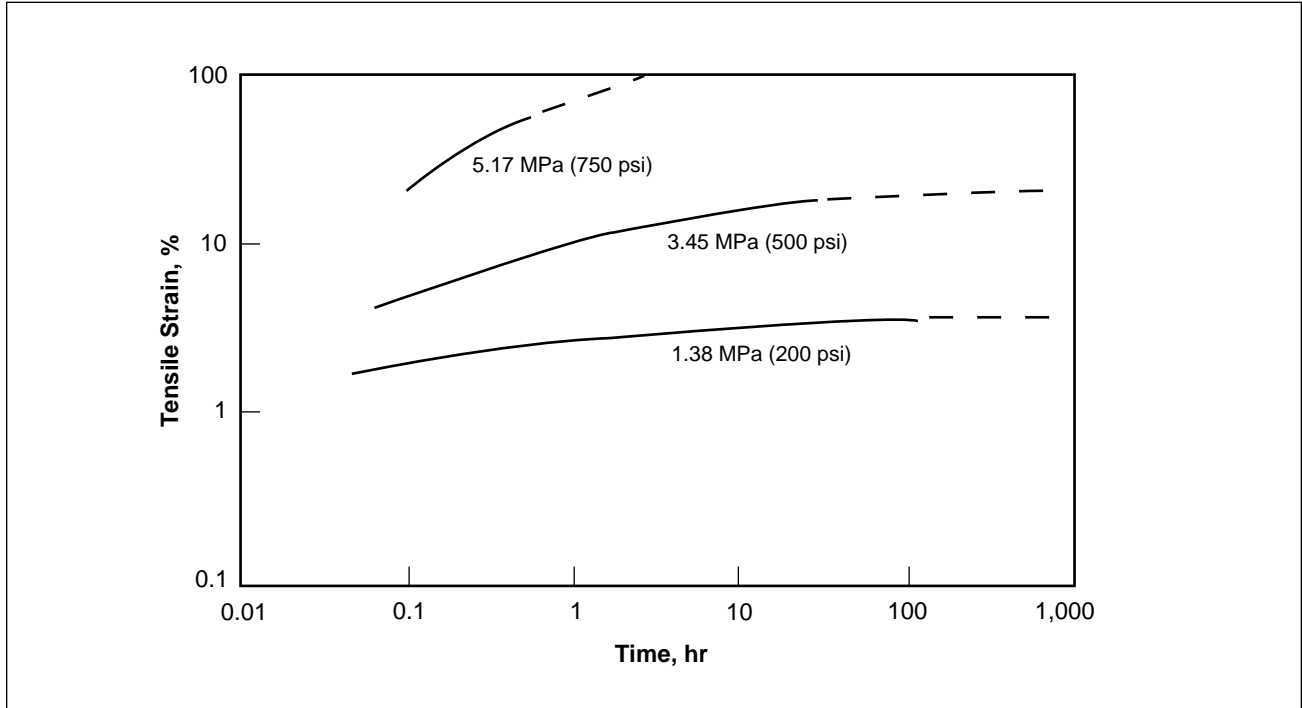


Figure 13. Total Deformation versus Time Under Load at 175°C (347°F), Teflon FEP 100

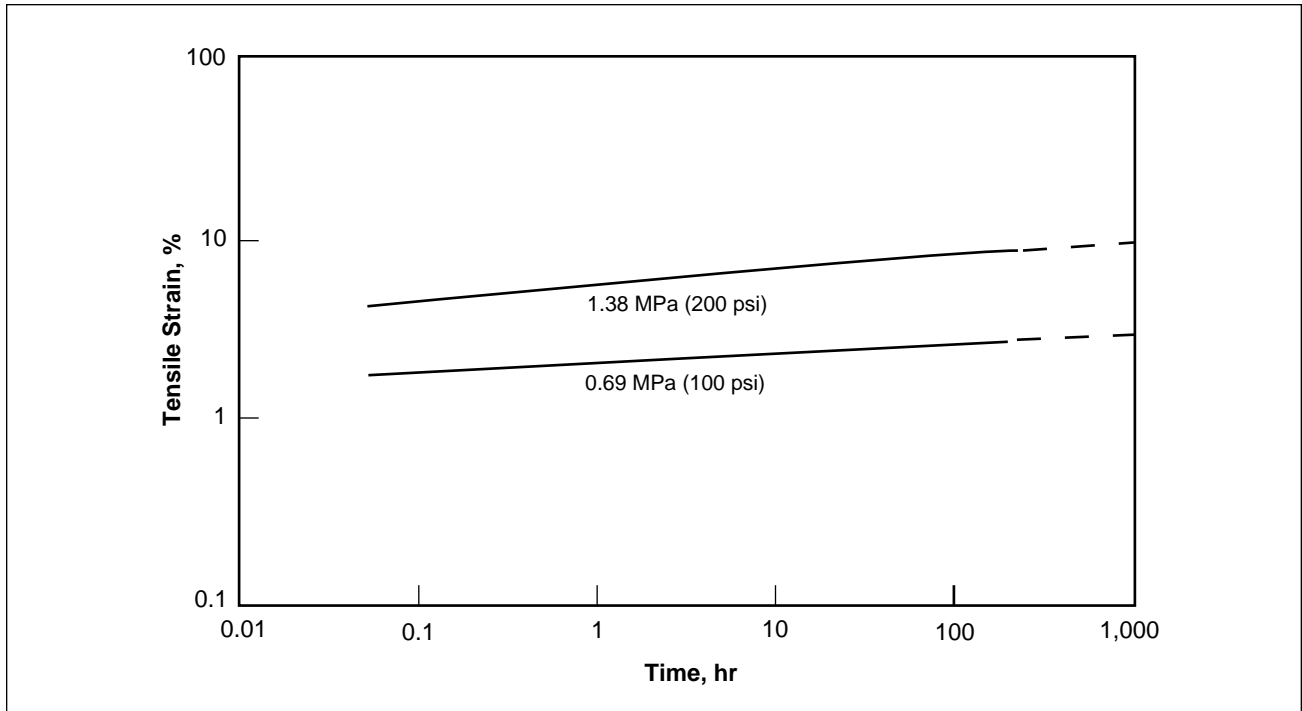


Figure 14. Total Deformation versus Time Under Compressive Load at 23°C (73°F), Teflon® FEP 100 Fluoropolymer Resin

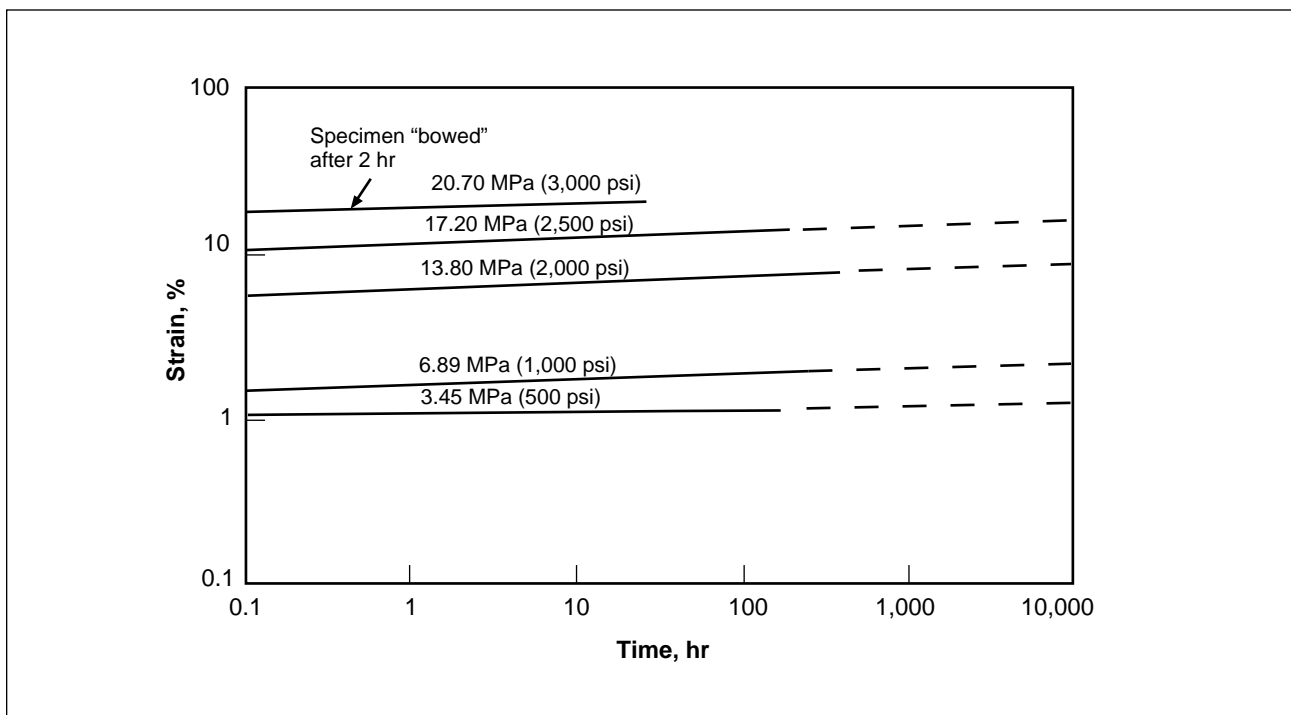
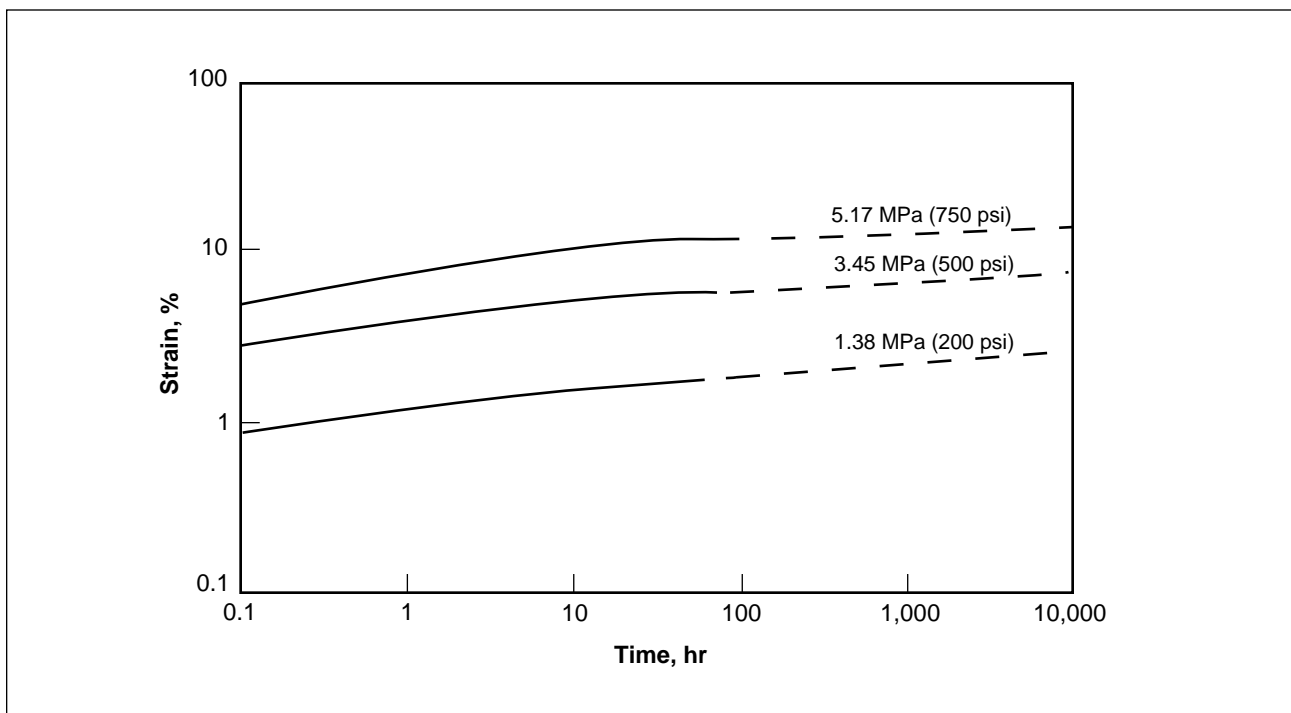


Figure 15. Total Deformation versus Time Under Compressive Load at 100°C (212°F), Teflon FEP 100



Apparent Modulus of Elasticity

The concept of “apparent modulus” is a convenient method for expressing creep because it takes into account initial strain for an applied stress plus the amount of deformation or strain that occurs with time. Thus, apparent modulus E_A is

$$E_A = \frac{\text{Stress (psi)}}{\text{Initial strain} + \text{creep}}$$

Because parts tend to deform in time at a decreasing rate, the acceptable strain based on service life of the part must be determined—the shorter the duration of load, the higher the apparent modulus and the higher the allowable stress. Apparent modulus is most easily explained with an example.

As long as the stress level is below the elastic limit of the material, modulus of elasticity E is obtained from the equation above. For a compressive stress of 1,000 psi, **Figure 9** gives a strain of 0.015 inch per inch for Teflon® FEP 100 fluoropolymer at 23°C (73°F). Then,

$$E_A = 1,000/0.015 = 66,700 \text{ psi (roughly)}$$

If the same stress level prevails for 200 hr, total strain will be the sum of initial strain plus strain due to time. This total strain is obtained from **Figure 14** where total deformation under compressive load for 200 hr is 0.02 inch per inch for Teflon FEP resin. Therefore,

$$E_A = 1,000/0.02 = 50,000 \text{ psi}$$

Similarly, E_A can be determined for one year. Extrapolation of the curve in **Figure 14** gives a deformation of 0.025 inch per inch, and

$$E_A = 1,000/0.025 = 40,000 \text{ psi}$$

When plotted against time, these calculated values for “apparent modulus” provide an excellent means for predicting creep at various stress levels. For all practical purposes, curves of deformation versus time eventually tend to level off. Beyond a certain point, creep is small and may be neglected for many applications.

Stress Relaxation

When materials that creep or cold-flow are used as gaskets in flanged joints, the phenomenon of stress relaxation is generally encountered. With Teflon® FEP fluoropolymer resin, an application where this is important is in lined valves or tees where an extension of the lining is generally used as the flange gasket. In flanged, bolted connections, parts of Teflon will cold-flow between the flange faces with a resultant decrease in bolt pressure. Such relaxation in gasket stock may result in a leaky joint. Tightening the flange bolts during the first day after installation will usually maintain bolting pressure and prevent leakage; thereafter, stress relaxation will be negligible.

Typical curves for tensile stress relaxation, **Figures 16** and **17**, illustrate the rates at which tensile stress decays when the specimen is maintained at constant strain.

Poisson's Ratio

Available values for Poisson's ratio at two temperatures for Teflon FEP 100 are listed in **Table 3**.

Table 3
Poisson's Ratio, Teflon FEP 100

Temperature		Poisson's Ratio
°C	°F	
23	73	0.48
100	212	0.36

Fatigue Resistance

Curves of stress versus strain are a sound basis for calculating the performance of statically loaded parts. However, they are not a good basis for design of parts subjected to repeated stress. As with ferrous alloys, there is a stress value—the fatigue endurance limit—below which Teflon FEP resins will not fail no matter how many times load is applied.

Figure 16. Tensile Stress Relaxation at 23°C (73°F), Teflon® FEP 100 Fluoropolymer Resin

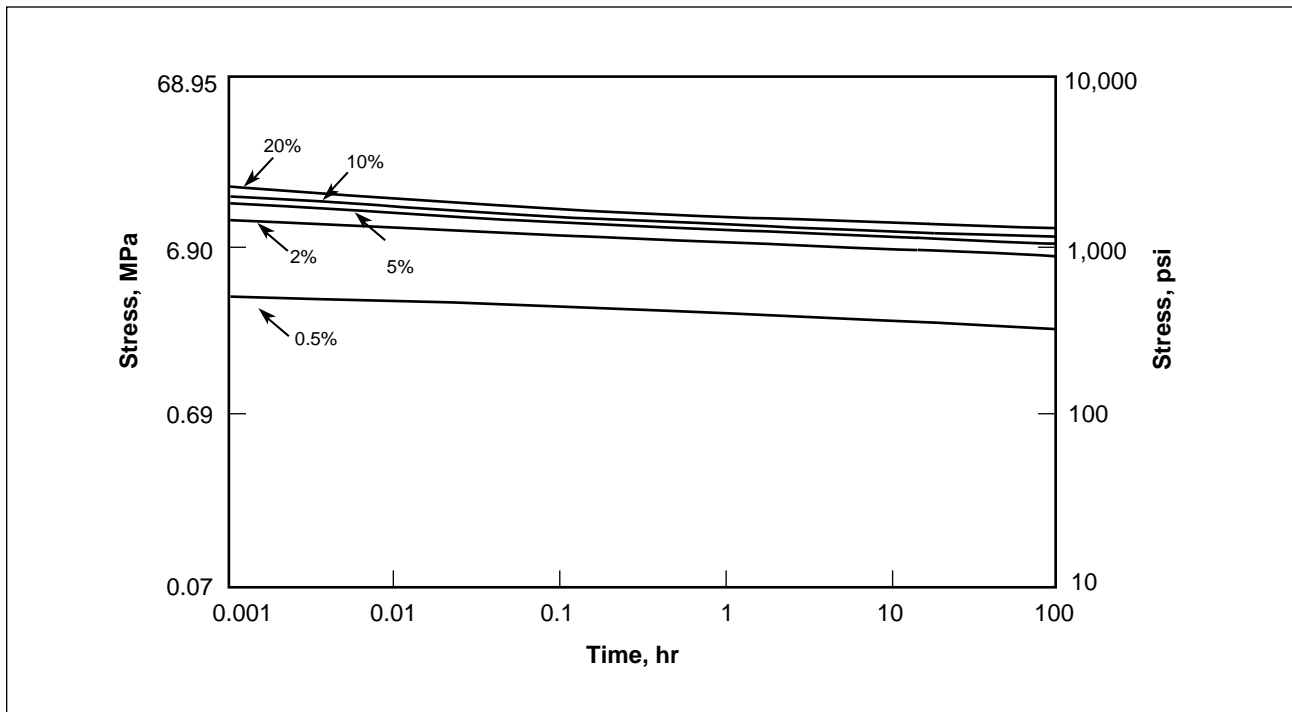
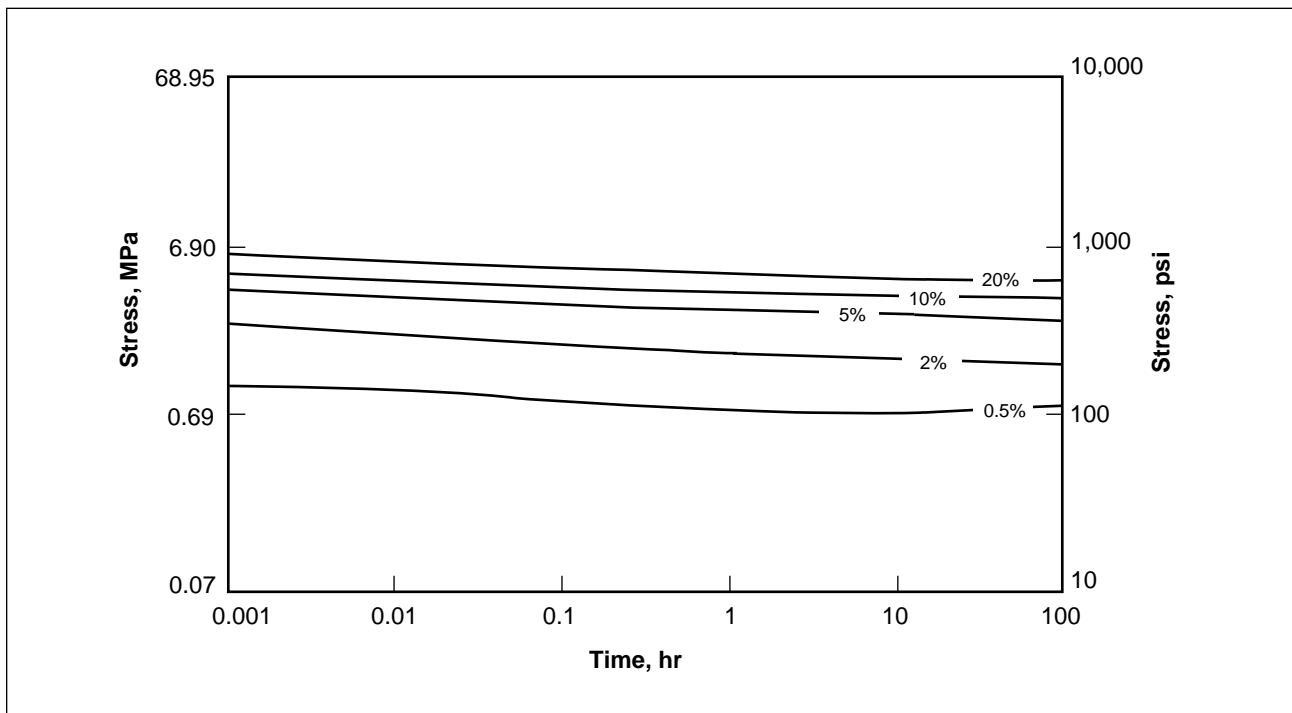


Figure 17. Tensile Stress Relaxation at 100°C (212°F), Teflon FEP 100



Typical fatigue data for Teflon® FEP 100 fluoropolymer resin, the grade most commonly used for injection molding, are given in **Table 4**. These measurements were made using a Sonntag-Universal machine.

Teflon FEP 140 and 160 are higher molecular weight resins and would be expected to require a higher number of cycles to cause failure at any given stress level.

Table 4
Fatigue Resistance of Teflon FEP 100
at 23°C (73°F)

Stress		Cycles to Failure
MPa	psi	
6.9	1,000	>7 million
9.65	1,400	>7.2 million
10.0	1,450	1,300
10.3	1,500	960

Impact Resistance

Ability to absorb impact energy, or impact toughness, is difficult to predict in a part because shape has a major effect on performance. Understanding how a part resists impact, however, helps in selecting a good design.

The energy of an impact has to be absorbed by a force developed within the part multiplied by the distance over which the part can deform. Designing flexibility into the part to lengthen the distance over which the energy is absorbed greatly reduces the internal force required to resist impact. The same factors that affect metals also affect plastics. As more and more flexibility is designed into a part subject to impact load, the better the part will perform.

Teflon FEP has excellent impact strength over a wide range of temperatures. In the notched Izod impact test, no breaks are incurred with Teflon FEP 100, 140, or 160 at temperatures as low as -60°C (-76°F).

There is no exact method for relating impact test data to actual design calculations or performance. Generally, in addition to incorporating flexibility, the most important method for obtaining toughness or impact resistance is to eliminate all sharp corners and other features subject to high stress concentration. For exact design, prototype models must be prepared and tested under actual loads.

Hardness

The hardness of Teflon FEP 100 by three different tests is shown in **Table 5**.

Tests using Teflon FEP 140 and 160 give similar results, indicating that molecular weight has little, if any, effect on hardness.

Table 5
Hardness at 23°C (73°F), Teflon FEP 100

Rockwell R Scale	Durometer D Scale	Durometer A Scale
25	56	96

Friction

Teflon FEP has a smooth surface and a slippery feel. Because of the low coefficient of friction, there have been many practical nonlubricated and minimally lubricated mechanical systems developed.

Teflon FEP resins exhibit very low friction in nonlubricated applications, especially at low surface velocities and pressures higher than 34 kPa (5 psi). The coefficient of friction increases rapidly with sliding speeds up to about 30 m/min (100 ft/min), under all pressure conditions. This pattern of behavior prevents “stick-slip” tendencies. Moreover, no “squeaking” or noise occurs, even at the slowest speeds. Above about 45 m/min (150 ft/min), sliding velocity has relatively little effect at combinations of pressure and velocity below the PV limit. **Figure 19** indicates that static friction of Teflon FEP decreases with increases in pressure. The incorporation of fillers does not appreciably alter the coefficient of friction.

PV limits presented in **Table 6** define the maximum combinations of pressure at which these materials will operate continuously without lubrication. PV limit does not necessarily define useful combinations of pressure and velocity since wear is not considered in its determination. The useful PV limit of a material cannot exceed the PV limit and must take into account the composition’s wear characteristics and the allowable wear for the application. The melting point of the resin is an additional limiting factor.

Wear factor, K, is a proportionality factor relating to the wear of a nonlubricating surface (operating against a specific mating surface at combinations of pressure and

Table 6
PV and Wear Performance

Property	Teflon® FEP 100 Fluoropolymer Resin	15% (by Volume) Glass-Filled	10% (by Volume) Bronze-Filled
PV Limit (lb/in × fpm)			
at 10 fpm	600	4,500	9,000
at 100 fpm	800	10,000	12,000
at 1,000 fpm	1,000	8,000	10,000
PV for 0.005 in Radial Wear in 1,000 hr (Nonlubricated)	<10	1,650	5,000
Wear Factor "K"	>5,000	30	10

velocity below the material's PV limit). The wear factors listed in **Table 6** can be used to predict wear for these compositions, against specific mating surfaces, using the following expression:

$$t = KPVT$$

where t = wear, in
 K = wear factor, $\frac{\text{in}^3 \cdot \text{min}}{\text{lb} \cdot \text{ft} \cdot \text{hr}}$

P = pressure, psi
 V = velocity, fpm
 T = time, hr

These measurements were made at ambient temperature and were based on unidirectional loading on a fixed bushing or using a thrust washer. The wear factor "K" values are based on operating unlubricated below the PV limit against soft carbon steels (R 20 to 25) finished to 12 to 20 microinches (AA). This factor is applicable for operation against most stainless steels and cast irons.

The coefficient of friction versus sliding speed for Teflon FEP 100 is shown in **Figure 18**, while the coefficient of friction versus load at low rates of speed is shown in **Figure 19**.

Thermal Properties

Teflon FEP is a copolymer of hexafluoropropylene and tetrafluoroethylene and, as such, has a melting range rather than a sharp melting point. The melting peak derived from differential thermal analysis (DTA) is 257–263°C (495–505°F). Other thermal properties are listed in **Table 1**.

The heat of combustion of Teflon FEP is extremely low. This property in combination with its very high oxygen index makes this product very useful in areas where fire hazards must be kept to a minimum.

Electrical Properties

Teflon FEP has a dielectric constant of 2.04–2.05 over a wide range of frequencies from 1 kHz to 13 GHz. The dissipation factor increases slowly from 0.00006 at 1 kHz to 0.0006 at 30 MHz and peaks out at 0.001 at 1 GHz. These relationships are shown graphically in **Figures 20** and **21**. The effects of temperature on these properties are shown in **Figures 22** and **23**. A glance at the figures will show that temperature has a significant effect on the dissipation factor, but the shapes of the curves are similar. The data were obtained from measurements made on Teflon FEP 100 but the values for Teflon FEP 140 and 160 should be similar.

Chemical Resistance

Teflon FEP fluoropolymer resins are essentially chemically inert. Up to the highest use temperature of 200°C (392°F), very few chemicals are known to react chemically with these resins. Those that do include molten alkali metals, fluorine, and a few fluorochemicals such as chlorine trifluoride, ClF₃, or oxygen difluoride, OF₂, which readily liberate free fluorine at elevated temperatures.

Figure 18. Coefficient of Friction versus Sliding Speed, Teflon® FEP 100 Fluoropolymer Resin

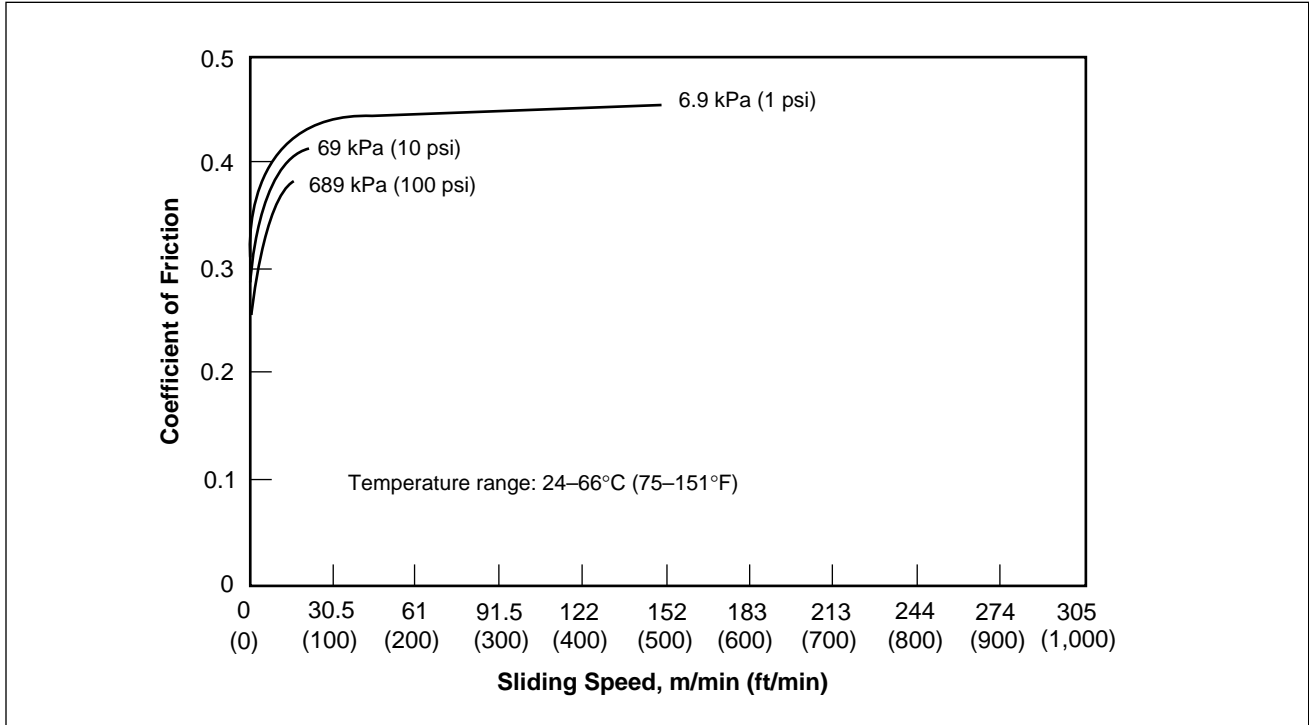


Figure 19. Coefficient of Friction versus Load (at <2 ft/min and room temperature), Teflon FEP 100

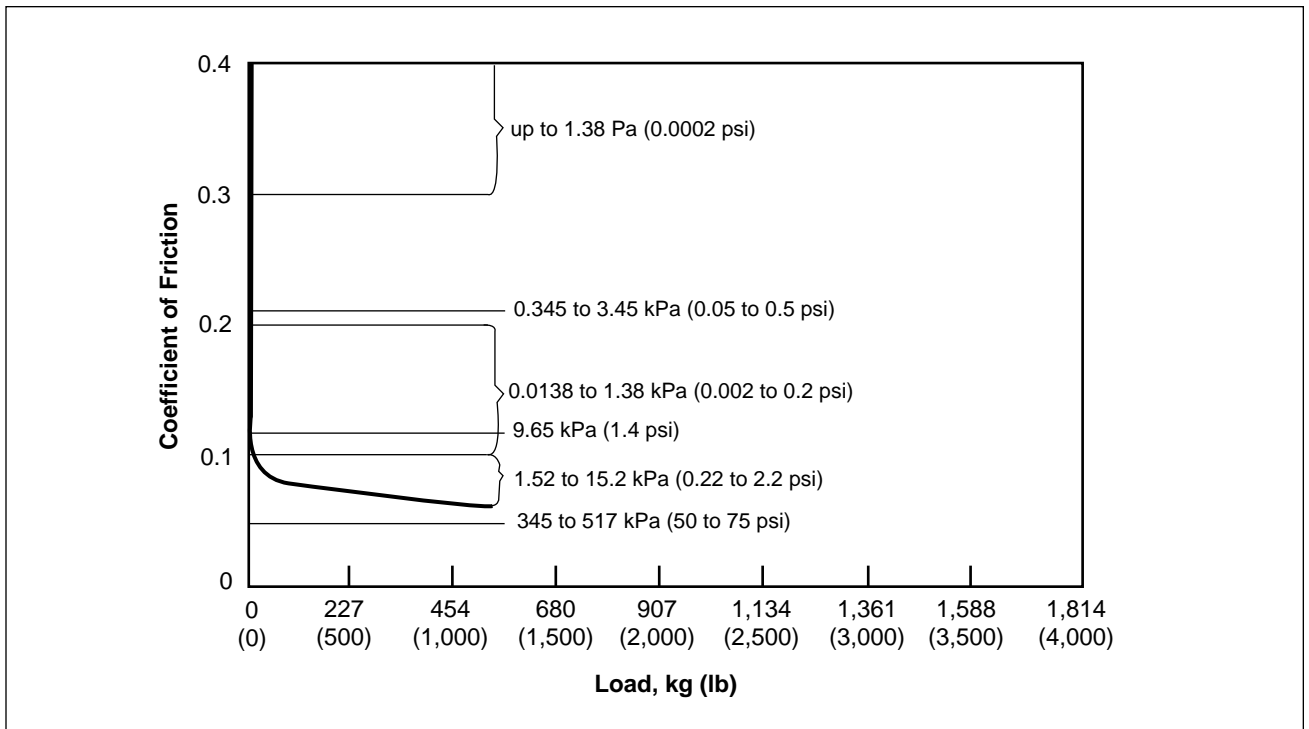


Figure 20. Dielectric Constant—Room Temperature, Teflon® FEP 100 Fluoropolymer Resin

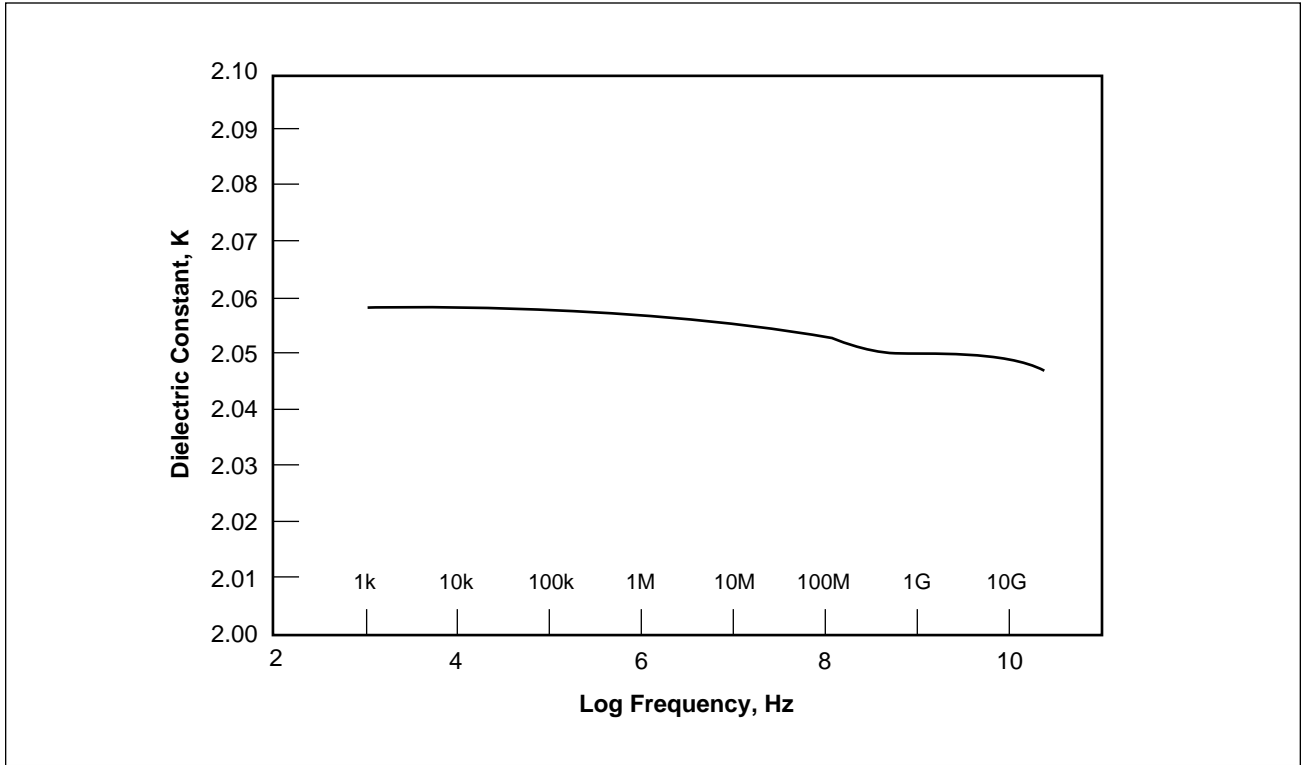


Figure 21. Dissipation Factor—Room Temperature, Teflon FEP 100

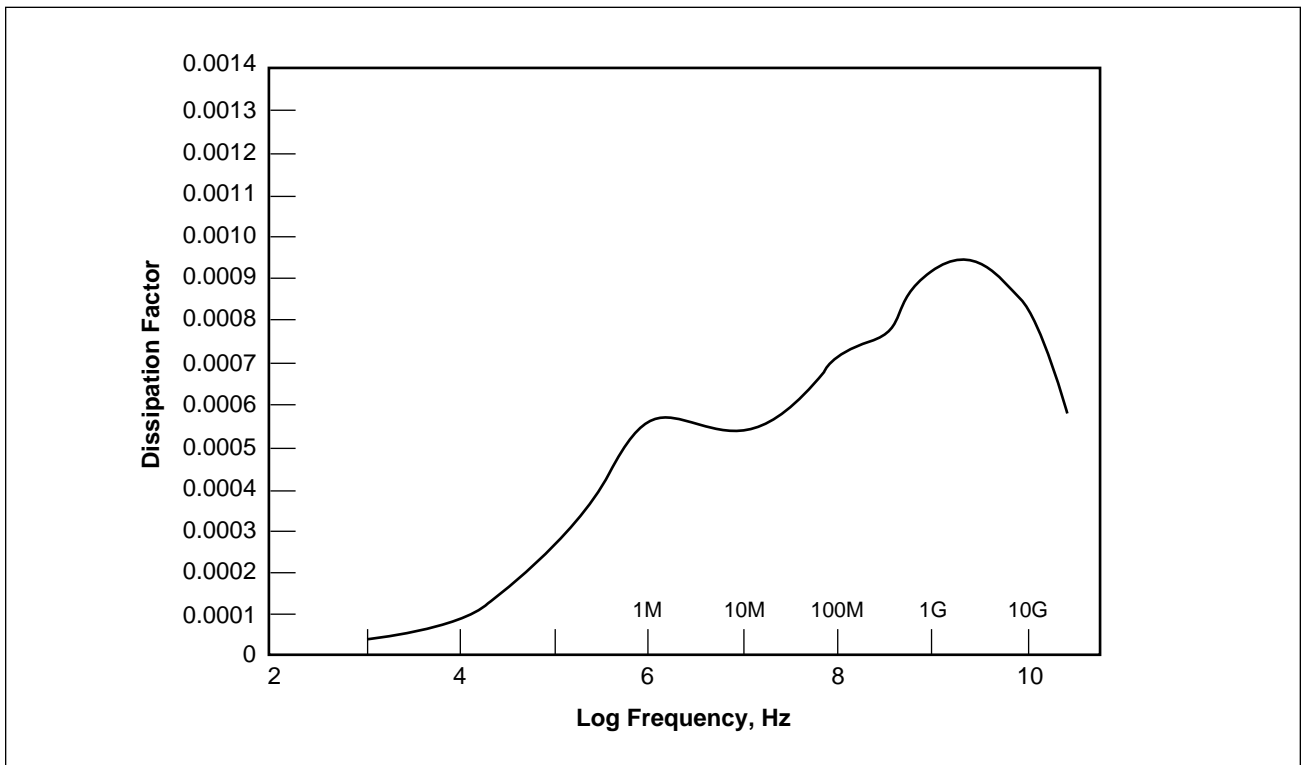


Figure 22. Dielectric Constant—Elevated Temperature, Teflon® FEP 100 Fluoropolymer Resin

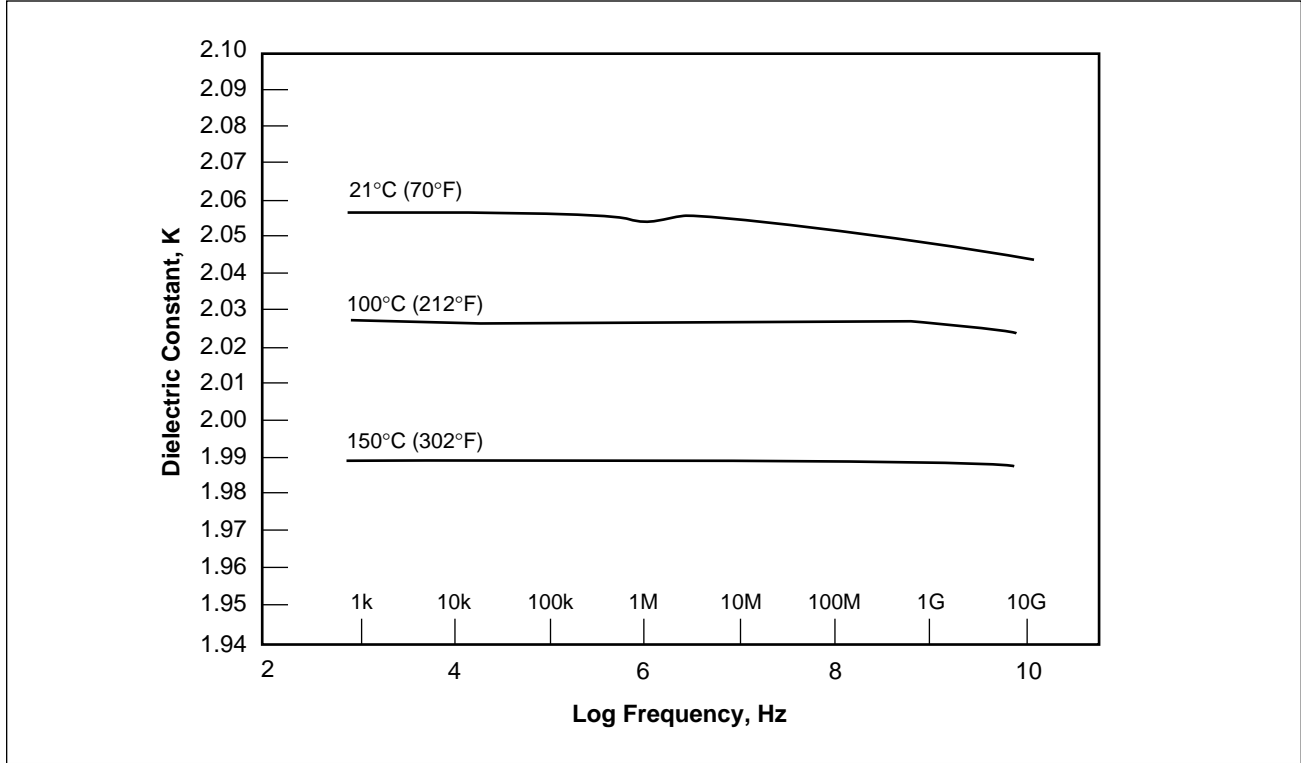
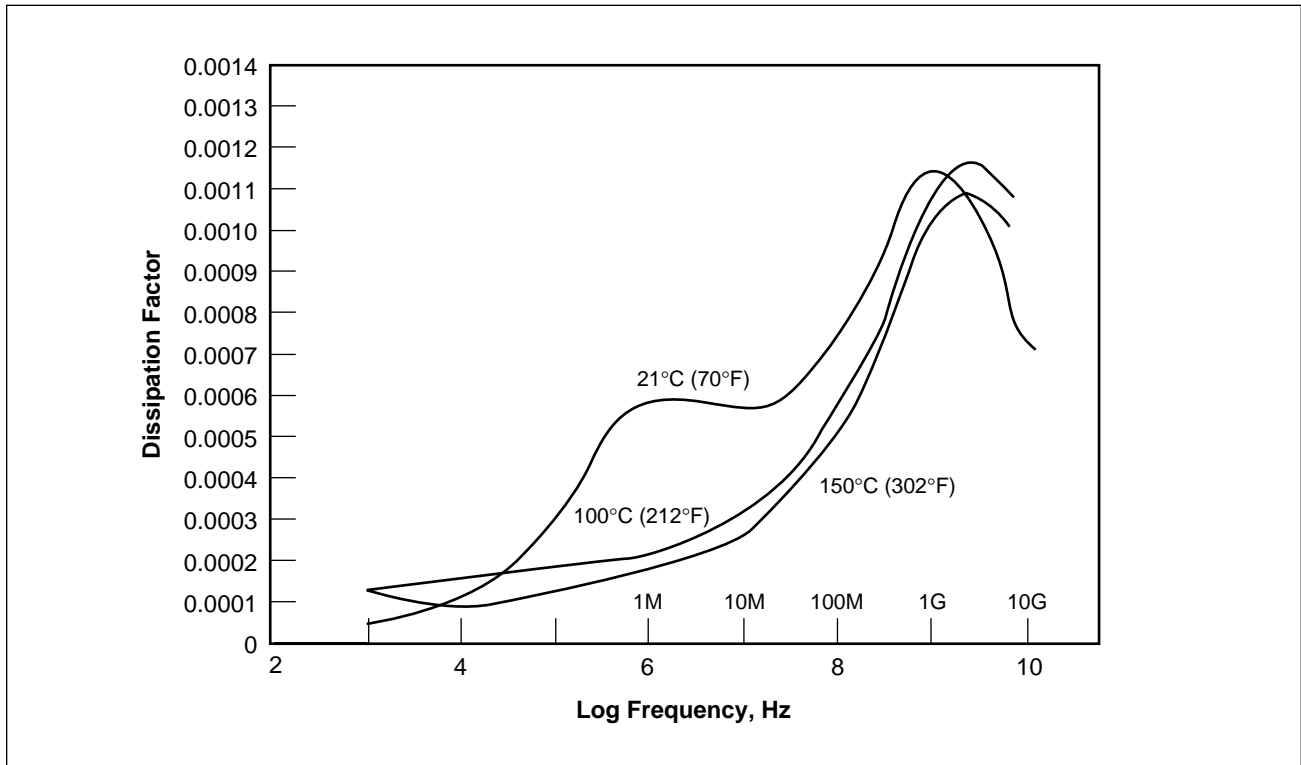


Figure 23. Dissipation Factor—Elevated Temperature, Teflon FEP 100



The unique degree of inertness of Teflon® fluoropolymer resins reflects its chemical structure. Molecules of Teflon FEP resins are formed simply from strong carbon-carbon and super-strong carbon-fluorine interatomic bonds; moreover, the fluorine atoms form a protective sheath around the carbon core of each molecule. This structure also produces other special properties, such as insolubility and low surface tension (which imparts nonwettability to many solvents), low coefficient of friction, and excellent nonstick characteristics. For example, sheeting or components of Teflon PTFE resins may be bonded to metal with molten Teflon FEP. Teflon FEP film is frequently used for this purpose.

To a minor degree, halogenated organic chemicals may be absorbed by fluoropolymer resins. This will cause a very small weight change and, in some cases, slight swelling. Teflon FEP is less permeable than Teflon PTFE resins and hence is affected to a lesser degree.

Absorption

Almost all plastics absorb small quantities of certain materials with which they come into contact. Submicroscopic voids between polymer molecules provide space for the material to be absorbed without chemical reaction. This phenomenon is usually marked by a slight weight increase and sometimes by discoloration.

Teflon FEP has unusually low absorption compared with other thermoplastics. It absorbs practically no common acids or bases at temperatures as high as 200°C (392°F) and exposures of one year. Even the absorption of solvents is very small. Weight increases are generally less than 1% when exposed at elevated temperatures for long periods. Aqueous solutions are absorbed very little by Teflon FEP. Moisture absorption is typically less than 0.01% at ambient temperature and pressure.

Permeability

Many gases and vapors permeate Teflon FEP at a much lower rate than for other thermoplastics. In general, permeation increases with temperature, pressure, and surface contact area and decreases with increased thickness. **Table 7** lists rates at which various gases are transmitted through Teflon FEP 100 film while typical

vapor transmission rates of Teflon FEP (at 1 mil [25 μm] film thickness) are shown in **Table 8**. Note that the pressure for each material is its vapor pressure at the indicated temperature.

Figure 24 shows water vapor transmission rate of Teflon FEP film at 40°C (104°F) as a function of thickness.

Table 7
Typical Gas Permeability Rates of
Teflon FEP 100 Film
1 mil (25 μm) Thickness
(ASTM D1434-75, 25°C [77°F])

Gas	Permeability Rate, cc/(m ² ·24 hr·atm)*
Carbon dioxide	25.9 × 10 ³
Hydrogen	34.1 × 10 ³
Nitrogen	5.0 × 10 ³
Oxygen	11.6 × 10 ³

*To convert to cc/(100 in²·24 hr·atm), multiply by 0.0645.

Weathering

Teflon FEP is essentially unchanged after 25 years of outdoor weathering in Florida. The tensile strength is unaffected although there seems to be some loss in ultimate elongation. However, the value remains quite high.

Cryogenic Service

Teflon FEP has performed satisfactorily in cryogenic service at temperatures below that of liquid nitrogen. When carefully cleaned of any organic substances, Teflon FEP is inert to LOX and is frequently used in LOX applications.

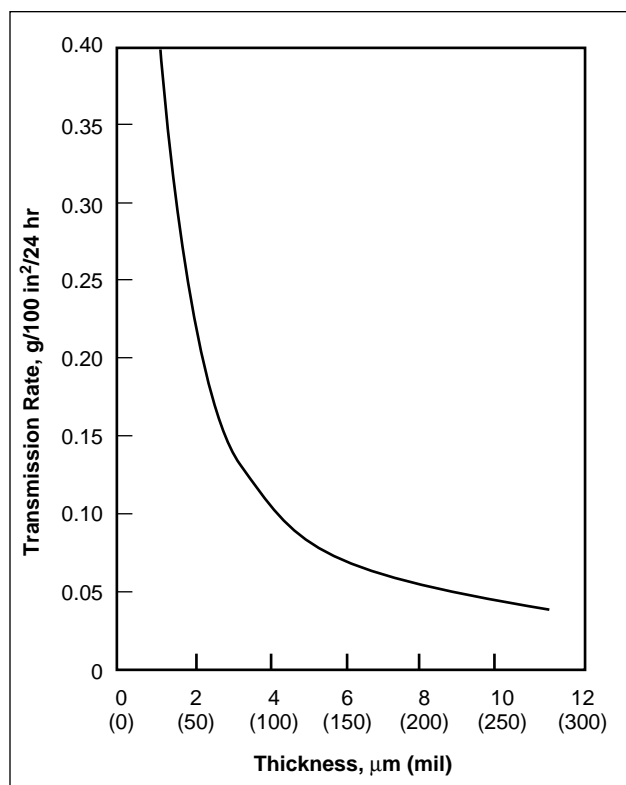
Mildew Resistance

Teflon FEP has been shown to be completely resistant to mildew growth by testing in humidity chamber, while inoculated with a spore suspension, and, in a soil burial test for three months.

Table 8
Typical Vapor Transmission Rates, Teflon® FEP 100 Fluoropolymer Resin
(1 mil film, ASTM E96 modified test)

Vapor	Temperature		Vapor Transmission Rate	
	°C	°F	g/m ² ·d	g/100 in ² ·d
Acetic acid	35	95	6.3	0.41
Acetone	35	95	14.7	0.95
Benzene	35	95	9.9	0.64
Carbon tetrachloride	35	95	4.8	0.31
Ethyl acetate	35	95	11.7	0.76
Ethyl alcohol	35	95	10.7	0.69
Freon® F-12	23	73	372	24
Hexane	35	95	8.7	0.56
Hydrochloric acid	25	77	<0.2	<0.01
Nitric acid (red fuming)	25	77	160	10.5
Sodium hydroxide, 50%	25	77	<0.2	<0.01
Sulfuric acid, 98%	25	77	2 × 10 ⁻⁴	1 × 10 ⁻⁵
Water	39.5	103	7.0	0.40

Figure 24. Water Vapor Transmission Rate of Teflon FEP Film at 40°C (104°F) per ASTM E96 (Modified)



Note: Values are averages only and not for specification purposes. To convert the permeation values for 100 in² to those for 1 m², multiply by 15.5.

FDA Compliance

Teflon FEP may be used as articles or components of articles intended to contact food in compliance with FDA regulation 21 CFR 177.1550.

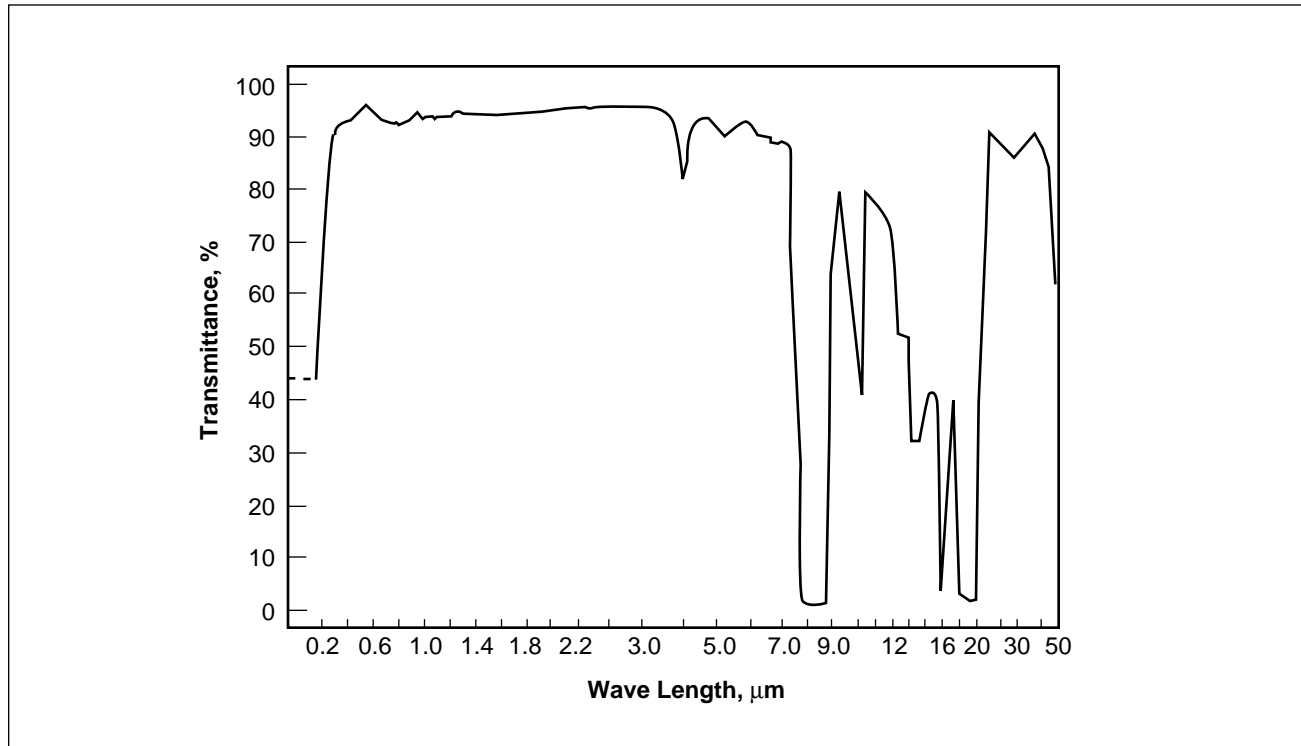
Optical Properties

In thin sections or films, Teflon FEP transmits a high percentage of ultraviolet and visible light. The solar transmission of Teflon FEP in thin-film form is approximately 96%. Teflon FEP is much more transparent in the infrared region of the spectrum than is glass. The infrared transmission spectrum for Teflon FEP in thin films is shown in **Figure 25**.

Fabrication Techniques

Teflon FEP, as a thermoplastic polymer, can be processed by most techniques applicable to the type of resin. Depending upon the grade, and hence the melt viscosity (melt flow number), Teflon FEP can be processed by injection, compression, transfer, or rotational molding. It can be extruded into a variety of complex shapes including rod, tubing, and film and can be coated

Figure 25. Transmission Spectrum for Teflon® FEP Fluoropolymer Film



onto wire as a primary insulation or for jacketing purposes. Teflon FEP 160 is usually the preferred material for transfer molding of liners, tubing, etc., where a high degree of stress crack resistance is required. However, the very high melt viscosity of this product results in considerably slower production rates and limits its use for some types of processing. Teflon FEP 100, being of lower viscosity and hence more easily processible, is the preferred resin for injection molding and general extrusion applications. Teflon FEP 140 is of intermediate viscosity and usually used where a modest improvement in stress crack resistance is required but where some degree of production rate reduction can be tolerated.

The specific techniques are discussed in DuPont guides for injection molding, extrusion, and transfer molding that are available from the nearest DuPont Fluoro-products office.

Forming and Fabrication

When extreme tolerance must be specified, when product shapes are very complex, or when just one or two prototypes are required, the machining of Teflon FEP basic shapes becomes a logical means of fabrication.

All standard operations—turning, facing, boring, drilling, threading, tapping, reaming, grinding, etc.—are applicable to Teflon FEP resins. Special machinery is not necessary.

When machining parts from Teflon FEP resin, either manually or automatically, the basic rule to remember is that this fluoropolymer resin possesses physical properties unlike those of most other commonly machined materials. It is soft, yet springy. It is waxy, yet tough. It has the cutting “feel” of brass, yet the tool-wear effect of stainless steel. Nevertheless, any trained machinist can readily shape Teflon FEP to tolerances of ± 0.001 in and, with special care, to ± 0.0005 in.

Choose Correct Working Speeds

One property of Teflon FEP resin is the exceptionally low thermal conductivity. It does not rapidly absorb and dissipate heat generated at a cutting edge. If too much generated heat is retained in the cutting zone, it will tend to dull the tool and overheat the resin. Coolants, then, are desirable during machining operations, particularly above a surface speed of 150 m/min (500 fpm).

Coupled with low conductivity, the high thermal expansion of Teflon® FEP fluoropolymer resins (nearly ten times that of metals) could pose supplemental problems. Any generation and localization of excess heat will cause expansion of the fluoropolymer material at that point. Depending on the thickness of the section and the operation being performed, localized expansion may result in overcuts or undercuts, and in drilling a tapered hole.

Machining procedures, then, especially at working speeds, must take conductivity and expansion effects into account.

Surface speeds from 60 to 150 m/min (200 to 500 fpm) are most satisfactory for fine finish turning operations; at these speeds, flood coolants are not needed. Higher speeds can be used with very low feeds or for rougher cuts, but coolants become a necessity for removing excess generated heat. A good coolant consists of water plus water-soluble oil in a ratio of 10:1 to 20:1.

Feeds for the 60 to 150 m/min (200 to 500 fpm) speed range should run between 0.05–0.25 mm (0.002–0.010 in)/revolution. If a finishing cut is the object of a high-speed operation (e.g., an automatic screw-machine running at 240 m/min [800 fpm]), then feed must be dropped to a correspondingly lower value. Recommended depth of cut varies from 0.005 to 6.3 mm (0.0002 to 0.25 in).

In drilling operations, the forward travel of the tool should be held to 0.13–0.23 mm (0.005–0.009 in)/revolution. It may prove advantageous to drill with an in-out motion to allow dissipation of heat into the coolant.

Properly Shape and Use Tools

Along with working speeds, choice of tools is quite important to control heat buildup. While standard tools can be used, best results come from tools specifically shaped for use with Teflon resins. Below is shape information important to proper single-point tool design:

Top rake	0–15 positive
Side rake and side angle	0–15
Front or end rake	0.5–10

Boring tools normally require the higher angles listed.

The quality of a tool's cutting edge not only influences the amount of heat generated, but it also controls tolerances in a different way. A tool that is not sharp may tend to pull the stock out of line during machining, thereby resulting in excessive resin removal. On the other hand, an improperly edged tool tends to compress the resin, resulting in shallow cuts.

An extremely sharp edge is, therefore, highly desirable, especially for machining work on filled compositions. "Stellite" and carbide-tipped tools will help to minimize required resharpening frequency.

To compensate partially for tool wear, it is helpful to grind tools with a slight nose radius. All drills, either twist or half-round, should have deep, highly polished flutes.

Adequate material support is also important, especially when machining long thin rods. If support is not provided, stock flexibility may lead to poor results.

Another characteristic of Teflon FEP resin will be noted immediately after beginning any turning operation. Rather than chips and ribbons of removed stock, as encountered during the machining of most materials, Teflon resin turns off as a long, continuous curl. If this curl is not mechanically guided away from the work, it may wrap around it, hampering the flow of coolant, or worse, forcing the work away from the tool. On an automatic screw machine, a momentary withdrawal of the tool from the stock will suffice.

Rules for Dimensioning and Finishing

Normally, Teflon resins are machined to tolerances of about ± 0.127 mm (0.005 in). While closer tolerances are occasionally required, they usually are not necessary. The natural resiliency of these resins allows machined parts to conform naturally to working dimensions. For example, a part with an interference can be press-fitted at much lower cost than required for final machining to exact dimensions, and the press-fitted part will perform equally well.

Closer Tolerances

When it is necessary to produce shapes with extremely close tolerances, it is usually essential to follow a stress-relieving procedure. By heating a Teflon FEP fluoropolymer resin stock to slightly above its expected service temperature (but not above its melting point), initial stresses are relieved.

Holding this temperature for 1 hr/2.5 cm (1 in) of thickness, followed by slow cooling, completes the annealing step. A rough cut will then bring the stock to within 0.38–0.76 mm (0.015–0.030 in) of final dimensions. Reannealing prior to a final finishing cut will remove stresses induced by the tool.

Measuring Tolerances

Personnel should exercise caution when measuring tolerances on parts machined from any Teflon® fluoropolymer resin. In general, results will be better if the measuring instruments do not exert excessive pressure on the piece. A micrometer used by inexperienced personnel could easily read slightly under the true dimension because of the compressibility of the Teflon FEP resin being used. Optical comparators are often useful in eliminating this type of error.

It is best to check dimensions at the expected service temperature, but temperature compensation will suffice if this is not practical. Parts machined to final size and measured at room temperatures or below will not meet specifications at higher temperatures. The reverse is also true.

Surface Finishes

Surface finishes better than 0.4 μm (16 microinches) are possible but are rarely needed because of the resin's compressibility and low coefficient of friction. Precision-honed and lapped cutting tools will produce a 0.4- μm (16-microinch) surface when required; standard equipment yields a finish of about 0.8 μm (32 microinches).

Lapping compounds may be used, but these as well as grinding compounds may become embedded in the resin and may prove to be very difficult to remove. Contaminants from machinery not used exclusively for Teflon FEP can also embed in the resin surface.

Safety Precautions

WARNING!

VAPORS CAN BE LIBERATED THAT MAY BE HAZARDOUS IF INHALED.

Before using *Teflon*®, read the Material Safety Data Sheet and the detailed information in the “Guide to the Safe Handling of Fluoropolymer Resins, 2nd Edition,” published by the Fluoropolymers Division of The Society of the Plastics Industry—available from DuPont.

Open and use containers only in well-ventilated areas using local exhaust ventilation (LEV). Vapors and fumes liberated during hot processing, or from smoking tobacco or cigarettes contaminated with *Teflon*® FEP, may cause flu-like symptoms (chills, fever, sore throat) that may not occur until several hours after exposure and that typically pass within about 36 to 48 hours. Vapors and fumes liberated during hot processing should be exhausted completely from the work area; contamination of tobacco with polymers should be avoided. Mixtures with some finely divided metals, such as magnesium or aluminum, can be flammable or explosive under some conditions.

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CAUTION: Do not use in medical applications involving permanent implantation in the human body. For other medical applications, see "DuPont Medical Caution Statement," H-50102.



Teflon®
Only by DuPont



Teflon® FEP

fluoropolymer resin



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