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Diving deep?

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BREAKTHROUGH FOR ENERGY-EFFICIENT A/C,

PTFE HANDLES FLEX-CABLE CONUNDRUMS,

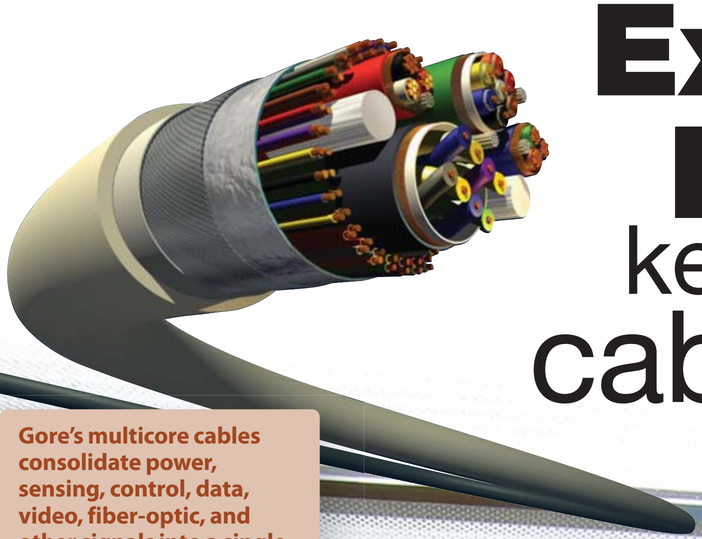
MOTION-CONTROL REFERENCE GUIDE

How to find load inertia

A clutch play for bottling lines

Electrohydraulics help test fasteners and adhesives

Expanded PTFE keeps cables flexible



Gore's multicore cables consolidate power, sensing, control, data, video, fiber-optic, and other signals into a single package. The ePTFE surrounding each core has a low dielectric constant that minimizes signal loss and cross-talk.

Gore's high-flex clean cables give off few particulates and don't outgas, making them suitable for clean-room and vacuum operations. The cables can be configured to eliminate segmented carriers that can hinder smooth motion and generate particles.

The material's wide temperature range, customizability, and inertness help it stand up to demanding cable applications.

Authored by:
Jessica Shapiro
jessica.shapiro@penton.com

Key points

- Expanding PTFE lets engineers tailor its form and properties.
- ePTFE in cable insulators, binders, and jackets can prolong flex life.
- The cables' low particulation and outgassing makes them good for clean-room environments.

Resources

Fraunhofer IPA, *ipa.fraunhofer.de/english/*

W. L. Gore and Associates, *gore.com*

"Even Containers Gotta Vent," Machine Design, June 7, 2007, *machinedesign.com/article/even-containers-gotta-vent-0607*

When you think of polytetrafluoroethylene (PTFE), the nonstick coating on your pots and pans might be the first thing that comes to mind. Some of the same properties that let food release from cooking surfaces have made PTFE attractive to engineers for applications from insulation to sliding surfaces since its discovery in 1938.

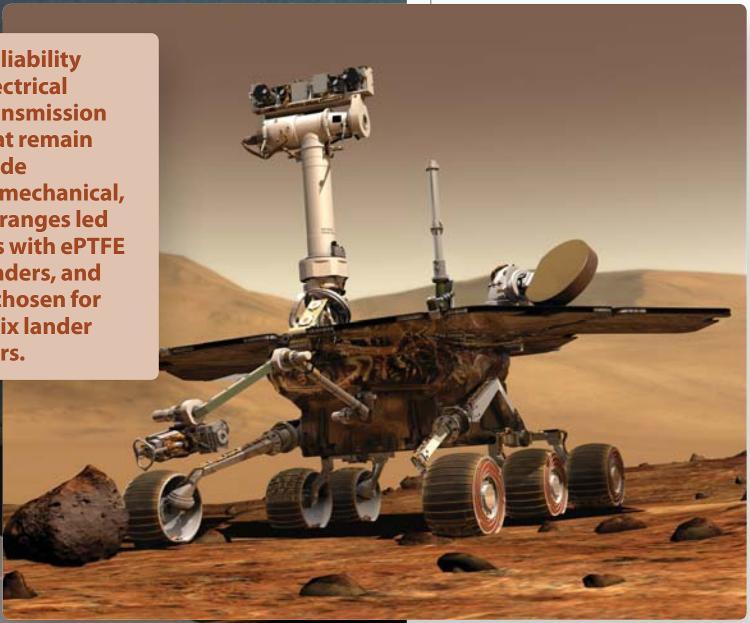
These same characteristics let PTFE and its expanded derivatives (ePTFE) work well in cables for today's demanding, high-flex, low-downtime applications. The materials can give cables long flex-life, extra strength, better signal transmission, and clean-room performance.

Cable capabilities

Cable designers generally want materials that shield, jacket, and act as dielectrics to be inert, hydrophobic, and insulating. The materials also need to perform over a wide temperature range and withstand repeated and varied flexing.

To determine material effectiveness, cables are often subjected to standard and customer-defined motions while technicians monitor signal attenuation and impedance. Rolling flexure, torsion, and random motions are common tests. The tick-tock motion, in which the cable repeatedly bends at a given angle at the same spot, is considered the most severe.

Cable size has the greatest effect on flex life because the further a material is from the cable's neutral axis, the greater the flexure



Mechanical reliability along with electrical and signal-transmission properties that remain stable over wide temperature, mechanical, and life-cycle ranges led GORE™ Cables with ePTFE insulators, binders, and jackets to be chosen for NASA's Phoenix lander mission to Mars.

Inside PTFE

Rapid application of tensile force to heated PTFE changes the polymer's microstructure, as Bob Gore discovered in 1969. Atomic-force microscopy reveals that PTFE's spiraled nodes expand into a network of nodes and fibrils. The network can be as much as 70% air, depending on expansion conditions.

The molecular structure of PTFE and other fluoropolymers give them properties that place them in a class of their own. A standard polyethylene molecule has a repeat unit of two carbon atoms, each joined with a single bond to its two neighboring carbons. Each carbon also bonds to two hydrogen atoms to form C_2H_4. In PTFE, fluorine atoms replace hydrogen atoms to form C_2F_4.

Fluorine is highly electronegative and has a larger atomic diameter than hydrogen. These two characteristics combine to make PTFE a hydrophobic, nonreactive thermoplastic. Fluorine's electronegativity repels the negative side of bipolar water molecules. The atom's size combines with a strong carbon-fluorine bond to physically block positively charged and nonpolar molecules, like oils and organic solvents, from reacting with the polymer backbone.

PTFE's inertness prevents cross-linking to form a harder thermoset but also minimizes flammability. PTFE is stable from –250 to 260°C. It is also an excellent electrical insulator and can be a good thermal insulator in its expanded form.

The absence of large functional groups and cross-linking mean the polymer chains tend to slide past each other, leaving the bulk plastic mechanically weak. This weakness lets it absorb mechanical energy and provides a low coefficient of friction. PTFE also tends to creep, a useful property for conformal seals.

Making PTFE starts with fluorspar, also known as fluorite, CaF_2. The mineral is dissolved in sulfuric acid to create hydrofluoric acid, the basic building block of tetrafluoroethylene resin. The resin is extruded to form blocks or sheets of PTFE or synthesized into powder for future use.

Heating the polymer to about 300°C, below its 327°C melting point, and then rapidly applying force, expands the polymer's microstructure to make ePTFE. The expanded polymer appears under atomic force microscopy as a network of densely coiled nodes connected by fibrils. This phenomenon was first discovered by W.L. Gore and Associates in 1969.

Controlling the expansion temperature, force, rate, and direction lets engineers dictate many microstructural attributes of ePTFE, including the network's openness, density of the fibrils, and distance between nodes. Each microstructural configuration, combined with the final product form – fiber,

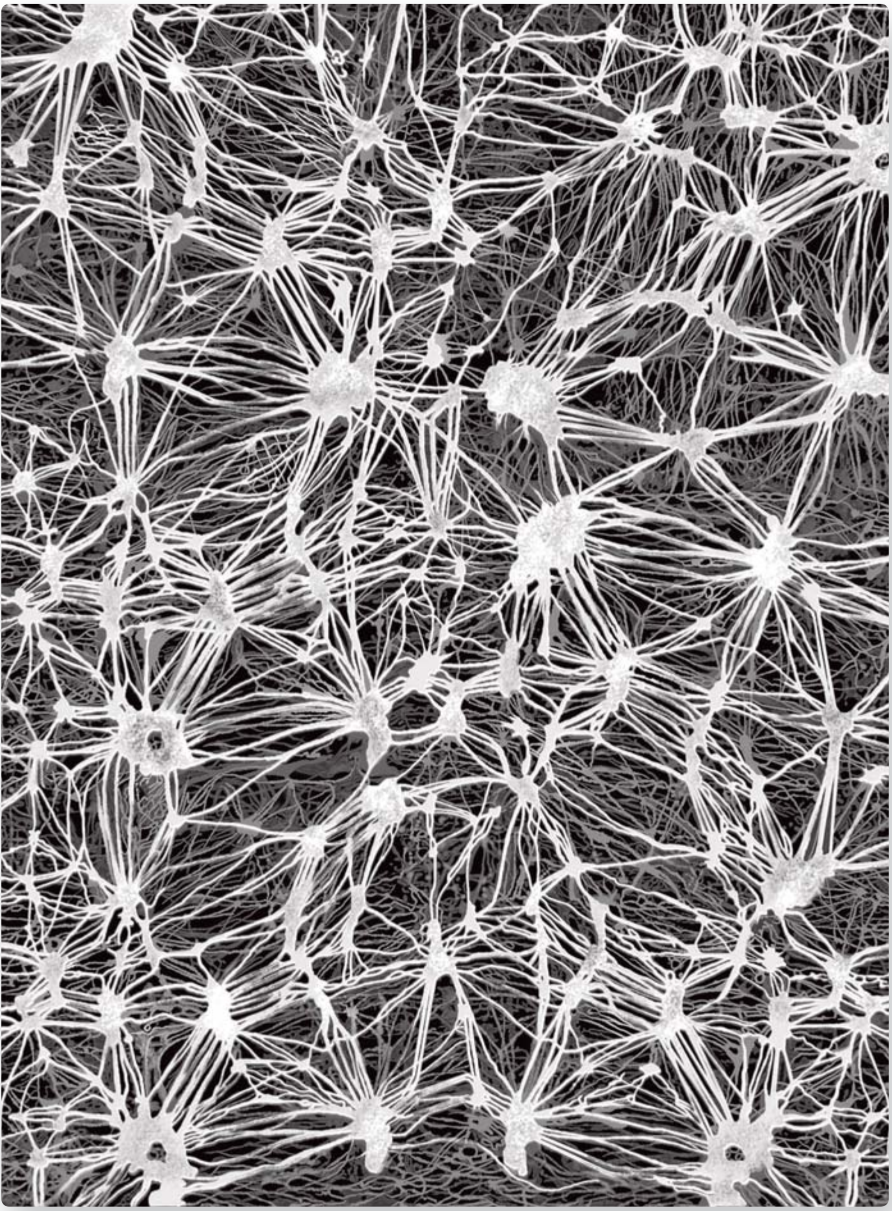
stress it sees. Consequently, cutting cable diameter and weight can extend longevity exponentially. The application dictates cable core diameter, but thin, light conductor insulation with a low dielectric constant, high dielectric withstanding voltage, and good tear resistance can help slim a cable's overall size and minimize flexural stress.

ePTFE is one material that fills the bill for a low dielectric constant. When technicians expand PTFE to make ePTFE, the resulting volume is up to 70% air. (See "Inside PTFE," above). This helps cut the overall dielectric constant from 2.1 for PTFE to 1.3.

Polyethylene foam is another common dielectric material, but its density can vary from wire to wire or along the length of a single wire. Because dielectric constant varies with density, controlled-impedance cables with this form of insulation often have lower high-frequency electrical signal integrity.

ePTFE insulator tape, on the other hand, has a tightly controlled thickness, density, and dielectric constant. Wrapping individual conductors in ePTFE can cut interference, noise, cross-talk, and signal attenuation. In some applications, ePTFE tape helps limit phase shift to 4.3° and signal attenuation to 0.05 dB at 110 GHz.

High-dielectric ePTFE insulation can be up to 50% thinner than other materials. For example, Gore's MIL-ENE insulation is rated for voltages of 300 V_{rms} at 0.004-in. thick.



tube, tape, or membrane – gives Gore's ePTFE products unique characteristics.

Expansion and additives can make ePTFE electrically and thermally conductive, or retain PTFE's insulating qualities. Though the expanded polymer is inherently chemically inert, engineers can impregnate substances that impart specific catalytic or chemical properties. They can also impregnate pigments, or engineer it to stick to other, notoriously difficult-to-bond fluoropolymers.

For instance, supercapacitors use ePTFE's porosity and increased surface area to store up to 5,000 f of charge and fuel cells rely on ePTFE to carry an ionomer catalyst.

ePTFE's open structure can be engineered to absorb water or chemicals or remain hydrophobic. Tailored expansion coupled with Gore capabilities can give the polymer high or low dielectric constants, surface energies, abrasion resistance, hardness, stiffness, and light transmission. A more open microstructure can be made absorbent or nonpermeable. This last property is the key to breathable fabrics and venting products.

It also makes ePTFE attractive in certain medical applications, like hernia patches, stent grafts, vascular grafts, and cardiac patches, where doctors want tissue to grow into the patch from one side but not the other. Its hydrophobicity cuts down on clotting, too.

The material maintains PTFE's wide temperature range of –250 to 260°C, staying flexible even in cold temperatures. And it blocks and resists degradation by ultraviolet rays.

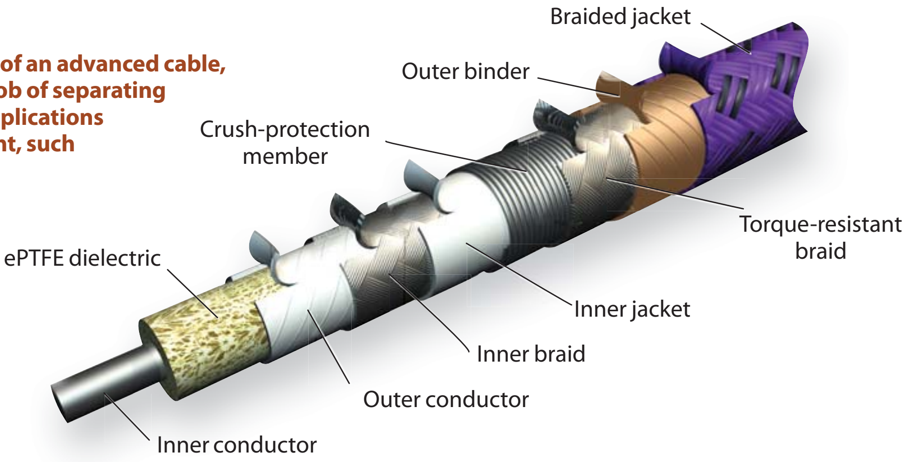
At higher voltages, corona discharge also becomes a concern. Engineers have modified PTFE for better performance in wires carrying 5 kV and higher voltages. Corona-resistant (CR) PTFE eliminates the microscopic voids between conductor and insulation that can be corona-discharge initiation sites, especially in high-altitude, military, and space applications.

Shielding is the furthest from the cable's neutral axis, so it sees the greatest flexure stress. Cutting shield-to-conductor and shield-to-jacket friction deters heat generation and keeps stress off the shield.

Placing 0.02-coefficient-of-friction ePTFE binders on either side of the shield lets each conductor slide past its neighbors and the outer shield with ease, making the cable as a whole more flexible in rotation and torque, and eliminating internal abrasion. Designers who know a cable will not lose strength over time through abrasion can tighten the design envelope and still extend cable life.

Any cable jacket must protect the shields and conductors from the environment and lend extra tensile and flexural strength. Like conductor insulators, jacket layers should be thin, resist tears, withstand fluid attack, and have high tensile strength.

Many applications use durable polyurethane (PU) jackets. For environments that require low particulation, polyvinylchloride (PVC) may be a better choice.



In the complex internal structure of an advanced cable, the dielectric has the important job of separating inner and outer conductors. In applications where signal integrity is important, such as this GORE™ Microwave Cable, the dielectric prevents cross-talk and minimizes signal degradation.

Jackets can also be made of ePTFE for additional insulation and resistance to chemical attack. If the cable assembly slides through other machine parts, abrasion-resistant ePTFE is a good choice for extending cable life.

Keeping it clean

For clean-room robot and motion-control applications, Gore's ePTFE composite jackets designed for clean manufacturing applications protect cables from chemicals including engine lubrication oil, aircraft grease, synthetic lubricants, petroleum-based hydraulic fluid, machine-tool oil, and harmonic-drive grease.

Cables such as these have a base longitudinal strength of 24.6 MPa. Hydraulic fluid drops longitudinal strength by 28%, and all other fluids have a 10% or smaller effect on strength.

Thermal aging for 120 hr at 121°C cuts cable strength by 10% to 22.1 MPa. The ePTFE jacket material itself retains 80% of its tensile strength and 85% of its tensile elongation after the same thermal conditioning.

Gore's ePTFE and PTFE cables designed for vacuum applications lose only 0.03% of their mass when heated to 125°C in a 10^{-5} Torr vacuum. The permissible limit, according to ESA PSS-01-702 and ASTM E-595 is 1.0%. The cables don't emit measurable collected volatile condensable materials, the permissible limit of which is 0.1% of total mass.

The cables are designed to operate with minimal outgassing down to 10^{-7} Torr. Any particles emitted during flexure are within ISO 14644-1 Class 1 limits, 0.1 micron/m^3.

To further cut particulates in clean-room environments, engineers may choose GORE™ Trackless Cables. Such cables can contain power, video, Ethernet, and signal carriers, as well as fiber optics, pneumatic tubes, and other cores.

GORE™ Trackless Cables hold their own weight with internal support members and remove the need for segmented cable carriers that generate particulates, noise, and jerky movements. This type of cable is also commonly used in high-precision measurement environments that cannot tolerate vibrations from cable tracks or carriers.

For shorter stroke lengths, ≤0.5 m, GORE™ Flat Cables typically hold their own weight. Consequently, users may be able to eliminate dividers for a smaller, lighter package that produces fewer particulates. **MD**

ePTFE: Enabling cabling

PRODUCT	APPLICATION	DESCRIPTION
GORE™ PHASEFLEX® Cables	Radio-frequency and microwave signals	When the cable using an ePTFE dielectric is bent 90° around a 1-in. mandrel, a 110-GHz signal only shifts 4.3° in phase and 0.05 dB. A 16-cm assembly at 110 GHz has about 2.1-dB insertion loss.
GORE™ OMNIBEND™ Fiber for High Performance Ropes	Ocean-based drilling platforms	ePTFE strands are woven as a solid lubricant into high-performance ropes that withstand the undersea environment and 900,000-lb tensile loads.
GORE™ High Flex Round Cables	Rolling flexure, random, and torsional-motion applications	Single or multiple cores encased in ePTFE bend around 55-mm radii at 2.54 m/sec and 39.2 m/sec^2 for 12 to 16 million cycles with a 1,000-mm stroke length for each cycle.
GORE™ High Flex Flat Cables	Linear-motion applications	A flat configuration of signal, power, fiber-optic, and pneumatic cores encased in ePTFE flexes around a 51-mm radius at up to 4 *g*s for up to 20 million cycles.

W.L. Gore and Associates employ ePTFE to enhance cables' performance, durability, and lifespan.

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