Halar® ECTFE

Ethylene-Chlorotrifluoroethylene

Design and Processing Guide

Solvay
Solexis

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INTRODUCTION

The company

Solvay Solexis results from the acquisition of Ausimont by the Solvay Group in 2002. The merger of both Ausimont and Solvay activities in fluorinated materials into the new company Solvay Solexis created a new leader on the market, totally dedicated to the development of fluoromaterials and their applications. Solvay Solexis is part of the Strategic Business Unit Specialty Polymers of the Solvay Group, and contributes to the group strategy by being a leader in specialty materials.

Solvay Solexis is an international group focused on socially sustainable and constantly growing businesses, based on the fluorine chemistry and benefits from a unique integrated value chain, from the Fluorspar to the ultimate fluorinated materials.

It is operating worldwide through five companies in Italy, France, Japan, Brazil and the USA. Solvay Solexis is headquartered in Bollate (Milano, Italy), which is also its main R&D facility. Local R&D support is also provided from Thorofare NJ for the NAFTA area.

The Products

Solvay Solexis is organized in four Business units:

Fluids
these sophisticated perfluoropolyethers commercialized under the brands Fomblin®, Fluorolink®, Solvera® and Galden® are used as high performance lubricants and heat transfer agents offering unmatched chemical resistance and excellent thermal stability.

Fluoroelastomers
Tecnoflon® covers a wide range of elastomers offering excellent chemical and thermal resistance to atmospheric agents, especially to oxygen and ozone, which are notably used in automotive, aerospace, chemical, mining, oil and semi-conductors industries

PTFE and coatings
Algoflon® PTFE and Polymist® PTFE exhibit outstanding physical, electric and non-stick characteristics, and particularly excellent resistance in aggressive environment, in a wide range of temperatures. They are notably used for producing gaskets, seals, pipes, fittings, to impregnate fabrics, as additives for plastics compounds, elastomers and inks.

Hylar® 5000 PVDF serves as the base resin for durable architectural coating.

Hyflon® PFA powders are used for very high temperature, harsh environment resistant coatings, in electronic, semi-conductors and processing fields.

Halar® ECTFE in powder forms allows the production of particularly smooth and weather-resistant coatings, combined with extremely good chemical and flame resistance.

Melt processable fluoropolymers
Solvay Solexis offers a wide range of fluoropolymers easily processed by injection, extrusion, and all conventional processing techniques:

Solef® and Hylar® PVDF (polyvinylidene fluoride)

Halar® ECTFE (copolymer of ethylene and chlorotrifluoethylene)

Hyflon® PFA (copolymer of tetrafluoroethylene and perfuoroalkoxyvinylethers).

Halar® ECTFE

At a glance, the key properties of Halar® ECTFE are

- excellent chemical resistance to acids and strong bases, up to pH 14,
- excellent barrier properties to oxygen, carbon dioxide, chlorine gas, hydrochloric acid,
- very good electrical properties,
- excellent abrasion resistance,
- broad use temperature range from cryogenic to +150°C (depending on the grade and stresses applied),
- good weathering resistance,
- excellent intrinsic fire resistance,
  UL class 94 V-0 at 0.18mm
  LOI >52 %
  Low flame spread, low smoke generation
- exceptional surface smoothness,
- very good impact strength,
- good mechanical properties.

Properties and processing techniques of Halar® ECTFE are detailed in this brochure.

CHEMISTRY

Halar® ECTFE is a semi-crystalline and melt-processable fluoropolymer from Solvay Solexis manufactured at its ISO-certified plant in Orange, Texas.

Because of its chemical structure -a 1:1 alternating copolymer of ethylene and chlorotrifluoroethylene- Halar® ECTFE offers a unique combination of properties.

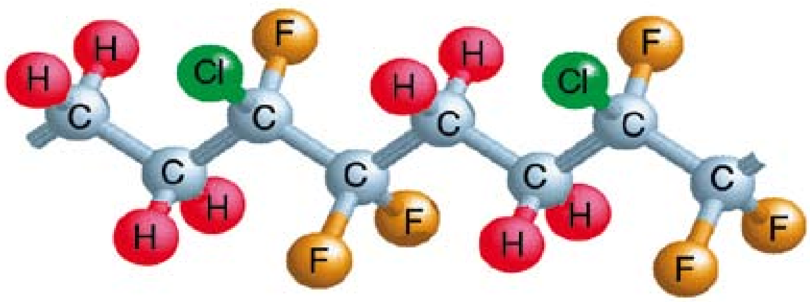
One of the principal advantages of Halar® fluoropolymer is the ease with which it can be processed. Halar® fluorocarbon resin is a true thermoplastic that can be handled by conventional techniques of extrusion as well as by blow, compression, injection, roto and transfer molding. Powder coating methods are also applicable. Halar® resin is available in various melt viscosities to suit virtually every processing technique.

Purity

Static soak testing in ultra-pure water and high purity chemicals show extremely low levels of metallic and organic extractables. Additional dynamic rinse data validates Halar® ECTFE as suitable for high purity systems in the semiconductor, biotech, and pharmaceutical industries. Halar® exhibits very low fluoride ion leachout.

Halar® ECTFE is used as a lining and coating for ultra-pure water systems in the semiconductor industry. FM Global 4922 complete exhaust duct systems use Halar® ECTFE coated stainless steel.

Chemical structure of Halar® ECTFE



TYPICAL APPLICATIONS

Chemical
Halar® ECTFE is used extensively in CPI due to excellent chemical resistance properties, even at elevated temperatures, and mechanical properties. Halar® ECTFE is used in pulp and paper applications due to its resistance to harsh acids, bases and halogens. Specific applications include: containers, diaphragms, protective linings/coatings for tanks, pumps, valves, pipes, scrubbing towers, reactors, thermocouple wells, centrifuge components, heat exchangers, unsupported pipe and tubing, tower packing, valve seats, filters, dust collectors, mist eliminators, closures, filter fabric, fittings, process system components.

Coatings
Halar® ECTFE electrostatic powder coatings possess excellent chemical resistance and good processability making it well-suited for the following: agitators; centrifuges; containers; hoods; membranes; filters; pumps; vessels; reactors; piping systems; caustic collectors; semiconductor chemical storage tanks; electroplating equipment. Contact Solvay Solexis for a copy of the Halar® ECTFE Powder Coating manual and/or the Halar® ECTFE Ductwork brochure for more detailed information.

Cryogenic and Aerospace
The excellent low temperature properties of Halar® ECTFE and wide temperature use range make it well suited for Cryogenic and Aerospace applications. Specific examples include: wire and cable insulation and jacketing; pump liners; seals; gaskets; valve seats; fittings; gaskets for liquid oxygen and other propellants; components for manned space vehicles and aircraft cabins, space suits; convoluted tubing and hose for conduit; expandable abrasion-resistant braid.

Electrical
The low dielectric constant and low loss factor for Halar® ECTFE makes it well suited for electrical applications. Specific examples include: wire and cable insulation and jacketing; foamed insulation in coaxial cable constructions; hook-up and other computer wire insulation; oil-well wire and cable insulation; jacketing for logging wire and cathodic protection; aircraft, mass transit, automotive wire; battery cases; fuel cell membranes; flexible printed circuitry and flat cable.

Filtration
Halar® Melt Blown Fiber is a fluoropolymer non-woven web that offers improve d chemical resistance (all acids and bases) and temperature resistance properties (up to 150ºC / 300ºF) versus polypropylene, nylon and polyester melt blown webs. Halar® melt blown webs also exhibit excellent radiation resistance and will not support combustion.

Food and Pharmaceutical
Halar® stabilized DA grades comply with the FDA's Register of Food Additive Regulations, Use B described at 21 C.F.R. 176.170(c), Table 2. Halar® unstabilized grades are suitable for repeated use applications at temperatures up to 100ºC (212ºF) in contact with non-fatty foods, under FDA 21 CFR 177.1380. Halar® is particularly suited for use with acidic food, fruit and juice processing.

Note: These are typical applications of Halar® ECTFE as at the date of publication. Solvay Solexis fluoropolymer products are gaining increasing acceptance in many industries. For further information on your specific application, please contact Solvay Solexis.


Halar High Purity Piping (Courtesy of Asahi America, Malden, MA)


Halar Powder Coated Tank Head (Courtesy of Sermatech, Limerick)


Mixed Polishing Bed Powder Coated (Courtesy of GDS Manufacturing (Komstuff) Wilkinston, Vermont)


Ozone-Resistant Filter Cartridge made with pleated media of Halar Melt Blown Fiber. (Courtesy of U.S. Filter, Timonium, MD)


Various moulded parts used in high purity processing.

PRODUCT RANGE

Halar® resins are available in a range of viscosities for extrusion and molding applications. Halar® powders are available in different particle sizes optimized for specific coating processes.

Commercially available grades

Table 1: Commercially available grades

Grade	Viscosity	Typical Melt Index @ 275°C and 2.16kg	Typical Use	Product form
Standard Copolymer Series				
901	High	0.8 – 1.3	Extrusion of sheet, pipe, and rod. Compression molding.	pellets
300	Med.	1.5 - 3	Film and rod extrusion.	pellets
350	Med.	3 - 6	Tube extrusion and injection molding of large parts.	pellets
930	Med.	3 - 6	Cable jacketing.	pellets
500	Low	15 - 22	Primary wire insulation and standard injection molding.	pellets
513	Low	18 - 20	Monofilament extrusion.	pellets
1450	very low	40 - 60	Injection molding of extremely small parts	pellets
Improved Thermal Stress Crack Resistant Series				
902	high	0.8 – 1.3*	Improved stress crack resistant grade for extrusion of sheet and rod. Compression molding	pellets
Specialty Wire & Cable Series				
558	Low	18 - 20	Foamable grade for wire coating.	pellets
Terpolymer Series				
600	Med.	10 – 15	Thick rod extrusion	pellets
650	Med.	5 – 9	Transparent grade for specialty applications	pellets
Powder Coating Series				
6014	Low	12	Electrostatic powder coating. Top coat.	powder
6514	Low	12	Electrostatic powder coating. Primer.	powder
6614	Low	12	Electrostatic powder coating. Primer.	powder
8014	Low	12	Electrostatic powder coating. Top coat, improvements in high-temperature stress cracking over 6014	powder

* melt index @ 275°C and 5kg

Specialty Formulations
All standard Halar® extrusion and molding grades are formulated to minimize Halar® fluoropolymer's corrosivity to materials of construction and are denoted "LC" or "DA".

- Halar® "LC" grades offer the best corrosion resistance to process machinery,
- Halar® "DA" grades are available and meet the FDA's condition of Use B, as described under 21 C.F.R. 176-170(c).

Contact Solvay Solexis for further information.

Packaging and Storage

Halar® resins are available in the following packaging:

- 55 lb (25 kg) drums,
- 175 lb (79,4 kg) drums,
- 500 kg big boxes,
- 2000 lb (907,4 kg) octabins.

Though they have an indefinite shelf life, it is recommended to store them in a clean area, protected from direct sunlight and possible contamination.

Typical properties

Table 2: Typical properties					
Property	**Test Method**	**Unit**	**Standard Copolymers**	**Terpolymer (Halar® 600)**	**Halar® 902**
PHYSICAL					
Density @ 23°C (73°F)	ASTM D792	g/cm^3 (lb/ft^3)	1.68 (105)	1.68 (105)	1.71 (107)
Water absorption	ASTM D570	%	<0.1	<0.1	<0.1
MECHANICAL (23°C)					
Tensile stress at yield	ASTM D638	MPa (psi)	30-32 (4300-4600)	30-32 (4300-4600)	30-32 (4300-4600)
Tensile stress at break		MPa (psi)	40-57 (5800-8300)	45-50 (6500-7300)	45-50 (6500-7300)
Elongation at yield		%	3-5	5	3-5
Elongation at break		%	250-300	325	250 - 300
Tensile Modulus		MPa (psi)	1400-2100 (203000-304000)	1500-1800 (218000-261000)	1400-2100 (203000-304000)
Flexural strength	ASTM D790	MPa (psi)	45-55 (6500-8000)	45-50 (6500-7300)	45-55 (6500-8000)
Flexural modulus		MPa (psi)	1600-1800 (232000-261000)	1600-1800 (232000-261000)	1600-1800 (232000-261000)
IZOD impact, notched @ 23°C (73°F)	ASTM D256	J/m	no break	no break	no break
IZOD impact, notched @ -40°C (-40°F)	ASTM D256	J/m	50-110	207	65
Hardness, Shore D	ASTM D2240	-	70-75	70-75	70-75
Hardness, Rockwell R	ASTM D785	-	90	80	90
Abrasion resistance	TABER	mg/1000 rev	5	5	5
Friction coefficient: static dynamic	ASTM D1894	-	0.1-0.2	0.2	0.1-0.2
		-	0.1-0.2	0.2	0.1-0.2
THERMAL (DSC)	**ASTM D3418**				
Melting point		°C (°F)	240-245 (464-473)	220-227 (428-440)	220-230 (428-446)
Heat of fusion		J/g	42	28	28
Cristallizing point		°C (°F)	222 (432)	205 (400)	205 (400)
Cristallization heat		J/g	40	28	28
Deflection temperature	ASTM D648				
load 0.46 MPa (66 psi)		°C (°F)	90 (195)	80 (175)	90 (195)
load 1.82 MPa (264 psi)		°C (°F)	70 (160)	65 (150)	70 (160)
Glass Transition (Tg)	DMTA	°C (°F)	85 (185)	80 (175)	85 (185)
Brittleness temperature	ASTM D746A	°C (°F)	<-76 (<-105)	<-76 (<-105)	<-76 (<-105)
Molding shrinkage		%	2.5	2.5	2.5
Thermal stability	TGA begin - at 1% weight loss in air	°C (°F)	405 (760)	405 (760)	405 (760)
Linear thermal expansion coef-ficient	ASTM D696	10^{-6} /K (10^{-6} /°F)	90 (50)	100 (56)	90 (50)
Thermal conductivity @ 40°C (104°F)	ASTM C177	W/m.K	0.15	0.15	0.15
Specific heat	23°C	J/g.K	0.95	0.95	0.95
ELECTRICAL					
Volume resistivity @ 23°C, 50% RH	ASTM D257	ohm.cm	> 10^{16}	> 10^{16}	> 10^{16}
		ohm.in	> 10^{16}	> 10^{16}	> 10^{16}
Dielectric strength @ 23°C, 3.2 mm thick	ASTM D149	kV/mm	15	14	15
		V/mil	385	350	385
Dielectric constant, 23°C @ 10^6 Hz	DIN 53483		2.6	2.6	2.6
FIRE RESISTANCE					
UL-94 Flammability test	UL-94	Class	V-0	V-0	V-0
Limiting Oxygen Index	ASTM D 2863	%	52	52	52

Note: All data for compression moulded samples unless otherwise specified.

PHYSICAL PROPERTIES

Thermal properties

Halar® ECTFE copolymers offer a wide useful surface temperature range from -80°C to +150°C in non load-bearing applications.

The maximum service temperature can be affected by the presence of system stresses and chemical environment. Stress cracking for standard grades may appear in the 125-150°C range, especially for high-MI grades. Halar® 902 was recently developed as an improved stress-crack resistant grade.

Halar® ECTFE shows excellent resistance to degradation by heat, high-energy radiation and weathering. It has low smoke properties and is non-flame propagating.

Table 3: Thermal properties

Property	Test Method	Unit	Standard Copolymers
Melting point	ASTM D3417	°C (°F)	240-245 (464-473)
Heat of fusion		J/g	42
Cristallizing point		°C (°F)	222 (432)
Cristallization heat		J/g	40
Specific heat (@ 23°C)	ASTM DSC	J/g.K	0.95
@ 100°C		J/g.K	1.26
@ 200°C		J/g.K	1.55
@ 300°C		J/g.K	1.64
Glass Transition (Tg)	DMTA	°C (°F)	85 (185)
Thermal stability	TGA begin - at 1% weight loss in air	°C (°F)	405 (760)
Deflection temperature	ASTM D648		
load 0.46 MPa (66 psi)		°C (°F)	90 (195)
load 1.82 MPa (264 psi)		°C (°F)	70 (160)
Maximum service Temp.		°C (°F)	150 (302)
Brittleness temperature	ASTM D746A	°C (°F)	<-76 (<-105)
Thermal conductivity @ 40°C (104°F)	ASTM C177	W/m.K	0.151
@ 95°C (203°F)			0.153
@ 150°C (302°F)			0.157
Flammability	UL 94	Rating	V-0
Limiting Oxygen Index	ASTM D2863	%	52

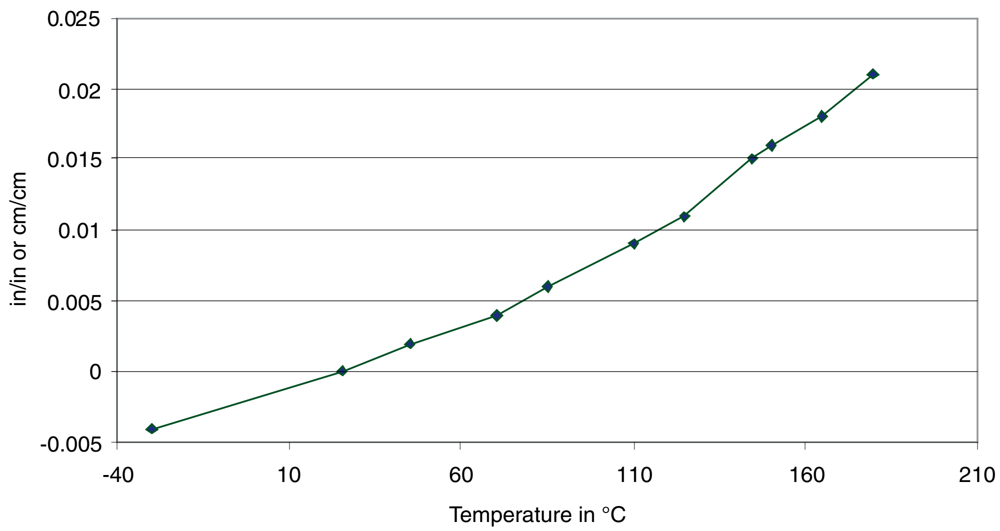
Coefficient of linear thermal expansion

The following table and figure 1 shows the linear thermal expansion coefficient for Halar® ECTFE.

Table 4: Coefficient of linear thermal expansion

Temperature range	in/in-°F	cm/cm-°C
-30 to +50°C (-22 to 122°F)	4.4×10^{-5}	8×10^{-5}
50 to 85°C (122 to 185°F)	5.6×10^{-5}	10×10^{-5}
85 to 125°C (185 to 257°F)	7.5×10^{-5}	13.5×10^{-5}
125 to 180°C (257 to 356°F)	9.2×10^{-5}	16.5×10^{-5}

Fig. 1: Linear thermal expansion of Halar® resin



Stress cracking temperature

Parts made from Halar® ECTFE resin have a limited resistance to crack formation under stress at elevated temperatures. This phenomenon can be observed by utilizing Fed. Spec. L-P-390C Class H, a test procedure originally designed for polyethylene. In this test, 1/4 in –wide strips of .05 in. thick sheet are wrapped around a ¼ in. diameter mandrel and exposed to various temperatures in forced-draft ovens. The calculated strain (elongation) of the strip wrapped on the 1/4 in. diameter mandrel is about 16 percent. The temperature at which Halar® resin will stress crack appears to be predominantly a function of molecular weight and molecular-weight distribution. Based on these results from the above test, the following grades of Halar® resin have the indicated stress-cracking temperatures.

Table 5: Stress cracking temperature

Halar® Grade	Melt Index	Stress –cracking Temperature
300	2 g/10 min	150°C (302°F)
500	18 g/10 min	140°C (284°F)

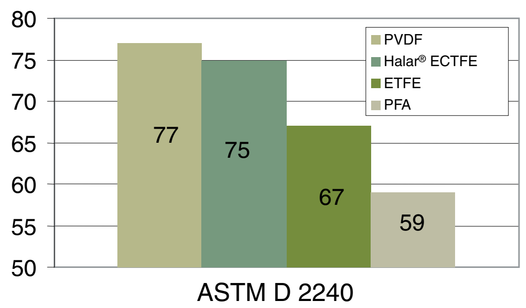
Halar® 902 was recently developed as an improved stress-crack resistant grade. It is particularly recommended for the extrusion and/or compression molding of thick shapes, for sheet thermoforming, load-bearing applications at high temperatures, higher thermal rating of cables, and rotomolding.

Hardness

Hardness is the material's resistance to indentation (penetration by a hard object). It is normally measured with a Shore durometer, which measures the depth of indentation achieved with a standard "indenter" for a given time under a given load, according to the ASTM D2240 testing method. Different Shore scales are defined depending on the material's hardness: for hard polymers like Halar® ECTFE the Shore D scale is normally used.

Shore D hardness values for the most common fluoropolymers are reported in the following diagram.

Fig. 2: Shore D



Surface properties

Halar® ECTFE resins have a critical surface tension of wetting comparable to that of the polymers of ethylene and chlorotrifluoroethylene, the two constituents that make up the Halar® copolymer. Halar® ECTFE is not wetted by water but oils and hydrocarbons readily spread on its surface. The wettability of Halar® can be markedly improved by etching with sodium-based etchants normally employed for PTFE.

Angle of contact and surface tension

Table 6: Critical surface tension wetting

Substrate	US unit	SI Unit
Halar® ECTFE	32 dynes/cm	0.032N/m
PCTFE	31 dynes/cm	0.031N/m
Polyethylene	31 dynes/cm	0.031N/m
PVDF	25 dynes/cm	0.025N/m
FEP	16 dynes/cm	0.016N/m

Table 7: Contact angle

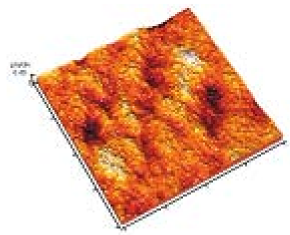
Surface	Water	Hexadecane
Halar® ECTFE	99°C	<5°
PCTFE	109°C	36°C
PVDF	105°C	41°C
HDPE	98°C	<5°

Surface smoothness

Halar® ECTFE is distinguished from all other fluoropolymers by its exceptional surface smoothness which precludes the shedding of particles and avoids particle trapping. The formation of biorganic films and bacterial colonies is significantly reduced.

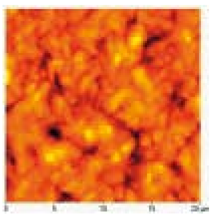
A comparison of pipe internal surfaces by Atomic Force Microscopy (20x20 µm) is shown in the following pictures.

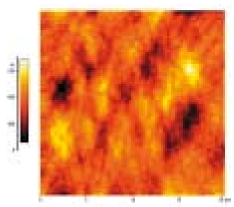
PVDF

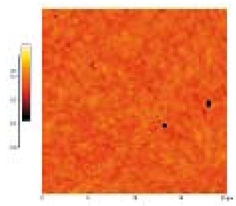


PFA

Halar® ECTFE







Halar® pipes exhibit a low incidence of microbial bio-fouling, making it ideal for use in UPW (ultra pure water) applications.

Fig. 3: Average direct cell count/cm²

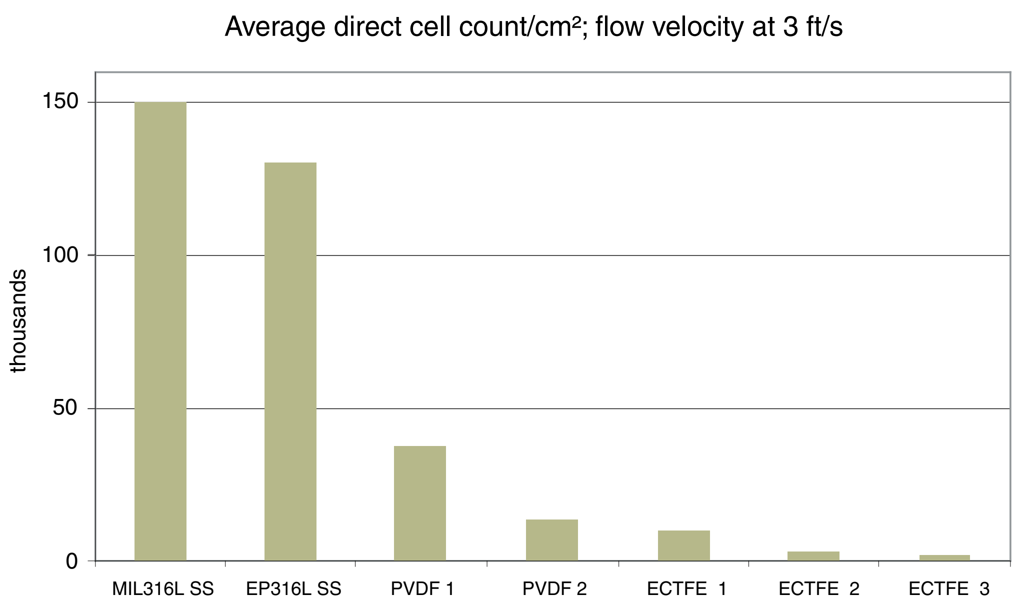
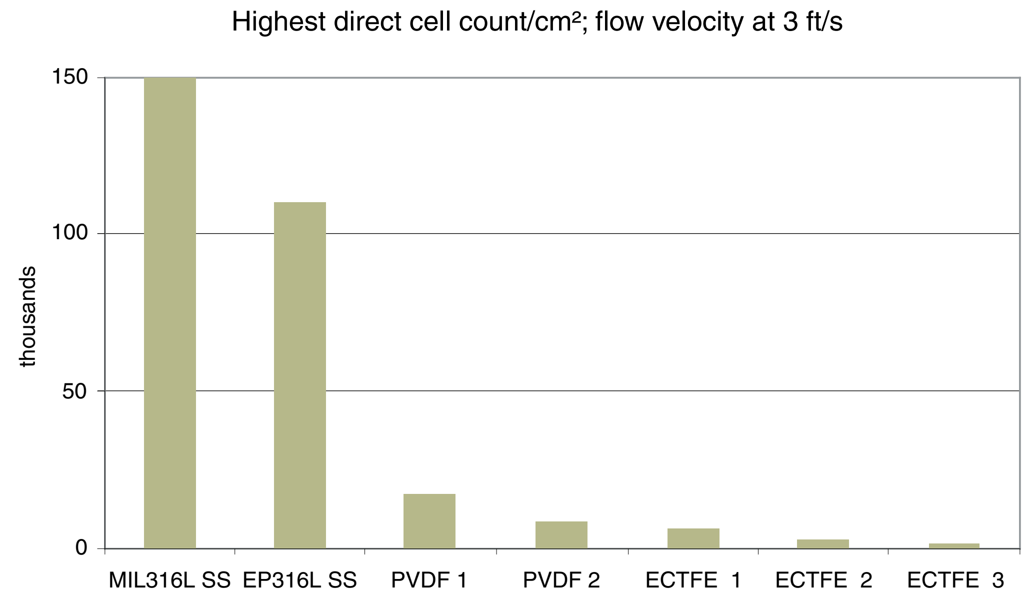


Fig. 4: Highest direct cell count/cm²

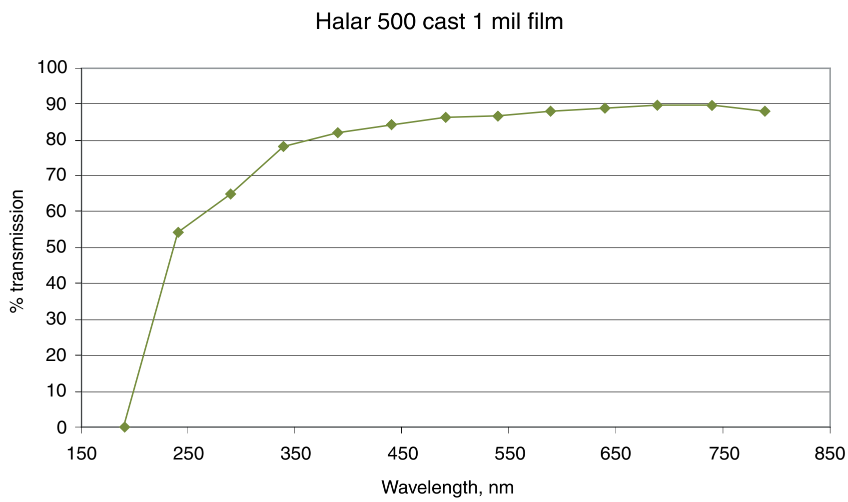


Optical properties – Appearance

Halar® ECTFE has excellent optical properties with low haze, as well as excellent light transmission throughout a wide range of wavelengths. The index of refraction of Halar 500 at 21°C for 589 nm light is 1.4476.

Fig. 5: Light transmission vs. wavelength

Fig. 6: Light transmission vs. wavelength

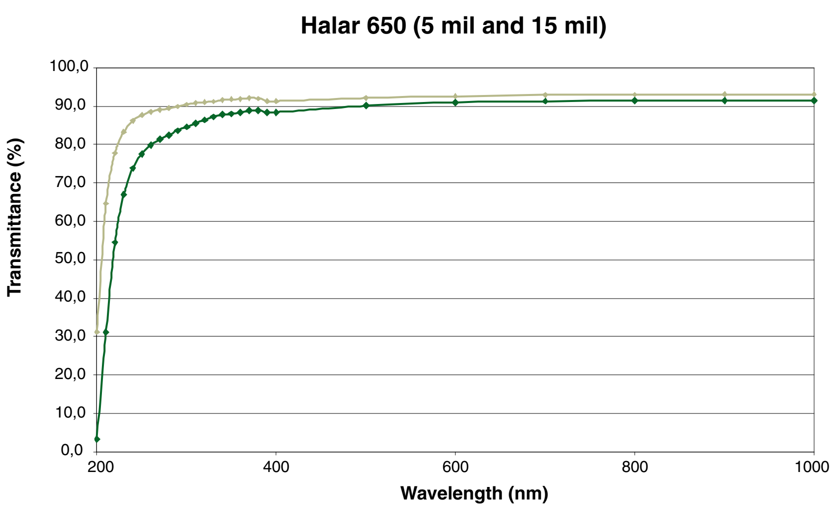


Halar® 650 is a clear grade that was designed for use in semiconductor work-bench environments (windows, sight glass). Its chemical composition was modified to reduce crystallinity, enhancing transparency.

Table 8: Physical properties of Halar® 650

Physical Properties	Method	Units	Typical values
Melting point	ASTM D 3418	°C (°F)	190-200 (374-392)
Glass Transition Temperature	DMS	°C (°F)	75° (167)
Max. Use Temperature	dimensional stability of extruded sheets	°C (°F)	60 (140)
Density	ASTM D 792		1.72
Melt flow index	ASTM D 1238		5 - 10
Tensile strength at yield	ASTM D 1708	MPa (psi)	30 (4300)
Tensile strength at break	ASTM D 1708	MPa (psi)	41 (5850)
Elongation at yield	ASTM D 1708	%	4
Elongation at break	ASTM D 1708	%	300

Fig. 7: Light transmission of Halar® 650



MECHANICAL PROPERTIES

Halar® ECTFE is a strong, hard, tough, abrasion resistant, highly impact-resistant material that retains its useful properties over a broad range of temperatures. Its low-temperature properties, especially those related to impact, are particularly outstanding. Halar® ECTFE also has good tensile, flexural and wear resistant properties. Mechanical property information is provided in the table and figures below.

Table 9: Mechanical properties

Property	Test Method	Unit	Standard Copolymers	Terpolymer (Halar® 600)	Halar® 902
Tensile stress at yield	ASTM D638	MPa (psi)	30-32 (4300-4600)	30-32 (4300-4600)	30-32 (4300-4600)
Tensile stress at break		MPa (psi)	40-57 (5800-8300)	45-50 (6500-7300)	45-50 (6500-7300)
Elongation at yield		%	3-5	5	3-5
Elongation at break		%	250-300	325	250 - 300
Tensile Modulus		MPa (psi)	1400-2100 (203000-304000)	1500-1800 (218000-261000)	1400-2100 (203000-304000)
Flexural strength	ASTM D790	MPa (psi)	45-55 (6500-8000)	45-50 (6500-7300)	45-55 (6500-8000)
Flexural modulus		MPa (psi)	1600-1800 (232000-261000)	1600-1800 (232000-261000)	1600-1800 (232000-261000)
IZOD impact, notched @ 23°C (73°F)	ASTM D256	J/m	no break	no break	no break
IZOD impact, notched @ -40°C (-40°F)	ASTM D256	J/m	50-110	207	65
Hardness, Shore D	ASTM D2240	-	70-75	70-75	70-75
Hardness, Rockwell R	ASTM D785	-	90	80	90
Abrasion resistance	TABER	mg/1000 rev	5	5	5
Friction coefficient: static	ASTM D1894	-	0.1-0.2	0.2	0.1-0.2
dynamic		-	0.1-0.2	0.2	0.1-0.2

Short term stresses

Tensile Properties

Tensile properties are determined by clamping a test specimen into the jaws of a testing machine and separating the jaws at a specified rate in accordance with ASTM D638. The force required to separate the jaws divided by the minimum cross-sectional area is defined as the tensile stress. The test specimen will elongate as a result of the stress, and the amount of elongation divided by the original length is the strain. If the applied stress is plotted against the resulting strain, a curve similar to that shown for instance in Figure 8 is obtained for ductile polymers like ECTFE.

Fig. 8: Tensile curve for Halar® ECTFE

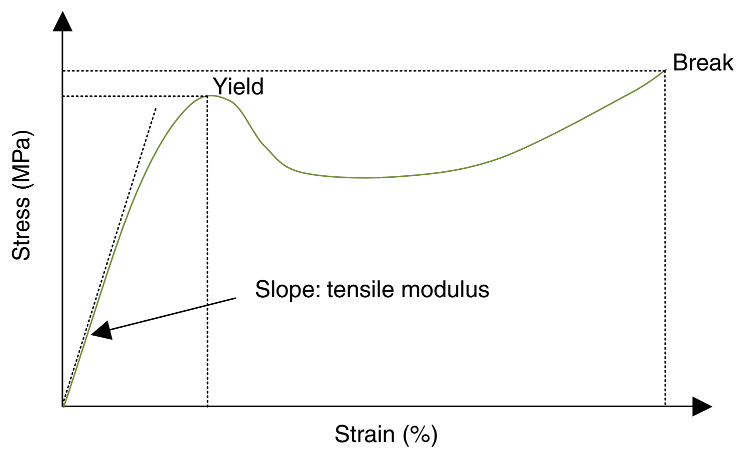


Fig. 9: Tensile modulus vs. temperature

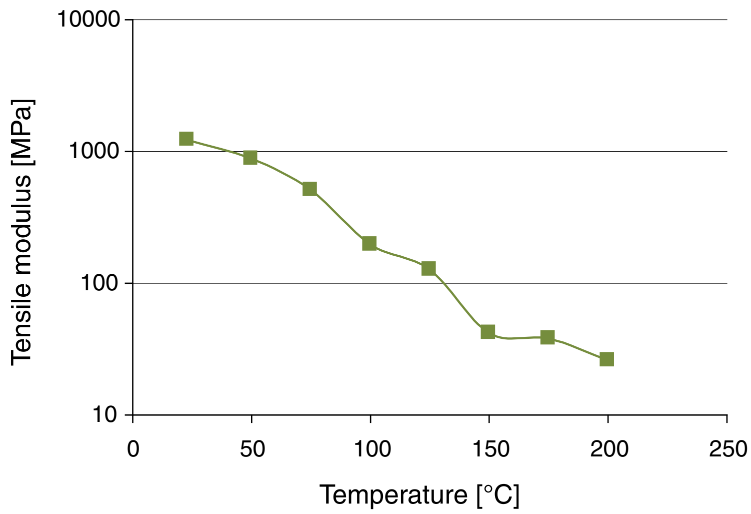
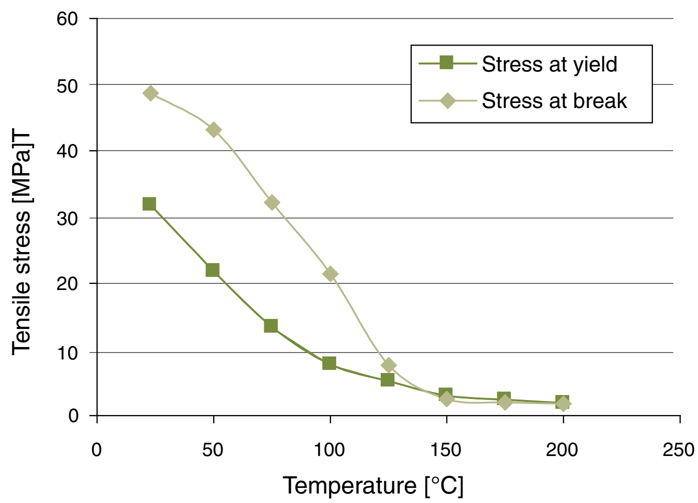


Fig. 10: Tensile stress vs. temperature

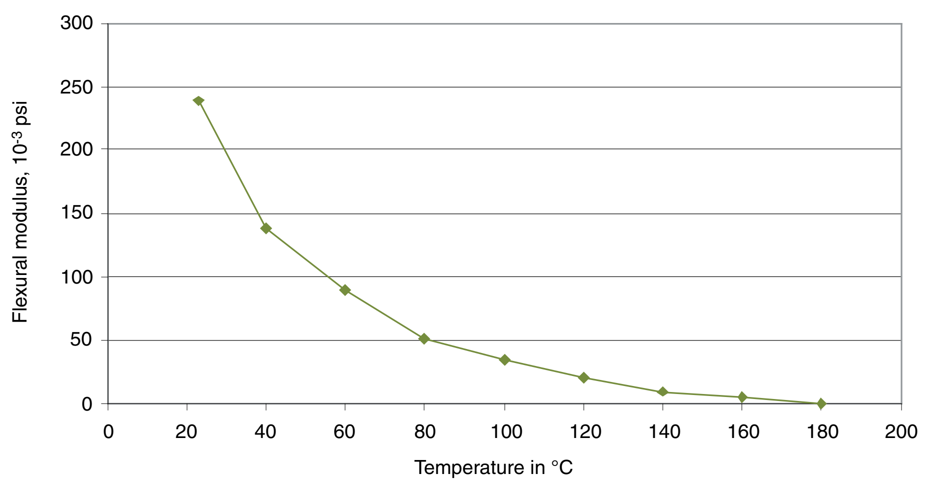


Flexural Properties
Flexural properties were determined in accordance with ASTM D790 using the three-point loading method. In this method the test specimen is supported on two points, while the load is applied to the center. The specimen is deflected until rupture occurs or the fiber strain reaches five percent.

Flexural testing provides information about a material's behavior in bending. In this test, the bar is simultaneously subjected to tension and compression.

Note: all data for compression moulded samples unless otherwise specified.

Fig. 11: Flexural modulus vs. temperature (ASTM D-790)



Long term static stress

Creep and Stress Relaxation
When a bar made of a polymeric material is continuously exposed to a constant stress, its dimensions will change in response to the stress. This phenomenon is commonly called "creep". In the simplest case, the tensile mode, the test bar will elongate as a function of time under stress. The term "strain" is used for the amount of length increase or elongation divided by the initial length.

Creep can also be observed and measured in a bending or flexural mode, or in a compressive mode. The creep information presented in this manual was developed using the tensile mode.

Tensile creep of Halar® ECTFE at various temperatures and under different stresses:

Fig. 12: Tensile creep of Halar® ECTFE @ 23°C

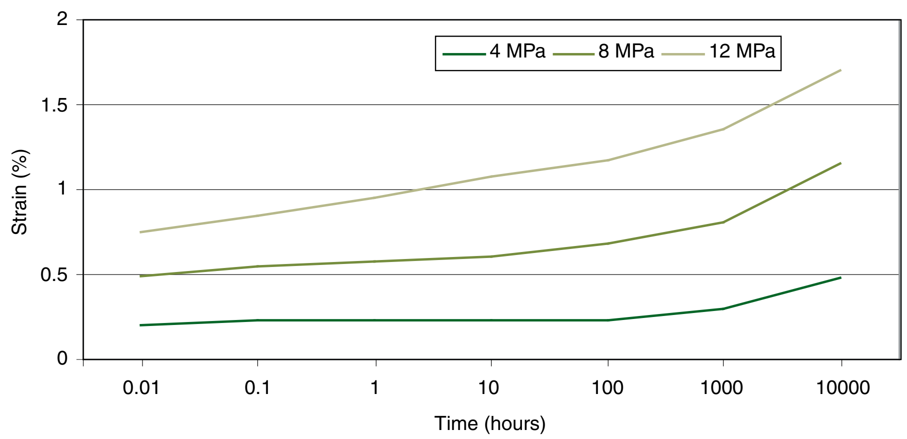


Fig. 13: Tensile creep of Halar® ECTFE @ 75°C

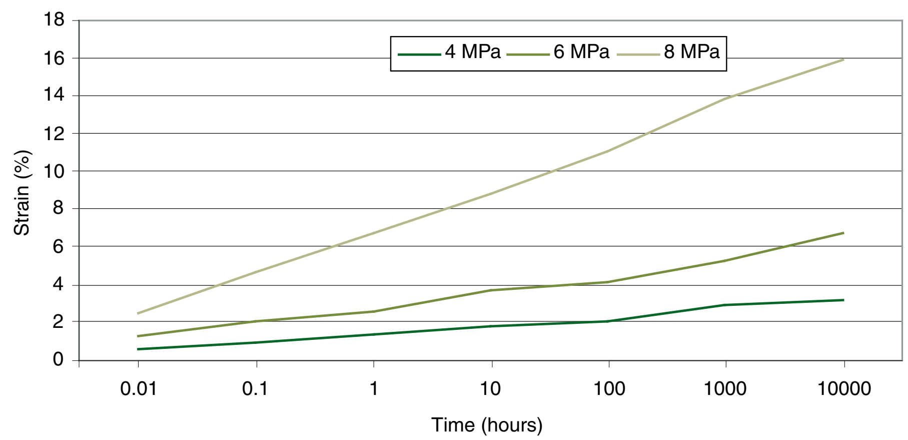


Fig. 14: Tensile creep of Halar® ECTFE @ 125°C

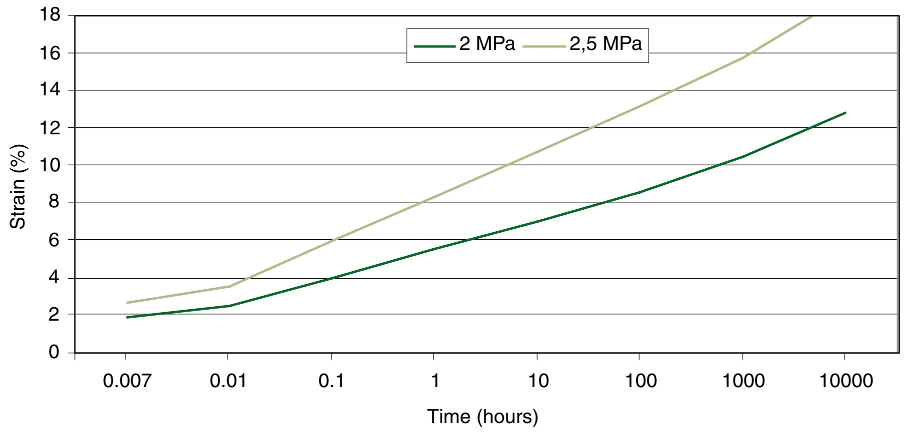
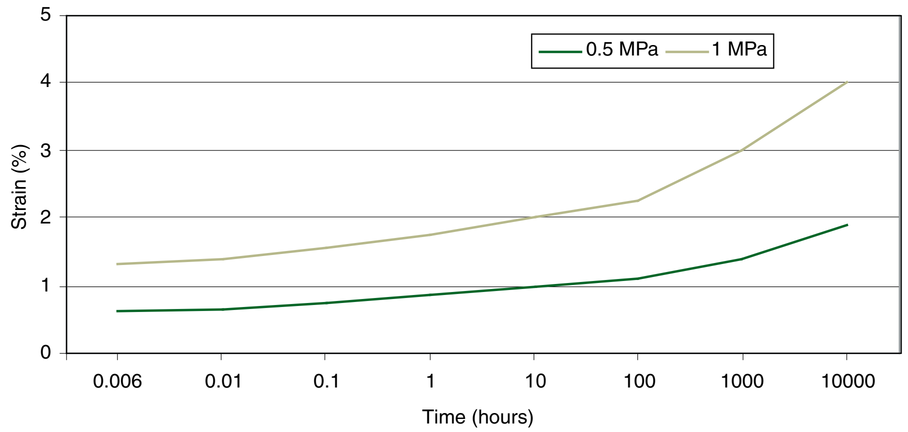


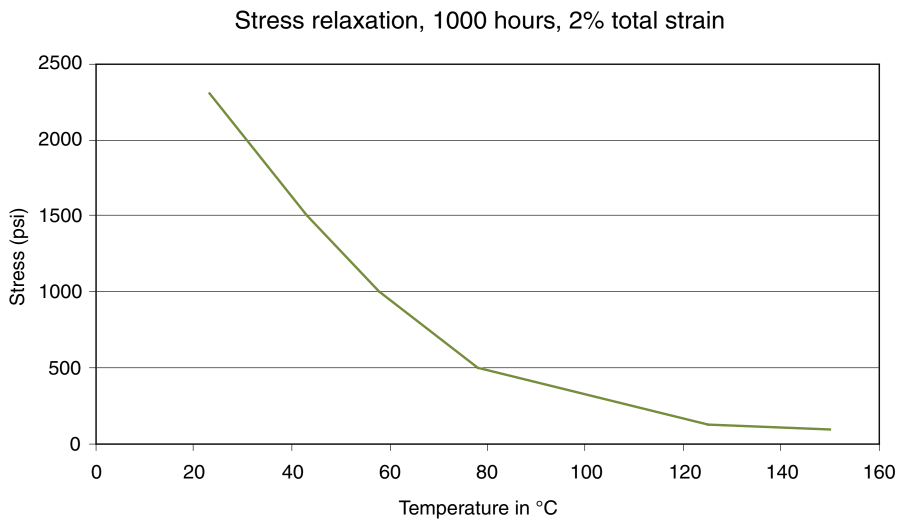
Fig. 15: Tensile creep of Halar® ECTFE @ 150°C



On the other hand if a specimen is deformed and kept for a long time at constant strain, the stress that must be applied to keep deformation constant decreases with time. This effect is known as "stress relaxation" and basically depends on the same physical phenomena as creep.

Stress relaxation after 1000 hours in Halar® ECTFE specimens deformed by 2% as function of temperature:

Fig. 16: Stress relaxation of Halar® ECTFE after 1000 hours



ELECTRICAL PROPERTIES

General characteristics

Halar® ECTFE standard and modified copolymers exhibit high bulk and surface resistivities, high dielectric strength, low dielectric constant, and moderate dissipation factor. The dissipation factor varies slightly with the frequency for frequencies above 1 kHz. Overall, the A.C. losses of Halar® ECTFE are much lower than the A.C. losses of PVDF. The dielectric constant of Halar® is stable across broad temperature and frequency ranges. Halar® ECTFE can be used as jacketing of plenum rated cables in more demanding applications. Its excellent electrical properties simplify the design of high-performance cables. The very low moisture absorption properties of Halar® ECTFE and the temperature insensitivity ensure that cables utilizing Halar® jackets maintain their electrical performance under a wide variety of environmental conditions. PVC jacketed cables have been shown to deteriorate significantly in electrical performance due to moisture absorption during aging. Halar® ECTFE low temperature properties allow installation in any season without risk of cracking or splitting.

Table 10: General electrical properties

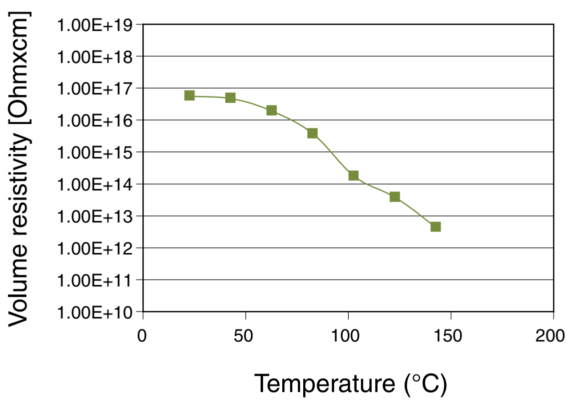
Property	ASTM	Halar® ECTFE
Volume resistivity (Ωxcm)	D 257	$>10^{15}$
Surface resistivity (Ω)	D 257	$>10^{14}$
Dielectric strength at 1mm thickness (kV/mm)	D 149	30-35
Relative dielectric constant	D 150	
at 1 kHz		2.5
at 1 MHz		2.6
Dissipation Factor		
at 1 kHz		0.0016
at 1 MHz		0.015

Many applications for thermoplastic resins depend upon their ability to function as electrical insulators. Several tests have been developed to provide the designer with physical parameters that help to predict how well a particular resin can perform that function.

Volume resistivity

Volume resistivity is defined as the electrical resistance offered by a material to the flow of current, times the cross sectional area of current flow per unit length of current path. The test is run by subjecting the material to 500 volts for 1 minute and measuring the current. The higher the volume resistivity, the more effective a material will be in electrically isolating components.

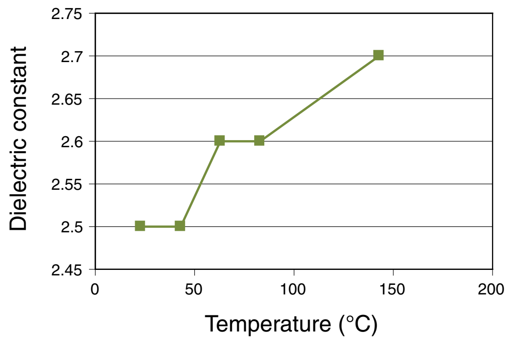
Fig. 17: Volume resistivity



Dielectric constant

Dielectric constant is defined as the ratio of the capacitance of a condenser using the test material as the dielectric to the capacitance of the same condenser having only vacuum as the dielectric. Insulating materials are used in two very distinct ways: (1) to support and insulate components from each other and ground, and (2) to function as a capacitor dielectric. In the first case, it is desirable to have a low dielectric constant. In the second case, a high dielectric constant allows the capacitor to be physically smaller.

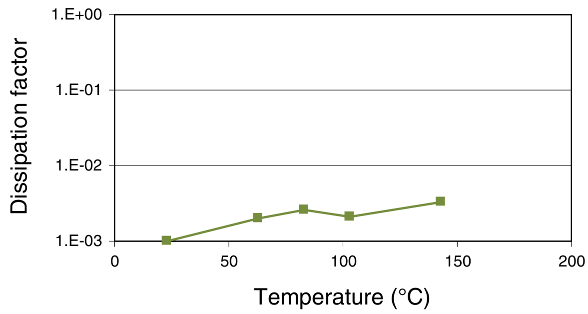
Fig. 18: Dielectric constant



Dissipation factor

Dissipation factor (also referred to as loss tangent or tg   delta) is a measure of the amount of heat (energy) dissipated by a material under alternating voltage. Low dissipation factors are desirable in most cable applications, especially with communications LAN copper wires.

Fig. 19: Dissipation factor



Halar® grades for Wire & Cable applications

Halar® ECTFE offers excellent abrasion resistance and mechanical properties over a broad range of temperatures and chemical resistance to a wide variety of acids, bases, and organic solvents. It is rated for continuous use from cryogenic temperatures up to 150°C and higher. It offers good electrical properties and fire and smoke performance. It is an ideal choice for various telecommunication applications, signal cables, coaxial, and jacketing requiring excellent weatherability and/or chemical resistance.

The improved copolymer structure of Halar® 902 imparts much improved thermal stress cracking resistance and an increased thermal rating temperature. This is a low melt index grade for heavy wall applications. For jacketing applications requiring a medium melt flow index, Halar® 930LC and Halar® 350LC are ideal candidates. Halar® 500LC is a high melt index grade for thin wall applications at high line speeds. For even thinner walls, Halar® 1450LC is a very high melt index grade for specialty applications.

Halar® 558 is a completely pre-compounded chemically foamed grade which provides similar performance to FEP with a dielectric constant up to 25 % lower depending on the wall thickness. Where cost reduction and/or lighter weight cable may be desired, Halar® ECTFE foam is a sound choice. Cables made from Halar® 558 have met the fire performance requirements in NFPA 90a and tested according to NFPA 262.

ENVIRONMENTAL RESISTANCE

General chemical resistance properties

Halar® ECTFE demonstrates excellent overall chemical resistance. In general only few species are known to chemically attack Halar® and a limited number of chemicals can significantly swell the polymer leading to a worsening of the performance of the material.

Halar® fluoropolymer is especially resistant to:

- strong and weak inorganic acids and bases,
- weak organic acids and bases,
- salts,
- aliphatic hydrocarbons,
- alcohols,
- strong oxidants,
- halogens.

However, Halar® ECTFE can be swelled, in particular at high temperatures, by some:

- esters,
- aromatic hydrocarbons,
- ethers,
- ketones,
- amides,
- partially halogenated solvents.

Halar® ECTFE can be attacked by amines, molten alkali metals, gaseous fluorine, and certain halogenated compounds such as ClF_3.

Chemical attack and swelling are very complex phenomena. The known factors affecting chemical suitability of Halar® ECTFE or any other plastic for a chemical application, not listed in order of priority, are as follows:

- Specific chemical or mixture composition,
- Temperature and temperature variation,
- Concentration of the attacking chemical which may be a complex completely different than the individual components,
- Exotherm or heat of reaction or mixing pressure, due primarily to the effect of pressure on concentration of a reactive gas,
- Time of exposure,
- Stress levels,
- Velocity,
- Suspended solids,
- Thickness,
- EMF potential of the supporting metal compared to the ground potential.

The recommended procedure to determine suitability of Halar® ECTFE is as follows:

- Determine as accurately as possible the chemicals in the stream in question,
- Determine the maximum temperature and the normal operating temperature,
- Review the maximum recommended temperature from the list provided.

The maximum recommended temperatures listed below typically refer to the exposure of non-stressed parts; if relevant stresses are present, a more severe effect on the material should be taken into account.

Moreover, the effect of synergism or reaction or complex formation with mixtures cannot be predicted by the table. In any case, appropriate chemical resistance tests using a representative sample of the stream should be performed.

Chemical resistance chart

The table below presents an overview of the chemical resistance of Halar® ECTFE to the most common chemicals.

Please note that the present document provides the reader a substantial overview. Nevertheless, in case of any doubt one should contact Solvay for further information.

Table 11: Overview of the chemical resistance of Halar® ECTFE

Chemical	Formula	Concentration	Max. Temp. [°C]
Acids			
Hydrochloric	HCl	37 %	150
Hydrofluoric	HF	50 %	150
Nitric	HNO_3	65 %	66
Phosphoric	H_3PO_4	85 %	150
Sulphuric	H_2SO_4	98 %	125
		oleum	23
Bases			
Ammonium hydroxide	$NH_4(OH)$	30 %	150
Potassium hydroxide	KOH	30 %	121
Sodium hydroxide	$NaOH$	50 %	121
Sodium hypochlorite	$NaClO$	5% - stabilized at pH 12	150
Hydrocarbons			
n-Hexane	$CH_3(CH_2)_4CH_3$	100 %	150
Toluene	$C_6H_5CH_3$	100 %	66
Alcohols and ethers			
Methanol	CH_3OH	100 %	65
Ethanol	CH_3CH_2OH	100 %	140
Organic acids, esters and ketones			
Acetic acid	CH_3COOH	100 %	> 100
		50 %	> 121
Acetone	CH_3COCH_3	100 %	66
Acetophenone	$C_6H_5COCH_3$	100 %	50
Ethyl Acetate	$CH_3COOCH_2CH_3$	100 %	50
Classic polymer solvents			
Dimethyl formamide	$CH_3CON(CH_3)_2$	100 %	50
Dimethyl sulphoxide	CH_3SOCH_3	100 %	> 100
N-Methylpyrrolidone		100 %	25
Halogenated solvents			
Chlorobenzene	C_6H_5Cl	100 %	66
Chloroform	$CHCl_3$	100 %	not resistant
Amines and nitriles			
Acetonitrile	CH_3CN	100 %	> 100
Aniline	$C_6H_5NH_2$	100 %	100
Dimethyl amine	$(CH_3)_2NH$	100 %	25
Peroxides			
Hydrogen peroxide	H_2O_2	30 %	> 88
Fluids used in the automotive industry			
Crude oil		100 %	150
Dexron II (gear oil)		100 %	150
Gasoline		100 %	150
Diesel Fuels		100 %	150
Mineral oil		100 %	150

Permeability

In general Halar® ECTFE offers an excellent permeation resistance to many chemicals.

Barrier properties strongly depend on the nature (polarity, size…) of the chemicals present in the environment and an overview on the permeation properties of the material can be given according to the features of the penetrating species.

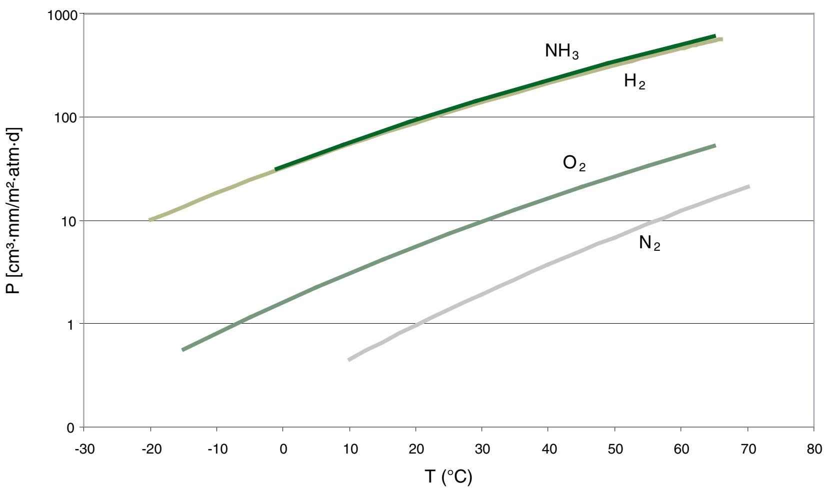
Gases

Halar® ECTFE has excellent permeation resistance to simple gases.

Figure 20 shows the permeability coefficients of hydrogen, nitrogen, oxygen and ammonia in Halar® ECTFE as a function of temperature. For simple gases – which do not form specific interactions with the polymer chains – permeability increases with decreasing molecular dimensions. Permeability of the polar molecule NH_3, on the other hand, is higher than expected simply basing on its size.

Figure 21 and 22 show the permeability coefficients of chlorine and hydrogen sulfide in Halar® ECTFE compared with those of other fluorinated and hydrogenated materials.

Fig. 20: Gas permeability in Halar® ECTFE*



* Data from L.K.Massey, *Permeability Properties of Plastics and Elastomers*, PDL (2003)

Fig. 21: Chlorine permeability of Halar® ECTFE compared with other polymers

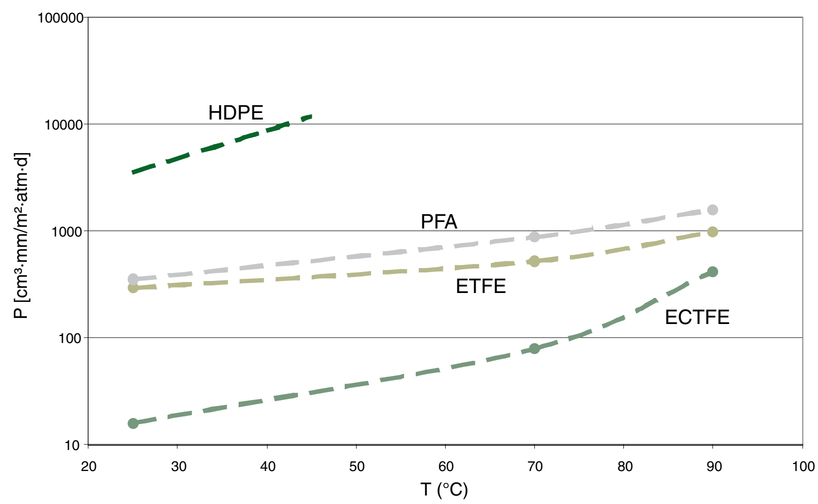
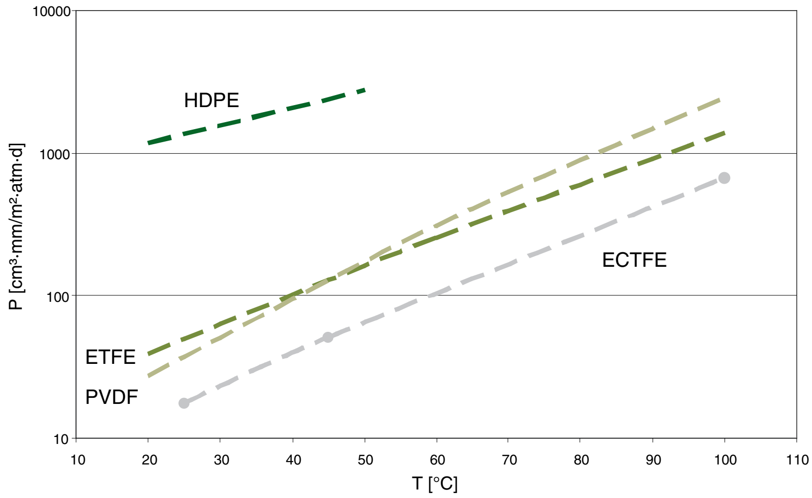


Fig. 22: Hydrogen sulfide permeability of Halar® ECTFE compared with other polymers



Water

Water is a small, polar molecule that can interact with polymer chains forming hydrogen bonds. Permeation resistance of Halar® ECTFE to water vapor is better than other fluoropolymers, as PVDF, and its permeability coefficients are close to perfluorinated polymers.

Water vapor permeability in Halar® ECTFE is about 750 $cm^3 \cdot mm/m^2 \cdot atm \cdot d$ at 23°C and 7600 $cm^3 \cdot mm/m^2 \cdot atm \cdot d$ at 90°C. It is worthwhile noting that in the same temperature range, the permeability coefficient in PVDF rises from values similar to Halar at room temperature to 37000 $cm^3 \cdot mm/m^2 \cdot atm \cdot d$, about five times higher than Halar®, at 90°C.

Figure 23: Water vapor permeability comparison of different polymers at 23°C

Figure 24: Water vapor permeability comparison of different polymers at 90°C [from C.M.Hansen, *Progr. Org. Coat.*, 42, 167-178 (2001)]

Fig .23: Water vapor at 23°C

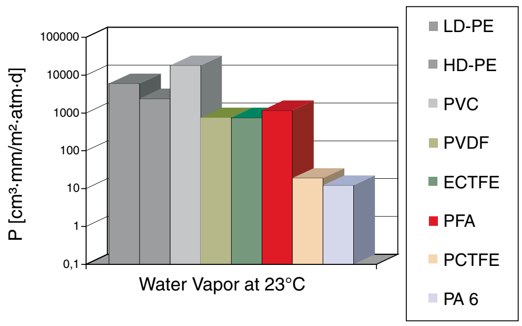
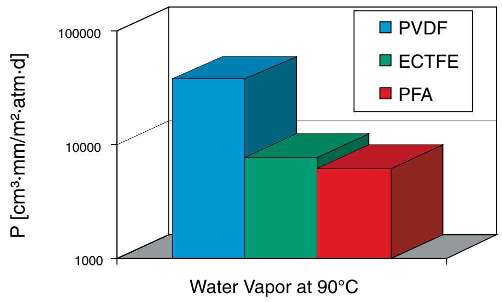


Fig. 24: Water Vapor at 90°C

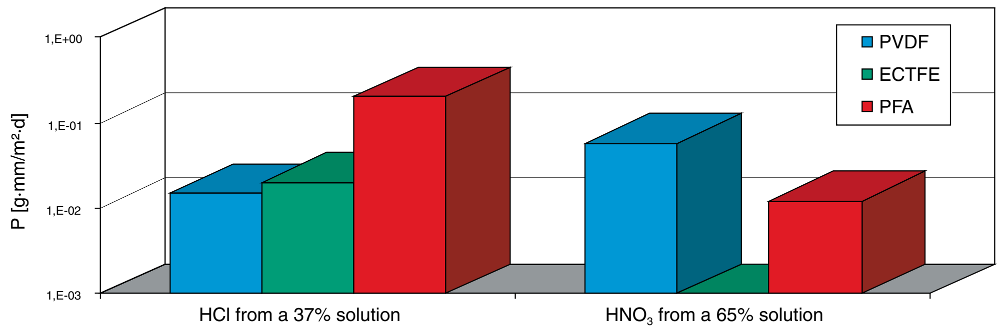


Aqueous electrolytes
The permeation of electrolytes $A_x^{n+}B_y^{m-}$ in Halar ECTFE – as in hydrophobic fluoropolymers – involves the passage of the neutral specie A_xB_y and not of the ions A^{n+} and B^{m-}. (see Figure 25)

In general the permeability coefficients of electrolytes are low even from conce ntrated solutions and they are related to the volatility of the electrolyte: only volatile species have a non negligible permeation rate, while the permeation of non volatile electrolytes can not be detected even after years.

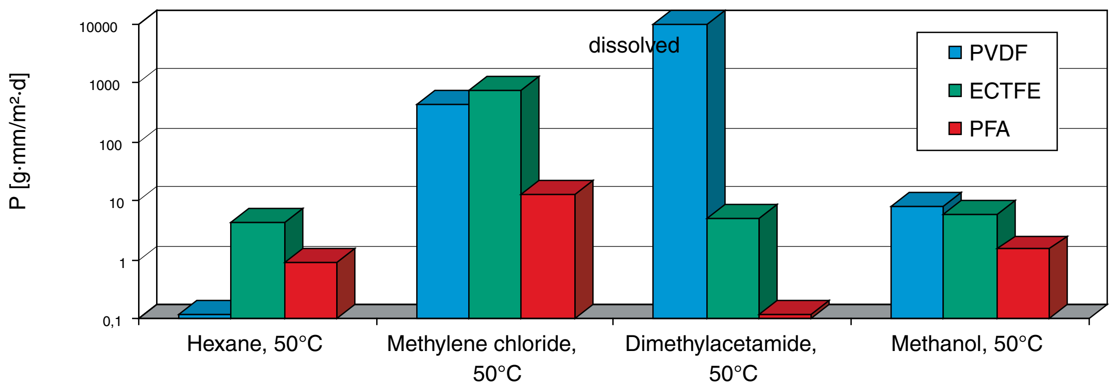
However, when considering the permeation of aqueous solution, also the permeation of water discussed above should be considered.

Fig. 25: Permeabilities of HCl and HNO_3 molecules in fluoropolymers from aqueous solutions



Organic chemicals
As the permeation process can be described as the sorption of the penetrating species on the material surface followed by its diffusion through the polymer chains, it should be clear the linkage between permeability and swelling: chemicals that are known as swelling agents for Halar® ECTFE (see the section above) are also expected to have a significant permeation rate in the polymer.

Fig. 26: Liquid permeabilities of a few common chemicals in Halar® ECTFE, compared with PVDF and PFA



Weathering resistance

Halar® ECTFE undergoes very little change in properties or appearance upon outdoor exposure to sunlight. Both accelerated and outdoor weathering studies demonstrate the remarkable stability of the polymer to UV light and weather. The properties of Halar® ECTFE are barely affected after 5000 hours exposure to the UVB-313 source of light in the QUV Weatherometer or after 9 years of the Florida outdoor weathering. The figures 27 and 28 below illustrate the exceptional weathering resistance of Halar® films.

Fig. 27: Florida exposure 45° South

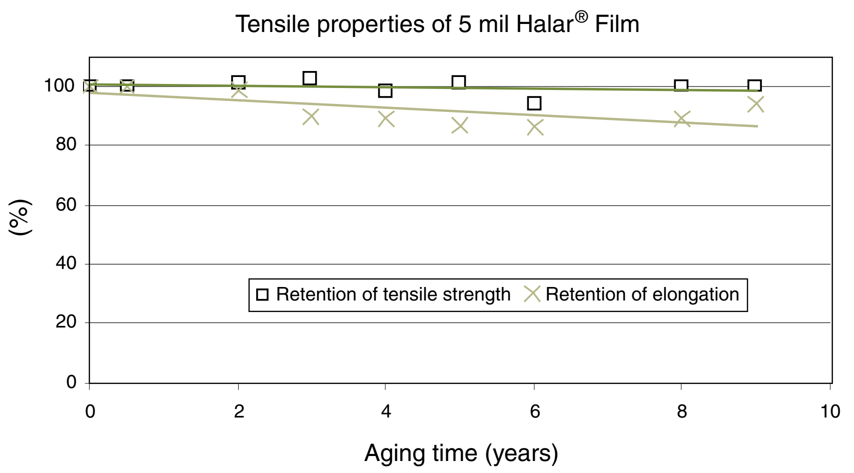
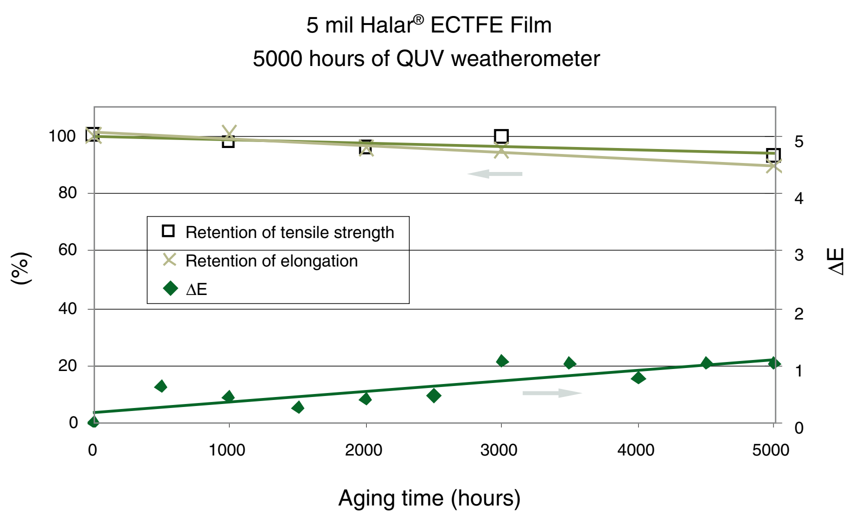


Fig. 28: QUV weatherometer



Resistance to high energy radiation

Halar® ECTFE has demonstrated excellent resistance to many sources of radiation up to 200 Mrad.

FIRE RESISTANCE

Halar® ECTFE offers a superior combination of properties in comparison to other partially fluorinated plastics, according to the following independent tests:

- UL-94,
- LOI limiting oxygen index,
- Auto ignition temperature,
- Factory Mutual (FM).

When placed in a flame, unlike most thermoplastics, Halar® ECTFE does not melt or drip. Char is formed, which serves as an oxygen and heat transfer barrier. On removal of flame, it immediately extinguishes. It will not ignite or propagate flame in atmospheres which contain up to 52% of oxygen. Halar® ECTFE has excellent low smoke properties.

Table 12: Fire resistance

UL 94	V-0 rating at 0.18 mm
Limiting Oxygen Index (ASTM D 2863)	> 52%
Auto-Ignition Temperature (ASTM D1929)	655°C
Factory Mutual (FM 4910)	compliant

There are two types of pre-selection test programs conducted on plastic materials to measure flammability characteristics.

The first determines the material's tendency either to extinguish or to spread the flame once the specimen has been ignited; this program is described in UL 94. Specimens moulded from the plastic material are oriented in either a horizontal or vertical position, depending on the specifications of the relevant test method, and are subjected to a defined flame ignition source for a specified period of time. The vertical rating V-0 indicates that the material was tested in a vertical position and self-extinguished within the shortest burn time after the ignition source was removed, and doesn't drip flaming particles, showing highest safety (see Table 12).

The second test program measures the ignition resistance of the plastic to electrical ignition sources. The material's resistance to ignition and surface tracking characteristics is described in UL 746A.

The basic tests used to evaluate a material's ability to resist ignition are (see Table 13):

- Hot-Wire Ignition (HWI): this test determines the resistance of plastic materials to ignition from an electrically heated wire,
- High-Current Arc Ignition (HAI): this test measures the relative resistance of insulating materials to ignition from arcing electrical sources,
- High-Voltage Arc Tracking Rate (HVTR): this test determines the susceptibility of an insulating material to track or form a visible carbonized conducting path over the surface when subjected to high-voltage, low current arcing,
- High-Voltage, Low-Current Dry Arc Resistance (D495): this test measures the time that an insulating material resists the formation of a conductive path due to localized thermal and chemical decomposition and erosion,
- Comparative Tracking Index (CTI): this test determines the voltage that causes a permanent electrically conductive carbon path after 50 drops of electrolyte have fallen on the material.

Table 13: Ignition resistance according to UL standard 746A

Thickness mm	Flame Class	HWI	HAI	HVTR	D495	CTI
0.18	V-0	-	-	2	7	0
1.5	V-0	2	0	2	7	0
3.0	V-0	2	0	2	7	0

Halar® grades tested according to the UL Standard 746A: 100, 200, 300, 400, 500, 5001, 5002.

UL Thermal Index (RTI)

Halar® ECTFE has been investigated with respect to retention of certain critical properties, according to UL Standard 746B. The end-of-life of a material is assumed to be the time when the value of the critical property has decreased to 50 percent of its original value. The maximum service temperature for a material, where a class of critical property will not unacceptably compromised through chemical thermal degradation is defined as Relative Temperature Index (RTI).

More than one RTI may be appropriate for a given material depending on the property requirements for a given application (see Table 14):

- **RTI Elec**: Electrical RTI, associated with critical electrical insulating properties,
- **RTI Mech Imp**: Mechanical Impact RTI, associated with critical impact resistance, resilience and flexibility properties,
- **RTI Mech Str**: mechanical Strength RTI, associated with critical mechanical strength where impact resistance, resilience and flexibility are not essential.

Table 14: UL Thermal Index (RTI)			
Thickness mm	**RTI Elec**	**RTI Mech Imp**	**RTI Mech Str**
0.18	150	150	150
1.5	160	150	160
3.0	160	150	160
Halar® grades tested according to the UL Standard 746B: 100, 200, 300, 400, 500, 5001, 5002.			

Limiting Oxygen Index – LOI

The oxygen index is defined by ASTM D 2863 as the minimum concentration of oxygen, expressed as volume percent, in a mixture of oxygen and nitrogen that will support flaming combustion of a material initially at room temperature under the conditions of this method.

Since ordinary air contains roughly 21 percent oxygen, a material whose oxygen index is appreciably higher than 21 is considered flame resistant because it will only burn in an oxygen-enriched atmosphere.

Table 15: Limiting Oxygen Index

	Halar® ECTFE	**ETFE**
LOI	> 52%	32%

SAFETY, HYGIENE, HEALTH EFFECTS

Fluoropolymer resins like Halar® ECTFE are known for their high chemical stability and low reactivity. Where toxicological studies have been conducted on fluoropolymers, no findings of significance for human health hazard assessment have been reported. None of the fluoropolymers is known to be a skin irritant or sensitizer in humans.

Following massive exposure to fluoropolymer resin dust by inhalation, increases in urinary fluoride were produced; however, no toxic effects were observed. Some Halar® resins are formulated with additives such as fillers, pigments, stabilizers, etc, to provide favourable processing, or other characteristics. These additives may present other hazards in the use of the resins.

The Safety Data Sheet, available for each of the commercial grades, should be consulted for specific health information and to follow all the necessary safety instructions.

For further details, please consult the brochure "Guide for the Safe Handling of Fluoropolymers Resins"

Toxicity of decomposition products

The main Halar grades must be processed at temperatures between 260°C and 280°C. Under these conditions, there is no risk of decomposition of the ECTFE polymer (except in the presence of contaminants)

In general, it is important to ensure good ventilation in the workplaces. In order to avoid decomposition, it is imperative that the material not be heated to a temperature above 350°C. The main fluorinated product emitted during combustion is hydrofluoric acid (HF) which is dangerous if inhaled or if it comes into contact with the skin or the mucous membranes.

As an indication with respect to HF, the ACGIHTLV-Ceiling value (the concentration that should not to be exceed during any part of the working exposure) is 2 ppm (1.7 mg/cm^3), the indicative occupational exposure limit values established by Directive 2000/39/EC is 3 ppm (2.5 mg/m^3) for short-term (15-minutes) exposure period and the IDLH (Immediately Dangerous to Life or Health Concentrations) value set by NIOSH is 30 ppm.

In the event of fire, it is preferable to extinguish it with sand or extinguishing powder; use of water may lead to the formation of acid solutions.

Approvals

Food Contact

The fluorinated monomers used in the Halar copolymers (ethylene, chlorotrifluoroethylene) and terpolymers (ethylene, chlorotrifluoroethylene, perfluoropropylvinylether) meet the requirements of European Commission Directive 2002/72/EC and its amendments, relating to plastics materials and articles intended to come into contact with foodstuffs.

Halar® ECTFE grades comply with the specifications of the United States Food and Drug Administration (FDA) 21CFR 178.1380.

Several grades of Halar® are recognized under each of these standards. Information on current listings for specific grades is available from your Solvay Solexis representative.

International Water Contact Standards

Listings expire periodically and depending on market demand they may or may not be recertified. Contact your Solvay Solexis representative for the latest listing.

National Sanitation Foundation

NSF International is a no-profit, non-governmental organization that develops standards for public health and safety. It also provides lists of materials that conform to their standards.

NSF Standard 61 – Drinking Water System Components – Health Effects

The table below lists the Halar® ECTFE polymers certified to meet NSF Standard 61 at 85°C (185°F)

Table 16: Halar® ECTFE in compliance with NSF Standard 61

Grade
Halar® 300LC - Halar® 350LC - Halar® 500LC Halar® 901 - Halar® 902

Medical Applications

Biological tests ca rried out on Halar® ECTFE according to USP chapter 88 "Biological reactivity tests, in vivo" have demonstrated its compliance with the requirements of USP Plastic Class VI.

Although USP Class VI testing is widely used and accepted in the medical products industry, it does not fully meet any category of ISO 10993-1 testing guidelines for medical device approval.

Each specific type of medical product must be submitted to appropriate regulatory authorities for approval. Manufacturers of such articles or devices should carefully research medical literature, test and determine whether the fluoropolymer is suitable for the intended use. They must obtain all necessary regulatory agency approvals for the medical product including any raw material components.

Solvay Solexis does not allow or support the use of any of its products in any permanent implant applications. If you have any questions regarding the company's implant policy, please contact your Solvay Solexis representative

PROCESSING

Introduction

Halar® ECTFE is a melt-processable fluoropolymer that can be processed like conventional thermoplastic materials. Basic processing recommendations are described below.

Materials of c onstruction

All parts coming into contact with hot Halar® resin should be made of corrosion resistant materials such as "Xaloy" 306, B.C.I. No.2, Duranickel, or Hastelloy C. The hoppers, slides and throats should be sufficiently corrosion resistant so that rust is not introduced to the resin. It is especially important to prevent contact of the melt with copper alloys and unprotected tool steel which can reduce the melt stability of the resin. However, corrosion testing on metal plaques of carbon steel show that the current Halar® ECTFE technology reduces the corrosivity of the polymer.

Extruder type

Table 17: Typical extruder design

Machine size	No limitation
Length/Diameter ratio	20:1 – 30:1
Barrel heating	Standard heating methods, three or more zones
Flange heating	Required
Screw type	Single flight Compression ratio 2.5:1 – 3:1 Metering length: 25% Smooth transition (at least 3-4 flights)
Breaker plate	Recommended
Screen pack	60, 80, 100, 60 mesh (optional)
Drive	Adjustable from 5 to 100 rpm
Melt thermocouple	Recommended
Pressure gauge	Recommended

General considerations

Temperatures should be set to produce a melt temperature in the range of 260° to 280°C (500° to 540°F). At startup, the melt is kept at the low end of the temperature range. When all equipment is running satisfactorily, the melt temperature is adjusted to produce the best extrudate. At the end of all runs, the Halar® resin should be purged from the machine and the temperature lowered below 200°C (400°F).

Handling

No special treatment is required. Drying is unnecessary since the resin will not absorb water. The low water absorption inhibits the dissipation of frictional static charges. Consequently, the resin container should be covered at all times to prevent the deposition of contaminants on the pellets or powder.

When bringing the resin from a colder room, the closed drum liner should not be opened until the resin has reached the temperature of the processing room. This avoids condensing atmospheric moisture on the pellets or the powder.

Regrind

Regrind can be used with no loss in properties. It can be blended with virgin Halar® at a level not to exceed 15%. Regrind which has excessively darkened should be discarded.

Safety

Refer to the Halar® ECTFE Material Safety Data Sheet for detailed recommended procedures for safe handling and use. As with all polymer materials exposed to high temperatures, good safety practice requires the use of adequate ventilation when processing Halar® ECTFE. Ventilation should be provided to prevent exposure to fumes and gases that may be generated. Excessive heating may produce fumes and gases that are irritating or toxic.

Thermal stability
Although Halar® resin is a stable material, degradation can occur if the maximum recommended processing temperature is exceeded. Degradation is a function of time, temperature and nature of the metal surface in contact with the molten resin. Development of a grey-tan color in the extrudant serves as a warning sign that degradation is occurring. Black specks in the extrudant indicate severe localized degradation at hot spots or spots in the system. If black specks appear in the extrudant, it is recommended that the equipment be shut down and thoroughly cleaned.

Temperature limitations
Thermogravimetric analysis (TGA) of Halar® resin indicates that the polymer decomposes thermally at 350°C (662°F). Thermal decomposition can also be expected at lower temperatures if the exposure time is long enough (e.g., excessive residence time that may be encountered in extruders and injection molding machines). In practice, discoloration, black specks, etc. may be encountered when the melt temperature exceeds 300°C (575°F) for an extended period of time. If interruptions in processing occur, the resin should be purged immediately from the barrel. Polypropylene or high density polyethylene may be employed for this purpose. If purging is not possible, the temperature should be lowered to 200°C (400°F) while repairs are being made.

Recommendations for extrusion

Corrosion-resistant materials are recommended for all surfaces in contact with hot resin. Halar® resin can thermally degrade to HCl which is corrosive to metal surfaces. Studies have indicated that the resin begins to degrade after 45 minutes at 270°C (520°F); thus, residence times in extruders should be held to a minimum and care should be taken not to overheat Halar® ECTFE resin during processing.

Corrosion-resistant materials of construction are recommended not only to insure reasonable equipment life but also to protect Halar® resin from degradation. Molten Halar® resin will decompose on extended contact with iron, copper or brass. The products of decomposition are a black degraded resin with HCl gas.

The recommended practice when extrusion is interrupted is to purge the equipment.

Table 18: Typical extruder operating conditions

	Halar® 500 - 300	Halar® 901
Equipment temperatures	°C (°F)	°C (°F)
Rear barrel Mid barrel Front barrel Clamp Die	235-260 (460-500) 260-270 (500-520) 260-277 (500-530) 265-277 (510-530) 270-280 (520-540)	250-265 (480-510) 260-270 (500-520) 270-280 (520-545) 270-280 (520-545) 277-290 (530-550)
Melt temperature at the die exit	270-295 (520-560)	290 (560)
Melt pressure at the die	70-200 bar (1000-3000 psi)	70-200 bar (1000-3000 psi)

Good extrusion practice recommends that the temperature profile be developed upward from the minimum temperatures recommended. This will ensure optimum results with no danger of degradation.

Recommendations for injection moulding

Conventional reciprocating single screw extruders are employed.

Corrosion-resistant materials are recommended for all surfaces in contact with hot Halar® ECTFE resin. This requirement pertains to inside cylinder walls and the screw. Some surface-hardened tool steels have been used successfully in limited duration runs. The standard practice of never allowing the hot resin to remain stagnant in the injection moulding equipment should be carefully followed. If moulding is interrupted, the resin should be purged out of the equipment immediately with polypropylene or high-density polyethylene. If purging is not possible, temperatures should be lowered to 200°C (400°F) while changes are being made.

Shot size

In injection moulding of Halar® resin, the recommended shot size (including sprue and runners) is between 40 and 70 % of machine capacity. If undersized shot weights are used, the resin tends to degrade because of long residence times in the cylinder. Oversized shots result in uneven heating and/or cold materials.

Injection moulding conditions

Part design, mould design, cycle time and plasticating capacity of the press cause moulding condition to vary from part to part. A certain amount of trial and error is therefore necessary to determine optimum moulding conditions. It is recommended to start at the lower temperature and pressure levels and gradually increase alternately until optimum is achieved.

Temperature of the injection cylinder

Temperatures higher than 287°C (550°F) should be avoided. As a general rule, temperatures should not be set higher than necessary to obtain rapid fill at reasonable injection pressures.

Injection pressure

Pressure exerted on the material can range from 50 bar (700 psi) to 1380 bar (20000 psi); thinner sections require higher pressures.

Mould temperature

Mouldings with good surfaces and optimum physical properties ordinarily require mould temperatures between 90 and 150°C (200-300°F). if only a water heater is available, it should be run as hot as possible. With this type of heater, the surface of the parts will be somewhat less glossy and small cavities may be difficult to fill. Oil or electrical heating is preferred.

Mould cycles

The time cycle required for a particular mould depends to a very large extent upon the design of the mould and the thickness of the part.

Usually total cycle time is 20-40 seconds for a part less than 3 mm (1/8 inch) thick. The ram forward time is approximately 10 seconds. A thicker part requires longer time with 60-150 seconds being typical for a part of over 6 mm (¼ inch) thickness. In this case, the ram forward time would be increased to 25 seconds.

Mould release

Halar® seldom requires a mould release agent. If it is found necessary to use a release agent, one that has been found to work well is FreKote 44-NC manufactured by Dexter Corporation (Seabrook, New Hampshire).

The typical injection moulding conditions are shown in Table 19.

Table 19: Typical injection moulding conditions	
Temperatures	
Rear cylinder	230-245°C (450-470°F)
Mid cylinder	245-260°C (470-500°F)
Forward cylinder	260-275°C (500-525°F)
Nozzle	255-265°C (490-510°F)
Mould	100-110°C (220-230°F)
Pressure exerted on material	55-140 bar (800-2000 psi)
Timing	
Total cycle (seconds)	20-150
Ram forward time (seconds)	10-25
Screw speed (rpm)	30-100

Recommendations for compression moulding

The following procedure can be followed as a guideline for a typical compression moulding cycle.

Use a positive pressure mould; it consists of a top plate, a bottom plate and a frame.

Heat the mould to 260°C (500°F).

Feed the room temperature pellets into the mould.

Apply a pressure of 15 bar (200 psi) for 5-10 seconds.

Reduce pressure to 5 bar (40 psi) and maintain pressure; the press will close gradually as the material melts; always keep the melt and plates in contact; complete melting will take approximately 1-10 hours for a 15 mm (5/8 inch) thick plaque.

Increase the pressure in steps throughout the melting cycle until 15 bar (200 psi) is reached.

After 1-10 hours, turn on the cold water.

Maintain 15 bar (200 psi) until the plaque is at room temperature (about 20 minutes for a 15 mm, 5/8 inch thickness)

NOTE: All the information given in these pages can only be considered as examples for processing of Halar® ECTFE. It cannot be considered as specifications or as a guarantee for successful extrusion or moulding of Halar® ECTFE.

SECONDARY PROCESSING

Welding

Halar® ECTFE is a thermoplastic material that can be welded using the standard techniques known for common plastics, for example PE or PVC. In particular, hot gas welding is routinely used to thermo-weld Halar® ECTFE liners. Tensile tests performed on the welded seams have proven that fusions are 100% as reliable as the original material.

The following general recommendations will apply when hot gas welding Halar® ECTFE liners.

Equipment
Use welding guns with heating power of 800 W or higher.

Proper temperature measurement is crucial to ensure consistent welds. It is good practice to measure the temperature of the gas stream inside the nozzle, at 5-7 mm (1/4") from the outlet.

Good quality Halar® ECTFE welds can be obtained when nitrogen or clean and dry air is used. Welding in nitrogen is recommended when the welding facility lacks a clean and dry source of air.

Different welding tips are available. High speed welding tips are used for the primary weld, while tacking tips can be used to hold in place the various sections of the liner.

Health, Safety and Environment
As with all polymers exposed to high temperatures, good safety practice requires the use of adequate ventilation when processing Halar® ECTFE. Excessive heating may produce fumes and gases that are irritating or toxic. Ventilation or proper breathing equipment should be provided to prevent exposure to fumes and gases that may be generated.

Refer to the Halar® ECTFE Material Safety Data Sheets for detailed recommended procedures for safe handling and use. Contact your regional Solvay Solexis office for a copy.

Recommendations for Welding
Use round welding rods made of the same Halar® grade of the profiles to be welded.

Warning: Welding together profiles made from different grades is not recommended. If it is unavoidable contact your regional Solvay Solexis Technical Service representative.

Scrape carefully the surfaces to be welded. When using fabric backed sheets, remove the fabric along the welding line (2 or 3 mm on each sheet) to prevent fibers inclusions. Align and hold the two sheets to be welded at a distance not larger than 0.5-1 mm (20-40 mils).

V-shape the groove between the two sheets using the appropriate scraper. Avoid the use of makeshift tools as it could result in an irregular weld bead. Thoroughly clean the welding area and the welding rod.

Warning: The use a cleaning solvent may cause fire hazard due to the heat generated by the gun.

Clean the nozzle of the welding gun with a brass brush, adjust the air flow at 50-60 standard liters/minute (1.8 – 2.1 cfm) and set the temperature of the welding gun as indicated in the table below.

Table 20: Welding gun temperature

Halar® ECTFE grade	Welding Gun Temperature
901, 300, 350, 500	380 - 425°C (380-400°C for thin liners)
902	425 - 495°C

Note: The temperatures recommended in this document must be intended as measured inside the nozzle. If the welding gun is equipped with a thermometer, check the readings using a thermocouple before commencing the welding operations.

Weld holding the gun at a 45-60° angle and adjust the welding pressure and speed ensuring that the welding rod and the sheets melt simultaneously. Welding speeds in the 0.1-0.5 cm/s (or 1/16"-1/4" per second) range are usually suitable.

If the speed is too low, the welding rod will overheat and start flowing; on the other hand, if the speed is too high, the welding rod will not melt properly and the groove between the two sheets will not be duly filled by the molten material.

Similarly, if the welding pressure is too low, the groove between the two sheets will not be completely filled, while an excessive force may cause dimples along the welding bead which will eventually act as stress concentrators.

Machining

The machining of Halar® ECTFE is very similar to that of nylon. The following procedures provide guidelines for successful machining operations with this versatile fluoropolymer.

Internal stresses may often be created during the machining of Halar® ECTFE. These stresses may lead to warping of a component. To avoid creating stresses during machining, attention should be given to the following points:

1. Use sharp tools
2. Avoid excessive clamping or cutting forces
3. Prevent overheating by use of coolants

Generally, when the above principles are followed, stress-free parts will be obtained. In those cases where optimal dimensional control is required, annealing is recommended.

Annealing consists of a heat treatment in oils or other liquids at temperatures about 50°F (30°C) above the maximum exposure temperature to be encountered. At 300°F (150°C) in sections of 1/2-inch, 15 minutes is adequate. On sections 1-inch in thickness, 4 hours is normal, and an additional 2 hours is added for each additional inch of thickness. Due to the low thermal conductivity of Halar® ECTFE, slow heating and cooling is required for this step.

Halar® ECTFE can easily be machined on most standard metal working machines. For best results, particularly on long production runs, the following should be considered:

1. Due to the previously mentioned low thermal conductivity, the surface temperature of the work will rise rapidly during machining. To prevent this, coolants are recommended.
2. The relatively low melting point of the material, 468°F (242°C), combined with the low thermal conductivity may cause softening of the work surface unless the proper machining procedures are followed.

For turning, the general type of tool used for machining soft metals such as aluminum is also suitable for Halar® ECTFE. For optimum results, the angles should be somewhat different. Rake angles of 30 to 40° with a side clearance angle of 5° as well as a 5° end clearance and end cutting edge angles of 8 to 10° are used. The cutting edge of the tool should be the same height as the turning center – too low a tool position causes "running" of the work on the tool and too high a position impairs the cutting action.

In order to obtain a smooth surface finish on the work, it is advisable to use a rounded tool for the final cut rather than the one described above which is intended for general purpose turning. In addition to the use of a coolant, the lapping of the tool face will contribute to a smoother finish.

For cut-off, a tool with 5° side reliefs, 10 to 15° end clearance, and 5° side clearances with the top side of the tool level to keep from "biting" into the work is recommended.

In turning Halar® ECTFE, there is a tendency to form a continuous ribbon which may wind around the work. This can be overcome by using the proper rake angle and adjusting the cutting speed. Burring can be avoided or minimized by using sharp, well designed tools, proper cutting speeds, and a good coolant. In order to prevent deformation of thin-walled parts, it may be desirable to clamp the work in a collet rather than at three or four points.

For milling, standard cutters (gear, wheel, face and side, cylindrical, key-way, and finger) can be used with Halar® ECTFE as with steel, provided they are sharp. The angles of these cutters need not be changed although the angles used on cutters designed for aluminum are the best since their shape is adapted to machining soft, tough materials.

Basically, the same RPM, feed, and cutting depth would be used in milling as in turning. A good coolant is also essential. In order to avoid distortion of the work and "biting" of the milling cutter, careful, uniform clamping is necessary.

To avoid the formation of burrs during milling, it may be advisable to back up the work with another plate. A less expensive material such as nylon could be used.

Halar® ECTFE can be readily sawed. When using a power hacksaw, there are no special procedures different from steel. There are no limits for the thickness of the material. It is desirable to use a coarse saw blade with about 4 to 6 teeth per inch, and there should be some set to these.

A vertical band saw may also be used but with a little more care. The speed of the band should not be too high (for example, 1500 ft/min for a 3-inch thickness). Again, a coarse tooth (4 to 6 per inch) such a skip tooth or buttress type should be used. No coolant is used normally in this method, and the material should not be pressed too hard against the blade.

When using circular saws, regular, hollow ground metal working blades are acceptable for thin sections up to about 1/3-inch. For heavier sections, special skip tooth or buttress type blades are required.

To drill Halar® ECTFE, standard drills are generally suitable. Sharp bits and a cooling fluid are advisable. Regular up and down movement of the drill helps in cooling and in clearing the hole. The feed should be reduced as the depth of the hole increases.

Due to the elasticity of Halar® ECTFE and because of the temperature rising during drilling, it may be necessary to use a drill diameter 0.004 to 0.020 inch greater than the size of the derived hole. When several holes have to be drilled close to one another, it may be necessary to plug holes already drilled to prevent deformation. These procedures are best established by experience.

Reaming is difficult because of the elasticity of the material. The best results are obtained by using a sharp, spiral fluted reamer. Some machinists fill the hole to be reamed with a wax or tallow prior to reaming.

Screw threading and tapping is quite easy with Halar® ECTFE. It is advisable to use a cutting oil to avoid excessive heat and ensure the best finish. The use of the first tap can be omitted and for very small holes only the third tap need be used.

Halar® ECTFE sheet can be punched easily. The tools must be carefully ground and lapped if possible. The work to be punched should be tightly clamped.

Halar® ECTFE rods and tubes can be centerless ground on conventional equipment. It is recommended that the work center be approximately 0.100 inches below the center line of the wheels and that water-soluble oil be used as a coolant.

NOTE: All the information given in these pages can only be considered as examples for processing of Solef® and Hylar® PVDF. Please contact Solvay Solexis for detailed information.

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