Continuous Scalable Process for Domestic Production of SiC Fibers for Low-Cost CMCs

AMMTO

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AMMTO & IEDO JOINT PEER REVIEW

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Abstract

The project entitled "Continuous Scalable Process for Domestic Production of Silicon Carbide (SiC) Fibers for Low-Cost Ceramic matrix composites (CMCs)" aims to demonstrate a highly scalable, continuous, in-line cost & energy efficient Silicon Carbide (SiC) fibers manufacturing process. The expected reduction in cost or manufacturing is approximately 80-90% less than today's commercial SiC fibers manufacturing process. SiC fibers are used as the reinforcing phase in CMCs to deliver the strength performance required in extreme environments. Current and potential future applications include efficient, lightweight jet aircraft engines, gas power turbines, nuclear fuel cladding with improved safety, concentrated solar power, hypersonic vehicles, and space structures. Oak Ridge National Laboratory (ORNL) is collaborating with a couple of industry partners to enable a domestic supply source of these fibers. Commercial industry has identified a need for affordable SiC fibers to meet performance, efficiency, and emissions goals for jet engines and a huge array of other high temperature products and markets. The project is demonstrating an all-domestic supply chain in contrast to today's partially foreign-sourced supply chain. It is charting a path to commercial production through scale-up at DOE's Carbon Fiber Technology Facility at ORNL. The scale-up will leverage COIC's Sylramic™ SiC fibers, widely recognized as the premier SiC fiber that is capable of performing at 2700°F in aerospace and nuclear applications. The project team is committed to enabling- a fully domestic, open-market SiC fiber that will meet performance, production volume, and affordability needs for clean energy applications.

Alignment with Office Mission

- This project is developing next-generation materials and manufacturing technology.
- Reduced manufacturing cost, increased scalability, and development of a fully domestic supply chain will increase U.S. industrial competitiveness.
- Applications in jet aircraft engines, gas power turbines, accident-tolerant nuclear fuel, and concentrated solar power will contribute to economy-wide decarbonization.

Challenges and Impact

Energy, Emissions, & Environment:
- Estimated reductions at full market penetration: 0.5% of US primary energy demand, 1.0% of US GHG emissions.

Cost & Competitiveness:
- Reduce SiC fiber cost by 80-90% Grow annual market from $20M to > $300M.

Technical & Scientific:
- World's first demonstration of in-line SiC fiber manufacturing and first inherently scalable SiC fiber manufacturing process.

Other Impacts:
- Converts partially foreign supply chain to fully domestic supply chain, creating US jobs and enabling certain military applications.

Project Outline

Innovation: World's first demonstration of continuous, in-line SiC fiber manufacturing by an inherently scalable process chain that will enable fully domestic commercial SiC fiber production

Project Lead: Oak Ridge National Laboratory

Project Partners: COI Ceramics, Honeywell, Rolls-Royce, Pratt & Whitney

Timeline: June 2021 through May 2024

Budget:

	FY21 Costs	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	$269,182	$1,315,867	$117,898	$2,000,000
Project Cost Share	$45,406	$269,775	$34,664	$600,000

End Project Goal: Demonstrate continuous in-line manufacturing of 500+ filament SiC fiber tow with required SiC fiber tensile strength and modulus at rate that is scalable to > 5,000 kg annual production capacity per commercial SiC fiber manufacturing line.

Background

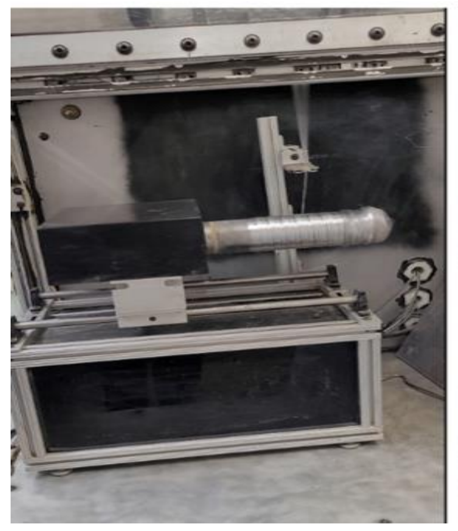
- Silicon carbide fibers are used for reinforcing composites that are used as structural materials for building energy generating turbines, aerospace shuttles, and nuclear reactors.
- Silicon carbide fiber reinforcement in composites is analogous to using steel-bars with cement in the construction industry where the silicon carbide fibers represent the steel bars.
- Silicon carbide fibers can handle fatigue well (cyclic-loading) at 1480 ^{o}C under an oxidizing environment while the metallic super alloys does not have the ability to handle fatigue under these conditions.
- Because of its high-temperature performance in oxidizing environment, it will potentially be used in making nuclear energy generation safer and energy generating turbines become more efficient.
- Silicon carbide fibers have tensile strength greater than 2 GPa while regular stainless steel has ~800 Mpa tensile strength and silicon carbide fiber is 1/3 of the weight of steel. Light weight of silicon carbide fiber composites allows significant energy savings when used in transportation.
- Currently, silicon carbide fiber cost is 10,000 USD/kg due to batch processing and legacy manufacturing technology that is not amenable to scale-up. Also, no domestic manufacturing is available for this critical material.

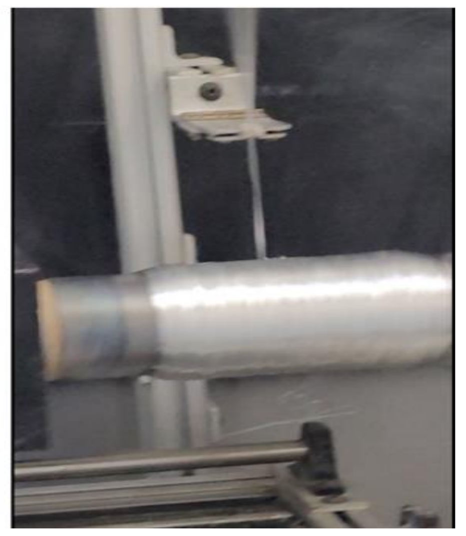
	Current	Target
Cost, USD/kg	10,000	1500
Manufacturing Technology	Batch	Continuous
Supply Chain	Foreign	Domestic

Results

A prototype SiC Fiber line was installed and commissioned at Carbon Fiber Technology Facility (CFTF) in Oak Ridge National Labs.

Polymer Synthesis, Melt Spinning, and Crosslinking
- Scaled-up synthesis to 2 kg scale.
- Two variants were produced to allow evaluation of different viscosity characteristics.
- A Melt spinning line to manufacture SiC fiber precursor was installed and commissioned.

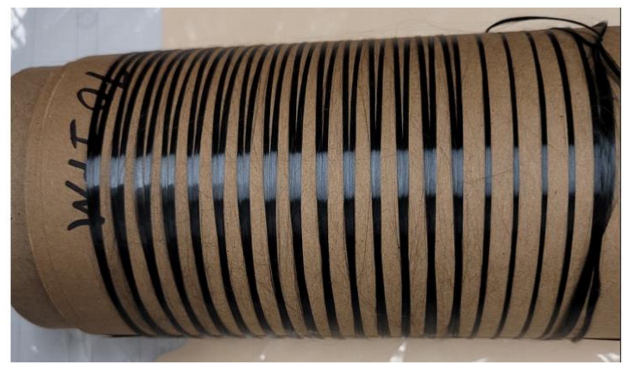




- Modification underway to improve balance of melt processibility and filament ductility.
- Initial laboratory synthesis was melt processible with good ductility.
- First synthesis by scalable polymerization process was melt processible but brittle filaments.
- Alternative synthesis by scalable polymerization process had improved filament ductility but poor melt processibility.
- Melt spinning trials are providing feedback to polymer formulation.
- Precursor filaments were stabilized using a proprietary low-cost crosslinking method without the need for expensive e-beam or gamma-irradiation methods.
- Demonstrated cross-linking with melt temperature >> 200 ^{o}C.
- This is the first reported demonstration of roll-to-roll devitrification process for manufacturing of SiC fibers.
- Currently optimizing continuous, roll-to-roll devitrification process.

Conclusions

- Continuous, in-line manufacturing of SiC fiber offers high-cost reduction and decarbonization potential.
- Key experimental equipment was procured and installed.
- Process development progress includes (i) melt spinning and cross-linking at commercially required rates and (ii) first reported continuous, in-line devitrification.
- Industrial manufacturing partner is highly committed to the project with strong customer pull.



Devitrified SiOC Fiber

Key Achievements

- Pre-ceramic fibers were successfully cross-linked at rate required for commercial manufacturing.
- World's first reported demonstration of continuous, in-line devitrification in SiC fiber processing.
- Prototype SiC fiber heat treatment line was installed with demonstration that it represents a feasible design for scaling-up continuous, in-line SiC fiber manufacturing.

Future Work

- SiC fiber precursor conversion work to continue to optimize scale up parameters.
- Polymer synthesis work to continue for optimizing spinning variables.
- Scale-up to multiple tows planned in a subsequent project
- Perform techno-economics analysis (TEA) to estimate unit production cost.

Technology Transfer

- COI Ceramics plans to transition the continuous, in-line SiC fiber manufacturing process to commercial US manufacturing.
  - Fully domestic supply chain.
  - Multi-year IRAD funding committed, and out-year CAPEX requirements identified in BOD's long-term plans.
- Scale up to make > 1 kg/day of SiC fiber using DOE's Carbon Fiber Technology Facility at ORNL.

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COIC COI Ceramics, Inc. Honeywell Rolls-Royce