



EVERFLON^{ACADEMIC}



— Extrusion Guide —

EVERFLON

FEP
PFA

ETFE

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.

Everflon™ Fluoropolymer resins have higher melting points and melt viscosities than most thermoplastics. They give excellent yields and production rates when processed using the techniques described in this guide.

Properties of Everflon™ Fluoropolymers for Extrusion

Property	Unit	ASTM standard	FEP	PFA	ETFE
Melting point	°C	D5€	260	310	260
MFR	g/10min		6-12	6-14	6-12
Specific gravity	--	D792	2.15	2.15	1.7
Tensile strength ^{23 °C}	MPa	D2116	24	26	45
Elongation 23 °C	%	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	

COLOR CONCENTRATES

Everflon™ FEP and PFA, as well as ETFE, may be colored using commercially available color concentrates, available from Everflon+™. Loadings vary but are usually of such small proportion as to have no appreciable effect on the end-use mechanical properties of the fluoropolymer. However, it is important that the color concentrate is mixed in the same base resin as will be used during the letdown. Most modern continuous extrusion operations use a commercial color meter addition system. If employing one of these, follow the meter manufacturer's directions for operation. This procedure below may be used if manufacturer's directions are not available.

The procedure below is for dry blending, or "letting down", color concentrate pellets into Everflon™ fluoropolymer resin pellets.

1. Dry the color concentrate for a few hours at 95 °C in a vented or vacuum oven. It is not necessary to dry the bulk resin; however, it is worth noting that resin brought from unheated storage areas in winter can display condensation formation once the resin enters the warm extrusion area. Allow the resin to equilibrate prior to use.
2. Weigh the concentrate to the proportion needed for the resin to be processed (e.g., 1%).
3. Add color concentrate to the bulk resin in a clean, dry container.
4. Mix or tumble the resin and color concentrate for at least 15 min or until well mixed. Feed the mixture to the extruder hopper. Keep covered by lid or aluminum foil during use.
5. Unused color concentrate pellets should be stored in air tight containers. Otherwise, they should be re-dried before further use.

EQUIPMENT

Extruder

The function of an extruder is to convert thermoplastic pellets into molten resin and deliver the melt at a uniform rate and even temperature. Conventional, single screw extruders are used for processing fluoropolymers. Length to diameter (L/D) ratios vary from 20/1 to 30/1. However, it has been found that longer extruders, of 28/1 length to diameter ratios or more, work best. These longer machines are capable of more stable outputs at high production rates. The energy needed to plasticate the resin comes from the viscous drag induced by the mechanical action of the turning screw and conducted external heat coming from the barrel heaters. The turning screw mixes the melt and, together with the metering section dimensions, determines the extruder melt output. Sizing the extruder to give the desired output of well mixed melt is critical to success.

Smaller diameter machines require faster screw RPM to achieve the output of slower, larger extruders. However, a reasonable RPM, in the range of 20 to 50, works best.

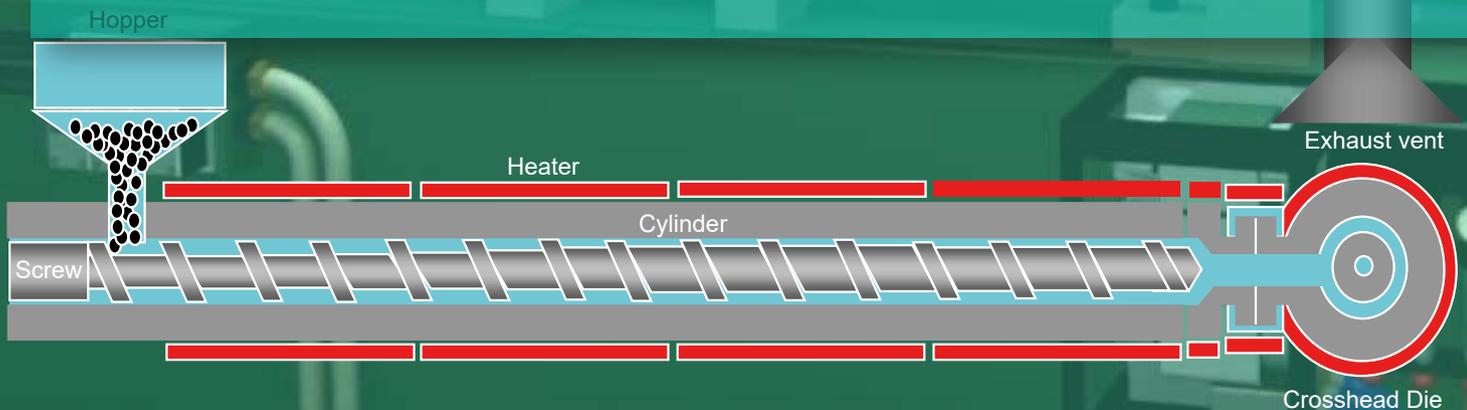
Processing problems such as the loss of melt strength have been experienced with small, short extruders that have to run at high temperatures and RPM to achieve the desirable output. Similarly, problems have been observed with large machines running slowly. Poor mixing and long residence time can lead to an unstable melt, which gives poor draw performance.

Materials of Construction

The melt processing of thermoplastic polymers causes some resin breakdown and the formation of byproducts. The by-products from molten fluoropolymer are corrosive to most metals. Corrosion is accelerated by decomposition of the resin and can be minimized by avoiding excessively high operating temperatures and the use of streamlined resin flow channels. Hold-up spots, dead corners, etc., trap resin where it can be degraded by exposure to high temperature for prolonged periods of time.

Therefore, it is necessary to use extrusion equipment made from corrosion-resistant, high nickel, low iron alloys.

All contact equipment, such as barrel liners, screens, breaker plates, adapters, crossheads, and tooling, must be made of these alloys. Exposed equipment, such as clamps, must be protected by high quality nickel plating. A range of such equipment is commercially available, and vendors can advise on their proper use with fluoropolymers.



Screw Design

Most conventional single screw designs will work satisfactorily for fluoropolymers. Performance will vary depending upon screw design. Screw designs with long feed sections, about 3:1 compression ratio, core progressive profiles and with low shear melt mixing elements have been used extensively and are the preferred choice. Limited experience indicates variable pitch and barrier type screws can be made to work with fluoropolymers. However, extruder operators should approach such designs with caution.

In a "square pitched screw", one flight turn moves one barrel diameter down the screw. A square pitched screw with a constant angle pitch of 17.7 degrees is common.

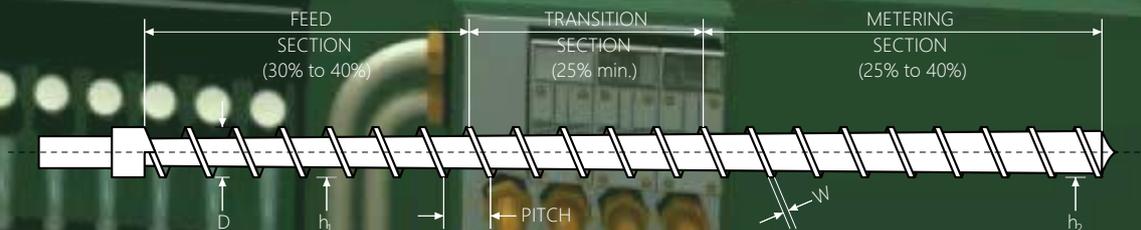
This conveniently means the L/D ratio equals the number of turns to be allocated across the screw sections, feed, transition, metering, and mixing. For example, a 28/1 length to diameter ratio screw of square pitch has 28 turns to allocate.

Conveying, melting, and mixing of the resin cubes takes place in the feed section. A long feed section, of at least 8 turns, provides the required residence time. It is important to have a good balance of energy input from mechanically induced viscous drag and the barrel heaters. This is accomplished by screw RPM. The flight depth must be adequate to allow the resin pellets to compact, but leave enough core diameter for mechanical strength.

The core progressive transition section connects the feed to the metering sections. Transition or compression occurs over 3 to 4 flight turns. As flight depth gradually becomes more shallow, the melting is completed and air or gas is driven back up the barrel to vent through the feed throat. This provides a volumetrically filled flight channel going into the metering section. This is vital to achieving constant melt output.

Melt is conveyed along the metering section of the screw by friction on the surfaces. Output is directly proportional to the screw RPM. A 5 to 7 flight metering section usually generates adequate pressure to convey the melt through the screen, head, and tooling. Metering section flight depths are shallow to maximize the surface area to volume ratio. This also minimizes the backflow of melt due to pressure build-up. It is important to understand this is a volumetric process. Output is determined by metering section cross-sectional dimensions and the screw RPM.

Large diameter, deeper metering channel designs will require much lower RPM than small diameter, shallow depth machines. When specifying new machines, or new screws for existing machines, start by calculating the metering section dimensions for mid-range RPM giving the application output required. From that basis, using a typical compression ratio (e.g., 3:1), the other screw dimensions can easily be determined.



Hopper Dryer

Fluoropolymer resins do not absorb water. They do, however, pick up surface moisture, especially when moved from cold storage to the warm processing room. Because color concentrates can be hygroscopic, resin and concentrate drying has proven effective in eliminating moisture-related flaws. Batch drying prior to extrusion is effective, but can be cumbersome when processing large resin quantities.

Fluoropolymers do not require dehumidified air. Once-through hot air can remove surface moisture. Temperatures of 120 to 160 °C, with 1 to 2 hr hold-up time, are generally effective. Exhaust from the hopper should be safely vented. Packaged hopper heater units for fluoropolymers are commercially available

Screen Pack and Breaker Plate

A breaker plate and screen pack may be used for the extrusion of fluoropolymers. They develop additional back pressure for better dispersion of pigment or filler into the melt. The process should be clean enough not to require the removal of contamination or color agglomerate by screening. Breaker plate holes should be chamfered on both sides to eliminate resin hold-up and shear over a sharp edge. A 120 mesh screen (0.125 mm) sandwiched between two 80 mesh screens (0.177 mm) is a typical setup. Screens should be made of fluoropolymer grade, corrosion resistant alloys.

Adapter

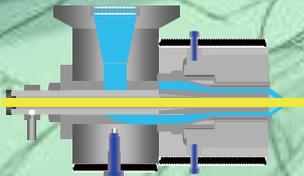
The adapter connecting the crosshead to the extruder barrel must be streamlined internally for proper melt flow. Conical cross-sectional reductions should be done at a maximum 30° included angle. It must also have a heater band with a temperature controller. The practice of compensating for inadequate adapter temperatures with higher barrel temperatures may lead to degradation and a potential safety problem during startup. Solidified resin inside the adapter will restrict the flow of melt from the extruder.

Crosshead

A conventional extruder crosshead design is commonly used. Other designs are also available. In-line or straight-through heads are used when extruding continuous profiles such as tubing. Many commercial variants are available.

It is important that the head has a simple streamlined flow pattern without hold-up spots. Size will depend on the desired extrusion end-product. However, the smallest volume, shortest residence time available that meets the end-product needs is the best choice. Melt fracture, discussed later in this document, may limit the production rate. However, Everflon™ fluoropolymers have good melt strength, allowing large draw-down ratios to minimize the melt fracture effect.

Equally important is the need to specify fluoropolymer grade, corrosion-resistant materials of construction. Vendors use different alloys balancing corrosion resistance with ease of machining and appearance after use with fluoropolymers.



Heater Bands

Heater bands should have enough capacity to permit a maximum temperature of 425 °C during operation. Power densities of 4.65 W/cm² or higher can be used. Proportional, integral, differential (PID) temperature controllers, or equivalent, are a requirement for stable melt extrusion output.

Local Exhaust Ventilation

The melt processing of all thermoplastic polymers, including thermoplastic fluoropolymers, causes some degradation that may release gases, vapors, or fumes that may be harmful to health or simply create undesirable odors. The most effective way to control these emissions is to “capture” them at the source and remove them by exhaust ventilation before they can be dispersed into the workplace atmosphere. This “capture” technique is called local exhaust ventilation (LEV).

LEV is effective as only a relatively small volume of air is required to “capture” and remove the airborne chemicals released from the plastic compared to the very large volumes required to try to change the air in an entire workspace or factory. Further, the “capture” of contaminants at the source can virtually eliminate the exposure to chemicals by workers.

EXTRUDER OPERATION

A successful extrusion operation requires close attention to many details, such as: the quality and flow of the feed material, a start-up and shutdown that will not degrade the polymer or put the equipment and operator at risk, an extruder temperature profile that will achieve and control the process at the desired melt temperature at the required production rate, an adequate local exhaust ventilation system, and resin handling

Resin Handling

Care should be taken to prevent condensation onto the surface of the resin. Moisture may be absorbed by some of the additives used, such as pigment or nucleating concentrates. Allow the resin to acclimate in the workplace for up to 24 hr prior to use.

Keeping the resin clean from contamination is strongly recommended. Bags and other containers of resin should be kept sealed prior to use. Avoid contamination by using covered hoppers and storage bins. Contaminants often result in faults in the extruded product, such as spark failure in wire insulation.

Melt Flow

Fluoropolymer resins are considerably more viscous at their recommended processing temperatures than most other thermoplastic resins. Melt viscosity and melt flow rate (MFR), the quantity of melt in grams passing through a given orifice under constant pressure and temperature over a 10-min period, are terms used to describe the flow of the polymer melt. These properties are measured under standard, specified conditions of shear and temperature.

ASTM standards define these values and their measurement methods. Viscosities (at constant shear stress) of these fluoropolymer resins vary inversely with their temperature. The melt flow of Everflon™ FEP and PFA fluoropolymers through small die orifices, or similar profile tooling, is limited by the polymers' high melt viscosity and low "critical shear rate". However, they have sufficient melt strength to allow extrusion through larger tooling and subsequent drawing to the required size. Everflon™ ETFE fluoropolymers have lower melt strength than those of Everflon™ FEP and PFA and cannot, therefore, be drawn down as much. However, the higher "critical shear rates" of Everflon™ ETFE fluoropolymer melts allows comparable extrusion rates.

Melt Fracture

When a thermoplastic resin flows through a die or profile orifice, the resultant melt flow is smooth surfaced. As the throughput is increased, the flow reaches a rate at which surface roughness can be seen. This roughness, called “melt fracture”, is caused by the friction between the melt and tooling wall surfaces. At lower throughputs, the friction slows the flow at the tooling wall. At higher rates, it wants to “stop” the flow; but, this is overcome by the process pressure pushing the melt forward. The result is an erratic or “surface turbulent” flow that causes the rough surface. Extruding at too high a rate for the melt viscosity, tooling size, and temperature of the setup is the most common cause of melt fracture.

Melt fracture occurs at flow rates above the polymer melts’ “critical shear rate”. This rate is temperature-dependent, so some increase in output is often possible by increasing the melt temperature. However, the melt temperature should always be below that which causes polymer degradation.

In cases where pigment or nucleating ingredients are being used, the cone is opaque; so, melt fracture can only be seen on the outside surface. It is important to run the extrusion under conditions that do not result in melt fracture.

Experimentation with unpigmented resin can be useful to initially determine those conditions. Examination of the extruded product, inside and outside, also helps illustrate the presence of melt fracture.

Roughness due to the presence of moisture, contamination, or filler can be mistaken for melt fracture. A brief reduction in throughput will reduce or remove melt fracture, if it is the cause of surface roughness. Conversely, if the roughness persists, even at low output rates, appropriate corrections should be made for moisture presence or contamination.



A typical tubing extrusion being drawn down into a vacuum sizer. The tube is shiny, smooth surfaced, and clear. There is no melt fracture present.



Same extrusion at a higher throughput rate with obvious melt fracture present in the cone.

Shear Stress and Shear Rate

Figure represents a map of possible flow conditions for Everflon™ FEP&PFA fluoropolymer resins, given constant melt and die temperature. Everflon™ ETFE fluoropolymers do not exhibit this regional pattern. The map is a plot of shear stress versus shear rate and illustrates how shear stress increases with increasing shear rate.

The map defines four possible regions of extrusion behavior. At very low output rates, there may be thermally induced resin degradation.

- Region I is the wide area of normal operation where almost all extrusion is done.
- Region II represents going from a smooth extrudate to a rough “melt fractured” extrudate by increasing the resin flow through the tooling. During this transition, the polymer melt goes through its “critical shear rate”. This critical shear rate applies to the specific extrusion conditions.
- A smooth extrudate is obtained again in Region III, normally referred to as the “super shear” region. Super shear occurs when the flow of the polymer melt has lost its adhesion to the surface of the tooling. This phenomenon is accompanied by a significant drop in extrudate head pressure, lowering the hindrance to melt flow. Higher output rates can be achieved in this way, but there is usually a change in the measured mechanical properties of the resultant product.
- In Region IV, the extrudate becomes excessively rough again.

For a given profile tooling geometry, the shear rate increases directly as the melt output is increased. The shear stress increases as the pressure is increased.

In common with many non-fluoropolymer thermoplastic melts, the shear stress in Everflon™ ETFE fluoropolymer resins demonstrates almost direct increase in shear stress with increasing shear rate. Depending upon molecular weight and processing temperature, these Everflon™ Fluoropolymer Resins resins can begin to melt fracture at shear rates as low as 10 to 100 reciprocal seconds. Everflon™ FEP 4622 at MFR 22 being extruded at a melt temperature of 400 °C will melt fracture at about 500 reciprocal seconds. Similarly, various grades of Everflon™ ETFE fluoropolymers will melt fracture between 200 and 3,000 reciprocal seconds.



Extrudate Appearance in Flow Regions I, II, III, IV

Extensional Fracture

When polymer melt is pushed through the tooling, the polymer is subjected to shear that will cause melt fracture when the critical shear rate is exceeded. The melt is drawn down in the cone immediately upon exiting the tooling. Additional shear is induced by this draw-down action.

When the shear limit is exceeded, the cone looks cloudy (if no pigment is being used) and pin holes and/or tears occur in the melt flow. In extreme conditions, the cone will break.

The rate at which the extension occurs is also important. Drawing down too fast will also cause holes, tears, and cone breaks.

The total amount of shear that a polymer can withstand in this process can be described as its "shear budget". This budget is used up in part by each of the three process stages that impact shear: tooling shear, extensional shear, and rate of extensional shear. When any one of these stages, or the combination of all three stages, exceeds the polymer melts' ability to withstand shear, the process destabilizes. There is some flexibility, however, to move the balance of work done on the melt from tooling to extensional shear. The addition of extensional and rate of extension shear effectively reduces the "process critical shear rate".

Everflon™ FEP 4622 at MFR 22, melt extruded at 400 °C, will exhibit melt fracture when purged out of the tooling, (i.e., tooling shear only) at about 550 reciprocal seconds. When drawn down onto wire (i.e., tooling, extensional, and rate of extension shear applied), the process is limited to a throughput equivalent to 350 reciprocal seconds. This explains why fluoropolymer processors rarely achieve the potential extrusion throughput described by the polymer's critical shear rate.

Draw-Down Ratio

The draw-down ratio (DDR) is defined as the ratio of the cross-sectional area of the tooling gap to the cross-sectional area of the finished profile.

Wire and cable insulation or jacketing is for the most part a drawn tube extrusion. Tubular profiling is the most common fluoropolymer extrusion setup, and the making of tubes and hoses is a drawn tube process. In tubular profiling of this nature, a circular tip (or mandrel) is set inside a circular die to form an annular gap of common center. The cross-sectional area is, therefore, that described by the die circumference minus the area described by the tip circumference. Similarly, the cross-sectional area of the product profile (tube or tubular insulation on the wire) is the area described by the outside circumference minus that described by the inside circumference. These four areas can easily be calculated from basic geometric formulae. However, as common terms cancel themselves, the DDR can very easily be calculated using the diameter squared term.

Increasing the draw-down ratio lowers the shear in the tooling. Melt fracture will not occur until a higher throughput is achieved. This gives the process the potential for increased line speeds. Higher DDR also reduces the risk of tip drool. In some limited experiments, higher DDR gave better electrical performance due to the polymer coming down tighter onto the wire.

Lower draw-down ratio increases the shear in the tooling, resulting in earlier onset of melt fracture. However, lower DDR gives a more stable draw-down cone. This reduces the tendency for cone breaks and improves the consistency of diameter control.

The practical production rate is one that is an acceptable balance between line speed and the final product quality needed. Small wire constructions are usually produced faster than the larger ones, and tube making, where diameter control and wall thickness concentricity are so important, is always run at low DDR and slow line speeds.

Draw Ratio Balance

Draw ratio balance (DRB) is defined as the rate the outside of the draw-down cone comes down, divided by the rate the inside of the cone comes down. A perfect balance equals 1.00.

Incorrect DRB is the most common source of tooling problems with Everflon™ fluoropolymer melt extrusion. When the DRB is significantly greater than 1.0, tearing occurs due to the excess polymer on the outside of the profile. When the DRB is significantly below 1.0, the excess polymer on the inside of the profile causes fold over. Therefore, sizing the tooling correctly is essential to good extrusion.

Cone Length Control

In wire coating, the cone length is shortened and controlled by applying vacuum to the inside of the cone through a hole bored through the cross-head core-tube.

This is the hole through which the conductor wire passes. Vacuum can easily be obtained from a vacuum pump and controlled by a needle valve.

Shortening the cone reduces the time spent drawing down the melt. This increases the rate of extension, leading to holes, tears, and cone breaks as the cone gets shorter and shorter. Long cone lengths lead to visible cone oscillation or wobble, which causes diameter fluctuations in the final product. Vacuum is usually operator adjustable to give a stable process between the faults of long and short cone length.

In tube making, the cone length is determined by the distance from the face of the tooling to the sizing die in the vacuum tank. The vacuum tank is usually adjustable.

Vacuum is sometimes applied to the inside of the cone to assist in the draw-down. In other cases where the drawdown ratio is small, or when the cone is drawn out to a larger diameter profile, some air is applied to the inside of the cone to help fill out the sizing die completely.

Melt Temperature

The effect of melt temperature on polymer viscosity and its draw characteristics is an important factor in the melt extrusion of Everflon™ FEP, PFA and ETFE.

The operator has to choose a melt temperature at which to run the process. Structured experiments have shown melt temperature and draw-down ratio to be the two most influential process setup factors governing output and quality.

The fluoropolymer should be completely melted just before it enters the metering section. Failure to adequately fill the metering section with melt can result in variable output.

A process contact melt temperature probe is essential. Melt temperature will vary considerably when throughput is changed, but the "heat profile" must be kept the same.

Wire Preheat

Wire coating process control and subsequent cable performance are greatly affected by the temperature of the wire conductor as the polymer melt is drawn down onto the wire. A cold conductor will also draw heat from the tip making melt fracture on the inside of the cone more likely. It is therefore recommended to preheat the wire. This is usually achieved by use of an in-line inductive preheater. However, experience has shown that there is a window of operation centered around 150 °C. Adhesion of the polymer to the conductor can be adjusted to some extent by vacuum and preheat control.

Quench Distance

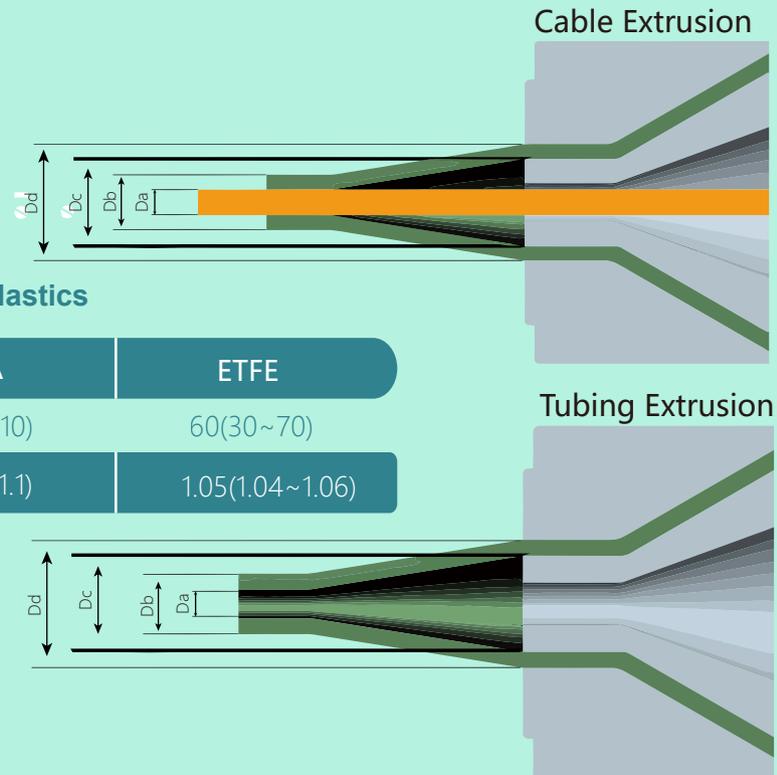
Tube profiles are cooled in the vacuum tank, usually by circulating controlled temperature water. Wire coating is cooled in air and then by the use of quench water. Everflon™ FEP, PFA and ETFE shrink when cooled to solid form again. Like most polymers, Everflon™ FEP, PFA and ETFE are good insulators. If the outside surface of a wire coating is cooled to solidify the polymer surface, the inside will shrink away from the wire as it loses its heat more slowly. The variable void this creates along the conductor will adversely affect cable performance. This variable cooling is best prevented by allowing the coated wire to cool in air for as long as possible before water quenching. As line speeds increase, the “air gap” in most processes becomes less effective. The water quench effect is sometimes controlled by using a short length of hot water quench before the air gap. In line setups where space limitation prevents long air gap, experimentation is necessary to determine the most effective cooling system that prevents the formation of voids along the conductor.

$$DDR = (D^2d - D^2c) / (D^2b - D^2a)$$

$$DRB = (D^2d - D^2b) / (D^2c - D^2a)$$

Recommended DDR and DRB for Everflon™ fluoroplastics

Materials	FEP	PFA	ETFE
DDR	100(90~110)	100(90~110)	60(30~70)
DRB	1.05(0.9~1.1)	1.05(0.9~1.1)	1.05(1.04~1.06)



STARTUP

Before Startup

1. Unless the same resin is already in the machine from a previous run, the entire extruder should be cleaned, including the feed hopper, barrel, screw, breaker plate, crosshead, die, and tip. If using screen packs, replace these at time of cleaning. Note: Be sure that fluoropolymer orrosion-resistant alloys have been used for all of these parts.
2. Check conditions and “fitness” of all heater bands and electrical connections.
3. Check that thermocouples are properly seated and their connections are secure.
4. Inspect the pressure transducers, and make sure the high pressure interlock shutdowns are set.
5. Ensure the melt flow path through the head is not blocked.
6. Ensure the local exhaust ventilation (LEV) system has adequate air flow.
7. Have a quench-pot partially filled with clean water to catch purging extrudate.

Start-Up Procedures

1. Set all temperature controllers to 177 °C, and allow all heats to equilibrate.
2. Be sure that all temperatures increase at a normal rate. Check for deviations that may indicate burnedout or runaway heaters. A strip-chart recorder is a useful way to watch temperature controllers and cycling.
3. Set all temperature controllers to 288 °C, and again allow all heats to equilibrate.
4. Check to ensure all temperatures have come up normally.
5. Set the individual temperatures to the desired temperature profile, and allow to equilibrate. Note: This profile is fine tuned at running speeds to give the desired melt temperature. Do not use the profile as a “control”. At a given profile, the melt temperature will vary with throughput (RPM).
6. Allow a “heat soak” time of at least 15 min after all of the temperatures have reached their set point. This is to ensure all polymer present is melted and will, therefore, minimize undue pressure increase when the screw turns.
7. Do not stand in front of the extruder during screw startup. Never look directly into the feed hopper because of the potential for blow back.
8. Start the screw and adjust to about 10 RPM. Purge for about 10 min. Watch for pressure or amperage spikes, and shut down if they occur.
9. Increase the RPM to about 25, and adjust the die to center around the tip. Note: This is not necessary on self-centering heads.
10. Start making product, and adjust the temperature profile to give the desired melt temperature at the production rate planned.

Shutdown Procedures

The procedure for shutting down will vary slightly depending on whether the machine is to be shut down and turned around for a new production run or simply stopped for a period before resuming the same production.

The objective is to avoid polymer degradation, which would contaminate the next production by minimizing the resin exposure to high temperatures. However, a machine dedicated to prolonged production based on the same resin does need to be disassembled and cleaned periodically.

If the same grade of resin is to be run in a subsequent operation and the temperature exposure to the resin in the equipment is controlled to a minimum, cleanout is not usually required. Change of resin grade does require disassembly and thorough cleanout. Do not be tempted to “save time” by purging one grade with another. Disassembly and cleanout is best done while the equipment is still at an elevated temperature.

Shutdown Without Cleanout of Extruder

Follow these steps for proper shutdown:

1. Empty the feed hopper through its discharge chute, and vacuum out the remaining resin pellets.
2. If coating wire, cut the wire and remove it from the crosshead. If making a tube, disconnect the melt flow from the sizing die.
3. Lower all of the temperature settings to the melting point of the last resin processed.
4. Reduce the screw revolutions to a moderately low rate (10 to 20 RPM) and allow the melt to purge into a bucket of quench water or other container set up to eliminate or capture the fumes coming off the melt.
5. When there is a significant drop in barrel pressure, or the extruder has purged empty, lower the temperature settings to 177 °C and stop the screw.

Note: Steps 4 and 5 must be completed before the temperature drops significantly.

6. If a breaker plate and screen packs are being used, disconnect the head and remove them for cleaning.

Shutdown With Cleanout of Extruder

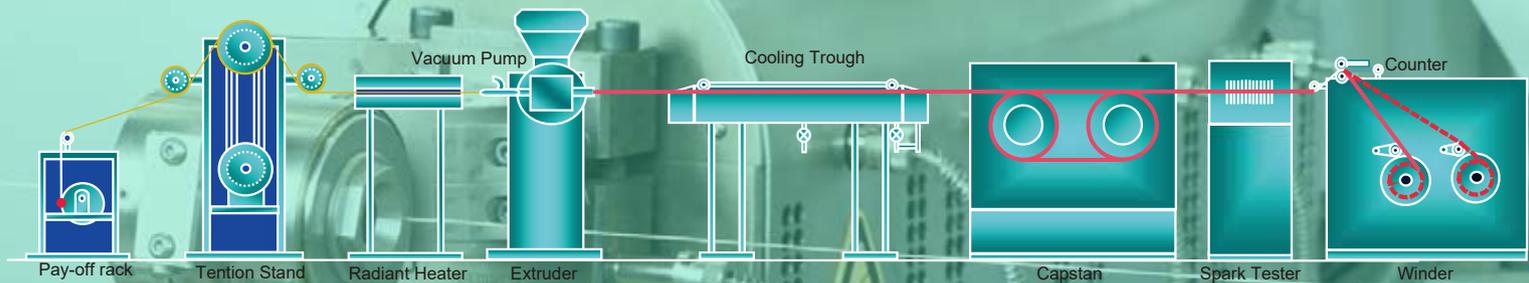
Follow these steps for proper shutdown:

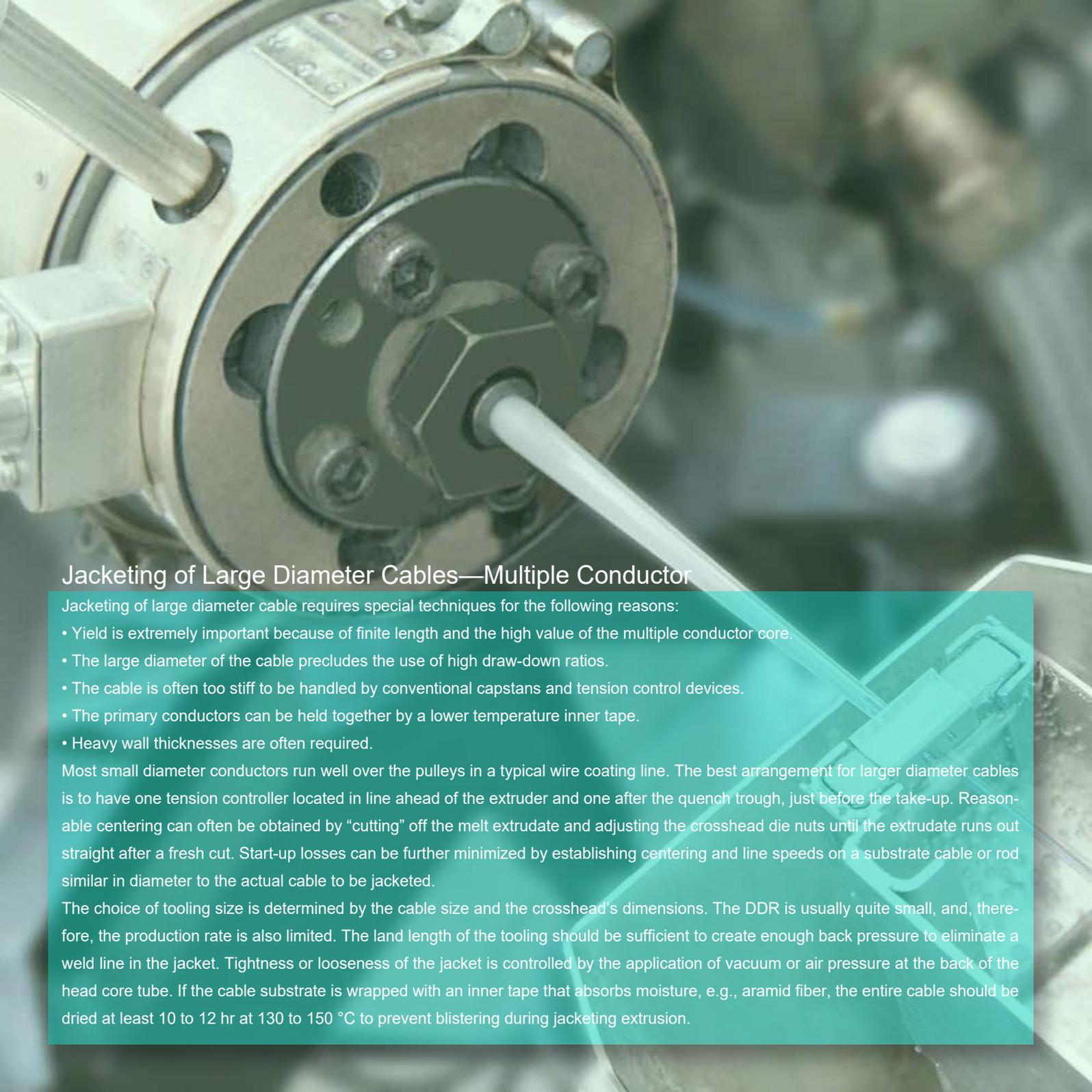
1. Empty the feed hopper as above.
2. If coating wire, stop the wire and remove it from the crosshead. If making a tube, disconnect the melt from the sizing die.
3. Lower all of the temperature settings: For Everflon™ FEP and PFA, adjust to ~288 °C. For Everflon™ ETFE, adjust the temperature to ~177 °C. Reduce the screw speed to a moderately low rate (10 to 20 RPM), and allow the melt to purge into a quench pot.
4. When the extruder appears to be empty, stop the screw.
5. Turn off and disconnect the head heaters.
6. Disassemble the head and clean under an exhausted hood work station while it is still hot. Remove the tooling and core tube, and clean with copper or brass spatulas and brushes. Remove all heaters and thermocouples. Small pieces of equipment can be “burned off” in a suitable muffle furnace. Do not “burn off” with a propane torch, as uneven heating may distort the component.
7. Push the screw out gradually while cleaning with a wire brush and copper scrubbing wool. Never use a propane torch to “burn off” resin. The alloy may lose some temper or distort. Repeat until all of the screw has been removed and cleaned.
8. Clean the barrel with copper scrubbing wool, and then polish with cotton cheesecloth wrapped around the reaming brush head.
9. Turn off heaters and isolate the process power supply.

As mentioned above, a ventilated muffle furnace set at 540 °C can be used to clean small parts.

Wire Coating

A typical wire coating line is shown in Figure 13. The line must be capable of running the wire with uniform tension at the desired production rate without variation or drift. The wire payoff, tension control, preheater, and take-up are usually designed for a range of wire sizes. Long periods of continuous wire insulation are facilitated by “fly” payoffs, designed to release the wire like fishing line from a fly rod reel. Many recent installations include an in-line wire draw machine. This is a good approach when insulating very long lengths of same size wire. Large, stiffer cable constructions usually require special large radii equipment.





Jacketing of Large Diameter Cables—Multiple Conductor

Jacketing of large diameter cable requires special techniques for the following reasons:

- Yield is extremely important because of finite length and the high value of the multiple conductor core.
- The large diameter of the cable precludes the use of high draw-down ratios.
- The cable is often too stiff to be handled by conventional capstans and tension control devices.
- The primary conductors can be held together by a lower temperature inner tape.
- Heavy wall thicknesses are often required.

Most small diameter conductors run well over the pulleys in a typical wire coating line. The best arrangement for larger diameter cables is to have one tension controller located in line ahead of the extruder and one after the quench trough, just before the take-up. Reasonable centering can often be obtained by “cutting” off the melt extrudate and adjusting the crosshead die nuts until the extrudate runs out straight after a fresh cut. Start-up losses can be further minimized by establishing centering and line speeds on a substrate cable or rod similar in diameter to the actual cable to be jacketed.

The choice of tooling size is determined by the cable size and the crosshead’s dimensions. The DDR is usually quite small, and, therefore, the production rate is also limited. The land length of the tooling should be sufficient to create enough back pressure to eliminate a weld line in the jacket. Tightness or looseness of the jacket is controlled by the application of vacuum or air pressure at the back of the head core tube. If the cable substrate is wrapped with an inner tape that absorbs moisture, e.g., aramid fiber, the entire cable should be dried at least 10 to 12 hr at 130 to 150 °C to prevent blistering during jacketing extrusion.

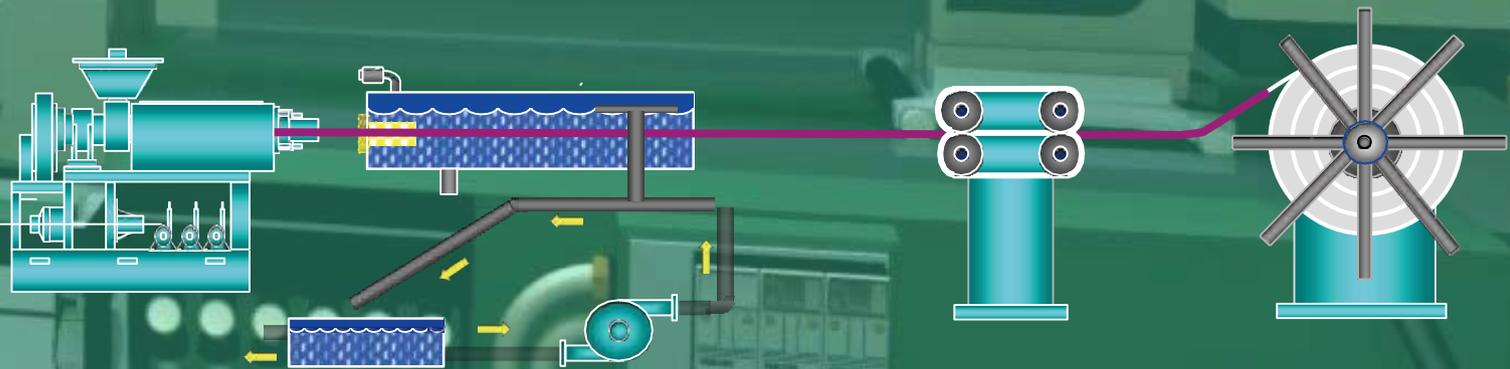
Pipe and Tube

The process for extruding tubing is similar to that for wire coating. However, the detailed techniques are different and dependent upon the size and type of tubing being made. Crosshead type dies may be used, but in-line heads are more commonly used.

Tubes and pipes can be extruded from Everflon™ fluoroplastics. These extrusions are usually applied in the transport of corrosive chemicals and, to a lesser extent, as linings.

Tube extrusion is quite similar to the wire insulation process. Processing details depend on the size and type of the tube. Tube can be manufactured by both inline and crosshead dies. Everflon™ FEP tubing can be produced with outside diameters as low as 1 mm to over 20 mm.

This range is broken into three processing zones based on the size of the outside diameter: small, medium, and large. The sizing die determines the outside diameter of the extrusion output and the line speed determines the inside diameter. Take-up speed and the die gap, and the difference between the inside diameter of the die and the outside diameter of the tip, set the wall thickness.



Small Tubing (Spaghetti)

Small tubing (<5 mm OD and <1 mm OD wall thickness) is usually produced by the free-extrusion method. This is similar to wire coating, but without the wire. Size and wall thickness depend on the tooling dimensions and balance between extruder output and tube take-up. The choice of tooling can be similar to that used for wire coating, however, a much lower draw-down ratio is used. DDR in the range of 7:1 to 10:1 is normal.

A sizing die located at the entrance to the quench bath can be used to control outside diameter. It is sometimes helpful to use slight air pressure inside the tube to make sure the sizing die is "filled".

Medium Tubing

Tubing of 10 mm or larger diameter is often made by the vacuum sizing method.

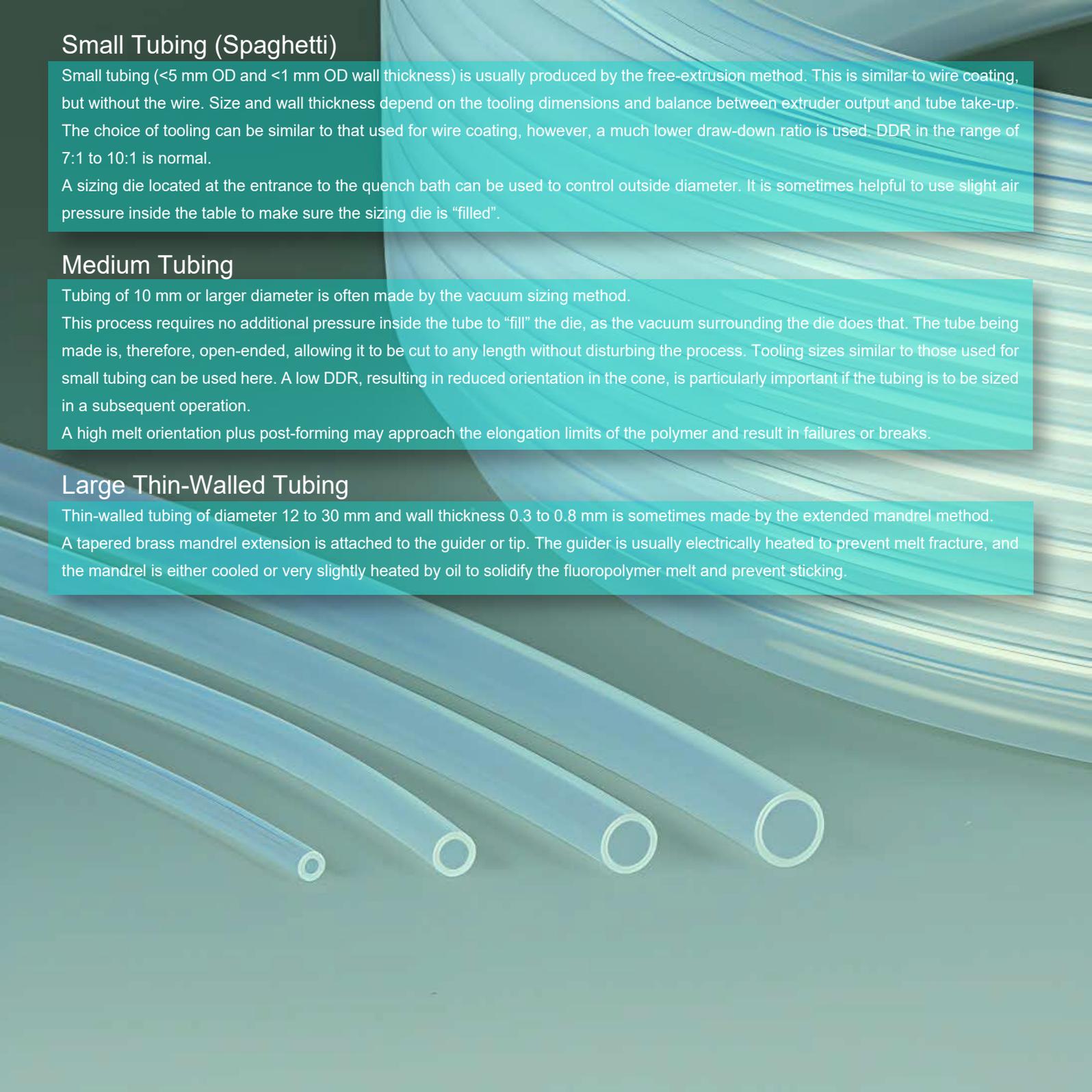
This process requires no additional pressure inside the tube to "fill" the die, as the vacuum surrounding the die does that. The tube being made is, therefore, open-ended, allowing it to be cut to any length without disturbing the process. Tooling sizes similar to those used for small tubing can be used here. A low DDR, resulting in reduced orientation in the cone, is particularly important if the tubing is to be sized in a subsequent operation.

A high melt orientation plus post-forming may approach the elongation limits of the polymer and result in failures or breaks.

Large Thin-Walled Tubing

Thin-walled tubing of diameter 12 to 30 mm and wall thickness 0.3 to 0.8 mm is sometimes made by the extended mandrel method.

A tapered brass mandrel extension is attached to the guider or tip. The guider is usually electrically heated to prevent melt fracture, and the mandrel is either cooled or very slightly heated by oil to solidify the fluoropolymer melt and prevent sticking.



Film and Sheet

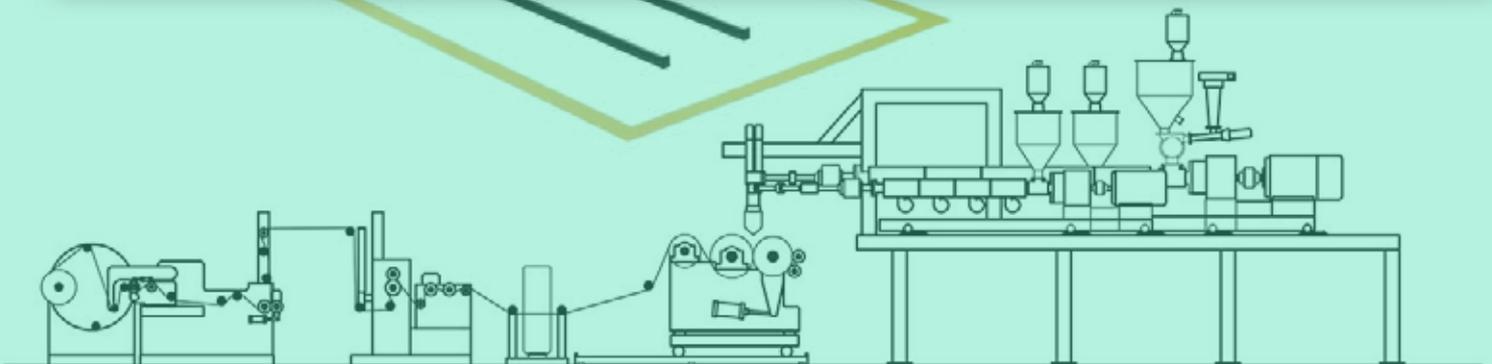
Everflon™ Fluoropolymer films have found applications where extreme high and low temperatures and aggressive chemicals are involved. For example, these films are used as release sheets in compression molding of high temperature parts with epoxy and phenolic resins. Another common application is, in general, as liners. One example is as roll cover to protect metal rolls from corrosion in chemical processing industries such as paper manufacturing. Other applications include glazing for solar collectors, gas and liquid sample bag and drug and food packaging. Partially fluorinated Everflon™ fluoroplastics provide films with especially excellent tensile strength and modulus for applications where mechanical strength is required.

Monoaxially and biaxially oriented films of Everflon™ fluoropolymer are made by melt extrusion of the resin into flat webs or tubes. The main function of orientation is to enhance the mechanical properties of the film such as tensile break strength and tear resistance. The decision to orient is usually made according to the requirements of the end use for mechanical properties.

The most common die to extrude a flat fluoroplastic film is the coat hanger die. Figure shows a schematic of a coat hanger die. The Everflon™ fluoropolymer melt enters the die near its lateral center and is redirected towards the two ends of the die. The melt travels through the channels that are angled towards the exit side of the die, thus distributes across the width of the die. The Everflon™ molten polymer flows through the die gap toward the exit slot, also called die lips. The gap is formed by two flat metal plates and is named the land area, as it is called in other types of dies. The two plates are usually formed by several sections, which can be independently adjusted to increase the control over the thickness of the extruded film/sheet.

The die is designed such that the channels restrict the melt flow in a way that all the melt experiences the same amount of shear. The distance of travel is equalized by the restraints designed in the flow channels.

The net effect is equal flow rates at the center and the far ends of the die, thus a uniform web thickness. This means that the flow in the center of the die is most restricted. One advantage of this approach is the uniformity of residence time in the die. This regime is called plug flow in that no internal shear is generated in the melt while flowing through the die.



TROUBLESHOOTING GUIDE

Processing Variations

Melt Fracture
 Extrusion Rate
 Too Slow
 Spark Failures
 Blisters
 Caliper Variation
 Poor Centering or
 Out-of-Round
 Pinholes, Tears

Possible Causes

Problem

Contamination			●					●	●
Resin Too Cold	●	●						●	●
Die Too Cold	●	●						●	●
Extrusion Rate Too Fast	●		●					●	●
Cone Length Too Short								●	●
Bubbles in Melt			●					●	●
Dirty, Wet, or Rough Substrate			●					●	●
Too Much Draw-Down			●					●	●
Cooling Water Splashing			●						●
Guider Tip Not Centered			●				●		
Center Hole in Guider Tip Too Large							●		
Inadequate Water Quench							●		
Insufficient Melt Tension							●		
Improper Draw Ratio Balance							●	●	●
Surging Resin Delivery						●	●		
Improper Screw Design		●					●		
Wire Speed Variations						●			
Vacuum Variations						●			
Cone Length Too Long						●			
Variations In Wire Diameter						●			
Rear Barrel Temperature Too Low		●							
Draw-Down Too Low	●	●							
Air Gap Too Long						●			
Outgassing of Substrate				●	●				
Resin Hold-Up Time Too Long					●				
Resin Temperature Too High					●				
Improper Die or Tip Design									●
Wet Resin or Pigment				●	●			●	●

TROUBLESHOOTING GUIDE

Extrudate Appearance

	Discoloration	Surface Roughness	Poor Color-Pigmented Constructions	Insulation Cracks	Bubbles	Contamination
Corrosion Products						●
Localized Resin Hold-Up	●				●	●
Resin Temperature Too High	●		●	●	●	●
Extruder Hopper Not Clean						●
Improper Handling or Storage				●		●
Hold-Up Time Too Long	●			●	●	
Excessive Tightness				●		
Broken Strands or Sharp Substrates					●	
Air Entrapment					●	
Excessive Wire Pre-Heat					●	
Wet Resin					●	
Dirty Substrate					●	
Shrinkage Voids from Improper Quench						
Die Too Cold		●		●		
Die Too Restrictive		●				
Resin Temperature Too Low		●		●		
Contamination		●				
Poor Die Surface		●				
Improper Guider Tip Positioning		●				
Improper Drawing of Melt		●		●		
Absorbed Moisture on Resin		●				
Roughness in Base Wire or Cable		●				
Weld Lines (Wrong Die and Tip)		●		●		
Wrong Color Concentrates Letdown Ratio			●			
Poor Dispersion of Pigment			●			
Extrusion Rate Too Fast		●				
Wrong Color Concentrate			●			



Everflon Academic Center

Tel: +86-185-7168-9228

info@everflon.com

www.everflon.com

For more information about our company, products and service, please visit our website at www.everflon.com or www.everflonultra.com