Teflon™ PFA

Fluoropolymer Resins

Properties Handbook

PFA 340
PFA 345
PFA 350
PFA 416HP
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PFA 440HPB
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Chemours™

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GENERAL

Introduction

As with any product, proper understanding of the capabilities and limitations of Teflon™ PFA fluoropolymer resins is essential for effective design and use of the material. The properties and characteristics of Teflon™ PFA fluoropolymer resins presented in this handbook are offered to help encourage the proper design of parts, to make fluoropolymer resins easier to use, and to increase the reliability of finished parts.

It is recommended that an experienced fabricator be involved early in the design stage because the method of fabrication may affect the product cost and properties of the finished article.

Products labeled with or without an X following the product name are equivalent, and all information in this document is applicable to both.

The Products

300 Series

Teflon™ PFA 300 series resins are general-purpose fluoropolymer resins designed to provide an easily molded or extruded thermoplastic with outstanding properties. Teflon™ PFA fluoropolymer resins are especially useful to designers and end-users who require a thermoplastic with excellent chemical stability, electrical properties, superior creep resistance at high temperatures, excellent low temperature toughness, and exceptional flame resistance. Products manufactured from Teflon™ PFA fluoropolymer resins can offer continuous service temperatures up to 260 °C (500 °F). Teflon™ PFA fluoropolymer resins are available in pellet form as PFA 340, PFA 345, and PFA 350. Each grade has a different melt flow rate (MFR) to meet the needs of any thermoplastic molding technique or application, including tube and film extrusion, as well as injection, transfer, compression, and blow molding.

400 Series

Teflon™ PFA 400 HP series resins are fully fluorinated fluoropolymer resins specifically tailored to meet the chemical fluid handling industry's needs for high purity and minimum extractables in the most demanding applications. Components made from Teflon™ PFA HP fluoropolymer resins have superior resistance to chemical and environmental stress cracking. Teflon™ PFA HP fluoropolymer resins are unaffected by virtually all chemicals and solvents. Teflon™ PFA HP fluoropolymer resins can be fabricated into components via efficient, versatile thermoplastic molding techniques, including tube and film extrusion, as well as injection, transfer, compression, and blow molding. Applications include piping, fittings, valves, and other components for transporting aggressive, ultrapure fluids; wafer carriers; linings for storage tanks and vessels; sinks for wet benches; fluid containers; and labware. Teflon™ PFA HP fluoropolymer resins are available in pellet form as PFA 416HP, PFA 440HPA, PFA 440HPB, PFA 445HP, PFA 450HP, PFA 450HP LM, and PFA 451HP.

Unless otherwise noted, all data in this document are applicable to both 300 and 400 series Teflon™ PFA fluoropolymer resins.

Teflon™ PFA is also available as a film and as a dispersion; for more information, contact your Chemours representative.

Typical Properties

Typical property data for Teflon™ PFA fluoropolymer resins is shown in Table 1.

Table 1. Typical Physical and Mechanical Properties of Teflon™ PFA Fluoropolymer Resins

Property	Units	Test Method	340	345	350	416HP
ASTM D3307 Type			I	III	II	IX
Melt Flow Rate	g/10 min	ASTM D3307/ISO 12086	14	5	2	42
Melting Point	°C (°F)	ASTM D4591	305 (581)	305 (581)	305 (581)	305 (581)
Specific Gravity	—	ASTM D792	2.15	2.15	2.15	2.15
Critical Shear Rate, 372 °C (702 °F)	1/sec	—	50	21	12	250
Tensile Strength	MPa (psi)	ASTM D3307/ISO 12086				
23 °C (73 °F)			25 (3,600)	27 (3,900)	28 (4,000)	25 (3,600)
250 °C (482 °F)			12 (1,800)	13 (1,900)	14 (2,000)	
Ultimate Elongation	%	ASTM D3307/ISO 12086				
23 °C (73 °F)			300	300	300	350
250 °C (482 °F)			480	490	500	
Flexural Modulus	MPa (psi)	ASTM D790/ISO 178				
23 °C (73 °F)			590 (85,000)	551 (80,000)	520 (75,000)	690 (100,000)
250 °C (482 °F)			55 (8,000)	45 (6,500)	35 (5,000)	
MIT Folding Endurance (0.20 mm, 8 mil film)[a]	Cycles	ASTM D2176[b]	15,000	50,000	500,000	4,000
Hardness Durometer	—	ASTM D2240/ISO 868	D55	D55	D55	D55
Dielectric Strength, Short Time, 0.25 mm (0.010 in)	kV/mm (V/mil)	ASTM D149/IEC 243	80 (2,000)	80 (2,000)	80 (2,000)	80 (2,000)
Dielectric Constant, 1 MHz (10^6 Hz)	—	ASTM D150/IEC 250	2.03	2.03	2.03	2.03
Dissipation Factor, 1 MHz (10^6 Hz)	—	ASTM D150/IEC 250	<0.0002	<0.0002	<0.0002	<0.0002
Volume Resistivity	ohm-cm	ASTM D257/ISO 1325	10^{18}	10^{18}	10^{18}	10^{18}
Water Absorption, 24 hr	%	ASTM D570	<0.03	<0.03	<0.03	<0.03
Weather and Chemical Resistance	—	—	Outstanding	Outstanding	Outstanding	Outstanding
Limiting Oxygen Index	%	ASTM D2863/ISO 4589	>95	>95	>95	>95
Continuous Service Temperature[c]	°C (°F)	—	260 (500)	260 (500)	260 (500)	260 (500)
Flammability Classification[d]	—	UL 94	V-0	V-0	V-0	V-0

continued

[a]Depending on fabrication conditions

[b]Historical Standard

[c]Definition of continuous service temperature: The continuous service temperature is based on accelerated heat-aging tests and represents the temperature at which tensile strength and ultimate elongation retain 50% of the original values after 20,000 hr thermal aging. Continuous service temperature above 260 °C (500 °F) may be feasible, depending on such factors as chemical exposure, support from the substrate, etc. When considering uses of Teflon™ PFA fluoropolymer resins above 260 °C (500 °F), preliminary testing should be done to verify suitability.

[d]These results are based on laboratory tests under controlled conditions and do not reflect performance under actual fire conditions; current rating is a typical theoretical value.

Typical properties are not suitable for specification purposes.

Statements or data regarding behavior in a flame situation are not intended to reflect hazards presented by this or any other material when under actual fire conditions.

Table 1. Typical Physical and Mechanical Properties of Teflon™ PFA Fluoropolymer Resins (continued)

Property	Units	440HPA	440HPB	445HP	450HP	450HP LM	451HP
ASTM D3307 Type		I	I	III	II	II	II
Melt Flow Rate	g/10 min	16	14	5	2	2	2
Melting Point	°C (°F)	305 (581)	305 (581)	305 (581)	305 (581)	305 (581)	305 (581)
Specific Gravity	—	2.15	2.15	2.15	2.15	2.15	2.15
Critical Shear Rate, 372 °C (702 °F)	1/sec	56	50	21	12	12	12
Tensile Strength	MPa (psi)						
23 °C (73 °F)		25 (3,600)	25 (3,600)	26 (3,800)	28 (4,000)	28 (4,000)	33 (4,800)
250 °C (482 °F)		14 (1,800)	14 (1,800)	10 (1,400)	14 (2,000)	14 (2,000)	18 (2,600)
Ultimate Elongation	%						
23 °C (73 °F)		300	300	320	300	300	360
250 °C (482 °F)		480	480	480	500	500	500
Flexural Modulus	MPa (psi)						
23 °C (73 °F)		590 (85,000)	590 (85,000)	551 (80,000)	625 (90,000)	625 (90,000)	410 (60,000)
250 °C (482 °F)		55 (8,000)	55 (8,000)	55 (8,000)	69 (10,000)	69 (10,000)	54 (7,800)
MIT Folding Endurance (0.20 mm, 8 mil film)[a]	Cycles	20,000	30,000	50,000	500,000	500,000	300,000
Hardness Durometer	—	D55	D55	D55	D55	D55	D55
Dielectric Strength, Short Time, 0.25 mm (0.010 in)	kV/mm (V/mil)	80 (2,000)	80 (2,000)	80 (2,000)	80 (2,000)	80 (2,000)	80 (2,000)
Dielectric Constant, 1 MHz (10^6 Hz)	—	2.03	2.03	2.03	2.03	2.03	2.03
Dissipation Factor, 1 MHz (10^6 Hz)	—	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Volume Resistivity	ohm-cm	10^{18}	10^{18}	10^{18}	10^{18}	10^{18}	10^{18}
Water Absorption, 24 hr	%	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Weather and Chemical Resistance	—	Outstanding	Outstanding	Outstanding	Outstanding	Outstanding	Outstanding
Limiting Oxygen Index	%	>95	>95	>95	>95	>95	>95
Continuous Service Temperature[c]	°C (°F)	260 (500)	260 (500)	260 (500)	260 (500)	260 (500)	260 (500)
Flammability Classification[d]	—	V-0	V-0	V-0	V-0	V-0	V-0

[a]Depending on fabrication conditions

[b]Historical Standard

[c]Definition of continuous service temperature: The continuous service temperature is based on accelerated heat-aging tests and represents the temperature at which tensile strength and ultimate elongation retain 50% of the original values after 20,000 hr thermal aging. Continuous service temperature above 260 °C (500 °F) may be feasible, depending on such factors as chemical exposure, support from the substrate, etc. When considering uses of Teflon™ PFA fluoropolymer resins above 260 °C (500 °F), preliminary testing should be done to verify suitability.

[d]These results are based on laboratory tests under controlled conditions and do not reflect performance under actual fire conditions; current rating is a typical theoretical value.

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MECHANICAL PROPERTIES

Tensile Strength

The tensile strength of Teflon™ PFA fluoropolymer resins vs. temperature is shown in Figure 1. As expected, tensile strength decreases with increasing temperatures. The change with temperature in ultimate elongation or elongation at break of Teflon™ PFA fluoropolymer resins is shown in Figure 2. Typically, the elongation of Teflon™ PFA fluoropolymer resins increases with increasing temperatures, at least through the rated continuous use temperature.

Stiffness

The stiffness of a plastic material is frequently of importance in determining its use as an engineering material. While fluoropolymer materials are not considered stiff among plastics, their combination of stiffness retention to 200 °C (392 °F), chemical inertness, and electrical properties has made them an integral part of the chemical process, semiconductor manufacturing, and high temperature electrical industries.

Flexural Modulus

The change in flexural modulus of Teflon™ PFA fluoropolymer resins with temperature is shown in Figure 3. Two samples of Teflon™ PFA fluoropolymer resins are presented to show the range of properties expected from typical variations in crystallinity. One sample (specific gravity = 2.140) was water quenched to decrease the crystallinity. This resulted in a decrease in stiffness of the material in the temperature ranges studied.

Figure 1. Teflon™ PFA Fluoropolymer Resins, Tensile Strength vs. Temperature

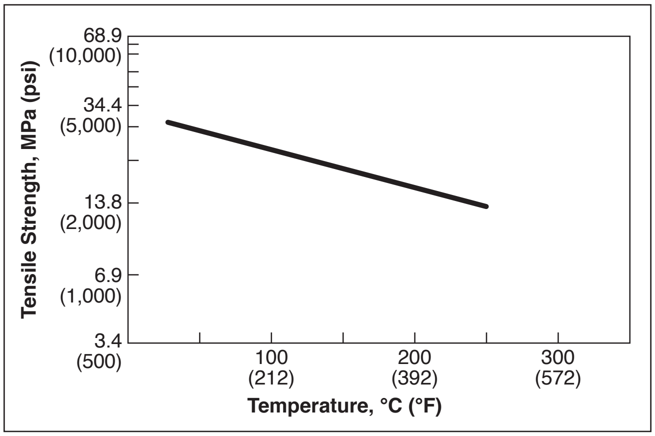


Figure 2. Teflon™ PFA Fluoropolymer Resins, Ultimate Elongation vs. Temperature

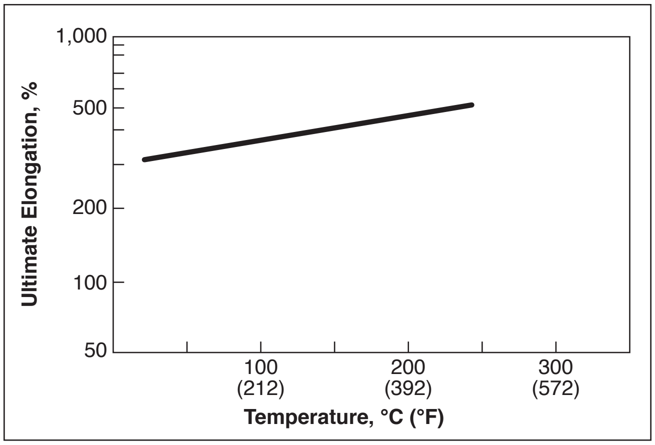
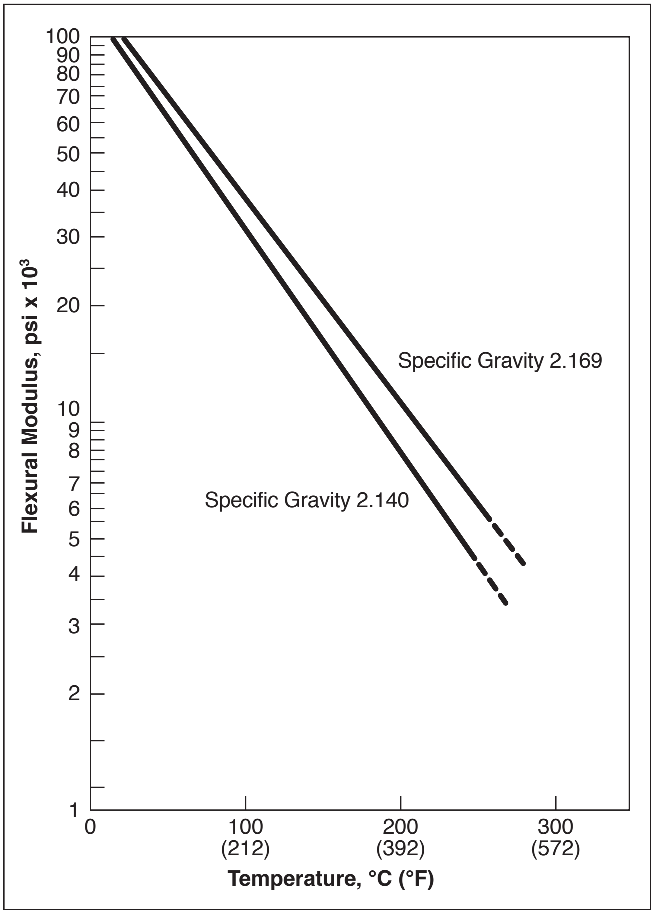


Figure 3. Teflon™ PFA Fluoropolymer Resins, Flexural Modulus vs. Temperature



Cold Flow (Creep)

Teflon™ PFA fluoropolymer resins, like other plastic materials, experience deformation when subjected to tensile or compressive stresses. This deformation, or cold flow (creep), occurs well below the yield point of the resin and is especially important when fluoropolymer resins are used in lined pipes, hoses, seals, gaskets, etc.

The resistance to creep in tension is described as the apparent modulus. It describes the sum of the initial response to tensile stress plus a time-dependent response. The numbers shown in Table 1 are the tensile moduli apparent after 10 hr under varying loads and temperatures.

The creep observed in a compressive situation is usually described as a percent strain under a given load. Figures 4, 5, and 6 show the tensile strain observed under various loads at three temperatures. Figure 7 shows compressive strain under various loads at one temperature. The figures give a picture of the initial strain under load and the slow increase with time on prolonged exposure.

Figure 4. Teflon™ PFA Fluoropolymer Resins, Total Deformation vs. Time Under Load at 23 °C (73 °F)

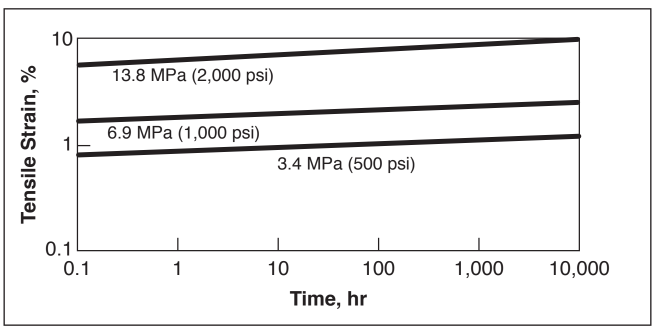


Figure 5. Teflon™ PFA Fluoropolymer Resins, Total Deformation vs. Time Under Load at 100 °C (212 °F)

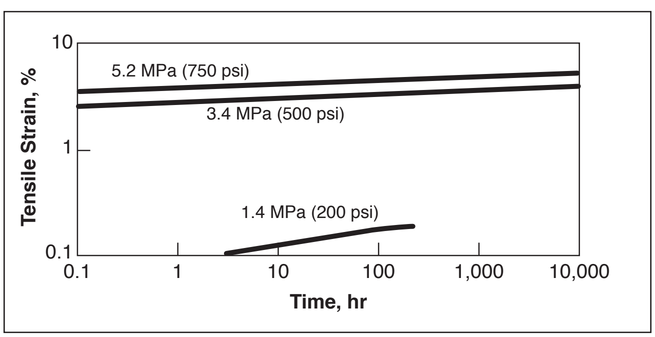


Figure 6. Teflon™ PFA Fluoropolymer Resins, Total Deformation vs. Time Under Load at 200 °C (392 °F)

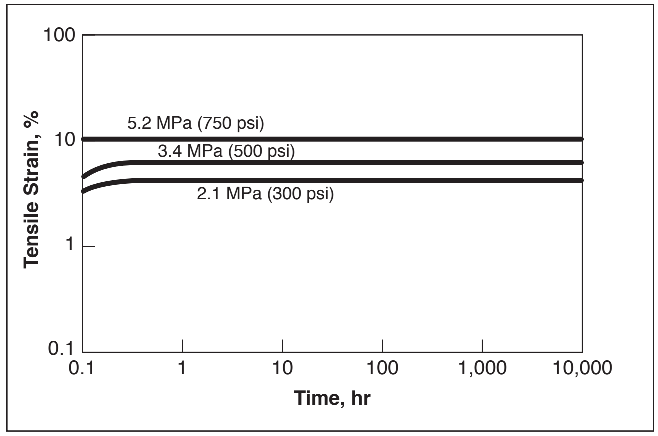
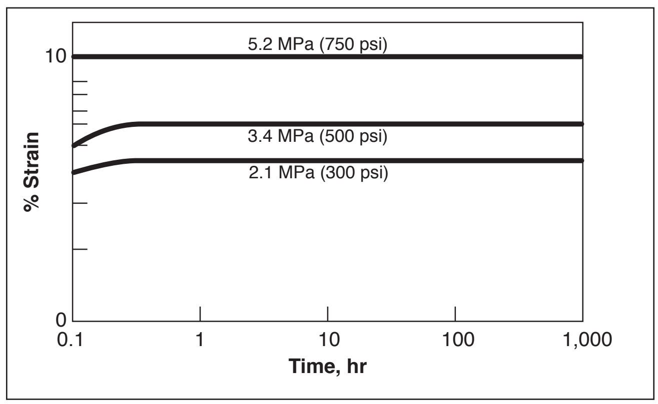


Figure 7. Cold Flow Properties of Teflon™ PFA Fluoropolymer Resins, Compressive Creep at 200 °C (392 °F)



Hardness

The hardness of Teflon™ PFA fluoropolymer resins is 55–57 durometer. This result was obtained in tests run on compression-molded panels according to ASTM D2240.

Cryogenic Temperature Effects

Tests made at liquid nitrogen temperatures indicate that Teflon™ PFA fluoropolymer resins perform well in cryogenic applications. The results of standard ASTM tests performed on samples at room and cryogenic temperatures are shown in Table 2.

Table 2. Cryogenic Properties of Teflon™ PFA Fluoropolymer Resins*

Property	ASTM Method	Unit	Value	
			Room Temperature, 23 °C (73 °F)	Cryogenic Temperature, −196 °C (−320 °F)
Yield Strength	D1708[a]	MPa (psi)	15 (2,100)	No Yield
Ultimate Tensile Strength	D1708[a]	MPa (psi)	18 (2,600)	129 (18,700)
Elongation	D1708[a]	%	260	8
Flexural Modulus	D790-71[b]	MPa (psi)	558 (81,000)	5,790 (840,000)
Impact Strength, Notched Izod	D256-72[c]	J/m (ft-lb/in)	No Break	64 (1.2)
Compressive Strength	D695	MPa (psi)	24 (3,500)	414 (60,000)
Compressive Strain	D695	%	20	35
Modulus of Elasticity	D695	MPa (psi)	69 (10,000)	4,690 (680,000)

*Data provided for historical testing of 300 series Teflon™ PFA fluoropolymer resins. Teflon™ PFA HP fluoropolymer resins expected to perform similarly.
[a]Crosshead speed B, 1.3 mm/min (0.05 in/min); used at both temperatures for more direct comparison.
[b]Method 1, Procedure B.
[c]Method A, Head weight is 4.5 kg (10 lb) at 23 °C (73 °F) and 0.9 kg (2 lb) at −196 °C (−320 °F).

Thermal Exposure

Teflon™ PFA fluoropolymer resins are rated for continuous use at temperatures up to 260 °C (500 °F). However, long-term heat treatment of Teflon™ PFA fluoropolymer resin plaques, tensile bars, and coated wires at 285 °C (545 °F) indicates that the resin can be continuously exposed to this temperature without deterioration of its mechanical or electrical properties.

In Figure 8, the change in the tensile strength of wire coating, measured at room temperature, is plotted versus hours of thermal treatment in air at 285 °C (545 °F). The tensile strength of the insulation of Teflon™ PFA 340 fluoropolymer resin, measured at room temperature, shows a gradual increase with time of about 15% after 20,000 hr at 285 °C (545 °F). Similar increases were observed when the tensile measurements were made at 200 °C (392 °F). The room temperature elongation of the tensile specimens increased about 25% with thermal treatment at 285 °C (545 °F) as shown in Figure 9.

The increase in tensile properties is attributed to an increase in molecular weight. This is indicated by a decrease in melt flow, shown in Figure 10. Flex life also improves with long-term thermal treatment.

Figure 8. Tensile Strength of Teflon™ PFA Fluoropolymer Resin Wire Coatings After Prolonged Thermal Treatment in Air

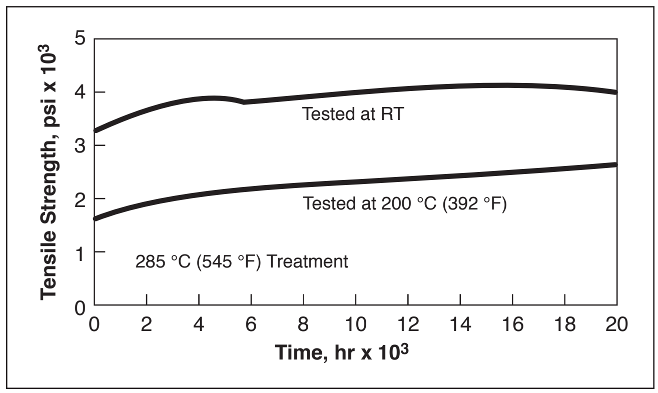


Figure 9. Ultimate Elongation of Teflon™ PFA Fluoropolymer Resin Wire Coatings After Prolonged Thermal Treatment in Air

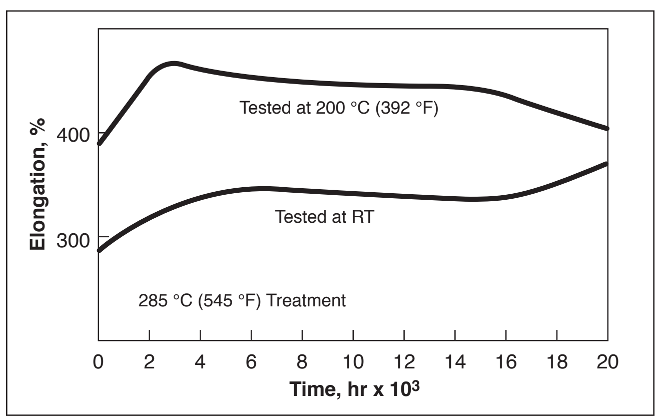
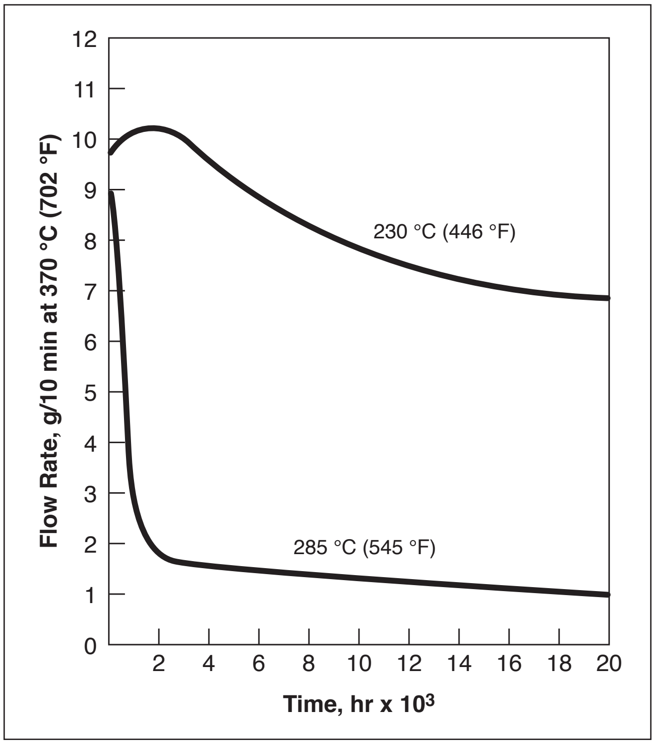


Figure 10. Change in Melt Flow Rate During Prolonged Thermal Treatment of Teflon™ PFA Fluoropolymer Resins at 230 °C (446 °F) and 285 °C (545 °F)



Wear and Frictional Data

Frictional and wear tests have been run on Teflon™ PFA fluoropolymer resins to indicate level of performance (unfilled) in mechanical applications, such as bearings and seals. Tests were run on molded thrust bearings at 0.7 MPa (100 psi) against AISI 1018, Rc20, 16AA steel; tests were run at ambient conditions in air with no lubrication.

Results, shown in Table 3, indicate a limiting PV* value of 5,000; but wear rate, rather than PV, will likely be the critical parameter. At PV = 1,000, for instance, Teflon™ PFA fluoropolymer resins will wear 5 mm (3/16 in) per 1,000 hr. Wear factors decreased over the PV range 1,000 to 5,000 from 1840 x 10^{-10} to 700 x 10^{-10}. Coefficient of friction ran 0.236.

*Pressure x Rubbing Velocity

Table 3. Teflon™ PFA Fluoropolymer Resins[a]: Wear and Frictional Data Thrust Bearing Wear Test Results

Velocity, ft/min	Wear Factor[b], K x 10^{-10}	Dynamic Coefficient of Friction	Duration, hr
3	1,591	0.210	103
10	1,837	0.214	103
30	983	0.229	103
50	694	0.289	103

[a]Test specimen: Teflon™ PFA 340. Similar results expected for other grades.
[b]Units: in^3 - min/lb - ft - hr

Mating Surface:	AISI 1018 steel, Rc20, 16AA
Contact Pressure:	100 lb/in^2
Ambient Temperature:	Room
Environment:	Ambient Air
Lubricant:	None

Adhesion

Teflon™ PFA fluoropolymer resins used as thin-film hot melt adhesives give strong, highly water-resistant bonds to a variety of thermally resistant substrates. Metals, glass, and other thermally resistant materials have been adhered using this technique. Typical results are shown in Table 4.

Table 4. Typical Tensile Shear Strengths of Lap Shear Joints Using Teflon™ PFA Fluoropolymer Resins as a Melt Adhesive*

Substrate	Bonding Pressures, MPa (psi)	Tensile Shear, MPa (psi)
Aluminum Alloy	0.055 (8)	10.2 (1,480)
Untreated Steel	0.138 (20)	16.1 (2,330)
Pre-oxidized Steel	0.138 (20)	15.6 (2,260)

*Bonding conditions: 330 °C (626 °F) for 30 min, 19 mm (0.75 in) overlap using Teflon™ PFA fluoropolymer resins with a melt flow number of 12 (ASTM 3304-73).

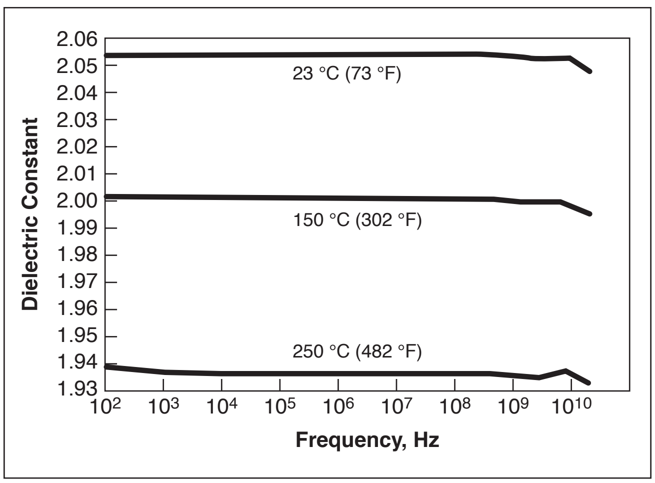
ELECTRICAL PROPERTIES

Electrical applications include extruded coatings for numerous wire constructions, heater cables, heavy wall conduit, cable jacketing, and geophysical cables. Teflon™ PFA fluoropolymer resins are also injection molded into electrical switch components, connector inserts, insulating bushings, and standoff insulators.

Dielectric Constant

The dielectric constant of Teflon™ PFA and Teflon™ PFA HP fluoropolymer resins is less than 2.1 over a wide range of frequencies, temperatures, and densities. The minor changes that occur with changes in these conditions are shown in Figure 11. The values for Teflon™ PFA fluoropolymer resins density vary only slightly (2.13–2.17), and the dielectric constant varies only about 0.03 units over this range—among the lowest of all solid materials. There is no measurable effect of humidity on the dielectric constant of Teflon™ PFA fluoropolymer resins.

Figure 11. Dielectric Constant of Teflon™ PFA Fluoropolymer Resins at Various Frequencies and Temperatures (by ASTM D150)



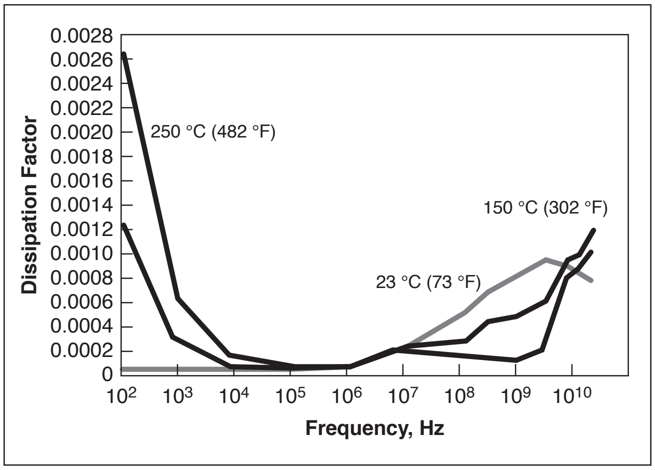
Dielectric Strength

The dielectric strength (short-term) of all Teflon™ PFA fluoropolymer resins is 80 kV/mm (2,043 V/mil) when measured on 0.25-mm (10-mil) films by ASTM D149. Thin films of FEP resin give similar results, while PTFE films are typically measured at 47 kV/mm (1,200 V/mil). As with other fluoropolymer resins, Teflon™ PFA will lose dielectric strength in the presence of corona discharge.

Dissipation Factor

The dissipation factor of Teflon™ PFA fluoropolymer resins varies with frequency and temperature, shown in Figure 12. The dissipation factor at low frequency (10^2–10^4 Hz) increases at higher temperatures. Little variation with temperature is seen in dissipation factor with frequencies in the range of 10^4–10^7 Hz. As frequencies increase to 10^{10} Hz, there is a steady increase in the dissipation factor. Increases are greatest when measured at room temperature. There is also an indication that a maximum exists at about 3 x 10^9 Hz. The fully fluorinated end groups found in Teflon™ PFA HP fluoropolymer resins result in lower dissipation factors at high frequencies. Teflon™ PFA HP fluoropolymer resins are preferred when considered for use as an electrical insulation material at high frequencies.

Figure 12. Dissipation Factor of Teflon™ PFA Fluoropolymer Resins at Various Frequencies and Temperatures (by ASTM D150)



Electrical Resistivity

The volume and surface resistivities of fluoropolymer resins are high and unaffected by time or temperature. Measurements of the volume resistivity of Teflon™ PFA fluoropolymer resins by the method outlined in ASTM D257 gave a value greater than 10^{18} ohm-cm. The surface resistivity was greater than 10^{18} ohm/sq.

Arc Tracking

When Teflon™ PFA fluoropolymer resins were tested by the method described in ASTM D495 using stainless steel electrodes, no tracking was observed for the duration of the test (180 sec), indicating that the resin does not form a carbonized conducting path.

CHEMICAL PROPERTIES

Teflon™ PFA fluoropolymer resins are known to retain high levels of mechanical performance after chemical exposure; in fact, the fully fluorinated Teflon™ PFA HP fluoropolymer resin series is known to have the highest levels of chemical inertness due to its lack of reactive end groups.

- They are not degraded by chemical systems commonly encountered in chemical processes.
- They are inert to:
  - Strong mineral acids
  - Inorganic bases
  - Inorganic oxidizing agents
  - Salt solutions
- They are also inert to such organic compounds as:
  - Organic acids
  - Anhydrides
  - Aromatics
  - Aliphatic hydrocarbons*
  - Alcohols
  - Aldehydes
  - Ketones
  - Ethers
  - Esters
  - Chlorocarbons
  - Fluorocarbons
  - Mixtures of the above compounds

As in the case of other perfluorinated products, Teflon™ PFA fluoropolymer resins can be attacked by certain halogenated complexes containing fluorine. These include chlorine trifluoride, bromine trifluoride, iodine pentafluoride, and fluorine itself. Teflon™ PFA fluoropolymer resins can also be attacked by such metals as sodium or potassium, especially in their molten states. Great care should be used when mixing finely divided fluoropolymers with finely divided metals, such as aluminum, magnesium, or barium, because these can react violently if ignited or heated to a high temperature. Certain complexes of these metals with ammonia or naphthalene (in either solvent) also attack the product. Indeed, these complexes are used to provide films or tubes of Teflon™ PFA fluoropolymer resins with a cementable surface. Certain metal hydrides, such as boranes (B_2H_6), aluminum chloride ($AlCl_3$), and certain amines have also been observed to attack fluorocarbon resins at elevated temperatures.

Physical damage resulting from absorption of various chemicals into the walls of fabricated articles (particularly when combined with cycling temperatures), rapid changes in pressure, and mechanical abuse provide the most frequent cause of failure in articles fabricated from Teflon™ PFA fluoropolymer resins.

Table 5 shows the performance in tensile testing and the weight gain of fabricated pieces of Teflon™ PFA fluoropolymer resins after immersion in inorganic chemical media. There is usually no measurable effect of the common inorganic reagents on the tensile properties of Teflon™ PFA fluoropolymer resins; however, if there is, a measurable weight gain or loss is observed. Sulfuryl chloride presents a special case in which a "hybrid" compound is absorbed by fabricated forms to give low retention of properties. In none of the above cases are chemically degradative interactions observed.

Table 5 also shows the change in tensile properties and the weight gained when fabricated forms of Teflon™ PFA fluoropolymer resins are subjected to typical organic liquids representing a range of classic compounds. Teflon™ PFA HP fluoropolymer resins resins have equivalent or better chemical resistance performance.

These data show that liquids that wet the resin will tend to give high weight gains and low retention of tensile strength, especially when heated to high temperatures. Therefore, liquids such as trichloroacetic acid, tributyl phosphate, perchloroethylene, and carbon tetrachloride, produce the largest weight gains.

The test procedure involves exposure of compression molded micro-tensile specimens, 50-mil thick, in a specific chemical medium at a selected temperature for one week (168 hr). The exposed samples are placed in sealed bottles immediately after removal from chemical exposure. Weight measurements are made within 2 hr after removal from exposure medium; tensile strength and elongation measurements are made within 8 hr after exposure. Changes in tensile strength less than 15%, elongation less than 10%, and weight gain less than 0.5% are considered insignificant.

*Some aliphatic hydrocarbons lower the elongation of samples of Teflon™ PFA fluoropolymer resins (see Table 5)

Table 5. Effect of Chemical Immersion on Teflon™ PFA 300 Series Fluoropolymer Resins (168 hr)

Chemical		Test Temperature °C	Test Temperature °F	% Retained Physicals Tensile	% Retained Physicals Elongation	% Weight Gain
Inorganic Chemicals						
Mineral Acid	Hydrochloric (Conc)	120	248	98	100	0.0
	Sulfuric (Conc)	120	248	95	98	0.0
	Hydrofluoric (60%)	23	73	99	99	0.0
	Fuming Sulfuric	23	73	95	96	0.0
Oxidizing Acids	Aqua Regia	120	248	99	100	0.0
	Chromic (50%)	120	248	93	97	0.0
	Nitric (Conc)	120	248	95	98	0.0
	Fuming Nitric	23	73	99	99	0.0
Inorganic Bases	Ammonium Hydroxide (Conc)	66	150	98	100	0.0
	Sodium Hydroxide (50%)	120	248	93	99	0.4
Peroxide	Hydrogen Peroxide (30%)	23	73	93	95	0.0
Halogens	Bromine	23	73	99	100	0.5
	Bromine	59*	138	95	95	No Data
	Chlorine	120	248	92	100	0.5
Metal Salt Solutions	Ferric Chloride	100	212	93	98	0.0
	Zinc Chloride (25%)	100	212	96	100	0.0
Other Inorganics	Sulfuryl Chloride	69*	156	83	100	2.7
	Chlorosulfonic Acid	151*	304	91	100	0.7
	Phosphoric Acid (Conc)	100	212	93	100	0.0
Organic Chemicals						
Acids/Anhydrides	Glacial Acetic Acid	118*	244	95	100	0.4
	Acetic Anhydride	139*	282	91	99	0.3
	Trichloracetic Acid	196*	384	90	100	2.2
Hydrocarbons	Isooctane	99*	210	94	100	0.7
	Naphtha	100	212	91	100	0.5
	Mineral Oil	180	356	87	95	0.0
	Toluene	110	230	88	100	0.7
Functional Aromatics	o-Cresol	191*	376	92	96	0.2
	Nitrobenzene	210*	410	90	100	0.7
Alcohol	Benzyl Alcohol	205*	401*	93	99	0.3
Amines	Aniline	185*	365	94	100	0.3
	n-Butylamine	78*	172	86	97	0.4
	Ethylenediamine	117*	242	96	100	0.1
Ether	Tetrahydrofuran	66*	151	88	100	0.7
Ketones/Aldehydes	Benzaldehyde	179*	355	90	99	0.5
	Cyclohexanone	156*	312	92	100	0.4
	Methyl Ethyl Ketone	80*	176	90	100	0.4
	Acetophenone	202*	396	90	100	0.6
Esters	Dimethylphthalate	220	392	98	100	0.3
	n-Butylacetate	125*	257	93	100	0.5
	Tri-n-Butyl Phosphate	200	392	91	100	2.0
Chlorinated Solvents	Methylene Chloride	40*	104	94	100	0.8
	Perchloroethylene	121*	250	86	100	2.0
	Carbon Tetrachloride	77*	171	87	100	2.3
Polymer Solvents	Dimethylformamide	154*	309	96	100	0.2
	Dimethylsulfoxide	189*	372	95	100	0.1
	Dioxane	101*	214	92	100	0.6

*Boiling Point

OTHER PROPERTIES

Permeability

The permeation of gases through thin film (0.08–0.13 mm [3–5 mil]) is dependent on the molecular size, shape, wettability, and soundness of the fabricated membrane. Attempts have been made to relate permeation rates through thin films to absorption of thicker films, sheets, tubes, pipe, etc. This has been generally unsuccessful. Thicker films and sheets represent an average set of properties obtainable from many thin films produced under a variety of conditions. To produce a thin film representative of this average is impossible from a practical viewpoint. Because permeation in well-fabricated articles is essentially a molecular transport phenomenon through fluorocarbon chains, it is affected by orientation, degree of crystallinity, and temperature. However, comparative data on identical tests can be used to predict performance in many thin film and coating applications. Table 6 shows comparative data as determined by ASTM tests.

Increased permeability with temperature parallels the decrease in specific gravity with increased temperature in the resin. This corresponds with increased spacing between molecules and increasing molecular activity, which allows easier diffusion of the gas through the specimen.

Table 6. Permeability of Teflon™ PFA Fluoropolymer Resins to Various Gases

	ASTM D1434 at 25 °C (77 °F)	
	(cc·mil thickness)/(100 in²·24 hr·atm)	(cc·mm thickness)/(m²·24 hr·Pa)
CO_2	2,260	0.00878
N_2	291	0.00113
O_2	881	0.00342

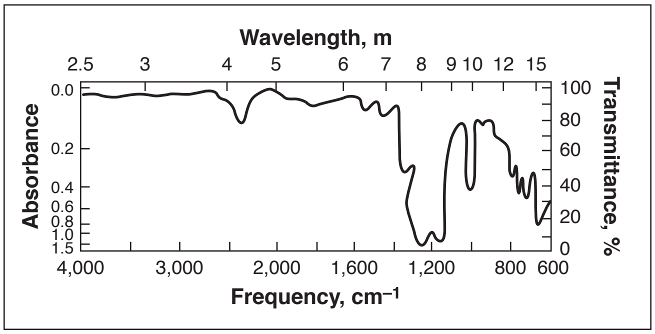
Optical Properties

In film form, Teflon™ PFA fluoropolymer resins have excellent optical properties with low haze as measured by ASTM methods. Specific values of percent transmission for given wavelengths are shown in Table 7. The refractive index of film made from Teflon™ PFA fluoropolymer resins is measured at 546 nm wavelength (green light) and room temperature. An infrared spectrum of Teflon™ PFA fluoropolymer resins is presented in Figure 13. This "fingerprint" is often useful for identifying the resin among other fluorocarbon polymers.

Table 7. Typical Optical Properties of Teflon™ PFA Fluoropolymer Resins

Property	Test Method	Value
Refractive Index	ASTM D542-50	1.350
Haze	ASTM D1003-52	4%
Light Transmission		
UV (0.25–0.40 µm)	(Cary Model 14) Spectrophotometer, 100-gauge (0.025-mm) film thickness	77–91%
Visible (0.40–0.70 µm)		91–96%
Infrared (0.70–2.40 µm)		96–98%

Figure 13. Infrared Absorption Spectrum for Film Made from Teflon™ PFA Fluoropolymer Resins, 16 mil (0.0016 in) Thick Film, Perkin-Elmer Model 287B Spectrophotometer



Glass Transition Temperatures

The glass transitions of fluoropolymer resins are generally described as relaxations that occur in the amorphous regions of these partially crystalline polymers. These glass transitions are also called second order transitions and are dependent on the frequency at which energy is added to the system.

The glass transition temperatures normally assigned to the resin are shown in Table 8.

Table 8. Glass Transition Temperatures of Teflon™ PFA Fluoropolymer Resins

	Glass I	Glass II
Teflon™ PFA Fluoropolymer Resins	90 °C (194 °F)	–80 °C (–112 °F)

Thermal Conductivity

Thermal conductivity of Teflon™ PFA fluoropolymer resins has been determined to be 0.19 W/(m·K) (1.32 Btu·in/[hr·ft²·°F]).

Specific Heat

The heat capacity of Teflon™ PFA fluoropolymer resins is 1,172 J/(kg·K) at 100 °C (0.28 Btu/[lb·°F] at 212 °F).

Liquid Oxygen Impact Sensitivity

There was no detonation when Teflon™ PFA fluoropolymer resin samples were subjected to Marshall Space Flight Center Specification 106 B. No detonation was effected when a sample was subjected to a 10 kg-m drop in an atmosphere of pure oxygen.

Weathering

Teflon™ PFA fluoropolymer resins are extremely hydrophobic and shed water almost totally. A moisture absorption of <0.03% has been reported after 24 hr in water at room temperature, followed by 2 hr in boiling water. They are also virtually unaffected by oxygen, ozone, and visible or UV light. Test samples, exposed for many years to practically all climatic conditions, have shown that Teflon™ PFA fluoropolymer resins are fully weather-resistant. There were no significant changes in tensile properties, specific gravity, or melt flow rate after this exposure. Results show neither aging nor embrittlement. Because no plasticizers, anti-oxidants, or other additives are used during its processing, there is no leaching out of substances.

Response to High-Energy Ionizing Radiation

The results of preliminary tests using a General Electric transformer to evaluate the radiation resistance of Teflon™ PFA fluoropolymer resins to high-energy ionizing radiation in air are presented in Table 9. Exposure of Teflon™ PFA fluoropolymer resins to radiation above 2 Mrd is not recommended.

Table 9. Teflon™ PFA Fluoropolymer Resins: Response to High-Energy Ionizing Radiation

Exposure, Mrd	Tensile Strength, MPa (psi)	% Elongation
Control	4,390 (30)	358
0.5	4,090 (28)	366
1.0	3,620 (25)	333
2.0	3,080 (21)	302
5.0	2,110 (15)	35
20	—	*
50	—	*

ASTM D1708
Samples: 0.25 mm (10 mil) compression molded films of Teflon™ PFA 340
Source: G.E. resonance transformer, 2 MeV capacity, at a current of 1 mA
*Elongation less than 5%

Flame Exposure

When exposed to flame, Teflon™ PFA fluoropolymer resins burn but do not continue to burn when the flame is removed. The fuel value is approximately 5.14 MJ/kg (2,300 Btu/lb). It passes the UL 83 vertical flame test and is classified 94 V-O according to UL in their burning test classification for polymer materials. The limiting oxygen index by ASTM D2863 is greater than 95%, and the smoke density figure (Dm) obtained with the NBS smoke chamber is 4. Based on ASTM D635, it has an average burn length of 10 mm (0.4 in). The numerical flame spread rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.

PROPERTIES OF FILLED COMPOSITIONS

The addition of fillers to Teflon™ PFA fluoropolymer resins produces unique properties unattainable with the resins alone. Fillers, in general, can do the following:

- Increase dimensional stability
- Reduce mold shrinkage
- Lower coefficient of thermal expansion
- Increase thermal conductivity
- Reduce static charge

Improvements in strength, stiffness, and creep resistance can be obtained by adding glass fibers. Increases in thermal conductivity can be achieved by adding metallic powders. Increased electrical conductivity can be attained by adding conductive carbon blacks. Radio opaque minerals can be added for X-ray identification.

Chemours has produced, experimentally, representative compositions to illustrate a few of the more commonly used filled systems. Many of these filled compositions are commercially available from custom compounders in the industry.

Table 10 shows the tensile properties and flexural modulus of several filled compositions, indicating the increased tensile strength, decreased elongation, and increased stiffness associated with the addition of thermally stable fillers. In a set of experiments designed to show the effects of reinforcing fillers, Teflon™ PFA fluoropolymer resins were filled with two types of glass fibers as shown in Table 10. One sample (glass fiber 497BB as sold by Owens Corning Fiberglas, Inc.) was treated with an amino silane coupling agent. The enhanced tensile strength and flexural modulus observed for the silane-treated fibers indicate chemical interaction between the glass and base resin, which provides enhanced properties over untreated fillers. Tensile bars made from these reinforced compositions have a characteristic "snap" when bent to destruction compared with a gradual breakdown observed in the unreinforced constructions. The mechanical properties of this composition were measured at elevated temperatures as shown in Table 11.

The improved tensile strength and flexural modulus are retained to a remarkable degree at temperatures as high as 250 °C (482 °F). The reinforced composition has about nine times the stiffness of the neat resin at this temperature. The wear characteristics and coefficient of friction were examined for several compositions, as shown in Table 12.

SAFETY PRECAUTIONS

WARNING! VAPORS CAN BE LIBERATED THAT MAY BE HAZARDOUS IF INHALED.

Before using Teflon™ PFA or Teflon™ PFA HP fluoropolymer resins, read the Safety Data Sheet and the detailed information in the "Guide to the Safe Handling of Fluoropolymer Resins," latest edition, published by the Plastics Industry Association (www.fluoropolymers.org) or by PlasticsEurope (www.plasticseurope.org).

Open and use containers only in well-ventilated areas using local exhaust ventilation (LEV). Vapors and fumes liberated during hot processing of Teflon™ PFA and Teflon™ PFA HP fluoropolymer resins should be exhausted completely from the work area. Contamination of tobacco with these polymers must be avoided. Vapors and fumes liberated during hot processing that are not properly exhausted, or from smoking tobacco or cigarettes contaminated with Teflon™ PFA and Teflon™ PFA HP fluoropolymer resins, may cause flu-like symptoms, such as chills, fever, and sore throat. This may not occur until several hours after exposure and will typically pass within about 24 hr. Mixtures with some finely divided metals, such as magnesium or aluminum, can be flammable or explosive under some conditions.

Table 10. Mechanical Properties of Glass-Filled and Glass-Reinforced Teflon™ PFA Fluoropolymer Resins

Filler, % by Weight	Tensile Strength, MPa (psi)	% Elongation	Flexural Modulus, MPa (psi)
Control (Unfilled Resin)	17.2 (2,500)	225	552 (80,000)
25% Glass (Filled)	20.1 (2,920)	19	1,463 (212,000)
25% Glass (Reinforced)	34.5 (5,000)	4	2,634 (382,000)

Note: Base resin—Teflon™ PFA 340; 127 mm (5 in) tensile bars.

Table 11. Effect of Temperature on Mechanical Properties of Glass-Reinforced Teflon™ PFA Fluoropolymer Resins (Filler, % by Weight)

	Unfilled			25% Glass-Filled		
Temperature	Tensile Strength, MPa (psi)	% Elongation	Flexural Modulus, MPa (psi)	Tensile Strength, MPa (psi)	% Elongation	Flexural Modulus, MPa (psi)
RT	17 (2,500)	225	552 (80,000)	35 (5,000)	4	2,634 (382,000)
150 °C (302 °F)	—	—	85 (12,4000)	17 (2,490)	4	717 (104,000)
200 °C (392 °F)	9 (1,300)	260	56 (8,100)	13 (1,810)	4	593 (86,000)
250 °C (482 °F)	—	—	41 (6,000)	8 (1,120)	4	379 (55,000)

Note: Base resin–Teflon™ PFA 340; 127 mm (5 in) tensile bars.

Table 12. Wear Characteristics and Coefficient of Friction of Filled Teflon™ PFA Fluoropolymer Resins

	Wear Factor x 10^{-3} (in^3–min)/(ft–lb/hr) x 10^{-10}	
	Measured	Coefficient of Friction
Control (Unfilled Resin)	700 (138)*	0.236
5% Glass/5% MoS_2	15 (30)	0.200
15% Glass Fiber	16 (32)	0.160
25% Glass Fiber	13 (26)	0.325
25% Glass Fiber (Reinforced)	11 (22)	—
15% Graphite	147 (290)	0.200

*(m^3·s)/(kg·m·s)
k x 10^{-5}

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