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ALL OF THE ABOVE

Can Energy R&D Make It Happen?

Miracle Fiber?

A new ceramic fiber reinforcing material developed at Idaho National Laboratory offers extraordinary potential in several industries

BY KEITH ARTERBURN

HUMAN HISTORY has had many identifiable ages-Stone, Bronze, Steel and Space. Soon, there may be the Alpha Silicon Carbide Fiber Age. Today, the chemical, mechanical and thermal properties of silicon carbide, or SiC, fiber make it an attractive degradation-resistant, high-temperature reinforcing ceramic for use in energy, transportation, aerospace, defense, industrial and nuclear applications.

SiC fibers are now possible in two forms: beta-SiC and the new alpha-SiC fibers. Since the early 1990s only beta-SiC fibers were being developed commercially using expensive raw materials and processes.

Previous attempts to make alpha-SiC fibers using similar processing methods have not been successful. Now, Idaho National Laboratory researchers John Garnier and George Griffith have developed a patent-pending, continuous manufacturing process breakthrough called Silicon Carbide (SiC) Direct that continuously fabricates alpha-SiC fibers for a palette of new fiber super-materials.

"Our process is a simple and efficient direct conversion process using inexpensive raw materials such as carbon fibers, silicon and silicon dioxide powder," said Garnier. "Alpha-SiC fibers will be readily available and production costs may be less than $100 per pound."

The beta-SiC materials currently are only available from overseas in limited quantities and at costs ranging from $500 to $6,000 per pound. These materials are used in high cost products, including high-temperature semi-conductors, abrasives, wear components, armor, rockets, turbine engines plus metal and ceramic matrix composites.

The alpha-SiC fiber ceramic material outperforms beta-SiC fiber by:

- Varying in compositional forms and application with high thermal shock resistance (up to 2730°C)
- Having higher tensile strength and durability
- Providing higher thermal conductivity
- Having chemical inertness and light weight
- Delivering greater mechanical and thermal stability in radiation environment
- Exhibiting extreme hardness and better "strain-to-failure" performance
- Resisting corrosion, wear and/or abrasiveness
- Performing as an excellent electrical conductor or insulator, depending on its configuration

"We coil the fibers on spools and already have produced lengths of a mile or longer," said Garnier. The fiber can be produced using various sources of commercial, small diameter carbon filaments, which can then be converted and braided into desired patterns.

Griffith said the process also can batch-process pre-woven or braided carbon forms to manufacture sheets, large three-dimensional forms and many other shapes. It also may be scalable for use in large manufacturing furnace operations.

SiC Direct benefits could include:

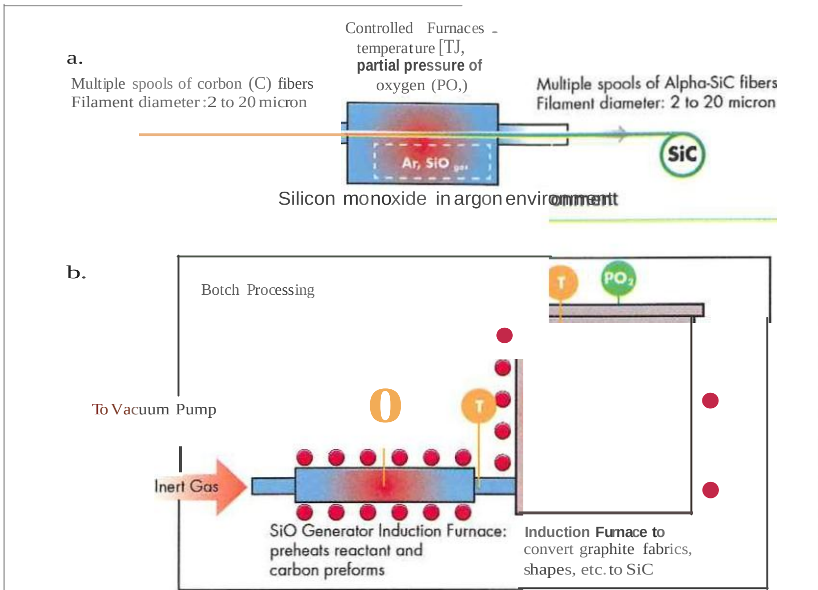
- Energy Consumption. Fabrication of alpha-SiC fibers consumes 60 percent less energy compared to beta-SiC commercial polymer processing.
- Materials. This process uses inexpensive silicon granules, sand and available carbon fibers.
- Capital Investment. Relatively small investment is required because readily available electric or induction furnaces can be used.
- Virtually No Waste. SiC Direct leaves only a trace amount of carbon monoxide.

THE PROCESS

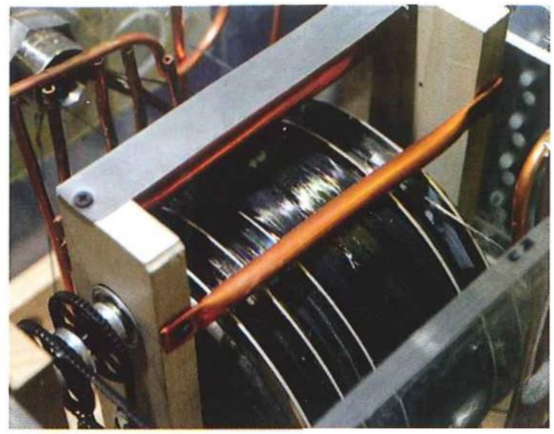
A mixture of silicon dioxide with silicon is heated in a ceramic crucible using a high temperature tube furnace to generate an oxidative silicon monoxide vapor. Commercially available carbon fibers are drawn through the furnace in the vapor at elevated temperatures (up to 1600°C). The carbon fibers convert into alpha-SiC and the fiber draw rate can be adjusted to achieve a variable percentage conversion. This process continuously converts carbon filan1ents into SiC fiber and takes about 12 minutes of exposure to produce fiber with a one micron thick SiC shell.

SIC DIRECT PRODUCTS

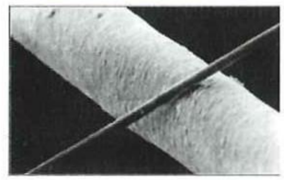
"SiC Direct offers great potential for improved commercial and industrial advancement," said Gary Smith, INL senior commercialization manager. "For starters, the transportation industry could benefit from up to a 30 percent weight savings for



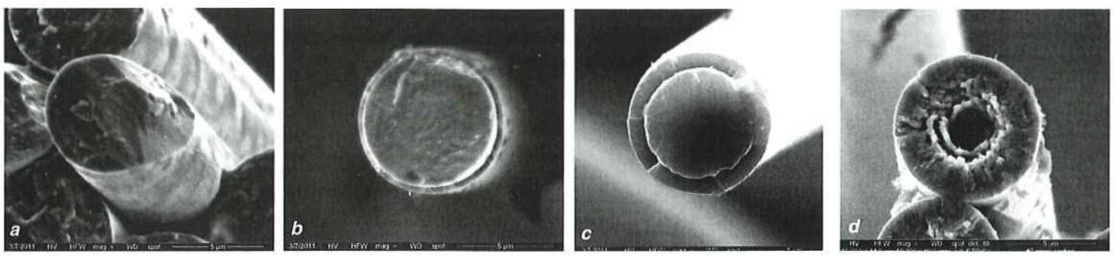
SiC Direct converts carbon fibers to alpha-SiC: (a) Continuous direct conversion alpha-SiC fibers, b) Continuous batch conversion of fibers, fabrics and other pre-form shapes.



ABOVE: INL's SiC Direct has produced alpha-SiC fibers in continuous coiled form with lengths of a mile or longer.



LEFT: A single 6-micron diameter carbon pan fiber filament Is positioned on top of a human hair for comparison. The SiC Direct process has demonstrated simultaneous conversion of groups of both 50,000 and 3,000 filaments.



These images were taken through a microscope showing carbon fibers during the SIC Direct conversion process to form alpha-SIC: (a) Commercially available carbon fibers before the process begins, (b) Partially converted carbon fiber early In the process that with about a 200-nanometer thick shell of alpha-SIC, (c) Partially converted carbon fiber further along in the process with 1,000 nanometers thick shell, (d) A fully converted alpha-SiC tube at the end of the conversion process.

vehicles, increasing miles per gallon performance and greater distances for electrified vehicles."

Alpha-SiC fibers used in composites could deliver stronger vehicle components (three to six times stronger than steel), which may increase personal safety to all drivers and passengers. A partial list of key products for transportation includes improved vehicle frames, engine blocks, exhaust systems and safety panels; lighter and stronger rail cars and semi-t111ck trailers; energy absorbing materials for collisions; and specialized materials for magnet and battery production and catalytic surfaces.

The energy industry also may benefit with lighter and stronger power lines that are safer and more efficient at delivering electricity; fluid cracking catalysts in oil refining; components for use in currently operating nuclear reactors to extend their use; permanent magnets for generators and improved composite blades for wind turbines; turbine engines for stationary power generation, and more.

The defense-aerospace industry could see better blast mitigation materials for body armor, vehicle protection and building reinforcement to increase personnel safety; lighter and stronger ships, aircraft and engines for speed and efficiency; thermal resistant materials for rockets and more.

Smith said "Alpha SiC fibers also could contribute to improving environmental management with an important overall reduction of carbon emissions associated with aluminum and other manufacturing, as well as more efficient and longer-lasting auto exhaust and pollution control systems."

Industry may be able to use smaller amounts of expensive and valuable materials like aluminum or develop stronger composites for better buildings, bridges, guard rails or other structural applications. Many more industrial uses are possible.

SiC Direct saves energy, uses inexpensive materials, and requires limited capital investment. It also makes available at affordable prices a revolutionary, super fiber material for use in redesigned and longer lasting products. Now available in two continuous direct conversion processes, alpha silicon carbide fiber materials could provide America and the world a new age of manufacturing and efficiency. **11**

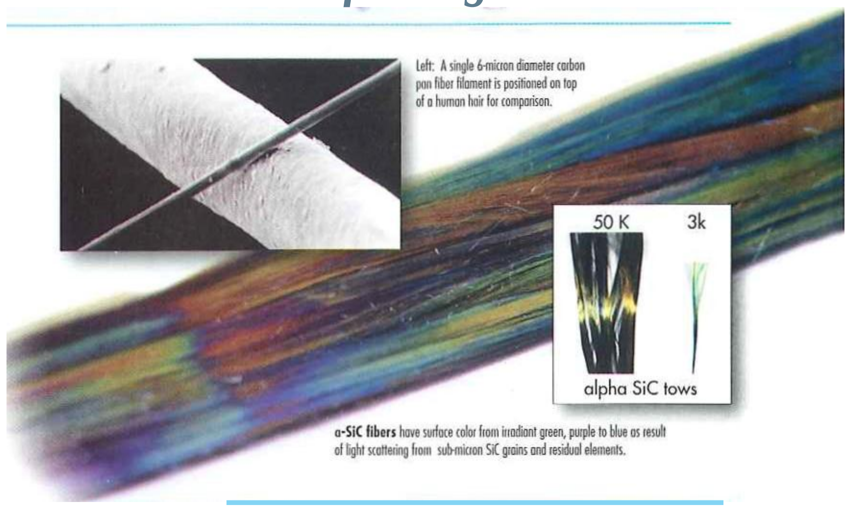
Keith Arterburn is senior media consultant at Idaho National Laboratory.

Producing A New Ceramic Fiber Reinforcing Material

a-SiC Performs

Degradation-resistant high temperature reinforcing ceramic for use in energy, transportation, aerospace, defense, industrial and nuclear applications by offering attractive qualities like –

- Range of fibers from a·SiC /C to a·SiC
- Higher thermal shock resistance (no phose change to the sublimation temperature up to 2730°0,
- Higher tensile strength and durability as o reinforcing fiber in metal matrix and ceramic matrix composites,
- Chemical inertness and light weight,
- Long·term mechanical and thermal stability in radiation environments,
- Extreme hardness with better fiber filament "stroin·to·foilure" performance (e.g. surpasses stretching of 2 percent and exceeds 10 percent in o multi·filoment tow form),
- Corrosion resistant, exceptional weor and/or abrasiveness,
- Excellent electrical conductor or insulator, depending on its configuration .



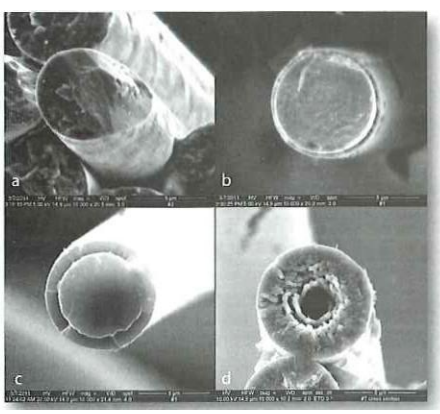
Left: A single 6-micron diameter carbon pan fiber filament is positioned on top of a human hair for comparison.

α-SiC fibers have surface color from irradiant green, purple to blue as result of light scattering from sub-micron SiC grains and residual elements.

SiC Dired Process.

Oegrodo orttesistonl high temperoture reinf01cing ceramic for use in energy, onsporto on, oerospoce, defense, industrial ond nudeor applicofions by offering oHrocftve quolmes like -

- Range of fibers from a·SiC /C to a·SiC.
- A mixture of Si02 with Si is heoted in n high temperature tube furnace generating SiO vapor.
- Commercial PAN-hosed corbon fiber lows ore drown tlrrough the furnace, exposing fibers to SiO vapor ot elevated temperatures (up to 16oo•o.
- Corbon fibers convert into a-SiC. wMe being drawn through tire lurnoce.
- fiber drow role (0.1 to 10 inches per minute) con be adjusted to ochieve voriobleconversion.



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INL inventors, left to right, George Griffith, John Garnier

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