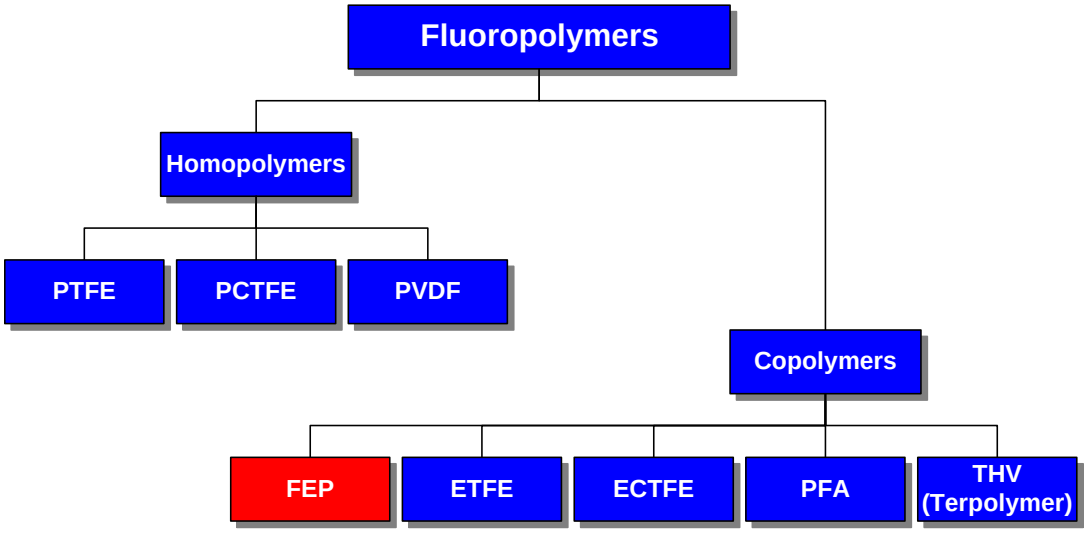
Focus on: FEP

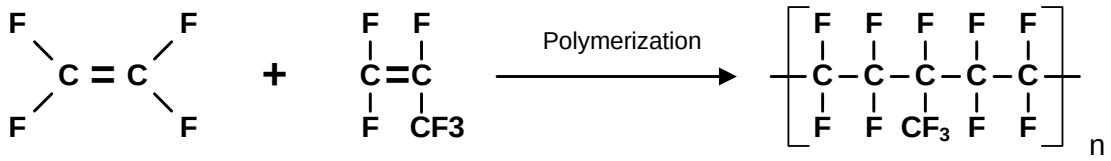
Introduction

Continuing our series of looking at the members of the fluoropolymer family in detail, this month we focus on FEP (fluoroethylene-propylene). FEP is a copolymer (these are polymers of the structure -A-B-A-B-A-B- where A and B are different repeating units) and fits into the fluoropolymer family as shown below.



FEP in the fluoropolymer family.

FEP is a fully fluorinated copolymer of tetrafluoroethylene (TFE), the base material for PTFE, and hexafluoropropylene (HEP). These combine in the -A-B-A-B-A-B- format to create the chemical structure of FEP as shown below:



Tetrafluoroethylene Hexafluoropropylene ***FEP***

Copolymerization of tetrafluoroethylene and hexafluoropropylene to give FEP

As with all fluoropolymers, the structure of FEP is semi-crystalline, giving it not only a distinct and sharp melting point, but also generally better mechanical properties than those of the amorphous type of polymers such as the polyolefins.

FEP was first produced by DuPont in 1956 as Teflon® FEP and was the first commercially produced material to combine the unique mechanical and chemical properties of the fluoropolymers with the melt-processability of more conventional polymers. Inevitably, the search for melt-processability required some minor trade-offs in mechanical and physical properties, and while FEP is superior to PTFE in some properties (i.e. impact strength), the general mechanical and chemical properties of FEP are very similar to those of PTFE. The major difference is that the maximum service temperature for FEP is 205°C and this is about 60°C lower than that of PTFE.

Properties

The general properties of FEP are typical of other semi-crystalline high performance thermoplastics:

- Very good temperature stability
- Outstanding electrical properties
- Outstanding chemical resistance
- Outstanding weathering resistance
- Low coefficient of friction
- Excellent toughness but generally low mechanical strength
- High cost

Physical and Mechanical

The physical and mechanical properties of FEP are broadly comparable to those of PTFE. However, the temperature of use is restricted to a smaller range (-240°C to +205°C) and some mechanical properties (such as cut through and abrasion resistance) are less than PTFE.

Typical mechanical and thermal properties are given in the table below.

Property	**Approximate Value Natural polymer**
Tensile Strength (@23°C)	**14 – 20 MPa**
Tensile Modulus (@ 1% strain @ 23°C)	**0.6 GPa**
Elongation at Break (@23°C)	**300 %**
Flexural Strength (@23°C)	**No Break**
Izod Notched Impact Strength (@23°C)	**No Break**
Coefficient of friction (dynamic)	**0.25**
Heat Deflection Temperature (0.45 MPa)	**60°C**
Low Temperature Toughness	**–240°C**
Coefficient of Thermal Expansion (20 – 100°C)	**5 x 10^{-5}/°C**
Long Term Service Temperature	**205°C**
Melting point	**260 °C - 270°C**

Specific Gravity	**2.1 – 2.2**
Water Absorption	**0.004 – 0.01% (50% rh)**
Appearance	**Transparent**

Thermal and Flammability

FEP is also one of the few plastics that is both suitable for high and low temperature applications and can be used over the range of temperatures –240°C to 205°C. This is only slightly less than the working temperature range of PTFE, but FEP has the advantage of being melt-processable.

The fire behavior of FEP is also excellent and has no difficulty in achieving UL 94 V-0 for flame resistance. The Limiting Oxygen Index (LOI) for FEP is greater than 95, which means that there must be over 95% oxygen present to support free combustion (air only contains approximately 21% oxygen and therefore a material with a LOI of greater than 21 will probably not support burning in an open air situation).

Even when FEP does burn, the heat of combustion is extremely low, the amount of smoke released is minimal, and the decomposition gases have very low corrosiveness, therefore minimizing the major factors in the damage caused by real fires with cable and building related products.

Electrical

FEP has excellent dielectric properties at high frequencies and both the dielectric constant and the dielectric loss tangent are low over a wide range. These properties make FEP an ideal material for insulating high-speed data transmission cables (such as Cat 5 and Cat 6 LAN cables).

Chemical Resistance

The fully fluorinated structure of FEP gives it a chemical resistance similar to that of PTFE and makes it suitable for applications in aggressive chemical environments at temperatures up to 205°C. This is particularly true for environments where mixed acids and solvents are present. FEP is resistant to virtually all chemicals, except molten alkali metals, fluorine (as a gas) and some other halogen complexes.

FEP is suitable for food contact and is FDA compliant for safe use (21CFR.17.1550). This is especially true for film grades, which contain no plasticizers or other additives, and have very low permeability to liquids, gases and moisture.

FEP is also suitable for medical applications. It is biocompatible to USP Class VI (non-toxic, non-hemolytic and non-pyrogenic), and FEP products can be sterilized by gamma, EtO, e-beam, or autoclaving.

FEP has good weathering resistance to sunlight, ozone and general weathering, and weathering tests in Florida show no measurable property changes even after 20 years.

Optical

FEP has a high transparency with good transmittance of both UV and visible wavelengths. FEP also has the lowest refractive index of all polymers (1.338) and films made from FEP are extremely clear and transparent.

FEP can be pigmented almost any color but only inorganic pigments can be used due to the high processing temperatures required for FEP.

Advantages and Limitations

Advantages	Limitations
Melt-processable fluoropolymer	**Higher cost in relation to some other polymers**
Very good high and low temperature performance for all mechanical properties	**Low cut through and abrasion resistance in the natural state**
Excellent electrical performance at high temperatures	**Lower maximum service temperature than PTFE**
Excellent chemical resistance over a wide range of temperatures	**Softer in relation to some other polymers**
High transparency with good transmittance of both UV and visible wavelengths and a very low refractive index (1.34)	**Processing requires specially treated equipment to avoid corrosion of equipment**
Very low coefficient of friction	**Processing requires suitable machines to cope with high melt viscosity**

Processing

As a melt-processable material, FEP can be processed by most of the traditional plastics processing methods. The material is used extensively for injection molding, extrusion, coating, and impregnating of fabrics and metals. Whichever processing method is used, the processing machinery must be suitable for use at the high processing temperatures and high melt viscosities required to process FEP. Molten FEP is also corrosive to many metals and corrosion resistant materials should be used for all parts of the machinery likely to come into contact with the molten material (i.e. nickel based alloys).

Processing Method	Applicable
Injection molding	**Yes**
Extrusion (profiles, films, sheet, tubing, heat shrink tubing, and cable coating)	**Yes**
Blow molding	**Yes**
Compression molding	**Yes**
Impregnation and coating	**Yes**

FEP Grades

FEP is produced in a variety of grades depending on the processing method to be used for the material. Specific grades are available for injection molding, extrusion, blow molding, cable coating, fabric impregnation (as aqueous dispersions), and even foamed cable insulation.

Finishing

FEP is available as semi-finished products in rod, tube, sheet and other formats suitable for further machining. These products can be machined using conventional machine tools to give an excellent finish for prototype evaluation or small run production. FEP machines easily and accurately using conventional machine tools with carbide or diamond tipped tooling. Speeds and feeds should be slow (as with any plastic material) to prevent excessive heat build up in the part.

FEP can also be provided as a transparent film that can be heat sealed, vacuum formed, laminated, thermoformed and even used as a hot-melt adhesive.

Typical Applications

The combination of many of the unique properties of PTFE with melt-processability allows FEP to be used in a wide range of applications where high temperature stability, chemical resistance and low coefficient of friction make it the ideal material despite the higher cost. Typical applications include:

- Semiconductor and pharmaceutical industries-due to excellent chemical resistance and low extractables (high purity)
- Protective linings for piping and tubing
- Wire and cable insulation for computers and electronics systems
- Wire and cable insulation for high-speed data transmission cables (such as Cat 5 and Cat 6 LAN cables) – the low coefficient of friction also means that cables are very easy to lay and replace in buildings
- Films for release surfaces
- Roll covers
- Glazing film for solar energy collectors
- Environmental monitoring equipment
- Thermal control materials (as used on the Hubble Space Telescope)

Summary

At its discovery FEP represented a major step in commercializing the fluoropolymers and in extending the applications for this remarkable family of materials. The melt-processability of FEP meant that the traditional plastics processing methods could be used to process fluoropolymers – fluoropolymers had left the ‘developmental’ and ‘interesting’ stage and had joined the ranks of the traditional polymers. Even compared to more recently developed fluoropolymers, FEP remains the best material for applications requiring excellent electrical or barrier properties and is a valuable addition to the fluoropolymer family. Zeus provides unsurpassed FEP products in a variety of forms, shapes and sizes for every imaginable application, including Multi-lumen, Co-extrusions, Sub-Lite-Wall®, Heat Shrink (1.3:1 and 1.6:1) and Dual Shrink, Lay-Flat, Heavy

Construction, Heavy Wall, and Convoluted. For more information on Zeus FEP tubing and the possibilities for your business, please visit **www.zeusinc.com**

How Zeus can help

With a technical inside and outside sales force backed up with engineering and polymer experts, Zeus is prepared to assist in material selection and can provide product samples for evaluation. A dedicated R&D department staffed with PhD polymer chemists and backed with the support of a world-class analytical lab allows Zeus an unparalleled position in polymer development and customization.

Since 1966 Zeus has been built upon the core technology of precision extrusion of high temperature plastics. Today, with a broad portfolio of engineered resins and secondary operations, Zeus can provide turnkey solutions for development and high-volume supply requirements.

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- Give us a call at (toll-free) 1.**866.272.4118** or (international) **+01.803.268.9500**
- Email the editor of the *Zeus Polymer Minute* directly at **editor@zeusinc.com**
- Request technical info or support at **support@zeusinc.com**