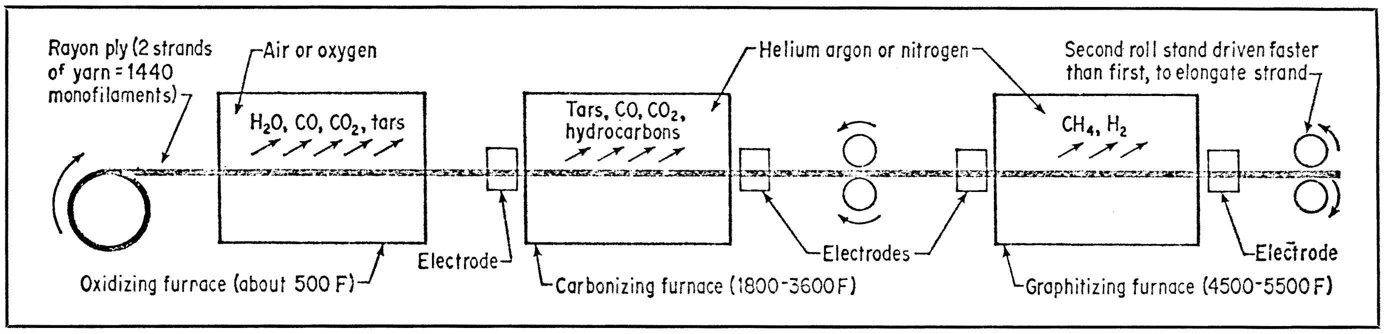



Machine Design

*U.S. (shown above) and British processes for making graphite fibers are alike except for starting materials.*

MATERIALS

# Graphite fibers coming of age

## Lighter and stronger than steel, capable of withstanding tremendous heat, the graphite fiber is ready to make its big push as an engineering material

by Edward Gross

Glass fibers created an engineering revolution when they were introduced as a strength-without-weight engineering material in the 1950's. And although they are still a material of choice in the aerospace and aviation industries, they are being hard pressed by boron fibers which, in turn, are being pursued by a newcomer to the field: graphite fibers, from which engineers expect another revolution.

Graphite fibers are only four years out of the laboratory, and only a few tons a year are being produced for still-developmental use in turbine fan blades and aircraft wings. But there is every reason to believe they are about ready to take off.

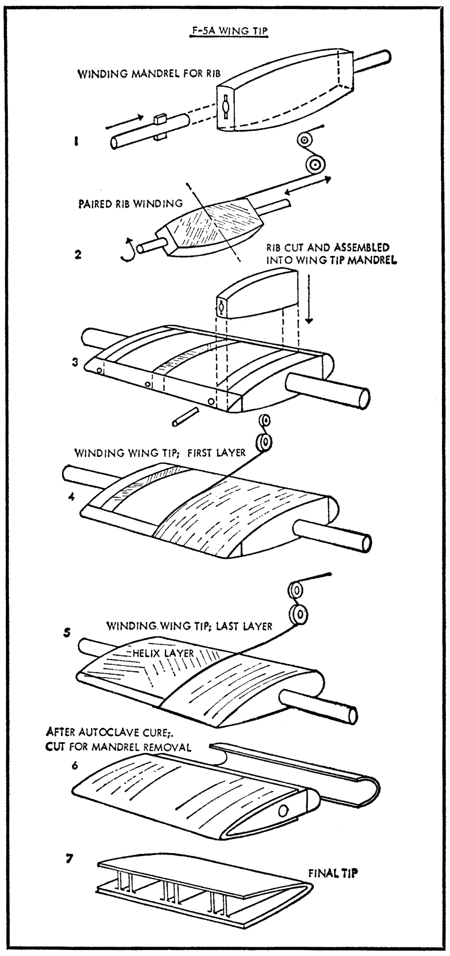
**"The potential,"** says Dr. Edward Epremian, general manager of the carbon products division of Union Carbide's advanced materials department, "is measured in hundreds of tons per year in the next decade."

He sees the areas of immediate application limited to jet engines, aircraft load-bearing members such as wing and tail assemblies, missile nosecones and helicopter rotor parts. "But down the road, as volume builds and the material gets cheaper," he contends, "it should be found in trains, buses and trucks as well as in equipment for the chemical process industries." By the 1980's, graphite fibers could be in anything from bridges and ships to skis and deep-sea submersibles.

The fibers now market for between $325 and $400 a pound, though they were over $500 two years ago. So far Union Carbide and HITCO of Gardena, Calif., are the principal U.S. producers. They caught the fiber fever from—or with—British companies like Morganite and Courtaulds, which, along with Rolls Royce, are establishing connections with U.S. companies like Lockheed Aircraft, the Whittaker Corp. of Los Angeles and Hercules, Inc., of Wilmington, Del., who will make the material by the British process (SN: 5/10, p. 462).

"Graphite fibers, with a tensile strength of 250,000 pounds per square inch and an elastic modulus of 50 milion pounds per square inch, are the highest strength-to-weight ratio engineering materials man has yet made commercially," says Carbide's Dr. William H. Dresher. He gives them 15 times the strength of steel and six times its stiffness, and the ability to reduce an airplane's weight by up to 30 percent.

**The fibers owe** three of their important properties, high heat resistance, electrical and heat conductivity and strength, to the atomic and crystalline make-up of graphite. The high heat resistance is due to the strong carbon-to-carbon bonds on the atomic level, bonds which can absorb a great deal of energy before breaking. At the crystalline level, heat and electrical conductivity depend on the line-up of graphite crystals, which fall in flat layers like pages in a book. Heat and electricity are then conducted along the longitudinal axes of the layers rather than cutting through them.



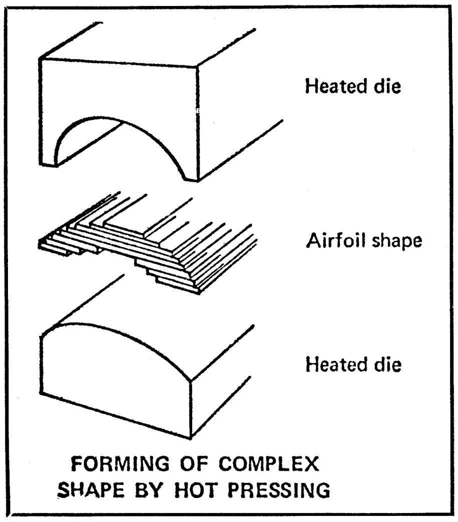

Aerospace Technology

*Graphite yarn wound into a wing tip.*

Graphite's heat-conductive property has been put to work in missile nosecones, where it disperses the heat upon reentry; its electrical conductivity has been put to work in a suit for linemen who repair high-voltage transmission lines. Composed of graphite and glass fibers, the suit conducts electricity away from the lineman's body.

The secret of graphite fiber strength lies in the small diameter of the fiber (6.6 microns). The thinness means that there is less opportunity for a flaw, or break, to occur. Similarly, the shorter the fiber, the stronger it will be. For that reason, the so-called whiskers,

## . . . Graphite fibers




Machine Design

*Stacked filaments pressed into shape.*

which are really short crystals, are the strongest of all fibrous materials. However, they are costly, aligning them is difficult and so is quality control.

Graphite is capable of withstanding temperatures as high as 5,000 degrees F. without melting or vaporizing. This allows graphite fibers to retain their form at temperatures twice that of the melting point of steel, an attribute invaluable for rocket or jet engines. It enables light-weight plastic composites of graphite fibers to replace metals, and Rolls Royce has been using a graphite fiber and epoxy resin in place of titanium in its jet engine turbine fan blades since September.

But graphite fibers are not all perfect, and they do have limitations. The major drawback to them is that they can't be used with most metals because they react readily with them. The result is an unstable composite. Nickel is one metal, however, that is suitable and research is being conducted to develop graphite-nickel composites at Union Carbide and also at the University of Nottingham in England.

**"A real problem** with graphite fibers," says Dr. W. Denney Freeston of Fabric Research Laboratories, Dedham, Mass., "is the difficulty in bonding the fiber to the resin to give the composite good shear strength." In making the composite, the yarn is either run through a bath of resin or woven into a fabric, which is impregnated with the resin. Bonding is then accomplished by heat. "Without good shear strength, the composite would be unsuitable for most structural applications," notes Dr. Freeston. "A second drawback is its very poor abrasion resistance. You can pulverize graphite fibers with your fingers. This poses a handling problem."

There are two processes for making graphite fibers. In the United States the Union Carbide process dominates. It entails taking a rayon precursor (a cellulose fiber containing carbon) and heating it to temperatures as high as 2,600 and 2,800 degrees C. Everything volatile in the rayon is boiled away, leaving only a graphitic carbon framework in the shape of the original rayon fibers. The fibers are stretched under tension to align the graphite crystals in a direction parallel to the fiber axis, giving the fiber its remarkable stiffness.

**In the British** process, developed by the Royal Aircraft Establishment at Farnborough, polyacrylonitrile fibers are used as the starting material. They are heated to 3,000 degrees C. As in the Union Carbide process, the heating causes the carbon atoms of the fibers to crosslink and form graphite crystals, which are lined up one behind the other parallel to the fiber axis. In the RAE process, however, there is no separate drawing or stretching step. The fiber is merely restrained to keep it from shrinking because of the heat, and this causes the crystals to align themselves.

The present British commercial process has advantages over the American. For one thing, it produces a fiber with a higher breaking point and greater stiffness. Its tensile strength is between 250,000 and 300,000 pounds per square inch, while the U.S. fiber ranges from 200,000 to 250,000 p.s.i. And the Young's modulus (stiffness measurement) of the British material is from 55 to 65 million p.s.i., while the U.S. product measures 50 million p.s.i. However, Union Carbide and Celanese Corp. have just reported new fibers with higher strengths and moduli.

**Also the British** are better able to tailor their fiber. With the U.S. fiber, as it increases in strength, it also increases in stiffness, and after a while the fiber becomes brittle. The British are able to make a trade-off between strength and stiffness because as their fiber increases in strength, it decreases in stiffness.

The chief disadvantage of the British fiber is that because of the starting material, it is difficult to make it into filaments longer than three or four feet—although lengths of 1,000 feet have been recently reported—while U.S. fibers are continuous.

Regardless of the process, the material has promise. "Studies we've made in the field indicate to us that the ultimate market and potential is astronomical," says Donald W. McGuffin, manager of the HITCO materials division. "The lower we can make the cost, the more applications there will be. There doesn't seem to be an end except for the cost factor." ◇