Extrusion Foaming of
DuPont™ Teflon® Fluorocarbon Resins

Applications and Processes
Introduction

DuPont has developed patented technology for the compounding and processing of fluoropolymer foam resins. The foam process involves the continuous injection of a gas such as nitrogen directly into an extruder filled with molten resin. A specially designed extruder screw is typically utilized to create the polymer gas mixture with an inert nucleating package contained in the resin to help promote cell growth. Foams of up to 60% voids have been demonstrated through the use of this process.

Applications for Melt Processable Perfluorinated Resins

DuPont Teflon® FEP and PFA perfluorinated resins possess melt viscosities low enough for processing in melt extruders. Additionally, FEP and PFA are well suited for extrusion foaming while maintaining their low dielectric constant and low dissipation factors, both necessary for twisted pair and coaxial cable insulations.

Data cables are used in the transmission of electronic signals in a variety of settings and applications. The key electrical properties required for these cables include a low dielectric constant and a low dissipation factor. These properties can be enhanced by foaming the insulation. Depending on the resin used, cables having a foamed insulation allow cable miniaturization, weight reduction of the end product, and the transmission of clear high-quality electrical signals at high signal speeds.

Foamed cables fabricated from DuPont fluoropolymer resins have become extremely popular in computer manufacturing and installation of network systems. Cables made with DuPont Teflon® FEP or PFA have low-flame and low-smoke attributes. These cables can be routed through plenums and other air handling ducts, reducing the need for the costly installation of electrical conduit.

Structure and Properties of Fluoropolymers

The discovery of PTFE by DuPont occurred in the 1930's, but at that time, the new perfluorinated resin could not be melt extruded. Further research by DuPont into the modification of the polymer architecture led to the development of a series of melt processable fluoropolymers such as FEP, PFA, and ETFE, solidifying DuPont as the world leader in fluoropolymer research.

The ability to melt extrude these polymers, combined with such characteristics as low dielectric constant and low flammability made FEP and PFA well suited for wire and cable applications.

Table 1 shows typical physical characteristics of PTFE, PFA, FEP, and ETFE.

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Methods</th>
<th>PTFE</th>
<th>PFA</th>
<th>FEP</th>
<th>ETFE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Specific Gravity</strong></td>
<td>ISO 1183/ASTM D792</td>
<td>2.16</td>
<td>2.15</td>
<td>2.15</td>
<td>1.71</td>
</tr>
<tr>
<td><strong>Melting Point (Ons) °C/F</strong></td>
<td>ASTM D4591</td>
<td>327 / 621</td>
<td>303 / 581</td>
<td>260 / 500</td>
<td>263 / 399</td>
</tr>
<tr>
<td><strong>Elongation, %</strong></td>
<td>ASTM D2176</td>
<td>325</td>
<td>320</td>
<td>325</td>
<td>200 - 375</td>
</tr>
<tr>
<td><strong>Flexural Modulus, MPa/psi</strong></td>
<td>ASTM D2216</td>
<td>600 / 81,000</td>
<td>655 / 94,000</td>
<td>650 / 94,000</td>
<td>1100 / 160,000</td>
</tr>
<tr>
<td><strong>Temperature Rating °C/F</strong></td>
<td>ASTM D5772</td>
<td>260 / 500</td>
<td>260 / 500</td>
<td>200 / 350</td>
<td>155 / 311</td>
</tr>
<tr>
<td><strong>Dielectric Constant</strong></td>
<td>ASTM D150</td>
<td>2.37</td>
<td>2.06</td>
<td>2.04</td>
<td>2.50</td>
</tr>
<tr>
<td><strong>Coefficient of Friction</strong></td>
<td>ASTM D1894</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Chemical Resistance</strong></td>
<td>ASTM D543</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Very Good</td>
</tr>
</tbody>
</table>

*Nominal Values
General Aspects of Foamed Insulation

The dielectric properties of polymeric insulation on wire can be improved by the inclusion of gaseous bubbles. However, this must be done in a way that results in small and evenly distributed voids throughout the insulation. Large bubbles can lead to failures within the insulation and uneven void distribution can cause mismatched performance around a conductor. DuPont has developed technology for the controlled nucleation of nitrogen gas in the fluoropolymer melt as it is extruded and drawn onto wire.

Foaming provides a collection of distinct advantages that are not achievable with conventional melt extrusion techniques. For FEP and PFA, when foaming technology is utilized, the dielectric constant drops as the void content increases. The reduced dielectric constant achieved through foaming increases the relative velocity of propagation while lowering capacitance. (See Figure 2). Because of these improved attributes over conventional melt extrusion, foaming also allows for reduced wall thickness, leading to a corresponding drop in overall weight of the required insulation.

Equipment Requirements for Foaming

Conventional extruder screws for melt extrusion have two key zones, a feed and a shallow metering zone. In foam extrusion applications, a 3 or 4 stage screw is used with feed, compression, metering, and mixing stages. A reduced diameter ring is machined at the middle of the first mixing section to reduce the pressure in that region, facilitating the gas injection.

Proper sizing of the extruder and appropriate screw design are key factors in the foaming process.

Improper sizing can result in poor mixing and melting (slow rpm) or excessive shear and heat (high rpm).

Figure 3 shows a typical extruder configuration for foam processes.

![Figure 3 – Typical Foam Extruder Configuration](image)

As the polymer is melted and fed through the extruder barrel, pressurized gas is injected at or about sonic velocity by a high pressure pump. Proper sizing of the injector via the metering orifice is required to deliver a controlled gas injection into the polymer at the desired levels.

Figure 4 depicts an example of an extruder injector and high pressure pump.

![Figure 4 – Pressure Probe, Gas Injector and High Pressure Pump](image)

Figure 5 shows an example of the estimated gas flow into the extruder versus the pressure (in psig) provided by the high-pressure injector.

![Figure 5](image)
The amount of gas metered into the extruder is controlled by varying the injection pressure as well as the size of metering orifice within the injector. For a stable process, it is desirable to operate the injector at pressures greater than 1.5X the barrel pressure in that region.

Gentle but thorough mixing is recommended to properly distribute the gas. The gas dissolves into the melt, forming a polymer/gas solution. Using low shear mixing elements, the continual division and recombination of the melt helps ensure the proper and even distribution of gas. This serves to provide consistency in the size and quantity of voids in the end product.

As the polymer/gas mixture exits the crosshead under pressure, the gas nucleates, forming "bubbles" in the insulation. Nucleating agents which are contained in the polymer mix assist in the formation of these voids. The polymer cools as it exits and "freezes" onto the wire structure. The optimal situation is to have the foaming occur once the extrudate is on the wire. (See Figure 6). Crosshead temperatures and tooling selection can be varied to keep the head pressure high enough so gas bubbles do not form until the melt is drawn down onto the wire.

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. Teflon® FEP and PFA can be processed over a wide range of Draw Down Ratios, depending upon melt temperature, the profile precision needed and required throughput rates. A DDR of 5:1 to 30:1 is typical for FEP and PFA foam extrusion.

Since foaming typically occurs once the material is on the wire, tooling factors such as DRB and DDR should be calculated utilizing the solid equivalent "pre-foamed" OD.

The process contact metals for the tooling, such as the tip and die, must be high-nickel, low-iron alloys suitable for fluoropolymer processing.

Figures 7 and 8 show the relationship between shear rate, shear stress, output and die geometry. For a given profile tooling geometry, the shear rate increases directly as the melt output is increased.
Safety Considerations

The major safety consideration for the extrusion of fluoropolymers and other organic polymers is the removal of off-gases released from hot polymers into work areas. This can be accomplished by the installation of exhaust hoods at the die and the hopper heaters, if utilized. Extruding into water – either a quench tank or a partially filled container – for purging is also recommended.

For additional safety information, refer to the following: Guide to the Safe Handling of Fluoropolymer Resins, published by The Society of the Plastics Industry, Inc.; safety articles published by Plastics Europe, available through their website library; and Material Safety Data Sheets provided with every DuPont product.

Rheology

Figure 9 represents a map of possible flow conditions typically seen in the processing of FEP and PFA fluoropolymer resins. The figure is a plot of shear stress versus shear rate and illustrates how shear stress increases with increasing shear rate. For a given profile tooling geometry, the shear rate increases directly as the melt output is increased. The shear stress also increases as the pressure is increased.

The map also defines four possible regions of extrusion behavior. The first region is the wide area of normal operation where almost all extrusion is typically performed. The second region 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". A smooth extrudate is obtained again in the third region, normally referred to as the "super shear" region. Super shear occurs when the flow of the polymer melt has lost its adhesion to the surfaces of the tooling. This phenomenon is accompanied by a drop in extrudate head pressure, allowing greater extrudate output. In the fourth region, the extrudate becomes excessively rough again.

Resin, Construction & Processing Considerations

Final wire construction is dictated by a balance of processing methods, consistency in operations, and the choice of resins used. Foaming of thicker-walled constructions such as RG6 cable (>20 mil wall) allow for higher void contents (>45%) and the use of lower melt flow rate resins, typically <15 MFR. Lower draw-down tooling is also required for these thick-walled constructions. Thinner-walled constructions, such as Cat 5e, Cat 6, 10Gig, and twisted pair applications (<20 mil wall) with lower void contents (<45%), are accomplished using higher melt flow rate resins (>15 MFR) and higher draw-down tooling.

One critical end-product property is the rate of return loss, or the amount of signal that is lost due to reflections along the length of a cable. Excellent return loss properties and good adhesion of the resin to the wire can be achieved through small and uniform cell structure, uniform material along the conductor, and consistent and good bonding between the wire conductor and the foamed insulation. The polymer, nucleant formulation, and processing are all contributing factors to producing uniform cells and better adhesion to the conductor. Figures 10 and 11 are excellent examples of small and uniform void distribution desirable for a foamed construction.
Nucleant type and loading can also have an effect on processing and cell structure, which in turn can impact the diameter, capacitance, and other electrical properties of the final wire/insulation product. Figure 12 shows how variations in the nucleant package can affect the ultimate foaming.

Figures 13 and 14 show the void morphology achieved when two different nucleant packages are utilized to make constructions of the same dimensions and measured capacitance.

Examples of Effects of Varying Nucleant Packages

Same wall thickness and same void content for each extrusion.

Nucleant A – Better capacitance, no straight-through holes in insulation.

Nucleant B - More variation in voids.

Additionally, process variables such as cone length, wire preheat temperature, and quench point can influence factors such as return loss and measured capacitance.
Alternative Methods of Processing

Variations on the foaming process have been developed to help enhance the performance characteristics of the insulation.

Process variants such as the inclusion of an outer skin material provide a smooth surface for improved contact for shielding and braiding, a protective layer to minimize blow-through issues, and facilitate better processing control. Figure 15 shows an example of a miniature foam/skin construction with a typical wall thickness between 30 and 50 mils.

![Figure 15 - Example of Miniature Foam/Skin Construction](image)

Additional variants include the addition of a solid film layer placed in contact with the wire conductor, providing a void-free uniform material and serving to improve return loss and adhesion properties.

Summary and Conclusions

The foaming of fluoropolymer resins such as DuPont Teflon® FEP and PFA, through the use of gas injection extrusion, provides a safe and economical way to produce plenum rated cables with reduced size, reduced weight, and improved electrical performance. Through foaming technology, the DuPont Fluoroproducts technical team has demonstrated why DuPont continues to be the leading innovator of advanced uses in fluoropolymers.

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