What's that stuff? Fiberglass

The lightweight, wispy material strengthens and reinforces thousands of products

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Among the objects that can be made from glass, jars and windows, made from soda lime glass, and kitchenware, made from borosilicate glass, are the older siblings of the family—the stalwarts. Fiber-optic cables, used to transmit nearly all our communications today, are the attention-grabbing youngest child. And fiberglass? It's the middle child, of course—equally important yet often lost in the shuffle.

"Behind the scenes" is the way Pennsylvania State University's John C. Mauro describes the roles often played by fiberglass. Mauro, a materials scientist and glass specialist who spent nearly 20 years at glassmaker Corning, notes that fiberglass quietly makes its way into carpeting, ceiling tiles, roofing shingles, and many construction materials. And when combined with plastics, the microscopic fibers make composites that are strong and stiff yet lightweight, which is why carmakers and other manufacturers use these reinforced materials to build fuel- and energy-efficient products.

"Many people may not realize that glass is made and used in fiber form because the applications are mostly hidden," says Michelle Korwin-Edson, a senior scientist at Owens Corning, a leading fiberglass manufacturer. Fiberglass is widely used as house and building insulation, she points out, but it may go unnoticed because it's usually covered by drywall or tucked away in an attic.

Fiberglass may not be a flashy material, but it's ubiquitous. It's also big business. "Today there are over 40,000 applications just for reinforcement glass fiber," Korwin-Edson says. Worldwide, manufacturers make some 5 million metric tons of the stuff annually, mainly for insulation and composites. Market analysts estimate that the amount produced in 2017 was worth nearly $14 billion. By 2025, they predict, that figure will climb to more than $21 billion.

Fiberglass makers have been producing the wispy material commercially since the 1930s, when it started gaining ground as a thermal insulation material for buildings. Much has changed since that time, as manufacturers have learned to tweak the glass fibers' composition to impart properties that better suit one application or another. But many of the basics, including the key starting materials—silica sand (mainly SiO_2), soda ash (or sodium carbonate, Na_2CO_3), and limestone ($CaCO_3$)—remain the same.

To form fibers in the 5-to-20-µm-diameter range, manufacturers deliver molten glass to an extrusion device that drives the hot liquid through a nozzle that has thousands of tiny holes. The setup and processing steps differ according to the type of fiber being produced. For example, making glass-wool fibers for insulation is initially similar to making cotton candy, Korwin-Edson says. Fine streams of glass emerge horizontally through holes in a rotating spinner and quickly solidify. Afterward, they are chopped by blasts of air that blow them down to a moving conveyor belt, where they are collected and formed into insulation products, including wools, mats, and boards.

Glassmakers typically use a vertical extrusion process to make so-called continuous fibers for reinforcing plastics. According to Hong Li, a senior scientist at Nippon Electric Glass, individual fibers are gathered in bundles of 200–6,000 filaments and woven into fabrics, treated with polymers (resins) to hold them together, or processed in other ways, depending on the application.

One of the first major applications for reinforcement fiber was printed circuit boards. Found in nearly every electronic device, these familiar green slabs contain E-glass fibers, which consist mainly of silica, alumina, calcium oxide (CaO), and boron oxide (B_2O_3), enveloped in an epoxy resin.

In addition to providing high strength and stiffness at low weight, which is typical of all glass fibers, E-glass also combines low values for dielectric constant and dielectric loss, critical properties for insulators used in high-speed electronics, Li explains. The fibers also resist thermal expansion, which keeps the size of the board constant as multiple drilling and assembly steps build complex circuitry.

Despite its name, E-glass also has applications far beyond electronics, making its way into pipes, tanks, and other industrial parts, as well as into products used in transportation and renewable energy. The long reach comes from customizing the fibers' chemical composition.

The boron oxide component typical of E-glass, for example, provides circuit boards with some important electrical properties. But it also lowers the material's guard against attack by acids and corrosive chemicals. So manufacturers came up with a boron-free version, dubbed E-CR, that provides acid and chemical resistance that's used, for example, in pipes that transport and tanks that store corrosives.

Renewable energy uses tons of E-glass—literally. Each of the three 38-meter-long blades in common models of wind turbines contains nearly 3 metric tons of E-glass fibers, Li says. The fibers impart strength to the blades while keeping them light and responsive to breezes. But turbine blades need to be much stiffer than circuit boards so that they don't flex too much and crash into the grounding pole to which they're attached. For standard-length blades, glassmakers address that requirement chemically and physically. They remove boron from circuit-board E-glass because that element weakens silica's glass network. And instead of forming bundles containing hundreds of 5-µm fibers, as they do for circuit-board use, they bundle several thousand fibers with diameters of 10 µm or larger.

When it comes to increasing stiffness, bigger is better. So, too, for boosting a generator's electrical output. That's why engineering firms keep increasing the length of windmill blades, with today's longest ones approaching 100 meters. Longer blades can capture more wind energy, but it's challenging to keep them rigid.

"For today's longer blades, traditional E-glass cannot deliver suitable stiffness," Li says. Enter R-glass, an aluminosilicate tailor made for rigidity. A number of manufacturers make R-glass fibers and keep the proprietary formulation details to themselves. In general, though, compared with E-glass, R-glass boosts stiffness by including magnesium oxide (MgO) at concentrations above 6%, reducing CaO to less than 20%, and leaving out boron.

Decades after first commercializing high-strength glass fibers, manufacturers continue searching for chemical formulations that lead to improved ways of making them. Researchers at Sinoma Science & Technology, in Nanjing, China, and PPG Industries, in Pittsburgh, recently teamed up to study the effects of varying the concentrations of Li_2O and B_2O_3 on magnesium aluminosilicate fibers.

They found that increasing the combined fraction of lithium and boron relative to magnesium lowered the glass's melting temperature and suppressed crystal growth. Those findings can benefit manufacturing by reducing the energy and cost of making fiberglass. They may also improve fiber uniformity, which can minimize breakage during the fiber drawing process (*J. Alloys Compd.* 2017, DOI: 10.1016/j.jallcom.2017.08.294).

By far the biggest uses of fiberglass are insulation and reinforcing lightweight objects. But a small amount is used for healing. Missouri-based Mo-Sci developed a nanofibrous bioactive borate glass for animal and human use that heals chronic skin ulcers and deep wounds. The antimicrobial fibers, which gradually dissolve and are absorbed by tissue, release bioactive ions in the wound, which stimulate blood vessel growth and promote tissue healing.

In another medical development, Aldo R. Boccaccini of Friedrich Alexander University Erlangen-Nuremberg and coworkers showed that depositing bioactive phosphate glass fibers in an aligned orientation on metal body implants nudges cells to proliferate in an orderly and directional fashion, which promotes bonding between the implant and bone (*ACS Appl. Mater. Interfaces* 2018, DOI: 10.1021/acsami.8b01378).

Fiberglass doesn't draw much attention, yet it's a common material important to modern life. "People may think glass fibers are low tech," Penn State's Mauro says, but tuning their composition to customize properties is "cutting-edge chemistry."

The individual fibers in fiberglass are too small to see, but don't be fooled by their size, Korwin-Edson says. "They're small, but they sure are mighty." ■