EVERFLON ACADEMIC

— Injection Molding Guide —

EVERFLON

FEP ETFE
PFA PVDF

Meltable Fluoropolymer Resins

Introduction

The melt processible fluoropolymer resins extend the product line by providing the desirable properties of Everflon ™ PTFE in products that can be processed by conventional thermoplastic techniques, such as injection molding and extrusion.

Applications encompass those where designers and end users require a thermoplastic with excellent chemical stability, dielectric properties, anti-stick characteristics and mechanical strength for use in extreme high- and low-temperature environments.

This versatile family of melt processible fluoropolymer resins is available from Everflon™ to meet specific enduse requirements and processing needs:

- Everflon™ FEP is rated for service to 200 °C and retains the chemical resistance and dielectric strength of Everflon™ PTFE fluoropolymer resins.
- Everflon™ PFA is a premium performance resin with good melt processing characteristics and unique thermal stability. It offers high-temperature strength and stiffness; excellent stress-crack resistance; high flex life and excellent electrical properties. Its high temperature service rating is 260 °C and it resists virtually all chemicals.
- Everflon™ ETFE is a strong, tough material with chemical resistance, electrical properties, and aging resistance approaching those of other Everflon™ fluoropolymer resins. Rated for use to 150 °C, Everflon™ ETFE has excellent processing properties using conventional thermoplastic techniques.

Fluoropolymer resins are different from most other thermoplastics because they have higher melting points and higher melt viscosities. Accordingly, Everflon™ fluoropolymer resins require relatively high processing temperatures and slow injection rates. Special consideration for mold design is needed because of the molding characteristics of these resins; also, process equipment needs to be constructed of corrosion-resistant materials.

Properties of Everflon™ Fluoropolymers for Injection Molding

Property	Unit	ASTM standard	FEP 4610	PFA 410	ETFE 4010
Melting point	℃	DSC	260	310	260
MFR	g/10min		6-12	6-14	6-12
Specific gravity	--	D792	2.15	2.15	1.7
Tensile strength23 ℃	MPa	D2116	24	26	45
Elongation 23 ℃	%	D2116	330	350	400
Impact strength(Izod)	kg-cm	D256A		No Break	
Hardness(Dorometer)	--	D2240	D56	D60	D70
Flexural modulus	Mpa	D790	550	580	1200
Volume resistivity	Ω-cm	D257		$>10^{17}$	
Dielectric constant	1 MHz	D150	< 2.1	< 2.1	< 2.6
Dielectric factor	1 MHz	D150	0.0007	0.0001	0.0007
Dielectric strength	kV/mm	D149	78	78	70
Flammability	--	UL94		V-0	
Oxygen index	--	D2863		>95	
Chemical resistance				Excellent	
Water absorption	%	D570		< 0.03	

EQUIPMENT

Although it is possible to injection mold Everflon™ fluoropolymer resins in ram type equipment, the reciprocating screw machine is recommended because the screw produces a thoroughly plasticated, uniform melt and provides a much more efficient transmission of pressure to the molten resin flowing into the mold.

Materials of Construction

Because molten Everflon™ fluoropolymer resins are corrosive to most metals, it is most important that corrosion-resistant metals be used for all parts in continuous contact with the molten resin. Traces of corrosion products that accumulate on the metal surfaces can break away, contaminating the finished product and possibly adversely affecting physical properties. It is suggested that “Hastelloy” C, “Hastelloy” C-2761, “Duranickel”, or “Monel” be used for the screw,
adapter, and nozzle. For the cylinder lining, the use of “Xaloy” 309, “Brux”, “ Reiloy” or “Bernex” is suggested.

Because high operating temperatures are the rule, it is recommended that a high temperature-resistant thread lubricant such as “Never Seez” be used to facilitate ease of machine part disassembly.

Because the mold is maintained at temperatures below the melting point of the resin, the corrosion rate of the mold surfaces will be less than for other parts of the machine. Except for long production runs, unplated molds of hardened tool steel, hardened stainless steel, or high quality chrome- or nickel-plated material may be satisfactory. For long runs, more corrosion-resistant materials of construction might be desirable.

Screw Design

It is a metering type screw witha metering section that occupies 25% of the total length. The screw should have a constant pitch and a flight depth ratio from the feed section to the metering section of 3:1. For Everflon™ ETFE, it is recommended that a 3-turn transition zone be used; while for Everflon™ fluoropolymer resins, a ½-turn transition section is recommended. Although other screw designs have been used successfully, the two designs described are recommended.

Nozzle

The bore should be as large as possible and tapered to prevent dead spots or rapid changes in resin velocity. The sprue should extend into the nozzle 13 to 25 mm to prevent formation of a cold slug. An included angle of 4° is suggested to permit the material in the tapered portion of the nozzle to be withdrawn with the shot. To decrease the possibility of peening the nozzle bore, which in turn could prevent removal of chilled material from the nozzle, it is recommended that the radius of the nozzle orifice exitbe 0.25 mm. To provide a smooth, uninterrupted flow path, the nozzle bore must match the adapter and be equipped with its own separate heater and temperature control.

Non-Return Valve

The non-return or check ring valve prevents the molten resin from flowing backward along the screw/flights during the injection process. The flow path must be streamlined, and the joint between the valve and the screw must be smooth and tight in order to avoid areas of stagnant resin flow or holdup. The tip of the screw should be pointed to provide a streamlined flow path for the resin and reduce the free volume in front of the screw after injection. A leaking valve will cause poor control of part packing and tolerances.

Smear Head

A smear head which can be used in place of a non-return valve, is a device that uses a small diametral clearance with the cylinder over an extended land length, thus restricting backward melt flow during the injection stroke of the screw. When the screw is rotating during retraction, the melt is forced forward through a narrow annulus; this shearing or smearing action increases melt temperature, improves mixing, and reduces effective packing pressure. The smear head may be preferred over the non-return valve for the following reasons:

- Less tendency for resin stagnation
- Lower possibility of overpacking the mold (with attendant delamination for Everflon™ fluoropolymer resins)
- Less tendency to form streaks in the molded part
- Less abrasion on relatively soft corrosion-resistant alloys

It is suggested that a check ring non-return valve be used when injection molding resins with lower viscosity. When molding Everflon™ PFA and FEP or ETFE 4010, a smear head would normally be used in place of the nonreturn valve.

Check rings may be constructed of Hastelloy C or Monel 400. Because no indestructible material of construction for check rings is known, wearing of the check ring should be monitored.

Temperature Control

It is recommended that three independently controlled heater zones be used for the cylinder and one for the adapter. A separate controller should be used on the nozzle. The heater controllers must be capable of accurate temperature control up to 371 °C for Everflon™ ETFE and up to 427 °C for Everflon™ FEP and PFA. This level of control requires a heater watt density of 4.6 to 6.2 W/cm2.

Hydraulic System

When injection molding Everflon™ fluoropolymer resins, it is often necessary to use an extremely slow injection rate in order to avoid either surface or internal melt fracture. The hydraulic system, therefore, should be capable of producing a very uniform and controlled ram speed as slow as 60 seconds per shot.

Streamlining

It is most important for the entire flow path of the resin through the machine to be streamlined and that there be no areas of stagnation. Localized holdup may exist in the non-return valve of a reciprocating screw machine, which can lead to thermal degradation of the resin and unacceptable production.

Sizing Injection Machines

In conjunction with the weight of the part and the runner, these melt densities should be considered for adequate injection machine size at normal processing conditions:

— For Everflon™ FEP and PFA~1492 kg/m3 (~0.054 lb/in3)

— For Everflon™ ETFE~1298 kg/m3 (~0.047 lb/in3)

Clamp tonnage should be appropriate to cavity mold pressure and the area of the mold cavity that will oppose the clamp tonnage. One expects that a clamp pressure of 5 ton/in2 of projected area should be adequate for molding parts from Everflon™ fluoropolymers.

MOLD DESIGN

Materials of Construction

Mold cavities can be constructed from corrosionresistant materials such as Hastelloy C, Monel, or Duranickel, but these materials provide a degree of corrosion resistance far greater than is usually necessary.

Should unprotected tool steel or hardened stainless steel be used, the mold should be thoroughly cleaned before storage with a moderately alkaline material (e.g., ammonia water), dried, and coated with a rust preventative to avoid rusting and pitting. This procedure is particularly

important where high humidity conditions prevail. Rusting and pitting may be avoided by plating the mold with either nickel or chrome (chrome should not be used with Everflon™PFA) to a thickness of 0.013 to 0.025 mm; to avoid stripping the plating from the mold, use a high quality plate devoid of pinholes.

Sprue Bushing

The diameter of the sprue bushing should be at least 1.6 mm greater in diameter than the main runner and just slightly greater than the nozzle orifice. Generally, a standard taper of 4 or 6 mm/m is used.

Runners

In order to minimize both heat and pressure losses, large diameter, full round runners of the shortest possible length should be used. A second preference would be trapezoidal runners that are usually easier to machine than round runners. Runner walls should be free of any restrictions and blend smoothly into the gates. Generally, the thicker the molded part, the larger and shorter the runner should be. Parts of average thickness, up to approximately 12.7 mm, require a runner diameter of 6.4 mm or larger. Thicker parts require the runner diameter to be ½ to 1x the thickness of the part. The runner length or layout dictates the amount of scrap produced and pressure drop. A runner system is “balanced” when the resin flow distances between cavities and sprue are equal. When the number of cavities results in a complex or lengthy resin flow, the “balanced” runner system is not recommended. A “lateral” runner system can be used with both short and long resin flow distances in most instances.

Gates

Gates should either be as large as possible or eliminated altogether. The land, or length, of the gate should be kept very short. Rectangular tab or fan type gates, generously flared into the mold cavity, are preferred over round gates, as they provide a more effective means of reducing stress in the resin. Round gates generally are easier to remove from a part, but do not permit the same degree of independent control of cavity fill and gate freeze-time as rectangular gates do. The thickness (diameter) of the gate should be ½ to 1x the thickness of the part. Transitions from the runner to the gate to the part should be smooth, with no abrupt changes in the direction of resin flow.

Diaphragm or ring gates can be used for molding cylindrical parts where concentricity is critical or weld lines cannot be tolerated. Pinpoint gates should be avoided except when molding small parts that are injected very rapidly as with Tefzel™ fluoropolymer resin. Tunnel gating.

Gate locations should be at the following points:

- Where the part will not be highly stressed by bending motion or impact while in use
- So that weld lines occur in non- critical areas
- Wherever finishing the gate site would be unnecessary or inexpensive
- At or near the thickest section in order to minimize sink marks and avoid pushing resin through a thin section to fill a thicker one
- At locations consistent with venting requirements (vents are normally required at weld lines or at the bottom of blind cavities)
- In the center of a circular part

Other Considerations

When the necessary functional and appearance requirements of the part have been established, the final part design should be made with the following considerations in mind:

- Generous filleting
- Streamlined angles and intersections
- Uniform wall thickness (if different wall thicknesses are required, blend as gradually as possible)
- Simplicity (the overall design should be kept as simple as possible)

In addition, the following are good practices for consideration:

- Post-molding operations, such as drilling holes in the part, are usually preferred to the incorporation of pins.
- The number of cavities should decrease as the complexity of the part increases.
- Jetting, the rapid flow of a thin resin stream across a mold cavity, should be avoided.

Mold Heating

Although a mold can normally be heated by use of a high temperature circulating oil heater, when an injection molding process requires a mold temperature in excess of 191 °C, electrical heating should be used. Both halves of the mold should be insulated from the platens to reduce heat losses. Sheets of “Transite” board 6.4 mm thick are satisfactory for this purpose.

DIMENSIONAL CONSIDERATIONS

Tolerances

The achievement of close tolerance molding is contingent upon precise control of operating parameters, such as resin feed rate to the cylinder, cylinder and melt temperature, ram or screw speed, pressure, and the overall cycle; all of which must be kept constant. Mold design is also a critical factor in meeting specified tolerances.

In any manufacturing process, as tolerance requirements tighten, the process becomes more complex and expensive.

Generally, plastic parts are capable of functioning with wider tolerances than metal counterparts because of the higher inherent resiliency of plastic.

A few general comments and cautions relating to tolerances are:

• Tolerances should never be specified closer than necessary.
• Cost increases when close tolerances are specified on several dimensions of a part.
• Do not specify close tolerances for parts with major variations in wall thickness.
• It is not good practice to specify fine tolerances across a parting line or for dimensions controlled by movable cores or sliding cams.

Shrinkage

Listed below are the basic factors affecting the shrinkage of parts injection molded from fluoropolymers:

• Increasing either part thickness or mold temperature increases the part shrinkage, as changes of this nature result in a slower cooling rate for the part, which in turn produces a higher level of crystallinity (order) along with some relaxation in internal stresses.
• Most plastic parts exhibit directional shrinkage differences; part shrinkage is lowest in the direction of resin flow due to the relatively high degree of molecular orientation in that direction. Generally, the straighter the path, the lower the shrinkage, which leads to the conclusion that it is advisable to design the part and locate the gates so as to create the straightest flow path in that direction having the greatest restriction upon dimensional tolerance.
• An increase in injection pressure causes a decrease in shrinkage.
• Generally, parts molded at higher stock temperatures will exhibit higher mold shrinkage
• The addition of filler material reduces part shrinkage.

MOLDING OPERATION

Shutdown and Startup Procedure

If molding equipment is turned off without following proper shutdown procedures, resin degradation may occur and severe corrosion of the equipment could also result if the equipment is constructed of non-corrosionresistant materials.

When overnight shutdown without cleanup is desired, the following shutdown procedure is recommended:

1. Reduce all temperature controllers to the following levels:

a) 310 °C for Everflon™ PFA or FEP

b) 280°C for Everflon™ ETFE

2. When all temperatures have been dropped to the levels indicated in Step 1, purge the machine to a dry condition, leave the injection screw in the forward position, and finally shut off the power supply.

The restart procedure is as follows:

1. Starting with the temperature controllers for the nozzle, then for the adapter, then the rearbarrel, followed by the front barrel and finally the middle barrel, sequentially raise all the temperature controllers at each zone to the following levels:

a) 310 °C for Everflon™ PFA or FEP

b) 280°C for Everflon™ ETFE

A heat soak of 1 hr may be necessary to melt all resin and heat all metal components to these set temperatures.

2. Start the machine slowly after all temperatures have stabilized, setting the temperature controllers to operating levels.

3. Commence production when operating temperatures have been reached.

Cleanout Procedure

The following steps outline a suggested cleanout procedure:

1. While maintaining operating temperatures, start rotating the screw and continue to rotate it until the resin ceases to flow from the nozzle.

2. Reduce cylinder temperatures to the following levels:

a) 310 °C for Everflon™ PFA or FEP

b) 280°C for Everflon™ ETFE

3. Shut off the screw and remove both the nozzle and the adapter. Be sure to clean the nozzle, while it is hot, with a soft metal scraper and copper mesh. Oven burnout is not required and should be avoided.

Note: At this point a purge compound of ground cast acrylic or polyethylene may be used when molding either Everflon™ FEP or ETFE.

4. Slowly remove the hot screw from the cylinder, cleaning it with a wire brush.

5. Clean the inside of the cylinder with copper mesh wrapped around a boiler tube brush for a tight fit; then wipe the cylinder clean with a lint-free cloth.

When operating in equipment constructed of corrosionresistant metal, it is permissible to leave a purge (either ground, cast acrylic, or polyethylene sheeting) in the equipment overnight without danger of damage to the metal.

Melt Temperature (resin leaving the nozzle)

• Decrease the melt temperature as holdup time is increased.

• Runner, gate, and orifice size are additional factors to be considered.

Temperature Profiles

• When operating with high melt temperature and a long holdup time (10 to 15 min), the rear zone should be set at a lower temperature than the front zone in order to minimize resin degradation.

• When operating with short holdup times, the temperature of the front and rear zones should be set at the same point.

• The location of the heater thermocouples, machine size, speed and type of the injection screw, shot size, and cycle time are additional factors for consideration.

• Occasionally, high melt temperatures result from mechanical working of the resin melt.

• If the temperature of the rear zone is too high, bridging may occur—resulting in erratic feed.

• If the temperature of the rear zone is too low, high torque loads created by the partially melted resin could cause the screw to stall, there-by, reducing the plasticating capacity of the equipment.

Injection Speed

• Allowable ram speed is dictated by the smallest channel through which the molten resin must pass.

• A rough or rippled surface indicates an inappropriate injection speed was used. If surface appearance is rough or frosty, injection speed was too fast; and conversely, if a rippled surface results, the injection speed was too slow.

• Shot size, melt temperature, and mold temperature are additional factors for consideration.

Injection Pressure

- Injection pressure should normally be as low as possible.
- Low injection pressure reduces frozen-in stresses and improves dimensional stability.
- To reduce sink marks or improve weld lines, injection pressure should be increased.
- Equipment and part design must also be considered.

Screw Rotation

- Generally, screw rotation should be as slow as possible.
- High screw speeds, combined with the appropriate back pressure, are used occasionally to produce high melt temperatures necessary for the molding of long, thin parts.

Mold Temperature

- Extremely hot molds should not normally be used for thick-walled sections.
- When the resin flow path is long relative to the part thickness, higher than normal mold temperatures are required.
- Increasing mold temperature reduces the probability of delamination.
- When adjusting mold temperature, consideration should be given to interrelated parameters, such as part geometry, surface finish, pressure drop, effect upon cycle time, stresses, ejectability of the part, and shrinkage.

Back Pressure

- Back pressure should normally be kept as low as possible.
- Increasing back pressure, however, can sometimes be an effective technique to increase the stock temperature.

Overall Cycle

Overall cycle time is influenced by a number of interrelated manufacturing variables, such as process temperatures and pressures, part geometry, tolerances, warping, and ejectability. Cycle time is usually estimated on the basis of 30 to 40 sec per 3.2 mm of thickness. Except for thin sections, the longest portion of the cycle is often devoted to the ram-in-motion.

“Packing” the resin, which involves leaving the ram in the forward position while under pressure, should be kept to a minimum. Normally, packing is used only when molding thick sections to reduce sink marks or eliminate voids. Excessive packing usually results in delamination of the part for Everflon™ FEP and PFA, but generally not for Everflon™ ETFE. Use of a smear head reduces the possibility of overpacking.

Suggested Molding Conditions for Everflon™ Fluoropolymers

Property	Unit	FEP 4610	PFA 410	ETFE 4010
Rear Cylinder	℃	-- 315–330	315–330	270–300
Center Cylinder	℃	330–345	330–345	270–320
Front Cylinder	℃	371	371	270–320
Nozzle	℃	371	371	345
Mold Temperature	℃	>93	149–260	190
Stock Temperature	℃	343–382	343–399	300–330
Injection Speed Slow Slow	-℃-	Slow	Slow	Moderately Fast
Injection Pressure	Mpa	21–55	21–55	21–100

TIPS

Pigmentation

Everflon™ fluoropolymer resins may be pigmented with Everflon+™ color concentrate that are thermally stable at the molding temperatures of the resins; inorganic pigments are the best choice.

The simplest method for coloring resin is to blend the unpigmented resin with color concentrates, although pigments may also be dry blended by the following procedure:

1. Dry the desired pigment overnight at 150 °C in a vacuum oven or a non-circulating air oven to remove absorbed gases and moisture.
2. Weigh the pigment and if greater opacity is desired, add and blend the appropriate amounts of titanium dioxide pigment to the color pigment.
3. Place the resin pellets in a clean container, such as the original shipping carton, and then screen the pigment through a 100-mesh screen directly onto the pellets.
4. Dry blend the color and pellets by rolling or tumbling the mixture for at least 15 min.
5. Use the pigmented resin pellets within 30 min or store them in an airtight container to prevent the absorption of moisture.

Thin-Section Molding

Generally it is difficult to injection mold very thin sections with most thermoplastic resins, particularly where a relatively large surface area is involved.With Everflon™ fluoropolymer resins, anything below 2.5 mm may be considered a thin section. When processing thin sections, a faster ram speed must be used as a full shot is of primary importance. There is, however, a problem in obtaining both a full shot and a part free of delamination.

The latter product property can generally be obtained only with a slow ram speed, an operating condition that usually produces a resin freeze in the gate or cavity for a thin-walled section before a full shot can be obtained.

Therefore, a high mold temperature in the range of 204 °C is necessary to minimize the tendency toward delamination. Packing should not be used, i.e., the ram should be retracted as soon as the mold is full.Laminations in parts of Everflon™ FEP and PFA may become apparent in a section that appears and feels smooth when it is subjected to either heat aging or repeated flexing. If a part is to maintain a good, smooth surface after being flexed, it must be thick enough to permit a slow ram speed.

Delamination is not a characteristic of Everflon™ ETFE and the precautions needed to avoid it with FEP and PFA resins are not needed when molding ETFE.

There are many variables in the injection molding process that affect product quality. The following table is a troubleshooting guide that can be used to help define causes of specific problems.

It should be noted, however, that many injection molding problems are compounded by the interaction of more than one variable.

The symptoms of more serious problems tend to mask minor ones. Thus, successful troubleshooting may require careful observation and the tackling of several problems in sequence.

Technical assistance on extrusion problems is available through your Everflon™ representative.

Trouble Shooting Guide

Suggested remedy / Problem	Black Specks in Part	Burn Spots on Part	Cold Slug in Part	Cracks in Part	Discoloration of Part	Erratic Screw Retraction	Flash	Laminations in Part	Part Sticks in Mold	Poor Weld Lines	Ripples on Part	Short Shots	Shot-to-Shot Part Weight Variaion	Skin Marks	Sprue Sticking	Surface Roughness	Unmelted Resin	Voids in Part	Warpage
Increase Injection Pressure										●		●		●				●	
Decrease Injection Pressure				●			●	●	●							●			●
Increase Injection Rate																			
Decrease Injection Rate		●		●			●	●	●					●		●		●	●
Increase Ram Forward Time													●	●				●	
Decrease Ram Forward Time				●			●	●	●						●	●			●
Increase Melt Temperature			●	●				●		●		●		●		●		●	●
Decrease Melt Temperature	●	●			●		●		●		●			●				●	
Increase Mold Temperature								●		●		●				●			
Decrease Mold Temperature				●			●				●			●					
Increase Cylinder Temperatures			●			●											●		
Increase Back Pressure						●											●		
Use Reverse Taper Nozzle															●				
Decrease Cycle					●														
Increase Cycle																	●		●
Check Pad Size (Cushion)												●	●	●				●	
Enlarge Nozzle Orifice												●	●	●				●	
Increase Clamp Pressure						●													
Check Screw Retraction														●					
Increase Taper																●			
Check for Burrs/Radius of Nozzle			●													●			
Increase Nozzle Temperature													●		●	●			
Increase Size of Gate									●				●		●			●	
Enlarge Vents		●									●		●					●	
Change Gate Location		●							●				●						
Reduce Screw Speed					●	●													
Check for Contamination	●				●														
Check for Resin Stagnation	●				●														
Check Materials of Construction	●				●														
Check for Resin Cross-Contamination	●				●				●										
Thoroughly Purge or Clean Barrel and Screw	●																		

Everflon Academic Center

Tel: +86-185-7168-9228

info@everflon.com

www.everflon.com

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