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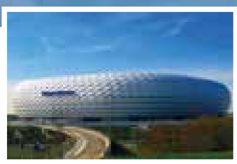
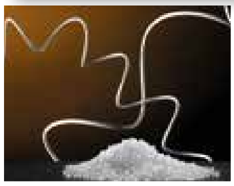
Chemistry for a Blue Planet

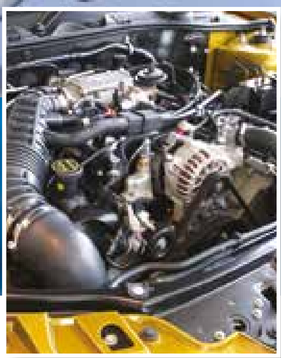
Fluon® ETFE

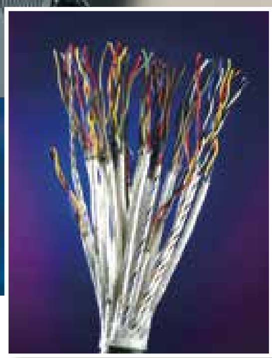
Ethylene-Tetrafluoroethylene Copolymer

Technical Data









Fluon® ETFE

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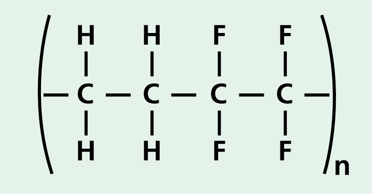
1 Fluon® ETFE and its Grades

Fluon® ETFE is a thermoplastic fluoropolymer developed by Asahi Glass. 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 fluoropolymers 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 Asahi Glass plus information that, hopefully, may serve as reference for the development of various applications for Fluon® ETFE.

Notice: All data given here in 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 Resins (natural)

Grade	Melt Flow Rate	Characteristics	Application	Moulding Method
C-55AP	3.9~6.5	Standard	General	Extrusion
C-55AXP	3.9~6.5	Stress crack resistant	Wire coating	Extrusion
C-88AXP	9.0~12.0			Extrusion, injection moulding
C-88AXMP-HT	24~43	High flow	Thin wire coating	Extrusion, injection moulding

Melt flow rate in accordance with ASTM D 3159 (297°C, 5 kg)

Table 2 Grades of Fluon® ETFE Powder

Grade	Coating Thickness	Coating Method	Characteristics and Usage
Z-8820X	50~80μm	Electrostatic powder coating	Non-stick coating for cookware
Z-885C	50~150μm	Electrostatic powder coating	Non-stick coating
	50~400μm	Fluid dip coating	Corrosion protection
ZL-520N	~1mm	Electrostatic powder coating (top coat)	Corrosion protection contains 20% carbon
ZL-521N	30~50μm	Electrostatic powder coating	For top coating on ZL-520, contains 5% carbon fibre
ZL-522F	2~5μm	Rotolining	Corrosion protection for chemical equipment
TL-581	2~5μm	Rotolining	
TL-081	~1mm	Electrostatic and fluid dip coating (top coat)	
CP-801XBK	50~150μm	Electrostatic powder coating	Black anti-corrosion coatings

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 the elongation value is reduced to half of the original value, after 10 years (100 thousand hours) at 150 °C.

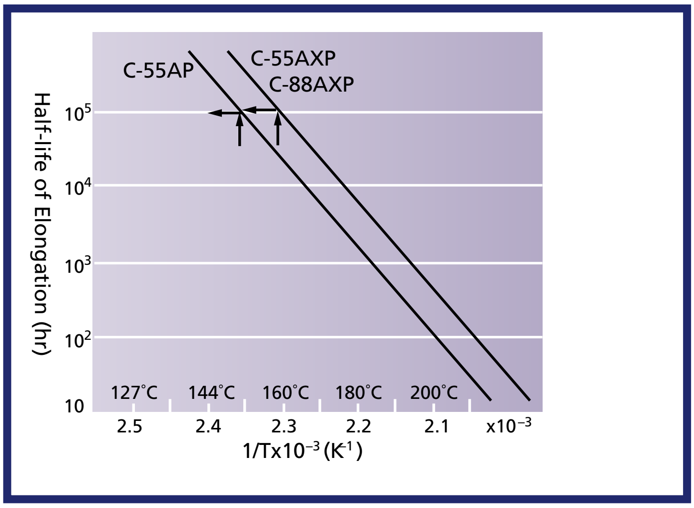


Figure 1 Half-life of Elongation and Temperature

2-2 Linear Thermal Expansion Coefficient

The thermal expansion and contraction of polymers are important properties when used for industrial applications, or mould design.

Table 4 Linear Thermal Expansion Coefficient of Plastics

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

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

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 small, and as result, the value only gives a general idea of the polymer’s heat resistance.

Table 5 Heat Distortion Temperature of Plastics

ASTM D648

Polymer		Fluon® ETFE C-88AXP	PTFE	PFA	FEP	ECTFE	PVDF	PVF	PE	PVC	PC
Heat Distortion Temperature °C	4.6kg/cm²	80	120	70	70	90-115	150-156	~	60-80	55-75	144
	18.5kg/cm²	50	50	50	50	66-76	95-100	~	~	~	135

2-4 Flammability

Although Fluon® ETFE has C_2H_4 units in the main chain, it is classified by UL standard subject 94, class 94V-0. Results of ASTM D 165 class also shows that it is noncombustible.
The oxygen index based on ASTM D 2863 is 32%

2-5 Thermal Decomposition

The decomposition temperature of ETFE (temperature ramp 10°C/min) is in the range 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.

At normal moulding 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 a situation, the gas generated by decomposition consists mostly of hydrogen fluoride.

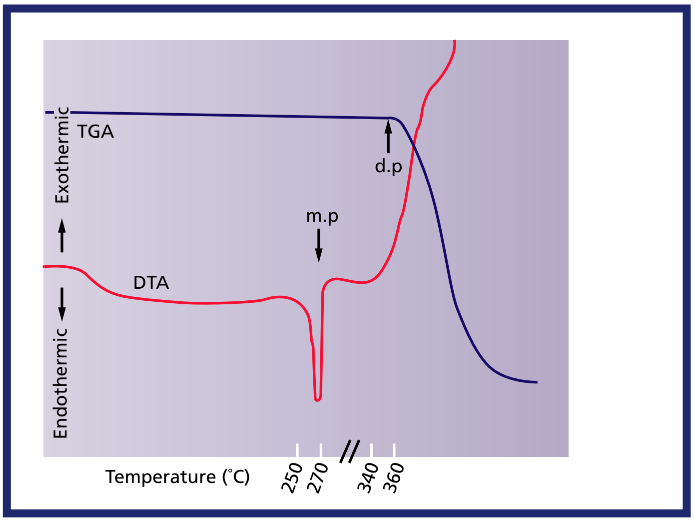


Figure 2 Differential Thermal Analysis and Heated Weight Loss

2-6 Summary of Thermal Properties

Table 6 Thermal Properties of Fluon® ETFE

Subject	Unit	Property	Method
Specific Heat	kJ/(kg K)	1.2	
Thermal Conductivity	W/(mK)	0.17	ASTM-D177
Heat of Fusion	J/g	40~50	-
Linear Thermal Expansion Coefficient	10^{-5}/k	11~14	ASTM-D696
Heat Distortion Temperature (181N)	°C	63	ASTM-D7207
Brittle Point	°C	-125	ASTM-D746
Flammability		NB (Noncombustible) 94V-0	ASTM-D635 UL
Oxygen Index	%	32	ASTM-D2863

3 Mechanical Properties of Fluon® ETFE

Fluon® ETFE has balanced tensile elongation and strength as well as toughness, ensuring good impact resistance 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.

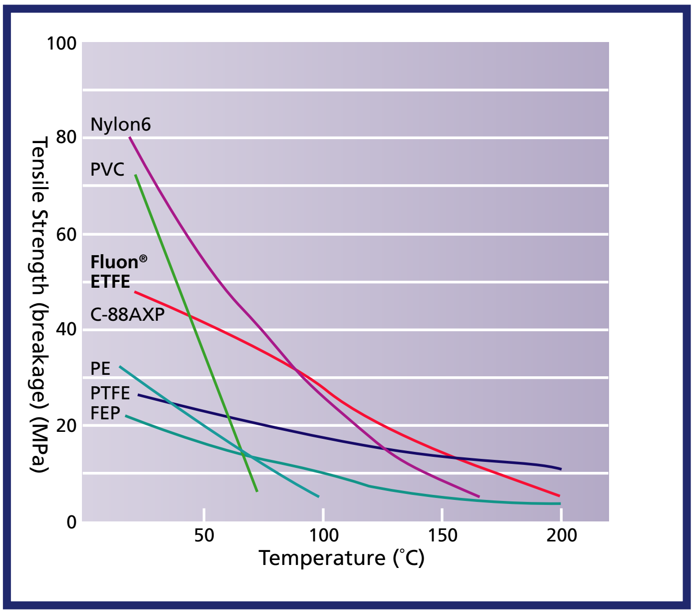


Figure 3 Effect of Temperature on Tensile Strength

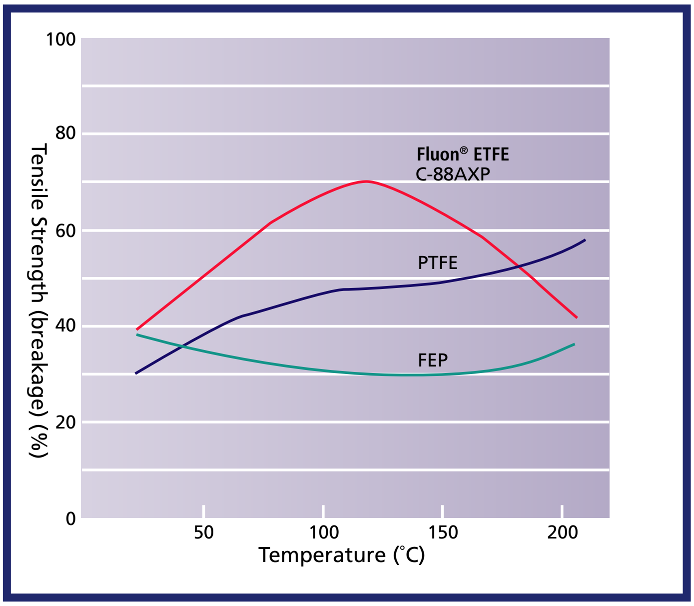


Figure 4 Effect of Temperature on Tensile Elongation

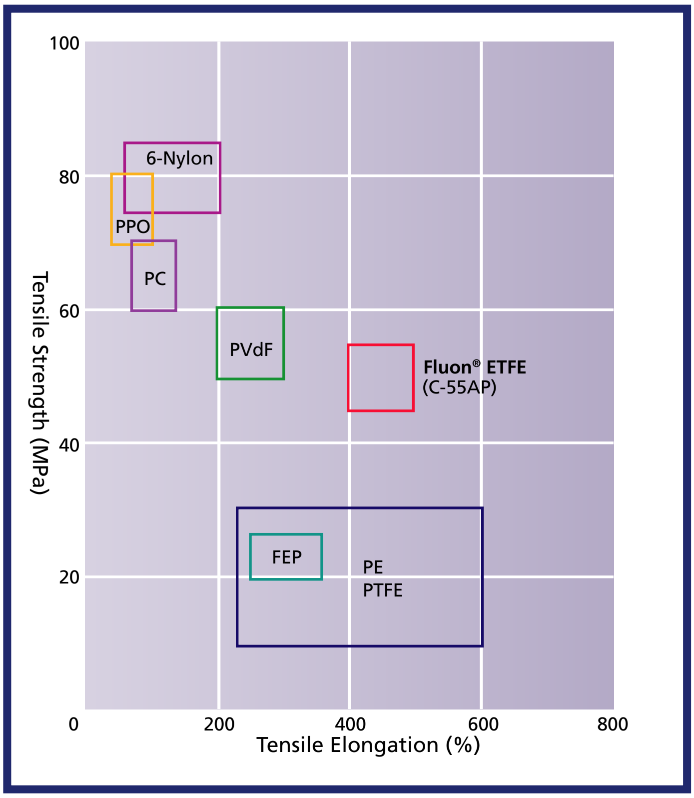


Figure 5 Strength vs. Elongation for Various Plastics

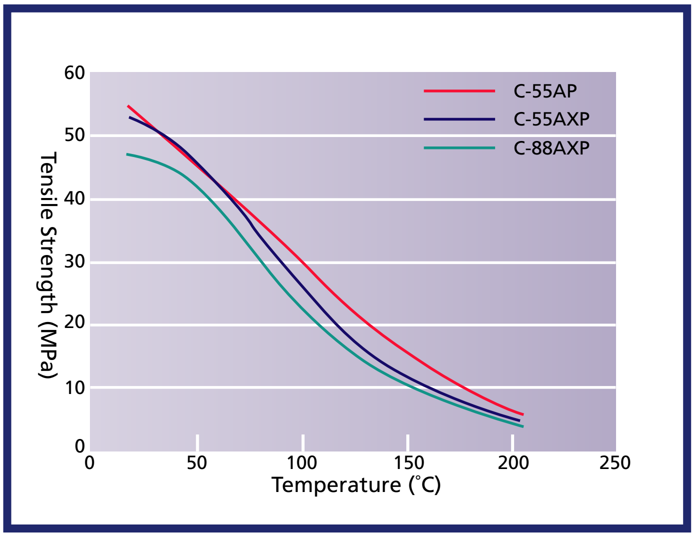


Figure 6 Effect of Temperature on Tensile Strength

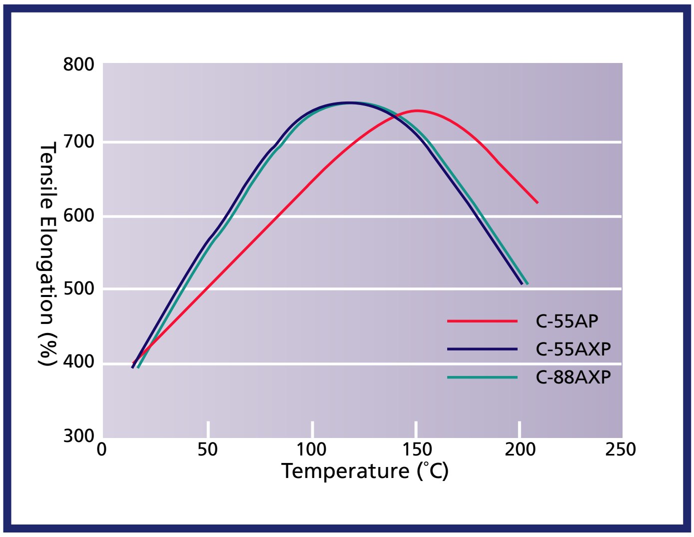


Figure 7 Effect of Temperature on Tensile Elongation

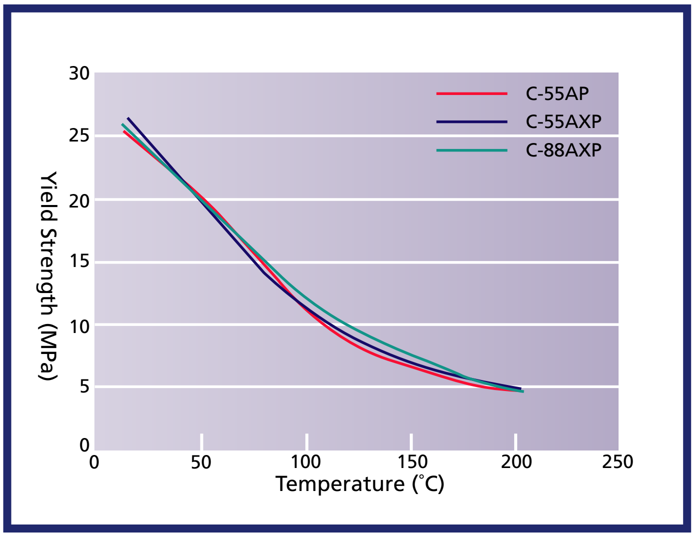


Figure 8 Effect of Temperature on Yield Strength

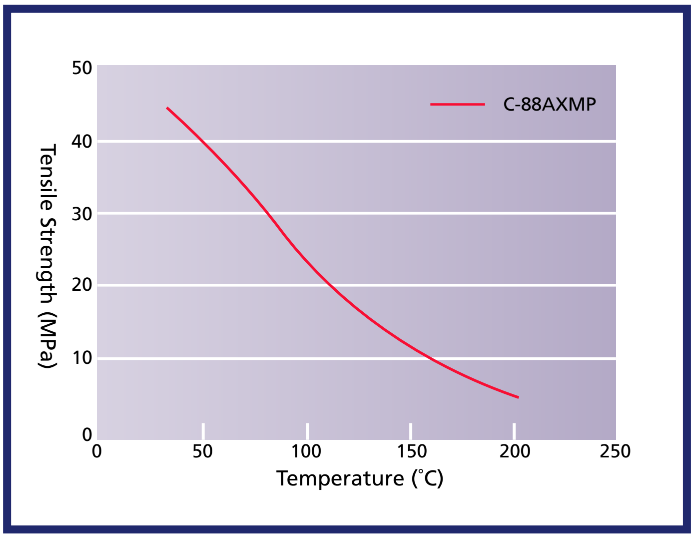


Figure 9 Effect of Temperature on Tensile Strength

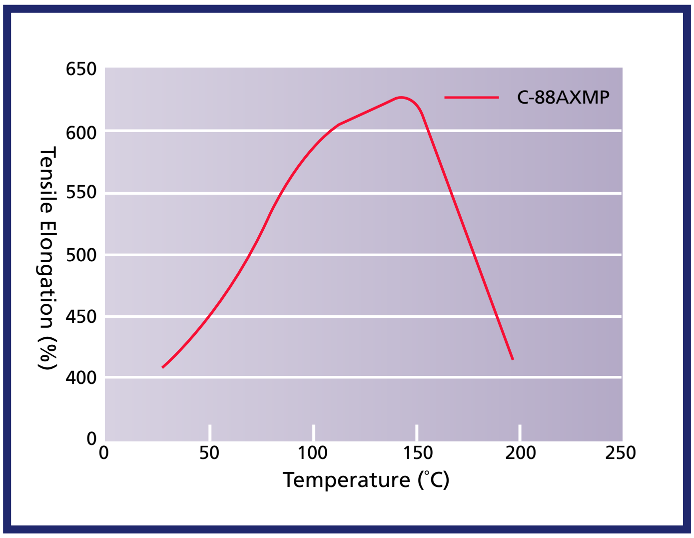


Figure 10 Effect of Temperature on Tensile Elongation

3-2 Tensile Creep Properties

Generally, when a constant load is applied to a polymer for a long period of time, irreversible plastic flow results, 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 situations where the material is subjected to mechanical forces. Tensile creep of Fluon® ETFE, the initial degree of distortion can vary widely depending on the applied load, as shown in Figure 11, but the creep rate is very small.

Figures 13~14 show tensile creeps of various fluoropolymers. At 100°C, polyvinylidene fluoride shows a small value, but at higher temperatures, Fluon® ETFE is found to have the best values among these fluoropolymers.

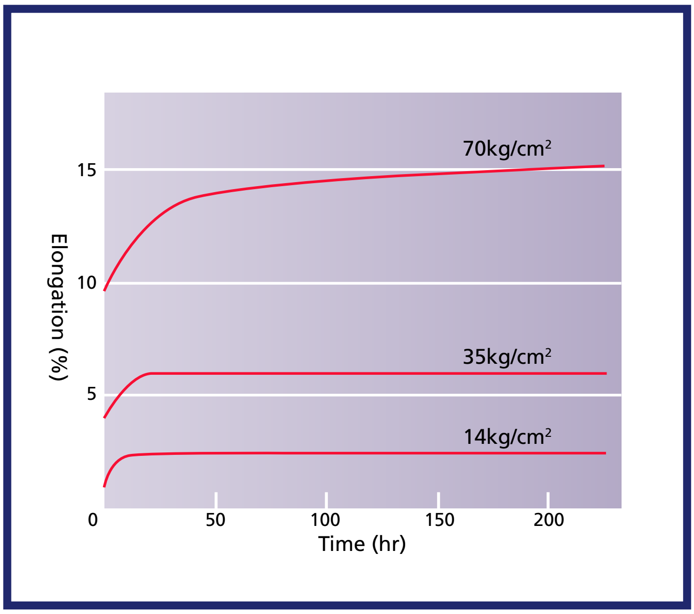


Figure 11 Tensile Creep of ETFE at 100°C (ASTM D 674-56)

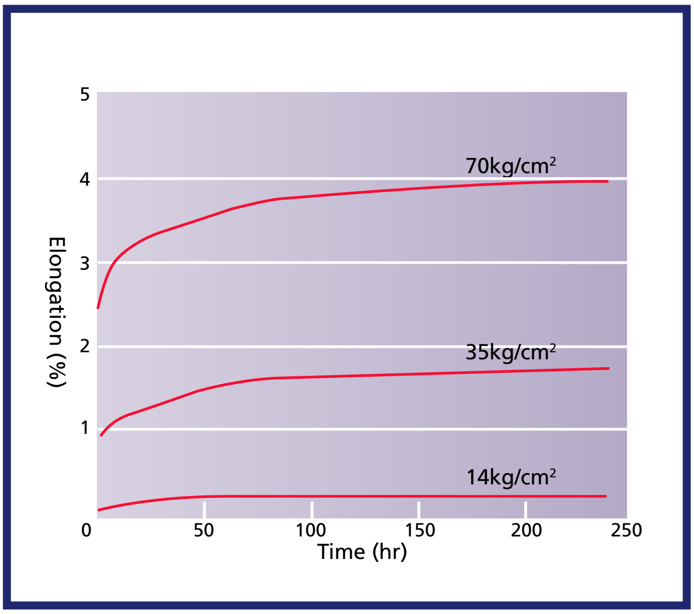


Figure 12 Tensile Creep of ETFE at room temperature

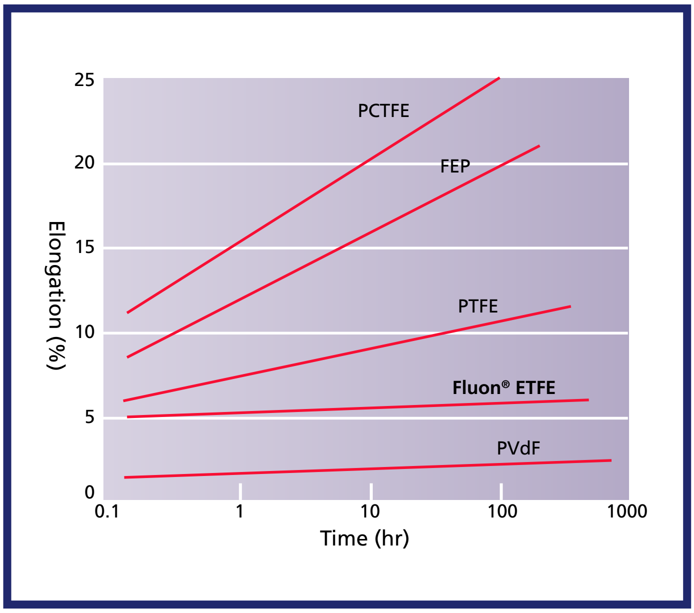


Figure 13 Tensile Creep of Various Fluropolymers (100°C, 35kg/cm²)

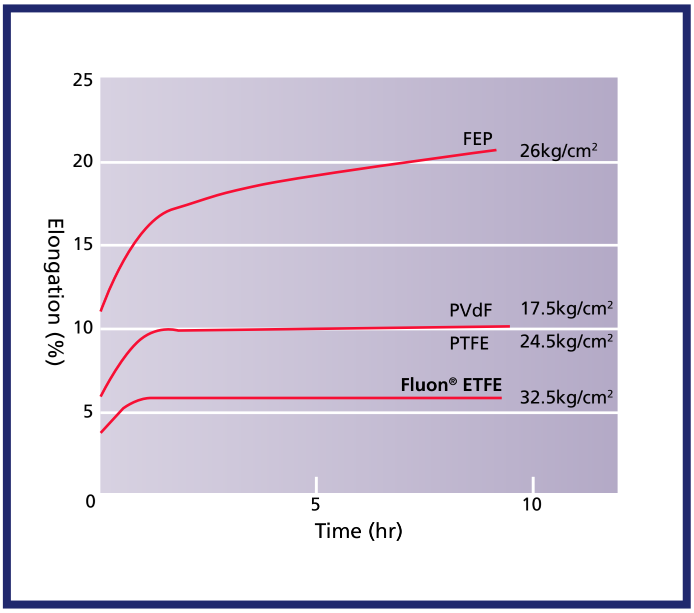


Figure 14 Tensile Creep of Various Fluropolymers (150°C, load: 1/2 of yield strength at 150°C)

3-3 Compression Properties

Figure 15 shows the compression stress-strain curve of Fluon® ETFE, and figure 16, the compression stress residual strain curve. Figures 17 and 18 illustrate the compression creep property and the compression stress relaxation property.

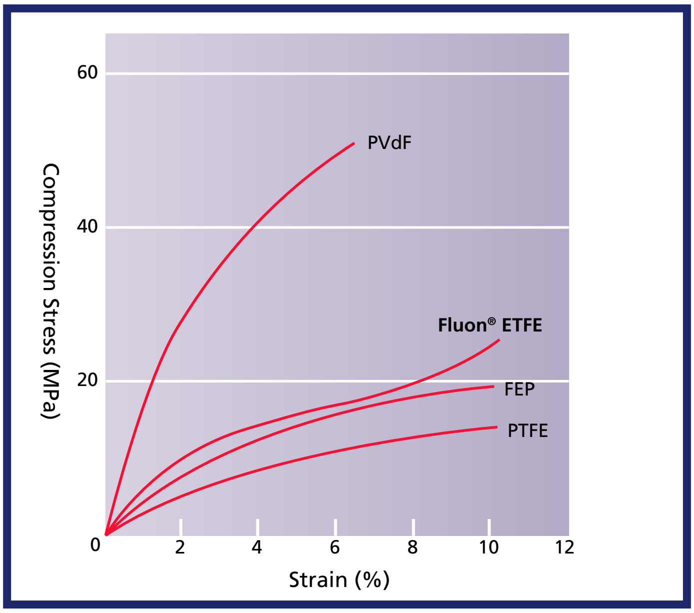


Figure 15 Compression Stress-Strain Curve

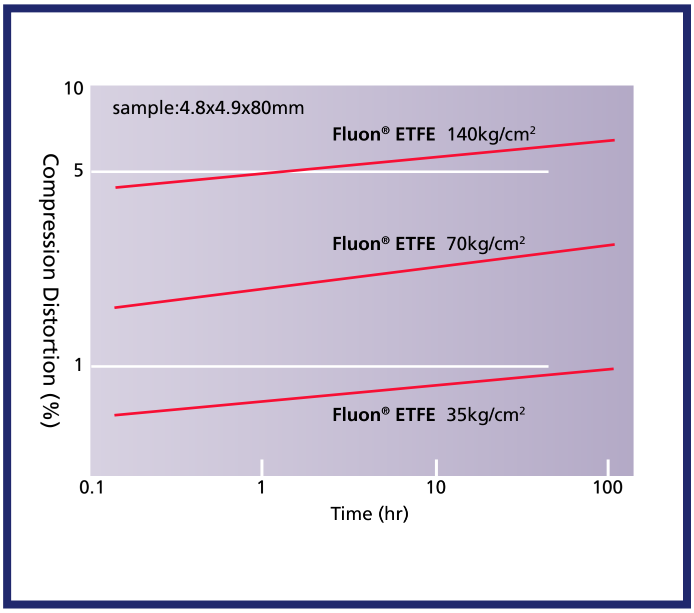


Figure 17 Dependence of Compression Creep Characteristics on Load (at room temp.)

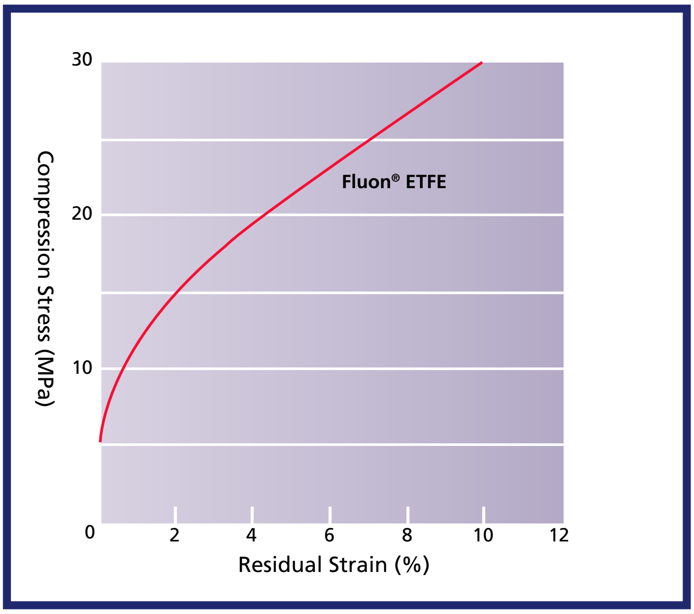


Figure 16 Compression Stress-Residual Strain Curve

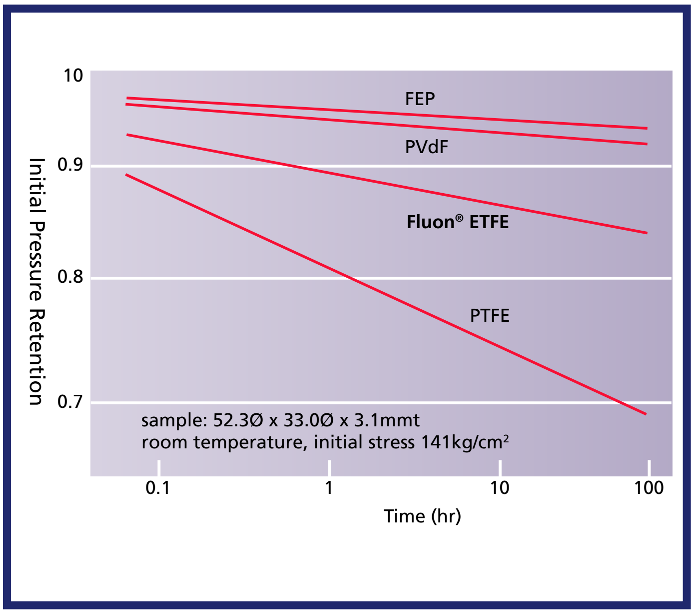


Figure 18 Compression Stress Relaxation (ASTM F38)

(Sample: 13 x 13 x 25mm, cross head speed: F1mm/min, at room temp.)

3-4 Flexural Properties

The effect of temperature on flexural strength and flexural modulus are shown in Figures 19~22.

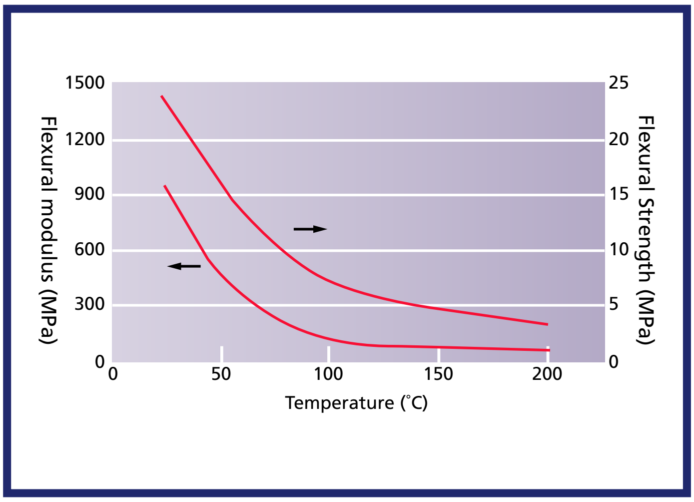


Figure 19 (Grade C-55AP)

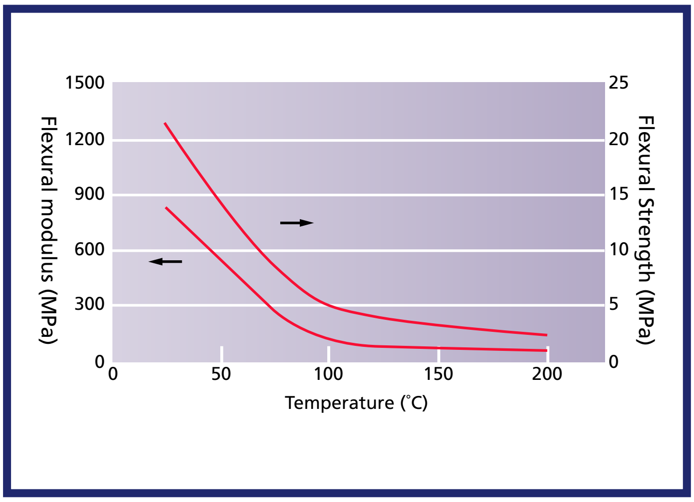


Figure 20 (Grade C-55AXP)

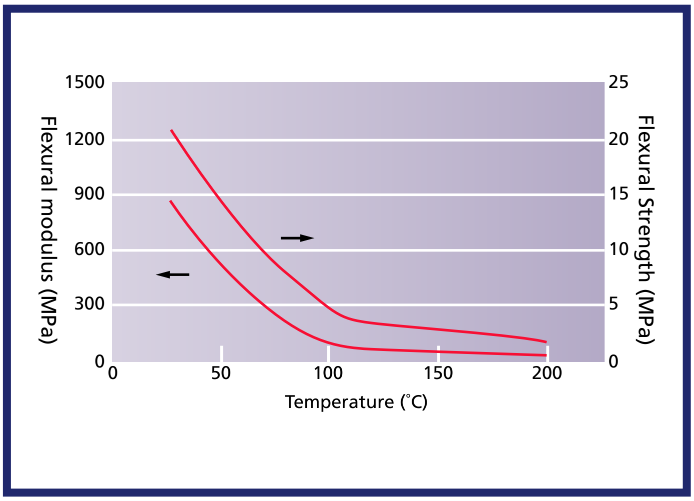


Figure 21 (Grade C-88AXP)

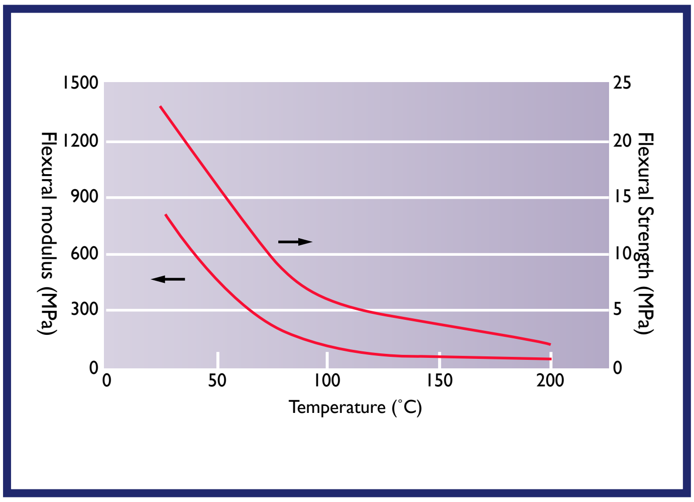


Figure 22 (Grade C-88AXMP)

Test sample	Injection moulding (t3.2x25x80 mm)
Cross Head Speed	2 mm/min
Span	50 mm

3-5 Impact Strength

Methods for evaluating impact strength of plastics are the Izod impact test, ASTM D256, or the Charpy impact test.

Fluon® ETFE has an extremely large capacity for absorbing impact energy, and maintains excellent impact resistance over a wide range of temperatures even in notched impact tests. Figure 24 shows the results of the Izod impact test on Fluon® ETFE and various plastics, at room temperature.

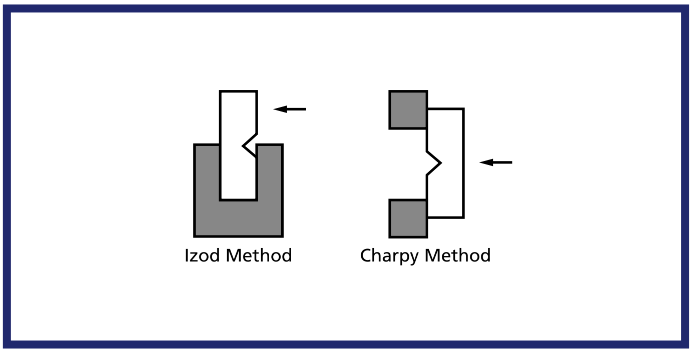


Figure 23 Methods of Testing Impact Strength

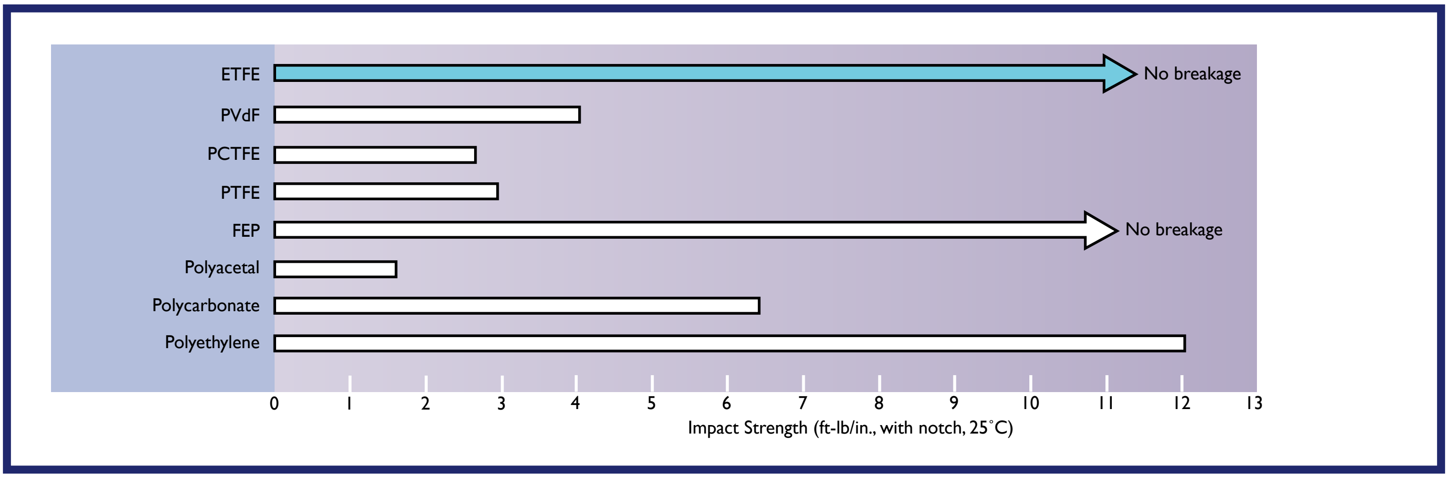


Figure 24 Izod Impact Test

Fluon® ETFE is also resistant against low temperature impact, and as shown in Figure 25, no impact breakage occurs down to -80°C. Destruction begins around l00°C and the energy required for breakage in the range of -120°C to -200°C is about constant. The brittle point according to ASTM D746 is -125°C, which suggests that the glass transition temperature of the noncrystalline portion of Fluon® ETFE is around this temperature.

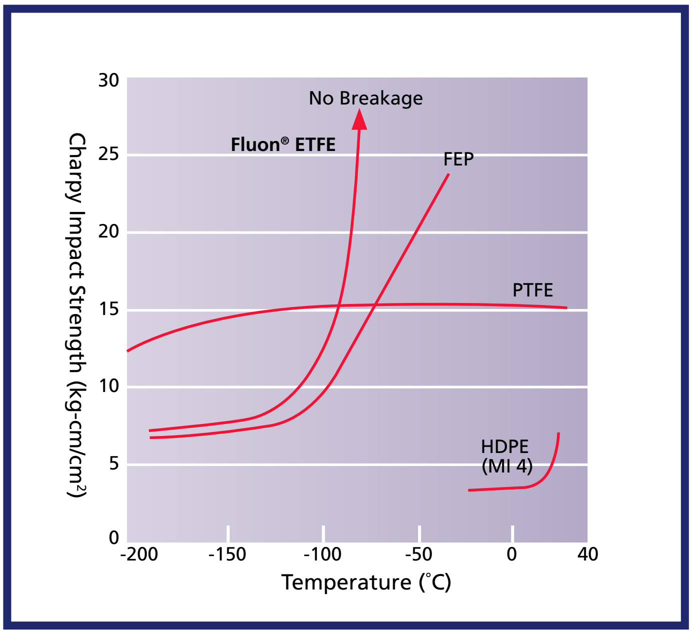


Figure 25 Effect of Temperature on Charpy Impact Strength

3-6 Surface Hardness

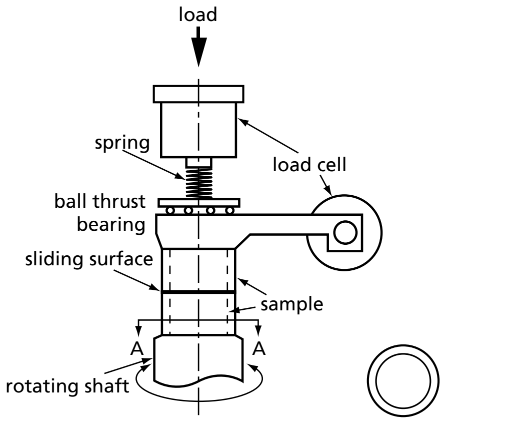
Table 7 shows the Rockwell hardness measured according to ASTM D785, represented on the R scale.

Table 7 Surface Hardness of Various Plastics

Plastic	Fluon® ETFE C-88AXP	PTFE	PFA	FEP	ECTFE	PVDF	PCTFE	PP	N	P
Hardness (R scale)	50	20	50	25	93	110	110	85-110	110	120

3-7 Friction and Wear Properties

The coefficient of friction and wear varies depending on the methods and conditions chosen. Thus, it is necessary to carry out a comparative test that suits the desired application.
Figures 26~31 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).



Ring-Ring Type

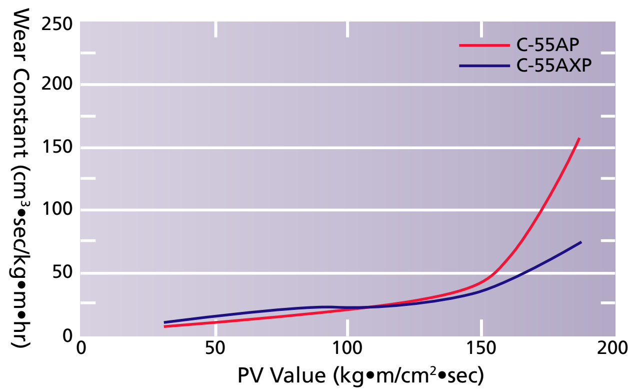


Figure 26 C-55AP, C-55AXP
Wear Constant and PV Value

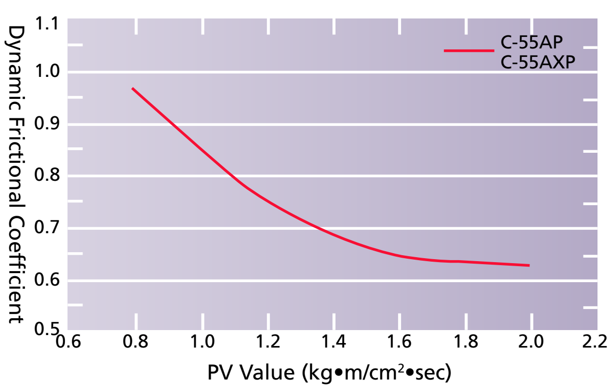


Figure 27 C-55AP, C-55AXP
Dynamic Friction Coefficient and PV Value

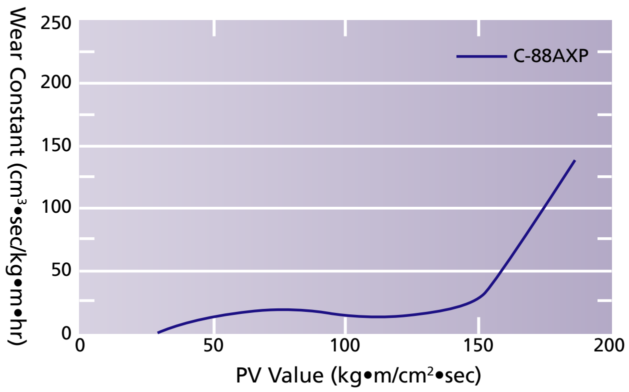


Figure 28 C-88AXP
Wear Constant and PV Value

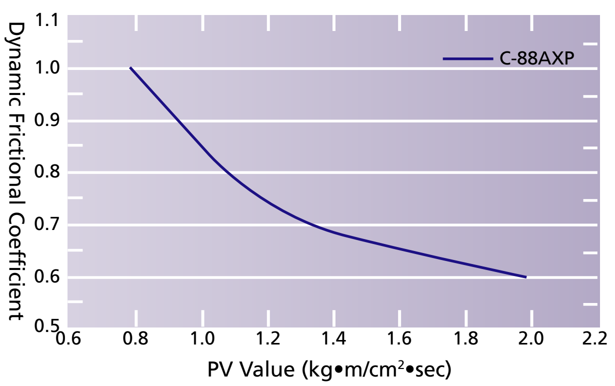


Figure 29 C-88AXP
Dynamic Friction Coefficient and PV Value

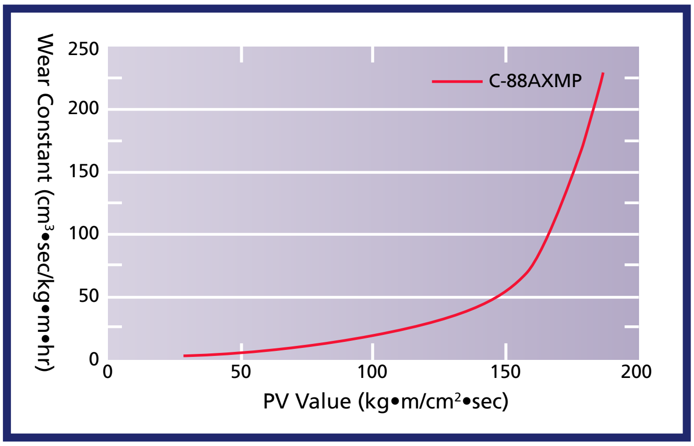


Figure 30 C-88AXMP
Wear Constant and PV Value

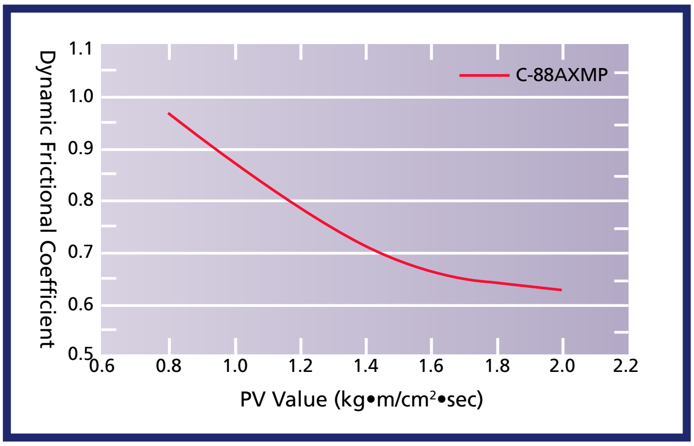


Figure 31 C-88AXMP
Dynamic Friction Coefficient and PV Value

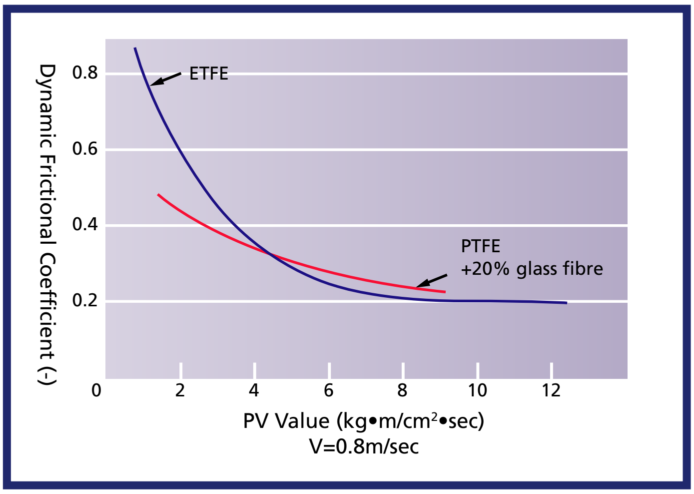


Figure 32 Dynamic Friction Coefficient and PV Value

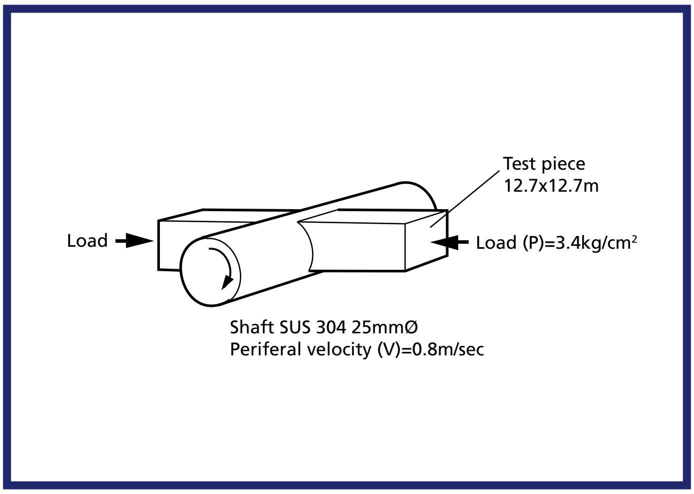


Figure 33 Journal-type bearing tester

Table 8 Abrasion Properties of **Fluon® ETFE**

		Dynamic Frictional Coefficient	Wear Constant (mm³. sec/kg.m.hr)	Critical PV Value (kg.m/cm².sec)
	Fluon® ETFE	0.53	$145x10^{-3}$	1.6
PTFE	Natural	0.28	$52x10^{-3}$	1.5
	20% glass fibre	0.34	$0.1 x10^{-3}$	11<
	15% graphite	0.30	$0.1x10^{-3}$	11<
N		0.50	$0.4x10^{-3}$	
P		0.32	Abnormal Wear	

3-8 Mechanical Properties of Various Plastics

Fluon® ETFE has all the advantages typical of fluoropolymers but with enhanced mechanical properties. Table 9 gives a comparison of mechanical properties of a range of plastics.

Table 9 Mechanical Properties of Various Plastics

	Fluon® ETFE	PTFE	PFA	ECTFE	PVdF	PE	PVC (hard)	Nylon 6	Polyacetal	ASTM No.
Specific Gravity	1.73~1.75	2.1~2.2	2.1~2.2	1.68~1.70	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	5~40	2700	3000~4500	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 Coefficent (against SUS)	0.20	0.09	0.20	0.20	0.21	0.35	0.45	0.15~0.40	0.14	

Insulation and dielectrical properties are the most important electrical properties of polymers. A high-frequency, electrical energy is converted into thermal energy by the dielectric effect, causing 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 tan δ is the dielectric tangent. Therefore, it is preferable that ε .tan δ, so called dielectric loss, is small.

4-1 Dielectric Properties

Figure 34 shows the frequency effect of the dielectric constant of some fluoropolymers. In the frequency range of 60~1010 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 36 shows the effect of frequency on the dielectric tangent (tanδ) for Fluon® ETFE. Tan δ in Fluon® ETFE has a maximum value close to 10^8 Hz. Figure 37 shows the temperature dependence of the dielectric tangent. Curves vary with frequency.

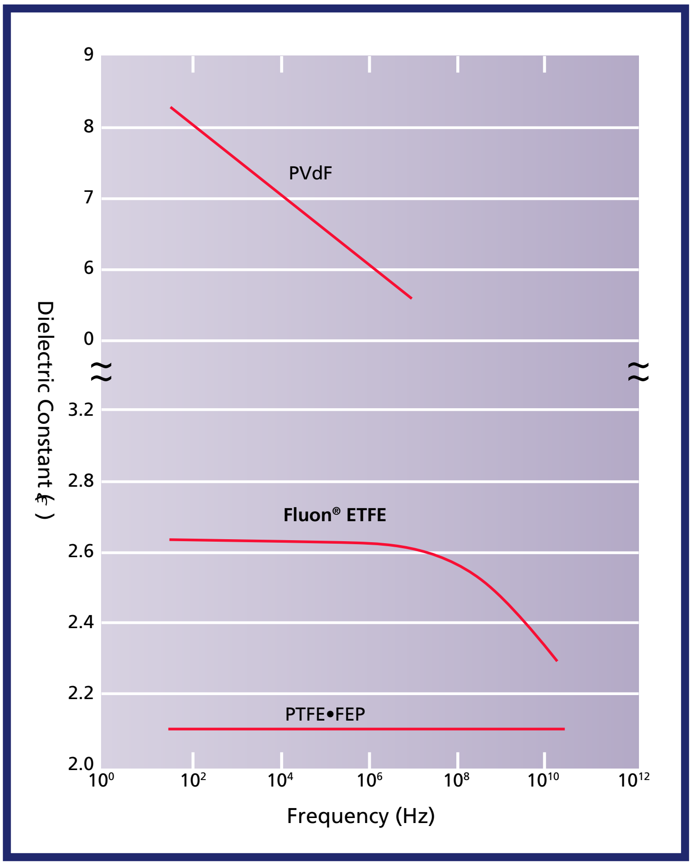


Figure 34 Effect of Frequency on Dielectric Constant (25°C)

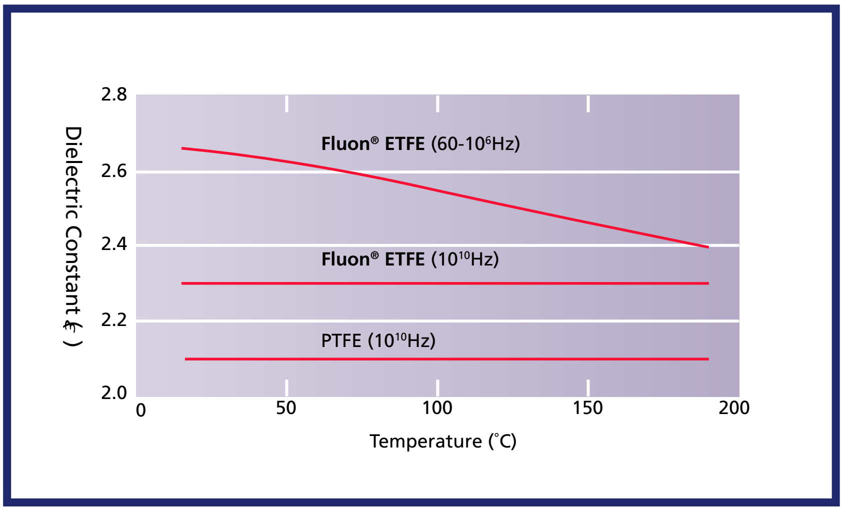


Figure 35 Effect of Temperature on Dielectric Constant

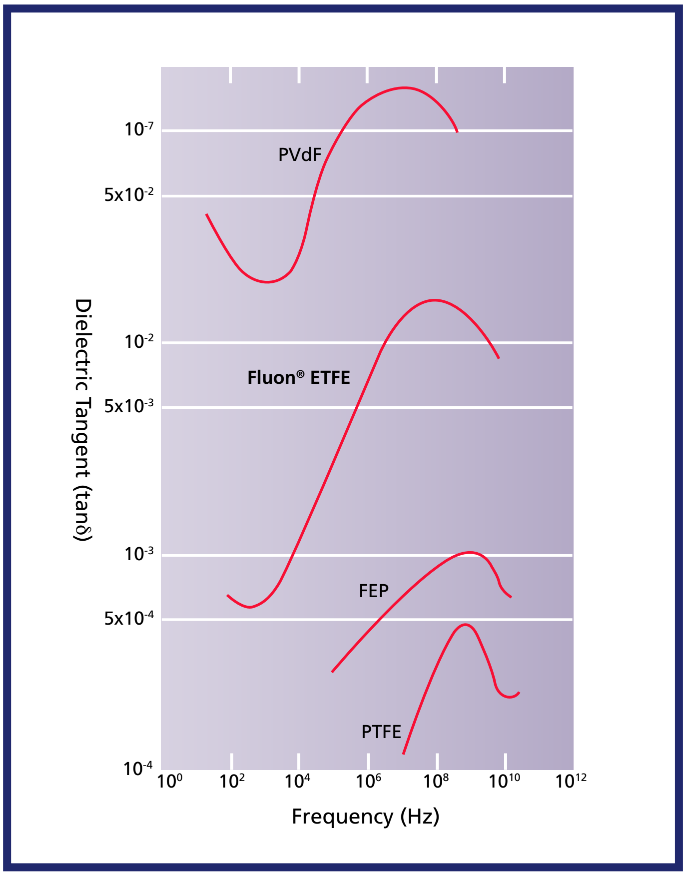


Figure 36 Effect of Frequency on Dielectric Tangent (25°C)

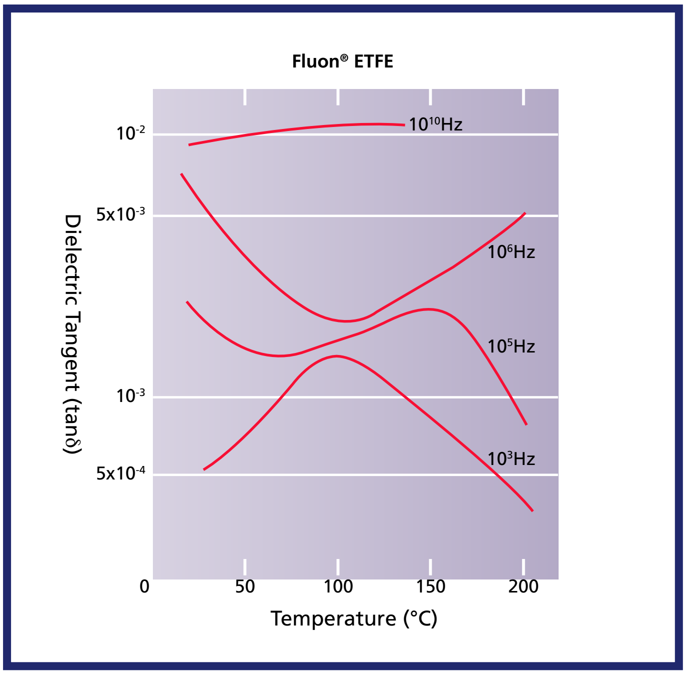


Figure 37 Effect of Temperature on Dielectric Tangent

4-2 Insulation

The insulation property is generally represented by the volume specific resistance, which indicates the degree by which the polymer resists the flow of electric current.
The larger this value, the better the polymer is as an insulator. With respect to the insulation breakdown 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 40 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.

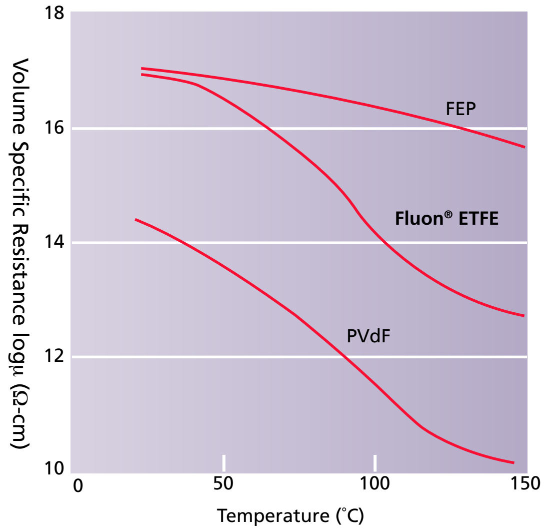


Figure 38 Temperature Dependence of Volume Specific Resistance

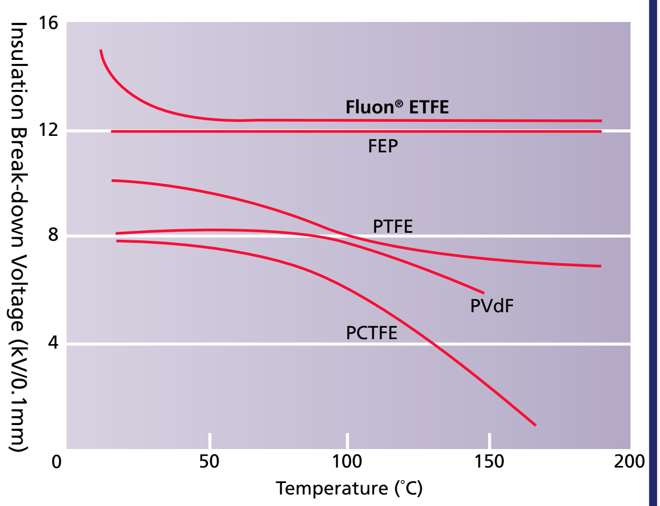


Figure 39 Temperature Dependence of Insulation Break-down Voltage

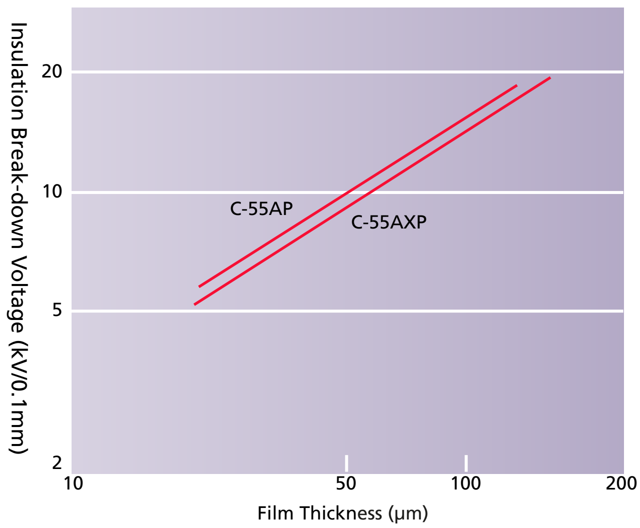


Figure 40 Dependence of Insulation Break-down Voltage on Sample Thickness (room temperature)

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 is decomposed by the arc into low molecular weight fluorocarbon, and conductive materials such as carbon.

4-4 Tracking Resistance

As a result of scintillation caused by the presence of electrolytes 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 tracking resistance, which represents an electric insulation property under special conditions.

The measurement method used here, is the electrolyte dropping method, defined by IEC. Table10 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 brackets.

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 the maximum load at which the insulation is still maintained, when the coated wire is placed on a sharp edge under load.

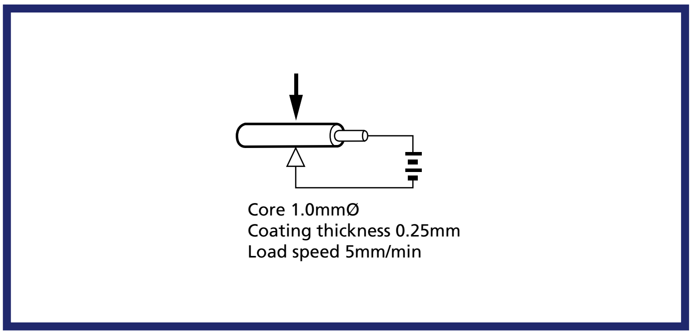


Figure 41 Method of Testing Cut-through Resistance

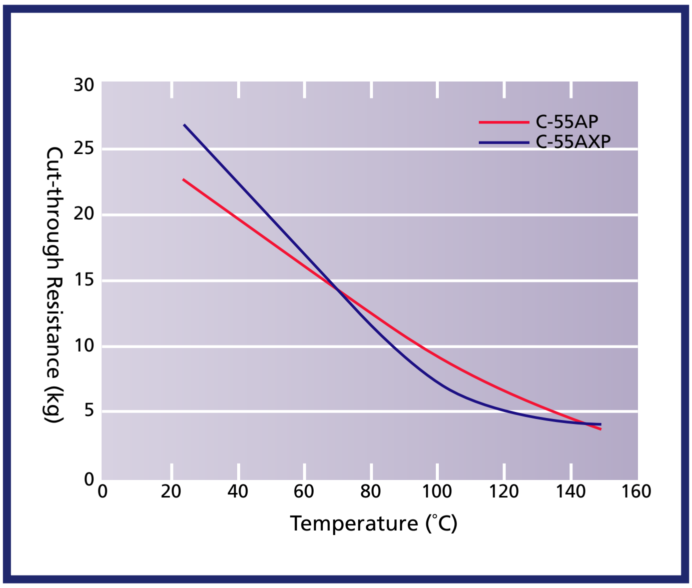


Figure 42 Effect of Temperature on Cut-through Resistance

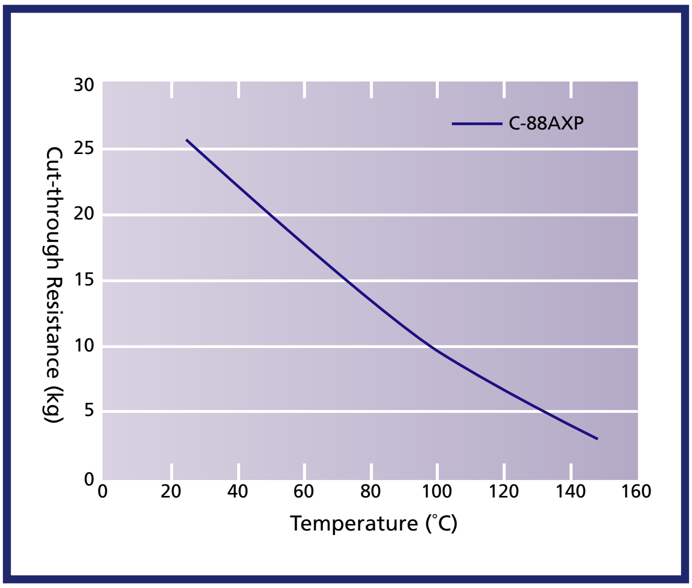


Figure 43 Effect of Temperature on Cut-through Resistance

5-1 Chemical Resistance

Fluon® ETFE is stable in most chemicals and has excellent chemical resistance. Table 11 shows the effect of various chemicals on Fluon® ETFE.
Fluon® ETFE shows excellent chemical resistance to inorganic acids, bases and organic solvents. Exceptions are strong oxidizing acids such as concentrated nitric acid, organic amines and sulfonic acid at high temperatures

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

Table 11 Chemical Resistance of **Fluon® ETFE**

Chemical Catagories	Chemical	Temp. (°C)	Days	Retention (%)	
				Elong.	Wt. gain
Inorganic Acids	Hydrochloric acid 35%	100	10	100	0.0
	Sulphuric acid 78%	121	10	100	0.1
	Sulphuric acid 98%	121	10	100	0.0
	Oleum	2	10	96	1.3
	Nitric acid 25%	100	14	100	-
	Nitric acid 60%	120	10	100	0.7
	Nitric acid 70%	60	60	100	-
	Nitric acid 70%	120	7	10	-
	Fuming nitric acid	25	10	92	0.6
	Hydrofluoric acid	25	7	95	0.1
	Phosphoric acid 30%	100	10	97	-0.4
	Phosphoric acid 85%	121	10	92	0.4
	Chromic acid 50%	100	10	98	0.3
Alkalis	Sodium hydroxide 10%	120	10	97	0.0
	Sodium hydroxide 50%	120	10	100	-0.3
	Potassium 20%	100	7	100	0.0
	Ammonium hydroxide 15%	66	7	98	0.1
Other Inorganic Compounds	Chlorine	90	10	94	-
		120	7	85	7.0
		150	10	41 (strength)	-
	Bromine	60	7	100	0.1
	Hydrogen peroxide	25	7	98	0.0
	Water	100	7	100	0.0
	Phosphorus trichloride	75	7	99	-
	Phosphorus oxychloride	100	7	99	-
	Silicon tetrachloride	55	7	100	-
	Sulphuric chloride	70	7	100	6.0
	Carbon disulfide	100	30	98	1.0
	Ferric Chloride 25%	70	7	100	6.0

Table 11 Chemical Resistance of **Fluon® ETFE** (Continued)

Chemical Catagories	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
	Chlororbenzene	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 disulphide	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

Table 11 Chemical Resistance of **Fluon® ETFE** (Continued)

Chemical Catagories	Chemical	Temp. (°C)	Days	Retention (%)	
				Elong.	Wt. gain
Ketones	Acetone	25	11	97	2.3
		56	11	93	2.5
	Methylethylketone	25	11	100	1.6
		80	11	100	3.1
	Methylisobutylketone	25	11	–	0.3
		116	11	100	3.3
	Acetophenone	121	11	80	2.5
	Cyclohexanone	121	11	72	5.2
Organic acid	Glacial acetic acid	25	11	87	0.7
		118	11	80	2.2
	Oxalic acid	120	11	100	0.1
	Citric acid	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	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
Ester	Ethyl acetate	25	11	100	2.3
		77	11	100	3.4
	Butyl acid	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
	Skidrol 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	–
	Dimethylsulfoxide	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 38 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 crack resistance chemical stress.

Table 12 Chemical Stress Crack of **Fluon® ETFE**

Chemical	Temperature (°C)	Number of cracked pieces (cracked/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	117	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 moulding, will not change in properties even when used outdoors as a coating material.

Table 13 Weatherability of **Fluon® ETFE Film**

		Film Grade 12µm thickness			Film Grade 16µm thickness (grey)		
		Exposure Time (Hours)			Exposure Time (Hours)		
Characteristic		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 6mm thick sheet, 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 1mm thick sheet in boiling water for a given amount of time.

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

Table 14 Water Absorption of **Fluon® ETFE**

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

Table 15 Boiling Water Resistance

Grade	Property	Characteristics After Soaking		
		0 Hour	260 Hours	2000 Hours
C-55AP	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., are 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, as shown in tables 16 and 17.

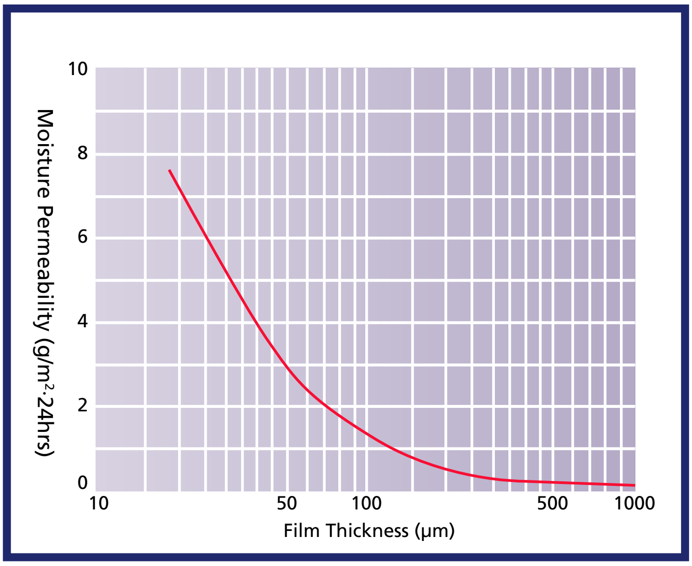


Figure 44 Effect of Film Thickness on Moisture Permeability (23°C, 0-90RH%) ASTM E96

Table 16 Gas Permeation

Gas Permeability
Temperature : 23°C
Unit : $10^{-11}cm^3(STP)\cdot cm/sec\cdot cm^2\cdot cmHg$

	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 0-90RH%
Unit : $g/m^2\cdot 24hrs\cdot 0.1mm$

Grade	Moisture Permeability
C-55AP	1.3

5-6 Light Transmittance

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

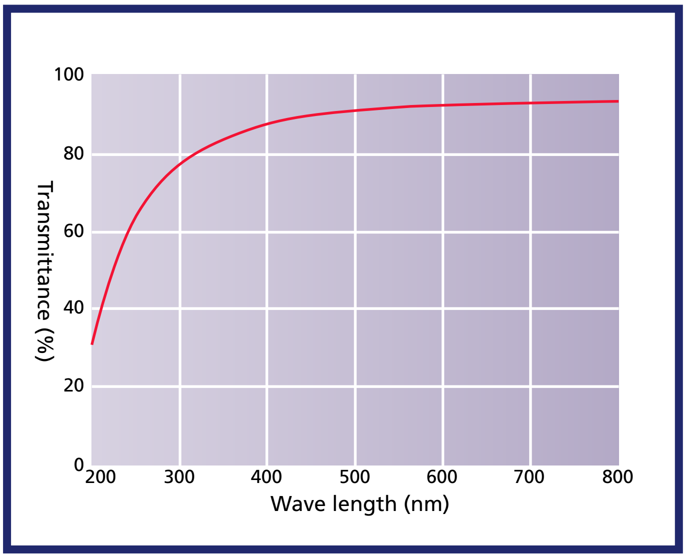


Figure 45 Light Transmittance (C55AXP, 50μm)

5-7 Radiation Resistance

Fluon® ETFE shows radiation resistance significantly higher than that of PTFE, but as a result of irradiation, cross linking and decomposition occur concurrently, and consequently, mechanical properties are reduced as shown in Figures 46~51.
The irradiation dose rate is lxl0⁶ rad/hr.

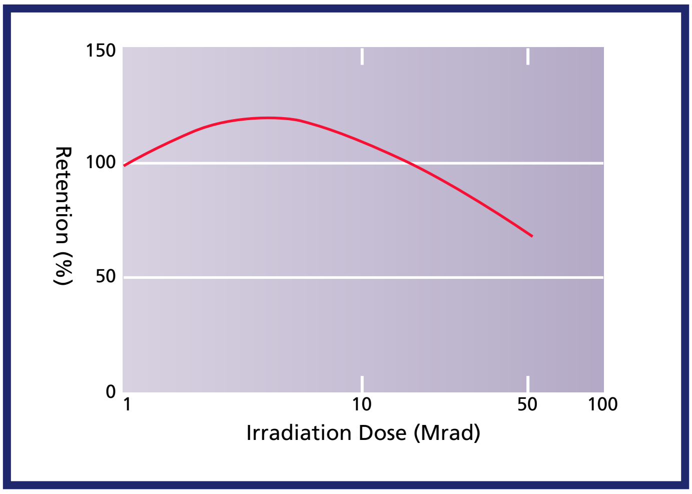


Figure 46 Change in Tensile Strength (C-55AP)

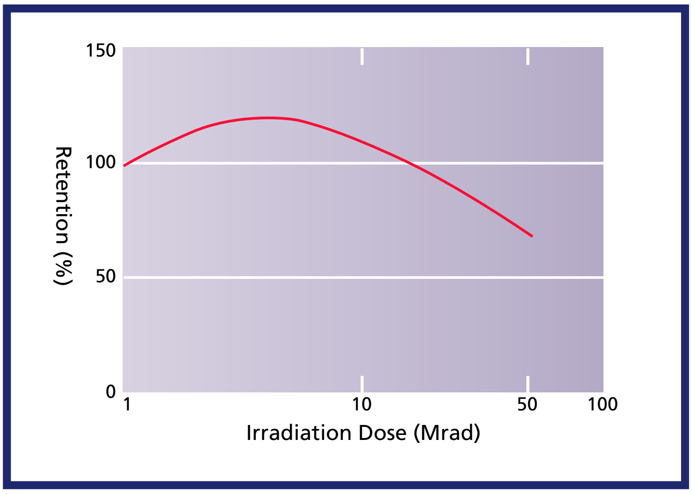


Figure 47 Change in Tensile Strength Elongation (C-55AP)

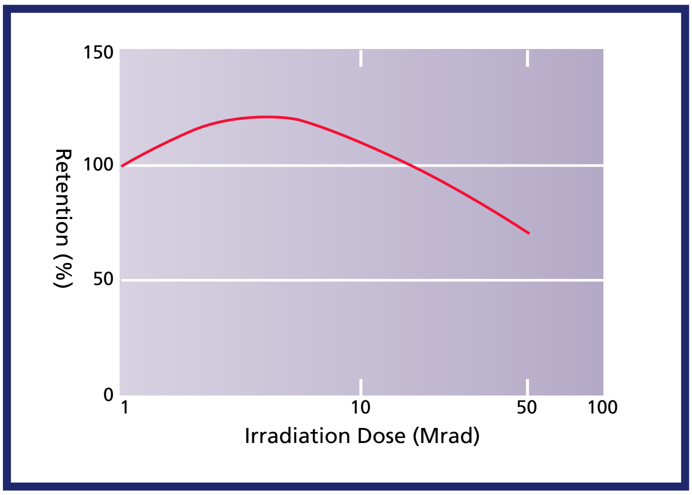


Figure 48 Change in Tensile Strength (C-55AXP)

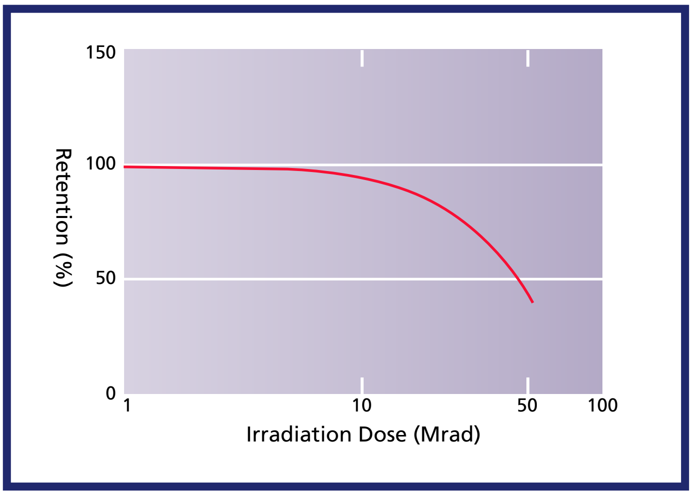


Figure 49 Change in Tensile Strength Elongation (C-55AXP)

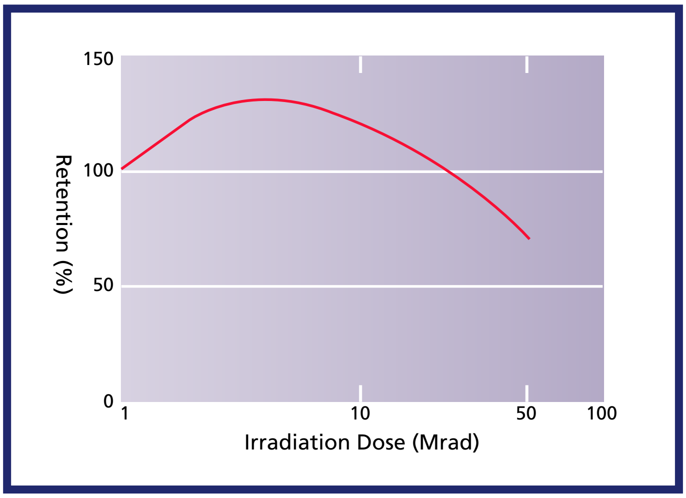


Figure 50 Change in Tensile Strength (C-88AXP)

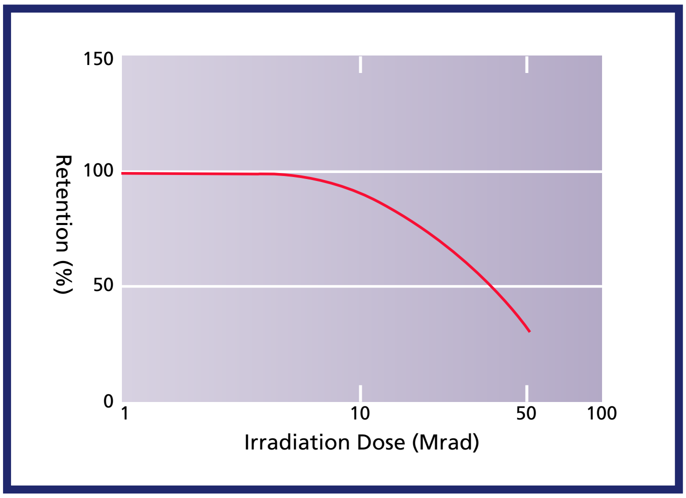


Figure 51 Change in Tensile Strength Elongation (C-88AXP)

5-8 Food Safety

Fluon® ETFE is thermally and chemically stable.
No plasticizer is added, and as a result, it is safe with respect to food hygiene.
For ETFE food contact (FDA) advice and confirmation, please contact AGC Chemicals Europe on tel.
+44 (0)1253 209560.

(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 (LD50)

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

Table 18 outlines the basic physical properties of Fluon® ETFE.

Table 18 Basic Physical Properties of **Fluon® ETFE**

Test	ASTM	Unit	C-55AP	C-55AXP	C-88AXP	C-88AXMP
Melt Flow Rate	D-3159	g/10min	3.9~6.5	3.9~6.5	9.0~12.0	27~43
Specific Gravity	D-792	-	1.74	1.73	1.73	1.73
Melting Point	-	°C	265	258	260	260
		°F	509	496	500	500
Tensile Strength	D-638	MPa	52	52	48	42
		Psi	7,500	7,500	7,000	6,100
Tensile Elongation	D-638	%	382	414	415	433
Flexural Modulus	D-790	MPa	960	930	890	870
		Psi	139,000	135,000	129,000	126,000
Flexural Strength	D-790	MPa	26	25	25	24
		Psi	3,800	3,600	3,600	3,500
Hardness (Shore D)	D-2240	-	67	67	67	67
Izod Impact Strength	D-256 (Notched)	J/m	Non break	Non break	Non break	Non break
Linear Thermal Expansion Coefficient	D-696	10^{-5}/°C	9.3	9.3	9.4	9.4
Oxygen Index	D-2863	%	32	32	32	32
Chemical Resistance	-	-	Excellent	Excellent	Excellent	Excellent
Dielectric Constant (10^2-10^6Hz)	D-150	-	2.6	2.6	2.6	2.6
Shrinkage (flow direction)	-	%	1.8	1.8	1.8	1.8

Unlike PTFE, Fluon® ETFE can be processed by conventional melt processes. Specifically, its melt viscosity at moulding temperature is 103~105 poise, which is about the same as that of conventional thermoplastics, and as a result, methods such as injection and extrusion, blow moulding, and powder coating, can be used.

7-1 Raw Resin and its Handling

The grades of Fluon® ETFE are described in Chapter 1; C-55 is suitable for heavy-gauge moulding, and C-88 for light-gauge moulding.

Since Fluon® ETFE is not hygroscopic, no preliminary drying of the 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 charge.

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 a long time. It is preferable not to leave the resin in a moulding machine for more than 30 minutes when interrupting the operation. In such situations, it is suggested that the temperature of the moulding machine is lowered.

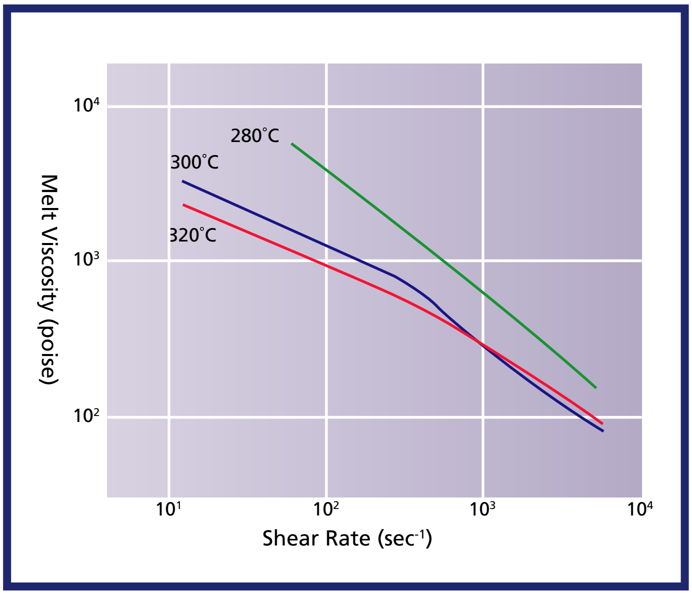


Figure 52 Effect of Shear Rate on Melt Viscosity (C-55AP)

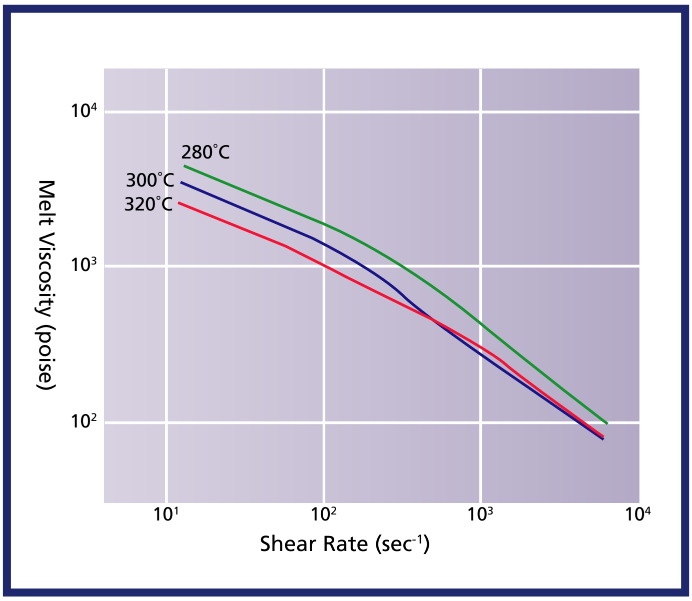


Figure 53 Effect of Shear Rate on Melt Viscosity (C-55AXP)

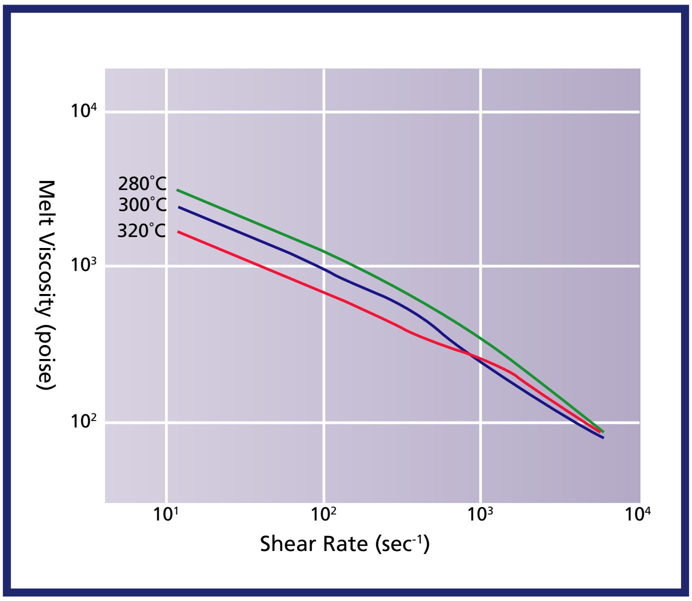


Figure 54 Effect of Shear Rate on Melt Viscosity (C-88AXP)

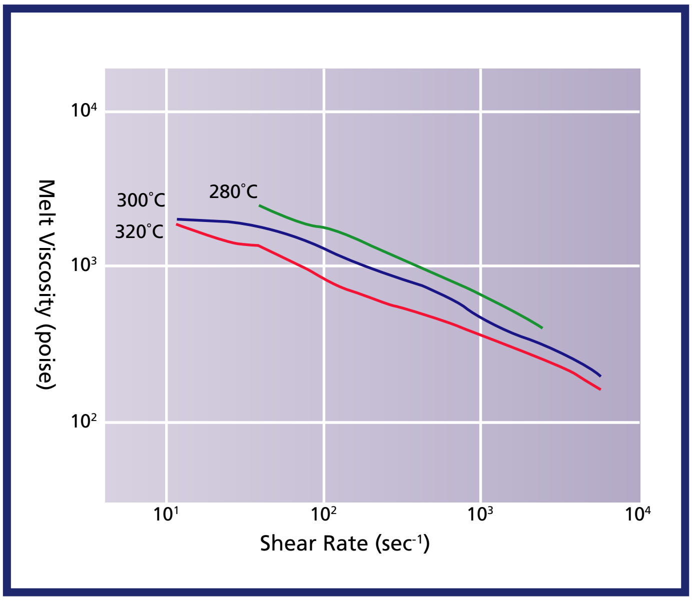


Figure 55 Effect of Shear Rate on Melt Viscosity (C-88AXMP)

7-2 Injection Moulding

(1) Injection Machine and Moulding Material

Any of the plunger-type and screw-in-line-type injection machines may be used for moulding, as long as the heater holds a heat capacity of up to 340°C. Corrosion resistant materials such as Hastelloy-C, X-alloy 306, Inconel, Duranickel, etc., are recommended for those parts coming into 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) Mould

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

(3) Moulding Conditions

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

Table 20 Injection Moulding Conditions for **Fluon® ETFE**

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

Figures 56~58 show the relationship of moulding temperature and fluidity, and Figures 59~60 show the relationship of various moulding conditions and contraction.
Moulding temperature and injection speed do not affect the fluidity much, but has the greatest effect on the surface smoothness.

Figure 58 show the relationship of the thickness of the moulded 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.

As 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 mould shown in Figure 59.

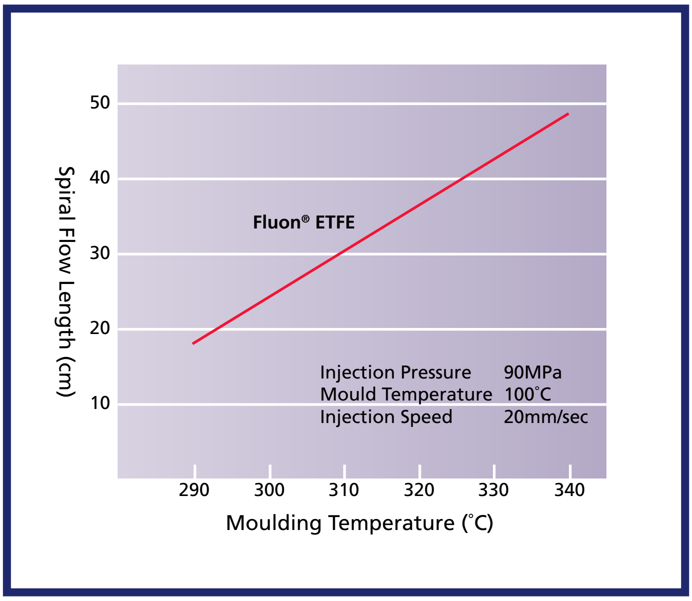


Figure 56 Moulding Temperature and Spiral Flow Length

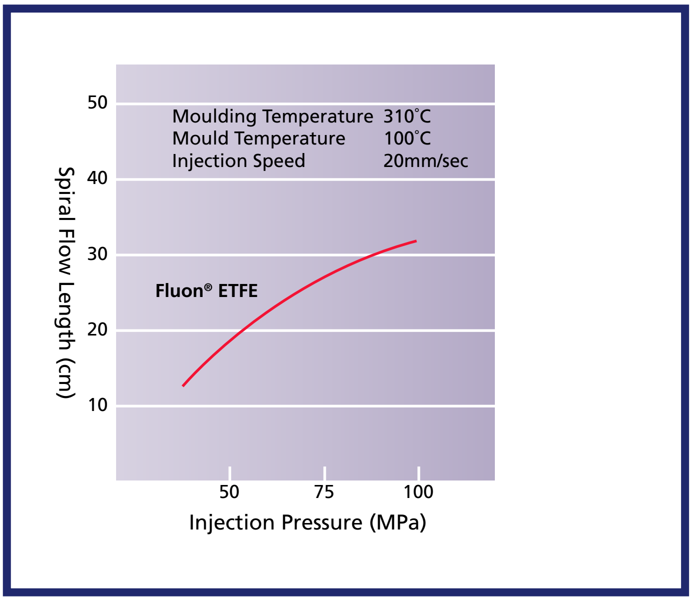


Figure 57 Injection Pressure and Spiral Flow Length

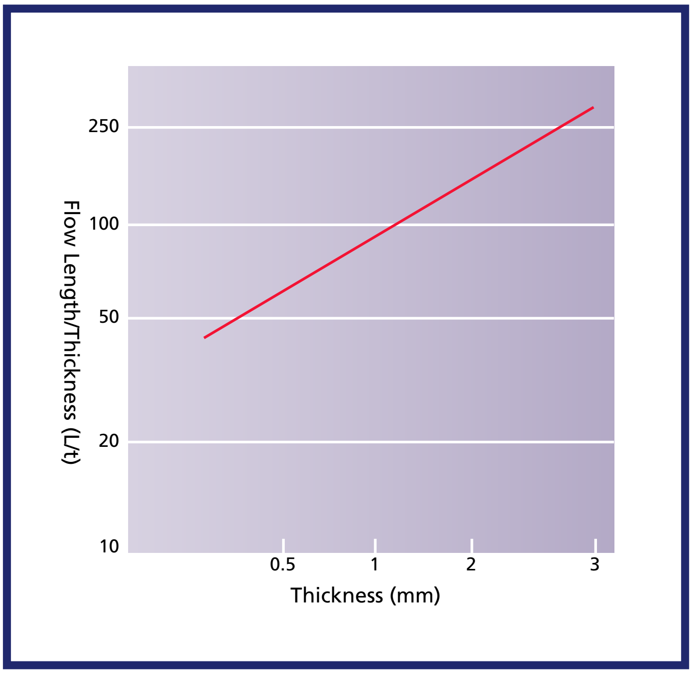


Figure 58 L/t and Thickness (Fluon® ETFE)

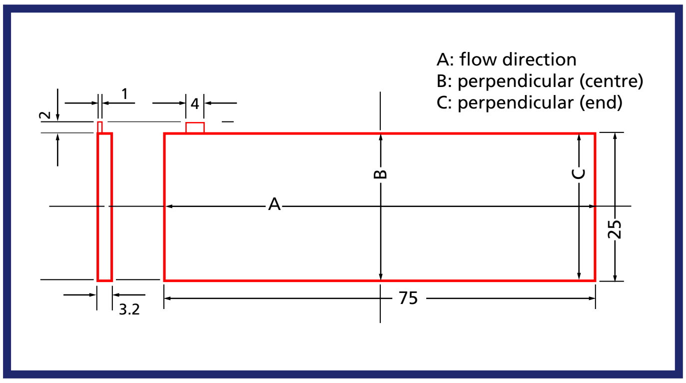


Figure 59 Cavity Scale of Mould (Unit : mm)

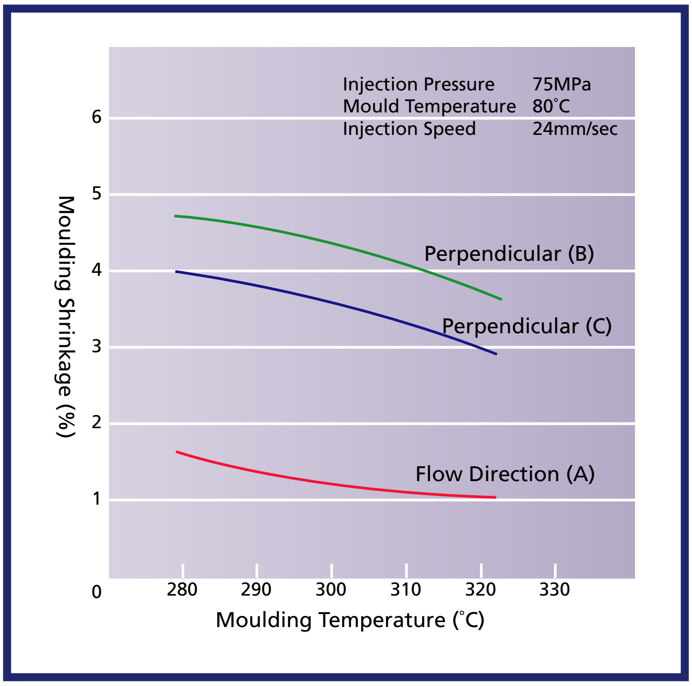


Figure 60 Moulding Temperature and Moulding Shrinkage

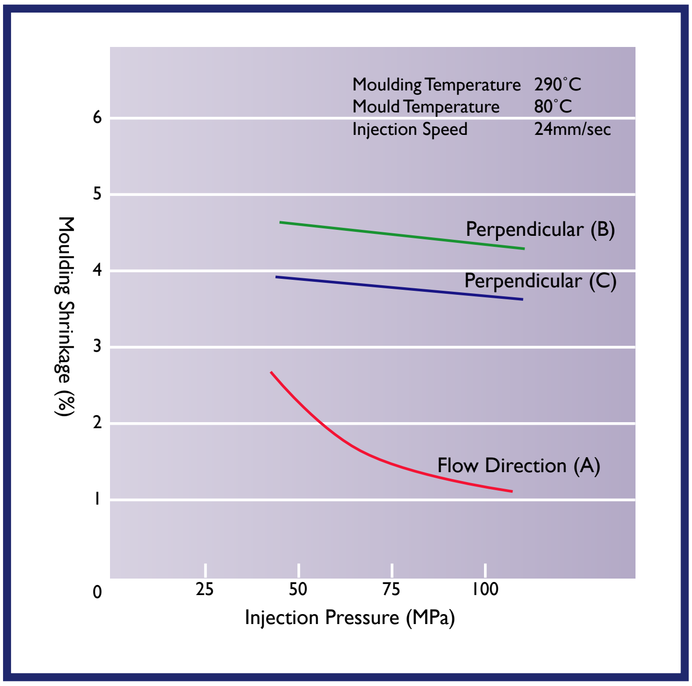


Figure 61 Injection Pressure and Moulding Shrinkage

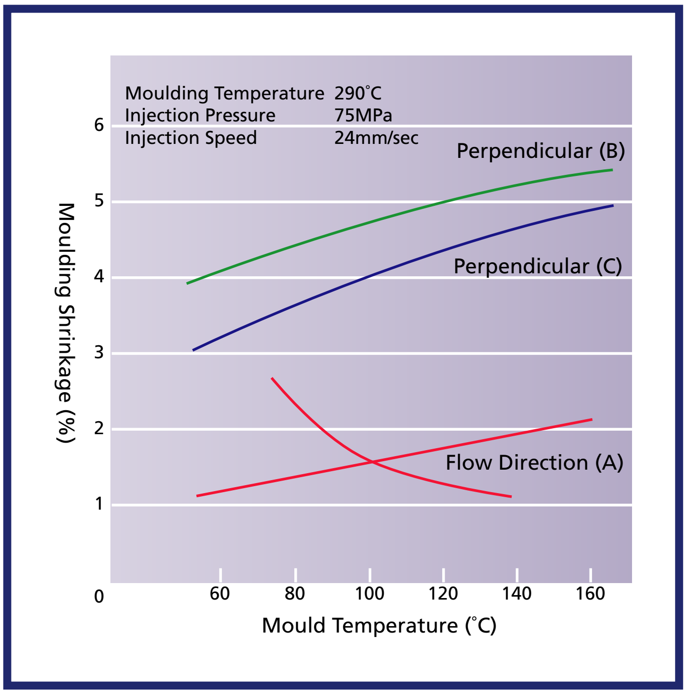


Figure 62 Moulding Temperature and Moulding Shrinkage

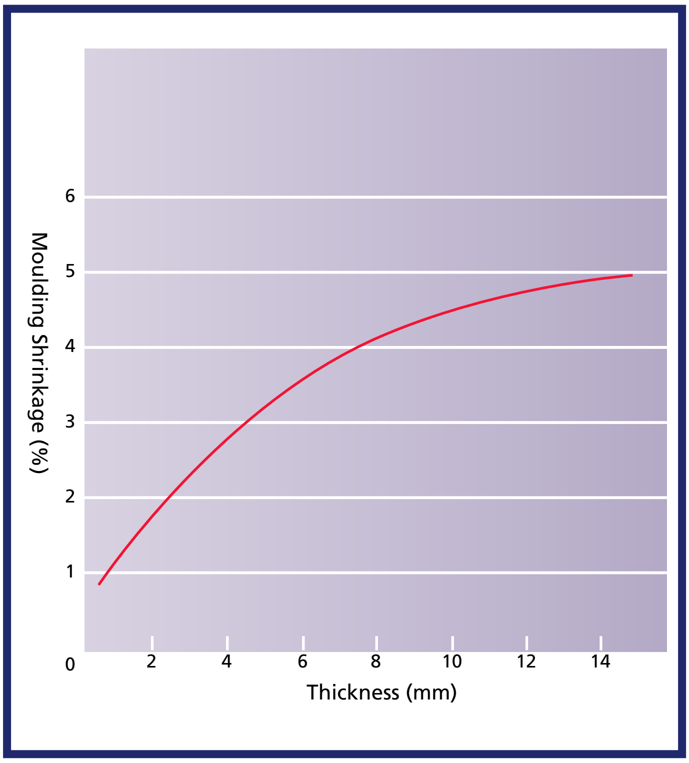


Figure 63 Thickness and Moulding Shrinkage

The shrinkage of Fluon® ETFE natural grades (C-55AP, C55AXP, C-88AXP), when moulded under ordinary conditions, is 1.5~2.0% in the flow direction, and 3.5~4.5% in the perpendicular direction.

Table 21 Moulding Contraction of **Fluon® ETFE**

Flow Direction (%)	1.5~2.0
Perpendicular to the Flow (%)	3.5~4.5

7-3 Extrusion

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

Table 22 Extrusion Conditions for **Fluon® ETFE**

	Specification	Electric Wire Coating	Film	Tube
Extruder	Screw Diameter	40mm	40mm	35mm
	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 2 each
Die	Die ID	4.3mm	Coat hanger Type manifold die	13.5mm
	Nipple OD	2.0mm		12.1mm
	Land Length	20mm	Lip spacing 0.2mm	
Product		Core : Tin-plated Soft copper wire	Film thickness: 25 μm	Tube ID: 9mmØ
		Core Ø:0.26mm	Film width:400mm	Tube OD 10mmØ
		Wall thickness:0.15mm		Wall thickness: 0.15mm
		Final Ø:0.56mm		
Moulding 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		80mm	100mm
	Draw down Ratio	59		die diameter/sizing die diameter 1.35
	Pull speed	80~150m/min	5m/min, cooling Roller temperature 120°C	4m/min vacuum sizing

7-4 Powder Coating

Powder coating methods such as electrostatic powder coating, fluid dipping, etc., can be used for Fluon® ETFE. The selection of the grade depends on the desired thickness and the application.
The polymer is not hygroscopic, but the powder flow is affected by moisture content. Compressed air used for flowing should be dried. Dust mixed in the polymer may cause pinholes and discoloration. The package should be closed or hoppers should be covered.

(1) Material and Shape of Substrate

As long as the material withstands temperatures in the range of 290~340°C, Fluon® ETFE can be used, 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 0.4~lmm, 3R or larger at extrusions and 5R or more at intrusions.

(2) Pretreatment

Table 23 Pretreatment

Steel Material (Thick Lining)	Degreasing : baking 400°C x 2 hrs or more Coarsening : blasting with 60 mesh-pass steel grid and sand (jet pressure 3~7kg/cm^2)
Steel, Stainless Steel Aluminum (30~50μm)	Degreasing : washing with trichloroethylene Coarsening : blasting with 100 mesh-pass steel grid and sand (jet pressure 3~7kg/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	Silan coupling agent treatment [(1) washing, (2) dipping in 30% nitric acid at 60°C x 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 30~150μm for the natural grades, and 1mm for the ZL-520N by coating with 5~7 layers, can be obtained. By fluid dipping with Z-885A, a film thickness of 0.6mm can be obtained with a substrate of 5mm thickness, and preheating to 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 thickness of the substrate, material, and 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

It is possible to weld Fluon® ETFE, although it does require a certain degree of skill. 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% of the mother material, and achieve a welding speed of 80mm/min.

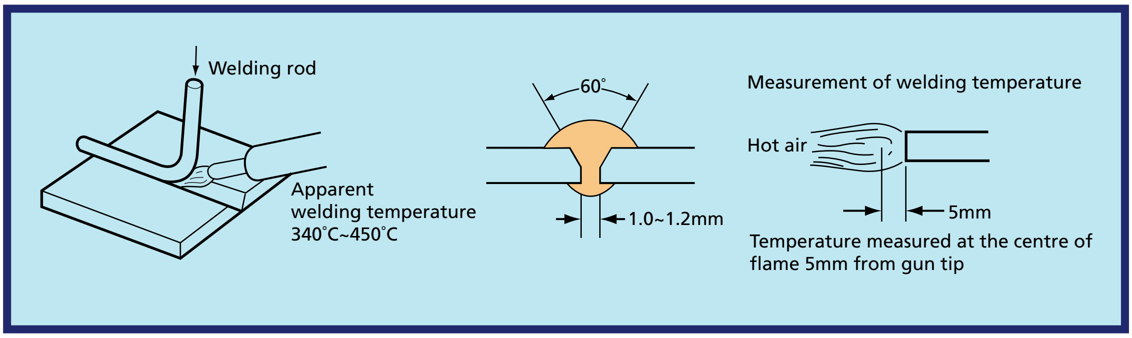


Figure 64 Welding of **Fluon® ETFE**

(2) Flaring of Fluon® ETFE

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

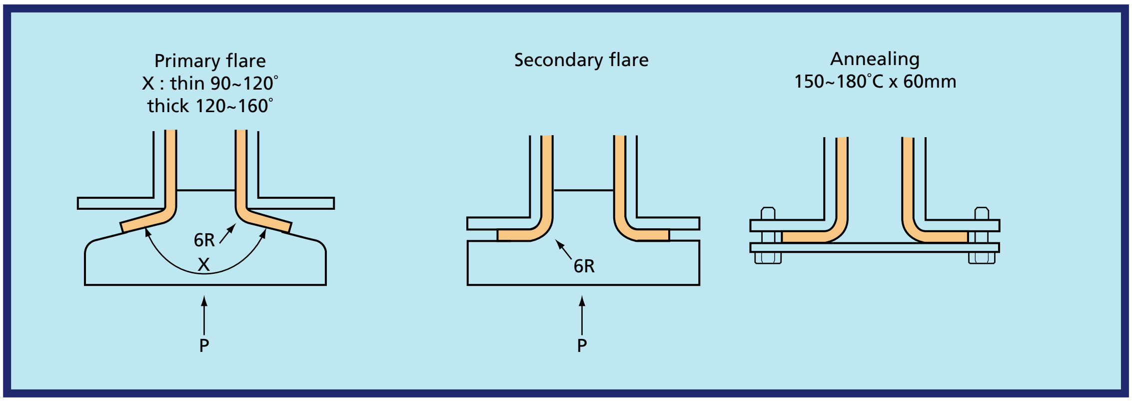


Figure 65 Flaring of **Fluon® ETFE**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- Fluoropolymer manufacturing in both Japan & Europe
- Compounding facility in USA
- Technical Service team offering customer support & advice
- Over 550 R&D technicians for continuous innovation
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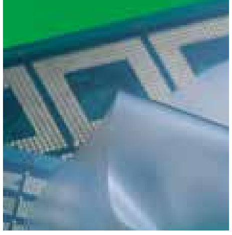

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