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Hyflon[®] PFA

Design & Processing Guide

**SPECIALTY
POLYMERS**

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Introduction

Hyflon® PFA is the range of melt processable perfluoroalkoxy (PFA) fluorocarbon resins specifically designed for high temperature service and virtually universal chemical resistance. It is a family of semi-crystalline resins that combines exceptional value with high performance properties.

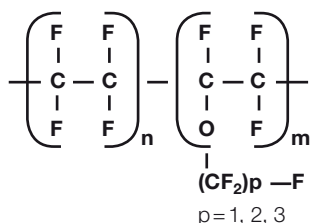
The Hyflon® PFA range consists of two product series: the P series and the M series. Both can be used in applications as diverse as tubing, fittings, tank linings, tower packing, fittings and valve linings, films, high purity, fibers, heat tracing wiring, avionics and specialty cables.

The excellent resistance against aggressive environments and against thermal stress cracking makes Hyflon® PFA particularly suitable for pipes and tubes in the field of transportation of chemicals and in the oil industry. Thanks to the ease of processing using transfer molding techniques, Hyflon® PFA resins can be used for linings of valves, tubes, and fittings where special requirements of thermal and chemical resistance are necessary. These resins can also be injection molded to obtain self-supported items like fittings and valves.

In the electrical industry, Hyflon® PFA products are used as primary insulation for high temperature hook-up wires. Hyflon® PFA can be used, under continuous service, up to temperatures of 250–260 °C. Outstanding thermal resistance makes these polymers suitable for insulation of heating cables as well. Thanks to their good dielectric properties, Hyflon® PFA resins are suitable for applications where low dissipations are required at very high frequencies (up to some Giga Hz), such as insulation of communication cables and components for electronic devices.

This design guide contains specific information about Hyflon® PFA products and provides the design engineer the specific information he needs to use them. This document focuses on the standard melt processable grades. Specially designed grades are also available to meet specific customer needs. To know more about the specialty grades or for any further information about Hyflon® PFA resins, contact your Solvay Specialty Polymers representative.

PFAs are copolymers of tetrafluoroethylene (TFE) and perfluoroalkylvinylethers with the following chemical formula:



The type and frequency of the side chains dictate the thermo-mechanical properties of the polymer. As a general rule a high number of side chains will provide:

- Lower thermal rating
(low melting point and low creep resistance)
- High tenacity (high stress/strain at break)
- High flex-life

Also the size of the side chain plays an important role. Methyl vinyl ether (MVE) side chains are smaller than ethyl vinyl ether (EVE) which in turn are smaller than propyl vinyl ether (PVE). The bigger the side chain, the lower amount of co-monomer is needed to achieve the same degree of backbone modification, thus allowing the design of higher thermal rating resins.

Table 1: Perfluoroalkoxy comonomers

MVE	$\text{CF}_2 = \text{CF} - \text{O} - \text{CF}_3$
EVE	$\text{CF}_2 = \text{CF} - \text{O} - \text{CF}_2 - \text{CF}_3$
PVE	$\text{CF}_2 = \text{CF} - \text{O} - \text{CF}_2 - \text{CF}_2 - \text{CF}_3$

The polymer molecular weight is another important parameter affecting the mechanical properties of a specific composition. Usually the melt flow index (MFI), measured at 372 °C with a 5 kg weight, is used to provide an indication of the molecular weight: a high molecular weight leads to high viscosity that is low MFI resin. As a general rule, low MFI resins show:

- High tenacity
- High flex-life

Again the size of the side chains can be used to balance the effect of low molecular weight and a big co-monomer will allow the design of high flex life materials even at high MFI.

Physical Properties

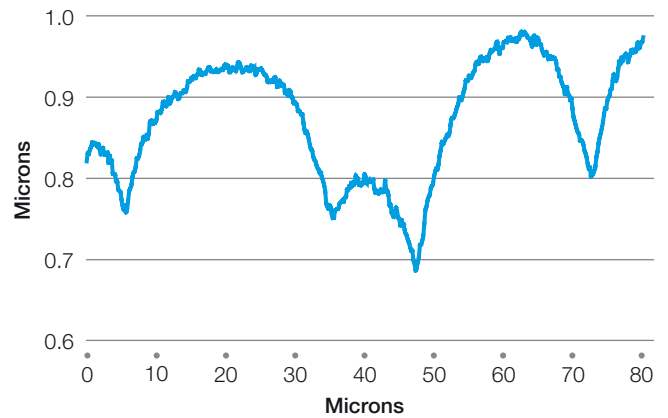
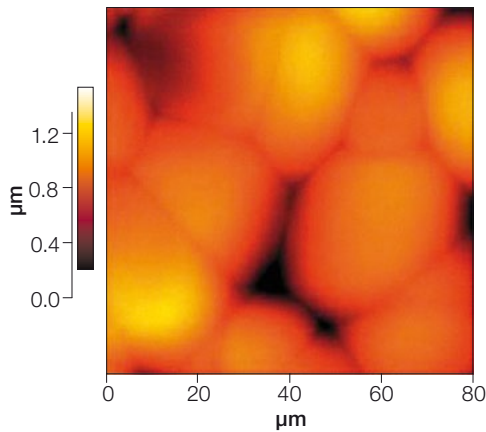
Surface Properties

Surface quality strongly depends on processing conditions, yet Hyflon® PFA M series resins offer lower surface roughness values in comparison with other perfluorinated products.

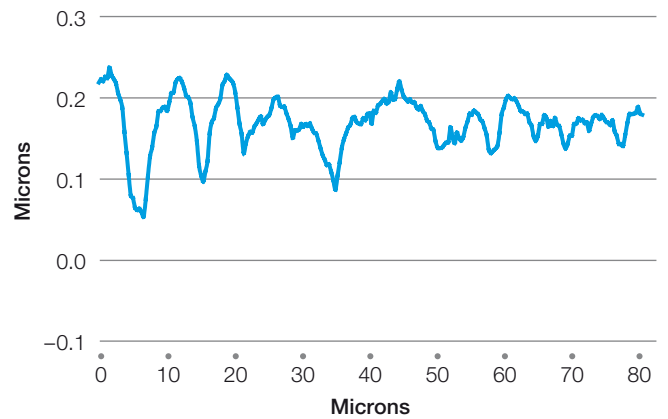
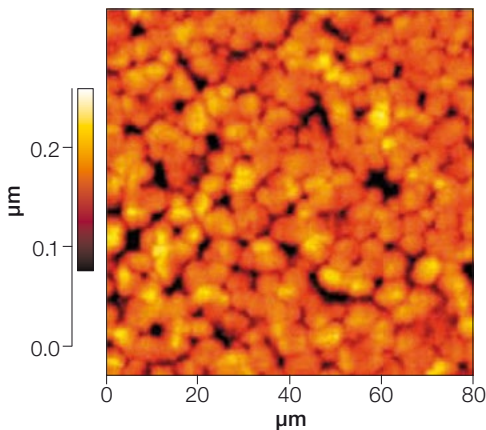
Comparative tests have shown that Hyflon® PFA M series resins can offer 2 to 10 times lower R_a values than competitive PFAs (R_a , or roughness average, is the average of peak and valley distances measured along the centerline of one cross section).

Fig. 1: Atomic force microscope pictures of the surface of PFA pipes

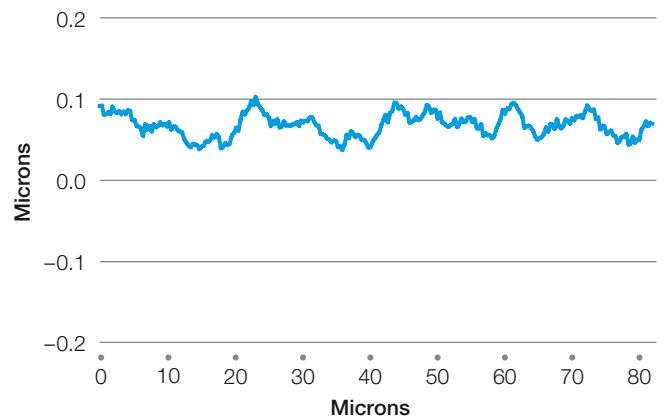
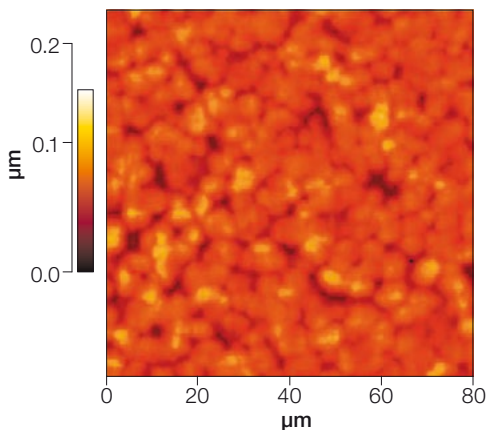
Competitive PFA



Hyflon® PFA P series



Hyflon® PFA M series



Optical Properties

Thanks to their characteristic crystal morphology, Hyflon® PFA resins show very low haze values and outstanding light transmission properties in the ultraviolet, visible and infrared regions. Transmittance is defined as the ratio of the transmitted to the incident light. Haze is defined as the light which in passing through the specimen deviates from the incident beam by forward scattering (> 2.5 degrees).

In Figure 2 the haze values measured in accordance to ASTM D1003 are charted vs. the specimen thickness. It is worth noting that the haze values cannot be projected for small thicknesses as surface roughness and/or defects can strongly affect the measured value.

In Figure 3 and 4, transmittance is charted vs. the incident light wavelength for Hyflon® PFA M and P series and for various thicknesses. The low transmittance in the UV region is due to the scattering that light undergoes in crystalline structures such as spherulites and lamellae.

Hyflon® PFA M series grades can offer better transmittance thanks to their unique formulation, which features a less crystalline structure. The Hyflon® PFA refractive index value is around 1.35.

Fig. 2: Hyflon® PFA haze vs. specimen thickness

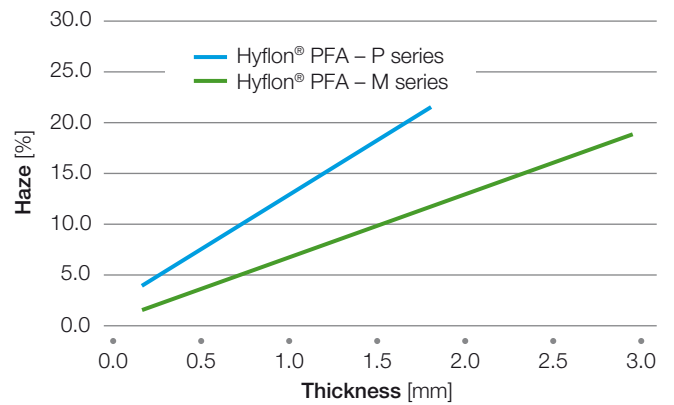


Fig. 3: Hyflon® PFA transmittance in the UV and visible region (film thickness = 500 microns)

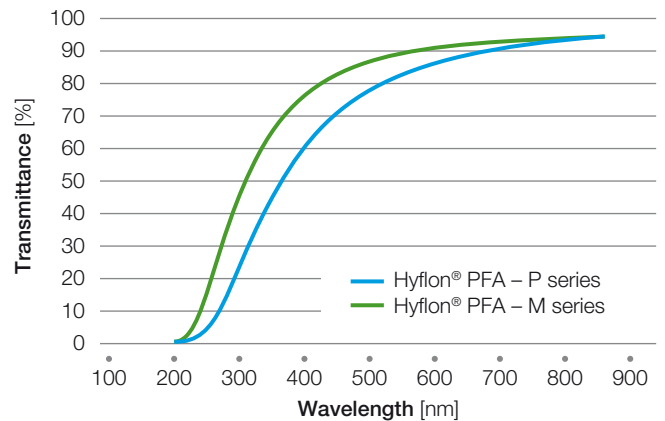
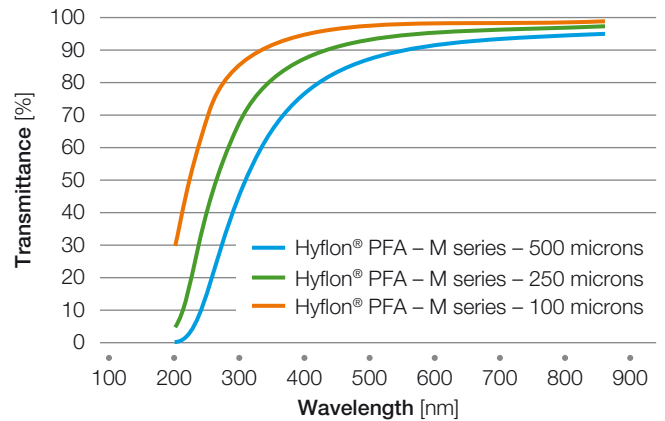


Fig. 4: Hyflon® PFA M series transmittance in the UV and visible region



Mechanical Properties

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 D1708. 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 5 is obtained for PFA resins. It is characterized by yielding, cold-draw and strain hardening.

Hyflon® PFA shows good mechanical properties over a broad range of temperatures, from cryogenic to 250–260 °C (482–500 °F). Of course, mechanical properties decrease as temperature increases. The typical tensile properties of Hyflon® PFA are given in the following Table and Figures.

Fig. 5: Typical PFA strain-stress curves

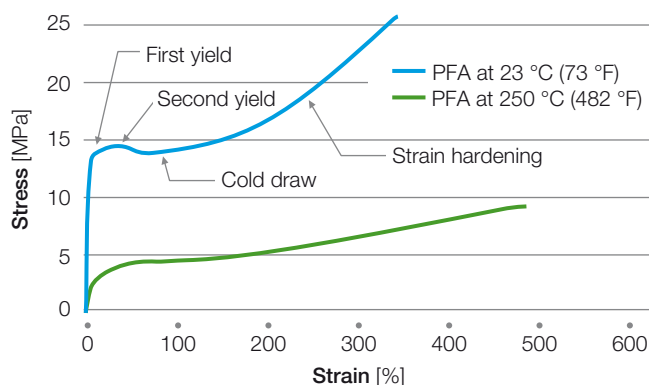


Table 2: Hyflon® PFA typical tensile properties

Properties	Units	Hyflon® PFA		Test Method
		M Series	P Series	
Young modulus				ASTM D1708, 1 mm/min
23 °C (73 °F)	MPa (kpsi)	500–600 (72.5–87)	500–600 (2.5–87)	
200 °C (392 °F)	MPa (kpsi)	17–23 (2.4–3.3)	44–48 (6–7)	
250 °C (482 °F)	MPa (kpsi)	16–22 (2.3–3.3)	30–40 (4–6)	
Stress at yield				ASTM D1708
23 °C (73 °F)	MPa (kpsi)	12–15 (1.7–2.2)	14–15 (2.0–2.2)	
200 °C (392 °F)	MPa (kpsi)	3–4 (0.4–0.5)	4–5 (0.6–0.7)	
250 °C (482 °F)	MPa (kpsi)	2–3 (0.3–0.4)	3–4 (0.4–0.6)	
Stress at break				ASTM D1708
23 °C (73 °F)	MPa (kpsi)	21–32 (3.0–4.6)	21–32 (3.0–4.6)	
200 °C (392 °F)	MPa (kpsi)	8–12 (1.1–1.7)	13–15 (1.9–2.2)	
250 °C (482 °F)	MPa (kpsi)	5–8 (0.7–1.1)	10–12 (1.4–1.7)	
Elongation at break				
23 °C (73 °F)	%	275–360	275–360	
200 °C (392 °F)	%	360–400	450–500	
250 °C (482 °F)	%	400–450	500–550	

Fig. 6: Hyflon® PFA modulus vs. temperature

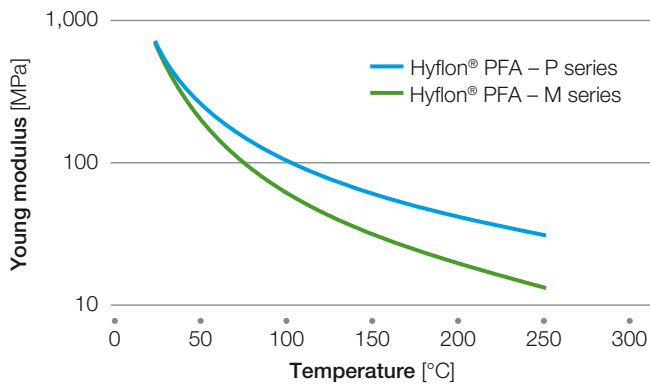


Fig. 7: Hyflon® PFA stress at yield vs. temperature

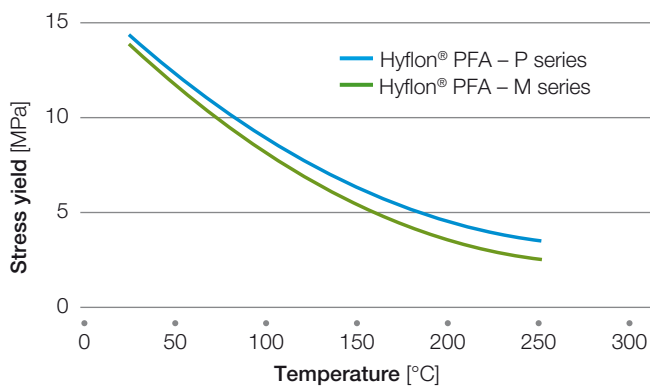


Fig. 8: Hyflon® PFA stress at break vs. temperature

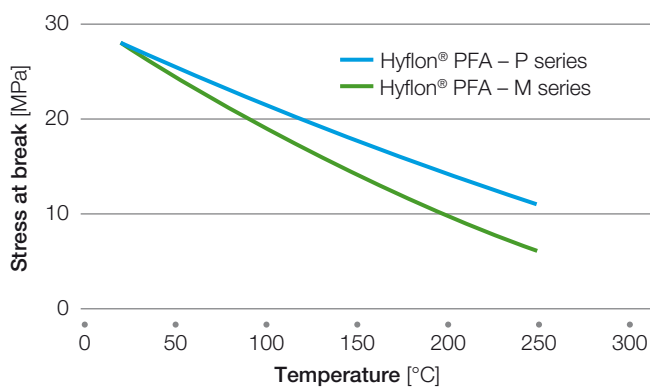
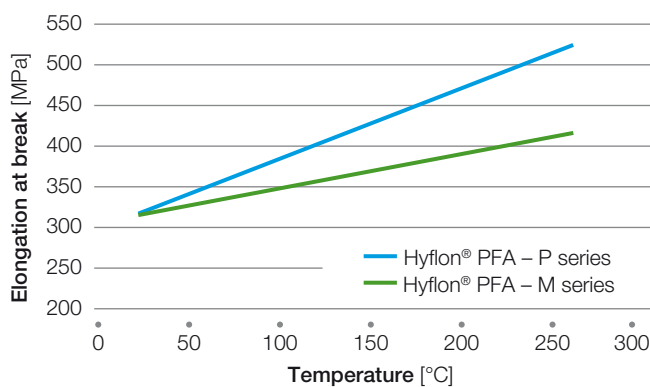


Fig. 9: Hyflon® PFA elongation at break vs. temperature



Creep Properties

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. Creep occurs below the yield point and it is very important for applications such as self supported tubes, hoses, gaskets and seals.

Hyflon® PFA does not undergo any progressive embrittlement at high temperature, i.e. it is not affected by thermal stress cracking failures up to 250–260 °C.

Fig. 10: Tensile creep curves at 200 °C, Hyflon® PFA M620

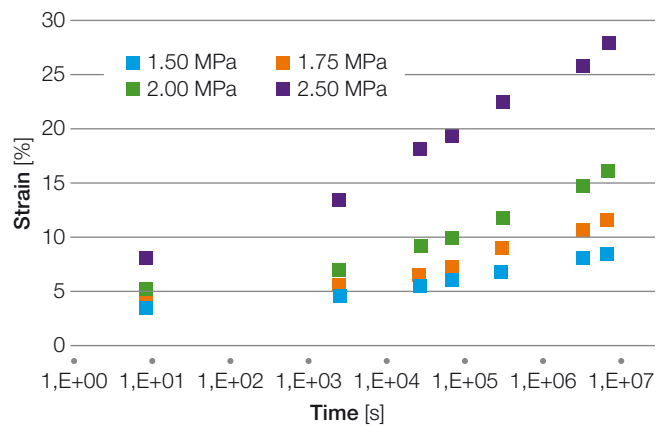


Fig. 11: Tensile creep curves at 200 °C, Hyflon® PFA P420

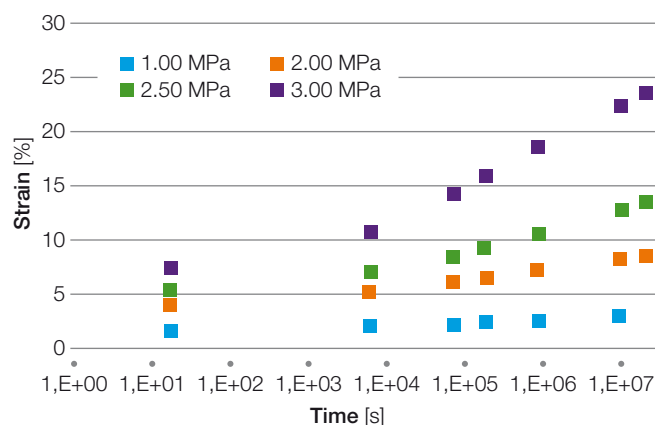
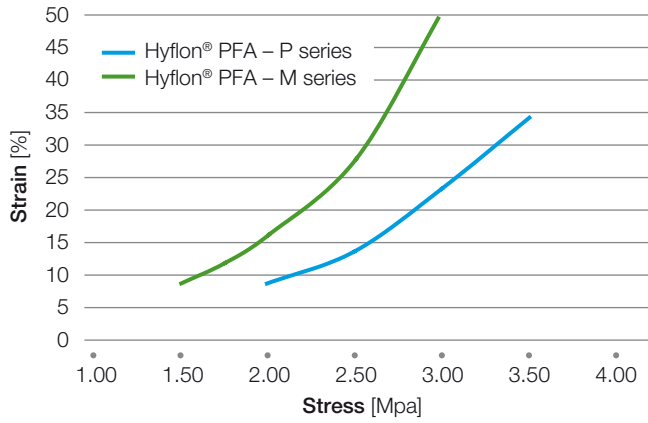


Fig. 12: Isochronous stress-strain curves for a 2,000 hour creep time at 200 °C



Folding Endurance and Stress Crack Resistance

Stress cracking and fatigue are among the most common failure mechanisms for plastics. Failures appear at point of stress concentration and may depend on a number of environmental conditions like load, temperature variations, presence of chemicals, etc.

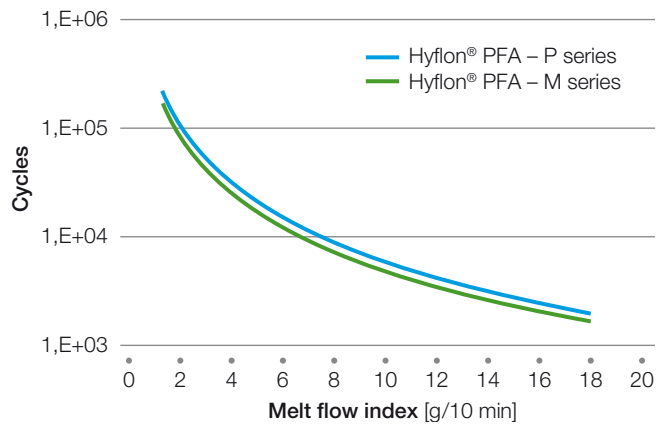
One test that can provide an indication of the stress crack and fatigue resistance of a material is the MIT folding endurance test (ASTM D2176). In this test a fixed strain is applied to a thin film folding it at a pre-set rate. The number of folding cycles to failure is called flex-life or folding endurance. The effect of changes in molecular weight and MFI on physical properties is shown in Table 3.

Table 3: Effect of changes in molecular weight and MFI

Properties	As Molecular Weight Increases, Property:	As Melt Flow Index Increases, Property:
Stress crack resistance	increases	decreases
Fatigue resistance	increases	decreases
Flex-life	increases	decreases

In Figure 13 the flex life of Hyflon® PFA resins is charted vs. the melt flow index for a 0.3 mm film (a thinner film would lead to higher flex-lives). It is important to note that the designer can use flex-life data as an indication only; service life calculation should include all the environmental conditions.

Fig. 13: Flex-life vs. melt flow index at 23 °C (ASTM D2176, thickness = 0.3 mm)



Electrical Properties

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

The volume resistivity is defined as the resistance of a unit cube of material. 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.

The 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 with a vacuum replacing 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.

The dissipation factor (also referred to as loss tangent or $\tan D$) is a measure of the dielectric loss (energy dissipated) of alternating current to heat. In general, low dissipation factors are desirable.

The electrical properties of Hyflon® PFA show very high values of volume and surface resistivity, which undergo insignificant changes with the temperature. The M series shows slightly lower dielectric constant than the P series over a wide range of temperatures and frequencies. The dissipation factor shows insignificant changes in the range of frequencies from 50 Hz to 100 kHz.

Table 4: Hyflon® PFA typical electrical properties

Properties	Units	Hyflon® PFA		Test Method
		M Series	P Series	
Volume resistivity	$\Omega \cdot \text{cm}$	$> 10^{17}$	$> 10^{17}$	ASTM D257
Surface resistivity	$\Omega \cdot \text{cm}$	$> 10^{17}$	$> 10^{17}$	ASTM D257
Arc resistance	s	> 200	> 200	ASTM D495
Dielectric constant				
at 50 Hz		2.10	2.10	ASTM D150
at 100 kHz		1.95	2.05	ASTM D150
Dissipation factor				
at 50 Hz		$< 5 \cdot 10^{-4}$	$< 5 \cdot 10^{-4}$	ASTM D149
at 100 kHz		$< 5 \cdot 10^{-4}$	$< 5 \cdot 10^{-4}$	ASTM D149
Dielectric strength at 50 Hz				
0.254 mm (10 mil) thick	kV/mm	90–100	90–100	ASTM D149
1 mm (39 mil) thick	kV/mm	35–40	35–40	ASTM D149

Environmental Resistance

Chemical Resistance

Hyflon® PFA have excellent chemical resistance over a wide range of temperatures and pressures. They are not attacked by inorganic bases, strong mineral acids, inorganic oxidizing agents commonly used in the chemical and process industry and to most of organic compounds.

Hyflon® PFA react with fluorine and molten alkali. Elemental alkali metals (for example sodium) can replace fluorine in the polymer. This property is widely used to etch the surface of PFA so that it can be bonded.

Chemical resistance data of Hyflon® PFA resins are available through Solvay Specialty Polymers' Tech Service or just downloading the product chemical resistance charts from www.SolvaySpecialtyPolymers.com

Permeability

The water and solvent permeation of PFA is in general very low. Since these resins are melt processed they are completely void free and the overall permeation is substantially lower than the permeation shown by PTFE. Independent testing shows that Hyflon® PFA polymers outperform competing materials in permeation resistance thanks to Solvay Specialty Polymers proprietary polymerization technology.

In Figure 14 Hyflon® PFA Permeability (P) is charted vs. temperature for various substances. The dependence on temperature is of the exponential type:

$$P = P_0 \cdot e^{E_p/RT}$$

where P_0 is the permeability constant, E_p the activation energy, R the gas constant and T is the absolute temperature.

Table 5: P_0 and E_p values

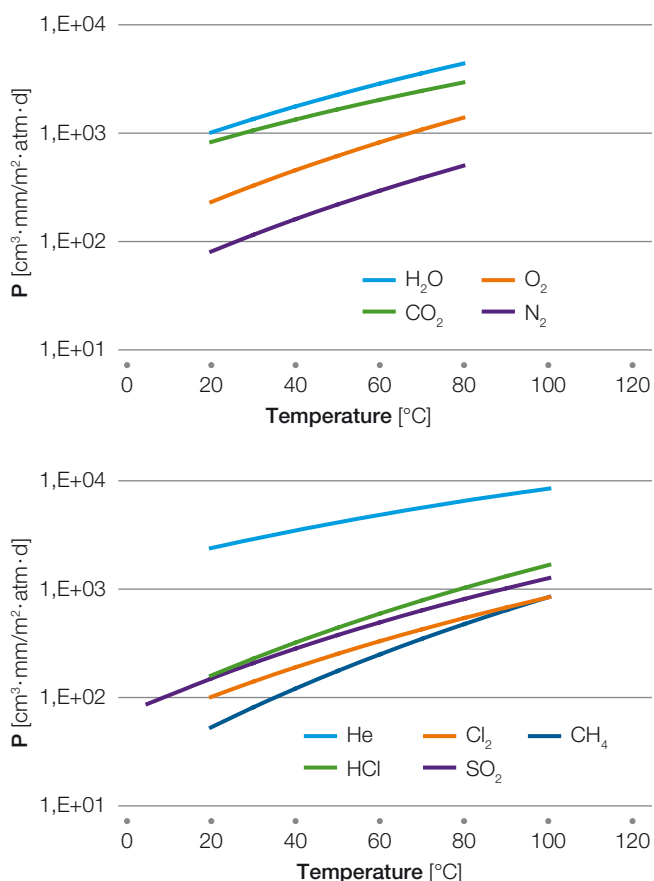
Chemical	P_0 [$\frac{\text{cm}^3 \cdot \text{mm}}{\text{m}^2 \cdot \text{atm} \cdot \text{day}}$]	E_p [kJ/mol]	Temperature Range [°C]
O ₂	$7.3 \cdot 10^6$	25.1	23–80
N ₂	$3.1 \cdot 10^6$	25.6	20–80
CO ₂	$1.2 \cdot 10^6$	17.7	20–80
H ₂ O	$4.7 \cdot 10^6$	20.5	20–80
He	$1.0 \cdot 10^6$	14.5	20–100
CH ₄	$2.6 \cdot 10^7$	31.8	20–100
SO ₂	$3.7 \cdot 10^6$	24.5	5–100
Cl ₂	$2.3 \cdot 10^6$	24.3	20–100
HCl	$1.1 \cdot 10^7$	27.0	20–80

Permeability and Diffusivity (D) data for more chemicals at 23°C (73°F) are listed in the table below.

Table 6: Permeability and diffusivity values

Chemical	T [°C]	P [g·mm/m ² ·day]	D [m ² /s]
HCl (from 37% solution)	23	0.20	$9.0 \cdot 10^{-11}$
HNO ₃ (from 65% solution)	23	0.01	$1.5 \cdot 10^{-11}$
SO ₃ (from Oleum 20%)	23	$2.9 \cdot 10^{-4}$	$2.0 \cdot 10^{-12}$
H ₂ SO ₄ (from 96% solution)	23	$< 10^{-4}$	$< 10^{-11}$

Fig. 14: Hyflon® PFA permeability to various chemicals vs. temperature



Thermal Aging

Hyflon® PFA resins have been designed to retain their properties over a wide range of temperatures from cryogenic to 250–260 °C (482–500 °F). Figure 15 and 16 show the effect of heat on yield stress and stress at break of Hyflon® PFA M series specimens exposed solely to hot air for extended periods of time.

Processing, applied stress and environmental conditions can influence the temperature rating of PFA resins as any other materials and designers have developed their own test methods for rating plastic products under specific service conditions.

For example in the Wire & Cable industry UL 1581 (Reference Standard for Electrical Wires, Cables and Flexible Cords, formerly UL 758) is often referenced and rates both Hyflon® PFA M and P series 250 °C; on the other hand NEMA 27500 (Standard for Aerospace and Industrial Electrical Cable, formerly Mil 27500) rates the Hyflon® PFA P series 260 °C.

It is important to note that the designer should always select the most proper test method and include all the environmental conditions in the service life calculation.

Weathering Resistance

PFAs are not attacked even after very long periods of exposure and retain virtually all their original physical properties and molecular characteristics. Specifically PFAs are not affected by ultraviolet (UV) light.

Resistance to High Energy Radiation

Like polytetrafluoroethylene (PTFE), perfluoroalkoxy resins have limited resistance to high energy ionizing radiation. Further to exposure, PFAs undergo a reduction of their tensile strength and elongation at break. For example a 5 MRad will cause a 95 % reduction of the resin's elongation at break. A 50 MRad exposure will cause complete polymer degradation.

Resistance to Fire

PFA resins have inherent flame resistance due to their high Limiting Oxygen Index (LOI).

The oxygen index is defined by ASTM D2863 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. 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.

The LOI of PFA resins is greater than 95 %.

Fig. 15: Stress at yield retention vs. exposure time at 250 and 270 °C for Hyflon® M series

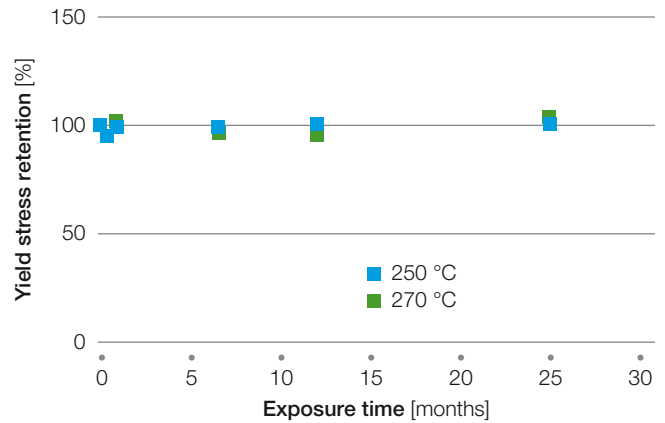
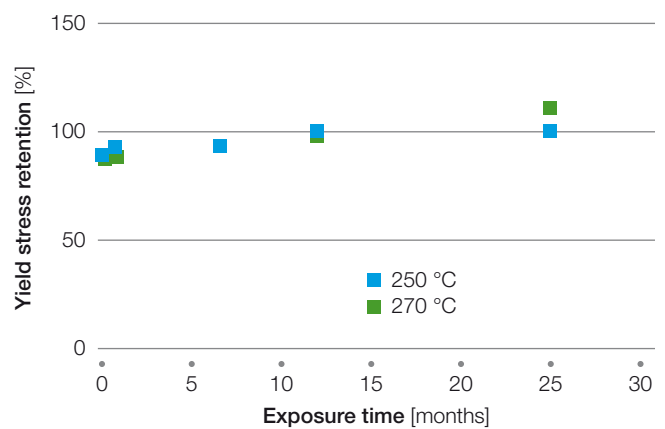


Fig. 16: Stress at break retention vs. exposure time at 250 and 270 °C for Hyflon® M series



Safety

Refer to the Hyflon® PFA Material Safety Data Sheets (MSDS) for detailed recommended procedures for safe handling and use. Contact your regional Solvay Specialty Polymers office for a copy.

As with all polymers exposed to high temperatures, good safety practice requires the use of adequate ventilation when processing Hyflon® PFA. 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.

Processing Basics

General Considerations

Hyflon® PFA are truly thermo-processable resins. They are semi-crystalline polymers. When heated above their melting point they do not cross-link and undergo a consistent reduction of viscosity which makes it possible to process them with the standard techniques known for common plastics, for example, polyethylene or PVC. The outstanding thermal stability of Hyflon® PFA allows long residence times in the molten state without degradation or reduction of properties.

Color Masterbatches

It is recommended only to use Hyflon® PFA based color masterbatches. Masterbatches based on other fluoropolymers can negatively influence the superior processing and electrical performance of Hyflon® PFA resins. A list of suppliers can be obtained from your Solvay Specialty Polymers sales representative.

Rheological Properties

The flow behavior of Hyflon® PFA is determined through dynamic rheology in the linear viscoelastic regime (10^{-2} – 10^2 rad/s) and through capillary rheometry (1 – 10^4 1/s).

At low shear rates, and independently of the shear viscosity value the flow behaviors are Newtonian. When critical shear rate values are reached, melt instability occurs. These values are inversely proportional to the shear viscosities. Processing must be done below the critical shear rate.

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. When bringing the resin from a colder room, the closed drum liner should not be opened until the resin has come to the temperature of the processing room. This avoids condensing of atmospheric moisture on the pellets. Provide for good ventilation and/or adequate suction equipment in working areas.

Materials of Construction

It is important to consider that all parts coming into prolonged contact with the molten Hyflon® PFA resin should be made with corrosion resistance materials. Chrome or nickel plating is normally sufficient protection in the case of brief processing tests.

Hyflon® PFA polymers are suitable for extrusion using techniques normally applied for other thermo-processable plastics, provided that the extruder is equipped with corrosion resistant alloys. Extruders with L/D ratio of 20 : 1 to 30 : 1 are recommended. Extruders should be equipped with independently controlled heaters capable of accurate temperature control up to 450 °C (840 °F).

Many different screw designs can be used. Single flight screws are recommended while barrier-flights should be avoided. A typical screw design consist of a long feed section (at least 12 flights), followed by a 2 to 6 flight transition and a 5 to 7 flight metering section. Breaker plate and screen pack are not normally used even when using color master batches.

Wire and Cable Extrusion

An overview of the temperature, tooling and equipment requirements for cable extrusion is given in Table 7. Temperatures set must be chosen and tuned according to the extruder size and to the maximum achievable flow rate. In general, the higher the flow rate, the higher the temperature profile must be and the shorter the extruder length, the higher the temperature profile. It is worthwhile noting that the most effective temperature for changing the melt temperature and thus the pressure at the die and the line speed is the temperature in the metering zone.

The practical maximum line speed achievable with Hyflon® PFA resins is limited by the appearance of the melt fracture or draw resonance (in tubing extrusion melt fracture usually appears first on the inside surface of the cone). This phenomenon can be reduced by increasing the temperature in the die until blisters or thermal degradation effects occur. A small reduction of the melt fracture can be obtained also by heating of the inner tip. The critical shear rate of the polymer can be considered a good parameter in order to predict the maximum extrusion speed. The higher this value is, the higher the achievable line speed. For example at the temperature of 372 °C, Hyflon® PFA M640 has a critical shear rate in the range of 50 to 70 sec⁻¹ while the Hyflon® PFA M620 value is in the 10 to 15 sec⁻¹ range.

Table 7: Typical M series and P series wire and cable extrusion temperature profile

	M Series [°C (°F)]	P Series [°C (°F)]
Z1 (rear barrel)	250 (480)	270 (515)
Z2	320 (610)	340 (645)
Z3	355 (670)	375 (705)
Z4	360 (680)	380 (715)
Z5 (front barrel)	380 (715)	400 (750)
Flange	380 (715)	400 (750)
Adapter	380 (715)	400 (750)
Crosshead	380 (715)	400 (750)
Die	400 (750)	420 (785)
Melt temperature	390–400 (735–750)	410–420 (770–785)

Table 8: Typical wire and cable extrusion conditions for Hyflon® PFA M640

Properties	Value
Cable diameter	1.5 mm (0.059 in)
Wall thickness	0.25 mm (0.010 in)
Draw down ratio	110
Draw ratio balance	1
Wire preheating	180 °C (356 °F)
Screw rate	20 rpm
Pressure	21 bar (305 psi)
Water gap	200–400 mm (8–16 in)
Line speed	61 m/min (200 ft/min)

Screw Diameter = 38 mm, L/D = 30

$$\text{where DDR} = \frac{D_{\text{die}}^2 - D_{\text{tip}}^2}{d_{\text{wire}}^2 - d_{\text{copper}}^2}$$

$$\text{and DRB} = \frac{D_{\text{die}} / D_{\text{tip}}}{d_{\text{wire}} / d_{\text{copper}}}$$

Table 9: Typical wire and cable extrusion conditions for Hyflon® PFA M640 jacketing extrusion

Properties	Value
Cable diameter	6 mm (0.236 in)
Wall thickness	0.25 mm (0.010 in)
Draw down ratio	25
Draw ratio balance	1
Wire preheating	–
Screw rate	5 rpm
Pressure	40 bar (580 psi)
Water gap	200–400 mm (8–16 in.)
Line speed	5 m/min (16 ft/min)

Screw Diameter = 38 mm, L/D = 30

Table 10: Wire and cable extrusion – typical DDR values

Grade	Wall Thickness	DDR
Hyflon® PFA M620	0.80–1.20 mm (30–50 mil)	50–25
	1.20–2.00 mm (50–80 mil)	25–5
Hyflon® PFA M640	0.10–0.25 mm (4–10 mil)	250–100
	0.25–0.45 mm (10–18 mil)	100–50

The DRB must be kept close to 1

Injection Molding

Hyflon® PFA can be injection molded following the same processes used for normal thermoplastic resins. The low viscosity grades are particularly designed for injection molding of complex shapes.

It is recommended to use three independently controlled heater zones for the barrel and one for the adaptor. The heater controllers must be capable of accurate temperature control up to 450 °C (845 °F).

Reciprocating screw equipment is recommended to assure proper plasticating and reduce polymer stagnation and thermal degradation. The screw should have a short transition section, a constant pitch and a flight depth ratio from the feed section to metering section of about 3 : 1.

Conventional type reverse tapered nozzle is recommended. The bore should be as large as possible and tapered to prevent dead spots or rapid changes in resin velocity. The non-return valve prevents the molten resin from flowing backward along the screw flights during the injection process.

Mold temperature should be set not lower than 180 °C (355 °F) to reduce delamination in the part. Optimization of mold temperature must take into account part thickness to minimize shrinkage, surface appearance and total cycle times.

Injection pressure should be set as low as possible, depending on the item to be molded. In general, low injection pressures reduce warpage thus resulting in improved dimensional stability. Injection pressure has to be set in function of the molded item, its thickness and the presence of weld lines. In most cases a hold pressure should be applied to reduce shrinkage and voids. Injection speed should be set moderately slow, thus resulting in good surface appearance without roughness.

Conversely, too low injection speeds must be avoided because they negatively affect the filling stage. Generally low rotational speeds are required, even if moderately low back pressure could result in better homogenization without unmelted particles. Increasing back pressure should be carefully checked to avoid increasing the melt temperature.

Temperature profile along the injection cylinder should be increased from the rear zone to the nozzle as reported hereinafter to avoid thermal degradation. Melt temperature should not be higher than 400 °C (750 °F) and hold-up or residence time must be obviously reduced if operating at the highest temperatures.

Table 11: Typical molding conditions for Hyflon® PFA M640 and Hyflon® PFA P450

	Units	M640	P450
Z1 (rear barrel)	°C (°F)	300 (570)	320 (610)
Z2	°C (°F)	325 (620)	345 (655)
Z3	°C (°F)	335 (635)	355 (670)
Z4	°C (°F)	340 (645)	360 (680)
Nozzle	°C (°F)	360 (680)	380 (715)
Melt temperature	°C (°F)	380 (715)	380 (715)
Mold temperature	°C (°F)	200–240 (390–460)	200–240 (390–460)
Injection pressure	kg/cm ² (psi)	270 (3,850)	345 (4,900)
Pack pressure	kg/cm ² (psi)	270 (3,850)	345 (4,900)
Screw velocity	cm/s (mil/s)	0.2 (80)	0.2 (80)
Screw rotation	rpm	21	21
Cycle time	s	100	100

Mold dimensions: 102 mm disk, 3 mm thick

Injection Molding Shrinkage and Post Shrinkage

An overview of the typical shrinkage is charted in Table 12. The dimensional analysis was carried out measuring the shrinkage of injection molded specimens obtained with a disk cavity mold. The diameter of the cavity was 102 mm (4 inches) and its depth 3 mm (120 mils). The equipment used was a 100 ton injection press with a 30 mm screw. The working conditions are the ones which granted the best quality as concerns color and superficial aspect.

For every condition at least five samples were molded and measured, so as to have a minimal statistical set of data. The shrinkage has been evaluated as percentage ratio between the linear dimensions of the molded disk and those of the mold considering the parallel and perpendicular flow direction. The post-shrinkage measurements were taken after conditioning the samples at three different levels of temperature (150, 200 and 250 °C) for 2.5 hrs in an oven.

Table 12: Typical shrinkage of Hyflon® PFA M640 and P450

	Injection/Pack Pressure [kg/cm ²]		
	259	344	431
After molding [%]			
M640	4.83	4.63	4.39
P450	–	4.66	4.43
After 2.5 hrs at 150 °C (300 °F) [%]			
M640	4.90	4.63	4.39
P450	–	4.70	4.50
After 2.5 hrs at 200 °C (390 °F) [%]			
M640	4.91	4.70	4.46
P450	–	4.73	4.53
After 2.5 hrs at 250 °C (480 °F) [%]			
M640	5.19	4.96	4.80
P450	–	5.07	4.92

Compression Molding

Hyflon® PFA can be molded by compression to obtain semi-finished items such as sheets, rods and film. The most suitable molding conditions must be selected according to the specific process and the shape of the final item. In all cases the molding temperature will be in the range of 340–380 °C (645–715 °F).

Transfer Molding

Hyflon® PFA can be used to produce lined items by transfer molding. This technique basically consists of the following steps:

- Melting and plasticizing
- Injection in a hot mold
- Packing and cooling

Typical transfer molding resins are the low-MFI grades, such as Hyflon® PFA P420 and Hyflon® PFA M620.

The mold temperature is customarily set above the resin melting point as opposed to injection molding where the mold is kept at a much lower temperature. The best results are normally achieved using slow injection speeds and by applying a certain hold time before cooling (see Table 13). A quick cooling is then recommended.

Operating conditions must be optimized for every single application. For example low melt temperatures are recommended for large items or when the resin is melted and plasticized in an oven. High melt temperatures are recommended for thin parts or when melting and plasticizing is carried out by an extruder.

Table 13: Typical Hyflon® PFA transfer molding processing conditions

Grade	Melt/Mold Temperature [°C (°F)]	Packing Specific Pressure [bar (kpsi)]
Hyflon® PFA P420	320–400 °C (610–750 °F)	150–300 bar (20–40 kpsi)
Hyflon® PFA M620	300–380 °C (570–715 °F)	150–300 bar (20–40 kpsi)

Hot Gas Welding

Hyflon® PFA are thermoplastic materials 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 thermoweld Hyflon® PFA liners. Tensile tests performed on the welded seams have proven that fusions are as 100 % reliable as the original material. The following general recommendations will apply when hot gas welding Hyflon® PFA liners.

Equipment

Use welding guns capable of good temperature control up to 650 °C (1,200 °F) and with heating power of 900–1,000 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.

If air is used for the welding, ensure that it is clean and dry.

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 Hyflon® PFA. 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 Hyflon® PFA Material Safety Data Sheets for detailed recommended procedures for safe handling and use. Contact your regional Solvay Specialty Polymers office for a copy.

Welding

Use round welding rods made of the same Hyflon® PFA 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 Specialty Polymers Technical Service representative to obtain proper assistance.

Carefully scrape the surfaces to be welded. When using fabric backed sheets, remove the fabric along the welding line (2–3 mm (80–120 mils) on each sheet) to prevent fiber 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 of a cleaning solvent may cause a 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, and set the temperature of the welding gun as indicated in table below.

Table 14: Hyflon® PFA hot gas welding temperatures

Grade	Welding Gun Temperature [°C (°F)]
Hyflon® PFA M620	500–590 (930–1,100)
Hyflon® PFA P420	560–620 (1,040–1,150)

Note: The temperatures recommended in this document are those 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 5–30 cm/min (2–12 in/min) range are usually suitable.

If the speed is too low, the welding rod will overheat and might break; 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.



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