Fluon® ETFE

Ethylene-Tetrafluoroethylene Copolymer

Technical Data

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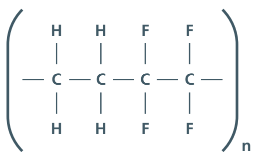
Contents

1 Fluon® ETFE and its Grades

Fluon® ETFE is a thermoplastic fluoropolymer developed by AGC Chemicals Company. It is a copolymer comprised of tetrafluoroethylene (C_2F_4) and ethylene (C_2H_4) and has the following basic structure:



Fluon® ETFE has electrical properties and chemical resistance comparable to those of typical fiuoropolymers such as polytetrafluoroethylene (PTFE) and tetrafluoroethylene-hexafluoropropylene copolymer (FEP), yet at the same time, is characterized by improved mechanical properties and outstanding processability.

This technical brochure provides data on various characteristics of Fluon® ETFE, as well as data on processing, obtained at the laboratories of AGC Chemicals Company — information that, hopefully, may serve as reference for the development of various applications for Fluon® ETFE.

Notice: All data given herein are measured values, believed to be accurate, but are presented without guarantee, warranty, or responsibility expressed or implied.

Plastics are expressed as abbreviations in text, tables, and figures. The names are as follows:

FEP: tetrafluoroethylene-hexafluoropropylene
PVdF: polyvinylidene fluoride
PCTFE: polychlorotrifluoroethylene
PE: polyethylene
PC: polycarbonate
PVC: polyvinyl chloride
HDPE: high-density polyethylene

Table 1 Grades of Fluon® ETFE (Natural)

Grade	Melt Flow Rate*1	Melt Index*2	Characteristic	Application	Molding Method
C-55AP	3.9~6.5	1~2	Standard	General	Extrusion
C-88AP	9.0~12.0	3~4	Standard	General	Extrusion, injection molding
C-55AXP	3.9~6.5	1~2	Stress-crack resistant	Wire insulation	Extrusion
C-88AXP	9.0~12.0	3~4			Extrusion, injection molding
C-88AXMP	27~43	10~16	High fluidity	Thin wire insulation, light gate	Extrusion, injection molding
C-88AXMP HT	23~35	10~16	High fluidity, high service temperature		

*1 Melt flow rate in accordance with ASTM D 3159 (297 °C, 5,000 gf)

*2 Melt index in accordance with ASTM D 1238 (300 °C, 2,160 gf)

Table 2 Grades of Fluon® ETFE (Powder)

Grade	Molded Thickness	Molding Method	Characteristic and Usage
Z-8820X	50~80 µm	Electrostatic coating	Non-sticking
Z-885C	50~150 µm	Electrostatic coating	Non-sticking
	50~400 µm	Fluid dip coating	Corrosion-proof plant machinery
ZL-520N	1 mm	Electrostatic coating (over-coat)	Corrosion-proof with 20% carbon
ZL-521N	30~50 µm	Electrostatic coating	For over-coating on ZL-520, contains 5% carbon fiber
ZL-522F	2~5 mm	Rotolining	Corrosion-proof for severe conditions: reactors, tanks, lines, pumps, impellers
TL-581	2~5 mm	Rotolining	
TL-081	1 mm	Electrostatic and fluid dip coating (over-coat)	
LM-2150	1 mm	Electrostatic coating	Low-melting, smooth surface
LM-2300N	2~5 mm	Rotolining	Low-melting, smooth surface

2 Thermal Properties of Fluon® ETFE

2.1 Heat Aging

Fluon® ETFE is a crystalline thermoplastic with a melting point in the range of 265~270 °C. In general, however, it is practical to use Fluon® ETFE at a continuous service temperature determined by the long-term change of tensile elongation, which accurately reflects thermal deterioration of the polymer.

For Fluon® ETFE, C-88AP and C-55AP grades, the elongation value in reduced to half of the original value, after 10 years at 150 °C.

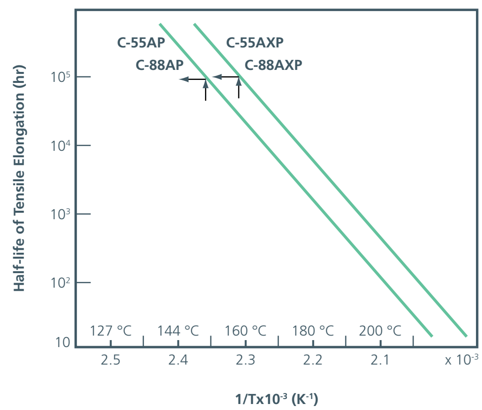


Figure 1 Half-life of Elongation and Temperature

2.2 Linear Thermal Expansion Coefficient

The thermal expansion and contraction of polymers are crucial when using polymers as industrial materials, or when designing molds for processing.

Table 4 Linear Thermal Expansion Coefficient of Plastics*1

Polymers	Fluon® ETFE		PTFE	PFA	FEP	ECTFE	PVdF	PVF	PE	PVC	PC
	C-88AP	C-88AXP									
Linear Thermal Expansion Coeff. 10^{-5}/°C	9~14	9~14	9~11	11~13	8~11	9~11	3~6	5~8	11~13	7~12	6~8

*1 ASTM D696 (temp. range: room temperature~60 °C)

2.3 Heat Distortion Temperature

The heat distortion temperature represents the temperature at which the test sample bends by 0.254 mm with 4.6 or 18.6 kg/cm² of load applied, and temperature increased at the rate of 2 °C/min. The degree of deformation is only slight, and as result, the value merely gives a general idea of the polymer's heat resistance.

Table 5 Heat Distortion Temperature of Plastics*2

Polymers		Fluon® ETFE		PTFE	PFA	FEP	ECTFE	PVdF	PVF	PE	PVC	PC
		C-88AP	C-88AXP									
Heat Distortion Temperature °C	4.6 kg/cm²	90	80	120	70	70	90~115	150~156	-	60~80	55~75	144
	18.6 kg/cm²	90	50	50	50	50	66~76	95~100	-	-	-	135

*2 ASTM D648

2.4 Flammability

Although Fluon® ETFE has C_2H_4 units in the main chain, according to evaluations by UL standard subject 94, it has a 94V-0 flammability. Results of ASTM D 165 also show that it is noncombustible. Furthermore, the oxygen index based on ASTM D 2863 is 32%.

2.5 Thermal Decomposition

The termination temperature of weight-decrease, when the temperature is raised at the rate of 10 °C/min is in the range of 350~360 °C in air, as shown in Figure 2, and 390~400 °C in nitrogen. The activation energy of thermal decomposition is about 30 kcal/mol in air, and about 55 kcal/mol in nitrogen.

Therefore, at normal molding temperature, thermal decomposition does not occur. However, even around 300 °C, if maintained for a long period of time, weight loss due to decomposition occurs. In such situations, the gas generated by decomposition consists mostly of hydrogen fluoride.

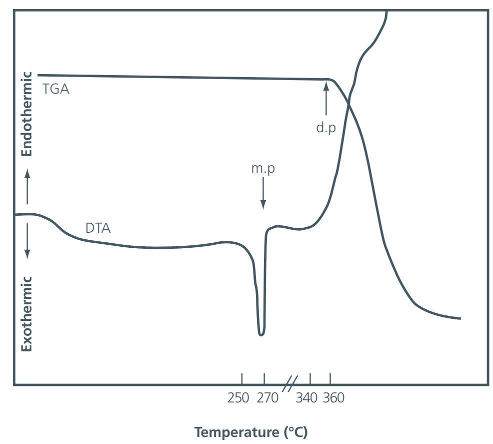


Figure 2 Differential Thermal Analysis and Heated Weight Loss

2.6 Summary of Thermal Properties

Table 6 Thermal Properties of Fluon® ETFE

Subject	Unit	Property	Method
Specific Heat	cal/g·°C	0.3	
Thermal Conductivity	cal/cm·sec·°C	$4x10^{-4}$	C177
Heat of Fusion	cal/g	10~12	-
Linear Thermal Expansion Coefficient	cm/cm·°C (-30~+100 °C)	9~14×10^{-5}	D696
Heat Distortion Temperature	4.6 kg/cm^2 °C	92~95	D648
	18.6 kg/cm^2 °C	63~67	D648
Fragility Temperature	°C	-125	D764
Flammability		NB (noncombustible)	D635
		94V-0	UL
Oxygen Index	%	32	D2863

3 Mechanical Properties of Fluon® ETFE

Fluon® ETFE has balanced tensile elongation and strength as well as toughness, ensuring no breakage by impact at room temperature.

3.1 Tensile Properties

Figures 3 and 4 show the tensile strength and elongation in relation to temperature. Figure 5 shows the relationship between tensile strength and elongation of various plastics.

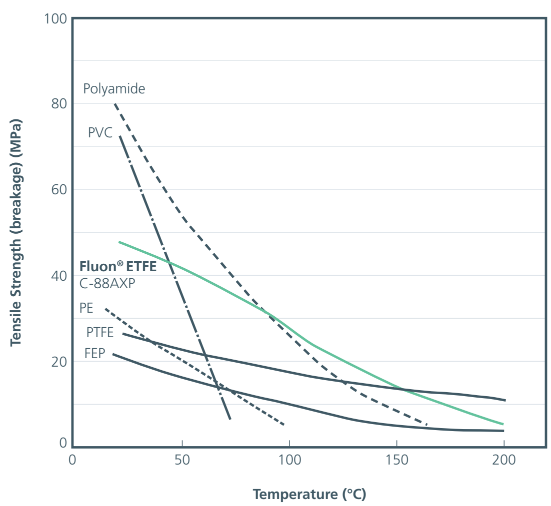


Figure 3 Effect of Temperature on Tensile Strength

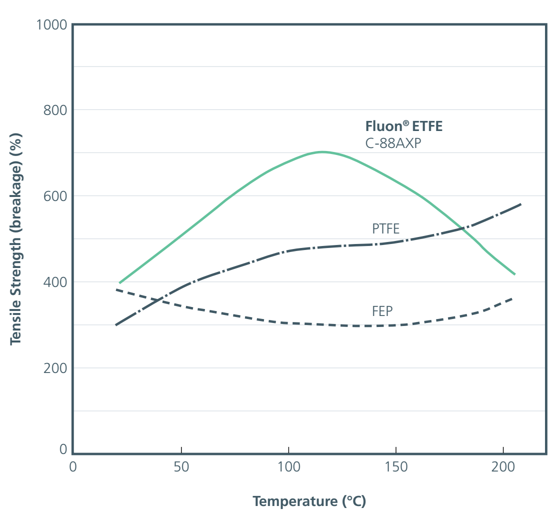


Figure 4 Effect of Temperature on Tensile Elongation

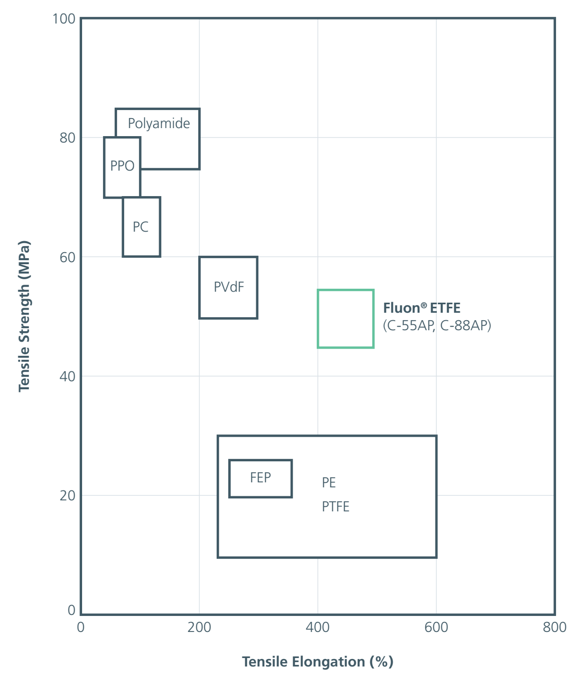


Figure 5 Strength vs. Elongation for Various Plastics

C-55AP

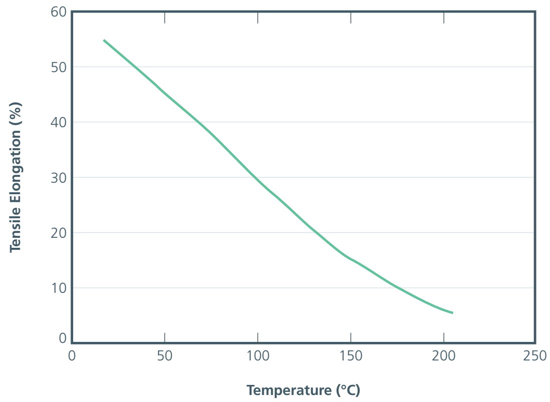


Figure 6 Effect of Temperature on Tensile Strength

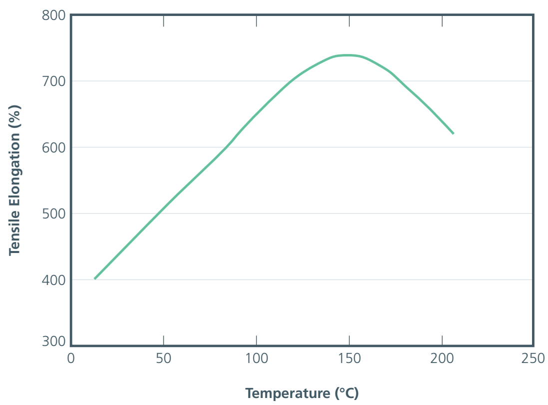


Figure 7 Effect of Temperature on Tensile Elongation

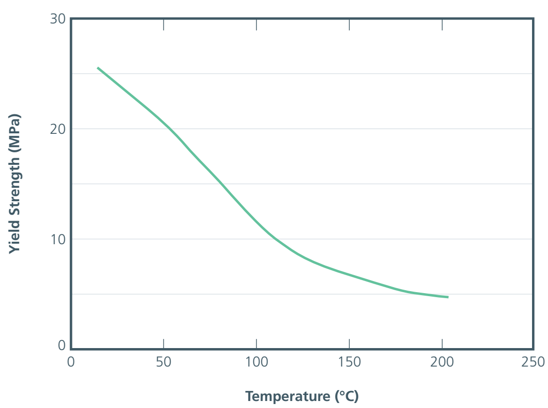


Figure 8 Effect of Temperature on Yield Strength

C-88AP

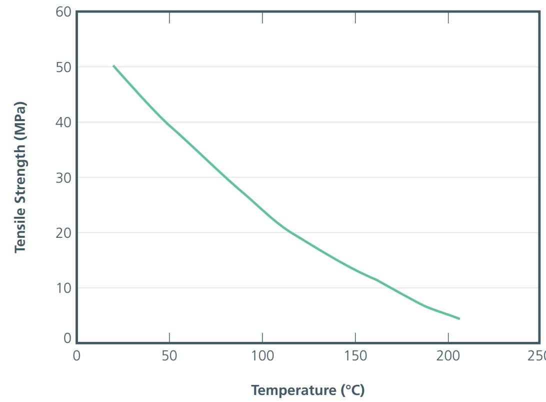


Figure 9 Effect of Temperature on Tensile Strength

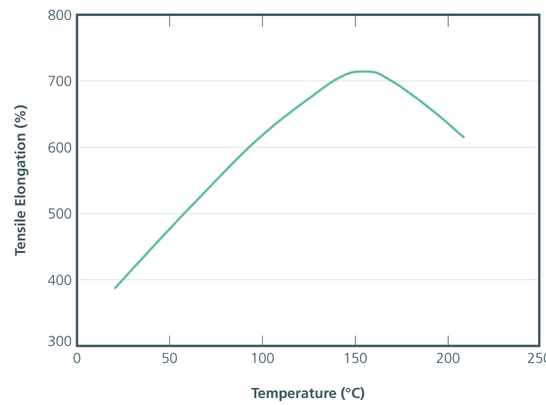


Figure 10 Effect of Temperature on Tensile Elongation

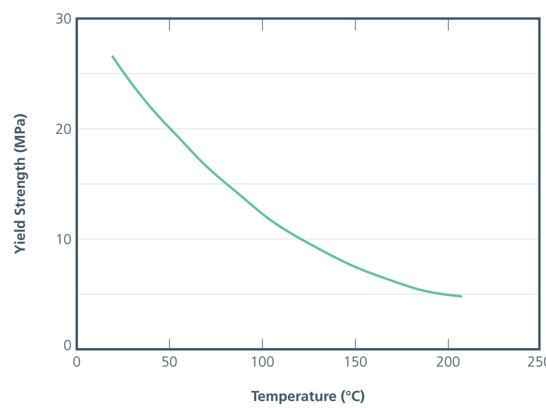


Figure 11 Effect of Temperature on Yield Strength

C-55AXP

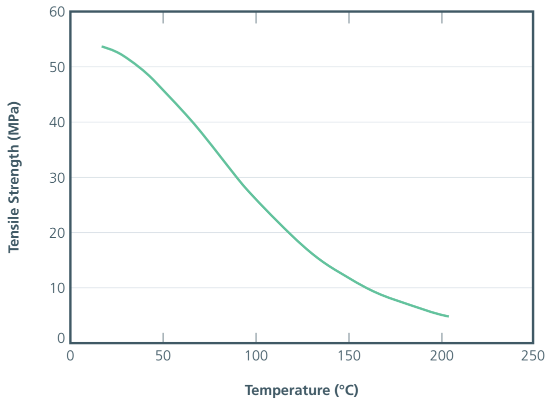


Figure 12 Effect of Temperature on Tensile Strength

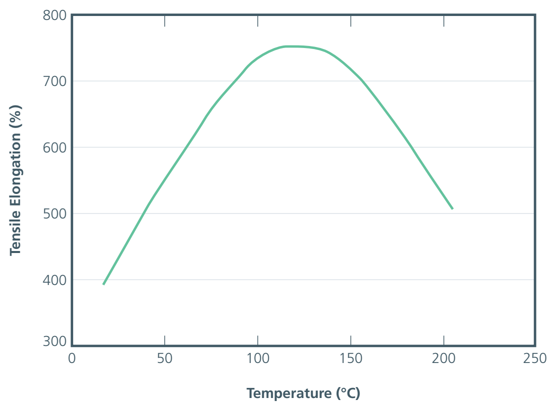


Figure 13 Effect of Temperature on Tensile Elongation

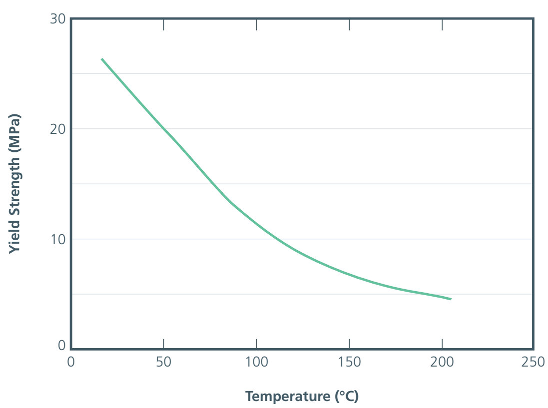


Figure 14 Effect of Temperature on Yield Strength

C-88AXP

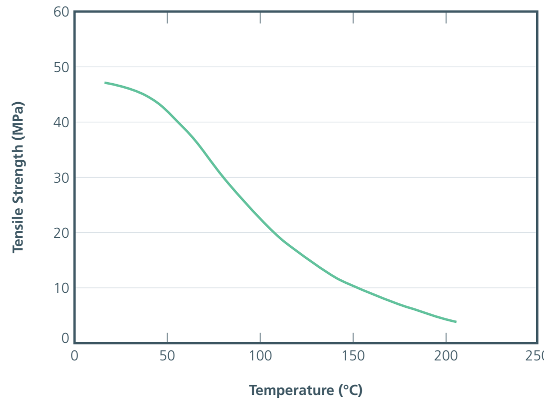


Figure 15 Effect of Temperature on Tensile Strength

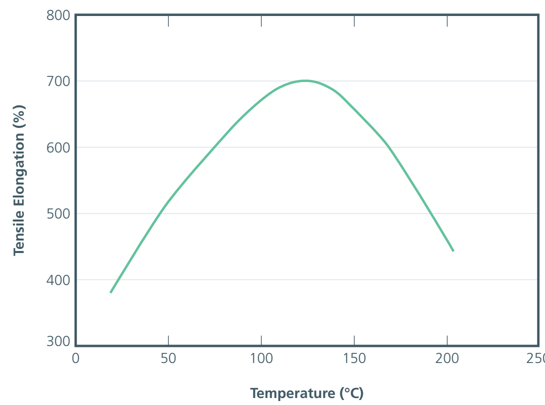


Figure 16 Effect of Temperature on Tensile Elongation

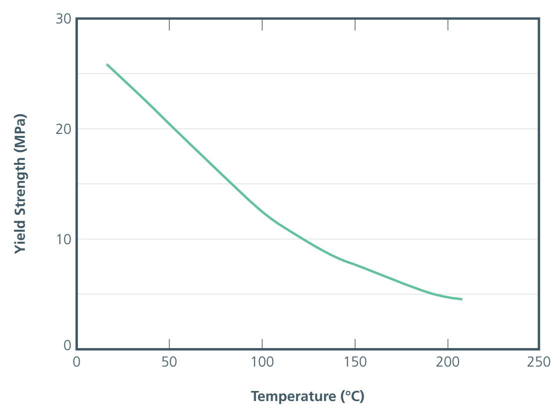


Figure 17 Effect of Temperature on Yield Strength

C-88AXMP

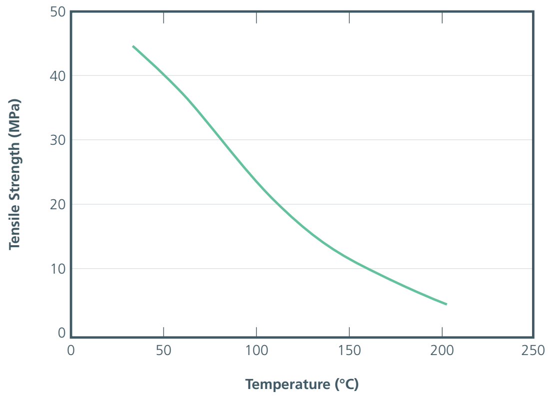


Figure 18 Effect of Temperature on Tensile Strength

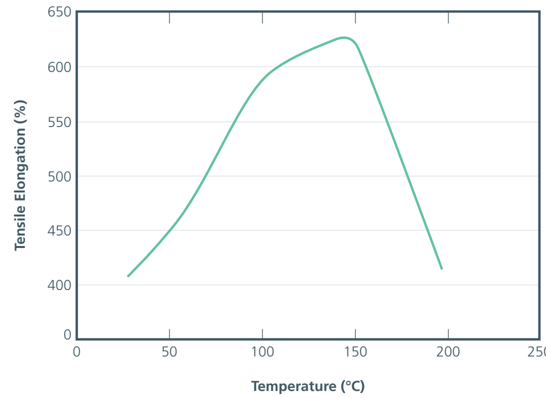


Figure 19 Effect of Temperature on Tensile Elongation

3.2 Tensile Creep Properties

Generally, when a constant load is applied to a plastic for a long period of time, irreversible plastic flow is caused, the amount of distortion increasing with time. This phenomenon is called creep or cold flow, and is an important property that needs to be considered when using polymers in mechanical parts etc., or in situations where the material is subjected to stress in some form. In the case of tensile creep in Fluon® ETFE, the initial degree of distortion varies widely depending on the applied load, as shown in Figure 20, but the creep rate is very small.

Figures 21~23 show tensile creeps of various fiuoropolymers. At 100 °C, polyvinylidene fluoride shows a small value, but at higher temperatures, Fluon® ETFE is found to have the best values among these fiuoropolymers.

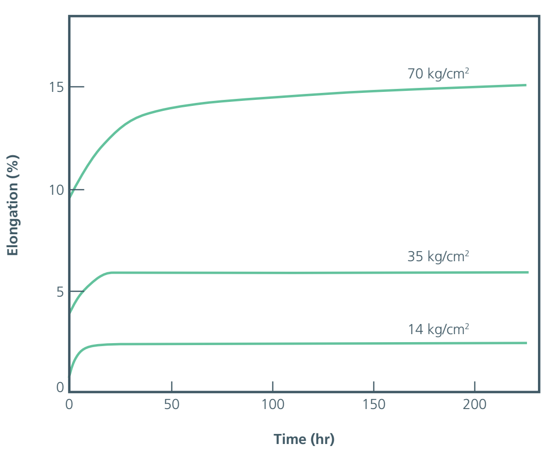


Figure 20 Tensile Creep at 100 °C (ASTM D 674-56)

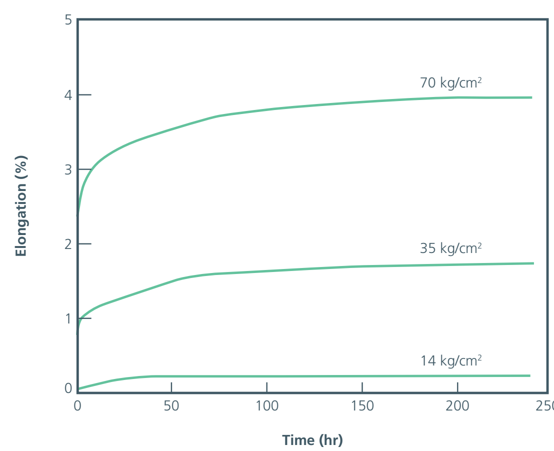


Figure 21 Tensile Creep of ETFE C-55AX (at room temp.)

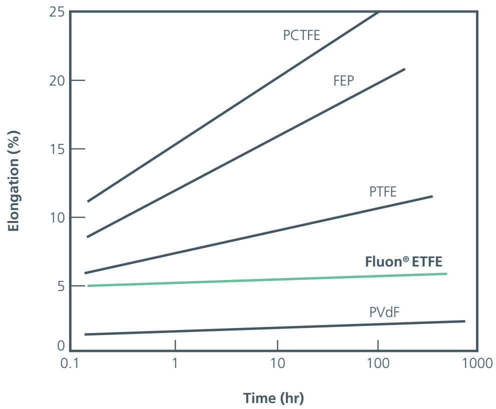


Figure 22 Tensile Creep of Various Fluoropolymers (100 °C, 35 kg/cm^2)

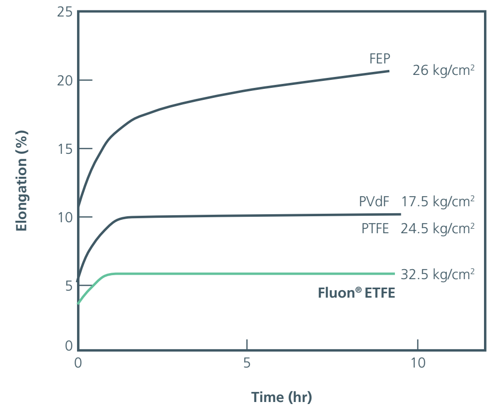


Figure 23 Tensile Creep of Various Fluoropolymers (150 °C, load: 1/2 of yield strength at 150 °C)

3.3 Compression Properties

Figure 24 shows the compression stress-strain curve of Fluon® ETFE, and Figure 25, the compression stress-residual strain curve. Also, Figures 26 and 27 illustrate the compression creep property and the compression stress relaxation property.

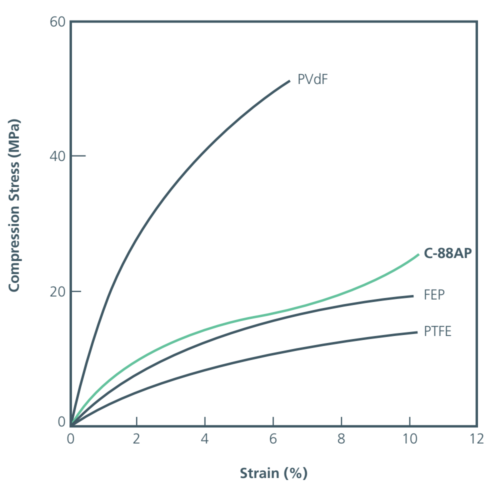


Figure 24 Compression Stress-Strain Curve

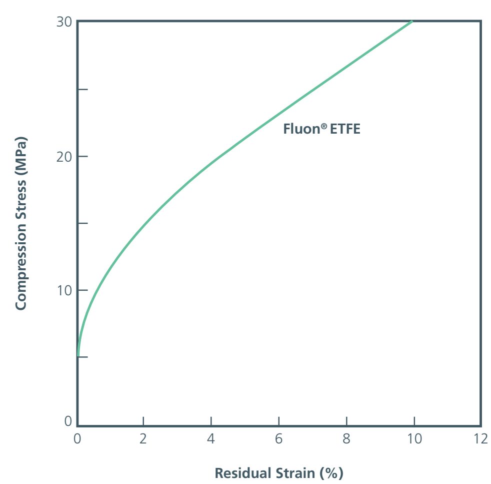


Figure 25 Compression Stress-Residual Strain Curve

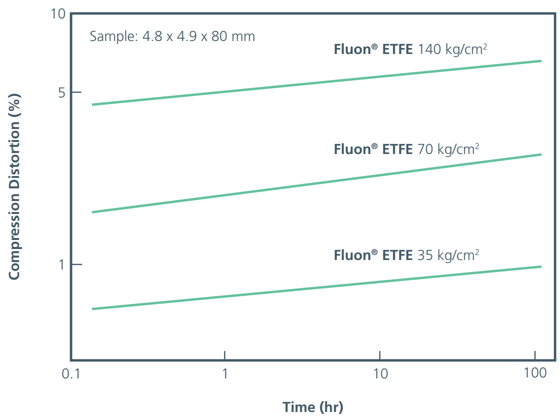


Figure 26 Dependence of Compression Creep Characteristics on Load (at room temp.)

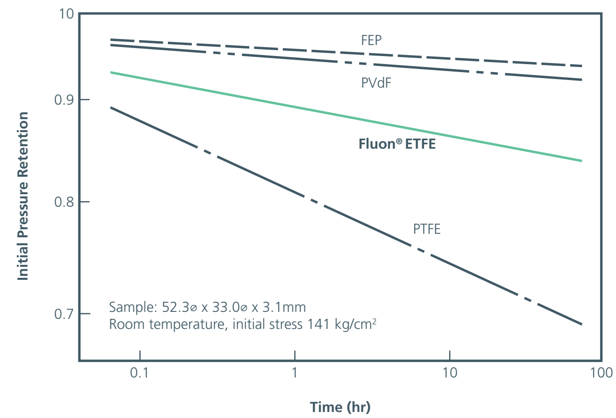


Figure 27 Compression Stress Relaxation (ASTM F38)

3.4 Flexural Properties

The effect of temperature on flexural strength and flexural modulus are shown in Figures 28~32.

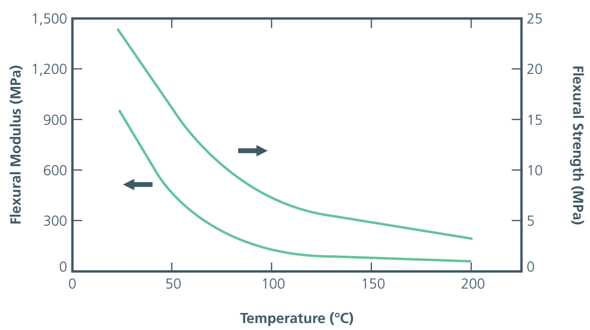


Figure 28 Grade C-55AP

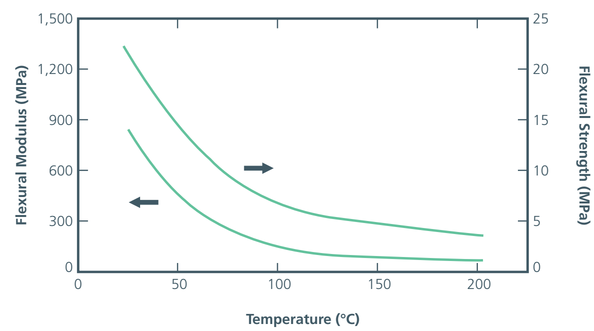


Figure 30 Grade C-88AP

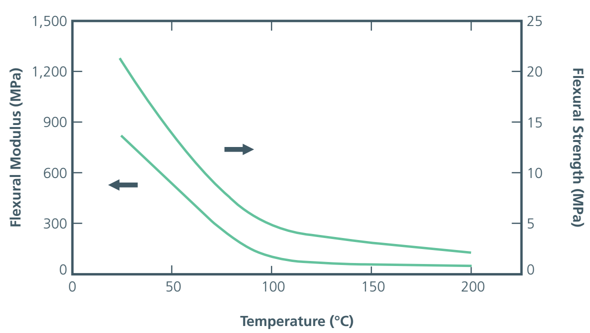


Figure 29 Grade C-55AXP

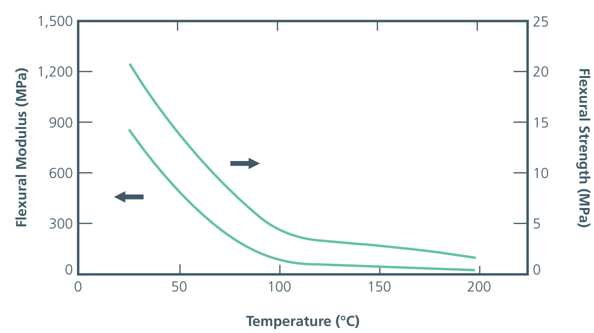


Figure 31 Grade C-88AXP

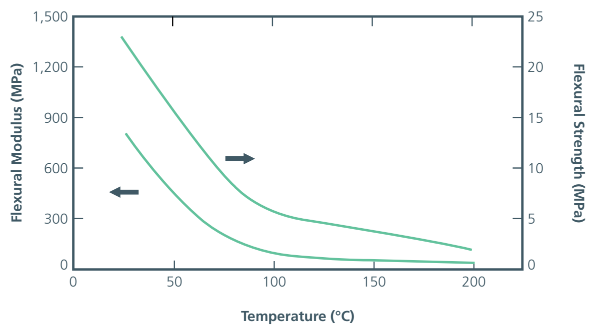


Figure 32 Grade C-88AXMP

3.5 Impact Strength

As a method of evaluating the impact strength of plastics, the Izod impact test, ASTM D256, or the Charpy impact test is used.

Fluon® ETFE has an extremely large capacity for absorbing impact energy, and maintains excellent impact resistance over a wide range of temperatures even in impact tests with a notch. Figure 34 shows the results of the Izod impact test on Fluon® ETFE and various plastics, at room temperature.

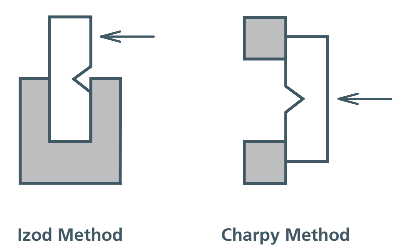


Figure 33 Methods of Testing Impact Strength

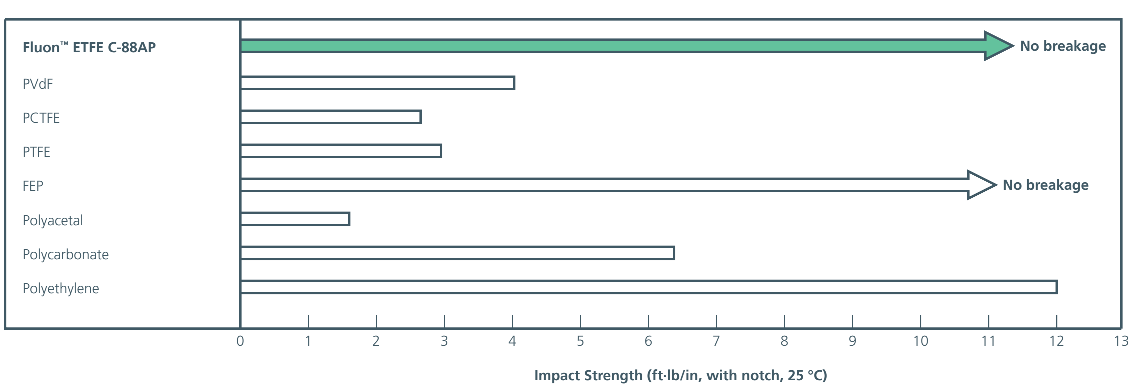


Figure 34 Izod Impact Test

Fluon® ETFE is also significantly resistant against low temperature impact, and as apparent from the results shown in Figure 35, no impact breakage occurs down to -80 °C. Destruction begins around -100 °C and the energy required for breakage in the range of -120 °C to -200 °C is about constant. The fragility point according to ASTM D746 is -125 °C, which suggests that the glass transition temperature of the noncrystalline portion of Fluon® ETFE exists around this range.

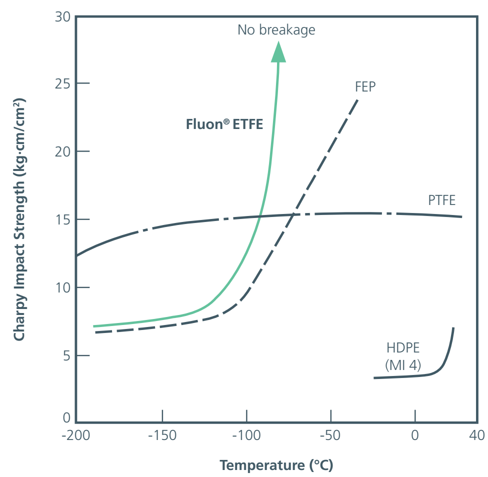


Figure 35 Effect of Temperature on Charpy Impact Strength

3.6 Surface Hardness

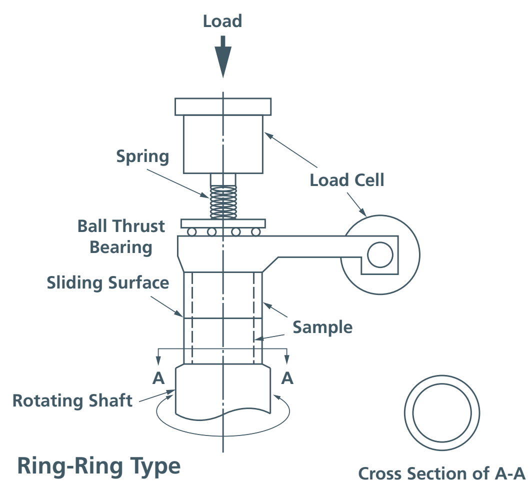
Table 7 shows the Rockwell hardness measured according to ASTM D785, represented on the R scale.

Table 7 Surface Hardness of Various Plastics

Plastic	Fluon® ETFE		PTFE	PFA	FEP	ECTFE	PVdF	PCTFE	PP	Nylon66	Polyacetal
	C-88AP	C-88AXP									
Hardness (R scale)	46	50	20	50	25	93	110	110	85~110	110	120

3.7 Friction and Wear Properties

The coefficients for determining the friction and wear properties vary depending on the methods and conditions chosen. Thus, it is necessary to carry out a comparative test that suits the desired application. Figures 36~41 show results obtained by the Matsubara method of friction measurement (cylindrical surface type, against SUS 316 L). The critical PV value of Fluon® ETFE is about 2.0 kg·m/cm²·sec.



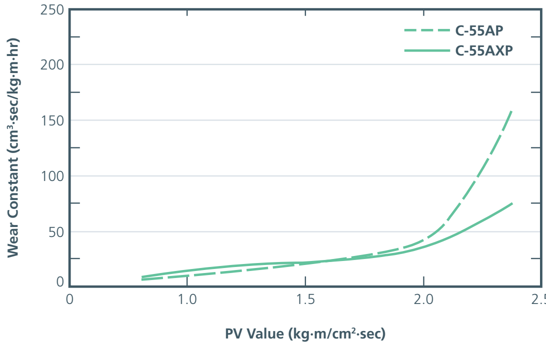


Figure 36 C-55AP, C-55AXP Wear Constant and PV Value

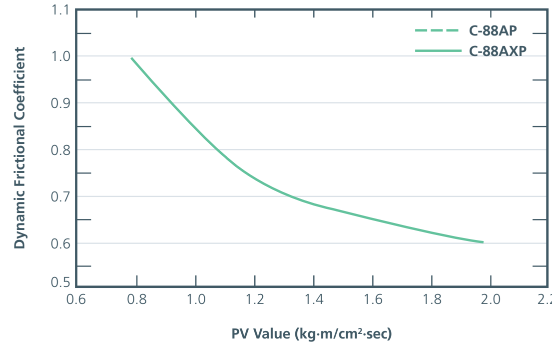


Figure 39 C-88AP, C-88AXP Dynamic Friction Coefficient and PV Value

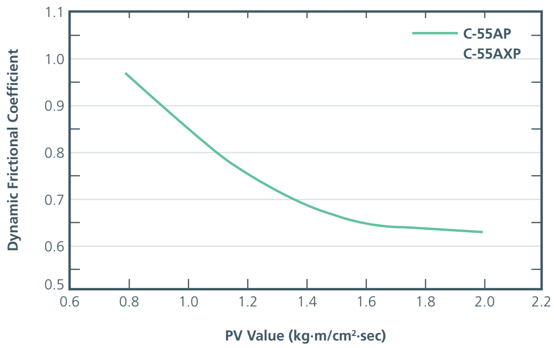


Figure 37 C-55AP, C-55AXP Dynamic Friction Coefficient and PV Value

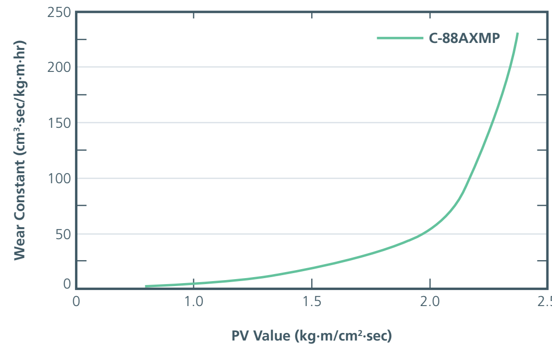


Figure 40 C-88AXMP Wear Constant and PV Value

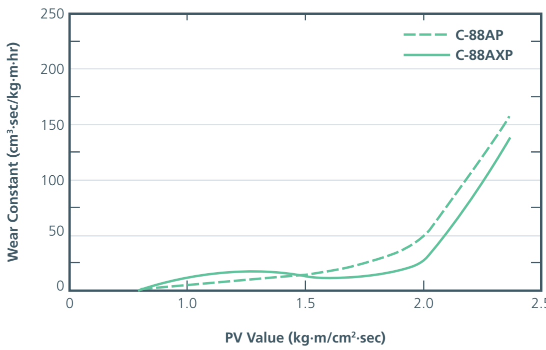


Figure 38 C-88AP, C-88AXP Wear Constant and PV Value

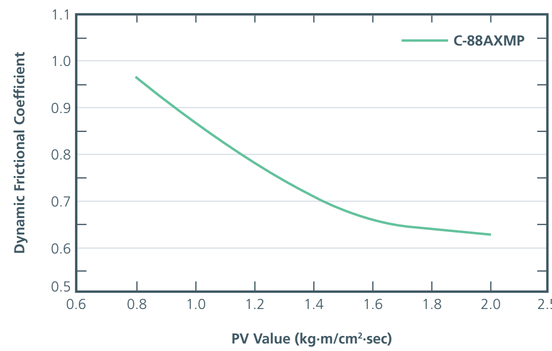


Figure 41 C-88AXMP Dynamic Friction Coefficient and PV Value

Figures 42, 43 and Table 8 show the dynamic friction coefficient, wear constant, and critical PV value measured by the journal-type bearing tester.

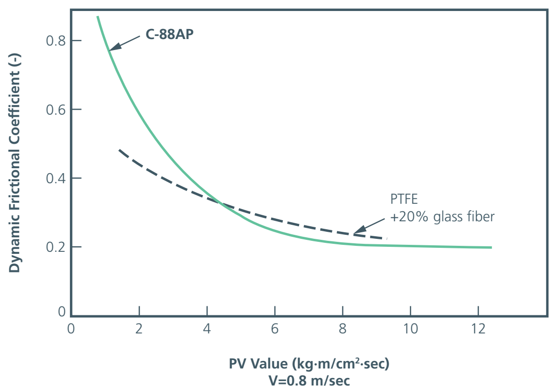


Figure 42 Dynamic Friction Coefficient and PV Value

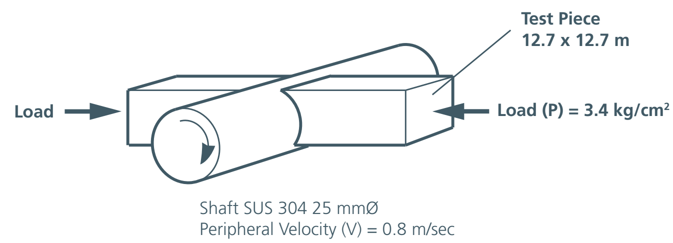


Figure 43 Journal-type Bearing Tester

Table 8 Abrasion Properties of Fluon® ETFE

		Dynamic Frictional Coefficient	Wear Constant (mm^3·sec/kg·m·hr)	Critical PV Value (kg·m/cm^2·sec)
Fluon® ETFE	C-88AP	0.53	$145x10^{-3}$	1.6
PTFE	Natural	0.28	$52x10^{-3}$	1.5
	20% glass fiber	0.34	$0.1x10^{-3}$	11<
	15% graphite	0.30	$0.1x10^{-3}$	11<
Nylon 66		0.50	$0.4x10^{-3}$	
Polyacetal		0.32	Abnormal wear	

3.8 Mechanical Properties of Various Plastics

Fluon® ETFE is a polymer in which the advantages of the previous fluoropolymers are retained, while the weak aspects have been improved to obtain resilient mechanical properties. Table 9 gives the mechanical properties of various plastics.

Table 9 Mechanical Properties of Various Plastics

	Fluon® ETFE	PTFE	PFA	ECTFE	PVdF	PE	PVC (hard)	Polyamide	Polyacetal	ASTM No.
Specific Gravity	1.73~1.75	2.1~2.2	2.1~2.2	2.15~2.17	1.76~1.77	0.92~0.96	1.3~1.4	1.10~1.14	1.42	D792
Tensile Strength (MPa)	40~54	20~39	32~39	19~22	49~60	10~44	40~70	50~80	60~70	D638
Elongation (%)	350~450	230~600	340~400	250~330	200~300	20~700	2~40	60	16	D638
Tensile Modulus (MPa)	500~800	400	-	350	800~1400	-	2500~4000	2700	3000~4500	D638
Flexural Modulus (MPa)	850~1000	400~600	530~630	670	1400~1800	500~1000	2500~2800	1000~2800	2600~2900	D790
Flexural Strength (MPa)	20~30 (yielding)	13 (yielding)	-	No breakage	-	11~110	70~110	56~110	100 (yielding)	D790
Compressive Modulus (MPa)	670	410	-	430	1300	-	-	-	4600	D695
Rockwell Hardness	R50~58	R18~20	R50	R25	R110	Shore D 50~70	M5~120	R100~120	R120	D785
Izod Impact Strength (ft/lb·in, with notch)	No breakage	3.0	No breakage	No breakage	3.5~3.8	0.5~20	0.5~20	1~3.5	1~4	D256
Frictional Coefficient (against SUS)	0.20	0.09	0.20	0.20	0.21	0.35	0.45	0.15~0.40	0.14	

4 Electrical Properties of Fluon® ETFE

Among the electrical properties of polymers, the most important ones are the insulation and dielectric properties. In the high-frequency range, electrical energy is converted to thermal energy by the dielectric effect, causing the loss of electrical energy. The amount of heat generated is proportional to f·ε·tanδ. Here, f represents the frequency, ε is the dielectric constant, and tanδ is the dielectric tangent. Therefore, it is preferred that ε·tanδ, so called dielectric loss, is small.

4.1 Dielectric Properties

Figure 44 shows the frequency effect of the dielectric constant of some fiuoropolymers. In the frequency range of 60~10^{10} Hz, the dielectric constant of Fluon® ETFE is not as small as that of PTFE and FEP, but is far smaller than that of PVdF. Furthermore, in high frequencies above 10^6 Hz, ε tends to be lower. In terms of the temperature dependence of the dielectric constant, ε remains constant over a wide range.

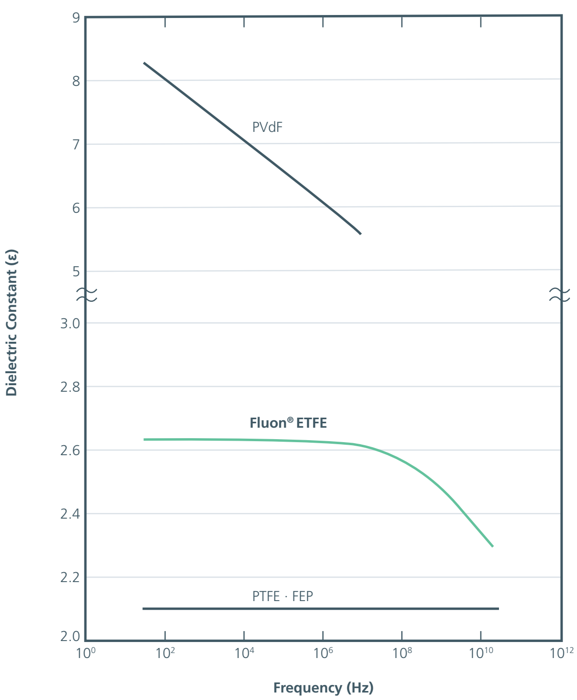


Figure 44 Effect of Frequency on Dielectric Constant (25 °C)

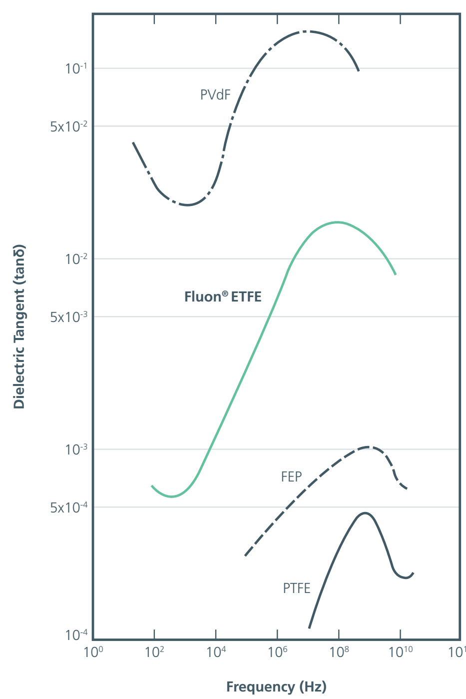


Figure 45 Effect of Frequency on Dielectric Tangent (25 °C)

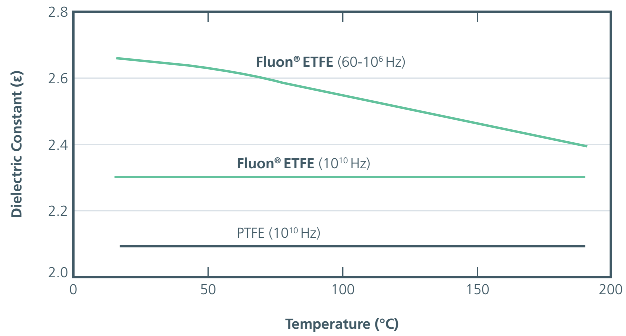


Figure 46 Effect of Temperature on Dielectric Constant

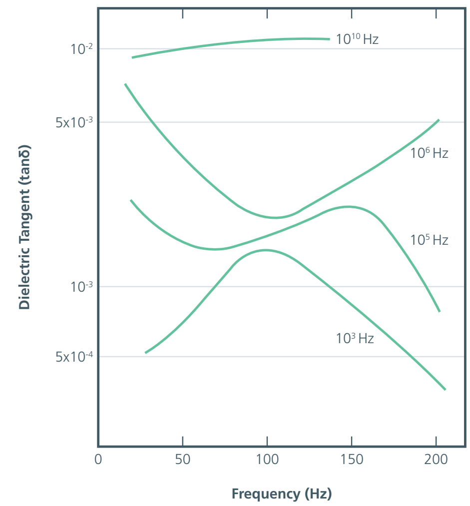


Figure 47 Effect of Temperature on Dielectric Tangent

4.2 Insulation

The insulation resistance is generally represented by the volume specific resistance, which indicates the degree by which the polymer, as an insulator, resists the flow of electric current through itself. The larger this value, the better the polymer is as an insulator. With respect to the insulation break-down voltage, another important characteristic of insulation materials, Fluon® ETFE proves to be an excellent material. The insulation break-down voltage depends on the thickness of the sample.

Figure 50 shows the results of the effect of film thickness on the break-down voltage, and indicates that the break-down voltage is proportional to 0.65 power of the thickness up to 100 µm.

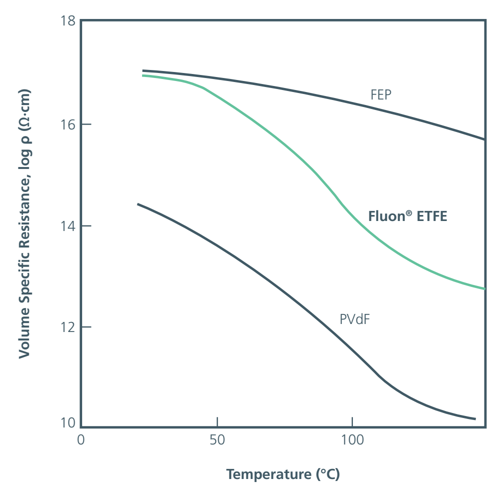


Figure 48 Temperature Dependence of Volume Specific Resistance

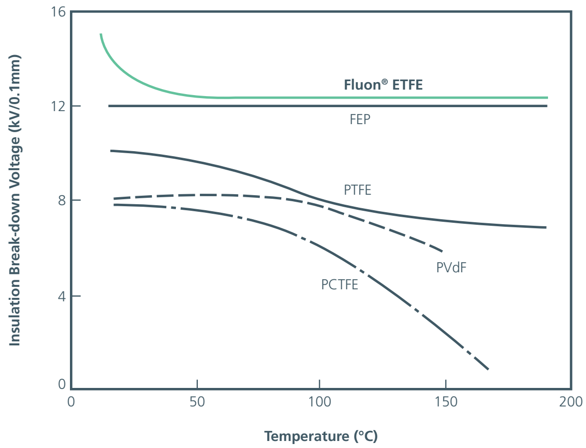


Figure 49 Temperature Dependence of Insulation Break-down Voltage

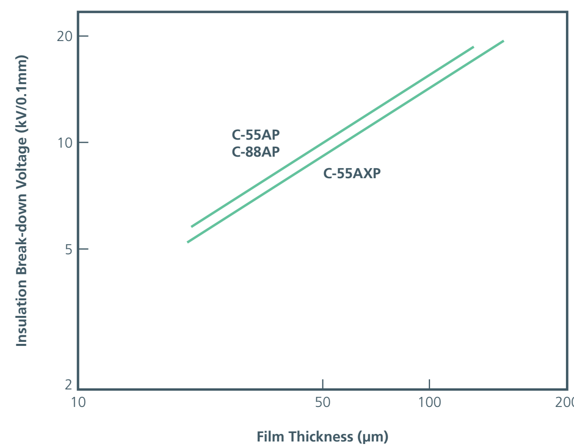


Figure 50 Dependence of Insulation Break-down Voltage on Sample Thickness (room temperature)

4.3 Arc Resistance

The arc resistance of Fluon® ETFE measured according to ASTM D495 is 120 seconds. It has been reported to be 300 seconds or higher for PTFE and 170 seconds or higher for FEP. This high value is said to be due to the fact that the polymer decomposed by the arc is dispersed in the form of low-molecular-weight fluoro-carbon, and conductive materials such as carbon do not remain in the polymer.

4.4 Tracking Resistance

As a result of scintillation caused by the presence of electrolyte on the surface, the surface of the polymer is carbonized, forming a track, and becomes conductive.

This phenomenon is called tracking, and the resistance to it is known as tracking resistance, which represents an electric insulation property under special conditions.

The measurement method used here, is the electrolyte dropping method, defined by IEC. Table 10 shows the results obtained.

In the table, the comparative tracking index is the voltage at which 50 drops cause tracking formation in the range of 0~600 V. If no destruction is observed with 600 V and 50 drops, the maximum depth (mm) of the tracking groove formed on the surface after dropping the 51st drop is measured and shown in ( ).

Fluon® ETFE is among the conventional polymers having the best tracking resistance.

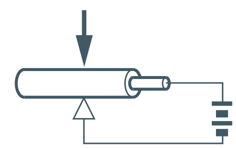
Table 10 Tracking Resistance

	Fluon® ETFE	PTFE	FEP	PCTF	Polyethlene	Polystyrene
Tracking Index (V)	(0)	(0)	(0)	(0)	310	540

4.5 Cut-through Resistance

Cut-through resistance is one method to evaluate electrical properties of materials used for wire coating.

The cut-through resistance is obtained as the maximum load at which the insulation is maintained, when the covered wire is placed on a sharp edge and put under a load.



Core 1.0 mmØ
Coating Thickness 0.25 mm
Load Speed 5 mm/min

Figure 51 Method of Testing Cut-through Resistance

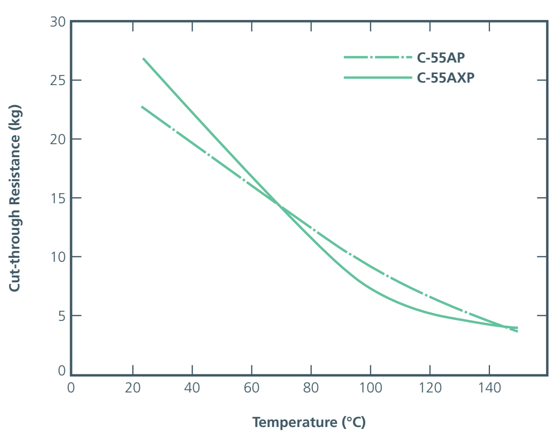


Figure 52 Effect of Temperature on Cut-through Resistance

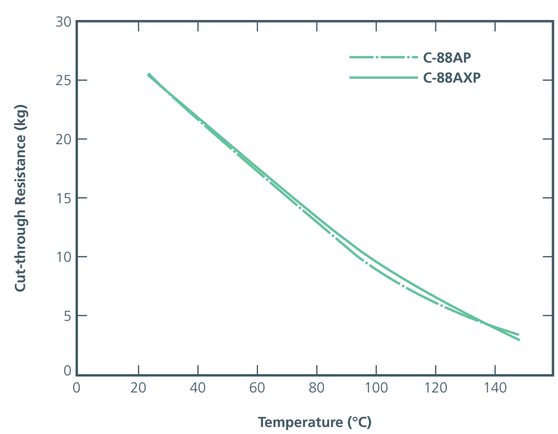


Figure 53 Effect of Temperature on Cut-through Resistance

5 Chemical Properties of Fluon® ETFE

5.1 Chemical Resistance

Fluon ETFE is stable against most chemicals and has excellent chemical resistance. Table 11 shows the effect of various chemicals on Fluon® ETFE. Other than being affected, to a certain degree, by strong oxidizing acids such as concentrated nitric acid, etc., organic amines, and sulfonic acid, at high temperature, Fluon® ETFE shows excellent chemical resistance to other inorganic acids and bases and organic solvents.

Table 11 shows the results obtained by using micro-dumbbells of 1 mm thickness. Property changes less than 15% should be no problem for usage.

Table 11 Chemical Resistance of Fluon® ETFE

Chemical Categories	Chemical		Temp. (°C)	Days	Retention (%)	
					Elong.	Wt. Gain
Inorganic Acids	Conc. hydrochloric acid	35%	100	10	100	0.0
	Sulfuric acid	78% 98%	121 121	10 10	100 100	0.1 0.0
	Oleum		25	10	96	1.3
	Nitric acid	25% 60% 70% 70%	100 120 60 120	14 10 60 7	100 100 100 10	- 0.7 - -
	Fuming nitric acid		25	10	92	0.6
	Hydrofluoric acid		25	7	95	0.1
	Phosphoric acid	30% 85%	100 121	10 10	97 92	-0.4 0.4
	Chromic acid	50%	100	10	98	0.3
Alkalis	Sodium hydroxide	10% 50%	120 120	10 10	97 100	0.0 -0.3
	Potassium	20%	100	7	100	0.0
	Ammonium hydroxide	15%	66	7	98	0.1
Other Inorganic Compounds	Chlorine		90 120 150	10 7 10	94 85 41 (Strength)	- 7.0 -
	Bromine		60	7	100	0.1
	Hydrogen peroxide		25	7	98	0.0
	Water		100	7	100	0.0
	Phosphorous trichloride		75	7	99	-
	Phosphorous oxychloride		100	7	99	-
	Silicon tetrachloride		55	7	100	-
	Sulfuric chloride		70	7	100	6.0
	Carbon disulfide		100	30	98	1.0
	Ferric chloride	25%	70	7	100	6.0

Chemical Categories	Chemical	Temp. (°C)	Days	Retention (%)	
				Elong.	Wt. Gain
Amines	Aniline	25	11	98	0.1
		120	30	82	1.6
	N-methylaniline	120	30	100	0.0
	N-butylamine	78	7	93	5.0
	N-dibutylamine	120	30	99	0.0
		159	7	72	-
	N-tributylamine	120	30	95	-
	Pyridine	116	11	100	3.8
	Ethylenediamine	25	11	100	-
		117	11	96	2.0
	Triethylamine	90	11	90	1.5
	Dimethylformamide	25	11	100	0.4
		120	11	95	2.7
	Dimethylacetamide	121	7	98	3.6
Aromatic Compounds	Phenol	100	11	100	0.3
		120	11	67	0.9
	Benzaldehyde	120	11	94	2.3
	Chlorobenzene	25	11	87	0.4
		120	11	98	3.6
	Nitrobenzene	25	11	98	0.2
		120	11	96	3.0
	Benzene	80	11	95	2.6
	Toluene	111	11	100	2.6
	Xylene	120	11	88	2.5
	Cresol	120	11	80	1.7
Chlorine Compounds	Chloroform	25	11	100	1.6
		61	11	80	1.7
	Carbon disulfide	25	11	100	0.1
		77	11	80	5.0
	Methylene chloride	40	11	100	3.9
	Trichloroethylene	87	11	100	4.8
	Perchloroethylene	77	11	100	5.5
	Ethylene dichloride	84	11	88	3.8
	Freon 113	47	11	-	3.8
	Epichlorohydrin	117	11	78	3.7
	Benzoyl chloride	120	30	100	0.0
Ethers	Propylene oxide	25	11	82	3.2
	Tetrahydrofuran	25	11	98	2.3
		66	11	92	4.2
	Dioxane	105	11	86	6.0
	Ethylether	25	11	87	1.0
	Cellosolve	121	11	88	1.3

Chemical Categories	Chemical	Temp. (°C)	Days	Retention (%)	
				Elong.	Wt. Gain
Ketones	Acetone	25 56	11 11	97 93	2.3 2.5
	Methylethylketone	25 80	11 11	100 100	1.6 3.1
	Methylisobutylketone	25 116	11 11	- 100	0.3 3.3
	Acetophenone	121	11	80	2.5
	Cyclohexanone	121	11	72	5.2
Organic Acids	Glacial acetic acid	25 118	11 11	87 80	0.7 2.2
	Oxalic acid	120	11	100	0.1
	Citric acids	120	11	87	0.1
	Stearic acid	120	11	83	0.1
	Formic acid	100	11	100	0.1
	Glycolic acid	120	11	98	0.0
	Chloroacetic acid	100	11	100	0.6
	Trichloroacetic acid	100	11	84	2.5
	Phthalic acid	120	11	100	0.1
	Lactic acid	119	11	98	0.1
Esters	Ethyl acetate	25 77	11 11	100 100	2.3 3.4
	Butyl acetate	120	11	88	3.5
	Dimethyl phthalate	25	11	87	0.4
Alcohols	Methanol	65	11	93	0.3
	Ethanol	78	11	98	0.6
	Cyclohexanol	120	11	88	1.2
	Benzyl alcohol	120	11	92	0.8
	Propyl alcohol	97	11	93	0.7
	Diacetone alcohol	120	11	91	2.8
Other Hydrocarbons	Hexane	69	11	84	1.1
	Skidroll 500B	120	11	100	0.6
	Mineral oil ASTM No.3	120	11	96	0.2
	Octane	120	11	98	0.2
	Octene	120	11	99	1.1
	Cyclohexane	81	11	94	1.4
	Decalin	120	7	95	-
	Dimethylsufoxide	120	11	89	1.3
	Acetonitrile	82	11	93	1.5

5.2 Chemical Stress Crack

Some polymer materials form cracks when placed under stress in chemicals over a long period of time. Table 12 shows the results of testing method ASTM D 1693, where a narrow strip of plastic sheet, 2.3 mm thick and 36 mm long, was bent 180° and soaked in chemicals for 10 days. The sheet was then examined for crack formation. The results obtained show that Fluon® ETFE has good adaptability in chemical stress.

Table 12 Chemical Stress Crack of Fluon® ETFE

Chemical	Temperature (°C)	Number of cracked pieces (cracks/tested)		
		C-55AP	C-88AP	C-55AXP
Nitrobenzene	121	0/3	0/3	0/3
Aniline	121	0/3	0/3	0/3
Benzaldehyde	121	0/3	0/3	0/3
Chlorobenzene	121	0/5	0/3	0/3
Ethylenediamine	121	0/5	0/3	0/3
Dimethylformamide	121	0/5	0/3	0/3
Dimethylsulfoxide	121	0/3	0/3	0/3
Dimethylacetamide	121	0/3	0/3	0/3
Nitric acid 60%	121	0/3	0/3	0/3

5.3 Weatherability

Fluon® ETFE shows good weatherablity, and "Fluon® ETFE Film", a film obtained by extrusion molding, will not change in properties even when used outdoors as a coating material.

Table 13 Weatherability of Fluon® ETFE Film

Characteristics	Film Grade	12 µm thickness			16 µm thickness (gray)		
	Exposure Time (hrs)	0	1000	2000	0	1000	2000
Tensile Strength	MPa	48	49	49	47	47	47
Tensile Retention	%	-	(102)	(102)	-	(100)	(100)
Elongation (breakage)	%	340	395	390	330	335	330
Modulus Retention	%	-	(116)	(115)	-	(101)	(100)
Tensile Modulus (kg)	MPa	780	820	820	780	760	760
Modulus Retention	%	-	(105)	(105)	-	(97)	(97)

Measurement method: JIS D205-1970 Sunshine-Weather-O-Meter

5.4 Hot Water Resistance

The water absorption of Fluon® ETFE was measured according to test methods ASTM D570, where a sheet, 6 mm in thickness, is soaked in boiling water for 2 hours. The results obtained are shown in Table 14. The water absorption is found to be extremely small, thus, indicating that the electrical and mechanical properties are not affected by the presence of moisture.

Table 15 shows the change in strength of Fluon® ETFE, measured at room temperature after soaking a 1 mm thick sheet in boiling water for a given amount of time.

As the chemical resistance data suggests, Fluon® ETFE shows excellent resistance to hot water, too.

Table 14 Water Absorption of Fluon® ETFE

Fluon® ETFE	Water Absorption (wt%)
C-55AP C-88AP	Less than 0.03

Table 15 Boiling Water Resistance

Grade	Property	Characteristics After Soaking		
		0 hrs	260 hrs	2000 hrs
C-55AP C-88AP	Tensile Strength (MPa)	44	43	43
	(retention %)		(99)	(98)
	Elongation (%)	430	405	480
	(retention %)		(94)	(113)

5.5 Gas Permeation and Moisture Permeation

The permeation of oxygen, nitrogen, carbon dioxide, etc., is approximately constant regardless of film thickness. The activation energy is 6~8 kcal/mol.

The gas permeation and moisture permeation of Fluon® ETFE are similar to those of polyethylene or polypropylene. Gas permeability was obtained by ASTM D1434, moisture permeability by the cup method of ASTM E96, and shown in Tables 16 and 17.

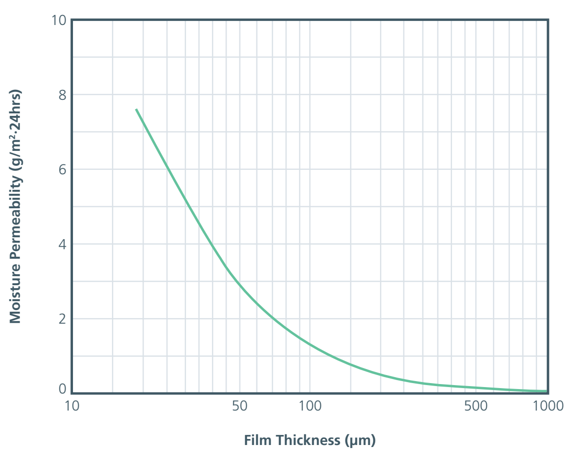


Figure 54 Effect of Film Thickness on Moisture Permeability (23 °C, 0-90 RH%) ASTM E96

Table 16 Gas Permeation
Gas Permeability
Temperature: 23 °C, unit: 10^{-11}cm^3 (STP)·cm/sec·cm^2·cmHg

	C-55AP	C-55AXP
Oxygen	6.1	8.9
Nitrogen	2.3	3.0
Helium	63	86
Carbon dioxide	25	46
Methane	0.8	-

Table 17 Moisture Permeation
Temperature: 23 °C, 0-90 RH%, unit: g/m^2·24hrs·0.1mm

Grade	Moisture Permeability
C-55AP C-88AP	1.3

5.6 Light Transmittance

The refractive index of Fluon® ETFE is 1.40, which is lower than that of conventional plastics.

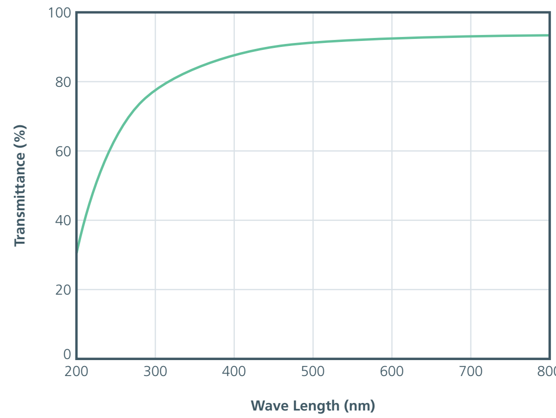


Figure 55 Light transmittance (C55AXP, 50 μm)

5.7 Radiation Resistance

Fluon® ETFE shows radiation resistance significantly higher than that of polytetrafluoroethylene, but as a result of irradiation, cross linking and decomposition occur concurrently, and consequently, mechanical properties are reduced as shown in Figures 56~63.

The irradiation dose rate is $1x10^6$ rad/hr.

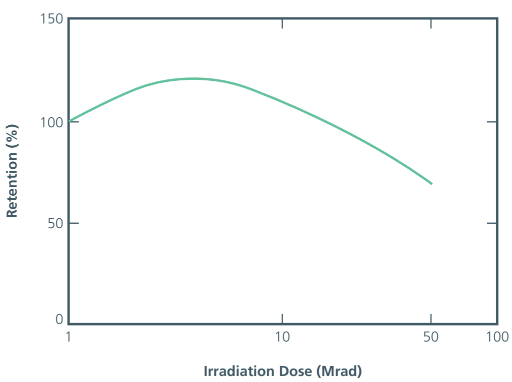


Figure 56 Change in Tensile Strength (C-55AP)

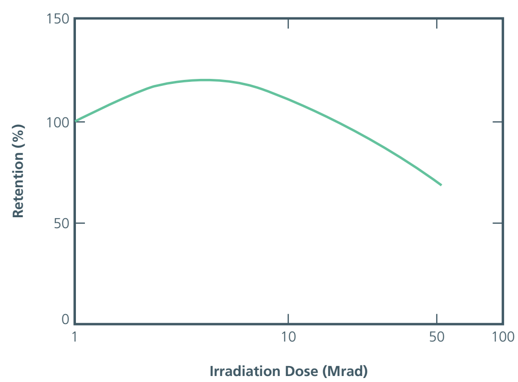


Figure 57 Change in Tensile Elongation (C-55AP)

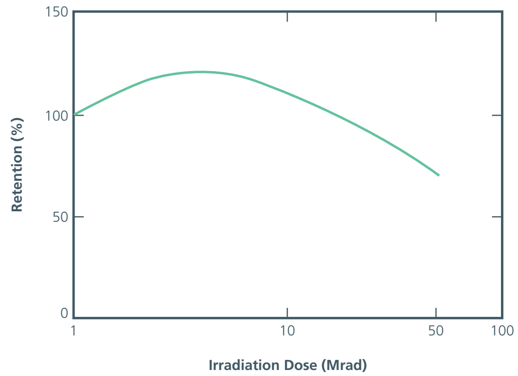


Figure 58 Change in Tensile Strength (C-88AP)

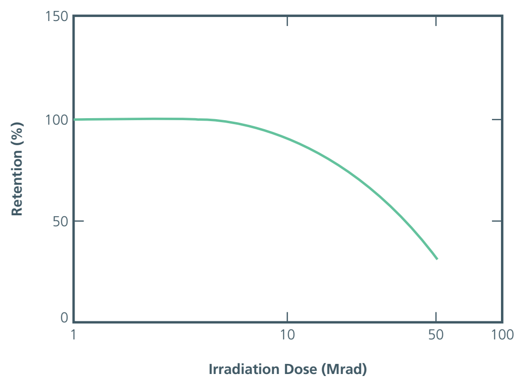


Figure 59 Change in Tensile Elongation (C-88AP)

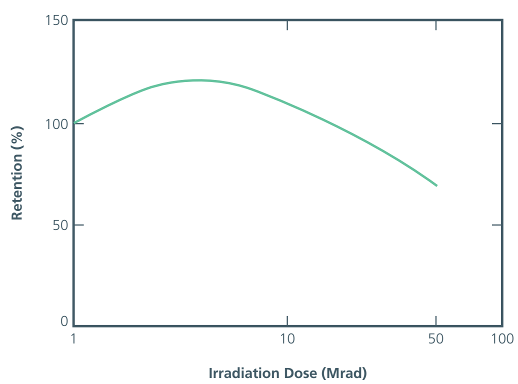


Figure 60 Change in Tensile Strength (C-55AXP)

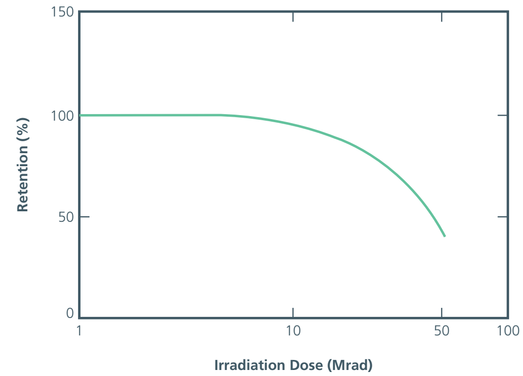


Figure 61 Change in Tensile Elongation (C-55AXP)

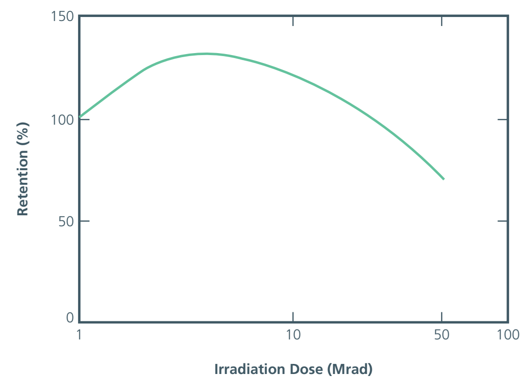


Figure 62 Change in Tensile Strength (C-88AXP)

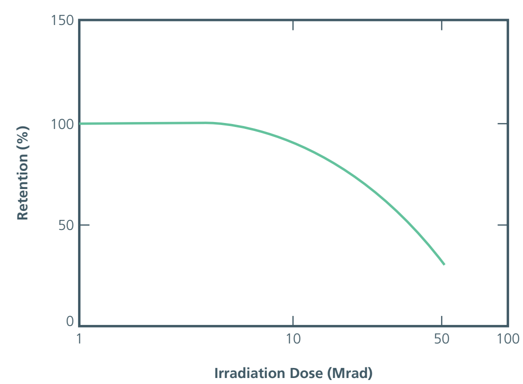


Figure 63 Change in Tensile Elongation (C-88AXP)

5.8 Food Safety

Fluon® ETFE is thermally and chemically stable. Furthermore, no plasticizer is added, and as a result, is safe with respect to food hygiene.

(1) Test according to the Ministry of Health, Labour and Welfare Notification No.20, No.370, and No.434

Results of tests carried out by the Chemical Product Testing Association show that the resin satisfies the requirements, with respect to potassium permanganate consumption, evaporation residue, heavy metal, formaldehyde, and phenol.

(2) Acute Toxicity Test (LDSO)

The acute toxicity test carried out by the Department of Public Health, Faculty of Medicine, Nihon University, revealed no toxicity.

(3) Food Hygiene Test in USA

The results of toxicity and extraction tests carried out by D and R Testing Institute (Spencerville, Ohio, USA), according to the guidelines of the US FDA showed the safety factor to be extremely high.

6 Fluon® ETFE Physical Properties

Table 18 Basic Physical Properties of Fluon® ETFE

Property	Unit	Test Method	C-55AP	C-55AXP	C-88AP	C-88AXP	C-88AXMP	C-88AXMP HT
Melt Flow Rate	g/10 min	D-3159	3.9~6.5	3.9~6.5	9.0~12.0	9.0~12.0	27.0~43.0	27.0~35.0
Melting Point	°C	D-3159	265	258	267	260	260	254
Specific Gravity		D-792	1.74	1.73	1.74	1.73	1.73	1.73
Hardness	Shore D	D-2240	67	67	67	67	67	67
Tensile Strength (23 °C)	psi	D-638	7,540	7,540	6,960	6,960	6,090	6,090
Tensile Elongation (23 °C)	%	D-638	382	414	415	415	433	433
Tensile Strength (200 °C)	psi	D-638	1,015	725	725	660	725	725
Tensile Elongation (200 °C)	%	D-638	620	530	610	470	410	410
Flexural Modulus (23 °C)	psi	D-790	139,200	134,850	131,950	129,050	126,150	126,150
Heat Deflection Temp. (66 psi)	°C	D-648	115	105	95	85	82	82
Heat Deflection Temp. (264 psi)	°C	D-648	85	65	67	64	62	62
Notched Izod Impact (23 °C)	ft·lb/in	C-256	No break	No break	No break	No break	No break	No break
Embrittlement Temperature	°C	D-764	-125	-125	-125	-125	-125	-125
CLTE (0 – 100 °C)	in/in/°F	D-696	7.3×10^{-5}	7.3×10^{-5}	7.3×10^{-5}	7.3×10^{-5}	7.3×10^{-5}	7.3×10^{-5}
Water Absorption (24 hours)	%	D-570	Less than 0.03	Less than 0.03	Less than 0.03	Less than 0.03	Less than 0.03	Less than 0.03
Dielectric Constant (1 mHz at 23 °C)		D-150	2.6	2.6	2.6	2.6	2.6	2.6
Volume Resistivity	Ω·cm	D-257	$>10^{17}$	$>10^{17}$	$>10^{17}$	$>10^{17}$	$>10^{17}$	$>10^{17}$
Dielectric Strength (10 mil film)	volts/mil	D-149	1,800	1,800	1,800	1,800	1,800	1,800
Heat of Combustion	BTU/lb	D-240	5,900	5,900	5,900	5,900	5,900	5,900
Specific Heat	cal/g·°C		0.3	0.3	0.3	0.3	0.3	0.3
Oxygen Index	%	D-2863	32	32	32	32	32	32
Flame Rating		UL-94	V-0	V-0	V-0	V-0	V-0	V-0
Upper Service Temperature	°C	UL-746	150	150	150	150	150	150
MIT Flex Life	cycles	D-2176	50,000	70,000	20,000	40,000	15,000	27,000

7 Molding of Fluon® ETFE

Unlike polytetrafluoroethylene, a typical fluoropolymer, Fluon® ETFE can be processed by conventional melt processes. Specifically, its melt viscosity at molding temperature is 10^3~10^5 poise, which is about the same as that of conventional thermoplastics, and as a result, methods such as injection, extrusion, blow molding, and powder coating, can be used.

7.1 Raw Resin and its Handling

The grades of Fluon® ETFE have been described in Chapter 1; C-55 is suitable for heavy-gage molding, and C-88 for light-gage molding.

Since Fluon® ETFE is not hygroscopic, no preliminary drying of the raw resin is necessary. However, during storage, it is preferable to have the container sealed tightly, so that no moisture is absorbed and the resin is not contaminated by dust due to static electricity.

Fluon® ETFE is a thermally stable resin, but if subjected to temperatures above 350 °C, thermal decomposition is induced. Thus, the resin cannot be kept at high temperatures for long periods of time. It is preferable not to leave the resin in a molding machine for more than 30 minutes when interrupting the operation. In such situations, it is suggested that the temperature of the molding machine be lowered.

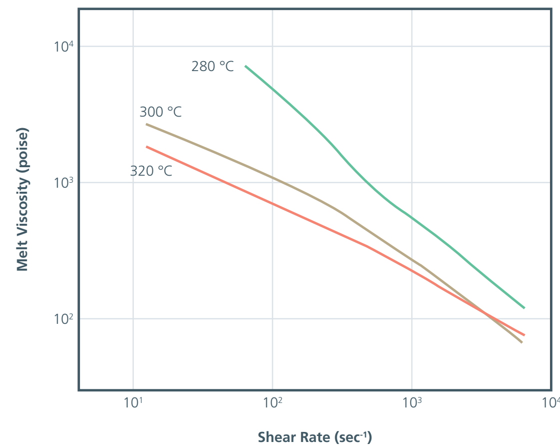


Figure 65 Effect of Shear Rate on Melt Viscosity (C-88AP)

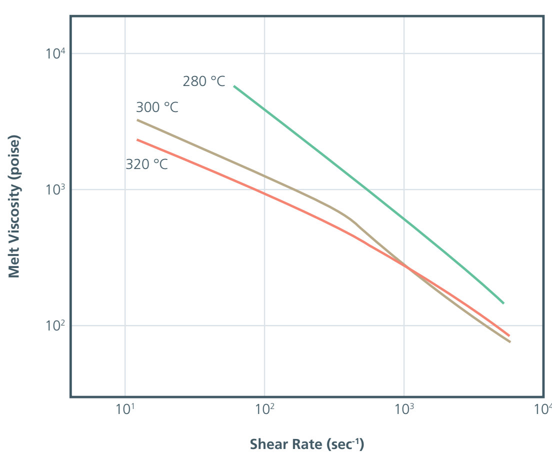


Figure 64 Effect of Shear Rate on Melt Viscosity (C-55AP)

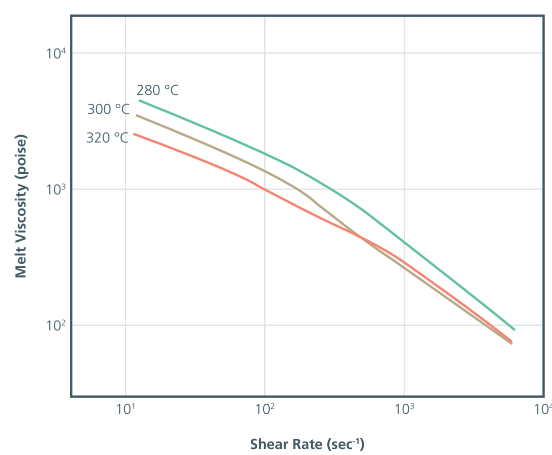


Figure 66 Effect of Shear Rate on Melt Viscosity (C-55AXP)

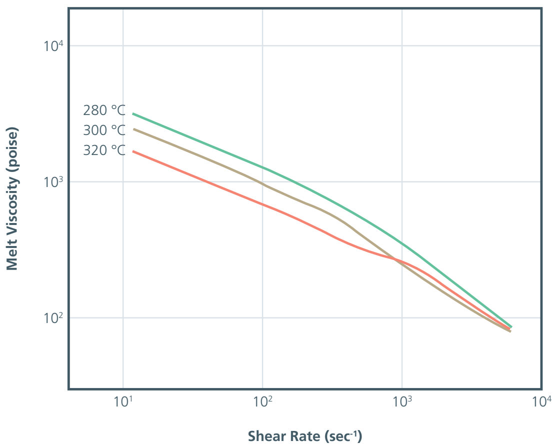


Figure 67 Effect of Shear Rate on Melt Viscosity (C-88AXP)

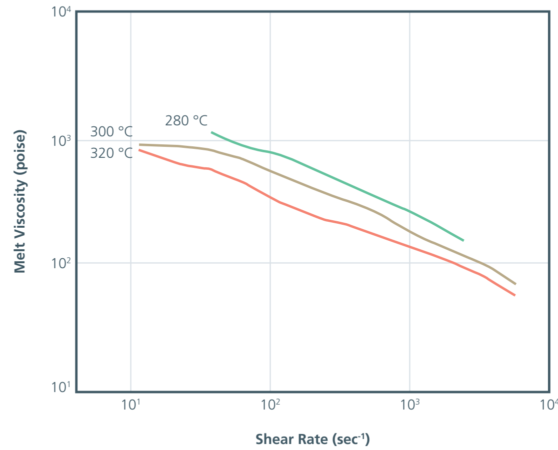


Figure 68 Effect of Shear Rate on Melt Viscosity (C-88AXMP)

7.2 Injection Molding

(1) Injection Machine and Molding Material

Any of the plunger-type and screw-in-line-type injection machines may be used for molding, as long as the heater holds a heat capacity of up to 340 °C. The material of the molding machine, corrosion resistant materials such as Hastelloy-C, X-alloy 306, Duranickel, etc., are recommended for those parts coming to contact with the polymer (inner surface of cylinder, screw, torpedo, nozzle, etc.). If not used as a machine exclusively for Fluon® ETFE, nitrided and hard-chromium-plated materials may also be used.

(2) Mold

The mold used, although depending on the number of shots, should be hard-chromium-plated on ordinary materials, and must be designed to stand temperatures up to 120 °C. The gate structure may be selected from side gate, pinpoint gate, film gate, etc., depending on the product desired. The runner is desired to be designed to have a round cross section, and as short a length as possible.

(3) Molding Conditions

Table 20 outlines the typical conditions for molding Fluon® ETFE. For light-gage molding (thinner than 0.5 mm), the speed should be increased, while for heavy-gage molding (thicker than 5 mm), the cooling time should be increased. Furthermore, to obtain a smooth surface, the injection speed should be reduced.

Table 20 Injection Molding Conditions for Fluon® ETFE

		Natural Grade
Molding Temperature (°C)	Back	260~280
	Middle	270~290
	Front	280~300
	Nozzle	290~320
Mold Temperature (°C)		60~120
Injection Pressure (MPa)		50~120
Injection Speed (ram speed) (mm/sec)		1~15
Molding Cycle (sec)		30~20

Figures 69~71 show the relationship of molding temperature and fluidity, and Figures 72~73 show the relationship of various molding conditions and molding contraction.

Molding temperature and injection speed do not affect the fluidity much, but has the greatest effect on the surface smoothness.

Figure 71 shows the relationship of the thickness of the molded product, and the flow length. L/t increases proportionally to $t^{1/2}$. In other words, when the thickness is 1 mm, the flow length is 100 mm, and when the thickness is 3 mm, the flow length about 550 mm.

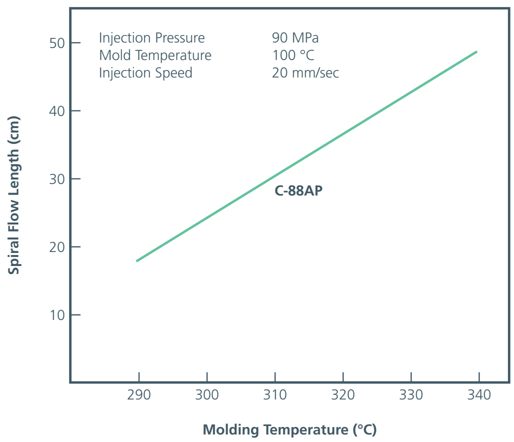


Figure 69 Molding Temperature and Spiral Flow Length

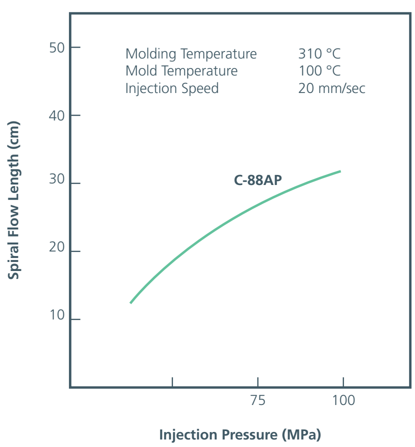


Figure 70 Injection Pressure and Spiral Flow Length

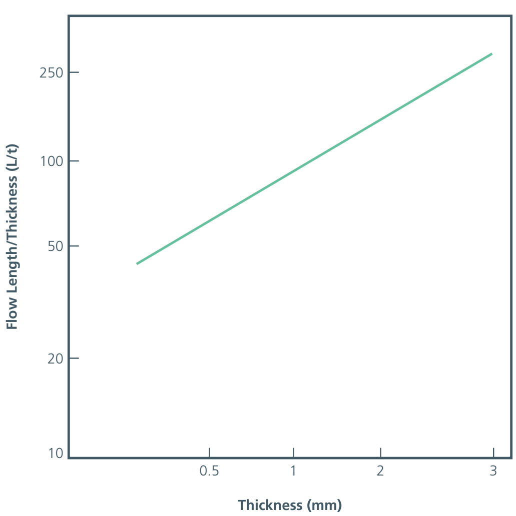


Figure 71 L/t and Thickness (C-88AP)

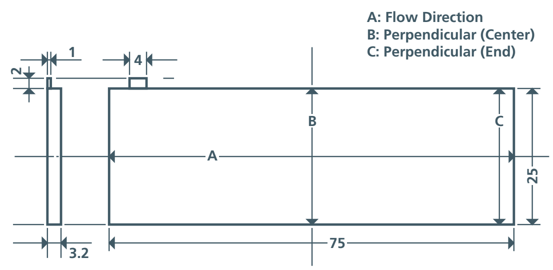


Figure 72 Cavity Scale of Mold (Unit: mm)

Because Fluon® ETFE is a crystalline polymer, the shrinkage is relatively large. The shrinkage was measured in the flow direction, and in the direction perpendicular to the flow, by using the mold shown in Figure 72.

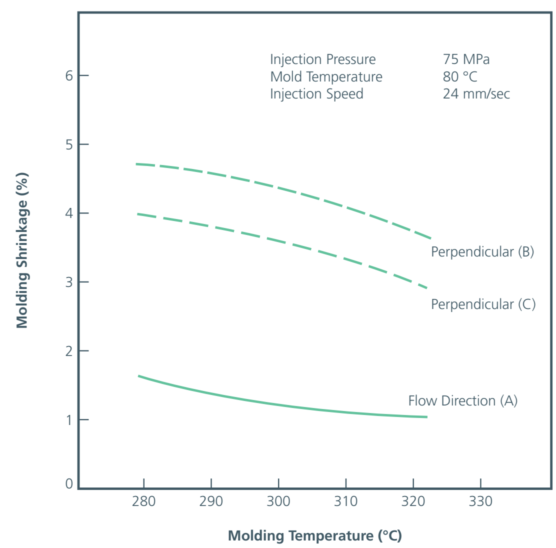


Figure 73 Molding Temperature and Molding Shrinkage

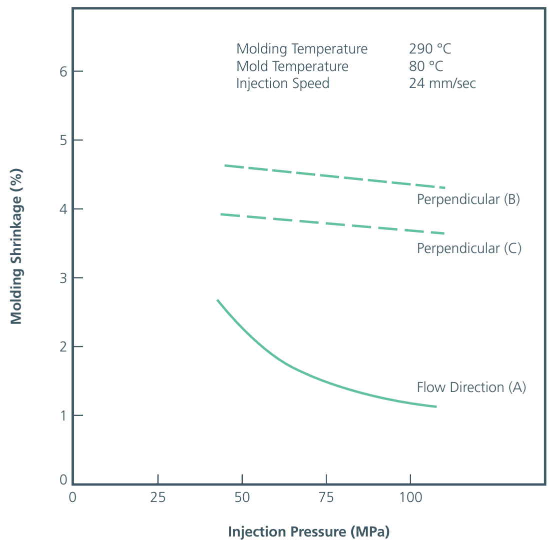


Figure 74 Injection Pressure and Molding Shrinkage

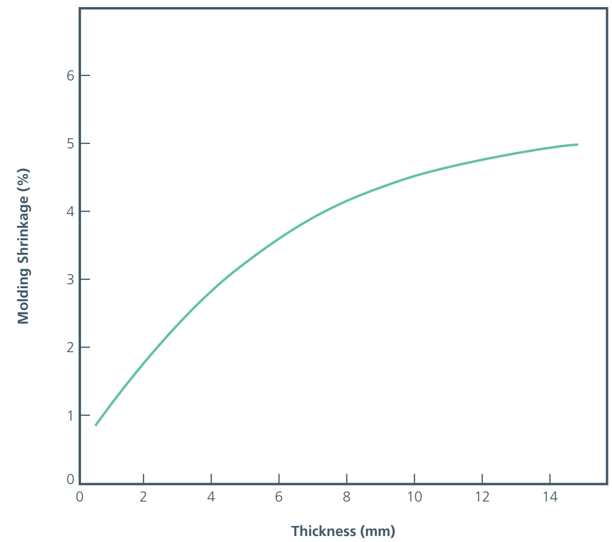


Figure 76 Thickness and Molding Shrinkage

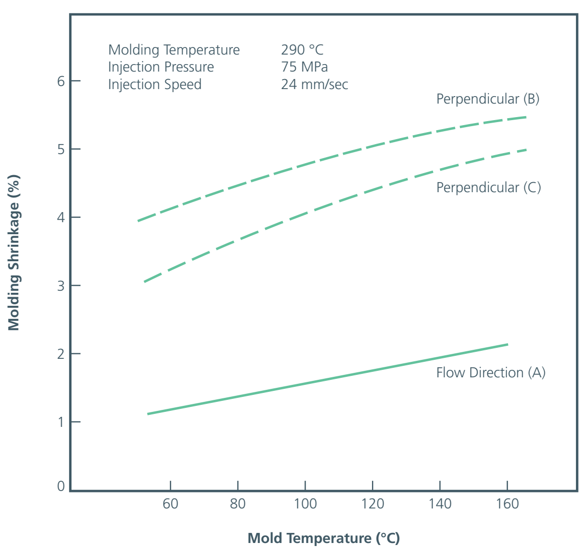


Figure 75 Mold Temperature and Molding Shrinkage

The shrinkage of Fluon® ETFE natural grades (C-55AP, C-88AP, C-55AXP, C-88AXP), when molded under ordinary conditions, is 1.5~2.0% in the flow direction, and 3.5~4.5% in the perpendicular direction.

Table 21 Molding Contraction of Fluon® ETFE

	C-88A
Flow Direction (%)	1.5~2.0
Perpendicular to the Flow (%)	3.5~4.5

7.3 Extrusion Molding

Fluon® ETFE can be molded by extrusion into small diameter (up to 10 mm⌀) rods, tubes, pipes, and electric wire coating, and by using the T-die, or by inflation molding, into films. Blow molding and uniform profile mold extrusion molding are also possible. Standard molding conditions are shown below.

Table 22 Extrusion Molding Conditions for Fluon® ETFE

	Specification	Electric Wire Coating	Film	Tube
Extruder	Screw diam.	40 mm⌀	40 mm⌀	35 mm⌀
	Screw type	Metering	Metering	Metering
	Screw L/D	25	22	22
	Screw comp. ratio	2.6 : 1	2.8 : 1	2.5 : 1
	Screen	80, 100 & 200 mesh, 2 each	80, 100 & 200 mesh, 2 each	80, 100 & 200 mesh, 1 each
Die	Die i.d.	4.3 mm	Coat hanger type manifold die	13.5 mm
	Nipple o.d.	2.0 mm		12.1 mm
	Rand length	20 mm	Lip spacing: 0.2 mm	
Product		Core: tin-plated soft copper wire	Film thickness: 25 μm	Tube i.d.: 9 mm⌀
		Core diam: 0.26 mm⌀	Film width: 400 mm	Tube o.d.: 10 mm⌀
		Thickness: 0.15 mm		Thickness: 0.15 mm
		Final diam: 0.56 mm⌀		
Molding conditions	Cylinder temp			
	C1	250~260 °C	270 °C	270 °C
	C2	270~290 °C	290 °C	290 °C
	C3	330~340 °C	310 °C	300 °C
	Cross head	330~340 °C		
	Die	350~360 °C	315 °C	310 °C
	Air gap		80 mm	100 mm
	Draw down ratio	59		Die diameter/sizing die diameter 1.35
	Pull speed	80~150 m/min	5 m/min, cooling roller temperature 120 °C	4 m/min vacuum sizing

7.4 Powder Coating

Powder coating methods such as electrostatic powder coating, fluid dipping, etc., can be used for Fluon® ETFE coating. The selection of the raw resin depends on the desired thickness and the application. The polymer is not hygroscopic, but the powder flow is affected by moisture content. Therefore, compressed air used for flowing should be dried prior to the process. Furthermore, as dust mixed in the polymer may cause pinholes are coloration, the package or the hopper should not be left open.

(1) Material and Shape of Substrate

As long as the material withstands temperatures in the range of 290~340 °C, Fluon® ETFE can be coated, not only on metallic surfaces, but on glass and ceramics, as well. The edges tend to shrink in thickness upon solidification. Therefore, it is necessary to provide a roundness of 1R, in thin layer lining, and for thick linings of 0.41 mm, 3R or larger at extrusions and 5R or more at intrusions.

(2) Pretreatment

Table 23 Pretreatment

Steel Material (Thick Lining)	Degreasing: baking 400 °C × 2 hrs or more Coarsening: blasting with 60 mesh-pass steel grid and sand (jet pressure 3~7 kg/cm^2)
Steel, Stainless Steel, Aluminum (30~50 μm)	Degreasing: washing with trichloroethylene Coarsening: blasting with 100 mesh-pass steel grid and sand (jet pressure 3~7 kg/cm^2)
Copper and Copper Alloy	At the time of baking, a fragile oxidation film is formed. Therefore, metal plating or copper oxide film treatment (5 min boiling in a mixture of 1 part potassium persulfate, 4 parts sodium hydroxide, and 95 parts water) is carried out.
Glass	Silane coupling agent treatment [(1) washing, (2) dipping in 30% nitric acid at 60 °C × 2 hrs, (3) soaking in 1% ethanol solution of silane coupling agent (Union Carbide A-1120) for 24 hrs, (4) air drying, (5) coating]

(3) Coating

Apply a voltage of 60~90 kV, using an electrostatic coating machine, and turn off immediately before inducing electrostatic repulsion. Film thickness of the 30~150 μm for the natural grades, and 1 mm for the ZL-520N by repeating 5~7 layers of coating, can be obtained. By the fluid dipping of Z-885A, a film thickness of 0.6 mm can be obtained with a substrate of 5 mm thickness, and preheating of 340~360 °C.

(4) Baking

Baking should be carried out at a temperature in the range of 290~340 °C, for 10~16 minutes, depending on the thickness of the substrate, the material, and the desired film thickness.

(5) Film Thickness Test

The film formed is tested by a method similar to the testing method for PTFE film, conforming to JIS K6894, as well as by other methods, such as the film thickness test, pinhole test, Erichsen test, corrosion resistance test, etc., depending on the application.

7.5 Other Processing

(1) Welding of Fluon® ETFE

Fluon® ETFE can be welded using HOTJET (FUJI MFG Co., LTD. Sold by Tokuhara-Kiko Tel. +81-3-3563-1621).

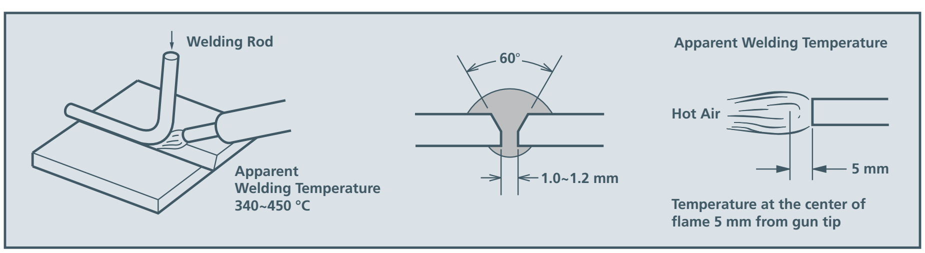


Figure 77

Welding requires a certain degree of skill, but by paying careful attention on the area to be welded, and by turning both the mother material and the welding rod into a waxy state, it is possible to obtain a strength equivalent to 60% that of the mother material, and achieve a welding speed of 80 mm/min.

(2) Flare Processing of Fluon® ETFE

A 90° flare processing of Fluon® ETFE pipes and injection moldings can be performed by using special tools. By heating the tool material at 130~150 °C, flare processing may be done at a rate of 60 mm/min.

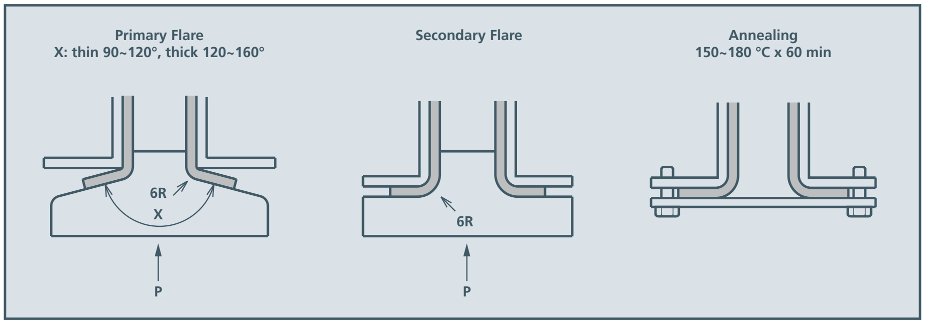


Figure 78

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