Extrusion Foaming of ETFE Fluoropolymer Resin

Stuart K. Randa, Carl R. Fyrwald and David P. Reifschneider

E. I. du Pont de Nemours & Co. (Inc.)

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ABSTRACT

Continuous gas foaming of "Tefzel" ETFE fluoropolymer resin, as presented in this paper, is a practical process for producing foam primaries. Thin-wall foam and foam-skin constructions, with void contents as high as 70 percent, have been made at high speed using this technique. Foam primaries are generally used in twisted pair, computer network cables.

INTRODUCTION

With the continued growth of computer networks, the use of twisted pair and coaxial cables has increased significantly. These cables provide the low capacitance required for high-speed data transmission. Twisted pair primaries insulated with foamed ETFE resin, a copolymer of tetrafluoroethylene and ethylene marketed under the trademark "Tefzel" ETFE fluoropolymer by Du Pont, provide the enhanced properties necessary for today's demanding data transmission requirements.

ETFE cables are physically tough, highly resistant to chemicals and able to withstand high temperatures. What's more, through foaming, the excellent electrical properties of ETFE cables are greatly enhanced.

ETFE foamed cables can be designed to meet the flame and smoke requirements of the National Electrical Code for plenum cable applications. Cables meeting these requirements can be installed in the air plenums above suspended ceilings without the use of metal conduit—saving both time and money.

Foamed "Tefzel" is a very versatile insulating material. It has been used to make thin insulations for small diameter wires in twisted pair cable constructions and for heavier industrial cables. Foam/skin extrusions permit the combination of many materials to achieve specific properties in the most cost-effective constructions. Cables made of foam "Tefzel" could be used for telecommunication and computer applications, as well as control cables for utilities. Two twisted pair ETFE foam cables are shown below.

The foaming process requires injection of a gas into an extruder. The ETFE resin used in this process contains a nucleant that has been compounded into the resin. The nucleant provides sites for foam cell growth. Final cell size is 1 to 3 mils in diameter. Void contents as high as 70 percent have been demonstrated.

These foams can be either a single uniform layer or a single layer surrounded by a thin, solid skin. The skin provides added dielectric strength and an easy way to color the insulation.

Foaming is an excellent way to achieve low mutual capacitance in twisted pair cables. In comparison to solid insulation, foam can be made much thinner, while still providing the desired impedance. In addition, foam insulation offers a weight savings and can allow the use of a larger conductor to achieve even lower cable attenuation.

PROCESS

Resin Characteristics

"Tefzel" ETFE fluoropolymer resin has the general polymeric repeat structure shown in Figure 3.

"Tefzel" ETFE possesses some of the toughness of nylon, almost the same inertness as "Teflon" and much of the radiation resistance of polyethylene.

The base resin used for foaming is "Tefzel" 220. Three

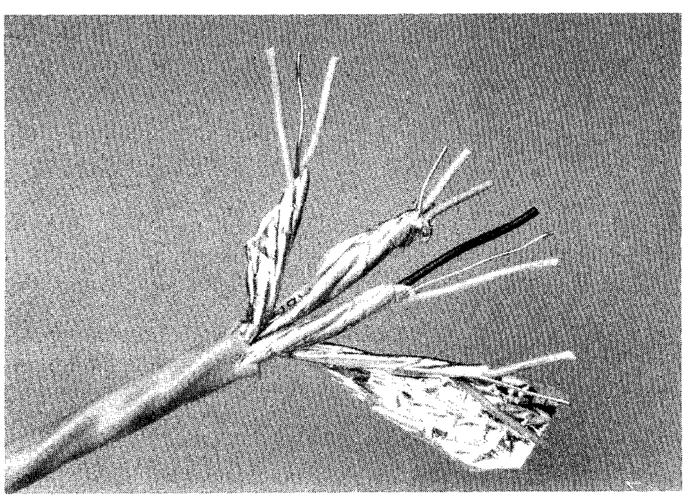


Figure 1. Foamed ETFE Cable of Shielded Pairs

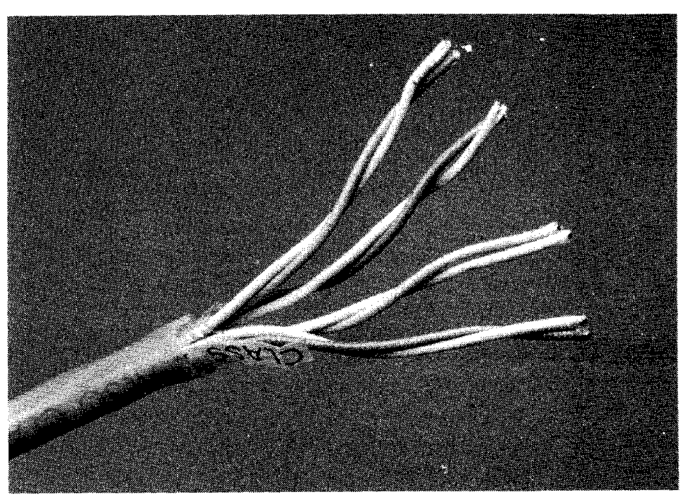


Figure 2. Foamed ETFE Cable of Unshielded Pairs

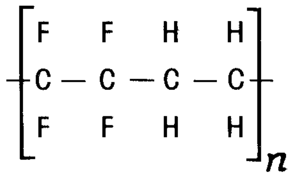


Figure 3. ETFE Molecular Structure

grades are supplied in cube form: 220 for solid skin, 220F for foaming and 220CC color concentrates.

The ETFE resin used in foaming is one of the most fluid ETFE resins available. The standard melt flow of this resin is greater than 20 grams/10 minutes at 298°C (568°F). This resin has been specially designed to meet the melt flow requirements of high-speed processing through dies having small orifices, while still retaining adequate mechanical properties for use as thin-wall foam.

The critical shear rate of this resin (the point prior to that rate where rough-surfaced extrudates are encountered), at 305°C and 340°C, is listed in Table I.

Table I. ETFE Resin Rheology

TEMPERATURE	MAXIMUM CRITICAL SHEAR RATE (Reciprocal Seconds)
305°C (581°F)	100,000
340°C (645°F)	500,000

The shear rate formula for pressure extrusion is shown in reference 1. This formula can be used to estimate possible production speeds for specific foamed wire constructions.

"Tefzel" resins for foaming have an approximate melting point of 270°C (518°F); a room temperature specific gravity of 1.7; and a specific gravity of 1.3 at 300°C (572°F).

The relatively low dielectric constant and dissipation factor make ETFE resin an attractive electrical insulating material, even as a solid. Table II shows these values at various frequencies.

Table II. Electrical Properties of ETFE 220 Resin

FREQUENCY	DIELECTRIC CONSTANT	DISSIPATION FACTOR
1 KHz	2.58	0.001
1 MHz	2.56	0.006
100 MHz	2.45	0.020

Foaming reduces the dielectric constant from 2.6 for a solid material toward the 1.0 value of air. Lower dissipation factors, necessary to achieve low cable attenuation, also accompany foaming. For example, an ETFE foam having 70 percent voids would possess a dielectric constant and a dissipation factor nearly half that of solid material. The relationship between dielectric constant and foam level is shown in Figure 4.

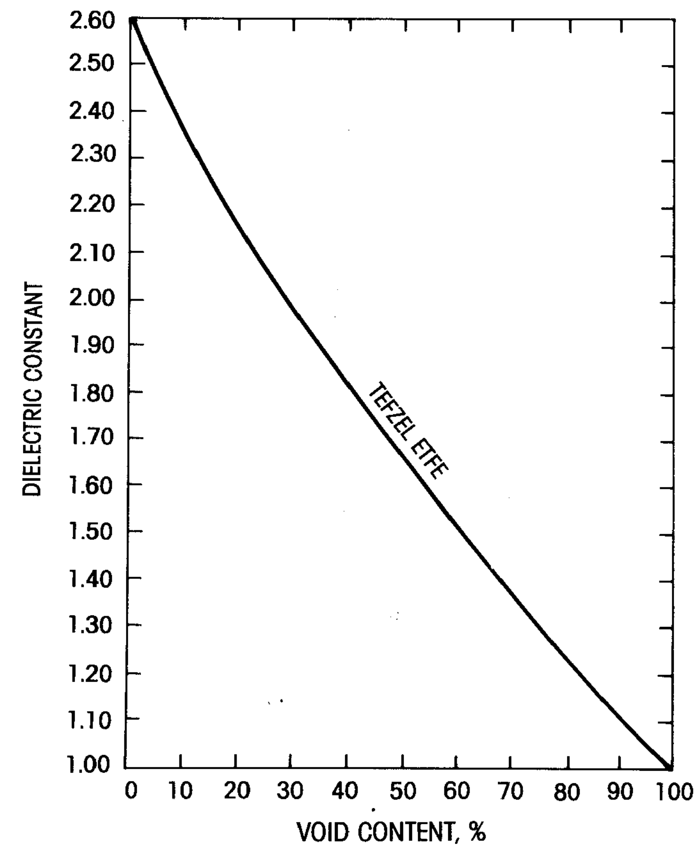


Figure 4. ETFE Dielectric Constant vs. Void Content

Equipment for Extrusion

1. Extruder

A special extruder screw is used. Five zones comprise the design of this screw: feed, meter, gas injection, pumping and mixing, as shown in Figure 5. The partially filled zone is where the gas is injected and dissolves into the molten resin.

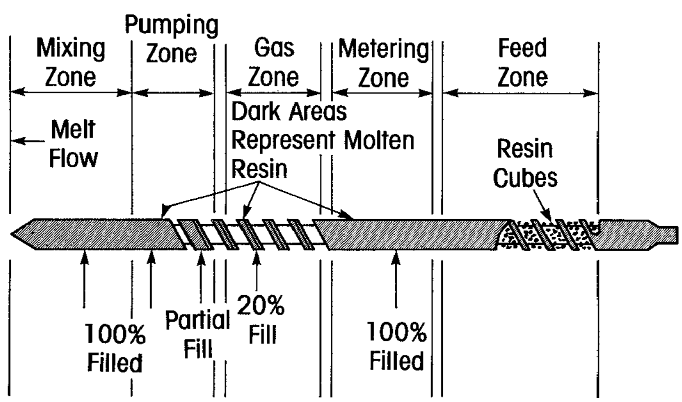


Figure 5. Schematic Drawing of a Melt-Filled Extrusion Foaming Screw for ETFE Resin

Details of the design of a 1.25-in. diameter ETFE foam extruder screw are shown in Table III. This design differs from that used for the foaming process of FEP resin (2). The main difference is that the channel depths are shallower.

Table III. Extruder Screw Details (1.25 in./31.75 mm diameter) Square Pitched Screw

EXTRUDER SCREW ZONES	NUMBER OF FLIGHTS	CHANNEL DEPTH (in./mm)
Feed	8.0	0.160/4.06
Transition	3.0	–
Metering	4.0	0.035/0.89
Transition	0.5	–
F-22 Injection	3.5	0.200/5.08
Transition	0.5	–
Pumping	6.8	0.054/1.37
Mixing Head and Tip	3.7	0.155/3.26
Total	30.0	

Screw diameters range from 1.25 to 2.35 inches. Standard length to diameter (L/D) ratios range from 28 to 35:1.

To obtain precision control of melt temperature, PID temperature controllers should be used. Motor control for wire conveying and screw melt delivery must also be precise (i.e., 0.1 to 0.5 percent D.C. control). Such equipment should result in acceptable capacitance and diameter control.

2. Gas Injection System

The gas injection system, shown in Figure 6, is comprised of a gas cylinder (1), a gas regulator (2), manual valves (3, 4 and 5), a pressure relief valve (6) and a gas injection probe (7).

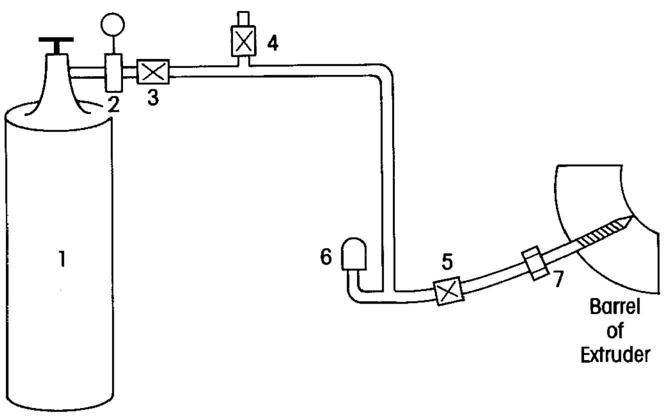


Figure 6. Gas Injection System

Gas pressure is adjusted with the regulator. The gas flows into the extruder barrel through the injection probe. For a given screw speed, void content is adjusted by varying the gas pressure. This type of gas injection is a simple process setup because no pumps or automatic control valves are required. In addition, the process allows the use of either nitrogen or "Freon" 22 as the foaming gas. The latter is preferred.

3. Crosshead

The 4/6F fixed center crosshead used in our ETFE foam development studies was made by the Maillefer Corporation of South Hadley, Massachusetts. Use of different center cartridges within the Maillefer crosshead allows simple foam extrusion or a foam-skin duplex extrusion. Cross-sectional views of this crosshead during both types of extrusion are shown in Figures 7 and 8. The information in these figures is presented courtesy of the Maillefer Company.

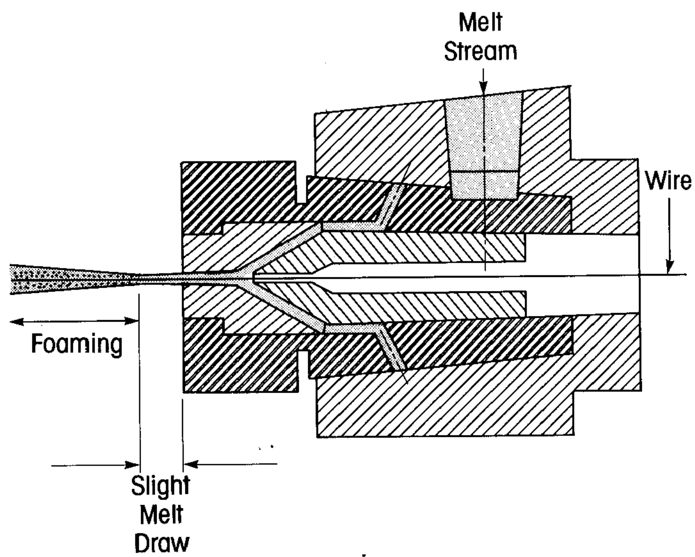


Figure 7. Maillefer 4/6F Wire Coating Crosshead, Single Extrusion

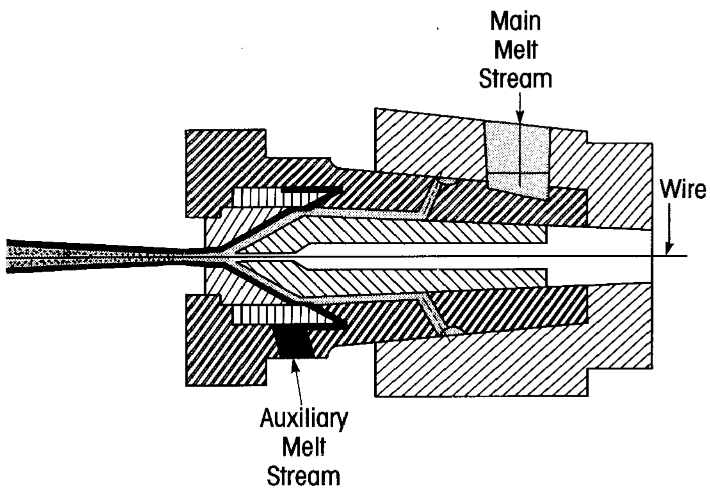


Figure 8. Maillefer 4/6F Wire Coating Crosshead, Foam-Skin Extrusion

In the foam-skin extrusion set-up, a smaller auxiliary extruder with a conventional type screw provides the molten ETFE resin for the outer skin coating of solid ETFE resin. The two extruders should be positioned head to head, as shown in Figure 9, to best accomplish the foam-skin extrusion.

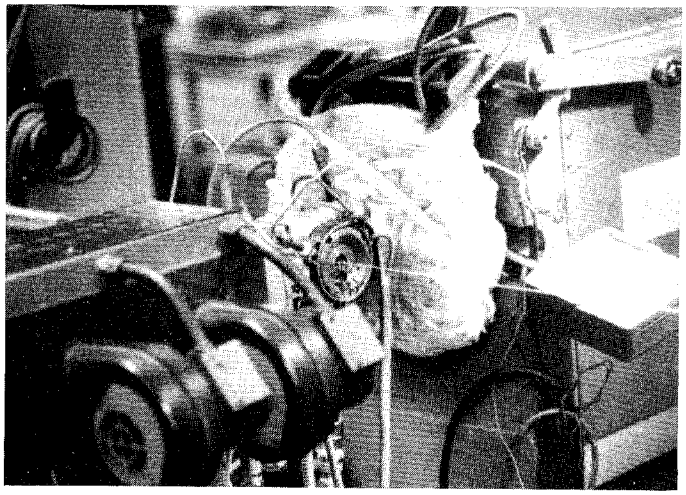


Figure 9. Dual Extrusion for Foam-Skin Production

ETFE resin extrusion foaming normally requires a pressure extrusion. With insulation thicknesses greater than 20 mils, a low melt draw extrusion (less than 5:1) may be used. However, in each type of extrusion, a slight melt draw is applied prior to foaming.

Pressure extrusion is preferred for foaming ETFE resin because this technique minimizes the occurrence of elongated foam cells.

Each of these extrusion techniques is shown schematically in the following figures.

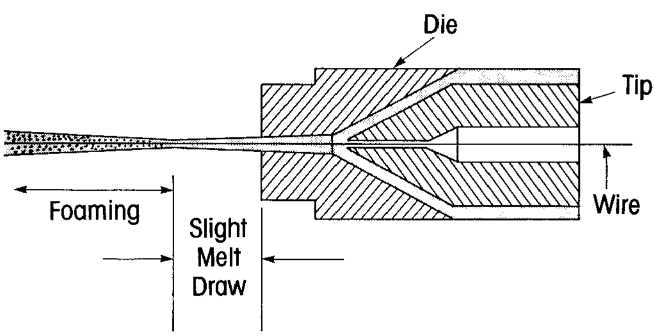


Figure 10. Pressure Extrusion Foaming

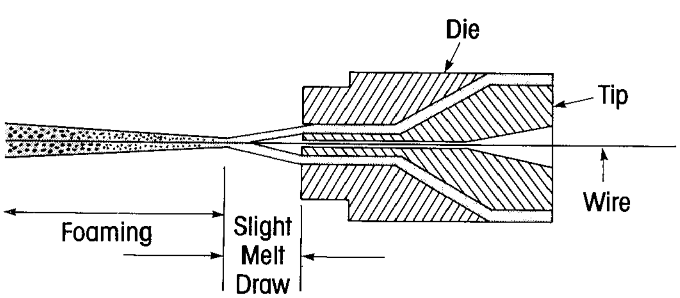


Figure 11. Melt Draw Extrusion Foaming

Extrusion Conditions

Extrusion conditions for production of a 6-mil foam on solid AWG 24 wire, which includes a 1-mil colored skin, are reviewed here. The production speed of the wire coating was 1,000 ft/min. Table IV lists the details of the extrusion equipment used; Table V lists the operational settings for this equipment; and Table VI shows the properties of the foamed primary wire.

Table IV. Equipment for Foam-Skin Extrusion

- 2-in. Diameter Foam Extruder
- 1-in. Diameter Extruder (Skin Coating)
- Dual Coating Maillefer Crosshead
- Die: 0.033-in. (0.88-mm) orifice
- Electronic Wire Preheater

Table V. Operational Settings at 1,000 ft/min Wire Speed

	2-in. Extruder	1-in. Extruder
Extruder	315°C (600°F)	315°C (600°F)
Crosshead and Die	332°C (630°F)	
Screw RPM	25	7
Melt Pressure (psi)	700	1,000
F-22 Gas (psi)	60	none
Melt Temperature	323°C (615°F)	
Shear Rate	107,000 sec^{-1}	
Wire Speed	1,000 ft/min (304 m/min)	

Table VI. Properties of the Foamed Primary Wire Construction

Construction Diameter	33 mil (0.84 mm)
Foam Thickness	6 mil (0.15 mm)
Skin Thickness	1 mil (0.025 mm)
Capacitance	56 pf/ft
Dielectric Constant	1.79
Resin Weight/1,000 ft	0.2 lb (0.09 kg/304 m)

At a shear rate of 100,000 reciprocal seconds, extrusion rates of 1,000 ft/min (304 m/min) have been demonstrated with a 7.5-mil (0.19-mm) foam coating on AWG 24 wire. The pressure die used had a 0.033-in. (0.84-mm) orifice. The melt temperature was 315°C (600°F) and the melt draw was 1.6:1.

WIRE PROPERTIES

Foam Structure

Figures 12 and 13 show the foam structure of this insulation magnified at 30X and 75X. Figure 12 shows a cutaway view from the side of the construction. Figure 13 shows an end view of the insulation. The presence of the black exterior skin can be seen in each photograph. Note the excellent uniformity of the insulation wall in Figure 13. This concentricity is a direct result of using the fixed centered crosshead.

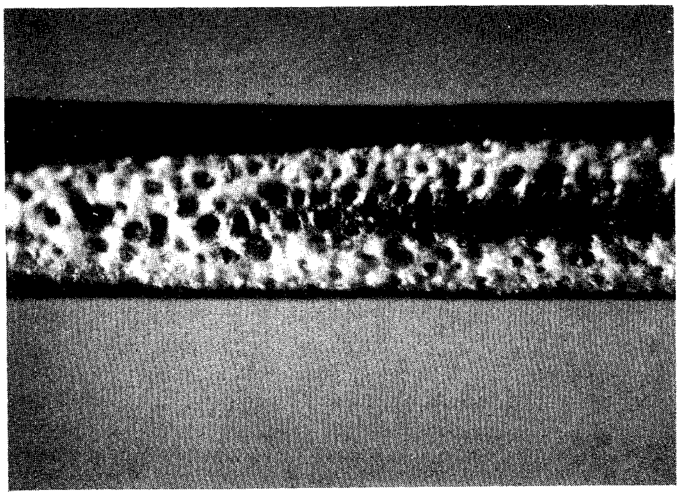


Figure 12. Foam-Skin ETFE Insulation, Top View @ 30X

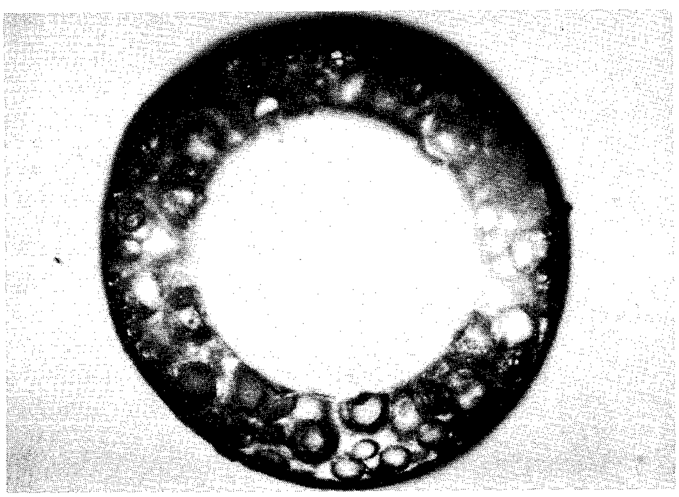


Figure 13. Foam-Skin ETFE Insulation, End View @ 75X

To obtain a foam without an outer skin, use the same approximate extrusion conditions with the crosshead in its single coating mode and without the auxiliary extruder.

Mechanical Properties

As foam-skin constructions, the ETFE resin could have an upper service temperature of 150°C (302°F). This temperature was established by Du Pont as a result of a study where the primaries were tested according to the Mil-22759 procedure, modified to a 1,000 volt breakdown.

Table VII shows a comparison of the mechanical properties of ETFE resin as solid and as foam.

Table VII. ETFE Resin Mechanical Properties: Solid Versus Foam Measured at 23°C (73°F) (2-in./min)

PROPERTY	UNFOAMED	FOAMED 45% voids*
Yield Strength	4,450 psi (30.7 x 10^6 pascal)	–
Tensile Strength	6,060 psi (41.8 x 10^6 pascal)	1,200 psi (8.3 x 10^6 pascal)
Elongation at Break	300%	125%
Flexural Modulus	170,000 psi	35,000 psi
GTE Crush Test, 5-mil Insulation (600 lb minimum)	>1,000 lb passes	>900 lb passes

*Five-mil thick foams, with or without the solid exterior skin.

Electrical Properties

The electrical properties of extruded wire coatings can be predicted using standard formulas. These formulas are also applicable to foamed ETFE.

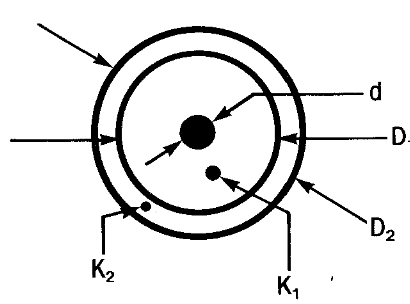
Coaxial capacitance, the capacitance measured in-line with the extrusion process, decreases with either increasing wall thickness or increasing void content.

For foam/skin combinations (layers of materials of differing dielectric constants) the coaxial capacitance is obtained by the following formula.

$$C = \frac{7.354}{\log\left[\left(\frac{D_1}{d}\right)^{\frac{1}{K_1}} \left(\frac{D_2}{D_1}\right)^{\frac{1}{K_2}}\right]}$$

where: C is in picofarads per foot
D_2 is the diameter over the outer layer
D_1 is the diameter over the inner layer
K_2 is the dielectric constant of the outer layer
K_1 is the dielectric constant of the inner layer
d is the conductor diameter

Refer to the schematic diagram below.



For an ETFE skin/foam construction, K_2 would be 2.6 and K_1 would be the dielectric constant of the foam. If no skin is used, K_2 would be 1.0, D_2 would equal D_1 and the formula would be the same as for a single layer of insulation.

Figure 14 is a graph of the coaxial capacitance of an AWG 24 wire where the insulation has an outer 1-mil skin of solid "Tefzel."

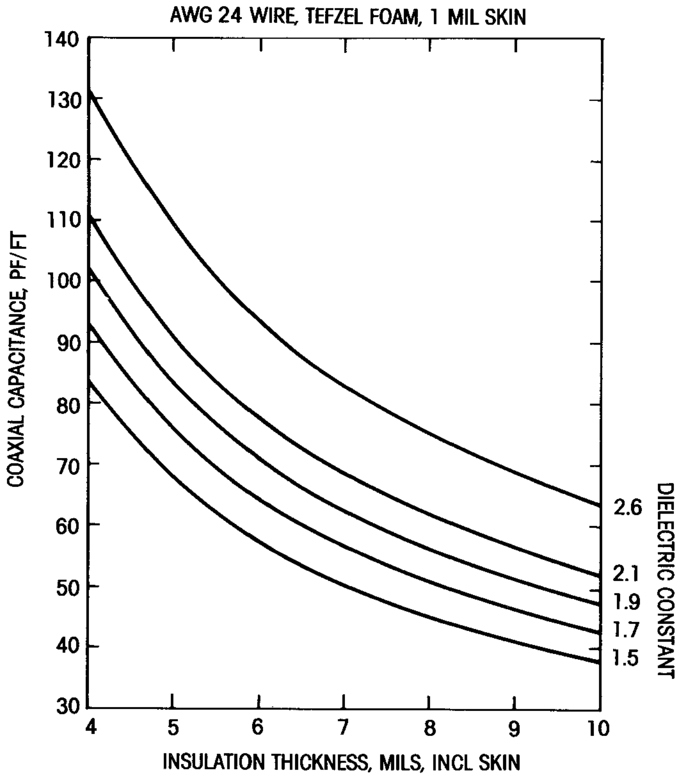


Figure 14. Coaxial Capacitance

The dielectric strength of a foam is typically lower than that of solid insulation, and ETFE foam is no exception. ETFE with 45 percent voids in a 5-mil wall would have a dielectric breakdown voltage of 1,000 volts. Adding a thin outer skin coating and/or increasing the foam thickness improves this breakdown voltage. A 10-mil foam having a 2-mil outer solid skin has a breakdown voltage of more than 3,000 volts.

Some telephone cable specifications require that the insulation withstand 2,500 volts D.C. for three seconds between paired conductors. Foams typically will not meet this specification. However, a 6-mil ETFE foam has withstood voltages of 1,500 to 2,000 volts D.C., and foam/skin constructions have far exceeded the 2,500 volts D.C. test.

CABLE PRODUCTS AND APPLICATIONS

Typical cables that can be fabricated using primary wires insulated with foamed "Tefzel" include: inside telephone cables for plenum use; computer interconnection cables, such as RS-232 types; and other instrumentation and control cables for Class 2 and 3 power-limited applications.

In scouting tests, foamed ETFE passed the flame and smoke requirements of the Underwriters' Laboratories 910 test. The cables tested were 4 and 12½ pairs with jackets of "Teflon" FEP. The AWG 24 primaries had 5-mil coatings each containing 50 percent voids.

In telephone cables, the mutual capacitance can be determined using traditional formulas with a value for the dielectric constant of the composite insulation (3). Figure 15 shows mutual capacitance as a function of insulation wall thickness.

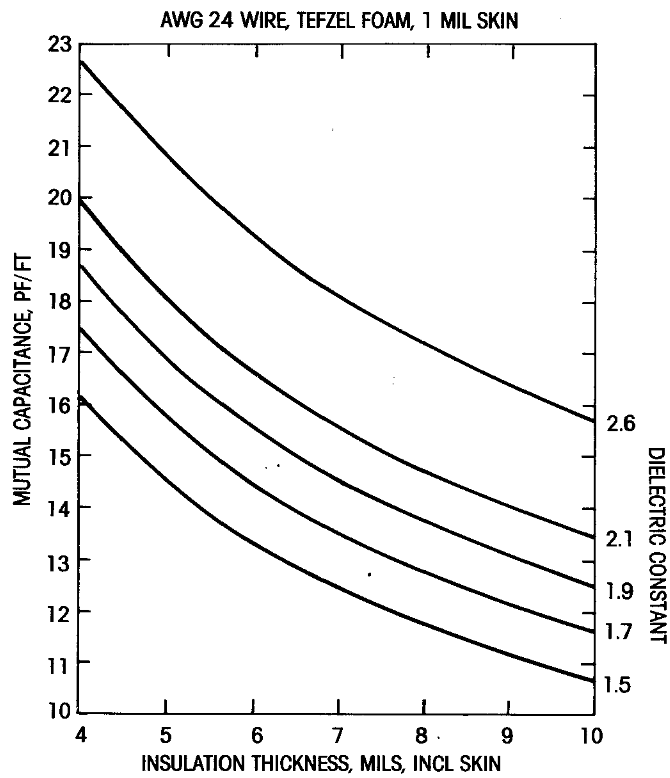


Figure 15. Mutual Capacitance

As previously discussed, an outer skin provides several important benefits. It can enable color coding without blending color into the foam concentrate and it gives greater electrical and mechanical durability to the wire coating. It may also contribute to easier stripping and termination.

Foamed ETFE for telephone cables has been made in a 5.5-mil coating on AWG 24 wire. The insulation was made up of a 4.5-mil foam of 55 percent voids and a 1-mil colored skin. The insulation weight was 0.16 lb/1,000 ft of primary wire. The mutual capacitance was less than 15 pf/ft, which is a significant improvement when compared to the 22 pf/ft industry norm.

The current trend in office automation is more cabling from a central wiring hub to individual offices. These computer cables must meet stringent controlled impedance requirements. One such requirement for telephone-type wiring is 100 ohms at 1 MHz; a requirement that can easily be met using foamed "Tefzel."

The foam extrusion process lends itself to meeting controlled impedance requirements because the foam level can be matched to wall thickness combinations. The specific combination of wall thickness and dielectric constant, as determined by foam level, can be chosen by design; however, it should be verified by actual cable tests since variations in manufacturing and shielding can significantly change the impedance.

During our study, we fabricated three cable constructions with the goal of having each cable exhibit 100 ohm impedance. Although this impedance level was not precisely achieved, each cable possessed a balanced combination of excellent properties.

The cables we fabricated were a 4-pair individually shielded, a 4-pair overall shielded and a 4-pair unshielded. Construction details, as well as measured data, are listed in Table VIII.

Table VIII. Four Pair Cable Data

INDIVIDUALLY SHIELDED

24 AWG conductor, 11-mil wall, foamed 50%
Inline coaxial capacitance 37.2 pf/ft
Resin weight, ~.40 lb/1,000 ft of conductor

Frequency	256k	1M	10M	20M
Attenuation db/100 ft	.48	1.3	3.8	5.6
Impedance, ohms	102	87	77	76

OVERALL SHIELD

24 AWG conductor, 7-mil wall, foamed 60%
Inline coaxial capacitance 49 pf/ft
Resin weight, ~.20 lb/1,000 ft of conductor

Frequency	256k	1M	10M	20M
Attenuation db/100 ft	.41	.87	2.7	3.9
Impedance, ohms	93	88	83	83

UNSHIELDED

24 AWG conductor, 7-mil wall, foamed 60%
Inline coaxial capacitance 49 pf/ft
Resin weight, ~.20 lb/1,000 ft of conductor

Frequency	256k	1M	10M	20M
Attenuation db/100 ft	.29	.59	2.1	3.2
Impedance, ohms	116	109	106	105

Coax cables are not likely candidates for the use of foamed "Tefzel." That's because coax cables require low attenuation values and the use of materials with low dissipation factors, such as "Teflon" FEP or polyethylene. "Tefzel" has dissipation factor values an order of magnitude higher than FEP or polyethylene. Thus, cable attenuation would be significantly higher.

If the higher attenuation can be tolerated, or shorter cable lengths used, a possible application area for ETFE coax cable might be in the nuclear power industry in radiation areas.

Cables of foamed "Tefzel" are currently being evaluated for use in aerospace, military electronics, transit, automotive and industrial applications.

REFERENCES

1. "Equipment and Design Changes in the Extrusion of Foamed Fluoropolymer Resins," 32nd Wire and Cable Symposium 11/20/83, E-85784.
2. "Extrusion Foaming of Coaxial Cables of Melt Fabricable Fluorocarbon Resins," 30th Wire and Cable Symposium 11/18/81, E-90839.
3. "Lee's abc of the Telephone," Riley & Acuna, Volume 7.

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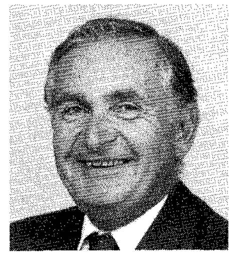

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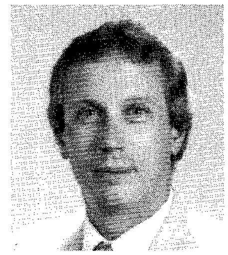

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